WASHINGTON NATURAL HERITAGE PROGRAM

Climate Change Vulnerability Index Reports for Selected Washington State Rare Plant Species: Phase IV

Prepared for

US Forest Service, Region 6

Prepared by

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WASHINGTON STATE DEPARTMENT OF
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Climate Change Vulnerability Index Reports for Selected Washington Rare Plant Species

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Note: In addition to being included in Appendix A of this report, individual CCVI reports from this study, as well as from earlier projects, are hosted on the Washington Natural Heritage Program website at: https://www.dnr.wa.gov/NHPclimatespecies

ON THE COVER: ***Phlox solivaga*** **(yeti phlox), a Washington endemic plant ranked as Extremely Vulnerable to climate change using the NatureServe Climate Change Vulnerability Index (Young et al. 2016).**

Photograph by Tynan Ramm-Granberg

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Introduction

Global climate change, with its projected increases in mean annual temperatures, alteration of precipitation patterns, and more unpredictable and extreme weather conditions, has emerged as one of the primary threats to the survival of many rare plant and animal species (IPPC 2014; Parmesan and Hanley 2015; Thomas et al. 2004). To develop conservation and mitigation strategies, it is imperative that land managers be able to predict how species and plant communities might respond to current and future changes in climate (Anacker et al. 2013; Glick et al. 2011; Still et al. 2015; Young et al. 2015).

The Climate Change Vulnerability Index (CCVI) was developed by NatureServe to assess the response of plant and animal species (Young et al. 2016) or vegetation types (Comer et al. 2019) to projected climate change. The CCVI employs 29 climatic and biological variables to derive an overall vulnerability score, ranging from extremely vulnerable to less vulnerable (or "insufficient evidence" if adequate data are not available). Climate variables include modeled and projected temperature increase, historical temperature variability, physiological thermal niche, moisture availability, historical variation in mean annual precipitation, physiological hydrologic niche, and dependence on snowpack. Biological variables include habitat specificity, dispersal ability, competition, pollination biology, and genetic diversity.

In 2019, the Washington Natural Heritage Program (WNHP) received funding from the US Fish and Wildlife Service (USFWS) to apply CCVI protocols to five federally listed plant species (Fertig 2021a; Kleinknecht et al. 2019). WNHP also received funding from the Interagency Special Status and Sensitive Species Program (ISSSSP) of the US Forest Service (USFS) and Bureau of Land Management (BLM) to apply the CCVI protocol to 47 plant species listed as agency Sensitive by USFS and BLM (ISSSSP 2021). Fertig (2020) provided a summary of this first set of completed models (hereafter referred to as "Phase I" of this project). In 2020, USFS provided additional funding for CCVI reports on 55 new plant species listed as BLM or USFS Sensitive or WNHP species of concern ("Phase II" of the project; Fertig 2021b; Fertig 2022). In 2023, another 20 species were assessed through additional funding for a "Phase III" (Miller et al. 2023). The current report represents "Phase IV" of the project, containing CCVI reports on 60 additional Washington rare plant species listed as sensitive and occurring on USFS and BLM lands (Fertig 2021b; ISSSSP 2021). To date, a cumulative 187 species, representing over 90% of Washington occurring species on the ISSSSP list (ISSSSP 2021), now have CCVIs available that were conducted using the most current version of the calculator (Release 3.02) and climate models (Young et al. 2016). These assessed species represent over 50% of the 371 species listed as state endangered, threatened, or sensitive in Washington by the Washington Natural Heritage Program as of August 2021 (Fertig 2021b).

Methods

CCVI reports were prepared using the NatureServe Climate Change Vulnerability Calculator Release 3.02 in MS Office Excel (https://www.natureserve.org/conservation-tools/climate-change-vulnerability-index). GIS maps of projected local temperature change, moisture availability (based on the ratio of actual to predicted evapotranspiration), historical thermal niche, and historical hydrological niche were developed for each species by intersecting base map layers from NatureServe (www.natureserve.org/ccvi and www.fs.usda.gov/ccrc/tool/climate-wizard) with element occurrence records from the Washington Natural Heritage Program database. An element occurrence, referred to hereafter as "occurrence", is a mappable record of a rare species location which may include one or more populations occurring in close proximity (usually within ½ mi or 1 km) within a defined area of land or water. Occurrences may be extant (verified as present within the last 40 years) or historical (not verified within the last 40 years). Both occurrence types are included in assessments and model maps for this report. Values from these maps were entered directly into the CCVI calculator and scored following criteria in the document *Guidelines for Using the NatureServe Climate Change Vulnerability Index* (Young et al. 2016).

Scores for environmental and life history traits of each species were derived from a review of pertinent literature. Information on current habitat characteristics were based on Biotics records, the Field Guide to Rare Plants of Washington (Camp and Gamon 2011; Washington Natural Heritage Program 2024), and Ecological Systems of Washington State: A Guide to Identification (Rocchio and Crawford 2015). Additional observational information and phenological information was derived from herbarium records sourced from the Consortium of Pacific Northwest Herbaria and SEINnet portal (Consortium of Pacific Northwest Herbaria 2024, SEINnet Portal Network 2024). Exposure to sea level rise was determined using the National Oceanic and Atmospheric Association Sea Level Rise Viewer (Office for Coastal Management, 2024) and potential for impacts from clean energy projects and/or forest health treatments was determined using the Washington Department of Natural Resources Clean Energy Parcel Viewer and Forest Health Treatment Tracker (Washington Department of Natural Resources, 2024a, 2024b). The geological affinities of each species and relevant distributions of geology and soils in Washington were based on the National Resources Conservation Service Official Soil Series Descriptions and ArcGIS maps (1:100,000) of surface geology from the Washington Division of Geology and Earth Resources (Soil Survey Staff, 2024; Washington Division of Geology and Earth Resources, 2016). Additional information on potential impacts from climate change to ecological systems was derived from Rocchio and Ramm-Granberg (2017).

Each of the 29 climatic and biological factors were scored as Greatly Increase, Increase, Somewhat Increase, or Neutral based on the likely response of each target species to climate change using scoring criteria defined by Young et al. (2016; Table 1, Table 2). If data were lacking, a score of "unknown" was given. A final Index Score was derived from these factor scores by the CCVI calculator and a confidence score provided based on the number of criteria assessed. CCVI scores fall into five categories ranging from Extremely Vulnerable to Less Vulnerable, depending on whether a species is likely to substantially decrease or become extirpated in the state by 2050 or is likely to be unimpacted by projected climate change (Young et al. 2016).

Table 1. Scoring for Individual Climate and Biological Factors used to Generate Climate Change Vulnerability Index Scores. Factors can also be scored as Unknown when appropriate. Intermediate scores (e.g., Somewhat Increase/Neutral) are allowed. See Young et al. (2016) for more details.

Section A: Local Climate		
Ranking Factor	**Condition**	**Score**
1. Temperature Severity (projected local temperature change)	>6.0° F (3.3°C) warmer	% of populations, based on map in Figure 1 of each CCVI (see appendix)
	5.6-6.0° F (3.2-3.3°C) warmer	
	5.0-5.5° F (2.8-3.1°C) warmer	
	4.5-5.0° F (2.5-2.7°C) warmer	
	3.9-4.4° F (2.2-2.4°C) warmer	
	<3.9° F (2.2°C) warmer	
2. Hamon AET:PET moisture (projected decrease in available moisture based on ratio of actual to potential evapotranspiration)	< -0.119	% of populations, based on map in Figure 2 of each CCVI (see appendix)
	-0.097 to -0.119	
	-0.074 to - 0.096	
	-0.051 to - 0.073	
	-0.028 to -0.050	
	>-0.028	
Section B: Indirect Exposure to Climate Change		
Ranking Factor	**Condition**	**Score**
1. Sea level rise (% of area subject to sea level rise)	>90%	Greatly Increase
	50-90%	Increase
	10-49%	Somewhat Increase
	<10%	Neutral
	Barriers completely or almost completely surround current range	Greatly Increase

2a. Distribution relative to natural barriers (degree to which natural barriers restrict the ability of a species to migrate) 2a. Distribution relative to natural barriers (degree to which natural barriers restrict the ability of a species to migrate)	Barriers will greatly impede migration	Increase
	Barriers somewhat impede migration	Somewhat Increase
	Barriers are minor or not present	Neutral

Section B: Indirect Exposure to Climate Change

Ranking Factor	Condition	Score
2b. Distribution relative to anthropogenic barriers (degree to which human-created barriers restrict the ability of a species to migrate)	Barriers completely or almost completely surround current range	Greatly Increase
	Barriers will greatly impede migration	Increase
	Barriers somewhat impede migration	Somewhat Increase
	Barriers are minor or not present	Neutral
3. Impacts from climate change mitigation (effects of seawalls, tree plantations, renewable energy projects and other infrastructure on life history of a species)	Known to be incompatible and likely to be constructed	Greatly Increase
	Known to be incompatible and may be constructed	Somewhat Increase
	Not likely to be impacted	Neutral

Section C: Sensitivity and Adaptive Capacity

Ranking Factor	Condition	Score
1. Dispersal and movements (degree to which a species is physically capable of dispersing)	Severely restricted dispersal (<10 m)	Greatly Increase
	Highly restricted dispersal (10-100 m)	Increase
	Moderately restricted dispersal (100- 1,000m)	Somewhat Increase
	Good to excellent dispersal (>1,000 m)	Neutral
2ai Change in historical thermal niche (exposure to large scale	Very small temperature variation (< 37˚F or 20.8˚C)	Greatly Increase

temperature variation in past 50 years) Based on Figure 3 in each CCVI report (see appendix)	Small temperature variation (37-47˚F or 20.8-26.3˚C)	Increase
	Slightly lower than average temperature variation (47.1-57˚F or 26.3-31.8˚C)	Somewhat Increase
	Average temperature variation (57.1-77˚F or 31.8-43.0˚C)	Neutral
Section C: Sensitivity and Adaptive Capacity		
Ranking Factor	**Condition**	**Score**
2aii. Change in physiological thermal niche (degree to which a species is dependent on cool or cold conditions)	>90% of occurrences restricted to cool or cold sites	Greatly Increase
	50-90% of occurrences restricted to cool or cold sites	Increase
	10-50% of occurrences restricted to cool or cold sites	Somewhat Increase
	Species is not restricted to cool or cold sites	Neutral
2bi. Changes in historical hydrological niche (exposure to precipitation variations in the past 50 years). Based on Figure 4 in each CCVI report (see appendix)	Very small precipitation variation (< 4 inches or 100 mm)	Greatly Increase
	Small precipitation variation (4-10 inches or 100-254 mm)	Increase
	Slightly lower than average precipitation variation (11-20 inches or 255-508 mm)	Somewhat Increase
	Average (20-40 inches or 508-1016 mm) or greater than average (>40 inches or >1016 mm) precipitation variation	Neutral
2bii. Changes in physiological hydrological niche (dependence on a narrowly defined precipitation or hydrologic regime or specific aquatic or wetland habitat (i.e., vernal pool, spring)	>90% of occurrences dependent on a specific aquatic or wetland habitat	Greatly Increase
	50-90% of occurrences dependent on a strongly seasonal water source or specific wetland habitat	Increase
	10-50% of occurrences dependent on a strongly seasonal water source or specific wetland habitat	Somewhat Increase

	Species not dependent on a strongly seasonal water source or specific wetland habitat	Neutral
Section C: Sensitivity and Adaptive Capacity		
Ranking Factor	**Condition**	**Score**
2c. Dependence on specific disturbance regime (effect of climate change on increasing disturbance or altering existing disturbance patterns)	Strongly affected by change in disturbance regime	Increase
	Moderately affected by change in disturbance regime	Somewhat Increase
	Little or no response to a specific disturbance regime	Neutral
2d. Dependence on ice or snow-covered habitats	>80% of populations dependent	Greatly Increase
	50-80% of populations dependent	Increase
	10-49% of populations dependent	Somewhat Increase
	Little dependence on ice or snow	Neutral
3. Restricted to uncommon landscape/geological features	Highly dependent (>85% of populations restricted to uncommon features)	Increase
	Moderately dependent (65-85% of populations restricted to uncommon features)	Somewhat Increase
	Not dependent, or found on widely occurring landscape or geologic features	Neutral
4a. Dependence on other species to generate required habitat	Required habitat is generated primarily by one species	Increase
	Required habitat is generated by only a few species	Somewhat Increase
	Required habitat is generated by many species, or not species-dependent	Neutral
4b. Dietary versatility (reliant on other species for nutrition)		Not applicable for plants

4c. Pollinator versatility (dependence on animal species for pollination)	Dependent on one species for pollination	Increase
	Dependent on 2-4 species for pollination	Somewhat Increase
	Dependent on 5 or more species for pollination, or not reliant on animals for pollination (i.e., wind-pollinated plants)	Neutral

Section C: Sensitivity and Adaptive Capacity

Ranking Factor	Condition	Score
4d. Dependence on other species for propagule (fruit or seed) dispersal	Completely or nearly completely dependent on a single animal species	Increase
	Dependent on a small number of species	Somewhat Increase
	Dispersed by many species, or not dependent on animals for dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies (vulnerability to disease or increased herbivory)	Strong negative impact from disease or herbivory due to climate change	Increase
	Moderate negative impact from disease or herbivory due to climate change	Somewhat Increase
	Not affected by disease or herbivory due to climate change, or impacts will be lessened	Neutral
4f. Sensitivity to competition from native or non-native species (competition for resources, such as space, light, and nutrients)	Strongly affected by competition that is likely to increase with climate change	Increase
	Moderately affected by competition that is likely to increase with climate change	Somewhat Increase
	Not affected by competition or competition is likely to decrease with climate change	Neutral
4g. Forms part of an interspecific interaction not covered	Requires an interaction with a single species for persistence	Increase

above (species with mutualistic relationships)	Requires an interaction with a group of similar species for persistence (e.g. mycorrhizal relationships)	Somewhat Increase
	Does not require an interaction with another species, or many species can fulfill this role	Neutral
Section C: Sensitivity and Adaptive Capacity		
Ranking Factor	**Condition**	**Score**
5a. Measured genetic diversity	Very low	Increase
	Low	Somewhat Increase
	Average	Neutral
5b. Genetic bottlenecks (likelihood of extremely low genetic diversity in the past due to reduced population numbers or number of occurrences)	Evidence that population was reduced to <250 mature individuals in 1 occurrence (or >70% range reduction) in past 500 years	Increase
	Evidence that population was reduced to 251-1000 mature individuals in <10 occurrences (or 30-70% range reduction) in past 500 years	Somewhat Increase
	No evidence that population was reduced to <1000 mature individuals or range was reduced by >30% in part 500 years	Neutral
5c. Reproductive system (breeding system of species and how it likely affects genetic variability; only used if C5a and C5b are “unknown”)	Species only reproduces asexually; genetic diversity assumed to be very low	Increase
	Species has mixed or obligate outcrossing, but genetic diversity assumed to be low due to barriers to gene flow, range disjunction, or outbreeding depression	Somewhat Increase
	Species with mixed or obligate outcrossing without major barriers to gene flow and presumed to have average genetic diversity	Neutral

Section C: Sensitivity and Adaptive Capacity		
Ranking Factor	**Condition**	**Score**
6. Phenological response to changing seasonal and precipitation dynamics	Seasonal temperature or precipitation has changed, but phenology has not changed	Increase
	Seasonal temperature or precipitation has changed, and phenology has changed to small degree	Somewhat Increase
	Seasonal temperature or precipitation and phenology have changed in similar way, or seasonal dynamics have not changed	Neutral
Section D: Documented or Modeled Response		
Ranking Factor	**Condition**	**Score**
D1. Documented response to recent climate change (range shifts or changes in abundance have occurred over last 10 years or 3 generations due to climate change)	Distribution or abundance undergoing major reduction (>70%)	Greatly Increase
	Distribution or abundance undergoing moderate reduction (30-70%)	Increase
	Distribution or abundance undergoing small reduction (10-30%)	Somewhat Increase
	Distribution or abundance not decreasing, or species is expanding range and increasing	Neutral
D2. Modeled future (2050) change in population or range size within the assessment area (based on “middle of road” climate projections)	Species is predicted to become extirpated	Greatly Increase
	Predicted range or abundance decreases 50- 99%	Increase
	Predicted range or abundance decreases 20- 50%	Somewhat Increase
	Predicted range or abundance remains static or increases	Neutral
Section D: Documented or Modeled Response		

Ranking Factor	Condition	Score
D3. Overlap of modeled future (2050) range with current range	No overlap between current and predicted future range	Greatly Increase
	Predicted future range overlaps with current range by 30% or less	Increase
	Predicted future range overlaps with current range by 30-60%	Somewhat Increase
	Predicted future range overlaps with current range by >60%	Neutral
D4. Occurrence of protected areas in modeled future (2050) distribution (protected areas include national parks, wildlife refuges, wilderness areas, and natural areas that are protected from outright habitat destruction by human activities)	<5% of modeled future distribution is encompassed by one or more protected areas	Increase
	5-30% of modeled future distribution is encompassed by one or more protected areas	Somewhat Increase
	>30% of modeled future distribution is encompassed by one or more protected areas	Neutral

Table 2. Definitions of Climate Change Vulnerability Index (CCVI) Summary Scores (from Young et al. 2016).

CCVI Summary Score	Definition
Extremely Vulnerable (EV)	Abundance or range extent within the assessment area is extremely likely to substantially decrease or disappear by 2050
Highly Vulnerable (HV)	Abundance or range extent within the assessment area is likely to decrease significantly by 2050
Moderately Vulnerable (MV)	Abundance or range extent within the assessment area is likely to decrease by 2050
Less Vulnerable (LV)	Available evidence does not suggest that abundance or range extent within the assessment area will change (increase or decrease) by 2050
Insufficient Evidence (IE)	Information to assess species vulnerability is inadequate

Results and Discussion

The 60 taxa assessed in Phase IV were associated with a wide variety of Washington's Ecological Systems but contained the greatest number of North Pacific Alpine & Subalpine Bedrock & Scree taxa (n=10) and Rocky Mountain Alpine-Montane Wet Meadow taxa (n=8), which together made up 30% of the taxa assessed in this phase. The greatest percentage of assessed taxa ranked as Highly Vulnerable to climate change (42%), followed by Extremely Vulnerable (40%) and Moderately Vulnerable (18%). No taxa ranked as Less Vulnerable to climate change. Many factors contributed to these ranks, but Extremely and Highly Vulnerable taxa were especially associated with vulnerable thermal niches (e.g., cooler microsites), vulnerable hydrological niches (e.g., snowmelt-dependent ecological systems), and had poor dispersal capabilities. Conversely, taxa determined to be less vulnerable to climate change were associated with warmer microsites, were not dependent on snowmelt, and had fewer biological vulnerabilities (e.g., poor dispersal, pollinator limitation). The patterns we identify below are broadly consistent with patterns documented in earlier phases of this project with some deviations as described below (Fertig 2020, Fertig 2022, Miller et al. 2023).

Extremely Vulnerable Taxa:

Of the 60 vascular plant taxa examined in Phase IV of this project, the second greatest percentage of taxa (n=24, 40%) scored as Extremely Vulnerable to climate change (Table 3, Table 4, Appendix A). The percentage of Extremely Vulnerable taxa identified in Phase IV was greater than in previous phases (Fertig 2021b, Fertig 2022, Miller et al. 2023), in part because of the high proportion of wet meadows and sparsely vegetated alpine ecological systems (e.g., fell-field, scree, talus) assessed. The plants occurring in these ecological systems tended to rank as more vulnerable to climate change based on their associations with cool air drainages or cold, high-elevation ecological systems in addition to their dependence on a steady supply of snowmelt for moisture. Wet meadow and alpine ecological systems were also ranked among the most vulnerable to climate change in Washington in a separate assessment of ecological systems vulnerability (Rocchio and Ramm-Granberg 2017). Accordingly, a large percentage of taxa ranked as Extremely Vulnerable were vulnerable based on their physiological thermal niche (66% ranked at least Somewhat Increase) and/or physiological hydrological niche (96% ranked at least Somewhat Increase) and occurred in areas where temperature variation has been historically low (68% ranked at least Somewhat Increase), which suggests that these taxa may not be able to adapt to changing temperatures (Table 3, Table 4; Young et al. 2016). Additionally, more than half (52%) of the Extremely Vulnerable taxa assessed occur in the Okanogan ecoregion (n=13; Table 3), which experiences some of the coldest temperatures in the state of Washington and is vulnerable to increasing temperatures (Rocchio and Crawford 2015).

Most of the Extremely Vulnerable taxa were also poor dispersers (Table 4; 88% ranked at least Somewhat Increase). Additionally, many taxa ranked as Extremely Vulnerable were identified as being at least somewhat pollinator limited (28% ranked at least Somewhat Increase) with low measured or potential genetic diversity (44% ranked at least Somewhat Increase). Taxa that ranked as Extremely Vulnerable in Phase IV but were associated with drier, low-elevation ecological systems were especially likely to have more than one of these biological vulnerabilities or restriction to a specific topographic or geographic feature (e.g., vernal pool, calcareous outcrops; 56% overall ranked at least Somewhat Increase for geology). Overall, Extremely Vulnerable taxa in Phase IV were strongly associated with vulnerable ecological systems and vulnerable thermal or hydrological niches but were also determined to be vulnerable due to biological factors and restrictions to microhabitats with limited distributions.

Highly Vulnerable Taxa:

The greatest percentage of taxa assessed in Phase IV ranked as Highly Vulnerable (n=25, 42%) to climate change, which is the second most frequent ranking across all Washington taxa assessed to date (Table 3, Table 4, Appendix A). Like Extremely Vulnerable taxa, taxa ranked as Highly Vulnerable were frequently associated with wet meadows and alpine ecological systems. However, more taxa found in peatlands and non-alpine sparsely vegetated ecological systems such as North Pacific Montane Massive Bedrock, Cliff & Talus and Rocky Mountain Cliff, Canyon, & Massive Bedrock were ranked as Highly Vulnerable rather than Extremely Vulnerable (Table 3). The latter sparsely vegetated ecological systems are not expected to be as vulnerable to climate change as they are presumably more adapted to harsh, water-limited conditions. Taxa in these ecological systems were not as strongly associated with physiological thermal or hydrological niches that ranked as vulnerable to climate change (Rocchio and Ramm-Granberg 2017). However, many of the Highly Vulnerable taxa were associated with cooler and damper microsites within their larger ecological systems, such as moist northern slopes, drainages, stream banks, and shaded forest edges (Table 3). Accordingly, Highly Vulnerable taxa overall were still frequently vulnerable based on their physiological thermal niche (64% ranked at least Somewhat Increase) and/or physiological hydrological niche (92% ranked at least Somewhat Increase) and occurred in areas where temperature variation has been historically low (83% ranked at least Somewhat Increase). Highly Vulnerable taxa were often poor dispersers (66% ranked at least Somewhat Increase) with lower genetic diversity (25% ranked at least Somewhat Increase) and a few were also pollinator limited (17% ranked at least Somewhat Increase). Many Highly Vulnerable taxa also occurred on geological features with a limited distribution in Washington, such as ultramafic and sandstone slopes, and ranked as having increased vulnerability due to these geological restrictions (38% ranked at least Somewhat Increase). Overall, vulnerable thermal and hydrological niches, biological vulnerabilities, and topographic/geographic restrictions were common but slightly less frequent to Highly Vulnerable taxa as compared to Extremely Vulnerable taxa in Phase IV (Table 4).

Moderately Vulnerable Taxa:

Only 11 taxa (18%) ranked as Moderately Vulnerable in Phase IV and no taxa ranked as Less Vulnerable to climate change. The percentage of Moderately Vulnerable taxa in Phase IV was less than in other phases (Fertig 2021b, Fertig 2022, Miller et al. 2023), though Moderately Vulnerable taxa still comprise the overall majority of Washington taxa cumulatively assessed with the CCVI (Table 5, Table 6). Unlike the taxa rated Extremely or Highly Vulnerable, the Moderately Vulnerable taxa were not strongly associated with specific ecological systems. However, they were broadly associated with habitats that occur at lower elevations (e.g., montane grasslands) with warmer physiological thermal niches (only 27% ranked at least Somewhat Increase) and minimal association with ice or snow (only 18% ranked at least

Somewhat Increase). The trend of thermophilic taxa scoring as Moderately Vulnerable was identified in earlier phases of the project, particularly for Columbia Plateau taxa, though Moderately Vulnerable taxa in Phase IV were not clearly clustered to one ecoregion (Table 3). As discussed in previous reports, caution should be taken when interpreting the vulnerabilities of these taxa as they are arguably pre-adapted to high temperatures but also may be closer to the threshold of their physiological tolerance ranges. This is supported by the fact that a large percentage of Moderately Vulnerable taxa occurred in areas which experienced lower than average temperature variation (64% ranked at least Somewhat Increase), a factor that can indicate a lack of ability to adapt to changing temperatures (Young et al. 2016). For taxa which are constrained to specific topographic or geological features (e.g., vernal pools, uncommon ultramafic substrates), which includes 36% of Moderately Vulnerable taxa (i.e., ranked at least Somewhat Increase for geologic restrictions), the risk of exceeding thermal thresholds is of particular concern as they cannot track shifting climate envelopes (Table 4; Caicco 2012). Moderately Vulnerable were less frequently associated with biological vulnerabilities such as dispersal limitation (only 45% ranked at least Somewhat Increase), low genetic variation (only 27% ranked at least Somewhat Increase), and pollinator limitation (0% ranked at least Somewhat Increase).

Other Factors:

Several factors used in the CCVI were not significant in determining vulnerability for these 60 taxa, either because they applied to nearly every taxa (e.g., natural barriers) or because they were employed infrequently (e.g., sea level rise, dependence on interspecific relationships). Very few taxa ranked as vulnerable based on historical variation in precipitation (historical hydrological niche) because much of Washington has experienced average or above average variation (Figure 4 in individual reports; Young et al. 2016). In many cases, data were not available on modeled current and future ranges, changes in distributions, or measured genetic variability. Only one species, *Lomatium laevigatum*, had sufficient available data to apply a vulnerability ranking for documented response to climate change in Washington. In other instances, factors such as dependence on other taxa for dispersal, sensitivity to natural enemies, and competition were surprisingly uninfluential for many of the ranks.

Table 3. Summary of Climate Change Vulnerability Index scores for 60 Washington rare plant taxa assessed in Phase IV. WA Status: BS = BLM Sensitive; FS = US Forest Service Sensitive; WE = Washington State Endangered, WS = Washington State Sensitive; WT = Washington State Threatened (Fertig 2021b).

Species (Common Name)	Heritage Rank	WA Status	Major Habitat	Ecoregion	CCVI Score
Achnatherum richardsonii (Richardson's needlegrass)	G5/S1	FS, WS	Dry meadow ridges	Okanogan, Canadian RM	Moderately Vulnerable
Actaea laciniata (Mt. Hood bugbane)	G4/S2	FS, WS	Moist talus & streambeds	W Cascades	Highly Vulnerable
Agoseris aurantiaca var. *carnea* (pink Agoseris)	G4Q/S2	FS, WS	Moist montane & subalpine meadows	Okanogan, E Cascades	Extremely Vulnerable
Agrostis mertensii (northern bentgrass)	G5/S1S2	BS, FS, WS	Alpine talus & dry meadows	E Cascades, Okanogan	Extremely Vulnerable
Antennaria corymbosa (meadow pussytoes)	G5/S1	BS, FS, WS	Moist meadows, stream banks, & open woods	Okanogan, Canadian RM, Blue Mountains	Highly Vulnerable
Botrychium michiganense (Michigan moonwort)	G3/S1	FS, WE	Meadow edges in pine-spruce forest	Canadian RM	Highly Vulnerable
Campanula lasiocarpa (Alaska harebell)	G5/S2	BS, FS, WS	Wet subalpine rock crevices	N Cascades	Moderately Vulnerable
Carex media (intermediate sedge)	G5T5/S2	BS, FS, WS	Moist meadows & streams	Okanogan, Canadian RM	Extremely Vulnerable
Carex obtusata (blunt sedge)	G5/S2	BS, FS, WS	Moist talus, meadows & floodplains	NW Coast	Highly Vulnerable
Carex scirpoidea ssp. *scirpoidea* (Canadian single-spike sedge)	G5T5/S2	BS, FS, WS	Moist meadows, rocky slopes, & streams	NW Coast, N Cascades, E Cascades, Okanogan	Extremely Vulnerable
Carex tenera var. *tenera* (quill sedge)	G5T5/S2	BS, FS, WS	Meadows, shrub wetlands, & open forest	Canadian RM, Okanogan	Extremely Vulnerable

Cassiope lycopodioides (clubmoss cassiope)	G5/S1	FS, WS	Rock faces & balds	N Cascades	Extremely Vulnerable
Cirsium remotifolium var. *remotifolium* (weak thistle)	G5TNR[T3]/S1	FS, WE	Moist meadows, stream banks, & rock outcrops	NW Coast, Puget Trough, E Cascades	Highly Vulnerable
Claytonia multiscapa ssp. *pacifica* (Pacific lanceleaved springbeauty)	G5T3T4/S1	FS, WS	Wet alpine & subalpine meadows	NW Coast	Highly Vulnerable
Collinsia sparsiflora var. *sparsiflora* (few-flower blue-eyed Mary)	G4T4/S1	BS, FS, WS	Vernal pools	Puget Trough, E Cascades	Extremely Vulnerable
*Cryptogramma stelleri (*Steller's rockbrake)	G5/S2	BS, FS, WS	Calcareous rock outcrops & wooded slopes	Okanogan, E Cascades, Canadian RM	Extremely Vulnerable
Draba aurea (golden draba)	G5/S1	BS, FS, WS	Fellfields, rocky slopes & meadows	Okanogan	Highly Vulnerable
Dryopteris cristata (crested shield-fern)	G5/S2	BS, FS, WS	Wet meadows & shrub/forest wetlands	Okanogan, Canadian RM	Extremely Vulnerable
Eleocharis mamillata ssp. *mamillata* (soft-stemmed spikerush)	G5T5/S1	FS, WS	Lake & pond shores, bogs & fens	N Cascades	Highly Vulnerable
Epilobium mirabile (Olympic Mountain willowherb)	G4Q/S1	FS, WS	Limestone talus & scree slopes	NW Coast, N Cascades	Highly Vulnerable
Erythranthe suksdorfii (Suksdorf's monkeyflower)	G4/S2S3	BS, FS, WS	Moist swales & vernal pools	E Cascades, Columbia Plateau, Okanogan	Extremely Vulnerable
Eurybia merita (subalpine aster)	G5/S2	FS, WS	Alpine talus, lithosols, & outcrops	Puget Trough, N Cascades, Okanogan, Canadian RM	Highly Vulnerable
Gentiana glauca (glaucus gentian)	G5/S2	BS, FS, WS	Moist alpine & subalpine meadows	N Cascades, Okanogan	Extremely Vulnerable
Geum rivale (water avens)	G5/S2S3	BS, FS, WS	Wet meadows, bogs, & riparian zones	Okanogan, Canadian RM	Extremely Vulnerable

Githopsis specularioides (common bluecup)	G5/S2S3	BS, FS, WS	Grassy balds & prairies, talus slopes	NW Coast, Puget Trough, W Cascades, E Cascades	Highly Vulnerable
Hackelia cinerea (gray stickseed)	G4?/S1	BS, FS, WS	Mossy rock cracks	Columbia Plateau	Highly Vulnerable
Hedysarum occidentale (western hedysarum)	G5/S2	FS, WS	Rocky meadows & talus	NW Coast, W Cascades	Highly Vulnerable
Hypericum majus (Canadian St. John's-wort)	G5/S2	FS, WS	Lake & pond shores, marshes, & fens	Puget Trough, N Cascades, Columbia Plateau, Canadian RM	Extremely Vulnerable
Isoetes minima (midget quillwort)	G1G2/S1	BS, FS, WE	Vernal pools & moist swales	Okanogan, E Cascades	Extremely Vulnerable
Isoetes nuttallii (Nuttall's quillwort)	G4?/S2	BS, FS, WS	Vernal pools & wet prairies	Puget Trough, E Cascades	Extremely Vulnerable
Juncus tiehmii (Tiehm's rush)	G4/S1	BS, WS	Moist granitic sand in seeps & depressions	Columbia Plateau	Moderately Vulnerable
Lathrocasis tenerrima (delicate gilia)	G5/S1	BS, FS, WS	Rock outcrops in sagebrush steppe	Okanogan, Columbia Plateau	Highly Vulnerable
Lomatium laevigatum (smooth desert-parsley)	G3/S2S3	BS, FS, WT	Basalt cliff crevices	Columbia Plateau	Moderately Vulnerable
Lomatium rollinsii (Rollins' desert-parsley)	G3/S2	BS, FS, WT	Steep canyon grassland slopes	Columbia Plateau	Extremely Vulnerable
Lomatium roneorum (Lomatium roneorum)	G1/S1	FS, WE	Arkosic sandstone slopes	E Cascades	Highly Vulnerable
Lycopodium lagopus (one-cone clubmoss)	G5/S1	FS, WS	Damp peat slopes	N Cascades	Moderately Vulnerable
Malaxis monophyllos var. *brachypoda* (white adder's-mouth orchid)	G5T4T5/S1	FS, WS	Lowland swamps & peatlands	NW Coast	Extremely Vulnerable
Montia diffusa (branching montia)	G4/S1S2	BS, FS, WS	Moist forests & open fir woodlands	NW Coast, Puget Trough, W Cascades, E Cascades	Highly Vulnerable

Ophioglossum pusillum (adder's-tongue)	G5/S2	BS, FS, WS	Seasonally wet pastures, floodplains, drainages, hillsides, bogs, & fens	Puget Trough, E Cascades, Okanogan, Canadian RM	Highly Vulnerable
Oxytropis campestris var. *gracilis* (slender crazyweed)	G5/S2	BS, FS, WS	Prairies, alpine meadows, & flooplains	Puget Trough, N Cascades, W Cascades, E Cascades, Okanogan	Highly Vulnerable
Packera bolanderi var. *harfordii* (Harford's ragwort)	G4TUQ/S1	FS, WE	Wet basalt cliffs, stream banks, shady forest	NW Coast, W Cascades, E Cascades	Highly Vulnerable
Parnassia palustris (marsh grass-of-Parnassus)	G5/S2	BS, FS, WS	Stream channels, moist meadows, bogs, & seeps	NW Coast	Highly Vulnerable
Pedicularis pulchella (mountain lousewort)	G3/S1	FS, WE	Alpine talus slopes & cliffs	E Cascades	Extremely Vulnerable
Pellaea brachyptera (Sierra cliffbrake)	G4G5/S2	BS, FS, WS	Arid rocky slopes	E Cascades	Moderately Vulnerable
Penstemon pennellianus (Blue Mountain penstemon)	G3/S2	BS, FS, WT	Openings in fir-pine forests	Blue Mountains	Moderately Vulnerable
Phlox solivaga (yeti phlox)	G1/S1	FS, WE	Paleosurfaces of basalt lithosols	Blue Mountains	Extremely Vulnerable
Platanthera chorisiana (Choris' bog-orchid)	G5/S1	BS, FS, WS	Bogs, wet meadows, stream banks, & seeps	N Cascades	Highly Vulnerable
Plectritis brachystemon (shortspur seablush)	G5?/S1?	FS, WS	Coastal bluffs, lowland prairies, & rocky balds	NW Coast, Puget Trough, E Cascades	Highly Vulnerable
Poa laxiflora (loose-flowered bluegrass)	G4G5/S2S3	FS, WS	Wet meadow edges, stream & river banks	NW Coast	Moderately Vulnerable
Polygonum austiniae (Austin's knotweed)	G5T4/S1	FS, WS	Dry lithosol flats & banks	E Cascades, Columbia Plateau, Blue Mountains	Highly Vulnerable

Polystichum californicum (California swordfern)	G4/S1	BS, FS, WS	Dry rocky cliffs & stream banks	W Cascades	Moderately Vulnerable
Potamogeton obtusifolius (bluntleaf pondweed)	G5/S2	FS, WS	Sloughs, flooded banks of lakes & streams	Puget Trough, N Cascades, Okanogan	Highly Vulnerable
Potentilla breweri (Brewer's cinquefoil)	G4/S1	BS, FS, WS	Margins of montane lakes & streams	NW Coast, E Cascades	Extremely Vulnerable
Potentilla nivea (snow cinquefoil)	G5/S2	BS, FS, WS	Alpine meadows & scree	Okanogan	Extremely Vulnerable
Ribes oxyacanthoides var. *irriguum* (Idaho gooseberry)	G5T4/S2	BS, FS, WS	Meadow openings along streams	Columbia Plateau, Blue Mountains	Extremely Vulnerable
Ribes wolfii (Wolf's currant)	G4/S2	FS, WS	Openings in fir-spruce forests	Blue Mountains	Highly Vulnerable
Sabulina basaltica (Olympic Mountain sandwort)	G2/S2	FS, WT	Basalt rock faces & crevices	NW Coast	Highly Vulnerable
Sabulina sororia (Twin Sisters sandwort)	G1/S1	FS, WE	Subalpine & alpine ultramafic slopes	N Cascades	Highly Vulnerable
Silene scouleri ssp. *scouleri* (Scouler's catchfly)	G5T3T5/S1	BS, FS, WS	Grassy bluffs & prairies, upland meadows	Puget Trough, E Cascades, Okanogan, Canadian RM, Columbia Plateau, Blue Mountains	Extremely Vulnerable
Sisyrinchium montanum var. *montanum* (strict blue-eyed-grass)	G5T5/S1	BS, FS, WS	Moist meadows, stream banks, & open woods	East Cascades, Canadian RM	Extremely Vulnerable

Cumulative Patterns of Vulnerability in Washington

A cumulative total of 187 taxa in Washington have now been assessed with the NatureServe Climate Change Vulnerability Index (CCVI), representing over 90% of Washington taxa listed by the Interagency Special Status/Sensitive Species Program (ISSSSP 2021). Most of these species rank as Moderately Vulnerable (n=90, 48%) or Highly Vulnerable (n=63, 34%). Only four taxa qualified as Less Vulnerable (2%) to climate change according to the CCVI, while 30 were determined to be Extremely Vulnerable (16%). Trends related to physiological and thermal niches, biological vulnerabilities, and geological restrictions across these taxa are largely congruent with the results discussed above for Phase IV and are not discussed in detail here, but comparisons are reviewed briefly below.

The cumulative analysis of vulnerabilities for ecological attributes across these 187 taxa (Table 5) shows that species with poor dispersal abilities, vulnerable historical or physiological thermal niches, and dependence on ice and snow were the mostly likely to rank highly. Pollinator limitation and low genetic variation (potential or recorded) were less influential but did increase the vulnerability rank for many taxa. Unlike the trends seen for Phase IV species, the cumulative results show that historical and physiological hydrological niches varied greatly across these species and did not strongly dictate whether a species ranked as Extremely or Highly Vulnerable. For example, 22 of the 30 taxa ranked as Extremely Vulnerable have experienced greater than average variation in precipitation (Neutral; Young et al. 2016) and 90% (10/11) of taxa which ranked as Greatly Increase for physiological hydrological niche still ranked as Moderately Vulnerable overall. Data on documented climate change responses were severely lacking for CCVI analyses, with most taxa ranking as "Unknown" or "Neutral" based on limited availability of trend data. Only 23 taxa ranked as Somewhat Increase or higher, and it should be noted that two of these species were among the four that ranked as Less Vulnerable overall to climate change.

Other significant trends identified in the distribution of climate change vulnerability across Washington (see Table 6) include the following:

- Extremely Vulnerable (EV) taxa were most frequently found in the relatively cold Okanogan and Canadian Rockies ecoregions and were proportionally more likely to occur in cold or wet ecological systems such as Forest and Shrub Swamps, Sparsely Vegetated Uplands (alpine), Alpine Vegetation, Marshes and Wet Meadows, and Riparian Areas. However, seasonally moist, low-elevation ecological systems such as Vernal Pools frequently ranked EV as well. Lower elevation systems in the arid Columbia Plateau, such as Sparsely Vegetated Uplands (non-alpine) and Upland Shrublands were least likely to rank EV. EV taxa were more often at the edge of their range in Washington (peripheral) than locally or regionally endemic.
- Highly Vulnerable (HV) taxa were associated with many ecoregions across Washington but were most frequently found on the Northwest Coast and in the Cascades (North and West). HV taxa were particularly associated with alpine and subalpine ecological systems including Sparsely Vegetated Uplands (alpine), Alpine Vegetation, and Subalpine-Montane Mesic Forests and Woodlands.

Associates of warmer, lower-elevation Upland Grasslands and Meadows also comprised a high proportion of HV taxa. Taxa that were found in the arid Columbia Plateau or that were associated with Upland Shrublands or Riparian Areas were proportionally least likely to rank as HV. Most HV species taxa were local or regional endemics.

- Moderately Vulnerable (MV) taxa were widespread across all ecoregions and most ecological systems but were particularly common to the Columbia Plateau and West Cascades in Aquatic Vegetation & Exposed Flats, Interior Alkaline Wetlands, Sand Dune Vegetation, and Tidal/Coastal Wetlands. Taxa associated with the wet Northwest Coast ecoregion or cold alpine ecosystems (Sparsely Vegetated Uplands (alpine) and Alpine Vegetation) were proportionally least likely to rank as MV. Locally endemic taxa were also least likely to rank as MV.
- Less Vulnerable (LV) taxa included only four species: *Nicotiana attenuata*, *Leptosiphon bolanderi*, *Allium campanulatum*, and *Polemonium carneum*. These taxa were found across multiple ecoregions, including the East Cascades, Columbia Plateau, Northwest Coast and Puget Trough and were associated with lower-elevation ecological systems including Upland Grasslands and Meadows, Dry Forests and Woodlands, and Upland Shrublands/Shrub-Steppe. LV taxa were not especially associated with a particular distribution pattern.

Table 4. Comparison of Selected Variables in Climate Change Vulnerability Index scores for 187 Washington rare plant taxa assessed in Phases I, II, III, & IV.

An * indicates species assessed in Phase IV. See sample CCVI reports in Appendix A for complete list of all variables used and Young et al. (2016) for scoring criteria. CCVI scores: EV = Extremely Vulnerable, HV = Highly Vulnerable, LV = Less Vulnerable, M = Moderately Vulnerable. The categories used in the CCVI are simplified here as Disp = Dispersal and Movements. Hist Therm = Historical Thermal Niche. Phys Therm = Physiological Thermal Niche. Hist Hydr = Historical Hydrological Niche. Phys Hydr = Physiological Hydrological Niche. Ice/Snow = Dependence on ice or snow-covered habitats. Geol = Restricted to uncommon landscape/geological features. Genes = combination of 3 criteria: Measured genetic variation, genetic bottlenecks, and reproductive system. Sub-rank scoring: GI = Greatly Increase Vulnerability; I = Increased Vulnerability, SI = Somewhat Increased Vulnerability; N = Neutral vulnerability, Unk = Unknown. Geographic distribution (Dist) is evaluated as follows (sensu Fertig 2021b): LocEnd= < 6,370 mi^2 (16,500 km^2), average county size. RegEnd= 6,370 to 96,525 mi^2 (16,500 to 250,000 km^2), ~ size of Washington. Disjunct= isolated from main range by 310 mi (500 km) or more. Periph= Washington populations at edge of main range. Sparse= < 20 populations across Washington. Widesp= > 20 populations across Washington.

Species (Common Name)	**CCVI Score**	**Dist**	**Disp**	**Hist Therm**	**Phys Therm**	**Hist Hydr**	**Phys Hydr**	**Ice/Snow**	**Geol**	**Genes**
Achnatherum richardsonii (Richardson's needlegrass)*	MV	Periph	N	N	N	N	SI	N	SI	N
Actaea laciniata (Mt. Hood bugbane)*	HV	RegEnd	I	I	SI	N	I	N	N	SI
Agoseris aurantiaca var. *carnea* (pink Agoseris)*	EV	Sparse	N	SI	I	N	I	SI	N	N
Agrostis mertensii (northern bentgrass)*	EV	Periph	SI	SI	I	N	SI	I	I	SI
Allium campanulatum (Sierra onion)	LV	Periph	SI	SI	N	N	N	N	N	N
Allium constrictum (constricted onion)	MV	LocEnd	SI	N	N	SI	GI	N	SI	SI
Anemone patens var. *multifida* (pasqueflower)	HV	Periph	I	SI	SI	N	SI	SI	SI	SI
Antennaria corymbosa (meadow pussytoes)*	HV	Periph	SI	SI	SI	N	GI	SI	SI	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Arabis olympica (Olympic rockcress)	HV	RegEnd	SI	SI	I	N	SI	I	SI	I
Arcteranthis cooleyae (Cooley's buttercup)	MV	Periph	SI-I	SI	I	N	SI	SI	SI	N
Astragalus arrectus (Palouse milkvetch)	MV	RegEnd	SI	N	N	SI	SI	N	N	N
Astragalus arthuri (Arthur's milkvetch)	MV	RegEnd	SI	N	N	SI	SI	N	N	N
Astragalus asotinensis (Asotin milkvetch)	HV	LocEnd	SI	N	N	SI	SI	N	I	N
Astragalus australis var. *cottonii* (Cotton's milkvetch)	HV	LocEnd	I	GI	I	N	SI	SI	SI	SI
Astragalus columbianus (Columbia milkvetch)	MV	LocEnd	SI	N	N	I	SI	N	N	N
Astragalus microcystis (least bladdery milkvetch)	MV	Sparse	SI	N-SI	SI-I	N	SI-I	SI	N-SI	N
Astragalus misellus var. *pauper* (pauper milkvetch)	MV	RegEnd	SI	N	N	I	SI	N	N-SI	N
Bolandra oregana (Oregon bolandra)	MV	RegEnd	N	I	SI	N	I	N	SI	U
Botrychium hesperium (western moonwort)	MV	Sparse	SI	N-SI	N	N	N	N-SI	N	SI
Botrychium lineare (skinny moonwort)	HV	Periph	SI	N	SI	N	SI	N	N	SI

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Botrychium michiganense (Michigan moonwort)*	HV	Periph	SI	N	SI	N	SI	N	N	N
Botrychium paradoxum (two-spiked moonwort)	MV	Sparse	SI	N-SI	N	N	N	N-SI	N	SI
Botrychium pedunculosum (stalked moonwort)	MV	Sparse	SI	N-SI	N	N-SI	N	N	N	SI
Calochortus macrocarpus var. *maculosus* (sagebrush lily)	MV	RegEn d	I	N-SI	N	N-SI	N	N	N	U
Campanula lasiocarpa (Alaska harebell)*	MV	Periph	SI	SI-I	I	N	SI	SI	N	N
Carex anthoxanthea (Yellow-flowered sedge)	MV	Periph	SI	GI	SI	N	SI	I	N	N
Carex chordorrhiza (Cordroot sedge)	HV	Periph	SI	I	SI	N	SI	I	N	N
Carex circinata (coiled sedge)	MV	Periph	SI	GI	I	N	SI	I	N	N
Carex gynocrates (yellow bog sedge)	EV	Periph	SI	N	SI	N-SI	I	SI	I	N
Carex heteroneura (smooth-fruited sedge)	HV	Sparse	SI	SI	I	N	I	SI	SI	SI
Carex media (intermediate sedge)*	EV	Sparse	SI	SI	SI	N	I	N	SI	N
Carex obtusata (blunt sedge)*	HV	Periph	SI	GI	I	N	SI	I	N	N
Carex pauciflora (few-flowered sedge)	HV	Sparse	SI-I	I	SI	N	I	SI	N	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Carex proposita (Smoky Mountain sedge)	MV	Disjunct	SI	SI	I	N	SI	I	N	N
Carex rostrata (Beaked sedge)	HV	Sparse	SI	N	I	N	I	N-SI	N	N
Carex scirpoidea ssp. *scirpoidea** (Canadian single-spike sedge)	EV	Periph	SI	SI	SI	N	I	I	N	N
Carex stylosa (long styled sedge)	HV	Sparse	SI	I-GI	SI	N	I	SI	N	SI-I
Carex sychnocephala (Many-headed sedge)	MV	Sparse	SI	SI	I	N	I	SI	SI	SI
Carex tenera var. *tenera* (quill sedge)*	EV	Sparse	SI	N	SI	N	I	N	N	N
Carex tenuiflora (Sparse-flowered sedge)	HV	Periph	SI-I	I	SI	N	I	SI	N	N
Carex vallicola (valley sedge)	HV	Periph	SI	SI	I	N	SI	I	N	N
Cassiope lycopodioides (clubmoss cassiope)*	EV	Periph	I	I	I	N	I	N-SI	N	N
Castilleja cryptantha (obscure paintbrush)	HV	LocEnd	SI	N	I	N	I	N-SI	N	N
Castilleja levisecta (Golden paintbrush)	HV	RegEnd	I	SI	N	N	N	N	N	N
Chaenactis thompsonii (Thompson's chaenactis)	MV	LocEnd	SI	SI	I	N	SI	SI	I	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Chrysolepis chrysophylla var. *chrysophylla* (Golden chinquapin)	MV	Periph	SI	I	N	N	N	N	N	SI
Chrysosplenium tetrandrum (Northern golden-carpet)	MV	Periph	SI	I	SI	N	SI	N	N	SI
Cicuta bulbifera (bulb-bearing water hemlock)	MV	Sparse	SI	N	I	N	SI	N-SI	N	SI
Cirsium remotifolium var. *remotifolium* (weak thistle)*	HV	Periph	N	I	N	N	SI	N	N	N
Claytonia multiscapa ssp. *pacifica* (Pacific lanceleaved springbeauty)*	HV	RegEn d	I	I	I	N	I	I	N	N
Collinsia sparsiflora var. *sparsiflora* (few-flower blue-eyed Mary)*	EV	Periph	SI	SI	N	N	I	N	SI	SI
Coptis aspleniifolia (spleenwort-leaved goldthread)	MV	Sparse	I	I	SI	N	SI	SI	N	N
Coptis trifolia (threeleaf Goldenthread)	HV	Periph	SI	GI	I	N	GI	N	N	U
Cryptantha leucophaea (Gray cryptantha)	MV	RegEn d	N	N	N	I	N	N	I	N
Cryptantha rostellata (beaked cryptantha)	MV	RegEn d	SI	N	N	SI	N	N	N	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Cryptantha spiculifera (Snake River cryptantha)	MV	Sparse	SI	N	N	SI	I	N	N	N
Cryptogramma stelleri (Steller's rockbrake)*	EV	Periph	SI	SI	I	N	SI	SI	SI	N
Cypripedium parviflorum (Yellow lady's-slipper)	MV	Sparse	N	N	SI	SI	SI	SI	N	N
Dactylorhiza viridis (frog orchid)	HV	Periph	N	N	SI	SI	I	SI	N	N
Damasonium californicum (fringed water-plantain)	MV	Periph	N	N	SI	SI	I	N-SI	N	N
Dendrolycopodium dendroid eum (tree clubmoss)	MV	Sparse	N-SI	I	SI	N	SI	SI	N	N-SI
Draba aurea (golden draba)*	HV	Periph	N	I	I	N	SI	I	N	N
Draba cana (lance-leaved draba)	EV	Periph	SI	I	I	N	SI	I	SI	N-SI
Draba taylorii (Taylor's draba)	HV	LocEn d	SI-I	SI	GI	N	SI	I	SI	Inc
Dryopteris cristata (crested shield-fern)*	EV	Periph	N	N	SI	N	I	N	SI	N
Eleocharis mamillata ssp. *mamillata* (soft-stemmed spikerush)*	HV	Periph	N	I	I	N	I	N	N	U
Eleocharis rostellata (smooth-fruited sedge)	MV	Sparse	SI	N	N	SI-I	SI	N-SI	I	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Epilobium mirabile (Olympic Mountain willowherb)*	HV	RegEnd	N	I-GI	SI-I	N	SI	N-SI	N-SI	SI
Erigeron aliceae (Eastwood's daisy)	MV	RegEnd	N	GI	I	N	SI	SI	N	N
Erigeron basalticus (basalt daisy)	MV	LocEnd	N	N	SI	I	I	N	I	N
Erigeron salishii (Salish fleabane)	MV	RegEnd	N	SI	GI	N	N	SI	N	N
Eriogonum codium (Umtanum desert buckwheat)	MV	LocEnd	SI	N	N	GI	I	N	I	N
Eriophorum viridicarinatum (Green-keeled cottongrass)	MV	Periph	N	N	SI	N	N	SI	SI	N
Eritrichium argenteum (pale alpine forget-me-not)	HV	Disjunct	I	SI	GI	N	SI	I	I	SI
Eryngium petiolatum (Oregon coyote-thistle)	MV	RegEnd	N	I	SI	N	I	N-SI	N-SI	N
Erythranthe pulsiferae (candelabrum monkeyflower)	MV	Sparse	N-SI	SI	SI	N	I	N-SI	N	N-SI
Erythranthe suksdorfii (Suksdorf's monkeyflower)*	EV	Sparse	SI	N	N	I	SI	N	SI	SI
Eurybia merita (subalpine aster)*	HV	Periph	N	SI	I	N	SI	SI	SI	N
Fritillaria camschatcensis (black lily)	MV	Periph	I	N-SI	SI-I	N	SI	N	N	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Gaultheria hispidula (Creeping snowberry)	MV	Periph	SI	N-SI	I	N	SI	SI	N	N
Gentiana douglasiana (swamp gentian)	HV	Periph	SI	GI	GI	N	GI	SI	N-SI	N
Gentiana glauca (glaucus gentian)*	EV	Periph	SI	I	I	N	SI	I	N	SI
Geum rivale (water avens)*	EV	Periph	SI	N	SI	N	I	N	I	N
Geum rossii var. *depressum* (Ross' avens)	HV	LocEnd	I	SI	GI	N	SI	Inc	I	N-SI
Githopsis specularioides (common bluecup)*	HV	Sparse	I	SI	N	N	SI	N	N	N
Hackelia cinerea (gray stickseed)*	HV	Periph	SI	N	N	SI	SI	SI	N	N
Hackelia hispida var. *disjuncta* (sagebrush stickseed)	MV	LocEnd	SI	N	N	I	SI	N	N	N
Hackelia taylorii (Taylor's stickseed)	HV	LocEnd	SI	SI	I	N	N	I	I	SI
Hedysarum occidentale (western hedysarum)*	HV	Sparse	SI	I	I	N	SI	SI	N	SI
Heterotheca oregona (Oregon goldenaster)	MV	Sparse	N	SI	SI	N	SI	SI	N	N
Howellia aquatilis (Water howellia)	EV	Sparse	I	SI	N	SI	GI	N	N	SI

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Hypericum majus (Canadian St. John's-wort)*	EV	Sparse	SI	N	SI	N	I	N	N	U
Impatiens noli-tangere (Western jewelweed)	MV	Sparse	I	I	SI	N	SI	SI	N	N
Isoetes minima (midget quillwort)*	EV	RegEnd	SI	SI	SI	SI	I	N	N	N
Isoetes nuttallii (Nuttall's quillwort)*	EV	Sparse	SI	SI	N	N	I	N	SI	N
Juncus howellii (Howell's rush)	MV	Sparse	N	SI	SI	N	SI	SI	N	N
Juncus tiehmii (Tiehm's rush)*	MV	Disjunct	SI	N	N	SI	I	N	N	N
Juncus uncialis (inch-high rush)	MV	Sparse	N	N	N-SI	SI	GI	SI	I	N
Kalmia procumbens (Alpine azalea)	EV	Periph	SI	I	I	N	N	GI	N	SI
Lathrocasis tenerrima (delicate gilia)*	HV	Sparse	SI	N	N	SI	SI	N	N	N
Leptosiphon bolanderi (Bolander's linanthus)	LV	Periph	N-SI	N	N-SI	N	N	N-SI	N	SI
Lomatium bradshawii (Bradshaw's lomatium)	MV	RegEnd	SI	I	N	N	I	N	N	N
Lomatium knokei (Knoke's biscuitroot)	HV	LocEnd	I	SI	SI	N	I	SI	I	N
Lomatium laevigatum (smooth desert-parsley)*	MV	LocEnd	I	N	N	SI	N-SI	N	N-SI	I

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Lomatium lithosolamans (Hoover's biscuitroot)	MV	LocEnd	I	N	N	SI	I	N	N-SI	N
Lomatium rollinsii (Rollins' desert-parsley)*	EV	RegEnd	I	N	N	SI	SI	N	N-SI	I
Lomatium roneorum (Lomatium roneorum)*	HV	LocEnd	GI	N-SI	N	N	SI	N	I	N
Lomatium serpentinum (Snake Canyon biscuitroot)	HV	RegEnd	SI-I	N	SI	SI	SI	N	N	I
Lomatium tuberosum (Hoover's desert-parsley)	MV	RegEnd	I	N	N	I	I	N	N-SI	N
Luzula arcuata ssp. *unalaschcensis* (curved woodrush)	HV	Sparse	SI	I	GI	N	N-SI	I	SI	N
Lycopodiella inundata (bog clubmoss)	MV	Sparse	N	GI	SI	N	SI	N	N	U
Lycopodium lagopus (one-cone clubmoss)*	MV	Disjunct	N	SI	SI	N	I	N	SI	U
Malaxis monophyllos var. *brachypoda* (white adder's-mouth orchid)*	EV	Periph	N	I	I	N	I	N	SI	SI
Micranthes tischii (Olympic saxifrage)	HV	RegEnd	I	GI	GI	N	SI	I	SI	N
Microseris borealis (northern microseris)	MV	Sparse	N	GI	SI	N	SI	N	N	U
Montia diffusa (branching montia)*	HV	RegEnd	SI	I	N	N	SI	N	N	N

Species (Common Name)	**CCVI Score**	**Dist**	**Disp**	**Hist Therm**	**Phys Therm**	**Hist Hydr**	**Phys Hydr**	**Ice/Snow**	**Geol**	**Genes**
Muhlenbergia glomerata (Marsh muhly)	MV	Periph	N	N	SI	N	SI	I	N	N
Myosurus alopecuroides (foxtail mousetail)	MV	Sparse	N	N	N-SI	SI	GI	N-SI	I	SI
Navarretia leucocephala ssp. *diffusa* (diffuse navarretia)	HV	LocEn d	SI	N	SI	SI	GI	N-SI	I	N
Navarretia tagetina (Marigold pincushion-plant)	MV	Periph	N	SI	N-SI	N	GI	SI	I	N
Nicotiana attenuata (Coyote tobacco)	LV	Sparse	SI	N	N	SI	N	N	N	N
Ophioglossum pusillum (adder's-tongue)*	HV	Sparse	N	N	SI	N	I	N	N	SI
Orthocarpus bracteosus (rosy owl's-clover)	HV	RegEn d	I	SI	SI	N	I	N-SI	N	N
Oxytropis campestris var. *gracilis* (slender crazyweed)*	HV	Sparse	I	SI	N	N	SI	N	SI	N
Oxytropis campestris var. *wanapum* (Wanapum crazyweed)	MV	LocEn d	I	N	N	I	I	N	I	N
Packera bolanderi var. *harfordii* (Harford's ragwort)*	HV	RegEn d	N	I	SI	N	SI	N	N	N
Packera porteri (Porter's butterweed)	HV	Disjunct	N	I	GI	N	N	SI	SI	SI

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Parnassia kotzebuei (Kotzebue's grass-of-Parnassus)	HV	Periph	SI	I	GI	N	SI	SI	SI	N-SI
Parnassia palustris (marsh grass-of-Parnassus)*	HV	Periph	SI	I	SI	N	I	N	SI	N
Pedicularis pulchella (mountain lousewort)*	EV	Disjunct	I-GI	SI	I	N	SI	SI	N	N
Pedicularis rainierensis (Mt. Rainier lousewort)	HV	LocEn d	SI	I	I	N	SI	I	SI	N
Pediocactus nigrispinus (Snowball cactus)	MV	RegEn d	SI	N	N	I	I	N-SI	N	N
Pellaea brachyptera (Sierra cliffbrake)*	MV	Disjunct	N	N	N	N	N	N	N	SI
Pellaea breweri (Brewer's cliffbrake)	MV	Sparse	SI	SI	SI	N	SI	SI	N	N-SI
Penstemon eriantherus var. *whitedii* (Whited's fuzzytongue beardtongue)	MV	RegEn d	SI	N	SI	SI	SI	N-SI	N-SI	N
Penstemon pennellianus (Blue Mountain penstemon)*	MV	RegEn d	I	SI	N	N	N	N	N	N
Penstemon wilcoxii (Wilcox's beardtongue)	MV	RegEn d	SI	N	SI	N-SI	SI	SI	N	N
Petrophytum caespitosum ssp. *caespitosum* (Rocky Mountain rockmat)	HV	Periph	SI	N	SI	SI	SI	N	I	SI

Species (Common Name)	**CCVI Score**	**Dist**	**Disp**	**Hist Therm**	**Phys Therm**	**Hist Hydr**	**Phys Hydr**	**Ice/Snow**	**Geol**	**Genes**
Petrophytum cinerascens (Chelan rockmat)	MV	LocEnd	SI	N	SI	SI	I	N	I	N
Phacelia lenta (Sticky phacelia)	MV	LocEnd	SI	N	SI	SI	I	N	I	N-SI
Phlox solivaga (yeti phlox)*	EV	LocEnd	I-GI	SI	N	N-SI	SI	N-SI	SI-I	SI
Pilularia americana (American pillwort)	MV	Disjunct	N	N	SI	SI	GI	N-SI	I	U
Platanthera chorisiana (Choris' bog-orchid)*	HV	Periph	N	SI-I	SI	N	I	N	SI	SI
Plectritis brachystemon (shortspur seablush)*	HV	Sparse	SI	I	N	N	N	N	N	I
Poa laxiflora (loose-flowered bluegrass)*	MV	Sparse	N	I	SI	N	SI	N	N	U
Polemonium carneum (Great polemonium)	LV	RegEnd	SI	I	N	N	N	N	N	N
Polemonium viscosum (sticky sky-pilot)	EV	Periph	I	I	G Inc	N	SI	I	I	SI
Polyctenium fremontii (Fremont's combleaf)	MV	Disjunct	SI	N	N	SI	GI	N	SI	N-SI
Polygonum austiniae (Austin's knotweed)*	HV	Sparse	I	SI	N	N-SI	N	N	N	N
Polystichum californicum (California swordfern)*	MV	Sparse	N	I	N	N	SI	N	SI	SI
*Potamogeton obtusifolius (bluntleaf pondweed)**	MV	Sparse	N	I	N	N	SI	N	N	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Potentilla breweri (Brewer's cinquefoil)*	EV	Sparse	SI	I	SI	N	SI	SI	N	I
Potentilla nivea (snow cinquefoil)*	EV	Periph	SI	SI-I	GI	N	SI	SI	N	SI-I
Pyrrocoma hirta var. *sonchifolia* (Sticky goldenweed)	MV	RegEnd	N	SI	SI	N	SI	SI	N	N
Ranunculus californicus (California buttercup)	MV	Periph	SI	GI	N	N	SI	N	SI	SI
Ranunculus populago (Mountain buttercup)	MV	Sparse	SI	SI	SI	N	SI	SI	N	N
Ribes cereum var. *colubrinum* (wax currant)	HV	RegEnd	N-SI	N	SI	SI	I	N-SI	N	N
Ribes oxyacanthoides var. *irriguum* (Idaho gooseberry)*	EV	RegEnd	SI	N	N	N	SI	N	N-SI	N
Ribes wolfii (Wolf's currant)*	MV	Periph	SI	SI	N	N	SI	SI	N	N
Rubus arcticus ssp. *acaulis* (Nagoonberry)	MV	Periph	N	SI	SI	N	SI	SI	N	SI
Sabulina basaltica (Olympic Mountain sandwort)*	HV	LocEnd	I	GI	SI	N	SI	N	SI	N
Sabulina nuttallii var. *fragilis* (Nuttall’s sandwort)	MV	Periph	SI	N	N	I	I	N	N	N
Sabulina sororia (Twin Sisters sandwort)*	HV	LocEnd	I	I	SI	N	SI	N	I	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Salix candida (Hoary willow)	HV	Periph	N	N	GI	N	SI	I	SI	N
Salix glauca var. *villosa* (Glaucous willow)	MV	Periph	N	SI	I	N	SI	I	N	N
Salix maccalliana (MacCalla's willow)	HV	Periph	N	N	I	N	SI	I	I	N
Salix pseudomonticola (False mountain willow)	MV	Periph	N	N	I	N	SI	I	SI	N
Sanicula arctopoides (bear's-foot sanicle)	MV	Sparse	N	GI	N	N	SI	N	SI	N
Saxifraga cernua (Nodding saxifrage)	HV	Periph	I	I	GI	N	SI	SI	N	N
Scribneria bolanderi (Scribner's grass)	MV	Periph	N	SI	N-SI	N	GI	SI	U	N
Sericocarpus oregonensis ssp. *oregonensis* (Oregon white-topped aster)	MV	RegEnd	N	SI	N	N	N	N	N	N
Sidalcea oregana var. *calva* (Wenatchee Mts checkermallow)	HV	LocEnd	SI	SI	N	N	I	SI	N	N
Silene scouleri ssp. *scouleri* (Scouler's catchfly)*	EV	Sparse	I	SI	N	SI	N	N	N	SI
Silene seelyi (Seely's catchfly)	MV	LocEnd	I	SI	I	N	SI	SI	SI	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Sisyrinchium montanum var. *montanum* (strict blue-eyed-grass)*	EV	Periph	I	N	N	N	I	N	SI	SI
Sisyrinchium sarmentosum (pale blue-eyed grass)	HV	Periph	N	I	SI	N	GI	SI	N	SI
Spartina pectinata (prairie cordgrass)	MV	Sparse	N	N	SI	SI	GI	SI	N	N
Spiranthes porrifolia (western ladies' tresses)	MV	Sparse	N	SI	SI	N	GI	N-SI	N	U
Sullivantia oregana (Oregon coolwort)	MV	LocEn d	N	I	SI	N	GI	N	I	U
Swertia perennis (Swertia)	MV	Periph	SI	SI	I	N	SI	SI	SI	N
Symphyotrichum boreale (rush aster)	MV	Periph	N	SI	SI	N	SI	N-SI	N	U
Thelypodium sagittatum ssp. *sagittatum* (Arrow thelypody)	MV	Disjunct	SI	N	N	SI	I	N	SI	N
Triglochin palustris (marsh arrowgrass)	EV	Periph	SI	N	SI	N-SI	I	SI	I	N
Trillium albidum ssp. *parviflorum* (small-flowered trillium)	MV	RegEn d	I	I	SI	N	SI	N	N	SI
Utricularia intermedia (flat-leaved bladderwort)	MV	Sparse	N-SI	I-GI	SI	N	I	SI	N	N
Vaccinium myrtilloides (Velvetleaf blueberry)	MV	Periph	N	N	I	SI	SI	SI	SI	N

Species (Common Name)	CCVI Score	Dist	Disp	Hist Therm	Phys Therm	Hist Hydr	Phys Hydr	Ice/Snow	Geol	Genes
Veronica dissecta var. *lanuginosa* (woolly kittentails)	HV	LocEnd	I	GI	I	N	SI	SI	I	SI

Table 5. Summary of Climate Change Vulnerability Index Results for 187 Washington Rare Plant Taxa Assessed from 2019-2024 based on Selected Ecological Attributes. See sample CCVI reports in Appendix A for complete list of all variables used and Young et al. (2016) for scoring criteria.
CCVI scores: EV = Extremely Vulnerable, HV = Highly Vulnerable, LV = Less Vulnerable, M = Moderately Vulnerable

Ecological Attribute/Score	**CCVI Result (Number of Species)**			
	EV	**HV**	**MV**	**LV**
Dispersal				
Greatly Increase (n = 3)	2	1	0	0
Increase (n = 39)	6	21	12	0
Somewhat Increase (n =92)	19	28	42	4
Neutral (n = 52)	3	13	36	0
Historical Thermal Niche				
Greatly Increase (n= 17)	0	9	8	0
Increase (n =44)	8	21	14	1
Somewhat Increase (n = 61)	12	18	30	1
Neutral (n = 65)	10	15	38	2
Physiological Thermal Niche				
Greatly Increase (n = 13)	2	10	1	0
Increase (n = 42)	9	17	16	0
Somewhat Increase (n = 73)	10	24	38	1
Neutral (n = 59)	9	12	35	3
Historical Hydrological Niche				
Greatly Increase (n = 1)	0	0	1	0
Increase (n = 11)	1	0	10	0
Somewhat Increase (n = 40)	7	9	23	1
Neutral (n = 135)	22	54	56	3
Physiological Hydrological Niche				
Greatly Increase (n = 16)	1	5	10	0
Increase (n = 53)	15	17	21	0
Somewhat Increase (n = 95)	12	36	47	0
Neutral (n = 23)	2	5	12	4
Dependence on Ice/Snow				
Greatly Increase (n = 1)	1	0	0	0
Increase (n =26)	5	15	6	0
Somewhat Increase (n = 77)	9	25	42	1
Neutral (n = 83)	15	23	42	3
Uncommon Geologic Feature				
Increase (n = 30)	6	11	13	0

Somewhat Increase (n = 53)	11	19	23	0
Neutral (n = 103)	13	33	53	4
Unknown (n = 1)	0	0	1	0
Pollinator Versatility				
Increase (n = 3)	1	1	1	0
Somewhat Increase (n = 18)	7	7	4	0
Neutral (n = 130)	21	43	63	3
Unknown (n = 35)	0	12	22	1
Genetic Variability or Breeding System				
Increase (n = 8)	3	4	1	0
Somewhat Increase (n = 49)	12	17	19	1
Neutral (n = 116)	14	39	60	3
Documented Response to Recent Climate Change				
Increase (n = 1)	0	1	0	0
Somewhat Increase (n = 21)	1	9	9	2
Neutral (n = 92)	1	22	68	1
Unknown (n = 72)	28	31	12	1

Table 6. Summary of Climate Change Vulnerability Index Results for 187 Washington Rare Plant Taxa Assessed in 2019-2024 Based on Ecoregion, Distribution Pattern, and Aggregated Ecological Systems (as described by Rocchio and Crawford 2015).

Attribute	CCVI Result (Number of Species)			
	EV	**HV**	**MV**	**LV**
Ecoregion				
Blue Mountains (n =18)	3	6	9	0
Canadian Rockies (n = 31)	9	8	14	0
Columbia Plateau (n = 47)	6	7	33	1
East Cascades (n = 60)	12	18	27	3
North Cascades (n = 28)	5	10	13	0
Okanogan (n = 62)	18	20	24	0
Pacific NW Coast (n = 36)	4	18	13	1
Puget Trough (n = 31)	5	11	14	1
West Cascades (n = 27)	0	10	17	0
Distribution Pattern				
Local Endemic (n = 28)	1	14	13	0
Disjunct (n = 10)	1	2	7	0
Peripheral (n= 65)	16	0	23	2
Regional Endemic (n = 34)	3	11	19	1
Sparse (n = 50)	9	12	28	1
Aggregated Ecological Systems				
Alpine Vegetation (n= 21)	6	12	3	0
Aquatic Vegetation & Exposed Flats (n = 2)	0	0	2	0
Dry Forests & Woodlands (n = 12)	0	4	6	2
Forested & Shrub Swamps (n = 3)	2	0	1	0
Interior Alkaline Wetlands (n = 2)	0	0	2	0
Lowland & Foothill Mesic Forests & Woodlands (n = 2)	0	0	1	1
Marshes & Wet Meadows (n = 45)	11	11	23	0
Peatlands (n = 35)	6	13	16	0
Riparian Areas (n = 18)	4	2	11	1
Sand Dune Vegetation (n = 2)	0	0	2	0
Shrub-Steppe (n = 9)	0	2	6	1
Sparsely Vegetated Upland Types (n =52)	8	20	24	0
Sparsely Vegetated Upland (alpine) (n = 23)	7	12	4	0
Sparsely Vegetated Upland (non- alpine) (n = 32)	2	10	20	0
Subalpine-Montane Mesic Forests & Woodlands (n = 6)	0	3	3	0
Tidal/Coastal Wetlands (n = 1)	0	0	1	0
Upland Grasslands & Meadows (n = 25)	5	11	8	1
Upland Shrublands (n = 9)	1	1	6	1
Vernal Pools (n = 17)	5	2	10	0

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Appendix A. Climate Change Vulnerability Index reports for 60 Washington Rare Plant Species Assessed in Phase IV

Climate Change Vulnerability Index Report

*Achnatherum richardsonii (***Richardson's needlegrass***)*

Date: 14 May 2024 Synonym: *Stipa richardsonii, Eriocoma richardsonii*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S1
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	17
	-0.097 to -0.119	66
	-0.074 to - 0.096	17
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All six known occurrences (100%) of *Achnatherum richardsonii* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

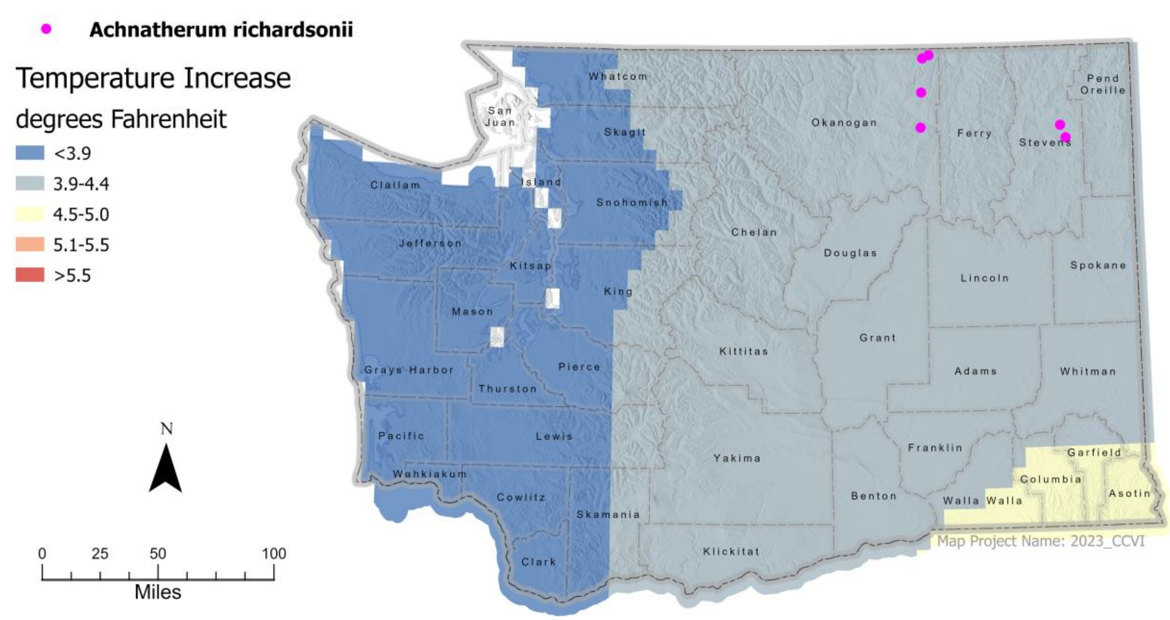

Figure 1. Exposure of *Achnatherum richardsonii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the six known occurrences (17%) of *Achnatherum richardsonii* in Washington, one is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) less than -0.119.

Another four (66%) are found in areas with a projected moisture decrease in the range of -0.097 to -0.119 (Figure 2). The remaining occurrence (17%) is found in an area with a projected decrease in the range of -0.074 to -0.096.

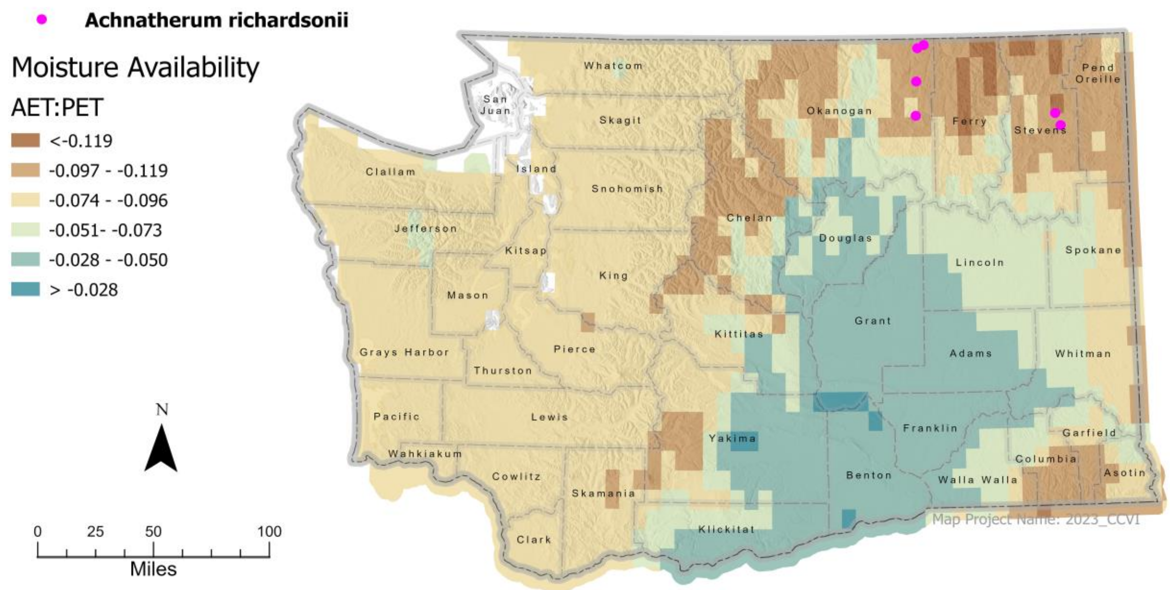

Figure 2. Exposure of *Achnatherum richardsonii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Achnatherum richardsonii occurs in intermontane grassland basins and meadows on ridgetops at mid elevations (2400-5150 ft (730-1570 m)) east of the Cascade crest (Washington Natural Heritage Program 2023). *Achnatherum richardsonii* occurrences in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2024)

B2a. Natural barriers: <u>Somewhat Increase</u>
The sub-mesic to dry meadow habitats that support *Achnatherum richardsonii* are naturally patchy within a larger matrix of pine or fir forest (Esser 1992, Washington Natural Heritage Program 2023). These Northern Rocky Mountains Dry-Mesic Montane Mixed Conifer Forest and Northern Rocky Mountains Lower Montane Foothill & Valley Grassland ecological systems are widespread along the northern border of Washington but occurrences in forest clearings are separated by 3-71 mi (5-114 km) of unsuitable habitat across separate mountain ranges,

including upland forests and canyons (Rocchio and Crawford 2015). This patchiness probably creates barriers to dispersal or migration that are relatively minimal.

B2b. Anthropogenic barriers: Neutral
There is a relatively minimal amount of development and agricultural land surrounding the Washington occurrences of *Achnatherum richardsonii*, except for one historical occurrence near Little Pend Oreille National Wildlife Refuge. Road development and logging are also somewhat common in the forested areas (Rocchio and Crawford 2015). Overall, fragmentation remains minimal and poses little barriers to dispersal of the species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the occurrences of *Achnatherum richardsonii* (Washington Department of Natural Resources 2024), and any potential forest health treatments would likely benefit this species, which prefers forest clearings.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
The seeds of *Achnatherum richardsonii* are medium sized and weighted cylindrical 1-seeded caryopsis fruits (Pinto et al. 2014). The caryopsis has attached long, twisted awns that expand and contract with moisture changes to drill into the soil surface (Esser 1992). They are also adapted for long-distance dispersal via wind and epizoochory (external attachment to animals). The inflorescence of this species can also release whole and tumble along the ground. This species is capable of long-distance dispersal (probably over ½ mi or 1 km).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Achnatherum richardsonii* occurrences in Washington. All six known occurrences (100%) are in areas that have experienced average (>57.1°F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these occurrences are expected to be mostly resilient to warming.

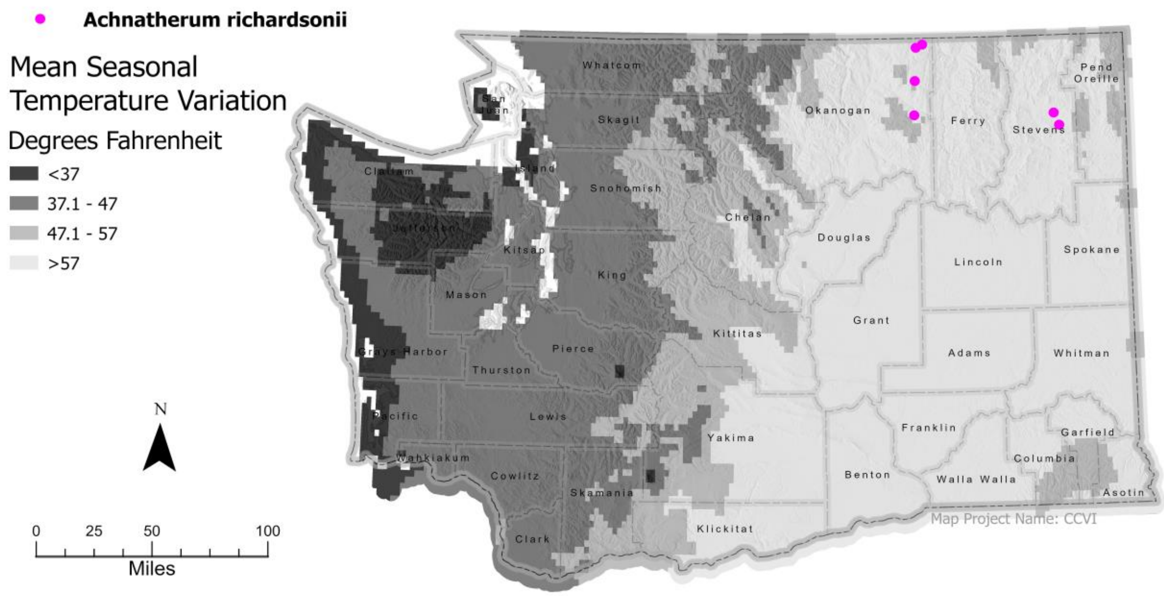

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Achnatherum richardsonii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Achnatherum richardsonii commonly occurs on south-facing, warm, dry sites within a larger cool valley matrix in the subalpine (Esser 1992) but tolerates a range of mesic to arid conditions. The ridgetops and slopes where it occurs are not associated with cold air drainages but basins may be. Increased temperatures will lead to more drought, insect outbreaks, and fire, and may combine with moisture stress to limit the adaptive capacity of component grasses in the ecological systems that support *Achnatherum richardsonii* but are expected to have a relatively low impact (Rocchio and Ramm-Granberg 2017). As a cool-season graminoid, *Achnatherum richardsonii* may be more sensitive to increasing temperatures and lengthening warm/drought conditions. However, one outplanting study found this species to prefer establishing under warmer spring conditions (Page and Bork 2005).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Achnatherum richardsonii* occurrences in Washington. Of the six known occurrences, four (67%) are in areas that have experienced slightly lower than average (11 - 20 in (255 - 508 mm)) precipitation variation over the historical period. According to Young et al. (2016) these occurrences are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The other two occurrences (33%) are in areas that have experienced average or greater than average

precipitation variation (>20 in/508 mm) over the historical period and are likely to be resilient to climate change induced shifts to precipitation and moisture regimes (Young et al. 2016).

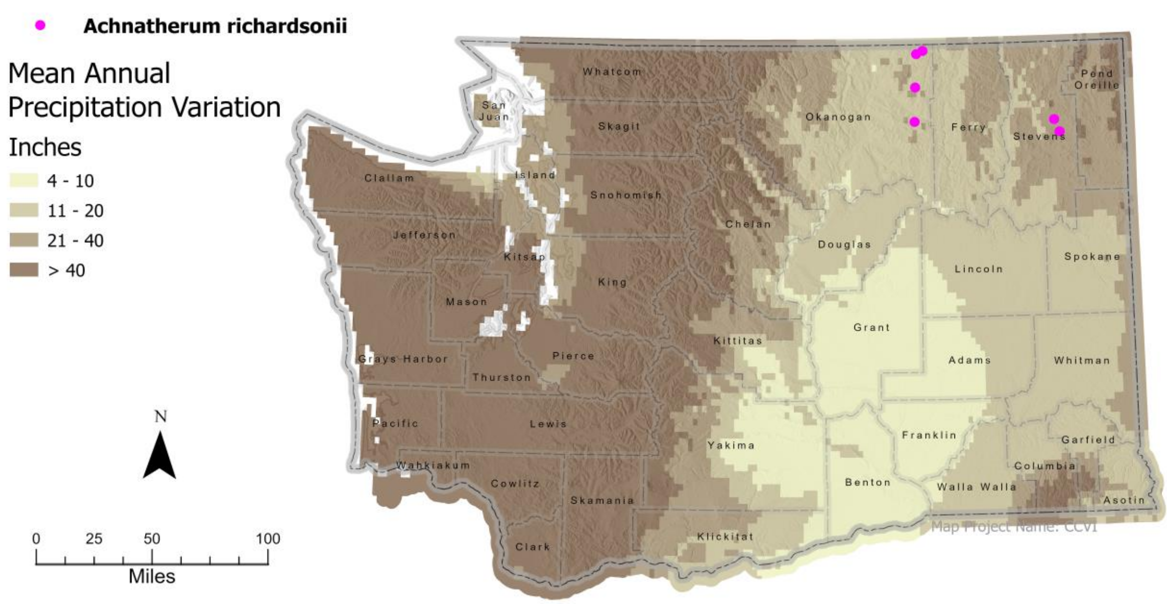

Figure 3. Historical hydrological niche (exposure to past variations in precipitation) of *Achnatherum richardsonii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
Achnatherum richardsonii is common on hillsides and dry benches but can also be found in bottomlands, swales, and among wooded slopes (Esser 1992). This species relies on winter snow and spring precipitation for most of its annual water budget as its habitats are not usually connected to groundwater (Rocchio and Crawford 2015). Changes in the duration and amount of snowpack and amount of summer precipitation, coupled with increased temperatures, are likely to make the montane meadow/forest ecotone habitat of *Achnatherum richardsonii* prone to drought and wildfire and favor conversion to drier grasslands or at least shifts in composition (Rocchio and Ramm-Granberg 2017). However, other more mesic forest types may convert to this forest type and expand its range. Increased drought stress will likely lead to extensive tree die-offs and mountain bark beetle outbreaks which could ultimately open more canopy habitat for *Achnatherum richardsonii*. This species is not drought tolerant as its roots are quite shallow (Esser 1992).

C2c. Dependence on a specific disturbance regime: <u>Increase</u>
The grasslands that support *Achnatherum richardsonii* are maintained by mixed severity fires, bark beetle mortality, and diseases that kill trees and create patchy forest openings in a landscape mosaic (Rocchio and Crawford 2015). Under future climate change scenarios, montane

meadow/forest habitats are likely to become drier and more prone to frequent wildfire and outbreaks of mountain pine beetle. This increase in disturbance could favor a shift to drier grasslands and invasion of non-native weedy species (Rocchio and Ramm-Granberg 2017). Conversely, fire suppression leads to tree and shrub encroachment. Bunchgrasses like *Achnatherum richardsonii* evolved with fire but *Achnatherum richardsonii* is nonrhizomatous and can only regenerate via seed (Esser 1992). Fire is more frequent on the dry slopes that this species prefers.

C2d. Dependence on ice or snow-cover habitats: Neutral
Achnatherum richardsonii is found in the Okanogan Mountains and Canadian Rockies where a significant portion of precipitation falls as snow and recharges the hydrological system as the snow melts (Trujillo and Molotch 2014, WRCC 2024). Snowfall in these areas is moderate and may collect in basin meadows where this species sometimes occurs and remain late into the year, though it probably melts early on the ridgetop and bench sites where *Achnatherum richardsonii* is found. Other than impacts to the water supply of the habitat, *Achnatherum richardsonii* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Achnatherum richardsonii occurs on ridgetops with low-fertility, slightly acidic to neutral soils with a range of soil textures ranging from gravelly to sandy or even clay-loam soil (Esser 1992, Washington Natural Heritage Program 2023, Soil Survey Staff 2024). These soils are derived from Vashon Stade continental glacial drift, Permian metacarbonate, and a variety of igneous intrusive rocks including dactite, acidic felsic pluton, and two-mica granite, along with Quaternary sedimentary rocks. The parent formations are of somewhat limited distribution in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The habitats of *Achnatherum richardsonii* are maintained mostly by disturbances such as fire and beetle-kill but herbivory can help to restrict woody species encroachment (Rocchio and Crawford 2015). Overgrazing can stress these ecological systems, particularly in concert with frequent fire.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Achnatherum richardsonii is wind-pollinated, and thus not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
The dry, one-seeded fruits of *Achnatherum richardsonii* are dispersed as a single caryopsis or whole inflorescence. The awn helps adhere the seeds to passing animals (Esser 1992). *Achnatherum richardsonii* can also disperse via wind and does not require an animal vector to disperse long-distances.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Endophytic *Epichloë* fungi form symbiotic relationships with cold‒season grasses including those of the genus *Achnatherum* and provide a number of systemic benefits such as promotion of

drought tolerance and disease resistance (Shi et al. 2020). Mycorrhizal colonization in grasses has been shown to increase with warming, so the endophyte relationship may benefit from warming until drought stress becomes too extreme. *Achnatherum richardsonii* is also an important forage species for livestock, used by deer, elk, bighorn sheep, though awns help to deter overgrazing. *Achnatherum richardsonii* is sensitive to overgrazing but succeeds best under light grazing (Esser 1992, Sinkins and Otfinowski 2012). Grazing is not expected to increase because of climate change.

C4f. Sensitivity to competition from native or non-native species: <u>Neutral</u>
Achnatherum richardsonii prefers moderate levels of disturbance but cannot persist in completely disturbed sites (Esser 1992). Excessive grazing and repeated burns of the grasslands which support *Achnatherum richardsonii* can increase the establishment of exotics, particularly bromes (*Bromus* spp. and *Ventenata dubia*; Rocchio and Crawford 2015). Conversely, fire suppression can lead to encroachment by competing shrubs. Studies have found that *Achnatherum richardsonii* can remain co-dominant with *Poa pratensis* and common exotic forbs and seems to tolerate competition from these species better than other native bunchgrasses (Hamilton 2020).

C4g. Forms part of an interspecific interaction not covered above: <u>Neutral</u>
Biocrusts that form between bunchgrass species in the habitat of *Achnatherum richardsonii* may increase survival but are not known to be required for this species (Hamilton 2020, Owen 2020).

C5a. Measured genetic variation: <u>Unknown</u>
The specific genetic variation of *Achnatherum richardsonii* is not documented. However, the congener *Achnatherum thuberianum* from the Great Basin shrub-steppe has low levels of genetic diversity and high rates of linkage disequilibrium and inbreeding due to self-fertilization (Osuna-Mascaró et al. 2022). The extremely small population sizes of *Achnatherum richardsonii* (as small as 3 individuals according to observational records) could make also make this species prone to inbreeding depression and lower rates of genetic diversity in Washington.

C5b. Genetic bottlenecks: <u>Unknown</u>

C5c. Reproductive System: <u>Neutral</u>
Achnatherum spp. can have both chasmogamous (predominately cross-fertilized) and cleistogamy (self-pollinated) flowers occur on the same plant, but complete self-pollination is also common (Culley and Klooster 2007, Osuna-Mascaró et al. 2022). *Achnatherum richardsonii* reproduces sexually and is nonrhizomatous (Esser 1992). Mixed mating systems are indicative of average to high genetic variation (Young et al. 2016). This species conservatively has at least average genetic diversity as it is unknown how much it relies on self-pollination.

C6. Phenological response to changing seasonal and precipitation dynamics: <u>Neutral</u>
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Achnatherum richardsonii* (June to July) has not changed significantly (Washington Natural Heritage Program 2023), though there are few available records to consider.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Two out of the six known occurrences of *Achnatherum richardsonii* are historical but have not been revisited since the 1940's when first collected and documented. The response of this species to climate change is not documented.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

*Actaea laciniata (***Mt. Hood bugbane***)*

Date: 31 October 2023 Synonym: *Cimicifuga laciniata*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	-
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 13 known occurrences (100%) of *Actaea laciniata* in Washington occur in areas with a projected temperature increase of less than or equal to 3.9° F (2.2°C ; Figure 1).

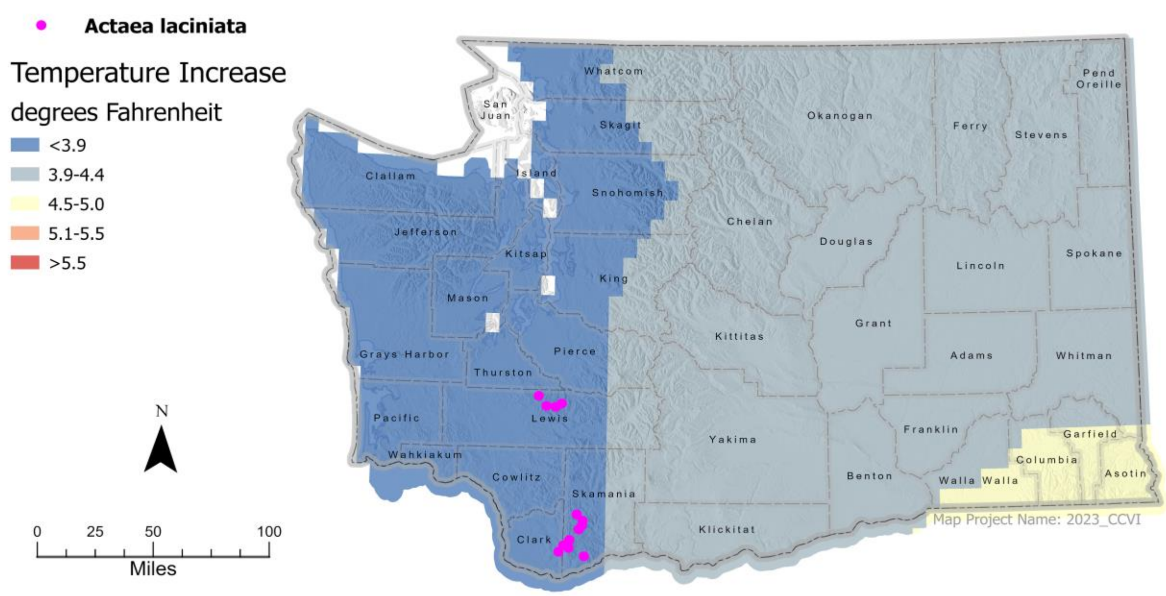

Figure 1. Exposure of *Actaea laciniata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 13 known occurrences (100%) of *Actaea laciniata* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

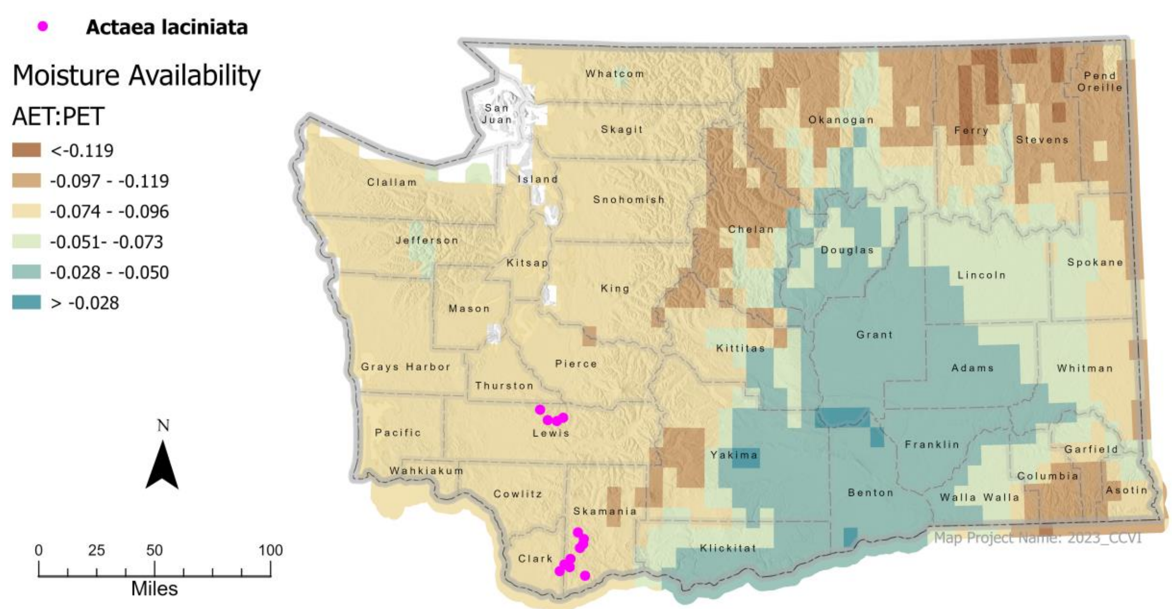

Figure 2. Exposure of *Actaea laciniata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Actaea laciniata occurs along rocky streams and moist talus slopes of mid-elevation (1250-4000 ft (380-1220 m)) montane riparian woodlands on the western slopes of the Cascade Range (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). *Actaea laciniata* occurrences in Washington are not expected to be affected by sea level rise based on their inland distribution and mid-elevation habitat but could be affected by river flooding (Office for Coastal Management 2023).

B2a. Natural barriers: Neutral
Actaea laciniata is found on moist slopes and near streambeds of the North Pacific Montane-Riparian Woodland and Shrubland ecological system that are located west of the Cascades crest in Washington and Oregon (Washington Natural Heritage Program 2023). Washington occurrences are separated by distances ranging from 2.5-74 mi (4-119 km) and are isolated from Oregon occurrences centered around Mount Hood by the Cascade mountains, the Columbia River, and the I-84 corridor. Otherwise, natural barriers between suitable moist forest sites are

expected to have relatively minimal impact as additional habitat is widespread and largely continuous with known occurrences.

B2b. Anthropogenic barriers: Neutral
Several occurrences of *Actaea laciniata* are located along roadcuts, roads, and trails. Field observations indicate trampling of trailside habitat and a few historical occurrences that have not been relocated in recent years were along road cuts or within the boundaries of clearcuts which may have opened the canopy too much for this species to persist (Washington Natural Heritage Program 2023). However, these activities don't appear to have impacted the landscape enough to pose a significant barrier to dispersal between habitats.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the occurrences of *Actaea laciniata* (Washington Department of Natural Resources 2023). Future forest health treatments which involve thinning the canopy could be detrimental or beneficial to this species that prefers filtered sunlight, depending on intensity. However, projects are not currently planned in the vicinity of the occurrences.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Actaea laciniata produces dry, flattened follicle fruits borne on long stalks in panicles which dehisce to release seeds (Washington Natural Heritage Program 2023). The seeds are heavy and not specially adapted for dispersal (Vargas et al. 2023). They are likely dispersed only short distances (< 328 ft (100 m)) by passive means such as wind and water. The follicles are not berry-like as in other *Actaea* spp. which are sometimes endozoochorous, but it is still possible that they are carried by rodents or on the hooves of herbivores. Other Pacific Northwest *Actaea* spp. have been shown to explosively dehisce a short distance (a few meters from parents), though this mechanism is unconfirmed for *Actaea laciniata* (Klinkenberg and Klinkenberg 2003).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Actaea laciniata* occurrences in Washington. Out of 13 known occurrences, 12 (92%) are in areas that have experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these occurrences are expected to be vulnerable to climate warming. The remaining occurrence (8%) in Skamania County is in an area that has experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) and is expected to be somewhat vulnerable to warming (Young et al. 2016).

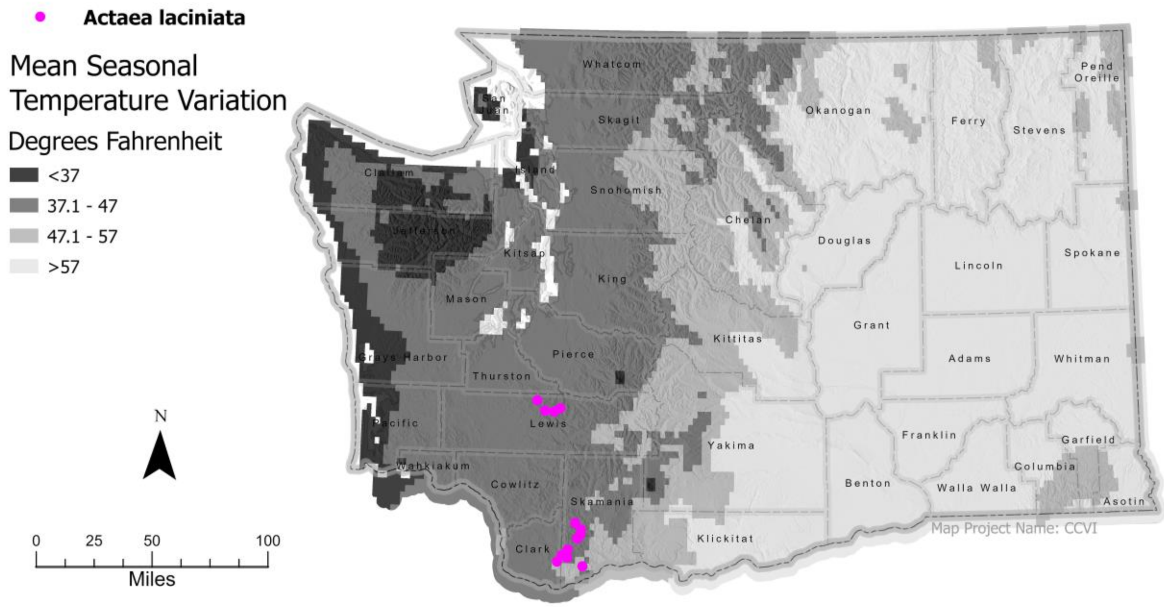

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Actaea laciniata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Somewhat Increase</u>
Actaea laciniata is found in shady, cool, and moist coniferous forests near streams and on permanently moist talus slopes with northern and western aspects (Washington Natural Heritage Program 2023). This species is likely to be somewhat sensitive to temperature increase as the narrow valleys and canyons that it associates with are areas of cold air drainage (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Actaea laciniata* occurrences in Washington. All 13 known occurrences are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these occurrences are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

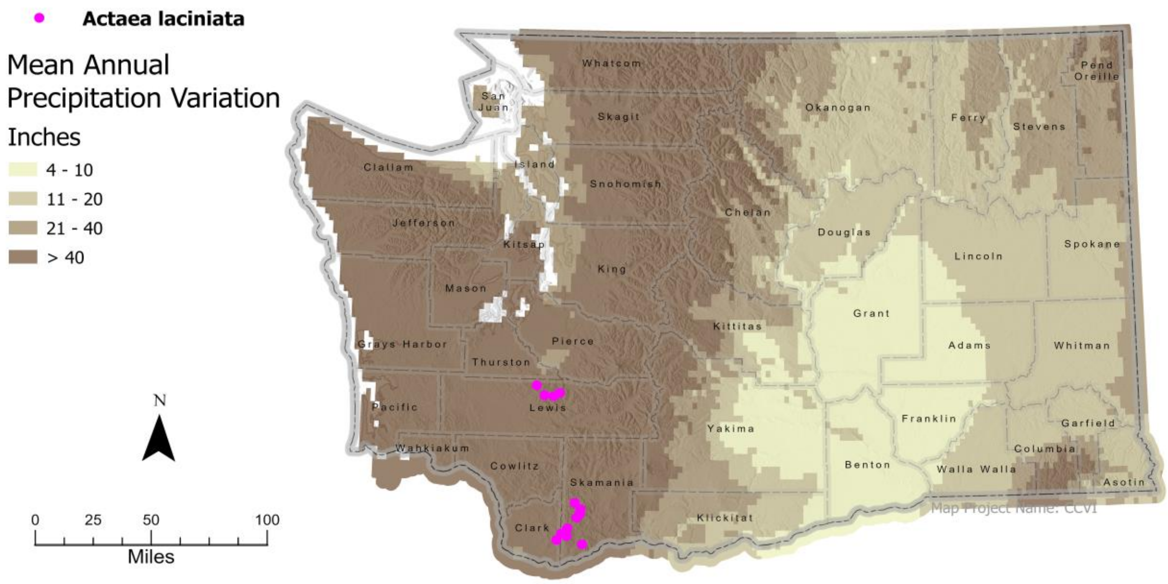

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Actaea laciniata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Actaea laciniata occurs on perennially moist slopes and in shady forest areas near streams and floodplains and is adapted to moderate moisture levels (Washington Natural Heritage Program 2023). Snowfall is a primary water source while the confined, narrow stream channels this species often occurs in reduces evapotranspiration, resulting in a moist environment. Streams often have step-pool channels formed by large boulders and debris (Rocchio and Crawford 2015). Increased winter and spring temperatures are likely to result in earlier snowmelt, resulting in a temporal shift in volume. These same hydrological changes could also alter the timing and duration of groundwater discharge. The number of intense flood and mass wasting events may also increase in the habitat of *Actaea laciniata* and could impact germination and survival due to the erosive action of stream flow (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Increase
North Pacific Montane Riparian Woodlands and Shrublands are shaped and maintained primarily by valley terrain, substrates, and episodic flooding patterns which include infrequent high-intensity flooding events (Rocchio and Crawford 2015). Spring and late-winter floods are critical for habitat maintenance and establishment of associated species (NatureServe 2023). Temporal shifts in groundwater discharge, flood timing, and flood magnitude related to earlier snowmelt

and drought are likely to alter the habitats which support *Actaea laciniata* (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Actaea laciniata is partially dependent on snowpack and associated snow melt which maintains stream flows and groundwater discharge critical for supporting the species habitat.

C3. Restricted to uncommon landscape/geological features: Neutral
Actaea laciniata is confined to steep valleys and canyons in mountain ranges with large boulders and coarse, shallow soils derived from granodiorite, volcaniclastic deposits, and sedimentary deposits (Rocchio and Crawford 2015, Washington Division of Geology and Earth Resources 2016). These substrates are not especially uncommon in Washington, though permanently moist slopes and streambeds are somewhat patchy on the landscape and differ in vegetation from the surrounding forested landscape (NatureServe 2023).

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beavers play a role in shaping the riparian woodland and shrubland habitat of *Actaea laciniata* by creating heterogenous pockets of open water, accumulations of nutrients, and anaerobic wetland areas within the forest landscape (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Actaea laciniata is a species with a mixed mating system as it produces nectar that can attract pollinators and is also able to self-fertilize, though it relies primarily on outcrossing (Cook 1993). The exact pollinators of *Actaea laciniata* are not well described, but other endemic Pacific Northwest species of *Actaea* are known to be pollinated primarily by bumblebee workers and secondarily by syrphid flies and do not appear to be pollinator limited (Pellmyr 1986).

C4d. Dependence on other species for propagule dispersal: Neutral
Seeds of *Actaea laciniata* may possibly be spread on hooves of native herbivores and by rodents like other *Actaea* species but this is unconfirmed.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Infestation and disease are probably not a major problem for *Actaea laciniata* which is reported to contain compounds which protect from insects and pathogens. Horticultural *Actaea* spp. are known to be relatively pest-free.

C4f. Sensitivity to competition from native or non-native species: Neutral
Actaea laciniata appears to be generally tolerant of shade and occurs in well-vegetated communities. Therefore, it is probably not especially sensitive to competition. No threats from non-native species were noted at any occurrences.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Actaea laciniata does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Somewhat Increase
Actaea laciniata is reported to possess a low number of polymorphic loci and little genetic variation, though it is a primarily outcrossing species (Cook 1993). Highly localized populations, such as those found in Washington, generally maintain lower genetic variation than widespread congeners and are more vulnerable to threats (Soltis and Soltis 1991).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Not Scored
This factor was not formally scored because of the inclusion of genetic diversity data (C5a) per Young et al. (2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Actaea laciniata* (late June-mid August) has not changed significantly since the first recorded collection in Washington (Washington Natural Heritage Program 2023). However, few of those records indicated the phenological phase. Further monitoring is warranted as many flood-adapted riparian species will time phenological events with historic stream flow patterns and climate change induced shifts in stream flows can cause changes in phenology (Rocchio and Ramm-Granberg 2017).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The impacts of climate change on *Actaea laciniata* are largely undocumented. Most known occurrences (10 of 13) have not been relocated since the 1980s, particularly those that were associated with clearcuts in Lewis County. However, there is no conclusive evidence that these occurrences have suffered the effects of climatic change.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
***Agoseris aurantiaca* var. *carnea* (pink Agoseris)**

Date: 26 December 2023
Synonym: *Agoseris lackschewitzii, Agoseris carnea*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington
Heritage Rank: G4Q/S2
Index Result: Extremely Vulnerable
Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All five known occurrences (100%) of *Agoseris aurantiaca* var. *carnea* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

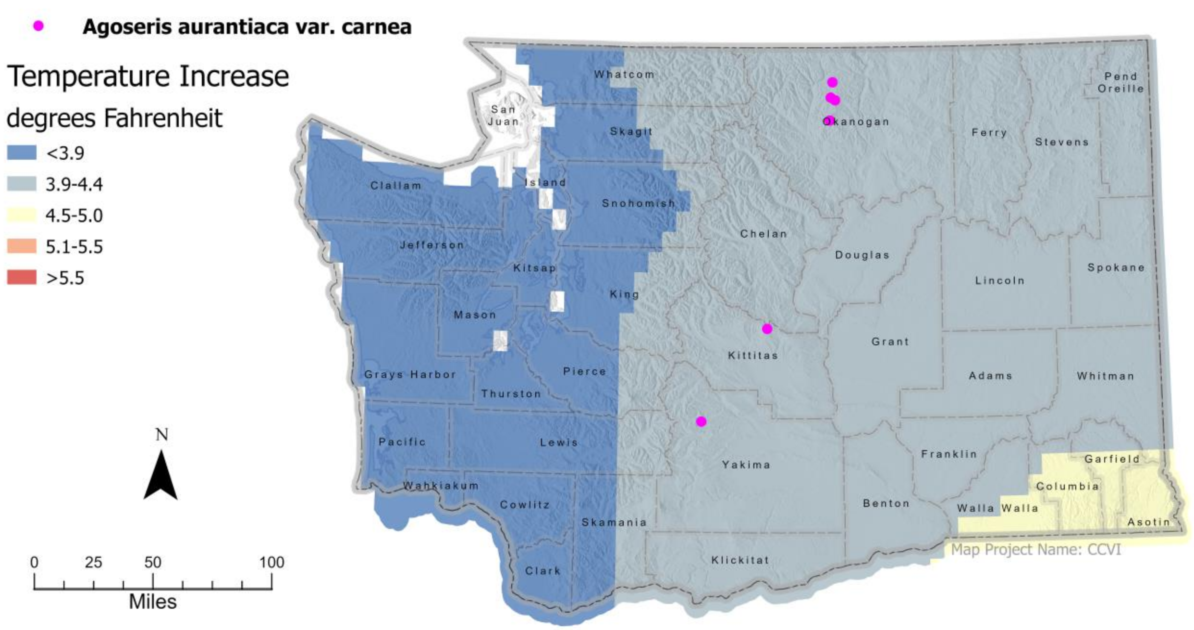

Figure 1. Exposure of *Agoseris aurantiaca* var. *carnea* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All five known occurrences (100%) of *Agoseris aurantiaca* var. *carnea* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

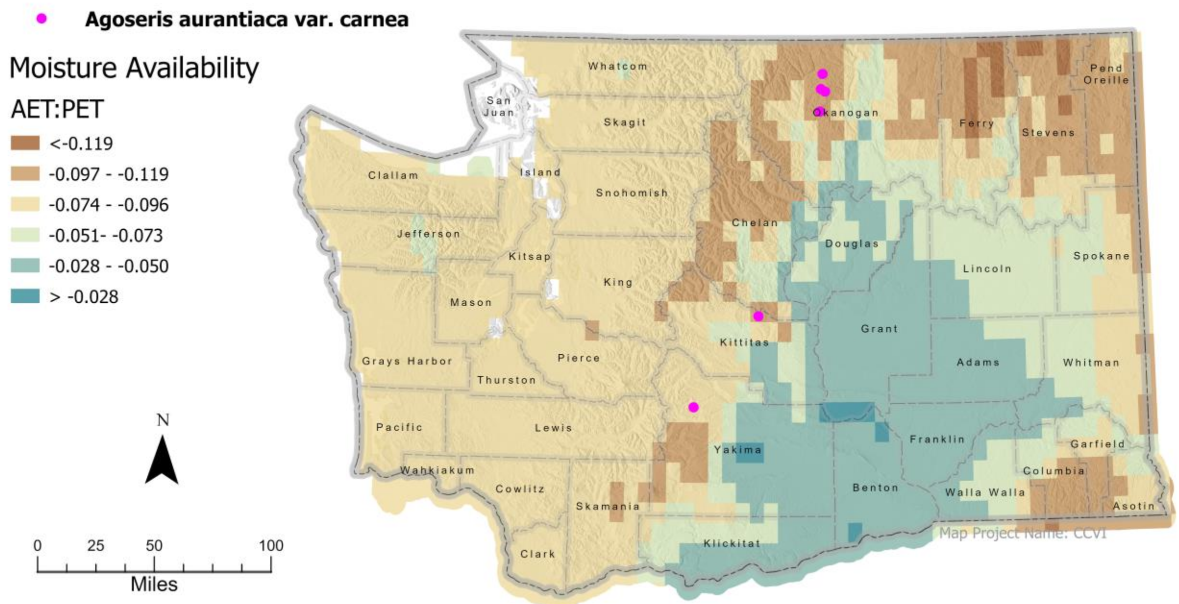

Figure 2. Exposure of *Agoseris aurantiaca var. carnea* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Agoseris aurantiaca var. *carnea* occurs in upper montane and subalpine meadows at mid to high elevations (4000-7000 ft (1220-2130 m)) along the eastern crest of the Cascade Range (Washington Natural Heritage Program 2023). *Agoseris aurantiaca* var. *carnea* occurrences in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023)

B2a. Natural barriers: <u>Somewhat Increase</u>
Habitats occupied by *Agoseris aurantiaca* var. *carnea* are part of the Rocky Mountain Alpine-Montane Wet Meadows and Rocky Mountain Subalpine-Montane Fens ecological systems which occur at the ecotone of lowland and upland forest (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). These ecological systems occur as small patches in valleys and lowland depressions where groundwater reaches the surface which are somewhat limited areas within the surrounding matrix of montane to subalpine conifer forests in the East

Cascades and Okanogan Highlands. Occurrences are separated by 2-94 mi (2-237 km) of unsuitable forest upland habitat. The occurrence near Wenatchee is genetically isolated from the other Okanogan occurrences by large stretches of forest and dry foothills which also act as somewhat of a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral
Agoseris aurantiaca var. *carnea* occurrences in Washington are mostly on Forest Service lands managed for multiple use where they are not formally protected. Some occurrences are near trails and several are near forest roads. These features may constrain future migration to some degree but are not expected to act as significant barriers to dispersal relative to natural barriers. According to notes from site visits, plants near trails have been trampled and off-road vehicle use is damaging occurrences and meadow habitats.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten Washington occurrences of *Agoseris aurantiaca* var. *carnea* in Washington, though there is some potential for future mitigation projects in the Okanogan National Forest (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Little is known about the specific dispersal distance of *Agoseris aurantiaca* var. *carnea* seeds, but *Agoseris* spp. produce achenes attached to a double pappus with numerous capillary bristles which are adapted for wind-dispersal (Henderson et al. 1990; Washington Natural Heritage Program 2023). Some species are thought to also be dispersed by water, gravity, or animals (Pavek et al. 1990). Dispersal distances depend on pappus to achene length and weight ratios, however, like other wind-dispersing species in the Asteraceae family, *Agoseris aurantiaca* var. *carnea* is probably not strongly dispersal limited (Andersen 1992; Vittoz and Engler 2007).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Agoseris aurantiaca* var. *carnea* occurrences in Washington. Four of five known occurrences (100%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these occurrences are expected to be somewhat vulnerable to climate warming. The remaining occurrence in Okanogan County is in an area that has experienced average (>57.1° F (31.8° C)) temperature variation over the historical period and is expected to be mostly resilient to warming (Young et al. 2016).

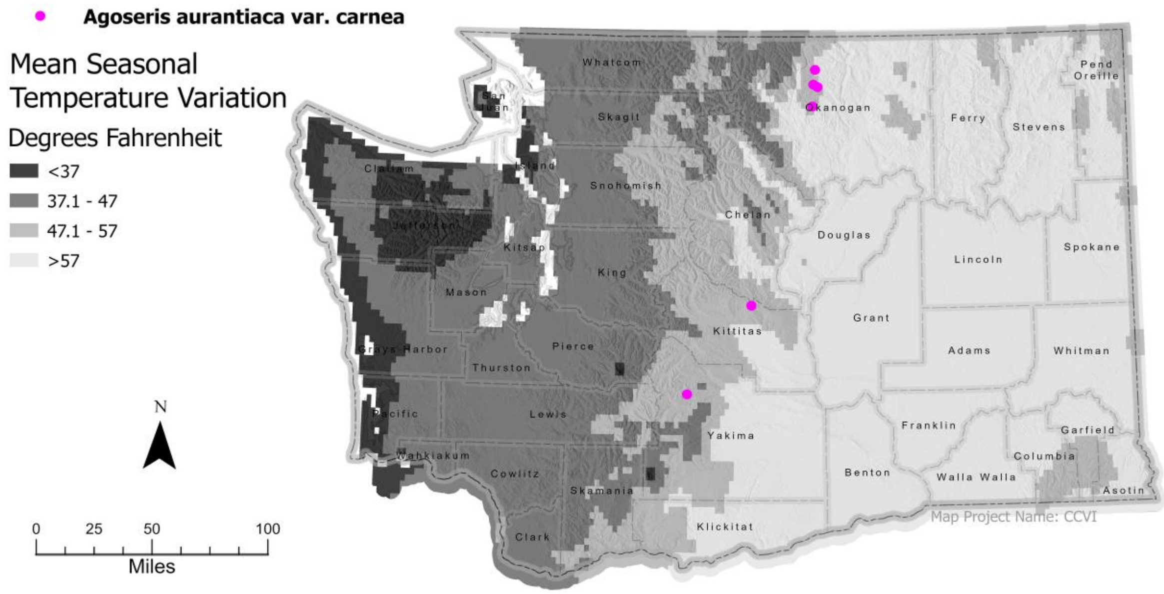

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Agoseris aurantiaca var. carnea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
The high elevation wet meadows that support *Agoseris aurantiaca* var. *carnea* are often found on gentle slopes and in montane valleys associated with cold air drainages and cooler soils and therefore would be vulnerable to warming (Pavek et al. 1990; Rocchio and Crawford 2015). The Rocky Mountain Alpine-Montane Wet Meadow ecological system is also vulnerable to drought from increased temperatures (Rocchio and Ramm-Granberg 2017). *Agoseris aurantiaca* var. *carnea* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Agoseris aurantiaca* var. *carnea* occurrences in Washington. All five known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these occurrences are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

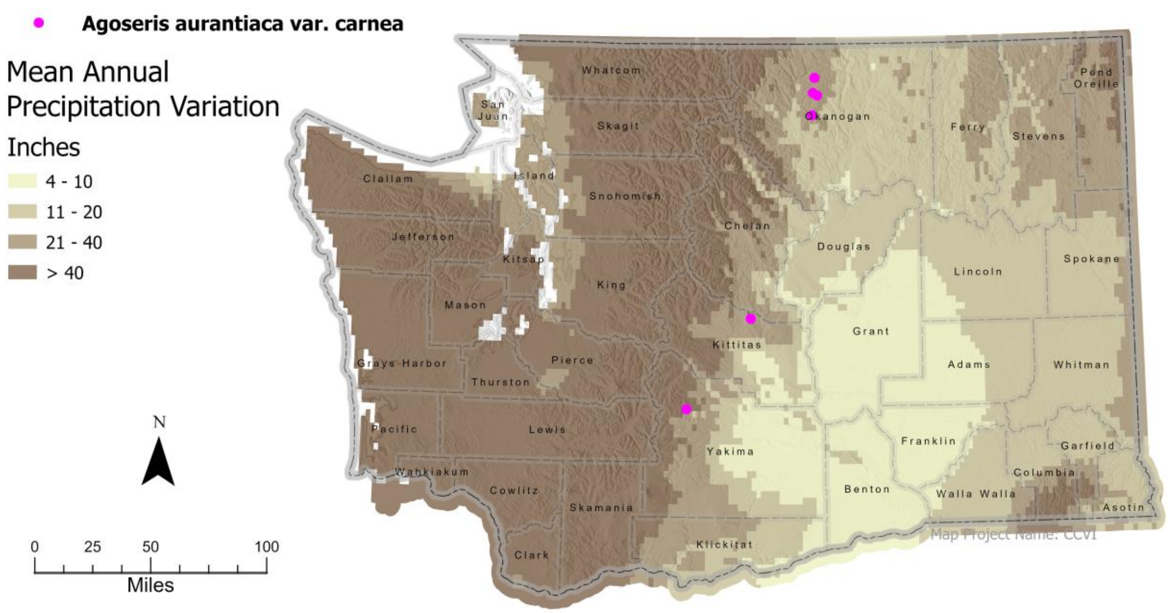

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Agoseris aurantiaca var. carnea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Agoseris aurantiaca var. *carnea* is associated with perennially wet soils and stable groundwater tables (Henderson et al. 1990; Rocchio and Crawford 2015). Habitats occupied by *Agoseris aurantiaca* var. *carnea* in the Rocky Mountain Alpine-Montane Wet Meadow ecological system are highly vulnerable to changes in the amount of snowpack, timing of snowmelt, changes in timing and amount of summer precipitation, increased summer temperatures and drought, and reduction in stream flows or depth to groundwater from projected climate change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
The wet meadow habitat of *Agoseris aurantiaca* var. *carnea* is not adapted to frequent disturbances, but unobstructed water flow, hydrological fluctuations, and periodic inundation are important for keeping encroaching conifers at bay (Rocchio and Crawford 2015). Wet meadow occurrences are currently not typically susceptible to fire but could become more vulnerable if water tables are lowered due to decreased snowpack or increased summer temperature or drought (Rocchio and Ramm-Granberg 2017). The Naneum Meadows occurrences of *Agoseris aurantiaca* var. *carnea* was potentially burned in the Table Mountain Fire of 2012. Grazing is likely also a threat in this ecological system.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
Wet meadows in the subalpine and alpine form on snow beds and in depressions below late-melting snow patches and depend on groundwater recharge from snow. Changes to snow depth and cover are likely to significantly alter the habitat of *Agoseris aurantiaca* var. *carnea* (Rocchio and Ramm-Granberg 2017; Rocchio 2006)

C3. Restricted to uncommon landscape/geological features: Neutral
Unlike some other *Agoseris* taxa, *Agoseris aurantiaca* var. *carnea* is not found on calcareous soils but rather on gentle slopes with perennially wet soils that range from gravelly to loamy, are typically shallow, and are derived from a broad array of parent materials (Pavek et al. 1990). These include alpine glacial till, outcrops of heterogeneous metamorphic and igneous rocks of the Tiffany complex, or felsic intrusives of the Cathedral Batholith (Washington Division of Geology and Earth Resources, 2016). These formations are relatively widespread in the Okanogan range.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beavers are an important hydrogeomorphic driver of wet meadows. When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006). Wet meadow sites may be enhanced by browsing by ungulates or other herbivores that contain the encroachment of woody vegetation.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Agoseris aurantiaca* var. *carnea* are not well known but bumblebees, butterflies, flies, and skippers have all been observed visiting the flowers of *Agoseris* spp. (Pavek et al. 1990; Pojar 1974). As an obligate outcrosser with an apparently broad array of potential pollinators, *Agoseris aurantiaca* var. *carnea* is not expected to be pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
It is unknown whether *Agoseris aurantiaca* var. *carnea* is dispersed by animals but adaptations for wind-dispersal mean that it is not dependent on other species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Alpine wet meadows are threatened by soil disturbance and compaction caused by grazing which can subsequently affect hydrological and nutrient cycles. *Agoseris* spp. are known to be an important component of the summer diets of elk, and field records for *Agoseris aurantiaca* var. *carnea* in Washington have noted that moose presence and evident trampling by cattle are likely to negatively impact this taxon (Jankovsky-Jones 1996; Rocchio 2006; Stevens 1965). There is also some evidence of herbivory in the form of small insect holes on leaves but no major impacts to survival have been recorded (Pavek et al. 1990). Despite the possibility of general increases in insect herbivory in response to climate warming, specific threats to *Agoseris aurantiaca* var. *carnea* are not expected to significantly increase.

C4f. Sensitivity to competition from native or non-native species: Increase
With increasing temperatures, montane wet meadows are at risk of drying and subsequent conifer encroachment (Ford and HilleRisLambers 2023; Rocchio 2006). Wet meadows are also susceptible to invasion by many non-native species, especially pasture grasses such as *Poa pratensis* and *Phleum pratense* as well as exotics species common to other wetland types such as *Cirsium arvense* and *Taraxacum officinale* (Rocchio and Crawford 2015). *Agoseris* spp. are moderately tolerant of close neighbors but will not persist in dense vegetation or thick sods (Pavek et al. 1990).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Agoseris aurantiaca var. *carnea* does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic variation of the polyploid *Agoseris aurantiaca* var. *carnea* has not been studied as it is often lumped with the orange-flowered *Agoseris aurantiaca* var. *aurantiaca* (Gardner 2023; Lee et al. 2003). It exhibits a strong degree of ecological isolation from conspecifics and other varieties and is not known to intergrade (Henderson et al., 1990). Populations tend to be fairly small in size and area covered and so could have lower genetic diversity due to genetic drift or inbreeding depression (Pavek et al. 1990). The Washington occurrences are also somewhat disjunct from the core range of the species which runs through the northern Rocky Mountains and might be expected to have lower genetic diversity due to founder effects or reproductive isolation.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
The parent species *Agoseris aurantiaca* is known to have bisexual, protogynous flowers (with stigmas being receptive before pollen is shed) and is effectively an obligate outcrosser that reproduces primarily sexually by seed (Pojar 1974). It may infrequently reproduce vegetatively from its branching caudex (Pavek et al. 1990).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Agoseris aurantiaca* var. *carnea* (July to August) has not changed significantly (Washington Natural Heritage Program, 2023a). *Agoseris aurantiaca* var. *carnea* is often found without flowers which may indicate that highly specific conditions are required to trigger flowering and that phenology will be sensitive to climatic change (Pavek et al. 1990).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Agoseris aurantiaca* var. carnea declining in response to climate change. All occurrences have been relocated and confirmed as extant since 2007.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

*Agrostis mertensii (*northern bentgrass*)*

Date: 15 May 2024 Synonym: *Agrostis borealis, Agrostis borealis* var. *americana*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S1S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	75
	-0.074 to - 0.096	25
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Not Ranked
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All eight known occurrences (100%) of *Agrostis mertensii* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

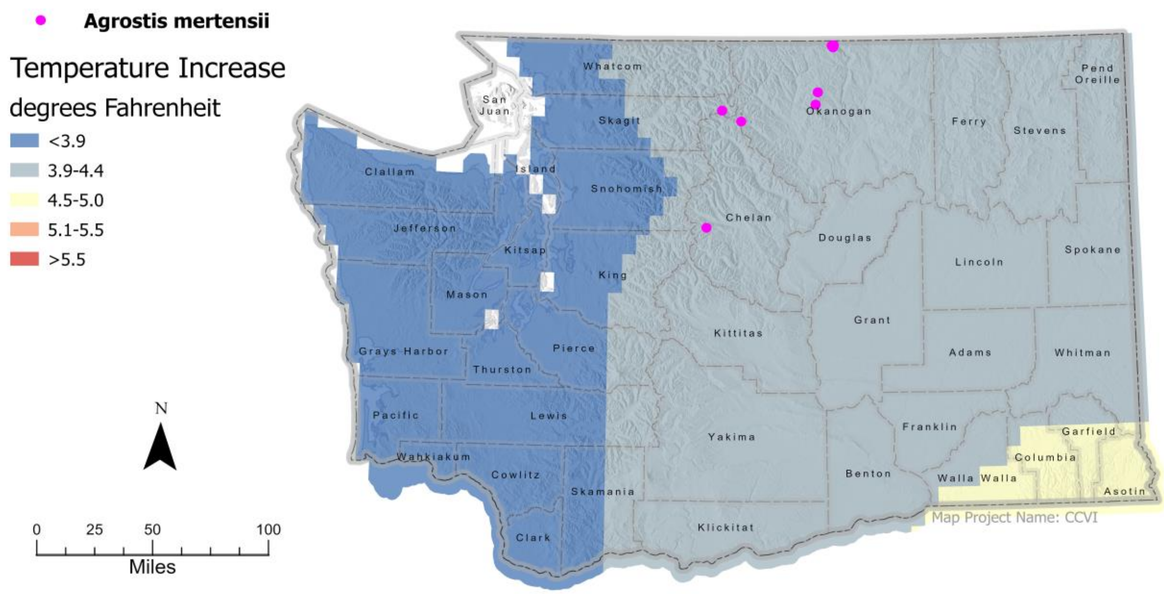

Figure 1. Exposure of *Agrostis mertensii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the eight known occurrences of *Agrostis mertensii* in Washington, six (75%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other two occurrences (25%) are found in areas with a projected decrease in the range of -0.074 to -0.096.

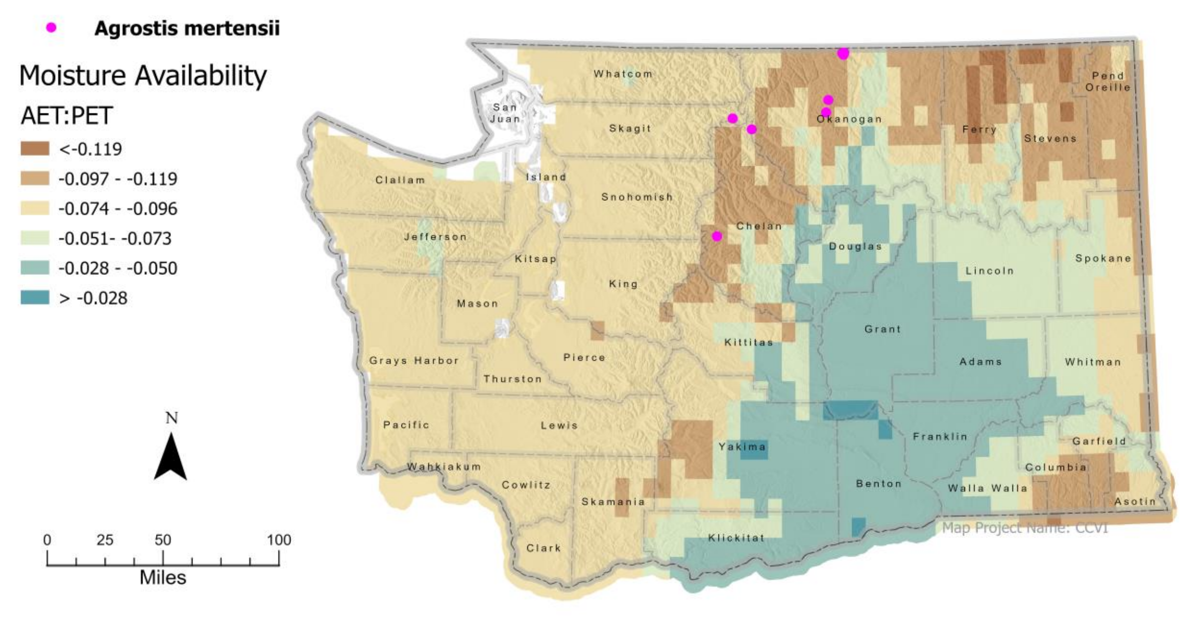

Figure 2. Exposure of *Agrostis mertensii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Agrostis mertensii occurs near mountain summits above treeline (7200-7650 ft (2195-2330 m)) in the alpine and is not at risk of sea level rise (Washington Natural Heritage Program 2023, Office for Coastal Management 2024).

B2a. Natural barriers: <u>Somewhat Increase</u>
Agrostis mertensii is a widespread species occurring east of the Cascade crest and along the Canadian border in Washington on talus slopes and in dry meadows between treeline and mountain summits (7200-7650 ft (2195-2330 m); Washington Natural Heritage Program 2023). These habitats are a part of the North Pacific Alpine and Subalpine Bedrock and Scree and Rocky Mountain Dwarf-Shrubland, Fell-Field, and Turf ecological systems, which occur in a patchy mosaic within a larger montane landscape in the Cascade Mountains (Rocchio and

Crawford 2015). Occurrences are separated by 1-56 mi (2-90 km) of unoccupied and unsuitable habitat. Individual occurrences are naturally separated by forested valleys, which create somewhat of a barrier to local dispersal and gene flow. There is limited room for this species to move upward with climate change.

B2b. Anthropogenic barriers: Neutral
The rugged, high elevation terrain where *Agrostis mertensii* occurs remains relatively uninhibited by direct anthropogenic barriers as there are few roads and little human infrastructure in the area, and many occurrences are in areas protected from development.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the occurrences of *Agrostis mertensii* (Washington Department of Natural Resources 2024). Future projects in the region are unlikely due to the rugged backcountry terrain and protected land status (National Park) of the occurrences.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Agrostis mertensii has seeds with long, abruptly bent awns that have sharp tips which may allow for attachment to animals for longer distance dispersal (Champlin 2022, Washington Natural Heritage Program 2023). It is probably also dispersed moderate distances (> ½ mi or 1 km) on wind at least occasionally but has been reported to have very weak dispersal compared to co-occurring species (Schori 2004, Barber 2015). Fruits of this species have also shown up in small quantities in reindeer feces, suggesting that endozoochory could be a dispersal method, though this viability of the seeds is unknown (Bråthen et al. 2007).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Agrostis mertensii* occurrences in Washington. Of the eight known occurrences, two (25%) are in areas that have experienced little (37 - 47° F (20.8 - 26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these occurrences are expected to be vulnerable to warming. Another five occurrences (63%) are in areas that have experienced lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation and are expected to be somewhat vulnerable to warming. The remaining occurrence (12%) is in an area that has experienced average (>57.1° F (31.8° C)) temperature variation over the historical period and is expected to be mostly resilient to warming.

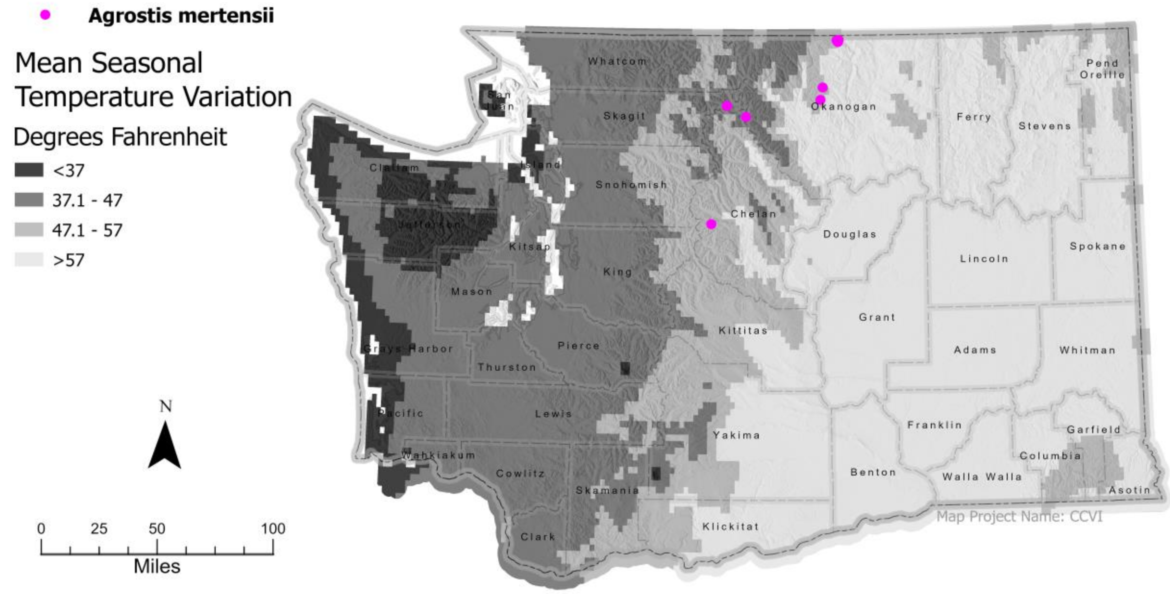

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Agrostis mertensii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
The rock crevices and meadows where *Agrostis mertensii* occurs are above treeline with exposure to high winds and some of the coldest growing season temperatures in Washington, particularly in the Okanogan range (Rocchio and Crawford 2015). These habitats are expected to be highly vulnerable to anticipated temperature increases (Rocchio and Ramm-Granberg 2017). *Agrostis mertensii* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022)

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Agrostis mertensii* occurrences in Washington. All eight known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are likely to be resilient to climate change induced shifts to precipitation and moisture regimes (Young et al. 2016).

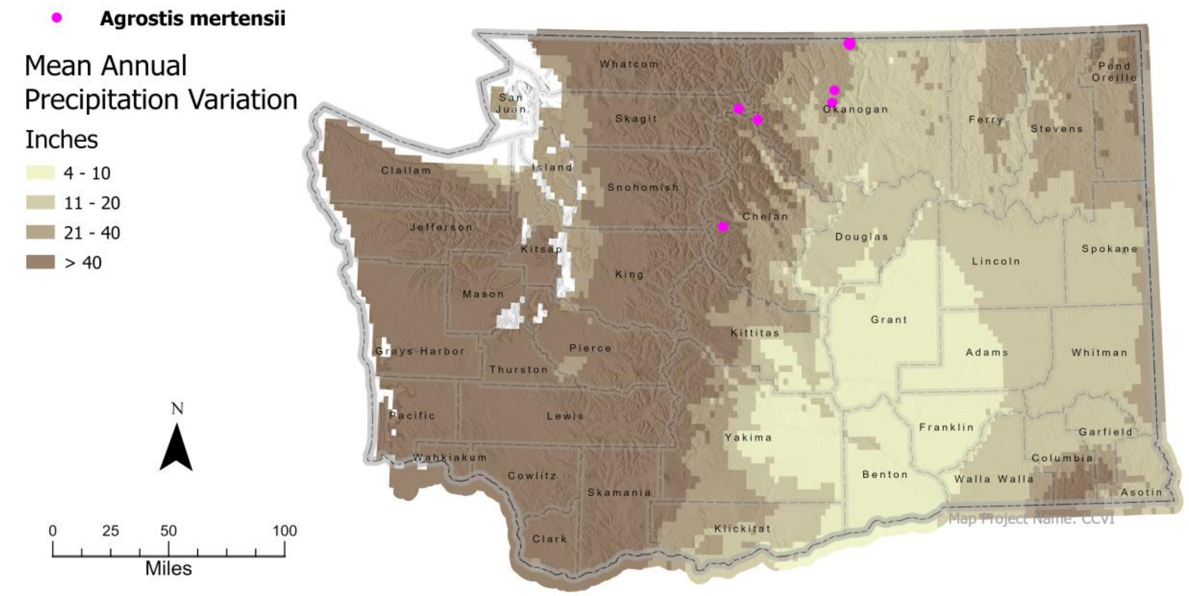

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Agrostis mertensii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
The alpine talus slopes and dry meadows where *Agrostis mertensii* occurs in Washington rely primarily on snowmelt for a steady supply of moisture throughout the growing season. It is unknown exactly how precipitation shifts from snow to rain and changes in the timing of snowmelt will affect individual species, but these hydrological changes are likely to significantly alter the preferred habitat of alpine scree plants which is already moisture limited due to a lack of connection to groundwater (Rocchio and Ramm-Granberg 2017). Conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and could initially increase the habitat available to *Agrostis mertensii* (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Agrostis mertensii occurs on alpine scree slopes and in turf meadows that are mostly maintained by natural erosion processes and are further facilitated by cold climatic conditions, shallow soils, and high winds that reduce soil formation and keep plant density low and prevent tree encroachment (Rocchio and Crawford 2015). Avalanches and freeze-thaw action further shape microclimates in these alpine communities. Additional periodic disturbances are not required to maintain this habitat and climate change is not expected to significantly impact these processes,

though small, moderate intensity fires occasionally occur due to lightning strikes (Rocchio and Ramm-Granberg 2017, NatureServe 2023)

C2d. Dependence on ice or snow-cover habitats: Increase
The high alpine regions of the Cascade Mountains where *Agrostis mertensii* occurs experience long, cold winters with moderate snow accumulation and most precipitation falling as snow (Western Regional Climate Center (WRCC) 2024). This species is known to associate with permanent snowfields which provide a steady stream of moisture to the otherwise arid alpine slopes and act as seed traps (Larsson and Molau 2001, Eskelinen et al. 2016).

C3. Restricted to uncommon landscape/geological features: Increase
Agrostis mertensii is found on talus and bedrock fell fields of ultramafic serpentinized dunite and peridotite (Chopaka), gneiss, metagabbro, and brown-red metasedimentary and metavolcanic rock (Washington Division of Geology and Earth Resources 2016, Soil Survey Staff 2024). The alpine soils found on these slopes are very thin, poorly developed, and well-drained (Schori 2004). These geological features, particularly ultramafic intrusions, are quite uncommon in Washington especially at high elevations.

C4a. Dependence on other species to generate required habitat: Neutral
North Pacific Alpine and Subalpine Bedrock and Scree ecological systems and associated dwarf shrubland, fell-field, and turf are shaped mostly by the processes of abiotic features such as erosion events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015). However, pocket gophers play a minor role in shaping the composition of these communities via soil disturbance and herbivory (NatureServe 2023). The activity of ground-burrowing mammals may increase with climate change but is expected to have minimal impacts (Lynn et al. 2018).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Agrostis mertensii is wind-pollinated, and thus not pollinator limited. Additionally, some *Agrostis* spp. are self-pollinating, having no reduction in seed set when isolated from external pollen sources (Tercek et al. 2003).

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
Agrostis mertensii has long awns that may aid in attachment to animal fur for dispersal (Champlin 2022, Washington Natural Heritage Program 2023). The only other main dispersal method for this species is wind. It is likely somewhat dependent on animals for longer-distance dispersal. The number of potential animals which can act as seed vectors is not known but is probably not highly limited.

C4e. Sensitivity to pathogens or natural enemies: Neutral
There are no reports of disease or predation being a threat to *Agrostis mertensii* (Schori 2004).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase

Agrostis mertensii occurs in sparsely vegetated alpine scree and turf communities which are typically dominated by non-vascular lichens and cushion plants (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of these ecological systems. *Agrostis mertensii* grows in short tufts to avoid harsh winds and is probably adapted more for survival of these harsh abiotic conditions and not for competition, which is normally limited in rocky alpine communities. Plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with deep enough soil, the tree line may also begin to encroach as the climate warms as is predicted for several alpine regions of Washington (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Agrostis mertensii does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Somewhat Increase
Even though *Agrostis* spp. are known to be highly genetically separated within species across different soil types, studies have shown that many *Agrostis* spp., including *Agrostis mertensii*, have surprisingly low genetic variation (regardless of edaphic endemism), possibly due to high rates of self-pollination (Tercek et al. 2003). *Agrostis mertensii* is also at the southwestern edge of its circumboreal range in Washington, which means that genetic diversity may be even lower for these occurrences (Caissy et al. 2020).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Not Ranked
Agrostis mertensii is a non-rhizomatous, short-lived, octoploid perennial grass that is able to outcross over significant distances and is likely able to self-pollinate as well (Schori 2004). This factor was not formally ranked due to the inclusion of genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (July to August) has not changed significantly (Washington Natural Heritage Program 2023), though there were few records available to analyze. In one experimental warming study, the floral abundance and overall cover of *Agrostis mertensii* was reduced, indicating that it may be phenological sensitive to future climatic change (Berthelsen 2022).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Of the 8 occurrences of *Agrostis mertensii* in Washington, 7 have been relocated since 2003 (most recently in 2021). Populations tend to be small (5-10 individuals), but this species is easily overlooked and may be more abundant than presently known. Trends in response to climate change are not known.

D2. Modeled future (2050) change in population or range size: Unknown

Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Antennaria corymbosa (meadow pussytoes)

Date: 28 July 2023 Synonym: *Antennaria dioica* var. *corymbosa*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	20
	3.9-4.4° F (2.2-2.4°C) warmer	80
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Neutral
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Four out of five (80%) of the occurrences of *Antennaria corymbosa* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C; Figure 1). The other occurrence is in an area with a projected temperature increase of 4.5-5.0°F (2.5-2.7°C).

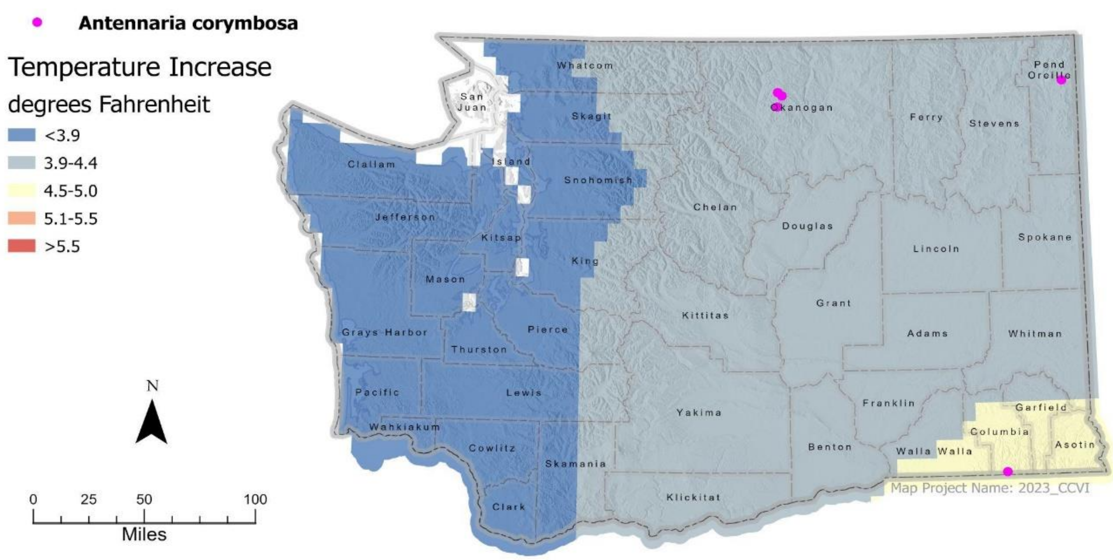

Figure 1. Exposure of *Antennaria corymbosa* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All five known occurrences *of Antennaria corymbosa* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

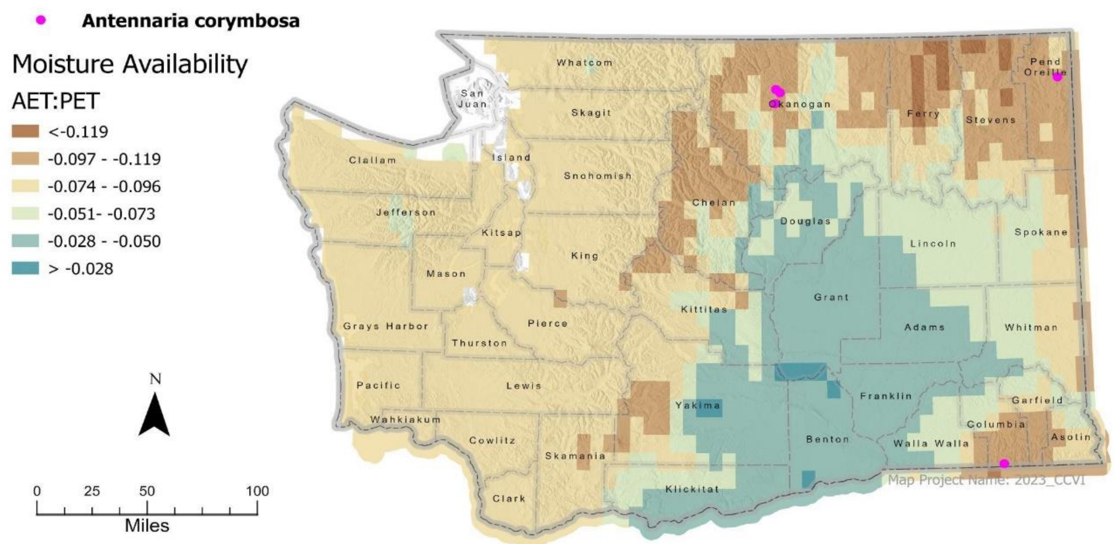

Figure 2. Exposure of *Antennaria corymbosa* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Washington occurrences of *Antennaria corymbosa* are within Rocky Mountain Alpine-Montane Wet Meadows and Rocky Mountain Subalpine-Montane Fens east of the Cascade Range that are located at elevations of 4000-6000 ft (1220-1829 m; Camp and Gamon 2011, Washington Natural Heritage Program 2023). These occurrences will not be inundated by projected sea level rise (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Somewhat Increase</u>
Antennaria corymbosa occurs in Rocky Mountain Alpine-Montane Wet Meadows and Rocky Mountain Subalpine-Montane Fens in lowland depressions surrounded by montane forest where groundwater meets the soil surface (Rocchio and Crawford 2015). This species occurs only in Okanogan, Colville, and Umatilla National Forests and surrounding lands. Occurrences are separated by the Columbia Plateau with distances between metapopulations ranging from 125-400 mi (201-644 km). Habitat is somewhat limited, and the surrounding forested uplands may restrict movement of this wetland associate.

B2b. Anthropogenic barriers: Neutral
The current habitat of *Antennaria corymbosa* is located within National Forest lands with limited roads and human infrastructure. Natural barriers are expected to create more significant obstacles to dispersal than the limited anthropogenic barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the known occurrences of *Antennaria corymbosa.*

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Seeds of *Antennaria* spp. are light and have specialized pappi to aid in wind-dispersal (Washington Natural Heritage Program 2023, Seed Information Database 2023), which is indicative of a long-distance dispersal syndrome (Thomson et al. 2011) that may be less affected by low patch connectivity (Jones et al. 2015). Though *A. corymbosa* is expected to travel far, its high site fidelity to isolated patches of suitable habitat warrants a ranking of somewhat increase (Young et al. 2016) .

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Antennaria corymbosa* occurrences in Washington. Four of five occurrences (80%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period and are expected to be somewhat vulnerable to climate warming (Young et al. 2016). The remaining occurrence is in an area that has experienced average variation (>57.1° F (31.8° C)). According to Young et al. (2016) this occurrence is likely to be mostly resilient to warming.

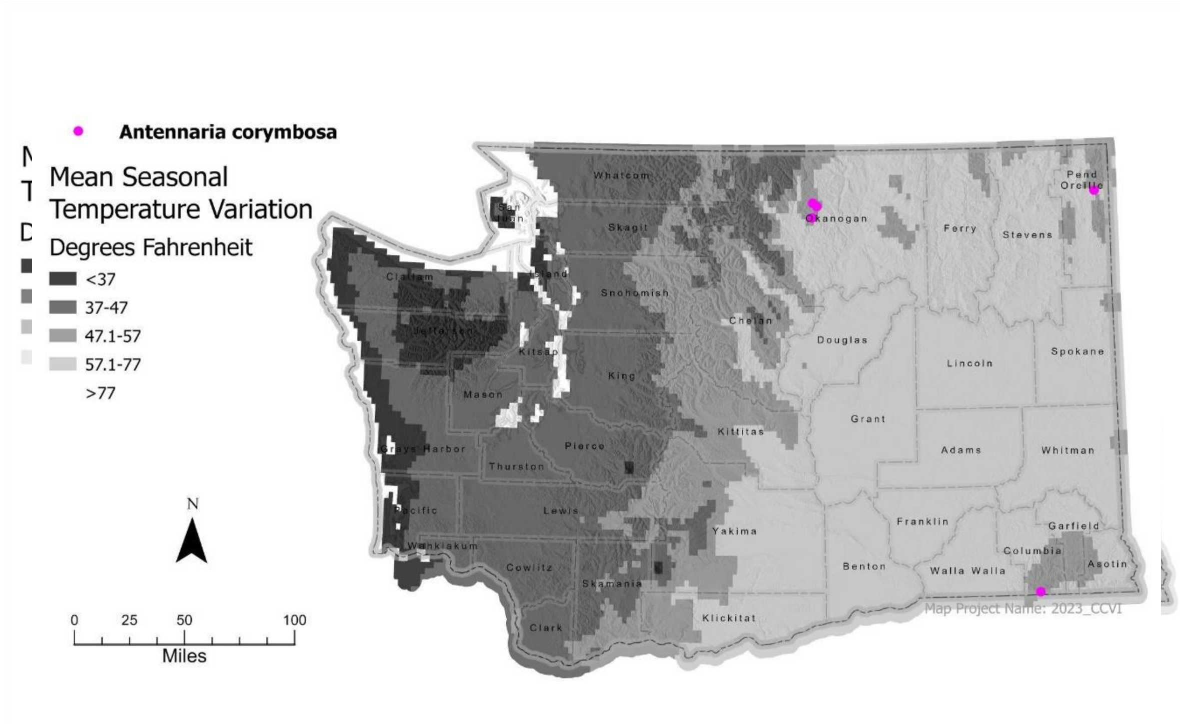

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Antennaria corymbosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Antennaria corymbosa is constrained to subalpine wet meadows and fens which are increasingly threatened by warmer, drier summers and earlier snowmelt (NatureServe 2023a, 2023b). These changes may result in lost connections to groundwater systems and reduction in spring inflows. The Rocky Mountain Alpine-Montane Wet Meadow ecological system is also vulnerable to drought from increased temperatures (Rocchio and Ramm-Granberg 2017). Risks related to hydrological change are documented in C2bii and risks related to tree encroachment due to warmer temperatures are documented in C4f. Subalpine species are expected to shift to higher elevations but have more upward terrain to shift to than alpine species and therefore are somewhat less vulnerable.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Antennaria corymbosa* occurrences in Washington. All five occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these occurrences are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

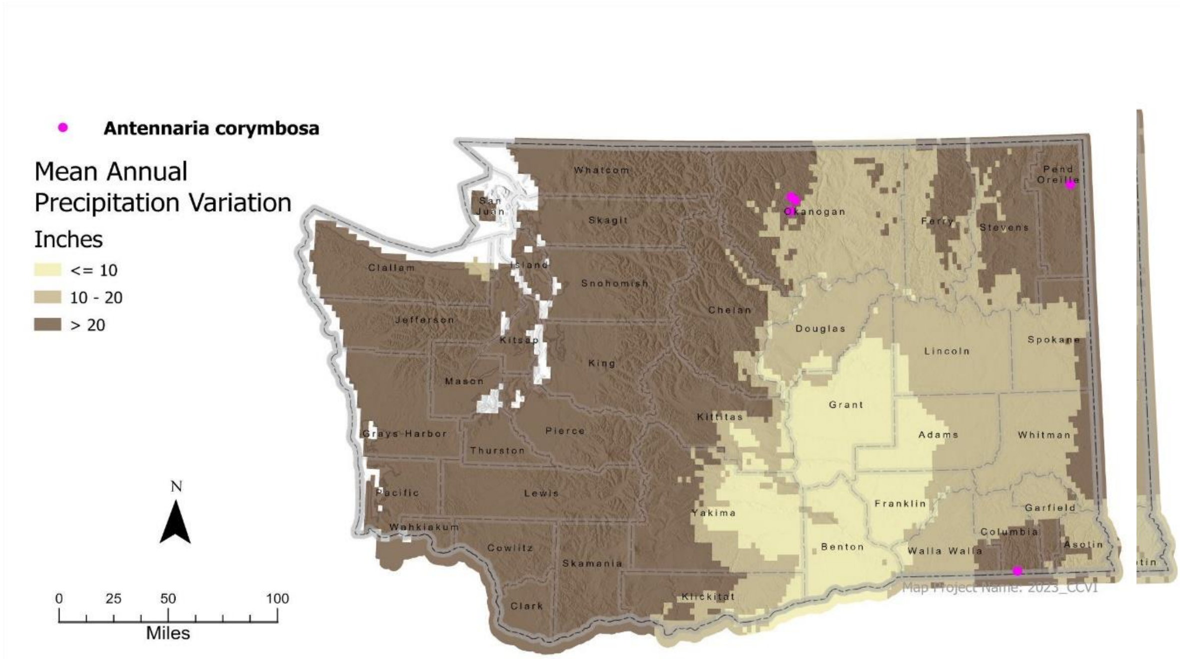

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Antennaria corymbosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Greatly Increase</u>
Antennaria corymbosa is associated with the narrow ecotone between wetland and forest and is one of the most mesophytic of *Antennaria* species (Bayer 1987b), occurring with other wetland species such as *Salix drummondiana* and *Carex scopulorum* var. *prionophylla*. It is likely to be somewhat negatively affected by changes to the hydrological regime (Washington Natural Heritage Program 2023). Groundwater tables for associated wet meadows and fens are typically quite stable and not well adapted to fluctuations or flooding disturbance though they can be either permanently or seasonally wet (NatureServe 2023a, 2023b). Montane wet meadows occur with groundwater discharge or seasonally high water tables as narrow strips boarding lakes and streams along gentle slopes. In alpine areas, sites are more tightly associated with snowmelt for groundwater recharge and do not typically experience flooding (Rocchio and Crawford 2015).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
The wet meadow and subalpine fen habitats of *Antennaria corymbosa* are not adapted to frequent disturbances, but healthy water flow, hydrological fluctuations, and periodic inundation are important for keeping encroaching conifers which can further dry out these ecological systems at bay. Grazing is likely a threat in this ecological system, though *Antennaria* spp., including *A.*

rosea (the parent of *A. corymbosa*), are increasers and frequently colonize disturbed areas of bare ground (Cooper 2003).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
Rocky Mountain Alpine-Montane Wet Meadows and Subalpine-Montane Fens depend on groundwater recharge from snow and changes to snow depth and cover are likely to significantly alter the habitat of *Antennaria corymbosa* (Rocchio and Crawford 2015). However, exact adaptability is unknown and may be higher due to the mesophytic nature of *Antennaria corymbosa*.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Fens are confined to specific environments where saturated soils and cool temperatures result in slow decomposition and result in the formation of histosols, hemic and fibric peat soils, through organic content accumulation (Rocchio 2015). Wet meadows are more widespread throughout subalpine areas of the Rocky Mountains and occur with typical hydric soil characteristics, including high organic content or low-chroma and redoximorphic features (Rocchio and Crawford 2015, NatureServe 2023a).

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beavers are an important hydrogeomorphic driver of wet meadows. When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The documented primary pollinators of other *Antennaria* spp. are a moderately diverse array of small Hymenopterans such as cuckoo bees (*Nomada* spp.) mining bees (*Andrena spp.*), sweat bees (*Halictus* spp.) bumble bees (*Bombus* spp.), and flies (O'Brien 1980, Hilty 2018, LaManna et al. 2021). The number and richness of pollinator visits to female flowers tend to be low for *Antennaria* spp. (Bierzychudek 1987, LaManna et al. 2021) and the small floral size and lack of showy pigmentation indicates a somewhat limited pollinator syndrome (Cappellari et al. 2022). Versatility has been ranked neutral because *Antennaria* spp. are also wind-pollinated and can self-pollinate or cross-pollinate with congeners (California Native Plant Society 2023).

C4d. Dependence on other species for propagule dispersal: Neutral
Antennaria spp. propagules are wind-dispersed, and individuals can autonomously propagate via clonal spread without the assistance of other species.

C4e. Sensitivity to pathogens or natural enemies: Neutral
The genus *Antennaria* is not recorded to have many natural enemies but there is some indication that seed predation from moths can be significant (Forbes 1954). Specifically, there are reports that *A. rosea*, the parent species to *A. corymbosa,* may be sensitive to an achene predator (Chmielewski 1995). Sensitivity is ranked as neutral because there are no major indications of climate change induced increases to any pathogens or seed predators.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
With increasing temperatures, montane wet meadows and subalpine fens are at risk of drying and subsequent conifer encroachment (Ford and HilleRisLambers 2023). Wet meadows are also susceptible to invasion by many non-native species, especially pasture grasses such as *Poa pratensis* and *Phleum pratense* as well as exotics species common to other wetland types such as *Cirsium arvense* and *Taraxacum officinale* (Rocchio and Crawford 2015). However, the parent species *Antennaria rosea* has proven to be moderately resistant to invasion in competition studies (Maron and Marler 2008).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Antennaria corymbosa does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
No data are available on the genetic diversity of *Antennaria corymbosa* in Washington, however the genetic diversity of *A. corymbosa* has been reported as above average as compared to all putative parent species of *A. rosea*. The *A. rosea* polyploid agamic complex, which includes *A. corymbosa*, is known to be very genetically and morphologically diverse due to ongoing frequent hybridization and introgression (Thapa et al. 2020).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Antennaria corymbosa is a part of the *Antennaria rosea* polyploid agamic complex that mostly reproduces by forming asexual seeds (Bayer 1987a). It has a mixed mating system which also includes vegetative clonal spread via stolons and sexual outcrossing with other progenitors of the complex (Bayer 1991) and therefore may be better able to adapt to novel environments (Young et al. 2016). The ability to self-fertilize and produce asexual seed may allow new populations to start with just a single individual (Baker 1955). However, the occurrences in Washington are at the northwestern edge of the continuous range and so could have lower genetic diversity due to founder effects or inbreeding depression. Marginal populations of the parent species *A. rosea* have been shown to have lower levels of genetic diversity than those at the core of the range (Bayer 1991).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Antennaria corymbosa* (late June to mid-August) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral
No significant change to the range or biology of *Antennaria corymbosa* or its congeners has been documented in the current literature. The distribution and range of this species is not known to be decreasing with climate change and has not changed notably in the last 50 years.

D2. Modeled future (2050) change in population or range size: Unknown

Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Botrychium michiganense (**Michigan moonwort*****)***

Date: 8 November 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G3/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Somewhat Increase

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Both documented occurrences (100%) of *Botrychium michiganense* in Washington occur in an area with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C; Figure 1).

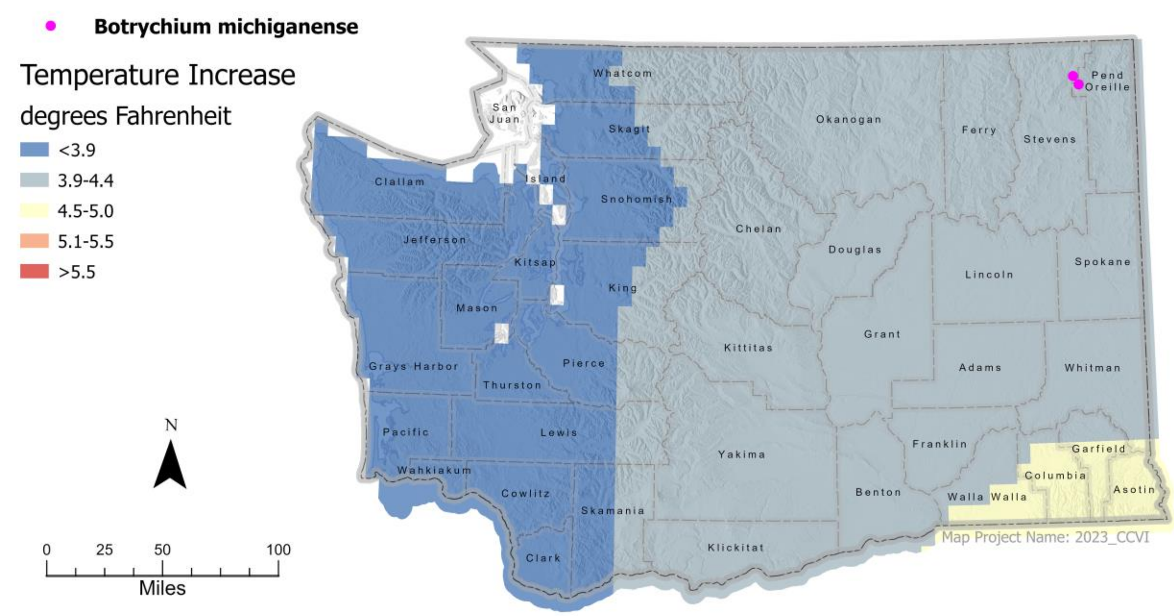

Figure 1. Exposure of *Botrychium michiganense* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both known occurrences (100%) of *Botrychium michiganense* in Washington occur in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119

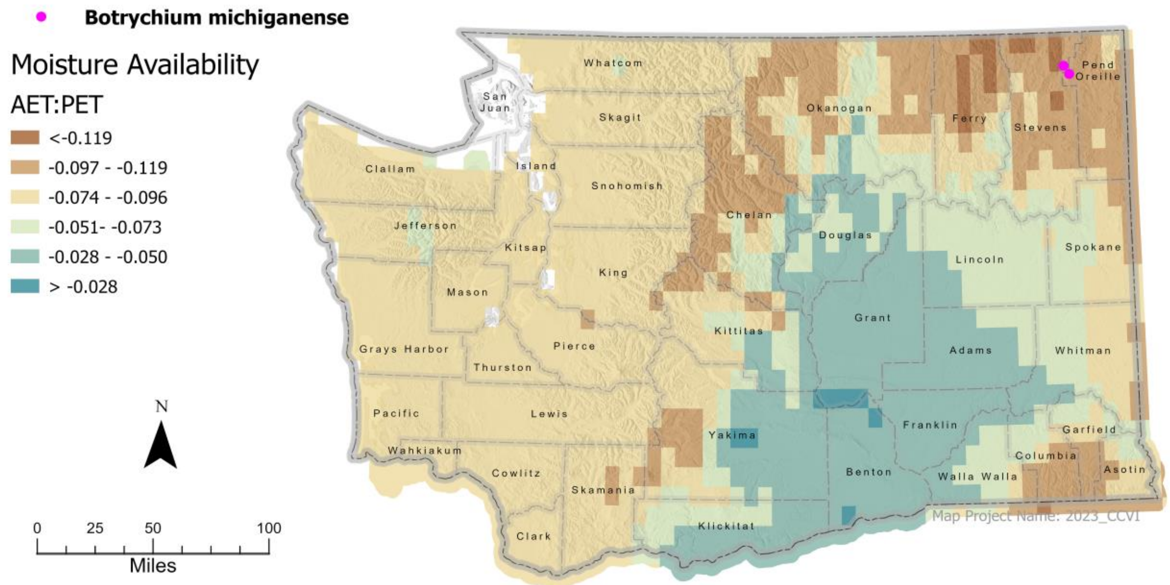

Figure 2. Exposure of *Botrychium michiganense* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

(Figure 2).

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Botrychium michiganense occurs on upper montane to subalpine rocky mountain grassy slopes, flats, and roadsides within open patches of mixed conifer and lodgepole pine forests at 3260-6000 ft (990-1100 m) in the Canadian Rockies (NatureServe 2023a, Washington Natural Heritage Program 2023). *Botrychium michiganense* occurrences in Washington are not expected to be affected by sea level rise based on their inland distribution and mid-elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Neutral</u>
Botrychium michiganense associates with small grassy openings to large, park-like grasslands in a matrix of coniferous forest at high latitudes in North America (NatureServe 2023b). This species has a patchy, scattered distribution in the Canadian Rockies, Middle Rockies, and northeastern North America. The two occurrences in Washington are separated by a relatively short distance of 4 mi (7 km). Unsuitable forest landscapes between grassy patches may pose a very slight barrier to dispersal and establishment but are not expected to significantly limit dispersal to suitable habitats.

B2b. Anthropogenic barriers: <u>Neutral</u>

Due to mountainous terrain within National Forest lands, the habitat of *Botrychium michiganense* remains relatively undisturbed by direct anthropogenic stressors. Timber harvests and off-road vehicles in the vicinity may pose a threat but are probably minor barriers to dispersal and migration, and this species appears to prefer clearings.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten the known occurrences of *Botrychium michiganense* and any potential forest health treatment such as thinning are not likely to pose a major threat to this species as it prefers forest openings (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Somewhat Increase</u>
Although the spores of *Botrychium* spp. can travel long distances via wind or water and some *Botrychium* spp. are also known to be distributed by animal attachment or ingestion, the majority of spores only disperse <10ft from the parent plant (Fryer 2014). These spores must be able to reach suitable grassland patches in the forest matrix in order to establish successfully.

C2ai. Historical thermal niche: <u>Neutral</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Botrychium michiganense* occurrences in Washington. Both known occurrences (100%) are in areas that have experienced average temperature variation average (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016), these occurrences are expected to be mostly resilient to climate warming.

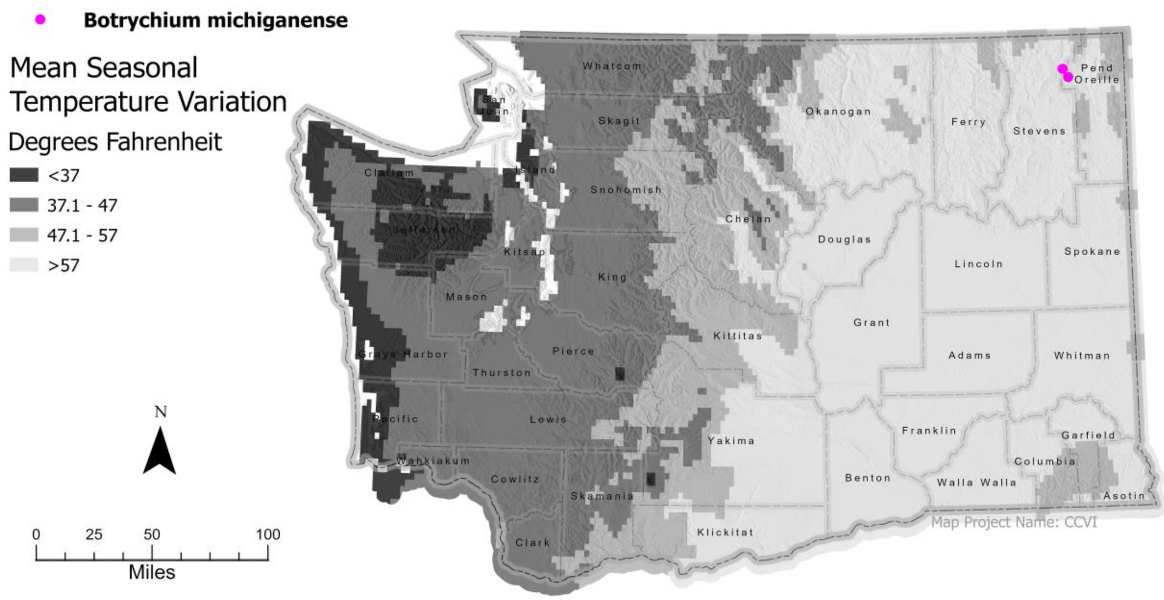

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Botrychium michiganese* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Somewhat Increase</u>
The temperature regime of the high elevation forest-grassland ecotone where *Botrychium michiganense* is found can be extreme, with frosts possible even during the growing season (NatureServe 2023a). This species prefers moderate temperatures with partial shade but can be found on exposed south-facing slopes (NatureServe 2023c). *Botrychium michiganense* occurrences closer to valley floors may in be cold air drainages and thus mitigated from extreme temperature changes (NatureServe 2023a).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Botrychium michiganense* occurrences in Washington. Both known occurrences (100%) are in areas that have experienced average or greater than average more than 20 in (508 mm) precipitation variation and are expected to be mostly resilient to climatic changes (Young et al. 2016)

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Botrychium michiganense* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Botrychium spp. are generally known to be sensitive to drought and moderate moisture availability (i.e., mesic but not wet) appears to be critical to *Botrychium* spp. and their supporting mycorrhizae (Williams and Waller 2015). However, *Botrychium michiganense* may be more resilient to hydrological change as it is one of the more xeric species of *Botrychium* and is often located on drier, south-facing slopes (NatureServe 2023c).

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Periodic disturbances and tree mortality events push back encroaching trees which would otherwise shade out *Botrychium michiganense* (Washington Natural Heritage Program 2023). Historically, the montane meadows this species occurs in experienced frequent, low intensity fires. Fire suppression has led to more stand-replacing fires which create larger grassland habitat patches (NatureServe 2023a). *Botrychium* spp. are known to thrive under light to moderate soil disturbance which can also promote fungi species that *Botrychium* spp. form mycorrhizal associations with (Williams and Waller 2015).

C2d. Dependence on ice or snow-cover habitats: Neutral
Washington occurrences of *Botrychium michiganense* are found in the Canadian Rockies ecoregion, which has an extreme temperature regime, with frosts possible even during the growing season and snowpack lingering into late spring. However, *Botrychium michiganense* is

not known to be particularly dependent on long-lasting ice or snow and occurs along lower elevation slopes and flats where snow melt occurs earlier in the year.

C3. Restricted to uncommon landscape/geological features: Neutral
Botrychium michiganense is restricted to areas of glacial outwash deposited by the Cordilleran Ice Sheet in Washington (Washington Division of Geology and Earth Resources 2016). This species is found in well-drained, mesic to dry calcareous slopes and flats associated with glacial outwash. Associated soils are typically gravelly-sandy, with low organic matter content (NatureServe 2023a, Washington Natural Heritage Program 2023). Some research shows that *Botrychium* spp. need bare mineral soils to germinate (Fryer 2014). These soil types are relatively widespread in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The montane-subalpine meadows where *Botrychium michiganense* occurs are primarily maintained by fire, tree mortality events, periodic drought, and shallow soils that prevent encroachment and shading and are not reliant on other species. Grazing by native ungulates play a minor role in maintaining these grassy openings.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Botrychium spp. do not depend on pollinators for their reproductive cycle. Instead, spores are spread via wind and gametophytes are produced vegetatively underground.

C4d. Dependence on other species for propagule dispersal: Neutral
Botrychium spores are mostly dispersed passively via wind or water. However, some species are known to have spores that can attach to animals or spread via ingestion as they are able to survive digestion (Fryer 2014).

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Deer and slugs are reported to sometimes eat the sporophytes of *Botrychium* spp., which can negatively impact growth in subsequent years (Williams and Waller 2015). It is unknown if their activity will increase with climate change. Livestock grazing is a reported threat within the meadows where *Botrychium michiganense* occurs in Washington. Adverse effects of climate change are expected to be amplified in heavily grazed areas, but light to moderate habitat disturbances are likely to be of benefit.

C4f. Sensitivity to competition from native or non-native species: Neutral
The montane grasslands where *Botrychium michiganense* occurs can be moderately to densely vegetated and are often comprised of tussock-forming grasses that create a dense sod which is hard for colonizers to penetrate (NatureServe 2023c). Non-native species are currently minimal where Washington occurrences are found. Tree encroachment may be of some concern because of fire suppression.

C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase

All *Botrychium* spp. are mixotrophic and depend on mycorrhizal associations with glomalean fungi to provide carbon to developing gametophytes and, to a lesser degree, mature sporophytes (Gilman et al. 2015, Williams and Waller 2015).

C5a. Measured genetic variation: Unknown
The specific genetic variation of *Botrychium michiganense* occurrences in Washington is unknown and unresolved taxonomic questions complicate a proper assessment. It is an allotetraploid with fixed heterozygosity (Gilman et al. 2015) that occurs in very small populations in Washington (one occurrence notes only one individual). Studies have found other members of the *Botrychium* genus to have low genetic variation due to frequent inbreeding (Beatty et al. 2003).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Botrychium michiganense is a perennial fern with leaves that are divided into a sterile photosynthetic segment (tropophore) and a fertile spore-bearing segment (sporophore) (Washington Natural Heritage Program 2023). It follows an alternation of generations reproductive strategy like all ferns and some species of *Botrychium* are also known to asexually produce vegetative buds (gemmae) that can generate new individuals (Williams and Waller 2015). *Botrychium* spp. are more versatile in their reproductive modes than many species, as they are able to employ a number of different sexual and asexual strategies (Fryer 2014).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the spores of *Botrychium michiganense* consistently mature in the summer around June (Washington Natural Heritage Program 2023) with no apparent changes over time, though there are few records. Other more widely distributed *Botrychium* spp. have been shown to release spores earlier in response to warming temperatures (Speed et al. 2022)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Botrychium michiganense was described in 2015 and has not been documented or studied for long enough to clearly identify any responses to climate change. One occurrence has been relocated in 2005 and the other has not been revisited since the late 1990s.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Campanula lasiocarpa (Alaska harebell)

Date: 15 Sept 2023 Synonym: *Campanula latisepala*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Moderately Vulnerable Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	12
	<3.9° F (2.2°C) warmer	88
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase/Greatly Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase/Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

Section A	Severity	Scope (% of range)
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	12
	<3.9° F (2.2°C) warmer	88
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral
6. Phenological response to changing seasonal and precipitation dynamics		Neutral
Section D		
D1. Documented response to recent climate change		Unknown
D2. Modeled future (2050) change in population or range size		Unknown
D3. Overlap of modeled future (2050) range with current range		Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution		Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Seven of the eight (88%) known occurrences of *Campanula lasiocarpa* in Washington occur in areas with a projected temperature increase of less than or equal to 3.9° F (2.2°C; Figure 1). The remaining occurrence in King County is in an area with a projected increase of 3.9-4.4° F (2.2-2.4°C).

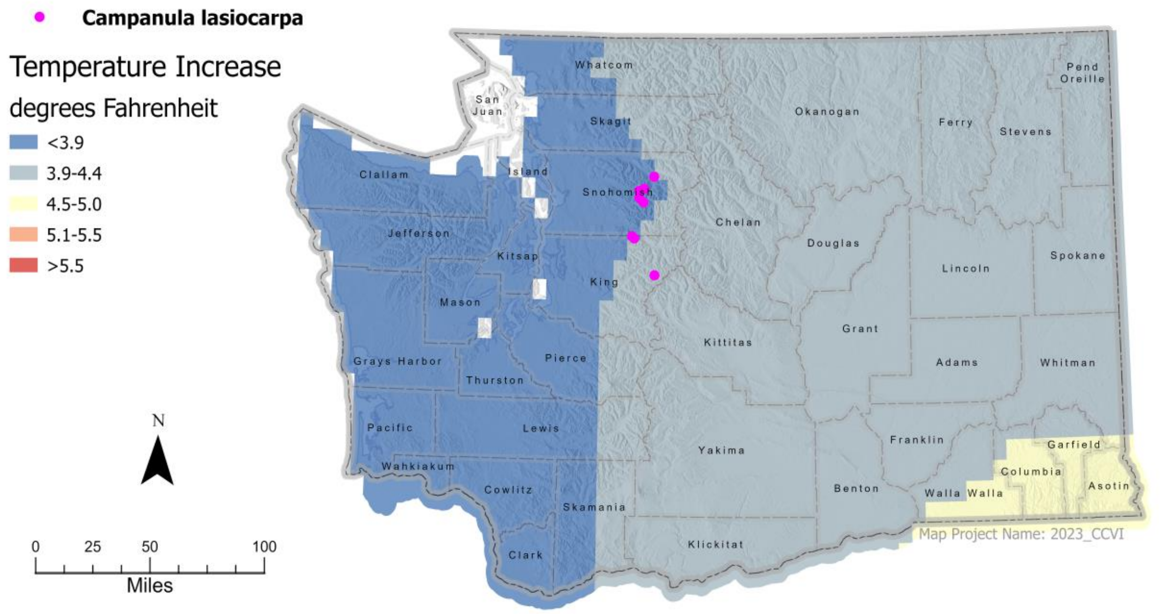

Figure 1. Exposure of *Campanula lasiocarpa* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All known occurrences (100%) of *Campanula lasiocarpa* in Washington are found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

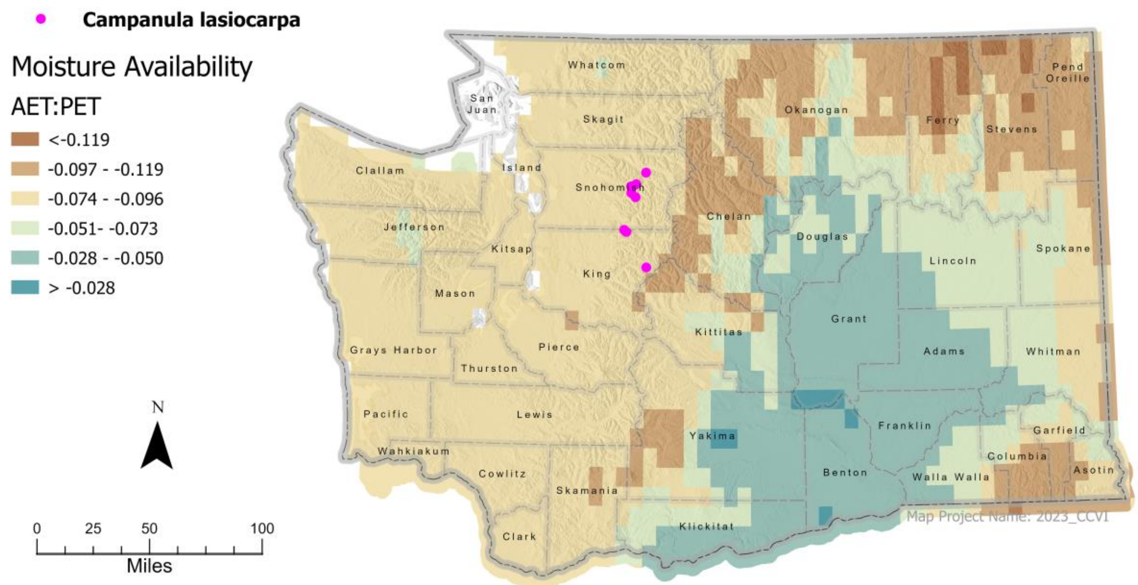

Figure 2. Exposure of *Campanula lasiocarpa* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Campanula lasiocarpa is restricted to subalpine and alpine rock crevices, heaths, and sandy tundra above tree line in the Wenatchee Range of Chelan County at elevations ranging from 2000-6840 ft (610-2085 m; Washington Natural Heritage Program 2023). *Campanula lasiocarpa* occurrences in Washington will not be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Increase to Greatly Increase
Campanula lasiocarpa is localized to the North Pacific Alpine & Subalpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). Occurrences are located sporadically in rock crevices and rubble on a few mountain sides separated by 2-42 mi (3-68 km) of unsuitable valley and forest habitat which acts as a barrier to propagule dispersal and results in low habitat connectivity. Field notes describe access to occurrences as obstructed by "formidable impasses" and "steep rocky slopes." There is limited room for this species to move upward with climate change. *Campanula lasiocarpa* may be at risk of following an "elevator to extinction" as the coolest climatic zones of the alpine are lost (Watts et al. 2022).

B2b. Anthropogenic barriers: Neutral
The rugged, high elevation terrain where *Campanula lasiocarpa* occurs remains relatively uninhibited by direct anthropogenic barriers as there are few roads and little human infrastructure in the area. However, recreation impacts are of concern and several field survey notes describe obvious trail erosion and trampling of individuals. Many of the occurrences are located within proximity to trails or are directly intersected by trails.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten occurrences of *Campanula lasiocarpa* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely due to the rugged subalpine to alpine terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Campanula lasiocarpa produces a cylindric capsule with multiple dehiscent valves that release numerous small, light seeds which are wind, water, or gravity dispersed and have low germination rates (Shetler and Morin 1986, Jensen et al. 2005, Voronkova et al. 2008, Tsuyuzaki and Miyoshi 2009). The seeds do not have specially adapted structures for aerial travel but can be wind-dispersed as capsules on stalks are swung in the wind (Watts 2015). Though wind-dispersal is a long-distance dispersal syndrome (Thomson et al. 2011) which can buffer the effects of low patch connectivity (Jones et al. 2015), it likely that the unique wind-dispersal mechanism of *Campanula lasiocarpa* only broadcasts seeds a short to moderate distance from parent plants.

C2ai. Historical thermal niche: Somewhat Increase/Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Campanula lasiocarpa* occurrences in Washington. Six of the eight (75%) known occurrences are in an area that has experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these occurrences are expected to be somewhat vulnerable to climate warming. The remaining two occurrences (25%) are in areas that have experienced lower than average temperature variation (37 - 47° F (20.8 - 26.3° C)) and are expected to be more vulnerable to warming (Young et al. 2016).

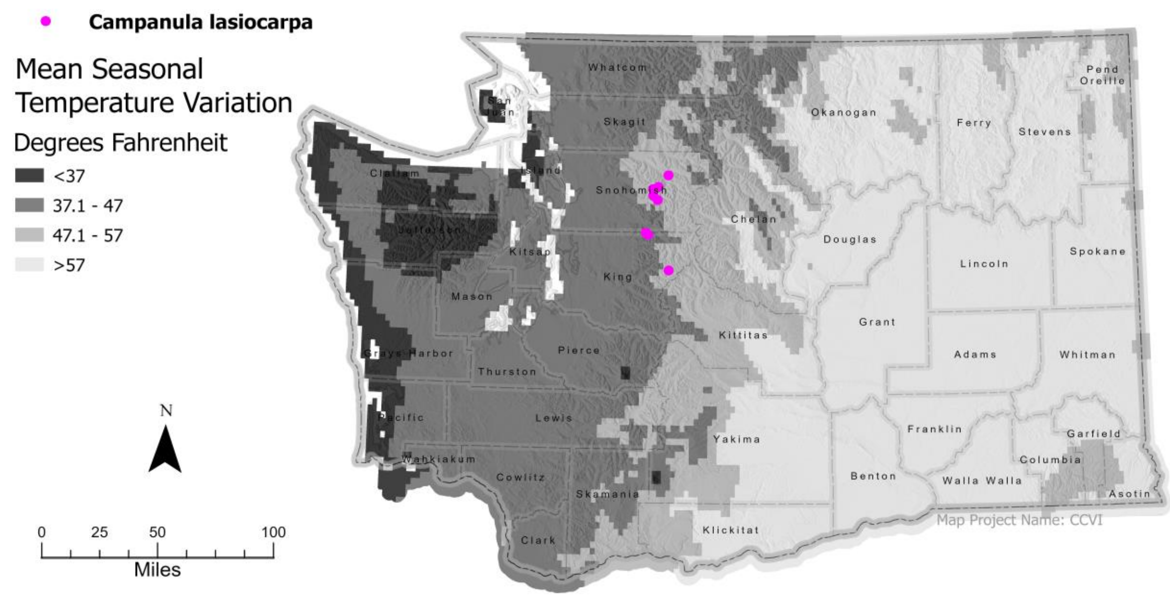

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Campanula lasiocarpa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
The North Pacific Alpine-Subalpine Bedrock & Scree communities which support *Campanula lasiocarpa* are found at some of the highest elevations of the Cascade Mountains which remain cold, and snow covered for much of the year (NatureServe 2023). Warming temperatures are expected to extend the growing season and potentially increase competition from other plants that are adapted to drier environments (Rocchio and Ramm-Granberg 2017). *Campanula lasiocarpa* may be resilient to warming as it already occurs on dry windswept ridges with full sun exposure.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Campanula lasiocarpa* occurrences in Washington. All known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these occurrences are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

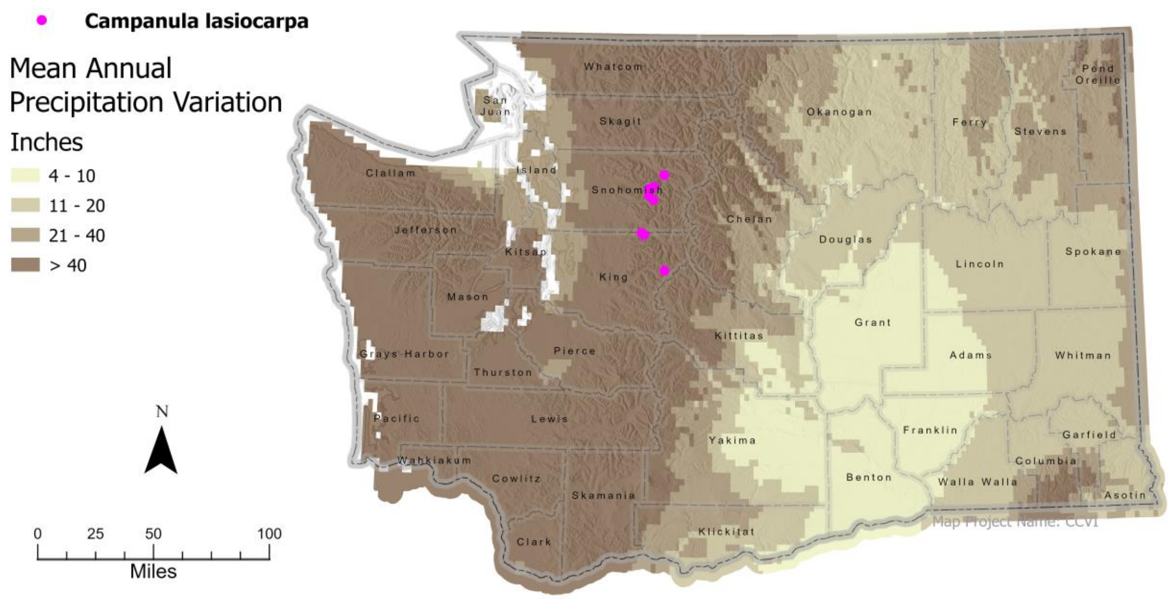

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Campanula lasiocarpa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Climate warming is expected to melt glaciers, decrease snowfall, and cause snowpack to melt earlier in the season in the Cascade Region (Raymond et al. 2014). Species of the water-limited alpine slopes, including *Campanula lasiocarpa*, depend on steady flow of water through the summer months from slow melting snow and ice in the surrounding landscape. It is unknown exactly how precipitation shifts from snow to rain and changes in the timing of snowmelt will affect individual species, but these hydrological changes are likely to significantly alter the preferred habitat of alpine scree plants (Rocchio and Ramm-Granberg 2017). Because *Campanula lasiocarpa* already occurs in areas where wind-scour prevents snow accumulation, it may be more tolerant of changes to snowmelt or may conversely be threatened by loss of a limited water supply.

C2c. Dependence on a specific disturbance regime: Neutral
Wind, water, and gravity are forces acting upon scree and talus habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004, Rocchio

and Ramm-Granberg 2017). Climate change may accelerate soil formation which is typically very minimal due to abiotic disturbances (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
The high alpine and subalpine regions above the tree line of the Wenatchee Range where *Campanula lasiocarpa* occurs experience long winters with the majority of annual precipitation falling as snow (Raymond et al. 2014). Ongoing and projected reductions in the amount of snow, conversion of snow to rain, and changes in the timing of snowmelt could alter the amount of moisture available for this species under climate change (Rocchio and Ramm-Granberg 2017). However, *Campanula lasiocarpa* occurs on exposed, steep, eastern-facing slopes where drying winds and sublimation from sun exposure can prevent snowpack from accumulating and persisting as late into the summer as surrounding basins (Montana Natural Heritage Program 2023). Conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and may actually increase the habitat available to *Campanula lasiocarpa* (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Campanula lasiocarpa occurs in the dry crevices of granite boulders and rock spires in unglaciated alpine zones within cool, wet subalpine areas (Washington Natural Heritage Program 2023). These microsites support thin, fine, sandy soils weathered from grandodiorite and are shaped strongly by wind abrasion. Granite and granodiorite are fairly common across the Cascade Range (Landes 1914), especially north of Snoqualmie Pass where *Campanula lasiocarpa* occurrences are located.

C4a. Dependence on other species to generate required habitat: Neutral
The North Pacific Alpine and Subalpine Bedrock and Scree ecological system is shaped mostly by abiotic processes and mass wasting events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015, NatureServe 2023).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The tubular-campanulate flower shape of *Campanula lasiocarpa* is sometimes associated with the attraction of specialist pollinators (DeChaine et al. 2014), but it has been reported that the flowers are visited by large bumblebees and “other large insects” that can reach the nectar held in a unique ring around the base of the style (Watts 2015). Little is reported about the specific pollinators of *Campanula lasiocarpa* but it does not appear to be exceptionally pollinator limited and other *Campanula* spp. with similar floral morphology are known to be pollinated as many as four to five families of bees (Milet-Pinheiro et al. 2021).

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Campanula lasiocarpa* are dispersed primarily by wind, water, or gravity and do not have adaptations for attachment to animals. The species is not dependent on animals for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral

Occurrence reports for *Campanula lasiocarpa* mention potential browsing by nearby populations of mountain goats (*Oreamnos americanus*) but note that no direct damage was observed. Large herbivores may nomadically graze in high alpine communities but are not expected to pose a major threat (Montana Natural Heritage Program 2023). No other major pathogens or enemies are documented for *Campanula lasiocarpa*.

C4f. Sensitivity to competition from native or non-native species: Neutral
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation North Pacific Alpine-Subalpine Bedrock & Scree ecological system that supports *Campanula lasiocarpa* (NatureServe 2023). *Campanula lasiocarpa* is probably adapted more for survival of these harsh abiotic conditions and not for competition, which is limited in rocky alpine communities. Studies have found this species to be four to five times more likely to establish on bare ground than in patches with higher vegetative cover (Uesaka and Tsuyuzaki 2005). Plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with deep enough soil, the tree line may also begin to encroach as the climate changes (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Campanula lasiocarpa does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Campanula lasiocarpa* has not been documented. However, the occurrences in Washington are found at the southeastern edge of the core range in North America (Washington Natural Heritage Program 2023). The peripheral status and small average sizes of Washington populations could mean that they have lower genetic diversity due to genetic drift or inbreeding depression. Field notes indicate that *Campanula lasiocarpa* may be hybridizing with *Campanula rotundifolia* where there is range overlap. If hybridization is occurring, it may put *Campanula lasiocarpa* at risk of genetic swamping (Todesco et al. 2016).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Campanula spp. are diploid to (occasionally) triploid hermaphrodites that are protandrous (functionally male before becoming functionally female) and possess mechanisms to remove pollen from the anthers before the stigma can be fertilized, effectively preventing or at least dampening self-pollination (Kovanda 1970, Shetler 1979). *Campanula lasiocarpa* is probably like other *Campanula* spp. and is likely a near-obligatory outcrosser that is quite reliant on insect pollination. There are no known major disruptions or barriers to gene flow among subpopulations. *Campanula lasiocarpa* has been described as a poor germinator with unreliable sexual production that instead largely relies upon vegetative reproduction long, branching rhizomes (Voronkova et al. 2008).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Campanula lasiocarpa has been reported to bloom from July through the end of August (Washington Natural Heritage Program 2023). Based on flowering dates of specimens in the

Consortium of Pacific Northwest herbaria website (pnwherbaria.org) and Washington Natural Heritage Program occurrence records, no major changes have been detected in phenology since the species was first collected in Washington in 1960. However, there are only a few records available to represent the phenological baseline and trends of *Campanula lasiocarpa* in Washington.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Campanula lasiocarpa* declining or shifting its range in response to climate change, but a comprehensive study of population trends has not been completed in Washington. One Canadian study of plant community change in alpine tundra found that *Campanula lasiocarpa* increased between 1968-2010 in an area known to be affected by climate change (Danby et al. 2011). Most of the Washington occurrences have been re-visited and located multiple times in relatively recent years.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled in Washington.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled in Washington.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled in Washington.

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Climate Change Vulnerability Index Report

*Carex media (***Intermediate sedge***)*

Date: 18 December 2023 Synonym: *Carex norvegica* ssp. *inferalpina*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	95
	-0.074 to - 0.096	5
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Somewhat Increase
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All the 19 known occurrences (100%) of *Carex media* in Washington occur in an area with a projected temperature increase in the range of 3.9-4.4° F (2.2-2.4°C; Figure 1).

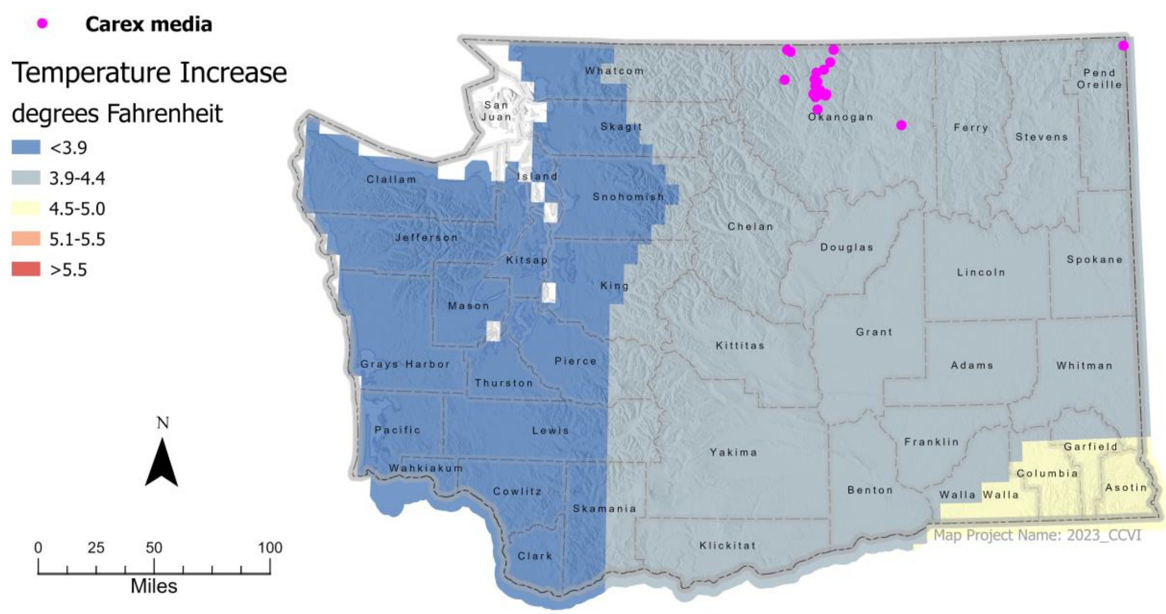

Figure 1. Exposure of *Carex media* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 19 known occurrences of *Carex media* in Washington, 18 (95%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The remaining occurrence (5%) in Pend Oreille County is in an area with a projected moisture decrease in the range of -0.074 to -0.096.

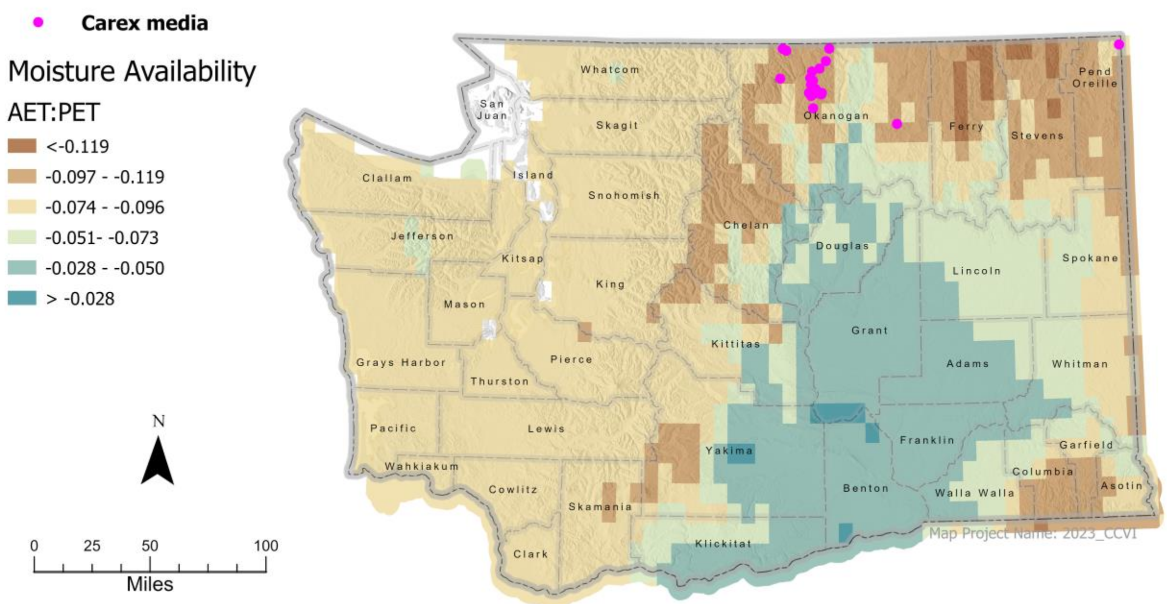

Figure 2. Exposure of *Carex media* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Carex media is restricted to moist meadows, perennial streams, and pond edges on the eastern side of the Cascade Mountains along the Canadian border at elevations ranging from 4900-7120 ft (1490-2170 meters; Washington Natural Heritage Program 2023). *Carex media* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and habitat (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Somewhat Increase</u>
Habitats occupied by *Carex media* are part of the Rocky Mountain Alpine-Montane Wet Meadow and Rocky Mountain Subalpine-Montane Riparian Woodland ecological systems Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). The valleys and gentle slopes with perennially wet soils where these ecological systems occur are somewhat limited and patchy within the surrounding matrix of montane to subalpine conifer forests.

Populations are separated by 1-147 mi (2-237 km) of unsuitable habitat and natural barriers such as mountain ridges which pose a somewhat significant impediment to dispersal in Washington.

B2b. Anthropogenic barriers: Neutral
Carex media occurrences in Washington are mostly undisturbed on public lands, wilderness areas, or conservation areas. However, on Forest Service lands managed for multiple use, there are trails running through populations, snowmobile activities, timber sale areas, and trampled areas due to heavy recreation. The small vegetation mats where *Carex media* occurs are highly sensitive to even minimal disturbances and roads and developed areas are known to fragment and alter the hydrology of riparian woodlands which support this species (Rocchio and Crawford 2015). These impacted areas are localized and probably pose less of a constraint to dispersal and future migration than natural barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten populations of *Carex media* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely to occur in wilderness areas and subalpine areas but may be a risk in the meadows, valleys, and floodplains where this species occurs.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
C*arex media* produces 3-seeded dry achene fruits that are light weight and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). *Carex* perigynia are able to float and those of section Racemosae, which includes *Carex media*, are somewhat flattened to facilitate periodic travel via strong winds (Wilson et al. 2014). Longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals or even endozoochory (ingestion by animals) (Allessio Leck and Schütz 2005; Newhouse et al. 1995). Dispersal distance for *Carex media* species is listed as “widespread” by Isle Royale National Park (Sanders et al. 2022)

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Carex media* occurrences in Washington. Three of the 19 known occurrences (16%) are in an area that has experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming. Another 11 occurrences (58%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation and are expected to be somewhat vulnerable to warming (Young et al., 2016). The remaining five occurrences (26%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation and are expected to be resilient to warming.

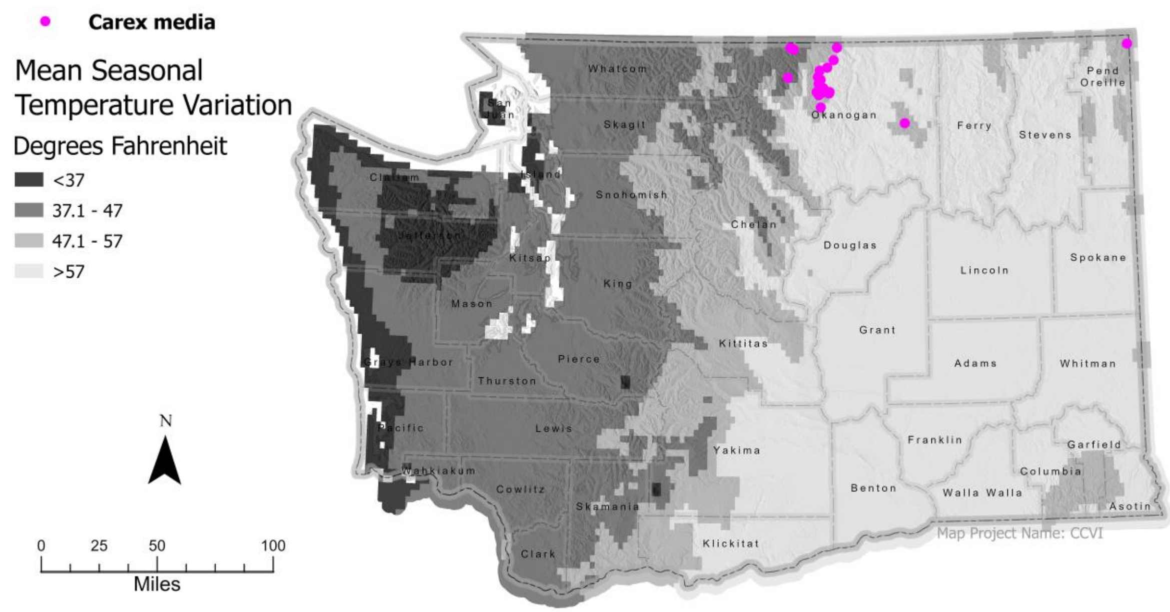

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex media* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase

Carex media is found within dry and cold portions of the East Cascades and Northern Rockies in areas that are mostly shaded by the forest canopy, which are likely cooler microhabitats, but can also be found in full sun (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). Populations of *Carex media* in Washington are found in wet meadows, at the edges of wetlands, and in riparian woodlands associated with cold air drainages such as V-shaped valleys. This species is likely to be vulnerable to changes in habitat quality and species composition associated with anticipated rising temperatures (Rocchio and Ramm-Granberg 2017). Increasing temperatures and evapotranspiration are likely to compound with shifts in groundwater discharge to alter inundation periods which will also increase wildfire frequency.

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Carex media* occurrences in Washington. Of the 19 known occurrences, 18 (95%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes. The remaining occurrence in Pend Oreille County (5%) has experienced slightly lower than average (11- 20 in (255 - 508 mm)) precipitation variation and is expected to be somewhat vulnerable to changing moisture regimes (Young et al. 2016).

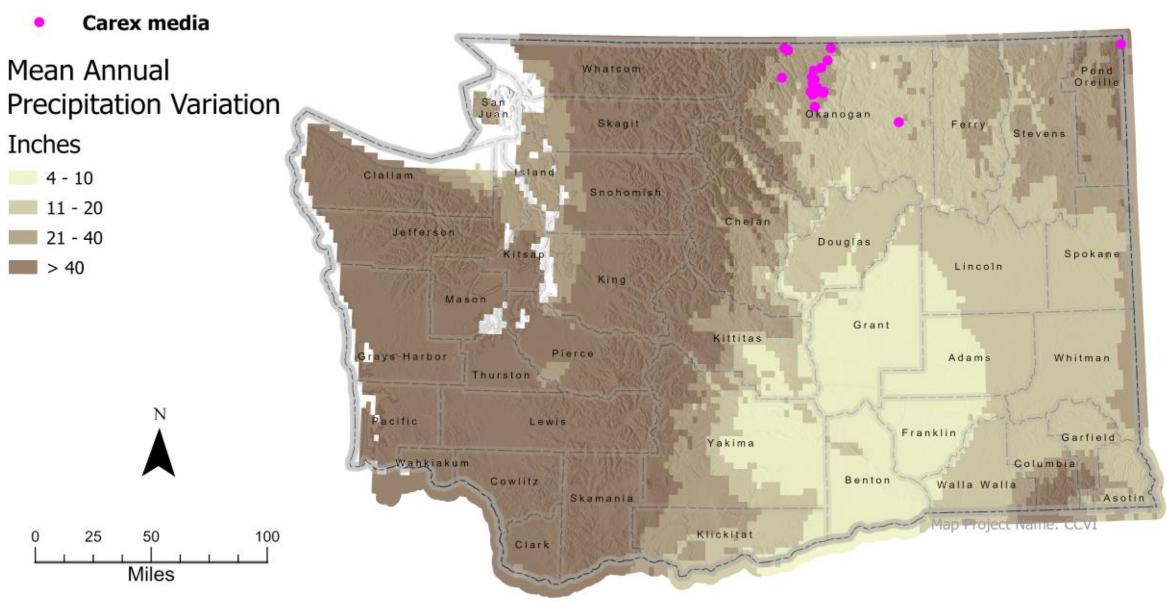

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex media* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Increase</u>
Carex media is dependent on seasonally to perennially flooded forests and woodland habitats in cold, dry portions of the Cascades and Northern Rockies in Washington (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). It is highly associated with water edges, seepy microsites within coniferous forest, and narrow floodplains. Riparian woodlands and wet meadows are anticipated to be negatively impacted by climate change induced shifts to the timing of groundwater discharge as a result of reduced snowpack, increases in summer temperatures and drought, which may lower water tables, as well as overall shifts in flood timing and magnitude which will alter tree regeneration and vegetation composition (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Riparian woodlands are primarily shaped by valley and floodplain type, flooding cycles, and stand replacing disturbances including fire, disease, and windthrow (Rocchio and Crawford 2015). Wet meadow populations are not typically susceptible to fire or other major disturbances but could become more vulnerable if water tables are lowered due to decreased snowpack or increased summer temperature or drought (Rocchio and Ramm-Granberg 2017). Some *Carex*

spp. benefit from fire but high intensity fires can kill shallow rhizomes (Wilson et al. 2014). Hydrological cycles and topography are generally more important for maintaining these ecological systems than major disturbances, though overbank flooding is required for regeneration in riparian woodlands.

C2d. Dependence on ice or snow-cover habitats: Neutral
The populations of *Carex media* in Washington are found in wet meadows and riparian woodlands just above the lower tree line which are fed primarily by groundwater or snowmelt Rocchio and Crawford 2015). *Carex media* is often associated with small depressions just below late-melting snow beds (Rocchio and Crawford 2015). Reduction in the amount or timing of snowmelt could alter the species composition in these communities, favoring plant taxa adapted to drier conditions (Rocchio and Ramm-Granberg 2017). However, *Carex media* is not especially reliant on ice or snow cover beyond recharge of the hydrological system.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Carex media is found on a variety of geologic substrates, including Tiffany Mountain gneiss, Doe Mountain tonalite, Cathedral batholith granodiorite, Loomis pluton, and other gneiss and metavolcanic formations (Washington Division of Geology and Earth Resources 2016). Many of these geologic types are relatively uncommon and limited mostly to the Okanogan region of Washington. Additionally, this species is restricted to small patch mineral soils with hydric characteristics and a significant amount of organic matter that are often found in draws or along dry channel beds (Rocchio and Crawford 2015).

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Wet meadow sites may be enhanced by browsing by ungulates or other herbivores that suppress the encroachment of woody vegetation. Beavers are also an important hydrogeomorphic driver of wet meadows. When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006). Beaver influence hydrology and vegetation in confined riparian woodlands but are even more critical in open meadow habitats (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Carex media, like other sedge species, is entirely wind-pollinated, and thus not dependent on animal pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral
Fruits of *Carex* spp. are mostly dispersed by gravity, water, or high winds. Occasionally dispersal may be abetted by animal vectors transporting fruits embedded in mud or via ingestion.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Carex spp. can be infected by host-specific smut fungi that infect and parasitize the gynoecia at the expense of seed production (Denchev et al. 2023). "Crop fungus" species are expected to increase infections with climate change (Stukenbrock and Gurr 2023). Cattle grazing is an active threat at many occurrences of C*arex media* with direct damage recorded in field surveys. *Carex*

spp. are a preferred food source for many ungulates, waterfowl, insects and mammals and heavy grazing will cause mortality (Newhouse et al. 1995; Wilson et al. 2014). There is no evidence that grazing will increase with climate change but it may compound to change water flows and infiltration, shift composition, and reduce woody species regeneration (Rocchio and Crawford 2015).

C4f. Sensitivity to competition from native or non-native species: Increase
Frequent flooding and stand replacing disturbances may allow the entry of pioneer species into riparian woodlands and, under projected climate change, competition could increase as wet meadows become drier and species composition shifts (Rocchio and Crawford 2015). Reductions in the water table, increased summer drought, and increased temperatures from climate change could result in replacement of wet meadow species by forest or dry meadow plants. This could increase competition for *Carex media* which is often found growing mostly with mats of relatively non-competitive lichens and mosses in its high elevation wetland habitats (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Some *Carex* spp. rely on mycorrhizal associations but most are facultative or not dependent. Wetland species generally lack mycorrhizae because the water-logged soil does not contain enough oxygen to support them. (Wilson et al. 2014).

C5a. Measured genetic variation: Unknown
The exact genetic variation of *Carex media* is unknown but it has a broad circumpolar distribution. However, its typically small population sizes (100 or fewer plants) could make this species sensitive to stochastic population dynamics and inbreeding depression.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Carex media is a wind-pollinated perennial graminoid that produces a gynaecandrous spike, unlike other *Carex* spp., which are usually monoecious obligate outcrossers. Like many other *Carex* spp., this species may be protogynous to promote outcrossing or may be self-compatible which is also common in the genus *Carex* (Friedman and Barrett 2009). Seeds of *Carex media* can remain dormant in soil for a long time and can act as reservoirs for genetic variation (Newhouse et al. 1995). The ploidy level and genetic variation of this *Carex* spp. is unknown but it could be expected to have at least average genetic variability based on its likely mixed mating system. Species of *Carex* section Racemosae, to which *Carex media* belongs, are expected to have a larger than typical genome size as they are a product of polyploidy (Więcław et al. 2021).

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Carex media* (early July to mid-August, fruiting as early as mid-July) has not changed significantly (Washington Natural Heritage Program 2023). In one study of herbarium records, *Carex media* was curiously found to flower later in the 1950–2018 period compared to 1900–1949, possibly because climate change

has lengthened the growing season and number of snow free days in the subalpine and flowering late confers some advantage to this species (Fazlioglu 2018).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Though there are no reports of *Carex media* declining in response to climate change over the last decade, this species has been moving northward since the last ice age and is expected to become increasingly rare at the southern edge of its range, which includes Washington (Wilson et al. 2014). All but one occurrence has been relocated and confirmed as extant in recent years.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

***Carex obtusata* (blunt sedge)**

Date: 19 December 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Greatly Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	-
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 6 known occurrences (100%) of *Carex obtusata* in Washington occur in areas with a projected temperature increase of less than 3.9° F (2.2°C; Figure 1).

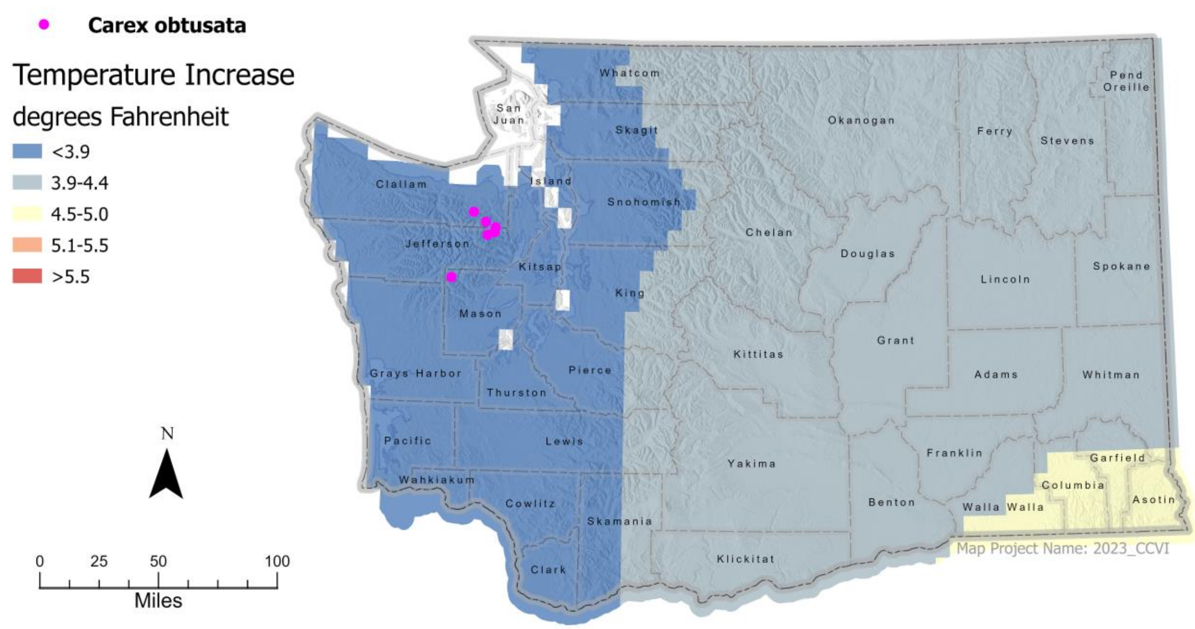

Figure 1. Exposure of *Carex obtusata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 6 known occurrences (100%) of *Carex obtusata* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2).

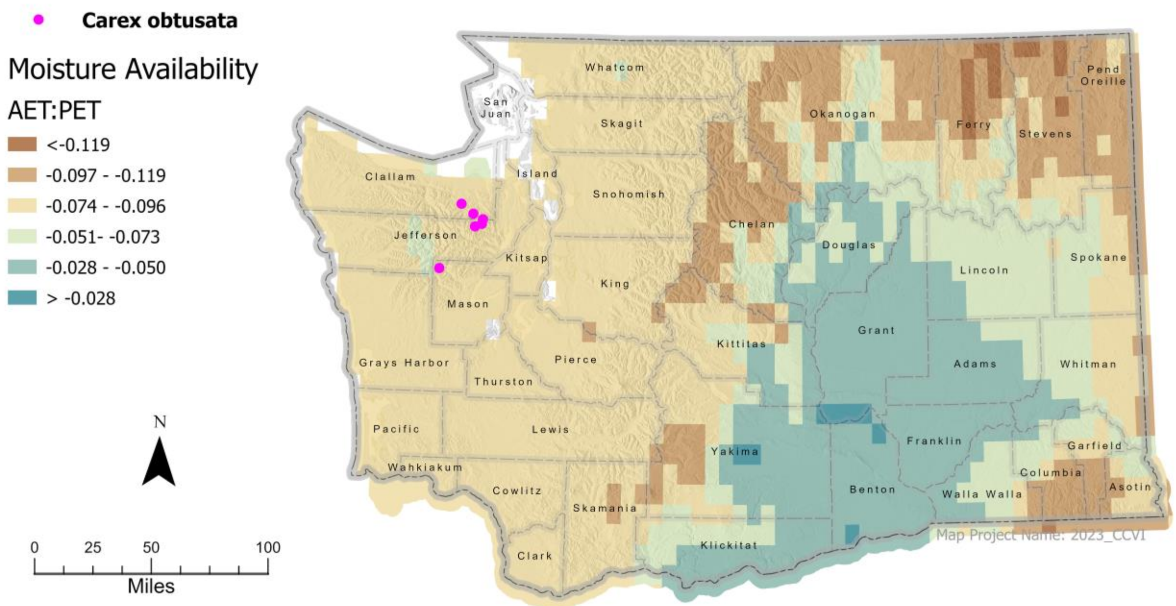

Figure 2. Exposure of *Carex obtusata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Carex obtusata is restricted to exposed rock and rubble in the Olympic Mountains at elevations ranging from 4700-6640 ft (1430-2025 meters; Washington Natural Heritage Program 2023). Despite their proximity to the Puget Sound, *Carex obtusata* populations in Washington are not expected to be affected by sea level rise due to their occurrence at high elevations (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Increase</u>
The grasslands, bluffs, scree meadows, and ridges occupied by *Carex obtusata* are part of the North Pacific Alpine and Subalpine Bedrock and Scree and Rocky Mountain Dwarf-Shrubland, Fell-Field, and Turf ecological systems which occur in a patchy mosaic within a larger montane landscape in the Olympic Mountains (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). Populations are separated by 3-30 mi (4-48 km) of unoccupied and unsuitable habitat. Individual occurrences are naturally separated by forested valleys, which create

somewhat of a barrier to local dispersal and gene flow. There is limited room for populations to move upward with climate change.

B2b. Anthropogenic barriers: Neutral
The backcountry, high elevation areas of wilderness, National Forest, and National Park where *Carex obtusata* occurs contain few anthropogenic barriers as there are few roads and little human infrastructure in the area. However, some occurrences are impacted by heavy recreational use with trails going through populations. Trampling and recreation impacts can be significant and result in erosion and bare ground pockets in fell-field and turf communities, which may pose a barrier to dispersal (Rocchio and Crawford 2015). These impacted areas are localized and probably pose less of a constraint to dispersal and future migration than natural barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Carex obtusata* in Washington (Washington Department of Natural Resources 2023). Future projects in the proximity of populations are unlikely due to their occurrence in rugged alpine terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Carex obtusata produces thick-walled dry achene fruits that are light weight and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). *Carex* perigynia can float well for water dispersal. Longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals or even endozoochory (ingestion by animals) (Allessio Leck and Schütz 2005; Newhouse et al. 1995)

C2ai. Historical thermal niche: Greatly Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Carex obtusata* occurrences in Washington. Two of the six known occurrences (33%) are in an area that has experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming. The remaining four occurrences (67%) are in an area that has experienced very little temperature variation (< 37° F (20.8° C)) and are expected to be highly vulnerable to warming (Young et al. 2015).

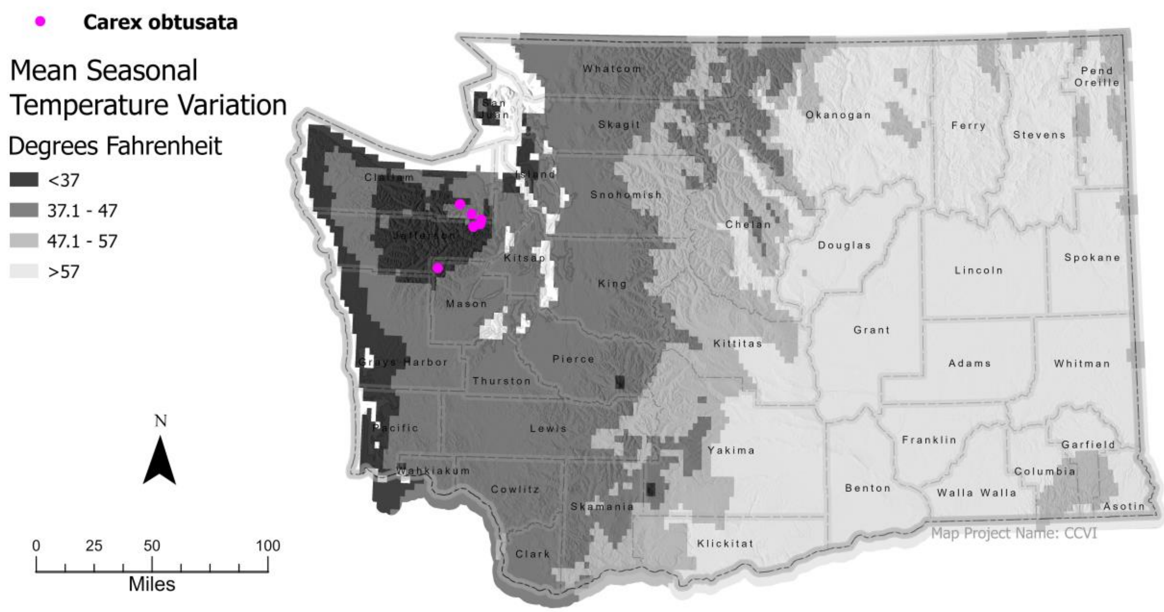

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex obtusata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase

The scree, fell-field, and turf communities that support *Carex obtusata* are found up to some of the highest elevations of the Olympic Mountains, which remain cold and snow covered for much of the year (NatureServe 2023). Warming temperatures are expected to extend the growing season and potentially increase competition from other plants that are adapted to drier environments (Rocchio and Ramm-Granberg 2017). *Carex obtusata* may be at risk of following an "elevator to extinction" as the coolest climatic zones of the alpine are lost (Watts et al. 2022). However, *Carex obtusata* may be more resilient to warming as it already occurs on drier, warming south-facing slopes and ridges in full sun (Øepka 2008). One study found this species to be unhindered or increased in abundance under warming treatment (Rudgers et al. 2014).

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Carex obtusata* occurrences in Washington. All six known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

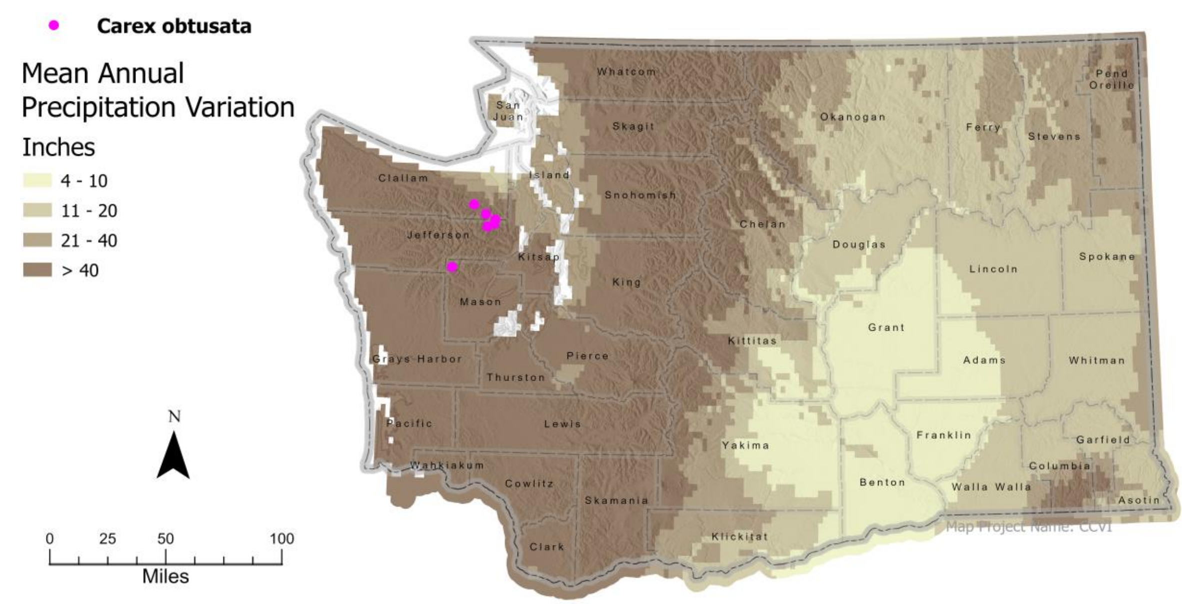

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex obtusata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
The dry to vernally moist slopes and scree meadows where *Carex obtusata* occurs rely primarily on snowmelt for a steady supply of moisture throughout the growing season. This species associates with concave topography with late-lying snow and subirrigation from surrounding snowmelt collecting in depressions (Rocchio and Crawford 2015). It is unknown exactly how precipitation shifts from snow to rain and changes in the timing of snowmelt will affect individual species, but these hydrological changes are likely to significantly alter the preferred habitat of alpine scree plants which is already moisture limited (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Carex obtusata occurs in alpine scree meadows that are mostly maintained by natural erosion processes and are further facilitated by cold climatic conditions and high winds that reduce soil formation and keep plant density low (Rocchio and Crawford 2015). Avalanches and freeze-thaw action further shape microclimates in these alpine communities. Additional periodic disturbances are not required to maintain this habitat and climate change is not expected to significantly impact these processes (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase

The high alpine regions where *Carex obtusata* occurs experience long winters with high snow accumulation as most precipitation falls as snow, with the Olympic Mountains averaging over 400 in (10 m) of snow annually (National Park Service 2021; Raymond et al. 2014). Ongoing and projected reductions in the amount of snow, conversion of snow to rain, and changes in the timing of snowmelt could alter the amount of moisture available for this species under climate change (Rocchio and Ramm-Granberg 2017). *Carex obtusata* occurrences note proximity to snow patches and concave topography with late-lying snow. Conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and could initially increase the habitat available to *Carex obtusata* (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: <u>Neutral</u>
Carex obtusata is found on coarse, sandy soils that are vernally moist and range from a thin, acidic, poorly developed composition to somewhat more developed with a thicker A horizon (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). Parent materials include Crescent Formation basalt flows and flow breccias and Eocene marine sedimentary rocks which are fairly widespread across the Olympic Peninsula (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: <u>Neutral</u>
North Pacific Alpine and Subalpine Bedrock and Scree ecological systems and associated montane meadows are shaped mostly by the processes of abiotic features such as fluctuating seasonal water tables and erosion events that shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015, NatureServe 2023).

C4b. Dietary versatility: <u>Not applicable for plants</u>

C4c. Pollinator versatility: <u>Neutral</u>
Carex obtusata, like other sedge species, is entirely wind-pollinated, and thus not dependent on animal pollinators.

C4d. Dependence on other species for propagule dispersal: <u>Neutral</u>
Fruits are dispersed by gravity, water, or high winds. Occasionally dispersal may be abetted by animal vectors transporting fruits embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: <u>Somewhat Increase</u>
Carex spp. can be infected by host-specific smut fungi that infect and parasitize the gynoecia at the expense of seed production (Denchev et al. 2023). “Crop fungi” are expected to increase infections with climate change (Stukenbrock and Gurr 2023)

C4f. Sensitivity to competition from native or non-native species: <u>Neutral</u>
Carex obtusata occurs in sparsely vegetated alpine scree and turf communities which are typically dominated by lichens (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). Few species are adapted to survive the desiccating winds, rocky substrates, and short growing seasons of these ecological systems. *Carex obtusata* is probably more adapted to tolerate harsh abiotic conditions than for competing with other vegetation, which is limited in

rocky alpine communities. Exotic plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with deep enough soil, the tree line may also encroach as the climate warms, according to predictions for several alpine regions of Washington (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Some *Carex* spp. rely on mycorrhizal associations but most are facultative or not dependent. Wetland species usually lack mycorrhizae because the water-logged soil does not contain enough oxygen to support them. (Wilson et al. 2014)

C5a. Measured genetic variation: Neutral
The diploid *Carex obtusata* has moderately high karyotypic variation in comparison to congeners (Rotreklová et al. 2011). It can be locally abundant with large populations (1 million + stems) that probably have relatively unrestricted gene flow.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Not scored
Carex obtusata is a perennial graminoid with horizontal creeping stolons that produces a solitary androgynous spike that bears achenes that enclose thick walled perigynia (Øepka 2008; Washington Natural Heritage Program 2023). It is wind-pollinated but is not necessarily an obligate outcrosser. It is unknown if *Carex obtusata* is capable of self-pollination. Seeds can remain dormant in soil for a long time and can act as reservoirs for genetic variation (Newhouse et al. 1995). This factor was not officially scored due to the inclusion of genetic variation and lack or information on the reproductive biology of *Carex obtusata* (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Carex obtusata* (mid-July to late August) has not changed significantly (Washington Natural Heritage Program 2023), though there were few records with phenological phase available to consider.

Section D: Documented or Modeled Response to Climate Change
D1. Documented response to recent climate change: Unknown
There are no reports of *Carex obtusata* declining in response to climate change. All occurrences but one have been relocated and confirmed as extant since 2010.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Carex scirpoidea* ssp. *scirpoidea (*Canadian single-spike sedge*)

Date: 20 December 2023 Synonym: *Carex athabascensis*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	60
	<3.9° F (2.2°C) warmer	40
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	33
	-0.074 to - 0.096	67
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	-
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the 15 known occurrences of *Carex scirpoidea* ssp. *scirpoidea* in Washington, nine (60%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C). The remaining six (40%) occur in areas with a projected temperature increase of less than 3.9° F (2.2°C; Figure 1).

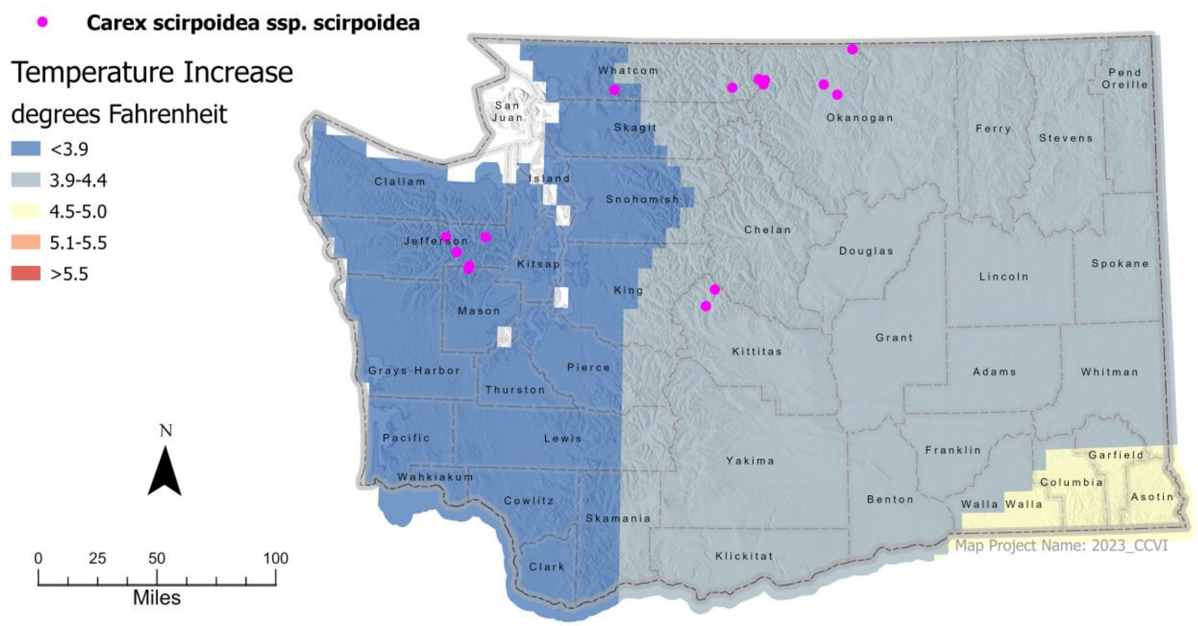

Figure 1. Exposure of *Carex scirpoidea* ssp. *scirpoidea* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 15 known occurrences of *Carex scirpoidea* ssp. *scirpoidea* in Washington, five (33%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other 10 (67%) are in areas with a projected moisture decrease in the range of -0.074 to - 0.096.

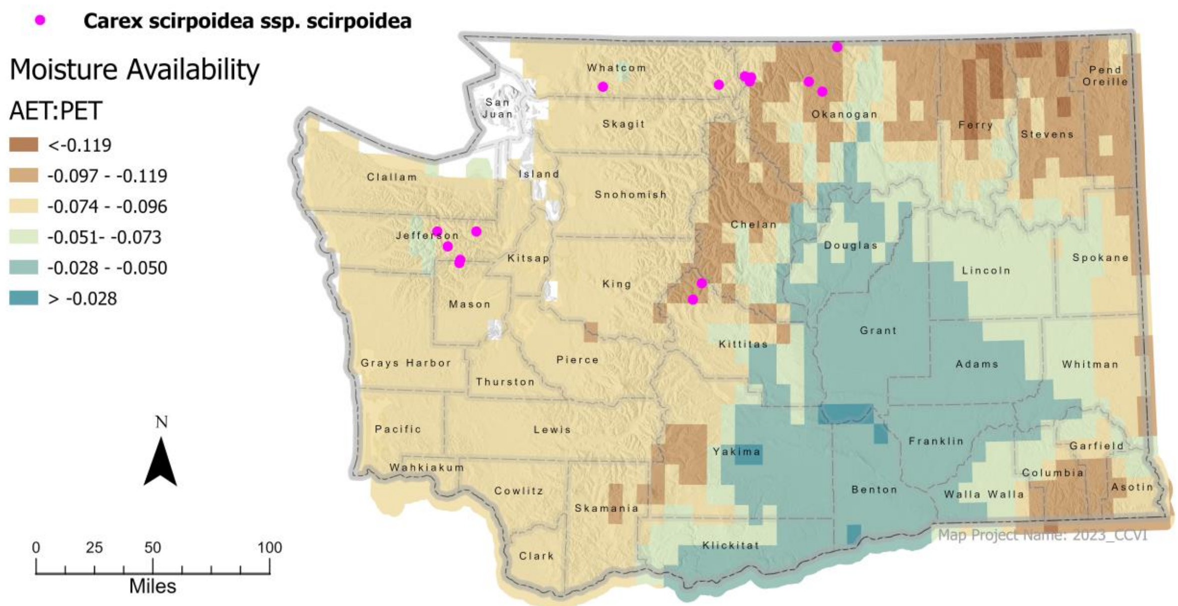

Figure 2. Exposure of *Carex scirpoidea* ssp. *scirpoidea* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Carex scirpoidea ssp. *scirpoidea* often occurs above timberline in rocky outcrops and scree slopes near mountain summits at elevations ranging from 4800-7600 ft (460-2315 m; Washington Natural Heritage Program 2023). *Carex scirpoidea* ssp. *scirpoidea* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Somewhat Increase
Carex scirpoidea ssp. *scirpoidea* is the widest ranging of the *Carex scirpoidea* subspecies with a circumboreal distribution occurring in Washington at high altitudes of the Olympic, Cascade, and Okanogan ranges within North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field, and Meadow; Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf; Rocky Mountain

Alpine-Montane Wet Meadow ecological systems (Rocchio and Crawford 2015; Shackleford 2003). Individual populations are found in rock outcrops, scree slopes, and boulder fields that are associated with moist meadows, stream banks, and seeps at cliff bases and are separated by 2-188 mi (4-302 km) of deep valleys and unsuitable forested habitat (Washington Natural Heritage Program 2023). Natural barriers are likely to somewhat restrict gene flow between populations in these ecological systems and impede future dispersal. However, the diversity of suitable high-elevation habitats for this species may facilitate future range shifts in response to climate change.

B2b. Anthropogenic barriers: <u>Neutral</u>
Most of the populations are within wilderness areas, conservation lands, or protected public lands and are generally in backcountry areas with few roads and minimal development. A few populations near roads may be impacted by herbicide drift and one population is in the direct path of a proposed road. Overall, barriers to dispersal and future migration remain minimal.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten populations of *Carex scirpoidea* ssp. *scirpoidea* (Washington Department of Natural Resources 2023). Future projects in the proximity of populations are unlikely due to their occurrence in backcountry alpine terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Somewhat Increase</u>
Carex scirpoidea ssp. *scirpoidea* produces dry achene fruits that are light weight and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Achenes do not readily release from spikes in this species which can further limit dispersal to some degree (Shackleford 2003). Longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals or even endozoochory (ingestion by animals; Newhouse et al. 1995, Allessio Leck and Schütz 2005).

C2ai. Historical thermal niche: <u>Somewhat Increase</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Carex scirpoidea* ssp. *scirpoidea* occurrences in Washington. Six of the 15 known occurrences (40%) are in an area that has experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. Another four occurrences (27%) have experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) and are expected to be vulnerable to warming. The remaining five occurrences (33%) are in an area that has experienced very little temperature variation (< 37° F (20.8° C)) and are expected to be highly vulnerable to warming (Young et al., 2015).

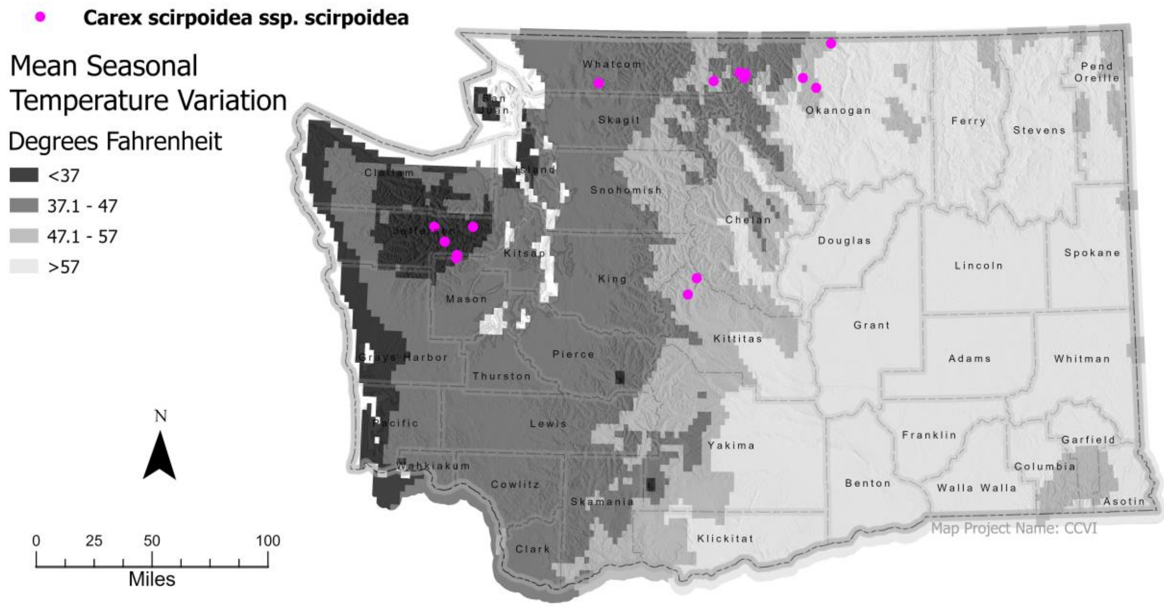

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex scirpoidea* ssp. *scirpoidea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
The subalpine and alpine rock and ledge habitat of *Carex scirpoidea* ssp. *scirpoidea* is exposed to high winds and some of the coldest growing season temperatures in Washington, particularly in the Okanogan range (Rocchio and Crawford 2015). These habitats are expected to be highly vulnerable to anticipated temperature increases (Rocchio and Ramm-Granberg 2017). *Carex scirpoidea* ssp. *scirpoidea* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022) However, this species may be somewhat resilient as it occurs almost exclusively on south-facing slopes which are slightly warmer than the surrounding landscape.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Carex scirpoidea* ssp. *scirpoidea* occurrences in Washington. All 15 known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

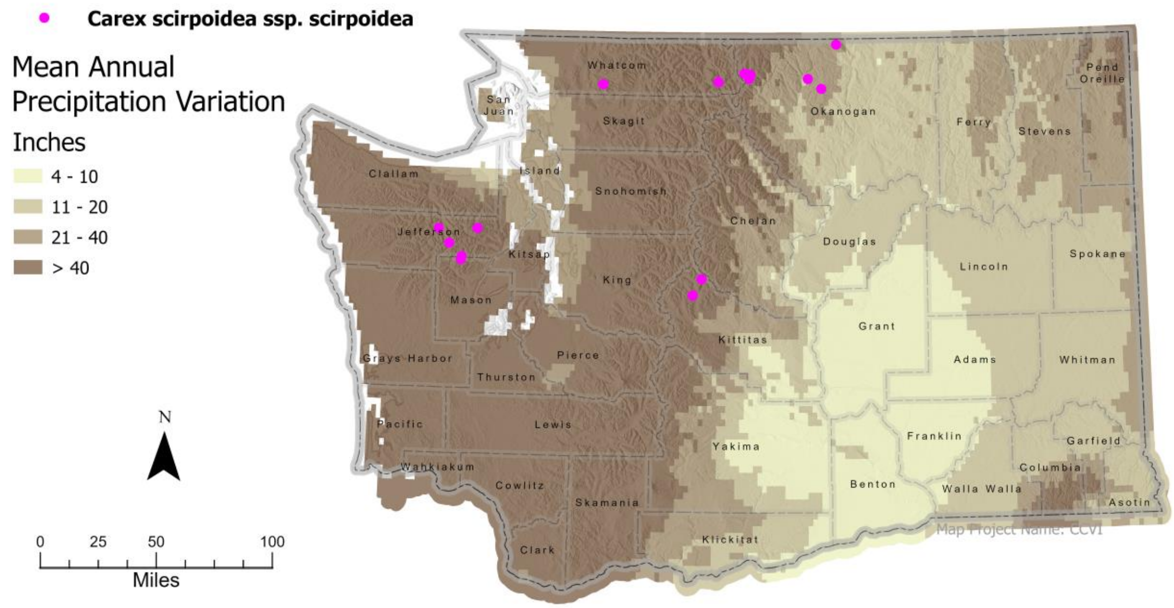

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex scirpoidea* ssp. *scirpoidea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Increase</u>
Carex scirpoidea ssp. *scirpoidea* occupies moister habitats than similar congeners, associating with wet seeps, late-lying snow, drainages of cirques, and stream banks among open rocky slopes (Washington Natural Heritage Program 2023). This species is dependent on winter snow and summer precipitation to feed subirrigation from surrounding slopes for a constant water supply through summer, as it is not directly associated with high water tables (Rocchio and Crawford 2015). As such, it is likely to be vulnerable to changes in the timing or amount of snow and rainfall and to warmer conditions changing the timing of snowmelt (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Dwarf-shrubland and fell-field habitats are mostly shaped by abiotic factors such as exposure to wind-scour, substrate erosion, and the short growing season (Rocchio and Crawford 2015). The wet meadow habitat of *Carex scirpoidea* ssp. *scirpoidea* is not adapted to frequent disturbances, but healthy water flow, hydrological fluctuations, and periodic inundation are important for keeping encroaching conifers at bay. Populations are not currently susceptible to fire or major drought but could become more vulnerable as a result of decreased snowpack or increased summer temperatures (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase
Carex scirpoidea ssp. *scirpoidea* is associated with depressions below late-melting snow patches or exposed rocky slopes which rely on subirrigation from melting snow on the surrounding slopes. Anticipated decreases in snow depth and cover are likely to significantly alter the habitat of *Carex scirpoidea* ssp. *scirpoidea* (Rocchio and Ramm-Granberg 2017; Rocchio 2006). This species may move upward to track suitable habitat with continued glacial retreat (Rocchio and Crawford 2015).

C3. Restricted to uncommon landscape/geological features: Neutral
Carex scirpoidea ssp. *scirpoidea* is often found on thin, rocky, calcareous soils but is not an obligate of these soil types (Dunlop 1990; Shackleford 2003; Washington Natural Heritage Program 2023). The soils with which it associates are often well drained, strongly acidic, low in organic matter, and poorly developed (Rocchio and Crawford 2015). Parent materials include basalt, phyllite, sandstone, granodiorite, gneiss, and a variety of other sedimentary and metamorphic complexes (Washington Division of Geology and Earth Resources 2016). Individually, these formations are somewhat uncommon in Washington but *Carex scirpoidea* ssp. *scirpoidea* itself is only slightly restricted as it can associate with any number of these geologic features.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
The alpine meadow and rocky slope habitat of *Carex scirpoidea* ssp. *scirpoidea* is mostly maintained by abiotic processes, such as snow distribution and mass wasting events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015). Beavers are an important hydrogeomorphic driver of wet meadows. When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006). Wet meadow sites may be enhanced by browsing by ungulates or other herbivores that contain the encroachment of woody vegetation.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Carex obtusata, like other sedge species, is entirely wind-pollinated, and thus not dependent on animal pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral
Fruits are dispersed by gravity, water, or high winds. Occasionally dispersal may be abetted by animal vectors transporting fruits embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Carex spp. can be infected by host-specific smut fungus which infect and parasitize the gynoecia at the expense of seed production (Denchev et al. 2023). "Crop fungus" species are expected to increase infections with climate change (Stukenbrock and Gurr 2023). *Carex* spp. are a preferred food source for many ungulates, waterfowl, insects and mammals and heavy grazing will cause mortality (Newhouse et al. 1995; Wilson et al. 2014). There is no evidence that grazing will increase with climate change but it may compound ecological system impacts to change water

flows and infiltration, shift composition, and reduce woody species regeneration (Rocchio and Crawford 2015).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation fell-field ecological systems which support *Carex scirpoidea* ssp. *scirpoidea* (Rocchio and Crawford 2015). Plant invasions remain relatively low in dwarf-shrubland and fell-field environments of the alpine but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). Wet meadows are susceptible to invasive species as non-natives and pasture species can easily dominate and alter species composition and hydrology (Rocchio 2006). Additionally, in areas with deep enough soil and in lower mesic areas of wet meadows, the tree line may also begin to encroach as the climate changes (Raymond et al. 2014). *Carex scirpoidea* ssp. *scirpoidea* is often a dominant species of windswept alpine slopes but is not a strong competitor, rather it exists among other species with different root morphologies where resource space is partitioned (Shackleford 2003)

C4g. Forms part of an interspecific interaction not covered above: Neutral
Some *Carex* spp. rely on mycorrhizal associations but most are facultative or not dependent. Wetland species generally lack mycorrhizae because the water-logged soil does not contain enough oxygen to support them. (Wilson et al. 2014).

C5a. Measured genetic variation: Neutral
Carex scirpoidea ssp. *scirpoidea* has been shown to have moderate levels of genetic diversity with more observed heterozygosity than expected, perhaps due to its wide, connected range and high potential for gene flow (DePrenger-Levin 2007; Yarbrough 2000). However, the fairly small population sizes of this species (<500 individuals) could make it sensitive to stochastic effects and inbreeding depression (Fertig and Kleinknecht 2020).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Not scored
Carex scirpoidea ssp. *scirpoidea* is a perennial graminoid with short rhizomes that produces 3-angled achenes and, unlike many other *Carex* spp., is dioecious (Dunlop 1990; Washington Natural Heritage Program 2023). As a result, it is an obligate outcrosser with less interbreeding and higher genetic variation than self-pollinating congeners (Shackleford 2003). This species may also infrequently produce clonally. This factor was not officially scored due to the inclusion of genetic variation data.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Carex scirpoidea* ssp. *scirpoidea* (June to late August) has not changed significantly (Washington Natural Heritage Program 2023), though there were few records with phenological phase available to consider.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Carex scirpoidea* ssp. *scirpoidea* declining in response to climate change. This species is known from 11 extant and 4 historic occurrences but most have not been revisited recently to document any potential declines.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Carex tenera var. *tenera (quill sedge)*

Date: 25 May 2024 Synonym: *Carex tenera* var. *echinodes, Carex tenera*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	91
	-0.074 to -0.096	9
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Unknown

4f. Sensitivity to competition from native or non-native species	Increase
4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 11 occurrences (100%) of *Carex tenera* var. *tenera* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C) (Figure 1).

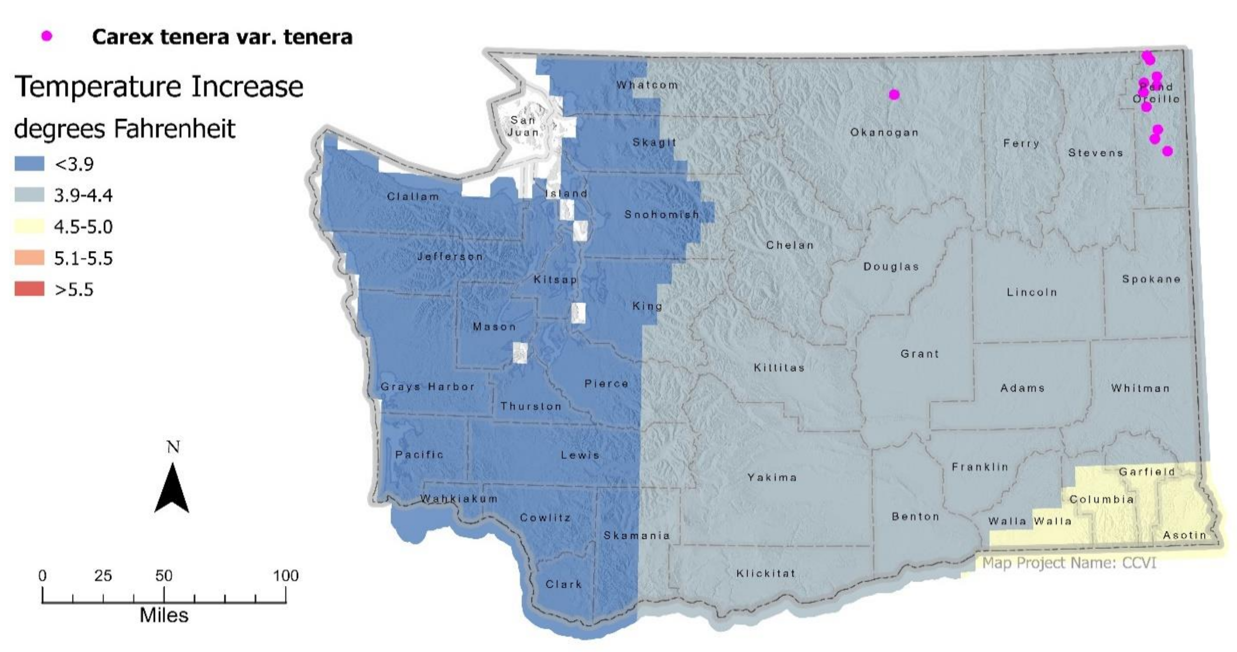

Figure 1. Exposure of occurrences of *Carex tenera* var. *tenera* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: One of 11 known occurrences (9%) of *Carex tenera* var. *tenera* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096. Ten of 11 known occurrences (91%) of *Carex tenera* var. *tenera* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

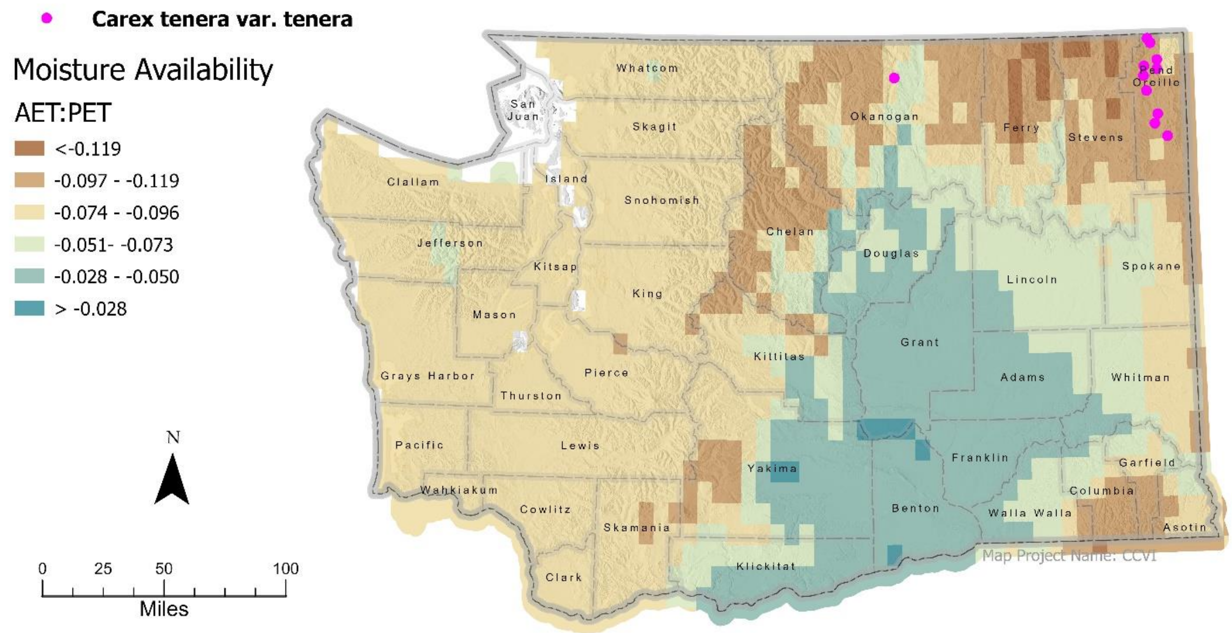

Figure 2. Exposure of occurrences of *Carex tenera* var. *tenera* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Carex tenera var. *tenera* occurs in meadows, open forests, shrub wetlands, and lakeshores in northeastern Washington, at elevations of 1460–3100 ft (445–945 m; Washington Natural Heritage Program 2024) and will not be affected by sea level rise based on their inland distribution (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
Carex tenera var. *tenera* occurs in habitats associated with North American Arid West Emergent Marsh, Rocky Mountain Alpine-Montane Wet Meadow, and Rocky Mountain Subalpine-Montane Riparian shrubland ecological systems (Washington Natural Heritage Program 2024).

These habitats are not uncommon in northeastern Washington but are frequently separated by a matrix of upland habitats (Rocchio and Crawford 2015). Occurrences of *Carex tenera* var *tenera* are 1–115 mi (2–185 km) apart in Washington. All but one of these occurrences are in the Pend Oreille River watershed with little topographic barriers between occurrences. However, the surrounding area of eastern Washington consists of large amounts of unsuitable arid habitats and mountain ranges that may pose additional barriers to gene flow for this species.

B2b. Anthropogenic barriers: <u>Somewhat Increase</u>
Most *Carex tenera* var. *tenera* occurrences in Washington are along the Pend Oreille River, in northeastern Washington. Timber harvest, roads, dams, and other human development are apparent throughout this area, fragmenting wetlands and riparian areas and decreasing habitat connectivity. Anthropogenic activities are known to fragment and reduce connectivity in all habitats in which *Carex tenera* var. *tenera* occurs, as well as connectivity between these habitats and upland ecosystems (Rocchio and Crawford 2015). Anthropogenic barriers likely pose at least some hindrance to gene flow for this species in Washington.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten populations of *Carex tenera* var. *tenera* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Somewhat Increase</u>
Carex tenera var. *tenera* produces small (1.3–1.7 mm) ovate achenes (Washington Natural Heritage Program 2024). Little information was available regarding dispersal for this taxon, but *Carex* seeds are likely to be passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals, or through endozoochory (Newhouse et al. 1995, Allessio Leck, and Schütz 2005).

C2ai. Historical thermal niche: <u>Neutral</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Carex tenera* var. *tenera* occurrences in Washington. All 11 occurrences (100%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

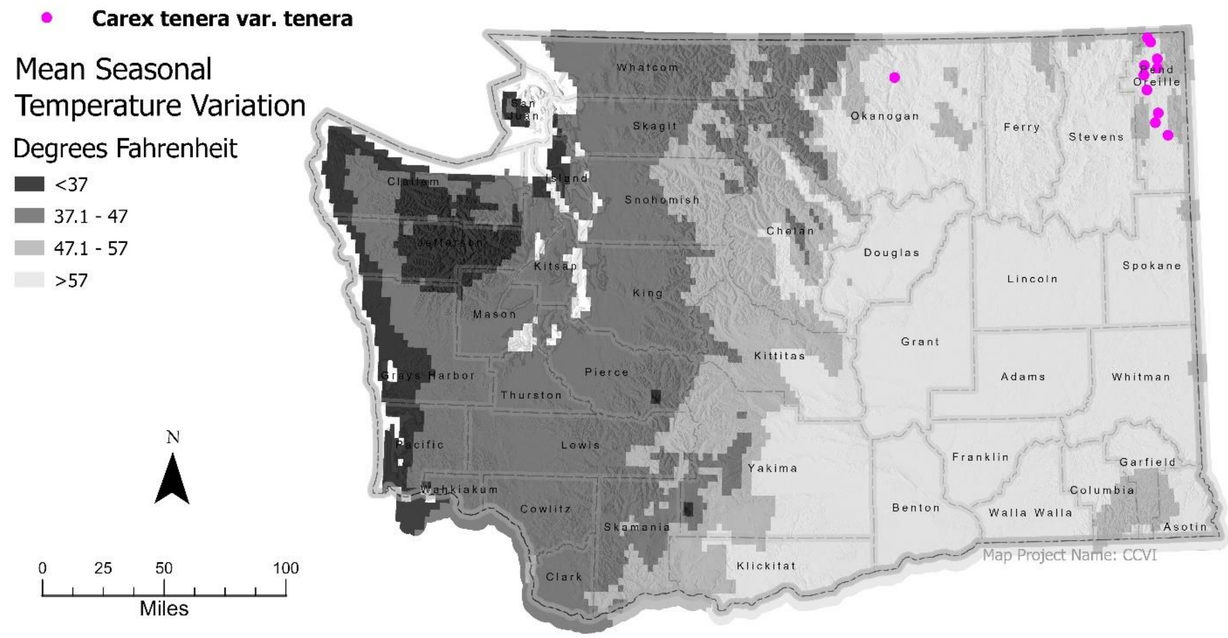

Figure 3. Historical thermal niche (exposure to past temperature variations) of occurrences of *Carex tenera* var. *tenera* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase

Marshes and wet meadows fed by surface water are sensitive to increases in air temperature, which may also raise water temperature and evaporation rates and ultimately lead to vegetation shifts towards more upland or invasive species (Rocchio and Ramm-Granberg 2017). The wetland habitats occupied by *Carex tenera* var. *tenera* are often associated with cool conditions or cold air drainage during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Carex tenera* var. *tenera* occurrences in Washington. One of 11 occurrences (9%) are in an area that has experienced slightly lower than average precipitation variation (11–20 in (255–508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. Ten of 11 occurrences (91%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

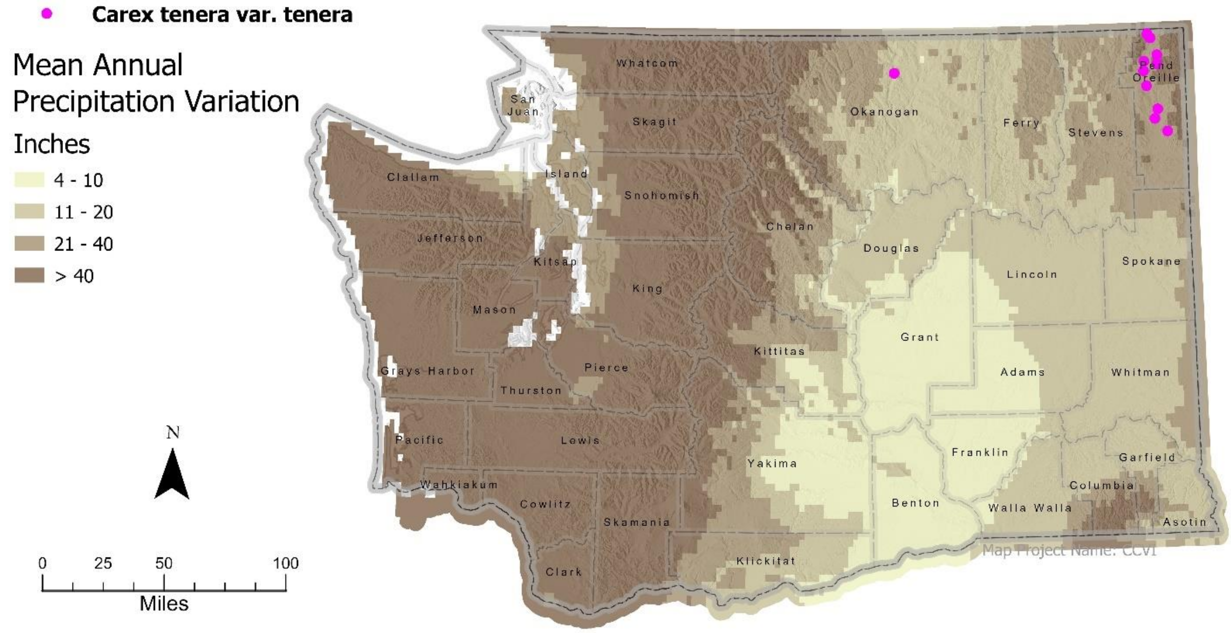

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Carex tenera* var. *tenera* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Increase
Fragmentation and other anthropogenic activities can change hydrology of riparian shrublands, emergent marshes, and wet meadows, potentially lowering water tables and shifting vegetation composition towards upland species or increasing the presence of invasive species (Rocchio and Crawford 2015). Marshes and wet meadows fed by groundwater may be vulnerable to changing snowpack, resulting in early drying and shifts to more upland and invasive species. Changes in flood patterns due to changes in timing and amount of precipitation could also shift community composition in streamside wetlands toward more upland and invasive species, while also affecting community structure (Rocchio and Ramm-Granberg 2017). *Carex tenera* var. *tenera* can also occur in mesic meadows and prairies and dry uplands (Rothrock et al. 2009, Washington Natural Heritage Program 2024), but in Washington, most occurrences are in wetlands, suggesting increased vulnerability to changes in hydrology due to climate change.

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Marsh and riparian shrubland ecological systems depend on flooding events or fluctuating water levels for creation and maintenance. Climate change is likely to change precipitation patterns, which could shift emergent marsh habitats to wet meadows and change the structure of riparian shrublands to favor more upland species (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Carex tenera var. *tenera* is not directly dependent on ice or snow-covered habitats. However, the wetland habitats this species prefers will be indirectly affected by reduced snowpack and earlier snowmelt, potentially shifting vegetation composition toward more upland and invasive species (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
In Washington, *Carex tenera* var. *tenera* appears mainly on sedimentary substrates and glacial outwash which is not uncommon Washington. This taxon is likely not restricted by substrate in any ecologically meaningful way (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beaver are important ecosystem engineers for emergent marshes and riparian shrublands, and removal of beaver in the west has likely reduced the availability of these habitats (Rocchio and Crawford 2015). At least one occurrence of *Carex tenera* var. *tenera* was associated with a beaver dam complex. Ongoing lack of beaver activity likely somewhat increases the vulnerability of *Carex tenera* var. *tenera* to climate change.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Carex tenera var. *tenera*, like other sedge species, is entirely wind-pollinated, and thus not dependent on animal pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral
While longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals, *Carex tenera* var. *tenera* is more likely dispersed by abiotic processes like wind, water, and gravity.

C4e. Sensitivity to pathogens or natural enemies: Neutral
No pathogens or natural enemies have been noted specifically for *Carex tenera* var. *tenera*. Other *Carex* spp. have been known to be infected by host-specific smut fungus which infect and parasitize the gynoecia at the expense of seed production (Denchev et al. 2023). Crop fungus species are expected to increase infections with climate change but the exact impacts to *Carex tenera* var. *tenera* are unknown (Stukenbrock and Gurr 2023). Grazing is a threat to some other *Carex* species, and ungulate grazing could potentially shift the wetland communities this taxon is found in towards more upland and invasive species though grazing is not anticipated to increase with climate change (Rocchio and Crawford 2015).

C4f. Sensitivity to competition from native or non-native species: Increase
A few occurrences of *Carex tenera* var. *tenera* are associated with introduced species, including *Phalaris arundinacea*, *Poa pratensis*, *Cirsium arvense*, and *Cirsium vulgare*. In Washington, emergent marsh, riparian shrubland, and wet meadow ecological systems are heavily impacted by the invasive grass *Phalaris arundinacea*. *Typha latifolia* can also invade disturbed emergent marshes and outcompete other native species. Non-natives such as *Poa pratensis*, *Phleum*

pratense, *Cirsium arvense*, and *Taraxacum officinale* are common invaders in wet meadows. Reductions in the frequency of flooding, increased drought, and changes in precipitation patterns due to climate change can lower water tables and lead to displacement by plants associated with wet meadows, riparian shrublands or emergent marshes. Grazing and other disturbances can also shift these habitats further toward upland and invasive species (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Unknown
No other species interactions were found in the literature search.

C5a. Measured genetic variation: Not Ranked
Data are lacking regarding the genetic diversity within and between populations of *Carex tenera* var. *tenera* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Neutral
In *Carex tenera* var. *tenera* pistillate inflorescences occur above the staminate inflorescences (Rothrock et al. 2009). *Carex* species are almost always protogynous (Friedman and Barrett 2009), so it is likely that the female flowers in *Carex tenera* var. *tenera* also mature before male flowers do. Both these traits are likely to promote outcrossing. *Carex* species can self-pollinate, but since *Carex tenera* var. *tenera* has mechanisms to promote outcrossing, this taxon's genetic diversity likely makes it somewhat resilient to climate change.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Carex tenera* var. *tenera* (May to August) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Carex tenera* var. *tenera* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

*Cassiope lycopodioides (*clubmoss cassiope, mountain heather*)*

Date: 28 Sept 2023
Synonym: *Andromeda lycopodioides*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington
Heritage Rank: G5/S1
Index Result: Extremely Vulnerable
Confidence: High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	50
	<3.9° F (2.2°C) warmer	50
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase/Increase
2b. Distribution relative to anthropogenic barriers		Neutral/Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral/Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: One of the two known occurrences (50%) of *Cassiope lycopodioides* in Washington occurs in an area with a projected temperature increase of less than 3.9°F (2.2°C; Figure 1). The other occurrence (50%) is in an area with a projected temperature increase of 3.9-4.4°F (2.2-2.4°C).

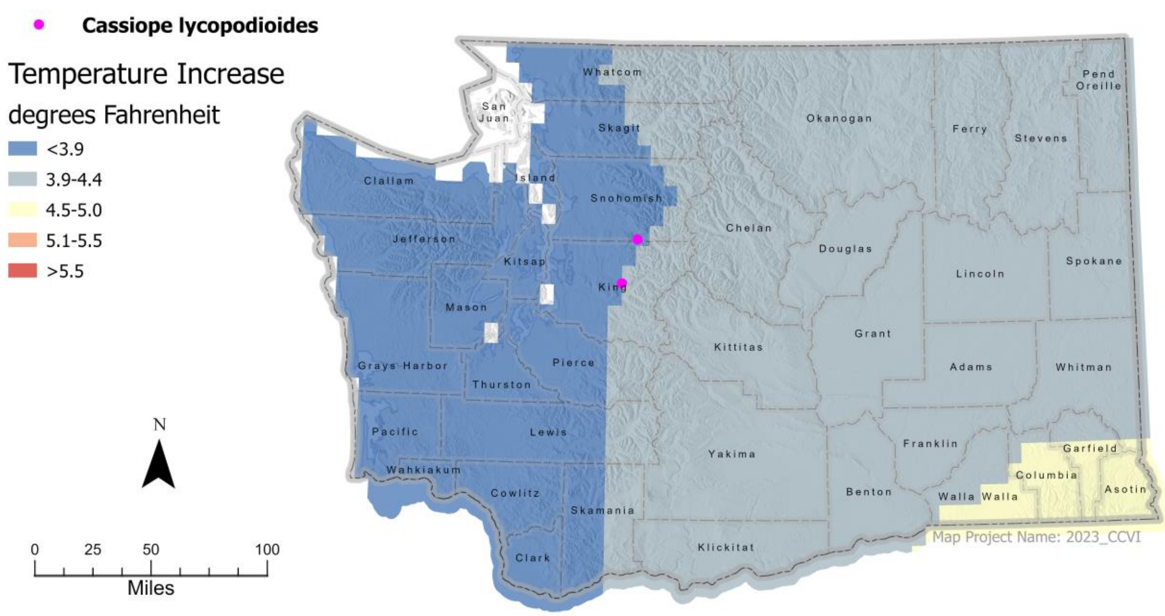

Figure 1. Exposure of *Cassiope lycopodioides* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both known occurrences (100%) of *Cassiope lycopodioides* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

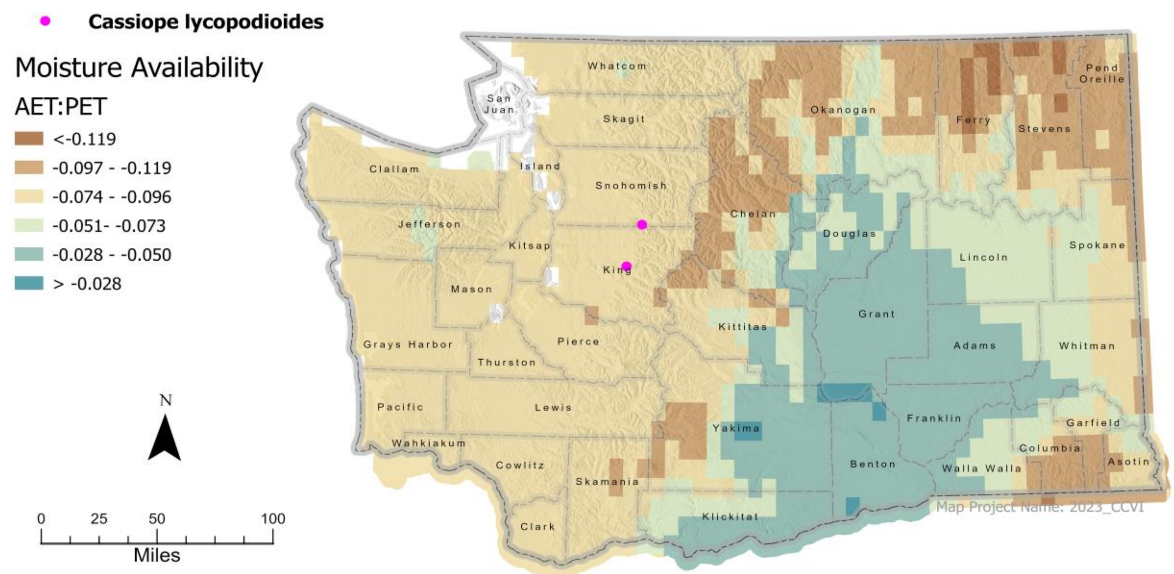

Figure 2. Exposure of *Cassiope lycopodioides* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Cassiope lycopodioides is restricted to moist rock faces on a few mountainsides in the Central Cascade Range at elevations ranging from 1900-5440 ft (580-1658 m; Washington Natural Heritage Program 2023). *Cassiope lycopodioides* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Somewhat Increase/Increase
Cassiope lycopodioides populations in Washington are associated with the North Pacific Alpine & Subalpine Bedrock and Scree ecological system and are documented as occurring on two northwest-facing rock walls near summits in the Cascades approximately 20-25 mi (32-40 km) east of Seattle (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). A third occurrence near Poodle Dog Pass in the Mt. Baker-Snoqualmie National Forest was documented very recently but is not included in climate change projections for this report as the data is still in processing. Additional surveys may yield more occurrences. The three known

occurrences are separated by 21- 37 mi (34-60 km) of unoccupied and unsuitable lower elevation forested and valley habitat that is a barrier to propagule dispersal to other areas of alpine scree. They are also disjunct from the core range that extends from British Columbia through Alaska and on to the Kuril Islands of Russia, which makes potential migration and outcrossing more difficult.

B2b. Anthropogenic barriers: Neutral/Somewhat Increase
Due to the rugged and rocky mountain terrain, the habitat of *Cassiope lycopodioides* remains relatively undisturbed by direct anthropogenic stressors and barriers. However, recreation impacts from hikers and climbers are of concern as there are popular trails and mountain summits nearby. Mount Si, the location of one occurrence, is estimated to be visited by 100,000 climbers a year. Significant urban development and cultivation has occurred approximately 20-20-25 mi (32-40 km) away in the greater Seattle metropolitan areas, but the natural isolation of rock walls scree slopes is expected to be a greater barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Cassiope lycopodioides* (Washington Department of Natural Resources 2023). Future projects in the region are of low concern due to the rugged backcountry terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Cassiope lycopodioides produces a round, dry capsule fruit with many seeds which do not possess any adaptations for long-distance dispersal and do not have fleshy berries to attract dispersing birds or mammals like other Ericaceae species (Ikeda et al. 2014, Washington Natural Heritage Program 2023). Other arctic *Cassiope* spp. are known to disperse limited distances via wind (Eidesen et al. 2007). The genetic structure of this species reveals limited long-distance gene flow.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Cassiope lycopodioides* occurrences in Washington. Both occurrences (100%) are in areas that have experienced small temperature variation (37-47° F (20.8-26.3° C)) over the historical period. According to Young et al. (Young et al. 2016) these populations are likely to be vulnerable to climate warming.

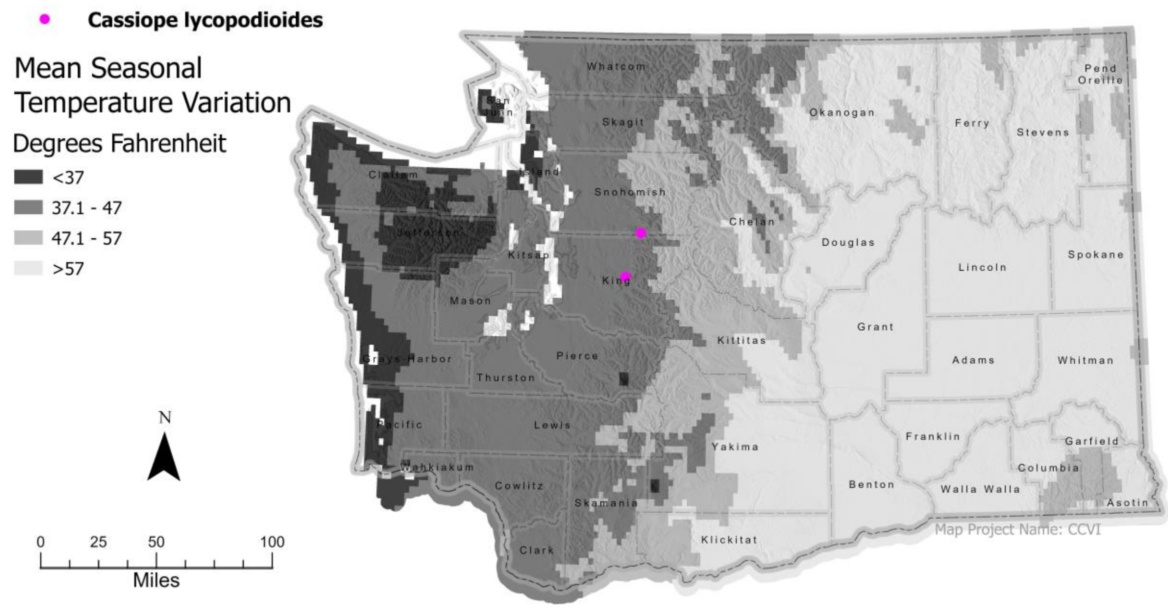

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cassiope lycopodioides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
One of the Washington occurrences of *Cassiope lycopodioides* is specifically located in a known cold air drainage of a steep, rocky ravine (Washington Natural Heritage Program 2023). In general, *Cassiope lycopodioides* is associated with high elevation shaded cliffs, rock crevices, and northern-facing summits which are all known to be cooler microtopographic regions that are likely to be sensitive to expected temperature increases of the North Pacific Alpine and Subalpine Bedrock and Scree ecological system (Rocchio and Ramm-Granberg 2017). *Cassiope lycopodioides* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Cassiope lycopodioides* occurrences in Washington. Both occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

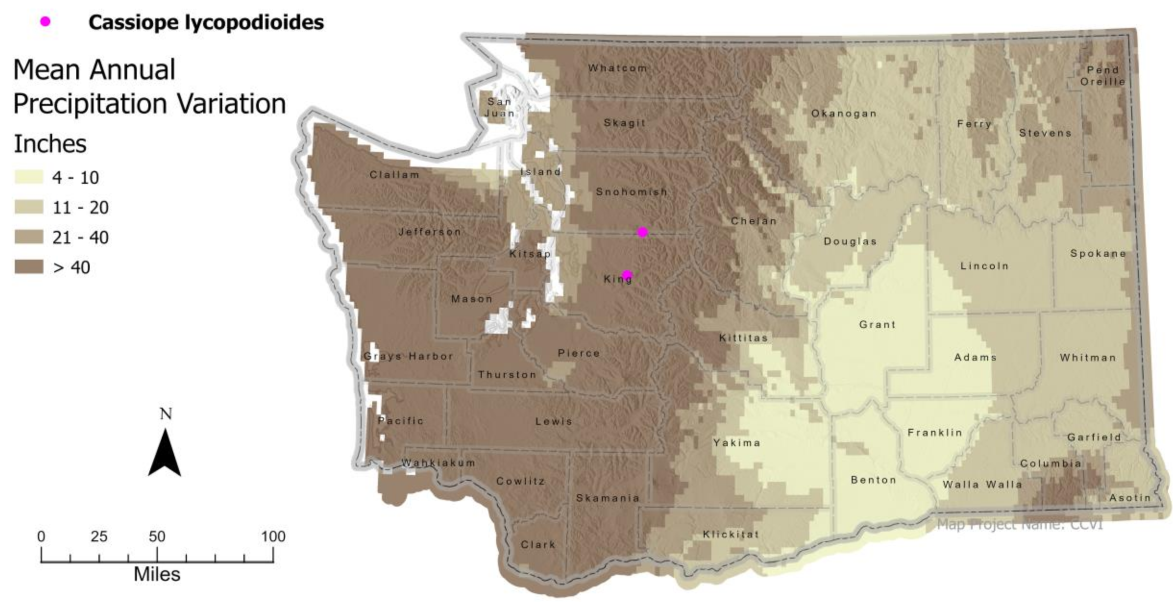

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cassiope lycopodioides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
The North Pacific Alpine and Subalpine Bedrock and Scree ecological system where *Cassiope lycopodioides* occurs relies primarily on snowmelt for a steady supply of moisture throughout the growing season. *Cassiope lycopodioides* is known to occur on wetter western slopes and is associated with cold air drainages at high elevations. It is often found near waterfalls, streams, or generally moist areas with several mesic to wetland associated species (Washington Natural Heritage Program 2023). Anticipated reductions in annual snowfall and earlier snowmelt timing (Rocchio and Ramm-Granberg 2017) is likely to adversely affect *Cassiope lycopodioides.*

C2c. Dependence on a specific disturbance regime: Neutral
Wind, water, and gravity are forces acting upon scree and talus habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The dominant disturbances are avalanche, soil movement, and freeze-thaw action and the resulting rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000, NatureServe 2023a). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004, Rocchio and Ramm-Granberg 2017). Climate change may accelerate soil formation which is typically very minimal due to abiotic disturbances (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase

Cassiope lycopodioides is a mesic/moisture loving species that occurs on north-facing exposures above treeline where water supply is generally constant from a high snowpack that lingers in slopes and depressions and subirrigates surrounding areas (NatureServe 2023b, 2023c). Heath species like *Cassiope lycopodioides* are known to occupy sites of deeper snow (NatureServe 2023c). However, the steep rocky exposures where *Cassiope lycopodioides* can be found are generally snow free due to the extreme relief and wind-scour.

C3. Restricted to uncommon landscape/geological features: Neutral
Unlike many other co-occurring disjunct arctic species, *Cassiope lycopodioides* is not restricted to calcareous sites (Jaques 1973) but rather is found on rock outcroppings, ridges, and summits where substrates are thin and composed of colluvium, residuum, or glacial till (NatureServe 2023b). More specifically *Cassiope lycopodioides* is found where volcanic breccias occur with intrusive rock layers of granite and quartzite. These substrates are fairly common in Washington and spread across a substantial portion of the Cascade Range that are known geologically as the mélange belts (Frizzell et al. 1987).

C4a. Dependence on other species to generate required habitat: Neutral
The North Pacific Alpine and Subalpine Bedrock and Scree ecological system is shaped mostly by abiotic processes and mass wasting events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015, NatureServe 2023a).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Cassiope lycopodioides* are not well understood or documented, however it is known that its bell-shaped flowers are structured for insect pollination (Ikeda et al. 2014). *Bumblebees (Bombus* spp*.)* have been reported to visit and forage upon the nectar of the congener *Cassiope tetragona* (Robinson 2014) but were observed to visit less frequently than normal due to a lack of sweet floral scents (Kevan 1973). *Cassiope*, and other Ericaceae genera such as *Vaccinium*, are known to be primarily buzz-pollinated by bumblebees (Sarwar 2007, Moquet et al. 2017), which may be the case for *Cassiope lycopodioides*. *Cassiope lycopodioides* may only attract one pollinator genus but is otherwise not expected to be limited in its pollinator versatility.

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Cassiope lycopodioides* are dispersed primarily by wind or gravity and do not have adaptations for attachment to animals. The species is not dependent on animals for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral/Somewhat Increase
Impacts from pathogens are not known for *Cassiope lycopodioides* specifically, but the high-arctic congener *Cassiope tetragona* is known to be infected by a detrimental parasitic fungus that is expected to increase in abundance under climate change (Moriana-Armendariz et al. 2022). It is possible that *Cassiope lycopodioides* may be sensitive to a similar fungal parasite. Due to its high elevation rock wall habitat, *Cassiope lycopodioides* receives minimal to no impacts from grazing, though it could be consumed by insects or rodents.

C4f. Sensitivity to competition from native or non-native species: Neutral
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation North Pacific Alpine-Subalpine Bedrock & Scree ecological systems which support *Cassiope lycopodioides* (NatureServe 2023). *Cassiope lycopodioides* is probably adapted more for survival of these harsh abiotic conditions and not for competition, which is usually limited within fell-fields and alpine ridges. Increases to plant competition are likely to pose a threat, though *Cassiope lycopodioides* can sometimes be found in dwarf-shrub communities with nearly closed canopy cover (Montana Natural Heritage Program 2023, NatureServe 2023d, Washington Natural Heritage Program 2023) Plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with deep enough soil, the tree line may also begin to encroach as the climate changes (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Cassiope lycopodioides does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic variation of *Cassiope lycopodioides* in Washington has not been studied.
It is thought that the disjunct high mountain populations of arctic-alpine species like *Cassiope lycopodioides* are remnants of past range expansions into unglaciated refugia formed during the Pleistocene around the Bering Land Bridge (Ikeda et al. 2014).

C5b. Genetic bottlenecks: Unknown
A study of disjunct populations in Japan found evidence of population expansion rather than contraction during Pleistocene climatic changes (Ikeda et al. 2014)

C5c. Reproductive System: Neutral
Not much information can be found regarding the specific reproductive system of *Cassiope lycopodioides.* However, most records of Ericaceae species indicate that they are autogamous with limited to moderate insect-mediated outcrossing (Kevan 1972). Obligate outcrossers are also frequent among Ericeceae genera such as *Vaccinium* and this may also be the preferred mode for *Cassiope lycopodioides.* It is likely to have average genetic variability based on these life history parameters (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Cassiope lycopodioides* (Jun-Aug) has not changed significantly (Washington Natural Heritage Program 2023). Further monitoring is warranted as the flowering times of snowbed species like *Cassiope lycopodioides* are strongly determined by snowmelt timing and are likely to be impacted by climate change (Kudo 2020)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown

There are no direct reports of *Cassiope lycopodioides* populations declining in response to climate change in Washington. Of the two known occurrences in Washington, one (50%) has not been found again since 2010. However, there is no conclusive evidence that these populations have suffered the effects of climatic change. Additional field exploration of the rugged habitat is expected to yield additional observations (NatureServe 2023e).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Cirsium remotifolium var. *remotifolium (*weak thistle*)*

Date: 16 May 2024 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5TNR/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	36
	<3.9° F (2.2°C) warmer	64
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	86
	-0.051 to - 0.073	14
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the 14 known occurrences of *Cirsium remotifolium* var. *remotifolium* in Washington, five (36%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1). The other nine (64%) occur in areas with a projected increase of less than 3.9° F (2.2° C).

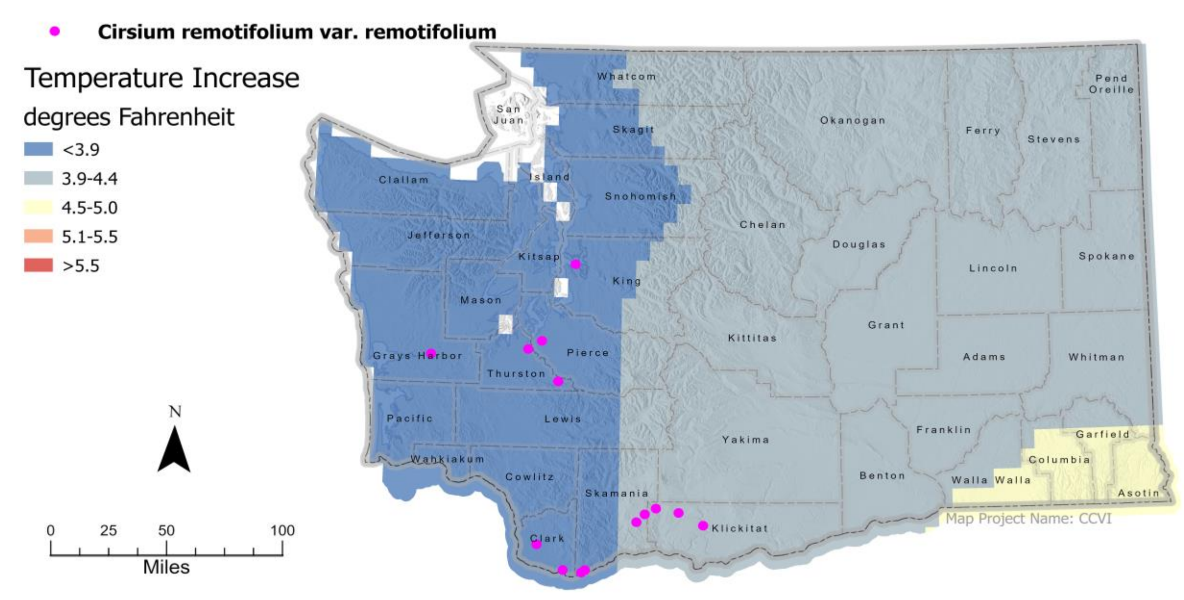

Figure 1. Exposure of *Cirsium remotifolium* var. *remotifolium* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 14 known occurrences of *Cirsium remotifolium* var. *remotifolium* in Washington, 12 (86%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2). The other two occurrences (14%) are found in areas with a projected decrease in the range of -0.051 to -0.073.

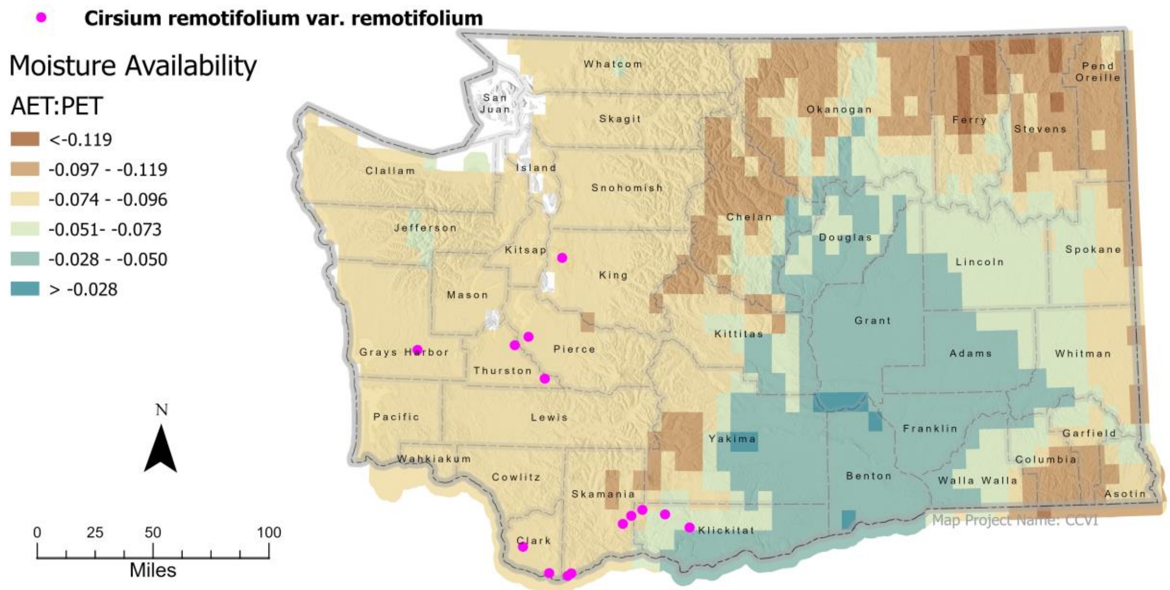

Figure 2. Exposure of *Cirsium remotifolium* var. *remotifolium* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Cirsium remotifolium var. *remotifolium* is found in brushy forest openings, fields, meadows at low to mid elevations (50-3000 ft (15-915 m); Washington Natural Heritage Program 2023). The occurrences of this species and surrounding suitable habitat near Montesano and Seattle are not likely to be at risk from even extreme sea level rise which not expected to exceed 10 ft maximum (Office for Coastal Management 2024). The remaining occurrences are too far inland to be affected.

B2a. Natural barriers: Neutral
Cirsium remotifolium var. *remotifolium* occurs on flats and gentle slopes at the ecotone between forest and meadow in the small to large patch matrix Rocky Mountain Alpine-Montane Wet Meadow and Willamette Valley Wet Prairie ecological systems (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Occurrences are separated by moderately large stretches (5-140 mi (8-225 km)) which includes some unsuitable forest and dry lowland habitat

as well as developed areas. Most of the suitable habitat has already been converted and therefore anthropogenic barriers to dispersal are probably more significant.

B2b. Anthropogenic barriers: Increase
Much of the wet meadow and prairie habitat that is suitable for *Cirsium remotifolium* var. *remotifolium* has been converted for agriculture and multiple occurrences are completely surrounded by developed land or even located directly in towns (historical occurrences). Development threatens the hydrology of surrounding habitat as well as it can lead to lower water tables, nutrient runoff, and sedimentation (Rocchio and Crawford 2015). Fragmentation of these habitats in the Puget Sound and Columbia River Gorge is extensive and stretches of developed land are expected to pose significant barriers to dispersal or migration.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no proposed wind and solar developments in the vicinity of Washington occurrences and ongoing integrated forest health projects in the Columbia River Gorge are likely to be of benefit to this species that prefers forest openings (Washington Department of Natural Resources 2024a, 2024b).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Cirsium remotifolium var. *remotifolium* produces achenes topped by a pappus of feathery bristles 0.5-0.9 in (13-23 mm) long. (Washington Natural Heritage Program 2023). Dispersal distances of members of the Asteraceae family depend on pappus to achene length and weight ratios, (Andersen 1992; Vittoz and Engler 2007). Unlike other members of the Asteraceae family, seeds of the genus *Cirsium* spp. have pappi that detach from mature seeds and therefore wind dispersal is somewhat more limited particularly for heavy seeded species (Ackerfield et al. 2020b). Some *Cirsium* spp. have elaiosomes to attract ants for ant-dispersal and can even be dispersed by some birds and rodents (Alba-Lynn and Henk 2010). Dispersal can also be achieved by water for some *Cirsium* spp. (Ackerfield et al. 2020b). Despite some limitations to wind-dispersal, the variety of potential dispersal methods and distances for *Cirsium* spp. suggests that *Cirsium remotifolium* var. *remotifolium* is probably not dispersal limited and able to travel long-distances (> ½ mi or 1 km) at least on occasion.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Cirsium remotifolium* var. *remotifolium* occurrences in Washington. Of the 14 known occurrences, nine (64%) are in areas that have experienced little (37 - 47° F (20.8 - 26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to warming. Another three occurrences (22%) are in areas that have experienced lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation and are expected to be somewhat vulnerable to warming. The remaining two occurrences (14%) are in areas that have experienced average or greater than average (>57.1° F (31.8° C)) temperature variation over the historical period and is expected to be mostly resilient to warming.

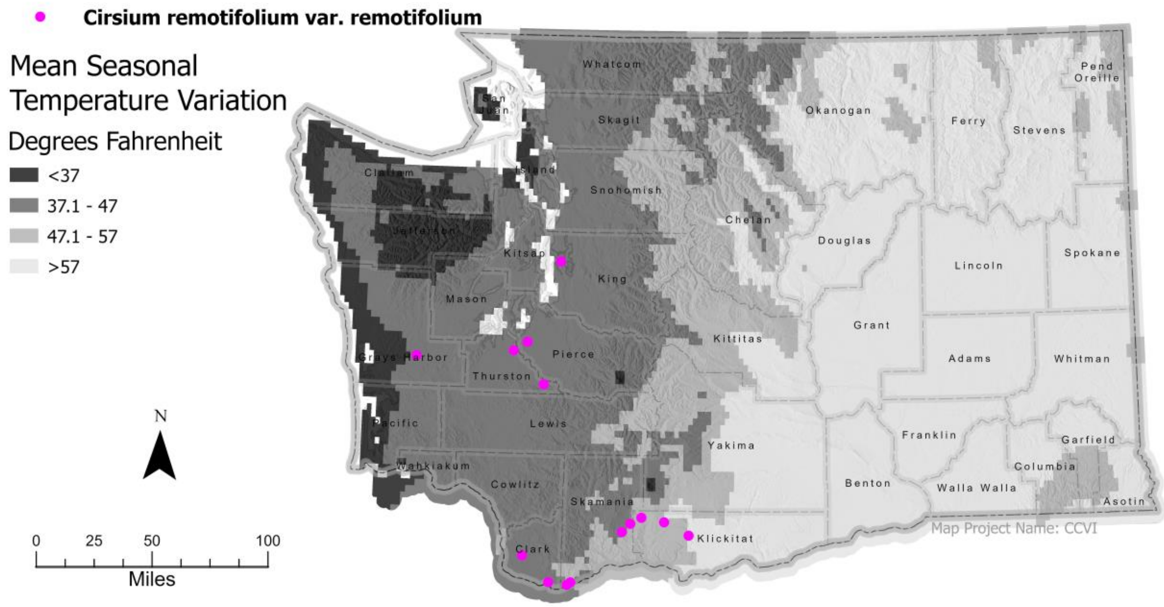

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cirsium remotifolium var. remotifolium* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
Cirsium remotifolium var. *remotifolium* occurs on low grounds in the woods, along meadow edges, and on exposed grassland balds in the transition between forest/woodland and open grassland bald communities and is not particularly associated with cold air drainages though some wet meadows may occur in valleys. The parent species *Cirsium remotifolium* tolerates moderate shading with only slight declines in cover and flowering effort in response to increasing cover (Celis et al. 2019). Warming temperatures will increase evapotranspiration, lead to prolonged droughts, and could lead to the drying out or conversion of wet prairies and meadows (Rocchio and Ramm-Granberg 2017). This species does not appear to be strongly associated with cool or warm microhabitats.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Cirsium remotifolium* var. *remotifolium* occurrences in Washington. All 14 known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are likely to be resilient to climate change induced shifts to precipitation and moisture regimes (Young et al. 2016).

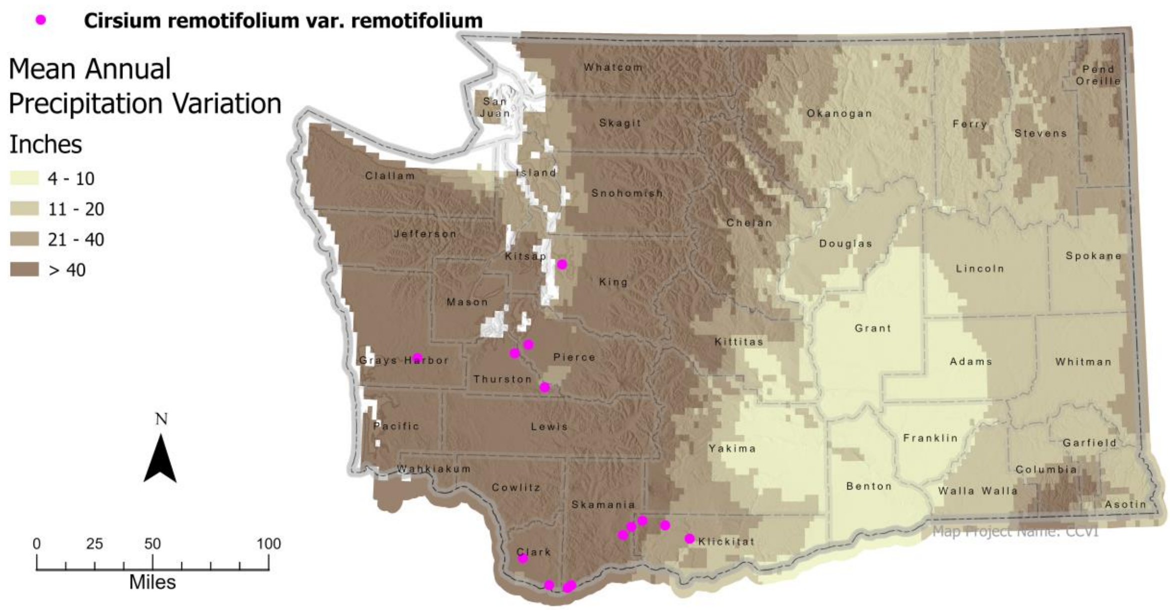

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cirsium remotifolium var. remotifolium* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
Wet meadows and prairies are transitional between semi-permanent and permanent wetlands and forested uplands and are generally associated with high water tables that are stable throughout the year (Rocchio and Crawford 2015). These ecological systems are somewhat vulnerable to changes in the amount of snowpack, timing of snowmelt, changes in timing and amount of summer precipitation, increased summer temperatures and drought, and reduction in stream flows or depth to groundwater from projected climate change (Rocchio and Ramm-Granberg 2017). However, groundwater-dependent wetlands may be more resilient than rainwater-dependent wetlands in the short-term.

C2c. Dependence on a specific disturbance regime: <u>Somewhat Increase</u>
Wet prairies developed with frequent low-intensity and dynamic fire, similarly to oak-prairie landscapes, which helps to prevent shrub encroachment (Rocchio and Crawford 2015). Climate change is anticipated to increase temperatures and shift the timing and type of precipitation in this ecological system, which could shift composition in wet prairies (Rocchio and Ramm-Granberg 2017). Wet meadow habitats are influenced more by hydrological cycles than natural disturbances but could become drier and more fire-prone in the future. However, increases in fire frequency in wet prairies could expand the range of wet prairies as woody species are cleared. One study has found the parent species *Cirsium remotifolium* to be highly sensitive to fire compared to co-occurring species (Halpern et al. 2019). These ecological systems are sometimes maintained by seasonal flooding but are rarely exposed to high disturbance floods (Rocchio and Crawford 2015).

C2d. Dependence on ice or snow-cover habitats: Neutral
Cirsium remotifolium var. *remotifolium* generally occurs in habitats that are too low in elevation to be tightly associated with late-melting snow or snowbeds (Rocchio and Crawford 2015). Climate change induced reductions to snowpack may speed drawdown of montane wetlands which rely on snow melt to recharge groundwater and may increase the probability of drying out, though anticipated increases in overall winter precipitation may offset these changes to some degree (Rocchio and Ramm-Granberg 2017). Other than potential impacts to the water supply of its habitat, *Cirsium remotifolium* var. *remotifolium* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Neutral
Cirsium remotifolium var. *remotifolium* occurs on gravely hillsides and open mineral soils with a moderate amount of organic matter and some hydric soil characteristics (Rocchio and Crawford 2015). These soils are a variety of textures, ranging from silty clay loam to ashy sandy loam to cobble loam (Soil Survey Staff 2024). Parent materials include Pleistocene outburst flood deposits, andesite flows, lava beds, Grande Ronde and Frenchman Springs basalt, and volcaniclastic deposits (Washington Division of Geology and Earth Resources 2016). These largely igneous geological features are relatively common in Western Washington.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
The wet meadow and prairie habitats of *Cirsium remotifolium* var. *remotifolium* are maintained largely by seasonal hydrological changes and fire but are influenced to some extent by browsing and grazing which contains the encroachment of woody vegetation. Beaver are also an important hydrogeomorphic driver in these ecological systems as they create dams that flood and kill large areas of shrublands that then give way to herbaceous wetlands (Rocchio 2006).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Cirsium remotifolium var. *remotifolium* is reported to be visited by bumblebees, bees, butterflies, beetles, and hummingbirds (Giblin 2024). This diverse array of pollinators is common the genus Cirsium (Ackerfield et al. 2020). Native and rare species of *Cirsium* have been shown to exhibit lower seed production, lower insect visitation, and less self-pollination than common exotic species (Powell and Knight 2009). For these species, generalist bumblebees are often the main pollinator. Still, *Cirsium remotifolium* var. *remotifolium* is probably not strongly pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
Cirsium remotifolium var. *remotifolium* is likely to be ant-dispersed and may also be dispersed by birds and rodents on occasion (Alba-Lynn and Henk 2010, Ackerfield et al. 2020). Because this species can also disperse on wind and possibly water, it is not strongly dependent on other species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase

Cirsium remotifolium var. *remotifolium* could be impacted negatively by biological controls targeting other *Cirsium* spp. such as weevils which predate seed heads (Louda et al. 2003). Post-dispersal seed predation also occurs in some species of *Cirsium* by vertebrates (rodents and birds) and insects that are also dispersal agents (Alba-Lynn and Henk 2010).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
With increasing temperatures, montane wet meadows and prairies are at risk of drying and subsequent conifer encroachment (Rocchio and Ramm-Granberg 2017). These ecological systems are also susceptible to invasion by many non-native species, especially pasture grasses such as *Poa pratensis* and *Phleum pratense* as well as exotic species common to other wetland types such as *Cirsium arvense* and *Phalaris arundinacea* (Rocchio and Crawford 2015). *Cirsium remotifolium* var. *remotifolium* has proven to be moderately resistant to invasion in competition studies and can tolerate moderate crowing by neighbors but was more sensitive to encroachment than several co-occurring species in its habitat (Celis et al. 2019).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Members of the genus *Cirsium* host cavity nesting bees (Megachilidae) that are potential pollinators (Ackerfield et al. 2020). It is unknown how this relationship might be altered by climate change but it is not obligatory for *Cirsium remotifolium* var. *remotifolium.*

C5a. Measured genetic variation: Unknown
Cirsium remotifolium var. *remotifolium* is a Pacific Northwest endemic with a relatively limited range from California to Washington (Washington Natural Heritage Program 2023) which may indicate somewhat lower genetic diversity. The specific genetic diversity of this species has not been documented.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Cirsium spp. are mostly diploid and exhibit a variety of reproductive strategies but often have mixed mating systems, with rare species tending more towards dependence on outcrossing with more limited rates of self-pollination (Bures et al. 2004, Powell and Knight 2009). Native species rely more heavily on insect pollination than invasive congeners. The parent species *Cirsium remotifolium* is non-clonal Celis et al. 2019). Polyploidy, a preference for outcrossing, and mixed mating systems are traits indicative of average to high genetic variation (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Cirsium remotifolium* var. *remotifolium* (June to September) has not changed significantly since the 1800s (Washington Natural Heritage Program 2023).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown

Cirsium remotifolium var. *remotifolium* is known from 4 extant and at least 14 historical occurrences. Most populations from Puget Trough prairies are historical and probably extirpated. However, *Cirsium* spp. tend to be under-collected and difficult to differentiate in the field, and this species may be more widespread than records suggest. (Washington Natural Heritage Program 2023) Trends appear to be downward historically but this is mostly due to loss of prairie habitat in the Puget Trough and has not been confirmed to be linked to climate change.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

Claytonia multiscapa* ssp. *pacifica (*Pacific lanceleaved springbeauty*)

Date: 12 Oct 2023 Synonym: *Claytonia lanceolata* var. *multiscapa*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T3T4/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All four (100%) known occurrences of *Claytonia multiscapa* ssp. *pacifica* in Washington occur in areas with a projected temperature increase of less than or equal to 3.9° F (2.2°C; Figure 1).

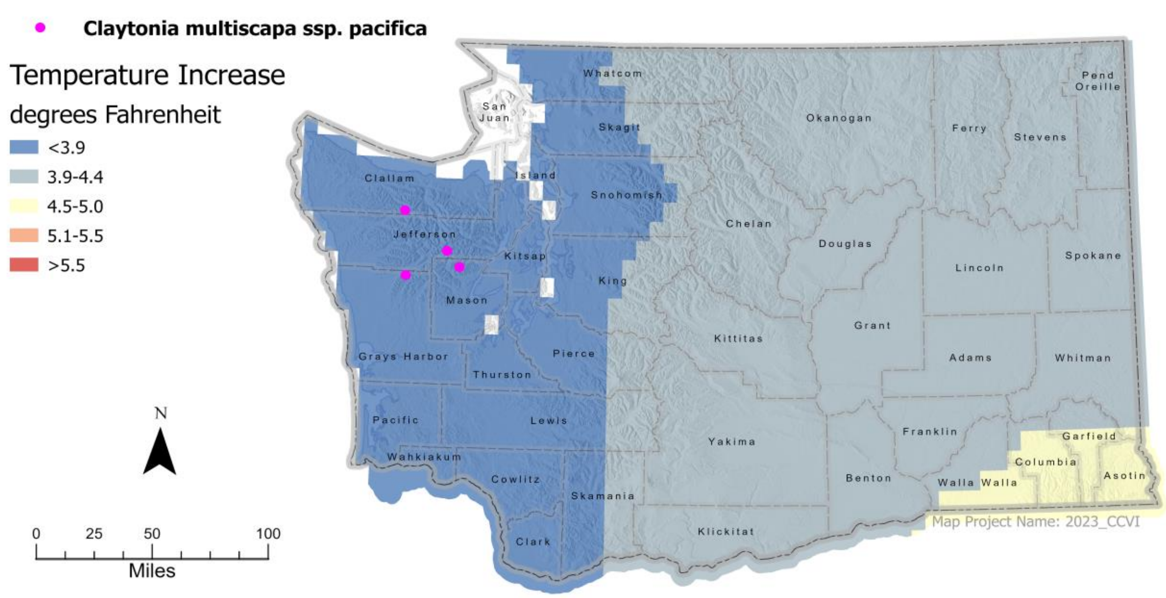

Figure 1. Exposure of *Claytonia multiscapa* ssp. *pacifica* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four known occurrences (100%) of *Claytonia multiscapa* ssp. *pacifica* in Washington are found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2).

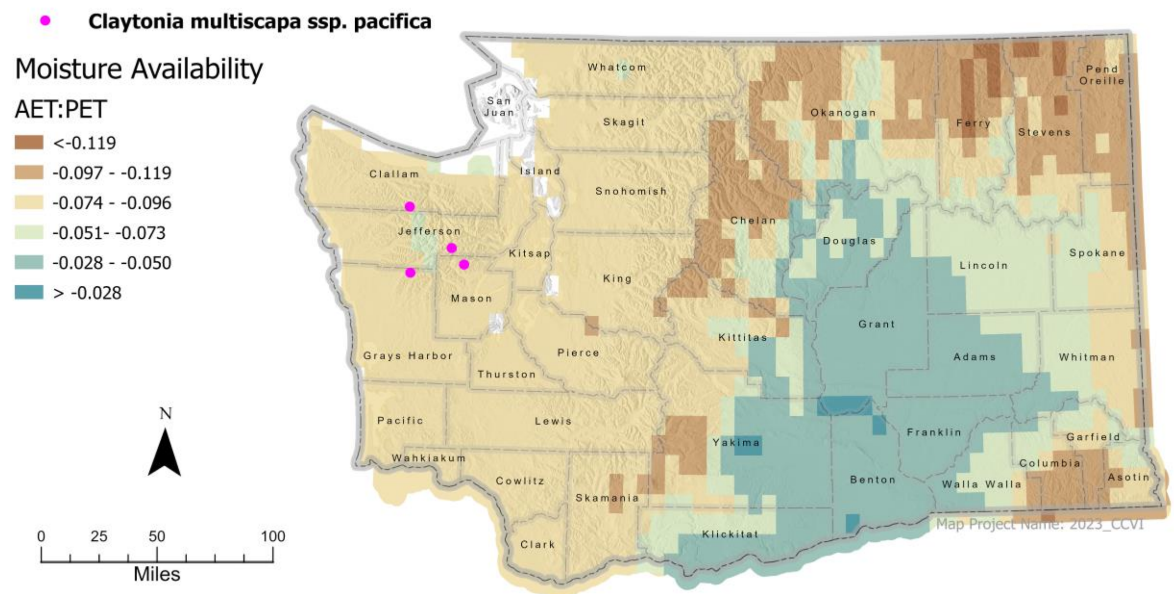

Figure 2. Exposure of *Claytonia multiscapa* ssp. *pacifica* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Claytonia multiscapa ssp. *pacifica* is associated with high elevation mountain basins and meadows, often occurring near summits at elevations ranging from 4145-5100 ft (1260-1645 m). *Claytonia multiscapa* ssp. *pacifica* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Somewhat Increase
Washington occurrences of *Claytonia multiscapa* ssp. *pacifica* are associated with the Pacific Subalpine-Montane Wet Meadow ecological system. The four occurrences are separated by 10-30 mi (15-48 km) of unsuitable lower elevation forested habitat that is a barrier to propagule dispersal among mountain basins and meadows which occur as small patches in the larger forest and alpine scree matrix. This species is endemic to Vancouver Island and the Olympic Mountains. Washington populations are disjunct from the core population on Vancouver Island

and are isolated from interbreeding by the Juan de Fuca Strait. *Claytonia multiscapa* ssp. *pacifica* may also be at risk of following an "elevator to extinction" as the coolest climatic zones of the alpine are lost (Watts et al. 2022).

B2b. Anthropogenic barriers: <u>Neutral</u>
The rugged, high elevation terrain where *Claytonia multiscapa* ssp. *pacifica* occurs remains relatively unobstructed by direct anthropogenic barriers as there are few roads and little human infrastructure in the area. However, recreation impacts are of concern because trampling by recreationists may pose a serious threat to alpine plants like *Claytonia multiscapa* ssp. *pacifica* (Rothmeyer 2023).

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Claytonia multiscapa* ssp. *pacifica* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely due to the rugged backcountry terrain and protected land status of the occurrence locations.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Increase</u>
The dispersal mechanisms of *Claytonia multiscapa* ssp. *pacifica* are not well understood. It produces oval capsules that split open as they dry to release numerous shiny, smooth seeds with no obvious adaptive features for long-distance wind or animal dispersal (Washington Natural Heritage Program 2023, Rothmeyer 2023). Other *Claytonia* spp. are known to spread seeds by explosive dehiscence or have seeds that are ant dispersed (Turnbull et al. 1983, Matthews 1993). *Claytonia multiscapa* ssp. *pacifica* probably can only disperse seeds short distances (328 ft (<100 m)) and are dispersal limited (Young et al. 2016).

C2ai. Historical thermal niche: <u>Increase</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Claytonia multiscapa* ssp. *pacifica* occurrences in Washington. Two of four (50%) known occurrences are in areas that have experienced lower than average temperature variation (37 - 47° F (20.8 - 26.3° C)) and are expected to be more vulnerable to warming (Young et al. 2016). The remaining two occurrences (50%) are in areas that have experienced very little temperature variation (< 37° F (20.8° C)) and are expected to be very vulnerable to warming (Young et al. 2016).

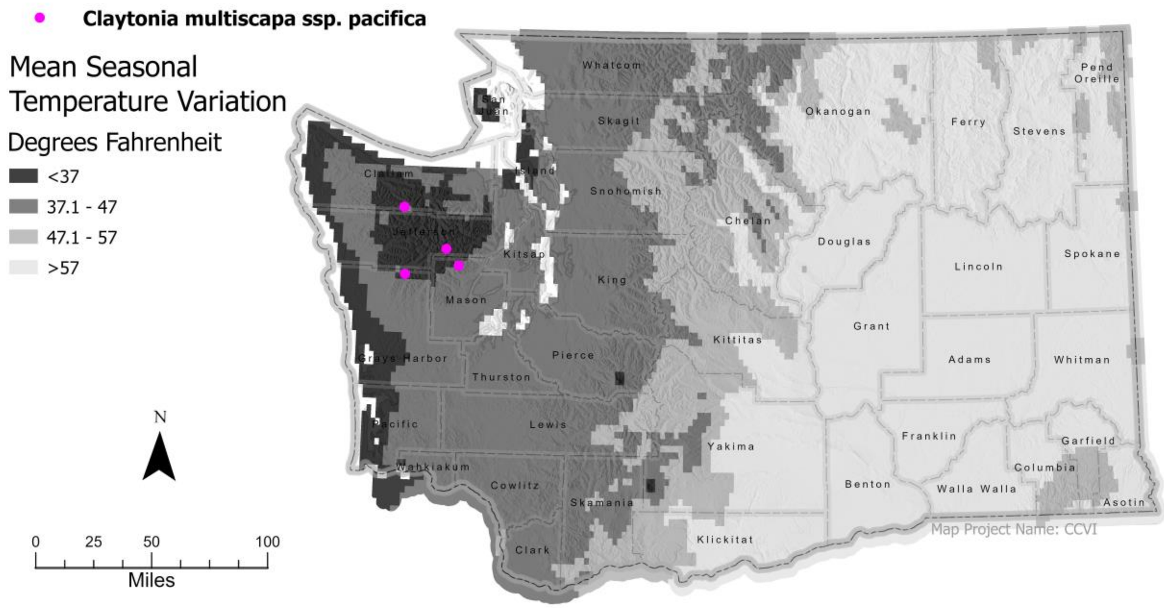

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Claytonia multiscapa* ssp. *pacifica* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase

The subalpine wet meadows where *Claytonia multiscapa* ssp. *pacifica* are typically north-facing and may associate with cold air drainages in mountain basins. As such, these locations probably remain cooler than the surrounding landscape throughout the growing season. Warming temperatures are expected to increase erosion rates, fire risk, and drought in talus slopes and montane basins and will affect freeze-thaw cycles (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Claytonia multiscapa* ssp. *pacifica* occurrences in Washington. All four occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 inches (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

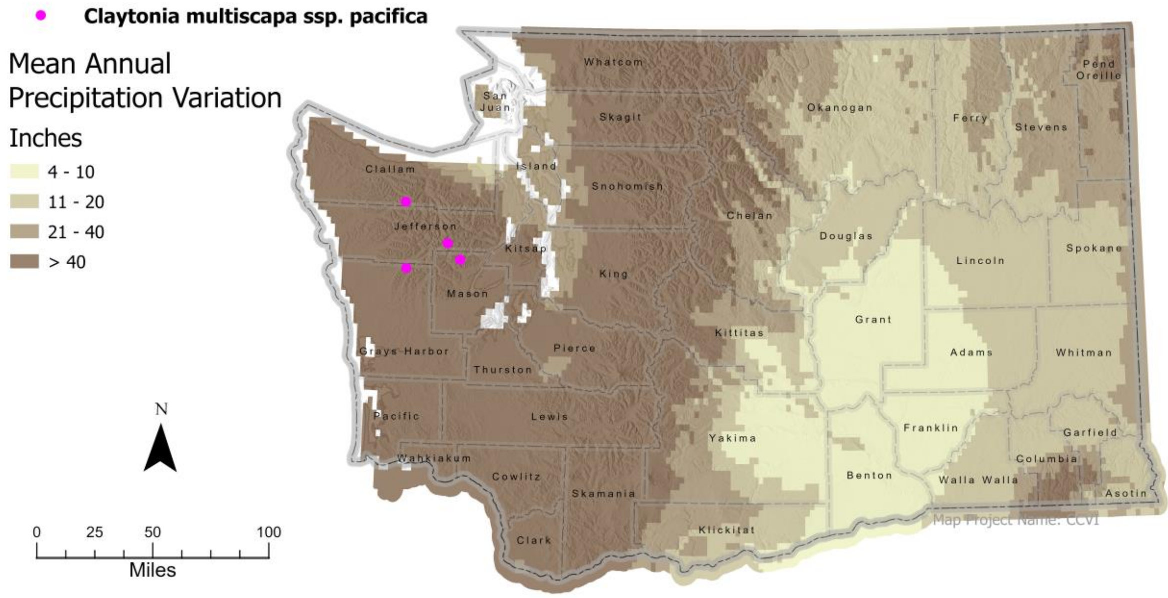

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Claytonia multiscapa* ssp. *pacifica* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Temperate Pacific Subalpine-Montane Wet Meadow habitats where *Claytonia multiscapa* ssp. *pacifica* occurs are supported by shallow groundwater flow associated with seasonal snowmelt for a steady supply of moisture throughout the growing season (Rocchio and Ramm-Granberg 2017, NatureServe 2023a). *Claytonia multiscapa* ssp. *pacifica* is known to occur near the edges of melting snowfields, in seasonally moist depressions, and is associated with high moisture capacity clay soils that drain slowly (NatureServe 2023b, Washington Natural Heritage Program 2023). Anticipated reductions in annual snowfall and earlier snowmelt timing may alter seasonal water availability and hydrological cycles and affect the habitat of *Claytonia multiscapa* ssp. *pacifica* (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
The high elevation wet meadows where *Claytonia multiscapa* ssp. *pacifica* occurs are primarily maintained by long-term climatic and hydrological cycles and are not typically subject to major disturbance events such as flooding (Rocchio and Crawford 2015, NatureServe 2023a).

C2d. Dependence on ice or snow-cover habitats: Increase
Claytonia multiscapa ssp. *pacifica* is closely associated with snowmelt dynamics (Stoughton et al. 2017, Washington Natural Heritage Program 2023). Anticipated reductions in annual snowfall averages and earlier snowmelt timing (Rocchio and Ramm-Granberg 2017) are likely to adversely affect *Claytonia multiscapa* ssp. *pacifica*.

C3. Restricted to uncommon landscape/geological features: Neutral
Claytonia multiscapa ssp. *pacifica* is found in montane basin meadows growing on a variety of thin to deep soils with some organic material and typical hydric characteristics (Stoughton et al. 2017, NatureServe 2023a). It associates with a range of soil types derived from Tertiary Crescent formation marine sedimentary sandstone and shale and submarine basalts that are frequently found in the Olympic Mountains. The range of soils which can support *Claytonia multiscapa* ssp. *pacifica* suggests that it is not highly restricted to an uncommon geological feature.

C4a. Dependence on other species to generate required habitat: Neutral
North Pacific Alpine and Subalpine Bedrock and Scree ecological systems and associated montane meadows are shaped mostly by abiotic processes such as fluctuating seasonal water tables and erosion events which shift critical microtopographic habitat conditions (Rocchio and Crawford 2015, NatureServe 2023a). Other species are not required to maintain these habitats.

Temperate Pacific Subalpine-Montane Wet Meadow

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The pollinators of *Claytonia multiscapa* ssp. *pacifica* are not well documented but, like other *Claytonia* spp., it probably has a mixed mating strategy with flowers that are self-compatible but protandrous (favoring outcrossing) and are able to attract both pollen-specialists and generalist small bees (Parker et al. 2018).

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Claytonia multiscapa* ssp. *pacifica* are probably dispersed by gravity or other passive means. The fruits of *Claytonia multiscapa* ssp. *pacifica* do not have specialized means of attachment. It is unknown if this species is ant-dispersed like some other *Claytonia* spp.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Impacts from pathogens are not known for *Claytonia multiscapa* ssp. *pacifica* specifically, but high elevation wet meadows can be threatened by livestock grazing which can compact soils, alter hydrology, and impact nutrient cycling (NatureServe 2023a). However, there are no major indications of climate change induced increases to livestock grazing or soil disturbance by herbivores.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Competition with invasive plant species is of some concern (Washington Natural Heritage Program 2023) as non-natives and pasture species can easily dominate and alter species composition and hydrology in wet meadows (NatureServe 2023a). Tree and shrub encroachment may increase in drier portions of wet meadows which could increase draw down of ground water and alter composition in this species' habitat.

C4g. Forms part of an interspecific interaction not covered above: Neutral

Claytonia multiscapa ssp. *pacifica* does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Claytonia multiscapa* ssp. *pacifica* in Washington has not been documented, but the small population sizes and restricted geography of the subspecies suggest that it may have low genetic variation.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Claytonia multiscapa ssp. *pacifica* is an allopolyploid which overwinters and regenerates from corms (Stoughton et al. 2017, Washington Natural Heritage Program 2023). It is a nectar-producing species that is part of a species complex that has been described both as an obligately outcrossing and as self-compatible (Motten 1986, Dalton 2019). It is likely that *Claytonia multiscapa* ssp. *pacifica* is protandrous and has a mixed mating system with a preference for outcrossing, like *Claytonia lanceolata* and *Claytonia virginica,* and therefore may be better able to adapt to novel environments (Young et al. 2016, Parker et al. 2018).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Claytonia multiscapa* ssp. *pacifica* (May to July) has not changed significantly since the species was first vouchered in Washington in the early 1900s. However, few records are available to establish a clear trend. Further phenological monitoring is warranted as studies show spring blooming/snowbed species to be at greater risk of phenological change in North America (Calinger et al. 2013) and phenological shifts have been documented for the congener *Claytonia lanceolata* (Gezon et al. 2016).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no specific studies of the response of *Claytonia multiscapa* ssp. *pacifica* to climate change, but research on other alpine endemics of the Olympic Mountains has predicted that decreasing snowpack and increasing drought will lead to significant and severe reductions in suitable habitat for all studied species (Wershow 2017). Loss of habitat due to climate change is a concern (Washington Natural Heritage Program 2023). Only one of four known occurrences (25%) has been observed in the last 40 years, though only two appear to have been resurveyed since the 1930s.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

***Collinsia sparsiflora* var. *sparsiflora* (Few-flower Blue-eyed Mary)**

Date: 6 February 2024
Synonym: *Collinsia sparsiflora* var. *bruceae*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington
Heritage Rank: G4T4/S1
Index Result: Extremely Vulnerable
Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	83
	<3.9° F (2.2°C) warmer	17
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	33
	-0.074 to - 0.096	17
	-0.051 to - 0.073	0
	-0.028 to -0.050	50
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Five of six known occurrences (83%) of *Collinsia sparsiflora* var. *sparsiflora* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1). The remaining occurrence (17%) in Clark County is in an area with an expected temperature increase of less than 3.9° F (2.2°C).

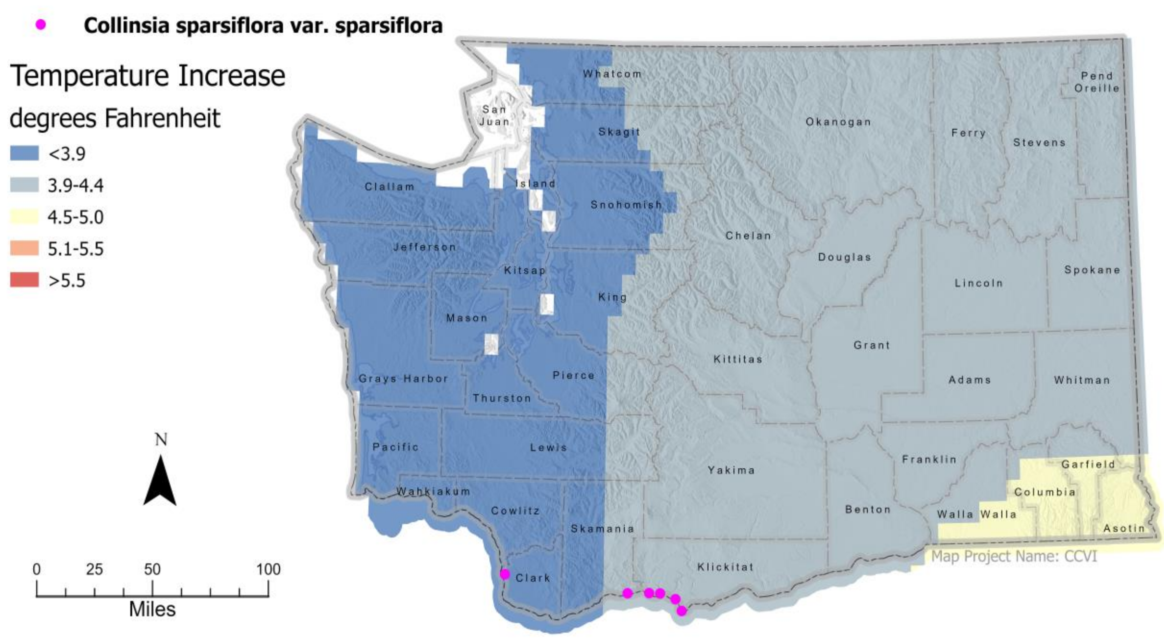

Figure 1. Exposure of *Collinsia sparsiflora var. sparsiflora* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the six known occurrences (33%) of *Collinsia sparsiflora* var. *sparsiflora* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). One occurrence (17%) is in an area with a project decrease in the range of -0.074 to - 0.096. The remaining three occurrences (50%) are in areas with a project decrease in the range of -0.028 to -0.050.

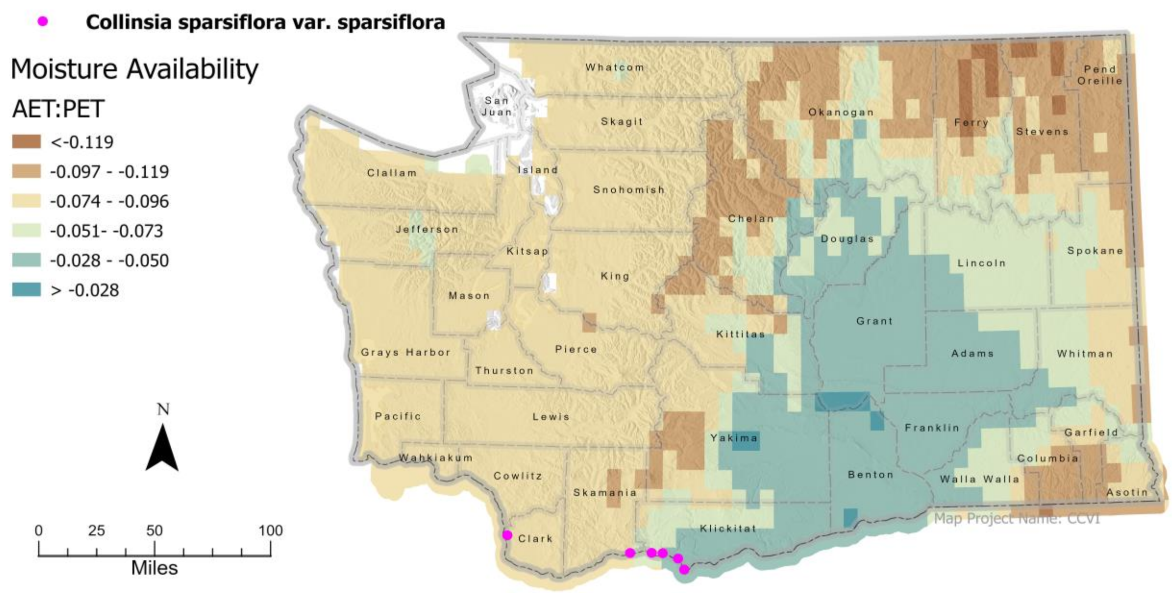

Figure 2. Exposure of *Collinsia sparsiflora var. sparsiflora* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Collinsia sparsiflora var. *sparsiflora* occurs on bluffs and gravel slopes at low elevations (200-1200 ft (60-365 m)) along the Columbia River Gorge (Washington Natural Heritage Program 2023). This species occurs too far inland to be affected by sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Increase</u>
The meadows, gravel slopes, and swale microsites which support *Collinsia sparsiflora* var. *sparsiflora* are part of the Modoc Basalt Flow Vernal Pool ecological system (Rocchio and Crawford 2015). This ecological system is very geographically limited, occurring as small patches within basalt scablands at the forest-grassland ecotone. Occurrences in Washington are separated by 4-107 mi (6-172 km) of unsuitable lowland habitat and developed lands. Vernal

pool habitats are strongly tied to landscape features that are themselves widely scattered and isolated by strong natural barriers, reducing the likelihood of successful dispersal.

B2b. Anthropogenic barriers: Somewhat Increase
Much of the matrix landscape in which the vernal pools that support *Collinsia sparsiflora* var. *sparsiflora* occur has been developed or converted to agriculture, often constraining potential suitable habitat to small strips between rivers and residential areas. Development and road construction is likely to alter hydrological systems in remaining habitat (Rocchio and Crawford 2015). Substantial off trail impacts from humans and collection of plants has also been observed at the occurrences. Collectively, these barriers probably pose a significant impediment to dispersal, but less so than the natural barriers imposed by the natural patchiness of vernal pools.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the Washington occurrences of *Collinsia sparsiflora* var. *sparsiflora* and there are no conflicting projects currently slated for Klickitat County according to their online energy projects map (Klickitat County 2022, Washington Department of Natural Resources 2024). However, the flat and open lands where *Collinsia sparsiflora* var. *sparsiflora* occurs could be targeted for wind or solar development in the future.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Little is known about the dispersal mechanisms of *Collinsia sparsiflora* var. *sparsiflora*, though the seeds of all *Collinsia* spp. are thought to be passively dispersed (Wright et al. 2006), having no specialized means of attachment. The flattened seeds released by all varieties of the parent species *Collinsia sparsiflora* are irregularly wing-margined which may allow them to travel very short distances on wind (Randle et al. 2009, Washington Natural Heritage Program 2023). Dispersal distances are probably relatively short (no more than 100 m).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Collinsia sparsiflora* var. *sparsiflora* occurrences in Washington. Four of six known occurrences (67%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining two occurrences (33%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation and are expected to be mostly resilient to warming (Young et al. 2016).

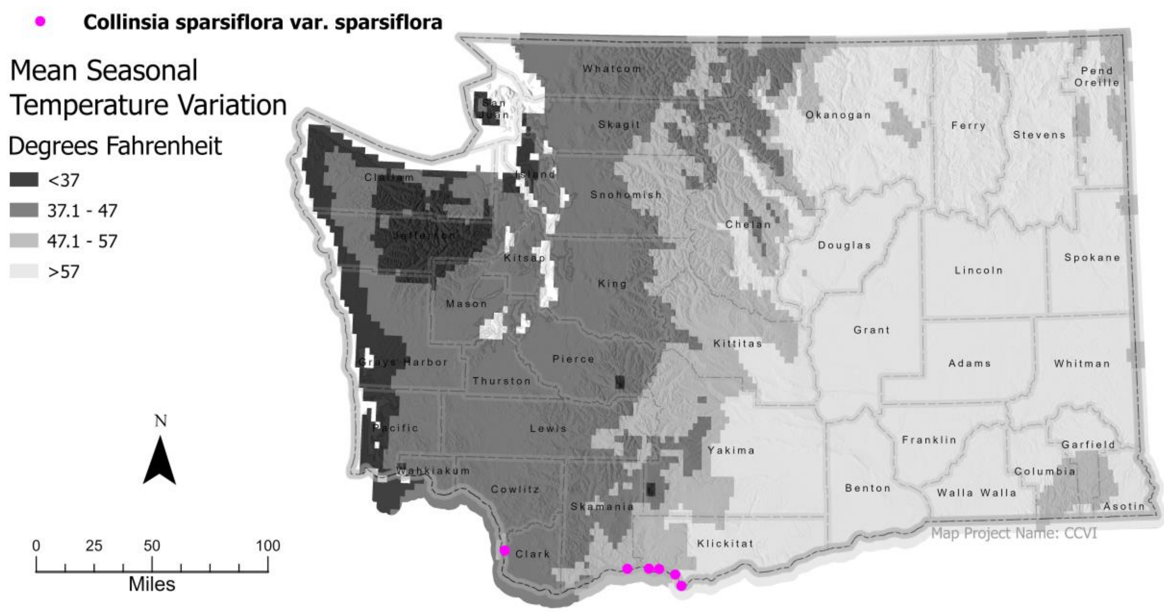

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Collinsia sparsiflora var. sparsiflora* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral

The ephemeral wetland and vernal pool habitat of *Collinsia sparsiflora* var. *sparsiflora* is not associated with cold air drainage during the growing season. These shallow wetlands would be vulnerable to long-term persistent drought and increased temperatures during the growing season which could lead to drying of the pools (Rocchio and Ramm-Granberg 2017). However, the microsites where this species occurs are on warm, south-facing slopes in exposed areas where solar radiation is high, which may indicate that it will be somewhat tolerant of warming.

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Collinsia sparsiflora* var. *sparsiflora* occurrences in Washington. Two of six known occurrences (33%) are in areas that have experienced slightly lower than average variation in precipitation (11 - 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The remaining four occurrences (67%) are in areas that have experienced average or greater than average precipitation variation (>20 inches (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

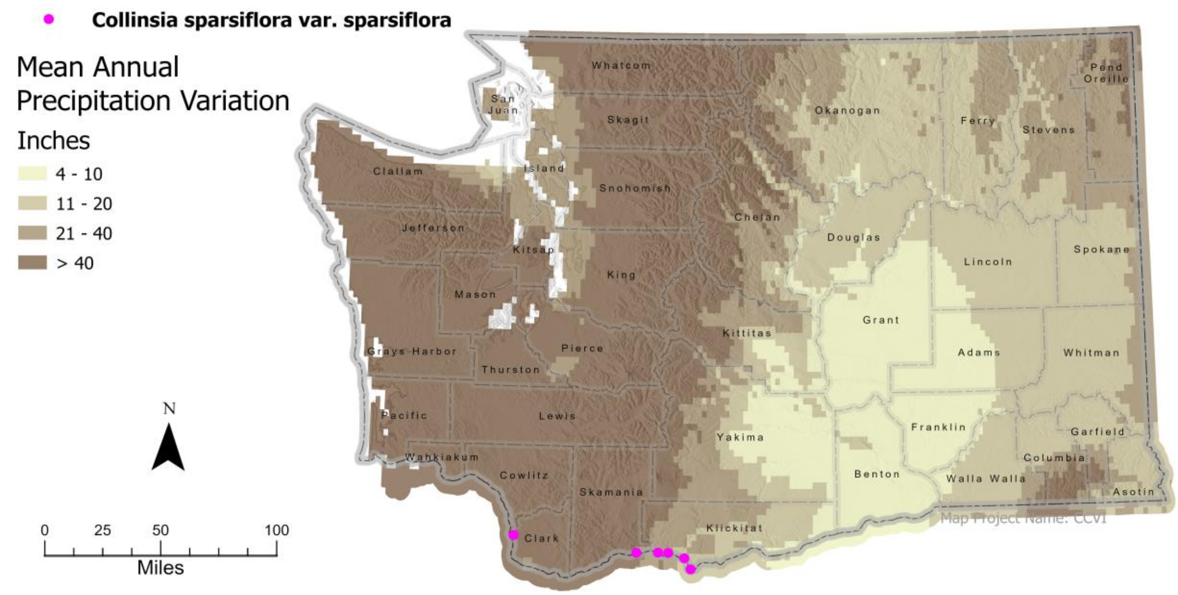

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Collinsia sparsiflora var. sparsiflora* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Collinsia sparsiflora var. *sparsiflora* associates with moist banks along the Columbia River and shallow, ephemeral vernal pools that occur in small depressions and swales. These microsites are moist in the spring but dry out by summer, relying more on early spring precipitation and snowmelt than groundwater or stream runoff (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Vernal pool hydrology could be altered by changes in precipitation type, timing and amount, drought, and warmer temperatures that lead to reduced water supply and/or enhanced evaporation that would likely alter community composition or lead to complete conversion to other ecological system types (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Modoc Basalt Flow Vernal Pools are largely shaped by seasonal hydrological changes and drying combined with basin morphology which together create different fine scale zones with different species composition (Rocchio and Crawford 2015). The duration and depth of inundation are the principal drivers of the ecological system rather than major disturbances. There is little evidence of recent disturbance in the vicinity of Washington occurrences according to observation records.

C2d. Dependence on ice or snow-cover habitats: Neutral

The range of *Collinsia sparsiflora* var. *sparsiflora* in Washington is within areas that receive relatively little snowfall, and thus drifting snow or snowmelt is a relatively minor component of the plant's annual water budget. Changes in the amount of snow or timing of its melt could affect hydrological conditions in these vernal pools (Rocchio and Ramm-Granberg 2017). Other than impacts to the water supply of the habitat, *Collinsia sparsiflora* var. *sparsiflora* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Collinsia sparsiflora var. *sparsiflora* occurs on thin, skeletal loam soils derived from basalt that are mixed with various proportions of rocks (Washington Natural Heritage Program 2023). It associated with alluvial deposits from the Missoula floods and both Grand Ronde and Saddle Mountains basalt formations (Washington Division of Geology and Earth Resources 2016). These substrates and geological formations are relatively widespread in the eastern part of Washington and the Columbia River Gorge. Vernal pools must be deep enough to flood in winter and early spring but shallow enough to dry in summer and are an uncommon feature on the landscape (Rocchio and Crawford 2015), making this species a habitat specialist. In California, this species is known to have an affinity for serpentine soils but does not occur in areas of Washington where serpentine is common.

C4a. Dependence on other species to generate required habitat: Neutral
The vernal pool habitat occupied by *Collinsia sparsiflora* var. *sparsiflora* is maintained by natural abiotic processes and geological conditions, rather than interactions with other species. Observation records indicate that this species has done well since cattle and horse grazing was discontinued in 1985 as the habitat was weedy when grazed.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Collinsia spp. are pollinated primarily by bees (Randle et al. 2009), with small-flowered species such as *Collinsia sparsiflora* var. *sparsiflora* attracting mainly small bee species that do not collapse the fused floral tubes upon visit (Armbruster 2014). The parent species *Collinsia sparsiflora* has been documented to attract a wide spectrum of generalist bee species, including members of the *Apis, Bombus*, and *Osmia* genera (Rust and Clement 1977). Though it is a bee specialist, *Collinsia sparsiflora* var. *sparsiflora* is probably not highly restricted in terms of pollinators beyond this guild.

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Collinsia sparsiflora* var. *sparsiflora* are dispersed by gravity or other passive means. This species is not known to be dependent on animals for transport and the achene fruits do not have barbs, hooks, or other specialized means of attachment.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
The parent species *Collinsia sparsiflora* can be attacked by several generalist herbivores, particularly lepidopteran larvae and flea beetles which decrease survival and persistence (Lau et al. 2008). Insect herbivory may increase in response to climate warming to the detriment of this species (Liu et al. 2024). Grazing is likely to have a negative effect on vernal pools and could

allow the introduction of non-natives and shift composition to favor native upland and wetland species over vernal pool obligates, as well as damaging soil crusts (Rocchio and Crawford 2015). However, there is no evidence that climate change is interacting with or increasing grazing in this ecological system.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
The vernal pools which support *Collinsia sparsiflora* var. *sparsiflora* can easily become invaded by several exotic species after grazing or other soil disturbances and upland species may encroach as pools dry out for longer periods (Rocchio and Crawford 2015). Rising temperatures may lead to increased evapotranspiration relative to precipitation and simultaneously increase native plant mortality while encouraging invasion by weeds (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
The parent species *Collinsia sparsiflora* is known to host arbuscular mycorrhizae, though it is not apparently dependent on the relationship.

C5a. Measured genetic variation: Unknown
The genetic diversity of *Collinsia sparsiflora* var. *sparsiflora* has not been documented but is probably low due to high rates of self-pollination (Allard and Kahler 1971). See C5c. Reproductive System for more details.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
All *Collinsia* species have a mixed mating system and are self-compatible to varying degrees (Randle et al. 2009). The parent species *Collinsia sparsiflora* has been documented to rely more heavily on a self-pollinating mating system than other *Collinsia* spp. as the stigmas of this species come into contact with pollen earlier in development, likely leading to less genetic variation and inbreeding depression (Allard and Kahler 1971). However, the ability to self-pollinate in arid ecological systems where pollinators may be infrequent can provide reproductive assurance (Rust and Clement 1977, Hanley 2005). Additionally, selfing *Collinsia* spp. often turn to cross-pollination later in the season which can help to maintain slightly more heterozygosity than strictly selfing species (Rust and Clement 1977).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (March to April) has not changed significantly (Washington Natural Heritage Program 2023). However, a study found that density-stress can cause early flowering and phenological mismatch in this species, which may indicate that it is prone to phenological shifts (Antonovics and Levin 1980). Further phenological monitoring is warranted as studies show spring blooming species to be at greater risk of phenological change in North America (Calinger et al. 2013).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Collinsia sparsiflora* var. *sparsiflora* declining in response to climate change. However, four of the six known occurrences in Washington are now historical and need revisits to confirm their status.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Cryptogramma stelleri (*Steller's rockbrake*)

Date: 8 January 2024 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	75
	-0.074 to - 0.096	25
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All eight known occurrences (100%) of *Cryptogramma stelleri* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

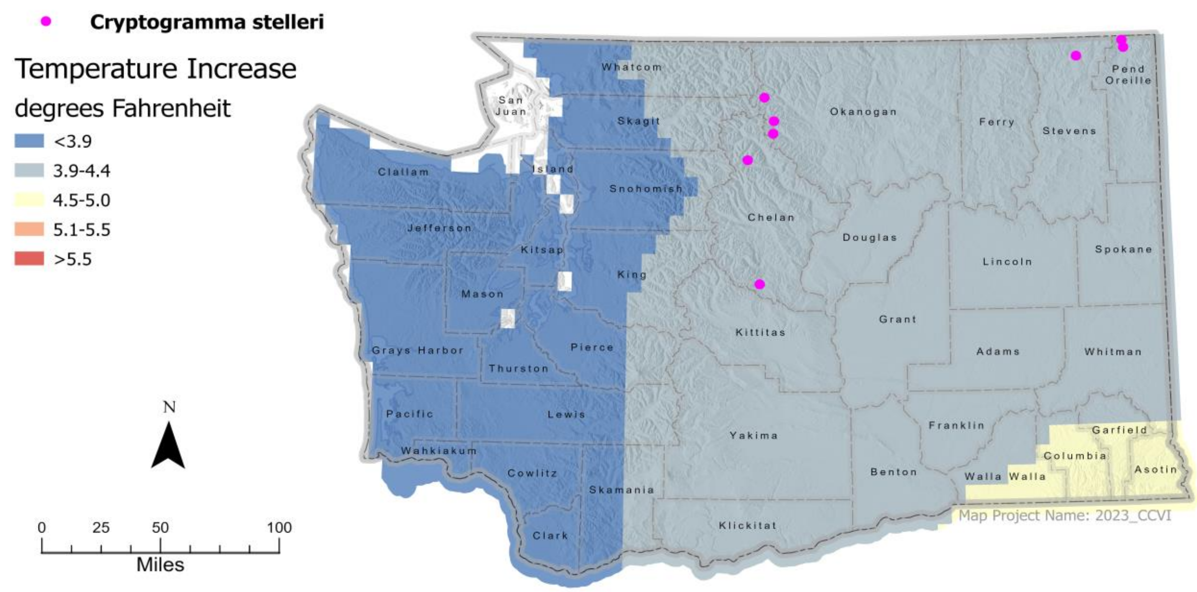

Figure 1. Exposure of *Cryptogramma stelleri* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the eight known occurrences (75%) of *Cryptogramma stelleri* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The remaining two occurrences (25%) are in areas with a projected moisture decrease in the range of -0.074 to -0.096.

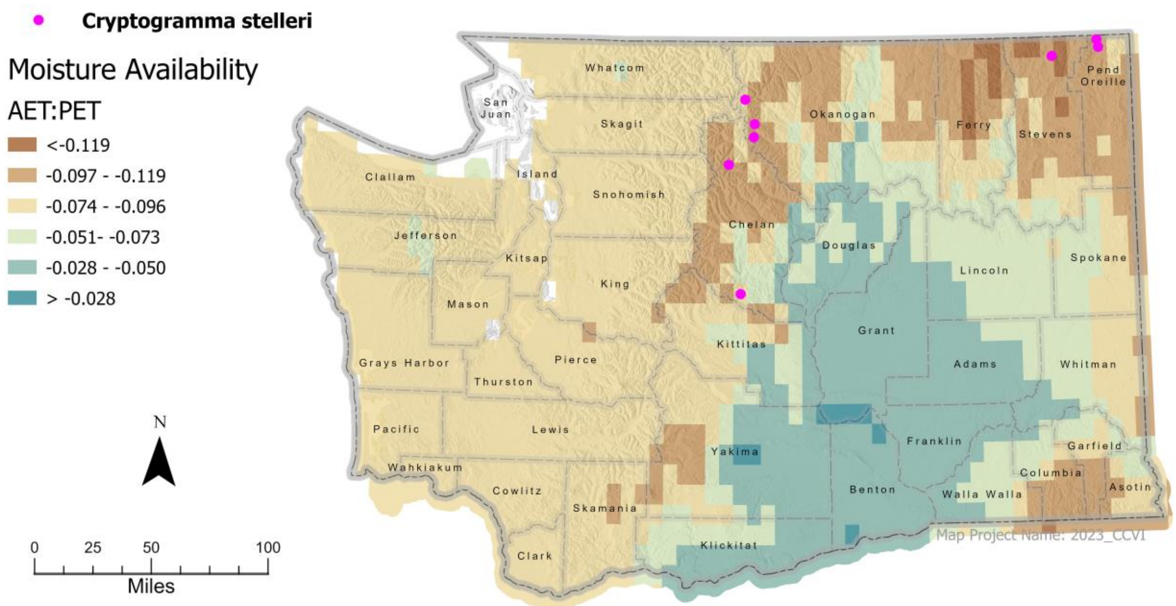

Figure 2. Exposure of *Cryptogramma stelleri* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Cryptogramma stelleri occurs in moist, shady crevices of calcareous cliffs and ledges and along wooded slopes at middle and upper elevations (2000-6000 ft (610-1830 m)) on the eastern crest of the Cascades and further east (Washington Natural Heritage Program 2023). *Cryptogramma stelleri* populations in Washington are not expected to be affected by sea level rise based on their inland distribution (Office for Coastal Management 2023).

B2a. Natural barriers: Somewhat Increase
Cryptogramma stelleri microsite habitats are somewhat uncommon at a local scale, being restricted to moist, shady crevices of limestone cliffs and ledges in wooded slopes of the Cascades and Canadian Rockies which are part of the Rocky Mountain Cliff, Canyon and Massive Bedrock ecological system (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). The surrounding forest canopy cover and ridgelines can restrict movement of

this species between rocky patches, limiting potential for dispersal and migration. Distances between populations range from 6-189 mi (9-303 km) with the Columbia Basin separating and preventing gene flow between populations of the two mountain ranges. This species disperses by tiny wind-borne spores which may have reduced mobility within densely forested areas.

B2b. Anthropogenic barriers: Neutral
Cryptogramma stelleri occurrences in Washington are mostly located in backcountry, rugged terrain requiring "bushwacking" to access per field notes. These are mostly protected areas of wilderness lands, natural areas, and National Forest lands. Populations are largely protected from human impacts but can be threatened by road construction, recreation, mining/quarrying (Rocchio and Crawford 2015). Historical populations are thought to have been lost due to inundation when the Boundary Dam was built and the dam could potentially have future impacts on available habitat depending on management.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten populations of *Cryptogramma stelleri* (Washington Department of Natural Resources 2023). Future projects in the vicinity of populations are unlikely due to the backcountry terrain and existence in wilderness areas.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
As is true for all ferns, spores of *Cryptogramma* spp. can travel long distances via wind or water and might also be distributed by animal attachment or ingestion in some cases. Most spores ultimately fall within a short distance of parents and dispersal distances depend on air currents (Rose and Dassler 2017). However, in more open areas, ferns theoretically have unlimited potential for dispersal over long distances and can easily travel nearly 250 mi (400km) (Peck 1985). *Cryptogramma stelleri* has a somewhat lower ability for long distance dispersal due to its production of heterosporous spores with poor viability (Peck et al. 1990).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Cryptogramma stelleri* occurrences in Washington. Three of the eight known occurrences (37.5%) are in areas that have experienced little temperature variation over the historical period (37 - 47° F (20.8 - 26.3° C)). According to Young et al. (2016), these populations are expected to be vulnerable to climate warming. Another two occurrences (25%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) and are expected to be somewhat vulnerable to climate warming (Young et al. 2016). The remaining three occurrences (37.5%) are in areas that have experienced average or above average temperature variation (>57.1° F (31.8° C)) and are expected to be mostly resilient to climate warming.

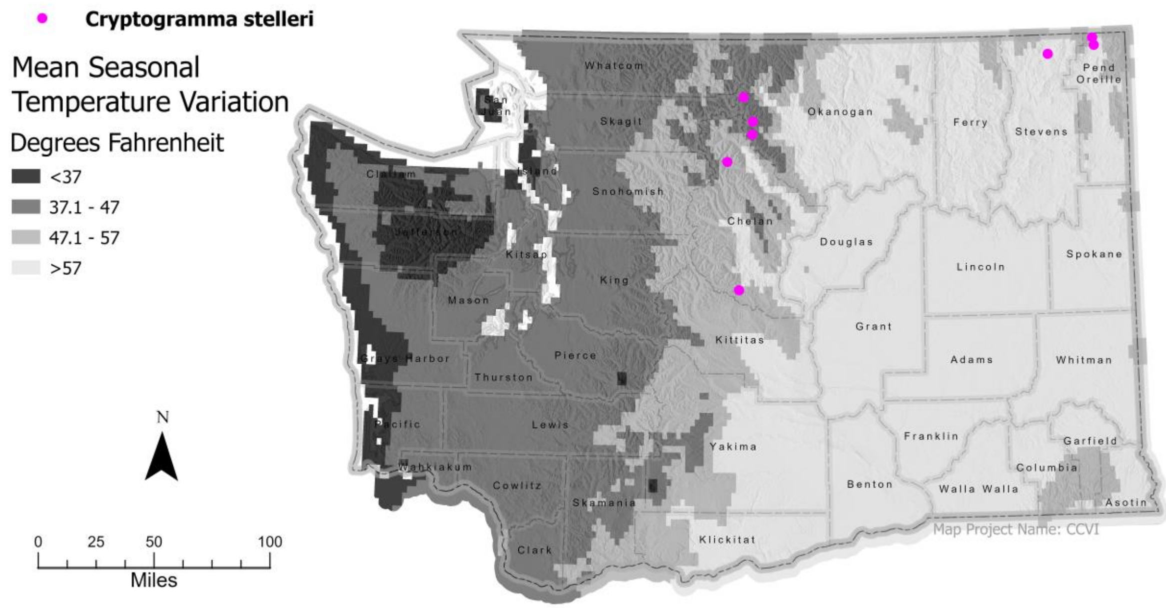

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cryptogramma stelleri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase
Cryptogramma stelleri is restricted to cool, shaded cliffsides and north-facing wooded slopes, avoiding exposure to sun (Washington Natural Heritage Program 2023). These microsites are likely to be susceptible to rising temperatures which can also increase fire risk or alter erosion rates (Rocchio and Ramm-Granberg 2017, Estevo et al. 2022). Climate models predict hotter and drier conditions that may result in a loss of suitable habitat for *Cryptogramma stelleri* (Handwerk et al. 2014).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Cryptogramma stelleri* occurrences in Washington. All eight known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

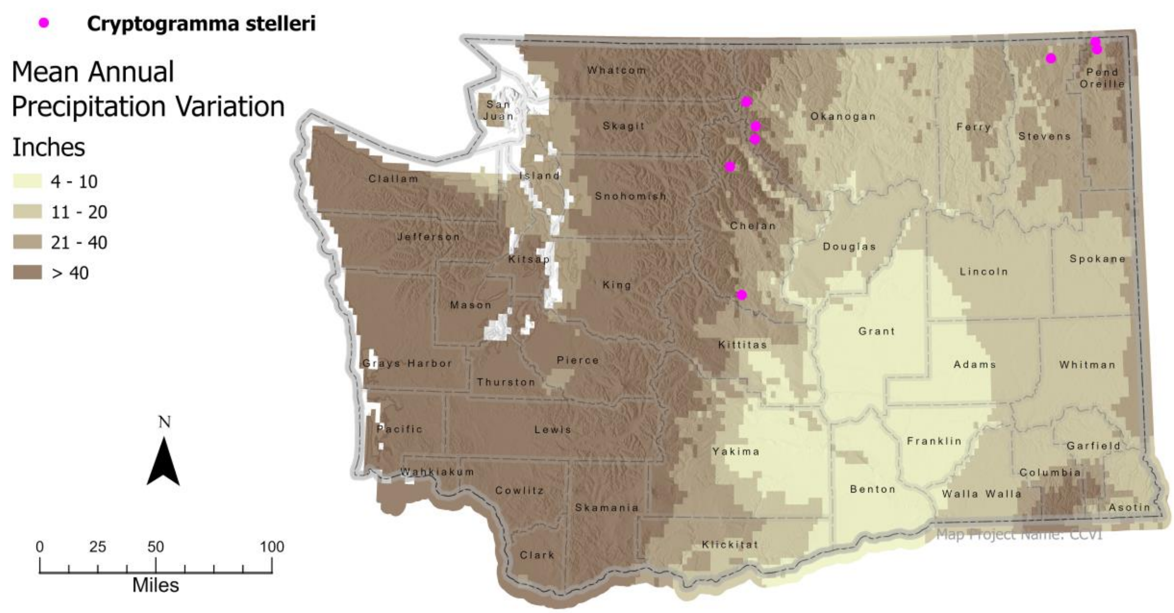

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cryptogramma stelleri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
The outcrops and slopes which support *Cryptogramma stelleri* are associated with dripping water that seeps through cracks to create suitable microhabitats. *Cryptogramma stelleri* is dependent on adequate snow and spring/summer rainfall for its moisture needs as it is not connected to perennial water sources or a high water table. Shifts in precipitation timing and amount and earlier snow melt combined with extended summer droughts are expected to have a moderate impact on Rocky Mountain Cliff, Canyon, and Massive Bedrock ecological systems (Rocchio and Ramm-Granberg 2017). The potential drying of cliff microhabitats where limited moisture is retained in crevices will be of particular concern for *Cryptogramma stelleri.*

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Wind, water, and gravity are forces acting upon cliff habitats which lead to continuous erosion and constant change to the microhabitats that support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004). However, the high exposure of these sites may make them susceptible to rising temperatures which can also

increase fire risk or alter the erosion rates of cliff communities (Rocchio and Ramm-Granberg 2017, Estevo et al. 2022).

C2d. Dependence on ice or snow-cover habitats: Neutral
Water infiltrating cracks and crevices in rock outcrops is an important moisture source during the growing season and associating with patches of slow melting snow is critical. Reductions in the amount of snowfall, or the timing of its melting due to climate change (Rocchio and Ramm-Granberg 2017), could have a negative impact on this species which occurs in habitats not directly associated with groundwater. However, *Cryptogramma stelleri* is not especially reliant on ice or snow cover beyond recharge of the hydrological system.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Cryptogramma stelleri is commonly referred to as a calciphile, described as occurring almost exclusively in shallow soils on limestone cliff bands, outcrops, and steep rock faces (Alverson 2008, NatureServe 2023). However, it is also occurs on a variety of other formations and parent materials including but not limited to alluvium deposits, tonalite, talus, orthogneiss, metavolcanic rock, and Pleistocene swamp/lake deposits (Washington Division of Geology and Earth Resources 2016). Limestone outcrops are uncommon in Washington, having mostly been buried by volcanic material, but are found below many outcrops in the Cascade Range (Danner 1966). The other formations listed are not particularly common but the combined availability of suitable geological features is not very limited for *Cryptogramma stelleri.*

C4a. Dependence on other species to generate required habitat: Neutral
Cliff and rocky slope habitats are shaped mostly by abiotic processes and erosion which shifts critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Cryptogramma spp. do not depend on pollinators for their reproductive cycle. Instead, spores are spread via wind and gametophytes are produced vegetatively underground.

C4d. Dependence on other species for propagule dispersal: Neutral
Cryptogramma spores are mostly dispersed passively via wind or water. Some species of ferns are known to have spores that can attach to animals or spread via ingestion if they are able to survive digestion, but it is unknown whether this is the case for *Cryptogramma stelleri* (Fryer 2014, Boch et al. 2016).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Most ferns are unpalatable to herbivores and ferns generally are not especially subject to insect attack (Lellinger 1985). However, a substantial number of arthropods have been found to eat large numbers of spores and some are lost to fungi (Peck 1985). The exact susceptibility of *Cryptogramma stelleri* is unknown.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase

Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to exposed calcareous rock outcrops and ledges (Rocchio and Crawford 2015). Under future climate change, the broader conifer forest matrix inhabited by this species will become drier, hotter, and more vulnerable to fire. Outcrops would become more likely to be invaded by weedy annuals or native perennials adapted to more open and drier sites, though fewer species are expected to colonize cliff microsites (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Cryptogramma stelleri is often associated with patches of moss and duff that retain moisture but does not have an obligate relationship with these species.

C5a. Measured genetic variation: Unknown
The genetic variation of C*ryptogramma stelleri* in Washington is not known. This is a widespread species that is nearly circumpolar but Washington populations are slightly disjunct from the core range, which runs through the Rocky Mountains of northwestern Montana. Other *Cryptogramma* ssp. have been documented to have average genetic variability that would be seen in an outcrossing species (Pajaro´n et al. 1999). The typically small population sizes of this species may make it vulnerable to inbreeding depression.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Cryptogramma stelleri is a diploid fern species that has distinguishable fertile and sterile leaves and a slender creeping rhizome (Washington Natural Heritage Program 2023). Like other pteridophytes, it follows a life cycle with two alternating independent generations; inconspicuous gametophytes that produce separate male and female organs and dominant homosporous sporophytes which can produce gametophytes with both sex organs (Soltis and Soltis 1990). This species is primarily an outcrosser and, like other *Cryptogramma* species, may control selfing by producing antheridia-inducing substances which control the timing of sex expression (Pajaro´n et al. 1999). It is reported to reproduce more frequently from rhizomes than spores due to low spore production (Peck et al. 1990). *Cryptogramma stelleri* probably has somewhat average genetic diversity but less than its tetraploid congeners (Soltis and Soltis 1990, Meirmans and Van Tienderen 2013, Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the sporulation period of *Cryptogramma stelleri* (early June to mid-August) has not changed significantly (Washington Natural Heritage Program 2023), though there were few records with phenological phase available to consider.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Of the eight known occurrences of *Cryptogramma stelleri* in Washington, four have been revisited and confirmed to be extant since 2020. Populations at these sites do appear to be declining, however, individuals are notoriously hard to locate and count due to cliff access and

obscurement by shrubs. There are no other reports of decline in response to climate change for this species.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Draba aurea (golden draba)

Date: 1 May 2024 | Synonym: none

Assessor: Molly S. Wiebush, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5/S1

Index Result: Highly Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	63
	-0.074 to -0.096	37
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All eight known occurrences (100%) of *Draba aurea* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

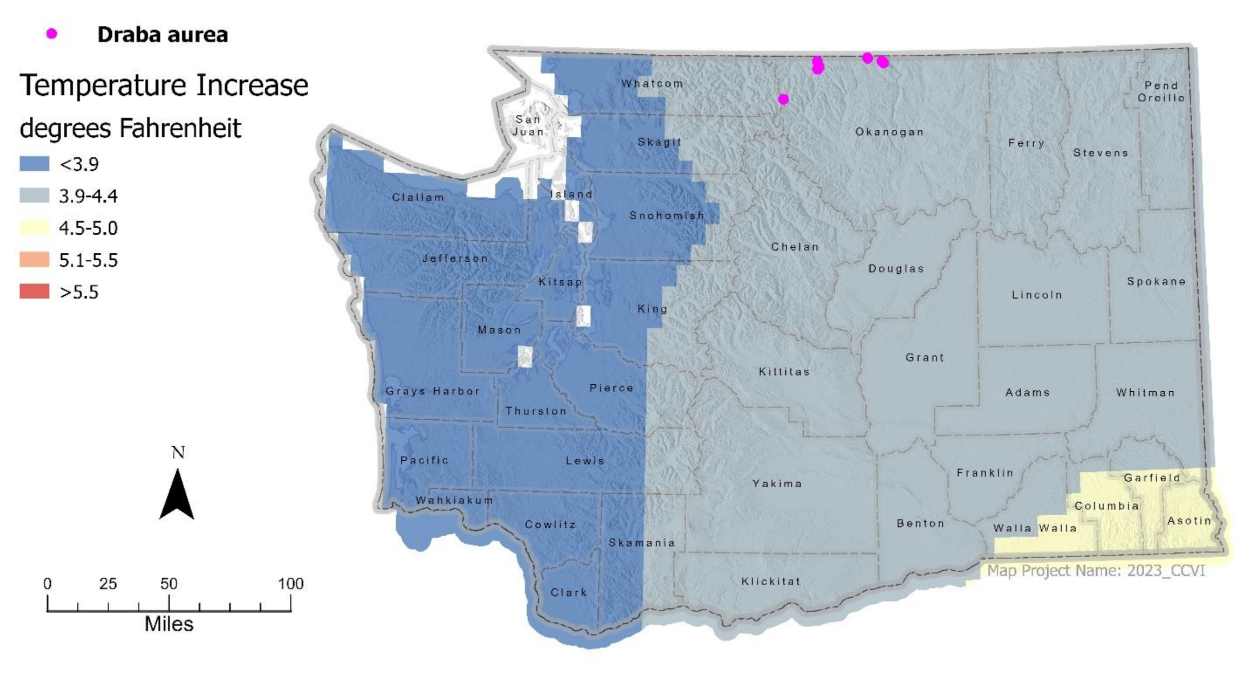

Figure 5. Exposure of occurrences of *Draba aurea* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Three of eight known occurrences (37%) of *Draba aurea* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096. Five of eight known occurrences (63%) of *Draba aurea* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.0119 (Figure 2).

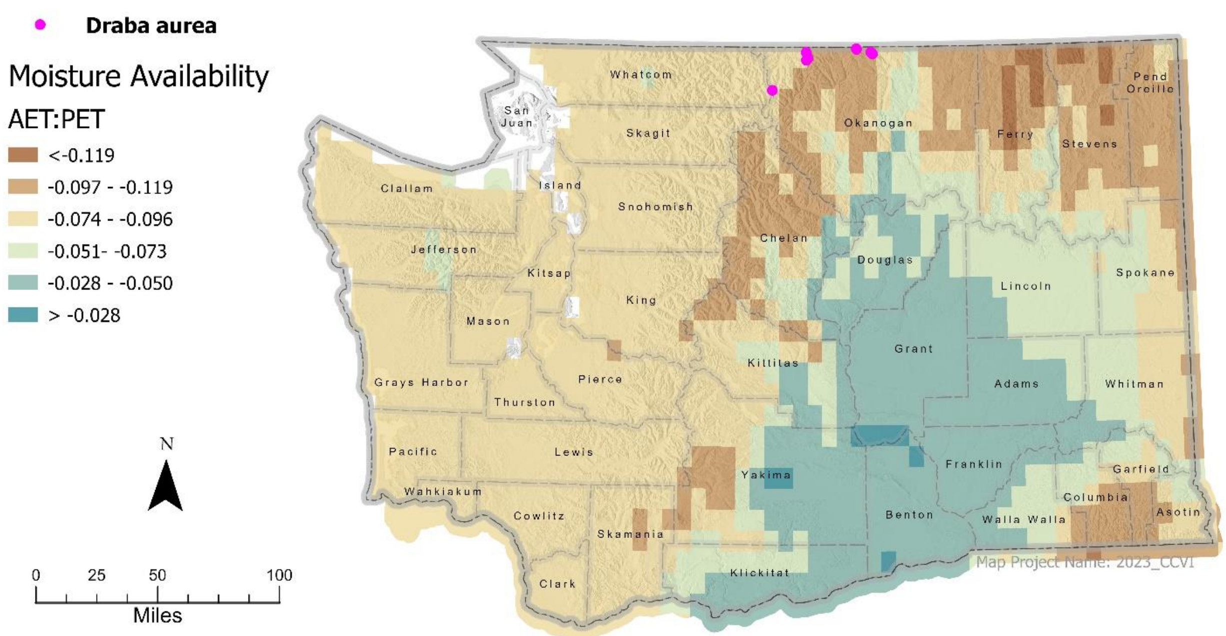

Figure 6. Exposure of occurrences of *Draba aurea* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Draba aurea is found in dry, relatively sunny habitats, including forested slopes and alpine meadows between 6800–7700 ft (2070–2350 m; Washington Natural Heritage Program 2024) and would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Increase</u>
In Washington, *Draba aurea* is found in the Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, & Turf ecological systems (Rocchio and Crawford 2015, Washington Natural Heritage Program 2024). These large-patch systems consist of turf and dwarf-shrublands separated by stretches of dry, wind-scoured slopes and subalpine forests (Rocchio and Crawford 2015). In

Washington, these systems are restricted to small alpine areas of the Okanogan Highlands, the East Cascades, and potentially Mt. Adams (Rocchio and Crawford 2015). Natural barriers of unsuitable habitat at lower elevations are likely to restrict *Draba aurea*'s ability to disperse to new areas in response to climate change.

B2b. Anthropogenic barriers: <u>Neutral</u>
All known occurrences of *Draba aurea* in Washington occur in protected areas, with six of eight records occurring either wholly or partially in the Pasayten Wilderness, and the remaining two records occurring in the Chopaka Mountain Natural Area Preserve. Recreation, grazing, and/or mining are the most likely anthropogenic influences within its range. A study from Rocky Mountain National Park reported *Draba aurea* as one of the common species found in roadcut plots (Greller 1974), and element occurrences for these species have been reported along the Pacific Crest Trail, near lookout platforms, and in areas with sheep grazing. Otherwise, the human footprint is negligible and does not present an additional barrier to dispersal for this species.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
All records of *Draba aurea* in Washington State occur in protected areas, with six of eight records occurring either wholly or partially in the Pasayten Wilderness, and the remaining two records occurring in the Chopaka Mountain Natural Area Preserve. There are no known ongoing or proposed clean energy projects that would threaten the populations of *Draba aurea* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Somewhat Increase</u>
Draba aurea seeds are wind-dispersed and probably not dispersal limited (Smyth 1997). Seeds are small (0.04 in (1 mm)), with 20-50 seeds per fruit. The seeds lack wings, hooks, barbs, or other structures to facilitate dispersal by animals, but their small size may allow transport by strong winds up to 3,280 ft (1,000 m). Secondary dispersal by foraging animals is also possible, once seeds land on the ground.

C2ai. Historical thermal niche: <u>Increase</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Draba aurea* occurrences in Washington. Four of eight known occurrences (50%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming. Three of eight known occurrences (37%) are in areas that have experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming. One of eight known occurrences (13%) are in areas that have experienced average or above average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

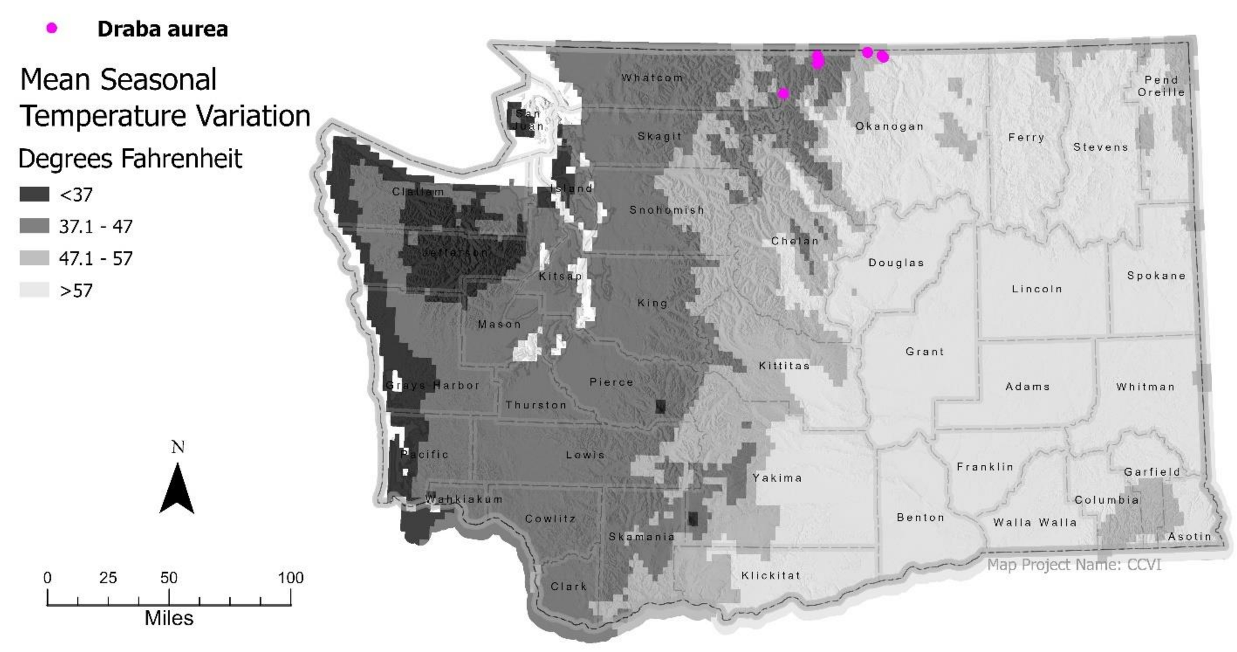

Figure 7. Historical thermal niche (exposure to past temperature variations) of occurrences of *Draba aurea* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Increase
Melting glaciers could expand suitable habitat for *Draba aurea* in alpine areas, but these gains could be offset over time by concurrent shifts in forested systems to higher altitudes (Rocchio and Crawford 2015). Alpine species may be at risk of following an “elevator to extinction” as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Draba aurea* occurrences in Washington. All eight known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 inches (508 mm)) over the historical period. According to Young et al. 2016, these populations are expected to be mostly resilient to changes in moisture availability.

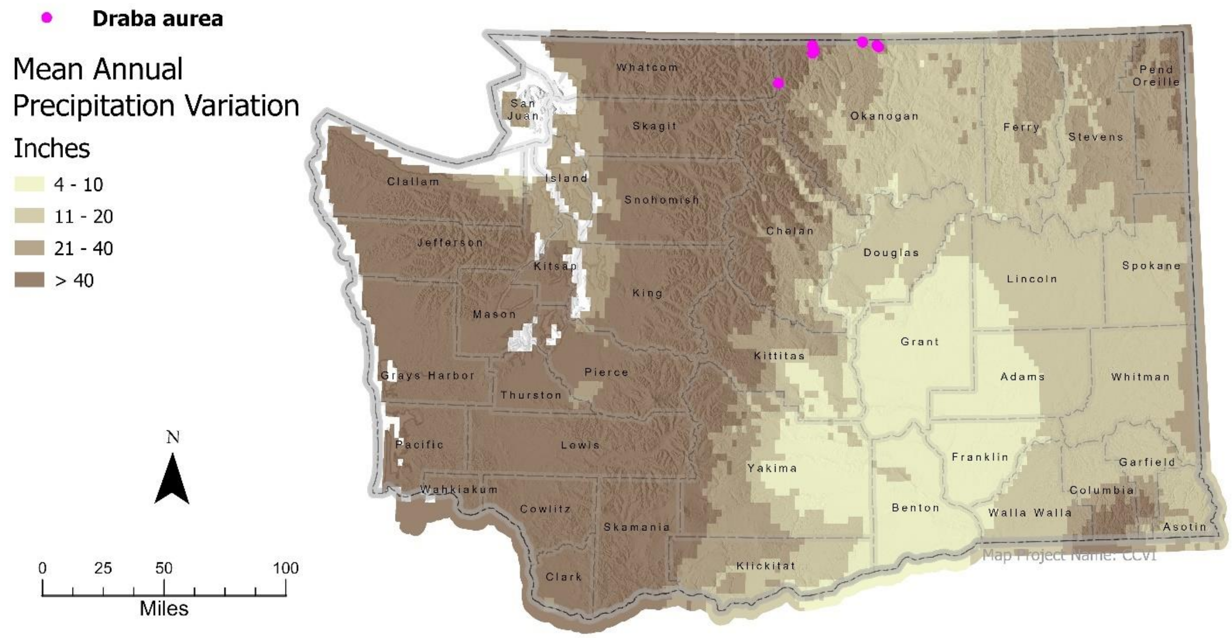

Figure 8. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Draba aurea* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
In Washington, *Draba aurea* generally occurs in fell-fields or talus on dry south- or west-facing slopes. These areas are frequently wind-scoured, with poorly developed soils that retain little moisture. *Draba aurea* can also be found in dwarf-shrubland and turf communities. Dwarf-shrublands typically occur on level or concave terrain that holds snow later in the year and generally receives water from surrounding slopes. Turf systems are found on level or sloped areas that generally hold water until the late summer (Rocchio and Crawford 2015). These habitats are expected to see reduced snowpack and changes in precipitation patterns with climate change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Wind, water, and gravity are the main forces acting upon fell-field habitats, leading to continuous erosion and constant change to the microhabitats supporting vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles codetermine which organisms occur on cliffs and talus slopes (Larson et al. 2000). These disturbance regimes are unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Chersich et al. 2015). *Draba aurea* has been documented growing in disturbed areas such as road cuts and trails, and observers have

pointed out the utility of studying whether it responds favorably to sheep grazing. However, this species does not appear to be dependent on a specific disturbance regime to maintain its habitat.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
While the fell-fields where most of Washington's *Draba aurea* occurrences are found can be snow-free even in the winter—due to high winds—the associated dwarf-shrublands and turf vegetation rely on snow retention and permafrost (Rocchio and Crawford 2015). Reductions in the amount of snow, or changes in the timing of snowmelt, could make these habitats drier in the future and more prone to invasion by plants from lower elevations. Most of the water in these habitats likely comes from precipitation in the form of snow, as these systems are generally not connected to groundwater. Since *Draba aurea* can also be found in dwarf-shrubland and turf habitats, changes to snowpack and permafrost extent could also potentially have some effect on this species (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Draba aurea occurs mainly on fell-fields and talus slopes but can be found across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems are shaped mostly by abiotic processes and erosion which shifts critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
No information is available on pollinators for *Draba aurea*. Self-pollination is common among arctic and alpine species of *Draba*. However, Hymenopteran and Dipteran species have been reported to visit *Draba* spp. in Norway and Canada. Artic and alpine *Draba* species may not be frequently visited by pollinators and don't appear to be pollen-limited (Brochmann 1993). Pollinator diversity may be reduced in alpine areas (Spira and Pollak 1986) but given the likelihood that *Draba aurea* is capable of self-pollination and not pollen-limited, this species is likely resilient to disruptions in plant-pollinator relationships due to climate change.

C4d. Dependence on other species for propagule dispersal: Neutral
Draba aurea seeds are wind dispersed and do not have adaptive structures to attach to animals (Smyth 1997).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Draba aurea has been documented as a food plant for pika in the La Sal Mountains of Utah (Smith et al. 2014) and a host plant for native Pierid (white or cabbage) butterflies in Colorado (Chew 1977). *Draba aurea* is not a preferred food for either of those taxa, and Pierid butterflies had low survival rates on *Draba aurea*. Herbivory is unlikely to increase with climate change.

C4f. Sensitivity to competition from native or non-native species: Neutral

Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to the harsh environmental conditions of the alpine zone. Vegetation cover is low in rocky talus slopes and fell-fields due to the paucity of germination sites and harsh climatic conditions impacting seedling survival. Under future climate change scenarios, these sites could be invaded by tree or shrub species or lower elevation forbs and grasses, resulting in increased soil accumulation, more litter, and enhanced probability of fire (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Unknown
No other interspecific interactions were found in the literature.

C5a. Measured genetic variation: Not Ranked
Data are lacking on the genetic diversity within and between populations of *Draba aurea* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Neutral
Little is known about the specific reproductive biology of *Draba aurea*. However, many other *Draba* species have a mixed mating system. A study of arctic *Draba* species found that polyploid species of *Draba* have much higher genetic variability than diploid species (Brochmann 1993) *Draba aurea* is polyploid, with a chromosome count that suggests it is hexaploid or higher (Al-Shehbaz et al. 2020).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period (June to August) of *Draba aurea* has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Draba aurea* declining in response to climate change. While some known occurrences have been revisited as recently as 2019, not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

***Dryopteris cristata* (crested shield-fern)**

Date: 22 December 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	4
	-0.097 to -0.119	92
	-0.074 to - 0.096	4
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 26 known occurrences (100%) of *Dryopteris cristata* in Washington occur in areas with a projected temperature increase in the range of 3.9-4.4° F (2.2-2.4° C; Figure 1).

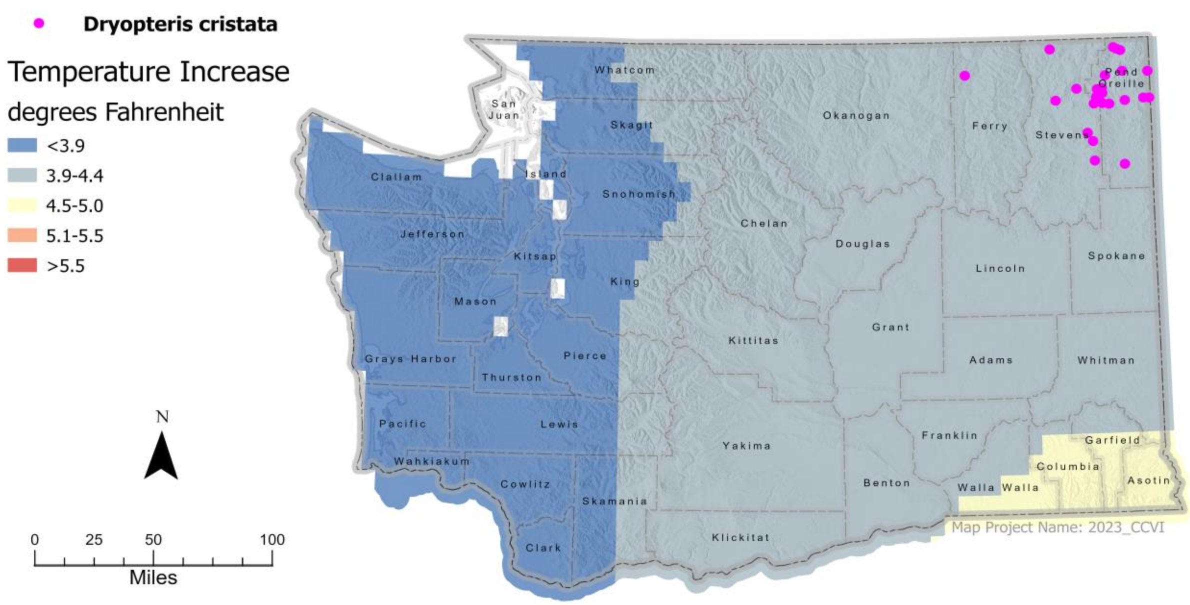

Figure 1. Exposure of *Dryopteris cristata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: One of the 26 known occurrences (4%) of *Dryopteris cristata* in Washington in Stevens County is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2). Another 24 occurrences (92%) are in areas with a projected moisture decrease in the range of -0.097 to -0.119. The remaining occurrence (4%) in Stevens County is in an area with a projected decrease in available moisture of less than -0.119.

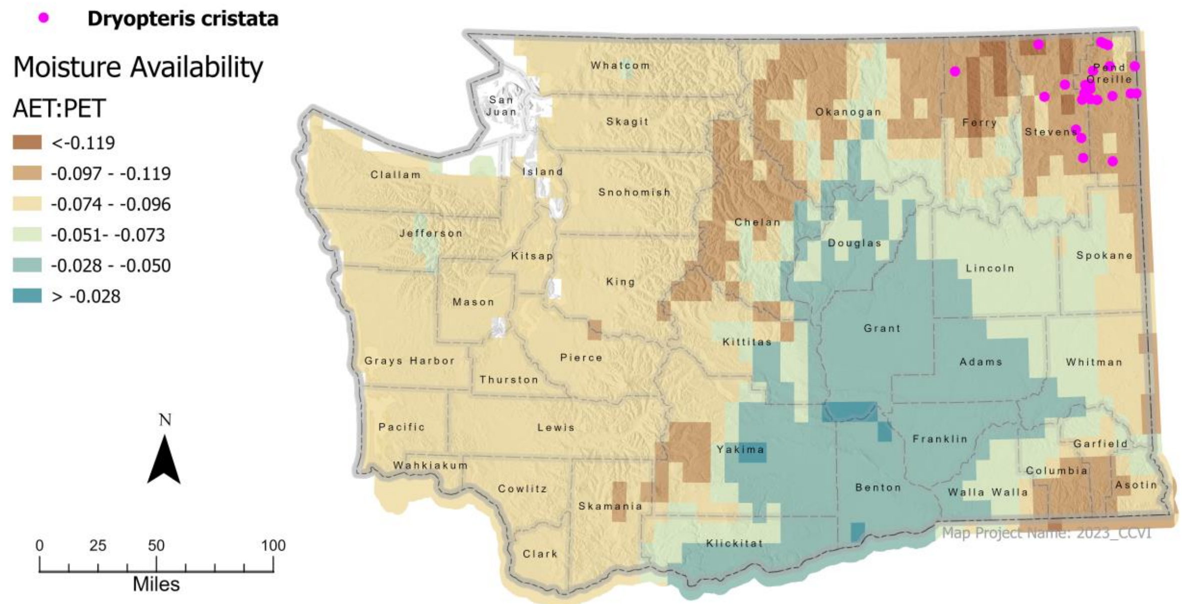

Figure 2. Exposure of *Dryopteris cristata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Dryopteris cristata occurs in wet meadows and at wetland edges at elevations ranging from 1800-4100 ft (550-1250 m; Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Populations in Washington are not expected to be affected by sea level rise based on their inland distribution (Office for Coastal Management 2023)

B2a. Natural barriers: Somewhat Increase
The boggy meadow patches and lake margins occupied by *Dryopteris cristata* are part of the Northern Rocky Mountain Conifer Swamp, Rocky Mountain Alpine-Montane Wet Meadow, and Rocky Mountain Subalpine-Montane Fen ecological systems (Washington Natural Heritage Program 2023). These habitats occur as large patches at the ecotone of open grassland and closed

canopy forest where groundwater reaches the surface, with composition of wetlands ranging from shrubby to somewhat forested (Rocchio and Crawford 2015). Populations are separated by 0.5-80 mi (0.7-129 km) of unsuitable forest upland habitat which acts as somewhat of a barrier to dispersal in Washington.

B2b. Anthropogenic barriers: Somewhat Increase
Washington occurrences of *Dryopteris cristata* are largely in wilderness areas or natural areas but some are also on National Forest lands that are managed for multiple use. Anthropogenic barriers are minimal, but timber sale allotments overlapping populations and adjacent to populations are likely to impact conifer swamp, meadow, and fen habitats by altering hydrology or increasing sedimentation (Rocchio and Crawford 2015). Some forest roads run near or directly through occurrences and culverts have been built near some of the wetlands. These converted or degraded areas may pose limited barriers to dispersal into suitable habitats.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten populations of *Dryopteris cristata* (Washington Department of Natural Resources 2023). Future projects in the vicinity of populations are less likely due to somewhat backcountry terrain and presence in wilderness areas.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
As is true for all ferns, spores of *Dryopteris* spp. can travel long distances via wind or water and might also be distributed by animal attachment or ingestion in some cases. Most spores ultimately fall within a short distance of parents and exact dispersal distances depend highly on air currents (Munger 2007, Rose and Dassler 2017). However, in more open areas, ferns theoretically have unlimited potential for dispersal over long distances and can easily travel nearly 250 mi (400km) in good conditions (Peck 1985). *Dryopteris* spp. produce a very high number of spores but few reproduce successfully.

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Dryopteris cristata* occurrences in Washington. Two of 26 known occurrences (8%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining 24 occurrences (92%) are in areas that have experienced average temperature variation (>57.1° F (31.8° C)) and are expected to be mostly resilient to warming (Young et al. 2016).

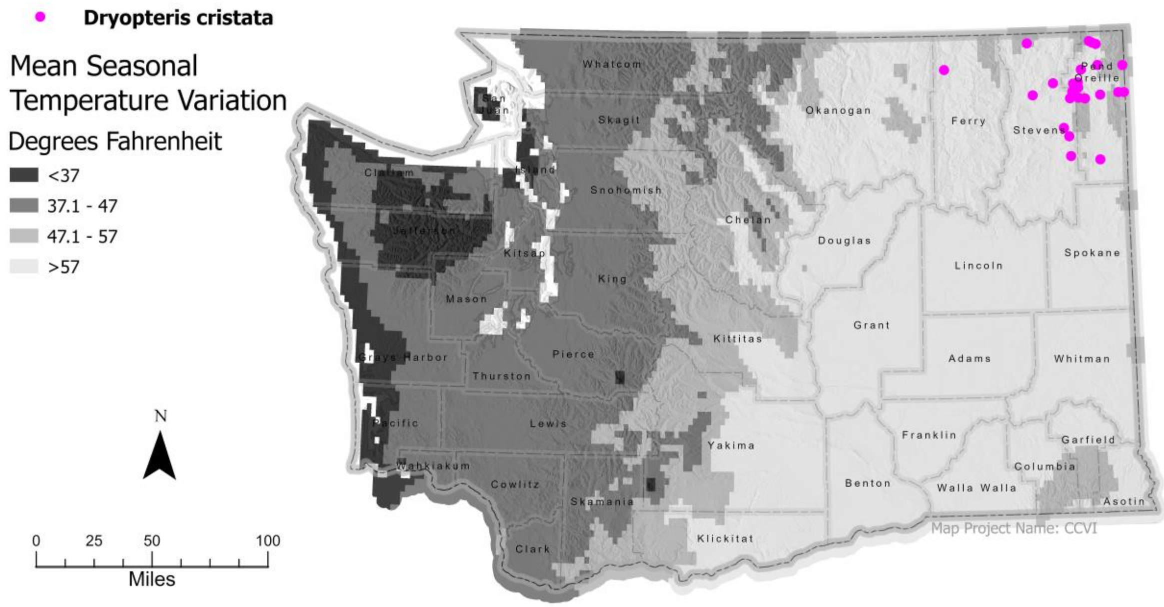

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Dryopteris cristata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Somewhat Increase</u>
The high elevation wet meadows, swamps, and fens that support *Dryopteris cristata* are often found on gentle slopes and in montane valleys associated with cold air drainages and cooler soils and therefore would be vulnerable to warming (Pavek et al. 1990, Rocchio and Crawford 2015). The Rocky Mountain Alpine-Montane Wet Meadow ecological system is also vulnerable to extended summer droughts, and changes to snowmelt timing and hydroperiods because of increased temperatures (Rocchio and Ramm-Granberg 2017). This species may be somewhat resilient to warming temperatures as field notes indicate that Dryopteris cristata is uncommon on shady shores and prefers partial shade to full sun. Trends in an area of Montana that has experienced increased summer temperatures show that Dryopteris cristata has increased in abundance (Lesica and Crone 2017).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Dryopteris cristata* occurrences in Washington. One of the 26 known occurrences (4%) in Ferry County is in an area that has experienced slightly lower than average precipitation variation (11 - 20 in (255 - 508 mm)) over the historic period. According to Young et al. (2016) this population is likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The remaining 25 known occurrences (96%) are in areas that have experienced average or

greater than average precipitation variation (>20 in (508 mm)) and are expected to be mostly resilient to shifting moisture regimes (Young et al. 2016).

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Dryopteris cristata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Increase</u>
Dryopteris cristata occurs in raised wetlands, meadows along stream and pond edges, and swamps (Washington Natural Heritage Program 2023). *Dryopteris cristata* requires balanced moisture with partial inundation but avoids getting roots to wet by perching on hummocks and tree bases. These habitats are associated with perennially wet soils and stable groundwater tables (Rocchio and Crawford 2015). These ecological systems are highly vulnerable to changes in the amount of snowpack, timing of snowmelt, changes in timing and amount of summer precipitation, increased summer temperatures and drought, and reduction in stream flows or depth to groundwater from projected climate change (Rocchio and Ramm-Granberg 2017). There may be a net gain of forested swamp area over the next 60+ years (Rocchio and Ramm-Granberg 2017), but field notes indicate that smaller ponds where this species occurs are already completely drying out.

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
The wet meadow and fen habitats of *Dryopteris cristata* are not adapted to frequent disturbances such as extreme flooding, but healthy water flow, hydrological fluctuations, and periodic inundation from groundwater discharge are important for ecosystem functioning (Rocchio and

Crawford 2015). These habitats are not typically susceptible to fire under the current regime but could become more vulnerable if water tables are lowered due to decreased snowpack or increased summer temperature or drought (Rocchio and Ramm-Granberg 2017). In forested swamps, windthrow opens the canopy and adds diversity to the terrain microtopography, allowing for establishment of plants with different hydrological and light requirements (Rocchio and Crawford 2015).

C2d. Dependence on ice or snow-cover habitats: Neutral
Climate change induced reductions to snowpack may speed drawdown of montane wetlands that rely on snow melt to recharge groundwater and may increase the probability of drying out, though overall winter precipitation may also increase and offset these changes to some degree (Rocchio and Ramm-Granberg 2017). Other than potential impacts to the water supply of the habitat which is reliant on recharge from precipitation, *Dryopteris cristata* is not particularly associated with ice or snow-cover. The Canadian Rockies in Washington receive much less overall snowfall than the other ranges in the state.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Dryopteris cristata occurs on poorly drained soils derived from woody peat and decomposing trees which are permanently saturated or seasonally flooded in a mosaic landscape of moving and stagnant water (Rocchio and Crawford 2015). These are often calcareous or mineral soils with deep humus layers that are found over limestone (Washington Natural Heritage Program 2023). These geologic types are relatively common in Washington. Other geologic features that *Dryopteris cristata* associates with include Uncas muck, Vashon Stade glacial drift (90%+ population on this soil type), Yocum Lake granodiorite, and Granite Pass two-mica granite (Washington Division of Geology and Earth Resources 2016). None of these geological types are particularly common in Washington but the variety of potential substrates for this species means that it is somewhat less restricted.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beaver are an important hydrogeomorphic driver of wet meadows and forested wetlands (and to a lesser degree in fens) and activity has been high in the vicinity of *Dryopteris cristata* occurrences in Washington (Washington Natural Heritage Program 2023). When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006). *Dryopteris cristata* populations may also be fully inundated by flooding, which has occurred in the past. Wet meadow sites may be enhanced by browsing by ungulates or other herbivores that contain the encroachment of woody vegetation.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Dryopteris spp. do not depend on pollinators for their reproductive cycle. Instead, spores are spread via wind and gametophytes are produced vegetatively underground.

C4d. Dependence on other species for propagule dispersal: Neutral
Dryopteris spores are mostly dispersed passively via wind or water. Some species of ferns have spores that can attach to animals or spread via ingestion, but it is unknown whether this is the case for *Dryopteris cristata* (Fryer 2014, Boch et al. 2016).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Unlike many other ferns, *Dryopteris cristata* is palatable to both cattle and deer and may be subject to browsing (Washington Natural Heritage Program 2023). Alpine wet meadows are threatened by soil disturbance and compaction caused by grazers and browsers which can subsequently affect hydrological and nutrient cycles (Rocchio and Crawford 2015). Several occurrences of *Dryopteris cristata* continue to be impacted by cattle, moose, and elk. Field notes indicate that populations are bigger and more vigorous in years where cattle have not been allowed to graze. Though the effects of grazing and browsing may compound climate change impacts, there is no evidence that herbivory by these species will increase.

C4f. Sensitivity to competition from native or non-native species: Increase
Dryopteris cristata is known to be an opportunistic colonizer of gaps and is usually later outcompeted as additional vegetation moves in (Bremer 2010). With increasing temperatures, montane wet meadows, fens, and conifer swamps are at risk of drying and subsequent conifer encroachment (Rocchio 2006, Rocchio and Ramm-Granberg 2017, Ford and HilleRisLambers 2023). These ecological systems are also susceptible to invasion by many non-native species, especially pasture grasses such as *Poa pratensis* and *Phleum pratense* as well as exotic species common to other wetland types such as *Cirsium arvense* and *Taraxacum officinale* (Rocchio and Crawford 2015). Exotic species such as *Phalaris arundinacea*, which has already been noted at some occurrences can be problematic where soils have been disturbed.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Dryopteris cristata is found mostly on slightly raised areas (hummocks) around bases of clumps of mountain alder (*Alnus incana* ssp*. tenuifolia*) but is not an obligate associate of this species.

C5a. Measured genetic variation: Unknown
The specific genetic variation of *Dryopteris cristata*, thought to be a hybrid of *Dryopteris ludoviciana* and the diploid species *Dryopteris semicristata*, has not been reported (Washington Natural Heritage Program 2023). However, it occurs in very small to moderately sized populations and might be expected to have lower genetic diversity due to founder effects or reproductive isolation.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Dryopteris cristata is an allotetraploid perennial fern with dimorphic leaves that have distinct sterile and fertile forms (Washington Natural Heritage Program 2023). Like other pteridophytes, it follows a life cycle with two alternating independent generations; inconspicuous gametophytes that produce separate male and female organs and dominant homosporous sporophytes which can produce gametophytes with both sex organs (Soltis and Soltis 1990). This species produces a gynaecandrous spike and is probably like other *Dryopteris* spp. that are capable of both selfing

and outcrossing (Munger 2007, Washington Natural Heritage Program 2023). Some *Dryopteris* spp. can also reproduce vegetatively via rhizomes but it is unknown how big a role this plays in the species' reproduction (Munger 2007). It probably has at least average genetic diversity due to its polyploidy and mixed mating system (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and Washington Natural Heritage Program records, the flowering period of *Dryopteris cristata* (mid/late June to late Sept) has not changed significantly (Washington Natural Heritage Program 2023).

Section D: Documented or Modeled Response to Climate Change
D1. Documented response to recent climate change: Unknown
Nearly all occurrences of *Dryopteris cristata* have been confirmed as extant between 2001 and 2019 and population trends appear to be stable (Washington Natural Heritage Program 2023).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Young, B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Page 48+app. NatureServe, Arlington, VA.

Climate Change Vulnerability Index Report

Eleocharis mamillata* ssp. *mamillata (soft-stemmed spikerush)

Date: 24 May 2024 Synonym: none
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T5/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to -0.096	100
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Unknown
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Both occurrences (100%) of *Eleocharis mamillata* ssp. *mamillata* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C) (Figure 1).

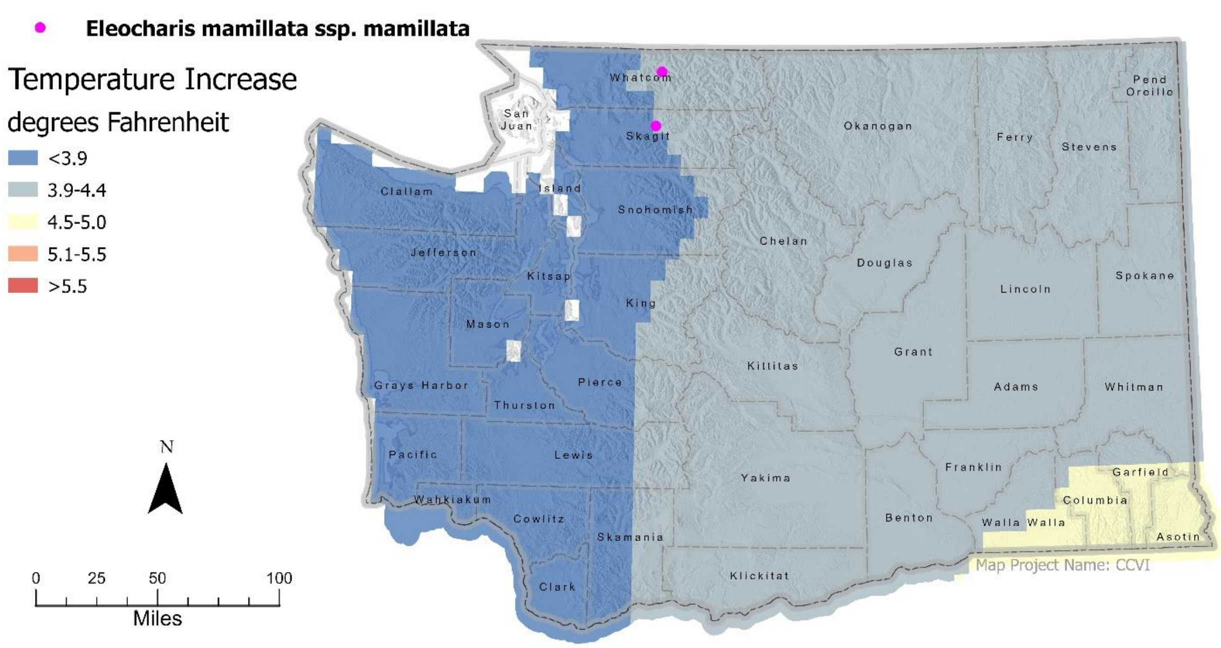

Figure 9. Exposure of occurrences of *Eleocharis mamillata* ssp. *mamillata* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both occurrences (100%) of *Eleocharis mamillata* ssp. *mamillata* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096.

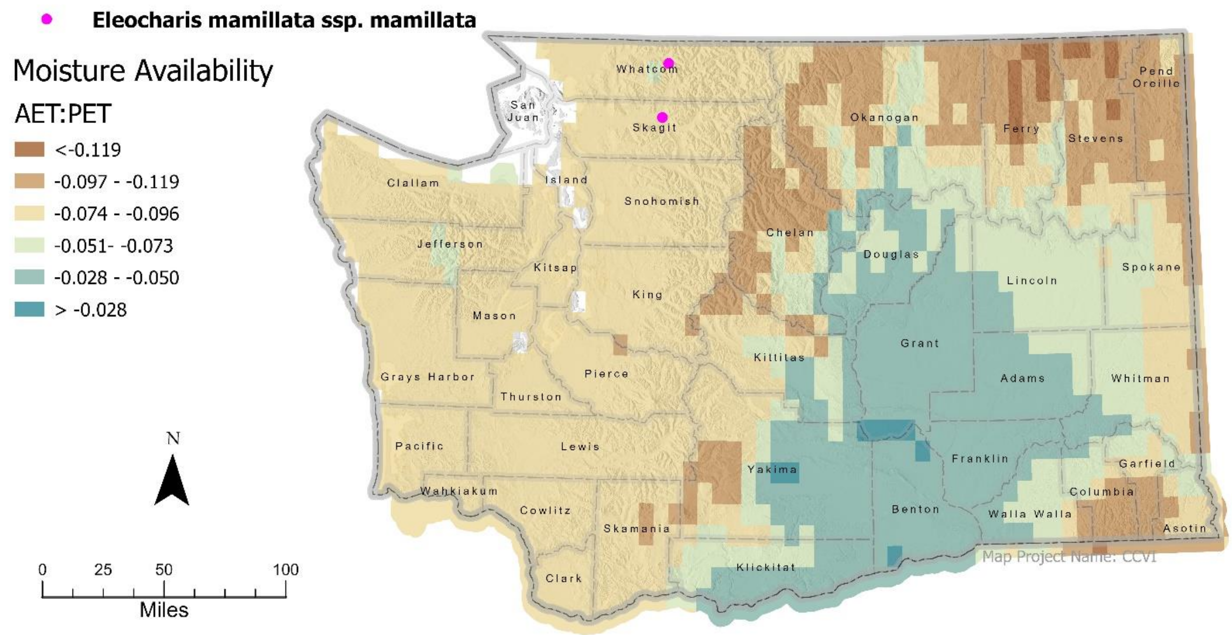

Figure 10. Exposure of occurrences of *Eleocharis mamillata* ssp. *mamillata* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
In Washington *Eleocharis mamillata* ssp. *mamillata* occurs on silty or peaty soil in shallow water along lakeshores at elevations of 670–4120 ft (200–1255 m; Washington Natural Heritage Program 2024). These areas would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Somewhat Increase</u>
Eleocharis mamillata ssp. *mamillata* occurs in Temperate Pacific Freshwater Emergent Marsh Ecosystems and Temperate Pacific Subalpine-Montane Wet Meadow ecological systems (Washington Natural Heritage Program 2024). These are both small-patch ecological systems occurring within a forested matrix. Wet meadow habitats are generally secure, but emergent marshes, though widespread, are declining in western Washington (Rocchio and Crawford 2015). The two occurrences in Washington are 22 mi (35 km) apart and are separated by rugged mountain ridges.

B2b. Anthropogenic barriers: Neutral
Human activities have increased fragmentation for subalpine-montane wet meadows and have caused significant declines and degradation in emergent marshes (Rocchio and Crawford 2015). Anthropogenic activities near the two occurrences of *Eleocharis mamillata* ssp. *mamillata* in Washington appear to be roads, logging, and recreational developments such as ski areas. In Washington, this taxon is found on wetland habitats in a matrix of second growth forest, and in Europe it has been documented in artificial pools and wetlands (Blinova and Gregor 2016, Washington Natural Heritage Program 2024), suggesting that this species is at least somewhat resilient to anthropogenic activities. Factoring in likely dispersal methods, spread of this species in Washington is unlikely to be limited by anthropogenic barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Eleocharis mamillata* ssp. *mamillata* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Eleocharis mamillata ssp. *mamillata* populations can occur far apart and are likely dispersed by migratory waterfowl (Blinova and Gregor 2016), which can travel up to several thousand kilometers between sites. In Russia and Scandinavia, occurrences of this taxon have been reported north of the Arctic Circle, from 86–130 miles (140–210 km) apart (Blinova and Gregor 2016), suggesting that this species is relatively capable of dispersal across harsh, unsuitable habitat. Seeds from the related *Eleocharis palustris* have been shown to maintain viability after passing through the digestive tracts of waterfowl (Wongsriphuek et al. 2008, Brochet et al. 2010). This taxon's dispersal capabilities likely provide some resilience to climate change.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Eleocharis mamillata* ssp. *mamillata* occurrences in Washington. Both occurrences (100%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming.

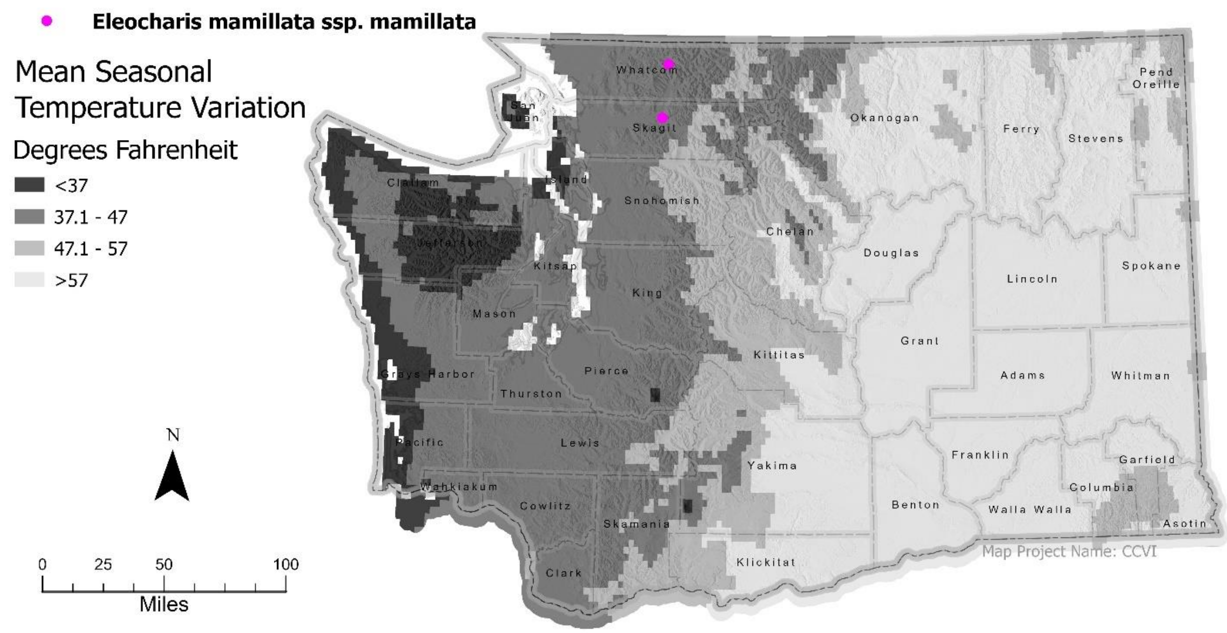

Figure 11. Historical thermal niche (exposure to past temperature variations) of occurrences *Eleocharis mamillata* ssp. *mamillata* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Increased temperatures may result in seasonally wet meadows drying earlier in the season. Emergent marshes that rely on surface water are also sensitive to increased temperatures (Rocchio and Ramm-Granberg 2017). This could result in shifts toward upland vegetation communities. Washington State is at the southern extent of the known range of *Eleocharis mamillata* ssp. *mamillata* in North America, so this species could already be at the limit of its thermal tolerances. Combined, these factors suggest this taxon has increased vulnerability to increased temperatures caused by climate change.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Eleocharis mamillata* ssp. *mamillata* occurrences in Washington. Both occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

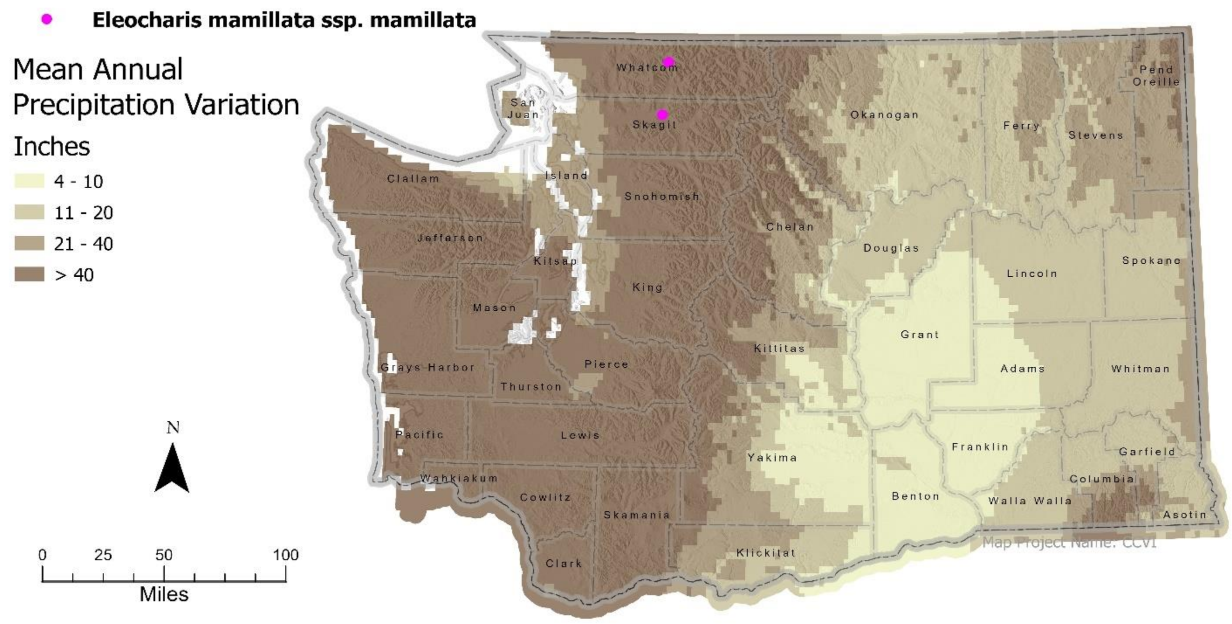

Figure 12. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Eleocharis mamillata* ssp. *mamillata* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Increase
Temperate Pacific Freshwater Emergent Marsh systems are likely to be affected by changes in flooding and precipitation patterns, which could potentially shift marshes to wet meadows (Rocchio and Ramm-Granberg 2017). Wet meadows are frequently associated with groundwater discharge, snowmelt, and seasonally high water tables, but are often dry by late summer (Rocchio and Crawford 2015). Meadows associated with groundwater discharge may be more resilient to climate change than meadows reliant on surface water. However, changes in snowmelt timing and snowpack will affect the ability to recharge groundwater, potentially shifting wet meadows to drier habitats with more upland species (Rocchio and Ramm-Granberg 2017). The potential for marshes to shift to wet meadows, and wet meadows to upland conditions suggests that *Eleocharis mamillata* ssp. *mamillata* will likely see an increase in vulnerability to climate change effects on the hydrology of its habitat.

C2c. Dependence on a specific disturbance regime: Neutral
Marsh ecosystems depends on flooding events or fluctuating water levels for creation and maintenance. Climate change is likely to change precipitation patterns, which could shift emergent marsh habitats to wet meadows (Rocchio and Ramm-Granberg 2017). However, wet meadows are often influenced by groundwater conditions and generally do not experience disturbances like flooding (Rocchio and Crawford 2015).

C2d. Dependence on ice or snow-cover habitats: Neutral
Eleocharis mamillata ssp. *mamillata* does not directly depend on ice or snow-covered habitats. However, snowmelt is important for feeding groundwater dependent wet meadows and emergent marshes. Reduced snowpack and precipitation shifts from snow to rain are likely threats to this taxon's habitat (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Eleocharis mamillata ssp. *mamillata* does not have enough occurrences in Washington to determine if it is restricted to uncommon geological substrates. However, the two documented occurrences are found on glacial outwash or volcanic substrates which are widespread in Washington, and the literature suggests that this taxon is not limited by geological substrates (Blinova and Gregor 2016, Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Beaver are important to creating emergent marsh habitat in montane ecological systems, and these ecological systems have declined with the decline and extirpation of beaver populations in the western U.S. However, both emergent marshes and wet meadows are likely more strongly influenced by abiotic factors and hydrology than disturbances (Rocchio and Crawford 2015). Given the importance of abiotic factors in maintaining its habitat, *Eleocharis mamillata* ssp. *mamillata* is likely somewhat resilient to the effects of climate change on biotic disturbances.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
As a graminoid, *Eleocharis mamillata* ssp. *mamillata* is wind-pollinated and does not depend on pollinators for reproduction.

C4d. Dependence on other species for propagule dispersal: Neutral
Eleocharis mamillata ssp. *mamillata* likely depends on waterfowl for seed dispersal, and seeds from related species are capable of being dispersed through endozoochory (Wongsriphuek et al. 2008, Brochet et al. 2010, Blinova and Gregor 2016). This relationship indicates some resilience to the effects of climate change on species interactions.

C4e. Sensitivity to pathogens or natural enemies: Neutral
The related *Eleocharis palustris* is palatable to cattle, but potentially resilient to grazing (Duncan and D'Herbès 1982, Marion et al. 2010). Seeds and vegetation are consumed by waterfowl (Wongsriphuek et al. 2008, Brochet et al. 2010). Since evidence in closely related species suggests that at least some viable seeds survive passage through the digestive tract of waterfowl, consumption of seeds may be a net benefit by providing a long distance dispersal mechanism for this taxon.

C4f. Sensitivity to competition from native or non-native species: Increase
In Washington, emergent marsh ecosystems are heavily impacted by the invasive grass *Phalaris arundinacea*. *Typha latifolia* will also invade disturbed emergent marshes and outcompete other native species. Reduction in the frequency of flooding or increased drought due to climate change could lower water tables. This could make emergent marshland habitats more vulnerable

to displacement by plants associated with wet meadows, riparian shrublands, or woodlands. Wet meadows can be invaded by *Poa pratensis, Phleum pratense, Cirsium arvense, Taraxacum officinale*, *Phalaris arundinacea*, and others, particularly after intensive grazing disturbances from cattle or wild ungulates (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). With increasing temperatures, montane wet meadows are also at risk of drying and subsequent conifer encroachment (Ford and HilleRisLambers 2023). Presence of a *Phalaris* species was noted at one of the occurrences of *Eleocharis mamillata* ssp. *mamillata* in Washington. *Eleocharis mamillata* ssp. *mamillata* is likely somewhat resilient to the disturbances that promote invasive species, but with only two occurrences in the state, this taxon may still be somewhat vulnerable to increased competition from invasives due to climate change.

C4g. Forms part of an interspecific interaction not covered above: <u>Unknown</u>
No evidence of other interspecific interactions for this taxon was found.

C5a. Measured genetic variation: <u>Not Ranked</u>
Data are lacking regarding the genetic diversity within and between populations of *Eleocharis mamillata* ssp. *mamillata* in Washington.

C5b. Genetic bottlenecks: <u>Not Ranked</u>

C5c. Reproductive System: <u>Unknown</u>
No information was found regarding the reproductive system of *Eleocharis mamillata* ssp. *mamillata*, so it may or may not be self-compatible or an obligate outcrosser. *Eleocharis* species can reproduce vegetatively through tubers, bulbs, stolons, and viviparous spikelets, as well as by seed. *Eleocharis* species within the *Eleocharis palustris* complex (which *Eleocharis mamillata* ssp. *mamillata* has previously been included in) are capable of hybridization with one another. These taxa also tend to have unstable chromosome numbers (Smith 2001). *Eleocharis* species are wind-pollinated, so the ability to outcross is not limited by the availability or timing of pollinators. While wind-pollination suggests maintenance of genetic diversity, there was no information found about the frequency of sexual propagation relative to vegetative propagation in this taxon. Further study may be needed to understand the capacity of *Elocharis mamillata* ssp. *mamillata* to adapt to climate change.

C6. Phenological response to changing seasonal and precipitation dynamics: <u>Unknown</u>
There is only one herbarium record for this species in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, therefore there is not enough data to determine if the flowering period of *Eleocharis mamillata* ssp. *mamillata* (June–September) has changed significantly in Washington.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: <u>Unknown</u>
Not enough survey data is available to determine population trends of *Eleocharis mamillata* ssp. *mamillata* in Washington.

D2. Modeled future (2050) change in population or range size: <u>Unknown</u>

Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Epilobium mirabile (Olympic Mountain willowherb)

Date: 26 Sept 2023
Synonym: *Epilobium glandulosum* var. *macounii*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington
Heritage Rank: G4Q/S1
Index Result: Highly Vulnerable
Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	50
	<3.9° F (2.2°C) warmer	50
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase/Increase
2b. Distribution relative to anthropogenic barriers		Neutral/Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase/Greatly Increase
2aii. Change in physiological thermal niche		Somewhat Increase/Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral/Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: One of the of the two documented occurrences (50%) of *Epilobium mirabile* in Washington occurs in an area with a projected temperature increase of less than 3.9°F (2.2°C). The other occurrence (50%) occurs in an area with a projected temperature increase of 3.9-4.4°F (2.2-2.4°C; Figure 1).

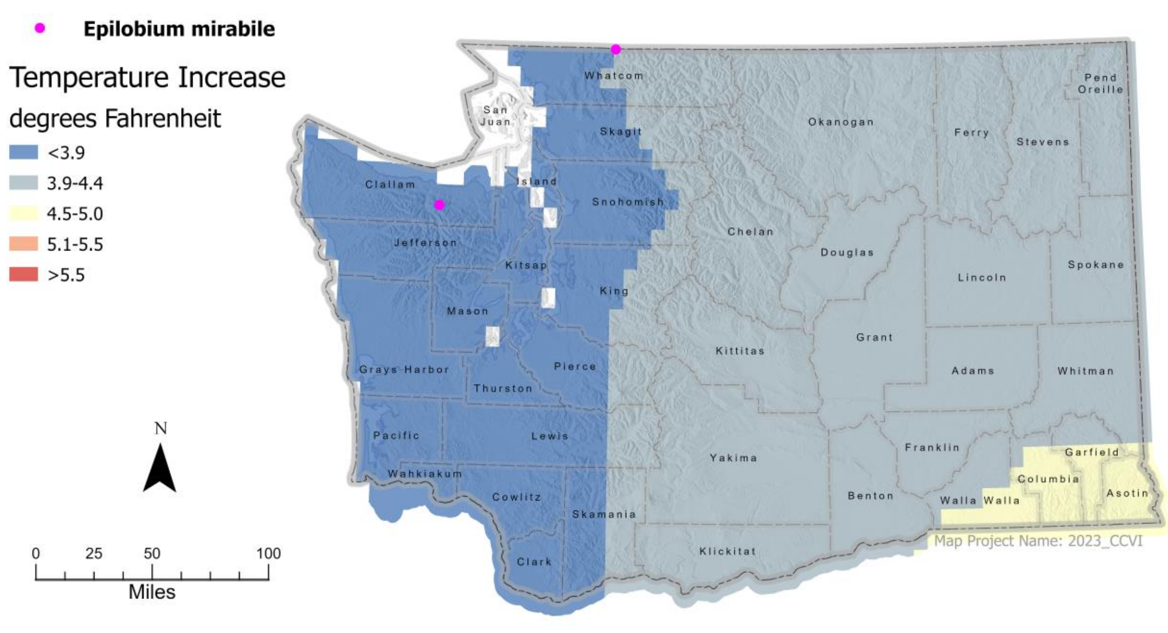

Figure 1. Exposure of *Epilobium mirabile* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both known occurrences of *Epilobium mirabile* in Washington (100%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.097 (Figure 2).

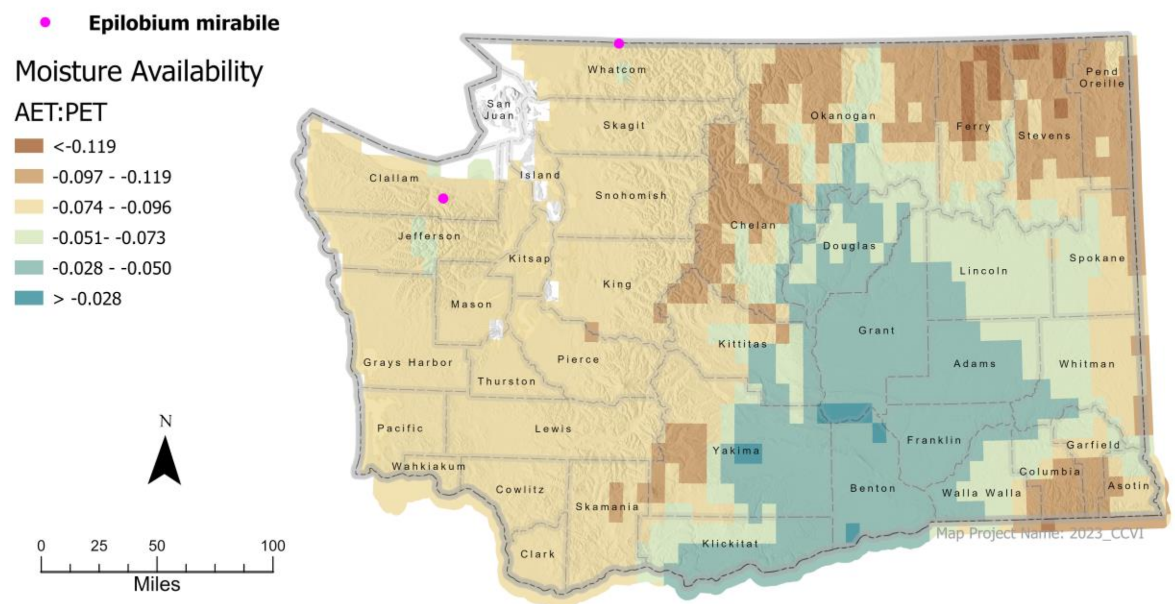

Figure 2. Exposure of *Epilobium mirabile* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Epilobium mirabile occurs on steep subalpine and alpine talus and scree slopes in the Olympic Mountains and Cascade Range (Washington Natural Heritage Program 2023). These populations will not be inundated by sea level rise as they are located at 4920-5150 ft (1500-1570 m) in elevation (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Somewhat Increase/Increase</u>
Epilobium mirabile is a regional endemic documented only on two disjunct limestone mountain slopes in the North Pacific Alpine & Subalpine Bedrock and Scree ecological system of Washington (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Only the population in the Cascades in Whatcom County remains verified as extant in Washington and is separated from the Olympic occurrence by 100 mi (162 km) of unoccupied and unsuitable lower elevation forested and valley habitat that presents a barrier to propagule dispersal. These

populations are somewhat disjunct from occurrences in British Columbia, Alberta, and Montana to the east, which makes potential migration and outcrossing more difficult. However, this species may be easily confused with a number of subalpine congeners and may be underrepresented in the occurrence data due to its restricted habitat (Hoch 2022b, Washington Natural Heritage Program 2023).

B2b. Anthropogenic barriers: Neutral/Somewhat Increase
Due to the rugged, rocky mountain terrain, the habitat of *Epilobium mirabile* remains relatively undisturbed by direct anthropogenic stressors and barriers. Recreation impacts can be of some concern in rocky alpine habitats and even light trampling may significantly reduce plant cover and growth. The occurrences of *Epilobium mirabile* in Washington are noted as growing near trails. Significant urban development and cultivation has occurred approximately 10 mi (16 km) away across the Canadian border in the sprawling Vancouver metropolitan area which surrounds the Cascades population to the northwest, but the natural isolation of scree slopes is expected to be a greater barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Epilobium mirabile* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely due to the rugged backcountry terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Like other *Epilobium* spp., *Epilobium mirabile* produces dehiscent capsules that release minutely plumed seeds which are well-adapted to disperse on the wind (Hoch 2022a, 2022b). Congeners such as *Epilobium angustifolium* are known to disperse across exceptionally great distances, traveling high in the air for up to 10 hours at a time over 62-186 mi (100-300 km) a day (Solbreck and Andersson 1987).

C2ai. Historical thermal niche: Increase/Greatly Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Epilobium mirabile* occurrences in Washington. The historical occurrence in the Olympic Mountains (50%) is in an area that has been thermally stable and has experienced very small temperature variation (less than 37°F (20.8°C)) over the historical period. According to Young et al. (2016), this population is expected to be highly vulnerable to climate warming. The remaining extant occurrence in Whatcom County (50%) has experienced small (37-47°F (20.8-26.3°C)) temperature variation over the historical period and is likely to vulnerable to warming (Young et al. 2016).

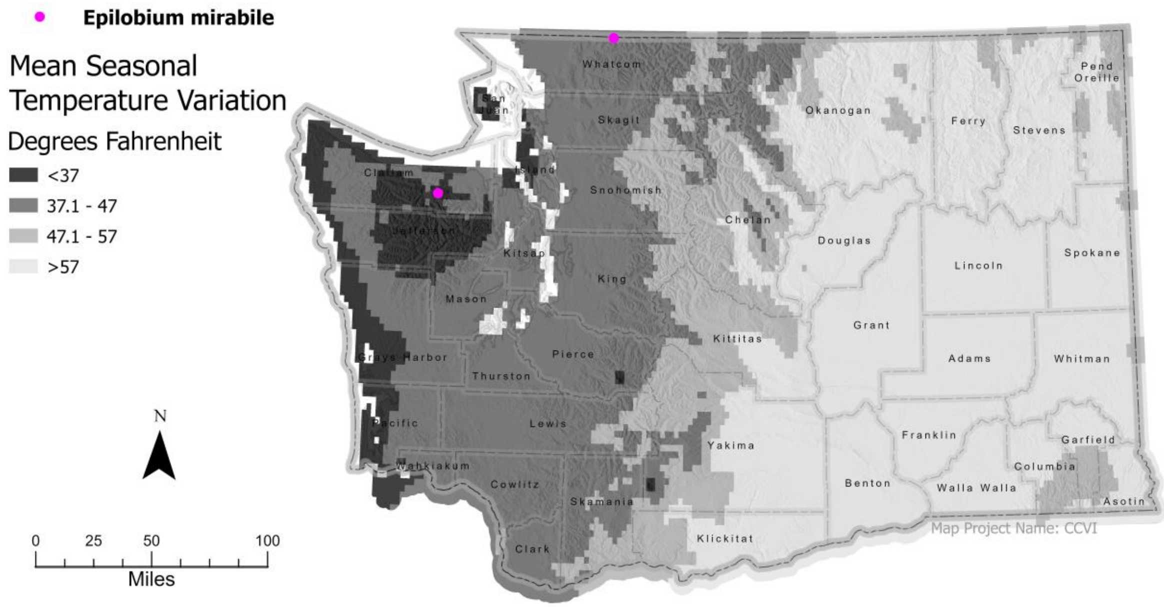

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Epilobium mirabile* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase/Increase

The subalpine scree and talus habitat of *Epilobium mirabile* is exposed to high winds and cold temperatures during the flowering season and is somewhat vulnerable to expected temperature increases from climate change (Rocchio and Ramm-Granberg 2017) . Most populations occur on south-facing slopes that are warmer than adjacent slopes and therefore may be somewhat resilient to temperature increases. Climatic warming could extend the growing season, increase competition from other plant species, and minimally increase thermal stress (Rocchio and Ramm-Granberg 2017). *Epilobium mirabile* may be at risk of following an “elevator to extinction” as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Epilobium mirabile* occurrences in Washington. Both occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

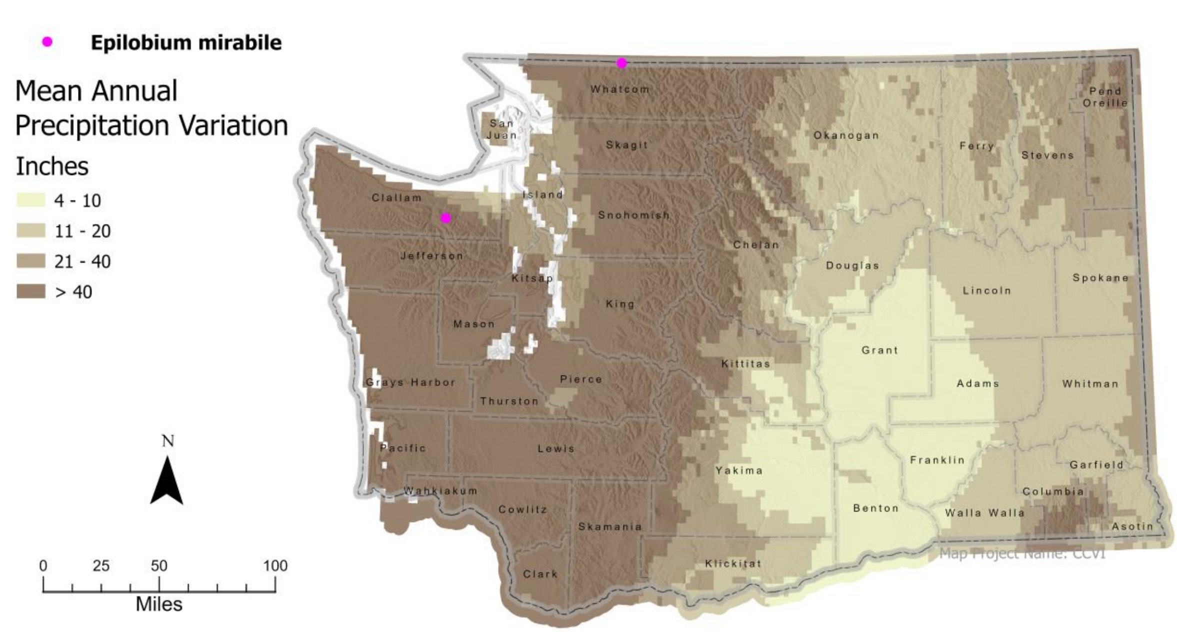

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Epilobium mirabile* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
The North Pacific Alpine and Subalpine Bedrock and Scree ecological system where *Epilobium mirabile* occurs receives a steady supply of moisture throughout the growing season, primarily from snowmelt. Though *Epilobium mirabile* is associated with dry, exposed slopes where wind-scour and sublimation keeps snowpack and available moisture to a minimum, it is likely subirrigated by snow collected in depressions across the surrounding landscape. Slight anticipated reductions in snowfall and earlier timing of snowmelt may impact the water-limited habitat of *Epilobium mirabile* but conversion of glacier and ice fields to subalpine scree ecological systems may expand its habitat (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Epilobium mirabile occurs on limestone scree and talus slopes that are maintained by natural

erosion processes and are further facilitated by cold climatic conditions and high winds that reduce soil formation and keep plant density low (Rocchio and Crawford 2015). Additional periodic disturbances are not required to maintain this habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase
The high alpine regions of the North Cascades where *Epilobium mirabile* occurs experience long winters with high snow accumulation as most precipitation falls as snow (Raymond et al. 2014). The Olympic Mountains average over 400 in (10 m) of snow annually (National Park Service 2021). Ongoing and projected reductions in the amount of snow, conversion of snow to rain, and changes in the timing of snowmelt could alter the amount of moisture available for this species under climate change (Rocchio and Ramm-Granberg 2017). However, *Epilobium mirabile* occurs on exposed, steep, southwest-facing slopes where wind-scour and sublimation reduce accumulation and prevent snowpack from persisting as late into the summer as surrounding basins (Montana Natural Heritage Program 2023). Conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and may actually increase the habitat available to *Epilobium mirabile* (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase
Epilobium mirabile is frequently associated with fine limestone shale scree on dry south-facing ridges and slopes in Washington. It appears to occur on other substrates throughout its broader range (the Olympic occurrence is on a section of basalt and breccia) but is noted to be co-occurring with limestone (Hitchcock et al. 2018). Permian limestone shale is common in Whatcom County and limestone talus is found below many outcrops in the Cascade Range (Danner 1966).

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Epilobium mirabile* is maintained by natural abiotic processes and local microsite conditions rather than by interactions with other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The exact pollinators of *Epilobium mirabile* are not well documented, but *Epilobium sect. Epilobium* is reported to be pollinated by a wide range of pollinators including bees, flies, and butterflies (Hoch 2022b). Most of the species (as many as 80%) in this section are also able to self-pollinate (Raven 1979).

C4d. Dependence on other species for propagule dispersal: Neutral
Dry capsule fruits of *Epilobium mirabile* split and release papillose seeds that are adapted to disperse by wind. The species is not dependent on animals for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Impacts from pathogens are not known. Due to its high elevation scree habitat, *Epilobium mirabile* receives minimal impacts from grazing, though it could be consumed by insects or rodents. Overall impacts appear to be low.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation North Pacific Alpine-Subalpine Bedrock & Scree ecological systems which support *Epilobium mirabile* (NatureServe 2023). *Epilobium mirabile* is probably adapted more for survival and quick growth under harsh abiotic conditions and not for competition (Keating et al. 1982), which is usually limited in the alpine scree fields. Plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Epilobium mirabile does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Epilobium mirabile* has not been documented. However, the populations in Washington occur on the southwestern edge of the intermittently fragmented regional range throughout the Canadian Cascade Arc and so could have lower genetic diversity due to genetic drift or inbreeding depression.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
All species of *Epilobium sect. Epilobium*, which includes *Epilobium mirabile*, are diploid perennials with a mixed mating system (Hoch 2022a). *Epilobium* spp. are largely self-compatible (83% of species are autogamous) but many are protandrous, with stamens ripening before pistils, which may be a strategy to limit selfing and increase outcrossing rates (Raven 1979, Routley and Husband 2003). Self-compatibility can be indicative of lower effective population sizes and recombination rate (Huang et al. 2019). Hybridization is reported to be common in *Epilobium* spp. with higher fertility in homozygous hybrids than heterozygous hybrids. Seed set is high for non-hybrids as a percentage of hybrid seeds are aborted (Feliner 1994).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website, the flowering period of *Epilobium mirabile* (June to August) has not changed significantly since the species was first documented in Washington in 1911. However, there are only a few records available to represent a baseline for *Epilobium mirabile* in Washington.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
One of the two documented populations of *Epilobium mirabile* in Washington that is disjunct in the Olympic Range has not been relocated since 1911 and is now ranked as historical. Whether this population is extirpated or has gone undetected/unsurveyed is not known.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

Erythranthe suksdorfii (*Suksdorf's monkeyflower*)

Date: 1 April 2024 Synonym: *Mimulus suksdorfii*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4/S2S3
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	12
	-0.074 to - 0.096	38
	-0.051 to - 0.073	45
	-0.028 to -0.050	0
	>-0.028	5
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Somewhat Increase
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Somewhat Increase
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 42 known occurrences (100%) of *Erythranthe suksdorfii* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

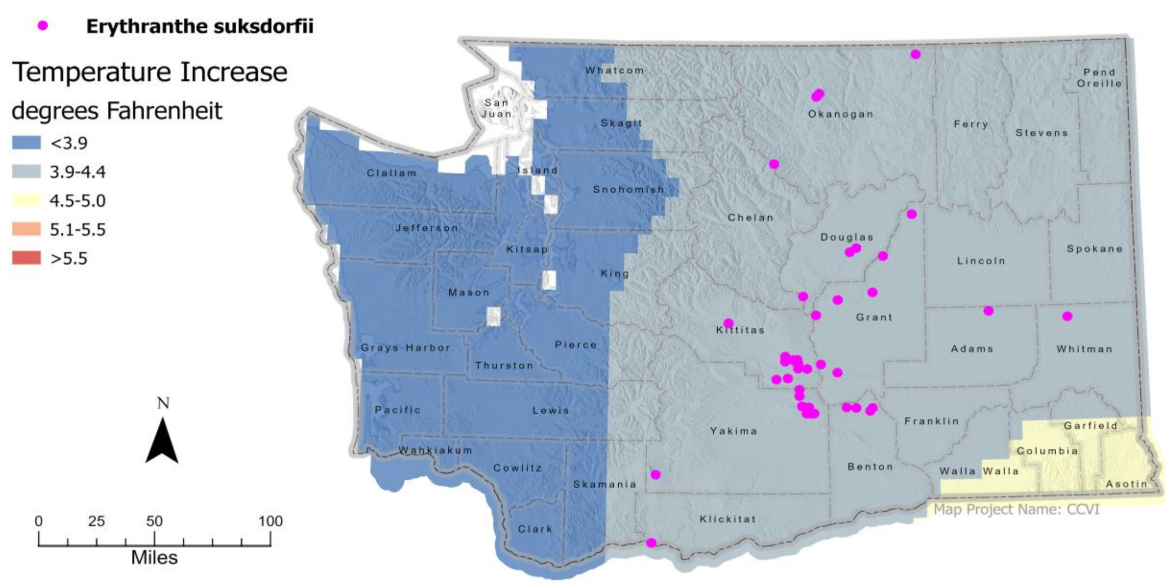

Figure 1. Exposure of *Erythranthe suksdorfii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Five of the 42 known occurrences (12%) of *Erythranthe suksdorfii* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). Another 16 occurrences (38%) are in areas with a projected decrease in the range of -0.074 to - 0.096 and 19 occurrences (45%) are in areas with a projected decrease of -0.051 to -0.073. The remaining two occurrences (5%) are in areas with a project decrease greater than -0.028.

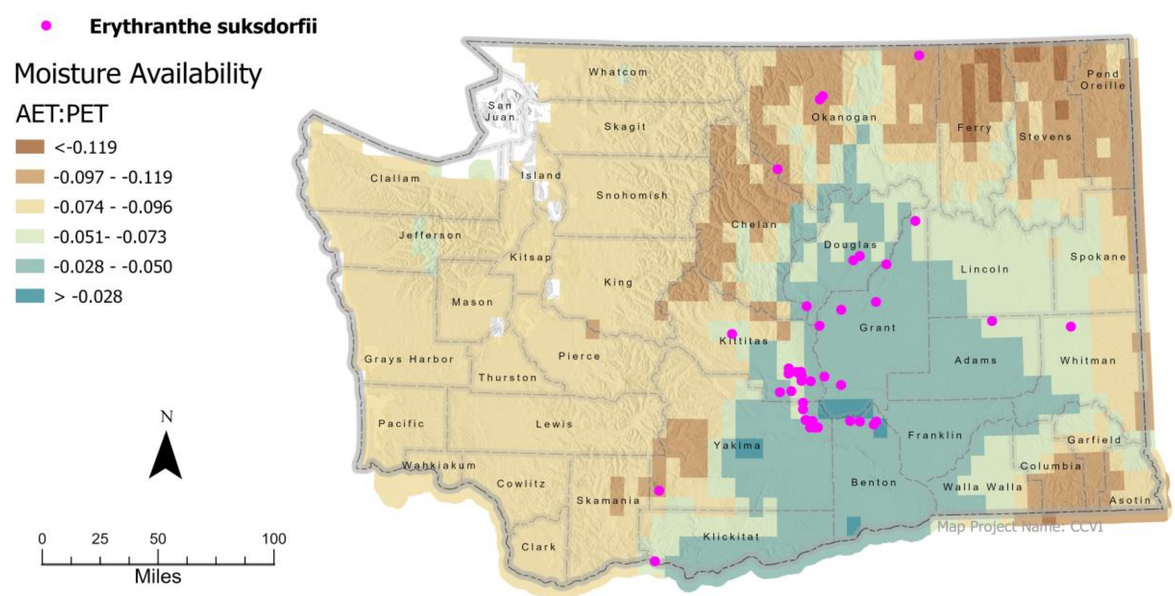

Figure 2. Exposure of *Erythranthe suksdorfii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Erythranthe suksdorfii occurs on flats, plateaus, and gentle to steep rocky slopes across a wide elevation gradient ranging from valleys and foothills to moderate or occasionally high elevations in the mountains (430-7100 ft (130-2165 m)) east of the Cascade crest (Washington Natural Heritage Program 2023). *Erythranthe suksdorfii* populations in Washington are not expected to be affected by sea level rise based on their inland distribution (Office for Coastal Management 2024)

B2a. Natural barriers: Increase
The vernal pool, scabland, and basin habitats of *Erythranthe suksdorfii* occur as large to small patches in a larger matrix of sagebrush steppe or open coniferous forest. Columbia Plateau Vernal Pools are strongly tied to landscape features that are themselves widely scattered and

isolated by strong natural barriers reducing the likelihood of successful dispersal. Inter-Mountain Basins Wash habitats are also patchy and are restricted to small pockets of the Columbia Basin, with the intermittently flooded streambeds occurring as distinct microsites from adjacent upland vegetation (Rocchio and Crawford 2015). Occurrences of *Erythranthe suksdorfii* are separated by 2-300 mi (3-483 km) of unsuitable upland habitat that poses a barrier to dispersal into areas with the appropriate microtopography and hydrology.

B2b. Anthropogenic barriers: Somewhat Increase
Multiple occurrences are partially or completely surrounded by agriculture or residential development (e.g. Hood River and Rock Lake regions) and several occur on lands managed for multiple uses that are not formally protected from development or disturbance from military training activities (Washington Natural Heritage Program 2023). Occurrences are frequently found on old dirt roads which, if used or maintained, could negatively impact populations. Others are located on undisturbed foothills that are bounded by developed lowlands and unsuitable forested uplands. However, land uses in the habitats that support *Erythranthe suksdorfii* are few due to rocky soils and sparse vegetation (Rocchio and Crawford 2015).

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase
There are several proposed wind and solar projects in the general area, with one Washington Department of Natural Resources clean energy parcel very near to but not intersecting an occurrence near Soap Lake (Washington Department of Natural Resources 2024). Wind farms and industrial solar panel "farms" have often been developed on scabland sites, leading to their conversion and fragmentation (Rocchio and Crawford 2015).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
The mechanisms of dispersal for *Erythranthe suksdorfii* are largely unknown but it produces dry capsules that split open at maturity to passively release numerous, small seeds that lack any ornamentation (feathery hairs, barbs, hooks) to facilitate dispersal by wind or animal vectors (Washington Natural Heritage Program 2023). The Great Basin sagebrush scrub congener *Erythranthe carsonensis* is thought to be dispersed only passively by wind, water, and gravity (Donnelly 2024). Most seeds probably fall within a short range of their parent (<100 m), but some could stick to mud on waterfowl and be transported longer distances.

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Erythranthe suksdorfii* occurrences in Washington. Two of the 42 known occurrences (5%) are in areas that have experienced low temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming. Four occurrences (9%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period and are expected to be somewhat vulnerable to climate change (Young et al. 2016). The remaining 36 occurrences (86%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation and are expected to be mostly resilient to warming (Young et al. 2016).

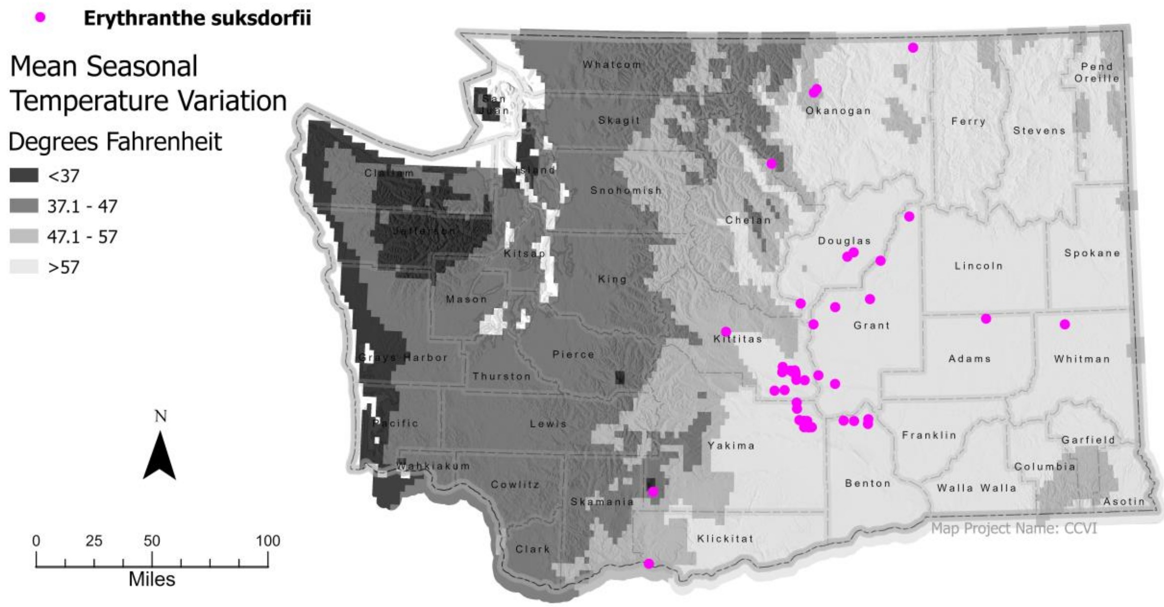

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Erythranthe suksdorfii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
Erythranthe suksdorfii occurs on both north and south-facing slopes in generally exposed, rocky, and dry valleys and foothills (Rocchio and Crawford 2015). Anticipated temperature increases are likely to increase evapotranspiration which may lead to drying of vernal pools and washes, leading to shifts towards xeric and drought adapted vegetation unless precipitation and flood events offset impacts (Rocchio and Ramm-Granberg 2017). However, this species is already subject to hot and dry conditions and is likely somewhat resilient to these conditions.

C2bi. Historical hydrological niche: Increase
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Erythranthe suksdorfii* occurrences in Washington. Of the 42 known occurrences, 15 (36%) are in areas that have experienced very small (< 10 inches (254 mm)) precipitation variation. According to Young et al. (2016) these populations are likely to be greatly vulnerable to climate change induced shifts to precipitation and moisture regimes. Another 21 occurrences (50%) are in areas that have experienced slightly lower than average variation in precipitation (11 - 20 in (255 - 508 mm)) over the historical period and are expected to be somewhat vulnerable to changes in available moisture. The remaining six occurrences (14%) are in areas that have experienced average or

greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

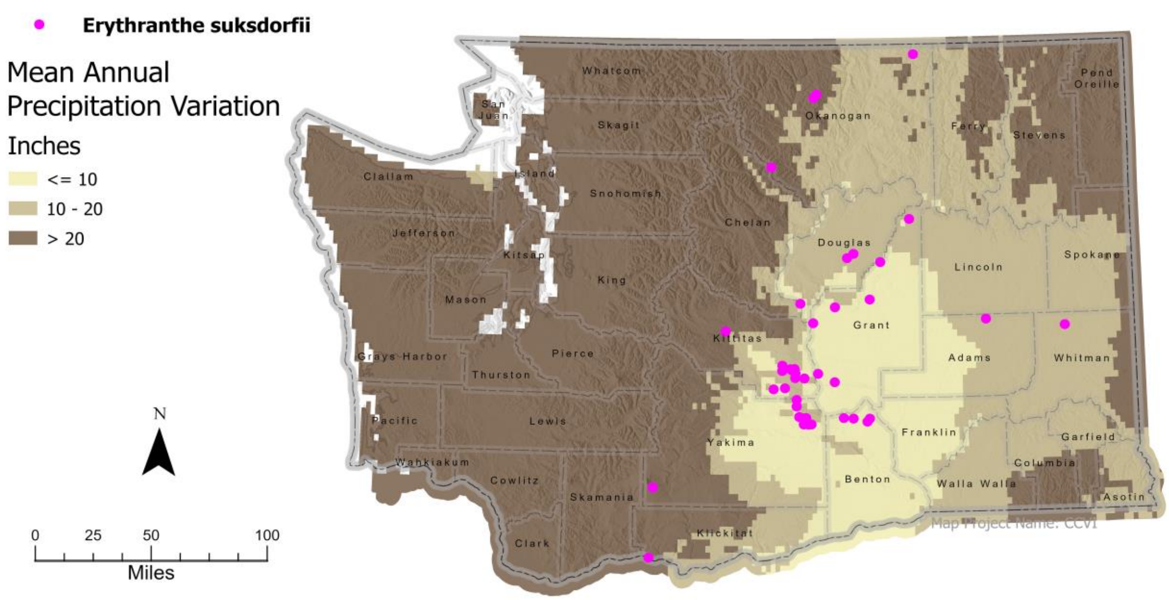

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Erythranthe suksdorfii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Erythranthe suksdorfii occurs in seasonally moist swales, drainages, or vernal pools within sagebrush steppe vegetation and basalt outcrop exposures (Washington Natural Heritage Program 2023). Though this species associates tightly with the edges of ephemeral wetlands and hydrological changes will pose a major threat, observational records indicate that this species is often found in dry mud, intermittently flooded wetlands which are not filled for many years, and in shallow, lithic soils or very sandy soils with little moisture retention (Rocchio and Crawford 2015). This may suggest that this species is somewhat more tolerant of drying. However, changes in precipitation type, timing and amount, and extended droughts are likely to negatively impact hydrological cycles of scablands, vernal pools, and basins wash ecological systems and may lead to extended droughts, shifts in composition, increases in fire frequency (though fuel will remain low), changes to flood timing and severity, and increased competition from invading exotic species (Rocchio and Ramm-Granberg 2017). These riparian areas in otherwise arid lands are vulnerable to climate change as they lack connections to groundwater and rely heavily on seasonal precipitation but may be somewhat resilient as they are already adapted to unpredictable hydrological flows (Rocchio and Crawford 2015).

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase
The ephemeral pools and intermittent riparian areas which support *Erythranthe suksdorfii* are maintained mainly by seasonal hydrological cycles, fast draining soils, and cycles of "frost-heaving" rather than major disturbances (Rocchio and Crawford 2015). However, periods of intense flooding and occasional fire do shape these habitats and are both expected to increase in intensity which may clear more suitable habitat in the scabland matrix or could lead to complete shifts in the vegetation type (Rocchio and Ramm-Granberg 2017, NatureServe 2023)

C2d. Dependence on ice or snow-cover habitats: Neutral
Anticipated shifts in precipitation from winter snow to rain are likely to cause earlier drying and extended drought in the ecological systems which support *Erythranthe suksdorfii* and could lead to compositional shifts or even shifts to more sparse community types (Rocchio and Ramm-Granberg 2017). Other than impacts to the water supply of the habitat, *Erythranthe suksdorfii* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
The distribution of Columbia Plateau Scabland Shrubland, which forms the greater matrix in which the ephemeral wetlands which support *Erythranthe suksdorfii* are found, is primarily determined by the presence of extremely shallow lithic soils. (Rocchio and Ramm-Granberg 2017). *Erythranthe suksdorfii* is found on generally poorly developed and thin (but sometimes deep) sandy/ashy gravel loams in depressions, swales, and channels (Rocchio and Crawford 2015, Soil Survey Staff 2024). These quick-draining soils are derived from various Miocene basalts (Grande Ronde and Wanapum basalts) or Quaternary alluvium which are relatively widespread geological features in the Columbia Basin (Washington Division of Geology and Earth Resources 2016). The specific landform characteristics associated with vernal pools (shallow depressions that are deep enough to be flooded in winter and early spring, but shallow enough to become dry in late spring and summer) are an uncommon feature, making this species partially a habitat specialist.

C4a. Dependence on other species to generate required habitat: Neutral
The swale and vernal pool habitats of *Erythranthe suksdorfii* are largely shaped by seasonal hydrological changes and are not dependent on other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
Erythranthe suksdorfii is a primarily self-pollinating species and the specific insect pollinators of this species are not well known (Donnelly 2024). Pollinators of the congener *Erythranthe carsonensis*, which occurs in Great Basin sagebrush scrub communities, include honeybees (*Apis mellifera*), skipper butterflies (Hesperiidae), and halictid bees (Halictidae) (Donnelly 2024). Other yellow-flowered species of *Erythranthe* are usually pollinated by bees of the genera *Bombus* or *Apis* (Roels and Kelly 2011). The very small flowers of Erythranthe suksdorfii probably further limit the potential suite of pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral

The seeds of *Erythranthe suksdorfii* are dispersed by gravity or other passive means. This species is not known to be dependent on animals for transport and the achene fruits do not have barbs, hooks, or other specialized means of attachment. Attachment to waterfowl via mud is unlikely due to the ephemeral hydrology and soil structure of its habitat.

C4e. Sensitivity to pathogens or natural enemies: <u>Neutral</u>
Impacts from pathogens are not known. This species is probably not negatively impacted by herbivory. Overgrazing and livestock trampling has impacted some sites and destroyed sensitive biocrusts (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023), though *Erythranthe suksdorfii* has reportedly been found growing in depressions left by hooves. Grazing is not expected to increase because of climate change.

C4f. Sensitivity to competition from native or non-native species: <u>Increase</u>
Vegetation is generally sparse in the vernal pool, scabland, and basin wash ecological systems which support <u>*Erythranthe suksdorfii*</u> (Rocchio and Crawford 2015). Weedy species already pose a threat at many occurrences with high abundances of species like *Draba verna* and *Bromus tectorum* noted in observational records. Soil disturbance, grazing, and increased drying of the ephemeral wetlands are likely to increase competition which may outcompete native species and significantly change the habitat structure .

C4g. Forms part of an interspecific interaction not covered above: <u>Neutral</u>
Erythranthe suksdorfii is not dependent on any other species but is often found below sagebrush (*Artemisia* spp.), a known "nurse" plant that can provide shade and help retain local moisture.

C5a. Measured genetic variation: <u>Unknown</u>
The specific genetic variation of *Erythranthe suksdorfii* has not been documented.

C5b. Genetic bottlenecks: <u>Unknown</u>

C5c. Reproductive System: <u>Somewhat Increase</u>
Erythranthe suksdorfii is a diminutive annual that is primarily a self-pollinating species, though most species within the genus *Erythranthe* produce seeds as a result of insect pollination between flowers of the same or different plants (Washington Natural Heritage Program 2023, Donnelly 2024). Selfing generally results in lower overall genetic diversity within populations but can increase diversity between populations.

C6. Phenological response to changing seasonal and precipitation dynamics: <u>Somewhat Increase</u>
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (May to July, fruiting as early as May) may have changed significantly (Washington Natural Heritage Program 2023). Records from the late 1800s/early 1900s document flowering into September while all records since the 1990s have not documented flowering later than July. It is difficult to know how much of this change can be attributed to sampling biases. Studies have shown that the flowering rates and phenology of some *Erythranthe* spp. respond strongly to the previous year's snowfall (Donnelly 2024)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The response of *Erythranthe suksdorfii* to climate change has not been studied. Only seven populations have been discovered or revisited since 2000 (Washington Natural Heritage Program 2023). Occurrences in the Hanford area have only been detected a few times and are thought to require high precipitation for germination (Salstrom et al. 2020). A model for the congener *Erythranthe guttata* which occurs near Mt. Rainier has predicted large uphill range shifts which could be exacerbated by indirect climate change impacts to disturbance regimes (Breckheimer 2017).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Young, B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app

Climate Change Vulnerability Index Report
*Eurybia merita (*subalpine aster*)*

Date: 12 March 2024 Synonym: *Aster sibiricus* var. *meritus*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	20
	-0.074 to - 0.096	60
	-0.051 to - 0.073	20
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All five known occurrences (100%) of *Eurybia merita* in Washington with model data occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1). The remaining occurrence in San Juan county does not have available model data to predict temperature increase and has been excluded from percentages.

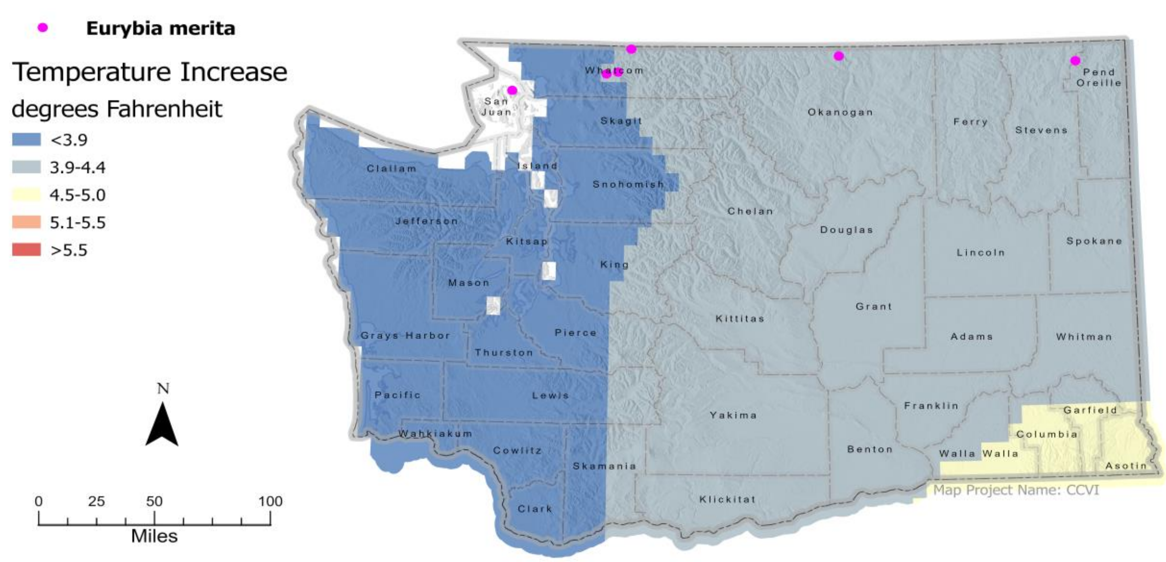

Figure 1. Exposure of *Eurybia merita* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: One of the five known occurrences (20%) of *Eurybia merita* with model data in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). Another three occurrences (60%) are in areas with a projected decrease in the range of -0.074 to - 0.096 and another single occurrence (20%) is in an area with a projected decrease of -0.051 to - 0.073. The remaining occurrence in San Juan county does not have available model data to predict the decrease in available moisture and has been excluded from percentages.

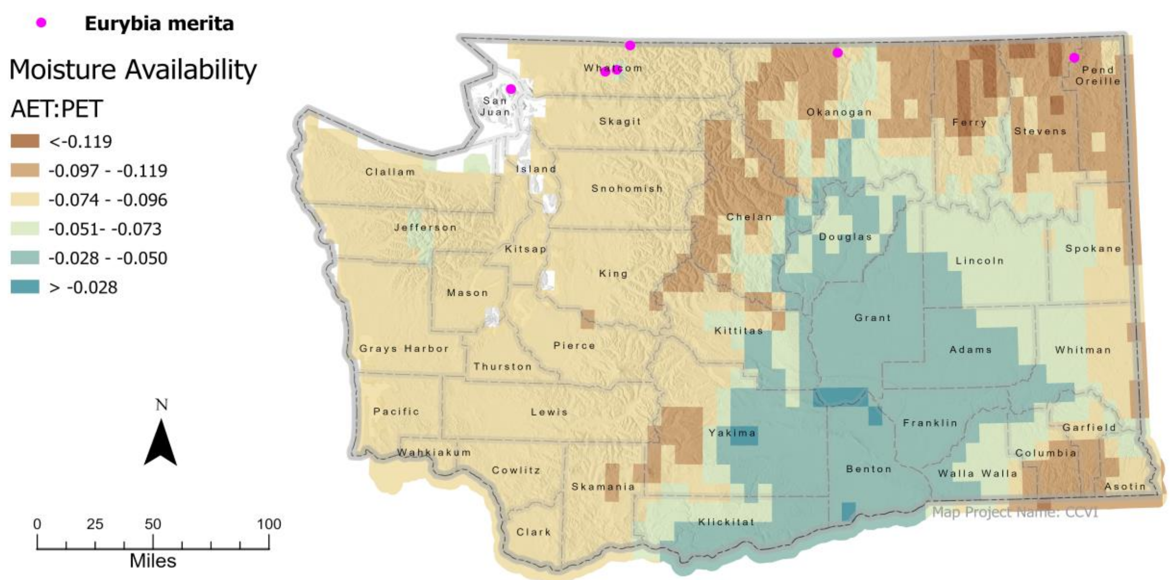

Figure 2. Exposure of *Eurybia merita* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Eurybia merita occurs on rocky outcrops and scree slopes at mid to high elevations (2400-7400 ft (730-2255 m)) along the Canadian border (Washington Natural Heritage Program 2023). Anticipated sea level rise is likely only to affect San Juan Island and will not reach the occurrence on Mt. Constitution (Office for Coastal Management 2023).

B2a. Natural barriers: Increase
Eurybia merita is localized to steep cliff faces, open canyon slopes, and rock outcrops in the naturally patchy North Pacific Alpine & Subalpine Bedrock & Scree, North Pacific Montane Massive Bedrock, Cliff, & Talus, and Rocky Mountain Alpine Bedrock & Scree ecological systems (Rocchio and Crawford 2015). Populations occur sporadically on a few mountain sides

separated by 5-245 mi (8-394 km) of unsuitable valleys, forests, and straits which act as significant barriers to propagule dispersal and result in low habitat connectivity. There is limited room for populations to move upward with climate change. *Eurybia merita* may be at risk of following an "elevator to extinction" as the coolest climatic zones of the alpine are lost (Watts et al. 2022).

B2b. Anthropogenic barriers: Neutral
The rugged, high elevation terrain where *Eurybia merita* occurs remains relatively uninhibited by direct anthropogenic barriers as there are few roads and little human infrastructure in the area. Observational records indicate that the Washington occurrences are hard to access, with glacier traverses and technical climbing sometimes required. However, habitat disturbance due to recreation could be of limited concern (Washington Natural Heritage Program 2023).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Eurybia merita* (Washington Natural Heritage Program 2023). Future projects in the region are unlikely due to the rugged montane to alpine terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Eurybia merita produces achenes with a pappus of short bristles which are adapted for wind-dispersal like other members of the Asteraceae family (Washington Natural Heritage Program 2023). The specific dispersal distances of *Eurybia merita* have not been documented but Washington congeners such as *Eurybia conspicua* are wind-dispersed over long distances to germinate on bare soil (Reed 1993). This species is probably not dispersal limited.

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Eurybia merita* occurrences in Washington. Three of the six known occurrences (50%) are in areas that have experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming. Two occurrences (33%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation and are expected to be mostly resilient to warming (Young et al. 2016). The remaining occurrence in San Juan county does not have available model data to determine the historical thermal niche.

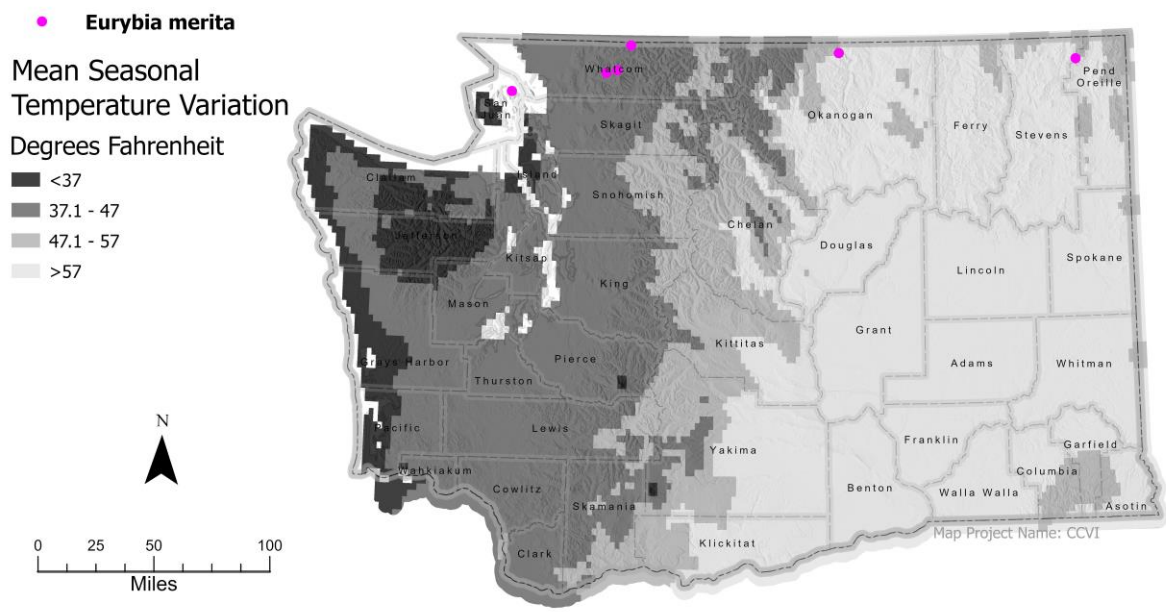

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Eurybia merita* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase
Eurybia merita is found on harsh, wind-exposed talus slopes and rocky outcrops of the subalpine to alpine with cooler and wetter northerly aspects (Washington Natural Heritage Program 2023). It is generally shade-intolerant, preferring open clearings and recently burnt areas where solar radiation is higher (Pearson 2022). These high-elevation rocky habitats experience short, cool growing seasons and long, cold winters and will be vulnerable to anticipated temperature increases (Rocchio and Ramm-Granberg 2017). There is not much room for upward movement as the higher elevations warm (Watts et al. 2022).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Eurybia merita* occurrences in Washington. Of the six known occurrences, five (83%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016). The remaining occurrence in San Juan county does not have available model data to determine the historical hydrological niche.

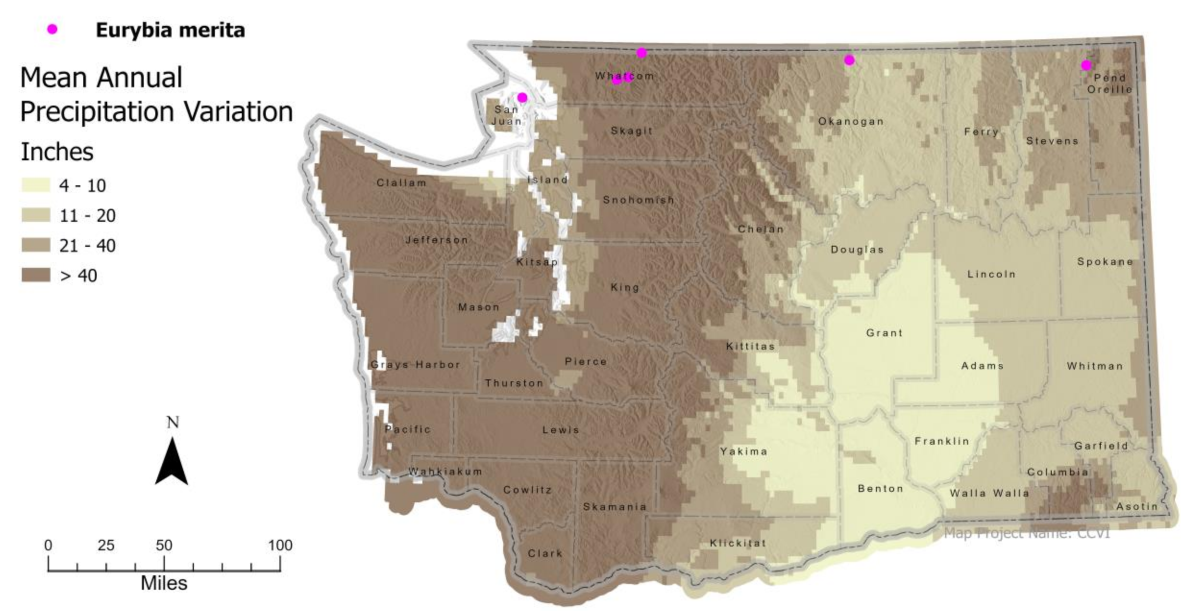

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Eurybia merita* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Eurybia merita occurs in mesic to dry gravelly slopes, sandy creek banks, and in areas bordering seeps and wet meadows which are not too dry or too wet. (Pearson 2022, Washington Natural Heritage Program 2023). Aspect and vertical position determine hydrology as these microhabitats are not replenished by groundwater and instead depend on slow seeping snowmelt (Clark 2012, Rocchio and Crawford 2015). Shifts in precipitation timing and amount combined with earlier snow melt and extended summer droughts are expected to have a low to moderate impact on scree and talus ecological systems (Rocchio and Ramm-Granberg 2017), but the potential drying of cliff microhabitats where limited moisture is retained in crevices will be of particular concern for *Eurybia merita*.

C2c. Dependence on a specific disturbance regime: Neutral
Wind, water, and gravity are forces acting upon scree and talus habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates and temperature increases may impact freeze-thaw cycles (Hampton and Griggs 2004, Rocchio and Ramm-Granberg 2017). Climate change may accelerate soil formation which is typically very minimal due to abiotic

disturbances (Rocchio and Ramm-Granberg 2017). Though these ecological systems are rarely subject to fire, increased temperatures and drought could lead to higher fire risk and potential damage to vegetation, which is slow to recover on the rocky substrate and thin soils found in this habitat (Rocchio and Ramm-Granberg 2017). Studies of other *Eurybia* spp. have shown them to survive light to moderate severity fire by resprouting from underground rhizomes and have found abundances to nearly double after long-interval (but not short interval) fires in Yellowstone (Reed 1993, Kiel et al. 2023)

C2d. Dependence on ice or snow-cover habitats: <u>Somewhat Increase</u>
Slow melting snow infiltrates cracks and crevices in rock outcrops and is an important moisture source during the growing season. Observational records mention that snow is retained near the occurrences late into the year. Reductions in the amount of snowfall, or changes to the timing of snowmelt due to climate change could have a negative impact on this species (Rocchio and Ramm-Granberg 2017). However, conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and may increase the habitat available to *Eurybia merita* (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: <u>Somewhat Increase</u>
Eurybia merita is associate with well-drained alpine lithosols, calcareous/limestone colluvium, unstable talus, and rock outcrops (Washington Natural Heritage Program 2023, Soil Survey Staff 2024). These substrates are derived from a variety of igneous, sedimentary, and metamorphic parent materials including Palmer Mountain Greenstone, Chopaka basic and mafic intrusive rocks (metagabbro and dunite), Maitlen Phyllite-limestone complexes, and Nooksack formation sedimentary rocks. Such geological formations are of somewhat limited distribution in the North Cascades and Canadian Rockies and are overall uncommon, often only occurring at the transition zones of different geological units (such as limestone separated by phyllite).

C4a. Dependence on other species to generate required habitat: <u>Neutral</u>
Bedrock, scree, and talus ecological systems are shaped mostly by abiotic processes and mass wasting events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: <u>Not applicable for plants</u>

C4c. Pollinator versatility: <u>Neutral</u>
The specific pollinators of *Eurybia merita* are not known, but the Washington congener *Eurybia radulina* is pollinated by bees, flies, and butterflies (Knoke and Giblin 2024) and *Eurybia* spp. are notorious pollinator plants for a diverse suite of insects (Pearson 2022). Another western species *Eurybia conspicua* has been reported to be visited primarily by non-specialist bees and was found to be visited by a comparatively high diversity of pollinators in one study as it was one of the latest available nectar sources (Glenny et al. 2022). *Eurybia merita* is probably not pollinator limited.

C4d. Dependence on other species for propagule dispersal: <u>Neutral</u>
Eurybia merita is wind-dispersed and does not require other species to disperse.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Eurybia merita is a key high elevation food source for deer and other herbivores but is generally tolerant to browsing (Pearson 2022).

C4f. Sensitivity to competition from native or non-native species: Neutral
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation scree and rock crevice ecological systems which support *Eurybia merita*, and most of the plants in these ecological systems are "cushion" or "turf" species (Rocchio and Crawford 2015). Plant invasions remain relatively low in alpine scree environments but could increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with deep enough soil, trees and shrubs may also begin to encroach as the climate changes (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Eurybia merita is not known to play a role in any other major interspecific relationships.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Eurybia merita* has not been documented.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Eurybia merita is a rhizomatous perennial which is gynomonoecious (has female and bisexual flowers on same plant). Plants in genus *Eurybia* can be either diploid or polyploid, are partially self-incompatible (favoring outcrossing), and can resprout asexually from extensive, creeping rhizomes (Reed 1993, Bertin and Kerwin 1998, Ferrer et al. 2009, Babin 2022). A mixed mating system with high rates of outcrossing is indicative of at least average genetic diversity and resilience to climate change (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (July to September) has not changed significantly. However, there were few records with documented phenology to examine.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The response of *Eurybia merita* to climate change has not been documented but two occurrences were not able to be relocated in recent surveys. Projected climate change scenarios for other *Eurybia* species have predicted near zero habitat suitability across three climate scenarios (Babin 2022).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown

Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Gentiana glauca (glaucus gentian)

Date: 6 May 2024 Synonym: none
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	67
	-0.074 to -0.096	22
	-0.051 to -0.073	11
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral

4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Not Modeled
D3. Overlap of modeled future (2050) range with current range	Not Modeled
D4. Occurrence of protected areas in modeled future (2050) distribution	Not Modeled

Section A: Exposure to Local Climate Change

A1. Temperature: All nine known occurrences (100%) of *Gentiana glauca* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

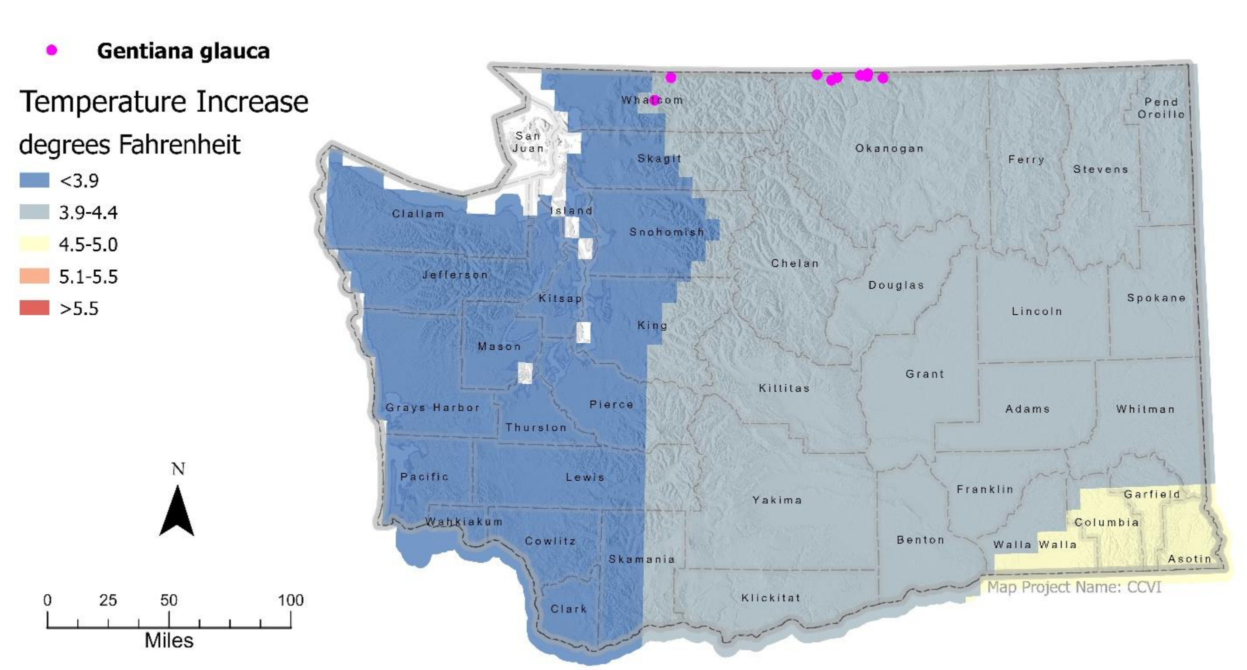

Figure 13. Exposure of occurrences of *Gentiana glauca* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: One of nine known occurrences (11%) of *Gentiana glauca* in Washington is found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to -0.073. Two (22%) are found in areas with a projected decrease in available moisture in the range of -0.074 to -0.096. The remaining six known occurrences (67%) are found in areas with a projected decrease in available moisture in the range of -0.097 to -0.0119 (Figure 2).

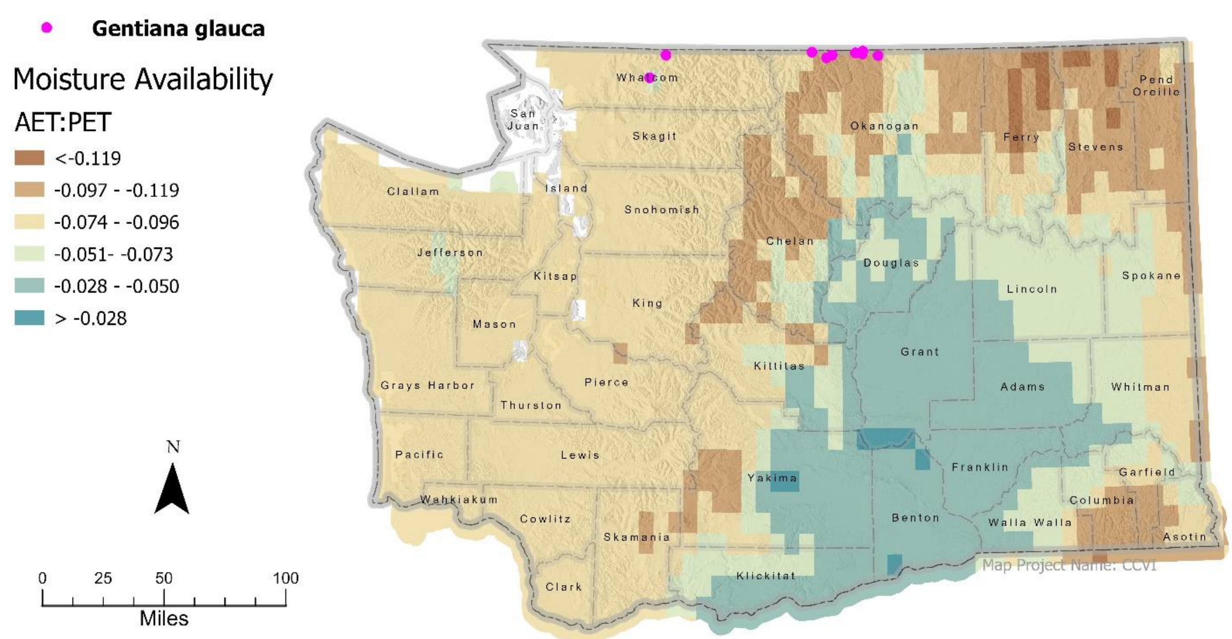

Figure 14. Exposure of occurrences of *Gentiana glauca* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Gentiana glauca is found in alpine and subalpine habitats between 6200–7700 ft (1890–2345 m; Washington Natural Heritage Program 2024) and would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Increase
In Washington, *Gentiana glauca* is usually found on hummocks and seeps in moist meadows in alpine and subalpine habitats associated with Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems (Washington Natural Heritage Program 2024). These large-patch systems consist of turf and dwarf-shrublands separated by stretches of dry, wind-scoured slopes and subalpine forests (Rocchio and Crawford 2015). In Washington, these systems are restricted to small alpine areas of the Okanogan Highlands, the East Cascades, and potentially

Mt. Adams (Rocchio and Crawford 2015). Natural barriers of unsuitable habitat at lower elevations are likely to strongly restrict dispersal and migration to new areas under climate change.

B2b. Anthropogenic barriers: Neutral
All occurrences of *Gentiana glauca* in Washington occur in protected areas, with one of nine records occurring in the Chopaka Mountain Natural Area Preserve, six of nine records in the Pasayten Wilderness, and two of nine records in the Mt. Baker Wilderness. Anthropogenic influences within its range are primarily recreation and grazing. Otherwise, the human footprint is negligible and does not present an additional barrier to dispersal for this species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Gentiana glauca* and future development is unlikely in the protected areas where this species is found (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Gentiana glauca reproduces by creeping rhizomes and small (0–1 mm) flattened, wing-margined seeds (Montana Natural Heritage Program 2024, Washington Natural Heritage Program 2024). The seeds lacks barbs, hooks, or hairs that could facilitate dispersal by animals. Seeds of most *Gentiana* species are wind-dispersed (Davitashvili and Karrer 2010), so it is likely that *Gentiana glauca* is wind-dispersed as well, at least up to 3,280 ft (1,000 m).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Gentiana glauca* occurrences in Washington. Five of nine known occurrences (66%) are in areas that have experienced small (37–47 ° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming. Four of nine known occurrences (44%) are in areas that have experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming.

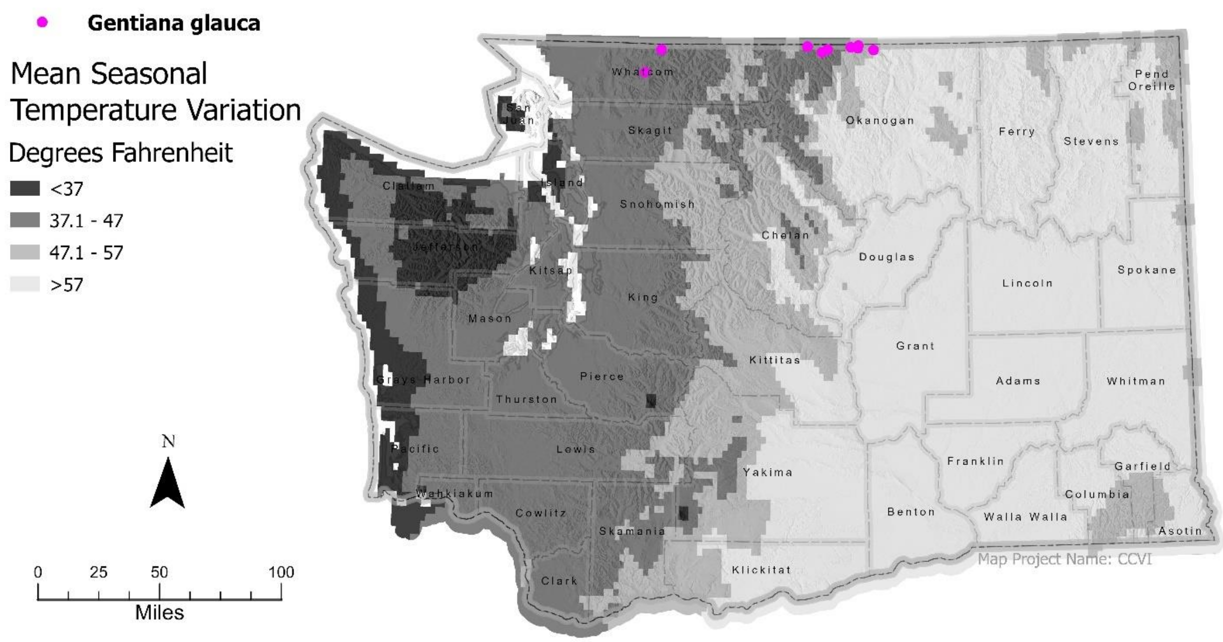

Figure 15. Historical thermal niche (exposure to past temperature variations) of occurrences of *Gentiana glauca* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Increase
Melting glaciers could expand suitable habitat for *Gentiana glauca* in alpine areas, but these gains could be offset over time by concurrent shifts in forested systems to higher altitudes (Rocchio and Crawford 2015). Alpine species may be at risk of following an “elevator to extinction” as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Gentiana glauca* occurrences in Washington. All nine known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 inches/508 mm) over the historical period. According to Young et al. (Young et al. 2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

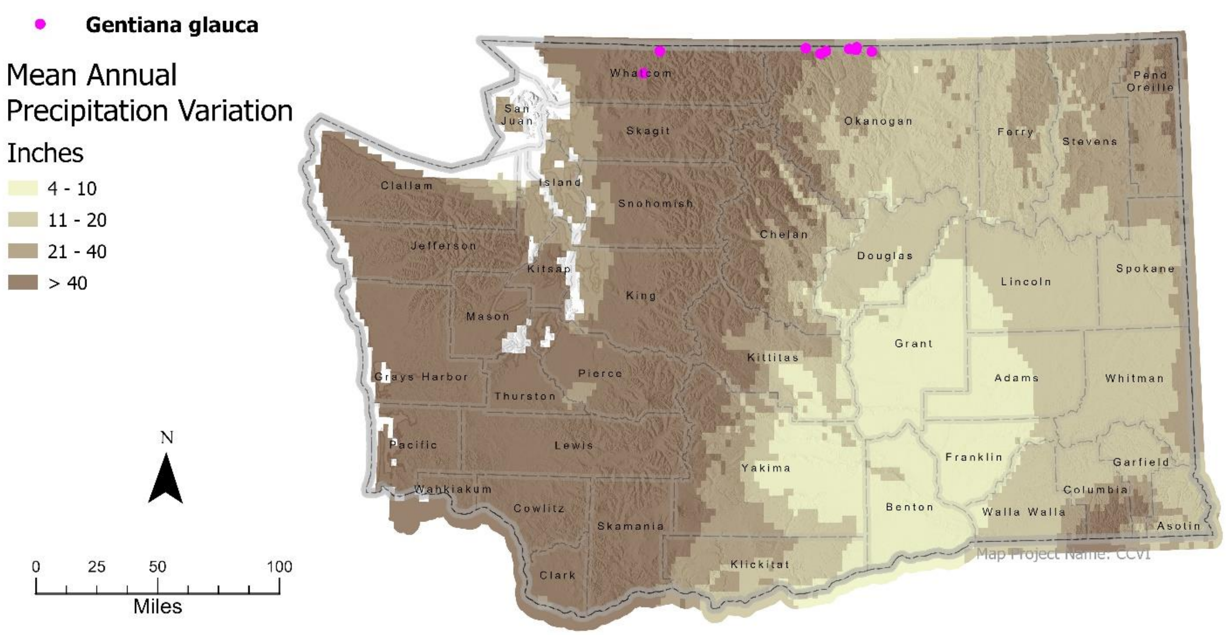

Figure 16. Historical hydrological niche (exposure to past variations in precipitation of occurrences of *Gentiana glauca* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
In Washington, *Gentiana glauca* is usually found on hummocks in moist meadows within alpine and subalpine habitats associated with Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems (Washington Natural Heritage Program 2024). Dwarf-shrublands occur in level or concave terrain that holds snow later in the year and generally receives water from surrounding slopes. Turf systems are found in level and sloped areas and hold water until the late summer (Rocchio and Crawford 2015). Reductions in the amount of snow, shifts from snow to rain, or changes in the timing of snowmelt due to higher temperatures could impact the amount of moisture available to this species in the growing season (Rocchio and Ramm-Granberg 2017), somewhat increasing this species' vulnerability to climate change.

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems are shaped mostly by abiotic processes and erosion, which create critical microhabitat conditions (Rocchio and Crawford 2015). This disturbance regime is unlikely to be strongly affected by climate change. However, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Chersich et al. 2015). Though fire is unlikely to carry through the sparse vegetation and rocky slopes where *Gentiana glauca* usually occurs, six of nine element occurrences are inside the perimeters of fires that occurred from 2006 to 2023. Disturbance from livestock grazing and recreation (hiking and horses) have also been documented for some *Gentiana glauca* occurrences.

C2d. Dependence on ice or snow-cover habitats: Increase
Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems rely on snow retention and permafrost and are sensitive to warmer temperatures, reduction in snowpack, and shifts in precipitation patterns. Most of the water in these habitats likely comes from snowpack, as these systems are generally not connected to groundwater. Changes to snowpack and permafrost extent will likely affect *Gentiana glauca*'s habitat. Reductions in the amount of snow, shifts from snow to rain, or changes in the timing of snowmelt due to higher temperatures could impact the amount of moisture available to this species in the growing season (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Gentiana glauca is primarily found on mossy hummocks in alpine and subalpine wetlands. Most of these areas were once glaciated, with thin soils over rocks. This species occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems are shaped mostly by abiotic processes and erosion, which shifts critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
Several bumblebee species (*Bombus*) have been documented visiting species in the genus *Gentiana*, and some studies (e.g. (Duan et al. 2007) have documented *Bombus* species as the dominant effective pollinators for *Gentiana* species with similar morphology and ecology to *Gentiana glauca*. Some morphologically similar species in this genus require pollinator visitations to reproduce due to the spatial separation of their stigma and anther, which otherwise prevents pollination. Pollinator diversity may be reduced in alpine areas (Spira and Pollak 1986), so it is possible that *Gentiana glauca* relies on only a few species of effective pollinators and could have somewhat increased vulnerability to disruption in plant-pollinator relationships due to climate change.

C4d. Dependence on other species for propagule dispersal: Neutral
Gentiana glauca seeds are likely wind-dispersed and do not have adapted structures to attach to animals (Washington Natural Heritage Program 2024).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Disturbance from livestock grazing and recreation (hiking and horses) has been documented for some *Gentiana glauca* occurrences. These activities may damage or reduce the hummocks that *Gentiana glauca* usually occurs on. Large herbivores also graze alpine turf areas nomadically but are not expected to have a high impact on *Gentiana glauca*. However, these activities are not expected to increase with climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the high elevation Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems that support *Gentiana glauca*. *Gentiana glauca* is adapted to survive in these harsh abiotic conditions and is unlikely to be a strong competitor. Though *Gentiana glauca* is usually found in dwarf-shrub and turf communities, increases to plant competition could still pose a threat (Washington Natural Heritage Program 2024). Plant invasions remain relatively low in alpine environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with relatively deep soil, the tree line may also begin to encroach as the climate changes (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Unknown
No other information on interspecific interactions were found for *Gentiana glauca*.

C5a. Measured genetic variation: Unknown
Data are lacking on the genetic diversity within and between populations of *Gentiana glauca* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Somewhat Increase
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the high elevation Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems that support *Gentiana glauca*. *Gentiana glauca* is adapted to survive in these harsh abiotic conditions and is unlikely to be a strong competitor. Though *Gentiana glauca* is usually found in dwarf-shrub and turf communities, increases to plant competition could still pose a threat (Washington Natural Heritage Program 2024). Plant invasions remain relatively low in alpine environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with relatively deep soil, the tree line may also begin to encroach as the climate changes (Raymond et al. 2014).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Gentiana glauca* (July to September) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no direct reports of *Gentiana glauca* responses to climate change in Washington. However, response to climate change has been reported for this species in northwestern Montana. One study documented a 44% decrease in *Gentiana glauca* density over time suggesting this species is beginning to experience a contraction at the southern extent of its range (Lesica and McCune 2004). A follow up study found *Gentiana glauca* declined by 6% in the absence of direct human disturbance between 1988 and 2014 in Northwestern Montana. At the

same time, researchers documented patterns of warming temperature and decreased precipitation in the species' range (Lesica and Crone 2017).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Geum rivale (**water Avens)**

Date: 11 January 2024 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2S3
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	26
	-0.097 to -0.119	74
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Increase
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 19 known occurrences (100%) of *Geum rivale* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

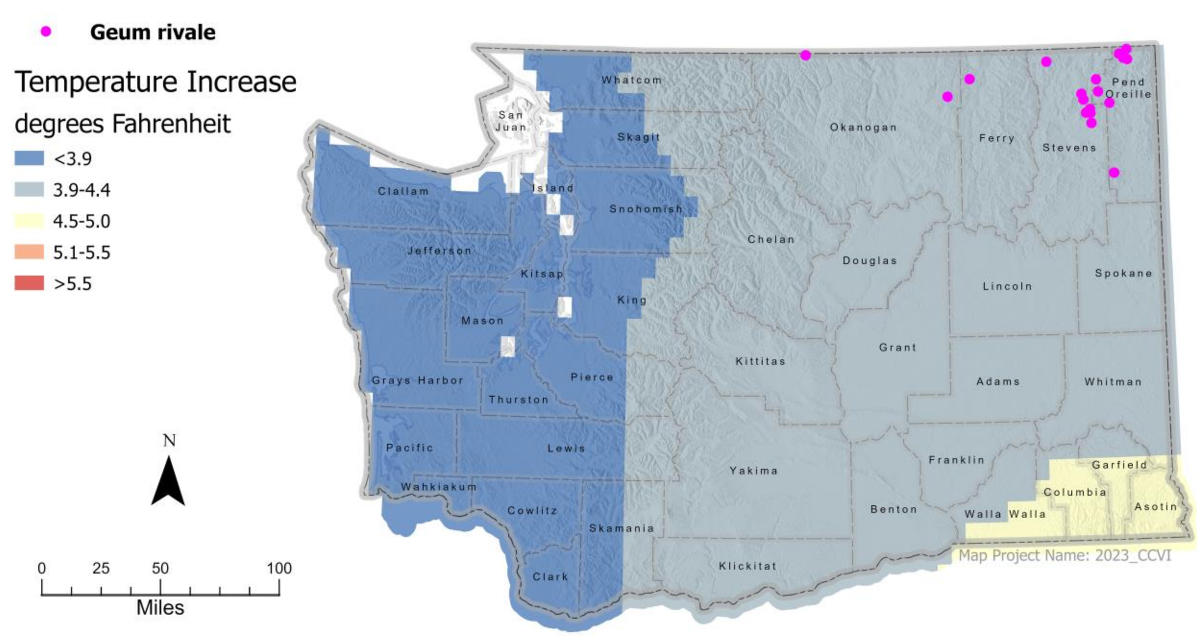

Figure 1. Exposure of *Geum rivale* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Fourteen of the 19 known occurrences (74%) of *Geum rivale* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other five occurrences (26%) are found in areas with a projected decrease in available moisture of less than -0.119.

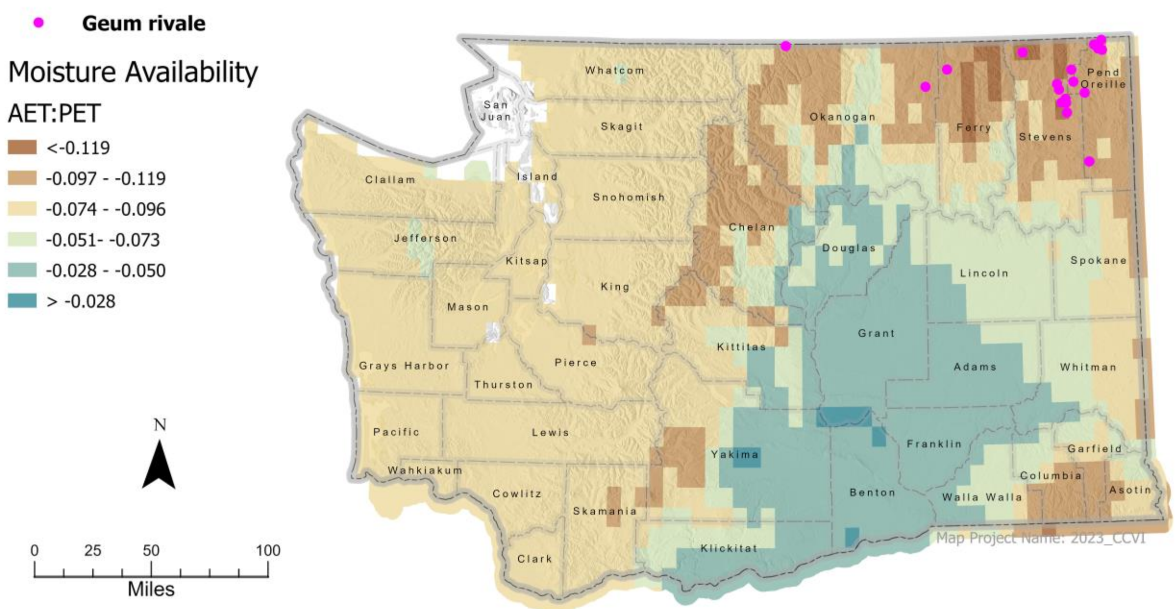

Figure 2. Exposure of *Geum rivale* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Geum rivale occurs in wet meadows, riparian zones, and bogs that are above lower tree line (2560-6440 ft (780-1960 m)) in northeastern Washington (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). *Geum rivale* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Somewhat Increase</u>
Habitats occupied by *Geum rivale* are part of the Rocky Mountain Alpine-Montane Wet Meadows and Rocky Mountain Subalpine-Montane Fen ecological systems which occur at the ecotone of lowland and upland forest (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). The valleys and lowland depressions that support these ecological

systems occur as small patches where groundwater reaches the surface. These features are somewhat limited within the surrounding matrix of montane to subalpine conifer forests in the Canadian Rockies and Okanogan Highlands. Populations are separated by 1-139 mi (2-224 km) of unsuitable forested uplands which pose somewhat of a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral
Geum rivale occurrences in Washington are mostly undisturbed on wilderness lands and Forest Service lands managed for multiple use that are not formally protected. Some populations are near to trails and several are near or intersected directly by trails but these are unlikely to constrain future migration to a significant degree.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There is a candidate parcel for Washington Department of Natural Resources clean energy projects that would overlap with an occurrence (Element Occurrence #1438) in Okanogan County if a project is initiated in the future (Washington Department of Natural Resources 2023). It is unknown to what degree this development would directly impact *Geum rivale* but it is unlikely that construction would take place in the wet meadows and fens on site.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Geum rivale produces heavy, hairy achenes with hooked styles that are well adapted to adhere to passing animals for dispersal (Washington Natural Heritage Program 2023). This species can travel a moderate distance on fur before releasing (up to 700 m maximum) but probably is mostly dispersed less than 25 m by gravity and small animals (rodents, lagomorphs) that have short foraging distances, such as pika, which are known to be significant dispersers of other *Geum* spp. (Huntly et al. 1986; Kiviniemi 1996). The seeds of this species do not have adaptations for wind-dispersal and do not appear to float well for water dispersal.

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Geum rivale* occurrences in Washington. One of the 19 known occurrences (5%) in Okanogan County is in an area that has experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), this population is expected to be vulnerable to climate warming. Two known occurrences (11%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period and are expected to be somewhat vulnerable to climate warming. The remaining 16 occurrences (84%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation and are expected to be mostly resilient to warming (Young et al. 2016).

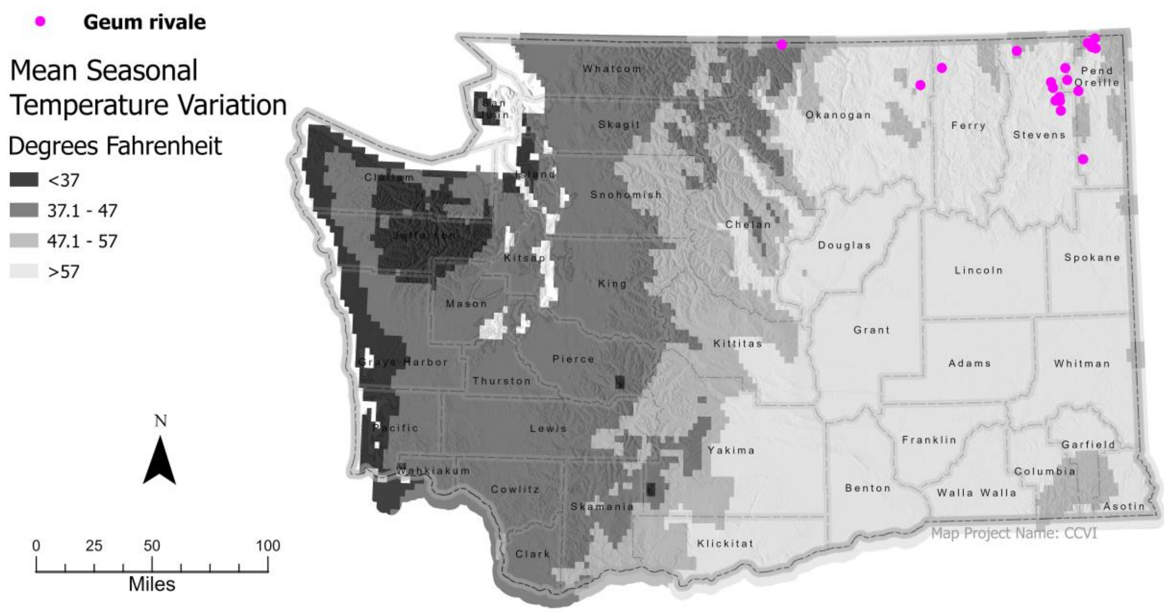

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Geum rivale* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Geum rivale is highly adapted to extreme cold and freezing conditions and occurs in a variety of light regimes but not under complete canopy or shrub cover (Taylor 1997; Washington Natural Heritage Program 2023). Wet meadows and fens are increasingly threatened by warmer, dryer summers and earlier snowmelt (Rocchio and Crawford 2015). These changes may result in lost connections to groundwater systems and reduction in spring inflows. The Rocky Mountain Alpine-Montane Wet Meadow ecological system is also vulnerable to drought from increased temperatures (Rocchio and Ramm-Granberg 2017). However, *Geum* spp. have been shown to perform well under experimental warming conditions with no reductions to vigor and may even be opportunistic with warming, even showing increased growth and reproduction in some cases (Prock and Körner 1996). However, *Geum rivale* is not drought tolerant (Taylor 1997).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Geum rivale* occurrences in Washington. Two of the 19 known occurrences (10%) are in areas that have experienced slightly lower than average (11- 20 in (255 - 508 mm)) precipitation variation. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The remaining 17 known occurrences (90%) are in areas

that have experienced average or greater than average precipitation variation (>20 in (508 mm)) and are expected to be mostly resilient to shifting moisture regimes (Young et al. 2016).

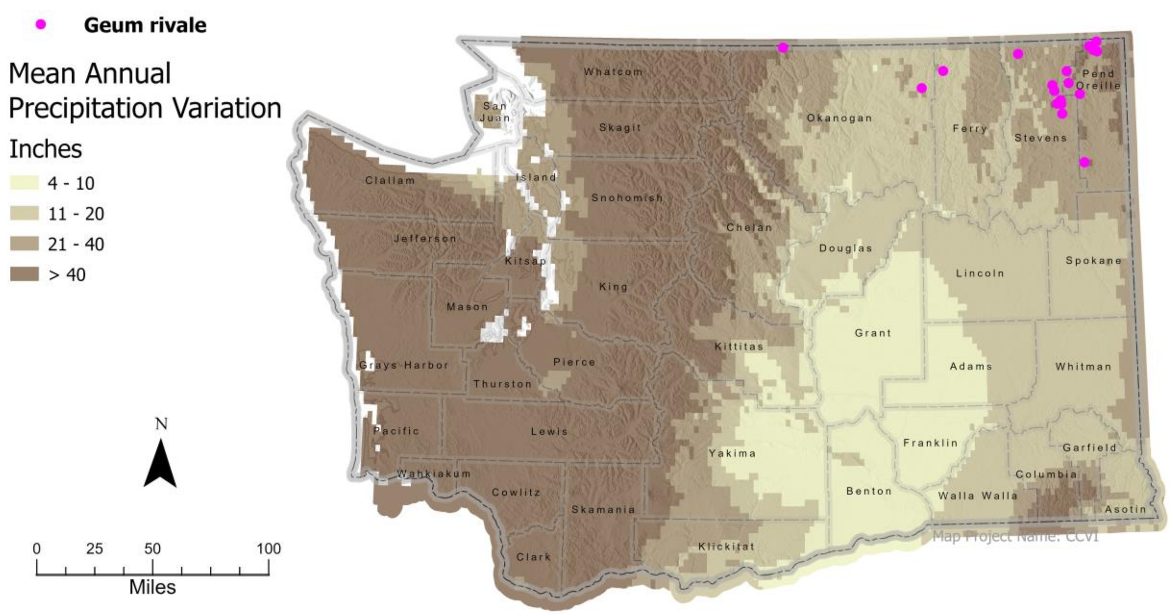

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Geum rivale* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Increase</u>
Geum rivale is associated with wet meadows, bogs, fens, moist woods, and stream sides connected to groundwater discharge or seasonally high water tables (Rocchio and Crawford 2015; Washington Natural Heritage Program 2023). Changes in the amount and timing of precipitation, especially anticipated reductions to snowpack, are expected to cause water tables to drop in these ecological systems. Effects will range from shifts in hydrology, water chemistry, and plant composition, to complete loss of peat or conversion to more drought tolerant community types (Rocchio and Ramm-Granberg 2017). *Geum rivale* has been found to be less drought tolerant than other *Geum* spp. (Taylor 1997).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
The wet meadow and fen habitats of *Geum rivale* are not adapted to frequent disturbances such as extreme flooding, but healthy water flow, hydrological fluctuations, and periodic inundation are important for ecosystem functioning. These habitats are not typically susceptible to fire but could become more vulnerable if water tables are lowered due to decreased snowpack or increased summer temperature or drought (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: <u>Increase</u>

Wet meadows in the subalpine and alpine form on snow beds and in depressions below late-melting snow patches and depend on groundwater recharge from snow. Changes to snow depth and cover are likely to significantly alter the habitat of *Geum rivale* (Rocchio and Crawford 2015; Rocchio 2006).

C3. Restricted to uncommon landscape/geological features: Increase
Geum rivale is often found on slightly acidic to calcareous peat or loam soils that are associated most often with limestone (NatureServe 2023; Taylor 1997; Washington Natural Heritage Program 2023). Limestone is more common in the Cascade Range but somewhat uncommon in the areas where *Geum rivale* occurs in Washington. This species may also be associated with Quartz Mountain gneiss, Klondike rhyolite, Mount Bonaparte pluton, Vashon State glacial drift, and Maitlen Phyllite metacarbonate (Washington Division of Geology and Earth Resources 2016). Many of these geologic types are relatively uncommon in Washington. The local topographic relief associated with high water tables and peat accumulation, such as glacial scours, kettles, ox-bows, or old ponds and lakes are also more limited features on the landscape (Rocchio and Crawford 2015).

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beavers are an important hydrogeomorphic driver of wet meadows. When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006). Wet meadow sites may be enhanced by browsing by ungulates or other herbivores that contain the encroachment of woody vegetation. Montane fens are maintained largely by edaphic and drainage patterns that favor the accumulation of thick organic soil layers favoring peatland vegetation over conifer forests (Banner et al. 1983).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Geum rivale produces pendulous flowers best adapted for bee pollination and is a predominantly outcrossing species (Jordan et al. 2017). Pollinators include *Bombus hortorum, Apis mellifera*, Syrphid flies, and Meligethes beetles (Taylor 1997). As the flower matures, elongation of the stamens ensures it self-fertilizes if not already cross-pollinated. *Geum rivale* is not especially pollinator limited.

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
The dry achene fruits of *Geum rivale* are dispersed by gravity or secondarily by insects and rodents.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Alpine wet meadows and fens can be severely threatened by grazing and soil compaction which can alter hydrology and nutrient cycling (Rocchio and Crawford 2015; Rocchio 2006). Heavy grazing impacts are mentioned in field notes of *Geum rivale* occurrences, noting that horse and cows are grazing "all flower stalks" at one site. G*eum rivale* has been shown to be suppressed by grazing, with experimental evidence for improved growth after fencing off populations, though grazing is not anticipated to increase as a result of climate change (Kiviniemi 2002; Taylor

1997). *Geum rivale* is also sometimes parasitized by *Peronospora gei*, a downy mildew, but mostly in horticultural settings (Taylor 1997). A few species of Hemiptera, Lepidoptera, Coleoptera, Hymenoptera, and Diptera larvae and caterpillars feed on stems and leaves and herbivory may increase with warming temperatures.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
With increasing temperatures, montane wet meadows and subalpine fens are at risk of drying and subsequent conifer encroachment (Ford and HilleRisLambers 2023). Wet meadows are also susceptible to invasion by many non-native species, especially pasture grasses such as *Poa pratensis* and *Phleum pratense* as well as exotics species common to other wetland types such as *Cirsium arvense* and *Taraxacum officinale* (Rocchio and Crawford 2015). *Hypericum perforatum* has also been documented at a few occurrences. Despite these risks, *Geum rivale* has been found to be a strong competitor with its dense clonal growth form and may be somewhat resilient to competition (Kiviniemi 2002; Taylor 1997).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Mountain alder (*Alnus incana* ssp. *tenuifolia*) is noted to be a common associate of *Geum rivale* per field notes but does not have any obligatory relationship.

C5a. Measured genetic variation: Unknown
The exact genetic variation of the circumpolar species *Geum rivale* has not been reported. However, most species of Geum are hexaploids, occupy a large range, and exhibit significant phenotypic variability which together suggest that genetic variability in this species is probably relatively high (Raynor 1952; Taylor 1997)

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
The hexaploid *Geum rivale* is a hemicryptophytic perennial with a well-developed branching rhizome that vegetatively produces many new rosettes annually (Kiviniemi 2002; Taylor 1997). This species is highly outcrossing due to its protogynous nature and can only successfully self-pollinate about 25% of the time but will default to this strategy if insect pollination is not successful (Ruhsam et al. 2011; Taylor 1997).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and Washington Natural Heritage Program records, the flowering period of *Geum rivale* (late May to July, fruiting as early as the beginning of July) does not appear to have changed significantly (Washington Natural Heritage Program 2023). However, a study in Massachusetts found that bloom time in *Geum rivale* has advanced by a moderate 11 days (Bertin et al. 2017).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown

There are no reports of *Geum rivale* declining in response to climate change. All occurrences have been relocated and confirmed as extant in recent years (as recent as 2012).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Githopsis specularioides (common bluecup)

Date: 11 Oct 2023 Synonym: *Githopsis calycina*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2S3
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	72
	<3.9° F (2.2°C) warmer	28
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	7
	-0.074 to - 0.096	48
	-0.051 to - 0.073	28
	-0.028 to -0.050	17
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Eight of the of the 29 documented occurrences (28%) of *Githopsis specularioides* in Washington occur in an area with a projected temperature increase of less than or equal to 3.9°F (2.2°C). The other 21 occurrences (72%) occur in an area with a projected temperature increase of 3.9-4.4°F (2.2-2.4°C; Figure 1).

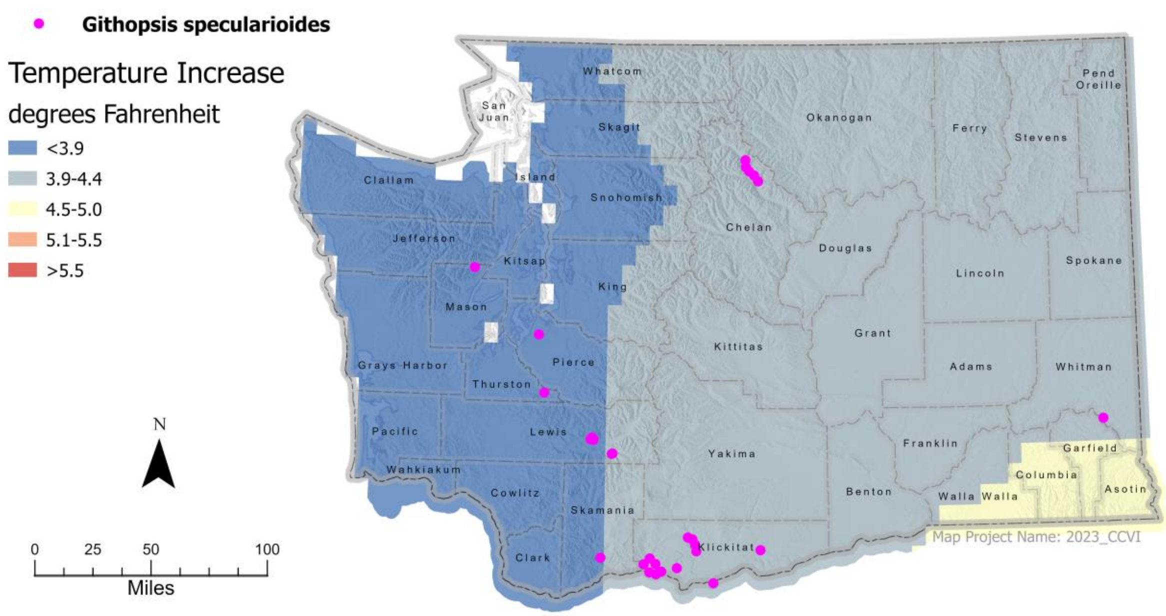

Figure 1. Exposure of *Githopsis specularioides* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 29 known occurrences of *Githopsis specularioides* in Washington, two (7%) occur in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119, 14 (48%) are in areas with a projected decrease in the range of -0.074 to -0.096, eight (28%) are in areas with a projected decrease in the range of -0.051 to -0.073, and five (%) are in areas with a projected decrease in the range of -0.028 to -0.050 (Figure 2).

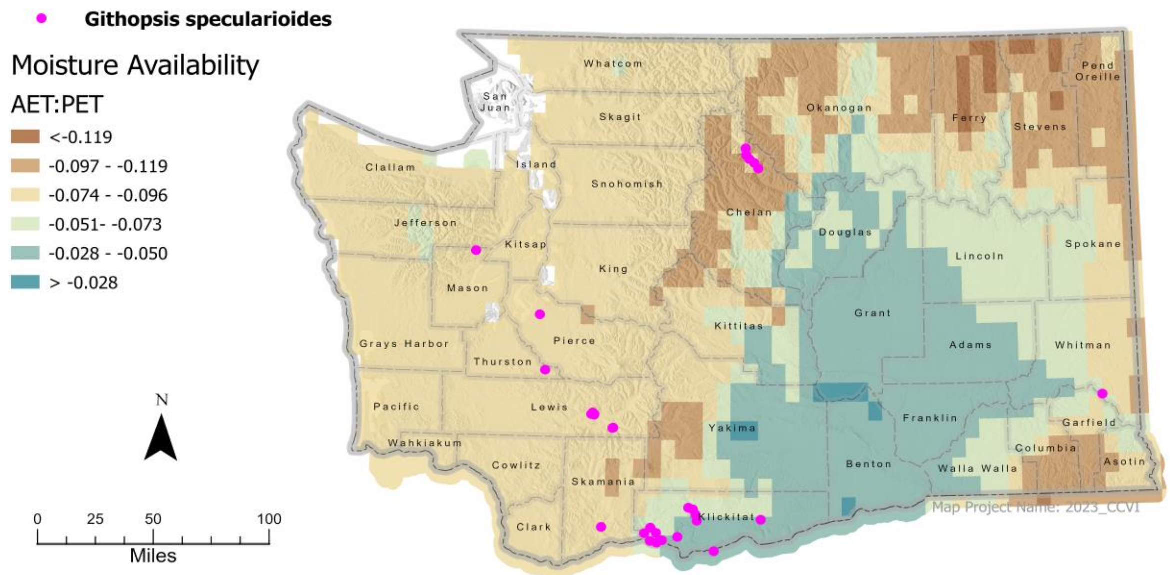

Figure 2. Exposure of *Githopsis specularioides* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Githopsis specularioides can be found on moist outcrops, grassy balds, and rocky slopes among oak-conifer and other types of conifer forests at or near lower treeline in the foothills of the Cascade Range at elevations ranging from 200-2500 ft (60-760 m; Camp and Gamon 2011, Washington Natural Heritage Program 2023). *Githopsis specularioides* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Neutral</u>
Githopsis specularioides is the only *Githopsis* in the Pacific Northwest but it also has the most extensive distribution in the genus (Morin 1983, Hitchcock et al. 2018). This species is found in multiple Washington ecological systems but always at low elevations on grassy cliffs, bluffs, or balds in small open areas surrounded by oak and/or conifer woodlands (Rocchio and Crawford

2015). Populations are separated by some stretches of unsuitable shaded woodlands but are likely to be able to disperse to various suitable habitats and therefore are not expected to be highly impeded by natural barriers, though oak-pine woodlands are not common in Washington.

B2b. Anthropogenic barriers: Neutral
A significant portion of known *Githopsis specularioides* occurrences are located on public lands or protected areas such as natural areas and wilderness areas. Development is limited to a few smaller towns and roads. A few occurrences are located just uphill from roadsides, ditches, 4WD tracks, or trails where disturbances could cause trampling or soil compaction (Garry Oak Ecosystems Recovery Team 2012). Though some potential habitat has already been lost to urban and agricultural development which has increased fragmentation of the ecological system, barriers to existing occurrences appear to be relatively minimal (Rocchio and Crawford 2015).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Githopsis specularioides* (Washington Department of Natural Resources 2023)

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Githopsis specularioides produces long, conical capsules which open at terminal pores or simply disintegrate to release numerous seeds (Morin 1983, Hitchcock et al. 2018, Washington Natural Heritage Program 2023). The seeds appear to be mostly restricted to dispersal by passive means but may occasionally be dispersed by birds when attached to feet or feathers from muddy soils (Garry Oak Ecosystems Recovery Team 2012, Germain et al. 2017). This species has been described as a weak disperser.

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Githopsis specularioides* occurrences in Washington. Six (21%) are in areas that have been thermally stable and have experienced small temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming. Another 11 (38%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) and are expected to be somewhat vulnerable to warming (Young et al. 2016). The remaining 12 occurrences (41%) are in areas that have experienced average (>57.1° F (43.0° C)) temperature variation in the historical period and are expected to be resilient to warming (Young et al. 2016).

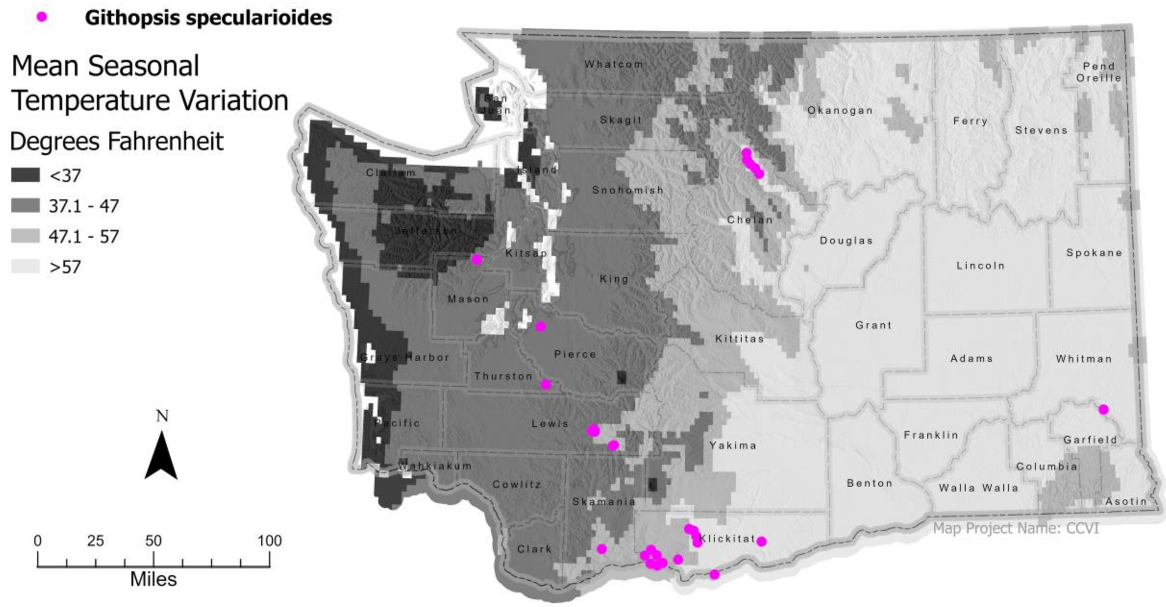

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Githopsis specularioides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
The balds, bluffs, and talus where *Githopsis specularioides* occurs are among the warmer and drier habitat types in eastern Washington, often marking the ecotone between woodland/forest and shrublands (Rocchio and Ramm-Granberg 2017). This species is well-adapted to dry, open places at lower elevations and is usually on open, warm, and windswept rocky seepage areas with sunny aspects (Garry Oak Ecosystems Recovery Team 2012, NatureServe 2023a, Washington Natural Heritage Program 2023)

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Githopsis specularioides* occurrences in Washington. Nine occurrences (31%) are in areas that have experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The other 20 occurrences (69%) are in areas that have experienced average or greater than average (>20 in (508 mm)) precipitation variation and are expected to be mostly resilient to climatic changes (Young et al. 2016).

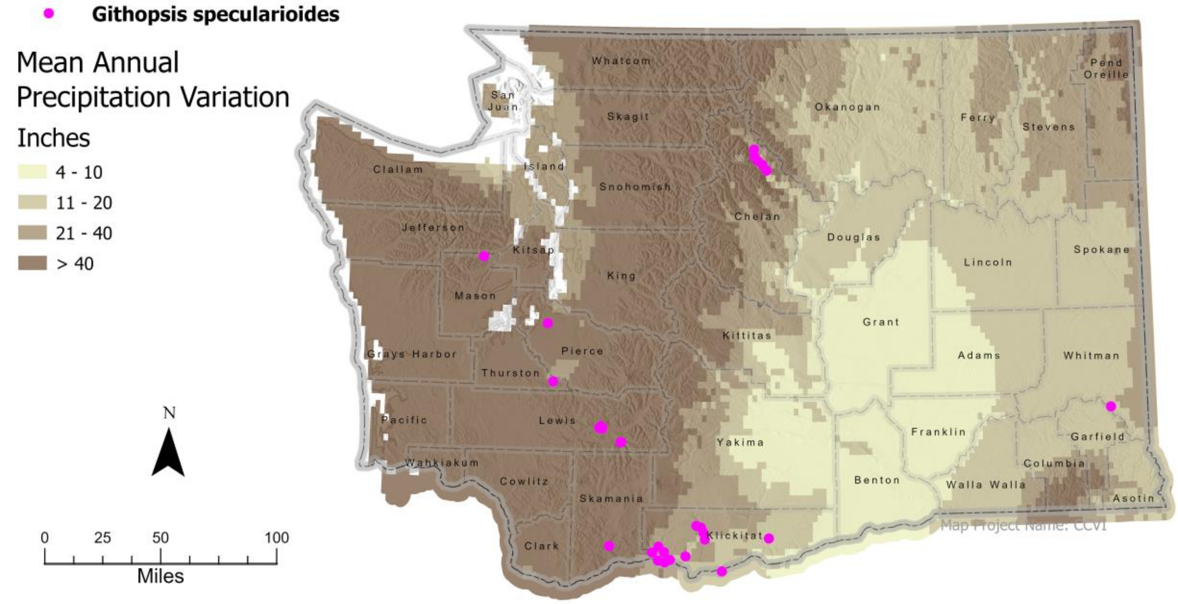

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Githopsis specularioides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Githopsis specularioides is an annual species that depends on vernally moist slopes and seepage through rocks to provide seasonal moisture in an otherwise dry, windswept environment with thin and gravelly drought-prone soils (Garry Oak Ecosystems Recovery Team 2012, Rocchio and Ramm-Granberg 2017). A lack of persistent moisture prevents competition from more robust perennials and trees or shrubs. Changes to precipitation regimes may impact this water limited system and shift composition.

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Overgrazing by livestock and fire suppression can lead to an increase in tree sprouting and canopy density which can eliminate understory species in the habitat of *Githopsis specularioides* (Rocchio and Crawford 2015). Frequent, low severity fire is necessary to prevent tree encroachment (NatureServe 2023b). Periodic soil drought also prevents tree encroachment and keeps an open canopy. More frequent fire may help prevent conifer encroachment but could also increase invasive species pressure (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Most of the sites that support *Githopsis specularioides* are sunny, exposed areas where there is little snowpack and snow is expected to melt sooner than the surroundings (NatureServe 2023a). This species is not particularly associated with cold air drainages, ice, or snow cover.

C3. Restricted to uncommon landscape/geological features: Neutral
Githopsis specularioides occurs on a wide breadth of soil types, including alluvial, ultramafic, and granitic soils ranging from coarse to fine (Morin 1983). Soils are most often thin, coarse loams and associated with basalt colluvium near rock outcrops, balds, and bedrock (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). These geological features are not uncommon in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The habitats which support *Githopsis specularioides* are shaped primarily by abiotic forces that dictate microsite availability and fire regimes which prevent tree and shrub encroachment. Other species are not required to maintain this habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Increase
The specific pollinators of *Githopsis specularioides* are not well documented but the flowers of this species open for only two days and likely attract a limited set of pollinators due to the small, tubular morphology of the flowers which close each night (Morin 1983). This species may rely mostly on selfing due to these limitations.

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Githopsis specularioides* are passively dispersed and appear to be generally unaided by other species (Germain et al. 2017). However, seeds may attach to the feet or feathers of birds from muddy soils on occasion (Garry Oak Ecosystems Recovery Team 2012).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Impacts from pathogens are not known. Some populations of *Githopsis specularioides* are in grazing allotments or areas with a history of light-heavy grazing and trampling by horses and livestock but grazing. Though livestock grazing is not expected to increase with climate change, grazing may compound the impacts of climate change and exacerbate changes to fire regimes.

C4f. Sensitivity to competition from native or non-native species: Increase
Non-native species such as *Bromus tectorum* and *Bromus hordeaceus* have already invaded several *Githopsis specularioides* occurrences and are abundant at sites where populations were unable to be relocated in recent years. Increases in fire frequency and decreases in soil moisture are anticipated to further increase exotic grasses in the primary habitat of this species (Rocchio and Crawford 2015). Competition with non-natives and encroaching trees and shrubs poses a significant threat to this species and may have been a major factor contributing to its present day rarity (Garry Oak Ecosystems Recovery Team 2012).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Githopsis specularioides does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown

The specific genetic diversity of *Githopsis specularioides* has not been documented, though this species tends to occur in small, relatively isolated populations which are susceptible to genetic drift and inbreeding depression (Garry Oak Ecosystems Recovery Team 2012).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Githopsis specularioides is a short lived annual tetraploid with a mixed mating system (Washington Natural Heritage Program 2023). Like other Campanulaceae species, it is allogamous but also capable of selfing (Garry Oak Ecosystems Recovery Team 2012). Pollen becomes available to pollinators before the stigma is receptive but upon the second and final day of flowering, style lobes curl back and effect self-pollination (Morin 1983).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (mid-April to mid-June) has not changed significantly (Garry Oak Ecosystems Recovery Team 2012). Further phenological monitoring is warranted as studies show spring blooming species to be at greater risk of phenological change in North America and the flowering time of *Githopsis specularioides* is known to be dependent on seasonal conditions (Calinger et al. 2013, Washington Natural Heritage Program 2023).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no direct reports of *Githopsis specularioides* populations declining in response to climate change in Washington. Most occurrences have been relocated in recent years and several of the historical occurrences in Washington simply have not been revisited since the late 1800s or late 1900s.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Hackelia cinerea (gray stickseed)

Date: 21 December 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4?/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	67
	-0.028 to -0.050	33
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All six known occurrences (100%) of *Hackelia cinerea* in Washington occur in areas with a projected temperature increase in the range of 3.9-4.4° F (2.2-2.4° C; Figure 1).

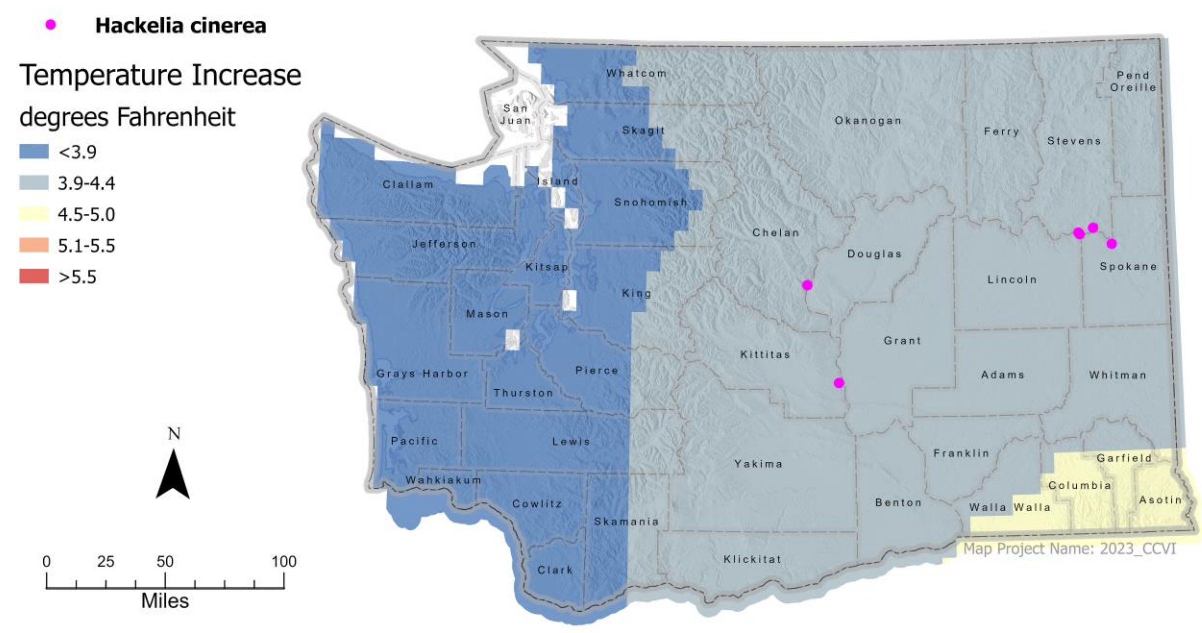

Figure 1. Exposure of *Hackelia cinerea* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of six known occurrences (67%) of *Hackelia cinerea* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to -0.073

(Figure 2). The remaining two occurrences (33%) are in areas with a project moisture decrease in the range of -0.028 to -0.050.

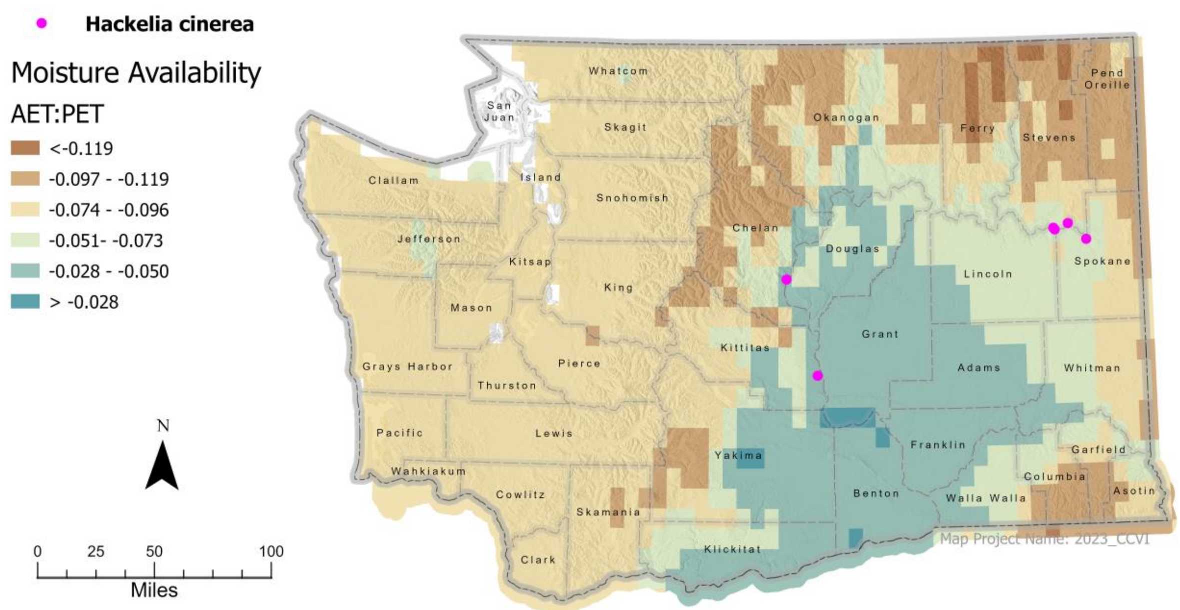

Figure 2. Exposure of *Hackelia cinerea* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Hackelia cinerea occurs in valleys, foothills, and along riverbanks at elevations ranging from 1040-2520 ft (315-770m) (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Populations in Washington are not expected to be affected by sea level rise based on their inland distribution but could be affected by river flooding or changes to levels of reservoirs near occurrences (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Somewhat Increase</u>
The sparsely vegetated cliffs, outcrops, and exposed rocky slopes occupied by *Hackelia cinerea* are part of the Rocky Mountain Cliff, Canyon, and Massive Bedrock ecological system (Rocchio and Crawford 2015). These features occur as small patches which are somewhat limited within the surrounding matrix of montane to subalpine conifer forests in and along the edges of the Columbia Plateau. Populations are separated by 1-132 mi (2-212 km) of unsuitable forest upland habitat which could impede dispersal in Washington as the natural heterogeneity of the landscape creates barriers to suitable microsites. Occurrences in the Okanogan region of

Washington are separated from those closer to the eastern edge of the Cascades by nearly the entire Columbia Plateau. The surrounding forest canopy cover and ridgelines could restrict movement of this species between rocky patches, but natural barriers are expected to have relatively minimal impact on dispersal in comparison to other factors.

B2b. Anthropogenic barriers: Increase
Approximately half of *Hackelia cinerea* occurrences in Washington are in state parks or on Forest Service lands managed for multiple use that are not formally protected, and the other half are on private lands. A few are near highways and multiple are just upstream of a dam. There is extensive agricultural development to the north and east of occurrences and a housing development immediately adjacent to one occurrence. Dam construction and potential loss of habitat are threats (Washington Natural Heritage Program 2023) and existing development poses a barrier to dispersal in the immediate region of *Hackelia cinerea* in Washington.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten populations of *Hackelia cinerea* (Washington Department of Natural Resources 2023), though its low elevation valley habitat could reasonable be targeted for wind or solar development in the future.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Hackelia cinerea produces nutlets with marginal glochidate prickles that can attach to the fur or feathers of animals for dispersal (Carr 1974, Al-Shehbaz 1991). Dispersal distances are thus dependent on the home range of ungulates, rodents, or rabbits, which may be limited to less than ½ mi or 1 km. Longer-distance dispersal is possible, but probably rare, as reflected in the limited natural range of the species. Observations of the related *Hackelia venusta* (which has similar fruits), suggest that most fruits are dropped close to the parent plant and may move downhill due to rock slides or erosion (Gamon 1997).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Hackelia cinerea* occurrences in Washington. All six known occurrences (100%) are in an area that has experienced average temperature variation (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

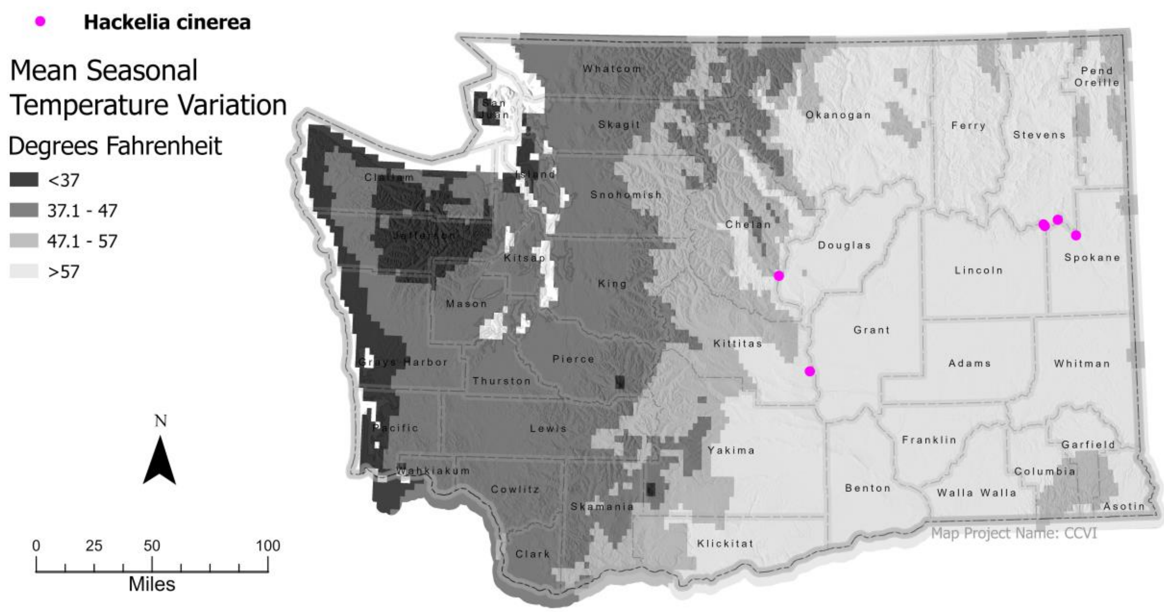

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Hackelia cinerea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Hackelia cinerea is not especially associated with cold temperatures or cold air drainages and can be found both on cool, shady northerly slopes and on warmer, fully exposed south slopes.

C2bi. Historical hydrological niche: <u>Somewhat Increase</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Hackelia cinerea* occurrences in Washington. Five of six known occurrences (83%) are in an area that has experienced slightly lower than average variation in precipitation (11 - 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The remaining occurrence is in an area that has experienced average or greater than average precipitation variation (>20 inches (508 mm)) over the historical period and is expected to be mostly resilient to changes in available moisture (Young et al. 2016)

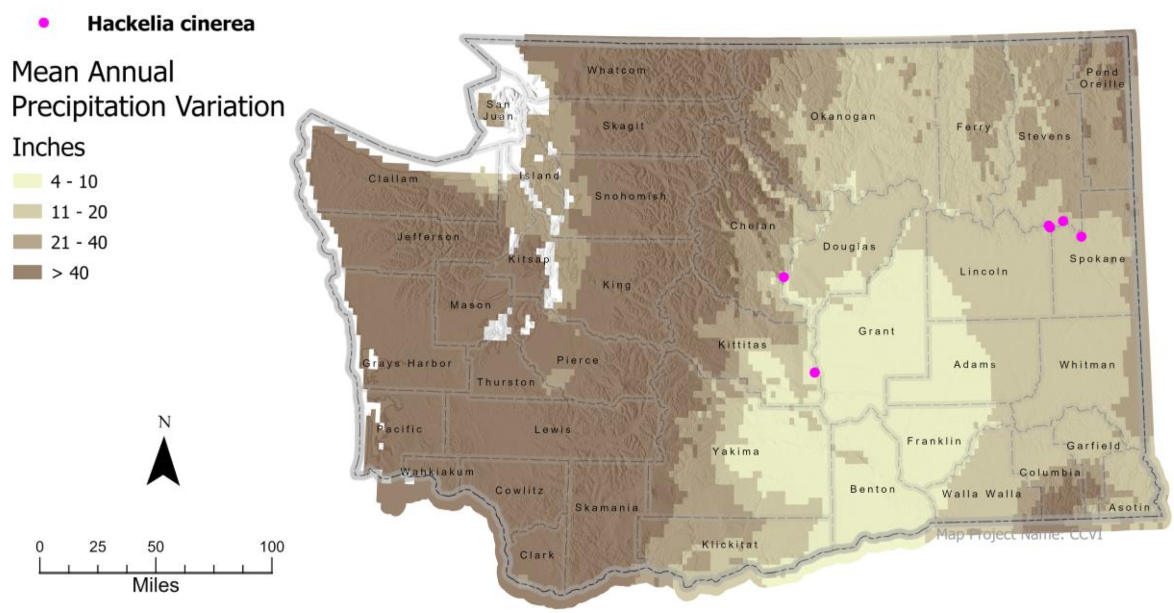

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Hackelia cinerea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
The mossy cracks in exposed rock where *Hackelia cinerea* occurs are right alongside the Columbia River. These cliff-faces are typically dry and sparsely vegetated with the composition of the plant community depending greatly on microtopographic cliff features, such as aspect and vertical position, which determine hydrology as the cliffs are not replenished by groundwater but instead depend on slow seeping snowmelt (Clark 2012, Rocchio and Crawford 2015). Shifts in precipitation timing and amount combined with earlier snow melt and extended summer droughts are expected to have a low to moderate impact on Rocky Mountain Cliff, Canyon, and Massive Bedrock ecological systems (Rocchio and Ramm-Granberg 2017), but the potential drying of cliff microhabitats where limited moisture is retained in crevices will be of particular concern for *Hackelia cinerea.*

C2c. Dependence on a specific disturbance regime: Neutral
Wind, water, and gravity are forces acting upon cliff and bedrock habitats which lead to continuous erosion and constant change to the microhabitats that support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as

rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
Slow melting snow infiltrates cracks and crevices in rock outcrops and is an important moisture source during the growing season. Reductions in the amount of snowfall, or the timing of its melting due to climate change (Rocchio and Ramm-Granberg 2017) could have a negative impact on this species.

C3. Restricted to uncommon landscape/geological features: Neutral
Hackelia cinerea is found in cracks of exposed basalt with a thin soil layer granitic sand or small talus (Carr 1974, Washington Natural Heritage Program 2023). It is most commonly associated with shallow lithosols and Miocene-age outcrops of Wanapum basalt and secondarily with Quaternary fill (Washington Division of Geology and Earth Resources 2016). These formations are widely distributed in the Columbia Basin and along the rim.

C4a. Dependence on other species to generate required habitat: Neutral
Rocky Mountain Cliff, Canyon and Massive Bedrock ecological systems are shaped mostly by abiotic processes and erosion which shifts critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Hackelia cinerea* are not well documented but species in the genus *Hackelia* are known to be predominately outcrossing and are able to attract a broad array of pollinators from three dipteran families: Tachinidae, Syrphidae, and Bombyliidae, and two hymenopteran families of generalist bees: Halictidae and Megachilida (Carr 1974, Taylor 2008).

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
Hackelia cinerea is dependent on small mammals or birds for long-distance dispersal.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Tetraploid *Hackelia* spp. like *Hackelia cinerea* are known to be more susceptible to fungal attack than congeners and seed predation by insects can be a threat (Carr 1974).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Tetraploid *Hackelia* spp. tend to have very specific habitat requirements and occur only in sandy/rocky sites where competition is minimal as they are apparently poor competitors (Carr 1974). *Hackelia cinerea* occurs in areas that are sparsely vegetated and has few native or introduced competitors under the current climate regime. Projected climate change could make its habitat more conducive for lower elevation meadow species to invade (Rocchio and Ramm-Granberg 2017). *Bromus tectorum* is already noted in the vicinity of a few populations.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Hackelia cinerea does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic variation of *Hackelia cinerea* has not been reported but it occurs in somewhat small populations (<200 individuals) and might be expected to have lower genetic diversity due to founder effects or reproductive isolation. However, a rarer and more narrowly distributed endemic congener, *Hackelia venusta*, was found to have average genetic variation (Hipkins et al. 2003)

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Hackelia cinerea is a perennial herb that produces nutlets and has dichogamous bisexual flowers in which the stamens and pistils mature at different times (dichogamy) to promote out-crossing (Carr 1974, Gentry and Carr 1976, Washington Natural Heritage Program 2023). Most obligate outcrossing species that are pollinated by a range of species, such as Hackelia *cinerea*, have moderate or average genetic variability (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Hackelia cinerea* (early May to mid-July, fruiting as early as mid-June) has not changed significantly (Washington Natural Heritage Program 2023). Cold exposure (vernalization) is critical for triggering flowering in the genus *Hackelia* which may be an indicator that warming will alter the phenology of *Hackelia cinerea* and further studies are warranted (Carr 1974).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no direct reports of *Hackelia cinerea* declining in response to climate change. This species is known from 5 extant occurrences and one potential misidentification in Washington that has not been revisited since 1975. Occurrence data appear to show declines for most populations, but further study is required to confirm trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Hedysarum occidentale **(western hedysarum)**

Date: 13 March 2024 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	86
	-0.051 to - 0.073	14
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Neutral

4g. Forms part of an interspecific interaction not covered above	Somewhat Increase
5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Not Ranked
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All seven known occurrences (100%) of *Hedysarum occidentale* in Washington occur in areas with a projected temperature increase of less than 3.9° F (2.2° C; Figure 1).

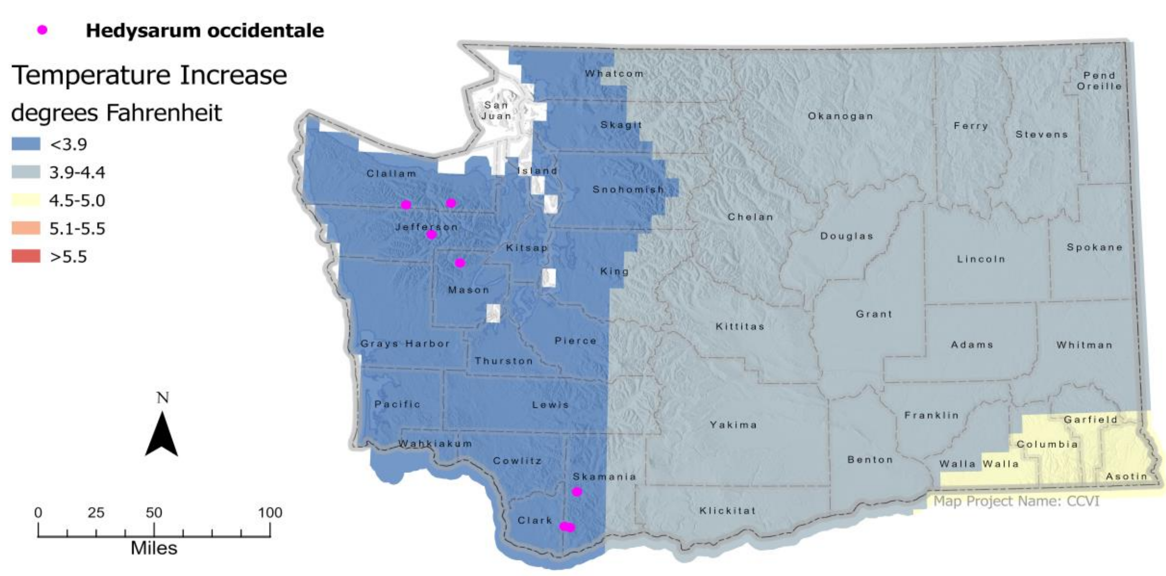

Figure 1. Exposure of *Hedysarum occidentale* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the seven known occurrences (86%) of *Hedysarum occidentale* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2). The remaining occurrence (14%) is in an area with a project decrease of -0.051 to - 0.073.

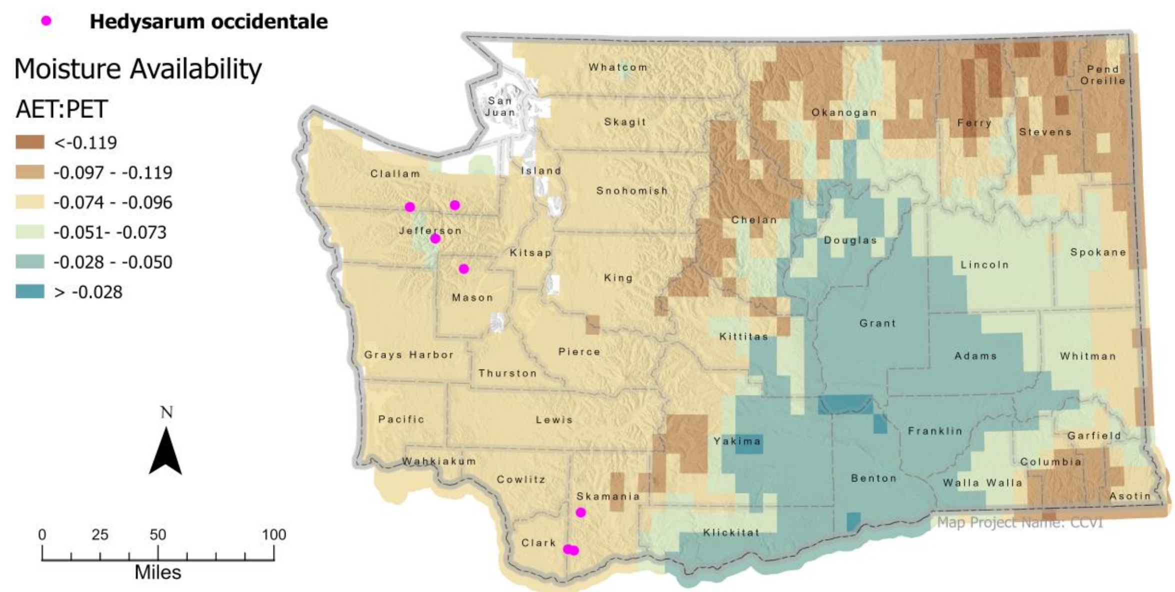

Figure 2. Exposure of *Hedysarum occidentale* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
The rocky ridges and alpine meadows where *Hedysarum occidentale* occurs are at and above timberline (3150-6500 ft (960-1980 m)) where sea level rise will not be a risk (Washington Natural Heritage Program 2023, Office for Coastal Management 2024).

B2a. Natural barriers: Increase
Hedysarum occidentale occurs among steep outcrops, summit ridges, and alpine meadows in the North Pacific Alpine & Subalpine Bedrock & Scree and North Pacific Montana Massive Bedrock, Cliff, & Talus ecological systems (Rocchio and Crawford 2015). These habitats are naturally very patchy and occur in disconnected mountain ranges in Washington with large areas of unsuitable habitat between them. Occurrences are separated by 18-165 mi (29-266 km) of dense forest and valley habitats which pose major barriers to dispersal and migration between ranges, resulting in low habitat connectivity. There is limited room for populations to move

upward with climate change. *Hedysarum occidentale* may be at risk of following an "elevator to extinction" as the coolest climatic zones of the alpine are lost (Watts et al. 2022).

B2b. Anthropogenic barriers: Neutral
The rugged, high elevation terrain where *Hedysarum occidentale* occurs remains relatively uninhibited by direct anthropogenic barriers as there are few roads and little human infrastructure in the area. However, recreation impacts and logging activities are of some concern due to their proximity to occurrences.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
Occurrences of *Hedysarum occidentale* are mostly on lands protected from development and occur in rugged subalpine to alpine terrain that is unlikely to be targeted for clean energy development, though there is a proposed parcel in the general vicinity of the Chopaka Mountain occurrence.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Hedysarum occidentale produces flattened pod fruits (loments) that are more conspicuously winged than other members of the genus (Welsh 1995, Holmgren et al. 2005, Washington Natural Heritage Program 2023), which could aid in short-distance dispersal on wind. Unlike other members of the genus, primarily in the *Hedysarum boreale* complex, this species does not have spines on the fruits to aid in animal dispersal (Northstrom and Welsh 1970). The similar erect stem structure of the congener *Hedysarum alpinum* is thought to slightly increase dispersal distance and this species is also thought to disperse by passive means such as gravity and water (Gucker 2007). *Hedysarum occidentale* probably exhibits local non-specific dispersal, mostly within a short distance of the parent plant (<1000 m).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Hedysarum occidentale* occurrences in Washington. One of the seven known occurrences (14%) is in an area that has experienced very little temperature variation (less than 37° F (20.8° C)) over the historical period. According to Young et al. (2016), this population is expected to be highly vulnerable to climate warming. The remaining six known occurrences (86%) are in areas that have experienced low temperature variation (37 - 47° F (20.8 - 26.3° C)) and are expected to be vulnerable to climate warming.

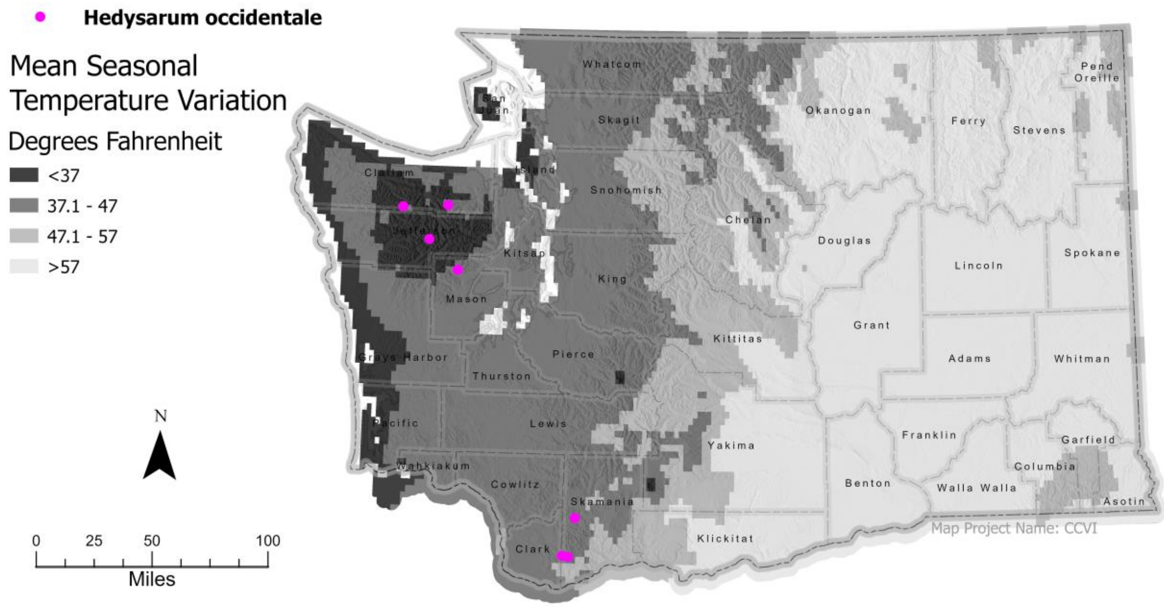

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Hedysarum occidentale* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
Hedysarum occidentale is found on rocky, exposed sites in the subalpine and alpine including meadows, shrublands, bare rock outcrops, and talus slopes (Washington Natural Heritage Program 2023). These microsites range from north-facing to south-facing, are typically dry, and remain cold and snow covered for much of the year due to their high elevation and exposure to high winds (NatureServe 2024). Warming temperatures are expected to extend the growing season and potentially increase competition from other plants that are adapted to drier environments and may increase thermal stress on the plant community (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Hedysarum occidentale* occurrences in Washington. All seven known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

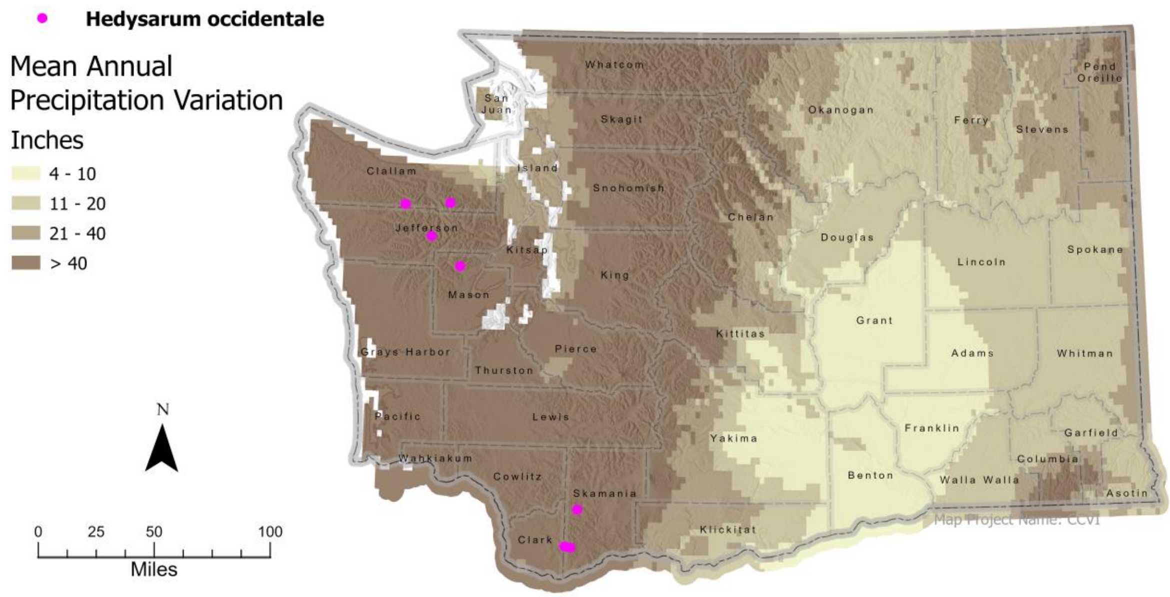

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Hedysarum occidentale* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
The North Pacific Alpine and Subalpine Bedrock and Scree habitats where *Hedysarum occidentale* occurs rely primarily on snowmelt for a steady supply of moisture throughout the growing season as they are not connected to groundwater (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). This species is found both on dry scree slopes receiving limited moisture and in moist meadows or moraines near streams which could subirrigate its habitat. Ongoing and projected reductions in the amount of snow, conversion of snow to rain, and changes in the timing of snowmelt could alter the amount of moisture available for this species under climate change (Rocchio and Ramm-Granberg 2017). However, conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and may increase the habitat available to *Hedysarum occidentale* (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Wind, water, and gravity are forces acting upon scree and talus habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation rather than major disturbance events (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes and associated meadows (Larson et al. 2000). These forces are unlikely to be strongly affected by climate change, however,

increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates and rising temperatures may impact freeze-thaw cycles and may even increase fire risk in these normally fire-free ecological systems (Chersich et al. 2015, Rocchio and Ramm-Granberg 2017). The congener *Hedysarum alpinum* is considered to be an early seral colonizer after disturbance, appearing after river scour and sometimes fire (Gucker 2007).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
The high elevation scree and meadow communities which support *Hedysarum occidentale* experience long winters with high snow accumulation as most precipitation falls as snow (Raymond et al. 2014). For example, the Olympic Mountains average over 400 in/10 m of snow annually (National Park Service 2021).

C3. Restricted to uncommon landscape/geological features: Neutral
Hedysarum occidentale is found growing at the edges of summits and cliffs in extremely shallow soils to deep soils (though soil development is usually limited) over bedrock or in shale/outcrops. Soils range from mesic to dry and are usually ashy or sandy loams. Parent materials include Needles Gray marine sedimentary rock, rhythmic sandstone and shale, andesite flows, and Crescent formation basalts. Most of these geological features are relatively common in Western Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The scree and talus ecological systems (and associated meadows) which support *Hedysarum occidentale* are shaped mostly by abiotic processes and mass wasting events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015, NatureServe 2024)

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The exact pollinators of *Hedysarum occidentale* have not been documented, but the major pollinators of other *Hedysarum* spp. in Alaska from similar dry alpine/subalpine slope habitats include Megachilid bees, especially *Bombus flavifrons* (McGuire 1993). The closely related congener *Hedysarum alpinum* requires insect visitors to set seed, also primarily bees (Gucker 2007). Like other *Hedysarum* spp., *Hedysarum occidentale* is probably pollinated by generalist Hymenopterans and does not appear to be pollinator restricted. Based on its low genetic diversity, *Hedysarum occidentale* may be expected to rely more on self-pollination but this is unconfirmed (Bushman et al. 2007).

C4d. Dependence on other species for propagule dispersal: Neutral
Hedysarum occidentale doesn’t have any specialized structures for animal attachment, unlike congeners such as *Hedysarum spinosissimum* which have prickles on fruits for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Hedysarum occidentale is a host to muscoid flies which are pre-dispersal seed and fruit predators (Kaye 1999). It is also a preferred forage source for mountain goats in the Olympic Mountains (Pfitsch and Bliss 1985) and is a key spring and autumn food for bears (Ransom et al. 2018). It is

unknown how foraging might change for this species with climate change, but insect herbivory is likely to increase and negatively impact the reproduction of this species (Liu et al. 2024).

C4f. Sensitivity to competition from native or non-native species: Neutral
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation scree, talus, and herbaceous bald ecological systems which support *Hedysarum occidentale*, and most of the plants in these ecological systems are "cushion", "turf", or "dwarf" species (Rocchio and Crawford 2015). Plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017). In areas with deep enough soil, trees and shrubs may also begin to encroach as the climate changes (Raymond et al. 2014). Weedy *Hieracium* spp. are already well established at some of the occurrences and could compete with *Hedysarum occidentale* (Washington Natural Heritage Program 2023).

C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase
Host-specific nitrogen fixing rhizobia colonize the roots of *Hedysarum* spp. (Krishna 1993). This relationship could be impacted by climate change in multiple directions. Nodule development may increase and help to provide drought protection to the plant under moderate warming but severe warming is expected to decrease or even stop rhizobial activity (Abd-Alla et al. 2014).

C5a. Measured genetic variation: Somewhat Increase
Hedysarum occidentale exhibits lower percentages of polymorphic loci and genetic diversity than congeners of the *Hedysarum boreale* complex (Bushman et al. 2007). Additionally, the occurrences in the Olympic Mountains are disjunct from the core range and other occurrence in Washington. Therefore, they are probably genetically distinct from other populations with which gene flow is not possible and so may have lower overall genetic diversity due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Not Ranked
Hedysarum occidentale is closely related to *Hedysarum alpinum* which is hermaphroditic but self-incompatible and can also spread vegetatively via rhizomes (Gallwey 2011). This factor was not formally ranked due to the inclusion of C5a. Measured genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Hedysarum occidentale* (June to August) has not changed significantly (Washington Natural Heritage Program 2023). However, SEINet (swbiodiversity.org) records from the early 1900s document flowering into September, though there are not enough records to establish a trend of change.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown

Hedysarum occidentale is known from at least 6 extant occurrences and 1 historical occurrence in Washington, most recently observed in 2020 (Washington Natural Heritage Program 2023). The direct response of this species to climate change is unknown. However, models of Olympic Mountain endemic species which overlay with part of the range of *Hedyarum occidentale* are projected to experience extensive habitat loss (Wershow 2017).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Hypericum majus (Canadian St. John's-wort)

Date: 15 May 2024 Synonym: *Hypericum canadense* var. *majus*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	70
	<3.9° F (2.2°C) warmer	30
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	50
	-0.074 to -0.096	35
	-0.051 to -0.073	0
	-0.028 to -0.050	5
	>-0.028	10
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Unknown
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Six of 20 known occurrences (30%) of *Hypericum majus* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C). The remaining 14 known occurrences in Washington are found in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4° C; Figure 1).

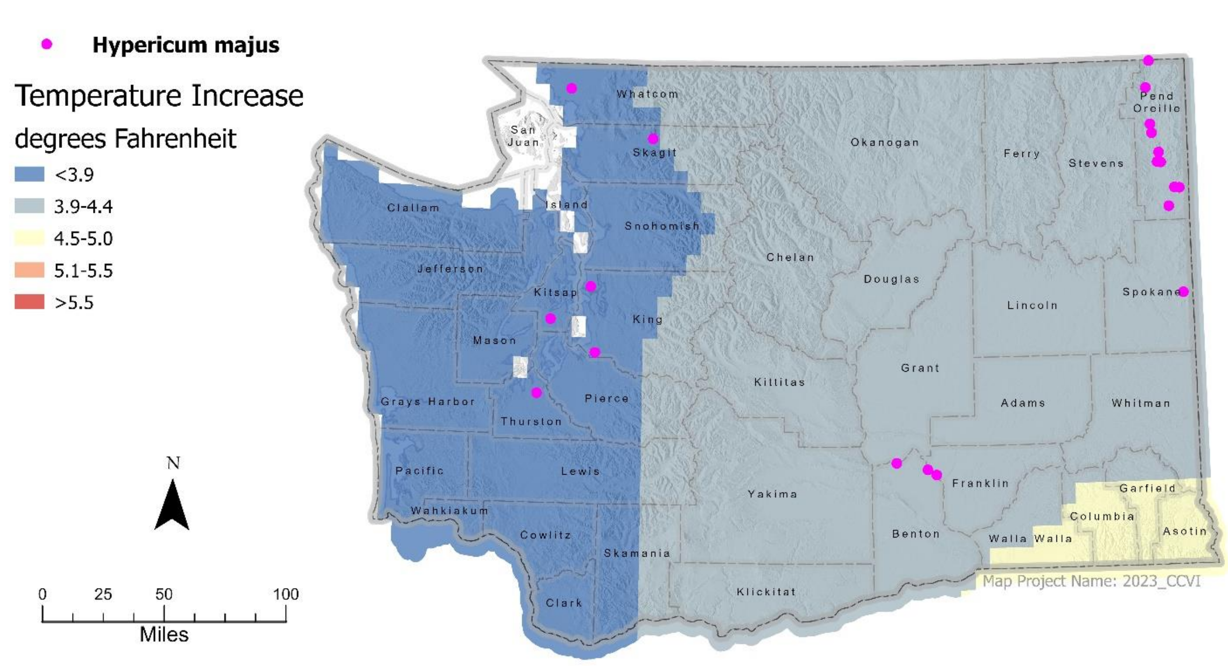

Figure 17. Exposure of occurrences of *Hypericum majus* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of 20 known occurrences (10%) of *Hypericum majus* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of >-0.028. One occurrence (5%) is found in an area with a projected decrease in available moisture in the range of -0.028 to -0.050. Seven (35%) are found in areas with a projected decrease in available moisture in the range of -0.074 to -0.096. The remaining 10 known occurrences (50%) in Washington are found in areas with a projected decrease in available moisture in the range of -0.097 to -0.119.

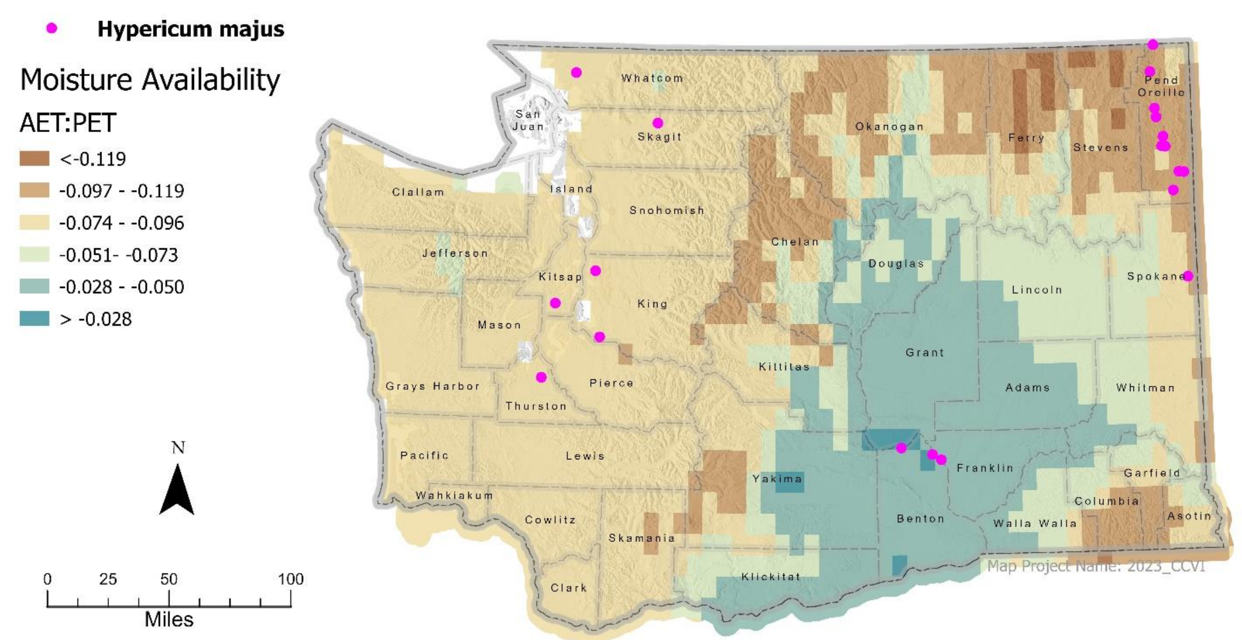

Figure 18. Exposure of occurrences of *Hypericum majus* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Hypericum majus is a facultative wetland species and usually occurs in habitats that are inundated for at least part of the year, either naturally or due to hydroelectric dams. This species occurs at elevations of 50–2340 ft (15–715 m; Washington Natural Heritage Program 2024). All element occurrences are inland and would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
Hypericum majus occurs in North American Arid West Emergent Marsh, Rocky Mountain Subalpine-Montane Fen, and Temperate Pacific Freshwater Emergent Marsh ecological systems

(Washington Natural Heritage Program 2024). These are all small-patch ecological systems. In eastern Washington, emergent marshes are not uncommon, but are separated by a matrix of arid upland habitat types. In western Washington, emergent marshes are separated by a matrix of upland forests. Temperate Pacific Freshwater Emergent Marsh ecological systems are widespread but declining (Rocchio and Crawford 2015).

B2b. Anthropogenic barriers: Somewhat Increase
Anthropogenic activities—including farming and wetland fill—have reduced the connectivity between marshes in eastern Washington. Temperate Pacific Freshwater Emergent Marsh ecological systems in western Washington have experienced significant declines and degradation due to human activities such as development, agriculture and timber harvest, or water management. In eastern Washington, nearly all emergent marshes are impacted by invasive species, water diversion, and grazing (Rocchio and Crawford 2015).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Hypericum majus* (Washington Department of Natural Resources 2024). However, existing hydroelectric dams (considered a clean energy source) currently affects the habitat for some occurrences of *Hypericum majus*. This species frequently grows in habitats that are inundated for part of the year, so existing hydroelectric dams may not present an additional threat to this species.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Hypericum majus has small (0.02 in (0.55 mm long)) seeds without wings, hairs, or other traits that suggest wind or animal dispersal (Washington Natural Heritage Program 2024). These seeds are smaller than in most other *Hypericum* species. *Hypericum majus* is invasive in Europe (Szkudlarz et al. 2019), where it likely was introduced from military equipment used in World War II (Milanović et al. 2018), indicating its capacity to establish vigorously in new habitats once it disperses. Seeds are potentially dispersed by wind and water (Hilty 2020), and though dispersal distances are not documented for this species, occasional dispersal of up to 3,280 ft (1000 m) seems likely.

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Hypericum majus* occurrences in Washington. Six of 20 known occurrences (30%) are in areas that have experienced small (37–47° F/20.8–26.3° C) temperature variation over the historical period. According to Young et al. (2016), these populations are expected have increased vulnerability to climate warming. The remaining occurrences (70%) are in areas that have experienced average (>57.1° F/31.8° C) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

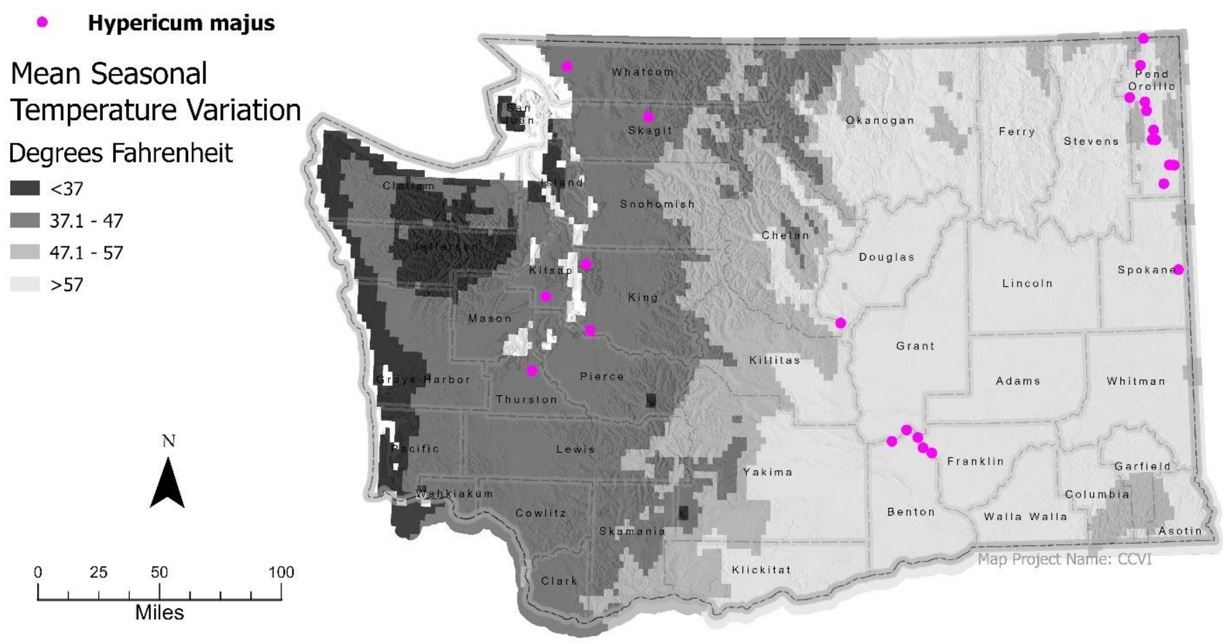

Figure 19. Historical thermal niche (exposure to past temperature variations) of occurrences of *Hypericum majus* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Arid marshes are sensitive to increased temperatures (Rocchio and Ramm-Granberg 2017). The pond, lake, fen, and marsh sites occupied by *Hypericum majus* are often associated with cool, conditions or cold air drainage during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 ("historical hydrological niche") across the distribution of known *Hypericum majus* occurrences in Washington. Three of 20 known occurrences (15%) are in areas that have experienced small precipitation variation (4–10 in (100–254 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be vulnerable to climate change-induced shifts in precipitation and moisture regimes. The remaining 17 known occurrences (85%) are in areas that have experienced average or greater than average precipitation variation (>20 inches/508 mm) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

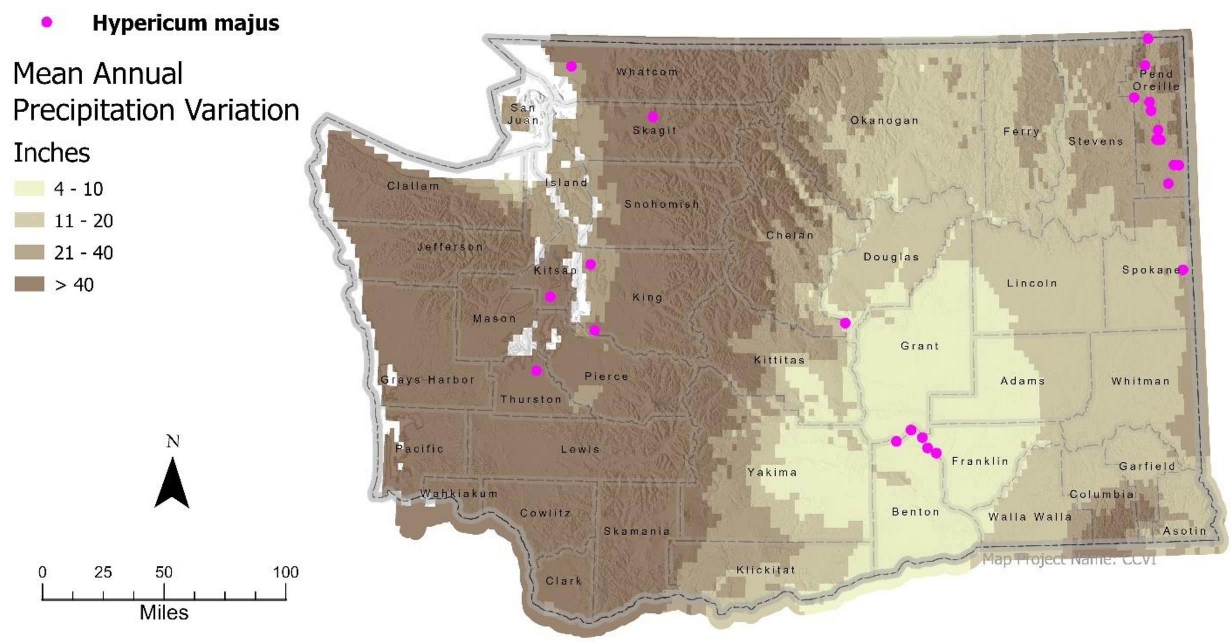

Figure 20. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Hypericum majus* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: <u>Increase</u>
Occurrences from eastern Washington in the North American Arid West Emergent Marsh ecological system are at risk from increased temperatures and reduced precipitation or snowpack leading to prolonged drought and potential shifts in vegetation from marsh to wet meadow. Occurrences from western Washington in the Temperate Pacific Freshwater Emergent Marsh are likely to be affected by changes in flooding and precipitation patterns, which could also potentially shift marshes to wet meadows. The occurrence from northeastern Washington found in the Rocky Mountain Subalpine-Montane Fen ecological system could be negatively affected by changes in the timing or amount of precipitation or winter snow, increased drought, and conversion of habitat to drier vegetation (Rocchio and Ramm-Granberg 2017). Together, this suggests that *Hypericum majus* faces increased climate vulnerability due to its hydrological niche.

C2c. Dependence on a specific disturbance regime: <u>Increase</u>
Marsh ecological systems depend on flooding events or fluctuating water levels for creation and maintenance. Climate change is likely to change precipitation patterns, which could shift emergent marsh habitats to wet meadows (Rocchio and Ramm-Granberg 2017). In Europe, this species is frequently found in disturbed areas (Milanović et al. 2018, Szkudlarz et al. 2019). However, human disturbance of emergent marshes in Washington are more likely to degrade

habitat for *Hypericum majus* (e.g. by altering hydrological processes this species depends on to maintain its habitat). Changes in hydrology from dams (either eliminating floods entirely or permanently inundating former habitat) is an important threat to this species (Camp and Gamon 2011). Increased drought or lower precipitation from climate change could make natural flooding events less common or less predictable in the future, hastening the conversion of emergent marsh habitat to wet meadow or riparian shrub or forest communities (Rocchio and Ramm Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: <u>Neutral</u>
Hypericum majus is not directly dependent on ice or snow-covered habitats. However, occurrences in fen habitats in northeastern Washington are vulnerable to shifts in vegetation towards wet meadows or swamp forests because of potential changes in the amount of available water from precipitation and snowpack (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: <u>Neutral</u>
Hypericum majus is found in mud and silty soils, frequently on glacial deposits or outwash, but also in other sedimentary deposits, basalt, and gneiss substrates, and does not appear to rely on any restricted geologic substrate (Washington Division of Geology and Earth Resources 2016). Marshes in eastern Washington may have alkaline chemistry, but this is widely variable between wetlands (Rocchio and Crawford 2015), and the fact that it also occurs in fens which are typically somewhat acidic suggests that it is not limited by water chemistry.

C4a. Dependence on other species to generate required habitat: <u>Neutral</u>
Beaver are important to creating emergent marsh habitat in montane ecological systems. Emergent marshes have declined with beaver populations in the western U.S. (Rocchio and Crawford 2015). However, abiotic factors may be a larger driver in creating and maintaining the habitats favored by *Hypericum majus*.

C4b. Dietary versatility: <u>Not applicable for plants</u>

C4c. Pollinator versatility: <u>Neutral</u>
Little information is available regarding the pollinator relationships of *Hypericum majus*. In general, *Hypericum* species are assumed to offer only pollen and not nectar as a reward, though pollen alone can be an effective pollinator reward. Where pollinators are documented for other species of *Hypericum*, bees appear to be the most effective (Boyle and Menges 2001, Bartoš et al. 2015, Hilty 2020). CCVI analysis carried out for populations in New Jersey included pollination as a point of vulnerability for *Hypericum majus* (Ring et al. 2013). However, bee diversity is likely high enough in *Hypericum majus* habitat that pollinator availability is unlikely to be a limiting factor for this species' ability to respond to climate change (Young et al. 2016).

C4d. Dependence on other species for propagule dispersal: <u>Neutral</u>
Hypericum majus has small seeds without wings, hairs, or other traits that suggest wind or animal dispersal (Washington Natural Heritage Program 2024). Long-distance dispersals to Europe were due to human activity (Milanović et al. 2018), but animal or human facilitated transportation is probably not the main mode of dispersal for this species in Washington.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Grazing is a threat to North American Arid West Emergent Marshes, and both cattle and native ungulate grazing could shift vegetation communities towards wet meadows (Rocchio and Crawford 2015). Grazing pressure is not expected to be affected by climate change. Other information on herbivores or pathogens is not available for this species.

C4f. Sensitivity to competition from native or non-native species: Increase
Phalaris arundinacea—a frequent threat in Washington's emergent marshes—is present in at least four *Hypericum majus* element occurrences in Washington. *Cirsium arvense* and other weeds are also a concern at some sites in Washington. *Typha latifolia* will also invade disturbed emergent marshes and outcompete other native species (Rocchio and Crawford 2015). Reductions in the frequency of flooding or increased drought (with a lowered water table) due to climate change are likely to make emergent marshland habitats more vulnerable to displacement by plants associated with wet meadows, riparian shrublands, or woodlands (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
No other interspecific interactions are documented for this species.

C5a. Measured genetic variation: Not Ranked
Data are lacking on the genetic diversity within and between populations of *Hypericum majus* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Unknown
There is no information available regarding the reproductive system of *Hypericum majus*. The genus *Hypericum* appears to have a wide range of reproductive strategies, with some apomictic species and others likely to be obligate outcrossers. This makes it difficult to draw conclusions about the specific reproductive system or genetic diversity of this species.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Hypericum majus* (July to September) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Hypericum majus* declining in response to climate change. Not enough population information is available from the survey data to determine population trends in Washington.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Isoetes minima (midget quillwort)

Date: 30 October 2023 Synonym: *Isoetes howellii*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G1G2/S1
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	80
	-0.074 to - 0.096	20
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All five known occurrences (100%) of *Isoetes minima* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C; Figure 1)

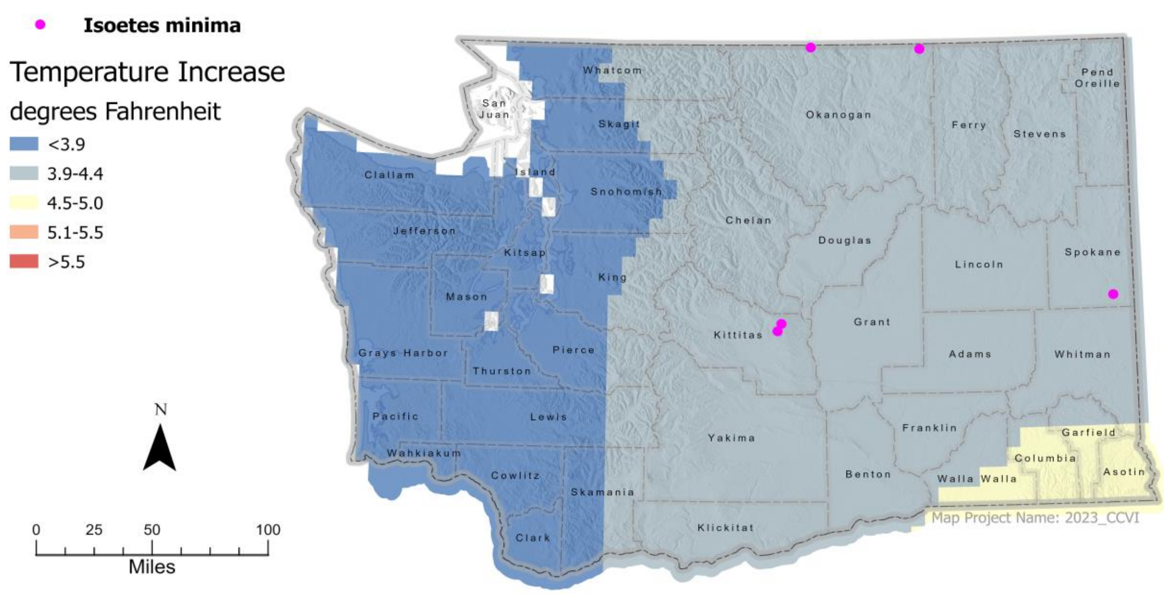

Figure 1. Exposure of *Isoetes minima* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four or five known occurrences (80%) of *Isoetes minima* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The remaining Spokane county occurrence (20%) is in an area with a projected moisture decrease of -0.074 to - 0.096.

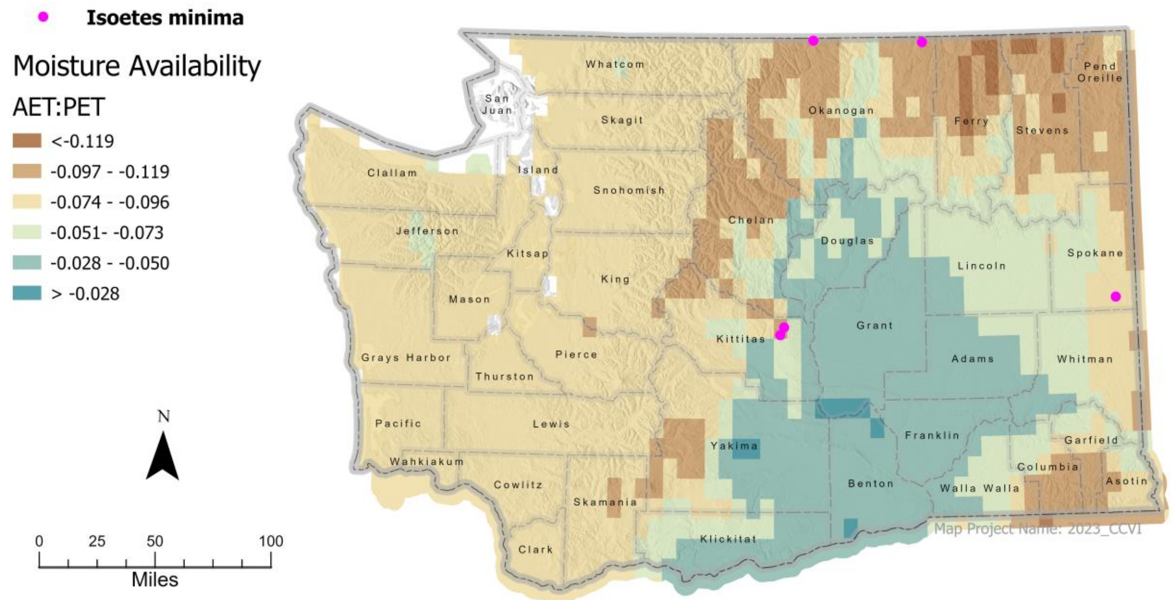

Figure 2. Exposure of *Isoetes minima* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Isoetes minima occurs in vernal pools, moist swales and on gentle slopes within montane grasslands at 4500-5390 ft (1370-1640 m). *Isoetes minima* populations in Washington are not expected to be affected by sea level rise based on their far inland distribution and mid-elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Increase
Populations occur in different disjunct mountain ranges separated by 5-141 mi (7-228 km) of unsuitable lowland habitat and cultivated lands. Vernal pool habitats are strongly tied to landscape features that are themselves widely scattered and isolated by strong natural barriers reducing the likelihood of successful dispersal.

B2b. Anthropogenic barriers: Neutral

Isoetes minima occurrences are found near roads, near trails, or within or adjacent to agricultural lands. Recreational activities such as mountain biking are known to impact the quality of *Isoetes minima* habitat and nearby roads are likely to pose a threat to current and potential habitat and but generally do not create a significant barrier to dispersal or migration (NatureServe 2023a). This habitat is generally safe from cultivation as the thin soils and bedrock are impractical for these uses (NatureServe 2023b).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the known populations of *Isoetes minima*, though grasslands and surrounding sagebrush-steppe may be targeted for solar and wind development (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Isoetes minima is a lycopod that releases both male and female spores which are largely dispersed by passive means and are thought to be highly reliant on water dispersion. Some *Isoetes* spp. are also transported short distances via animal attachment or ingestion (Troia 2016). Colonization and dispersal is more difficult for heterospores as both spores must establish and produce nearby gametophytes to allow sexual reproduction. Overall, *Isoetes* has a somewhat limited dispersal ability (Maslovat et al. 2022), though spores may travel long distances on occasion.

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Isoetes minima* occurrences in Washington. Three occurrences (60%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The other two occurrences (40%) are in areas that have experienced average temperature variation of the historic period (>57.1° F (31.8° C)) and are expected to be mostly resilient to warming.

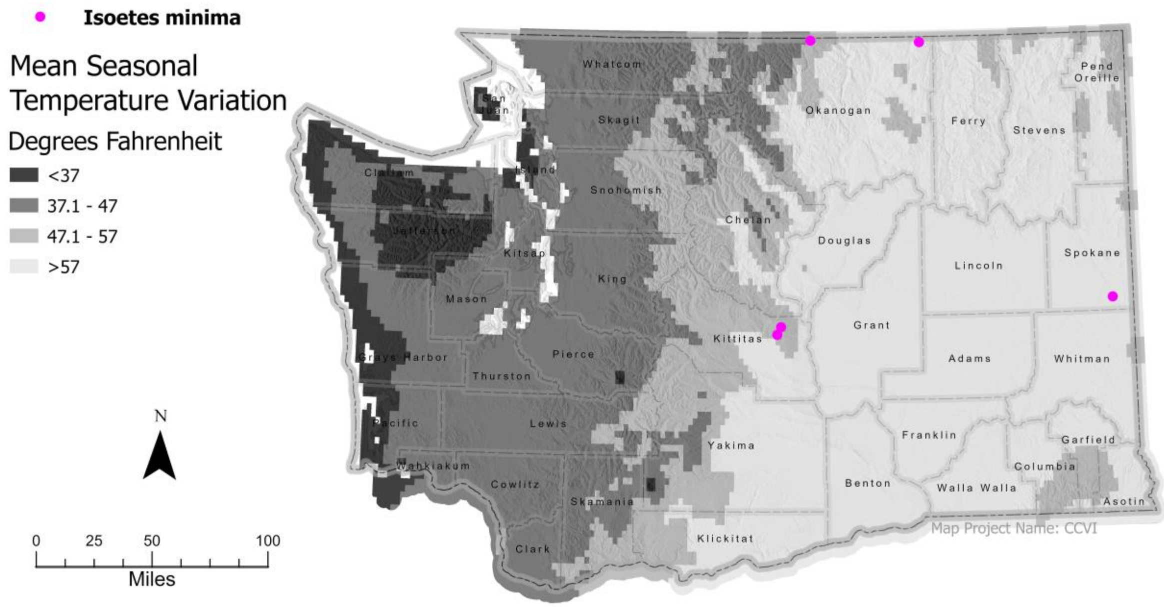

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Isöetes minima* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Somewhat Increase</u>
Isoetes minima is restricted to small vernal pools that often occur in full sun, upslope of exposed bedrock (Maslovat et al. 2022). Winters and springs are cold and wet, while summers are long and warm. Temperature increase is anticipated in these habitats, which will increase evapotranspiration and could lead to drying out of vernal pools (Rocchio and Ramm-Granberg 2017, NatureServe 2023b). Additionally, anticipated extreme heat events will likely have negative impacts on *Isoetes minima* (Maslovat et al. 2022).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Isoetes minima* occurrences in Washington. Two of the five known occurrences (40%) are in areas that have experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts in precipitation and moisture regimes. The other three occurrences (60%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) and are expected to be mostly resilient to climate change (Young et al. 2016).

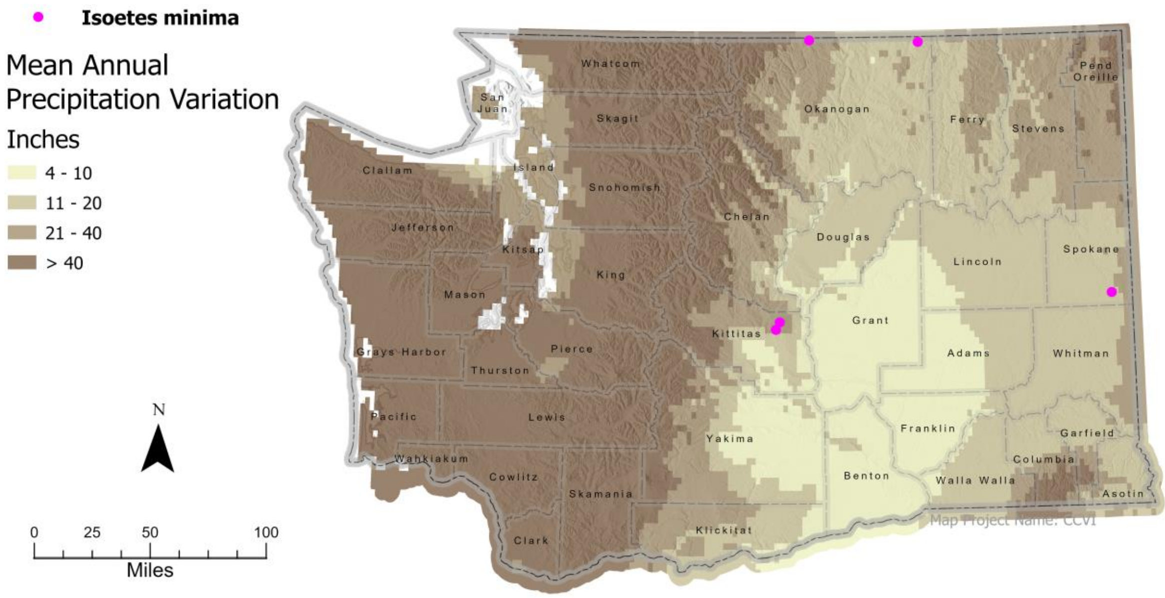

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Isöetes minima* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Isoetes minima is associated with vernal pools, seasonally wet depressions and swales, and vernal seeps in otherwise dry grasslands (Fertig 2021, NatureServe 2023a). The lifecycle of this species is closely connected to moisture availability and therefore it is threatened by activities that impact hydrology such as logging or road construction (NatureServe 2023a). Anticipated changes to precipitation type, timing, and amount combined with extended droughts may interfere with spore production, dispersal, and habitat availability by altering hydrological cycles (Rocchio and Ramm-Granberg 2017, Maslovat et al. 2022).

C2c. Dependence on a specific disturbance regime: Neutral
Columbia Plateau Vernal Pools are characterized by having strongly seasonal hydrology on top of basalt lithosols. The hydrological regime, combined with basin morphology, result in distinct vegetation zonation (Rocchio and Crawford 2015). The duration and depth of inundation are the principal drivers. Not much is known about the fire regimes of vernal pools but fire has been shown to have positive effects by reducing encroachment and non-natives (NatureServe 2023b).

C2d. Dependence on ice or snow-cover habitats: Neutral
Isoetes minima is often found on southern to eastern aspects that are free from snow in the early spring and in areas where ephemeral underground moisture travels on top of shallow bedrock.

Anticipated shifts in precipitation from winter snow to rain are likely to cause earlier drying of the ecological system (Rocchio and Ramm-Granberg 2017, Maslovat et al. 2022). Other than impacts to the water supply of the habitat, *Isoetes minima* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Neutral
Isoetes minima grows on thin, moist mineral soils over impermeable basalt bedrock and granodiorite which are relatively common in Washington. (Rocchio and Crawford 2015, Washington Division of Geology and Earth Resources 2016, NatureServe 2023a, 2023b). *Isoetes minima* does not appear to be highly restricted to an uncommon geological feature.

C4a. Dependence on other species to generate required habitat: Neutral
The vernal pool habitat of *Isoetes minima* is largely shaped by seasonal hydrological changes and is not dependent on other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Lycopods like *Isoetes minima* produce and self-release spores and do not have pollinators. Fertilization instead depends on water to allow sperm to be motile and travel to egg cells.

C4d. Dependence on other species for propagule dispersal: Neutral
There is some evidence of animal transport over short distances via zoochory and endozoochory in *Isoetes* spp., though these modes of dispersal are not primary (Troia 2016).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Livestock grazing is likely to have a negative effect on vernal pools as it may allow for the establishment of non-native species and shift composition to favor perennial native upland and wetland species over vernal pool obligates which are typically annual species (Rocchio and Crawford 2015, NatureServe 2023b). However, there is no evidence that climate change is interacting with or increasing livestock grazing in this ecological system.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
The thin soils and limited moisture of *Isoetes minima* habitats somewhat limit the establishment of vigorous competitors and other vegetation is either absent or largely comprised of moss (Maslovat et al. 2022). However, drying of the vernal pools, combined with recreation and other anthropogenic activities, can increase the establishment of non-natives, such as *Centaurea stoebe, Cirsium arvense,* and *Phalaris arundinacea* and allow tree and shrub encroachment (NatureServe 2023a, 2023b, Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). These species can shade out *Isoetes minima,* alter hydrology by absorbing seepage flow, and increase fuel loading (Rocchio and Crawford 2015).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Isoetes minima does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Isoetes minima* has not been well studied but its global rarity (fewer than 10 populations) and small population sizes make this species sensitive to stochastic effects (NatureServe 2023a) and inbreeding depression. However, despite limited dispersal abilities, other *Isoetes* spp. have been shown to have moderate to high levels of genetic diversity (Chen et al. 2005, Gentili et al. 2010).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Like other pteridophytes, *Isoetes minima* follows a life cycle with two alternating independent generations; gametophytes that depend on mycorrhizae and produce separate male and female organs and dominant heterosporous sporophytes (Washington Natural Heritage Program 2023). This species is a sexual diploid and therefore probably does not have especially low genetic diversity (Young et al. 2016, Maslovat et al. 2022). Some *Isoetes* spp. require sexual outcrossing while others can also self-fertilize and/or spread via rhizomes.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the sporulation period of late-June to mid-August has not changed significantly (Washington Natural Heritage Program 2023), though there are few available records which note phenological phase. Some studies have shown that increasing temperatures may cause asynchronous production of microspores and macrospores which can lead to decreased fertilization (Čtvrtlíková et al. 2014)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The impacts of climate change on *Isoetes minima* are largely undocumented and population trends in Washington are poorly understood, though Canadian populations are thought to be sustaining (Maslovat et al. 2022). Three of four known occurrences have been revisited and confirmed since 2000 and a new population has possibly been documented as of 2021 in a roadside ditch in the Blue Mountains (Washington Natural Heritage Program 2023). The historical population was in what is now a converted/cultivated grassland near Spokane.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled in Washington. Downscaled climate model projections in the Kootenay Region of Canada predict increased temperatures and decreased snowpack in the range of *Isoetes minima,* which are likely to interfere with spore production and dispersal (Maslovat et al. 2022).

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

***Isoetes nuttallii* (Nuttall's quillwort)**

Date: 6 November 2023 Synonym: *Isoetes opaca, Isoetes suksdorfii*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4?/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	67
	<3.9° F (2.2°C) warmer	33
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	40
	-0.074 to - 0.096	33
	-0.051 to - 0.073	27
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the 15 known occurrences of *Isoetes minima* in Washington, 10 (67%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C), and five (33%) occur in areas with a projected increase of less than 3.9° F (2.2°C; Figure 1). One island occurrence in San Juan county was excluded because no projections were available.

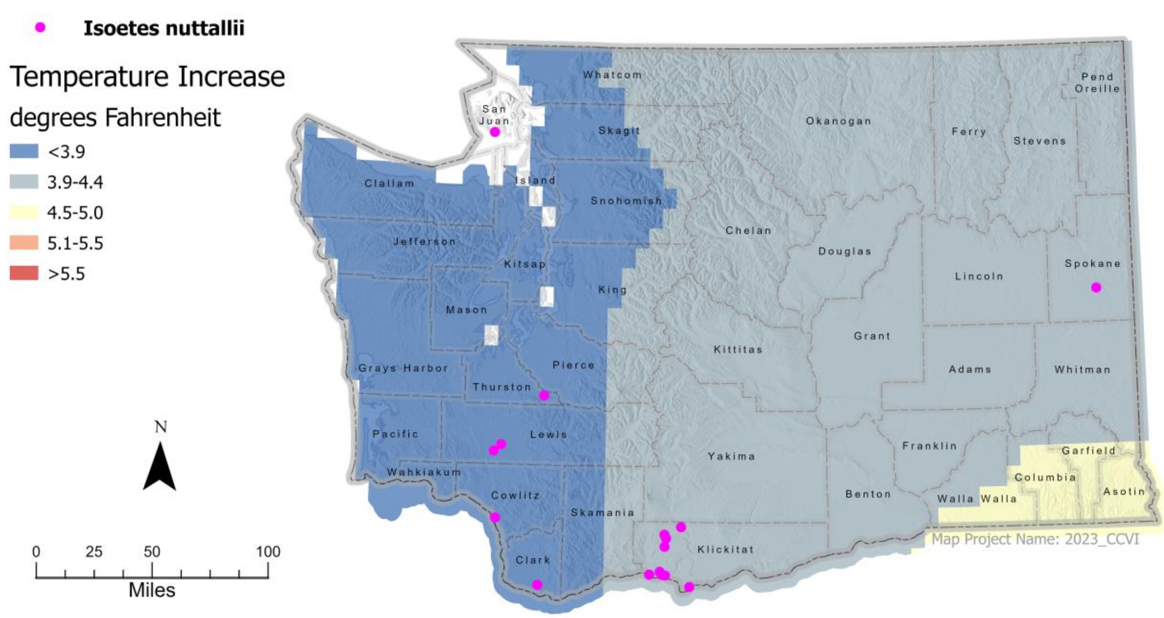

Figure 1. Exposure of *Isoetes nuttalii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six known occurrences (40%) of *Isoetes nuttallii* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2). Five occurrences (33%) are in areas with a projected moisture decrease of -0.051 to - 0.073. The remaining four occurrences (27%) are in areas with a projected moisture decrease of -0.028 to - 0.050. Note: one island occurrence was excluded because no projections were available.

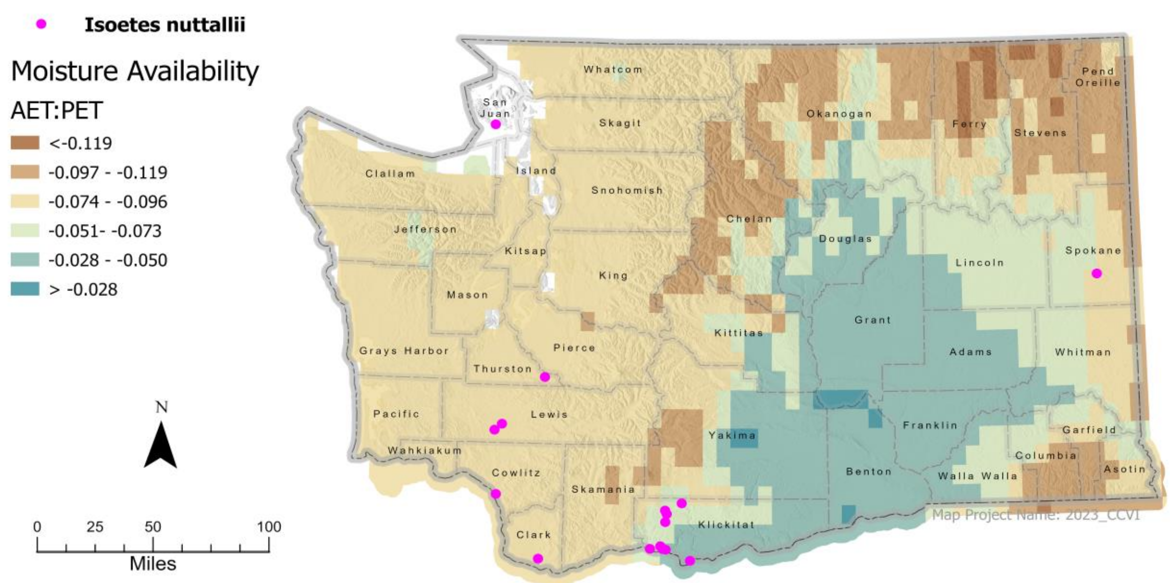

Figure 2. Exposure of *Isoetes nuttallii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Isoetes nuttallii is found in vernal seeps and pools among grasslands at low to mid-elevations ranging from 200-345 ft (60-105 m; Washington Natural Heritage Program 2023). Most occurrences are too far inland to be at risk of direct exposure to sea level rise and the single coastal occurrence near Longview will not be at risk as sea level rise is not anticipated to exceed a maximum of 10 ft (Office for Coastal Management 2023).

B2a. Natural barriers: Increase
Isoetes nuttallii is restricted to shallow ephemeral water bodies (vernal pools) in wet prairies along the Columbia River and in the Puget Sound region (Rocchio and Crawford 2015). Occurrences of this species are very fragmented across Washington state, and some are not well connected to the core range which spans from British Columbia to California. These occurrences

are separated by large stretches of unsuitable forest and dry lowland habitat between occurrences ranging from 2-279 mi (3-449 km) apart. Otherwise, there is moderate access to suitable habitat that may be locally abundant and available for dispersal from extant populations but occurs in small patches in a larger forest matrix. Dispersal between populations is naturally restricted.

B2b. Anthropogenic barriers: <u>Somewhat Increase</u>
Roads, development, and cultivated land occur between many occurrences and potentially pose a barrier to dispersal and movement of this species. Several occurrences are unprotected on private lands or along highway corridors, while some are within protected areas such as natural areas and state parks. Surrounding cultivated and developed land that was once potentially suitable habitat and that has now been degraded or reduced significantly,

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten the known occurrences of *Isoetes nuttallii*, though its low lying grassland habitats may be targeted for solar and wind development in the future (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Somewhat Increase</u>
Isoetes nuttalii is a lycopod that releases both male and female spores which are largely dispersed by passive means and are thought to be highly reliant on water dispersion. Some *Isoetes* spp. are also transported short distances via animal attachment or ingestion (Troia 2016). Colonization and dispersal is more difficult for heterospores as both spores must establish and produce nearby gametophytes to allow sexual reproduction. Overall, *Isoetes* has a limited dispersal ability (Maslovat et al. 2022), though spores may at times travel long distances.

C2ai. Historical thermal niche: <u>Somewhat Increase</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Isoetes nuttallii* occurrences in Washington. Five of the 15 known occurrences (33%) are in areas that have experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016) these populations are likely to be vulnerable to climate warming. Another six occurrences (40%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) and are expected the be somewhat vulnerable to warming (Young et al. 2016). The remaining four occurrences (27%) are in areas that have experienced average variation average (>57.1° F (31.8° C)) and are expected to be mostly resilient to warming (Young et al. 2016). Note: one island occurrence in San Juan County was excluded because no projections were available.

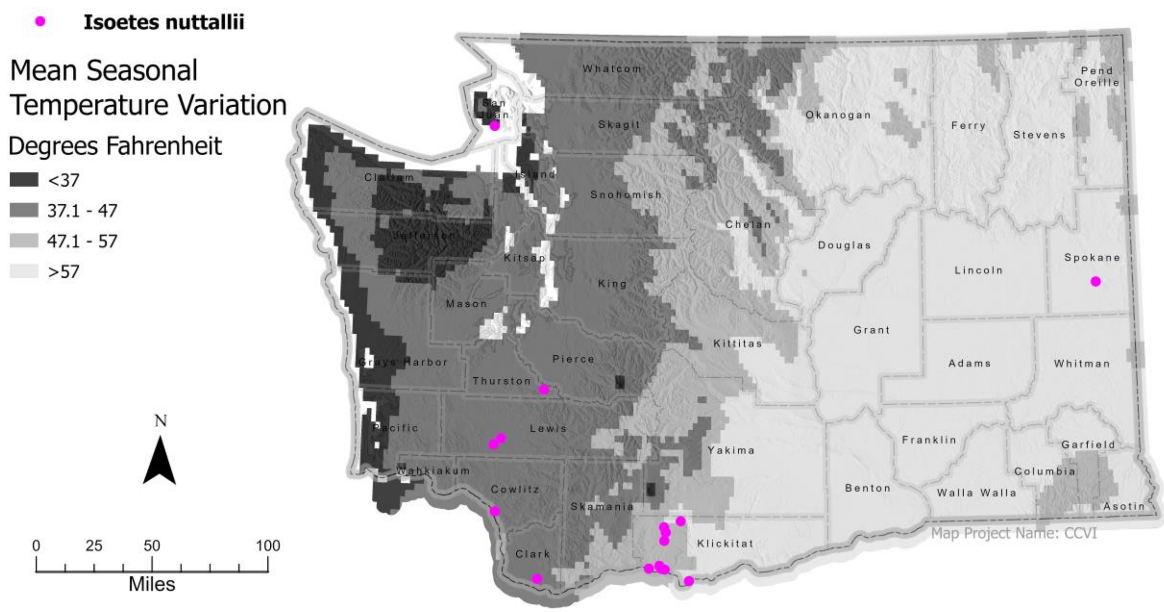

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Isoetes nuttallii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Isoetes nuttallii is restricted to vernal seeps and pools that often occur in full sun, on south-facing balds and in grassy openings (Maslovat et al. 2022). Winters and springs are cold and wet, while summers are warm. Warming temperatures will increase evapotranspiration and could lead to temporal changes in the hydrology of this species' habitat (Rocchio and Ramm-Granberg 2017, NatureServe 2023). Anticipated extreme heat events will likely have negative impacts on *Isoetes nuttallii* (Maslovat et al. 2022), but this species may be somewhat resilient due to its occurrence in warmer and dryer microsites.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Isoetes nuttallii* occurrences in Washington. Three of the 15 known occurrences (20%) are in areas that have experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The remaining 13 occurrences 87%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) and are anticipated to be mostly resilient to changes (Young et al. 2016).

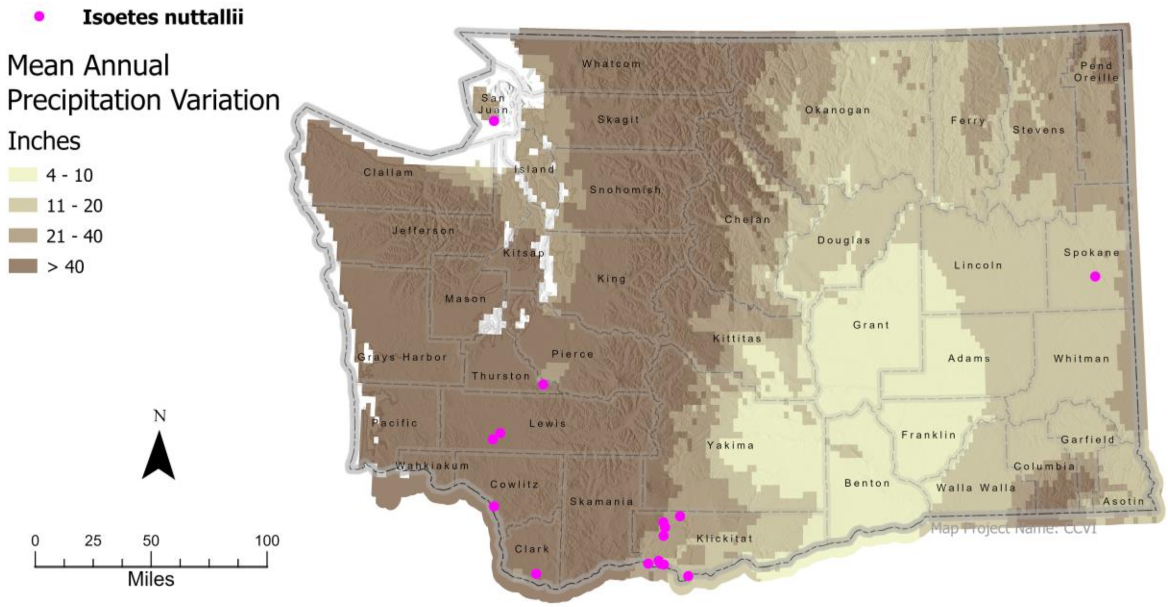

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Isoetes nuttalii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
The lifecycle of *Isoetes nuttallii* is closely connected to a seasonal hydrological regime, where slight inundation often occurs in winter and spring followed by steady decreases in soil moistures by summer's end (Rocchio and Crawford 2015). Changes in precipitation timing and amount, and extended droughts are likely to interfere with spore production, dispersal, and habitat availability. Hydrological changes from climate change could result in some vernal pools being lost from the landscape while other pools may simply be reduced in size or lose ecological function (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Vernal pools are characterized by having strongly seasonal hydrology which can result in distinct vegetation zonation (Rocchio and Crawford 2015). The duration and depth of inundation are the principal drivers of the ecological system rather than major disturbances. Not much is known about the fire regimes of vernal pools but fire has been shown to have positive effects by reducing encroachment and non-natives (NatureServe 2023). Wet prairies in western Washington developed with periodic and dynamic fire, similarly to oak-prairie landscapes, which helps to prevent shrub encroachment (Rocchio and Crawford 2015). Climate change is anticipated to increase temperatures and shift the timing and type of precipitation in this ecological system, which will change the inundation frequency, timing, and duration of vernal

pools and could shift composition in wet prairies (Rocchio and Ramm-Granberg 2017). However, increases in fire frequency in wet prairies could expand the range of wet prairies as woody species are cleared.

C2d. Dependence on ice or snow-cover habitats: Neutral
Anticipated shifts in precipitation from winter snow to rain may reduce flow of seepages and cause earlier drying in *Isoetes nuttallii* habitat (Maslovat et al. 2022). Other than impacts to the water supply of the habitat, *Isoetes nuttallii* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Isoetes nuttallii grows on clay-rich soils, ashy loams, and Aqualfs. Western Washington populations are generally associated with the Willamette Valley Wet Prairie ecological system. This ecological system type is primarily found on clay-rich soils in the South Sound region, glacial outwash prairies in Lewis and Cowlitz counties, on in areas affected by the Missoula floods in Clark County (Rocchio and Crawford 2015). The northerly wet prairies are restricted to swales and riparian areas where surface topography intersects local groundwater tables (Easterly et al. 2005). Aquitards may have also formed from lahars or volcanic ash in these areas, resulting in wet prairie development (Easterly et al. 2005).

C4a. Dependence on other species to generate required habitat: Neutral
The vernal pool and wet prairie habitat of *Isoetes nuttallii* is largely shaped by seasonal hydrological changes and fire and is not dependent on other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Lycopods like *Isoetes minima* produce and self-release spores and do not have pollinators. Fertilization instead depends on water to allow sperm to travel to egg cells.

C4d. Dependence on other species for propagule dispersal: Neutral
There is some evidence of animal transport over short distances via zoochory and endozoochory in *Isoetes* spp., though these modes of dispersal are not primary (Troia 2016).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Pathogens have not been documented. Livestock grazing is known to have a negative effect on vernal pools and wet prairies and could allow the introduction of non-natives and shift composition to favor native upland and wetland species over vernal pool obligates, as well as damage soil crusts (Rocchio and Crawford 2015, NatureServe 2023). However, there is no evidence that climate change is interacting with or increasing grazing in this ecological system.

C4f. Sensitivity to competition from native or non-native species: Increase
The clay soils which are periodically water-logged in the habitat of *Isoetes nuttallii* typically limit the establishment of vigorous competitors and other vegetation is either absent or largely comprised of moss (Maslovat et al. 2022). However, drying of the ecological system combined with recreation and grazing can quickly increase the establishment of non-natives, such as *Hieracium caespitosum* and *Phalaris arundinacea,* and allow tree and shrub encroachment

(Rocchio and Crawford 2015, NatureServe 2023). These species can shade out *Isoetes nuttallii,* alter hydrology, and increase fuel loading (Rocchio and Ramm-Granberg 2017). Field observations indicate that invasive species are locally a severe problem, especially when water remains low for extended periods of time.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Isoetes minima does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Isoetes nuttallii* has not been well studied. However, despite limited dispersal abilities, other *Isoetes* spp. have been shown to have moderate to high levels of genetic diversity (Chen et al. 2005, Gentili et al. 2010).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Like other pteridophytes, *Isoetes nuttallii* follows a life cycle with two alternating independent generations; gametophytes that depend on mycorrhizae and produce separate male and female organs and dominant heterosporous sporophytes (Washington Natural Heritage Program 2023). This species is probably a sexual diploid and therefore does not have especially low genetic diversity (Young et al. 2016, Maslovat et al. 2022). Some *Isoetes* spp. require sexual outcrossing while others can also self-fertilize and/or spread via rhizomes.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (early-May to late-July) has not changed significantly (Washington Natural Heritage Program 2023). Additional monitoring is warranted as some studies have shown that increasing temperatures may cause asynchronous production of microspores and macrospores which can lead to decreased fertilization (Čtvrtlíková et al. 2014).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The impacts of climate change on *Isoetes nuttallii* are largely undocumented and population trends in Washington are poorly understood. Most occurrences have been relocated and confirmed to be extant in recent years. *Isoetes nuttalli* may actually be even more widespread in Washington than is currently known, as it is an inconspicuous species that can be easily looked over (Washington Natural Heritage Program 2023).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Young, B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report
Juncus tiehmii **(Tiehm's rush)**

Date: 19 Oct 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4/S1
Index Result: Moderately Vulnerable Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	100
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral/Somewhat Increase

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: The single known occurrence (100%) of *Juncus tiehmii* in Washington occurs in an area with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C) (Figure 1).

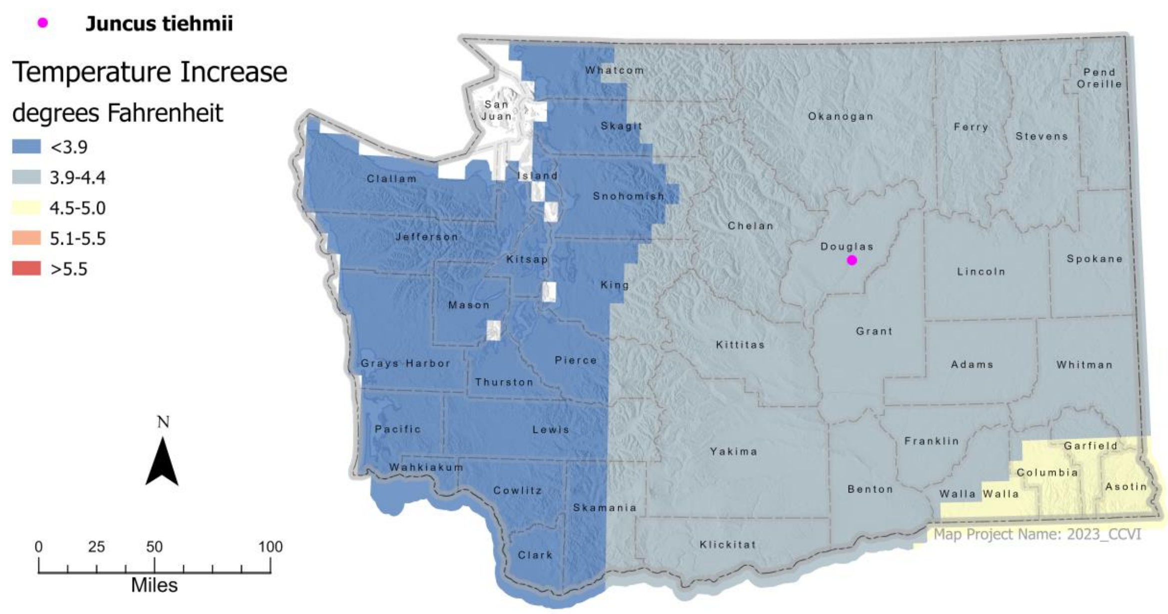

Figure 1. Exposure of *Juncus tiehmii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single known occurrence (100%) of *Juncus tiehmii* in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.028 to -0.050 (Figure 2).

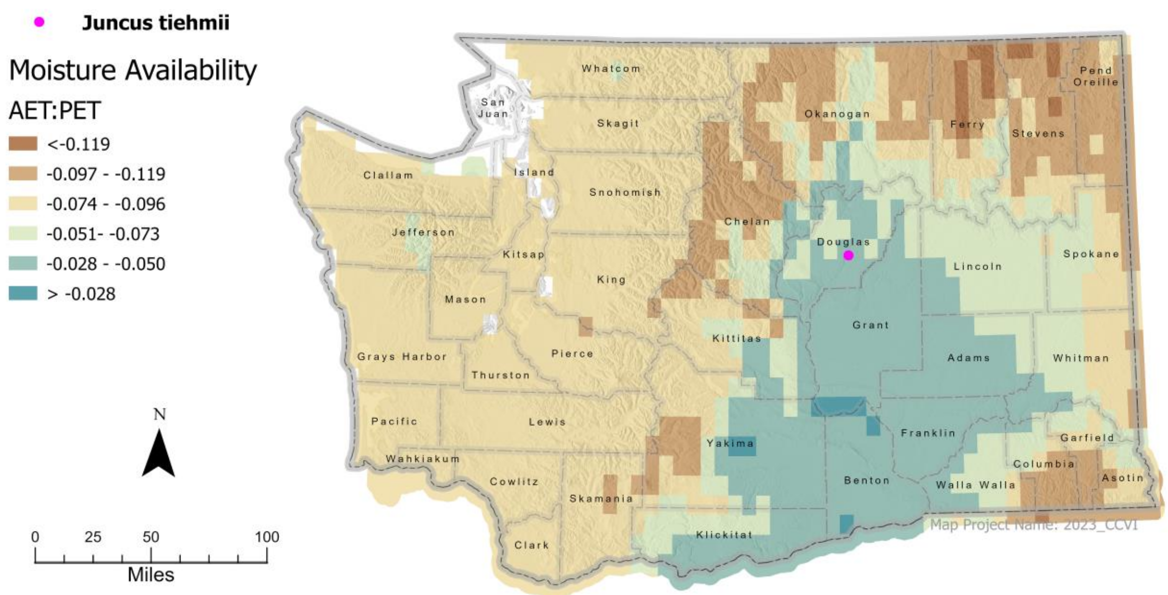

Figure 2. Exposure of *Juncus tiehmii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Juncus tiehmii is associated with moist areas around outcrops, rocky benches, and meadow depressions within sagebrush steppe at low elevations (Washington Natural Heritage Program 2023). The only occurrence in Washington grows around 1970 ft (600 m; NatureServe 2023) in Douglas County. These populations are not expected to be affected by sea level rise based on their far inland distribution and mid-elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Increase</u>
The Washington population of *Juncus tiehmii* occurs on a seepy bench above a canyon in the Columbia Plateau Vernal Pool ecological system (Washington Natural Heritage Program 2023). This occurrence is disjunct from the core range of this species which is located near the borders of California, Oregon, and Nevada (Washington Natural Heritage Program 2023). Vernal pools occur as small to large patches that are separated by unsuitable dry upland habitat (e.g., shrub steppe) which may pose a barrier to movement of this species.

B2b. Anthropogenic barriers: Neutral
The Washington population occur on BLM managed lands managed for multiple use and on private lands but are currently not particularly threatened by major roads or development.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the population of *Juncus tiehmii* (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Juncus tiehmii produces a 2-3 chambered capsule which dehisces to release multiple heavy seeds with no special adaptations for dispersal (Washington Natural Heritage Program 2023). The specific dispersal mechanisms of this species are not well studied or documented but it may be like other *Juncus* spp. which rely primarily on passive means of dispersal over short distances by wind and water. Additionally, some *Juncus* spp. are covered in sticky mucilage that allows for animal attachment and dispersal (Salisbury 1974).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of the known *Juncus tiehmii* occurrence in Washington. The single known occurrence (100%) is in an area that has experienced average or greater than average temperature variation (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016), this population is expected to be resilient to climate warming.

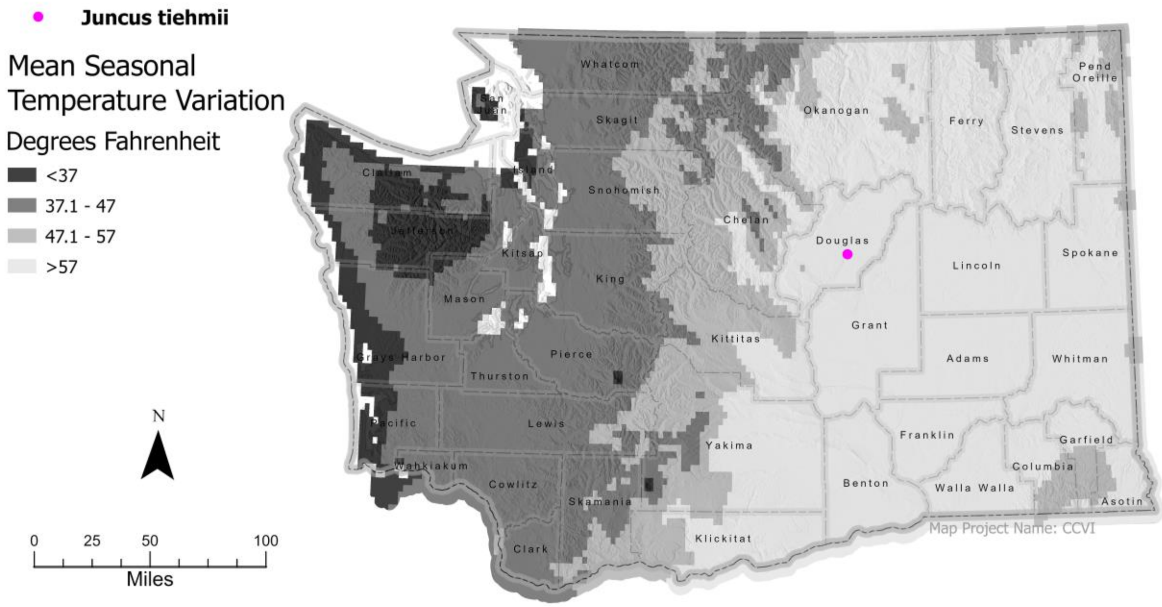

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Juncus tiehmii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Juncus tiehmii tolerates a wide temperature gradient across its continental range but prefers cooler temperatures that do not fully evaporate vernal pools or ephemeral water sources. Washington's vernal pools experience extreme seasonal changes where cool winters are followed by hot, dry summers. (Crowe et al. 1994). Winters (and summers) in this ecological system are expected to get warmer, which will increase evapotranspiration and could lead to some pools permanently drying out while others may contract in extent from increased drying (Rocchio and Ramm-Granberg 2017, NatureServe 2023). However, this species is already exposed to these conditions in the summertime and may be somewhat resilient to warming.

C2bi. Historical hydrological niche: <u>Somewhat Increase</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") for the known *Juncus tiehmii* occurrence in Washington. The single known occurrence (100%) is in an area that has experienced slightly lower than average precipitation (11-20 in (255-508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes.

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Juncus tiehmii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Across its range, *Juncus tiehmii* associates with bare areas of moist granitic sand near streams, seeps, and meadow depressions which are dependent on winter and early spring precipitation to maintain hydrology (Washington Natural Heritage Program 2023). This species is found in the portions of vernal pools that retain soil moisture into the summer months or at the edge of more permanent water bodies. Anticipated changes to precipitation type, timing, and amount combined with extended droughts may interfere with habitat availability and could lead to drying of vernal pools (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Columbia Plateau Vernal Pools are largely shaped by seasonal inundation patterns which, combined with basin morphology, create fine scale zonal patterns of vegetation (Rocchio and Crawford 2015). The duration and depth of inundation are the principal drivers of the ecological system rather than other major disturbances. Not much is known about the fire regimes of vernal pools but fire has been shown to have positive effects by reducing encroachment and non-natives (NatureServe 2023).

C2d. Dependence on ice or snow-cover habitats: Neutral
Anticipated temporal shifts in precipitation from winter snow to rain are likely to cause earlier drying of the ecological system (Rocchio and Ramm-Granberg 2017). Other than impacts to the

water supply of the habitat, *Juncus tiehmii* is not particularly associated with ice or snow-cover and occurs at lower elevations where snow may not persist late into the year.

C3. Restricted to uncommon landscape/geological features: Neutral
Juncus tiehmii grows on shallow soils over impermeable basalt bedrock that prevents drainage (NatureServe 2023). Soils range from silt to clay and with varying proportion of sand. This species associates with natural seeps and small to large depressions on basalt bedrock, glacial till, or impermeable caprock which may be rare in some landscapes but is locally common in eastern Washington (Rocchio and Crawford 2015, Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
The vernal pool habitat of *Juncus tiehmii* is largely shaped by seasonal hydrological changes and is not generally dependent on other species, though this species is commonly found in association with mosses which may help to maintain seasonal moisture later into the year.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Juncus tiehmii is probably wind-pollinated like other graminoids and *Juncus* spp. A few *Juncus* species have been found to also be pollinated by a generalist set of insects, including flies, bees, butterflies, beetles. Some are also capable of self-fertilization. *Juncus tiehmii* probably has a similar mixed mating system which is indicative of average genetic variation (Young et al. 2016)

C4d. Dependence on other species for propagule dispersal: Neutral
Juncus spp. depend primarily on passive means of dispersal such as wind and water but may have the ability to attach to animals to enhance dispersal distances.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Livestock grazing can result in the introduction of non-natives and shift composition to favor perennial upland and wetland species over vernal pool obligate, annual species, as well as damaging soil crusts (Rocchio and Crawford 2015, NatureServe 2023). However, there is no evidence that climate change is interacting with or increasing grazing in this ecological system.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Field observations for the Washington *Juncus tiehmii* population note the presence of some non-native species after soil disturbance from grazing livestock. Climate change induced drying of the ecological system combined with recreation and other anthropogenic activities can increase the establishment of non-natives, such as *Centaurea stoebe,* and allow tree and shrub encroachment (NatureServe 2023). These species can shade out *Juncus tiehmii,* alter hydrology by absorbing seepage flow, and increase fuel loading (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral/Somewhat Increase
Juncus tiehmii plants frequently grow in moss patches, probably because the moss mats help to retain moisture. Anticipated warming and drying of vernal pools may reduce moss survival and enhance moisture stress on *Juncus tiehmii.*

C5a. Measured genetic variation: Unknown
Juncus tiehmii occurs as a single, isolated disjunct population in Washington which makes outcrossing unlikely and increases the likelihood of lower genetic diversity due to genetic drift or inbreeding depression.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Juncus tiehmii is an annual graminoid that is hermaphroditic and slightly protogynous with flowers that only open for a couple of days, possibly in synchronized pulses (Michalski and Durka 2007, Washington Natural Heritage Program 2023). Vernal pool species like *Juncus tiehmii* are often annuals that complete their life cycles before soil moisture dries in summer (Crowe et al. 1994). Protogny probably indicates that *Juncus tiehmii* is largely outcrossing since selfing is inhibited and therefore probably has average genetic diversity (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of early-June to late-July has not changed significantly (Washington Natural Heritage Program 2023). However, there is only one record in Washington to indicate phenological phase.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The response of *Juncus tiehmii* to climate change has not been well studied or documented and there is no suitable data available to assess population trends in Washington. The single known population in Washington has remained relatively stable.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Young, B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Lathrocasis tenerrima (delicate gilia)

Date: 7 March 2024 Synonym: *Gilia tenerrima*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	67
	-0.028 to -0.050	33
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral/Somewhat Increase
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Not Ranked
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All three known occurrences (100%) of *Lathrocasis tenerrima* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

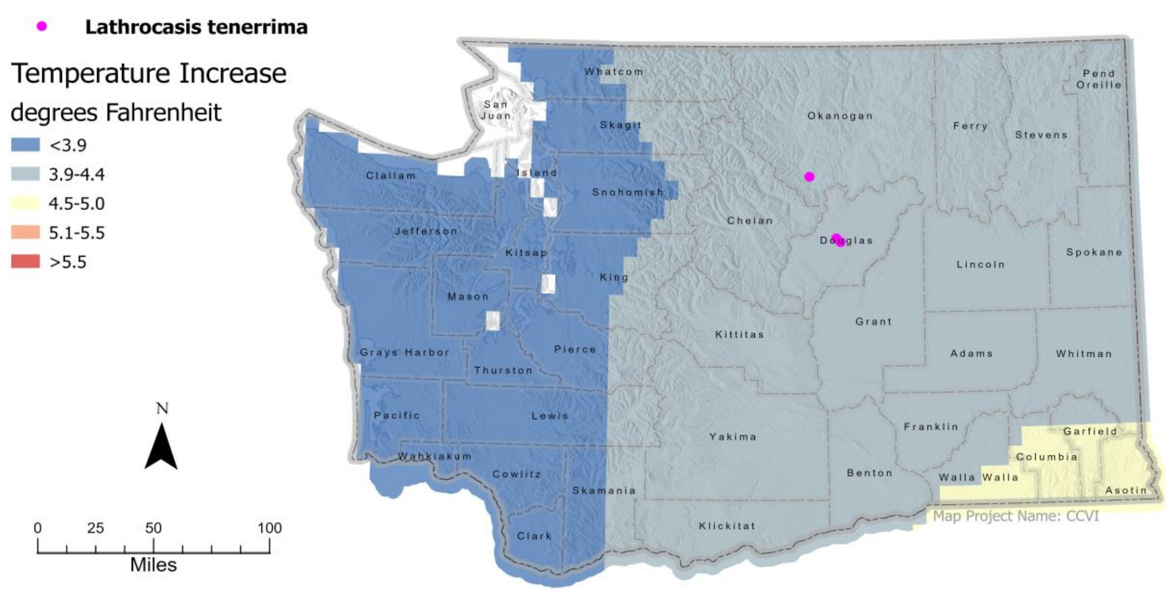

Figure 1. Exposure of *Lathrocasis tenerrima* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the three known occurrences (67%) of *Lathrocasis tenerrima* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to - 0.073 (Figure 2). The remaining occurrence (33%) is in an area with a project decrease of -0.028 to -0.050.

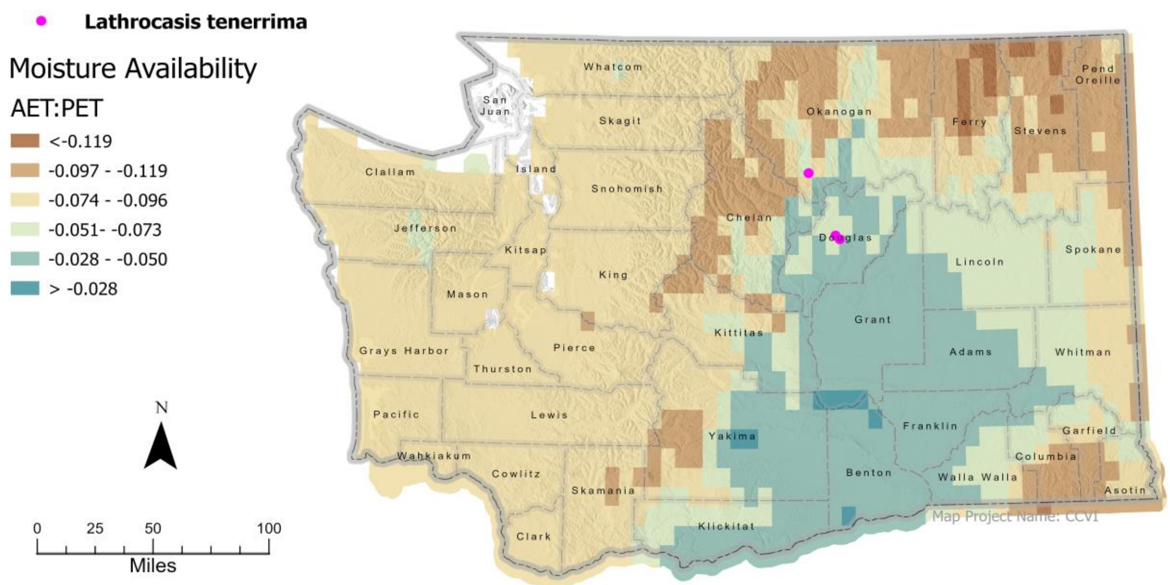

Figure 2. Exposure of *Lathrocasis tenerrima* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Lathrocasis tenerrima occurs on rock outcrops and openings in sagebrush steppe at mid elevations (1650-5380 ft (500-1640 m)) east of the Cascade crest (Washington Natural Heritage Program 2023). It is not at risk of sea level rise based on its inland distribution (Office for Coastal Management 2024)

B2a. Natural barriers: Neutral
Lathrocasis tenerrima occurs on ridge crests, rocky outcrops, and silty-gravelly openings in the Inter-Mountain Basins Big Sagebrush Steppe ecological system which is widely distributed but has been highly degraded and fragmented by agricultural development (Rocchio and Crawford 2015). These habitats are natural somewhat patchy in a landscape mosaic reflecting differences in topography and soils. Suitable microsites are still frequent within the mosaic and are not anticipated to cause major barriers to dispersal and occurrences in Washington are in close proximity. However, the Washington populations are extremely disjunct from the core range and are likely to be genetically isolated and unable to disperse to and from the core range.

B2b. Anthropogenic barriers: Increase

Much of the Inter-mountain Basins Big Sagebrush steppe that supports *Lathrocasis tenerrima* has been converted due to agriculture, though the rockier areas that this species prefers are spared. Two out of three occurrences in Douglas County (six occurrences total) are almost surrounded by agriculture with only small areas of suitable habitat remaining. Developed areas are significant and fragment suitable habitat, posing a significant barrier to dispersal and range shifts.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known clean energy projects intersecting the Washington occurrences but the development of the Pacific Northwest Hydrogen Hub may bring more development in the region (Washington Department of Natural Resources 2024). Flatter areas of the sagebrush steppe could be candidates for solar and fusion development in the future.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Somewhat Increase</u>
Lathrocasis tenerrima produces a one-seeded capsule fruit that dehisces at the valves to release seeds that become mucilaginous when wet (Washington Natural Heritage Program 2023, Day 2024). Sometimes the entire fruit releases and acts as a dispersal unit. The mucilaginous nature of seeds is common in the family Polemoniaceae and is often an adaptation to dry habitats that also prohibits dispersal to unfavorable habitats and allows for both endozoochorous and/or epizoochorous dispersal (Hsiao and Chuang 1981, Kreitschitz et al. 2021). *Lathrocasis tenerrima* does not have any other specialized structures to aid in longer distance dispersal and is probably passively dispersed a short distance from parents (328 ft (<100 m)) but may be able to disperse moderate distances on occasion with the aid of animals (328-3,280 ft (100-1000 m)).

C2ai. Historical thermal niche: <u>Neutral</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Lathrocasis tenerrima* occurrences in Washington. All three known occurrences (100%) are in areas that have experienced average temperature variation (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

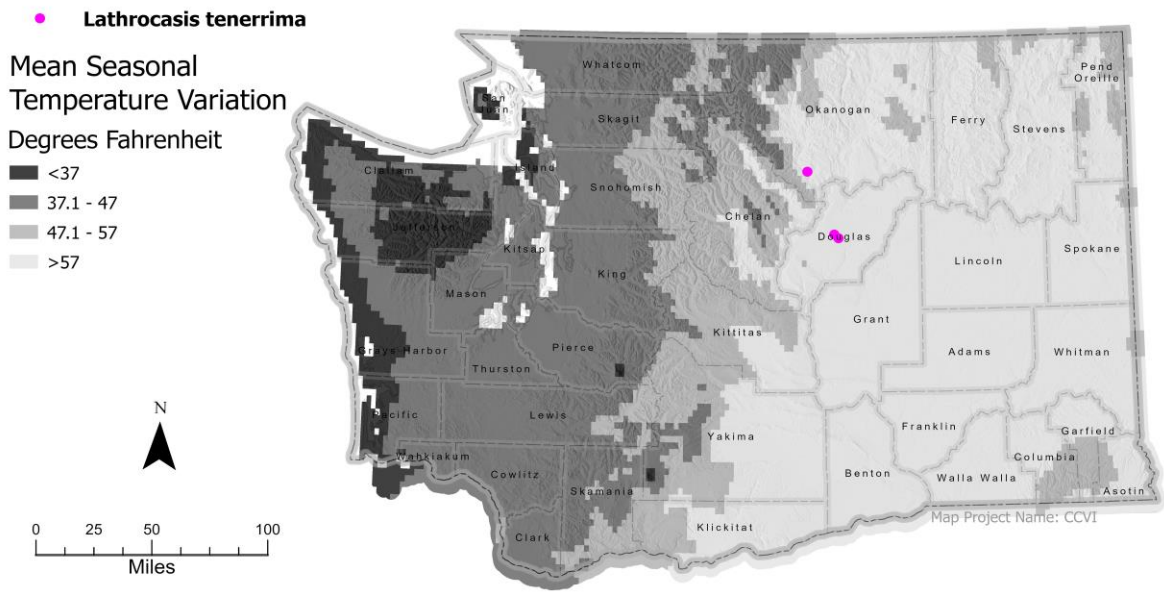

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lathrocasis tenerrima* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
Lathrocasis tenerrima occurs on bare gravel soils in sandy sagebrush scrub on south-facing embankments and slopes that are warm and dry (Washington Natural Heritage Program 2023). The Inter-Mountain Basins Big Sagebrush Steppe habitat of this species is not particularly associated with cold air drainage during the growing season and would have neutral vulnerability to climate change. However, warming soil temperatures and increased evapotranspiration could shift species composition in this ecological system (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Somewhat Increase

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Lathrocasis tenerrima* occurrences in Washington. All three known occurrences (100%) are in areas that have experienced slightly lower than average precipitation variation (11 - 20 in (255 - 508 mm)) over the historical period and are expected to be somewhat vulnerable to changes in available moisture (Young et al. 2016).

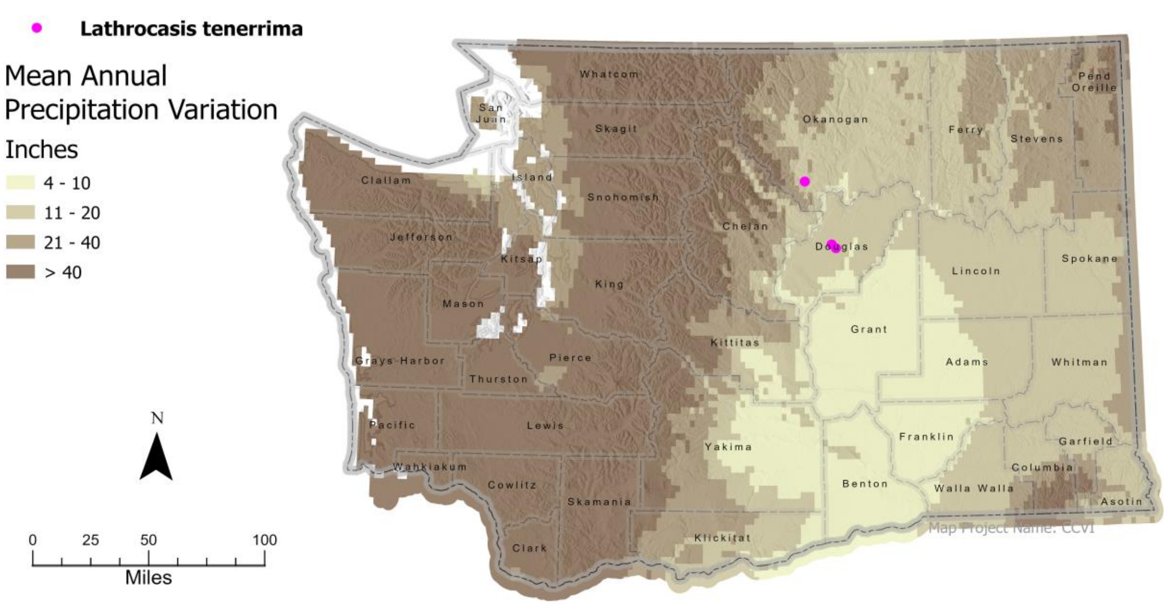

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lathrocasis tenerrima* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
The sagebrush steppe mosaic that supports *Lathrocasis tenerrima* is maintained primarily by fire regimes and soil moisture and is generally arid with varying amounts of winter precipitation (Rocchio and Crawford 2015). As this ecological system is not associated with groundwater and is dependent on adequate precipitation for its moisture requirements, it is vulnerable to anticipated changes in the timing and amount of precipitation coupled with increasing temperatures. Changes to these regimes may lead to more frequent severe drought, compositional changes that have the greatest impact on forbs, and increased fire frequency (Rocchio and Ramm-Granberg 2017). *Lathrocasis tenerrima* is known to prefer somewhat higher elevations with moderately increased precipitation in an otherwise arid landscape and may not be as resilient to drying (Johnson and Weese 2000).

C2c. Dependence on a specific disturbance regime: <u>Increase</u>

The sagebrush steppe ecological system that supports *Lathrocasis tenerrima* depends on periodic, low-intensity fire to maintain grassy openings and encourages perennial forbs (Rocchio and Crawford 2015). Altered fire regimes (e.g., increased frequency) will negatively impact this ecological system by shifting it to grassland habitat and/or increasing exotic species such as *Bromus tectorum* which can further alter fire cycles and lead to complete conversion (Rocchio and Ramm-Granberg 2017). Conversely, fire suppression can allow shrub encroachment which can lead to a decline in native grasses and forbs.

C2d. Dependence on ice or snow-cover habitats: Neutral
Snowpack is relatively low in the Columbia Plateau of eastern Washington where *Lathrocasis tenerrima* occurs and is a relatively minor component of this species' annual water budget.

C3. Restricted to uncommon landscape/geological features: Neutral
Lathrocasis tenerrima occurs on dry, barren silt-loam hills and gravel patches that are moderately deep over glacial till (Soil Survey Staff 2024). These soils are often calcareous at some depth and are relatively high in natural fertility. Soils are derived from a variety of parent materials including pre-Cretaceous orthogneiss, Pleistocene continental glacial drift, and Wanapum basalt (Washington Division of Geology and Earth Resources 2016). These substrates and parent materials are relatively common in the Columbia Basin.

C4a. Dependence on other species to generate required habitat: Neutral
Browsing by ungulates, rodents, and insects could help maintain open areas within big sagebrush steppe vegetation occupied by *Lathrocasis tenerrima* but drought and periodic low-intensity fire are more significant drivers (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral/Somewhat Increase
The specific pollinators of *Lathrocasis tenerrima* are not well documented but the tiny, short-funnelform flowers of this species are known to favor self-pollination (Johnson and Weese 2000, Landis et al. 2016). The family Polemoniaceae exhibits strong pollination syndromes based on the "lock and key" relationship between potential pollinators (bees, beetles, lepidopterans, hummingbirds, flies, and selfing/autogamy) and floral morphology (Rose and Sytsma 2021). The small white-lavender flowers of *Lathrocasis tenerrima* suggest dominant pollination by bees and bee-flies but this species may be an obligate self-pollinator which would mean that it is not pollinator limited at all (Landis et al. 2018).

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
The mucilaginous nature of the seeds of *Lathrocasis tenerrima* suggest that they may be attached to animals or spread through digestion, though this is unconfirmed (Hsiao and Chuang 1981, Kreitschitz et al. 2021). This species does not have any other adaptations for long-distance dispersal and would have to be transported by animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral

There are no known pathogens or major herbivores of *Lathrocasis tenerrima*, though trampling and grazing can damage biological soil crusts and are threats in this species' habitat (Washington Natural Heritage Program 2023).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Grazing, soil disturbances, and fire can remove the biological soil crust in this ecological system and open areas for exotic annual grasses such as cheatgrass (*Bromus tectorum)* to establish. Under projected future climate change, Inter-mountain Basins Big Sagebrush communities will be more prone to drought and increased frequency of wildfires, which in turn could lead to increased competition with non-native annual weeds (Rocchio and Ramm-Granberg 2017). A feedback cycle then occurs, with annual grasses spreading fires more broadly and homogenizing the formerly patchy distribution of shrubs. *Lathrocasis tenerrima* associates with open microsites with limited to moderately dense shrub cover and may not be negatively affected by the remove of shrubs but could struggle to compete and persist in cheatgrass monocultures.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Lathrocasis tenerrima does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Neutral
Despite being a highly-selfing species, *Lathrocasis tenerrima* appears to have moderate to high genetic diversity based on nucleotide variation and the diversity between its haplotypes exceeds levels of diversity seen between entirely separate species in the Polemoniaceae family (Johnson and Weese 2000). It is a tetraploid (Grant 2004), which may help to buffer climate change as latent pools of genetic diversity can allow better for range expansion (Johnson and Weese 2000, Young et al. 2016).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Not Ranked
Lathrocasis tenerrima is an annual with flowers that open only for one day and stigmas that are primed to make direct contact with anthers to facilitate self-pollination (autogamy) in the absence of pollinators (Johnson and Weese 2000, Landis et al. 2016). There are no studies which confirm whether self-pollination in this species is facultative or obligatory. This factor was not formally ranked due to the inclusion of information on genetic diversity.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Lathrocasis tenerrima* (May to June, fruiting by early June) has not changed significantly (Washington Natural Heritage Program 2023). However, there were few historical records available to assess trends.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Lathrocasis tenerrima is known from six extant occurrences in Washington that have all been rediscovered since 2004 (most recently in 2015) (Washington Natural Heritage Program 2023).

There is not enough census data available to determine trends. Additionally, it is an inconspicuous species which may be more abundant than known at present.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Lomatium laevigatum (smooth desert-parsley)

Date: 6 Sept 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G3/S2S3
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	100
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Neutral/Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	100
	>-0.028	0
5a. Measured genetic diversity		Increase
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		-
6. Phenological response to changing seasonal and precipitation dynamics		Neutral
Section D		
D1. Documented response to recent climate change		Somewhat Increase/Increase
D2. Modeled future (2050) change in population or range size		Unknown
D3. Overlap of modeled future (2050) range with current range		Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution		Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 10 (100%) of the occurrences of *Lomatium laevigatum* in Washington occur in areas with a projected temperature increase of 3.9-4.4°F (2.2-2.4°C; Figure 1).

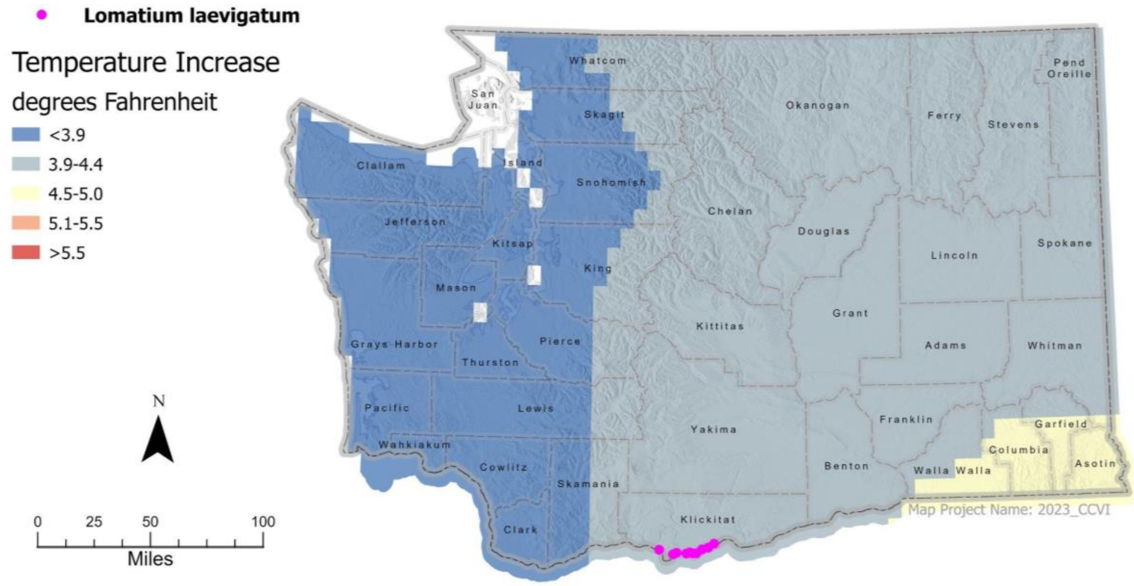
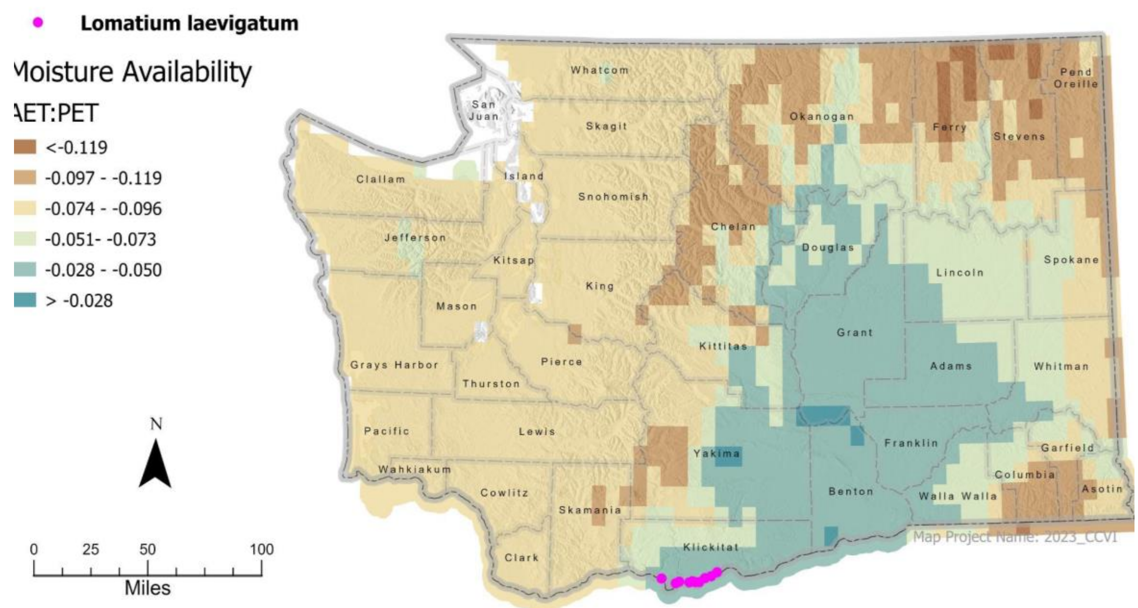


Figure 1. Exposure of *Lomatium laevigatum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 10 known occurrences of *Lomatium laevigatum* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.028 to -0.050 (Figure 2).



Fi **l**
moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Lomatium laevigatum grows in the crevices of basalt cliffs or bluffs and adjacent rocky slopes of Columbia Plateau Steppe-Grassland and Intermountain Basin Cliffs and Canyons adjacent to but above the high-water line of the Columbia River in Klickitat County, Washington (Camp and Gamon 2011, Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). These populations will not be inundated by sea rise as they are located inland at 165-985 ft (50-300 m) in elevation (Office for Coastal Management 2023), though lower portions of cliffside habitat may be affected by the expected rise of the Columbia River and flooding of the surrounding basin (Queen et al. 2021).

B2a. Natural barriers: Somewhat Increase
All existing and historical occurrences of *Lomatium laevigatum* in Washington are clustered along a single 27-mile-long strip of steep exposed basalt outcroppings and talus slopes which are bordered to the south by the Columbia River. Additional areas of Columbia Plateau Steppe-Grassland and Intermountain Basin Cliffs and Canyons occur to the north (Washington Division of Geology and Earth Resources 2016), but the rolling topography may not provide appropriate outcroppings as additional observations have not been made in this area. The river corridor

provides a potential route for dispersal, however intervening uplands and the river channel may also present moderate barriers.

B2b. Anthropogenic barriers: Neutral
Several highways border the extant and historical *Lomatium laevigatum* populations but do not appear to impact the occurrences which are elevated on bluffs and cliffsides. Some of the possible historical habitat to the south of the existing populations across the Columbia River has been converted into towns, agricultural fields, and the Dalles Dam. However, barriers that naturally exist due to the affinity of *Lomatium laevigatum* to rocky outcroppings are expected to create more significant obstacles to dispersal than the limited anthropogenic barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
No major impacts are anticipated directly in the area of known *Lomatium laevigatum* populations, however there is a growing interest in the drilling and injecting of CO_2 into basalt for carbon sequestration in the Pacific Northwest (Flatt 2023) which could prove detrimental to *Lomatium laevigatum* if caution is not exercised.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Lomatium laevigatum produces hairless, dry elliptical fruits called schizocarps (Washington Natural Heritage Program 2023). Each fruit segment has a narrow, thin wing along the margins to facilitate dispersal by wind over short distances. Dry fruits are also dispersed by gravity, water, or other passive means. Other structures, such as hooks, barbs, or rough hairs for attachment to animals are not present, although rodent caching has been reported for some *Lomatium* spp. (Thompson 1985). In general, *Lomatium* spp. have poor dispersal ability (less than 328 ft (100 meters)) which may account for their unusually high degree of endemism in western North America (Marsico and Hellmann 2009). High site fidelity to isolated basalt outcroppings warrants a higher vulnerability ranking (Young et al. 2016).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Lomatium laevigatum* occurrences in Washington. All 10 occurrences (100%) are in areas that have experienced average temperature variation (>57.1°F (31.8°C)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate warming.

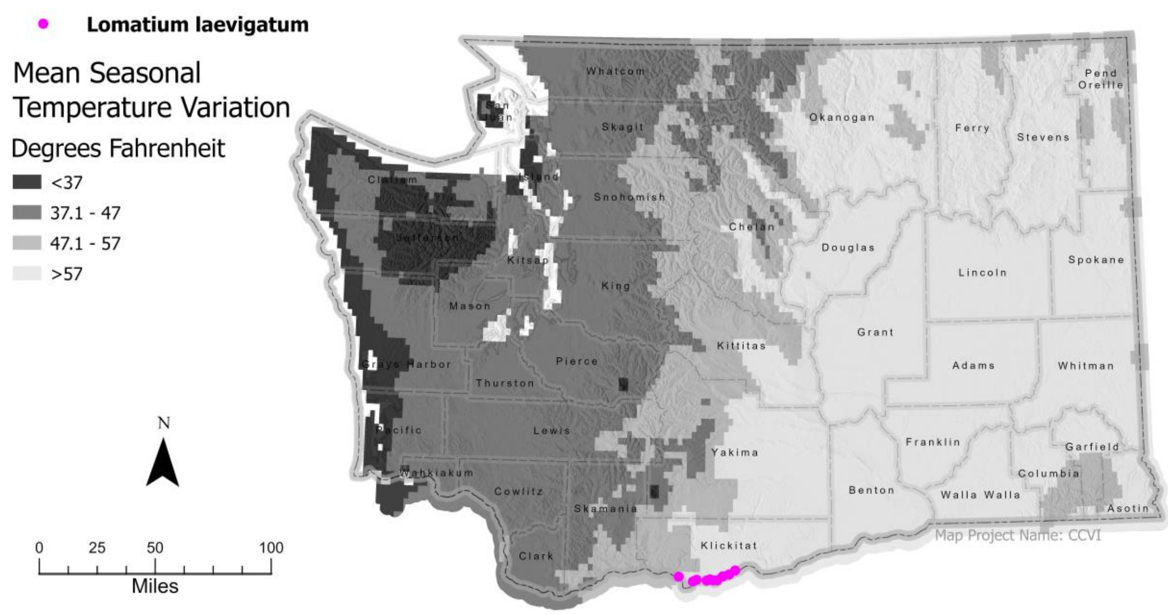


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium laevigatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
The semi-arid Columbia Plateau Steppe-Grasslands and Intermountain Basin Cliffs and Canyons that support *Lomatium laevigatum* are not especially cool during the growing season (NatureServe 2023) and would have neutral vulnerability to temperature changes due to global warming (Young et al. 2016).

C2bi. Historical hydrological niche: <u>Somewhat Increase</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Lomatium laevigatum* occurrences in Washington. All 10 occurrences (100%) are in areas that have experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes.

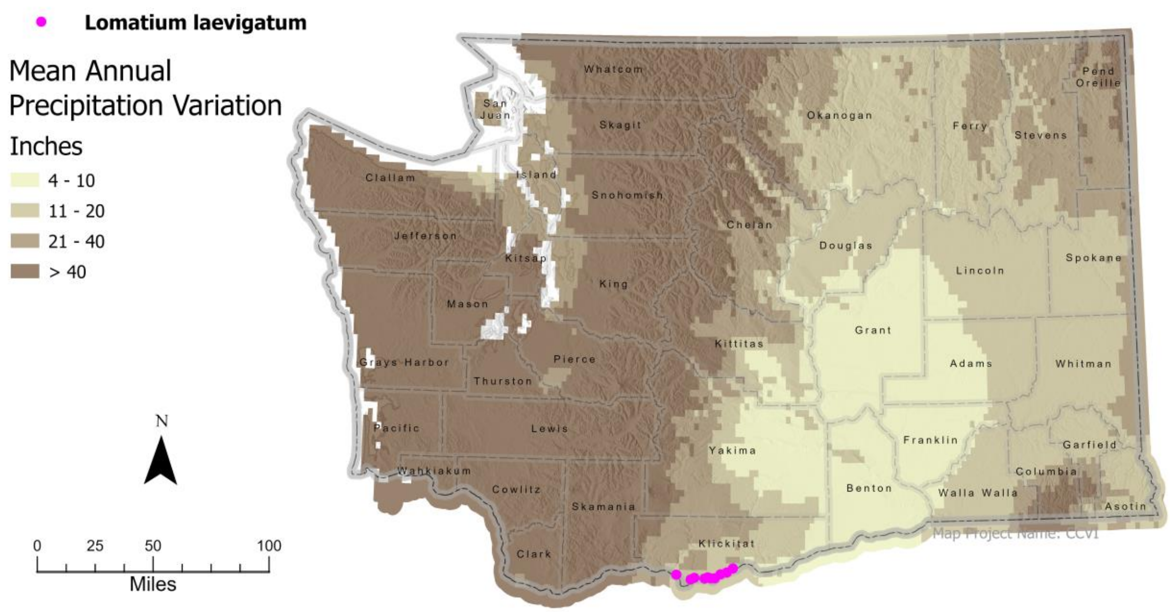


Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium laevigatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Neutral/Somewhat Increase</u>
Much of the precipitation in the Columbia Basin falls as snow or spring rain and growing-season drought is characteristic in Columbia Plateau Steppe-Grasslands and Intermountain Basin Cliffs and Canyons (NatureServe 2023). *Lomatium laevigatum* is dependent on precipitation and winter snow for its moisture requirements as water percolates through the top layers of permeable basalt to the water table which sits far below the root zone of cliff dwelling species underneath the Columbia River Plateau (Bauer and Hansen 2000). Expected changes in precipitation falling as rain rather than snow and extended summer droughts (Independent Science Advisory Board 2007, Rocchio and Ramm-Granberg 2017) are likely to negatively impact the habitat of *Lomatium laevigatum*, though this species may be moderately resilient as it is adapted to an arid environment with moderate inter-annual variation in precipitation.

C2c. Dependence on a specific disturbance regime: <u>Neutral/Somewhat Increase</u>

Fire is an important driver of the Columbia Plateau Steppe and Grassland habitat where *Lomatium laevigatum* is found but rarely has a direct influence on cliffs and canyon vegetation which is shaped more by erosion and other abiotic processes (Rocchio and Crawford 2015). In the surrounding grasslands, a rapid fire-return (< 20 years) interval maintains grass dominance and slows the invasion of shrubs which can otherwise convert the community type over time (Rocchio and Ramm-Granberg 2017, NatureServe 2023), however rock surfaces of outcrops may buffer fires and act as refugia for fire-sensitive species (Fitzsimons and Michael 2017). Other *Lomatium* spp. have been found to benefit from fire through increased growth and density after disturbance (Pendergrass et al. 1999). When fire becomes too frequent, invasion by *Bromus tectorum* and other non-native annuals can become a risk (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Lomatium laevigatum occurs in a semi-arid and cool temperature climate with most of the precipitation falling in the winter as snow, followed by spring rains (NatureServe 2023). This species is largely dependent on winter snow for its moisture requirements because its habitat is not associated with springs, streams, or groundwater. However, rocky cliffs that are exposed to the elements are unlikely to accumulate significant snowpack or persistent ice.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase
Lomatium laevigatum is restricted to Miocene-age outcrops of the Grande Ronde and Wanapum Basalt at the edge of Quaternary alluvium, dune sand, loess, and artificial fill along the Columbia river and the Middle Columbian Hood (Washington Division of Geology and Earth Resources 2016). These formations are widely distributed across the Columbia Basin. Soils where Columbia Plateau Steppe and Grassland occur are variable, ranging from deep and fine-textured with coarse fragments, non-saline with a biological soil crust, stony volcanic-derived clays, to alluvial sands (NatureServe 2023). However, *Lomatium laevigatum* only occurs in cracks and pockets of steep basalt cliffs with very thin soils and appears to be restricted to these landscape feature as it has not been reported in other areas of Grande Ronde and Wanapum Basalt or other Columbia Plateau Steppe and Grasslands.

C4a. Dependence on other species to generate required habitat: Neutral
The basalt bluffs, cliffs, and talus habitats of *Lomatium laevigatum* are consequences of erosion and other natural abiotic processes rather than ecosystem engineering by other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The exact pollinators of *Lomatium laevigatum* are undocumented, however, most *Lomatium* species are monoecious, perennial herbs that are pollinated by generalists (Diptera, Hymenoptera and Coleoptera), and have high outcrossing rates (Hardin 1929). Other *Lomatium* species are pollinated by solitary bees, syrphid flies, tachinid flies, muscid flies, bee flies, and beetles (Schlessman 1982). Some species have also been found to be self-compatible (Cane et al. 2020). The diversity of potential pollinators suggests that reproduction in *Lomatium laevigatum* is not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral

The dry fruits of most *Lomatium* spp. are dispersed primarily by wind, gravity, or other passive means. The species is not apparently dependent on animals for transport and does not have barbs, hooks, or rough hairs for attachment, however there are some reports of rodent caching improving the germination of other *Lomatium* spp. (Thompson 1985)

C4e. Sensitivity to pathogens or natural enemies: Neutral
The Columbia Plateau Steppe-Grassland did not evolve with heavy grazing and therefore the ecological system is sensitive to soil disturbance, trampling, and displacement of biological soil crusts because of grazing (NatureServe 2023). However, the steep basalt cliffs where *Lomatium laevigatum* currently occurs are unlikely to be reached by grazers. Post-dispersal seed predation by ground-foraging beetles and mammals has been reported for other *Lomatium* spp. (Thompson 1985), but the impacts of predation at the population level are not well documented and do not appear to be severe. Sensitivity is ranked as neutral because there are no major indications of climate change induced increases to any natural enemies.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to the basalt rock outcrops where *Lomatium laevigatum* occurs. Columbia Plateau Steppe-Grasslands and Intermountain Basin Cliffs and Canyons typically maintain minimal bare ground, with spaces between plants covered in biological soil crusts and mosses (NatureServe 2023). Any soil disturbances can allow invasion by several non-native grasses of concern, including *Bromus tectorum,* which has the capacity to alter fire cycles and further increase susceptibility to invasion on the landscape (Rocchio and Ramm-Granberg 2017). Changes to the timing of precipitation are likely to alter plant composition and extended droughts may allow the introduction of potential competitors that are better adapted to arid environments.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Lomatium laevigatum does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Increase
Soltis et al. (1997) report that *Lomatium* spp. which are endemics to the Columbia River, including *Lomatium laevigatum,* have significantly lower genetic variability than their widespread congeners and have very low levels of allozymic polymorphism within and between populations. Several *Lomatium* species have been reported as self-compatible which is typically indicative of lower effective population sizes and recombination rates (Huang et al. 2019).

C5b. Genetic bottlenecks: Unknown
Soltis et al. (1997) suggest that past genetic bottlenecks could contribute to the low overall genetic diversity of Columbia River endemic *Lomatium* spp.

C5c. Reproductive System:
This factor was not formally scored because of the inclusion of genetic diversity data (C5a) per Young et al. (2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website

(pnwherbaria.org) and WNHP records, the flowering period of *Lomatium laevigatum* (early April to late May) has not changed significantly since the species was first documented in Washington in the 1940s. Further phenological monitoring is warranted as studies show spring blooming species to be at greater risk of phenological change in North America (Calinger et al. 2013)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: <u>Somewhat Increase/Increase</u>
Some information about the historical range of *Lomatium laevigatum* describes it as "drastically declining" across its historic range, stating that it previously ranged across basalt cliffs east of the Cascade Mountains in Kittitas and Yakima Counties (Siddall and Chambers 1979, Meinke 1980). Current element occurrences and herbarium records in Washington only appear in Klickitat County. *Lomatium laevigatum* may have undergone a slight range contraction, particularly on the south side of the Columbia River, as 50% of element occurrences are historical and several herbarium records appear to remain unlocated since the 1970s or 1980s. However, it is difficult to confirm if this is a potential response to climate change or an artifact of declining survey frequency or other factors.

D2. Modeled future (2050) change in population or range size: <u>Unknown</u>
Not modeled.

D3. Overlap of modeled future (2050) range with current range: <u>Unknown</u>
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: <u>Unknown</u>
Not modeled.

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Climate Change Vulnerability Index Report

Lomatium rollinsii (Rollins' desert-parsley)

Date: 11 Sept 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G3/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	100
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	80
	-0.051 to - 0.073	20
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral/Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Somewhat Increase
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase/Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	100
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	80
	-0.051 to - 0.073	20
	-0.028 to -0.050	0
	>-0.028	0
5a. Measured genetic diversity		Increase
5b. Genetic bottlenecks		-
5c. Reproductive system		-
6. Phenological response to changing seasonal and precipitation dynamics		Neutral
Section D		
D1. Documented response to recent climate change		Unknown
D2. Modeled future (2050) change in population or range size		Unknown
D3. Overlap of modeled future (2050) range with current range		Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution		Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 10 (100%) of the occurrences of *Lomatium rollinsii* in Washington occur in areas with a projected temperature increase of 4.5-5.0° F (2.5-2.7°C) (Figure 1).

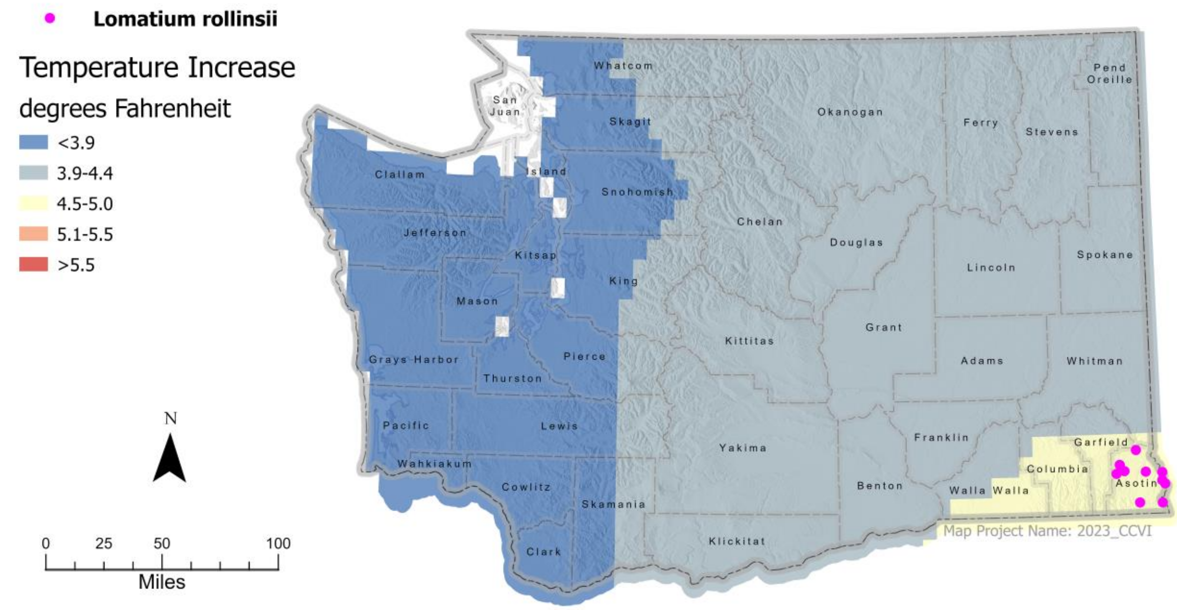

Figure 1. Exposure of *Lomatium rollinsii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 10 known occurrences of *Lomatium rollinsii* in Washington, 80% are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2). The other 20% are in areas projected to experience moisture decrease in the range of - 0.051 to - 0.073.

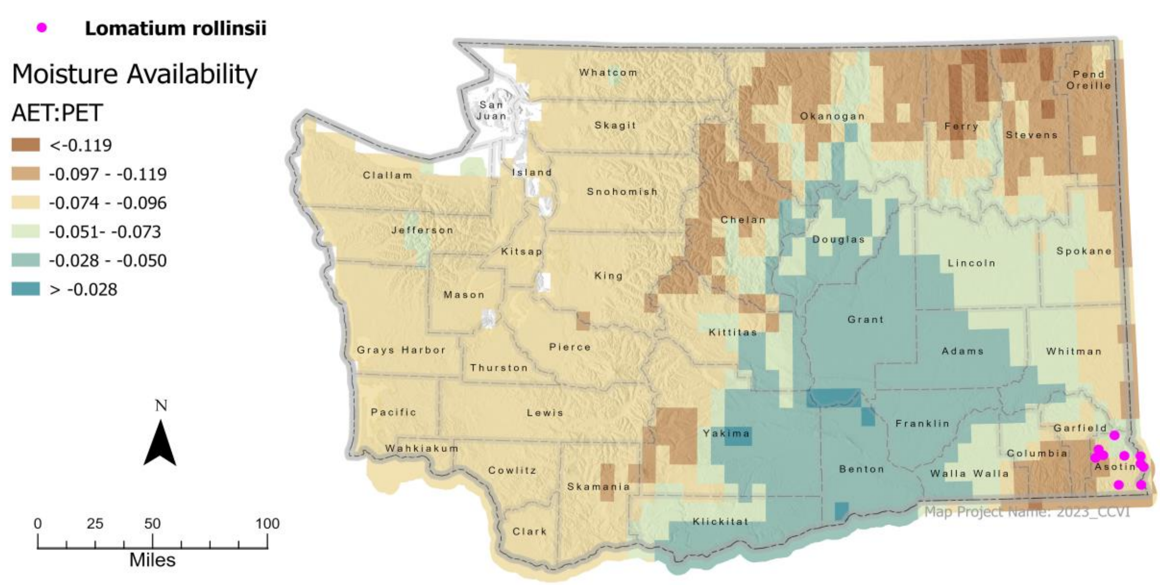

Figure 2. Exposure of *Lomatium rollinsii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Lomatium rollinsii is found at mid-low elevations (900-4300 ft (275-1310 m)) in the Columbia Basin Foothill and Canyon Dry Grassland ecological system along Asotin Creek and the Snake River in southeastern Washington adjacent to but above the high-water line of river corridors (Mancuso 1988, NatureServe 2023a, Washington Natural Heritage Program 2023). *Lomatium rollinsii* populations are not expected to be inundated by sea rise based on their inland distribution (Office for Coastal Management 2023), though floodplains along river corridors may be affected by climate change induced flooding (Queen et al. 2021).

B2a. Natural barriers: <u>Neutral/Somewhat Increase</u>
Lomatium rollinsii occurs on northern/eastern exposures along gentle to steep slopes of canyon grasslands and is endemic to the remote Snake River and lower Salmon River corridors in southeastern Washington, northeastern Oregon, and western Idaho (Mancuso 1988, Washington Natural Heritage Program 2023). Distances between Washington populations range from 2 to 22 mi (3 to 35 km). The river corridor provides a potential route for dispersal to other areas of suitable habitat, but intervening upland slopes and basalt outcrops between canyons may present somewhat of a barrier. The distribution of the Columbia Basin Foothill and Canyon Dry Grassland ecological system is limited in Washington.

B2b. Anthropogenic barriers: Increase
The river corridors and canyons where *Lomatium rollinsii* occurs are surrounded by grasslands that have been severely degraded or fragmented by grazing and cultivation (e.g. wheat farming) that has been ongoing since at least the 1900s in the region (NatureServe 2023b). Steeper slopes where occurrences are notes may act as refugia but the loss of extensive areas of suitable habitat pose a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase
There is potential leasing for DNR Solar/Clean Energy Development along the north fork of Asotin Creek near Bracken Point and other areas of potentially suitable habitat in the vicinity of the known occurrences (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Lomatium rollinsii produces hairless, dry elliptical fruits called schizocarps which shatter to release seeds (Washington Natural Heritage Program 2023). Each fruit segment has a narrow, thin wing along the margins to facilitate dispersal by wind over short distances. Dry fruits are also dispersed by gravity, water, or other passive means. Other structures, such as hooks, barbs, or rough hairs for attachment to animals are not present, although rodent caching has been reported for some *Lomatium* spp. (Thompson 1985). In general, *Lomatium* spp. have poor dispersal ability (less than 100 meters) which may account for their unusually high degree of endemism in western North America (Marsico and Hellmann 2009).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Lomatium rollinsii* occurrences in Washington. Of the 10 Washington occurrences, 70% are in areas that have experienced average temperature variation (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate warming. The remaining 20% are in areas that have experienced less than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) and are expected to somewhat increase in vulnerability under warming conditions (Young et al. 2016).

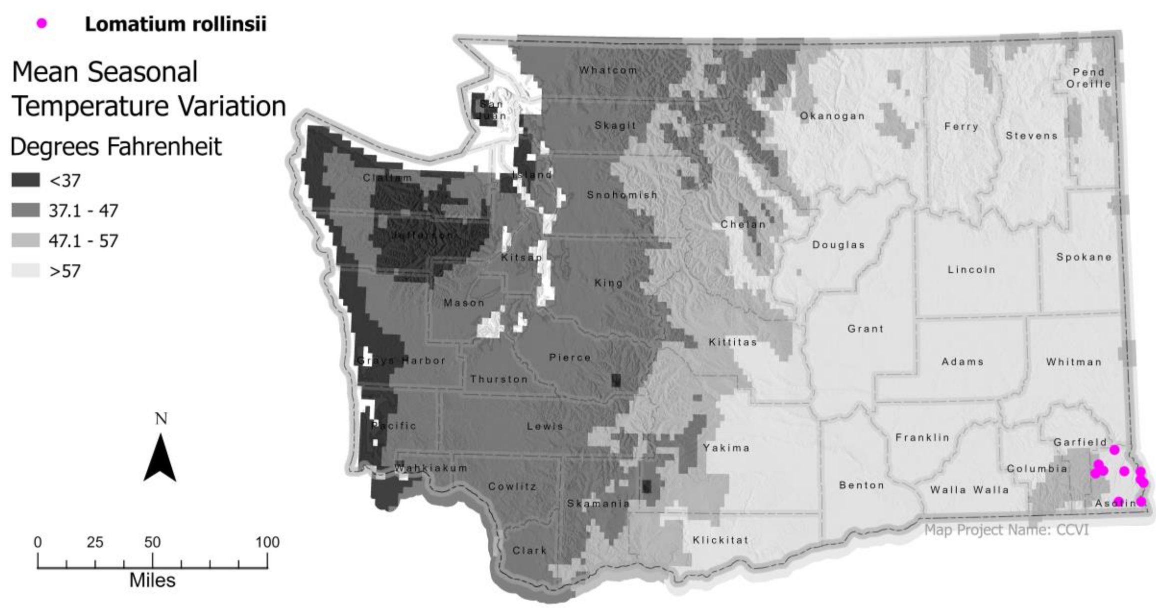

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium rollinsii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral

The arid foothill grassland habitat that supports *Lomatium rollinsii* can be hot during the growing season and regularly experiences long and dry summers (Rocchio and Crawford 2015), indicating that *Lomatium rollinsii* would likely have neutral vulnerability to temperature changes due to global warming (Young et al. 2016). Climate change is expected to increase fire frequency and severity in the foothill grasslands which may benefit the habitat by preventing shrub encroachment but is also likely to result in conversion to a non-native annual dominant composition (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Somewhat Increase

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Lomatium rollinsii* occurrences in Washington. All 10 occurrences (100%) are in areas that have experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes.

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium rollinsii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
Much of the precipitation in foothill grasslands falls as winter rain and seasonal, summer drought is characteristic. Annual precipitation is quite low overall, ranging from 5-10 in (12-25 cm) but individual grasslands range from arid to somewhat mesic (Rocchio and Crawford 2015). *Lomatium rollinsii* is restricted to slightly mesic areas in foothill grassland communities in canyons and along river corridors in the Columbia Basin (Mancuso 1988, Soltis et al. 1997). Changes to precipitation timing and amount are expected to shift the composition of the foothill grasslands that support *Lomatium rollinsii* and may favor more drought tolerant species or allow for shrub encroachment as increased drought frequency couples with extreme precipitation events (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Somewhat Increase/Increase</u>
Fire is an important driver in the Columbia Basin foothill grassland habitat where *Lomatium rollinsii* is found, as a rapid fire-return (< 20 years) interval maintains grass dominance and

slows the invasion of shrubs which can otherwise convert the community type over time (NatureServe 2023b). Other *Lomatium* spp. have benefited from fire through increased growth and density after disturbance (Pendergrass et al. 1999). When fire becomes too frequent on the landscape, invasion by annual grasses like *Bromus tectorum* may become a risk (Rocchio and Ramm-Granberg 2017). Climate change is expected to increase fire frequency in the foothill grasslands. Trampling from grazing herbivores, anthropogenic soil disturbance, and extreme precipitation events due to climate change can severely impact biological soil crusts which usually serve to stave off invasion of annual non-natives and allow moisture to infiltrate the soil (Rocchio and Crawford 2015).

C2d. Dependence on ice or snow-cover habitats: <u>Neutral</u>
Lomatium rollinsii occurs in an arid environment with most precipitation falling as winter rains (NatureServe 2023b). This species is not associated with persistent snowpack or ice.

C3. Restricted to uncommon landscape/geological features: <u>Neutral/Somewhat Increase</u>
Lomatium rollinsii is restricted to canyon grassland habitats on residuum soils of the Miocene Columbia River Basalt Group which are not ubiquitous in Washington but are locally common. These soils are wind-blown surface deposits and can range from shallow and rocky to rich loams and often have significant patches of bare ground covered in biological soil crusts (NatureServe 2023b, Washington Natural Heritage Program 2023). However, *Lomatium rollinsii* appears to be restricted to the canyons of the Snake and Salmon Rivers as it has not been found elsewhere in the Columbia River Basin and, therefore, is a habitat specialist.

C4a. Dependence on other species to generate required habitat: <u>Somewhat Increase</u>
The arid foothill grasslands which support *Lomatium rollinsii* are shaped primarily by surface disturbances from slope failures and frequent low intensity fires (NatureServe 2023b). Columbia Plateau grasslands did not evolve with frequent ungulate grazing in the same way as the Great Plains grasslands (Burkhardt 1994). However, large native grazers do play a role in soil disturbance and subsequent community dynamics as do burrowing animals (Rocchio and Crawford 2015). The effects of climate change may indirectly compound upon natural soil disturbance events and lead to the establishment of non-native species and larger than normal patches of bare ground (Rocchio and Ramm-Granberg 2017).

C4b. Dietary versatility: <u>Not applicable for plants</u>

C4c. Pollinator versatility: <u>Neutral</u>
The exact pollinators of *Lomatium rollinsii* are not well documented, however, most *Lomatium* spp. species are monoecious, perennial herbs that are pollinated by generalists (Diptera, Hymenoptera and Coleoptera), and have high outcrossing rates (Hardin 1929, Schlessman 1982). Potential pollinators include solitary bees, syrphid flies, tachinid flies, muscid flies, bee flies, and beetles (Schlessman 1982). Many *Lomatium* spp. are pollinated by several species of ground nesting bees in the genus *Andrena* (Cane et al. 2020). Some *Lomatium* spp. have also been found to be self-compatible (Cane et al. 2020). The diversity of potential pollinators suggests that reproduction in *Lomatium rollinsii* is not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
The dry fruits of most *Lomatium* spp. are dispersed primarily by wind, gravity, or other passive means. The species is not apparently dependent on animals for transport and does not have barbs, hooks, or rough hairs for attachment, however there are some reports of rodent caching improving the germination of other *Lomatium* spp.(Thompson 1985)

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Foothill grasslands did not evolve with heavy grazing and therefore the ecological system is sensitive to soil disturbance, trampling, and displacement of biological soil crusts (Burkhardt 1994, Rocchio and Crawford 2015). Overgrazing is a large potential threat that has already altered a significant portion of the habitat since being used for rangeland since the early 1900s and has allowed the invasion of several non-native annual grasses and forbs which could displace *Lomatium rollinsii* (Mancuso 1988, NatureServe 2023b). There have been active grazing leases at known occurrences of *Lomatium rollinsii*. Field surveys report that *Lomatium rollinsii* is sought after by cattle and horses during its early spring growth and that the species does not appear on heavily grazed sites. Post-dispersal seed predation by ground-foraging beetles and mammals has also been reported for other *Lomatium* spp. (Thompson 1985), but the impacts of predation at the population level are not well documented and do not appear to be severe. Adverse effects of climate change are expected to be amplified in heavily grazed areas.

C4f. Sensitivity to competition from native or non-native species: Increase
Foothill grasslands typically have minimal bare ground, with spaces between plants covered in biological soil crusts (NatureServe 2023b). Mesic north aspects of foothill grasslands, like those that support *Lomatium rollinsii*, are often at risk of invasion by shrubs, especially where fire has been excluded (NatureServe 2023b). Non-native annual grasses including *Bromus tectorum* and *Poa bulbosa* are also frequent invaders of disturbed soil patches, as are *Centaurea* spp. Annual grasses that invade foothill grasslands can severely alter fire regimes and completely convert the habitat type over time to a novel ecosystem dominated by invasive species (Rocchio and Crawford 2015). Climate change induced droughts, extreme precipitation events, and altered fire regimes are expected to increase the already high invasion rates in this ecological system (Rocchio and Ramm-Granberg 2017). Changes to codominant species in the habitat of *Lomatium rollinsii* are anticipated to pose a significant threat.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Lomatium rollinsii does not have any other known interspecific interactions to note. However, foliose lichens and biological soil crusts play a critical role in the ecological health of foothill grasslands (Rocchio and Crawford 2015).

C5a. Measured genetic variation: Increase
Soltis et al. (1997) report that *Lomatium* spp. that are endemics, including *Lomatium rollinsii,* have significantly lower genetic variability than their widespread congeners and have very low levels of allozymic polymorphism within and between populations. This may be due to a past genetic bottleneck or the recent evolutionary origin of *Lomatium rollinsii* (Washington Natural Heritage Program 2023). Several *Lomatium* species have been reported as self-compatible which can be indicative of lower effective population sizes and recombination rates (Huang et al. 2019).

C5b. Genetic bottlenecks: Not Scored
This factor was not formally scored because of the inclusion of genetic diversity data (C5a) per Young et al. 2016.

C5c. Reproductive System: Not Scored
This factor was not formally scored because of the inclusion of genetic diversity data (C5a) per Young et al. 2016, but the mixed mating system of *Lomatium rollinsii*, which includes both outcrossing and selfing (Mancuso 1988), is expected to allow for better adaptation to novel environments and buffering of the effects of climate change (Mancuso 1988, Young et al. 2016)

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on flowering dates from specimens in the Consortium of Pacific Northwest herbaria website, no major changes have been detected in phenology since the species was first collected in Washington in the 1920s. *Lomatium rollinsii* has consistently flowered from March to May with fruits maturing as soon as mid-May at lower elevations (NatureServe 2023a, Washington Natural Heritage Program 2023). Further phenological monitoring is warranted as studies show spring blooming species to be at greater risk of phenological change in North America (Calinger et al. 2013)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no long-term population studies of *Lomatium rollinsii* but outplantings have been largely unsuccessful (Mancuso 1988) and 30% of known occurrences are now considered to be historical with low estimated viability due to cultivation and grazing. This species may be more common than currently known because it is hard to locate in remote canyons and is easily confused for other co-occurring *Lomatium* spp. (Mancuso 1988).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled in Washington.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled in Washington.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled in Washington.

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Climate Change Vulnerability Index Report
***Lomatium roneorum* (Rone's biscuitroot)**

Date: 13 Sept 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G1/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	67
	-0.074 to - 0.096	0
	-0.051 to - 0.073	33
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Greatly Increase
2ai Change in historical thermal niche		Neutral/Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

Section A	Severity	Scope (% of range)
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	67
	-0.074 to - 0.096	0
	-0.051 to - 0.073	33
	-0.028 to -0.050	0
	>-0.028	0
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral
6. Phenological response to changing seasonal and precipitation dynamics		Neutral
Section D		
D1. Documented response to recent climate change		Unknown
D2. Modeled future (2050) change in population or range size		Unknown
D3. Overlap of modeled future (2050) range with current range		Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution		Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All six (100%) of the occurrences of *Lomatium roneorum* in Washington occur in areas with a projected temperature increase of 3.9-4.4°F (2.2-2.4°C; Figure 1).

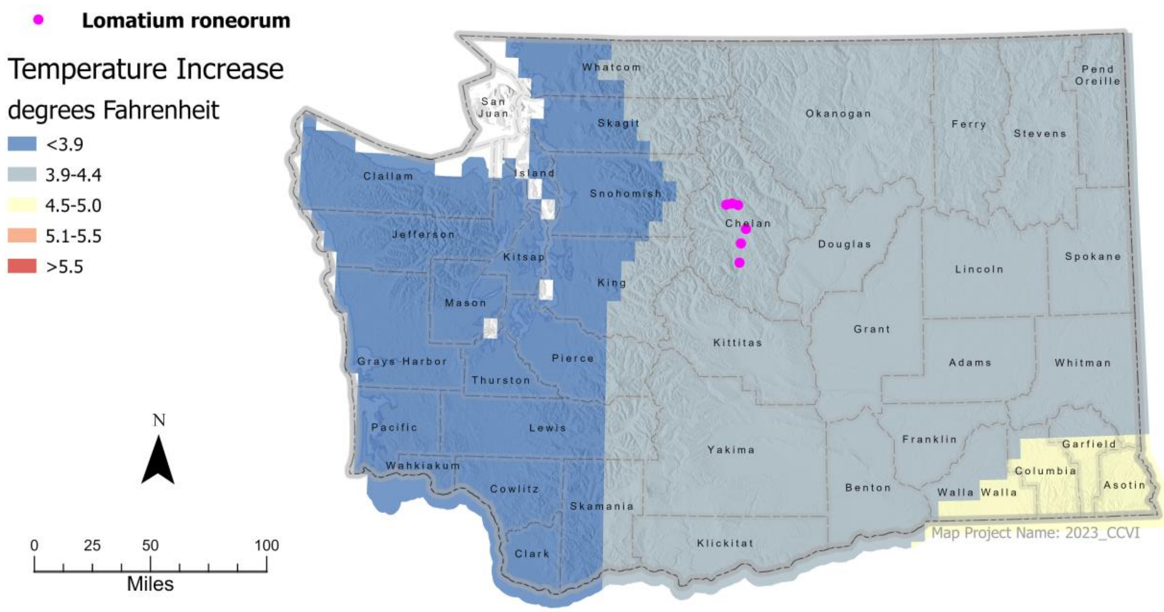

Figure 1. Exposure of *Lomatium roneorum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the six occurrences of *Lomatium roneorum* in Washington, 67% (four out of six) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The remaining 33% (two out of six) are in areas with a lower projected moisture availability decrease in the range of -0.051 to - 0.073.

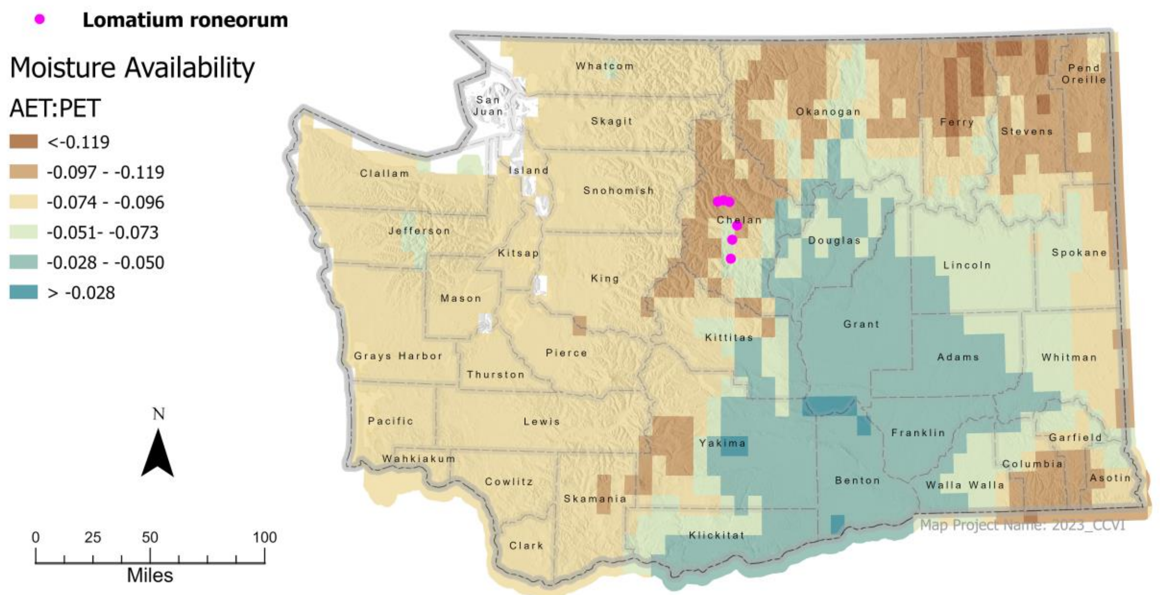

Figure 2. Exposure of *Lomatium roneorum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Lomatium roneorum is restricted to steep sandstone slopes on the eastern side of the Cascade Mountains at elevations ranging from 2080-5570 ft (635-1698 m; Washington Natural Heritage Program 2023). *Lomatium roneorum* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Somewhat Increase
Occurrences of *Lomatium roneorum* are limited to a few mountains slopes and ridges of the Cascades in Chelan County restricted to a 97 square mi^2 (250 km^2) area (NatureServe 2023, Washington Natural Heritage Program 2023). In Washington, this Rocky Mountain Cliff, Canyon & Massive Bedrock ecological system is restricted and only occurs within isolated ranges of the East Cascades across a broad elevation range (Rocchio and Crawford 2015, NatureServe 2023). The surrounding forest canopy cover and ridgelines could restrict movement of this species between patches, but natural barriers are expected to have relatively minimal impact on dispersal compared to biological limitations discussed in C1. Dispersal and Movements.

B2b. Anthropogenic barriers: Neutral

Three of the six occurrences of *Lomatium roneorum* are listed near trails and two are bordered by the towns of Plain and Leavenworth. These anthropogenic features do not appear to pose any major barriers to nearby potential habitat as plants occur on steep slopes that are not directly intersected by human infrastructure, but minimal recreational impacts may be present.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Lomatium roneorum* (Washington Department of Natural Resources 2023) and future mitigation projects are unlikely to occur in its steep slope habitats.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Greatly Increase
Lomatium roneorum produces hairless, dry elliptical fruits called schizocarps (Darrach 2018, Washington Natural Heritage Program 2023). Each fruit segment has a narrow, thin wing along the margins to facilitate dispersal by wind over short distances. Dry fruits are also dispersed by gravity, water, or other passive means. Other structures, such as hooks, barbs, or rough hairs for attachment to animals are not present, although rodent caching has been reported for some *Lomatium* spp. (Thompson 1985). Like other *Lomatium* spp. which are known to have poor dispersal ability (less than 328 ft (100 meters)), *Lomatium roneorum* has been described as an "inefficient seed disperser" (Marsico and Hellmann 2009, Darrach 2018). High site fidelity to feldspar-rich sandstone slopes where recruitment levels are low (Darrach 2018) warrants a higher vulnerability ranking (Young et al. 2016).

C2ai. Historical thermal niche: Neutral/Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Lomatium roneorum* occurrences in Washington. Half (50%) of the occurrences are in areas that have experienced slightly lower than average temperature variation (47.1 - 57°F (26.3 - 31.8°C)) over the historical period. According to Young et al. (Young et al. 2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining 50% of occurrences have experienced average (>57.1°F (31.8°C)) temperature variation over the historical period and are likely to be mostly resilient to warming (Young et al. 2016).

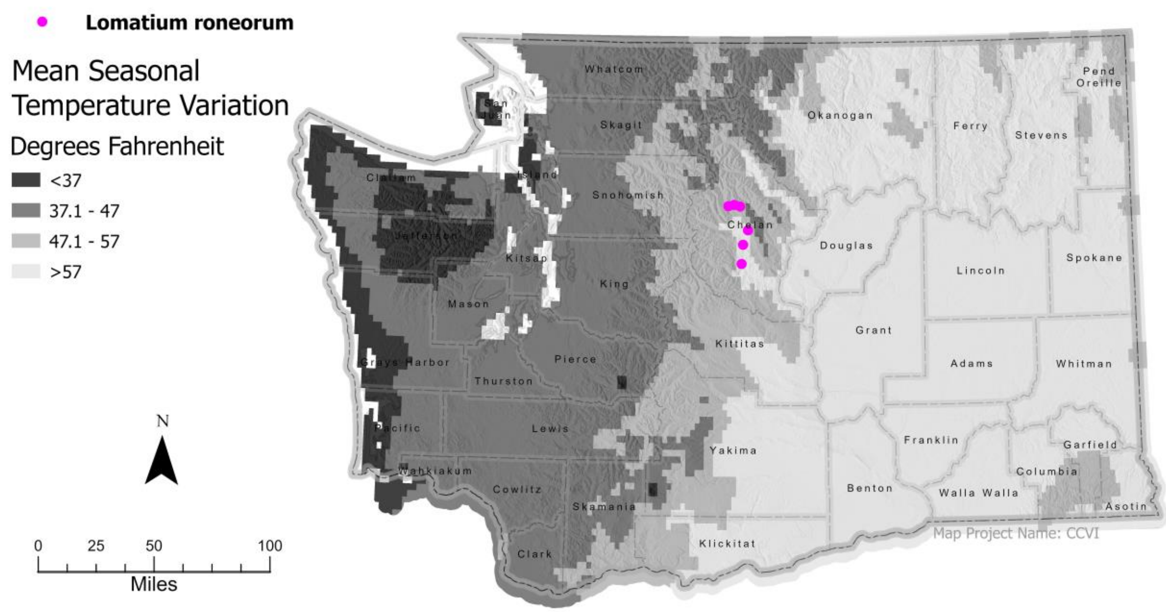

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium roneorum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral

The mid-elevation, south-facing sandstone slopes that *Lomatium roneorum* occupies are warm, dry, and exposed resulting in earlier snow melt than the surrounding landscape (Estevo et al. 2022). *Lomatium roneorum* is not particularly dependent on a cold climate during the growing season and would have neutral vulnerability to climate change (Young et al. 2016). However, the high exposure of these sites may make them susceptible to rising temperatures which can also increase fire risk or alter the erosion rates of communities (Rocchio and Ramm-Granberg 2017, Estevo et al. 2022).

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Lomatium roneorum* occurrences in Washington. All six occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

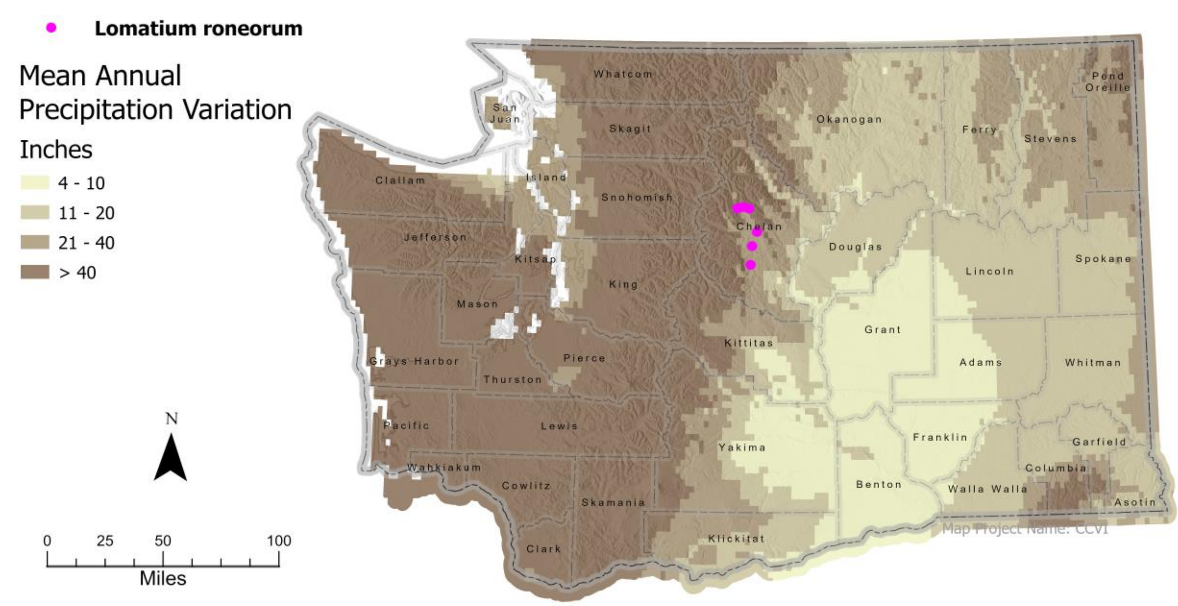

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium roneorum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Much of the precipitation in Chelan County falls in the winter as snow and growing-season drought is characteristic. The sandstone slopes which support *Lomatium roneorum* are typically dry and sparsely vegetated with the composition of the plant community depending on microtopographic features, such as aspect and vertical position. These features determine hydrology as the slopes are not replenished by groundwater but instead rely on seasonal precipitation for moisture (Clark 2012, NatureServe 2023). Shifts in precipitation timing and amount combined with extended summer droughts are expected to have a low to moderate impact on Rocky Mountain Cliff, Canyon, and Massive Bedrock systems (Rocchio and Ramm-Granberg 2017). However, potential severe drying of moist microhabitats in crevices may be of particular concern for *Lomatium roneorum* (Rocchio and Crawford 2015).

Rocky Mountain Cliff, Canyon & Massive Bedrock

C2c. Dependence on a specific disturbance regime: Neutral
Wind, water, and gravity are forces acting upon cliff and bedrock habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as

rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004).

C2d. Dependence on ice or snow-cover habitats: Neutral
Lomatium roneorum occurs in montane elevations of the Cascade Range which receive moderate precipitation, primarily in the form of snow (WRCC 2024). Projections show that climate warming in the Pacific Northwest is likely to cause more precipitation to fall as rain instead of snow and that snowmelt could occur much earlier in the year by 2030 (Montgomery Water Group et al. 2003). Changes to snow-cover could have adverse effects on the water-limited rocky habitat of *Lomatium roneorum*, with these areas drying out earlier in the year, though snow accumulation is already low on the sandstone slopes where this species occurs. Other than minor impacts to the limited water supply of the habitat, *Lomatium roneorum* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Increase
Lomatium roneorum is restricted to crumbly, acidic, and feldspar-rich sandstone substrates of the late Eocene Chumstick Formation and Mesozoic metamorphic on the east slopes of the Cascade Mountains (Darrach 2018, NatureServe 2023). These features are restricted to a small region of the central Cascade Range and are otherwise not common in Washington (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Rocky Mountain Cliff, Canyon and Massive Bedrock ecological systems are shaped mostly by abiotic processes and erosion which shifts critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Lomatium roneorum* are not well documented, however, most *Lomatium* species are andromonoecious, perennial herbs that are pollinated by generalists (Diptera, Hymenoptera and Coleoptera), and have high outcrossing rates (Hardin 1929, Schlessman 1982). Other *Lomatium* species are pollinated by solitary bees, syrphid flies, tachinid flies, muscid flies, bee flies, and beetles (Schlessman 1982). Some species have also been found to be self-compatible (Cane et al. 2020). The diversity of potential pollinators suggests that reproduction in *Lomatium roneorum* is not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
The dry fruits of *Lomatium roneorum* are dispersed short distances by passive means such as wind and gravity. The species is not dependent on animals for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Post-dispersal seed predation by ground-foraging beetles and mammals has been reported for other *Lomatium* spp. (Thompson 1985). The impacts of predation at the population level are not well documented but do not appear to be severe. Sensitivity is ranked as neutral because there

are no major indications of climate change induced increases to seed predators and no other major pathogens or enemies are documented for *Lomatium roneorum*.

C4f. Sensitivity to competition from native or non-native species: Neutral
Lomatium roneorum grows on rocky slopes with sparse vegetation which may indicate that it is not adapted to compete well with other vegetation and is susceptible to being shaded out by competitors when fire is absent (Darrach 2018). The habitat of extant populations is somewhat invaded by *Bromus tectorum,* though threats of direct competition appear minor as few plants are as well-adapted to the sandstone cliffs as *Lomatium roneorum* (Fertig 2020).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Lomatium roneorum does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic diversity of *Lomatium roneorum* has not been documented but Soltis et al. (1997) report that other endemic *Lomatium* spp. have significantly lower genetic variability than their widespread congeners. Several *Lomatium* spp. have been reported as self-compatible which is typically indicative of lower effective population sizes and recombination rates (Huang et al. 2019).

C5b. Genetic bottlenecks: Unknown
Individual populations of *Lomatium roneorum* tend to be very small (Darrach 2018) and the entire extant population is thought to be as few as 1,000 plants (Fertig 2020), however there is no clear evidence of a past bottleneck.

C5c. Reproductive System: Neutral
Both male and hermaphroditic flowers occur on single individuals of *Lomatium roneorum* (Darrach 2018). Most *Lomatium* spp. are pollinated by generalists with high outcrossing rates and many are also self-compatible (Hardin 1929, Schlessman 1982, Huang et al. 2019), which suggests that *Lomatium roneorum* is likely to have a mixed mating system and therefore may be better able to adapt to novel environments (Young et al. 2016). Though seed viability and germination rates appear to be suitable, recruitment levels for *Lomatium roneorum* are generally low as few seedlings survive on the loose, rocky substrates where the parent individuals occur (Darrach 2018).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on fruiting dates from specimens in the Consortium of Pacific Northwest herbaria website (pnwherbaria.org) and WNHP records, no major changes have been detected in phenology since the species was first described and documented in Washington in 2018. *Lomatium roneorum* is reported to flower from late-April to late-May with fruits maturing by mid-June (Darrach 2018). Further phenological monitoring is warranted as studies show spring blooming species to be at greater risk of phenological change in North America (Calinger et al. 2013) and there are only a few records available to develop a baseline for *Lomatium roneorum*.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Lomatium roneorum* declining in response to climate change. However, *Lomatium roneorum* was just described as a new species in 2018 (Darrach 2018) and therefore the historical extent may not be fully known. The current restriction to cliffside habitats could be because the cliffs have acted as refugia (Larson et al. 2000) for *Lomatium roneorum* as changes occurred in a wider preferred habitat but there is no conclusive evidence.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

Lycopodium lagopus (one-cone clubmoss)

Date: 7 May 2024

Synonym: *Lycopodium clavatum* var. *lagopus*

Assessor: Molly S. Wiebush, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G5/S1

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral

4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Unknown
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Somewhat Increase
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All four known occurrences (100%) of *Lycopodium lagopus* in Washington occur in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4° C; Figure 1).

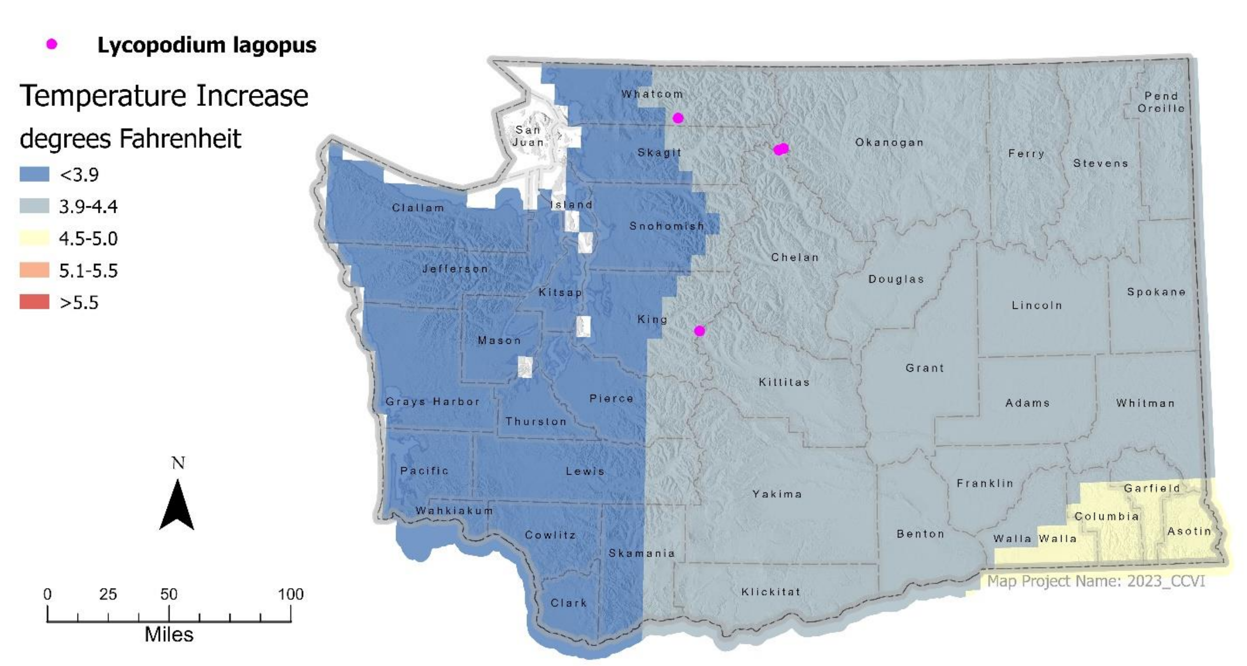

Figure 21. Exposure of occurrences of *Lycopodium lagopus* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four known occurrences (100%) *Lycopodium lagopus* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096.

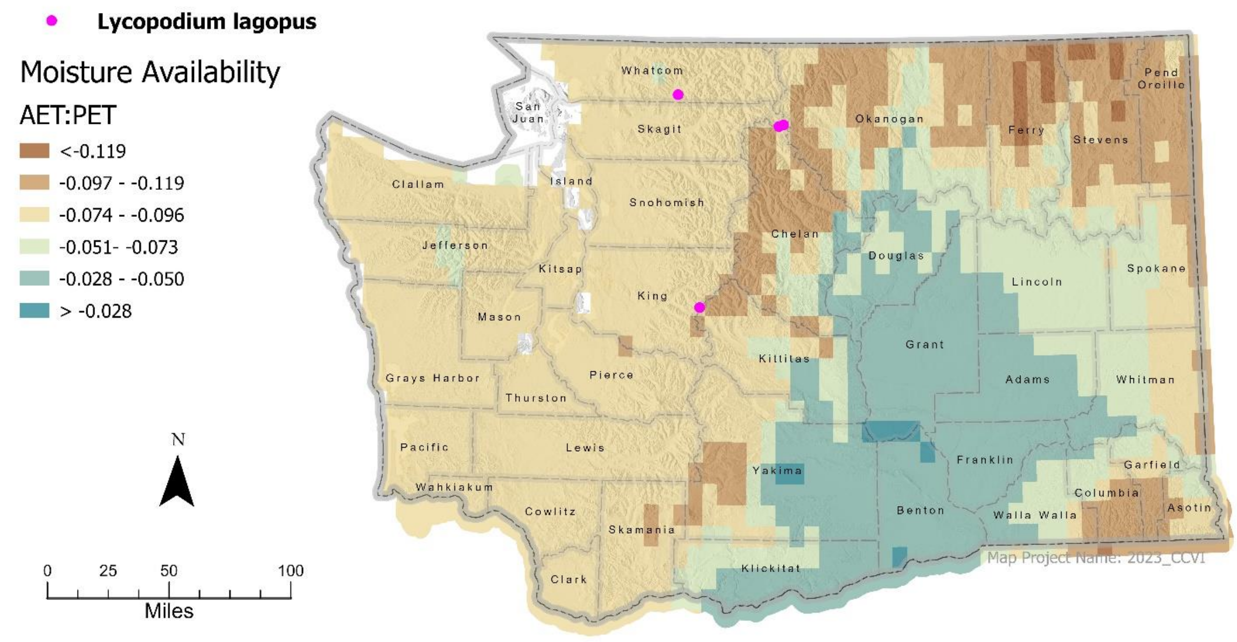

Figure 22. Exposure of occurrences of *Lycopodium lagopus* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Lycopodium lagopus is found in montane and subalpine habitats between 3030–5280 ft (925–1610 m; Washington Natural Heritage Program 2024) and would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
Lycopodium lagopus is found in North Pacific Bog and Fen and Rocky Mountain Subalpine-Montane Fen ecological systems, which are scattered, uncommon systems in Washington. These peatland habitats are naturally small and isolated within a matrix of unsuitable forest, agricultural, and urban/rural lands that create a barrier to migration and dispersal.

B2b. Anthropogenic barriers: Somewhat Increase

Many peatlands in the North Pacific Bog and Fen ecological system have been isolated or damaged by logging and roads (Rocchio and Crawford 2015), potentially creating barriers to migration for some species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Lycopodium lagopus* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
While dispersal information on *Lycopodium lagopus* is limited, information is available on other species in the genus. *Lycopodium* bulbils can be dispersed up to several inches by raindrops (Brodie 1956). Lycopodium species can also reproduce vegetatively through rhizomes (Nauertz and Zasada). Spores of some *Lycopodium* species are wind-dispersed and likely travel long distances (Parris 2001). One study estimated *Lycopodium* spores were able to travel up to 205 mi (330 km), based on their falling velocity, but this has not been tested against real life conditions and may be an overestimate of their actual dispersal capabilities (Vittoz and Engler 2007).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Lycopodium lagopus* occurrences in Washington. One of four known occurrences (25%) is in an area that has experienced small (37 - 47° F (20.8 - 26.3° C)) temperature variation over the historical period. According to Young et al. (2016), this population is expected to be vulnerable to climate warming. The remaining three known occurrences (75%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming.

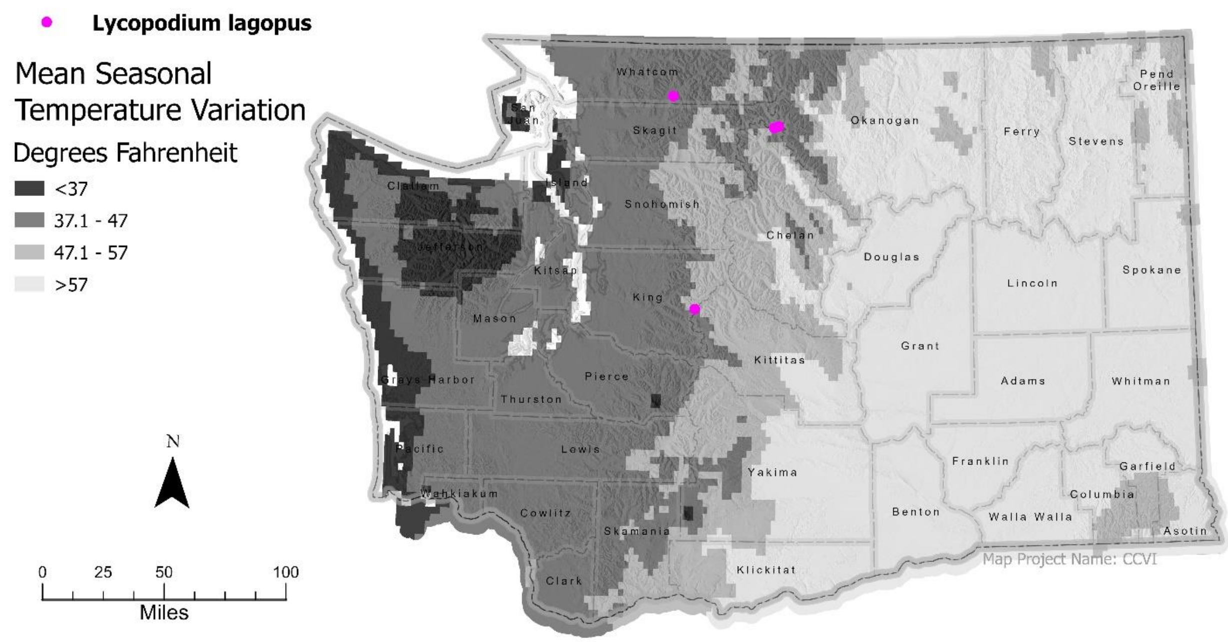

Figure 23. Historical thermal niche (exposure to past temperature variations) of occurrences of *Lycopodium lagopus* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase
In Washington, *Lycopodium lagopus* is found in montane and subalpine habitats in the North Pacific Bog and Fen and Rocky Mountain Subalpine-Montane Fen ecological systems (Washington Natural Heritage Program 2024). In all occurrences where slope was documented, *Lycopodium lagopus* was found on north-facing slopes in Washington. Increases in temperature could accelerate drying in peatlands and increases in water temperature could lead to commensurate changes in their biological communities (Rocchio and Ramm-Granberg 2017). Peatland habitat is often associated with cold air drainage sites in montane settings that are somewhat cooler than the surrounding matrix vegetation. Given this, *Lycopodium lagopus* is likely to be somewhat vulnerable to warming.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Lycopodium lagopus* occurrences in Washington. All four known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

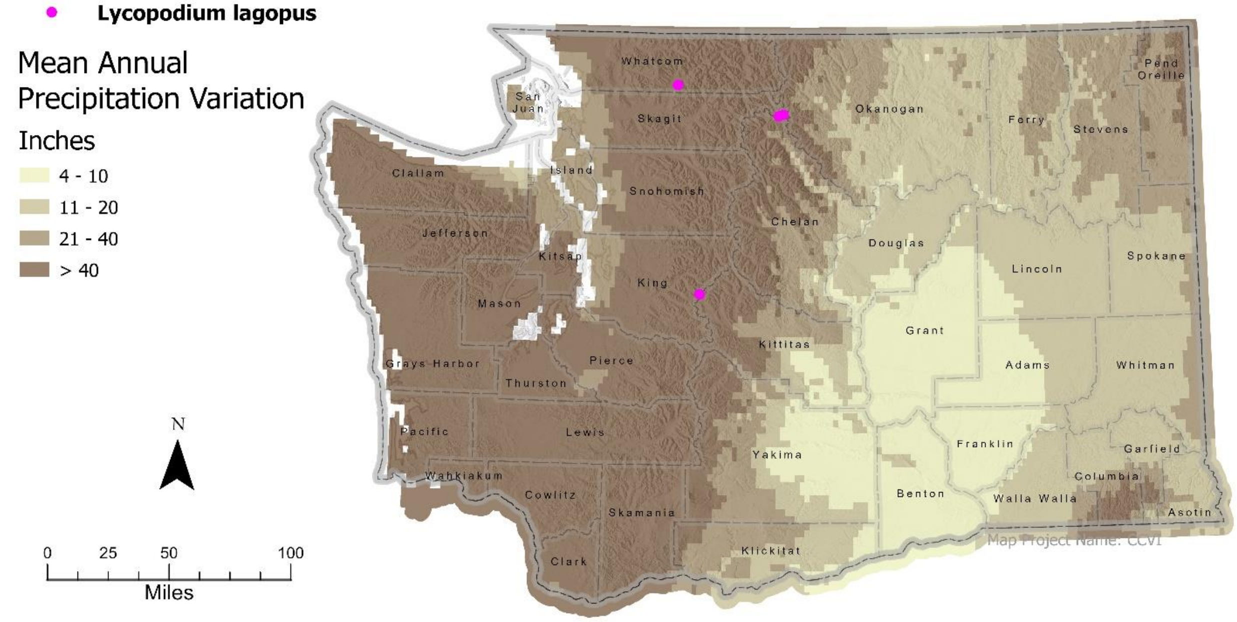

Figure 24. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Lycopodium lagopus* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: <u>Increase</u>
This species is strongly dependent on precipitation and groundwater to maintain the high water table necessary for accumulation of peat. Bog and fen habitats, which may also depend on surface water, are sensitive to drier conditions. Decreases in moisture can lead to increased invasion of dry-adapted species or tree encroachment on these habitat types (Rocchio and Ramm-Granberg 2017). *Lycopodium lagopus*'s hydrological niche and dependence on these peatland habitats greatly increases this species' vulnerability to the effects of climate change.

C2c. Dependence on a specific disturbance regime: <u>Somewhat Increase</u>
Peat accumulates at an approximate rate of 1 inch/40 years in Washington and peat depth ranges from a few to over 50 feet (Rocchio and Ramm-Granberg 2017). This suggests that minimal disturbance is important for fen species like *Lycopodium lagopus*. Still, at least some *Lycopodium* species may have fire adaptations. For example, fire reduced germination time for spores in one species of *Lycopodium* from nine months to three or four weeks, and the plants frequently show some resistance to burning (Vogel et al. 2011). *Lycopodium lagopus* has been found 28 years post-fire in Siberian fens (Heim et al. 2022). However, even with potential fire

adaptations, increased disturbance from fire or fire-suppression activities along with climate change is likely to lead to somewhat increased vulnerability for this species.

C2d. Dependence on ice or snow-cover habitats: Neutral
While *Lycopodium lagopus* does not rely directly on ice or snow-covered habitats, reduced snowpack and precipitation shifts from snow to rain is a significant threat to fen habitats (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Lycopodium lagopus occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016). However, landscape features associated with fens may be sporadic, contributing to the overall rarity of the species in the state.

C4a. Dependence on other species to generate required habitat: Neutral
Bogs and fens are created and maintained by abiotic factors, including groundwater and precipitation patterns, water chemistry, and history of glaciation (Rocchio and Crawford 2015). The peatland habitat of *Lycopodium lagopus* is maintained largely by edaphic and drainage patterns that favor the accumulation of thick organic soil layers favoring peatland vegetation over conifer forests and does not require other species for maintenance (Banner et al. 1983).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The sporophyte generation of *Lycopodium* reproduces by spores and does not require pollinators. The gametophyte phase reproduces by motile sperm that do not require pollinators for assistance.

C4d. Dependence on other species for propagule dispersal: Neutral
The spores of *Lycopodium lagopus* are likely wind-dispersed. This species has no traits that suggest its propagules are animal dispersed.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Lycopodium species produce complex alkaloid compounds and some species in this genus are used in medicine. These alkaloid compound function as defenses against herbivory and disease in *Lycopodium* (Duhin et al. 2022). However, there is no information whether disease or herbivore pressure will increase on *Lycopodium* species with climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Under present conditions, competition from non-native species is low, as relatively few introduced plants are adapted to the harsh environmental conditions of peatlands. This could change under projected climate change, as higher temperatures, reduced precipitation, and more frequent drought are likely to shift these sites from peat accumulation to decomposition. Resulting changes in soil moisture could shift these communities to wet meadows or coniferous

forests. If drying also brings increased wildfire, these areas would be more prone to invasion by native and introduced plant species adapted to drier conditions (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Unknown
Some *Lycopodium* species have gametophyte generations that do not produce chlorophyll and rely on fungal partners for carbon (mycohetertrophy; Field et al. 2015). No information was available on specific mycorrhizal relationships for *Lycopodium lagopus*.

C5a. Measured genetic variation: Somewhat Increase
Data are lacking on the genetic diversity within and between populations of *Lycopodium lagopus* in Washington and little research appears to be publicly available on genetic diversity in *Lycopodium* species. However, one study found populations of *Lycopodium lucidulum* to have very few genotypes and were usually dominated by a single genotype (Levin and Crepet 1973). If this is a genus-wide trait, *Lycopodium lagopus* could also have limited genetic diversity within populations, limiting this species' ability to adapt to climate change.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Not Ranked
Lycopodium lagopus, like other ferns and fern-allies, has a complex life cycle involving alternation of two distinct growth phases: the familiar sporophyte phase and a much-reduced gametophyte phase. *Lycopodium* species reproduce asexually by bulbils and rhizomes, and sexually via spores.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the reproductive period of *Lycopodium lagopus* has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Lycopodium lagopus experienced a 5% decline in the absence of direct human disturbance between 2000 and 2014 in Northwestern Montana (the southern extent of its range). At the same time, researchers documented patterns of warming temperature and decreased precipitation in the habitats this species occurred in (Lesica and Crone 2017). However, trend data are not available for Washington occurrences.

D2. Modeled future (2050) change in population or range size: Somewhat Increase
Researchers modeled predicted range shifts for Pacific Northwest pteridophytes, including *Lycopodium lagopus*, using 19 different predicted climate variables projected through 2070. This model predicted range contractions for most Lycopodiaceae in the Pacific Northwest, including

Lycopodium lagopus (Link-Perez and Laffan 2018). However, the degree of range contraction was unspecified.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Malaxis monophyllos* var. *brachypoda (white adder's-mouth orchid)

Date: 17 May 2024 Synonym: *Malaxis monophyllos* ssp. *brachypoda*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T4T5/S1
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Increase

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: The single known occurrence (100%) of *Malaxis monophyllos* var. *brachypoda* in Washington occurs in an area with a projected temperature increase in the range of 3.9-4.4° F (2.2-2.4° C; Figure 1).

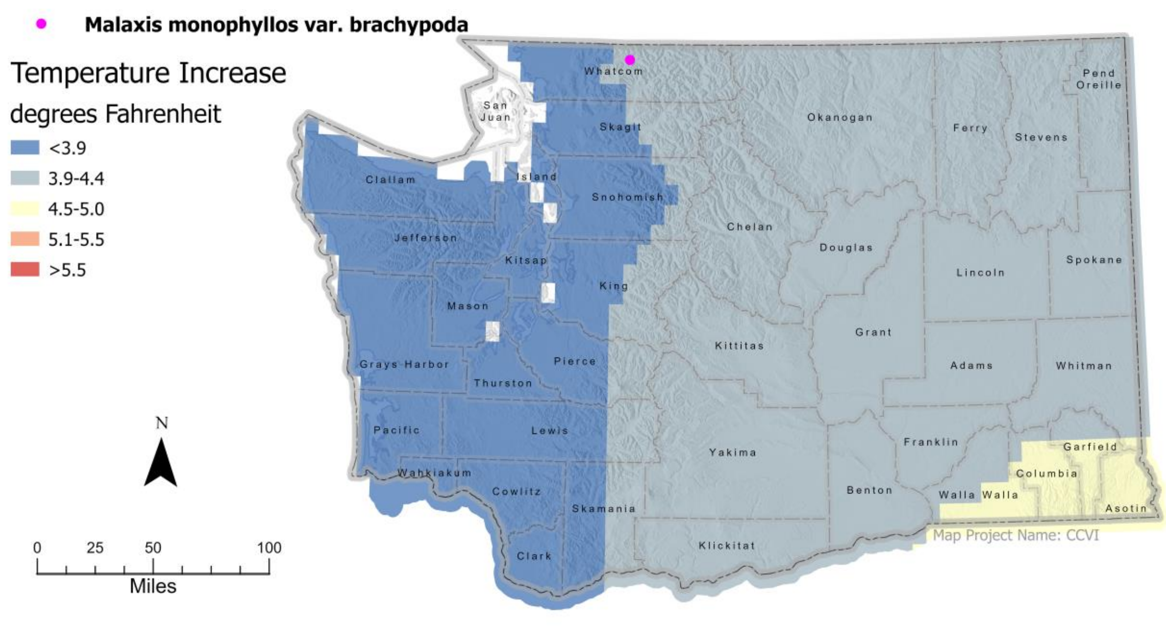

Figure 1. Exposure of *Malaxis monophyllos* var. *brachypoda* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single known occurrences (100%) of *Malaxis monophyllos* var. *brachypoda* in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2).

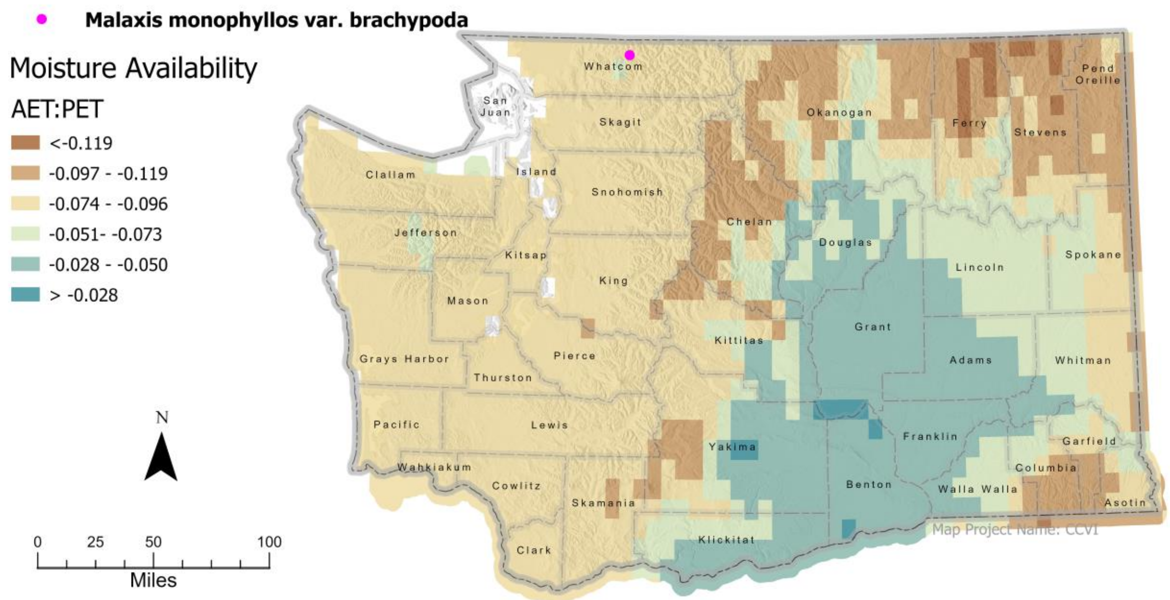

Figure 2. Exposure of *Malaxis monophyllos* var. *brachypoda* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Malaxis monophyllos var. *brachypoda* is found in montane and subalpine swamps and peatlands in the North Cascades of Washington state and is not subject to sea level rise due to its inland distribution (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
Malaxis monophyllos var. *brachypoda* occurs in the North Pacific Bog & Fen ecological system in Washington (Washington Natural Heritage Program 2024). These peatland habitats occur as naturally small patches isolated within a matrix of unsuitable forest, agricultural, and urban/rural lands that create a barrier to migration and dispersal between hydrologically isolated wetlands (Rocchio and Crawford 2015). There is only a single known occurrence in Washington which is separated from the nearest populations in Canada by large stretches of unsuitable dry ecological

systems and the Strait of Juan de Fuca, which creates a significant barrier to dispersal and genetic transfer. However, there is likely some accessible suitable habitat in the vicinity of the single Washington occurrence which could facilitate dispersal and/or migration.

B2b. Anthropogenic barriers: Somewhat Increase
Most of the bog and fen habitat in the vicinity of the Washington occurrence of *Malaxis monophyllos* var. *brachypoda* is located in isolated and undisturbed areas, though there is a road running nearby (NatureServe 2023). Ongoing clearcutting, habitat fragmentation, and disruption of hydrological cycles due to land development could pose somewhat of a threat to this species, but the Washington occurrence is otherwise less impacted by human infrastructure than most lowland plant species (Rocchio and Crawford 2015, Washington Natural Heritage Program 2024). The patchy and specific hydrologic requirements of its natural habitat is a more significant barrier to dispersal or migration than human impacts.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no ongoing or proposed clean energy projects in the vicinity of the *Malaxis monophyllos* var. *brachypoda* occurrence in Washington and future projects are unlikely due to the rugged backcountry terrain (Washington Department of Natural Resources 2024a). However, wildfire mitigation, tree and shrub planting, and other integrated forest health projects are taking place in the vicinity and could alter the surrounding habitat (Washington Department of Natural Resources 2024b). Major tree and shrub encroachment is unlikely due to the saturated soils of this species' habitat (Rocchio and Crawford 2015).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Malaxis monophyllos var. *brachypoda* produces an elliptic capsule fruit containing thousands of extremely tiny seeds which are inflated and well adapted for long distance wind-dispersal and sometimes dispersal on water (Arditti and Ghani 2000, Washington Natural Heritage Program 2024). Orchids are one of the longest dispersing plant species when compared to other wind-dispersers, though germination success can be very low if the right mycorrhizal fungi are not found in the soil (Anderson 2006, Tatarenko et al. 2022). One study suggests that the parent species *Malaxis monophyllos* is also dispersed by wind and gnats, furthering the long distance dispersal capabilities of this species (Fink and Scheidegger 2021).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Malaxis monophyllos* var. *brachypoda* occurrences in Washington. The single known occurrence (100%) is in an area that has experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), this population is expected to be vulnerable to climate warming.

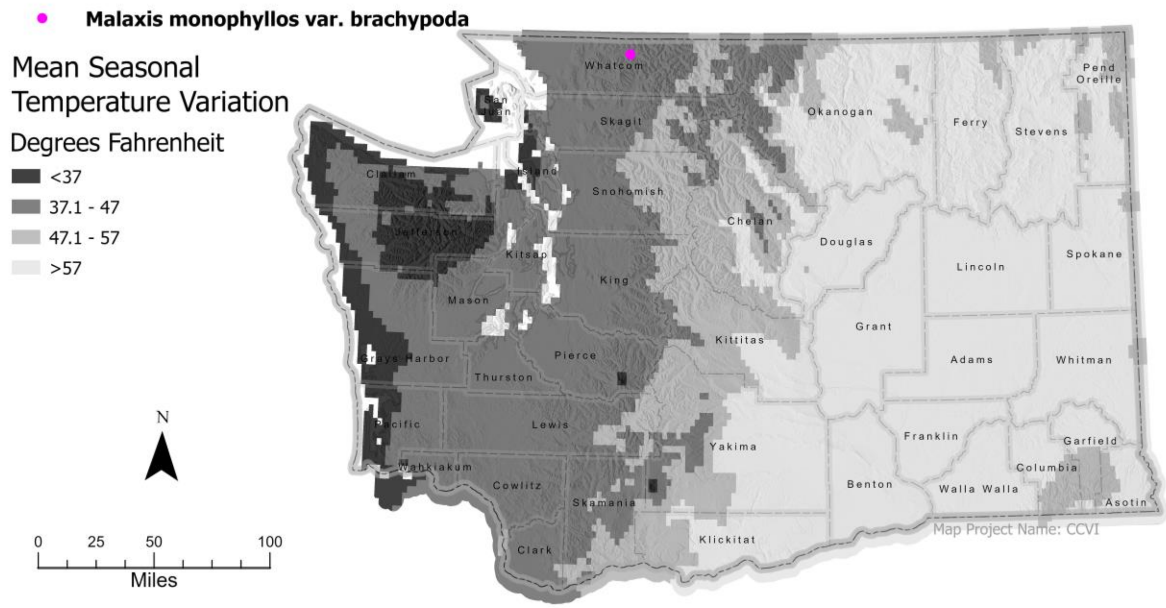

Figure 3. Historical thermal niche (exposure to past temperature variations) of occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Increase</u>
The peatland habitat of *Malaxis monophyllos* var. *brachypoda* is often associated with cold air drainage sites and would likely be negatively impacted by increasing temperatures.
in montane settings and are cooler than the surrounding matrix vegetation. Increased temperatures may increase peat decomposition, causing loss of peat mass or could lead to increased productivity. Could also lead to prolonged droughts and ultimately convert to non-peatland wetland type. Tree cover may increase with drying in some areas, though acidic conditions typically prevent tree encroachment (Rocchio and Ramm-Granberg 2017). In the northern part of its range, the parent species *Malaxis brachypoda* "occurs abundantly in open wet meadows in full sun (NatureServe 2023). Therefore, this species may be slightly resilient to warming based on its preferred microsites.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Malaxis monophyllos* var. *brachypoda* occurrences in Washington. The single known occurrence (100%) is in an area that has experienced greater than average precipitation variation (>20 in (508 mm)) over the historical period and is expected to be mostly resilient to changes in available moisture (Young et al. 2016).

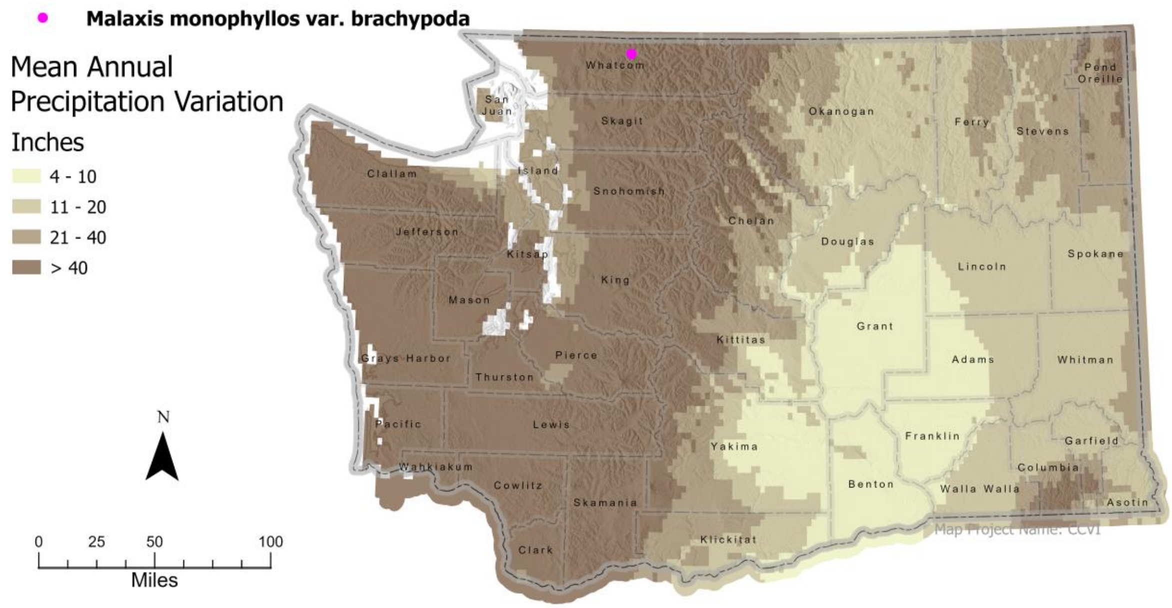

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Malaxis monophyllos* var. *brachypoda* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
The peatland habitat of *Malaxis monophyllos* var. *brachypoda* is dependent on adequate year-round moisture (particularly from groundwater and snowmelt recharge). Changes in the amount of precipitation, shifts from snow to rain, decreased snowpack, or changes in timing of snowmelt could result in a drop in water table depth and changes to water chemistry that in turn would facilitate a transition to wet meadow vegetation (Rocchio and Ramm-Granberg 2017). Fens associated with groundwater discharge from large or deep aquifers may be slightly more resilient to hydrological change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
The bog and fen habitats which support *Malaxis monophyllos* var. *brachypoda* are maintained mostly by soil and water chemistry, including pH, mineral concentration, available nutrients, and cation exchange capacity which together shape the vegetation and prevent tree encroachment (Rocchio and Crawford 2015). The balance of water inputs with evapotranspiration is also critical to peat accumulation (Rocchio and Ramm-Granberg 2017). Additional disturbances are usually not required to maintain these habitats.

C2d. Dependence on ice or snow-cover habitats: Neutral

While *Malaxis monophyllos* var. *brachypoda* does not rely directly on ice or snow-covered habitats, melting snow is a significant contributor to groundwater recharge in peatland habitats and reductions to snowpack may lower the water table and facilitate shifts to species adapted to drier ecological systems such as wet meadows as peat is reduced (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Malaxis monophyllos var. *brachypoda* is found in glacial peatlands on calcareous soils derived from Quaternary alluvium and Nooksack formation marine sedimentary rocks (Anderson 2006, Washington Division of Geology and Earth Resources 2016, NatureServe 2023). These substrates are relatively common in Washington but the topographic features that allow development of peatlands, such as glacial scours, , kettles, ox-bows, or old ponds and lakes are more uncommon features on the landscape (Rocchio and Crawford 2015).

C4a. Dependence on other species to generate required habitat: Neutral
The bog and fen habitat of *Malaxis monophyllos* var. *brachypoda* is maintained largely by edaphic factors and drainage patterns that favor the accumulation of thick organic soil layers favoring peatland vegetation over conifer forests (Rocchio and Crawford 2015). Other species are not required to maintain this habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
North American *Malaxis* spp. have some of the smallest flowers in the orchid family and possess a lower lip (labellum) that acts as a landing pad for visiting pollinators and probably secretes nectar (Ames 1938, Anderson 2006). The low genetic diversity of the parent *species Malaxis monophyllos* may indicate the presence of a self-incompatible, pollinator-dependent mating system (Jermakowicz et al. 2022). The specific pollinators of *Malaxis monophyllos* var. *brachypoda* are unknown but are probably limited to fungus gnats and small flies based on floral morphology, suggesting that this species is somewhat pollinator limited (Anderson 2006).

C4d. Dependence on other species for propagule dispersal: Neutral
Orchid species such as *Malaxis monophyllos* var. *brachypoda* are dispersed primarily by wind, water, or occasionally by insects (Arditti and Ghani 2000, Fink and Scheidegger 2021, Washington Natural Heritage Program 2024). There is no evidence of dispersal by animals (Anderson 2006).

C4e. Sensitivity to pathogens or natural enemies: Neutral
There are no major pathogens or enemies documented for *Malaxis monophyllos* var. *brachypoda.*

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Under present conditions, competition from non-native species is low, as relatively few introduced plants are adapted to the high acidity and soil saturation of bogs and fens (Rocchio and Crawford 2015). Climate change may lead to higher temperatures, reduced precipitation, and more frequent drought which are likely to shift these sites from accumulating peat to losing organic material from increased decomposition (Rocchio and Ramm-Granberg 2017). Resulting

changes in soil moisture could shift these communities to wet meadows or conifer forests. If drying also leads to increased wildfire, these areas would be more prone to invasion by native and introduced plant species adapted to drier conditions (Rocchio and Ramm-Granberg 2017). The parent species *Malaxis monophyllos* has been described as "nonaggressive and noncompetitive" but is able to persist in areas with little disturbance (Anderson 2006).

C4g. Forms part of an interspecific interaction not covered above: Increase
Like all other orchid species*, Malaxis monophyllos* var. *brachypoda* is expected to rely on a symbiotic relationship with mycorrhizal fungi for seed germination (Yoder et al. 2000). *Rhizoctonia repens* is the only fungus that has been detected on the roots of the parent species *Malaxis brachypoda,* suggesting that this species has high symbiotic specificity (Anderson 2006). It is unknown exactly how this symbiotic relationship may be impacted by climate change, but the reliance on this interspecific relationship generally increases the vulnerability of *Malaxis monophyllos* var. *brachypoda* (Young et al. 2016).

C5a. Measured genetic variation: Unknown
Malaxis monophyllos var. *brachypoda* is known from only one occurrence in Washington which is disjunct from the core range, with the nearest populations found on Vancouver Island and in B.C. This population is probably completely genetically isolated and at risk of inbreeding and genetic drift, but the specific genetic diversity of the Washington population is unknown. The parent species *Malaxis monophyllos* has been shown to have low genetic diversity in the European part of its range due to small population sizes and inbreeding (Jermakowicz et al. 2015).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
Malaxis monophyllos var. *brachypoda* is a perennial herb that is thought to be self-incompatible and fully pollinator dependent as an obligate outcrosser, though it can sometimes reproduce vegetatively from corms (Anderson 2006, Jermakowicz et al. 2015). It produces pollinia, or packets of pollen that can be transported as a single unit, to increase the odds of fertilizing its large numbers of ovules (Anderson 2006). Lack of a mixed mating system and reliance on pollinators for outcrossing suggests that this species may have somewhat reduced genetic diversity (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (July to August) has not changed significantly (Washington Natural Heritage Program 2024). However, there are not enough records to truly assess trends. The parent species *Malaxis brachypoda* is expected to be phenologically sensitive to spring moisture levels as other related species of *Malaxis* have demonstrated earlier flowering after wet vs. dry springs (Anderson 2006).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown

The trends of *Malaxis monophyllos* var. *brachypoda* in Washington are not well known but have generally been assumed to be stable as this species occurs in largely undisturbed peatlands in somewhat remote areas (NatureServe 2023). However, site visit records indicate that plants were not found in recent years after multiple visits when the water level was higher than normal. The parent species *Malaxis monophyllos* has been declining at the southern end of its range in the United States, in Colorado, and in Russia, but the causes have not been clearly linked to climate change (Anderson 2006, Efimov 2012, NatureServe 2023).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Montia diffusa (branching montia)

Date: 16 May 2024 Synonym: *Claytonia diffusa*, *Limnalsine diffusa*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4/S1S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	50
	<3.9° F (2.2°C) warmer	50
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	5
	-0.074 to -0.096	78
	-0.051 to -0.073	17
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Unknown
4e. Sensitivity to pathogens or natural enemies		Unknown
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Nine of 18 known occurrences (50%) of *Montia diffusa* in Washington occur in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4° C). The remaining known occurrences (50%) of *Montia diffusa* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C) warmer (Figure 1).

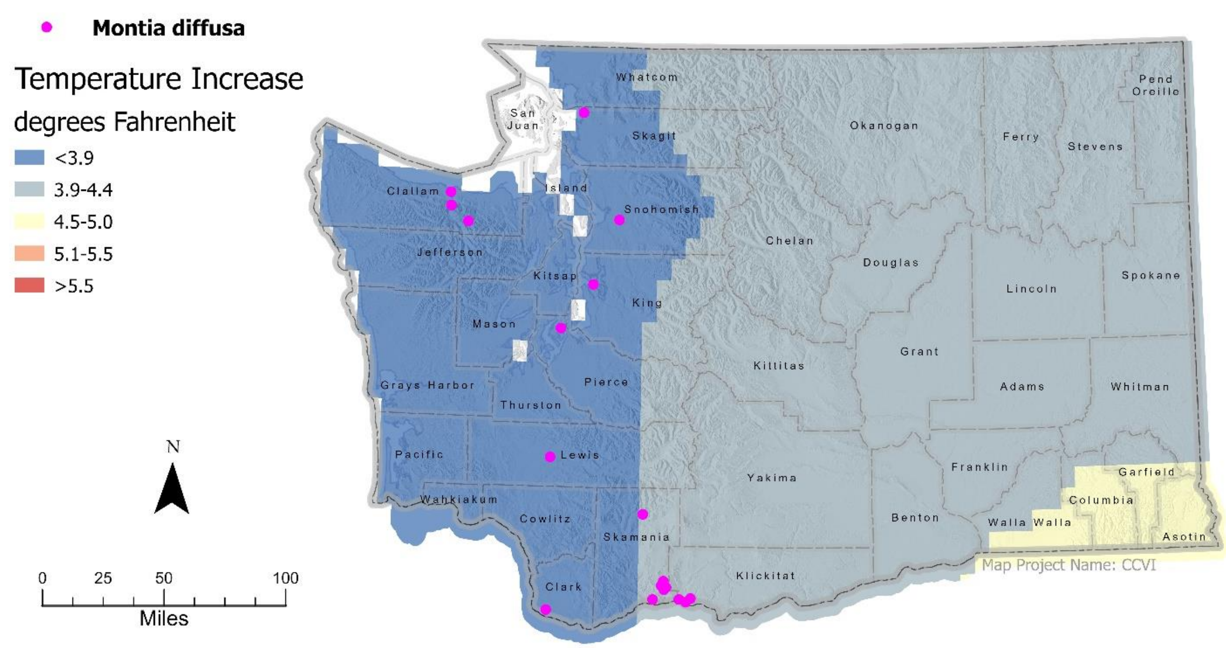

Figure 25. Exposure of occurrences of *Montia diffusa* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi.

A2. Hamon AET:PET Moisture Metric: Three of 18 known occurrences (17%) of *Montia diffusa* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to - 0.073. Fourteen (78%) are found in areas with a projected decrease in available moisture in the range of -0.074 to - 0.096. One occurrence (5%) is found in an area with a projected decrease in available moisture in the range of -0.097 to -0.119 (Figure 2).

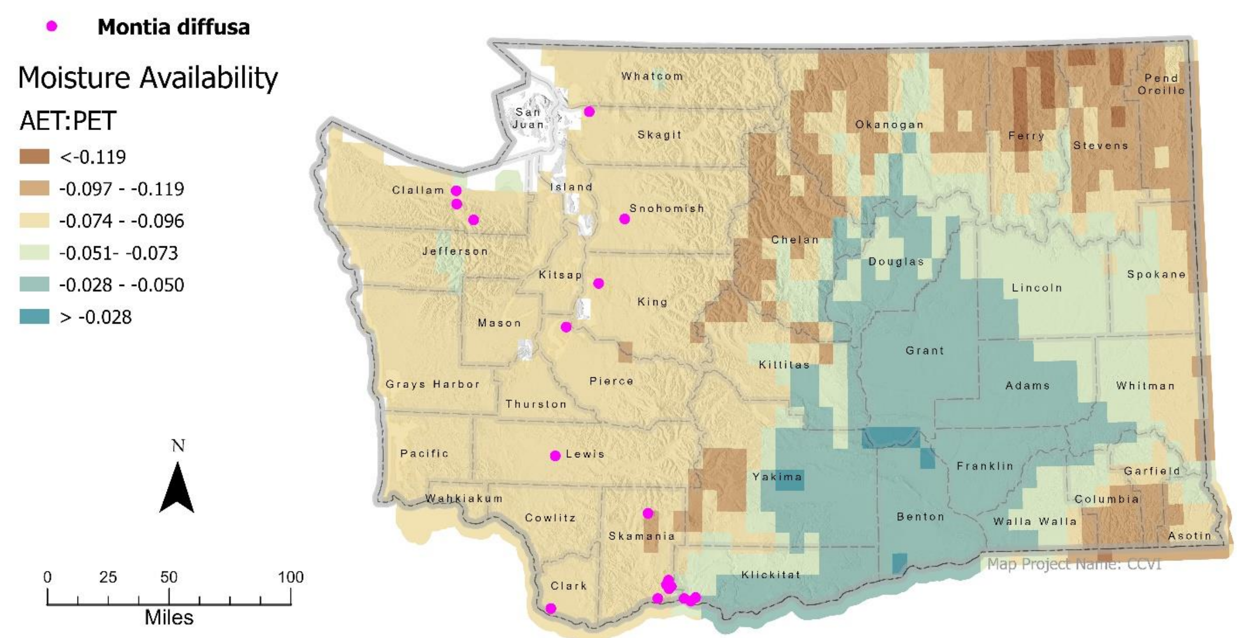

Figure 26. Exposure of occurrences of *Montia diffusa* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi.

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Montia diffusa is found in forest and woodland habitats between 850–2900 ft (260–885 m; Washington Natural Heritage Program 2024) and will not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Neutral</u>
Montia diffusa occurs in the Northern Rocky Mountain Ponderosa Pine Woodland and Savanna ecological system, as well as North Pacific Dry Douglas-Fir Forest and Woodland. Ponderosa pine woodlands are a matrix ecosystem in eastern Washington, while dry Douglas-fir forest occur sporadically as small to large patches within a matrix of lowland forest, remnant prairie, and anthropogenic environments (Rocchio and Crawford 2015). *Montia diffusa* is unlikely to experience significant natural barriers to dispersal or migration.

B2b. Anthropogenic barriers: Somewhat Increase
North Pacific Dry Douglas-Fir Forest and Woodland occurs in the Puget Trough, where it is threatened by habitat conversion due to development. Logging and other human activities have fragmented and reduced overall abundance of this habitat type (Rocchio and Crawford 2015). Northern Rocky Mountain Ponderosa Pine Woodland and Savanna is also affected by anthropogenic (agricultural, rural, and urban) environments. Based on *Montia diffusa*'s presumed dispersal abilities, anthropogenic barriers somewhat increase this species' vulnerability to climate change.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Montia diffusa* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Little information is available on seed dispersal and movement in *Montia diffusa*. Some species of *Montia* and the closely related *Claytonia* genus are myrmecochorous (dispersed by ants) (Handel 1978). Some *Claytonia* also spread seeds by explosive dehiscence (Matthews 1993a), or colonize disturbed sites via long-lived seeds in the seed bank that germinate, flower, and reseed profusely after disturbances such as fire (Matthews 1993b). *Montia diffusa* produces 3-valved capsules that hold one to three small (0.06 in (1.5 mm)) black seeds. The seeds have a short conical appendage, but otherwise have no adaptive features for long-distance dispersal (Matthews 1993b, Washington Natural Heritage Program 2024). The appendage could potentially aid ant dispersal, but evidence is lacking. Given these traits, *Montia diffusa* probably has only moderate dispersal capabilities via seeds traveling short to medium distances.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Montia diffusa* occurrences in Washington. Two of 18 known occurrences (12%) are in areas that have experienced very small (< 37° F (20.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have greatly increased vulnerability to climate warming. Eight of 18 known occurrences (44%) are in areas that have experienced small (37 - 47° F (20.8 - 26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming. Eight of 18 known occurrences (44%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming.

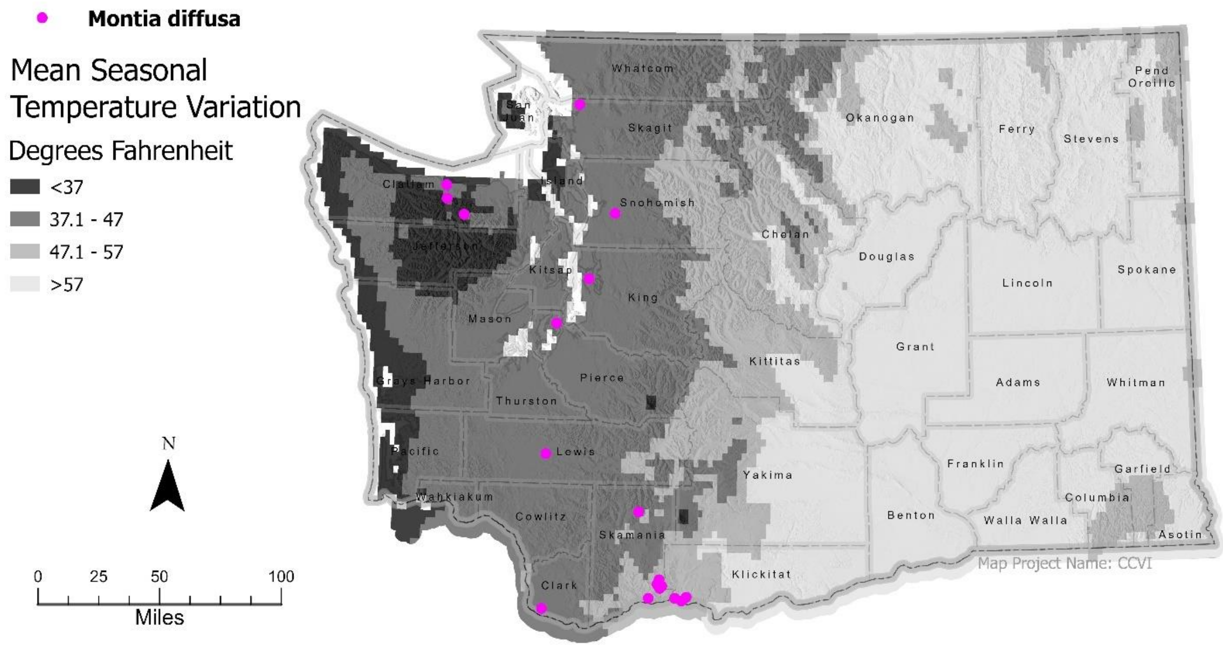

Figure 27. Historical thermal niche (exposure to past temperature variations) of occurrences of *Montia diffusa* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
North Pacific Dry Douglas-Fir Forest and Woodland systems consist of species that occur in warm and dry areas across a wide range of temperature regimes and are unlikely to be sensitive to shifts in temperature (Rocchio and Ramm-Granberg 2017). Northern Rocky Mountain Ponderosa Pine Woodland and Savanna occurs on warm, dry, exposed slopes (Rocchio and Crawford 2015). The habitats of *Montia diffusa* are not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change. *Montia diffusa* prefers moist areas within this habitat and may be more vulnerable to increases in average temperature than its surrounding habitat, but likely remains largely resilient to the effects of climate change on its thermal niche.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Montia diffusa* occurrences in Washington. All 18 known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change- induced shifts in precipitation and moisture regimes.

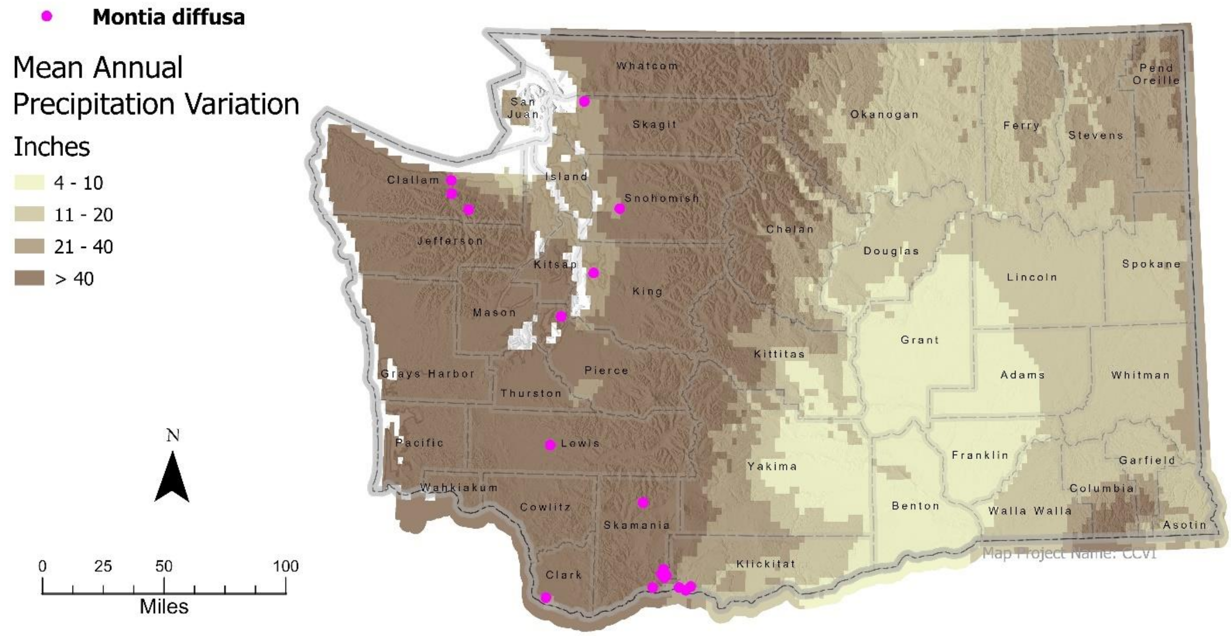

Figure 28. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Montia diffusa* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
The Douglas-fir and ponderosa pine woodlands in which *Montia diffusa* occurs are relatively dry habitats that historically receive moisture in the winter and then experience summer droughts. Most precipitation in ponderosa pine woodlands falls as snow. These habitats are both more likely to be sensitive to reduced moisture than to changes in temperature. Decreased moisture could increase the frequency and severity of fires and insect outbreaks. This could result in shifting vegetation communities (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). *Montia diffusa* prefers moist areas within these habitats and may be especially vulnerable to changes in moisture.

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Montia diffusa may be a “fire-following” species. In Oregon, this species was documented as an early colonizer of burned areas, with population sizes diminishing two years after the fire (Kayes et al. 2010), or only occurring in areas burned in the previous 20 years (Neiland 1958). Both North Pacific Dry Douglas-Fir Forest and Woodland and Northern Rocky Mountain Ponderosa Pine Woodland and Savanna are dependent on fire. Fire suppression and other human activities have made these ecosystems more homogenous and more vulnerable to stand-replacing fire (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). While *Montia diffusa* might benefit from more frequent low- and moderate-severity fires, stand-replacing fires could potentially result in unsuitable habitat for this species. While below-ground propagules are

generally well-insulated from fire (Wiggers et al. 2013), fires fueled by wood debris build up due to past fire suppression could potentially sterilize soil and damage the seedbank for this species.

C2d. Dependence on ice or snow-cover habitats: Neutral
Montia diffusa does not directly rely on ice or snow-covered habitats. However, most precipitation in Northern Rocky Mountain Ponderosa Pine Woodland and Savanna falls as snow (Rocchio and Crawford 2015), so changes in snowfall patterns could still have some effect on this species' habitat.

C3. Restricted to uncommon landscape/geological features: Neutral
Montia diffusa occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016). This species prefers ecological systems that are generally found on coarse, neutral to slightly acidic soils with good drainage (Rocchio and Crawford 2015). These ecological systems are widely distributed and are unlikely to unduly restrict *Montia diffusa*.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Outbreaks of pathogens or insect herbivores (such as bark beetles) are one of the processes that structure Douglas-fir and ponderosa woodlands. These outbreaks are likely to increase in intensity with climate change (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). Abiotic factors such as fire and precipitation probably have a more important influence on these habitats but an increase in bark beetle outbreaks could potentially have some impact on habitat availability for *Montia diffusa*, somewhat increasing its vulnerability to climate change.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
No information was available on pollinator relationships with *Montia diffusa*. However other *Montia* and *Claytonia* species have mixed mating strategies and are both self-compatible but protandrous (favoring outcrossing) and are able to attract both pollen-specialist and generalist small bees (Dembicz et al. 2015, Parker et al. 2018). *Montia diffusa* is likely also a pollinator generalist species and may be at least somewhat resilient to the effects of climate change on plant-pollinator relationships.

C4d. Dependence on other species for propagule dispersal: Unknown
The seeds of *Montia diffusa* are probably dispersed by gravity or other passive means. The fruits of *Montia diffusa* do not have barbs, hooks, or other specialized means of attachment. It is unknown if this species is ant-dispersed like some other *Montia* and *Claytonia* species.

C4e. Sensitivity to pathogens or natural enemies: Unknown
No information was found regarding *Montia diffusa*'s direct sensitivity to enemies or pathogens.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Grazing and other ground disturbances can result in introduced herbaceous species invading the understory of Douglas-fir and ponderosa pine woodlands (Rocchio and Crawford 2015). A study in Oregon also found that *Montia diffusa* decreases in the understory as time since fire increases

(Kayes et al. 2010), suggesting this species is somewhat vulnerable to competition from both native and non-native plants.

C4g. Forms part of an interspecific interaction not covered above: Unknown

C5a. Measured genetic variation: Unknown
Data are lacking regarding the genetic diversity within and between populations of *Montia diffusa* in Washington.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
No information is available on *Montia diffusa* reproduction. However, other *Montia* and *Claytonia* species have a mixed mating strategy—they are self-compatible but protandrous (favoring outcrossing) (Dembicz et al. 2015, Parker et al. 2018). If *Montia diffusa* is also protrandrous, it likely maintains at least average genetic diversity.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Montia diffusa* (April to July) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Montia diffusa* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Ophioglossum pusillum (adder's-tongue)

Date: 9 May 2024 Synonym: *Ophioglossum vulgatum [misapplied], Ophioglossum vulgatum* var. *alaskanum, Ophioglossum vulgatum* var. *pseudopodum*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	89
	<3.9° F (2.2°C) warmer	11
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	46
	-0.074 to -0.096	11
	-0.051 to -0.073	32
	-0.028 to -0.050	11
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral

4e. Sensitivity to pathogens or natural enemies	Neutral
4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Somewhat Increase
5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Not Ranked
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Two of 19 Washington occurrences of *Ophioglossum pusillum* with modelled data (11%) occur in areas with a projected temperature increase of <3.9° F (2.2°C). Seventeen (89%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4°C; Figure 1). The two records of *Ophioglossum pusillum* from the San Juan Islands do not have temperature data available from the model used for CCVI.

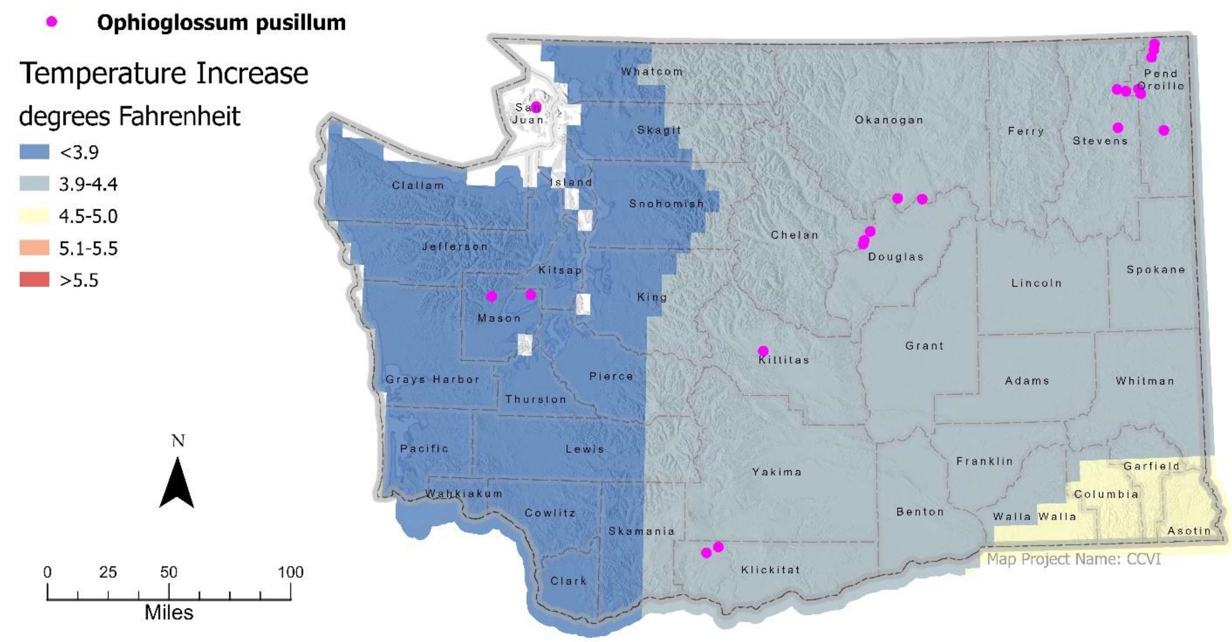

Figure 29. Exposure of occurrences of *Ophioglossum pusillum* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of 19 known Washington occurrences of *Ophioglossum pusillum* with modelled data (11%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.028 to -0.050. Six (32%) are found in areas with a projected decrease in available moisture in the range of -0.051 to -0.073. Two (11%) are found in areas with a projected decrease in available moisture in the range of -0.074 to -0.096. The remaining nine known occurrences with modelled data (46%) are found in areas with a projected decrease in available moisture in the range of -0.097 to -0.119 (Figure 2). The two records of *Ophioglossum pusillum* from the San Juan Islands do not have moisture data available from the model used for CCVI.

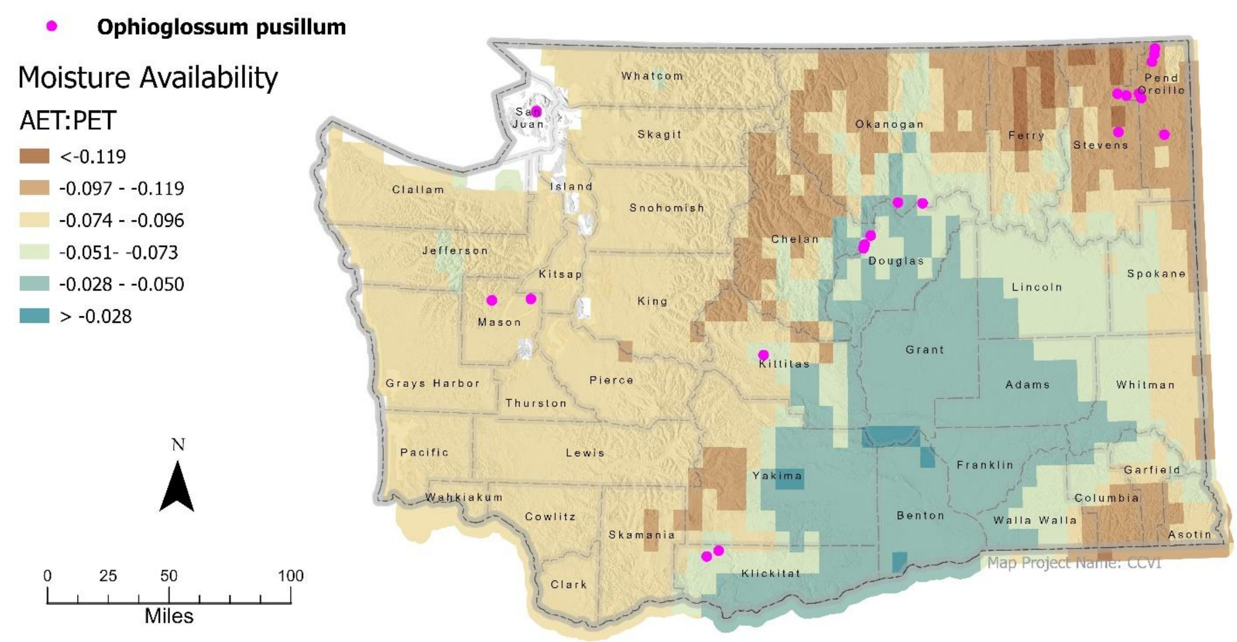

Figure 30. Exposure of occurrences of *Ophioglossum pusillum* in Washington to projected moisture availability (based on ration of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Ophioglossum pusillum occurs in a wide variety of wet and seasonally wet habitats, including moist meadows, creek sides, wetlands, and peatlands at elevations of 40–3200 ft (12–975 m; Washington Natural Heritage Program 2024). These populations occur inland or above the highest projected sea level rise, and they would not be inundated.

B2a. Natural barriers: <u>Neutral</u>
Ophioglossum pusillum occurs in the Northern Rocky Mountain Subalpine-Upper Montane Grassland, North Pacific Bog and Fen, and Rocky Mountain Subalpine-Montane Fen ecological systems (Washington Natural Heritage Program 2024). This species is found in large and small-patch ecological systems with a scattered distribution throughout Washington. Based on its potential for long-distance dispersal, however, these conditions are unlikely to restrict *Ophioglossum pusillum* dispersal.

B2b. Anthropogenic barriers: <u>Somewhat Increase</u>
Several occurrences of *Ophioglossum pusillum* are near roads or highways, reservoirs, or other human developments. Timber harvesting and agricultural activities, including grazing, are also

apparent in the surrounding areas for several occurrences of this species. The major anthropogenic threat to montane grasslands is grazing (cattle and horses) and recreation, which can change the vegetation structure and compact soil. Many peatlands in the North Pacific Bog and Fen ecological system have been isolated or damaged by logging and roads (Rocchio and Crawford 2015), potentially creating barriers to migration for some species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Ophioglossum pusillum* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
This species produces “a cloud of yellow … spores” that are capable of dispersing long distances by wind. Fern spores are frequently dropped from the air by rainstorms (McMaster 1994, Link-Perez and Laffan 2018). Pteridophytes like *Ophioglossum pusillum* are wind-dispersed and frequently capable of dispersing over long distances (McMaster 1994). In open areas, ferns theoretically have unlimited potential for dispersal over long distances and can easily travel nearly 250 mi (400 km; Peck 1985), suggesting that dispersal capabilities will not limit this species ability to respond to climate change.

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 (“historical thermal niche”) across the distribution of known *Ophioglossum pusillum* occurrences in Washington. Two of 19 modelled occurrences (11%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected have increased vulnerability to climate warming. One of 19 modelled occurrences (5%) is in an area that has experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming. Sixteen of 19 modelled occurrences (84%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming. The two records of *Ophioglossum pusillum* from the San Juan Islands do not have historical thermal niche data modelled.

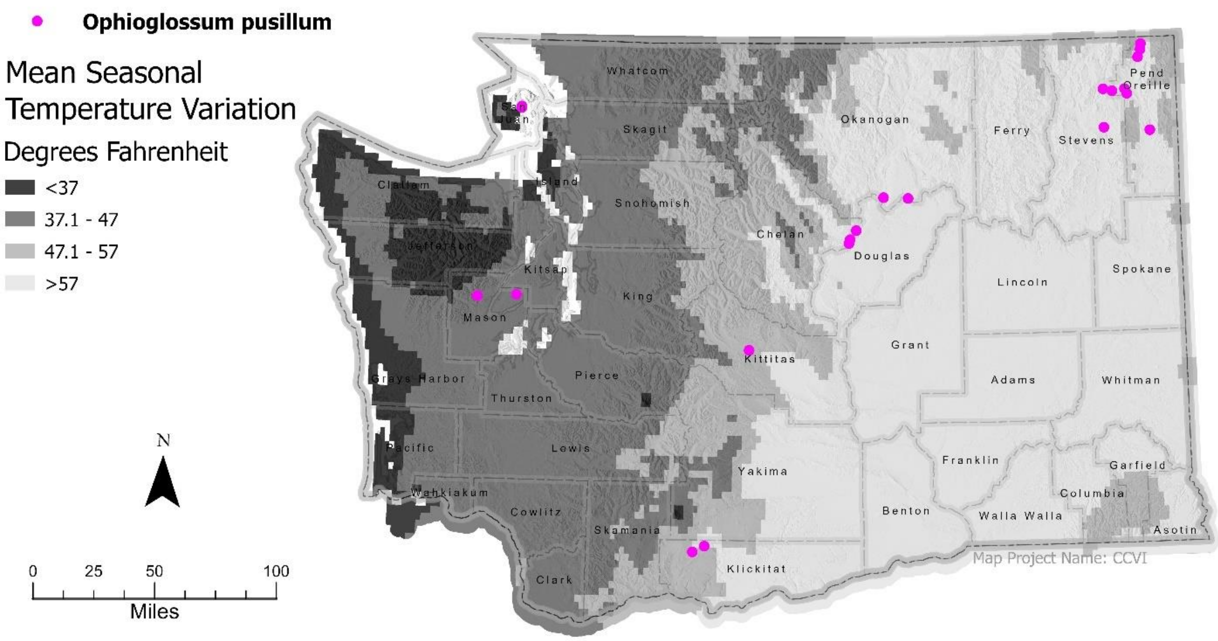

Figure 31. Historical thermal niche (exposure to past temperature variations) of occurrences of *Ophioglossum pusillum* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase
In Washington, *Ophioglossum pusillum* occurs in seasonally to perennially wet areas in Northern Rocky Mountain Subalpine-Upper Montane Grassland, North Pacific Bog and Fen, and Rocky Mountain Subalpine-Montane Fen ecological systems (Washington Natural Heritage Program 2024). In montane grasslands, increases in temperature may help prevent encroachment from trees, by creating an environment too warm and dry for tree species to establish. Increases in temperature could accelerate drying in peatlands and increases in water temperature could lead to commensurate changes in their biological communities. Peatlands and seasonally moist grasslands are often associated with cold air drainage sites in montane settings and are cooler than the surrounding matrix vegetation, perhaps making them more sensitive to changes in temperature (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Ophioglossum pusillum* occurrences in Washington. Three of the 19 modeled occurrences (16%) are in an area that has experienced small precipitation variation (4–10 in (100–254 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be vulnerable to climate change induced shifts to precipitation and moisture regimes. Two of the 19 modeled occurrences (11%)

are in areas that have experienced slightly lower than average precipitation variation (11–20 in (255–508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. Fourteen of the 19 modeled occurrences (73%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes. The two records of *Ophioglossum pusillum* from the San Juan Islands do not have historical hydrological niche data modelled.

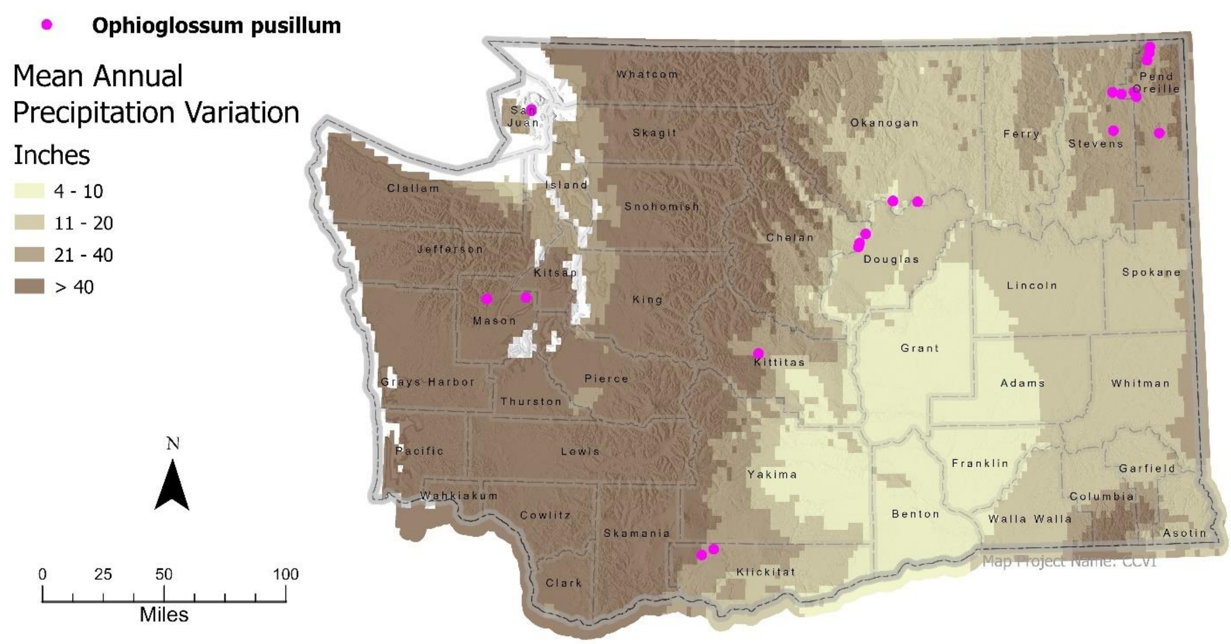

Figure 32. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Ophioglossum pusillum* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Increase

In Washington and elsewhere, *Ophioglossum pusillum* frequently occurs in mesic and wetland sites, including wet meadows, creek sides, peatlands, and other wetlands. The Northern Rocky Mountain Subalpine-Upper Montane Grassland habitats this species occurs in are likely to experience decreases in water availability and snowpack. Decreases in water availability accompanied with increases in temperature could reduce the chances of tree invasion in these habitats (Rocchio and Ramm-Granberg 2017). Peatland habitats, where this species also occurs, are dependent on precipitation and groundwater (along with cool temperatures) to maintain a high water table necessary for peat accumulation. Reductions in the amount of precipitation and increased temperatures could shift the balance from peat accumulation to peat decomposition, accelerating conversion to wet meadow habitats, or favoring encroachment by conifer forests

(Rocchio and Ramm-Granberg 2017). While *Ophioglossum pusillum* may be less vulnerable than species that depend only on peatland habitats, changes in hydrology within its habitat, including those caused by drought, are still likely to threaten this species (Stone 2021).

C2c. Dependence on a specific disturbance regime: Neutral
Ophioglossum pusillum is frequently associated with disturbance, such as grazing, and appears to benefit from disturbances that reduce tree cover (McMaster 1994). *Ophioglossum pusillum* has underground gametophytes, which may aid in its ability to survive dry spells or disturbances such as fire (McMaster 1994). At least one observation of this species in Washington notes unusually vigorous individuals post-fire, and several occurrences are found near roads and reservoirs in Washington. Fire plays an important role in maintaining the small meadows and large open parks of montane grasslands, one of the ecosystem types that this species regularly occurs in. *Ophioglossum pusillum* might benefit from more frequent low and moderate severity fires, and the low cover of woody species in its habitat reduces the likelihood of fires severe enough to harm propagules under the soil surface (Wiggers et al. 2013). Though fire frequency is expected to increase with climate change, the habitat and fire response of *Ophioglossum pusillum* suggest that these changes are unlikely to have a negative effect on the range or abundance of this species, as long as site hydrology is not unduly disrupted.

C2d. Dependence on ice or snow-cover habitats: Neutral
While *Ophioglossum pusillum* does not rely directly on ice or snow-covered habitats, reduced snowpack and precipitation shifts from snow to rain are significant threats to fen habitats and could result in warmer and drier conditions in montane grassland habitats (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Ophioglossum pusillum occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Both the montane grasslands and the peatlands that support *Ophioglossum pusillum* are maintained by abiotic factors, including groundwater and precipitation patterns, water chemistry, and history of glaciation and fire (Rocchio and Crawford 2015). However, this species appears to favor disturbed sites, and this includes sites affected by grazing by domestic and wild ungulates, or by human activities (McMaster 1994).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The sporophyte generation of *Ophioglossum* species reproduces by spores and does not require pollinators. The gametophyte phase reproduces by motile sperm and does not require pollinators for assistance.

C4d. Dependence on other species for propagule dispersal: Neutral
The spores and gametes of *Ophioglossum* species do not require animal species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: <u>Neutral</u>
Northern Rocky Mountain Subalpine-Upper Montane Grasslands can become degraded and eroded under heavy grazing from cattle or elk and these effects could be compounded by climate change (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). However, based on *Ophioglossum pusillum*'s preference for disturbed habitat, this species may be resilient to grazing pressure which is also not expected to increase as a result of climate change.

C4f. Sensitivity to competition from native or non-native species: <u>Somewhat Increase</u>
Phalaris arundinacea and *Iris pseudacorus* have been documented at least at one location for *Ophioglossum pusillum* in Washington. This species can be outcompeted by graminoids and may do better in locations with some shrub cover (McMaster 1994). Competition with other herbaceous plants and encroachment from trees are reported as threats to *Ophioglossum pusillum* based on element occurrence data from California (Stone 2021). This species preference for recently disturbed sites also suggests some vulnerability to competition. Climate change may favor competitors in some habitats (e.g. tree encroachment in fens) but not in others (e.g. increases in fire disturbance).

C4g. Forms part of an interspecific interaction not covered above: <u>Somewhat Increase</u>
The gametophyte generation and the initial stages of the sporophyte generation in all *Ophioglossum* species are incapable of photosynthesis and obtain their carbon from mycoheterotrophy. Research on a related species, *Ophioglossum vulgatum*, identified a mutualistic relationship with a specific fungal partner, *Glomus macrocarpum* (Field et al. 2015). This suggests that *Ophioglossum pusillum* may also rely on specific fungal partners for some or all its lifecycle.

C5a. Measured genetic variation: <u>Somewhat Increase</u>
A study of *Ophioglossum pusillum*'s genetic variation in Massachusetts found almost no genetic diversity in populations (McMaster 1994). *Ophioglossum pusillum* also reproduces vegetatively, and some populations in Massachusetts were found to be all or mostly clones of one genetic individual. While this appears to favor colonization of new sites that already have favorable conditions, it suggests that *Ophioglossum pusillum* may not be able to adapt to changing conditions (McMaster 1996, Stone 2021).

C5b. Genetic bottlenecks: <u>Not Ranked</u>

C5c. Reproductive System: <u>Not Ranked</u>

C6. Phenological response to changing seasonal and precipitation dynamics: <u>Neutral</u>
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the sporulating period of *Ophioglossum pusillum* (June–September) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: <u>Unknown</u>

There are no reports of *Ophioglossum pusillum* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Oxytropis campestris var. *gracilis* (slender crazyweed)

Date: 5 March 2024 Synonyms: *Oxytropis campestris* var. *spicata, Oxytropis monticola*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	56
	<3.9° F (2.2°C) warmer	44
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	25
	-0.074 to - 0.096	62
	-0.051 to - 0.073	13
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral/Somewhat Increase
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the 16 known occurrences of *Oxytropis campestris* var. *gracilis* in Washington with model data, seven (44%) occur in areas with a projected temperature increase of less than 3.9° F (2.2° C; Figure 1). Another nine (56%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C). Two other occurrences in San Juan county do not have available model data to predict temperature increase and have been omitted from percentages.

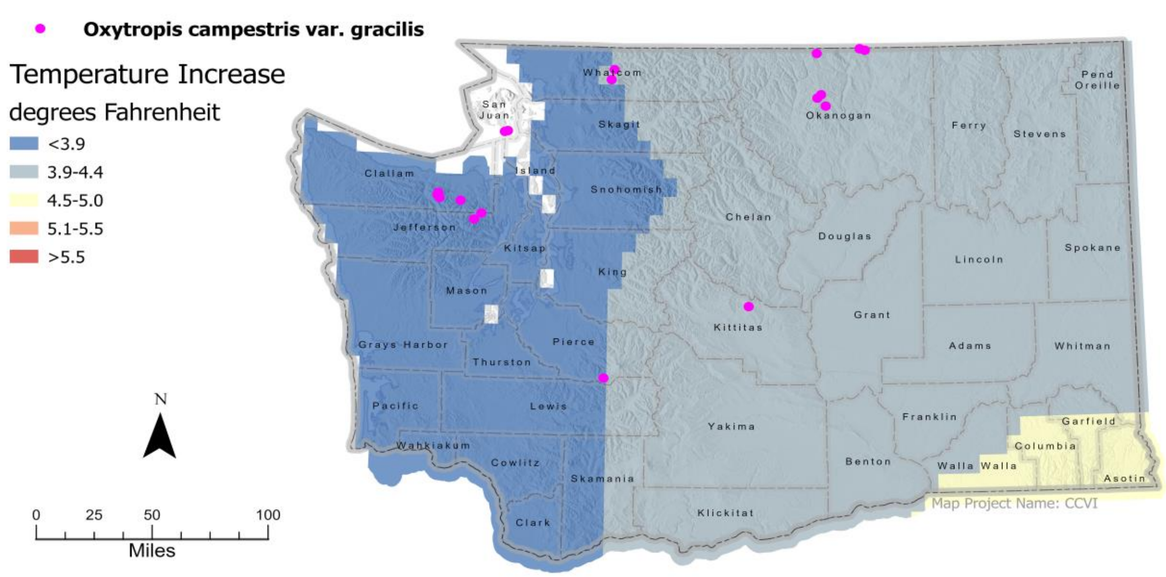

Figure 1. Exposure of *Oxytropis campestris var. gracilis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the 16 known occurrences (13%) of *Oxytropis campestris* var. *gracilis* with model data in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to - 0.073 (Figure 2). Another 10 (62%) are in areas with a moisture decrease in the range of -0.074 to -0.096. The remaining four occurrences with model data (25%) are in areas with a projected decrease of -0.097 to -0.119. Two other occurrences in San Juan county do not have available model data to predict the decrease in available moisture and have been omitted from percentages.

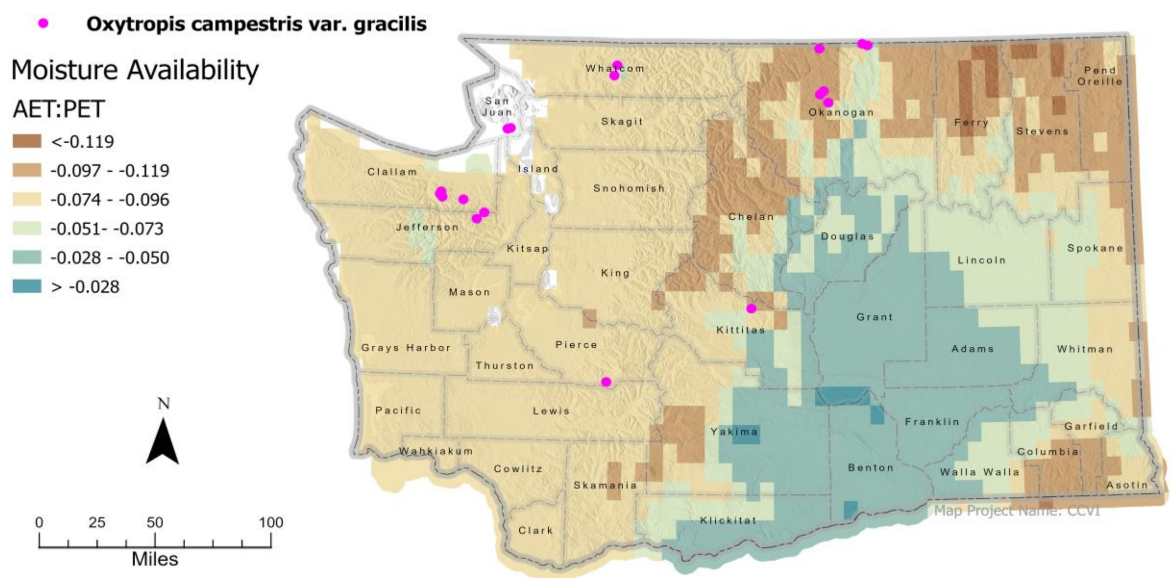

Figure 2. Exposure of *Oxytropis campestris* var. *gracilis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Oxytropis campestris var. *gracilis* occurs on scree slopes, rock outcrops, and in meadows and balds at low to high elevations (3-7600 f (/1-2317 m; Washington Natural Heritage Program 2024). Most of the occurrences are at too high of an elevation to impacted by sea level rise but the San Juan Island occurrences could be impacted if extreme sea level rise occurs (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Somewhat Increase</u>
Oxytropis campestris var. *gracilis* associates with multiple ecological systems, ranging from moderately steep scree and turf slopes to flat prairies on glacial outwash terraces (Washington

Natural Heritage Program 2024). These are generally open and rocky areas with shallow soils that occur as pockets in a larger coniferous forest matrix (Rocchio and Crawford 2015). Populations occur in disjunct mountain ranges (Olympics, Rainier, Cascades/Okanogan) separated by unsuitable developed lands, lowland valleys and forested areas, and the Salish Sea which may create significant barriers to dispersal and migration. However, the diversity of potential habitats for this species is likely to offset the impact of natural barriers to dispersal and migration.

B2b. Anthropogenic barriers: Neutral
Most occurrences of *Oxytropis campestris* var. *gracilis* in Washington are in backcountry areas or in rugged terrain that may even require technical climbing. Some occurrences are well protected from development within wilderness areas and National Parks (Washington Natural Heritage Program 2024). Development is minimal and limited to a few roads and trails that run near occurrences. However, trampling and recreation impacts can be significant and result in erosion and bare ground pockets in fell-field and turf communities (Rocchio and Crawford 2015). Overall barriers are few and probably pose less of a constraint to dispersal and future migration than natural barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Oxytropis campestris* var. *gracilis* (Washington Department of Natural Resources 2024). Future projects are unlikely as many of the occurrences are in rocky, backcountry areas or in rugged mountain terrane.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Oxytropis campestris var. *gracilis* produces papery and strongly inflated pods which fall off unopened and split to release seeds as they roll in the wind (Rydberg 1928, Montana Natural Heritage Program 2024). Dispersal distances are probably relatively short (< 100 meters) and depend solely on passive means (such as gravity, wind). Genetic data from other varieties of *Oxytropis campestris* suggest limited gene flow between populations due to poor dispersal (Chung et al. 2004).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Oxytropis campestris var. gracilis* occurrences in Washington with available model data. Of the 16 known occurrences, four (25%) are in areas that have experienced average temperature variation (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming. Three occurrences (19%) are in areas that have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) temperature variation and are expected to be mostly resilient to warming. Four occurrences (25%) are in areas that have experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) and are expected to be vulnerable to warming. The remaining five occurrences (31%) with available model data are in areas that have experienced very little temperature variation (less than 37° F (20.8° C)) and are expected to be

highly vulnerable to warming. Two other occurrences in San Juan county do not have available model data to predict the decrease in available moisture and have been omitted from percentages.

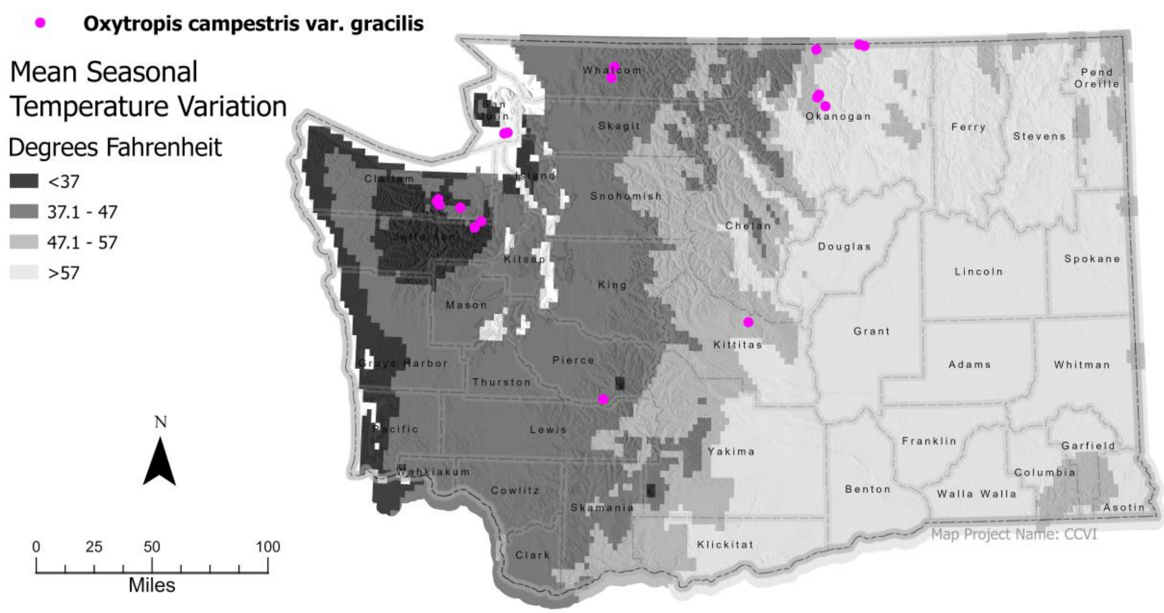

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Oxytropis campestris* var. *gracilis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
Oxytropis campestris var. *gracilis* is found in a variety of habitats which occur in forest openings with full sun exposure, ranging from clearings in deciduous woodlands and pine forests to open grasslands on steep, dry slopes (Washington Natural Heritage Program 2024). These microsites often occur on southern or southwestern exposures with high winds which are generally warmer and drier than the surrounding landscape (Rocchio and Crawford 2015). Future temperature increases could increase drought, increase fire severity, and favor arid-adapted species (Rocchio and Ramm-Granberg 2017). However, *Oxytropis campestris var. gracilis* is likely to be more resilient to these changes based on the microsite conditions that it prefers.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Oxytropis campestris* var. *gracilis* occurrences in Washington. Of the 16 known occurrences with available model data in Washington, three (19%) are in areas that have experienced slightly lower than average precipitation variation (11 - 20 in (255 - 508 mm)) over the historical period and are expected to be somewhat vulnerable to changes in available moisture (Young et al. 2016). The remaining 13 occurrences with data (81%) have experienced greater than average variation (>20 in (508 mm)).

Two other occurrences in San Juan county do not have available model data to predict the decrease in available moisture and have been omitted from percentages.

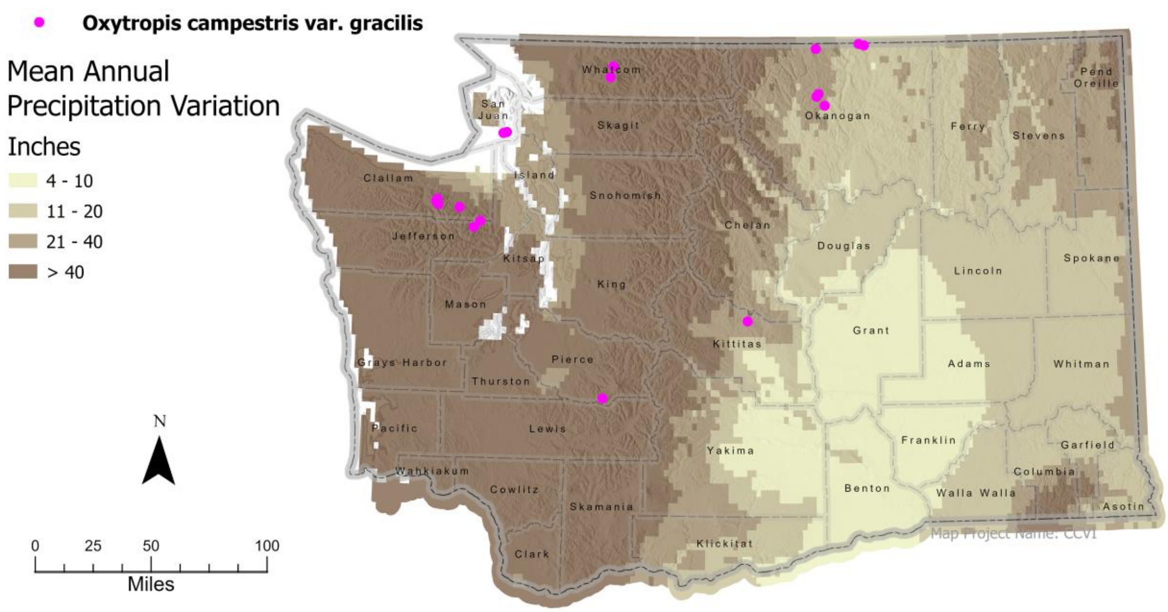

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Oxytropis campestris var. gracilis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
The vernally moist to mostly dry scree slopes and meadows/prairies where *Oxytropis campestris* var. *gracilis* occurs rely primarily on precipitation and snowmelt for a steady supply of moisture throughout the growing season due to lack of connection to groundwater (Rocchio and Crawford 2015). Anticipated increases in drought severity, and changes in precipitation type and timing will affect extent and composition of the communities and may lead to conversion to a drier and more sparse community type, though impacts to these ecological systems are expected to be relatively minimal (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Scree, talus, and turf ecological systems are mostly maintained by natural erosion processes and are further facilitated by cold climatic conditions and high winds that reduce soil formation, create somewhat droughty conditions, keep plant density low, and prevent tree encroachment (Rocchio and Crawford 2015). Avalanches and freeze-thaw action further shape microclimates in these alpine communities. Additional periodic disturbances are not required to maintain this habitat and climate change is not expected to significantly impact these processes (Rocchio and Ramm-Granberg 2017). In the Willamette Valley Upland Prairie and Savanna ecological system,

fire frequency is anticipated to increase which could either cause conversion of the prairies or could expand this habitat in areas where woody species are cleared.

C2d. Dependence on ice or snow-cover habitats: Neutral
Oxytropis campestris var. *gracilis* associates both with habitats along the edges of alpine snow banks and habitats on ridgetops which remain snow-free for much of the winter, though snowfall is relatively high in the alpine areas where this species can be found (Douglas and Bliss 1977, Raymond et al. 2014, National Park Service 2021). Ongoing and projected reductions in the amount of snow, changing precipitation regimes, and changes in the timing of snowmelt could alter the amount of moisture available for this species under climate change (Rocchio and Ramm-Granberg 2017). Other than impacts to the water supply of the habitat, *Oxytropis campestris* var. *gracilis* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Oxytropis campestris var. *gracilis* frequents a variety of landscapes that can include glacial outwash terraces, alpine lithosols, granite rubble, rocky meadows, basalt and shale outcrops and, on occasion, limestone and serpentine pockets (Montana Natural Heritage Program 2024, Washington Natural Heritage Program 2024). Soils are typically shallow ashy-sandy loams in complexes with rock outcrops (Soil Survey Staff 2024). Parent materials include marine sedimentary rock (Lummi and Nooksack), basalt flows (Crescent and Grand Ronde), mixed metamorphic and igneous rock, mass wasting deposits, and dactite and quartz inclusions. Some of these geological features are relatively uncommon, but the diversity of preferred substrates does not indicate that this species is edaphically restricted.

C4a. Dependence on other species to generate required habitat: Neutral
The scree, turf, and prairie habitats that support *Oxytropis campestris* var. *gracilis* are shaped largely by abiotic processes such as seasonal drought, fire, and erosion events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
Oxytropis campestris var. *gracilis* is visited almost exclusively by bees, primarily of the genus *Bombus*, and exhibits moderate rates of pollinator visitation (Kozuharova 2000, Robson et al. 2017, Montana Natural Heritage Program 2024). Spontaneous self-pollination and geitonogamy (pollination by different flowers on the same plant) may be possible but this is unconfirmed. This species is probably somewhat pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Oxytropis campestris* var. *gracilis* are dispersed passively by gravity and wind (Rydberg 1928, Montana Natural Heritage Program 2024). It is not known if this species may be transported short distances by animals (which may be seed or fruit predators). The number of potential seed vector species is not known but *Oxytropis campestris* var. *gracilis* is not reliant on other species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Impacts from pathogens are not known. Weevils (genus *Tychius*) are probably important fruit and seed predators (Clark 1970) and may increase herbivory with climate change (Hamann et al. 2021). Observational records indicated that grazing and trampling are threats and that "something has been eating the flower heads." Exotic ungulates can also have noticeable impacts on the habitat of *Oxytropis campestris* var. *gracilis* (e.g., mountain goats in the Olympic Mountains) (Rocchio and Crawford 2015). However, *Oxytropis* spp. are generally of low palatability due to chemical defense compounds (at least for mammalian herbivores) (Cook et al. 2009) and grazing is not expected to increase as a result of climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Oxytropis campestris var. *gracilis* is generally found growing on solid rocks and gravel where vegetation is sparse and limited to cushion plants, though the grasslands which support it sometimes form dense sods which help to prevent tree encroachment (Rocchio and Crawford 2015). Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of these ecological systems. *Oxytropis campestris* var. *gracilis* is probably adapted more for survival of these harsh abiotic conditions and not for competition, which is limited in rocky alpine and subalpine communities. Plant invasions remain relatively low environments but may increase with warming as more competitive species advance up the mountain (Rocchio and Ramm-Granberg 2017, Dainese et al. 2017). In areas with deep enough soil, the tree line may also begin to encroach as the climate warms as is predicted for several alpine regions of Washington (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Oxytropis campestris var. *gracilis* does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic variation of *Oxytropis campestris* var. *gracilis* has not been recorded.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
The *Oxytropis campestris* complex is polyploid (Jorgensen 2001). Varieties of this species range between facultative to obligate out-crossers with low rates of self-pollination and no clonal growth (Chung et al. 2004, Kozuharova et al. 2015). Polyploidy, a propensity for outcrossing, and mixed mating systems are traits indicative of average to high genetic variation (Young et al. 2016). Genetic diversity has been found to be high within and between populations of the edaphic endemic, *Oxytropis campestris* var. *chartacea* in Wisconsin and other varieties in the *Oxytropis campestris* complex (Chung et al. 2004).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Oxytropis campestris* var. *gracilis* (May to July) has not changed significantly (Washington Natural Heritage Program 2024).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Oxytropis campestris var. *gracilis* is known from 10 extant and 9 historical occurrences in Washington. Only three populations have been discovered or relocated since 2010 (most recently in 2019) (Washington Natural Heritage Program 2024). Long term trends are probably downward, as some occurrences have not been relocated, though the relationship to climate change is unknown (Fertig and Kleinknecht 2020). Another species of Oxytropis was found to be increasing over time despite warming trends in Italy (Lodetti et al. 2024).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Packera bolanderi* var. *harfordii (Harford's ragwort)

Date: 22 May 2024 Synonyms: *Senecio bolanderi* var. *harfordii, Senecio harfordii*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4TUQ/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	33
	<3.9° F (2.2°C) warmer	67
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to -0.096	100
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Four of six known occurrences (67%) of *Packera bolanderi* var. *harfordii* in Washington occur in areas with a projected temperature increase of < 3.9° F (2.2° C). Two of six known occurrences (33%) of *Packera bolanderi* var. *harfordii* in Washington occur in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4° C; Figure 1).

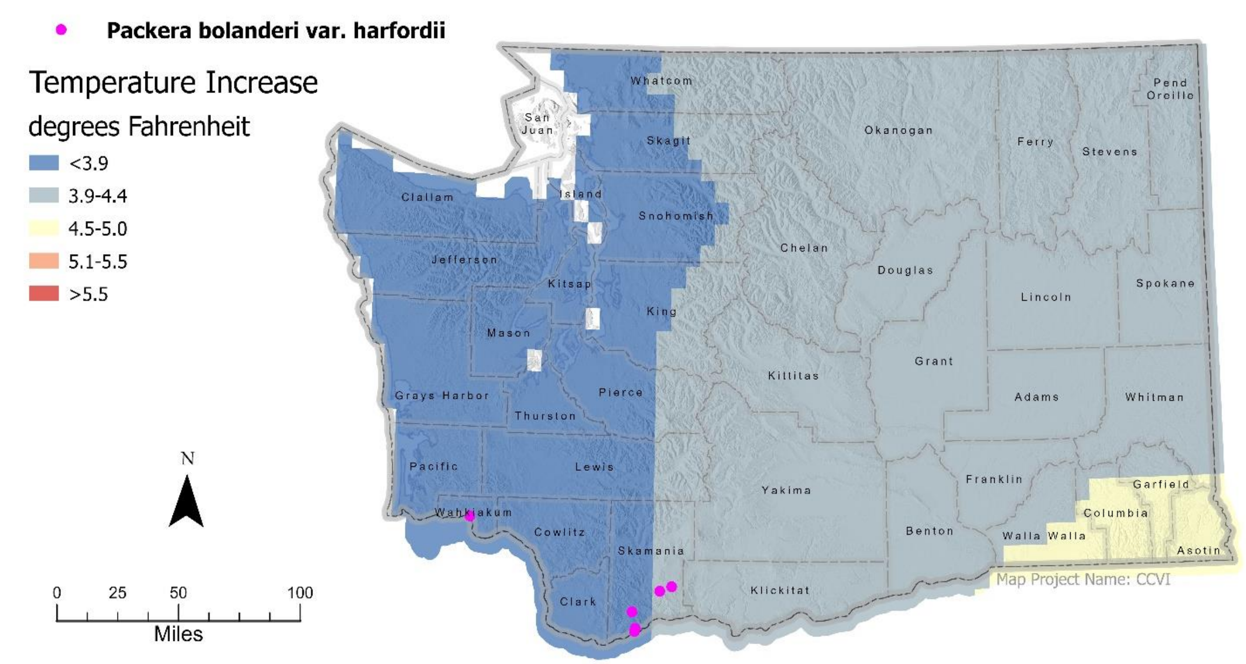

Figure 33. Exposure of occurrences *Packera bolanderi* var. *harfordii* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All six known occurrences (37%) *Packera bolanderi* var. *harfordii* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

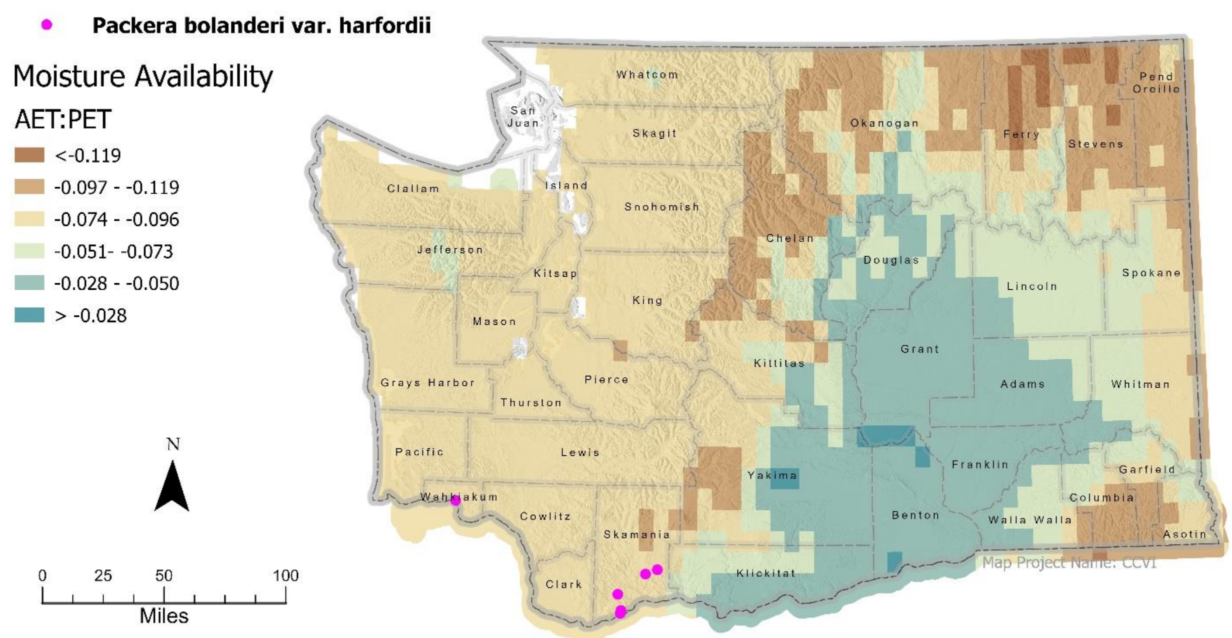

Figure 34. Exposure of occurrences of *Packera bolanderi* var. *harfordii* in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi.

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Packera bolanderi var. *harfordii* occurs on wet basalt cliffs, rocky streambeds, and in well-shaded Douglas-fir/hemlock forests at elevations of 160–2700 ft (50–825 m). Historical records from Chelan and Okanogan counties are likely misidentifications (Washington Natural Heritage Program 2024). Reports of this species occurring in Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland habitat may be related to the misidentified specimens from Okanogan, Chelan, and Snohomish counties. Such habitats are generally found above the elevation range that *Packera bolanderi* var. *harfordii* occurs in (Rocchio and Crawford 2015). While one historical and likely extirpated record near Astoria may be vulnerable to inundation from sea level rise, the two extant occurrences of *Packera bolanderi* var. *harfordii* in Washington are far enough inland that they would not they would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase

All confirmed records of *Packera bolanderi* var. *harfordii* occur along the Columbia River. The two extant records of *Packera bolanderi* var. *harfordii* occur approximately 18 miles apart in the Columbia Gorge. Historic records are up to 90 miles apart. Cliff and barren ecological systems, like the moist cliff faces and rocky stream sides *Packera bolanderi* var. *harfordii* occupies, are strongly linked to specific, local conditions (Rocchio and Crawford 2015). These moist cliff faces are more common on the south side of the Columbia Gorge, which receives less solar radiation than the north side (Lawrence 1939). In Washington, suitable habitat for this species may be limited, and potentially separated by long distances of hot, dry, uplands, potentially limiting gene flow and dispersal for this species.

B2b. Anthropogenic barriers: <u>Somewhat Increase</u>
The two extant occurrences of *Packera bolanderi* var. *harfordii* occur on public lands (Beacon Rock State Park and Gifford Pinchot National Forest). The most apparent human impacts in these areas are major roads and logging activities. Cliffs can be a refugia from human activity (Rocchio and Crawford 2015). However, human development, resource extraction, and recreation could all potentially contribute to a lack of suitable habitat for *Packera bolanderi* var. *harfordii* dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Packera bolanderi* var. *harfordii* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Neutral</u>
Packera species have a pappus of small, barbed (barbellulate) bristles (Trock 2024) which aid in dispersal by wind (estimated up to ½ mi or 1 km for some species of *Packera* in windy, open areas). In *Packera bolanderi* var. *harfordii* the seeds are topped by pappi of white bristles 5–7 mm long (Washington Natural Heritage Program 2024). Given the potential for wind dispersal, available habitat may be more limiting than dispersal capability for this species.

C2ai. Historical thermal niche: <u>Increase</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Packera bolanderi* var. *harfordii* occurrences in Washington. Four of six known occurrences (67%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to experience an increased vulnerability to climate warming. Two of six known occurrences (33%) are in areas that have experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming.

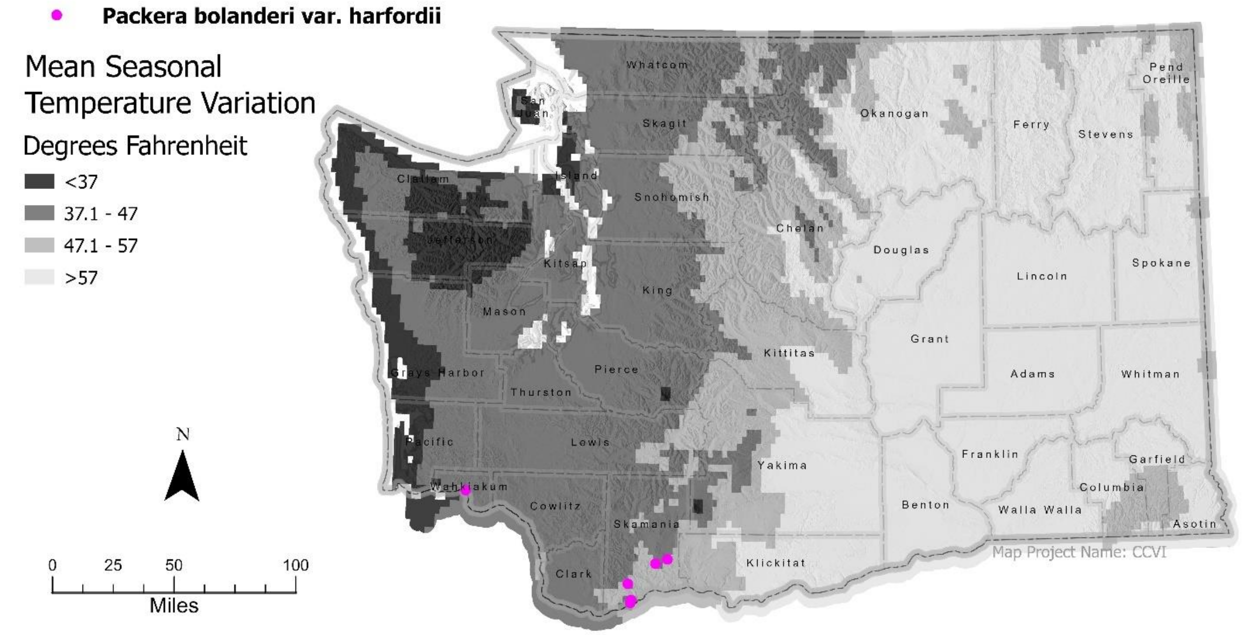

Figure 35. Historical thermal niche (exposure to past temperature variations) of occurrences of *Packera bolanderi* var. *harfordii* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Packera bolanderi var. *harfordii* is reportedly characteristic of the moist cliff faces on the south side of the Columbia Gorge, which is both cooler and wetter than the north side of the Columbia Gorge (Lawrence 1939). It is likely associated with cool air drainages and could be sensitive to increased temperatures with climate change.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 ("historical hydrological niche") across the distribution of known *Packera bolanderi* var. *harfordii* occurrences in Washington. All six known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

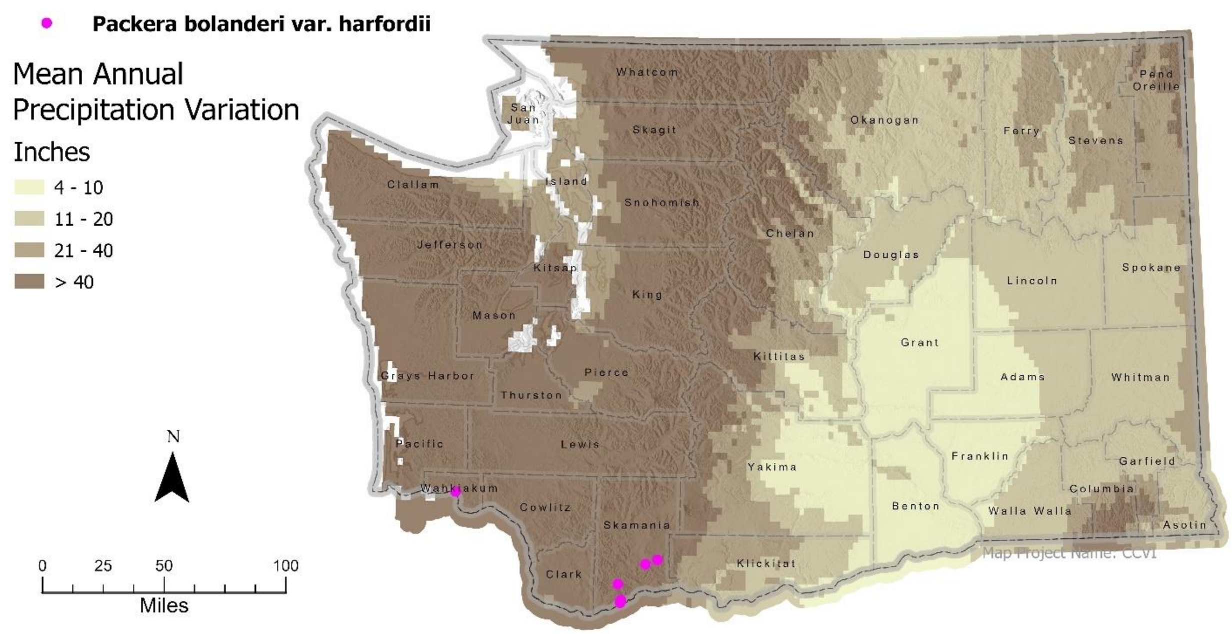

Figure 36. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Packera bolanderi* var. *harfordii* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Drought is a major force that shapes the North Pacific Montane Massive Bedrock, Cliff and Talus ecological systems where *Packera bolanderi* var. *harfordii* is found (NatureServe 2024). Within these habitats, *Packera bolanderi* var. *harfordii* is frequently found in moist places (e.g. streamsides, moist cliff faces). The outcrops and slopes which support *Packera bolanderi* var. *harfordii* are associated with dripping water which seeps through cracks to create suitable microhabitats. *Packera bolanderi* var. *harfordii* is dependent on adequate snow along with spring and summer rainfall for its moisture needs, as it is not connected to groundwater or other perennial water sources. Shifts in precipitation timing and amount and earlier snow melt combined with extended summer droughts are expected to have a moderate impact on Rocky Mountain Cliff, Canyon, and Massive Bedrock systems (Rocchio and Ramm-Granberg 2017). The potential drying of cliff microhabitats will be of particular concern for *Packera bolanderi* var. *harfordii*.

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Packera bolanderi var. *harfordii* occurs on cliff faces, rocky stream sides and other moist places within forested areas. Wind, water, and gravity are forces acting upon cliff habitats that lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles codetermine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be

strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004). The high exposure of these sites may make them susceptible to rising temperatures which can also increase fire risk or alter the erosion rates of cliff communities (Rocchio and Ramm-Granberg 2017, Estevo et al. 2022). Newly opened rock outcrop sites could become too dry to sustain this species or be invaded by competing plant species. Under predicted future climate change, forested sites could be more vulnerable to wildfire due to increased drought and reduced precipitation (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Packera bolanderi var. *harfordii* does not directly depend on snow or ice.

C3. Restricted to uncommon landscape/geological features: Neutral
The confirmed records of *Packera bolanderi* var. *harfordii* are found on both sedimentary and volcanic substrates which are widespread in Washington, suggesting that substrate type is not limiting for this species (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
The rock outcrop and conifer forest habitat occupied by *Packera bolanderi* var. *harfordii* is maintained largely by natural abiotic conditions (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The exact pollinators of *Packera bolanderi* var. *harfordii* have not been documented, but other *Packera* and *Senecio* species have unspecialized inflorescences that can be pollinated by a wide variety of insects, including bees, flies, butterflies, and beetles. *Packera* species in general are regarded as important sources of both pollen and nectar for pollinators in North America (Robson 2014). This suggests that *Packera bolanderi* var. *harfordii's* pollinator relationships are relatively resilient to the effects of climate change.

C4d. Dependence on other species for propagule dispersal: Neutral
Packera bolanderi var. *harfordii* seeds are adapted for wind dispersal and are not reliant on other species to transport propagules.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Studies have been done to see if *Packera bolanderi* is vulnerable to herbivory from *Tyria jacobaeae*, a moth used as a biological control agent for *Jacobaea vulgaris* (= *Senecio jacobaea*), a related List B weed in Washington. *Tyria jacobaeae* were not found on *Packera bolanderi*, perhaps due to its shaded habitat, which the moths avoided (Fuller 2002). Some species of *Packera* have been used as traditional herbal remedies, and have been found to have active defensive chemicals (Fragoso-Serrano et al. 2012), so it is possible that *Packera bolanderi* var. *harfordii* also has chemical defenses against herbivory.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase

Under present conditions, competition from non-native species is minor on the moist rock outcrops which support *Packera bolanderi* var. *harfordii*. Under future climate change, conifer forests inhabited by *Packera bolanderi* var. *harfordii* will become drier, hotter, and more vulnerable to fire. Exposed rock outcrops could become more likely to be invaded by weedy annuals or native perennials adapted to more open and drier sites (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Unknown
Documentation of other interspecific interactions with *Packera bolanderi* var. *harfordii* were not found.

C5a. Measured genetic variation: Unknown
Data are lacking on the genetic diversity within and between populations of *Packera bolanderi* var. *harfordii* in Washington. This variety is at the northern end of its range in Washington, and this could potentially limit the genetic variation in Washington populations, though research in other plant species has shown that genetic variation is not necessarily limited at the edges of a species' range (Sheth and Angert 2016), so further study is needed.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Neutral
In *Packera* species, the ray flowers are pistillate and fertile, and the disc flowers are bisexual and fertile (Trock 2024). No information was found on the breeding system of *Packera bolanderi* var. *harfordii*, but the presence of bisexual flowers suggests that a mixed mating system is possible for this species. *Packera* species frequently hybridize in nature, and often exhibit polyploidy (Moore-Pollard and Mandel 2023). Species with mixed mating systems generally have average to high genetic variation, which can provide those species with some resilience to climate change.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, there is not enough data to determine if the flowering period of *Packera bolanderi* var. *harfordii* (June to July) has changed significantly in Washington.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Packera bolanderi* var. *harfordii* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown

Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Parnassia palustris (marsh grass-of-Parnassus)

Date:23 May 2024 Synonyms: *Parnassia palustris* var. *neogaea, Parnassia palustris* var. *tenuis*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Not Ranked
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 14 occurrences (100%) of *Parnassia palustris* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C) (Figure 1).

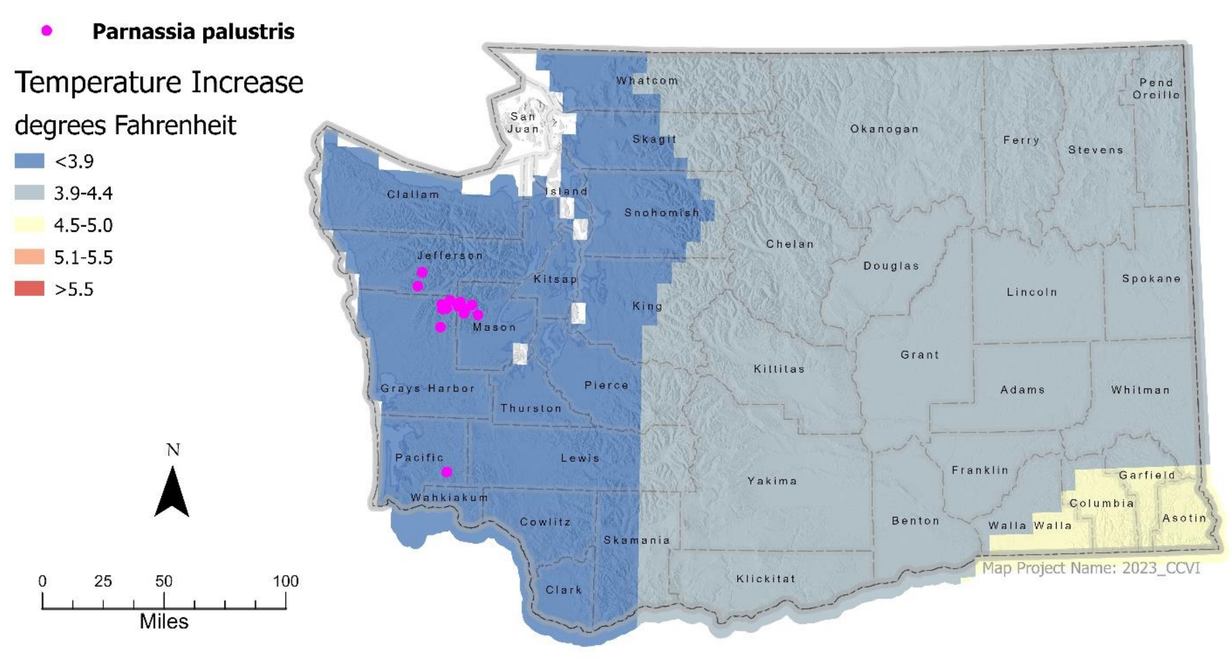

Figure 1. Exposure of occurrences of *Parnassia palustris* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 14 known occurrences (100%) of *Parnassia palustris* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

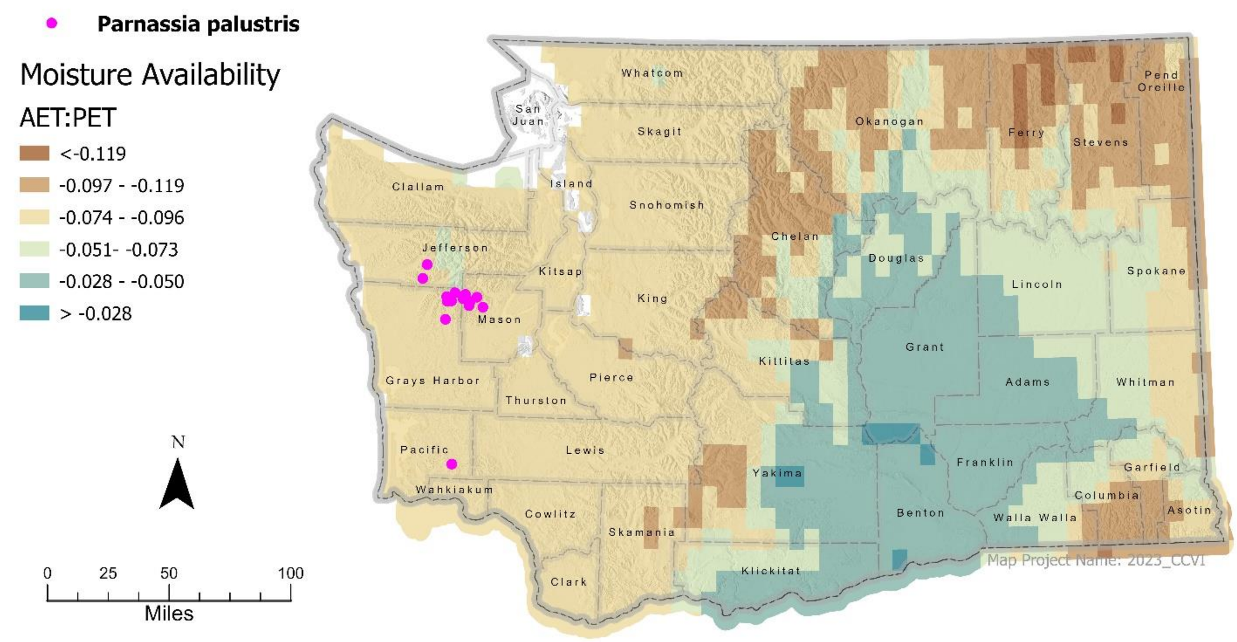

Figure 2. Exposure of occurrences of *Parnassia palustris* in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
In Washington, *Parnassia palustris* occurs in moist meadows, seeps, and stream channels at elevations of 360–3300 ft (110–1005 m) and will not be affected by sea level rise (Washington Natural Heritage Program 2024).

B2a. Natural barriers: Somewhat Increase
Parnassia palustris is found in the Temperate Pacific Subalpine-Montane Wet Meadow ecological system. This is a small patch ecological system, occurring within forest matrix (Rocchio and Crawford 2015). *Parnassia palustris* is dispersed by wind and water (Seed Information Database 2024), but unsuitable habitat between populations or unoccupied wet meadows may be barriers to dispersal for this species.

B2b. Anthropogenic barriers: Neutral
Parnassia palustris occurs primarily on national forest and other public lands, providing some protection from anthropogenic barriers. Anthropogenic threats for *Parnassia palustris* in

Washington include timber harvest, grazing, dam building (which could result in changing hydrology) and trampling (Washington Natural Heritage Program 2024). Studies on anthropogenic fragmentation of *Parnassia palustris* in Europe have found reduced gene flow between populations (Bossuyt 2007), suggesting that anthropogenic barriers somewhat increase this species' vulnerability to climate change. Though the high elevation wetlands where *Parnassia palustris* occurs in Washington are usually less impacted by human land use, anthropogenic disturbance has generally resulted in fragmentation and loss of connectivity in Temperate Pacific Montane-Subalpine Wet Meadows (Rocchio and Crawford 2015).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Parnassia palustris* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Parnassia palustris produces small (10–12 mm) ovoid fruits that contain hundreds of seeds. Seeds are dispersed passively by wind and water (Seed Information Database 2024). A study in Europe found that *Parnassia palustris* demonstrated gene flow within metapopulations, but gene flow between metapopulations was less likely (Bossuyt 2007), suggesting this species is somewhat limited in dispersal.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Parnassia palustris* occurrences in Washington. six of 14 occurrences (43%) are in areas that have experienced very small (< 37° F (20.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have greatly increased vulnerability to climate warming. Eight of 14 modelled occurrences (53%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming.

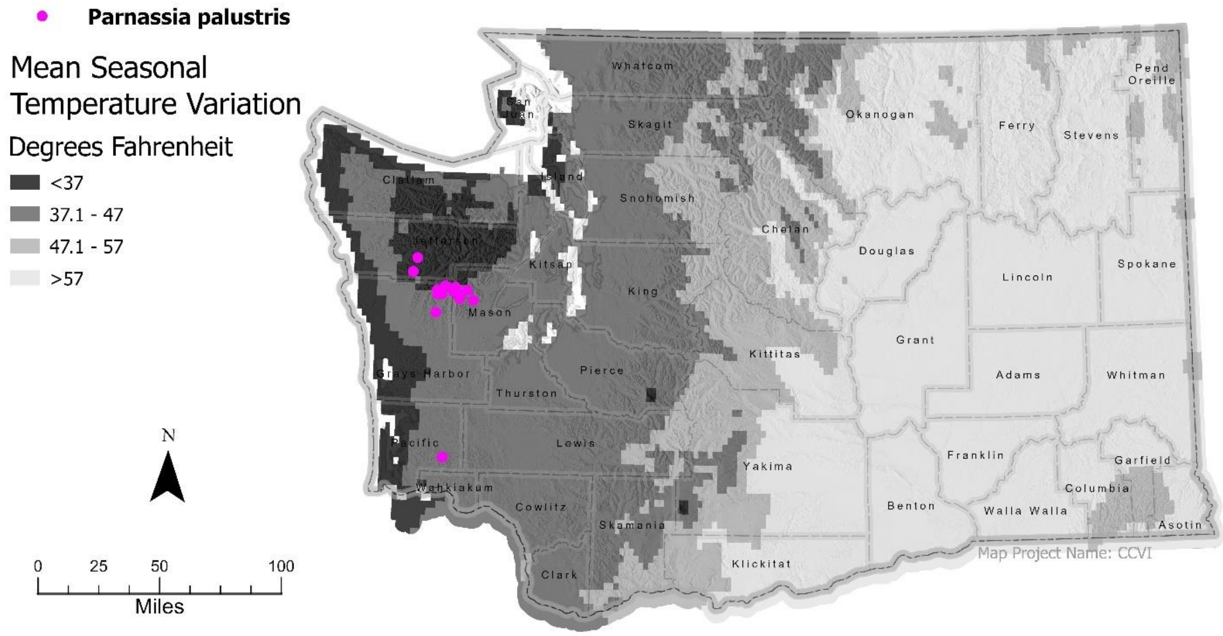

Figure 3. Historical thermal niche (exposure to past temperature variations) of occurrences of *Parnassia palustris* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Increased temperatures may result in seasonally wet meadows drying earlier in the season (Rocchio and Ramm-Granberg 2017). This could result in shifts toward more upland vegetation communities and suggests that *Parnassia palustris* may have somewhat increased vulnerability to increased temperatures caused by climate change.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 ("historical hydrological niche") across the distribution of known *Parnassia palustris* occurrences in Washington. All 14 occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change.

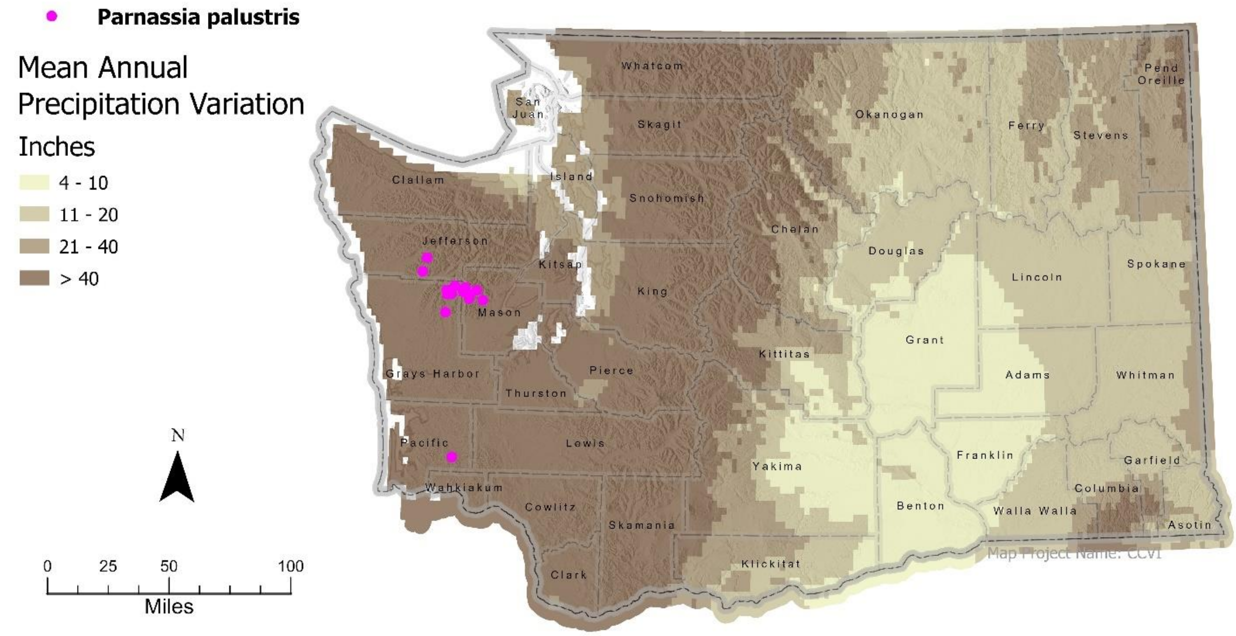

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Parnassia palustris* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Increase
The wet meadows *Parnassia palustris* is found in are frequently associated with groundwater discharge, snowmelt, and seasonally high water tables. Wet meadows are often dry by late summer (Rocchio and Crawford 2015). Meadows associated with groundwater discharge may be more resilient to climate change than other meadows. However, changes in snowmelt timing and snowpack will affect the ability to recharge groundwater, potentially shifting meadows to dry habitat with more upland species (Rocchio and Ramm-Granberg 2017). *Parnassia palustris* probably has increased vulnerability to climate change effects on the hydrology of its habitat.

C2c. Dependence on a specific disturbance regime: Neutral
The habitat where *Parnassia palustris* is found in Washington is influenced by hydrological processes and does not rely on disturbances such as flooding (Rocchio and Crawford 2015). Data from herbarium records and element occurrences suggest that *Parnassia palustris* is at least somewhat resilient to disturbance. While it is also found in areas with undisturbed old growth, it has frequently been documented in roadside ditches, rehabbed logging roads, clearcuts, and areas that have experienced multiple timber harvest efforts.

C2d. Dependence on ice or snow-cover habitats: Neutral

Parnassia palustris does not rely directly on ice or snow-covered habitat. However reduced snowpack could change the hydrology of subalpine and montane wet meadows, shifting vegetation towards upland plant communities (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
In Washington, *Parnassia palustris* is often associated with limestone, but appears on a wide variety of soil and substrate types and appears more often on volcanic substrates than sedimentary ones (Washington Division of Geology and Earth Resources 2016). One source from Europe also noted that this species occurred in calcareous habitats in Norway (Sandvik and Eide 2009). Given this species frequently—but not always—occurs on limestone, substrate preference may somewhat increase this species' vulnerability to climate change.

C4a. Dependence on other species to generate required habitat: Neutral
Parnassia palustris' habitat is maintained by abiotic factors, and disturbance does not appear to be required to maintain habitat quality in Washington. Based on herbarium and element occurrence records, *Parnassia palustris* does appear to be at least somewhat resilient to anthropogenic disturbances such as road building and maintenance and logging.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Parnassia palustris is strongly dependent on pollinators for successful reproduction. Pollinators for this species are mainly Syrphids (hoverflies) and other Diptera (Bossuyt 2007). This species likely has enough diversity of floral visitors to provide some resilience to the effects of climate change on plant-pollinator relationships.

C4d. Dependence on other species for propagule dispersal: Neutral
Parnassia palustris seeds are wind and water-dispersed and do not require animal interactions for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Heavy grazing by elk was noted at some populations of *Parnassia palustris* in Washington. Grazing from both domestic and wild ungulates can have negative effects on wet meadow habitats (Rocchio and Crawford 2015). Grazing pressure is not expected to increase with climate change. No other information on pathogens or natural enemies was found for this species.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Temperate Pacific Subalpine-Montane Wet Meadow habitats are susceptible to invasion from introduced grass species like *Poa pratensis*, *Phleum pratense*, and *Phalaris arundinacea*. *Cirsium arvense* and *Taraxacum officinale* are also common exotic plants in these habitats (Rocchio and Crawford 2015). Currently, most occurrences of *Parnassia palustris* in Washington are noted as relatively intact with few invasive species apparent. However, the

potential for increased disturbance and changes in vegetation community due to climate change likely leave this species somewhat vulnerable to competition from introduced species.

C4g. Forms part of an interspecific interaction not covered above: Unknown
No other interspecific interactions were found in the literature search for this species.

C5a. Measured genetic variation: Neutral
In one study, outcrossing between metapopulations of *Parnassia palustris* resulted in greater seed set than crosses within metapopulations in populations that had been fragmented by anthropogenic activities (Bossuyt 2007). Other studies have found no evidence of inbreeding depression in *Parnassia palustris* populations (Bonnin et al. 2002), as well as high levels of genetic diversity within populations (Borgen and Hultgård 2003), suggesting that gene flow is not a common problem in this species.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Not Ranked
Parnassia palustris has a mixed mating system but is mostly an outcrossing species. Flowers are protoandrous, rarely self-pollinate, and self-pollination results in reduced seed set. Increased temperatures due to climate change could potentially increase reproductive success in high elevation populations of *Parnassia palustris* and there likely won't be an increase in reproductive costs with temperature increases for this species in the short term (Sandvik and Eide 2009).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Parnassia palustris* (July to August) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Parnassia palustris* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Pedicularis pulchella (mountain lousewort)

Date: 14 Sept 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G3/S1
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Greatly Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase/Greatly Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral/Somewhat Increase

Section A	Severity	Scope (% of range)
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
4g. Forms part of an interspecific interaction not covered above		Neutral/Somewhat Increase
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral
6. Phenological response to changing seasonal and precipitation dynamics		Neutral
Section D		
D1. Documented response to recent climate change		Unknown
D2. Modeled future (2050) change in population or range size		Unknown
D3. Overlap of modeled future (2050) range with current range		Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution		Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: The single known occurrence of *Pedicularis pulchella* in Washington occurs in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

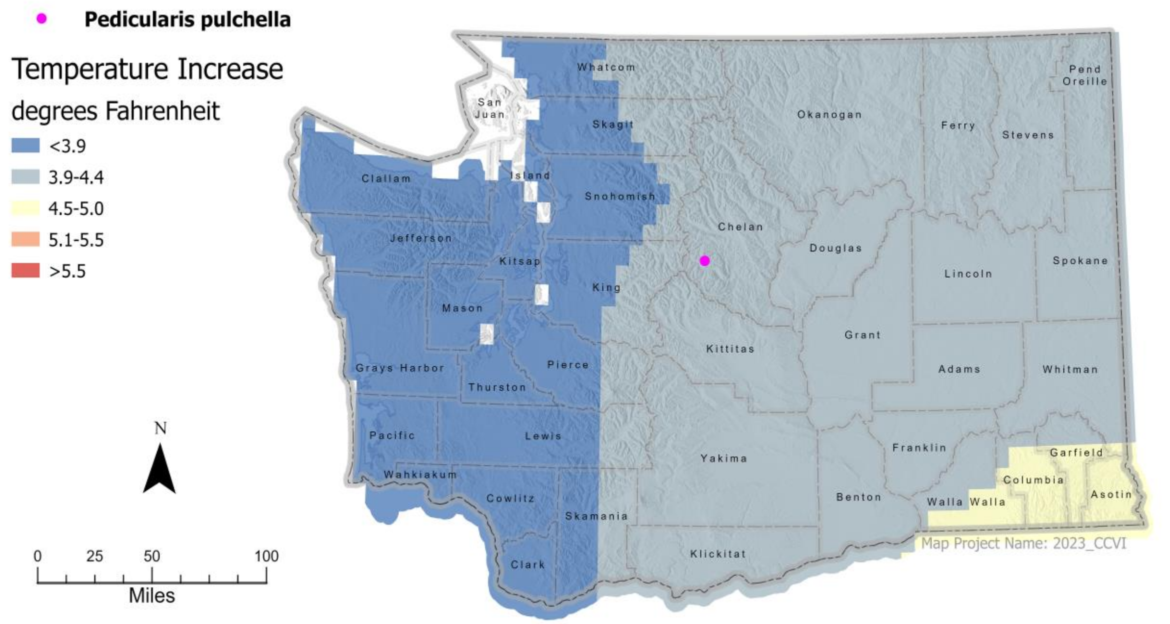

Figure 1. Exposure of *Pedicularis pulchella* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Pedicularis pulchella* in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

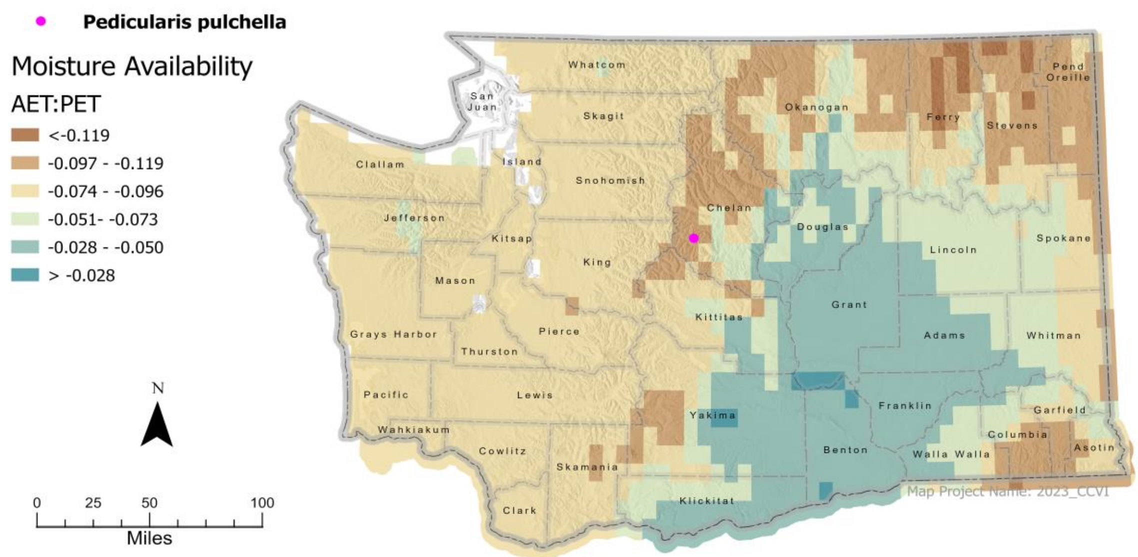

Figure 2. Exposure of *Pedicularis pulchella* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Pedicularis pulchella is restricted to alpine slopes and talus above tree line in the Wenatchee Range of Chelan County at elevations ranging from 6800-7300 ft (2070-2225; NatureServe 2023a). *Pedicularis pulchella* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Greatly Increase
Because *Pedicularis pulchella* already occurs on a ridgeline at one of the highest elevations in the Wenatchee Mountains (NatureServe 2023a), there is little room for populations to move upward with climate change and warm lowlands pose a barrier to movement across alpine slopes which have low connectivity (Halsey 2017). It is locally endemic to one Washington mountain ridge that is disjunct from the core range in the Rocky Mountains of Montana and Wyoming, which further prevents outcrossing with other populations. *Pedicularis pulchella* may also be at risk of following an "elevator to extinction" as the coolest climatic zones of the alpine are lost (Watts et al. 2022).

B2b. Anthropogenic barriers: Neutral

Due to the rugged, high elevation terrain, the habitat of *Pedicularis pulchella* remains relatively undisturbed by direct anthropogenic stressors and barriers. Recreation impacts can be of some concern in rocky alpine areas and even light trampling may significantly reduce plant cover and growth. The single known location of *Pedicularis pulchella* in Washington is in an area with low-moderate recreation and relatively few trails.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Pedicularis pulchella* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely due to the rugged backcountry terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase/Greatly Increase
Pedicularis pulchella produces a dry capsule fruit that dehisces to release numerous seeds. The dispersal mechanisms of *Pedicularis pulchella* are not well understood or documented, but it is generally assumed that seeds of *Pedicularis* spp. are dispersed passively over very short distances due to large seed sizes and a lack of specialized appendages for wind or animal dispersal (Liu et al. 2013). Other *Pedicularis* spp. have been known to disperse seeds via explosive dehiscence (Ulaszek 2023), water (Robart et al. 2015), and ant movement but there is no current support for *Pedicularis pulchella* dispersal by these methods.

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Pedicularis pulchella* occurrences in Washington. The single known occurrence is in an area that has experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming.

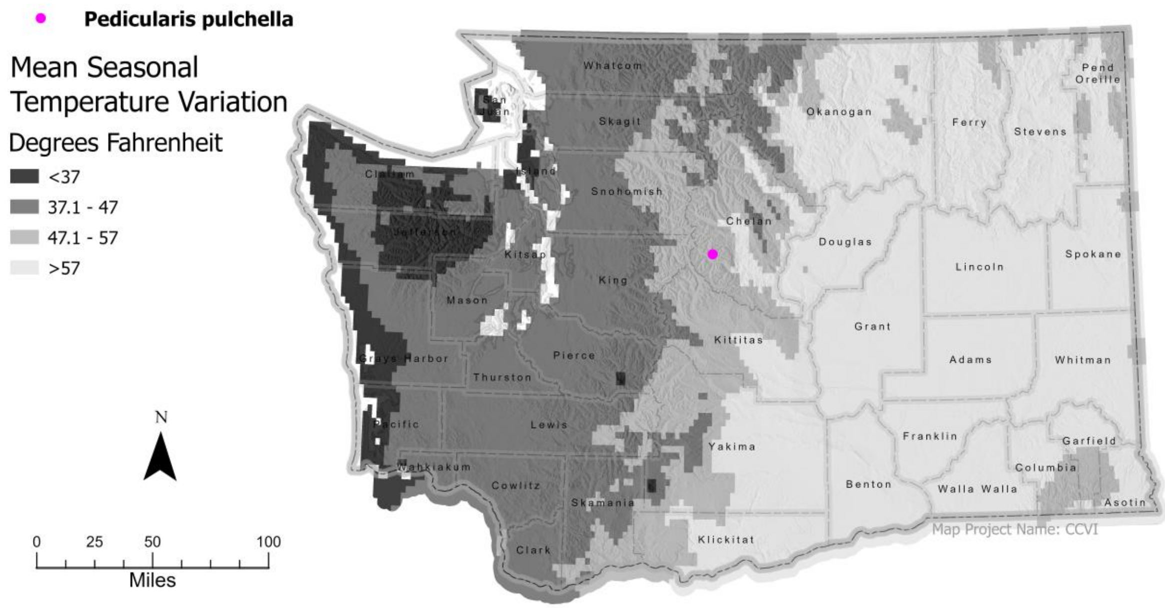

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Pedicularis pulchella* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase
The North Pacific Alpine-Subalpine Bedrock & Scree communities which support *Pedicularis pulchella* remain cold and snow covered for much of the year (NatureServe 2023b). Warming temperatures are expected to extend the growing season and potentially increase competition from other plants that are adapted to drier environments (Rocchio and Ramm-Granberg 2017). Direct impacts of warming on *Pedicularis pulchella* are unknown and may be positive or negative for population growth.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Pedicularis pulchella* occurrences in Washington. The single known occurrence is in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) this population is likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

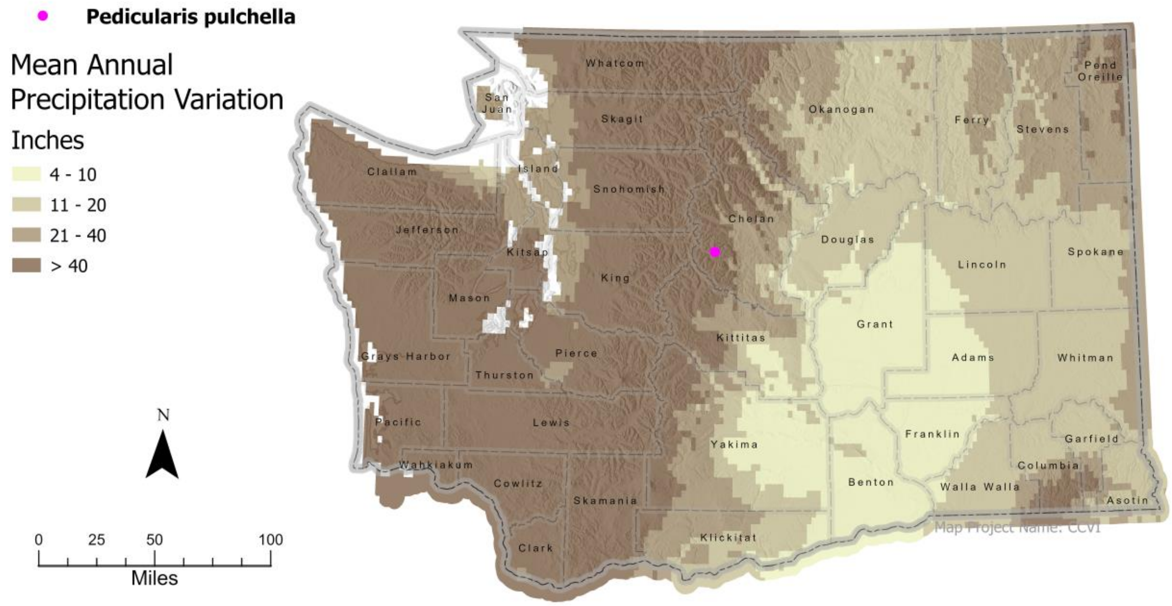

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Pedicularis pulchella* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Climate warming is expected to melt glaciers, decrease snowfall, and cause snowpack to melt earlier in the season in the Cascade Region (Raymond et al. 2014). Species of the water-limited alpine slopes, including *Pedicularis pulchella,* depend on steady flow of water through the summer months from slow melting snow and ice. It is unknown exactly how precipitation shifts from snow to rain and changes in the timing of snowmelt will affect individual species, but these hydrological changes are likely to significantly alter the preferred habitat of alpine scree plants (Rocchio and Ramm-Granberg 2017). Because *Pedicularis pulchella* already occurs in areas where wind-scour prevents snow accumulation, it may be more tolerant of changes to snowmelt or may conversely be threatened by loss of a limited water supply.

C2c. Dependence on a specific disturbance regime: Neutral
Wind, water, and gravity are forces acting upon scree habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Chersich et al. 2015).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
The high alpine and subalpine regions above the tree line of the Wenatchee Range where *Pedicularis pulchella* occurs experience long winters with most of the annual precipitation

falling as snow. Overall precipitation is much less on the eastern side of the Cascades than on the western slopes (Raymond et al. 2014). *Pedicularis pulchella* occurs on a north-facing slope where snow may be retained later into summer, though the steepness and exposure of the slopes may also prevent snow accumulation. Ongoing and projected reductions in the amount of snow, conversion of snow to rain, and changes in the timing of snowmelt could have adverse effects on the water-limited rocky habitat of *Pedicularis pulchella*. (Rocchio and Ramm-Granberg 2017)

C3. Restricted to uncommon landscape/geological features: Neutral
Pedicularis pulchella is restricted to humid, frigid alpine tundra talus fields (Macior 1986), which are common at high elevations across several mountain ranges in Washington and is not known to associate with a specific uncommon substrate.

C4a. Dependence on other species to generate required habitat: Neutral
The North Pacific Alpine and Subalpine Bedrock and Scree ecological system is shaped mostly by abiotic processes and mass wasting events which shift critical microtopographic habitat conditions without the aid of other species (Rocchio and Crawford 2015, NatureServe 2023b).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
Like other *Pedicularis* spp., *Pedicularis pulchella* produces flowers with nectar rewards and is obligately outcrossed by bumblebees (Macior 1986). Only three pollen-foraging bumblebee species are reported as pollinators and they do not appear to have high fidelity to *Pedicularis pulchella.* The limited set of potential pollinators and low fidelity may explain the lower fruiting rates of *Pedicularis pulchella* compared to nearby congeners (Macior 1986).

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Pedicularis pulchella* are dispersed primarily by gravity or other passive means. The species is not known to be dependent on animals for transport, though other *Pedicularis* spp. have been reported to be dispersed by ants, beetles, and other insects.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Some *Pedicularis* spp. have been documented as alternate hosts for white pine blister rust (*Cronartum ribicola*) but the direct impacts to *Pedicularis* are not described (McDonald et al. 2006). Due to its high elevation scree habitat, *Pedicularis pulchella* receives minimal impacts from grazing, though it could be consumed by insects or rodents. Overall impacts appear to be low.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation North Pacific Alpine-Subalpine Bedrock & Scree ecological system that supports *Pedicularis pulchella* (NatureServe 2023b). *Pedicularis pulchella* is probably adapted more for survival and quick growth under harsh abiotic conditions and not for competition, which is usually limited in the alpine scree fields due to wind-scour. Plant invasions remain relatively low in alpine scree environments but may increase with warming as more competitive species advance up the mountain (Dainese et al. 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral/Somewhat Increase
Pedicularis pulchella, like many other *Pedicularis* spp., is a root hemiparasite (Macior 1986). Some species are facultative, and others require a host to develop past the seedling stage and many differ in host preference and specificity (Li et al. 2012). It is unknown if *Pedicularis pulchella* is facultative but dependency on a specific host could have contributed to its limited distribution in Washington.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Pedicularis pulchella* has not been documented. However, the population occurs as a disjunct to the west of the core range in the Rocky Mountains and so could have lower genetic diversity due to genetic drift or inbreeding depression, similarly to other extreme endemic *Pedicularis* spp (Waller et al. 1987).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
The specific reproductive system of *Pedicularis pulchella* is not well-described but may be like other *Pedicularis* spp. that produce showy flowers and are obligate outcrossers and are dependent on insect pollination (Macior 1973, Macior et al. 2001). It is likely to have average genetic variability based on these life history parameters (Young et al. 2015).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Pedicularis pulchella has been reported to bloom from mid-June to mid-July (Macior 1986). Based on flowering dates of specimens in the Consortium of Pacific Northwest herbaria website, no major changes have been detected in phenology. There are a few specimens documented as flowering in early August, but these range from the 1970s to the 1990s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no targeted studies of the response of *Pedicularis pulchella* to climate change and no notable population changes on record. This species is thought to be stable across its range (Montana Natural Heritage Program 2023).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

***Pellaea brachyptera* (Sierra cliffbrake)**

Date: 10 January 2024 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4G5/S2
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All five known occurrences (100%) of *Pellaea brachyptera* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

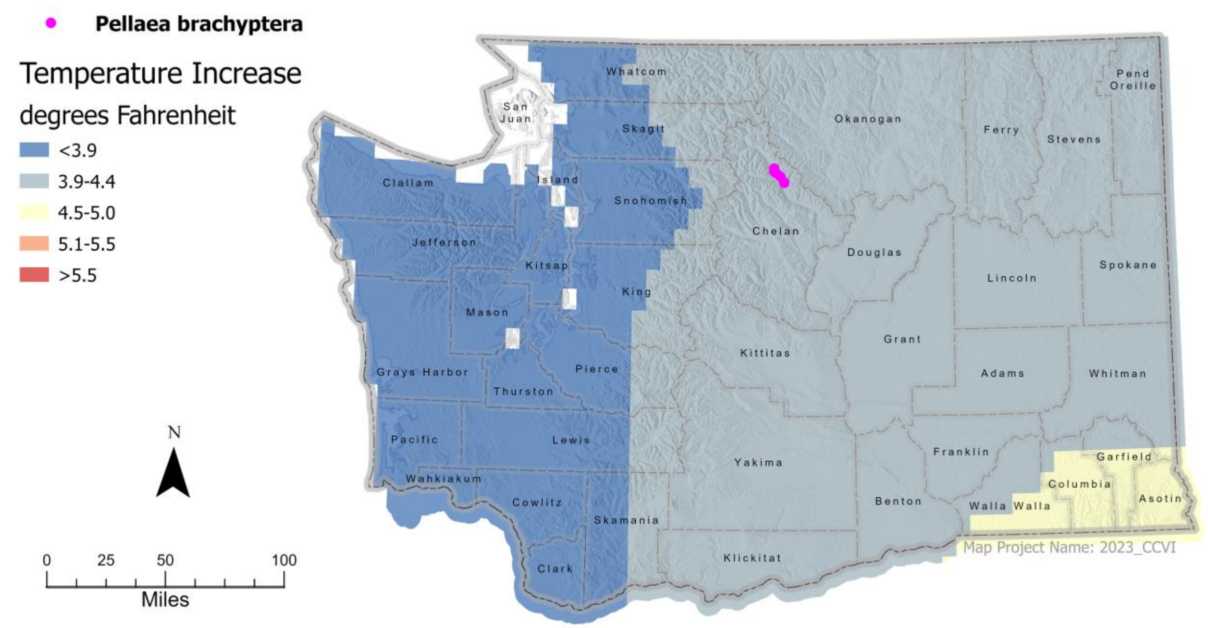

Figure 1. Exposure of *Pellaea brachyptera* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All five known occurrences (100%) of *Pellaea brachyptera* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

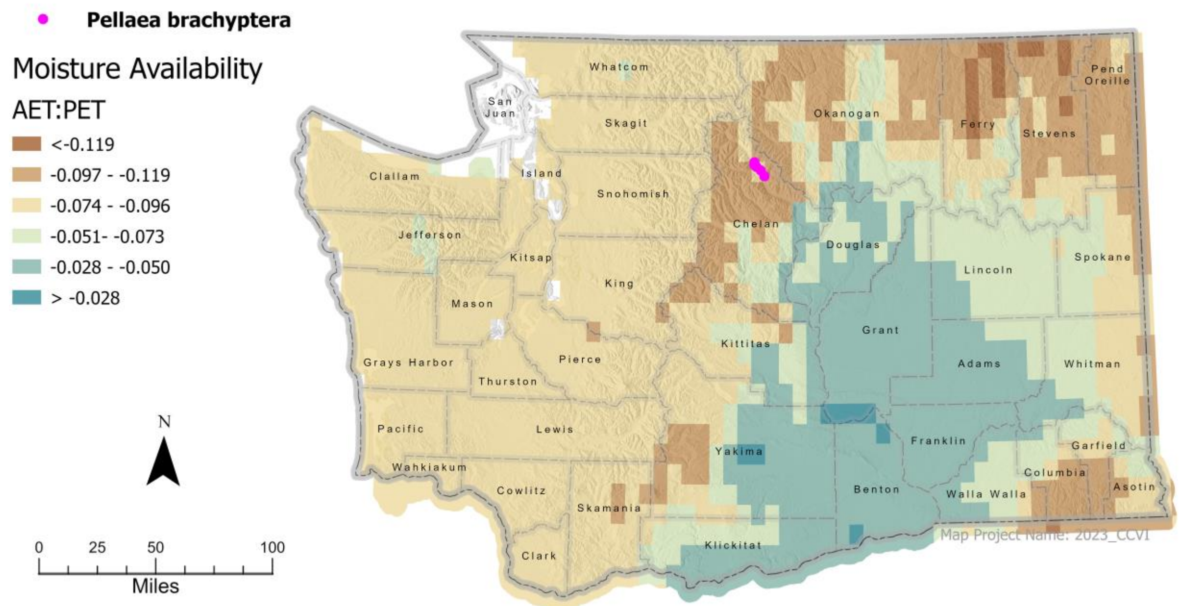

Figure 2. Exposure of *Pellaea brachyptera* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Pellaea brachyptera is restricted to rock crevices and talus slopes along a small section of Lake Chelan at elevations ranging from 1100-3500 ft (335-1065 m; Washington Natural Heritage Program 2023). *Pellaea brachyptera* populations in Washington will not be affected by sea level rise based on their inland distribution but could be affected by changes to reservoir inflows and anticipated flooding in the region (Office for Coastal Management 2023)

B2a. Natural barriers: Increase
Pellaea brachyptera is geographically restricted in Washington, growing only in a narrow low elevation band on rocky slopes and cliffs just above Lake Chelan in the Eastern Cascades in the Rocky Mountain Cliff, Canyon and Massive Bedrock ecological system (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Populations are separated from one another by just 1-8 mi (2-13 km) of unsuitable habitat but are extremely disjunct from the species' core range in the Sierra Mountains of California which limits gene flow and migration. Suitable

habitat is patchy in dry openings and restricted to unique microtopographic features within a larger continuous forest matrix (Fertig and Kleinknecht 2020)

B2b. Anthropogenic barriers: Neutral
Pellaea brachyptera occurs exclusively within the Lake Chelan Sawtooth Wilderness and is almost completely protected from major anthropogenic impacts (Washington Natural Heritage Program 2023). There are limited roads and few trails in the area, which are mostly accessible by boat. Changes to Lake Chelan water levels associated with dam management may impact the habitat of this species. This species has historically been at risk of collection for the florist trade (Tryon 1957).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Pellaea brachyptera* (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
The spores of *Pellaea* spp. can travel long distances via wind or water and might also be distributed by animal attachment or ingestion in some cases. Most spores ultimately fall within a short distance of parents and exact dispersal distances depend on air currents (Rose and Dassler 2017). However, in more open areas, ferns theoretically have unlimited potential for dispersal over long distances and may travel nearly 250 miles (400 km; Peck 1985). *Pellaea* spp. are homosporous, meaning that spores can produce gametophytes with both sex organs which aids in species dispersal, especially in comparison to heterosporous ferns (Peck et al. 1990).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Pellaea brachyptera* occurrences in Washington. All five known occurrences (100%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

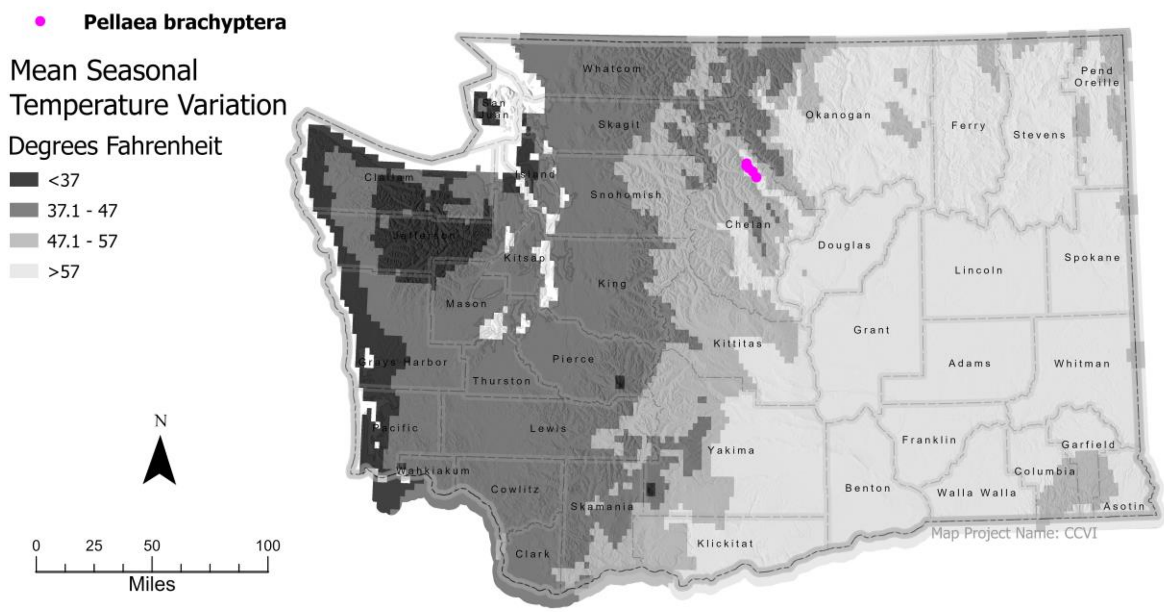

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Pellaea brachyptera* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Pellaea brachyptera occurs in open south and west-facing slopes that are warm, dry exposures in a larger forest matrix (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). The exposed slope habitat of this species enhances the effects of hot, dry summers and cool, snowy winters where it occurs (Alverson and Arnett 1986). Additionally, the spores and gametophytes of other Pellaea spp. have been shown to be tolerant to desiccation (Tryon 1957).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Pellaea brachyptera* occurrences in Washington. Two of the five known occurrences (40%) are in an area that has experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The remaining three occurrences (60%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changing moisture regimes (Young et al. 2016).

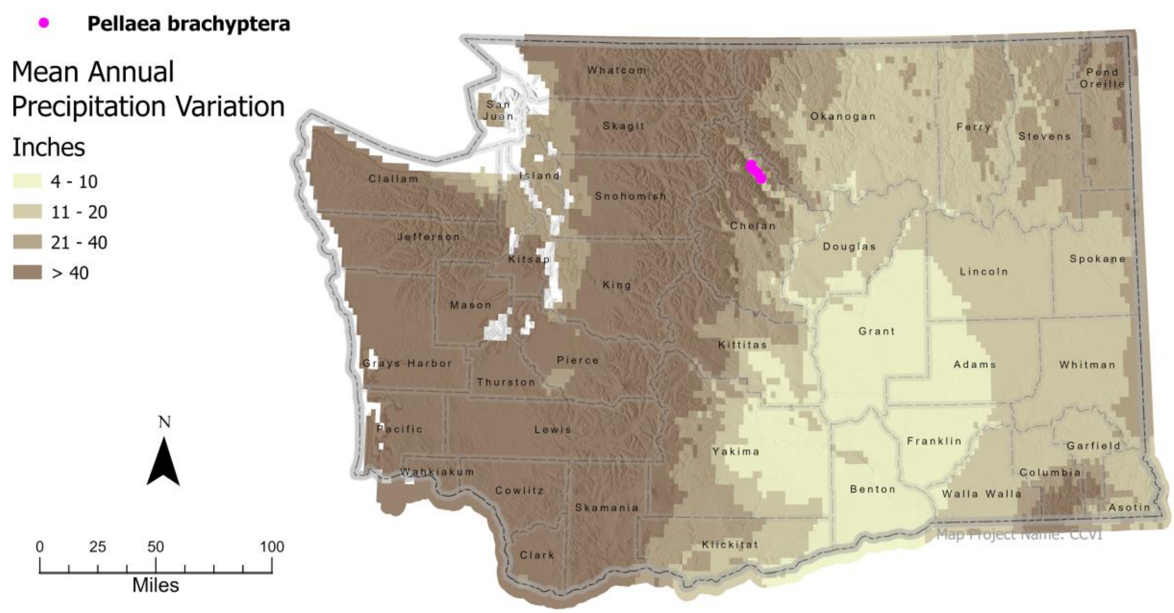

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Pellaea brachyptera* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Neutral</u>
Pellaea brachyptera is found on xeric to aridic slopes and bases of boulders associated with extremely well drained soils. These habitats are found in areas without a high water table and are more dependent on precipitation for moisture (Rocchio and Crawford 2015). Though this species is not associated with wetlands or mesic sites and is not considered to be at risk in this category (Young et al. 2016), increased temperatures and drought could lead to higher fire risk and potential damage to vegetation, which is slow to recover on rocky substrates and thin soils (Rocchio and Ramm-Granberg 2017). Potential drying of cliff and rocky slope microhabitats where limited moisture is retained in crevices may also be of particular concern.

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Wind, water, and gravity are forces acting upon cliff habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004, Rocchio and Ramm-Granberg 2017). Fire is unlikely to carry through the sparse vegetation or reach crevices in outcrops but can occur in the area, as occurrence records indicate that two fires burned

through the general region of *Pellaea brachyptera* occurrences in Washington between 1980 and 1990.

C2d. Dependence on ice or snow-cover habitats: Neutral
The low elevation foothills and ridges in the East Cascades that support *Pellaea brachyptera* receive relatively small quantities of snow and are not especially associated with cold air drainages (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Reduced snowpack due to climate change could still decrease the amount of moisture available through runoff in these areas (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Pellaea brachyptera is found on rocky, well drained soils and at the bottom of boulders derived from Skagit Gneiss metamorphosed supracrustal rocks and orthogneiss, occasionally accompanied by alluvial till and glacial outwash (Alverson and Arnett 1986, Washington Division of Geology and Earth Resources 2016). The Skagit Gneiss Complex forms a nearly continuous terrane within the northern, more deeply eroded part of the North Cascade Range but is somewhat uncommon in Washington as a whole.

C4a. Dependence on other species to generate required habitat: Neutral
The Rocky Mountain Cliff, Canyon and Massive Bedrock ecological system is shaped mostly by abiotic processes and erosion which shifts critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The sporophyte generation of *Pellaea* reproduces by spores and does not require pollinators. The gametophyte phase reproduces by motile sperm that do not require pollinators for assistance.

C4d. Dependence on other species for propagule dispersal: Neutral
The spores and gametes of *Pellaea* ssp. do not require animal species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral
There are no major pathogens or enemies documented for *Pellaea brachyptera*. Decades of past and continuing grazing at several sites pose a threat to this species (Washington Natural Heritage Program 2023).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to forested rock outcrops (Rocchio and Ramm-Granberg 2015, Washington Natural Heritage Program 2023). Under future climate change, conifer forests inhabited by this species will become drier, hotter, and more vulnerable to fire. Exposed rock outcrops would become more likely to be invaded by weedy annuals or native perennials adapted to more open and drier sites (Rocchio and Ramm-Granberg 2017). A few occurrences that have been burned in recent

years are now dominated by *Ceanothus velutinus* which appears to be shading out *Pellaea brachyptera*.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Pellaea brachyptera does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
Data are lacking on the genetic diversity within and between populations of *Pellaea brachyptera* in Washington. The Chelan County populations are clustered around a small area of Lake Chelan and are disjunct over 310 mi (500 km) away from any other populations. Therefore, they are probably genetically distinct from other populations and may have lower overall genetic diversity due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
Little is known about the specific reproductive biology of the evergreen fern *Pellaea brachyptera.* Like other pteridophytes, it follows a life cycle with two alternating independent generations; inconspicuous gametophytes that produce separate male and female organs and dominant homosporous sporophytes that can produce gametophytes with both sex organs (Soltis and Soltis 1990). However, this species may be like many other *Pellaea* spp. which are frequently triploids that are obligately apogamous, especially in dry habitats (Tryon 1957). Genetic variation in asexual species is expected to be lower (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the sporulation period of *Pellaea brachyptera* (May to July) has not changed significantly, though there was only one Washington specimen available and therefore the range wide collections had to be used for assessment (Washington Natural Heritage Program 2023)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Pellaea brachyptera* declining in response to climate change. Known occurrences have not been revisited to confirm population vigor since 1998. The trends of this species appear to be downward at two sites from 1984 to 1998 but further survey is required to confirm (Fertig and Kleinknecht 2020).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Penstemon pennellianus (Blue Mountain beardtongue)

Date: 7 November 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G3/S2
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	100
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	87
	-0.074 to - 0.096	13
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All of the of the 31 documented occurrences (100%) of *Penstemon pennellianus* in Washington occur in an area with a projected temperature increase of less than or equal to 4.5-5.0° F (2.5-2.7°C; Figure 1).

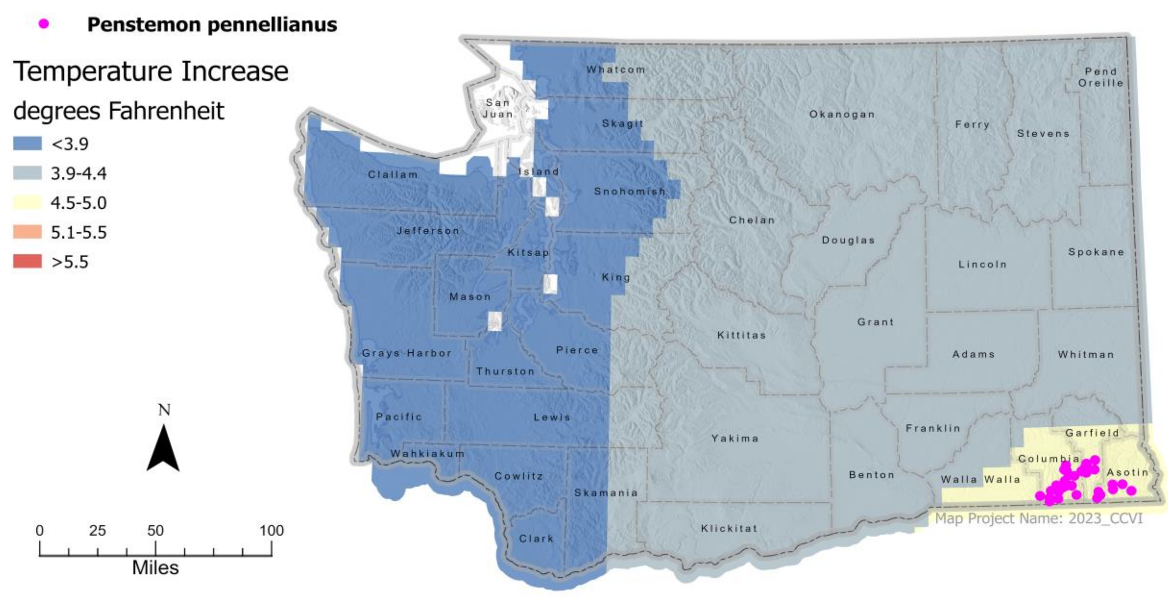

Figure 1. Exposure of *Penstemon pennellianus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 31 known occurrences of *Penstemon pennellianus* in Washington, 27 (87%) occur in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119. The remaining four (13%) are in areas with a projected decrease in the range of -0.074 to -0.096 (Figure 2).

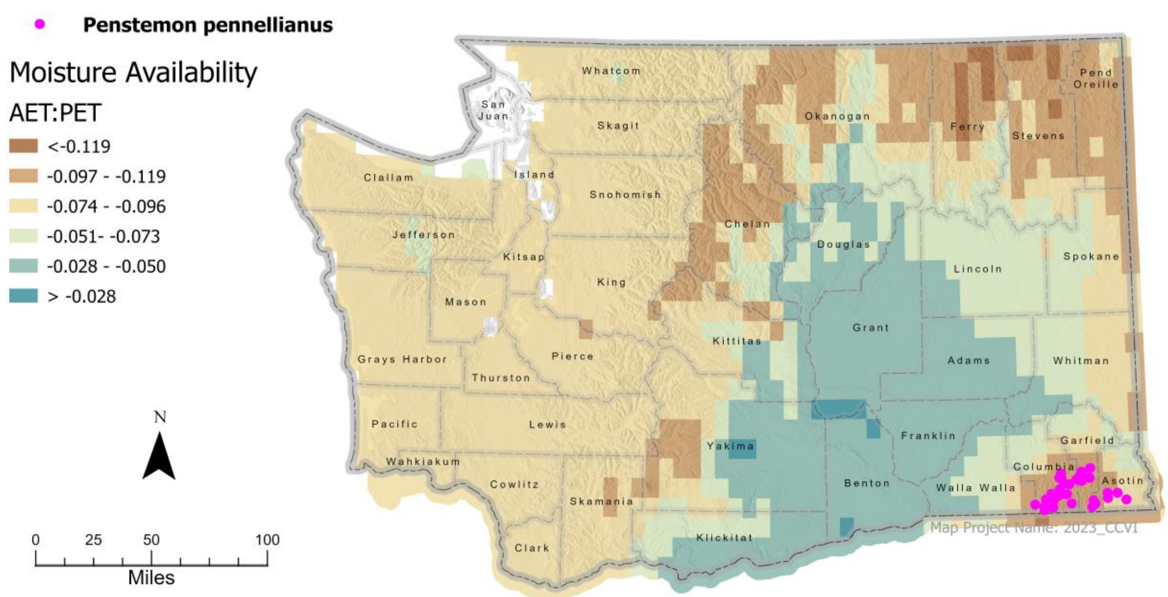

Figure 2. Exposure of *Penstemon pennellianus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Penstemon pennellianus is found on sparsely vegetated slopes of open montane forests, ridgetop scablands, roadcuts, and windswept cushion plant communities at elevations ranging from 3800-6300 ft (1160-1920 m; Washington Natural Heritage Program 2023). *Penstemon pennellianus* populations in Washington are not expected to be affected by sea level rise based on their far inland distribution and mid-elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Neutral
Penstemon pennellianus occurs on steep, rocky slopes and exposed ridges of Northern Rocky Mountain Lower Montane Foothills & Valley Grasslands which are patchy in distribution among lower montane forests and shrub-steppe but range from small grasslands to open parks (Rocchio and Crawford 2015, NatureServe 2023). This species is endemic to the Blue Mountains of Washington and Oregon and all populations are clustered within a short distance. Populations are

somewhat separated from one another and additional suitable habitat by deep canyons but generally face limited barriers to dispersal.

B2b. Anthropogenic barriers: Neutral
Most of the populations are in or near the Umatilla National Forest and are in backcountry areas with few roads and minimal development, though the surrounding area is now bounded by agricultural development in the flats at the base of the slopes where *Penstemon pennellianus* occurs. A few populations that are found on bare road cuts or along Forest Service roads may be impacted by traffic, maintenance, or herbicide spraying (Washington Natural Heritage Program 2023). Some populations are on unprotected/private lands. Overall, threats and barriers to dispersal remain minimal on the steep slopes and ridges where this species occurs.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Penstemon pennellianus* (Washington Department of Natural Resources 2023). Future projects are unlikely to occur on the steep slopes and ridgetop scab lands where it occurs.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Penstemon spp. rely primarily on wind and gravity dispersal as seeds lack any specialized structures for dispersal (Meinke 1995). It is possible that local dispersal by foraging insects or rodents helps to distribute some species but this is unconfirmed.

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Penstemon pennellianus* occurrences in Washington. Twenty seven (87%) are in areas that have been thermally stable and have experienced slightly lower than average (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining four populations (13%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation over the historical periods and are expected to be generally resilient to warming (Young et al. 2016).

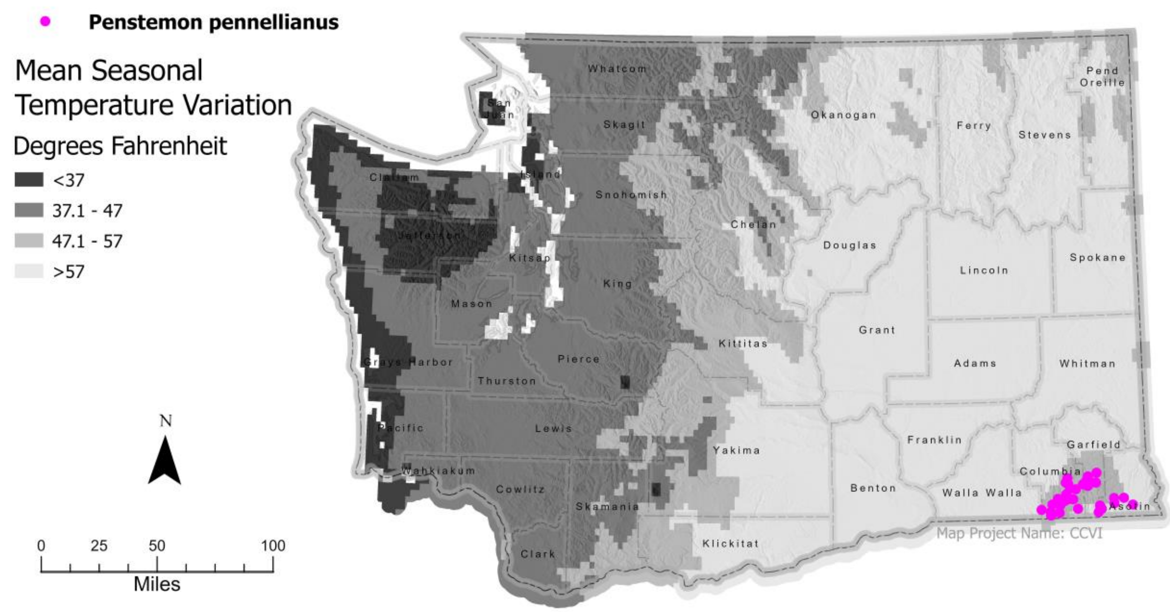

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Penstemon pennellianus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Penstemon pennellianus is found at low to high elevations on exposed southern and eastern slopes or ridgetops growing in full sun (Washington Natural Heritage Program 2023). The foothill and valley grassland habitat of *Penstemon pennellianus* is expected to increase in range in response to climate change as forests are converted. However, temperature increases may combine with drought stress to limit adaptive capacity of grasses and grasslands, increase wildfire severity and insect outbreaks, and select for species more common to hotter, drier sites (Rocchio and Ramm-Granberg 2017, NatureServe 2023). *Penstemon pennellianus* is likely to be somewhat resilient due to its preference for warmer, drier habitats.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Penstemon pennellianus* occurrences in Washington. Four occurrences (13%) are in areas that have experienced slightly lower than average precipitation variation (11- 20 in (255 - 508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. The other 27 occurrences (87%) are in areas that have experienced average or greater than average (>20 in (508 mm)) precipitation variation and are expected to be mostly resilient to climatic changes (Young et al. 2016).

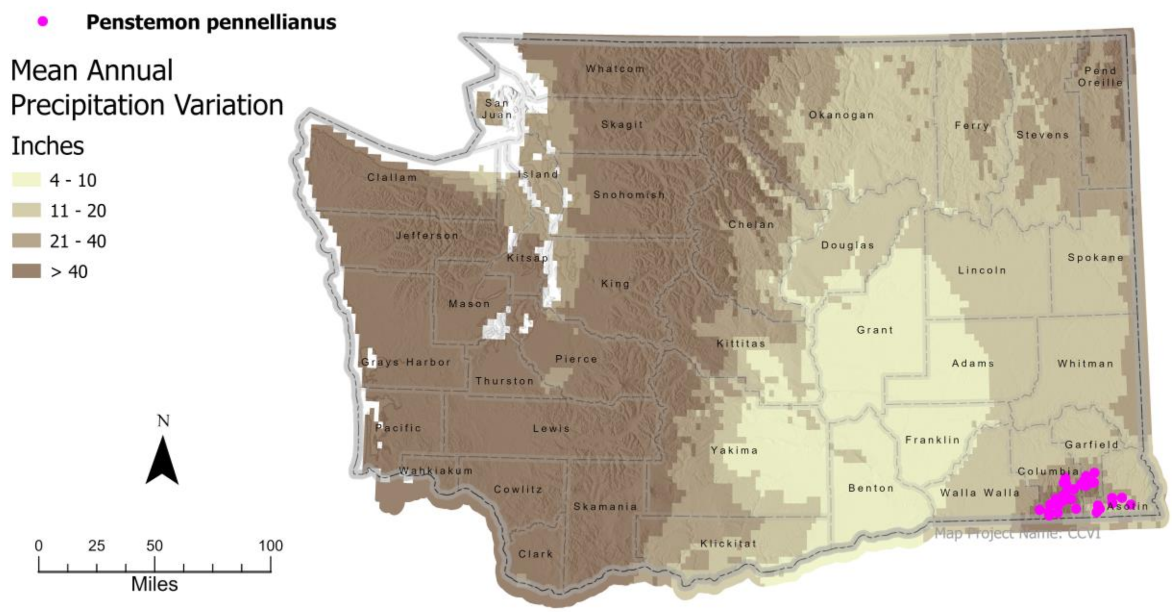

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Penstemon pennellianus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral
Penstemon pennellianus occurs on drought-prone rocky soils in dry to mesic grasslands surrounded by montane or subalpine forest (Rocchio and Crawford 2015). Summers in this region are warm and dry with most precipitation falling as snow in winter or secondarily as spring rains (NatureServe 2023). Anticipated shifts in precipitation type and timing and reductions to snowpack could impact the habitat composition of these grasslands, though they may be somewhat adapted to aridity as they occur in the rain shadow of the Cascade Range.

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Northern Rocky Mountain Lower Montane Foothills & Valley Grasslands depend on a high frequency, mixed severity fire regime and seasonal drought to prevent shrub invasion and maintain grassland habitat (NatureServe 2023). Fire suppression leads to tree and shrub encroachment. Increases in wildfire frequency may expand this habitat type but may also increase non-natives and compound on reductions in available moisture to limit the adaptive capacity of native species in this ecological system (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Penstemon pennellianus is associated with dry, windswept grasslands on moderate to steep slopes above valleys which partially rely on snow melt for moisture supply. The region where

this species occurs experiences short, dry summers and long, cold winters but is in the rain shadow of the Cascade Range, leading to a somewhat arid climate in the foothills and valleys. *Penstemon pennellianus* is not especially reliant on ice or snow cover beyond recharge of the hydrological system.

C3. Restricted to uncommon landscape/geological features: Neutral
Penstemon pennellianus is found on young soils derived from recent glacial and alluvial material on a large basalt bedrock plateau (NatureServe 2023, Washington Natural Heritage Program 2023). These platey, basaltic soils are often red or copper and are mixed with coarse fragments. This species is not restricted to a particularly uncommon soil type or geology.

C4a. Dependence on other species to generate required habitat: Neutral
The Northern Rocky Mountain Lower Montane Foothills & Valley Grasslands which support *Penstemon pennellianus* are primarily maintained by fire and seasonal drought and are not dependent on other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Penstemon spp. with large blue corollas tend to be pollinated by medium to large-sized Hymenopterans, such as nectar-collecting bumblebees (Wilson et al. 2004). *Penstemon pennellianus* is reported to be a bee specialist as bees are better able to access nectar from the unique tubular flowers, but this species is probably not highly restricted in terms of pollinators beyond this guild (Wessinger et al. 2019).

C4d. Dependence on other species for propagule dispersal: Neutral
It is possible that insects or small rodents disperse *Penstemon* seeds but there is no conclusive evidence (Meinke 1995).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Excessive grazing of Lower Montane Foothills & Valley Grasslands stresses the ecological system, leads to slope failure, reduces infiltration, increases runoff, and encourages soil disturbance that allow the establishment of exotic annual brome grasses which can replace native species (NatureServe 2023, Washington Natural Heritage Program 2023). However, there is no evidence that livestock grazing in this ecological system will increase with climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Penstemon pennellianus is found in sparsely vegetated meadows and cushion plant communities with moderately sparse vegetation cover as is probably not highly adapted for competition (Washington Natural Heritage Program 2023). The habitat is somewhat sensitive to soil disturbances which damage soil crusts and allow the introduction of non-native species such as *Bromus tectorum*, though the isolation of grassland patches can help to limit seed dispersal by encroachers and colonizers (NatureServe 2023)

C4g. Forms part of an interspecific interaction not covered above: Neutral
Penstemon pennellianus does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Penstemon pennellianus* has not been documented but it may be a hybrid and is typically found in small populations (Washington Natural Heritage Program 2023). Endemic plant species such as *Penstemon pennellianus* are generally expected to be less genetically diverse than more widespread congeners (Soltis and Soltis 1991).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
The specific reproductive system of *Penstemon pennellianus* has not been well-described but several congeners with similar habitats in the Columbia River Basin, some of which are thought to hybridize with *Penstemon pennellianus,* are predominantly or obligately outcrossing with pollen transfer remaining localized (Meinke 1995).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Penstemon pennellianus* (late May-mid July, fruiting as early as mid-June) has not changed significantly since the time of the first recorded collection in Washington in 1896 (Washington Natural Heritage Program 2023).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Penstemon pennellianus* declining in response to climate change. Most known occurrences have been relocated in recent years (though some have not been revisited since the mid-late 1990s) and the majority of historical occurrences simply have not been revisited since the late 1970s.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Phlox solivaga (yeti phlox)

Date: 4 Oct 2023 Synonym: *Phlox solivagus*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G1/S1
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	100
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase/Greatly Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral/Somewhat Increase
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Somewhat Increase/Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral/Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 10 (100%) known occurrences of *Phlox solivaga* in Washington occur in areas with a projected temperature increase of 4.5-5.0° F (2.5-2.7°C; Figure 1).

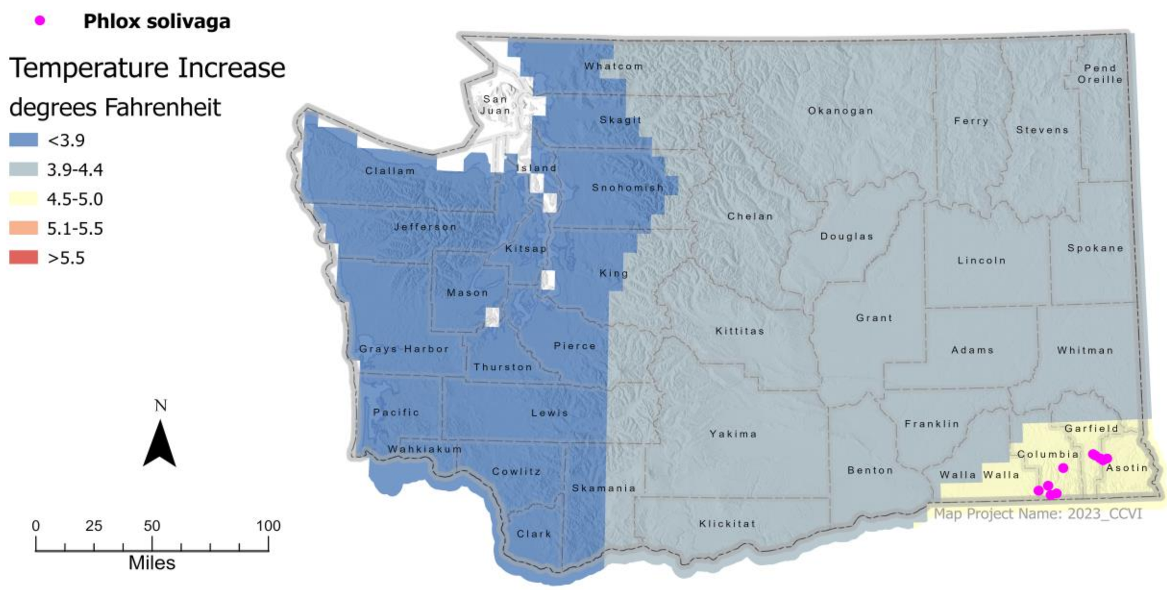

Figure 1. Exposure of *Phlox solivaga* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All five known occurrences *of Phlox solivaga* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

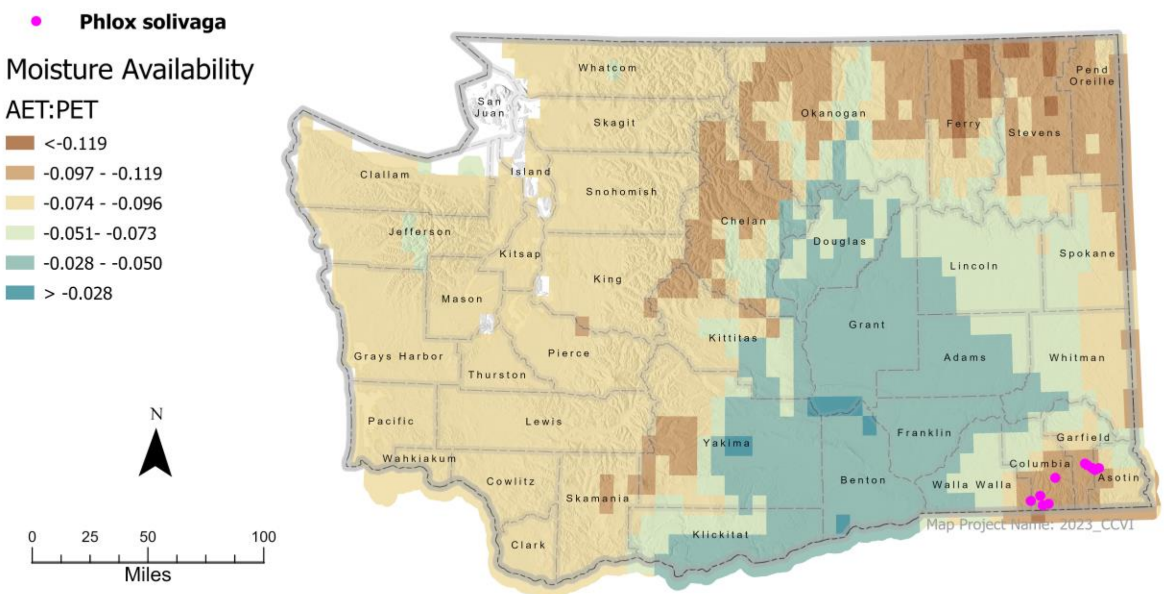

Figure 2. Exposure of *Phlox solivaga* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Phlox solivaga occurs on upper montane to subalpine rocky mountain slopes at elevations ranging from 4460-5960 ft (1360-1815 m; Washington Natural Heritage Program 2023). *Phlox solivaga* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Neutral
Phlox solivaga is endemic to gradual slopes of Northern Rocky Mountain Subalpine-Upper Montane Grasslands in the Blue Mountains ecoregion of southeastern Washington (Washington Natural Heritage Program 2023). Populations are separated by 2-33 mi (2-53 km) of distance, some of which is unsuitable lower elevation forest habitat that could pose a barrier to dispersal. However, there is other apparently unoccupied suitable habitat in the area adjacent to the known occurrences. This species may have a wider range than is currently known (Ferguson et al. 2015).

B2b. Anthropogenic barriers: Neutral

Due to the isolated mountain terrain and National Forest lands, the habitat of *Phlox solivaga* remains relatively undisturbed by direct anthropogenic stressors and barriers other than potential recreational impacts. However, *Phlox solivaga* is known to occur on hard-packed cobblestone unpaved roads with little use (Washington Natural Heritage Program 2023). Roadside occurrences could be compacted or dislodged by vehicle traffic but this poses a minimal barrier to dispersal. Some *Phlox* spp. are cultivated as rock garden ornamentals, and the rarity and unusual gray woolly foliage of this species might make it vulnerable to over-exploitation (Fertig 2020).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the known populations of *Phlox solivaga* (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase/Greatly Increase
The fruits of *Phlox solivaga* are longitudinally dehiscent capsules which contain three seeds that lack any special structures for long-distance dispersal (Washington Natural Heritage Program 2023). Little more is known about the specific dispersal mechanisms of *Phlox solivaga* but many *Phlox* spp. exhibit explosive seed dispersal mechanisms that can spread seed short distances (3.7-13.1 ft (1.1-4 m)) from parent individuals (Levin and Kerster 1968, Campbell 1992). The seeds of *Phlox* spp. are thought to sometimes be eaten and dispersed by birds (Levin 1978). The high site fidelity of *Phlox solivaga* to erosional paleosurfaces of basalt lithosols warrants a higher ranking (Young et al. 2016).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Phlox solivaga* occurrences in Washington. All occurrences but one (90%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period and are expected to be somewhat vulnerable to climate warming (Young et al. 2016). The remaining occurrence is in an area that has experienced average variation (>57.1° F (31.8° C)). According to Young et al. (2016) this population is likely to be mostly resilient to warming.

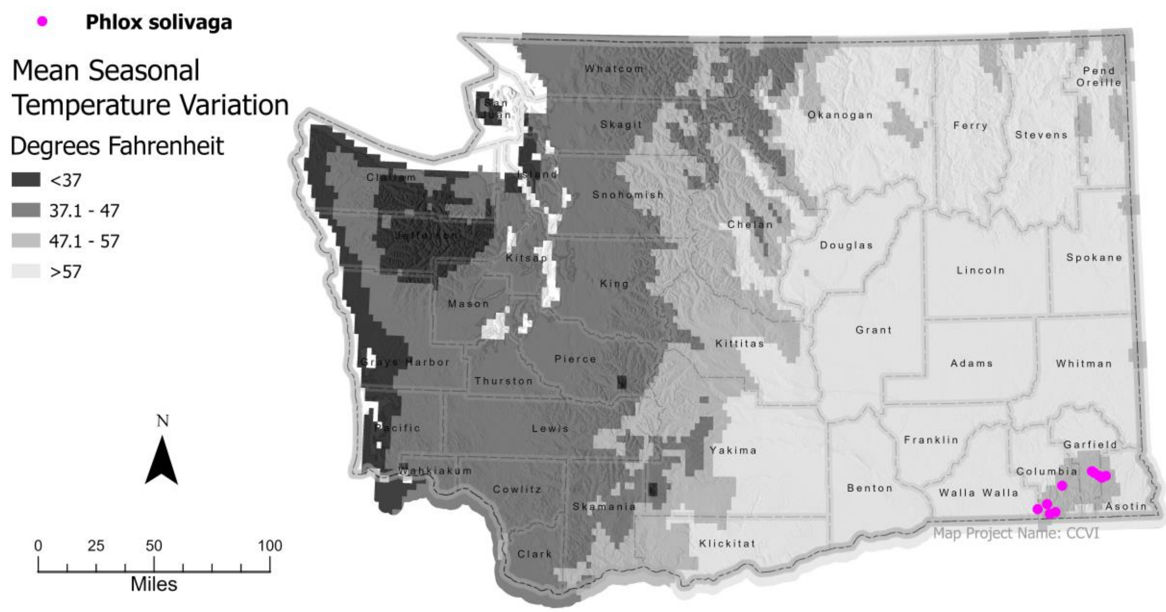

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Phlox solivaga* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
Phlox solivaga is constrained to rocky ridges and peaks of the upper montane to subalpine. These high-elevation rocky habitats experience short, cool growing seasons and long, cold winters (NatureServe 2023a) and will be vulnerable to anticipated temperature increases (Rocchio and Ramm-Granberg 2017). However, the microsites where *Phlox solivaga* occurs are dry, south-facing slopes that receive full sun exposure and are warmer than the surrounding landscape. *Phlox solivaga* may be slightly more tolerant of shifting temperatures and may be able to move to higher alpine environments as the climate changes.

C2bi. Historical hydrological niche: Neutral/Somewhat Increase
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Phlox solivaga* occurrences in Washington. All occurrences but one (90%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to climate change induced shifts to precipitation and moisture regimes (Young et al. 2016). The remaining occurrence is in an area that has experienced slightly lower than average precipitation variation (11 - 20 in (255 - 508 mm)). According to Young et al. (2016) these populations are likely to be resilient somewhat vulnerable to precipitation and moisture regimes shifts.

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Phlox solivaga* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Neutral</u>
The Northern Rocky Mountain Subalpine-Upper Montane Grasslands where *Phlox solivaga* occurs rely primarily on snowmelt for a steady supply of moisture throughout the growing season. Though *Phlox solivagus* is associated with dry, exposed ridges where wind-scour and sublimation keeps snowpack and available moisture to a minimum, it is likely subirrigated by snow collected in depressions across the surrounding landscape. Anticipated reductions in snowfall, early snowmelt, and extended seasonal drought will impact the water-limited habitat of *Phlox solivaga* and shift community composition toward drought-adapted species (Rocchio and Ramm-Granberg 2017). *Phlox solivaga* may be slightly resilient to these changes as it has been found in other areas of its range spanning across broad precipitation gradients which may indicate that it has broader climatic envelope than it appears (Ferguson et al. 2015)

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Frequent fire plays an important role in maintaining the small meadows and large open parks of montane grassland that support *Phlox solivaga* and helps to prevent tree encroachment from the surrounding forests, though these sites are often too harsh and dry to support trees (Rocchio and Crawford 2015, NatureServe 2023a). Areas where fire has been excluded have sometimes experienced invasion of *Abies lasiocarpa* and *Pinus albicaulis* but seasonal drought and wind-scour generally prevent establishment. Changes to wildfire regimes and increasing fire frequency are likely to have minor impacts on the habitat of *Phlox solivaga*, with some changes to composition and potential for invasion expected (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase
Phlox solivaga occurs in the subalpine zone on flat to gently sloping ridges and southwestern facing exposures where little snow accumulates in the winter due to wind-scour and sun exposure, though snow may linger late in the season in the surrounding landscape. Expected temperature increases, reductions to snowpack, and changes in snowmelt timing are not anticipated to greatly spur tree invasion, but conversion to drier *Festuca idahoensis* dominant communities with less plant cover is likely (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase/Increase
Phlox solivaga is narrowly restricted to flat to gradual windswept ridges and exposed erosional surfaces of basalt lithosols or volcanic bedrock and rubble (Ferguson et al. 2015, Washington Natural Heritage Program 2023). Known occurrences are on a large plateau of Miocene Grande Ronde Columbia River Basalt that could contain additional suitable habitat. Similar flood basalts extend across southeastern Washington through to Oregon and Idaho, though the necessary paleosurfaces that support *Phlox solivaga* are limited in areal extent (Ferguson et al. 2015, Cascades Volcano Observatory 2023).

C4a. Dependence on other species to generate required habitat: Neutral
Large herbivores aid in the maintenance of open grassy spaces between subalpine forest but are not as critical to the preservation of this ecological system as abiotic factors (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
The exact pollinators of *Phlox solivaga* are not well documented but Lepidopterans are reported to account for the majority of pollination in *Phlox* spp. (Levin and Kerster 1968). Some bees and other insects may also visit *Phlox* spp. but most are poorly adapted to feed from the narrow corolla tubes which are better suited to long-tongued pollinators. Though *Phlox solivaga* is not exclusively pollinated by a single or few species, the pollinators it is likely to attract are somewhat limited based on floral morphology.

C4d. Dependence on other species for propagule dispersal: Neutral
The exact dispersal mechanisms of *Phlox solivaga* are not well understood but seeds are thought to be mainly by passive means or by explosive dehiscence (Levin and Kerster 1968, Campbell 1992). The structure of the seeds does not point to specialization for wind dispersal or other long-distance dispersal syndromes. There are some reports that other *Phlox* spp. may be spread by animal ingestion (Levin 1978, Minnesota Department of Natural Resources 2018), but it is unknown if *Phlox solivaga* can be dispersed in this manner.

C4e. Sensitivity to pathogens or natural enemies: Neutral/Somewhat Increase
Grazing can be a major threat to *Phlox* spp. and some species are known to be desirable to groundhogs, rabbits, and deer (Springer et al. 2013, Minnesota Department of Natural Resources 2018, Colorado State University Extension, Jefferson County 2023). Northern Rocky Mountain subalpine-upper montane grasslands which support *Phlox solivaga* can become degraded and

eroded under heavy grazing from cattle or elk and these effects could be compounded by climate change (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). Some light cattle grazing has been documented in the vicinity of known *Phlox solivaga* occurrences. The low stature and spiny herbage of *Phlox solivaga* may help to somewhat deter herbivores (Fertig 2020). Horticultural *Phlox* spp. are also known to be widely susceptible to the ubiquitous powdery mildew disease (Farinas et al. 2021), but the incidence rates in wild *Phlox* spp. are undescribed.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
The rocky rubble and wind exposure of the montane grasslands where *Phlox solivaga* occurs keep plant cover relatively low and reduce the number of species that can thrive alongside *Phlox solivaga*. Invasive annual grasses such as *Ventenata dubia, Bromus hordeaceus, and Apera interrupta* have been noted as encroaching threats which may shade out *Phlox solivaga* and field notes indicate that *Phlox solivaga* is absent from areas with deeper soils dominated by native or invasive grasses (Washington Natural Heritage Program 2023). Plant invasions in the alpine are expected to increase with warming as more competitive species advance up the mountain (Dainese et al. 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Phlox solivaga does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Phlox solivaga* has not been documented. Endemic plant species are generally expected to be less genetically diverse than more widespread congeners (Soltis and Soltis 1991).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
The specific reproductive system of *Phlox solivaga* is not well-described, but *Phlox* spp. are generally polyploids (diploid to hexaploid) that are self-incompatible and are primarily outcrossers (Fehlberg and Ferguson 2012). Different floral morphologies attract a specific suite of floral visitors that differ among congeners or even cytotypes and prevent gene flow, leading to endemism of plants with certain ploidy levels. Many populations experience genetic isolation as a result.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and Washington Natural Heritage Program records, the flowering period of *Phlox solivaga* consistently begins in mid-May and extends into late June with no apparent changes to the flowering period over time. The original species description indicates that *Phlox solivaga* only flowers into early June (Ferguson et al. 2015). This does not appear to be a result of phenological change but rather a slight discrepancy between recorded flowering times across the datasets. Further phenological monitoring is warranted as studies show spring blooming species to be at greater risk of phenological change in North America (Calinger et al. 2013).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Range shifts or contractions may be hard to detect as this *Phlox solivaga* was just described in 2015 and the full range extent may not even be fully known as there are extensive areas of suitable habitat that have not yet been surveyed (Fertig 2020). All but one recorded occurrence has been confirmed as extant in recent years. Though *Phlox solivaga* is thought to be in decline due to the population structure being skewed to mature individuals (Ferguson et al. 2015), there is not enough population data available to clearly assess trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Young, B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app

Climate Change Vulnerability Index Report
Platanthera chorisiana (Choris' bog-orchid)

Date: 8 May 2024
Synonym: *Habenaria chorisiana*
Assessor: Molly S. Wiebush WA Natural Heritage Program
Geographic Area: Washington
Heritage Rank: G4/S2
Index Result: Highly Vulnerable
Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	10
	<3.9° F (2.2°C) warmer	90
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to -0.096	100
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase/Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Somewhat Increase
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Nine of ten known occurrences (90%) of *Platanthera chorisiana* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C) warmer. One of ten known occurrences (10%) of *Platanthera chorisiana* in Washington occurs in an area with a projected temperature increase of 3.9–4.4° F (2.2–2.4° C; Figure 1).

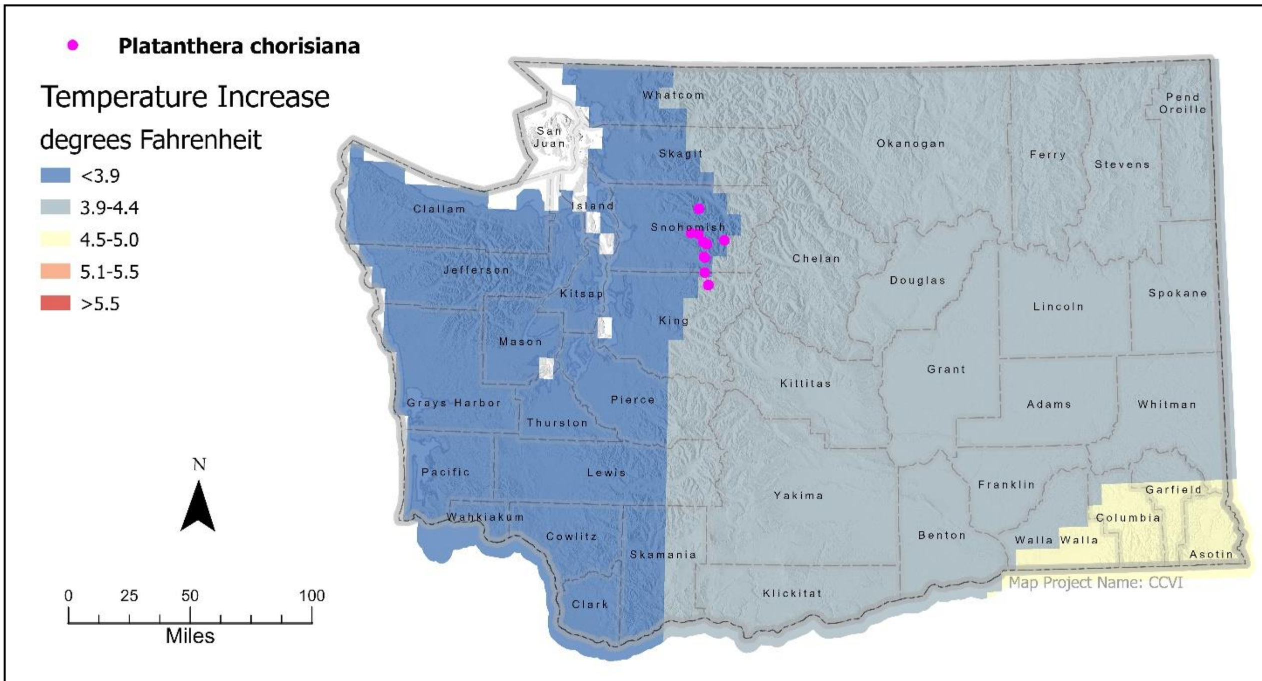

Figure 37. Exposure of occurrences of *Platanthera chorisiana* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All ten known occurrences (100%) *Platanthera chorisiana* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096. (Figure 2).

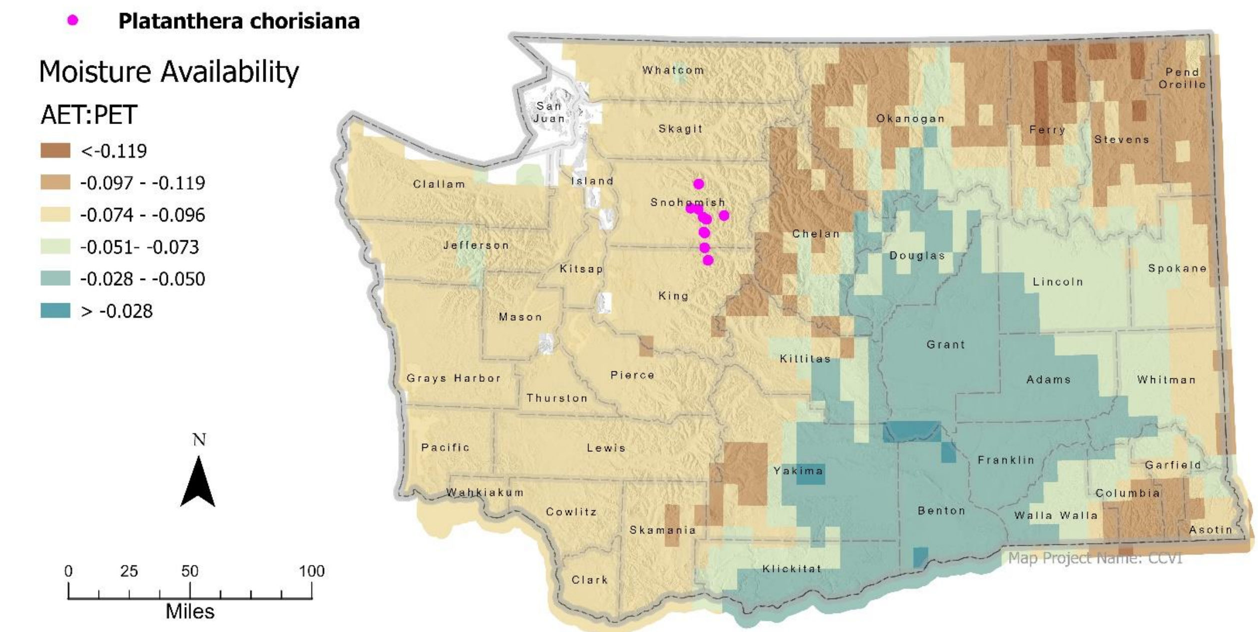

Figure 38. Exposure of occurrences of *Platanthera chorisiana* in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Platanthera chorisiana is found in bogs and other wetland habitats between 2540–4300 ft (774–1310 m; Washington Natural Heritage Program 2024) and would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
Platanthera chorisiana is found in the North Pacific Bog and Fen ecological system, which occurs as small patches and is not very abundant in Washington. These peatland habitats are naturally small and isolated within a matrix of unsuitable forest, agricultural, and urban/rural lands that create a barrier to migration and dispersal.

B2b. Anthropogenic barriers: Neutral

Most records for *Platanthera chorisiana* in Washington occur in protected areas, with four of ten records occurring in Wilderness Areas, and four other records occurring in the Morning Star Natural Resource Conservation Area. Many peatlands in the North Pacific Bog and Fen ecological system have been isolated or damaged by logging and roads (Rocchio and Crawford 2015), potentially creating barriers to migration for some species. Several occurrences are near trails and are affected by outdoor recreation, particularly hiking and camping. However, *Platanthera chorisiana* seeds are likely wind-dispersed, potentially over very long distances and the ability of this species to migrate may not be significantly limited by these conditions.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
The majority of records for *Platanthera chorisiana* in Washington occur in protected areas. Additionally, there are no known ongoing or proposed clean energy projects that would threaten populations of *Platanthera chorisiana* and future projects in peatlands are unlikely (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Neutral</u>
Orchids are generally assumed to be capable of long-distance wind dispersal, due to the small size and buoyant nature of their seeds (Arditti and Ghani 2000). The current distribution of *Platanthera chorisiana* ranges from Washington State north to Alaska, and west to Japan. This distribution suggests that *Platanthera chorisiana* is capable of long-distance dispersal (> ½ mi or 1 km; Sing-Chi 1983).

C2ai. Historical thermal niche: <u>Somewhat Increase/Increase</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Platanthera chorisiana* occurrences in Washington. Five of ten known occurrences (50%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming. Five of ten known occurrences (50%) are in areas that have experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming.

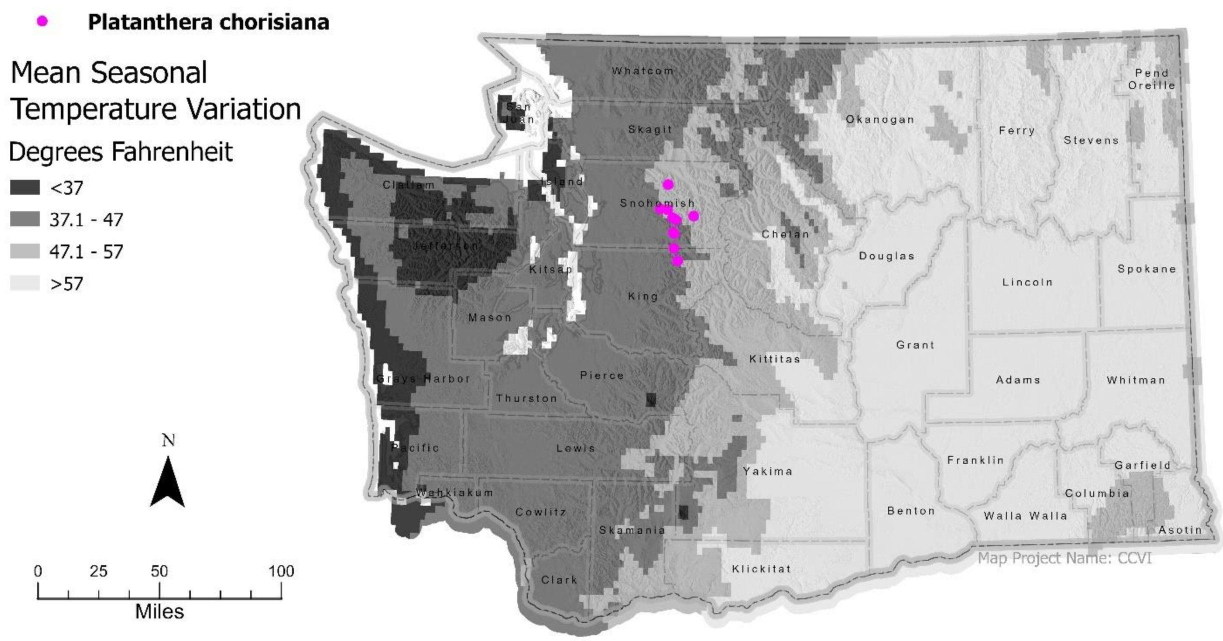

Figure 39. Historical thermal niche (exposure to past temperature variations) of occurrences of *Platanthera chorisiana* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Somewhat Increase

In Washington, *Platanthera chorisiana* is found in montane and subalpine habitats in the North Pacific Bog and Fen ecological system (Washington Natural Heritage Program 2024). Increases in temperature could accelerate drying in peatlands and increases in water temperature could lead to commensurate changes in their biological communities (Rocchio and Ramm-Granberg 2017). Peatland habitat is often associated with cold air drainage sites in montane settings and are cooler than the surrounding matrix vegetation. Such areas may have increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Platanthera chorisiana* occurrences in Washington. All ten known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

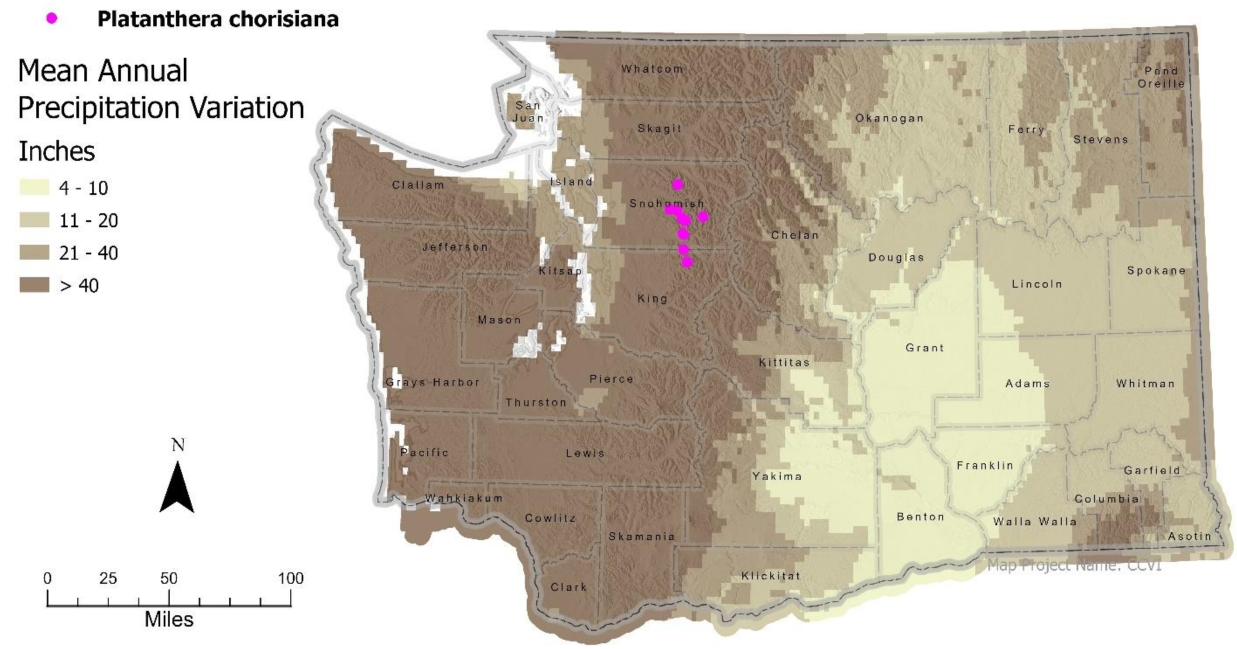

Figure 40. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Platanthera chorisiana* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Increase
This species is strongly dependent on precipitation and groundwater to maintain the high water table necessary for accumulation of peat. Bog and fen habitats, particularly habitats the depend on precipitation and surface water, are sensitive to drier conditions. Decreases in moisture can lead to increased invasion of dry-adapted species or tree encroachment on these habitat types (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase
Little information is available on *Platanthera chorisiana* responses to disturbance. In Washington, peat accumulates at an approximate rate of 1 inch per 40 years, with peat depth ranging from a few inches to over 50 feet (Rocchio and Ramm-Granberg 2017). This suggests that minimal disturbance is important for fen species like *Platanthera chorisiana*. This species may have somewhat increased vulnerability to climate change associated with increased disturbance, such as fire or fire suppression activities.

C2d. Dependence on ice or snow-cover habitats: Neutral
While *Platanthera chorisiana* does not rely directly on ice or snow-covered habitats, reduced snowpack and precipitation shifts from snow to rain is a significant threat to fen habitats (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Platanthera chorisiana is frequently found on granite and gneiss substrates in Washington. These substrates are common in Washington and should not limit habitat availability for *Platanthera chorisiana* (Washington Division of Geology and Earth Resources 2016). However, landscape features associated with fens may be sporadic, contributing to the overall rarity of the species in the state.

C4a. Dependence on other species to generate required habitat: Neutral
The bogs and fens in which *Platanthera chorisiana* is found are created and maintained by abiotic factors, including groundwater and precipitation patterns, water chemistry, and history of glaciation (Rocchio and Crawford 2015). Edaphic and drainage patterns in these systems favor the accumulation of thick organic soil layers that support peatland vegetation over conifer forests (Banner et al. 1983).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Platanthera species frequently have specialist pollinator relationships (Efimov 2012). In Japan, Oedemerid beetles (false blister beetles) pollinate *Platanthera chorisiana*, based on its short nectar spur (Funamoto 2019). However, no insect pollinators have been documented for this species in North America (Bowles and Armstrong 2019). The high seed set of this species suggests it is capable of autogamy (Efimov 2012), and it has been found to self-pollinate in Canada (Bowles and Armstrong 2019). The demonstrated ability to self-pollinate likely provides some resilience against disruptions in plant-pollinator relationships caused by climate change.

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Platanthera chorisiana* are likely wind-dispersed. This species has no traits that suggest its propagules are animal dispersed.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Herbivory has been noted for a small number of observations of *Platanthera chorisiana*. Orchid species may face increased insect herbivory (particularly from beetles) with climate change (Light and MacConaill 2012), but no information specific to pathogens or natural enemies is available for *Platanthera chorisiana*.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Phalaris arundinacea has been documented at one location for *Platanthera chorisiana* in Washington. Otherwise, under present conditions, competition from non-native species is low, as relatively few introduced plants are adapted to the harsh environmental conditions of peatlands. This could change under projected climate change, as higher temperatures, reduced precipitation, and more frequent drought are likely to shift these sites from peat accumulation to decomposition. Resulting changes in soil moisture could shift these communities to wet

meadows or coniferous forests. If drying also brings increased wildfire, these areas would be more prone to invasion by native and introduced plant species adapted to drier conditions (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase.
All known orchid species rely on symbiotic relationships with mycorrhizal fungi for seed germination (Yoder et al. 2000). Little information on mycorrhizal relationships in *Platanthera chorisiana* is available, and it is unknown how climate change could affect these relationships. Still, the relationship between fungi and orchids is generally thought to somewhat increase orchid vulnerability to climate change (Young et al. 2016).

C5a. Measured genetic variation: Not Ranked
Data are lacking on the genetic diversity within and between populations of *Platanthera chorisiana* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Somewhat Increase
Platanthera chorisiana likely has a mixed mating system. While the positions of the stigma and anther in the flower suggest some physical barriers to self-pollination, studies have reported self-pollination with high seed set for this species (Efimov 2012). Pollinators are not documented for this species in North America (Efimov 2012, Bowles and Armstrong 2019), suggesting that in Washington *Platanthera chorisiana* likely relies on self-pollination for most of its seed set. While high seed production suggests that inbreeding depression is not currently a problem for this species. Selfing can reduce genetic diversity within populations, potentially increasing vulnerability to climate change.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Platanthera chorisiana* (July and August) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Platanthera chorisiana* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

Plectritis brachystemon (shortspur seablush)

Date: 24 May 2024 Synonym: *Plectritis congesta* ssp. *brachystemon*
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5?/S1?
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	50
	<3.9° F (2.2°C) warmer	50
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to -0.096	64
	-0.051 to -0.073	36
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Increase
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Not Ranked
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Seven of 14 occurrences with modeled data (50%) of *Plectritis brachystemon* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C). The remaining seven occurrences with modeled data (50%) of *Plectritis brachystemon* in Washington occur in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4°C) (Figure 1). Six additional records of *Plectritis brachystemon* in Washington do not have temperature data modeled.

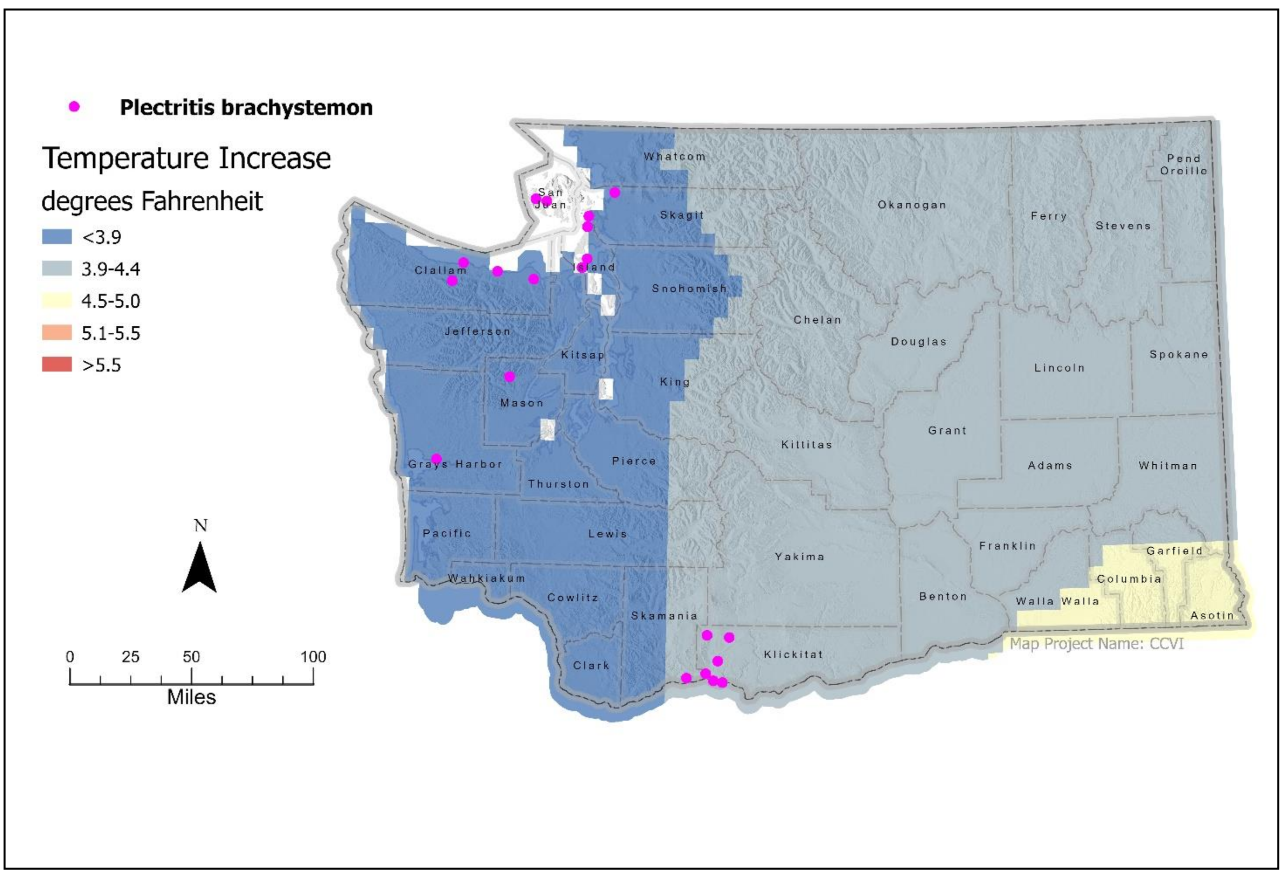

Figure 41. Exposure of occurrences of *Plectritis brachystemon* in Washington to projected local temperature change. Base map layers form www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Five of 14 known occurrences with data modeled (36%) for *Plectritis brachystemon* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range -0.051 to -0.073. Nine of 14 known occurrences with modeled data (64%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096. Six additional records of *Plectritis brachystemon* in Washington do not have temperature data modeled.

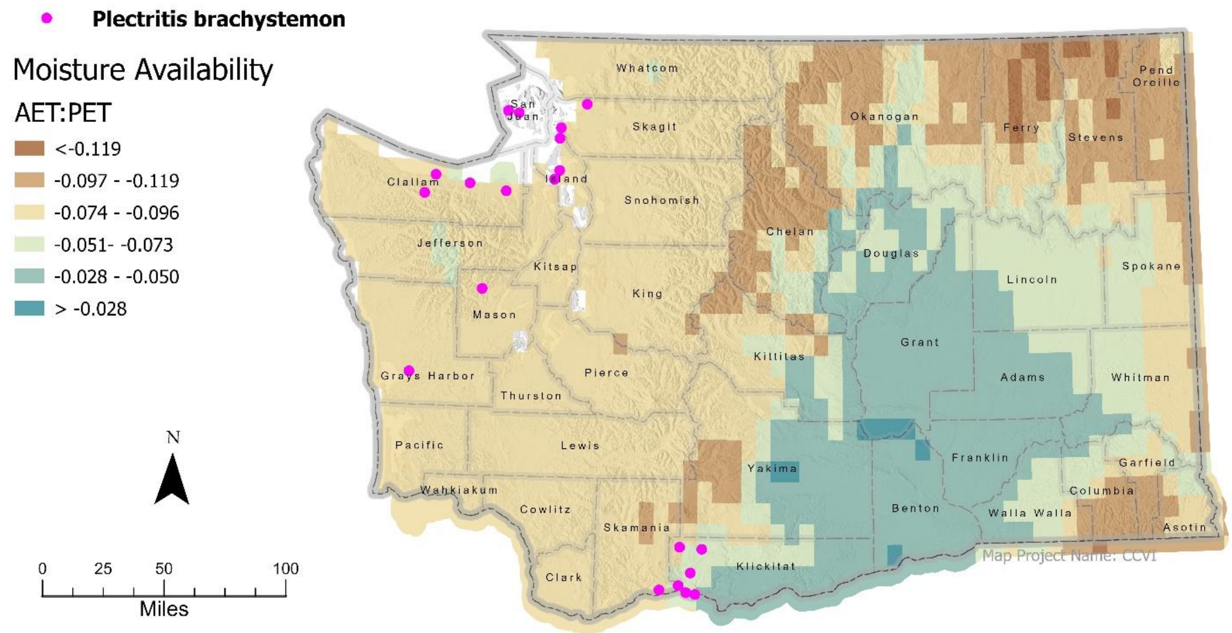

Figure 42. Exposure of occurrences of *Plectritis brachystemon* in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Plectritis brachystemon occurs on coastal bluffs, lowland prairies and rocky balds within *Pseudotsuga menziesii* and *Acer macrophyllum* forests at elevations of 130–1800 ft (40–550 m; Washington Natural Heritage Program 2024) and would not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Somewhat Increase</u>

Plectritis brachystemon is found in North Pacific Herbaceous Bald and Bluff and Willamette Valley Upland Prairie and Savanna ecological systems. Balds generally occur as small patches within a matrix of lowland forest, remnant prairie, and anthropogenic (agricultural, rural, and urban) environments. Over 90% of the Willamette Prairie has been converted by agriculture and development, with the highest concentration remaining in Washington in the South Puget Sound region and the San Juan Islands (Rocchio and Crawford 2015). Current occurrences of *Plectritis brachystemon* are separated by 4.5–74 miles (7–119 km). Barriers to gene flow are less influenced by natural barriers than anthropogenic barriers.

B2b. Anthropogenic barriers: Increase
Over 90% of Willamette Valley Upland Prairie and Savanna habitats have been converted by agriculture and development (Rocchio and Crawford 2015). Gene flow in *Plectritis brachystemon* is likely more restricted by anthropogenic than natural barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Plectritis brachystemon* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Plectritis brachystemon produces triangular achenes that may or may not be winged, with a raised keel (Washington Natural Heritage Program 2024). Wings and trichomes on *Plectritis* seeds aid may in dispersal by wind and animals. Unwinged seeds may be more likely to be washed away by rain (Jacobs et al. 2010).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Plectritis brachystemon* occurrences in Washington. Five of 19 modeled occurrences (26%) are in areas that have experienced very small (< 37° F (20.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have greatly increased vulnerability to climate warming. Seven of 19 modeled occurrences (38%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected have increased vulnerability to climate warming. Six of 19 modeled occurrences (31%) are in areas that have experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have somewhat increased vulnerability to climate warming. One of 19 modeled occurrences (5%) is in an area that has experienced average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), this population is expected to be mostly resilient to climate warming. One record of *Plectritis brachystemon* does not have historical thermal niche data modeled.

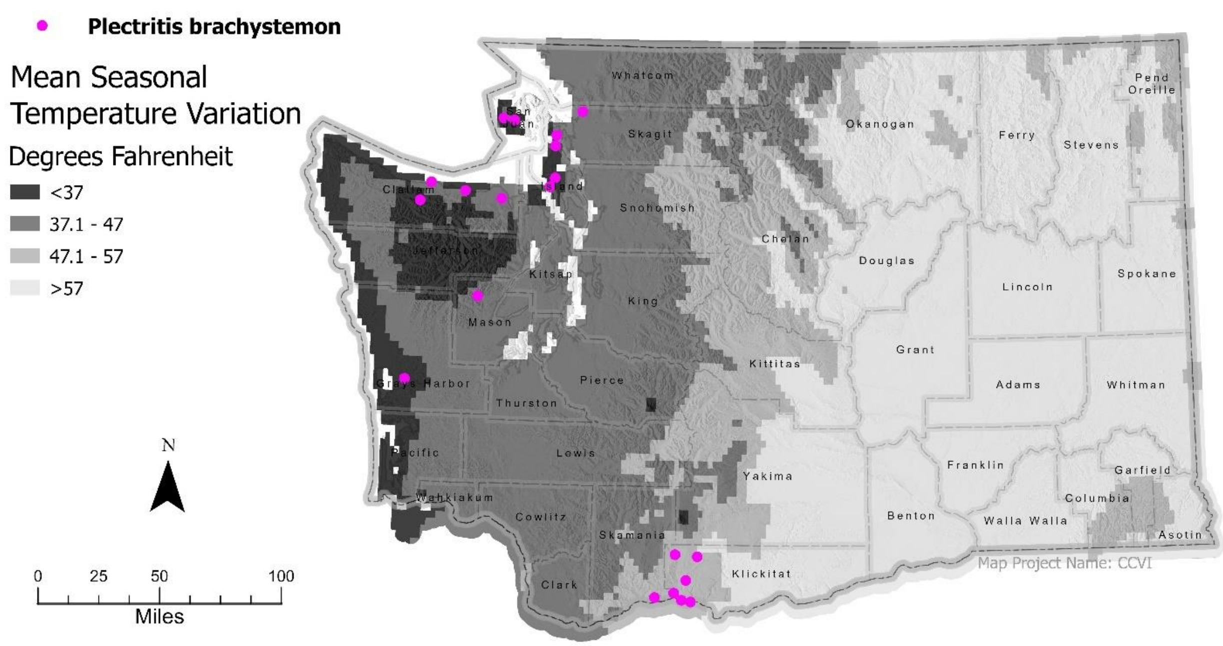

Figure 43. Historical thermal niche (exposure to past temperature variations) of occurrences of *Plectritis brachystemon* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: <u>Neutral</u>
Plectritis brachystemon generally grows in places that are too warm and dry for trees and shrubs to establish (or that experience frequent enough fires to prevent trees and shrubs from establishing). Bald and bluff habitats generally support species adapted to warm and dry conditions, due to shallow soil prone to drought (Rocchio and Ramm-Granberg 2017, NatureServe 2024a). A shift to warmer, drier summers could potentially benefit prairie species like *Plectritis brachystemon* (NatureServe 2024b).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Plectritis brachystemon* occurrences in Washington. All 19 modeled occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes. One record of *Plectritis brachystemon* does not have historical hydrological niche data modeled.

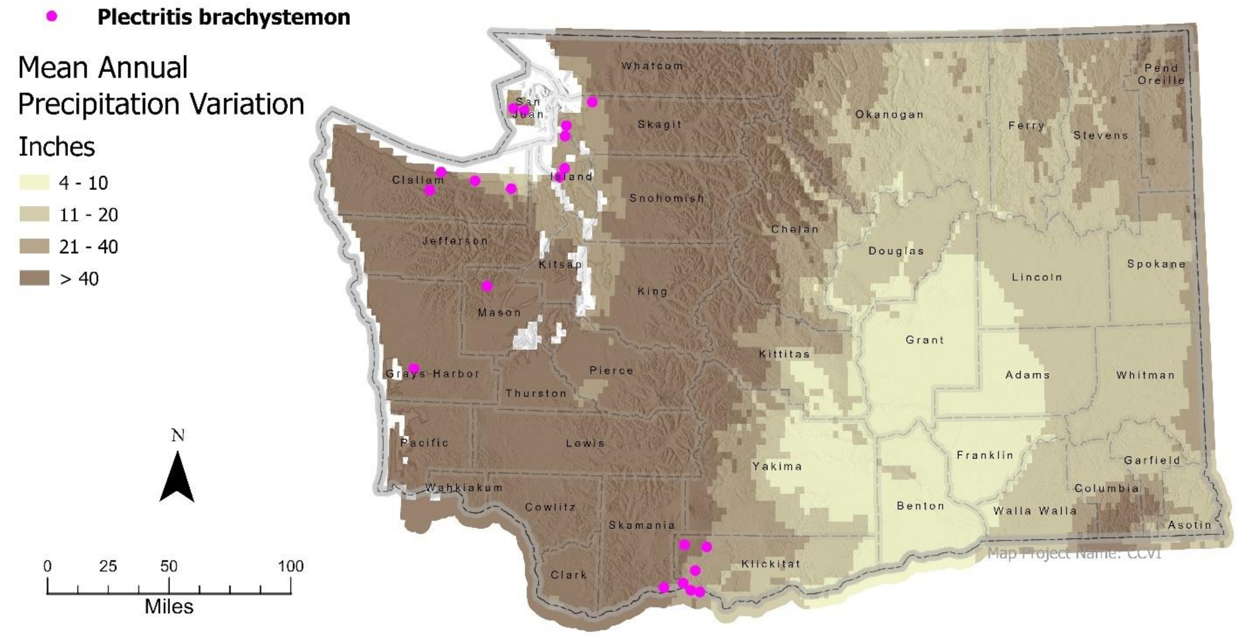

Figure 44. Historical hydrological niche (exposure to past variations in precipitation) of *Plectritis brachystemon* occurrences in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Neutral
The habitats *Plectritis brachystemon* is found in are defined by warm and dry summers and are likely to be mostly resilient to increases in temperature and decreases in moisture. Increased drought and temperatures in the growing season could lead to an increased risk of wildfire, but this could potentially benefit *Plectritis brachystemon* by maintaining or increasing the open habitats it prefers (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
The open habitats *Plectritis brachystemon* prefers are maintained by summer droughts and frequent low-severity fires to prevent the encroachment of trees and shrubs (Rocchio and Crawford 2015). Fire is particularly important in maintaining prairies and savannas in areas that otherwise receive enough rain to support trees and shrubs (e.g., Willamette Prairie ecosystems), and historically, these habitats have been maintained by cultural fire. Increased temperatures and decreased precipitation projected from climate change are likely to increase the frequency and intensity of wildfires, which could benefit this species by favoring grasslands over forests. Reduced soil moisture, however, could impact herbaceous plants, like *Plectritis brachystemon*, and increased disturbance could result in greater competition from invasive non-native plants (Rocchio and Ramm-Granberg 2017, NatureServe 2024b, 2024a).

C2d. Dependence on ice or snow-cover habitats: Neutral

Plectritis brachystemon occurs in habitats that get most of their precipitation as rainfall and does not directly depend on ice or snow-covered habitats.

C3. Restricted to uncommon landscape/geological features: Neutral
Plectritis brachystemon occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Abiotic process, particularly fire, droughty soils, and dry summers are the most important factors in structuring the communities *Plectritis brachystemon* inhabits (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Plectritis brachystemon is a self-compatible, annual herb with small, pale pink to white flowers that have poorly developed spurs on the corolla and little fragrance. Flowers are not noticeably protoandrous and stigmas and anthers are in close proximity to one another. This species also has very low measures of heterozygosity, suggesting that it is almost exclusively self-pollinating (Layton and Ganders 1984). It will likely be resilient to disruptions in plant-pollinator relationships caused by climate change.

C4d. Dependence on other species for propagule dispersal: Neutral
Wings and trichomes on *Plectritis* seeds aid in dispersal by wind and animals. Unwinged seeds may be more likely to be washed away from the parent plants by rain (Jacobs et al. 2010). *Plectritis brachystemon* seeds rely at least partially on abiotic dispersal, so this species is likely resilient to disruptions to biotic seed dispersal caused by climate change.

C4e. Sensitivity to pathogens or natural enemies: Neutral
A study of *Plectritis congesta* comparing grazed and ungrazed populations on islands near Vancouver, BC found that plants that experienced herbivory were shorter and produced mainly wingless fruits (Skaien and Arcese 2018). Another study found herbivory was more limiting to *Plectritis congesta* than competition was for both seedlings and established plants (Gonzales and Arcese 2008). While *Plectritis brachystemon* may also be vulnerable to ungulate herbivory, there is no indication that climate change will increase herbivore pressure on this species.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Introduced annual and perennial grasses are a significant threat to the open grassland and savanna habitats that *Plectritis brachystemon* prefers (Rocchio and Crawford 2015). Invasive plant species could have an indirect effect on *Plectritis brachystemon* by increasing grazing pressure from native ungulates on native plant species (Gonzales and Arcese 2008). However, at least one study found that *Plectritis congesta* was able to outcompete a closely related introduced species, *Valerianella locusta* when these two species co-occurred (Johnson and Williams 2020). Given the impact of introduced grass species on grassland and savanna habitats, *Plectritis brachystemon* is still likely somewhat vulnerable to increased competition due to climate change.

C4g. Forms part of an interspecific interaction not covered above: Unknown
No other interspecific interactions of note were found in the literature search.

C5a. Measured genetic variation: Increase
At study sites on Vancouver Island, *Plectritis brachystemon* showed a deficiency in heterozygotes of 86–100%, with an estimate of only 0–7.4% of the population outcrossing. In comparison, co-occurring *Plectritis congesta* had an average heterozygote deficiency of 10–40%, with estimates of 42%–100% of the population outcrossing. These estimates were confirmed by inheritance studies and gel electrophoresis (Layton and Ganders 1984).

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Not Ranked

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Plectritis brachystemon* (April to June) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Plectritis brachystemon* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

***Poa laxiflora* (loose-flowered bluegrass)**

Date: 16 May 2024 Synonym: none
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4G5/S2S3
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to -0.096	100
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Unknown
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 16 known occurrences (100%) of *Poa laxiflora* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C) warmer (Figure 1).

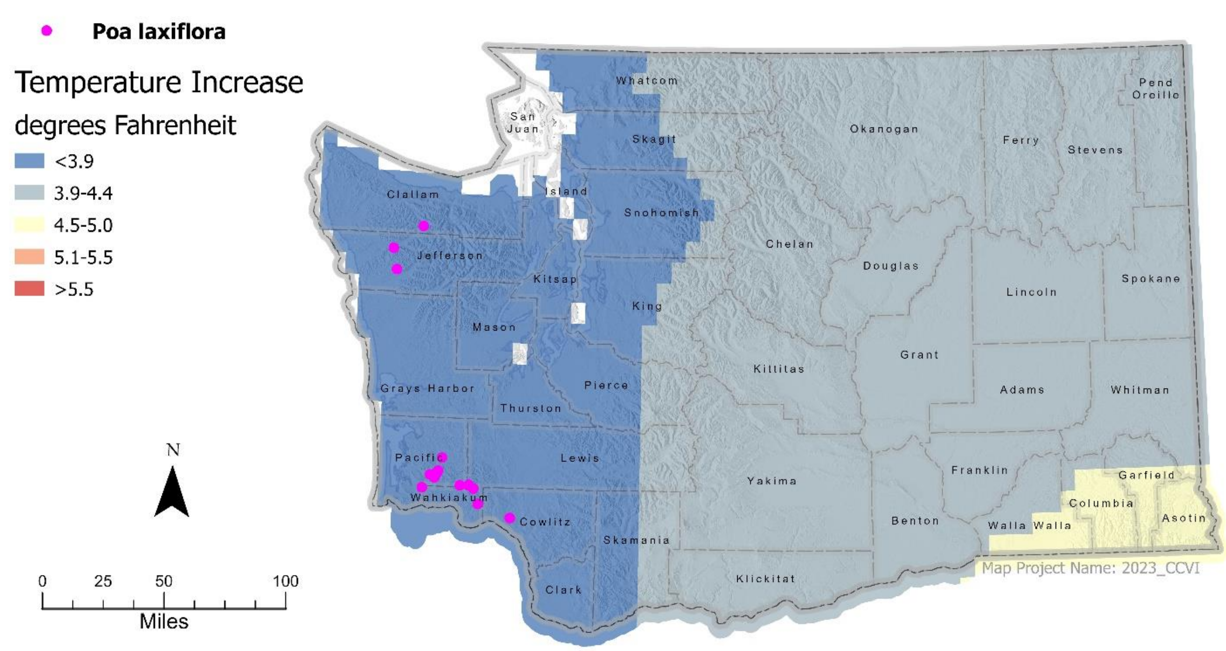

Figure 45. Exposure of occurrences of *Poa laxilflora* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 16 known occurrences (100%) *Poa laxiflora* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

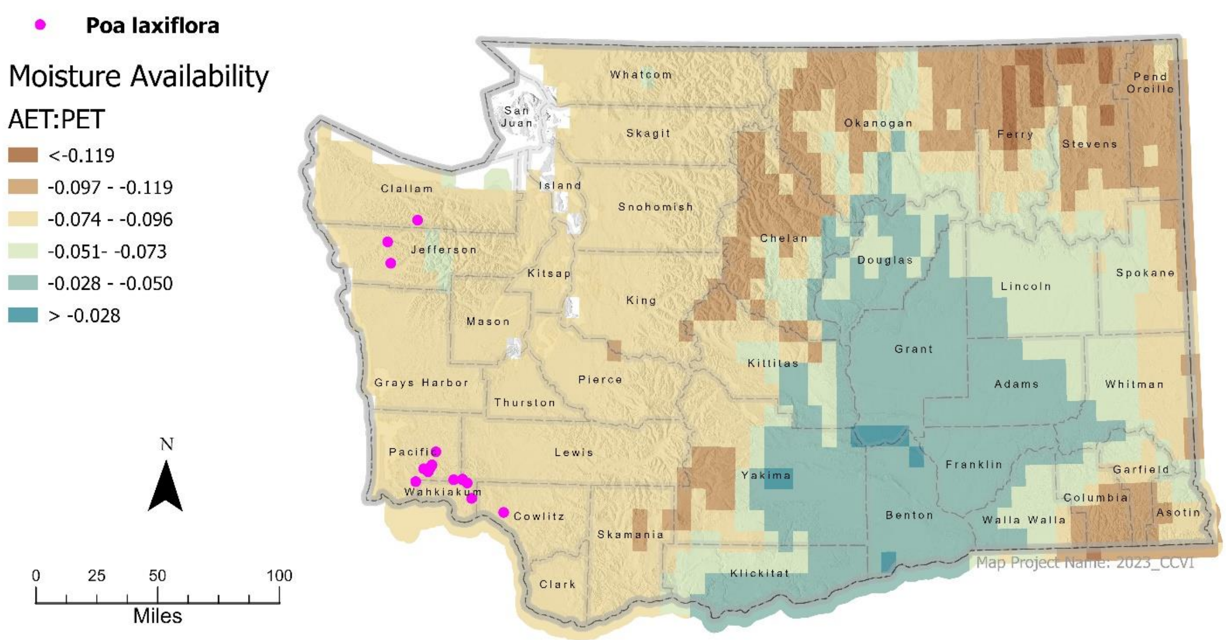

Figure 46. Exposure of occurrences of *Poa laxiflora* in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Poa laxiflora is found in streamside and other moist habitats between 50–3700 ft (15–1125 m; Washington Natural Heritage Program 2024). One of 16 occurrences, on the Naselle River, is potentially vulnerable to a projected 10 ft sea level rise, but impacts are unlikely (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Somewhat Increase</u>
The low elevation riparian habitats that *Poa laxiflora* grows in are generally limited to floodplains and confined by valleys, inlets, or terraces on rivers and streams (Rocchio and Crawford 2015). Populations occur mainly in the Northwest Coast ecoregion and are separated by 0.25–120 mi (0.5–190 km). North Pacific Lowland Riparian Forest and Shrubland ecological systems are a relatively widespread habitat, so natural barriers to dispersal may only be somewhat limiting for this species.

B2b. Anthropogenic barriers: <u>Somewhat Increase</u>

Human activities have fragmented and reduced connectivity in North Pacific Lowland Riparian Forest and Shrubland, with over half of this ecological system estimated to have been lost (Rocchio and Crawford 2015). Logging appears to be the main anthropogenic activity in the areas were *Poa laxiflora* occurs. These changes in connectivity and habitat could somewhat increase *Poa laxiflora*'s vulnerability to climate change.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Poa laxiflora* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Poa laxiflora has an open, loose panicle with widely spreading branches. Lemmas are not awned, and structures that might aid in wind or animal dispersal are otherwise not noted (Washington Natural Heritage Program 2024). Other *Poa* species are known to be capable of long-distance dispersal, notably by wind and endozoochory (Pazos et al. 2013, Lepková et al. 2018). Based on this evidence it seems likely that dispersal capability may be mostly resilient to the effects of climate change in this species.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 ("historical thermal niche") across the distribution of known *Poa laxiflora* occurrences in Washington. One of 16 known occurrences (6%) are in areas that have experienced very small (< 37° F (20.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have greatly increased vulnerability to climate warming. Fifteen of 16 known occurrences (94%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming.

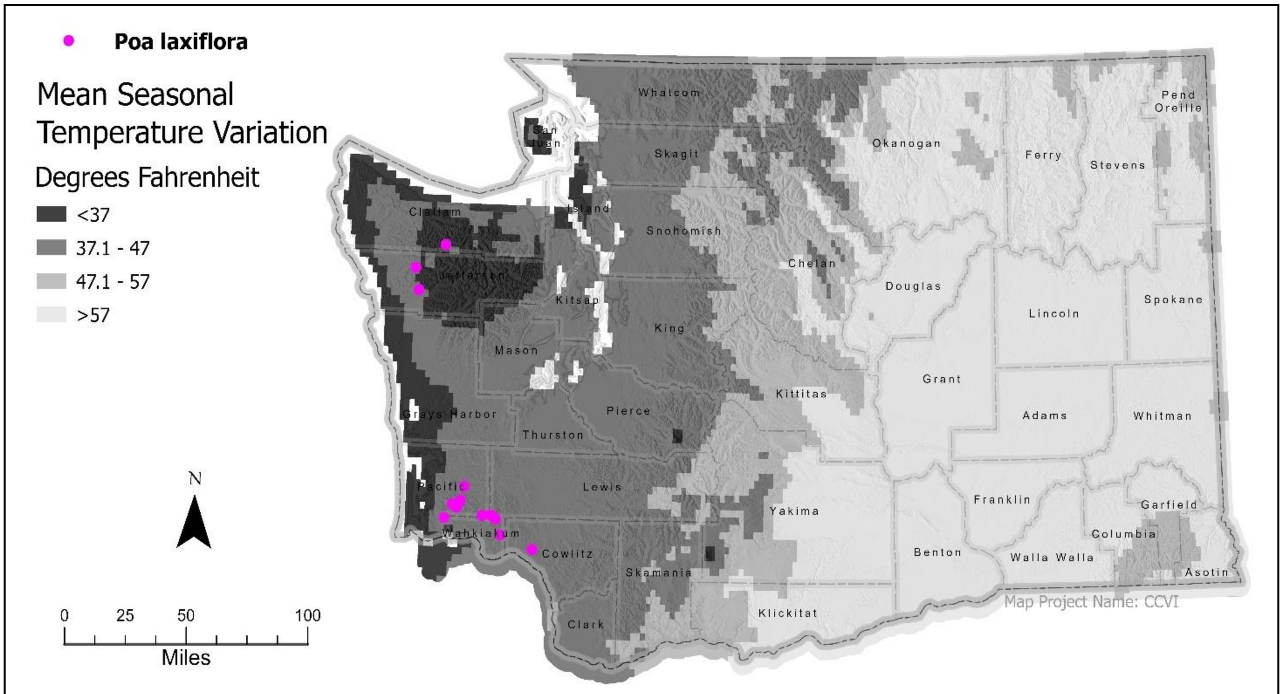

Figure 47. Historical thermal niche (exposure to past temperature variations) of occurrences of *Poa laxiflora* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: <u>Somewhat Increase</u>
Populations of *Poa laxiflora* in Washington are found mostly along streambanks and other areas that have cold air drainage during the growing season and could be adversely impacted by warming temperatures.

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 (“historical hydrological niche”) across the distribution of known *Poa laxiflora* occurrences in Washington. All 16 known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes.

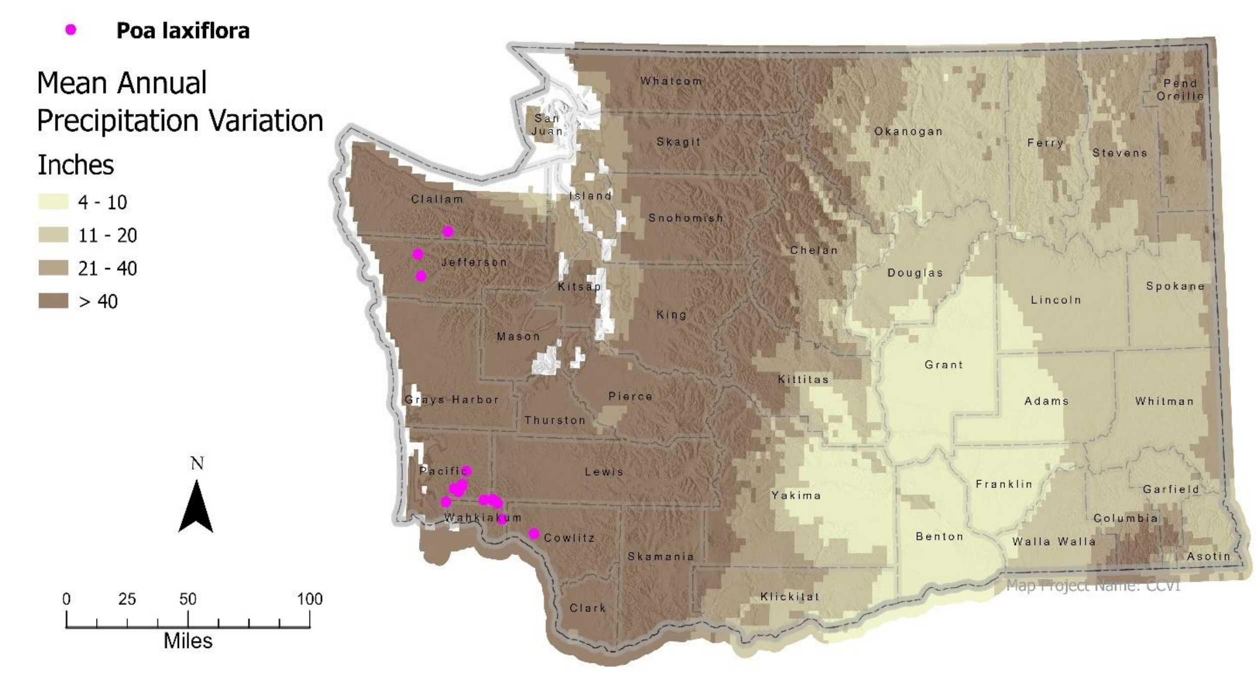

Figure 48. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Poa laxiflora* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
Under project climate change, North Pacific Lowland Riparian Forest and Shrubland ecological systems are likely to experience more drought or lower base flows during the summer due to changes in the amount or timing of precipitation. Streamside plant populations might also experience more flooding, or changes in the timing of flooding, especially if affected by snowmelt from higher in the watershed (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Somewhat Increase</u>
Annual flooding is the most important process for maintaining riparian habitats. Periodic major flooding also contributes to the structure and heterogeneity of these communities (Rocchio and Crawford 2015). Riparian habitats are sensitive to changes in flooding patterns (Rocchio and Ramm-Granberg 2017). Expected changes to these flooding patterns due to climate change somewhat increases *Poa laxiflora's* vulnerability.

C2d. Dependence on ice or snow-cover habitats: <u>Neutral</u>
Reduced snowpack will likely affect the hydrology and flooding patterns of *Poa laxiflora's* preferred habitats, but *Poa laxiflora* does not directly depend on snow or ice.

C3. Restricted to uncommon landscape/geological features: <u>Neutral</u>

Poa laxiflora occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
Beaver activities contribute to the structure and composition of North Pacific Lowland Riparian Forest and Shrubland ecological system (Rocchio and Crawford 2015). However, beaver are only one of several factors that can create and maintain the habitats favored by *Poa laxiflora*, and abiotic factors likely have a greater influence on this species habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
While no specific information is available for pollination in *Poa laxiflora*, grass species are almost always wind-pollinated, suggesting that pollination will be mostly resilient to the effects of climate change in this species.

C4d. Dependence on other species for propagule dispersal: Neutral
There is evidence that some *Poa* species can be dispersed through endozoochory (Lepková et al. 2018), but Poa species do not rely exclusively on endozoochory and are likely resilient to disruptions to any animal dispersers due to climate change. No information was found on dispersal in *Poa laxiflora*,

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase
Leafspot fungi have been identified on *Poa laxiflora* (Sprague 1962), but no data was available on severity of infections or on their response to climate change. Crop fungi species are expected to increase infections with climate change (Stukenbrock and Gurr 2023).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Exotic plant species, in particular *Phalaris arundinacea*, are abundant in many occurrences of North Pacific Lowland Riparian Forest and Shrubland communities. *Phalaris arundinacea* was noted as present in at least one occurrence of *Poa laxiflora* in Washington.

C4g. Forms part of an interspecific interaction not covered above: Unknown
No other interspecific interactions are reported in the literature.

C5a. Measured genetic variation: Not Ranked
Data are lacking on the genetic diversity within and between populations of *Poa laxiflora* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Unknown
Reproductive information for *Poa laxiflora* is limited. Like the majority of *Poa* species, *Poa laxiflora* is hermaphroditic (Giussani et al. 2016). One record of *Poa laxiflora* reported finding bulbils (a form of asexual reproduction) on some plants, but bulbils have otherwise not been

reported for this species. Some species of *Poa* reproduce almost entirely via asexual methods (Giussani et al. 2016) Given the variation of reproductive strategies in *Poa* species, it is difficult to make inferences on *Poa laxiflora*'*s* reproductive system or genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Poa laxiflora* (June to July) may not have changed significantly. However, the limited phenological data reported for this species makes changes in flowering season difficult to determine.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Poa laxiflora* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

References

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Climate Change Vulnerability Index Report
Polygonum austiniae (Austin's knotweed)

Date: 18 March 2024 Synonym: *Polygonum douglasii ssp. austiniae*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T4/S1
Index Result: Highly Vulnerable Confidence: Low

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	57
	3.9-4.4° F (2.2-2.4°C) warmer	43
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	43
	-0.074 to - 0.096	29
	-0.051 to - 0.073	14
	-0.028 to -0.050	14
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Somewhat Increase
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral/Somewhat Increase
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the seven known occurrences of *Polygonum austiniae* in Washington, three (43%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1). The other four (57%) occur in areas with a projected temperature increase of 4.5-5.0° F (2.5-2.7° C).

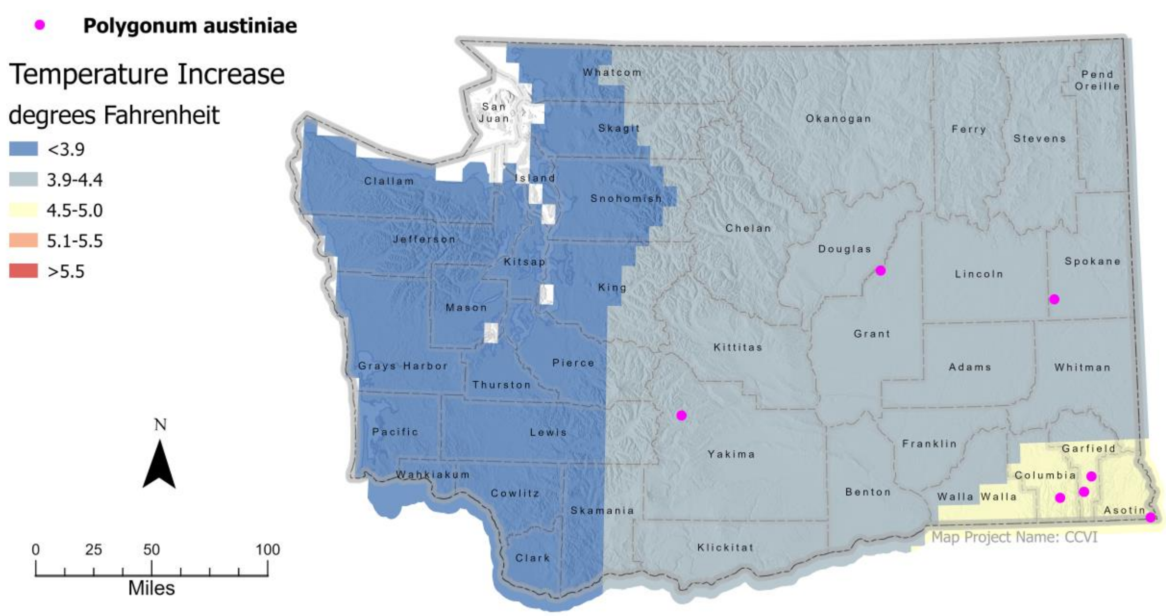

Figure 1. Exposure of *Polygonum austiniae* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Three of the seven known occurrences (43%) of *Polygonum austiniae* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). Two occurrences (29%) are in areas with a projected moisture decrease in the range of -0.074 to -0.096, one occurrence (14%) is in an area with a project moisture decrease in the range of -0.051 to -0.073, and the remaining occurrence (14%) is in an area with a projected moisture decrease in the range of -0.028 to -0.050.

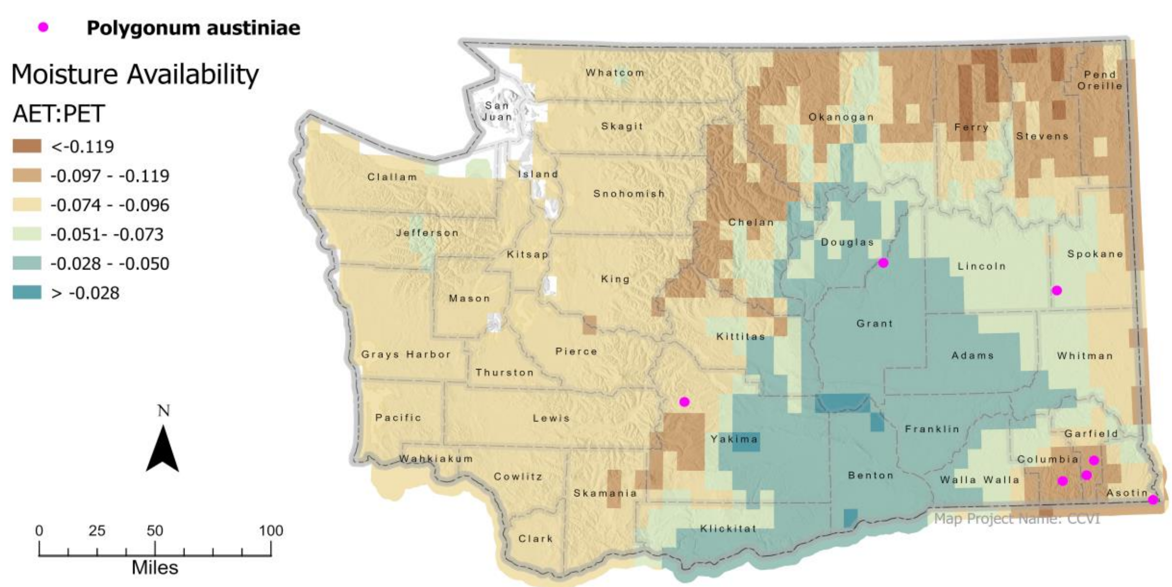

Figure 2. Exposure of *Polygonum austiniae* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Polygonum austiniae occurs from the sagebrush plains to lower mountain foothills east of the Cascade crest at mid elevations (1470-2240 ft (450-680 m)) below the upper treeline (Washington Natural Heritage Program 2023). This species is not at risk from sea level rise based on its inland distribution (Office for Coastal Management 2024).

B2a. Natural barriers: <u>Neutral</u>
The Columbia Plateau Scabland Shrubland and Northern Rocky Mountain Subalpine-Upper Montane Grassland ecological systems which support *Polygonum austiniae* are fairly widespread but associate strongly with shallow, lithic soils and steep, rocky slopes in open patches among coniferous forest. This species occurs on flats, plateaus, and gentle to steppe slopes which are separated by 9-206 mi (14-332 km) of both unoccupied suitable habitat and unsuitable forest

habitat that could pose a small barrier to dispersal. Overall, natural barriers are minimal and nearby suitable habitat is relatively plentiful, though the Blue Mountains occurrences are quite disjunct and separated from other occurrences by significant stretches of agricultural land.

B2b. Anthropogenic barriers: Somewhat Increase
Occurrences of *Polygonum austiniae* are primarily in lands that are managed for multiple use and are not fully protected from development. Land uses in these regions are few due to the rocky soils but there is still a threat of ongoing habitat conversion due to agriculture in some areas (Washington Natural Heritage Program 2023). Two of the occurrences of *Polygonum austiniae* in the Columbia Basin are nearly surrounded by development which has greatly fragmented the remaining available suitable habitat. Other populations have more available undeveloped habitat in their vicinity. These developed areas pose somewhat of a barrier to dispersal and movement of *Polygonum austiniae* populations.

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase
There are no known plans for clean energy development that intersect directly with the *Polygonum austiniae* occurrences, though a large number of parcels have been marked for development just outside of Sun Lakes-Dry Falls State Park where this species occurs (Washington Department of Natural Resources 2023). The scablands and grasslands on the flats in these areas have frequently been converted and fragmented by wind and solar development and are at risk of development (Rocchio and Crawford 2015)

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Polygonum austiniae produces a 3-sided, smooth, and elliptic achene which is contained within the sepals at maturity and acts as the dispersal unit (Washington Natural Heritage Program 2023). *Polygonum* spp. are reported to be dispersed by wind, water, and sometimes by attachment to animal fur or birds, though unassisted dispersal is predominant (Kostikova et al. 2014). Water dispersal is less successful in the genus Polygonum (Staniforth and Cavers 1976) and unlikely to be a major dispersal method for *Polygonum austiniae* based on its habitat. The achenes of *Polygonum austiniae* do not have special adaptations for dispersal found in a few other *Polygonum* spp., such as persistent styles that aid in attachment to fur (Reed and Smoot 1906). Other species of Polygonum are dispersed by endozoochory as they are eaten by ducks and rabbits (Staniforth and Cavers 1977, Farmer et al. 2017), which may be the case for *Polygonum austiniae*. Dispersal of this species is primarily by gravity and perhaps secondarily by endozoochory, but the total distance is probably relatively short compared even to other *Polygonum* spp. (no more than 100 m).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Polygonum austiniae* occurrences in Washington. Of the seven known occurrences, four (57%) are in areas that have experienced less than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining three occurrences (43%) are in areas that have experienced

average temperature variation (>57.1° F (31.8° C)) over the historical period and are expected to be mostly resilient to climate warming (Young et al. 2016).

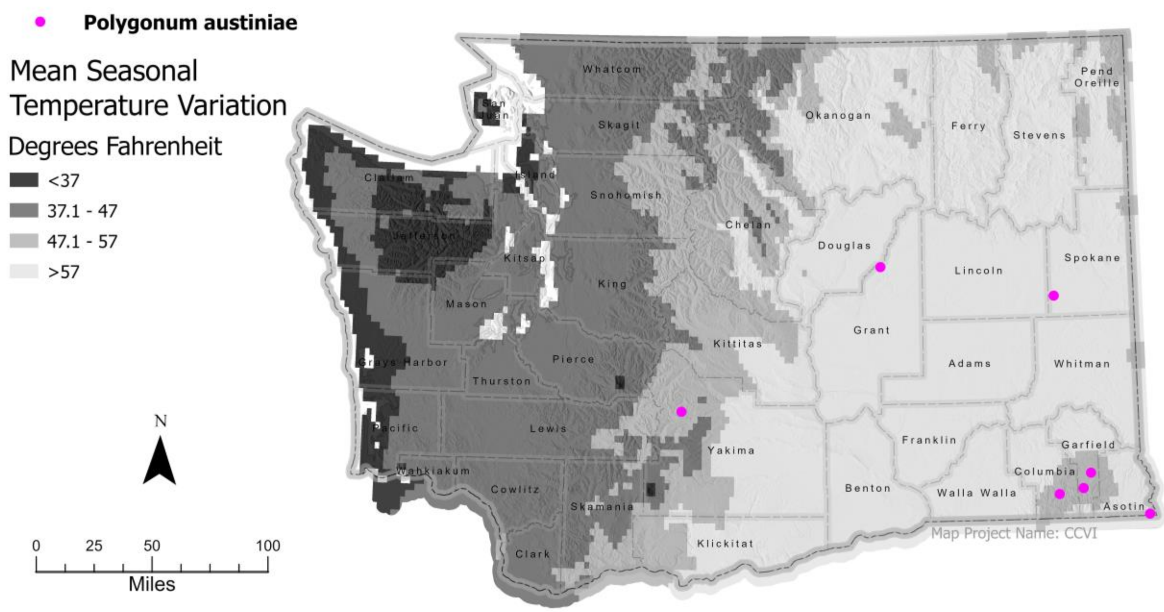

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Polygonum austiniae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral

Polygonum austiniae generally occurs on exposed and mostly barren southern and southwestern ridges and slopes which receive direct solar radiation. Increasing temperatures could lead to more severe drought in these already water-limited habitats but will probably not lead to complete conversion to other types as these ecological systems are already adapted to extreme moisture conditions (Rocchio and Ramm-Granberg 2017). *Polygonum* spp. are often associated with warmer, drier microhabitats with warmer soil temperatures in locations that melt out earlier in the year (Reynolds 1984).

C2bi. Historical hydrological niche: Neutral/Somewhat Increase

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Polygonum austiniae* occurrences in Washington. Of the seven known occurrences, one (14%) is in an area of Grant County that has experienced very little precipitation variation (less than 10 in (254 mm)) over the historical period. According to Young et al. (2016), this population is expected to be highly vulnerable to changes in available moisture. Two occurrences (29%) are in areas that have experienced slightly lower than average precipitation variation (11 - 20 in (255 - 508 mm)) over the historical period and are expected to be somewhat vulnerable to changes in available moisture (Young et al. 2016). The remaining four occurrences (57%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

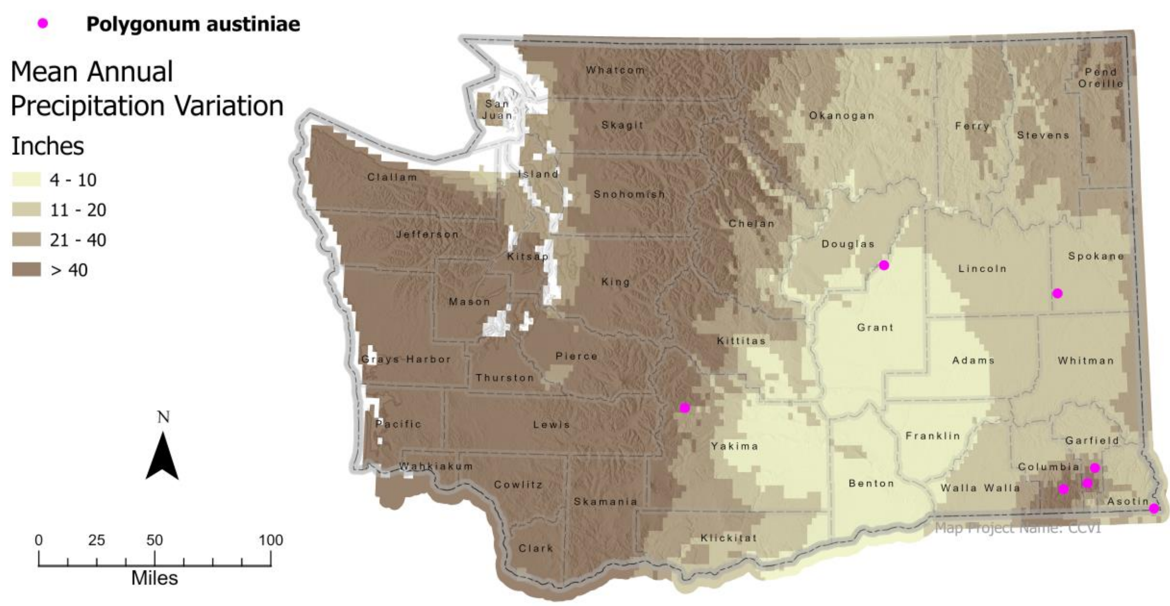

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Polygonum austiniae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral

The scablands and montane grasslands which support *Polygonum austiniae* generally receive most of their moisture as winter precipitation and become very dry in the summer as wind-scour and shallow, rocky soils prevent water storage (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). However, this species sometimes occurs in slight depressions which are somewhat more mesic. Anticipated changes to precipitation timing, amount, and type will extend the dry season and could lead to compositional shifts to drier, more sparse community types, though complete conversion is unlikely (Rocchio and Ramm-Granberg 2017).

These arid-adapted ecological systems may be somewhat resilient to moisture changes but may also be more sensitive as they are already extremely moisture limited and lack connections to groundwater.

C2c. Dependence on a specific disturbance regime: Neutral
The scabland shrublands and montane grasslands which support *Polygonum austiniae* are shaped by droughty conditions, "frost-heaving" cycles that churn soil, fire, and big game browsing that prevents tree and shrub encroachment and maintains grassy openings (Rocchio and Crawford 2015). *Polygonum austiniae* is known to be somewhat sensitive to disturbance but does appear in disturbed areas (U.S. Forest Service n.d.). Increased evapotranspiration due to warming is likely to increase fire to some degree but a full fire regime shift is not likely (Rocchio and Ramm-Granberg 2017). Moderate increases to fire may expand these ecological systems as woody species are cleared. The other forces which shape these ecological systems are not anticipated to change in response to climate.

C2d. Dependence on ice or snow-cover habitats: Neutral
Snowpack is lower over the range of *Polygonum austiniae* in the foothills of the Blue Mountains and Columbia Basin scablands in eastern Washington than in other areas of the state and is a moderate to small component of the annual water budget in these regions (Trujillo and Molotch 2014). Additionally, *Polygonum* spp. are often associated with warmer, drier microhabitats that melt out earlier in the year due to wind-scour and exposure (Reynolds 1984).

C3. Restricted to uncommon landscape/geological features: Neutral
Polygonum austiniae occurs in intermixed thin, dry lithosols (though occasionally deeper) and fine basalt gravels (Washington Natural Heritage Program 2023). Soils range in texture from cobbly loams to hard volcanic clays where this species can be found growing in the cracks and are usually poorly developed (Rocchio and Crawford 2015, Soil Survey Staff 2024). Parent materials include Pleistocene outburst flood deposits and Columbia Basin basalts (Grande Ronde and Wanapum) and occasionally intrusive andesite. These geological features are relatively common in eastern Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The scablands and grasslands which host *Polygonum austiniae* are mostly shaped by abiotic factors such as limited precipitation and shallow, rocky soils (Rocchio and Crawford 2015). However, native ungulates help to churn soils and maintain the low vegetation structure of these ecological systems. Overgrazing/browsing can lead to large shifts in composition and increase the abundance of exotic species (Rocchio and Crawford 2015). Ungulate activity shapes these plant communities but is not required for their maintenance.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Polygonum austiniae* have not been documented. However, the closely related congener *Polygonum douglasii* is predominantly pollinated by a variety of bumblebees (*Bombus* spp.) and "wool-carder" bees (*Anthidium* spp.) (Pow 2019, Montana Natural Heritage Program 2024). The exotic *Polygonum aviculare* has been recorded to attract

visits from over 36 insect taxa in California, consisting of both aerial and terrestrial species due to the low positioning of the flowers (Stone 2010) Additionally, *Polygonum* spp. have both chasmogamous and cleigostamous flowers and often favor self-pollination (Graham and Wood 1965, Kawano et al. 1990, Stone 2010). *Polygonum austiniae* is probably not especially pollinator limited.

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
Other species of Polygonum are dispersed by endozoochory as they are eaten by ducks and rabbits (Staniforth and Cavers 1977, Farmer et al. 2017), which may be the case for *Polygonum austiniae*. This would be the only mechanism by which it could disperse substantial distances from the parent plant. Otherwise, this species does not have special adaptations for animal dispersal and is mostly dispersed by gravity.

C4e. Sensitivity to pathogens or natural enemies: Neutral
There is ongoing cattle grazing in the vicinity of the Polygonum austiniae occurrences which can cause soil disturbance and increase invasion by exotic grasses (Rocchio and Crawford 2015). However, grazing is not expected to increase in these ecological systems as a result of climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Polygonum austiniae tends to grow on lithosols and barren gravel where vegetation is sparse and rock cover is high due to dry and shallow soils, though the grasslands where it occurs are sometimes comprised of dense sods which can limit colonization (Stone 2010, Rocchio and Crawford 2015). Observational records indicate that Washington occurrences of *Polygonum austiniae* generally remain to be weed free, though the competitive exotic grass *Ventenata dubia* is present and could become a threat in the future. Soil disturbance in these ecological systems from livestock or vehicles can increase the potential for invasion (Rocchio and Crawford 2015). *Polygonum austiniae* appears to prefer sparse and disturbed open areas where competition is low and therefore is likely to be somewhat vulnerable to increased competition from invasive species. However, the moisture limitation of its preferred habitats may buffer against invasion to some degree.

C4g. Forms part of an interspecific interaction not covered above: Neutral
Polygonum austiniae does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic variation of *Polygonum austiniae* has not been documented. *Polygonum aviculare*, which is widespread exotic species in North America, exhibits high genetic polymorphism and high phenotypic plasticity (Stone 2010). However, the more restricted range of *Polygonum austiniae* suggests that it probably does not exhibit such high variation.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Members of the *Polygonum douglasii* complex like *Polygonum austiniae* generally have bi-sexual flowers, are tetraploid, and have a mixed mating system that favors outcrossing (Löve and

Löve 1956, Graham and Wood 1965, Costea and Tardif 2005). *Polygonum* spp. may have two flower types, one being chasmogamous (cross-pollinating) and the other being cleistogamous (closed, self-pollinating) (Graham and Wood 1965, Kawano et al. 1990, Stone 2010). The annual *Polygonum austiniae* does not reproduce vegetatively via rhizomes like some other *Polygonum* spp. Polyploidy, a preference for outcrossing, and mixed mating systems are traits indicative of average to high genetic variation (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: <u>Neutral</u>
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (June-August) has not changed significantly. However, there are few historical records available to assess trends. The phenology and population dynamics of the annual *Polygonum austiniae* have been documented as fluctuating drastically following inter-annual climatic cycles, but there is no documentation of the direction of trends in response to longer term climatic changes (U.S. Forest Service n.d.).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: <u>Unknown</u>
Polygonum austiniae is known from seven extant occurrences, all discovered or relocated since 2002. Three new occurrences were documented in the Blue Mountains in 2018-2019. (Washington Natural Heritage Program 2023). There are limited census data available to evaluate trends and the diminutive nature of this species may suggest that it is easily overlooked and is more common than the records suggest (Fertig and Kleinknecht 2020). Trends in response to climate change are unknown.

D2. Modeled future (2050) change in population or range size: <u>Unknown</u>
Not modeled.

D3. Overlap of modeled future (2050) range with current range: <u>Unknown</u>
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: <u>Unknown</u>
Not modeled.

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Climate Change Vulnerability Index Report
Polystichum californicum **(California swordfern)**

Date: 22 December 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4/S1
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All four known occurrences (100%) of *Polystichum californicum* in Washington occur in areas with a projected temperature increase of less than 3.9° F (2.2°C; Figure 1).

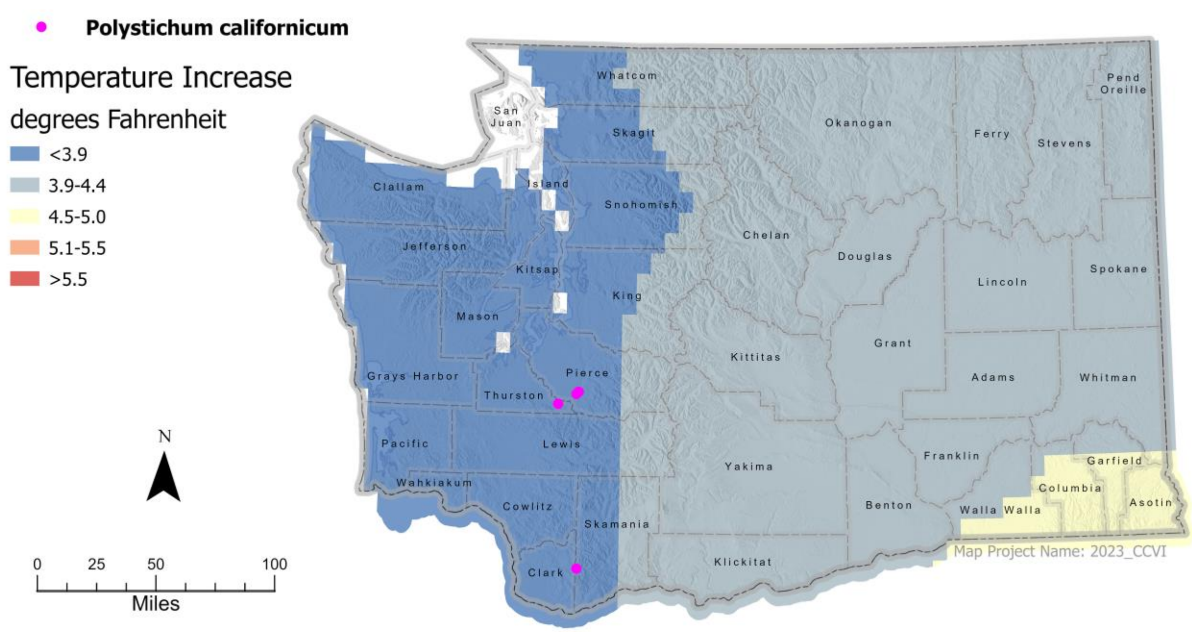

Figure 1. Exposure of *Polystichum californicum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four known occurrences (100%) of *Polystichum californicum* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

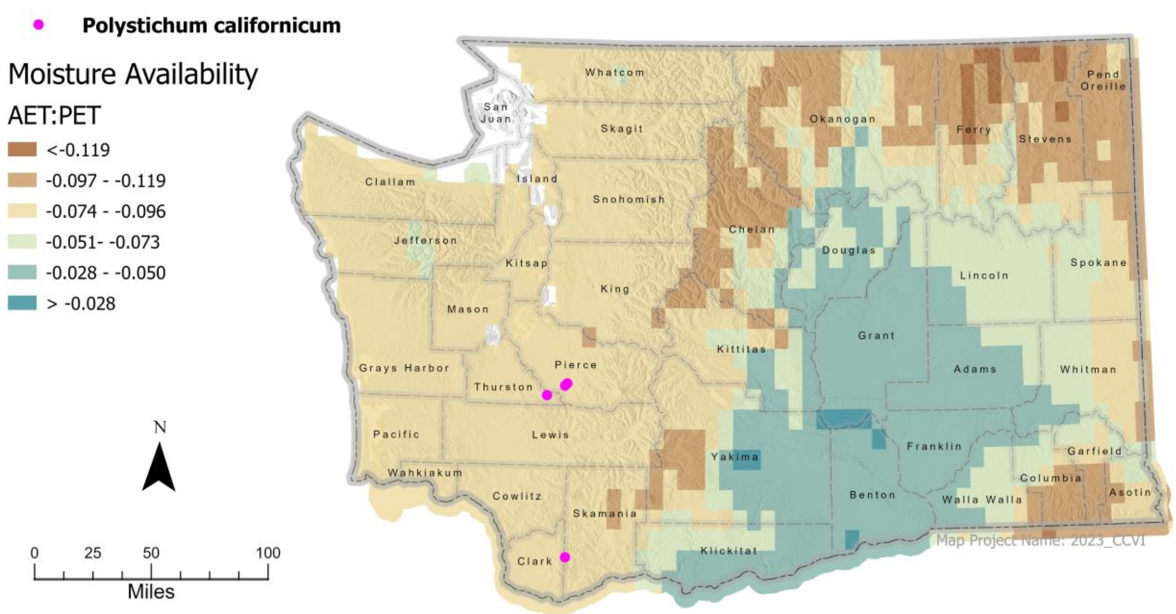

Figure 2. Exposure of *Polystichum californicum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Polystichum californium occurs in the crevices of cliffs and rock outcrops at cliff bottoms ranging from lowlands near the coast to mountain ranges at low-middle elevations (800-1000 ft (240-300m); Washington Natural Heritage Program 2023). *Polystichum californium* populations in Washington are not expected to be affected by sea level rise (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Increase</u>
Polystichum californicum microsite habitats are highly uncommon at a local scale, restricted to small shady crevices of andesite cliffs and ledges which are part of the North Pacific Montane Massive Bedrock, Cliff, and Talus ecological in the rainforest belt of western Washington

(Rocchio and Crawford 2015). The surrounding forest canopy cover and ridgelines can restrict movement of this species among rocky patches, limiting potential for dispersal and migration. Distances between populations range from 1-74 mi (2-120 km).

B2b. Anthropogenic barriers: Neutral
Washington occurrences of *Polystichum californicum* are not well protected from anthropogenic impacts as they are mostly on private lands or lands managed for multiple uses (Washington Natural Heritage Program 2023). However, they are still largely buffered simply due to challenging site access and are most at risk of damage from recreation, followed by timber harvests. These barriers to dispersal are minimal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Polystichum californicum* in Washington, and future projects that would negatively impact rock outcroppings are unlikely (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
The spores of *Polystichum* spp. can travel long distances via wind or water and might also be distributed by animal attachment or ingestion in some cases (Zouhar 2015). Most spores ultimately fall within a short distance of parents and exact dispersal distances depend highly on air currents (Rose and Dassler 2017). However, in more open areas, ferns theoretically have unlimited potential for dispersal over long distances and can easily travel nearly 250 mi (400 km; Peck 1985).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Polystichum californicum* occurrences in Washington. All four known occurrences (100%) are in an area that has experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming.

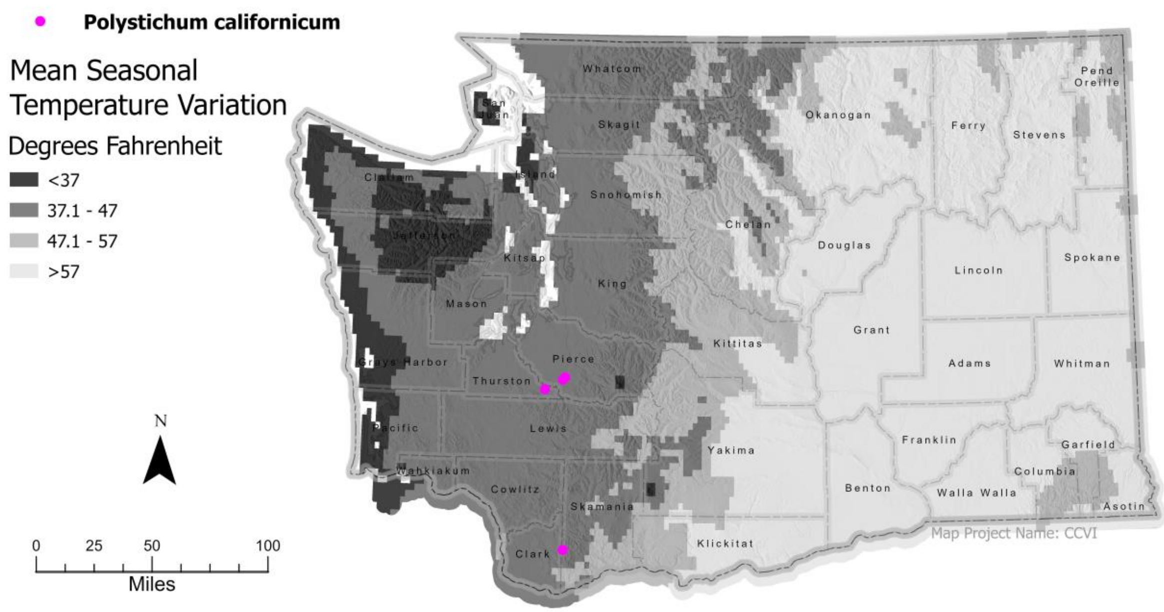

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Polystichum californicum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral
Habitats that support *Polystichum californicum* range from moist, shaded cliff crevices in old growth forest to south-facing open habitats and dry rocky woods (Washington Natural Heritage Program 2023). *Polystichum californicum* is not particularly dependent on cold climate or cold air drainages during the growing season and would have mostly neutral vulnerability to climate change (Young et al. 2015). However, the high exposure of these cliff and talus sites may make them susceptible to rising temperatures which can also increase fire risk or alter erosion rates (Estevo et al. 2022; Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Polystichum californicum* occurrences in Washington. All four known occurrences (100%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

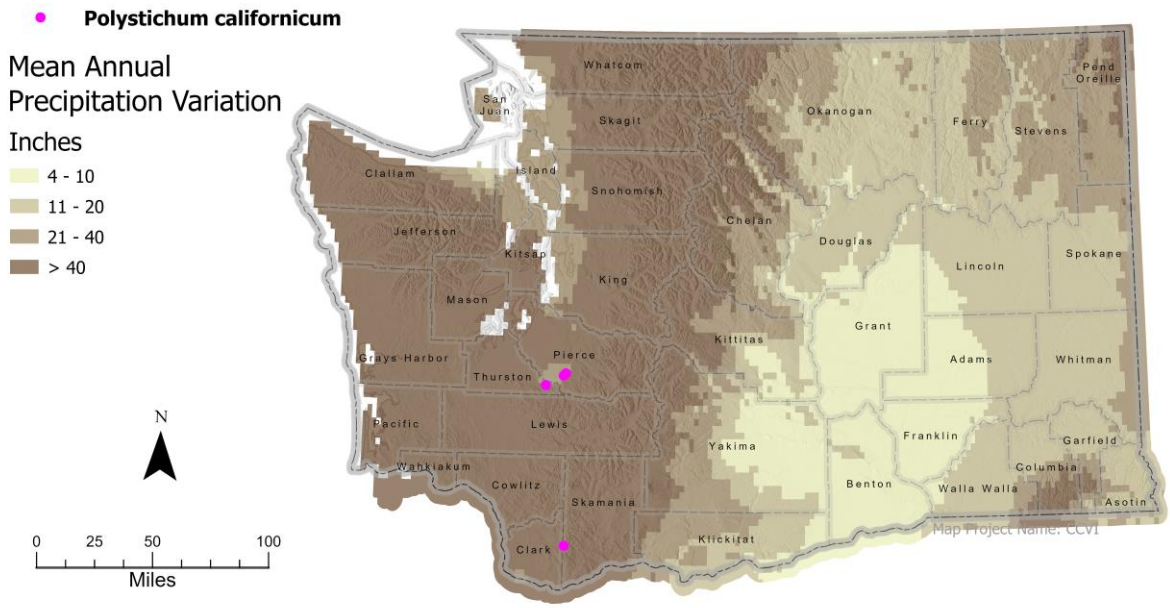

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Polystichum californicum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
Polystichum californicum has a somewhat broad hydrological niche, ranging from moist cliff crevices to dry slopes, and is never found in fully saturated conditions or at extremely high elevations (Washington Natural Heritage Program 2023). It is typically associated with northerly aspects which are relatively cool and moist. Cliff occurrences are greatly dependent on precipitation that infiltrates cracks and other microtopographic cliff features that determine hydrology, such as aspect and vertical position, since cliffs are not replenished by groundwater (Clark 2012; Rocchio and Crawford 2015). Shifts in precipitation timing and amount combined with extended summer droughts are expected to have a low to moderate impact on Montane Bedrock, Cliff, and Talus ecological systems (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
Wind, water, and gravity are forces acting upon cliff habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Hampton and Griggs 2004). However, the high exposure of these sites may make them susceptible to rising temperatures which can also

increase fire risk or alter the erosion rates of cliff communities (Estevo et al. 2022; Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Polystichum californicum occurs among cliffs and dry rocky terrain at low elevations that are just above cold air drainages where there is less snowfall. Exposed cliffs are unlikely to accumulate significant snowpack or persistent ice. Other than potential impacts to the water supply of the habitat which is reliant on recharge from precipitation, *Polystichum californicum* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Polystichum californicum is mostly associated with rock crevices at andesite cliff bottoms and forest floors, which are fairly uncommon in Washington and localized within the Cascade Mountains (NatureServe 2023). However, this species can also occur within narrow canyons, outcrops, and talus/scree at base of cliffs derived from various igneous, sedimentary, and metamorphic bedrock types with limited soil development (Rocchio and Crawford 2015). Associated formations include tuff breccias, volcaniclastic deposits, Vashon State glacial outwash and Mashel formation rocks (Washington Division of Geology and Earth Resources, 2016). None of these geological types are particularly common in Washington but the variety of potential substrates for this species means that it is less restricted.

C4a. Dependence on other species to generate required habitat: Neutral
Cliff and talus ecological systems are shaped mostly by abiotic processes and erosion that creates critical microhabitat conditions without the aid of other species (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Polystichum spp. do not depend on pollinators for their reproductive cycle. Instead, spores are spread via wind and gametophytes are produced vegetatively underground.

C4d. Dependence on other species for propagule dispersal: Neutral
Polystichum spores are mostly dispersed passively via wind or water. However, some species are known to have spores that can attach to animals (Zouhar 2015).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Most ferns are unpalatable to herbivores and ferns generally are not especially subject to insect attack (Lellinger 1985).

C4f. Sensitivity to competition from native or non-native species: Neutral
Under present conditions, competition from non-native species is minor and patchy, as few introduced plants are adapted to wind-exposed surfaces of cliffs or talus (Rocchio and Crawford 2015). Under projected climate change, competition from invasive weeds could increase if these rocky sites become even more exposed due to wildfire removing surrounding forest cover (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Polystichum californicum does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
Polystichum spp. exhibit a wide range of genetic variation levels for reasons other than differences in mating systems (Soltis and Soltis 1990). The specific genetic variation of *Polystichum californicum* has not been reported. However, it occurs in very small populations and might be expected to have lower genetic diversity due to founder effects or reproductive isolation.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
Polystichum californicum is a tetraploid evergreen fern that is the hybrid of *Polystichum munitum* and *Polystichum imbricans* (NatureServe 2023; Soltis and Soltis 1992). Like other pteridophytes, it follows a life cycle with two alternating independent generations; inconspicuous gametophytes that produce separate male and female organs and dominant homosporous sporophytes which can produce gametophytes with both sex organs (Soltis and Soltis 1990). Unlike other *Polystichum* spp. that are typically highly outcrossing, this species has a higher rate of intragametic self-fertilization that either diploid parent (Soltis and Soltis 1992). *Polystichum californicum* probably has at least moderate genetic variability, being a polyploid that may be able to outcross but relies primarily on selfing (Young et al. 2016). Fixed heterozygosity could help to reduce inbreeding depression.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the sporulation period of *Polystichum californicum* (November to March) has not changed significantly (Washington Natural Heritage Program 2023)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Polystichum californicum* declining in response to climate change. However, plants were unable to be relocated at one site and population size was only two individuals at another as of last survey. Data are not available to confirm trends through time and further study is needed.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Potamogeton obtusifolius (bluntleaf pondweed)

Date: 25 May 2024 Synonym: none
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	12
	<3.9° F (2.2°C) warmer	88
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to -0.096	100
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Unknown
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Seven of eight occurrences with modeled data (88%) of *Potamogeton obtusifolius* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C). One of eight occurrences with modeled data (12%) of *Potamogeton obtusifolius* in Washington occur in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4°C) (Figure 1). The five records of *Potamogeton obtusifolius* from the San Juan Islands do not have temperature data modeled.

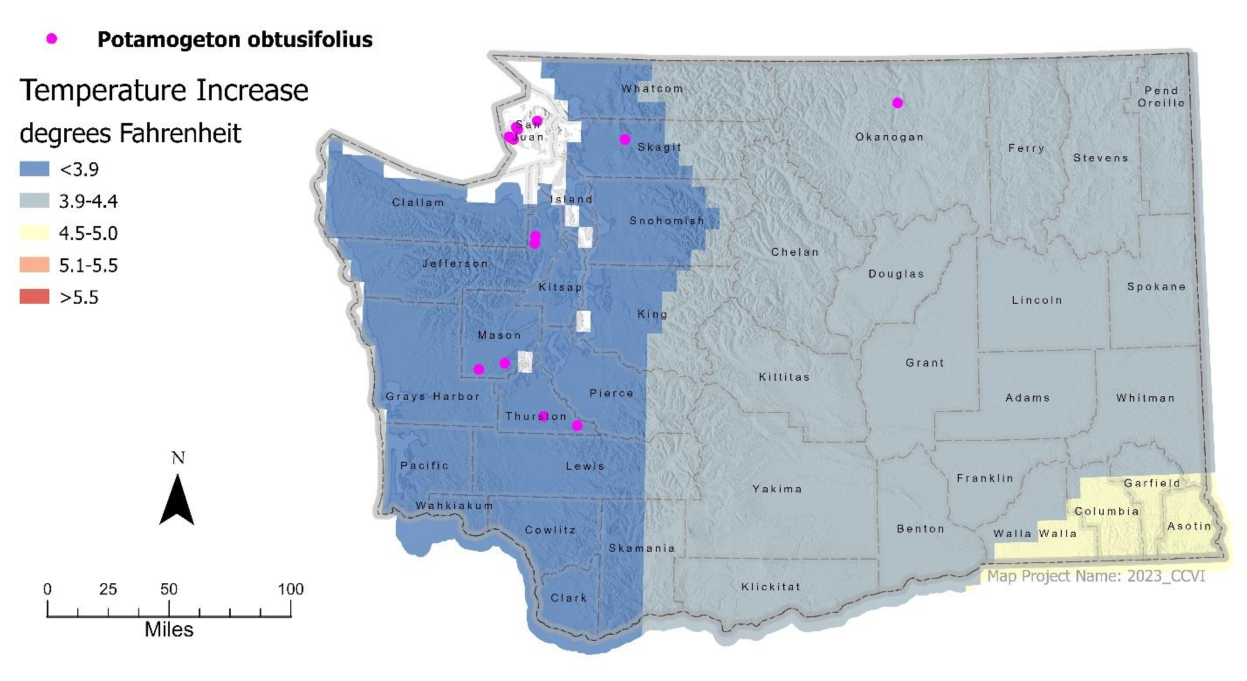

Figure 49. Exposure of occurrences of *Potamogeton obtusifolius* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All eight known occurrences with data modeled (100%) of *Potamogeton obtusifolius* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096. (Figure 2). The five records of *Potamogeton obtusifolius* from the San Juan Islands do not have moisture data modeled.

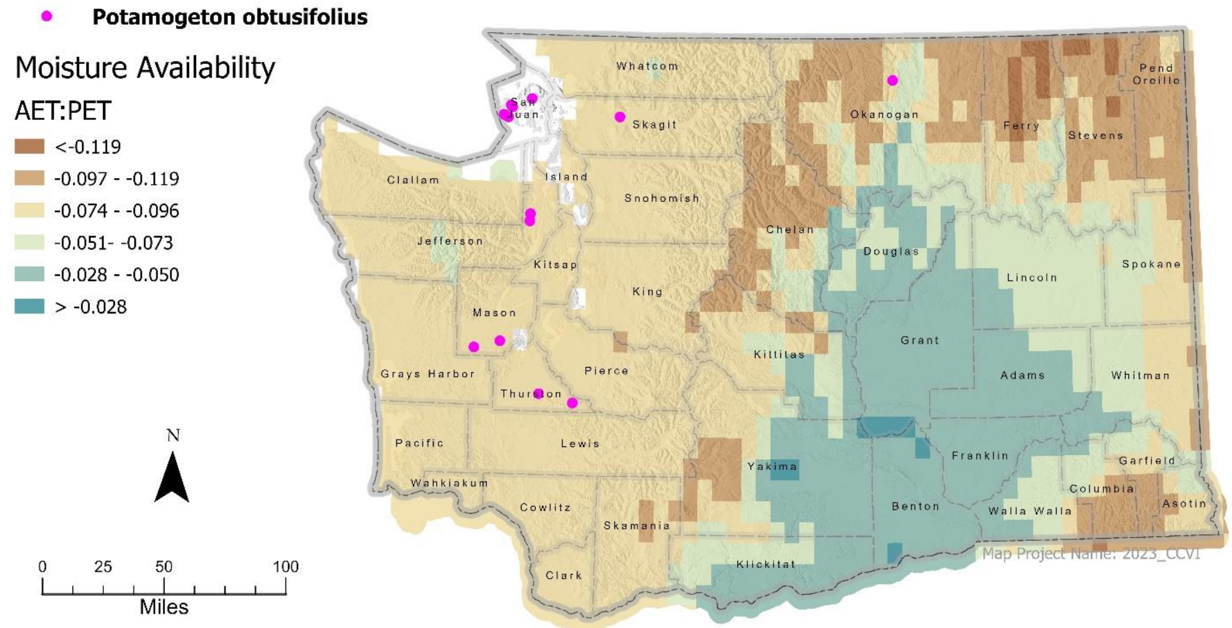

Figure 50. Exposure of occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration.) Base map layers from www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Potamogeton obtusifolius is an aquatic plant that occurs on the banks of lakes, sloughs, and slow-flowing streams at elevations of 100–515 ft (30–156 m; Washington Natural Heritage Program 2024). No occurrences will be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Increase
Potamogeton obtusifolius is found in Temperate Pacific Freshwater Aquatic Bed ecological systems (Washington Natural Heritage Program 2024). Individual populations are separated by 1–200 miles (2–322 km). Populations are separated from one another by a matrix of upland vegetation, development, and for occurrences on the San Juan Islands, sea water.

B2b. Anthropogenic barriers: Somewhat Increase
Some human activities may increase available habitat for the species that make up Temperate Pacific Freshwater Aquatic Beds communities (Rocchio and Crawford 2015). However urban development in the Puget Sound is probably also a barrier to dispersal for this species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Potamogeton obtusifolius* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral
Potamogeton obtusifolius produces small (2.5–3.6 mm long) egg-shaped achenes (Washington Natural Heritage Program 2024), and is described as “heavily fruiting” (Muenscher 1936). *Potamogeton* reproductive spikes are submerged when fruiting (Haynes 1974). Seeds are likely dispersed by water and water birds. *Potamogeton* seeds recovered from the stomach of ducks germinated readily, and in some locations, large amounts of *Potamogeton* seeds have been found washed up on shorelines. Dried *Potamogeton* seeds were frequently inviable (Muenscher 1936). *Potamogeton obtusifolius* likely has somewhat limited ability to disperse across unsuitable habitat by abiotic means but can be transported long distances by endozoochory.

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951–2006 (“historical thermal niche”) across the distribution of known *Potamogeton obtusifolius* occurrences in Washington. Two of 12 modeled occurrences (17%) are in areas that have experienced very small (< 37° F (20.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected have greatly increased vulnerability to climate warming. Nine of 12 modeled occurrences (75%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected have increased vulnerability to climate warming. One of 12 modeled occurrences (8%) are in an area that has experienced average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming. One of the records of *Potamogeton obtusifolius* from the San Juan Islands does not have historical thermal niche data modeled.

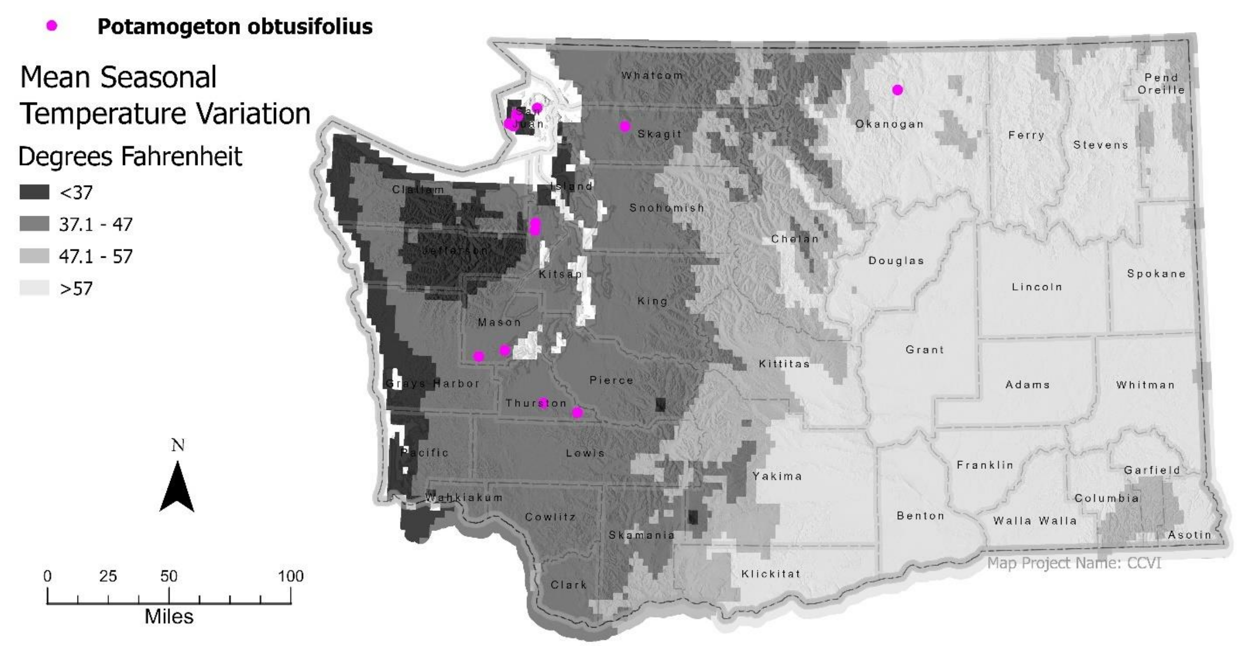

Figure 51. Historical thermal niche (exposure to past temperature variations) of occurrences of *Potamogeton obtusifolius* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Neutral
Increased temperature from climate change could potentially increase water temperatures in Temperate Pacific Freshwater Aquatic Beds. However, this ecological system is frequently part of larger aquatic ecological systems that could potentially insulate *Potamogeton obtusifolius* from most of the effects of increased temperature (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951–2006 ("historical hydrological niche") across the distribution of known *Potamogeton obtusifolius* occurrences in Washington. One of the 12 modeled occurrences (8%) is in an area that has experienced slightly lower than average precipitation variation (11–20 in (255–508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. Eleven of the 2 modeled occurrences (92%) are in an area that has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be mostly resilient to climate change induced shifts to precipitation and moisture regimes. One record of *Potamogeton obtusifolius* from the San Juan Islands does not have historical hydrological niche data modeled.

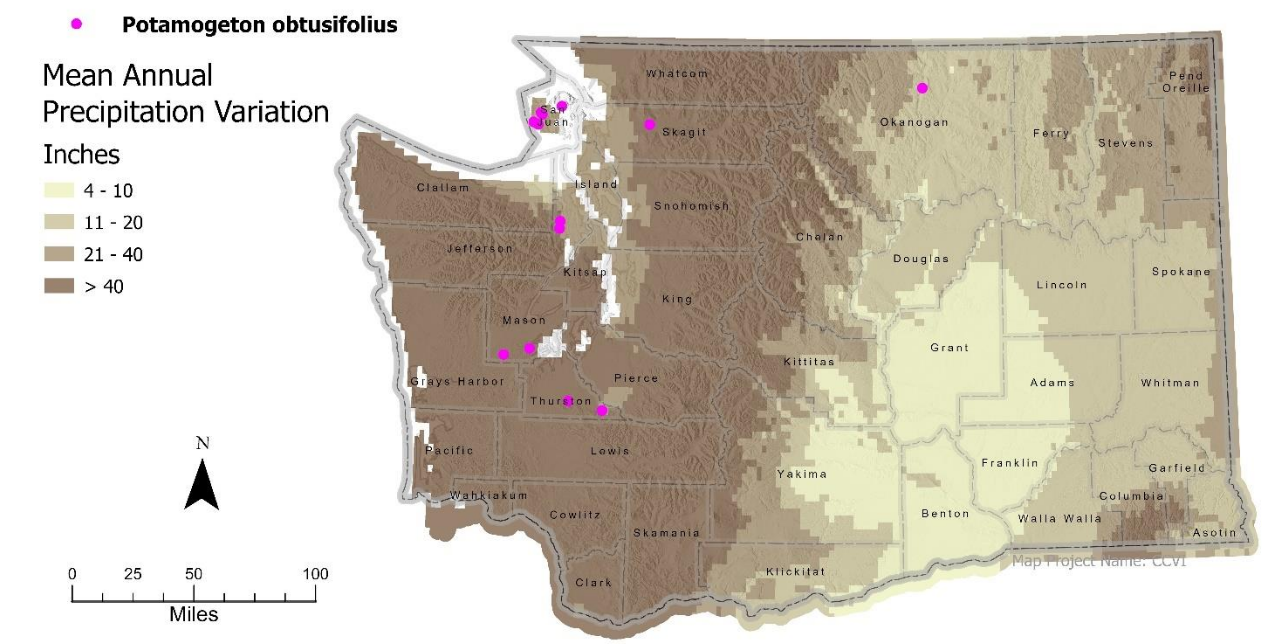

Figure 52. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Potamogeton obtusifolius* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Populations of *Potamogeton obtusifolius* are vulnerable to changes in water depth resulting from either increased spring flooding from early snowmelt or enhanced drawdown from changes in the timing or amount of precipitation. Human activities (e.g., logging, road building, or development, could also affect the hydrology of Temperate Pacific Freshwater Aquatic Bed habitats. However, this ecological system is frequently part of larger aquatic systems that could potentially insulate *Potamogeton obtusifolius* from some of the effects of changes in hydrology (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Potamogeton obtusifolius is not dependent on disturbances to maintain its aquatic habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral
While changes in snow melt timing could affect *Potamogeton obtusifolius*'s habitat, this species is not directly dependent on ice or snow-covered habitats.

C3. Restricted to uncommon landscape/geological features: Neutral
Potamogeton obtusifolius appears mainly on sedimentary and glacial outwash substrates in Washington, but these substrates are common within the state, and do not limit this species'

ability to respond to climate change (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
The loss of beaver may have reduced the occurrence of Temperate Pacific Freshwater Aquatic Bed habitats in western Washington (Rocchio and Crawford 2015), but the persistence of these ecological systems probably depends more on abiotic factors.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown
Little information appears to be publicly available on *Potamogeton* pollination. *Potamogeton* species produce flowering spikes are usually extended above the water, except when fruiting (Haynes 1974). The flowers are small and inconspicuous, suggesting that they might be wind-pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral
Waterfowl could potentially be important for long distance dispersal of *Potamogeton obtusifolius*, but this species is also dispersed by water, and does not rely solely on biotic relationships for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Potamogeton species are an important food for ducks, herbivorous fish, and aquatic insects (Haynes 1974), with one study suggesting that *Potamogeton* and related *Stuckenia* species account for 50% of food consumed by waterfowl in North America (Wersal et al. 2005). *Potamogeton obtusifolius* is apparently less palatable, at least to pond snails, than other species of *Potamogeton*, so it may have more resistance to herbivory than other species in the genus (Elger et al. 2009). Herbivory pressure from waterfowl does not seem likely to increase with climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Egeria densa, *Sagittaria rigida*, and *Myriophyllum heterophyllum* were all noted as invaders at occurrences of *Potamogeton obtusifolius*, though *Egeria densa* appeared to be decreasing and *Potamogeton obtusifolius* increasing in the location where they co-occurred. (Muenscher 1936). Alteration of hydrology could also potentially lead to invasion of the native *Typha latifolia* (Rocchio and Crawford 2015). This species has somewhat increased vulnerability to competition from other species with climate change.

C4g. Forms part of an interspecific interaction not covered above: Unknown
No information was found on other interspecific relationships with *Potamogeton obtusifolius*.

C5a. Measured genetic variation: Not Ranked

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Unknown

Most *Potamogeton* species reproduce vegetatively via tubers, turions, and rhizomes. Reproduction via seeds is much rarer in this genus, though it has been demonstrated in *Potamogeton obtusifolius,* which has been described as "heavily fruiting" (Muenscher 1936). The mating system was not described for this species, but the likelihood of wind-pollination and the production of many fruits suggest that this species could have good genetic diversity relative to the rest of the genus.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Potamogeton obtusifolius* (July to August) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Potamogeton obtusifolius* declining in response to climate change. Not enough population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report
Potentilla breweri (Brewer's cinquefoil)

Date: 8 Nov 2023
Synonym: *Potentilla drummondii* ssp. *breweri*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington
Heritage Rank: G4G5/S1
Index Result: Extremely Vulnerable
Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	83
	<3.9° F (2.2°C) warmer	17
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	67
	-0.074 to - 0.096	33
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
cabland4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the 6 known occurrences of *Potentilla breweri* in Washington, 5 (83%) occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1). The remaining occurrence in Clallam County (17%) is projected to experience an increase of less than or equal to 3.9° F (2.2°C).

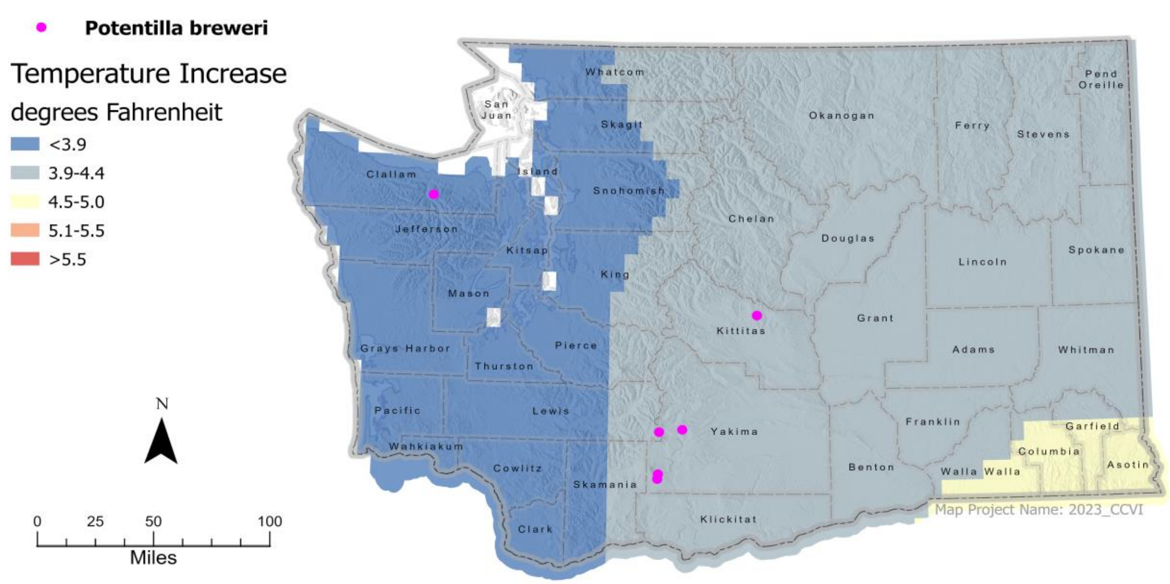

Figure 1. Exposure of *Potentilla breweri* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 6 known occurrences of *Potentilla breweri* in Washington, 4 (67%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097- -0.119 (Figure 2). The remaining two occurrences (33%) are in areas with a projected moisture decrease in the range of -0.074 to -0.096.

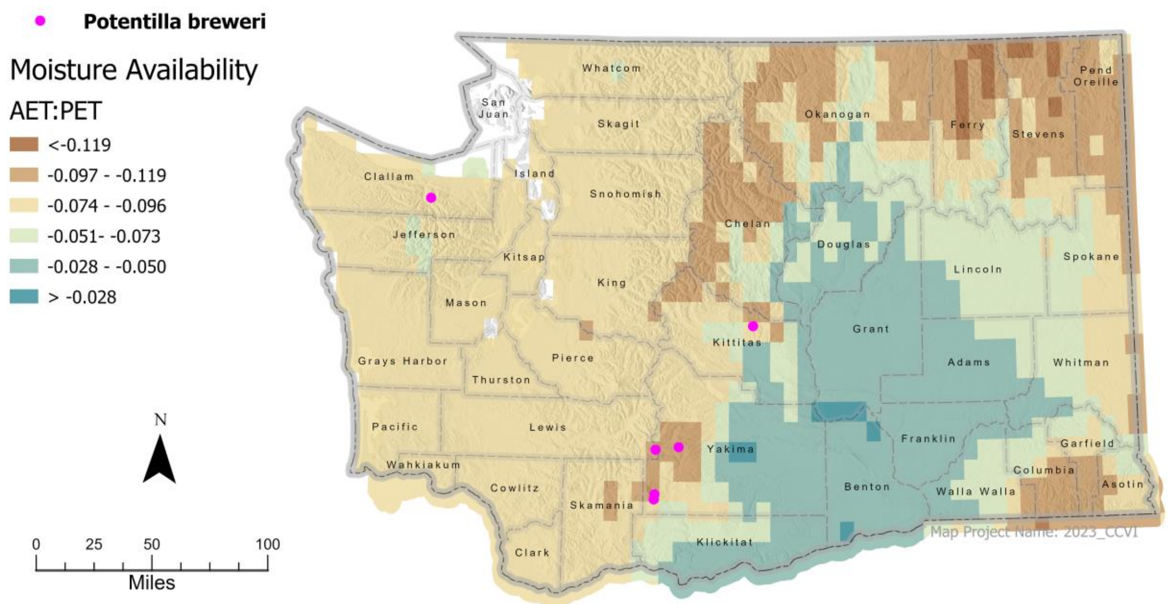

Figure 2. Exposure of *Potentilla breweri* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Potentilla breweri occurs in mesic montane meadow patches along the margins of lakes and streams or on dry, exposed slopes at mid to high elevations (5000-6000 ft (1525-1830 m)) along the eastern crest of the Cascade Range, with a historical disjunct occurrence in the Olympic Mountains (Washington Natural Heritage Program 2023). *Potentilla breweri* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Somewhat Increase
Potentilla breweri is found in moist grassy meadows and rock outcrops among a matrix of forest just below the alpine line up to mountain summits (Rocchio and Crawford 2015). This species has a scattered distribution with 3-161 mi (5-260 km) of unsuitable forested lowland and

cultivated habitat between populations which may pose a barrier to reaching additional patches of North Pacific Alpine and Subalpine Dry Grasslands or Northern Rocky Mountain Subalpine-Montane Mesic Meadows. Mountainous terrain between populations is also likely to pose a barrier to movement. *Potentilla breweri* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022). Suitable habitat is separated by extensive areas of subalpine forest and steep valleys that present a barrier to gene flow and dispersal, but these habitats can occur in large patches.

B2b. Anthropogenic barriers: Neutral
Due to the mountainous terrain, the habitat of *Potentilla breweri* remains relatively undisturbed by direct anthropogenic stressors and barriers. No major roads or developments occur in the vicinity of occurrences; however, a few populations are near Forest Service roads and could be damaged by vehicles. Recreation impacts from climbing and hiking can be of some concern in mountain meadow habitats. Though some of the slopes which support *Potentilla breweri* are partially surrounded by cultivated land, anthropogenic barriers are minimal compared to natural barriers and stretches of unsuitable habitat between mountains are typical for the terrain.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Potentilla breweri* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely due to the high elevation backcountry terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Potentilla breweri produces clusters of dry achene fruits. The dispersal mechanisms of *Potentilla breweri* are not well understood or documented, but the seeds of *Potentilla* spp. are probably dispersed passively over short distances due to large seed sizes and a lack of specialized appendages for wind or animal dispersal. The achenes of other *Potentilla* spp. have been documented to contain an air-layer which allows the fruit to remain buoyant on water for long distances (Eriksson 1986).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Potentilla breweri* occurrences in Washington. Of the 6 known occurrences, two (33%) are in areas that have experienced very little temperature variation (less than 37° F (20.8° C)) are expected to be highly vulnerable to climate warming (Young et al. 2016). Three occurrences (50%) are in areas that have experienced lower than average temperature variation (37 - 47° F (20.8 – 26.3° C)) over the historical period and are expected to be vulnerable to warming (Young et al. 2016). A single occurrence (50%) is in an area that has experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period and is expected to be somewhat vulnerable to climate warming (Young et al. 2016).

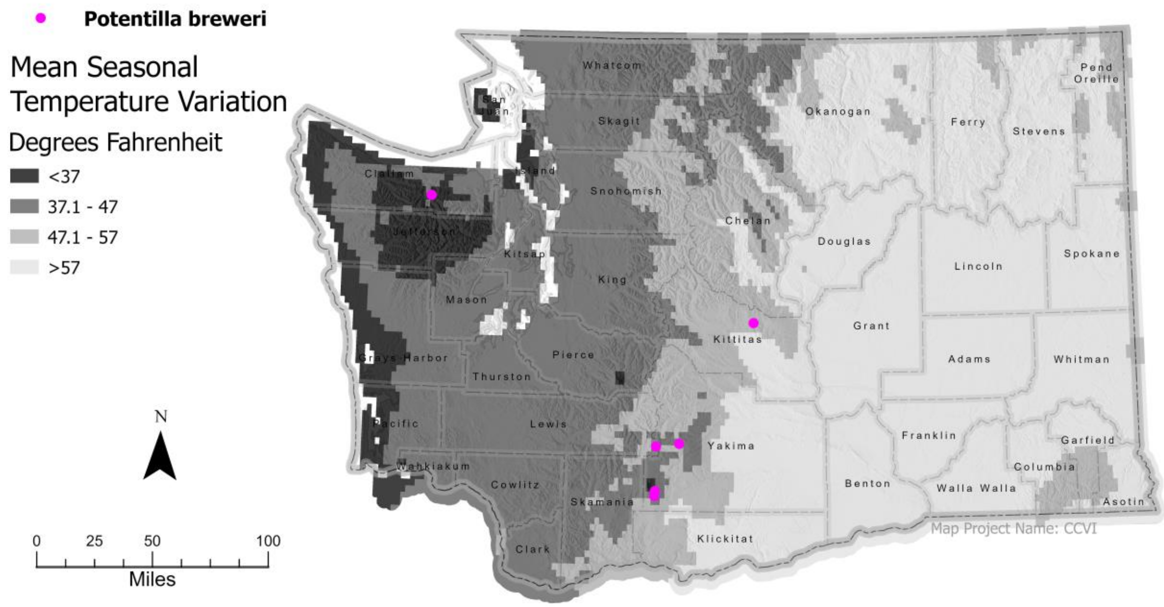

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Potentilla breweri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: <u>Somewhat Increase</u>
Potentilla breweri occurs in grasslands and rock outcrops usually found on dry, south-facing slopes embedded in alpine and subalpine forests (Rocchio and Ramm-Granberg 2017). Warming temperatures may impact plant phenology, increase drought, and alter fire cycles (Rocchio and Ramm-Granberg 2017) *Potentilla breweri* may be at risk of following an “elevator to extinction” as cool climatic zones of the alpine are lost, though its proclivity for dry slopes may mean it is somewhat resilient to warming (Watts et al. 2022).

C2bi. Historical hydrological niche: <u>Neutral</u>
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Potentilla nivea* occurrences in Washington. All 6 occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

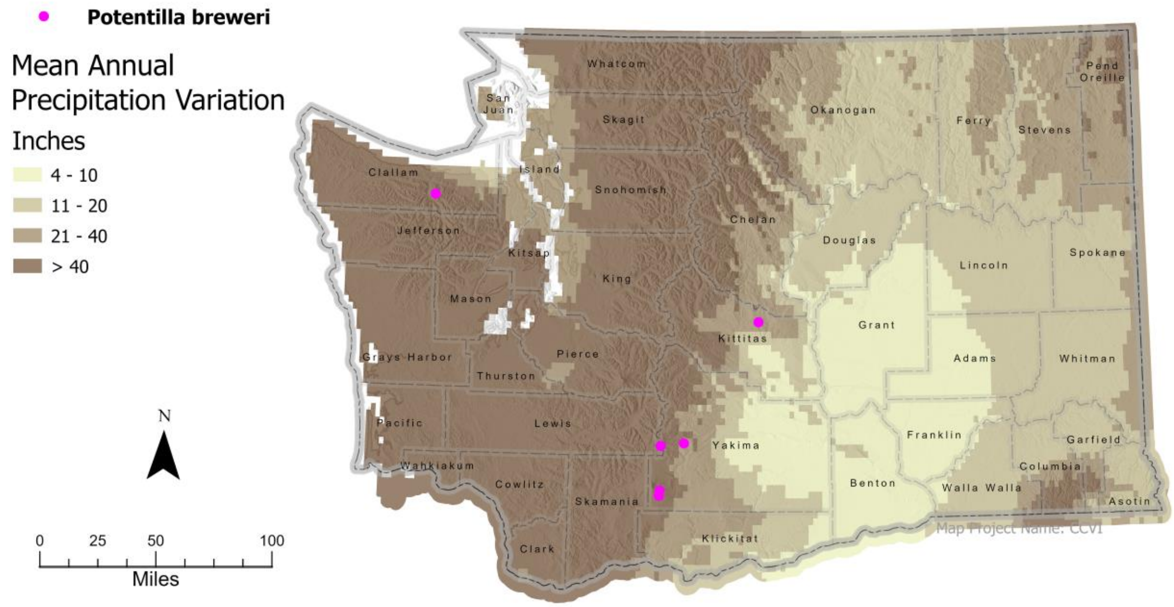

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Potentilla breweri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Potentilla breweri prefers seasonally wet habitats that are moist to saturated in spring and dry out by summer as these areas are too dry to support trees that could shade out the habitat. It associates with dry, windswept flats and draws and is moderately tolerant of drought (Wagner 1965, Rocchio and Crawford 2015). The water-limited habitat of *Potentilla nivea* is likely to be somewhat impacted by expected reductions to snowpack and earlier melting of snow. (Rocchio and Ramm-Granberg 2017). Altered hydrology, soil moisture, and snowmelt volume/timing may drive shifts in species composition towards a drier, more sparse community type and potentially reduce the habitat extent.

C2c. Dependence on a specific disturbance regime: Neutral
The habitats of *Potentilla breweri* are primarily shaped by abiotic conditions that create suitable microsites and prevent tree encroachment. Aspect, microsite size, and cliff surfaces dictate composition and bedrock habitats are shaped primarily by erosion, chemical and physical processes, and gravity (Rocchio and Crawford 2015). Mixed severity to stand replacing fires have been common and help to maintain the habitat in addition to seasonal drought, deep snow pack, and wind-scour which limit tree establishment (Rocchio and Crawford 2015).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase

Potentilla breweri is known to inhabit sites where snow remains late into the season. Changes to snowpack and snowmelt timing are anticipated to change composition of the habitat and may even lead to conversion to drier, more sparse communities (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
The soils of the wet meadows and dry grasslands that support *Potentilla breweri* are well to poorly drained and vernally moist clays or silts loams, sometimes with hydric soil inclusions or gravel content (Rocchio and Crawford 2015). Soil development may be limited to somewhat deep with a substantial organic matter content. These soils are derived from a variety of parent materials, particularly basalts and breccias in Washington (Washington Division of Geology and Earth Resources 2016). These substrates are common in Washington and the wide range of soils which can support *Potentilla breweri* suggests that it is not highly restricted to an uncommon geological feature.

C4a. Dependence on other species to generate required habitat: Neutral
Natural burrowing by small animals is common in the habitat of *Potentilla breweri* and can help to increase community diversity (Rocchio and Crawford 2015). Studies suggest that soil disturbance from ground-burrowing mammals may increase with climate change, which may allow new competition in the habitat of *Potentilla breweri but* is not expected to lead to major negative impacts (Lynn et al. 2018).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The exact pollinators of *Potentilla breweri* are not well documented. However, *Potentilla breweri* is like other *Potentilla* spp. in that it is able to attract several generalist pollinators with its nectar reward and is recorded as being visited by bees, flies, butterflies, beetles, moths, wasps (Guillén et al. 2005, Knoke and Giblin 2023).

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Potentilla breweri* are dispersed by gravity or other passive means. The species is not known to be dependent on animals for transport and the achene fruits do not have barbs, hooks, or other specialized means of attachment.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Impacts from pathogens are not known. The ecological systems that support *Potentilla breweri* are tolerant of some grazing but intense grazing can lead to invasion of non-natives and noxious weeds species that pose a threat to structure and diversity of mesic meadows (Rocchio and Crawford 2015). Trampling and soil compaction are a problem in this slow growing ecological system. Historical sheep grazing, introduced mountain goals, and elk all have impacted or could alter the habitat of *Potentilla breweri.* Though grazing is not expected to increase with climate change, impacts may be compounded.

C4f. Sensitivity to competition from native or non-native species: Increase
Potentilla breweri occurs in highly vegetated grasslands/meadows to sparsely vegetated rocky ledges and outcrops but appears to prefer areas which are too windswept and dry to support trees

and where competition for sunlight is minimal (Rocchio and Crawford 2015). Warming temperatures and earlier snowmelt are likely to change community composition but unlikely to allow tree encroachment due to seasonal drought and wind exposure (Rocchio and Ramm-Granberg 2017). This ecological system is already threatened by invasive species such as *Hieracium caespitosum, Hieracium aurantiacum, Ranunculus acris,* and *Leucanthemum vulgare* which are known to invade with disturbance and grazing and can upset the structure and diversity of the meadows. Climate change related promotion of these species could be highly damaging to the habitat of *Potentilla breweri* (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Potentilla breweri does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Potentilla breweri* has not been documented, though *Potentilla* spp. are polyploids that are generally expected to have higher genetic diversity (Soltis and Soltis 2000).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Increase
Apomixis is common in the polyploid genus *Potentilla* and the combination of facultative self-reproduction and hybridization with congeners has probably contributed to the morphological and genetic complexity of the genus (Eriksen and Töpel 2006). Seeds are mostly clones of parent plants. Self-compatibility is typically indicative of lower effective population sizes and recombination rates (Huang et al. 2019).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Potentilla breweri* (mid-June to mid Aug, fruiting as early as mid-July) has not changed significantly since the time of the first recorded collection in Washington in 1899 (Washington Natural Heritage Program 2023). Additional monitoring is warranted as studies of other *Potentilla* spp. differ in response to warming and snowmelt timing (zhu et al. 2016, Dorji et al. 2020, Vorkauf et al. 2021) and ecological systems which support *Potentilla breweri* are sensitive to temperature increases which can affect flowering phenology and associated pollinators (Rocchio and Ramm-Granberg 2017).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no direct reports of *Potentilla breweri* populations declining in response to climate change in Washington. Of the six known occurrences in Washington, four have been classified as historical but simply have not been revisited since the 1940s-1950s and two were relocated in the early 2000s. There is no conclusive evidence that these populations have suffered the effects of climatic change.

D2. Modeled future (2050) change in population or range size: Unknown

Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Potentilla nivea (snow cinquefoil)

Date: 5 Oct 2023 Synonym: *Potentilla nivea* var. *nivea*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5/S2
Index Result: Extremely Vulnerable Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	85
	-0.074 to - 0.096	15
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase/Increase
2aii. Change in physiological thermal niche		Greatly Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase/Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 20 (100%) known occurrences of *Potentilla nivea* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

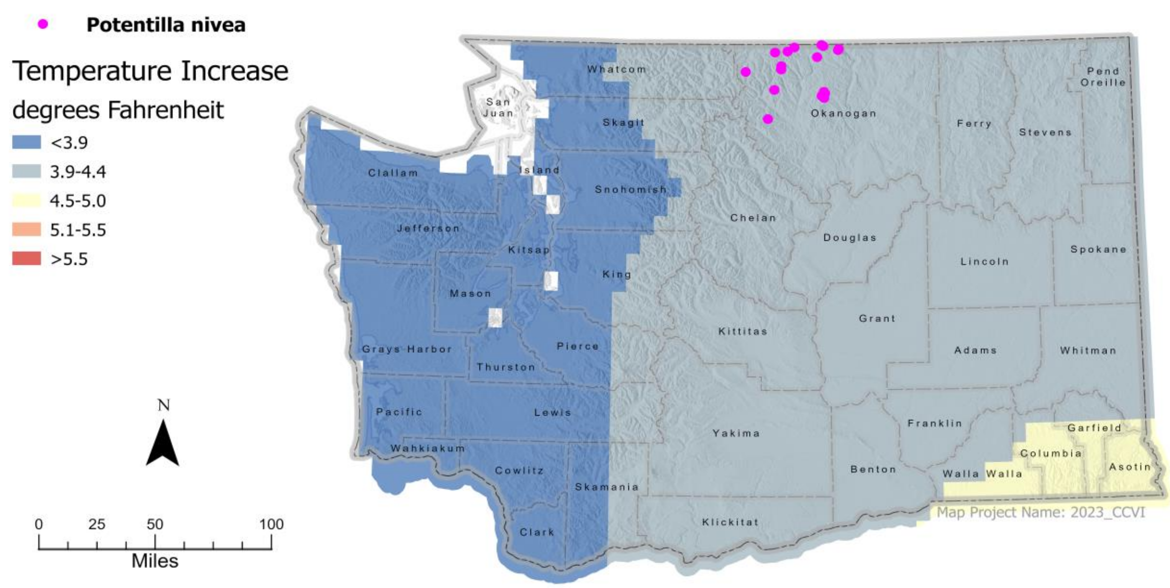

Figure 1. Exposure of *Potentilla nivea* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 20 known occurrences *of Potentilla nivea* in Washington, 17 (85%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097- -0.119 (Figure 2). The remaining three occurrences (15%) are in areas with a projected moisture decrease in the range of -0.074 to -0.096.

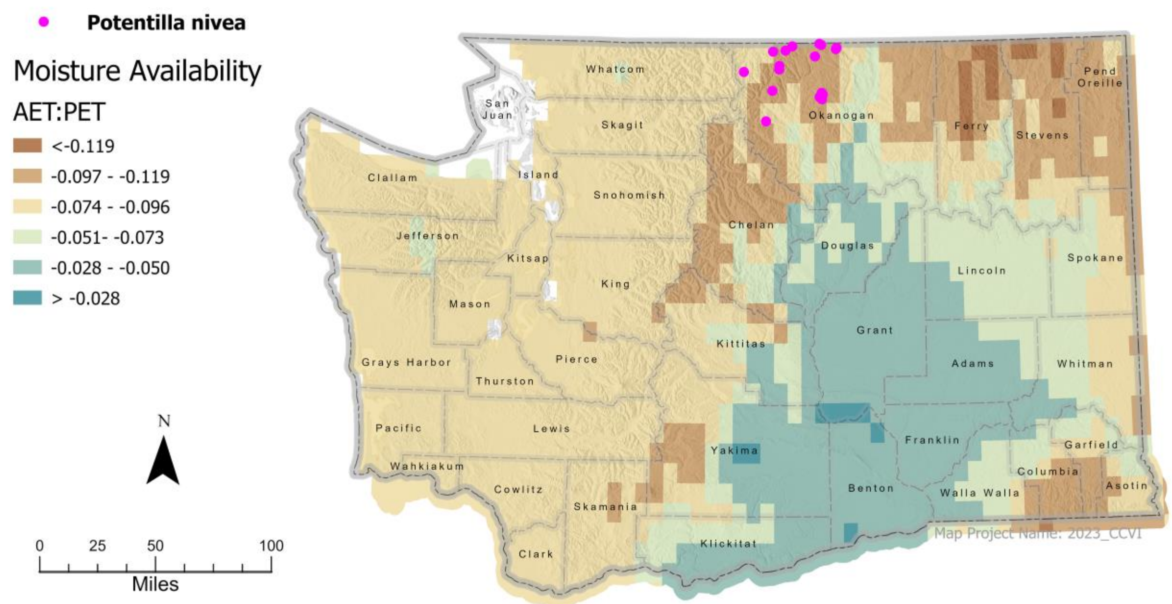

Figure 2. Exposure of *Potentilla nivea* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Potentilla nivea is restricted to alpine fellfields and meadows near or above tree line at elevations ranging from 7200-8100 ft (2195-2470 m; Washington Natural Heritage Program 2023). *Potentilla nivea* populations in Washington are not expected to be affected by sea level rise based on their inland distribution and high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: Neutral
Potentilla nivea is a circumpolar species that occurs only at some of the highest elevations in the Okanagan Range of Washington (NatureServe 2023a, Washington Natural Heritage Program 2023), which sits between the core of the Cascade Mountains and the Rocky Mountains. Some Washington populations occur in isolation near mountain peaks while others occur in clusters along mountain ridges, with distances between populations ranging from 0.1-44 mi (0.2-71 km).

Potentilla nivea is primarily found growing among rocky fellfields and ridge tops but it can also thrive in alpine meadows (Washington Natural Heritage Program 2023). Lower elevation valleys and forests between ridges and peaks may represent unsuitable habitat but do not appear to significantly inhibit dispersal as *Potentilla nivea* is wide ranging across multiple continents and discontinuous mountain ranges. *Potentilla nivea* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022).

B2b. Anthropogenic barriers: Neutral
Due to the rugged, rocky terrain, the habitat of *Potentilla nivea* remains relatively undisturbed by direct anthropogenic stressors and barriers. Recreation impacts from climbing and hiking can be of some concern in rocky alpine habitats, but natural barriers are expected to impact dispersal more than anthropogenic land use.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Potentilla nivea* (Washington Department of Natural Resources 2023). Future projects in the region are unlikely due to the rugged, high elevation backcountry terrain.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
Potentilla nivea produces a dry achene containing a single seed (Washington Natural Heritage Program 2023). The dispersal mechanisms of *Potentilla nivea* are not well understood or documented, but the seeds of *Potentilla* spp. are probably dispersed passively over short distances due to large seed sizes and a lack of specialized appendages for wind or animal dispersal. The achenes of other *Potentilla* spp. have been documented to contain an air-layer which allows the fruit to remain buoyant on water for long distances (Eriksson 1986).

C2ai. Historical thermal niche: Somewhat Increase/Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Potentilla nivea* occurrences in Washington. Of the 20 known occurrences, eight (40%) are in areas that have experienced lower than average temperature variation (37 - 47° F (20.8 – 26.3° C)) over the historical period and are expected to be vulnerable to climate warming (Young et al. 2016). Another 10 occurrences (50%) are in areas that have experienced slightly lower than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period and are expected to be somewhat vulnerable to climate warming (Young et al. 2016). The remaining two occurrences (10%) are in areas that have experienced average variation (>57.1° F (31.8° C)). According to Young et al. (2016) these populations are likely to be mostly resilient to warming.

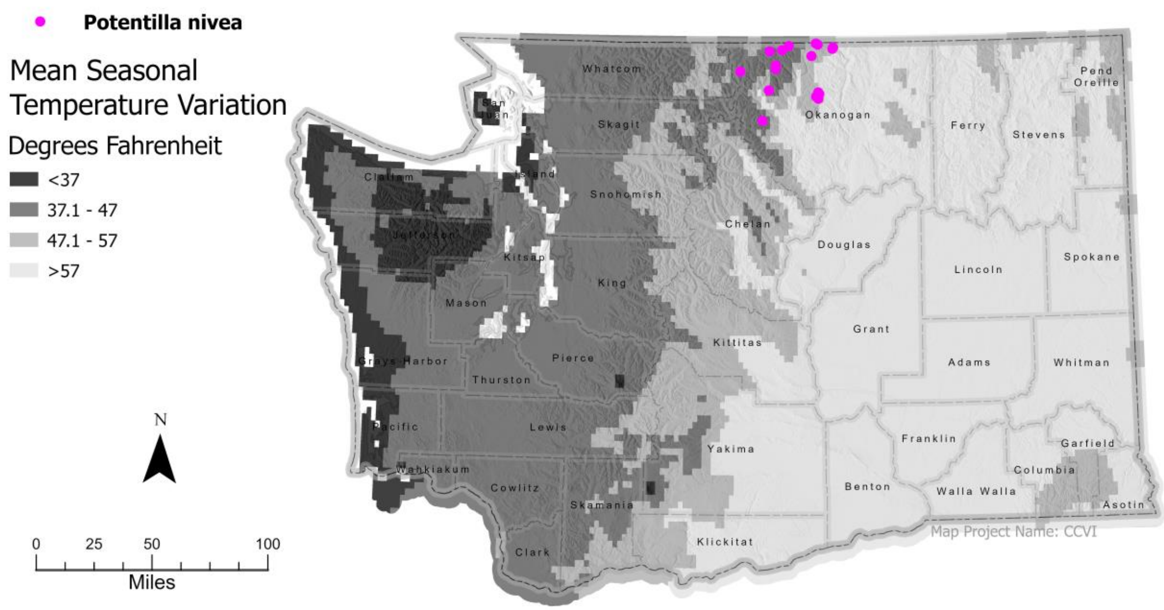

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Potentilla nivea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Greatly Increase
Potentilla nivea occurs in fell-field, turf, and meadow habitats at some of the highest elevations above treeline in Washington and is found in the Okanagan ecoregion, which is one of the coldest regions in the state. These habitats are part of the Rocky Mountain Alpine Dwarf Shrubland, Fell-field, and Turf ecological systems and are expected to be highly vulnerable to anticipated temperature increases (Rocchio and Ramm-Granberg 2017). *Potentilla nivea* may be at risk of following an "elevator to extinction" as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Potentilla nivea* occurrences in Washington. All 20 occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 inches/508 mm) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

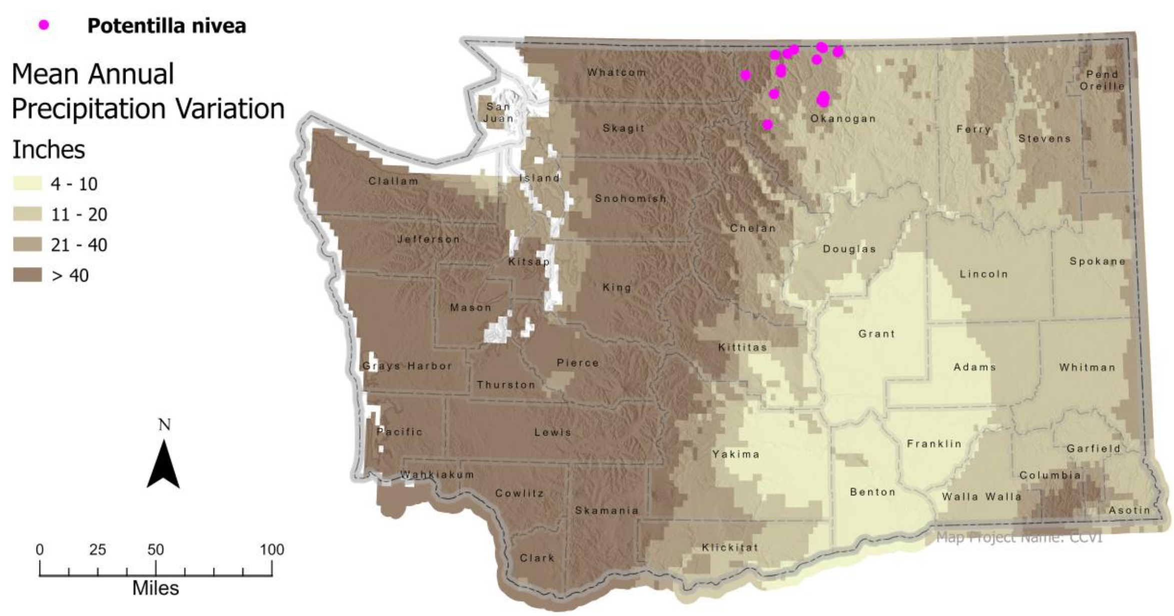

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Potentilla nivea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral/Somewhat Increase

The exposed ridges and wind-scoured fell-fields where *Potentilla nivea* occurs remain largely free of snow throughout the winter (NatureServe 2023b) but receive constant moisture from nearby depressions with late lying snow and subirrigation from snow melting on surrounding slopes. The water-limited habitat of *Potentilla nivea* is likely to be somewhat impacted by expected reductions to snowpack and earlier melting of snow. (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral

Potentilla nivea occurs on exposed alpine fell-fields and meadow edges that are mostly maintained by natural erosion processes and are further facilitated by cold climatic conditions and high winds that reduce soil formation and keep plant density low (Rocchio and Crawford 2015). Avalanches and freeze-thaw action further shape microclimates in these alpine communities (NatureServe 2023b). Additional periodic disturbances are not required to maintain this habitat, though small, moderate intensity fires occasionally occur due to lightning strikes (NatureServe 2023d).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
Potentilla nivea is a circumpolar alpine species and the Okanagan ecoregion where it occurs in Washington is one of the coldest regions of the state with moderate snow accumulations that are diminished by the rain shadow of the Cascades (NatureServe 2023e). The exposed ridges and wind-scoured fell-fields where *Potentilla nivea* occurs remain largely free of snow throughout the winter (NatureServe 2023b) but receive moisture from nearby depressions with late lying snow and subirrigation from snow melting on surrounding slopes.

C3. Restricted to uncommon landscape/geological features: Neutral
The soils of the alpine fell-fields and meadows which support *Potentilla nivea* are typically shallow and gravely, deriving from a granitic parent material. These soils range from unproductive, poorly developed, and dry to stable and acidic with some peat and organic matter content (NatureServe 2023b). These substrates are very common in alpine areas of Washington and the range of soils which can support *Potentilla nivea* suggests that it is not highly restricted to an uncommon geological feature.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Soil disturbance and herbivory from pocket gophers and voles can shape composition by killing off preferred food species and opening pockets for other plants to colonize but abiotic processes are the major drivers that create the alpine habitat of *Potentilla nivea* (NatureServe 2023d). Studies suggest that soil disturbance from ground-burrowing mammals may increase with climate change which may allow new competition in the habitat of *Potentilla nivea* (Lynn et al. 2018).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Potentilla nivea can be pollinated and is primarily recorded as attracting flies and some bees, but apparently is also capable of self-pollination as it can still produce fruits when pollinators are excluded (Kevan 1972, Montana Natural Heritage Program 2023). The exact pollinators of *Potentilla nivea* are not well documented but it is probably like other *Potentilla* spp. in that it is able to attract several other generalist pollinators with its nectar reward (Guillén et al. 2005). However, its flowers are nearly closed at maturity which makes it difficult for pollen transfer to occur and favors autogamy.

C4d. Dependence on other species for propagule dispersal: Neutral
The seeds of *Potentilla nivea* are dispersed by gravity or other passive means. The species is not known to be dependent on animals for transport and the achene fruits do not have barbs, hooks, or other specialized means of attachment.

C4e. Sensitivity to pathogens or natural enemies: Neutral

Impacts from pathogens are not known. Due to its high elevation scree habitat, *Potentilla nivea* receives minimal impacts from grazing, though grazing threats used to be common in the alpine turf ecological systems and nearby meadows (NatureServe 2023d). Large herbivores also graze alpine turf areas nomadically but are not expected to have a high impact on *Potentilla nivea.*

C4f. Sensitivity to competition from native or non-native species: Neutral
Few species are well-adapted to survive the desiccating winds, rocky substrates, and short growing seasons of the of the high elevation fell-field, turf, and meadow habitats which support *Potentilla nivea,* and most of the plants in these habitats are "cushion" or "mat-forming" species (NatureServe 2023f). *Potentilla nivea* is probably adapted more for survival and quick growth under harsh abiotic conditions and not for competition, which is usually limited in the alpine. However, it can occur as a co-dominant in alpine meadows which may suggest that it is able to be somewhat resilient in the face of competition (Washington Natural Heritage Program 2023).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Potentilla nivea does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetic diversity of *Potentilla nivea* has not been documented, though *Potentilla* spp. are polyploids that are generally expected to have higher genetic diversity (Soltis and Soltis 2000).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase/Increase
Apomixis is common in the polyploid genus *Potentilla* and the combination of facultative self-reproduction and hybridization with congeners has probably contributed to the morphological and genetic complexity of the genus (Eriksen and Töpel 2006). *Potentilla nivea* has been confirmed to be self-compatible and the nearly closed structure of the flowers automatically favors autogamy over outcrossing, though pollinators do visit its flowers and may aid in self-pollination by transferring movement to the anthers (Guillén et al. 2005). Seeds are mostly clones of parent plants but when sexual reproduction does occur, seed set is enhanced in *Potentilla nivea.* Self-compatibility is typically indicative of lower effective population sizes and recombination rates (Huang et al. 2019).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (late June-early August) has not changed significantly since the first recorded collection in Washington in 1971. However, experimental studies of phenology in *Potentilla nivea* have found flowering, leafing, and senescence dates to be somewhat sensitive to nutrient deposition, air temperature, and soil moisture (Xin et al. 2014, Wang et al. 2014)

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown

There are no direct reports of *Potentilla nivea* populations declining in response to climate change in Washington. Of the 20 known occurrences in Washington, six (30%) have been classified as historical or have not been relocated since the 1970s-1990s. There is no conclusive evidence that these populations have suffered the effects of climatic change.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled in Washington. Bioclimatic envelope modeling of *Potentilla nivea* in British Columbia's Central Interior has predicted that the suitable climate space of *Potentilla nivea* var. *pentaphylla* will not decrease by the year 2080 (Rose 2010).

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled in Washington.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled in Washington.

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Climate Change Vulnerability Index Report

Ribes oxyacanthoides var. *irriguum* (Idaho gooseberry)

Date: 6 February 2024 Synonym: *Ribes oxyacanthoides* ssp. *irriguum*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T4/S2
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	58
	3.9-4.4° F (2.2-2.4°C) warmer	42
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	17
	-0.074 to - 0.096	58
	-0.051 to - 0.073	25
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Increase
3. Impacts from climate change mitigation		Somewhat Increase
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Of the 12 known occurrences of *Ribes oxyacanthoides* var. *irriguum* in Washington, five (42%) occur in areas with a projected temperature increase of 3.9-4.4° F/2.2-2.4° C (Figure 1). The other seven (58%) occur in areas with a projected temperature increase of 4.5-5.0° F/2.5-2.7° C.

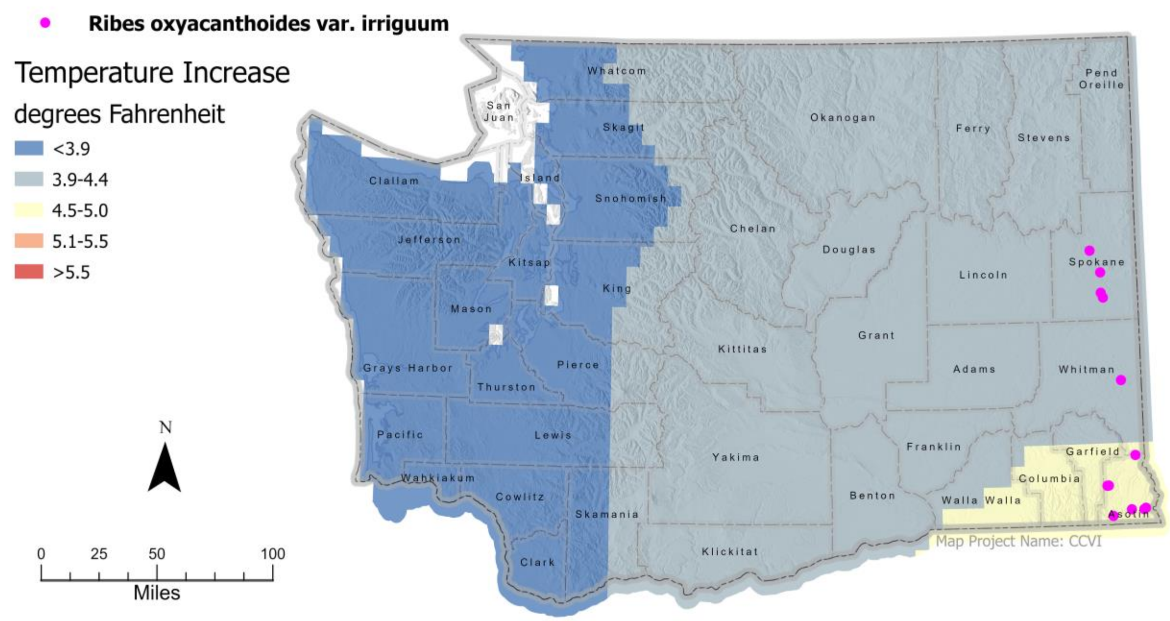

Figure 1. Exposure of *Ribes oxyacanthoides* var. *irriguum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the 12 known occurrences (17%) of *Ribes oxyacanthoides* var. *irriguum* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). Seven occurrences (58%) are in areas with a projected moisture decrease in the range of -0.074 to -0.096. The remaining three occurrences (25%) are in areas with a projected moisture decrease in the range of -0.051 to -0.073.

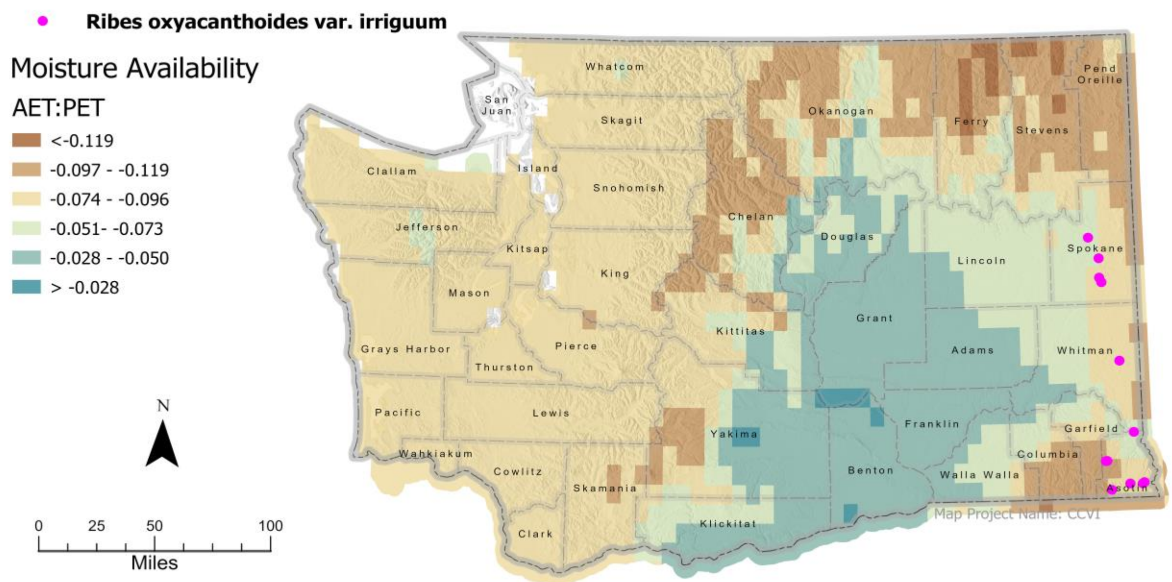

Figure 2. Exposure of *Ribes oxyacanthoides* var. *irriguum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Ribes oxyacanthoides var. *irriguum* can be found along streams and other waterways in meadow openings and steep grassy slopes at mid elevations (1850-5000 ft (560-1525 m; Washington Natural Heritage Program 2023). This species is not at risk from sea level rise based on its elevation and inland distribution (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
The Columbia Basin Foothill & Canyon Dry Grassland and Rocky Mountain Lower Montane Riparian Woodland & Shrubland ecological systems where *Ribes oxyacanthoides* var. *irriguum* occurs on stream banks and dry grassland ridges ranges from large to small patches or near islands interspersed between coniferous forests. Dry grasslands are quite limited in overall distribution and associated mostly with the canyons of the Snake River and tributaries. Occurrences of *Ribes oxyacanthoides* var. *irriguum* are separated by 2-114 mi (3-184 km) of

both potential suitable habitat and unsuitable forest habitat. Barriers posed to dispersal are relatively minimal and probably less than those created by fragmentation due to agriculture.

B2b. Anthropogenic barriers: Increase
The occurrences of *Ribes oxyacanthoides* var. *irriguum* are actively threatened by nearby land sales and development and much of the suitable habitat for this species has already been decreased or fragmented due to agriculture and residential construction (many occurrences in these areas are now historical). These stretches of unsuitable developed habitat pose a significant barrier to dispersal and migration and can further alter the hydrology of undeveloped surrounding woodlands and shrublands which support this species. Most of the Washington occurrences are located on lands managed for multiple use (State Park, National Forest) that are not formally protected from future development. The last remaining habitat is on thin eyebrows/ridges which are too steep and/or rocky for conversion and are highly fragmented.

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase
There is potential development for clean energy around the north fork of Asotin Creek in the immediate vicinity of one occurrence (Washington Department of Natural Resources 2024). Some of the less steep surrounding slopes may be targeted for energy infrastructure but have largely already been converted and developed.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
The berry fruits of *Ribes* spp. are eaten and dispersed by a wide variety of bird and animal species that cannot digest the seeds (Pfister and Sloan 2008). Potential dispersal distances vary depending on the home range and foraging habits of the species that feed on berries but are likely to be 100-1000 meters or more on occasion. However, most seeds fall right below the parent plants (<100 m).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Ribes oxyacanthoides var. irriguum* occurrences in Washington. Of the 12 known occurrences, two (17%) are in areas that have experienced less than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining 10 occurrences (83%) are in areas that have experienced average temperature variation (>57.1° F (31.8° C)) over the historical period and are expected to be mostly resilient to climate warming (Young et al. 2016).

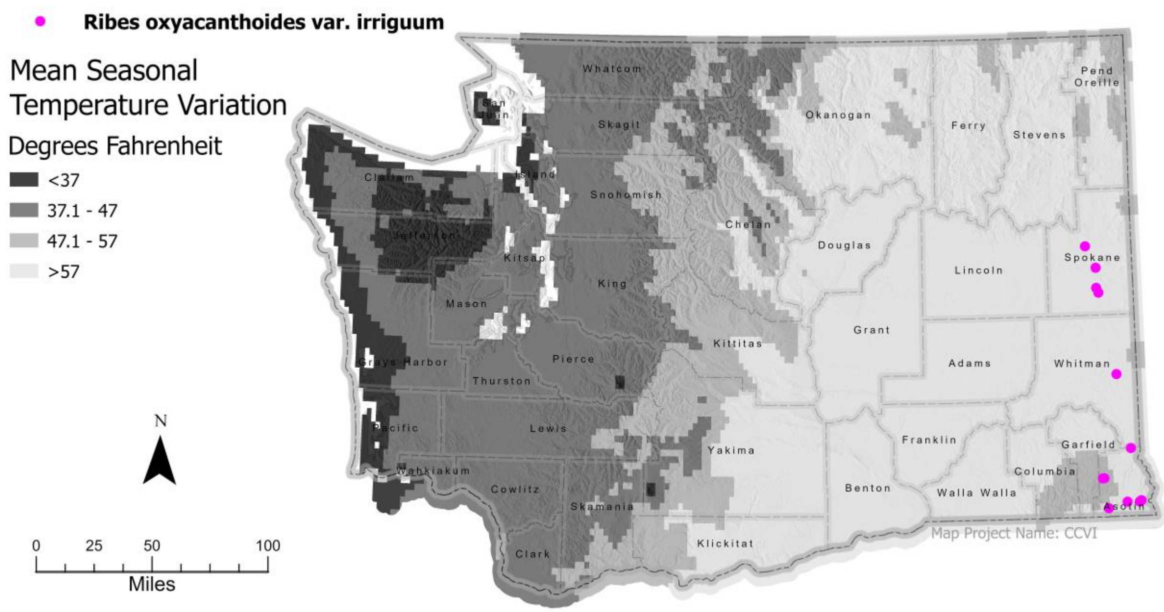

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Ribes oxyacanthoides* var. *irriguum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Ribes oxyacanthoides var. *irriguum* occurs primarily on north-facing slopes and cliffs with partial rather than total shade but is occasionally recorded as occurring on warmer and drier canyon sides (Washington Natural Heritage Program 2023). These slopes are probably above cold air drainages. Increased temperatures may increase evaporative stress, and drier and warmer conditions may increase fire risk for lower montane riparian woodlands and shrublands, which has historically experienced low fire activity (Rocchio and Crawford 2015). This species may be somewhat tolerant but prefers slightly cooler, mesic conditions within its broader habitat.

C2bi. Historical hydrological niche: Somewhat Increase
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Ribes oxyacanthoides* var. *irriguum* occurrences in Washington. Of the 12 known occurrences, 10 (83%) are in areas that have experienced lower than average (11 - 20 in (255 - 508 mm)) precipitation variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to changes in available moisture. The remaining two occurrences (17%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
Ribes oxyacanthoides var. *irriguum* is a riparian associate found along moist forest edges and stream terraces (Carey 1995, Washington Natural Heritage Program 2023). Reduced snowpack, snow melt, and changes to precipitation timing and volume will change flooding regimes and impact germination, soil moisture, and community composition in this ecological system as water flows are dependent on recharge from melting snow at higher elevations or on seasonal precipitation. (Rocchio and Ramm-Granberg 2017). Drought and fire frequency may increase in intensity as a result.

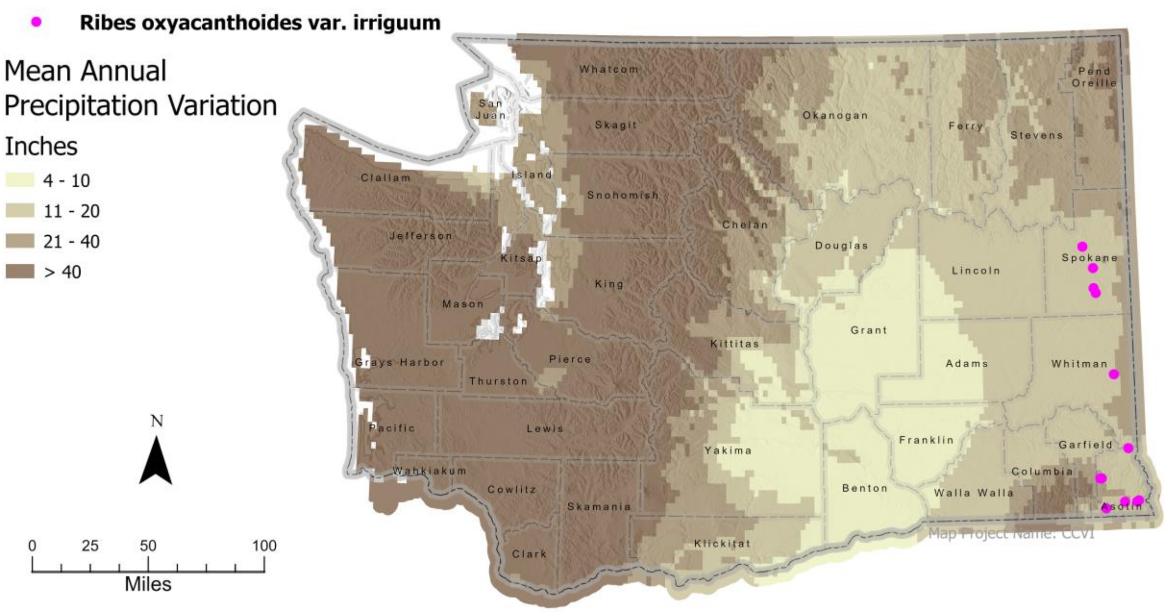

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Ribes oxyacanthoides* var. *irriguum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2c. Dependence on a specific disturbance regime: <u>Somewhat Increase</u>
Ribes oxyacanthoides var. *irriguum* is dependent on infrequent wildfire to reduce encroachment from less fire-adapted shrub species and to maintain open grassland habitat (Rocchio and Crawford 2015). Increased drought and reduced summer precipitation might make wildfires too frequent and result in replacement of native perennial bunchgrass and riparian vegetation with annual introduced grasses (Rocchio and Ramm-Granberg 2017). The parent species *Ribes oxyacanthoides* is known to regenerate after low severity fire from long-lived seed banks (fire stimulates germination) and via resprouting from underground, making this species somewhat resilient to fire (Timoney 2012) In riparian areas, extreme precipitation events could increase

runoff and erosion, altering the flood cycles of riparian woodlands and shrublands along with species composition and succession.

C2d. Dependence on ice or snow-cover habitats: Neutral
Snowpack is lower over the range of *Ribes oxyacanthoides* var. *irriguum* in the foothills of the Blue Mountains and the Palouse in southeastern Washington than in other montane areas of the state and is a moderate to small component of the annual water budget in these regions (Trujillo and Molotch 2014). *Ribes oxyacanthoides* var. *irriguum* is not otherwise known to especially depend on snow or ice.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase
Ribes oxyacanthoides var. *irriguum* occurs in moist muck and rich alluvial silt-loam soils with interspersed areas of bare ground, gravel and rock (Rocchio and Crawford 2015, Soil Survey Staff 2024). These soils are derived from Missoula glacial lake outburst flood deposits, basalt flows (Saddle Mountains), and Palouse eolian deposits (Washington Division of Geology and Earth Resources 2016). These geological features are somewhat restricted to the eastern border of Washington and the soil types preferred by this species are slightly uncommon on the landscape.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Grazing and browsing by elk, deer and bighorn sheep maintains the open grasslands occupied by *Ribes oxyacanthoides* var. *irriguum,* although drought and fire probably play a larger role. Beaver activity can be significant and critical to hydrological regimes in riparian woodlands and shrublands as dams can flood and kill large areas of shrubland which then becomes colonized by herbaceous vegetation (Rocchio 2006, Rocchio and Crawford 2015)

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Ribes oxyacanthoides var. *irriguum* is reported to be pollinated by bumblebees, bees, and hummingbirds (Giblin 2024). This diversity of pollinators is common among western North American *Ribes* spp., with most visited primarily by bumblebees (*Bombus* spp.) (Kalt 2000). *Ribes* spp. are also often wind-pollinated (Pfister and Sloan 2008). This species is probably not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
The edible berries produced by *Ribes oxyacanthoides* var. *irriguum* are probably eaten and dispersed by a wide variety of bird and mammal species and cannot disperse long distances without animal aid (Pfister and Sloan 2008).

C4e. Sensitivity to pathogens or natural enemies: Neutral
Ribes oxyacanthoides var. *irriguum* is an alternate host for an alternate host for *Cronartium ribicola*, the invasive fungus that causes white pine blister rust in some species of pine (Pinus spp) (Arsdel and Geils 2004, Kearns et al. 2008). Infection does not usually harm the *Ribes* spp. This species is also component of grizzly bear, mule, and elk diets across the parent species'

range (Carey 1995), but there is no evidence that herbivory by these species will increase with climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Predicted climate change is likely to make the dry grasslands and open areas riparian woodlands and shrublands that support *Ribes oxyacanthoides* var. *irriguum* drier, warmer, and more vulnerable to wildfire in the future (Rocchio and Ramm-Granberg 2017), which can lead to increased competition from invasive weeds and dominance by arid-adapted grasses but can also prevent shrub encroachment (Rocchio and Crawford 2015). Weedy grasses and exotics such as *Leucanthemum vulgare* and *Hypericum perforatum* are already common at Washington occurrences according to observations. Many *Ribes* species are vigorous colonizers of disturbed areas, but the parent species *Ribes oxyacanthoides* is thought to be moderately shade tolerant and is probably not strongly sensitive to competition (Carey 1995, Kalt 2000).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Ribes oxyacanthoides var. *irriguum* does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic variation of *Ribes oxyacanthoides* var. *irriguum* has not been documented.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Many *Ribes* spp. in the North American west are polymorphic, and usually at least diploid (Kalt 2000). Most also reproduce vegetatively via rhizomes in addition to seed and sometimes act as self-incompatible by aborting fruits (Arasu 1970, Kalt 2000, Pfister and Sloan 2008). *Ribes oxyacanthoides* var. *irriguum* is likely a near-obligate outcrosser, though its small hermaphroditic flowers may self-pollinate. Polyploidy, a preference for outcrossing, and mixed mating systems are traits indicative of average to high genetic variation (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Ribes oxyacanthoides* var. *irriguum* (May to June, fruiting as early as June) has not changed significantly (Washington Natural Heritage Program 2023). Some records from the 1990s document flowering in April but there are not enough cases to detect any trend.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Ribes oxyacanthoides var. *irriguum* is known from 12 occurrences in Washington, of which only five are extant (last observed in 2022) and seven historical (Washington Natural Heritage Program 2023). Recent revisits to two occurrences by Rare Care in 2015 did not relocate the species. Census data is lacking for many occurrences but population trends are probably down due to habitat conversion. It is unknown whether climate change is influencing population

trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Young, B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app

Climate Change Vulnerability Index Report
***Ribes wolfii* (Wolf's currant)**

Date: 3 April 2024 Synonym: *Ribes mogollonicum*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G4/S2
Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	100
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	80
	-0.074 to - 0.096	20
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 10 known occurrences (100%) of *Ribes wolfii* in Washington occur in areas with a projected temperature increase of 4.5-5.0° F (2.5-2.7° C; Figure 1).

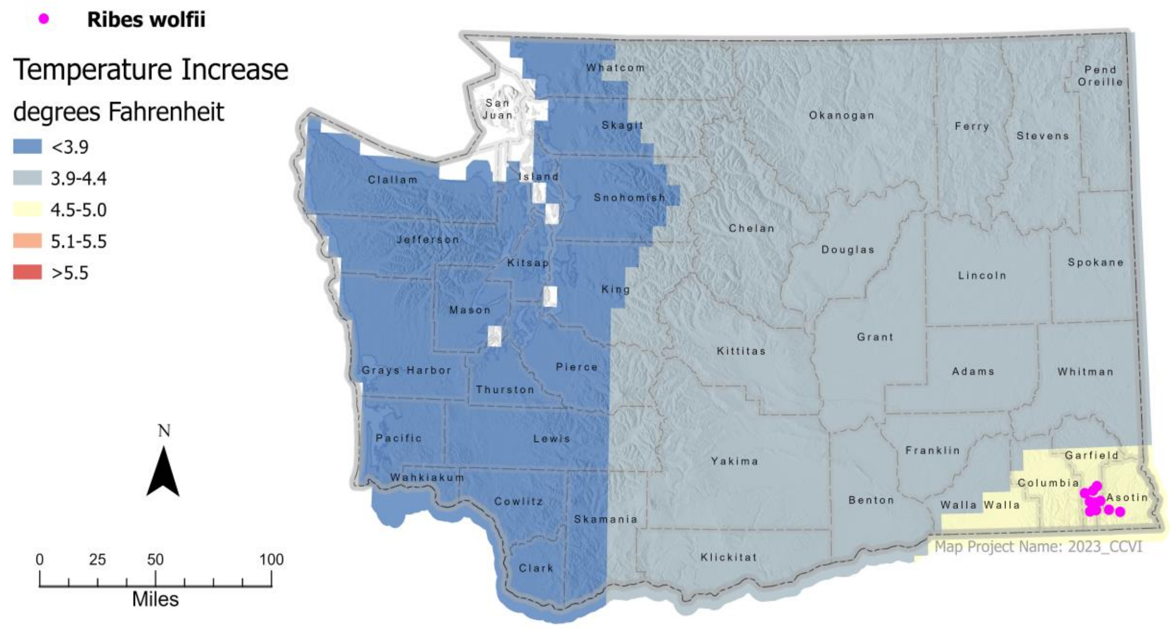

Figure 1. Exposure of *Ribes wolfii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Eight of the 10 known occurrences (80%) of *Ribes wolfii* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The remaining two occurrences (20%) are in areas with a projected moisture decrease in the range of -0.074 to -0.096.

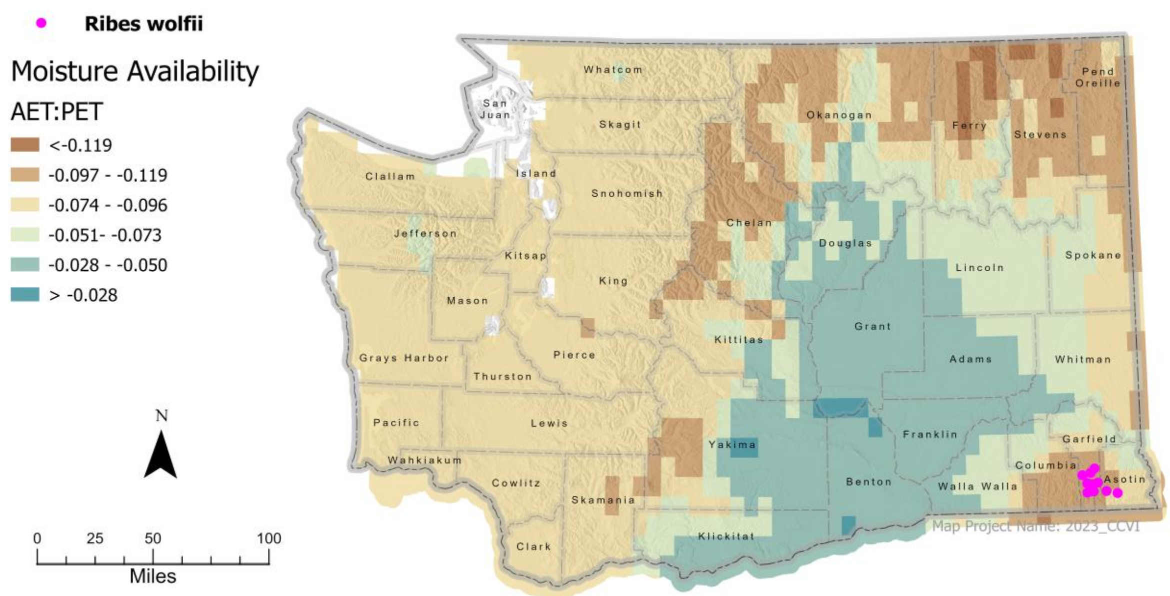

Figure 2. Exposure of *Ribes wolfii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Ribes wolfii occurs in meadow clearings at the forest ecotone at mid to high elevations in southeastern Washington (5200-6375 ft (1585-1944 m); Washington Natural Heritage Program 2023). This species is not at risk from sea level rise based on its elevation and inland distribution (Office for Coastal Management 2024).

B2a. Natural barriers: Neutral
Ribes wolfii is found in clearings, meadows, and grassy slopes along the edge of moist forests in the Northern Rocky Mountain Subalpine-Upper Montane Grassland ecological system (Rocchio and Crawford 2015). Suitable habitat is found on flat to gently rolling terrain which occurs in relatively large patches within the greater forest matrix. Occurrences are relatively close together (1-17 mi (2-27 km) apart) and forest breaks are separated by only a few minor barriers to dispersal and gene flow created by ridgelines and areas with high canopy cover.

B2b. Anthropogenic barriers: Neutral
Disturbed areas in the Blue Mountains where *Ribes wolfii* is found are relatively minimal though there are some clear cuts and old road cuts near some of the occurrences. These features are expected to pose very minimal barriers to dispersal, and this species may be able to utilize some of the cleared forest areas.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Ribes wolfii* (Washington Department of Natural Resources 2024), and any potential forest health treatments would likely benefit this species which prefers forest clearings.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase
The berry fruits of *Ribes* spp. are eaten and dispersed by a wide variety of bird and animal species that cannot digest the seeds (Pfister and Sloan 2008). Potential dispersal distances vary depending on the home range and foraging habits of the species that feed on berries but are likely to be 100-1000 meters or more on occasion. However, most seeds fall right below the parent plants (<100 m).

C2ai. Historical thermal niche: Somewhat Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Ribes wolfii* occurrences in Washington. Of the 10 known occurrences, nine (90%) are in areas that have experienced less than average temperature variation (47.1 - 57° F (26.3 - 31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. The remaining occurrence (10%) is in an area that has experienced average temperature variation (>57.1° F (31.8° C)) over the historical period and is expected to be mostly resilient to climate warming (Young et al. 2016).

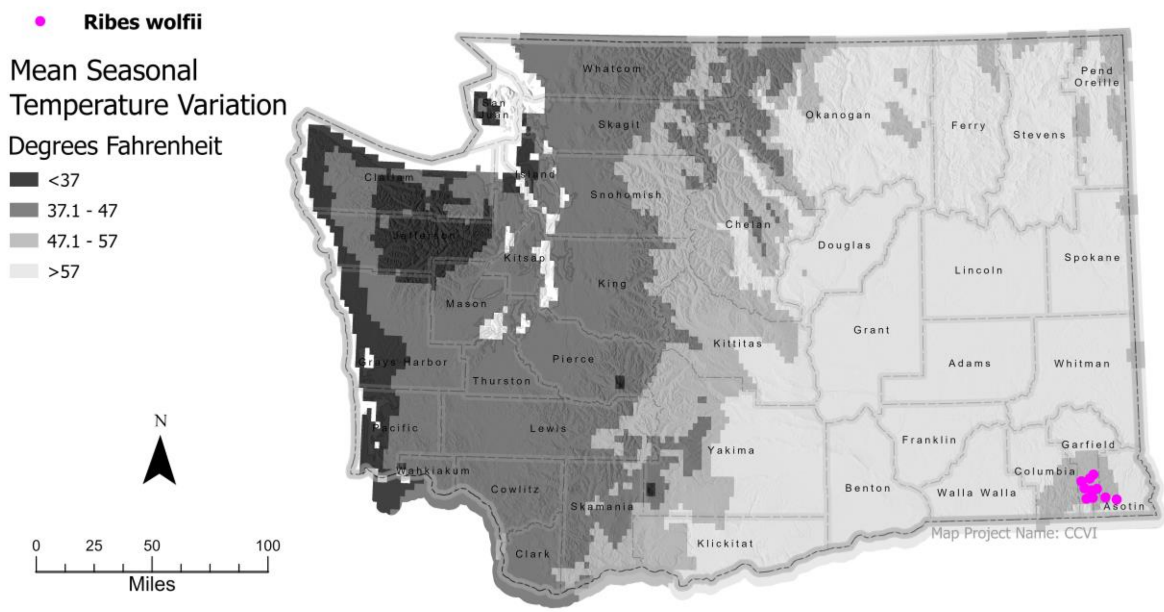

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Ribes wolfii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral

Ribes wolfii is found in grassy clearing and meadows at the edge of mesic forests with southern exposures in full sun to partial shade, according to observational records (Washington Natural Heritage Program 2023). Too much or too little canopy cover can cause this species to drop out of a community, suggesting that it has a narrow light and or thermal niche but it does not particularly prefer warm or cold conditions (Mancuso and Moseley 1994). The slopes where it occurs are convex on ridge crests and probably occur above cold air drainages.

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Ribes wolfii* occurrences in Washington. Of the 10 known occurrences, two (20%) are in areas that have experienced lower than average (11 - 20 in (255 - 508 mm)) precipitation variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to changes in available moisture. The remaining eight occurrences (80%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Ribes wolfii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase
Ribes wolfii prefers the ecotone at the edge of mesic to dry forest openings and meadow clearings with partial shade (Washington Natural Heritage Program 2023). This species occurs near wet pockets and moist meadows but will not establish directly in riparian zones (Mancuso and Moseley 1994). These subalpine meadows are dependent on adequate amounts of winter snow and spring/summer rainfall as they are not directly connected to groundwater. Changes in the amount of snowfall, the timing of snow melt, the amount and timing of rainfall, or increased drought (from higher summer temperatures) could have negative impacts on moist meadow sites and result in changes to composition towards a drier grassland type but probably not a complete type conversion (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
The subalpine meadows and mesic forest-edge habitats which support *Ribes wolfii* are largely maintained by precipitation and edaphic factors, more than natural disturbance patterns though fire is important for maintaining forest clearings (Rocchio and Crawford 2015). Under future climate change scenarios, these sites could become more susceptible to wildfire associated with drought or higher temperatures, though fires may also increase the amount of suitable forest openings (Rocchio and Ramm-Granberg 2017). The seeds of many *Ribes* spp. are stimulated to germinate by fire and members of this genus often increase after burns, though high severity fires can kill their shallow root systems (Pfister and Sloan 2008). Big game browsing plays a more minor role in maintaining open, grassy areas but is not required.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase
Ribes wolfii has been documented as occurring near late-lying snow along the edge of trees and meadows. It is also found along the margins of small lakes and streams in areas with high winter snow accumulation. Reductions in the amount of snowpack or timing of snow melt could shift vegetation composition towards plants adapted to drier meadows which may negatively impact *Ribes wolfii* (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral
Ribes wolfii is found on grassy slopes on fractured Grande Ronde basalt (Washington Division of Geology and Earth Resources 2016, Washington Natural Heritage Program 2023). The soils it prefers are generally fine, deep, and well-drained volcanic ash-loams and colluvium with high mineral content and ample humus (Mancuso and Moseley 1994, Soil Survey Staff 2024). These geological features are relatively common in eastern Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The meadow clearing and mesic forest-edge habitats of *Ribes wolfii* are maintained largely by natural abiotic conditions such as precipitation regimes and fire and do not require other species for maintenance, though ungulate browsing may help to maintain grassy clearings

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
Congener *Ribes* spp. in Washington are reported to be pollinated by bumblebees, bees, and hummingbirds (Giblin 2024). This diversity of pollinators is common among western North American *Ribes* spp., with most visited primarily by bumblebees (*Bombus* spp.) (Kalt 2000). *Ribes* spp. are also often wind-pollinated (Pfister and Sloan 2008). This species is probably not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Somewhat Increase
The edible berries produced by *Ribes wolfii* are probably eaten and dispersed by a wide variety of bird and mammal species and cannot disperse long distances without animal aid (Pfister and Sloan 2008).

C4e. Sensitivity to pathogens or natural enemies: Neutral

Ribes wolfii is an alternate host for an alternate host for *Cronartium ribicola*, the invasive fungus that causes white pine blister rust in some species of pine (*Pinus* spp). but is considered to be of low importance as a host as it is not highly susceptible to infection (Arsdel and Geils 2004, Kearns et al. 2008). Infection does not usually harm the *Ribes* spp. This species is also component of grizzly bear, mule, and elk diets across the parent species' range (Carey 1995), but there is no evidence that herbivory by these species will increase with climate change. However, overgrazing can stress the habitats of these species by exposing bare soils, increasing erosion, and encouraging invasion by exotic grasses such as *Poa pratensis* (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023).

C4f. Sensitivity to competition from native or non-native species: Neutral
Many *Ribes* spp. are quick to colonize disturbed areas such as clearcuts and roadsides and often appear in early seral communities, though some species occurring in Washington are known to be fairly shade-tolerant (Carey 1995, Kalt 2000). Observational records indicate that *Ribes wolfii* struggles to compete with quick colonizing *Ceanothus* in clear cut and recently burned areas in Washington. However, herbaceous cover at the meadow/mesic forest ecotone where *Ribes wolfii* is found is relatively high, indicating that this species is probably not highly sensitive to competition outside of other shrubs. Under projected climate change, the composition of these habitats might shift towards species adapted to drier conditions, but overall cover is not likely to be affected (Rocchio and Ramm-Granberg 2017). Tree encroachment is unlikely to be an issue as the soils of these communities are too droughty and sods prevent root penetration (Rocchio and Crawford 2015).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Ribes wolfii does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The genetic variation of *Ribes wolfii* has not been documented. However, the occurrences in southeastern Washington are disjunct from the core range and represent a distinct concentration of populations separated by over 200 mi (320 km). These genetically isolated populations may be at risk of lower genetic diversity due to inbreeding depression and genetic drift.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Many *Ribes* spp. in the North American west are polymorphic, and usually at least diploid (Kalt 2000). Most also reproduce vegetatively via rhizomes in addition to seed and sometimes act as self-incompatible by aborting fruits (Arasu 1970, Kalt 2000, Pfister and Sloan 2008). *Ribes wolfii* is likely a near-obligate outcrosser, though its small hermaphroditic flowers may self-pollinate. Polyploidy, a preference for outcrossing, and mixed mating systems are traits indicative of average to high genetic variation (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website

(pnwherbaria.org) and WNHP records, the flowering period of *Ribes wolfii* (May to July) has not changed significantly (Washington Natural Heritage Program 2023), though there were few records available with which to assess trends.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Ribes wolfii is known from at least 9 extant occurrences and one historical report (Washington Natural Heritage Program 2023). There are not enough census data available to establish any trends for Washington populations. However, in western Colorado, *Ribes wolfii* has moved slightly upslope and decreased in relative abundance and community rank between 1950 and 2014 (Zorio et al. 2016).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

***Sabulina basaltica* (Olympic Mountain sandwort)**

Date: 21 May 2024 Synonym: *Minuarta rossii, Arenaria rossii*
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G2/S2
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Greatly Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All four known occurrences (100%) of *Sabulina basaltica* in Washington occur in areas with a projected temperature increase of less than 3.9° F (2.2° C; Figure 1).

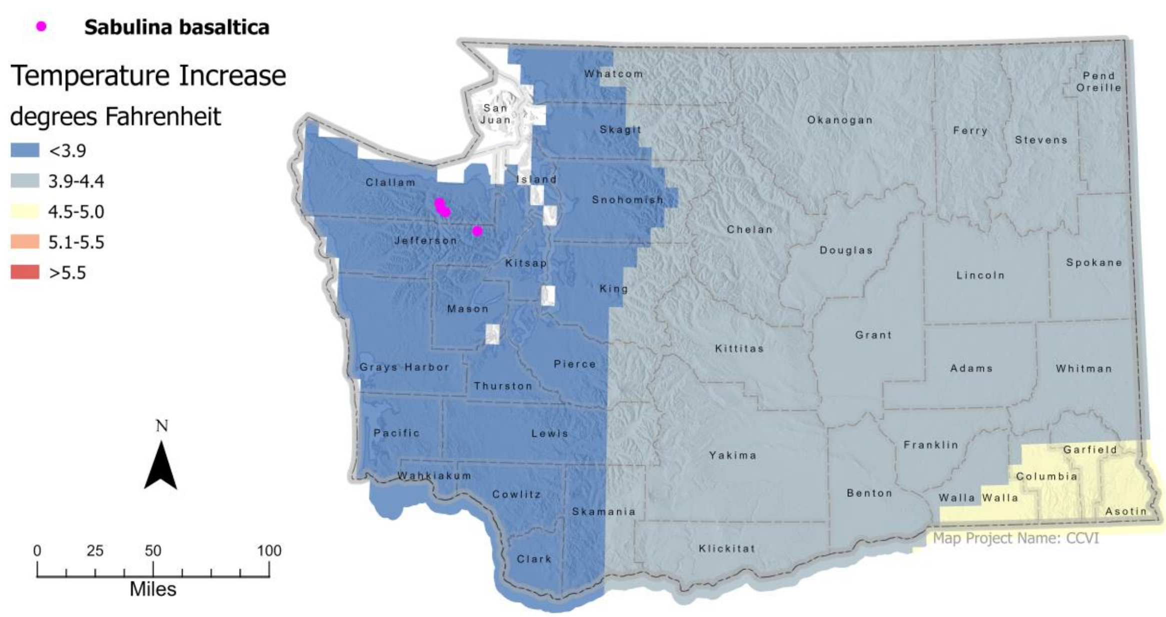

Figure 1. Exposure of *Sabulina basaltica* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four known occurrences (100%) of *Sabulina basaltica* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096.

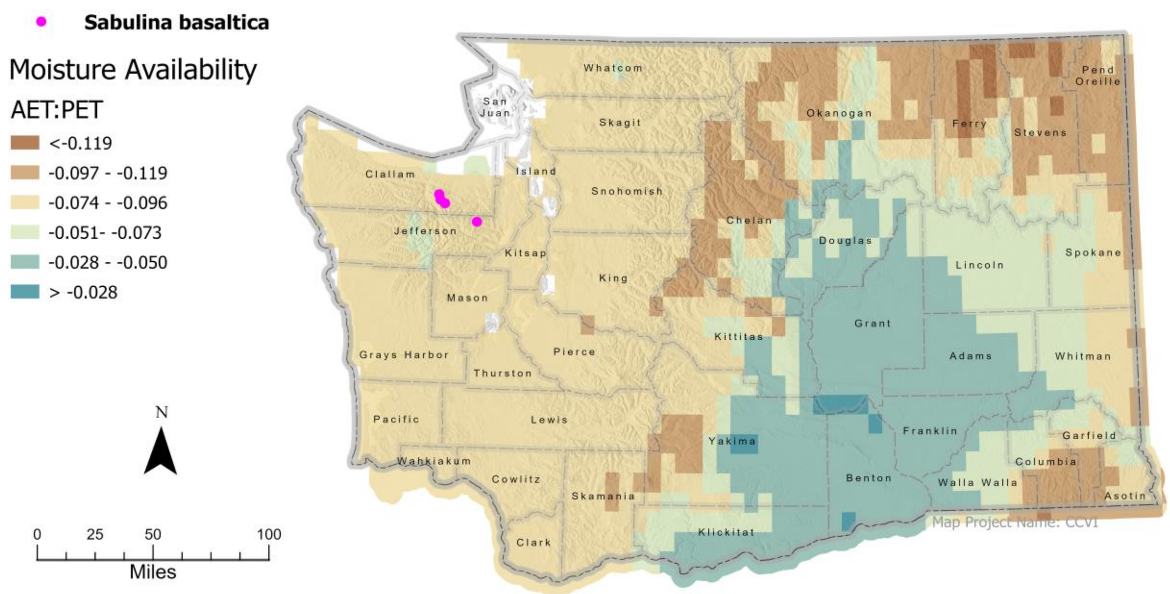

Figure 2. Exposure of *Sabulina basaltica* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Sabulina basaltica occurs on rock faces and crevices of cliffs in the alpine (5415-6890 ft (1650-2100 m)) at elevations that are too high to be impacted by sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Increase
Sabulina basaltica occurs on rock faces and crevices in the subalpine to alpine in the North Pacific Alpine & Subalpine Bedrock & Scree ecological system, restricted to the northeastern rim of the Olympic Mountains (Rocchio and Crawford 2015). This is a naturally patchy ecological system and occurrences are separated by 3-20 mi (5-32 km) of unsuitable lowland valley and forest habitat, which creates a barrier to local dispersal and gene flow. The isolation of the Olympic Range also constrains potential migration to other alpine mountain ranges north and east of the Salish Sea/Puget Sound.

B2b. Anthropogenic barriers: Neutral
The rugged, high elevation terrain where *Sabulina basaltica* occurs remains relatively unobstructed by direct anthropogenic barriers as there are few roads and little human infrastructure in the area. Threats are probably low from hikers due to the remote location of the

populations and rugged terrain, though a few occurrences are near climbing trails (Washington Natural Heritage Program 2023)

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Sabulina basaltica* (Washington Department of Natural Resources 2024). Future projects in the region are unlikely due to the rugged backcountry terrain and protected land status (National Park) of the occurrence locations.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Sabulina basaltica produces conical capsules that split open at three valves to release a small number of seeds (4-6) which lack wings or other special structures for dispersal (Washington Natural Heritage Program 2023). A congener of serpentine soils in California is thought to be carried very short distances on wind and potentially longer distances by water but the specifics have not been confirmed (Holguin and Dean 2020). Other North American *Sabulina* species have been documented as threatened by extreme rain events which can wash away seedlings and prevent them from germinating in suitable habitats (Nicola and Pozner 2013). This species is probably dispersed passively within a short distance of the parent via gravity (<100 m) but may occasionally disperse farther (100-1000 m) if there is enough water flow or wind flow among the rock crevices where it occurs.

C2ai. Historical thermal niche: Greatly Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Sabulina basaltica* occurrences in Washington. Three of the four known occurrences (75%) are in areas that have experienced very little temperature variation (>37° F (20.8° C)) over the historical period. According to Young et al. (2016), these occurrences are likely to be highly vulnerable to climate warming. The remaining occurrence (25%) is in an area that has experienced little temperature variation (37 - 47° F (20.8 - 26.3° C)) over the historical period and is expected to be vulnerable to warming (Young et al. 2016).

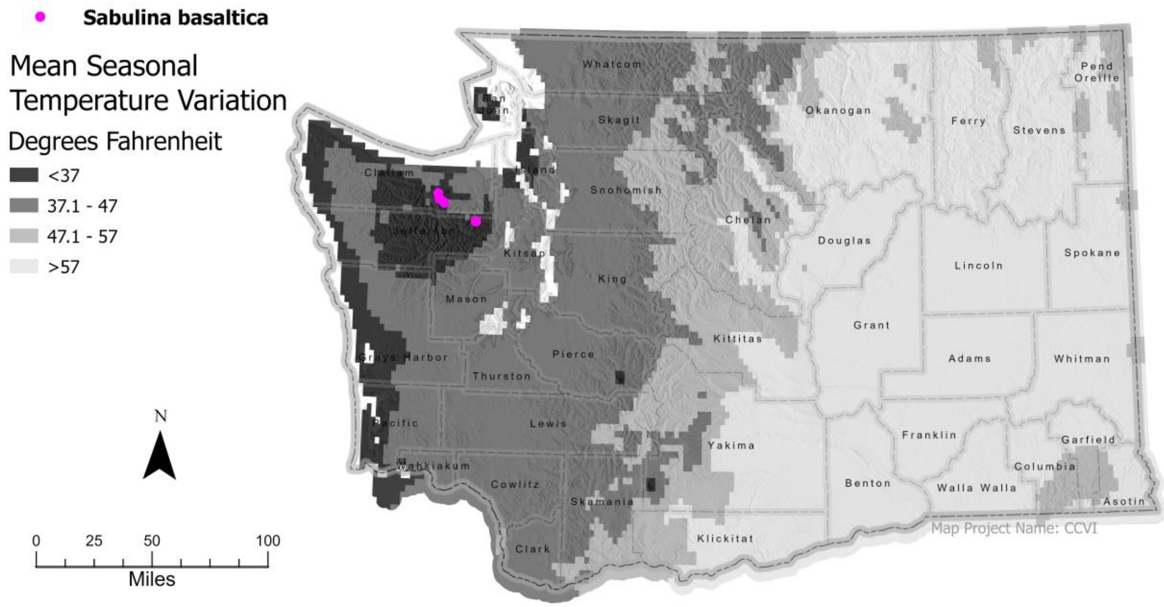

Figure 3. Historical thermal niche (exposure to past temperature variations) of occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Sabulina basaltica occurs on rocky exposures at high elevations in the Olympic Mountains where winds are high and conditions are cool-cold year round (Washington Natural Heritage Program 2023). Plants in these environments are highly adapted to harsh conditions and are unlikely to be extremely sensitive to warming temperatures (Rocchio and Ramm-Granberg 2017). According to observational records, *Sabulina basaltica* prefers slightly warmer microclimates in full sun on south-facing slopes where snow melt is earlier and, therefore, may be slightly more resilient to warming. However, warming temperatures are expected to increase erosion rates, fire risk, and drought in talus slopes and montane basins and will affect freeze-thaw cycles in its scree habitat (Rocchio and Ramm-Granberg 2017). *Sabulina basaltica* may be at risk of following an “elevator to extinction” as cool climatic zones of the alpine are lost (Watts et al. 2022).

C2bi. Historical hydrological niche: Neutral
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Sabulina basaltica* occurrences in Washington. All four known occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016).

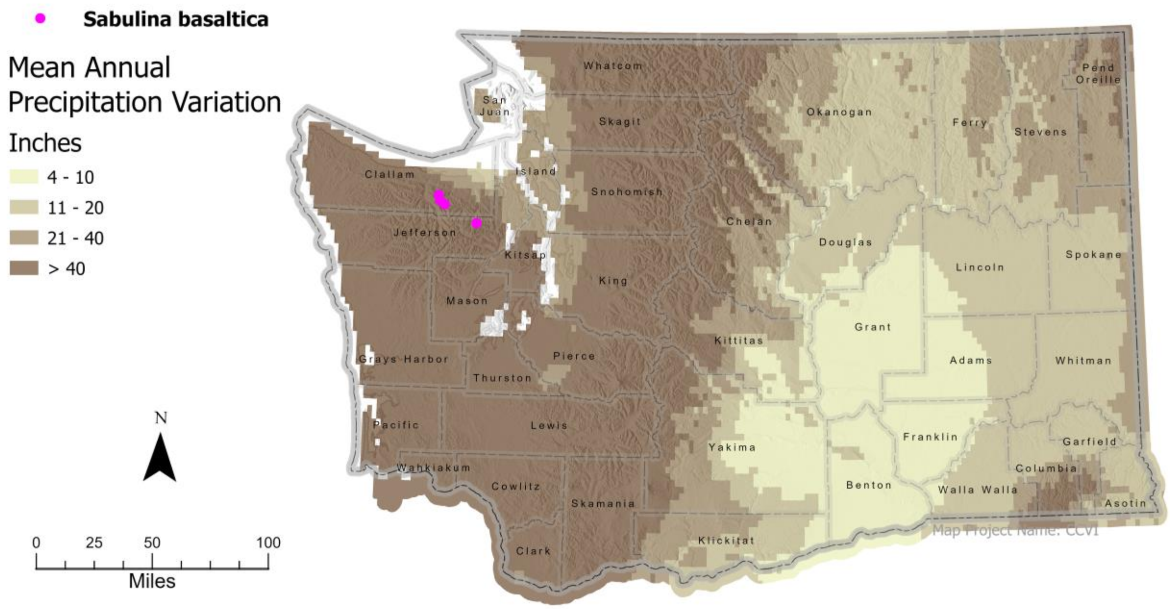

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Sabulina basaltica* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: <u>Somewhat Increase</u>
The habitat of *Sabulina basaltica* relies primarily on snowmelt for a steady supply of moisture throughout the growing season but occurs on exposures where wind-scour and sun cause snow to melt out earlier in the year (Legler and Dillenberger 2017). The northeastern Olympics are in a rain shadow, and conditions in this area are especially dry in the summer as compared to other bedrock and scree habitats (Rocchio and Crawford 2015, Western Regional Climate Center (WRCC) 2024). Hydrological changes are likely to alter the preferred habitat of alpine scree plants which is already moisture limited due to a lack of connection to groundwater (Rocchio and Ramm-Granberg 2017). *Sabulina basaltica* may be somewhat resilient based on its microhabitat conditions. Conversion of North American Glacier and Ice Fields to North Pacific Alpine and Subalpine Bedrock and Scree is expected under climate change and could initially increase the habitat available to *Sabulina basaltica* (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: <u>Neutral</u>
The high elevation rock faces and crevices where *Sabulina basaltica* occurs are mostly maintained by natural erosion processes and are further facilitated by cold climatic conditions and high winds that reduce soil formation and keep plant density low (Rocchio and Crawford 2015). Avalanches and freeze-thaw action further shape microclimates in these alpine communities. Additional periodic disturbances are not required to maintain this habitat and

climate change is not expected to significantly impact these processes (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Though overall snowfall is quite high in the alpine of the Olympic Mountains (National Park Service 2021), the ridgelines and rock faces where *Sabulina basaltica* occurs are exposed to high winds where snowmelt occurs much earlier than on adjacent slopes due to wind ablation (Legler and Dillenberger 2017). Observational records indicate that these microsites remain ice-free for much of the year.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Sabulina basaltica occurs on steep rock faces and in crevices composed of pillow basalts and breccia of the Crescent Formation in the subalpine to alpine zone (Washington Natural Heritage Program 2023). Soils are extremely thin on top of broken rock layers of marine sediments, sandstone, and shale (Soil Survey Staff 2024). These geologic formations are somewhat uncommon in Washington, and are restricted to high-elevation, basalt rocks in the northeastern Olympic Mountains (Legler and Dillenberger 2017).

C4a. Dependence on other species to generate required habitat: Neutral
The North Pacific Alpine and Subalpine Bedrock and Scree ecological system which supports *Sabulina basaltica* is primarily maintained by abiotic processes, such as erosion events which shift critical microtopographic habitat conditions and does not require other species for maintenance (Rocchio and Crawford 2015).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Sabulina basaltica* are not documented but the closely related (former) congener *Minuarta rossii* has a similar floral morphology and is visited by a considerable variety of nectafarious insects but is pollinated especially by bees and flies (Wolf et al. 1979, Holguin and Dean 2020). Many other *Sabulina* spp. possess floral nectaries which attract a variety of insect pollinators, including flies, bees, and butterflies (Rabeler et al. 2005). *Sabulina basaltica* is probably not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
Seeds of *Sabulina basaltica* have no morphologic features to promote dispersal by wind or for attaching to fur or feather of animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral
*Sabulina basaltica c*ould potentially be impacted by trampling or grazing by introduced mountain goats in the Olympics, as observational records indicate that goats were spotted nearby to occurrences (though direct grazing was not observed) (Legler and Dillenberger 2017, Washington Natural Heritage Program 2023). However, the likelihood of herbivory by this species is not anticipated to increase with climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase

Sabulina basaltica occurs in sparsely vegetated rock faces and crevices where competition from other plant species is naturally low and limited to other cushion plants (Rocchio and Crawford 2015, Legler and Dillenberger 2017). Under projected climate change, cover of weedy annual species might increase. Prolonged drought might also shift species composition from vascular plants to lichens (Rocchio and Ramm-Granberg 2017). Additionally, in areas with deep enough soil and in lower mesic areas of wet meadows, the tree line may also begin to encroach as the climate changes (Raymond et al. 2014).

C4g. Forms part of an interspecific interaction not covered above: <u>Neutral</u>
Sabulina basaltica does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: <u>Unknown</u>
The specific genetic variation of *Sabulina basaltica* has not been documented but is probably limited as this species is a very local endemic of the northeastern rim of the Olympic Mountains in Clallam and Jefferson counties and occurs on somewhat restricted geological features.

C5b. Genetic bottlenecks: <u>Unknown</u>

C5c. Reproductive System: <u>Neutral</u>
Sabulina basaltica may be like other *Sabulina* spp. or *Arenaria* spp. which are often gynoecious tetraploids and exhibit strong protandry which causes outcrossing to be favored, though self-pollination is usually still possible (Wolf et al. 1979). The degree of protandry varies on a spectrum among species (Wyatt 1990). Polyploidy, a preference for outcrossing, and mixed mating systems are traits indicative of average to high genetic variation (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: <u>Neutral</u>
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of (July to August, fruiting as early as mid-July) has not changed significantly (Washington Natural Heritage Program 2023).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: <u>Unknown</u>
Sabulina basaltica is known from four extant occurrences with the last visit documented in 2016. There are no specific studies of the response of *Sabulina basaltica* to climate change, but research on other alpine endemics of the Olympic Mountains has predicted that decreasing snowpack and increasing drought will lead to significant and severe reductions in suitable habitat for all studied species (Wershow 2017).

D2. Modeled future (2050) change in population or range size: <u>Unknown</u>
Not modeled.

D3. Overlap of modeled future (2050) range with current range: <u>Unknown</u>
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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<u>Climate Change Vulnerability Index Report</u>

***Sabulina sororia* (Twin Sisters sandwort)**

Date: 19 October 2023 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G1/S1
Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Greatly Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Both known occurrences (100%) of *Sabulina sororia* in Washington occur in areas with a projected temperature increase of less than or equal to 3.9° F (2.2°C; Figure 1).

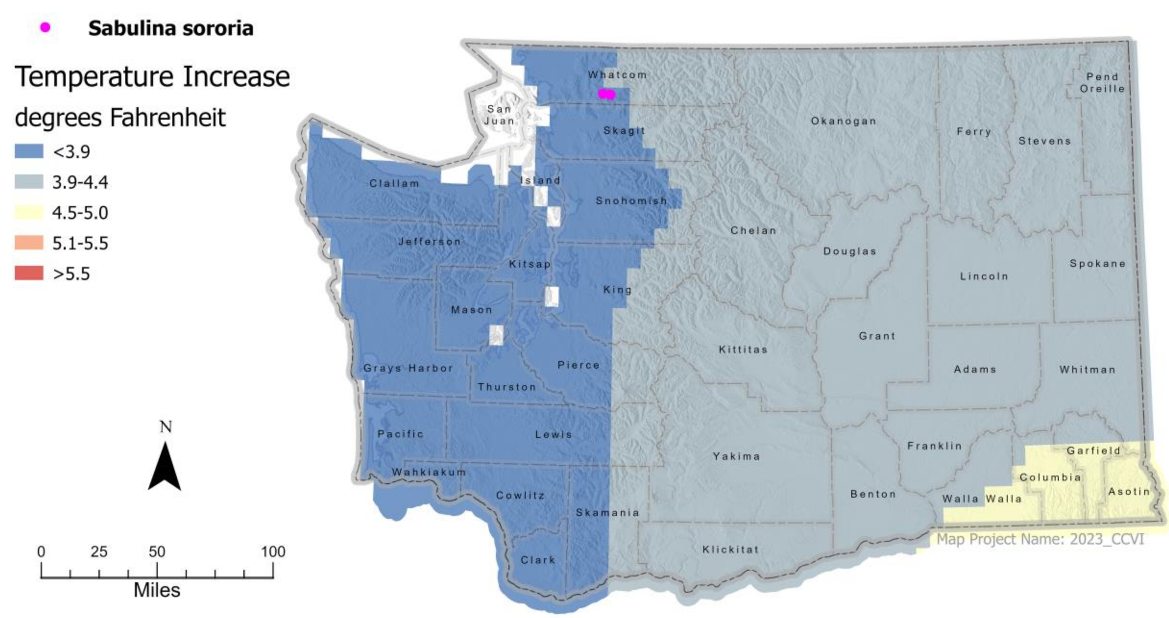

Figure 1. Exposure of *Sabulina sororia* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both known occurrences (100%) of *Sabulina sororia* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to - 0.096 (Figure 2).

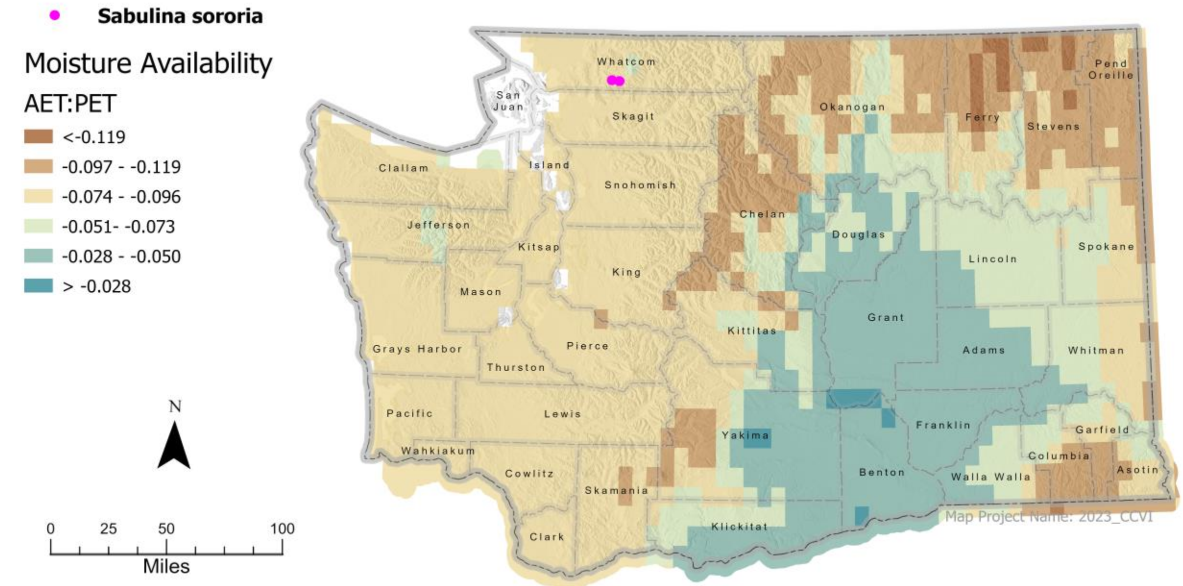

Figure 2. Exposure of *Sabulina sororia* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: <u>Neutral</u>
Sabulina sororia occurs in North Pacific Serpentine Barrens in the Twin Sisters Mountains of the Cascade Range at elevations ranging from 2500-7000 ft (760-2100 m; NatureServe 2023a). *Sabulina sororia* populations in Washington are not expected to be affected by sea level rise based on their inland distribution in Whatcom County and mid to high elevation habitat (Office for Coastal Management 2023).

B2a. Natural barriers: <u>Greatly Increase</u>
Sabulina sororia is restricted to steep montane slopes and fell-fields with loose, sparsely vegetated, gravely soils derived from serpentine bedrock (NatureServe 2023a). This habitat is part of the North Pacific Serpentine Barren ecological system (Rocchio and Crawford 2015). Populations are separated from each other by 3 mi (5 km) of unoccupied and unsuitable forested habitat and alpine ridges. These populations are probably within the dispersal range of this species, and so natural barriers are relatively small; however future migration in response to

climate change will be restricted as serpentine soils are very uncommon, especially in the alpine (U.S. Forest Service 2023).

B2b. Anthropogenic barriers: Neutral
The montane habitat of *Sabulina sororia* in Washington is located on National Forest lands in the Twin Sisters range and vicinity. Although there are some roads and trails within this range, dispersal is probably not limited by anthropogenic impacts. Recreational impacts and limited mining disturbances may be of minor concern.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Sabulina sororia* (Washington Department of Natural Resources 2023).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Sabulina sororia produces egg-shaped capsules which split into three valves to release a few extremely tiny seeds (Washington Natural Heritage Program 2023). Seed dispersal in *Sabulina sororia* is not well understood but the seeds do not have any special adaptations for dispersal (Legler and Dillenberger 2017). The dispersal of *Sabulina sororia* may be similar to that of other *Sabulina* spp. in that seeds can be passively dispersed over short distances by wind or long distances by water and may be able to attach to birds and small animals in mud (Holguin and Dean 2020). Average dispersal distances are probably short (<1000 m), though long-distance dispersal events may occur. High site fidelity to serpentine barrens warrants a higher vulnerability ranking (Young et al. 2016).

C2ai. Historical thermal niche: Increase
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Sabulina sororia* occurrences in Washington. Both known occurrences (100%) are in areas that have experienced little (37 - 47° F (20.8 - 26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be vulnerable to climate warming.

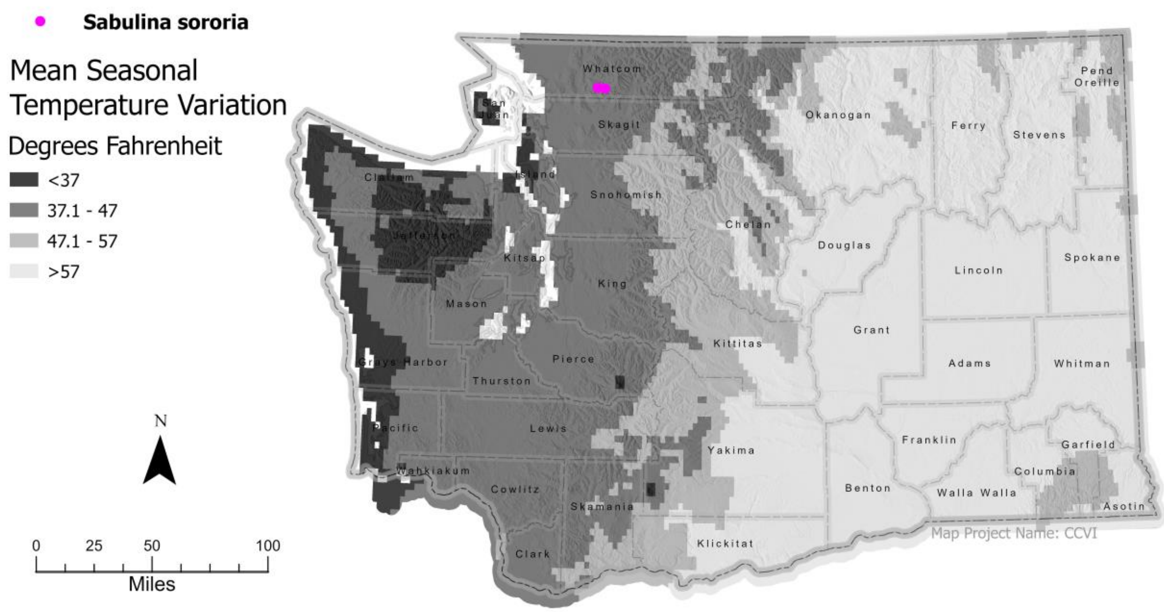

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Sabulina sororia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase
Sabulina sororia occurs at mid to high elevations on the western crest of the Cascades where summers are cool, winters are moderately cold, and the growing season is short (Raymond et al. 2014). However, the serpentine barrens that support this species are generally exposed subalpine ridges with full sun and warmer temperatures than the surrounding landscape (NatureServe 2023a, Washington Natural Heritage Program 2023). *Sabulina sororia* is moderately associated with cold environments and is found across a somewhat broad elevation range.

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Sabulina sororia* occurrences in Washington. Both occurrences (100%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes.

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Sabulina sororia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase

Sabulina sororia requires a mesic environment with balanced moisture availability. The alpine regions of the North Cascades where *Sabulina sororia* occurs experience long winters with high snow accumulation as most precipitation falls as snow (Raymond et al. 2014). Species of the water-limited alpine slopes depend on steady flow of water through the summer months from slow melting snow and ice. Little is documented regarding effects of climate change on alpine serpentine barrens but reduced snowfall, earlier snowmelt, and increased drought are expected to compound harsh soil chemical conditions to create challenging conditions for survival (Rocchio and Ramm-Granberg 2017, NatureServe 2023b).

C2c. Dependence on a specific disturbance regime: Neutral

The high elevation serpentine barrens where *Sabulina sororia* occurs are shaped primarily by geology and associated harsh chemical conditions (Rocchio and Crawford 2015, NatureServe

2023a).Wind, water, and gravity are additional forces acting upon fell-field habitats which lead to continuous erosion and constant change to the microhabitats which support vegetation (Rocchio and Crawford 2015). The rate of erosion and size of rock particles co-determine which organisms occur on cliffs and talus slopes (Larson et al. 2000). This disturbance regime is unlikely to be strongly affected by climate change, however, increases in precipitation falling as rain could increase runoff or ground saturation and alter erosion rates (Chersich et al. 2015).

C2d. Dependence on ice or snow-cover habitats: Neutral
The subalpine to alpine regions of the North Cascades where *Sabulina sororia* occurs experience long winters with high snow accumulation as most precipitation falls as snow (Raymond et al. 2014). However, *Sabulina sororia* tends to avoid areas of late-lying snow and instead appears on exposed flats and slopes with sparse vegetation (Legler and Dillenberger 2017).

C3. Restricted to uncommon landscape/geological features: Increase
The localized patches of serpentine barren and loose, thin, ultramafic (peridotite, serpentine) soils with harsh chemical conditions to which *Sabulina sororia* is endemic are an uncommon ecological system, especially in the alpine (Rocchio and Crawford 2015, NatureServe 2023a). These montane areas of ultramafic rock range from extremely local to many square miles in extent and are surrounded by much larger stretches of coniferous forest. The three regions of Washington that are known to contain significant areas of ultramafic rock are in the Wenatchee Mountains which is out of the dispersal range of the *Sabulina sororia* occurrences in Whatcom County (Washington Division of Geology and Earth Resources 2016). Small subalpine exposures of ultramafic rock in Skagit and Snohomish counties may represent additional suitable and accessible habitat.

C4a. Dependence on other species to generate required habitat: Neutral
The subalpine and alpine serpentine barren habitat occupied by *Sabulina sororia* is maintained primarily by natural abiotic conditions and geology.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral
The specific pollinators of *Sabulina sororia* are not well known but this species possesses nectaries at base of outer stamens (Legler and Dillenberger 2017). Many other *Sabulina* spp. possess floral nectaries which attract a variety of insect pollinators, including flies, bees, and butterflies (Rabeler et al. 2005). *Sabulina sororia* may be like the congener *Sabulina nuttallii,* another western species that also inhabits serpentine soils, which appears to not be pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
Seeds of *Sabulina sororia* have no morphologic features to promote dispersal by wind or for attaching to fur or feather of animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Impacts from pathogens are not known. The low growth form and prickly foliage of this taxon probably reduces herbivory from ungulates and livestock, but not smaller grazers (insects or

rodents). Impacts from grazing are probably minimal on the steep mountain slopes where *Sabulina sororia* occurs.

C4f. Sensitivity to competition from native or non-native species: Neutral
Few species can survive the cold temperatures combined with the harsh soil chemistry of high elevation serpentine communities which support *Sabulina sororia* (U.S. Forest Service 2023), and therefore competition is naturally low. Under projected climate change, these naturally barren sites may become even less hospitable to other plant species due to increased drought stress (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Sabulina sororia does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Unknown
The specific genetics of *Sabulina sororia* in Washington have not been documented but the congener *Sabulina nuttallii,* a western species that also inhabits serpentine soils, is a tetraploid with 2n=36 chromosomes (Hartman 1971).

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Neutral
Sabulina sororia plants range from monoecious to nearly dioecious and reproduce vegetatively from a branching taproot which produces axillary fascicles on new stems (Legler and Dillenberger 2017). The congener *Sabulina nuttallii,* a western species that also inhabits serpentine soils, appears to be an obligate outcrosser. *Sabulina sororia* is likely also an obligate outcrosser and is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Sabulina sororia* (July to August) has not changed significantly since the species was first vouchered in Washington in the early 1900s. However, few records are available to establish a clear trend.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
Sabulina sororia was newly described in 2017 and has not been documented or studied for long enough to clearly identify any responses to climate change. Of the two documented occurrences, one has been relocated and the other has not been revisited since 1961. Further phenological monitoring is warranted as arctic-alpine *Sabulina* spp in the UK have already suffered declines of >50% and are still undergoing range contractions (Watts et al. 2022).

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown

Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

***Silene scouleri* ssp. *scouleri* (Scouler's catchfly)**

Date: 17 May 2024 Synonym: none
Assessor: Molly S. Wiebush, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T3T5/S1
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	12
	3.9-4.4° F (2.2-2.4°C) warmer	50
	<3.9° F (2.2°C) warmer	38
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	25
	-0.074 to -0.096	67
	-0.051 to -0.073	4
	-0.028 to -0.050	4
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Not Ranked
5b. Genetic bottlenecks	Not Ranked
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Nine of 24 occurrences with modeled data (38%) of *Silene scouleri* ssp. *scouleri* in Washington occur in areas with a projected temperature increase of <3.9° F (2.2°C). Twelve of 24 occurrences with modeled data (50%) of *Silene scouleri* ssp. *scouleri* in Washington occur in areas with a projected temperature increase of 3.9–4.4° F (2.2–2.4°C). Three of 24 occurrences with modeled data (12%) of *Silene scouleri* ssp. *scouleri* in Washington occur in areas with a projected temperature increase of 4.5–5.0° F (2.5–2.7°C; Figure 1). One record of *Silene scouleri* ssp. *scouleri* does not have temperature data modeled.

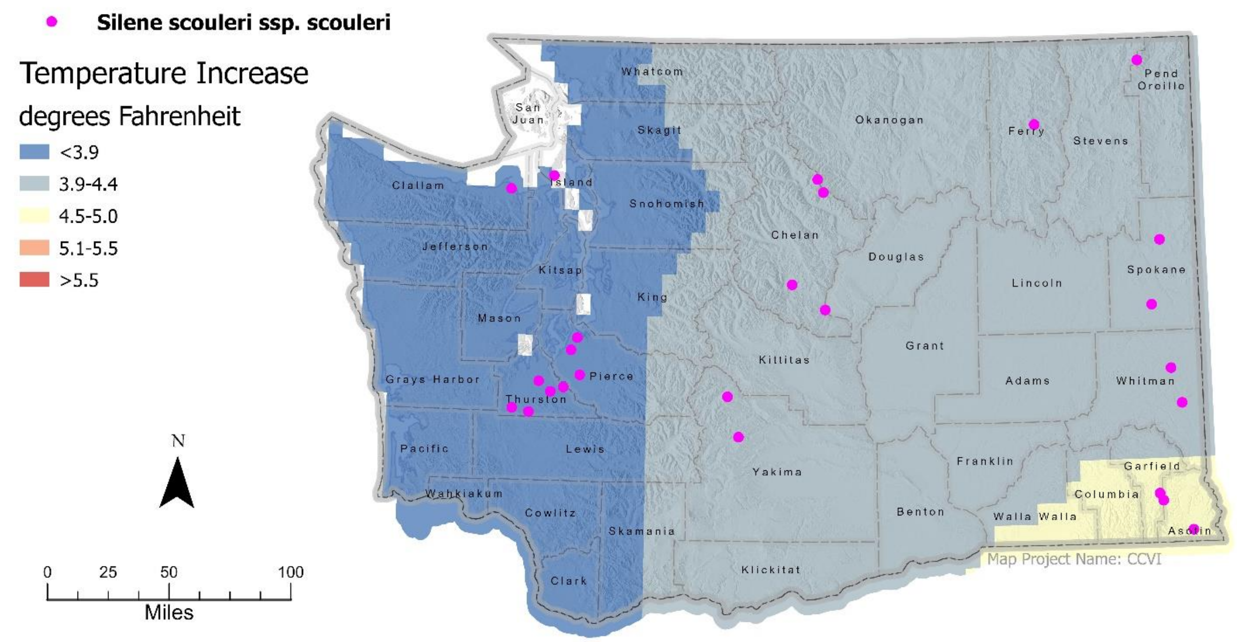

Figure 53. Exposure of occurrences of *Silene scouleri* ssp. *scouleri* in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: One of 24 modeled occurrences (4%) *Silene scouleri* ssp. *scouleri* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.028 to -0.050. One of 24 modeled occurrences (4%) *Silene scouleri* ssp. *scouleri* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to -0.073. Sixteen of 24 modeled occurrences (67%) *Silene scouleri* ssp. *scouleri* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096. Six of 24 modeled occurrences (25%) *Silene scouleri* ssp. *scouleri* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). One record of *Silene scouleri* ssp. *scouleri* does not have moisture data modeled.

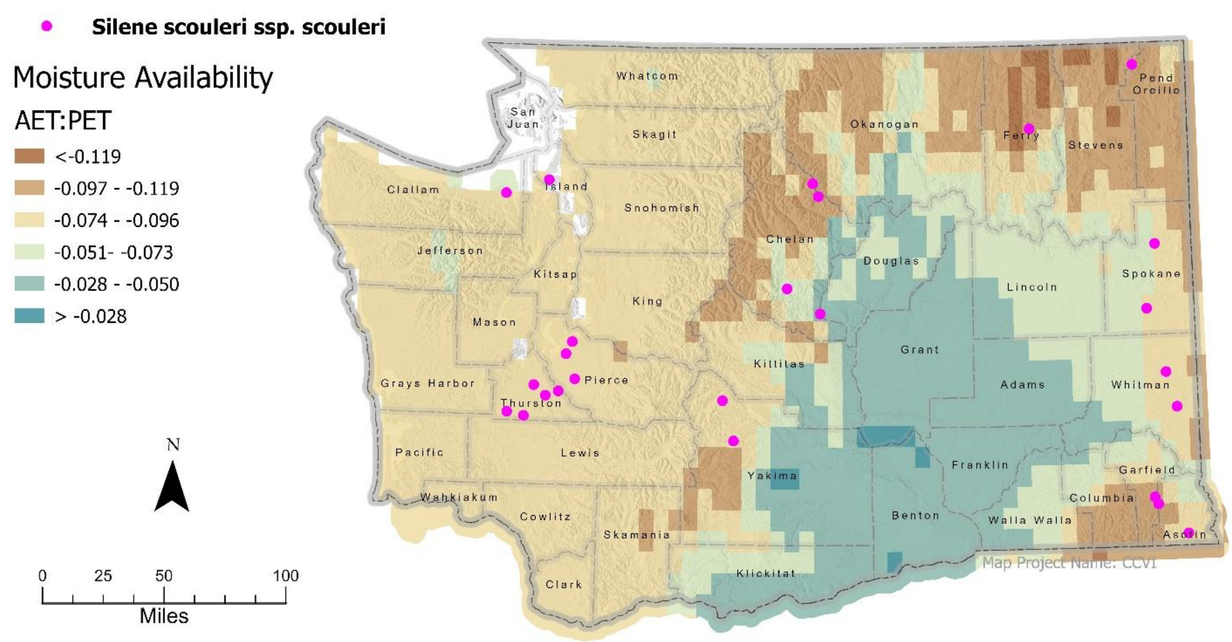

Figure 54. Exposure of occurrences of *Silene scouleri* ssp. *scouleri* in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers form www.natureserve.org.ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Silene scouleri ssp. *scouleri* occurs in dry upland meadows, grasslands, and savannas at elevations of 190–6900 ft (60–2100 m; Washington Natural Heritage Program 2024). Based on inland distribution and/or elevation, populations of this species will not be inundated by projected sea level rise (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
The dry, open grassland and savanna habitats *Silene scouleri* ssp. *scouleri* prefers are widely distributed throughout Washington, though they are most common in northeastern Washington (Rocchio and Crawford 2015). These habitats generally have a patchy distribution, occurring sporadically within a matrix of lowland forest, remnant prairie, and anthropogenic (agricultural, rural, and urban) environments. Current occurrences of *Silene scouleri* ssp. *scouleri* range from 20–300 mi (30–480 km) apart. Barriers to gene flow are probably equally influenced by natural and human barriers.

B2b. Anthropogenic barriers: Somewhat Increase
Silene scouleri ssp. *scouleri* occurs in North Pacific Herbaceous Bald and Bluff; Northern Rocky Mountains Lower Montane, Foothill and Valley Grassland; and Willamette Valley Upland Prairie and Savanna ecological systems. Over 90% of Willamette Valley Upland Prairie and

Savanna has been converted by agriculture and development, and Northern Rocky Mountains Lower Montane, Foothill and Valley Grassland has been fragmented by grazing and alterations to the fire regime (Rocchio and Crawford 2015), likely increasing barriers to gene flow. Gene flow in *Silene scouleri* ssp. *scouleri* is likely equally restricted by natural and anthropogenic processes.

B3. Predicted impacts of land use changes from climate change mitigation: <u>Neutral</u>
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Silene scouleri* ssp. *scouleri* (Washington Department of Natural Resources 2024).

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: <u>Increase</u>
Limited information was found on dispersal in *Silene scouleri* ssp. *scouleri*. The small (1–1.5 mm) seeds have no obvious adaptations for dispersal (Washington Natural Heritage Program 2024). Other *Silene* species in similar habitats have demonstrated poor colonization abilities even within populations, and dispersal ability of *Silene scouleri* ssp. *grandis* (considered as *Silene scouleri* ssp. *scouleri* in the Flora of North America) is also assumed to be poor (Fairbarns and Wilkinson 2002).

C2ai. Historical thermal niche: <u>Somewhat Increase</u>
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”) across the distribution of known *Silene scouleri* ssp. *scouleri* occurrences in Washington. Nine of 24 modeled occurrences (38%) are in areas that have experienced small (37–47° F (20.8–26.3° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to have increased vulnerability to climate warming. Six of 24 modeled occurrences (24%) are in areas that have experienced slightly lower than average (47.1–57° F (26.3–31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be somewhat vulnerable to climate warming. Nine of 24 modeled occurrences (38%) are in areas that have experienced average (>57.1° F (31.8° C)) temperature variation over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming. One record of *Silene scouleri* ssp. *scouleri* does not have thermal data modeled.

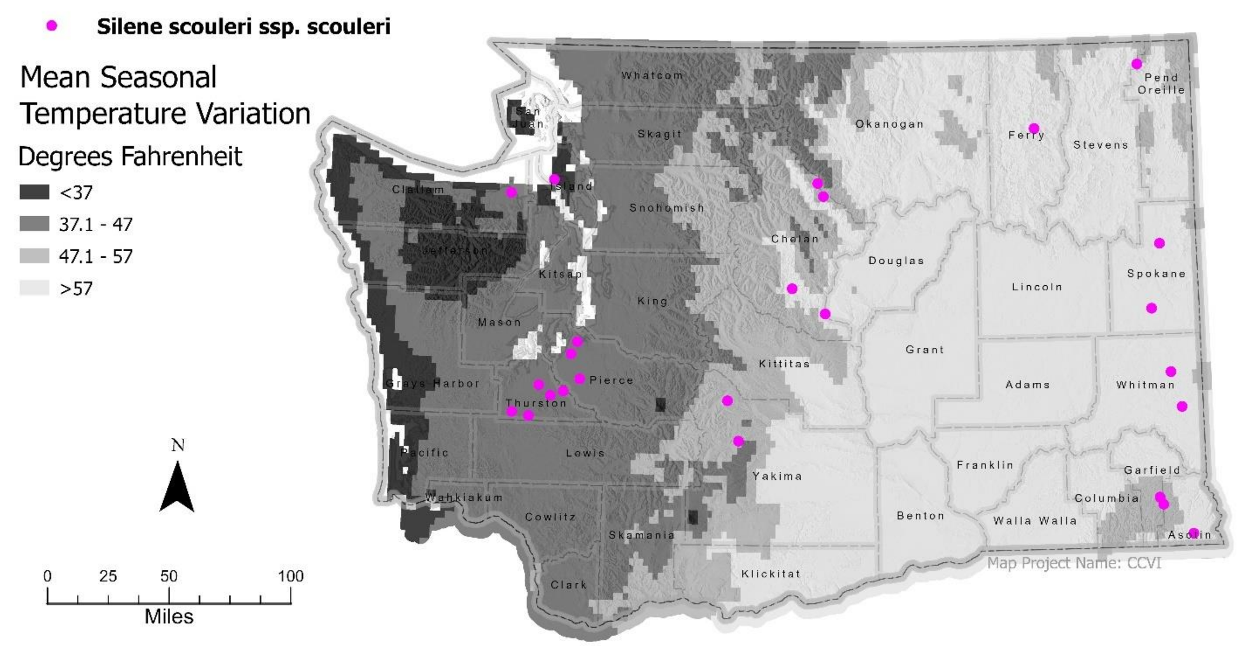

Figure 55. Historical thermal niche (exposure to past temperature variations) of occurrences of *Silene scouleri* ssp. *scouleri* in Washington. Base map layers from www.natureserve.org.ccvi

C2aii. Physiological thermal niche: Neutral
Silene scouleri ssp. *scouleri* generally grows in places that are too warm and dry for trees and shrubs to establish (or that experience frequent enough fires to prevent trees and shrubs from establishing). Bald and bluff habitats generally support species adapted to warm and dry conditions, due to shallow soil prone to drought. Foothill and valley grassland habitats are expected to increase in range in response to climate change as forests are converted. Temperature increases may combine with drought stress to limit adaptive capacity of grasses and grasslands, increase wildfire severity and insect outbreaks, and select for species more common to hotter, drier sites (Rocchio and Ramm-Granberg 2017, NatureServe 2023).

C2bi. Historical hydrological niche: Somewhat Increase
Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 (“historical hydrological niche”) across the distribution of known *Silene scouleri* ssp. *scouleri* occurrences in Washington. One of the 24 modeled occurrences (4%) are in an area that has experienced small precipitation variation (4–10 in (100–254 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be vulnerable to climate change induced shifts to precipitation and moisture regimes. Eighteen of the 24 modeled occurrences (75%) are in an area that has experienced slightly lower than average precipitation variation (11–20 in (255–508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be somewhat vulnerable to climate change induced shifts to precipitation and moisture regimes. Five of the 24 modeled occurrences (21%) are in an area that

has experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period. According to Young et al. (2016) these populations are likely to be resilient to climate change induced shifts to precipitation and moisture regimes. One record of *Silene scouleri* ssp. *scouleri* does not have hydrological data modeled.

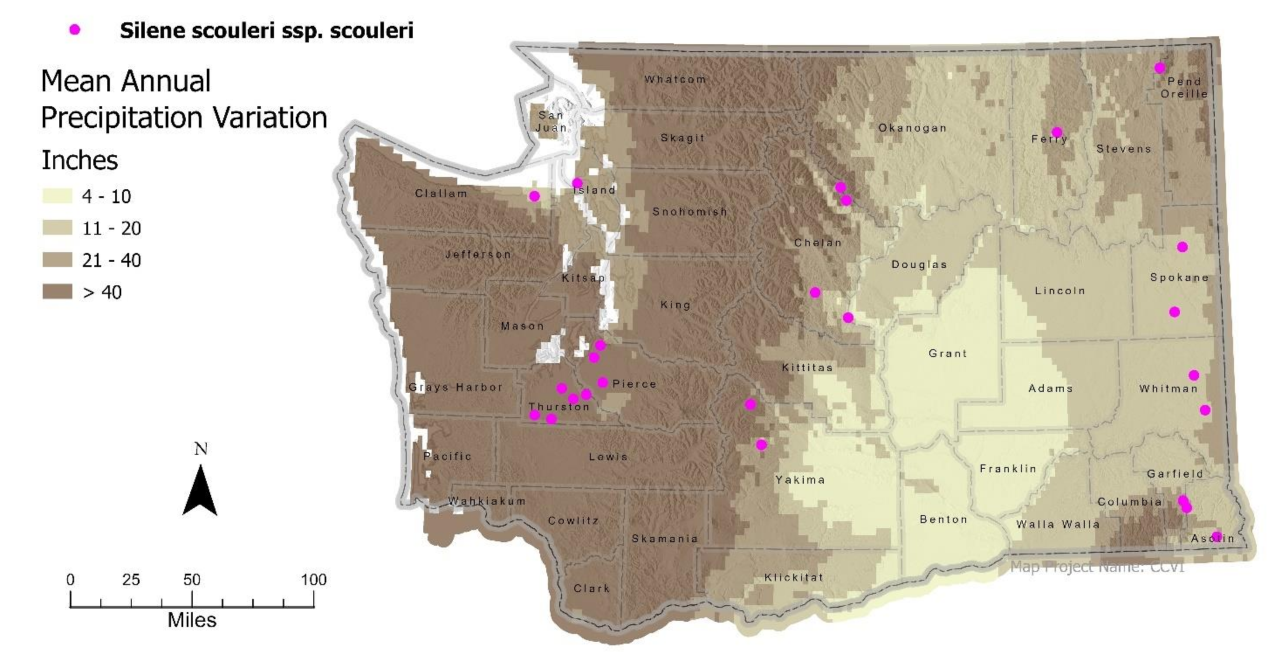

Figure 56. Historical hydrological niche (exposure to past variations in precipitation) of occurrences of *Silene scouleri* ssp. *scouleri* in Washington. Base map layers from www.natureserve.org.ccvi

C2bii. Physiological hydrological niche: Neutral
The habitats *Silene scouleri* ssp. *scouleri* is found in are characterized by warm and dry summers and are likely to be mostly resilient to increases in temperature and decreases in moisture. Increased drought and temperatures in the growing season could lead to an increased risk of wildfire, but this could potentially benefit *Silene scouleri* ssp. *scouleri* by maintaining or increasing the open habitats it prefers (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
The open habitats *Silene scouleri* ssp. *scouleri* prefers are maintained by summer droughts and frequent low-severity fires to prevent the encroachment of trees and shrubs (Rocchio and Crawford 2015). Fire is particularly important in maintaining prairies and savannas in areas that otherwise receive enough rain to support trees and shrubs (e.g., the Willamette Valley Upland Prairie and Savanna ecological system). Historically, these habitats have been maintained by cultural fire. Increased temperatures and decreased precipitation projected from climate change are likely to increase the frequency and intensity of wildfires (Rocchio and Ramm-Granberg 2017), which could benefit this species by favoring grasslands over forests. Reduced soil

moisture, however, could impact herbaceous plants like *Silene scouleri* ssp. *scouleri* and increased disturbance could result in greater competition from invasive non-native plants.

C2d. Dependence on ice or snow-cover habitats: Neutral
While Northern Rocky Mountains Lower Montane, Foothill and Valley Grassland habitats where some occurrences of *Silene scouleri* ssp. *scouleri* are found receive a significant portion of their precipitation as snow (Rocchio and Crawford 2015), this species does not have direct dependence on snow or ice-covered habitats.

C3. Restricted to uncommon landscape/geological features: Neutral
Silene scouleri ssp. *scouleri* prefers habitats associated with well drained or shallow soils. This species occurs across a wide variety of geological substrates and does not appear to be restricted to any uncommon formations or soil types (Rocchio and Crawford 2015, Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
In Northern Rocky Mountains Lower Montane, Foothill and Valley Grassland habitats, grazing helps prevent encroachment of woody species. However abiotic process, particularly fire, droughty soils, and dry summers are the most important factors in structuring the communities *Silene scouleri* ssp. *scouleri* inhabits (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
While little specific pollination is available for *Silene scouleri* ssp. *scouleri*, pollination is relatively well studied for the genus *Silene*. *Silene* species are visited by a wide range of pollinators, including hummingbirds, but not all these visitors are reliable pollinators. Specific plant-pollinator relationships have been documented for several *Silene* species, including relationships with bumblebees, hummingbirds, and night-flying moths. These studies also found significant declines in fruit set and seed production when pollinators were excluded, even in species that were capable of self-pollinating (Lesica 1993, Menges 1995, Reynolds et al. 2009). *Silene scouleri* ssp. *scouleri* flowers range from pale to dark pink (CalPhotos 2024), so they are more likely to be insect than bird pollinated. The likely requirement for pollinator visitation and the potential for a specialist pollinator relationship suggests this species faces somewhat increased vulnerability to climate change.

C4d. Dependence on other species for propagule dispersal: Neutral
Silene scouleri ssp. *scouleri's* small seeds have no obvious adaptations for dispersal by animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Heavy grazing pressure could have an indirect effect on *Silene scouleri* ssp. *scouleri* by increasing soil disturbances and invasion by introduced plant species (Rocchio and Crawford 2015), but no direct threats by pathogens or enemies is documented for this species.

C4f. Sensitivity to competition from native or non-native species: Increase

Introduced annual and perennial grasses are a significant threat to the open grassland and savanna habitats that *Silene scouleri* ssp. *scouleri* prefers. Perennial grasses and other introduced species (e.g., *Vicia* spp.) can outcompete native species for resources, as well as increasing thatch cover, potentially preventing seeds from reaching the soil. In the absence of fire, Willamette Valley Upland Prairie and Savanna ecological systems can also be invaded by woody plants that can shade out native grassland species. In some of these systems, complete replacement of native species by exotic species is possible (Rocchio and Crawford 2015).

C4g. Forms part of an interspecific interaction not covered above: Neutral
At least one *Silene* species (*Silene regia*) been investigated as protocarnivorous, based on its ability to capture insects with sticky, glandular hairs. No evidence of carnivory was discovered, but it appears that these sticky hairs do serve as a defense against herbivory, in particular preventing flowers and seeds from being eaten (Dienno 2017).

C5a. Measured genetic variation: Not Ranked
Data are lacking on the genetic diversity within and between populations of *Silene scouleri* ssp. *scouleri* in Washington.

C5b. Genetic bottlenecks: Not Ranked

C5c. Reproductive System: Somewhat Increase
Silene scouleri ssp. *scouleri*, like most North American *Silene* species, is polyploid with reported ploidies of 4x and 8x (Popp and Oxelman 2007). Kruckeberg (1961) conducted hybridization experiments in greenhouse settings and found *Silene scouleri* ssp. *scouleri* to be capable of hybridizing with and producing some fertile F1 progeny with *Silene parryi*. *Silene parryi* also occurs in Washington and these two species do co-occur, but no records of hybrids have been reported from the wild (CPNWH 2024). *Silene* are frequently protoandrous, which promotes outcrossing while still allowing the possibility of selfing. In *Silene spaldingii*, another rare grassland species found in Washington, both pollinator limitation and inbreeding depression were observed when pollinators were excluded (Lesica 1993). The potential for inbreeding depression in *Silene* suggests that this species may have somewhat increased vulnerability to climate change effects that disrupt its ability to outcross. Where plant species have multiple ploidy levels, natural populations tend to have all the same ploidy number and mixing ploidy numbers in populations can result in sterile offspring, even between plants of the same species (Kruckeberg 1961).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Silene scouleri* ssp. *scouleri* (June–August) has not changed significantly.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
There are no reports of *Silene scouleri* ssp. *scouleri* declining in response to climate change, but little population information is available from the survey data to determine population trends.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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Climate Change Vulnerability Index Report

Sisyrinchium montanum var. montanum (strict blue-eyed-grass)

Date: 6 April 2024 Synonym: none
Assessor: Sienna Wessel, WA Natural Heritage Program
Geographic Area: Washington Heritage Rank: G5T5/S1
Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	67
	-0.074 to - 0.096	0
	-0.051 to - 0.073	33
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All three known occurrences (100%) of *Sisyrinchium montanum var. montanum* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (2.2-2.4° C; Figure 1).

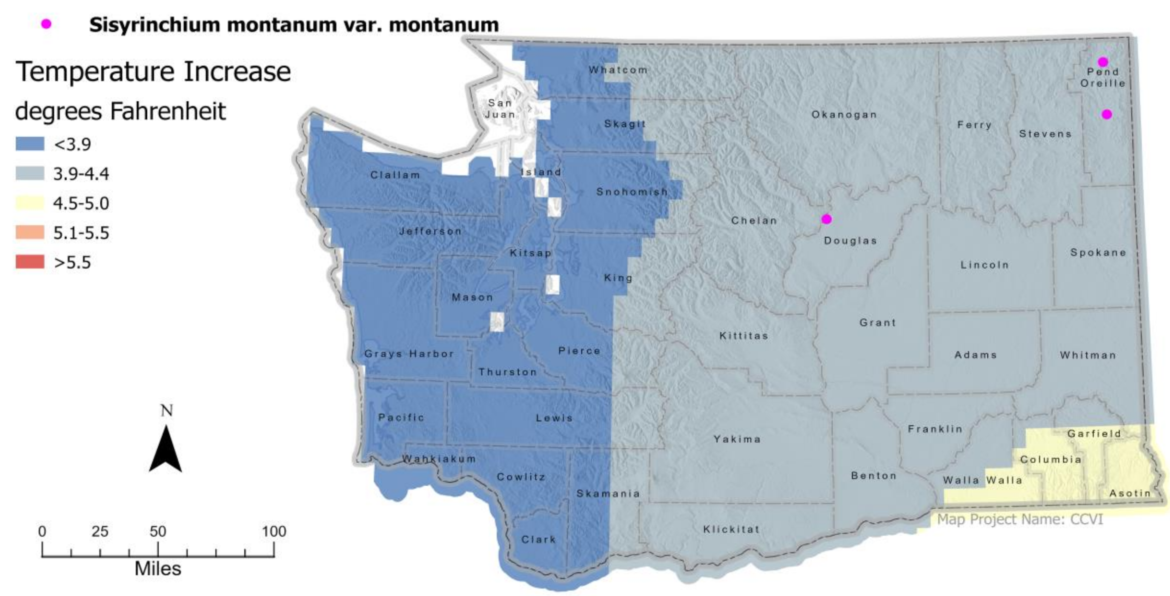

Figure 1. Exposure of *Sisyrinchium montanum* var. *montanum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the three known occurrences (67%) of *Sisyrinchium montanum* var. *montanum* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The remaining occurrence in Douglas County (33%) is in an area with a projected moisture decrease in the range of -0.051 to -0.073.

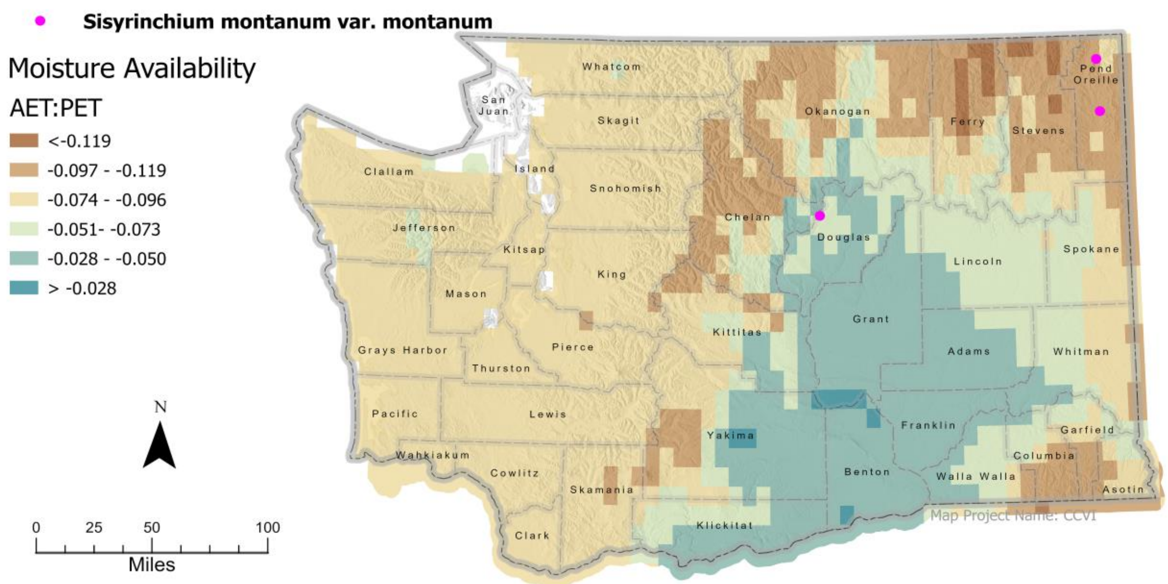

Figure 2. Exposure of *Sisyrinchium montanum var. montanum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral
Sisyrinchium montanum var. *montanum* occurs in moist forest openings and lowland depressions at low elevations (700 ft (215 m)) east of the Cascade crest (Washington Natural Heritage Program 2023). *Sisyrinchium montanum* var. *montanum* in Washington are not expected to be affected by sea level rise based on their inland distribution (Office for Coastal Management 2024).

B2a. Natural barriers: Somewhat Increase
The vernally moist forest openings where *Sisyrinchium montanum* var. *montanum* occurs in the Columbia Plateau Vernal Pool and Rocky Mountain Alpine-Montane Wet Meadow ecological systems are naturally patchy on the landscape (Rocchio and Crawford 2015, Washington Natural Heritage Program 2023). Vernal pool habitats are strongly tied to landscape features that are themselves widely scattered and isolated by strong natural barriers, reducing the likelihood of successful dispersal. Wet meadows occur as small to large patches in a larger forest matrix.

Unsuitable habitat between these patches is likely to pose a moderate barrier to dispersal, though the ability of this species to colonize both habitat types may reduce the impacts of barriers.

B2b. Anthropogenic barriers: Neutral
Development in the areas surrounding Washington occurrences of *Sisyrinchium montanum* var. *montanum* is relatively minimal, though agriculture partially surrounds one occurrence and occurrences are on lands that are not formally protected from development (e.g. National Forest) (Washington Natural Heritage Program 2023). The biggest anthropogenic threats to occurrences are trampling from recreational activities due to nearby campgrounds and trails, but these pose very minimal barriers to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral
There are no known ongoing or proposed clean energy projects that would threaten the populations of *Sisyrinchium montanum* var. *montanum* (Washington Department of Natural Resources 2024), and any potential forest health treatments would likely benefit this species which prefers forest clearings.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Little information on the dispersal distance of *Sisyrinchium montanum* var. *montanum* is available but this species produces globose capsules with numerous, large black seeds (Washington Natural Heritage Program 2023). This species is expected to have a very low dispersal capability based on its large seeds and short stature Laurin 2012). Most seeds fall right below the parent plants (<100 m).

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche") across the distribution of known *Sisyrinchium montanum* var. *montanum* occurrences in Washington. All three known occurrences (100%) are in areas that that have experienced average temperature variation (>57.1° F (31.8° C)) over the historical period. According to Young et al. (2016), these populations are expected to be mostly resilient to climate warming.

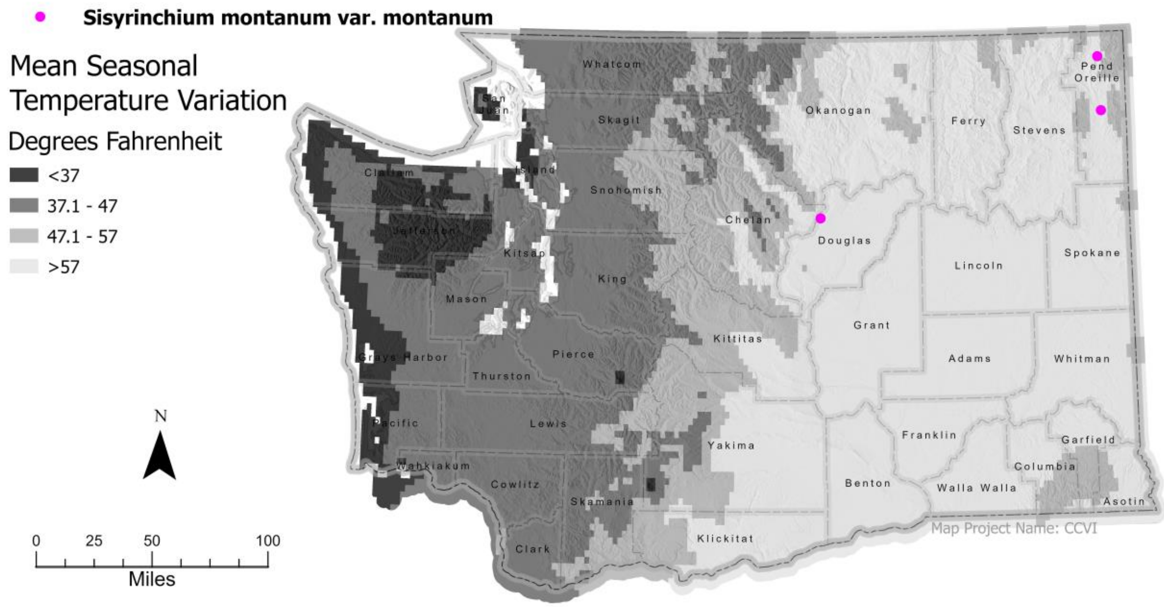

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Sisyrinchium montanum var. montanum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral

The vernal pools and wet meadows which support *Sisyrinchium montanum* var. *montanum* occur in areas which experience extreme seasonal changes where cool winters are followed by hot, dry summers (Crowe et al. 1994, Rocchio and Crawford 2015). These ecological systems are increasingly threatened by warming temperatures which will increase evapotranspiration, cause earlier snowmelt, and could lead to drying of these habitats (Rocchio and Ramm-Granberg 2017). This species already experiences arid conditions during the summertime and may be somewhat resilient to warming.

C2bi. Historical hydrological niche: Neutral

Figure 4 depicts the mean seasonal precipitation variation for the period from 1951-2006 ("historical hydrological niche") across the distribution of known *Sisyrinchium montanum var. montanum* occurrences in Washington. Of the three known occurrences, one in Douglas County (33%) is in an area that has experienced lower than average (11 - 20 in (255 - 508 mm)) precipitation variation over the historical period. According to Young et al. (2016), this population is expected to be somewhat vulnerable to changes in available moisture. The remaining two occurrences (67%) are in areas that have experienced average or greater than average precipitation variation (>20 in (508 mm)) over the historical period and are expected to be mostly resilient to changes in available moisture (Young et al. 2016)

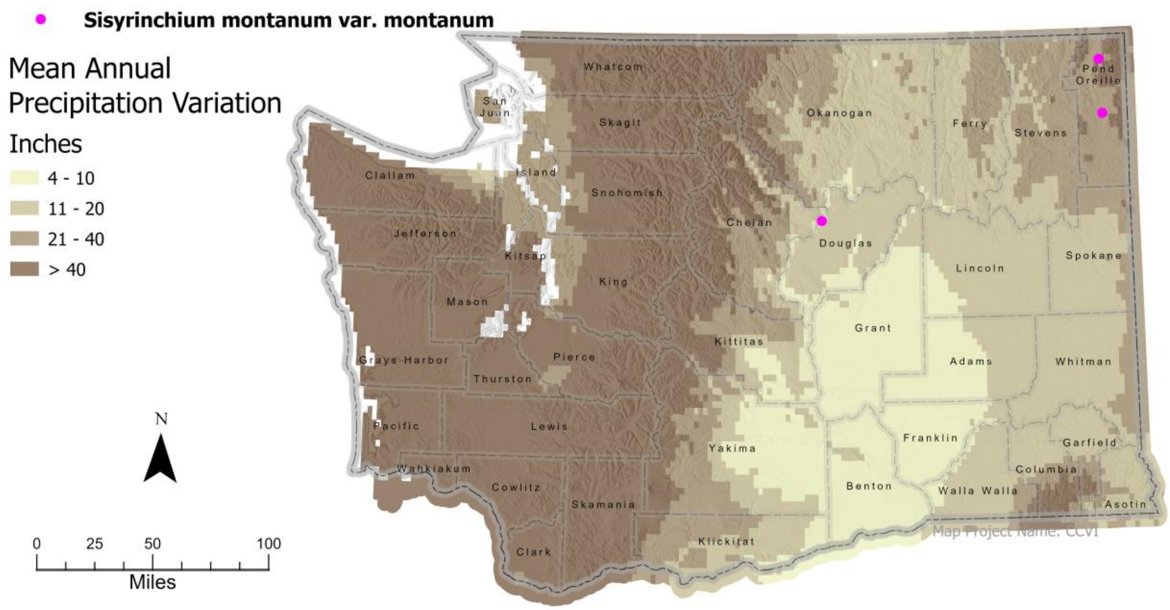

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Sisyrinchium montanum var. montanum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase
Sisyrinchium montanum var. *montanum* associates with vernally moist meadows and depressional pools in otherwise dry steppe and montane forest zones (Washington Natural Heritage Program 2023). It is found growing along natural seeps and springs and just above the high water levels of larger waterways such as rivers in the floodplain as it prefers seasonally mesic conditions but does not tolerate full soil saturation. Changes in the amount and timing of precipitation, especially anticipated reductions to snowpack, are expected to cause water tables to drop in these ecological systems and could lead to the drying out of vernal pools and wet meadows which are not connected to perennial groundwater sources. Effects may include shifts in hydrology, water chemistry, and plant composition (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral
Vernal pools and wet meadows are largely shaped by seasonal hydrological changes and drying combined with basin morphology which together create different fine scale zones with different species composition (Rocchio and Crawford 2015). The duration and depth of inundation are the principal drivers of these ecological systems rather than major disturbances. These habitats are currently not typically susceptible to fire but could become more vulnerable if water tables are lowered due to decreased snowpack or increased summer temperature or drought (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
Anticipated shifts in precipitation from winter snow to rain are likely to cause earlier drying of the wet meadows and moist depressions which support *Sisyrinchium montanum* var. *montanum* (Rocchio and Ramm-Granberg 2017). Other than impacts to the water supply of the habitat, *Sisyrinchium montanum* var. *montanum* is not particularly associated with ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase
Sisyrinchium montanum var. *montanum* occurs on mossy silt loam soils that are shallow to moderately deep and derived from residuum and colluvium with a component of loess. Parent materials include migmatite and various metamorphic and igneous rocks as well as Pleistocene glaciolacustrine deposits (Washington Division of Geology and Earth Resources 2016, Soil Survey Staff 2024). These geological features range from limited to widespread in distribution. Vernal pools must be deep enough to flood in winter and early spring but shallow enough to dry in summer and are an uncommon feature on the landscape (Rocchio and Crawford 2015), making this species a habitat specialist.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
Beavers are an important hydrogeomorphic driver of wet meadows. When dams are initially created, they often flood and kill large areas of shrublands that are eventually colonized by herbaceous emergent and submergent vegetation (Rocchio 2006). Wet meadow sites may be enhanced by browsing by ungulates or other herbivores that contain the encroachment of woody vegetation (Rocchio and Crawford 2015). Vernal pools are maintained more by abiotic forces.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase
Sisyrinchium spp. are often either self-incompatible or still require insect pollinators to accomplish self-pollination (Beyer 2003) which are typically solitary bees of the family Megachilidae. Pollinator exclusion experiments shows that *Sisyrinchium montanum* var. *montanum* is capable of producing a high number of fruits without insect pollination (Wheelwright et al. 2006). This species is not especially pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral
Sisyrinchium montanum var. *montanum* is dispersed passively by gravity and does not rely on other species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral
Wet meadows and vernal pools can be negatively impacted by grazing as it causes both soil compaction and disturbance which can alter hydrology and nutrient cycling and favor upland species that can shift the community composition (Rocchio 2006, Rocchio and Crawford 2015). However, *Sisyrinchium montanum* var. *montanum* appears to be moderately resistant to grazing (Laurin 2012). Grazing is not expected to increase because of climate change.

C4f. Sensitivity to competition from native or non-native species: Increase
Sisyrinchium montanum var. *montanum* is generally an early seral species that can become quite dense after light disturbance; therefore, succession is a major threat as this species needs a

somewhat open canopy. Observational records indicate that occurrences in Washington are already facing a lot of herbaceous competition from exotic species such as *Phalaris arundinacea* (reed canary grass) and *Medicago sativa* (alfalfa). Anticipated drying of the wet meadow and vernal pool habitats that support *Sisyrinchium montanum* var. *montanum* could increase the establishment of non-natives and allow for tree and shrub encroachment in areas with deep enough soil (Rocchio 2006, Raymond et al. 2014, Rocchio and Crawford 2015).

C4g. Forms part of an interspecific interaction not covered above: Neutral
Sisyrinchium montanum var. *montanum* does not have any other known interspecific interactions to note.

C5a. Measured genetic variation: Neutral
The genetic variation of *Sisyrinchium montanum* var. *montanum* has not been documented.

C5b. Genetic bottlenecks: Unknown

C5c. Reproductive System: Somewhat Increase
The parent species *Sisyrinchium montanum* is dodecaploid with many aneuploid races in North America (Ingram 1968). This species has a mixed mating system that allows for both insect pollination and self-pollination with a high number of fruits produced without insect visitation (Wheelwright et al. 2006). The closely related *Sisyrinchium montanum* ssp. *cerebrum* is known to lack cytological complexity because it is almost an obligate self-pollinator due to its floral structure (Ingram 1968). Some species of *Sisyrinchium* can also propagate vegetatively from axils. Polyploidy and mixed mating systems are traits indicative of average to high genetic variation but the near reliance on selfing may indicate lower genetic variation (Young et al. 2016). This species probably has moderate genetic diversity.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown
Based on herbarium specimens in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP records, the flowering period of *Sisyrinchium montanum* var. *montanum* (May-June) has not changed significantly (Washington Natural Heritage Program 2023). However, there are not enough records available to truly assess trends in Washington. A study of this species in Massachusetts found flowering times to be 8 days earlier on average between 1980 and 2015 based on herbarium specimens (Bertin et al. 2017).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown
The response of *Sisyrinchium montanum* var. *montanum* to climate change has not been clearly documented. However, the Pend Oreille County population discovered in 1981 could not be relocated in 2014 and the Douglas County population decreased from about 50 plants to 6 from 1999 to 2005 (Fertig and Kleinknecht 2020). Trends are probably downward but the relationship to climate change is not clear.

D2. Modeled future (2050) change in population or range size: Unknown
Not modeled.

D3. Overlap of modeled future (2050) range with current range: Unknown
Not modeled.

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown
Not modeled.

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