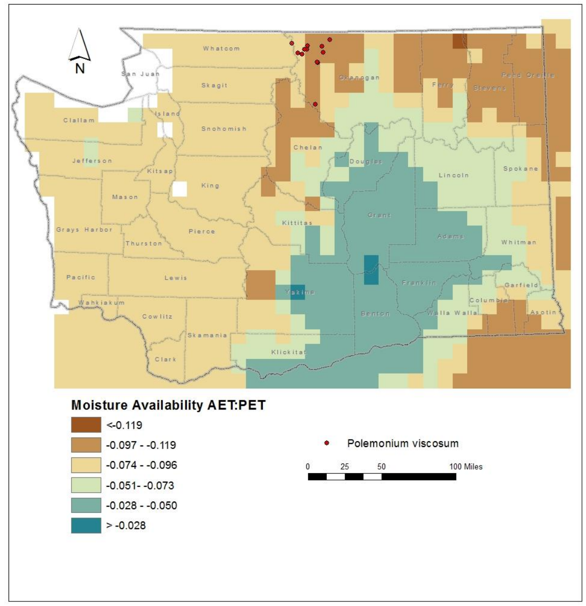
WASHINGTON NATURAL HERITAGE PROGRAM



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

Prepared for

US Forest Service, Region 6

Prepared by

Walter Fertig

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

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Note: Individual CCVI reports from this study and earlier projects are hosted on the Washington Natural Heritage Program website at: https://www.dnr.wa.gov/NHPclimatespecies

ON THE COVER: Sticky sky-pilot (*Polemonium viscosum*) and map of its distribution in Washington relative to projected moisture availability.

Photograph by Walter Fertig.

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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). In order 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 (ISSSP 2019). 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 "Phase II", consisting of CCVI reports for 55 new plant species listed as BLM or USFS Sensitive or WNHP species of concern (Fertig 2021b). The following report includes the results of these Phase II assessments (Appendix A), as well as a summary of all 107 CCVI reports completed from 2019-2021 for Washington rare plant species.

Methods

In 2020, ISSSSP staff identified an initial set of 124 USFS and BLM Sensitive species for potential CCVI assessment as part of Phase II of this project, of which 55 were completed (Appendix A). These species were selected to represent a variety of taxonomic groups and a cross section of habitats, geographic patterns, and rarity types (such as narrow endemics, regional endemics, disjuncts, or species at the periphery of their range). Some species from the intial target list were excluded because they were dropped from the draft 2021 ISSSSP Sensitive species list (released after the project began) (Fertig 2021b).

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 WNHP Biotics database. Values from these maps were entered directly into the CCVI calculator or 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 2021), and *Ecological Systems of Washington State: A Guide to Identification* (Rocchio and Crawford 2015). 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 (Table 1) and using scoring criteria defined by Young et al. (2016). 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 (Table 2), depending on the degree to which a species is likely to be impacted by climate change in the state by 2050 (Young et al. 2016).

Results and Discussion

Phase II Results

Of the 55 vascular plant species examined in Phase II of this project, only two (*Draba cana* and *Polemonium viscosum*) scored as Extremely Vulnerable to climate change (Table 3, Appendix A). Both of these are alpine species from the Okanogan Range that occur in areas projected to have increased temperatures, more pronounced temperature variability, and reduced snowpack (Tables 3, 4). These species also have limited dispersal capability, occur on uncommon geologic substrates, and have potential reproductive constraints (Table 4).

Twenty-one species in Phase II scored as Highly Vulnerable to climate change (Table 3). Nine of these species (43%) are from alpine habitats and eight (38%) occur in peatlands, wet meadows, or riparian sites. Eighty-one percent of Highly Vulnerable species have somewhat to greatly increased risk from rising temperatures (historical thermal niche) and 100% are associated with cool or cold environments (physiological thermal niche) (Table 4). These species are also correlated with moister sites (90% based on the ratio of actual to potential evapotranspiration) and are strongly dependent on seasonal moisture sources (100% have somewhat to greatly increased risk based on their physiological hydrological niche), and adequate winter ice or snow (90%) (Table 4). Highly vulnerable species are also associated with specialized geologic substrates or landforms (71%), have dispersal limitations (90%), or low genetic variability or reproductive constraints (52%) (Table 4).

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 (i.e. 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
2a. Distribution relative to natural barriers (degree to which natural 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
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

Ranking Factor	Condition	Score
2ai Change in historical thermal niche (exposure to large scale temperature variation in past 50 years) Based on Figure 3 in each CCVI report (see appendix)	Very small temperature variation (<37˚F or 20.8˚C)	Greatly Increase
	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
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
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
Ranking Factor	**Condition**	**Score**
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

Ranking Factor	Condition	Score
4a. Dependence on others 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
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 above (species with mutualistic relationships)	Requires an interaction with a single species for persistence	Increase
	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
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

Ranking Factor	**Condition**	**Score**
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
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
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

The majority of species assessed in Phase II (31 of 55) scored as Moderately Vulnerable to climate change (Table 3). Unlike the species rated Extremely or Highly Vulnerable, the Moderately Vulnerable taxa are not strongly correlated with specific geographic areas or habitats. Moderately Vulnerable species are distributed over 14 different geographic regions of the state, with the highest number (13 taxa or 42%) from the Columbia Plateau ecoregion. Species rated Moderately Vulnerable occur in 15 major habitat types, of which the largest number (10 taxa or 32%) are found on cliffs or talus. In general, Moderately Vulnerable species are more likely to be associated with drier or hotter sites than species rated Extremely or Highly Vulnerable. Only 48% of Moderately Vulnerable species are at somewhat to greatly increased risk from rising temperatures (historical thermal niche) and 68% are associated with cool or cold environments (physiological thermal niche) (Table 4). Likewise, Moderately Vulnerable taxa are less correlated with moister sites (52% based on AET:PET ratio) or dependent on sufficient winter ice and snow (58%) (Table 4). These species are also less restricted to uncommon geologic types or landforms (48%), have dispersal limitations (74%), or reproductive/genetic issues (29%) (Table 4).

Leptosiphon bolanderi is the only species assessed in Phase II to score as Less Vulnerable to climate change (Table 3). This species occurs in naturally disturbed soils within Oregon oak communities in the southern Cascades and is adapted to dry and warm sites (Table 4). It may actually benefit from increased disturbance from fire or drought under projected climate change (Appendix A). **[continued on page 18]**

Table 3. Summary of Climate Change Vulnerability Index scores for 55 Washington rare plant taxa assessed in Phase II. WA Status: BS = BLM Sensitive; FS = US Forest Service Sensitive; WE = Washington State Endangered, WEx= Washington State Extirpated; WS = Washington State Sensitive; WT = Washington State Threatened (Fertig 2021b). CCVI Score: EV = Extremely Vulnerable; HV = Highly Vulnerable; LV = Less Vulnerable; MV = Moderately Vulnerable.

Species (Common Name)	Heritage Rank	WA Status	Major Habitat	Geographic Distribution	CCVI Score
Allium constrictum (constricted onion)	G2G3/S2S3	BS, WS	Vernal pools	NW Columbia Plateau	MV
Anemone patens var. *multifida* (pasqueflower)	G5T5/S1	BS, FS, WS	Montane talus slopes & meadows	Wenatchee Mountains	HV
Arabis olympica (Olympic rockcress)	GH/SH	FS, WEx	Alpine meadows	Olympic Range	HV
Arcteranthis cooleyae (Cooley's buttercup)	G5/S1	BS, FS, WS	Rocky cliffs	Olympic Range & North Cascades	MV
Astragalus arrectus (Palouse milkvetch)	G2G4/S2	BS, FS, WT	Sagebrush & grasslands	E Columbia Plateau	MV
Astragalus arthuri (Arthur's milkvetch)	G4/S2	BS, FS, WS	Palouse grasslands	Blue Mountain foothills	MV
Astragalus australis var. *cottonii* (Cotton's milkvetch)	G2Q/S2	BS, FS, WT	Alpine talus & scree	Olympic Range	HV
Astragalus microcystis (least bladdery milkvetch)	G5/S2	BS, FS, WS	Alpine and riverbank gravel	Olympic Range & NE Washington rivers	MV
Astragalus misellus var. *pauper* (pauper milkvetch)	G3T3/S2	BS, WT	Sagebrush ridges	W Columbia Plateau	MV
Carex circinata (coiled sedge)	G5/S1	BS, FS, WS	Cliffs & wet meadows	Olympic Range	MV
Carex heteroneura (smooth-fruited sedge)	G5/S2S3	FS, WS	Montane moist meadows	Okanogan Range	HV
Carex pauciflora (few-flowered sedge)	G5/S2	BS, FS, WS	Peatlands	North Cascades & Puget Trough	HV
Carex vallicola (valley sedge)	G5/S2	BS, FS, WS	Montane dry meadows & sagebrush	Okanogan Plateau & N Columbia Plateau	HV
Castilleja cryptantha (obscure paintbrush)	G2G3/S2S3	BS, FS, WS	Alpine/sub-alpine meadows	West Cascades	HV
Chaenactis thompsonii (Thompson's chaenactis)	G3/S3	BS, FS, WS	Serpentine slopes	Wenatchee Mountains	MV
Cicuta bulbifera (bulb-bearing water hemlock)	G5/S2S3	BS, FS, WS	Peatlands, marshes, floaring mats	Canadian Rockies, East Cascades, & Puget Trough	MV
Coptis aspleniifolia (spleenwort-leaved goldthread)	G5/S2	BS, FS, WS	Wet areas in old growth red cedar/hemlock forests	Olympic Peninsula & North Cascades	MV

Species (Common Name)	Heritage Rank	WA Status	Major Habitat	Geographic Distribution	CCVI Score
Cryptantha rostellata (beaked cryptantha)	G4/S2	BS, FS, WS	Sagebrush slopes	Columbia Plateau	MV
Dactylorhiza viridis (frog orchid)	G5/S1	BS, FS, WS	Seasonally moist areas in Douglas-fir/aspen forests	E Okanogan Range	HV
Damasonium californicum (fringed water-plantain)	G4/S1	FS, WS	Shallow scabland ponds	Columbia River Gorge	MV
Dendrolycopodium dendroideum (tree clubmoss)	G5/S2	BS, FS, WS	Rock outcrops at edge of conifer forests	Canadian Rockies & North Cascades	MV
Draba cana (lance-leaved draba)	G5/S1	BS, FS, WS	Alpine slopes	Okanogan Range	EV
Draba taylorii (Taylor's draba)	G1G2/S1	FS, WE	Alpine/sub-alpine slopes	Okanogan Range	HV
Erigeron aliceae (Eastwood's daisy)	G4/S2	BS, WS	Talus slopes & wet meadows	Olympic Range & Willapa Hills	MV
Erigeron basalticus (basalt daisy)	G2/S2	BS, WT	Basalt cliffs	Yakima River Canyon	MV
Eritrichium argenteum (pale alpine forget-me-not)	G4/S1	BS, FS, WS	Alpine meadows	Okanogan Range/East Cascades	HV
Eryngium petiolatum (Oregon coyote-thistle)	G4/S2	WS (formerly BS & FS)	Seasonally wet meadows	Puget Trough & East Cascades	MV
Erythranthe pulsiferae (candelabrum monkeyflower)	G4?/S2	BS, FS, WS	Seasonally wet meadows & forest openings	Columbia River Gorge & southern Cascades	MV
Gentiana douglasiana (swamp gentian)	G5/S2	FS, BS, WS	Moist meadows, often seasonally flooded	Olympic Peninsula & central Cascades	HV
Geum rossii var. *depressum* (Ross' avens)	G5T1/S1	FS, WE	Alpine/sub-alpine talus	Wenatchee Mountains	HV
Hackelia hispida var. *disjuncta* (sagebrush stickseed)	G4T3/S3	BS, WS	Basalt cliffs & talus	NW Columbia Plateau	MV
Juncus uncialis (inch-high rush)	G3G4/S2	BS, WT	Vernal pools	N Columbia Plateau	MV
Leptosiphon bolanderi (Bolander's linanthus)	G4G5/S2	BS, FS, WS	Bare rocky opening in white oak forest	Southern Cascades & Columbia River Gorge	LV
Lomatium knokei (Knoke's biscuitroot)	G1/S1	BS, FS, WE	Seasonally moist meadows	Cle Elum Ridge, East Cascades	HV
Lomatium lithosolamans (Hoover's biscuitroot)	G2G3/S2S3	BS, WS	Sagebrush steppe on lithosols	W Columbia Plateau & East Cascades	MV
Lomatium serpentinum (Snake Canyon biscuitroot)	G4/S2	BS, WS	Basalt cliffs above river	Snake River drainage, SE Washington	HV

Species (Common Name)	**Heritage Rank**	**WA Status**	**Major Habitat**	**Geographic Distribution**	**CCVI Score**
Luzula arcuata ssp. *unalaschcensis* (curved woodrush)	G5T4T5/S1	FS, WS	Alpine/sub-alpine ridges & meadows	Okanogan Mountains and Cascades	HV
Micranthes tischii (Olympic saxifrage)	G2/S1?	FS, WE	Alpine/sub-alpine ridges	Olympic Range	HV
Myosurus alopecuroides (foxtail mousetail)	G3?/S2	BS, WT	Vernal pools	Columbia Plateau	MV
Orthocarpus bracteosus (rosy owl's-clover)	G3?/S2	BS, FS, WT	Moist meadows	Southern Cascades & Puget Trough	HV
Pellaea breweri (Brewer's cliffbrake)	G5/S2	FS, WS	Bedrock cliffs	Olympic Range, Cascades, & Okanogan Range	MV
Penstemon eriantherus var. *whitedii* (Whited's fuzzytongue beardtongue)	G4G5T2/S2	BS, FS, WT	Sparsely vegetated ridges & canyons	East Cascades & Columbia River	MV
Petrophytum caespitosum ssp. *caespitosum* (Rocky Mountain rockmat)	G5T5/S1	BS, WS	Limestone cliffs	Blue Mountains	HV
Phacelia lenta (Sticky phacelia)	G2?/S2?	BS, WT	Basalt cliffs	NW Columbia Plateau	MV
Polemonium viscosum (sticky sky-pilot)	G5/S2	BS, FS, WS	Alpine talus slopes	Okanogan Mountains	EV
Ranunculus californicus (California buttercup)	G5/S1	BS, WS	Coastal bluffs & grasslands	San Juan Islands	MV
Ribes cereum var. *colubrinum* (wax currant)	G5T3/S1	BS, FS, WE	Streams in rocky canyons	Snake River Canyon & Blue Mountains	HV
Sabulina nuttallii var. *fragilis* (Nuttall's sandwort)	G5T4/S1	BS, WS	Basalt talus ridges	Columbia Plateau	MV
Salix maccalliana (MacCalla's willow)	G5/S1	BS, FS, WS	Peatlands & forested wetlands	Okanogan Mountains & Canadian Rockies	HV
Sanicula arctopoides (bear's-foot sanicle)	G5/S1	BS, WS	Coastal bluffs	San Juan Islands & Pacific Coast	MV
Silene seelyi (Seely's catchfly)	G3/S3	BS, FS, WS	Shady cliffs	Wenatchee Mountains	MV
Spartina pectinata (prairie cordgrass)	G5/S2	BS, FS, WS	River banks & marshes	Columbia River & tributaries	MV
Trillium albidum ssp. *parviflorum* (small-flowered trillium)	G4G5T2T3/S2S3	WS (formerly BS, FS)	Moist areas in Oregon ash/ white oak forest	Puget Trough	MV
Utricularia intermedia (flat-leaved bladderwort)	G5/S2S3	BS, FS, WS	Ponds, streams, & wet meadows	Olympic Peninsula & Cascades	MV
Veronica dissecta var. *lanuginosa* (woolly kittentails)	G4T3/S2	BS, FS, WT	Alpine talus & meadows	Olympic Range	HV

Table 4. Comparison of Selected Variables in Climate Change Vulnerability Index scores for 107 Washington rare plant taxa assessed in Phases I and II.

An * indicates species assessed in Phase II. 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. AET:PET (Moisture Availability): the 6 categories used in the CCVI are simplified here as "drier" (for values ranging from > -0.073) and "moister" (for values < -0.074). Disp = Dispersal and Movements. Hist Therm N = Historical Thermal Niche. Phys Therm N = Physiological Thermal Niche. Hist Hydr N = Historical Hydrological Niche. Phys Hydr N = 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. **Scoring**: G Inc: = Greatly Increased vulnerability; Inc = Increased vulnerability, S Inc: = Somewhat Increased Vulnerability; Neut = Neutral vulnerability, Unk = Unknown.

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Allium campanulatum (Sierra onion)	LV	Moister	S Inc	S Inc	Neut	Neut	Neut	Neut	Neut	Neut
**Allium constrictum* (constricted onion)	MV	Drier	S Inc	Neut	Neut	S Inc	G Inc	Neut	S Inc	S Inc
**Anemone patens* var. *multifida* (pasqueflower)	HV	Moister	Inc	S Inc	S Inc	Neut	S Inc	S Inc	S Inc	S Inc
**Arabis olympica* (Olympic rockcress)	HV	Moister	S Inc	G Inc	Inc	Neut	S Inc	Inc	S Inc	Inc
**Arcteranthis cooleyae* (Cooley's buttercup)	MV	Moister	Inc/ S Inc	S Inc	Inc	Neut	S Inc	S Inc	S Inc	Neut
**Astragalus arrectus* (Palouse milkvetch)	MV	Drier	S Inc	Neut	Neut	S Inc	S Inc	Neut	Neut	Neut
**Astragalus arthuri* (Arthur's milkvetch)	MV	Moister	S Inc	Neut	Neut	S Inc	S Inc	Neut	Neut	Neut
Astragalus asotinensis (Asotin milkvetch)	HV	Moister	S Inc	Neut	Neut	S Inc	S Inc	Neut	Inc	Neut
**Astragalus australis* var. *cottonii* (Cotton's milkvetch)	HV	Moister	Inc	G Inc	Inc	Neut	S Inc	S Inc	S Inc	S Inc
Astragalus columbianus (Columbia milkvetch)	MV	Drier	S Inc	Neut	Neut	Inc	S Inc	Neut	Neut	Neut
**Astragalus microcystis* (least bladdery milkvetch)	MV	Moister	S Inc	S Inc/ Neut	Inc/S Inc	Neut	Inc/S Inc	S Inc	S Inc/ Neut	Neut
**Astragalus misellus* var. *pauper* (pauper milkvetch)	MV	Drier	S Inc	Neut	Neut	Inc	S Inc	Neut	S Inc/ Neut	Neut

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Carex anthoxanthea (Yellow-flowered sedge)	MV	Moister	S Inc	Gr Inc	S Inc	Neut	S Inc	Inc	Neut	Neut
Carex chordorrhiza (Cordroot sedge)	HV	Moister	S Inc	Inc	S Inc	Neut	S Inc	Inc	Neut	Neut
**Carex circinata* (coiled sedge)	MV	Moister	S Inc	G Inc	Inc	Neut	S Inc	Inc	Neut	Neut
**Carex heteroneura* (smooth-fruited sedge)	HV	Moister	S Inc	S Inc	Inc	Neut	Inc	S Inc	S Inc	S Inc
**Carex pauciflora* (few-flowered sedge)	HV	Moister	Inc/ S Inc	Inc	S Inc	Neut	Inc	S Inc	Neut	Neut
Carex proposita (Smoky Mountain sedge)	MV	Moister	S Inc	S Inc	Inc	Neut	S Inc	Inc	Neut	Neut
Carex rostrata (Beaked sedge)	HV	Moister	S Inc	Neut	Inc	Neut	Inc	S Inc/ Neut	Neut	Neut
Carex sychnocephala (Many-headed sedge)	MV	Drier	S Inc	Neut	S Inc	S Inc	S Inc	S Inc	Neut	Neut
Carex tenuiflora (Sparse-flowered sedge)	HV	Moister	S Inc	S Inc	S Inc	Neut	Inc	S Inc	S Inc	Neut
**Carex vallicola* (valley sedge)	HV	Moister	S Inc	Neut	S Inc	S Inc	S Inc	S Inc	Neut	Neut
**Castilleja cryptantha* (obscure paintbrush)	HV	Moister	Inc	Inc	G Inc	Neut	S Inc	S Inc	Inc	Inc
Castilleja levisecta (Golden paintbrush)	HV	Moister	Inc	Gr Inc	Neut	Neut	Neut	Neut	Neut	Neut
**Chaenactis thompsonii* (Thompson’s chaenactis)	MV	Moister	S Inc	S Inc	Inc	Neut	S Inc	S Inc	Inc	Neut
Chrysolepis chrysophylla var. *chrysophylla* (Golden chinquapin)	MV	Moister	S Inc	Inc	Neut	Neut	Neut	Neut	Neut	S Inc
Chrysosplenium tetrandrum (Northern golden-carpet)	MV	Moister	S Inc	Inc	S Inc	Neut	S Inc	Neut	Neut	S Inc
**Cicuta bulbifera* (bulb-bearing water hemlock)	MV	Moister	S Inc	Neut	Inc	Neut	S Inc	S Inc/ Neut	Neut	S Inc
**Coptis aspleniifolia* (spleenwort-leaved goldthread)	MV	Moister	Inc	Inc	S Inc	Neut	S Inc	S Inc	Neut	Neut

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Cryptantha leucophaea (Gray cryptantha)	MV	Drier	Neut	Neut	Neut	Inc	Neut	Neut	Inc	Neut
**Cryptantha rostellata* (beaked cryptantha)	MV	Drier	S Inc	Neut	Neut	S Inc	Neut	Neut	Neut	Neut
Cryptantha spiculifera (Snake River cryptantha)	MV	Drier	S Inc	Neut	Neut	S Inc	Inc	Neut	Neut	Neut
Cypripedium parviflorum (Yellow lady's-slipper)	MV	Moister	Neut	Neut	S Inc	S Inc	S Inc	S Inc	Neut	Neut
**Dactylorhiza viridis* (frog orchid)	HV	Moister	Neut	Neut	S Inc	S Inc	Inc	S Inc	Neut	Neut
**Damasonium californicum* (fringed water-plantain)	MV	Drier	Neut	Neut	S Inc	S Inc	Inc	S Inc/ Neut	Neut	Neut
**Dendrolycopodium dendroideum* (tree clubmoss)	MV	Moister	S Inc/ Neut	Inc	S Inc	Neut	S Inc	S Inc	Neut	S Inc/ Neut
**Draba cana* (lance-leaved draba)	EV	Moister	S Inc	Inc	Inc	Neut	S Inc	Inc	S Inc	S Inc/ Neut
**Draba taylorii* (Taylor's draba)	HV	Moister	Inc/ S Inc	S Inc	G Inc	Neut	S Inc	Inc	S Inc	Inc
**Erigeron aliceae* (Eastwood's daisy)	MV	Moister	Neut	G Inc	Inc	Neut	S Inc	S Inc	Neut	Neut
**Erigeron basalticus* (basalt daisy)	MV	Drier	Neut	Neut	S Inc	Inc	Inc	Neut	Inc	Neut
Erigeron salishii (Salish fleabane)	MV	Moister	Neut	S Inc	Gr Inc	Neut	Neut	S Inc	Neut	Neut
Eriogonum codium (Umtanum desert buckwheat)	MV	Drier	S Inc	Neut	Neut	Gr Inc	Inc	Neut	Inc	Neut
Eriophorum viridicarinatum (Green-keeled cottongrass)	MV	Moister	Neut	Neut	S Inc	Neut	Neut	S Inc	S Inc	Neut
**Eritrichium argenteum* (pale alpine forget-me-not)	HV	Moister	Inc	S Inc	G Inc	Neut	S Inc	Inc	Inc	S Inc
**Eryngium petiolatum* (Oregon coyote-thistle)	MV	Moister	Neut	Inc	S Inc	Neut	Inc	S Inc/ Neut	S Inc/ Neut	Neut

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
**Erythranthe pulsiferae* (candelabrum monkeyflower)	MV	Drier	S Inc/ Neut	S Inc	S Inc	Neut	Inc	S Inc/ Neut	Neut	S Inc/ Neut
Gaultheria hispidula (Creeping snowberry)	MV	Moister	S Inc	S Inc/Neut	Inc	Neut	S Inc	S Inc	Neut	Neut
**Gentiana douglasiana* (swamp gentian)	HV	Moister	S Inc	G Inc	G Inc	Neut	G Inc	S Inc	S Inc/ Neut	Neut
**Geum rossii* var. *depressum* (Ross' avens)	HV	Moister	Inc	S Inc	G Inc	Neut	S Inc	Inc	Inc	S Inc/ Neut
**Hackelia hispida* var. *disjuncta* (sagebrush stickseed)	MV	Drier	S Inc	Neut	Neut	Inc	S Inc	Neut	Neut	Neut
Hackelia taylorii (Taylor's stickseed)	HV	Moister	S Inc	S Inc	Inc	Neut	Neut	Inc	Inc	S Inc
Heterotheca oregona (Oregon goldenaster)	MV	Moister	Neut	S Inc	S Inc	Neut	S Inc	S Inc	Neut	Neut
Howellia aquatilis (Water howellia)	EV	Moister	Inc	S Inc	Neut	S Inc	Gr Inc	Neut	Neut	S Inc
Impatiens noli-tangere (Western jewelweed)	MV	Moister	Inc	Inc	S Inc	Neut	S Inc	S Inc	Neut	Neut
Juncus howellii (Howell's rush)	MV	Moister	Neut	S Inc	S Inc	Neut	S Inc	S Inc	Neut	Neut
**Juncus uncialis* (inch-high rush)	MV	Drier	Neut	Neut	S Inc/Neut	S Inc	G Inc	S Inc	Inc	Neut
Kalmia procumbens (Alpine azalea)	EV	Moister	S Inc	Inc	Inc	Neut	Neut	Gr Inc	Neut	S Inc
**Leptosiphon bolanderi* (Bolander's linanthus)	LV	Drier	S Inc/ Neut	Neut	S Inc/Neut	Neut	Neut	S Inc/ Neut	Neut	S Inc
Lomatium bradshawii (Bradshaw's lomatium)	MV	Moister	S Inc	Inc	Neut	Neut	Inc	Neut	Neut	Neut
**Lomatium knokei* (Knoke's biscuitroot)	HV	Drier	Inc	S Inc	S Inc	Neut	Inc	S Inc	Inc	Neut
**Lomatium lithosolamans* (Hoover's biscuitroot)	MV	Drier	Inc	Neut	Neut	S Inc	Inc	Neut	S Inc/ Neut	Neut
**Lomatium serpentinum* (Snake Canyon biscuitroot)	HV	Moister	Inc/ S Inc	Neut	S Inc	S Inc	S Inc	Neut	Neut	Inc

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Lomatium tuberosum (Hoover's desert-parsley)	MV	Drier	Inc	Neut	Neut	Inc	Inc	Neut	S Inc/ Neut	Neut
**Luzula arcuata* ssp. *unalaschcensis* (curved woodrush)	HV	Moister	S Inc	Inc	G Inc	Neut	S Inc/ Neut	Inc	S Inc	Neut
**Micranthes tischii* (Olympic saxifrage)	HV	Moister	Inc	G Inc	G Inc	Neut	S Inc	Inc	S Inc	Neut
Muhlenbergia glomerata (Marsh muhly)	MV	Moister	Neut	Neut	S Inc	Neut	S Inc	Inc	Neut	Neut
**Myosurus alopecuroides* (foxtail mousetail)	MV	Drier	Neut	Neut	S Inc/Neut	S Inc	G Inc	S Inc/ Neut	Inc	S Inc
Navarretia tagetina (Marigold pincushion-plant)	MV	Drier	Neut	S Inc	S Inc/Neut	Neut	Gr Inc	S Inc	Inc	Neut
Nicotiana attenuata (Coyote tobacco)	LV	Drier	S Inc	Neut	Neut	S Inc	Neut	Neut	Neut	Neut
**Orthocarpus bracteosus* (rosy owl's-clover)	HV	Drier	Inc	S Inc	S Inc	Neut	Inc	S Inc/ Neut	Neut	Neut
Oxytropis campestris var. *wanapum* (Wanapum crazyweed)	MV	Drier	Inc	Neut	Neut	Inc	Inc	Neut	Inc	Neut
Packera porteri (Porter's butterweed)	HV	Moister	Neut	Inc	Gr Inc	Neut	Neut	S Inc	S Inc	S Inc
Parnassia kotzebuei (Kotzebue's grass-of-Parnassus)	HV	Moister	S Inc	Inc	Gr Inc	Neut	S Inc	S Inc	S Inc	S Inc/ Neut
Pedicularis rainierensis (Mt. Rainier lousewort)	HV	Moister	S Inc	Inc	Inc	Neut	S Inc	Inc	S Inc	Neut
Pediocactus nigrispinus (Snowball cactus)	MV	Drier	S Inc	Neut	Neut	Inc	Inc	S Inc/ Neut	Neut	Neut
**Pellaea breweri* (Brewer's cliffbrake)	MV	Moister	S Inc	S Inc	S Inc	Neut	S Inc	S Inc	Neut	S Inc/ Neut
**Penstemon eriantherus* var. *whitedii* (Whited's fuzzytongue beardtongue)	MV	Drier	S Inc	Neut	S Inc	S Inc	S Inc	S Inc/ Neut	S Inc/ Neut	Neut

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Penstemon wilcoxii (Wilcox's beardtongue)	MV	Moister	S Inc	Neut	S Inc	S Inc/ Neut	S Inc	S Inc	Neut	Neut
**Petrophytum caespitosum* ssp. *caespitosum* (Rocky Mountain rockmat)	HV	Moister	S Inc	Neut	S Inc	S Inc	S Inc	Neut	Inc	S Inc
Petrophytum cinerascens (Chelan rockmat)	MV	Drier	S Inc	Neut	S Inc	S Inc	Inc	Neut	Inc	Neut
**Phacelia lenta* (Sticky phacelia)	MV	Drier	S Inc	Neut	S Inc	S Inc	Inc	Neut	Inc	S Inc/ Neut
Polemonium carneum (Great polemonium)	LV	Moister	S Inc	Inc	Neut	Neut	Neut	Neut	Neut	Neut
**Polemonium viscosum* (sticky sky-pilot)	EV	Moister	Inc	Inc	G Inc	Neut	S Inc	Inc	Inc	S Inc
Polyctenium fremontii (Fremont's combleaf)	MV	Drier	S Inc	Neut	Neut	S Inc	Gr Inc	Neut	S Inc	S Inc/ Neut
Pyrrocoma hirta var. *sonchifolia* (Sticky goldenweed)	MV	Moister	Neut	S Inc	S Inc	Neut	S Inc	S Inc	Neut	Neut
**Ranunculus californicus* (California buttercup)	MV	Moister	S Inc	G Inc	Neut	Neut	S Inc	Neut	S Inc	S Inc
Ranunculus populago (Mountain buttercup)	MV	Moister	S Inc	S Inc	S Inc	Neut	S Inc	S Inc	Neut	Neut
**Ribes cereum* var. *colubrinum* (wax currant)	HV	Moister	S Inc/ Neut	Neut	S Inc	S Inc	Inc	S Inc/ Neut	Neut	Neut
Rubus arcticus ssp. *acaulis* (Nagoonberry)	MV	Moister	Neut	S Inc	S Inc	Neut	S Inc	S Inc	Neut	S Inc
**Sabulina nuttallii* var. *fragilis* (Nuttall's sandwort)	MV	Drier	S Inc	Neut	Neut	Inc	Inc	Neut	Neut	Neut
Salix candida (Hoary willow)	HV	Moister	Neut	Neut	Gr Inc	Neut	S Inc	Inc	S Inc	Neut
Salix glauca var. *villosa* (Glaucous willow)	MV	Moister	Neut	S Inc	Inc	Neut	S Inc	Inc	Neut	Neut
**Salix maccalliana* (MacCalla's willow)	HV	Moister	Neut	Neut	Inc	Neut	S Inc	Inc	Inc	Neut

Species (Common Name)	CCVI Score	AET: PET	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Salix pseudomonticola (False mountain willow)	MV	Moister	Neut	Neut	Inc	Neut	S Inc	Inc	S Inc	Neut
**Sanicula arctopoides* (bear's-foot sanicle)	MV	Moister	Neut	G Inc	Neut	Neut	S Inc	Neut	S Inc	Neut
Saxifraga cernua (Nodding saxifrage)	HV	Moister	Inc	Inc	Gr Inc	Neut	S Inc	S Inc	Neut	Neut
Scribneria bolanderi (Scribner's grass)	MV	Drier	Neut	S Inc	S Inc/Neut	Neut	Gr Inc	S Inc	Unk	Neut
Sericocarpus oregonensis (Oregon white-topped aster)	MV	Moister	Neut	S Inc	Neut	Neut	Neut	Neut	Neut	Neut
Sidalcea oregana var. *calva* (Wenatchee Mts checkermallow)	HV	Moister	S Inc	S Inc	Neut	Neut	Inc	S Inc	Neut	Neut
**Silene seelyi* (Seely's catchfly)	MV	Moister	Inc	S Inc	Inc	Neut	S Inc	S Inc	S Inc	Neut
**Spartina pectinata* (prairie cordgrass)	MV	Drier	Neut	Neut	S Inc	S Inc	G Inc	S Inc	Neut	Neut
Swertia perennis (Swertia)	MV	Moister	S Inc	S Inc	Inc	Neut	S Inc	S Inc	S Inc	Neut
Thelypodium sagittatum ssp. *s.* (Arrow thelypody)	MV	Drier	S Inc	Neut	Neut	S Inc	Inc	Neut	S Inc	Neut
**Trillium albidum* ssp. *parviflorum* (small-flowered trillium)	MV	Moister	Inc	Inc	S Inc	Neut	S Inc	Neut	Neut	S Inc
**Utricularia intermedia* (flat-leaved bladderwort)	MV	Moister	S Inc/ Neut	G Inc/Inc	S Inc	Neut	Inc	S Inc	Neut	Neut
Vaccinium myrtilloides (Velvetleaf blueberry)	MV	Moister	Neut	Neut	Inc	S Inc	S Inc	S Inc	S Inc	Neut
**Veronica dissecta* var. *lanuginosa* (woolly kittentails)	HV	Moister	Inc	G Inc	Inc	Neut	S Inc	S Inc	Inc	S Inc

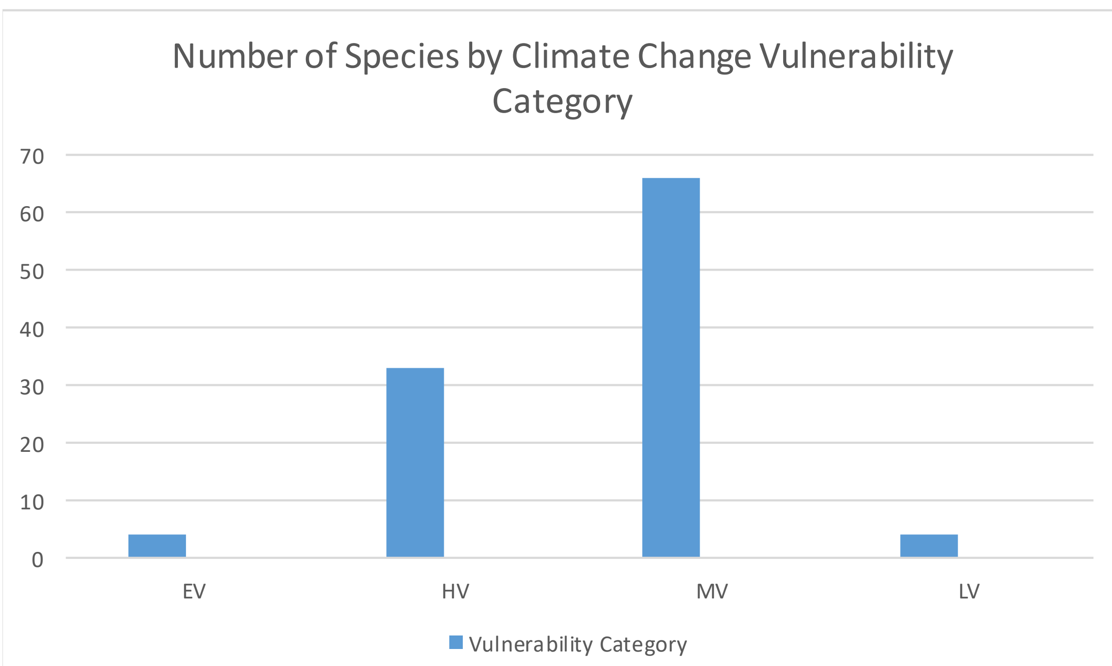
Cumulative Results from Phase I, Phase II and USFWS CCVI assessments, 2019-2021

Since 2019, 107 of the 371 vascular plant taxa tracked as state species of conservation concern have been assessed using the NatureServe CCVI protocol (Table 4). Some interesting patterns are beginning to emerge from this cumulative dataset:

- The majority of species assessed (61.7%) are ranked as Moderately Vulnerable to climate change (66 of 107 speies). The second highest number (33 of 107 species) are scored as Highly Vulnerable (30.9%). Relatively few species (4 of 107) are rated as either Extremely Vulnerable (3.7%) or Less Vulmerable (3.7%) (Figure 1).

- Species ranked as Extremely or Highly Vulnerable are strongly associated with wetter habitats (based on AET:PET ratio), average to greater than average precipitation variation (neutral historical hydrological niche scores), and areas with high winter ice or snow accumulation (Tables 4, 5).

Figure 1. Summary of Climate Change Vulnerability Index scores for 107 Washington rare plant taxa assessed from 2019-2021. EV = Extremely Vulnerable, HV = Highly Vulnerable, MV = Moderately Vulnerable, LV = Less Vulnerable. Includes results from Phase II (appendix A), Phase I (Fertig 2020) and USFWS assessments by Fertig (2021a) and Kleinknecht et al. (2019).



- Extremely or Highly Vulnerable species are associated with sites that have historically stable temperatures (historical thermal niche scores of increased to greatly increased risk) and cool to cold microhabitats (physiological thermal niche scores of increased to greatly increased risk) (Table 5).
- Extremely or Highly Vulnerable species also tend to be associated with uncommon geologic or landscape features (because these habitat features are rare, species may not be able to find suitable new sites through migration), have greatly increased dispersal limitations, somewhat to increased dependency on few pollinators, and somewhat to increased susceptibility to low genetic variability or breeding system problems (Table 5).
- Moderately Vulnerable species are less easy to characterize. In general, they are only slightly more likely to be from wetter habitats that drier ones (compared to Extremely or Highly Vulnerable taxa) and more likely to be from hotter areas or sites with more stable temperature variability (historical and physiological thermal niches scores are more likely to be neutral). Moderately vulnerable species are less frequently associated with uncommon geologic features, more prone to have a neutral score for dependence on ice and snow features, less likely to be dispersal limited, less dependent on specific pollinators, and less impacted by low genetic variability or breeding system limiations (Table 5).
- Species that are scored as Less Vulnerable to climate change generally are not strongly impacted by projected changes in temperature or precipitation, are not dependent on ice or snow, are not associated with unusual geologic features, and are not pollinator limited or have low genetic diversity (Table 5). These species tend to be adapted to early successional habitats and in some cases may actually benefit from anthropogenic changes.
- Only 20% of the species evaluated have a documented negative response to recent climate change, characterized primarily by a range contraction (Table 5). About half of these species were ranked as Extremely or Highly Vulnerable. Just over 69% of the evaluated species currently have a neutral response to climate change. This could change in the near future if warming trends continue or accelerate and more populations become extirpated and ranges begin to shrink.
- The Okanogan and Blue Mountains ecoregions have a higher percentage of rare species scored as Extremely or Highly Vulnerable to climate change than other ecoregions (Table 6). Alpine species from the Okanogan Range have a high AET:PET ratio (near the wetter end of the moisture availability spectrum) (Figure 2) coupled with small temperature variability (historical thermal niche at increased risk) (Figure 3). This combination of environmental attributes is not matched anywhere else in the state. Species from the Blue Mountains are likely to experience the largest temperature increases in the state (Figure 4) and also have relatively high AET:PET ratios (Figure 2).

Figure 2. Projected moisture availability (based on ratio of actual to predicted evapotranspiration) in Washington. Yellow to brown values are correlated with projected wetter conditions, while green to blue values correspond with projected drier conditions. Red ellipse denotes the Okanogan Range and black rectangle the Blue Mountains ecoregion. This map is the base layer for figure 2 of each CCVI report in Appendix A. Map layers from www.natureserve.org/ccvi

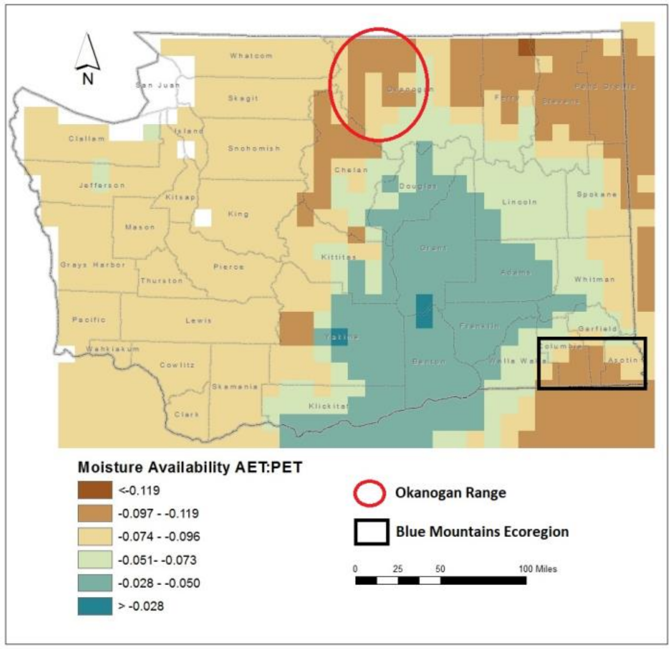


Figure 3. Historical thermal niche (exposure to past temperature variations) in Washington. Darker shades depict areas of cooler temperatures. Red ellipse denotes the Okanogan Range This map is the base layer for figure 3 of each CCVI report in Appendix A. Map layers from www.natureserve.org/ccvi

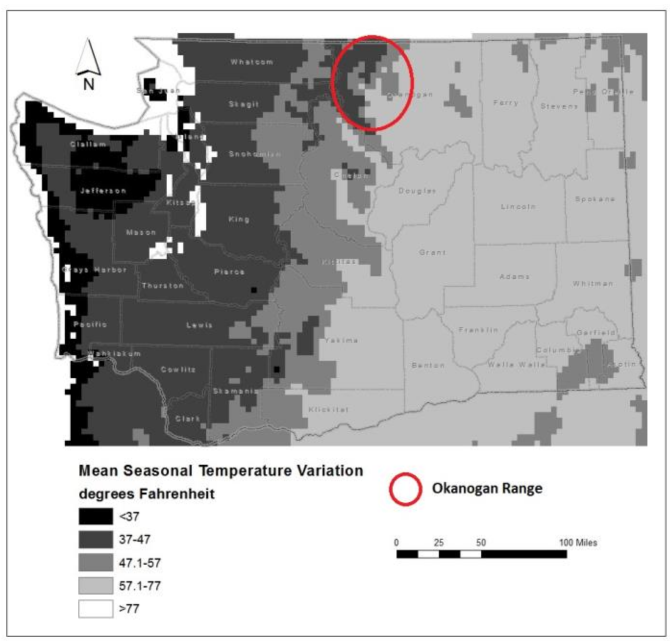
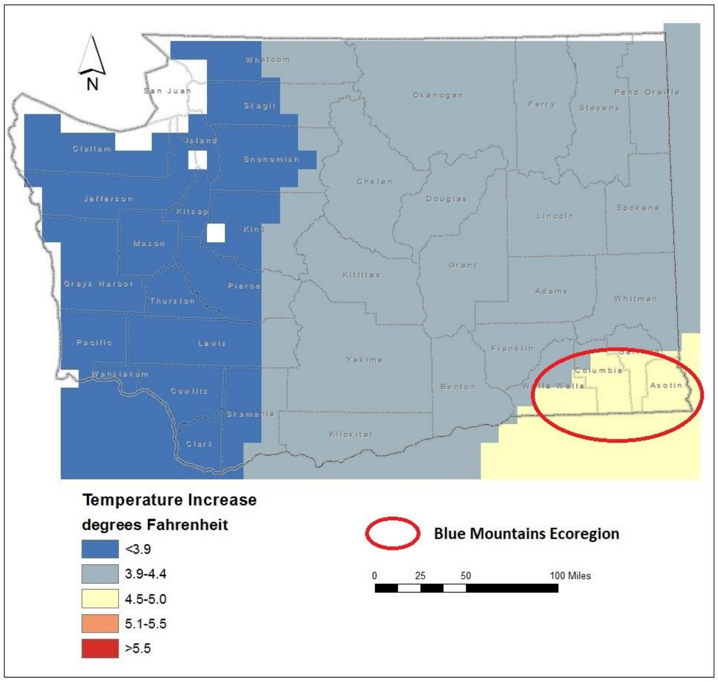


Figure 4. Projected local temperature change in Washington. Blue Mountains ecoregion highlighted in red ellipse. This map is the base layer for Figure 1 of each CCVI report in Appendix A. Map layers from www.natureserve.org/ccvi



- Moderately Vulnerable species comprise at least 50% of the species analyzed from each of the nine ecoregions in Washington (Table 6). The Columbia Plateau is especially over-represented, with 86% of its rare species being rated as Moderately Vulnerable while only 11% are scored as Extremely or Highly Vulnerable. Columbia Plateau species tend to occur in habitats that are already adapted to warm temperatures and low rainfall and snowfall (Figures 2-4, Table 6), and thus may be predisposed to withstand changing climatic conditions (although the upper limits of their physiological tolerance to extreme temperatures or drought may be unknown). Many of these species are edaphic endemics that may be unable to migrate to new areas with suitable geologic substrates in the future or evolve to tolerate extreme hot or dry conditions (Caicco 2012; Fertig 2020).

- Vascular plant species that are local endemics (extremely small global ranges) have a strong probability of being scored as Extremely or Highly Vulnerable to climate change (Table 6). Such taxa tend to be restricted to unusual geologic substrates, have specialized pollinators, or low genetic diversity. Species that are disjunct (isolated from the core of their geographic range) or peripheral (at the extreme edge of their continuous range) in Washington also are more likely to be Extremely or Highly Vulnerable to climate change. Disjunct and peripheral **[continued on page 26]**

Table 5. Summary of Climate Change Vulnerability Index Results for 107 Washington Rare Plant Species Assessed from 2019-2021 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**
AET:PET ratio (moisture availability)				
Wetter (n = 75)	4	31	38	2
Drier (n = 32)	0	2	28	2
Dispersal				
Increase (n = 24)	2	14	8	0
Somewhat Increase (n =56)	2	15	35	4
Neutral (n = 27)	0	4	23	0
Historical Thermal Niche				
Greatly Increase (n= 12)	0	6	6	0
Increase (n =20)	3	8	8	1
Somewhat Increase (n = 31)	1	10	19	1
Neutral (n = 44)	0	9	33	2
Physiological Thermal Niche				
Greatly Increase (n = 13)	1	11	1	0
Increase (n = 33)	2	18	13	0
Somewhat Increase (n = 42)	0	11	30	1
Neutral (n = 29)	1	3	22	3
Historical Hydrological Niche				
Greatly Increase (n = 1)	0	0	1	0
Increase (n = 9)	0	0	9	0
Somewhat Increase (n = 27)	1	6	19	1
Neutral (n = 70)	3	27	37	3

Ecological Attribute/Score	CCVI Result (Number of Species)			
	EV	HV	MV	LV
Physiological Hydrological Niche				
Greatly Increase (n = 9)	1	1	7	0
Increase (n = 26)	0	9	17	0
Somewhat Increase (n = 58)	2	20	36	0
Neutral (n = 14)	1	3	6	4
Dependence on Ice/Snow				
Greatly Increase (n = 1)	1	0	0	0
Increase (n = 19)	2	11	6	0
Somewhat Increase (n = 54)	0	18	35	1
Neutral (n = 33)	1	4	25	3
Uncommon Geologic Feature				
Increase (n = 20)	1	9	10	0
Somewhat Increase (n = 31)	1	13	17	0
Neutral (n = 55)	2	11	38	4
Unknown (n = 1)	0	0	1	0
Pollinator Versatility				
Increase (n = 2)	1	0	1	0
Somewhat Increase (n = 7)	0	4	3	0
Neutral (n = 60)	2	16	39	3
Unknown (n = 38)	1	13	23	1
Genetic Variability or Breeding System				
Increase (n = 4)	0	4	0	0
Somewhat Increase (n = 28)	4	10	13	1
Neutral (n = 75)	0	19	53	3
Documented Response to Recent Climate Change				
Increase (n = 1)	0	1	0	0
Somewhat Increase (n = 21)	0	10	9	2
Neutral (n = 74)	0	18	55	1
Unknown (n = 11)	4	4	2	1

Table 6. Summary of Climate Change Vulnerability Index Results for 107 Washington Rare Plant Species Assessed in 2019-2021 Based on Ecoregion, Distribution Pattern, and Aggregated Ecological Systems. Ecoregion classification is from Camp and Gamon (2011) and Washington Natural Heritage Program (2021). Distribution Pattern based on Fertig (2021b). Aggregated Ecological Systems were derived by clustering similar ecological systems defined by Rocchio and Crawford (2015). CCVI summary scores: EV = Extremely Vulnerable, HV = Highly Vulnerable, MV = Moderately Vulnerable, LV = Less Vulnerable (Young et al. 2016).

Attribute	CCVI Result (Number of Species)			
	EV	HV	MV	LV
Ecoregion				
Blue Mountains (n =10)	0	4	5	1
Canadian Rockies (n = 15)	0	3	12	0
Columbia Plateau (n = 37)	1	3	32	1
East Cascades (n = 47)	1	15	28	3
North Cascades (n = 13)	1	3	9	0
Okanogan (n = 31)	2	13	16	0
Pacific NW Coast (n = 20)	1	6	12	1
Puget Trough (n = 15)	1	3	10	1
West Cascades (n = 15)	0	4	10	1
Distribution Pattern				
Local Endemic (n = 21)	0	10	11	0
Disjunct (n = 5)	0	2	3	0
Peripheral (n= 34)	3	11	18	2
Regional Endemic (n = 23)	0	6	16	1
Sparse (n = 24)	1	4	18	1
Aggregated Ecological Systems				
Alpine Vegetation (n= 14)	2	8	4	0
Aquatic Vegetation & Exposed Flats (n = 0)	0	0	0	0
Dry Forests & Woodlands (n = 9)	0	2	5	2

Attribute	CCVI Result (Number of Species)			
	EV	HV	MV	LV
Forested & Shrub Swamps (n = 2)	0	0	2	0
Interior Alkaline Wetlands (n = 1)	0	0	1	0
Lowland & Foothill Mesic Forests & Woodlands (n = 1)	0	0	0	1
Marshes & Wet Meadows (n = 24)	2	6	16	0
Peatlands (n = 16)	0	8	8	0
Riparian Areas (n = 10)	0	0	9	1
Sand Dune Vegetation (n = 2)	0	0	2	0
Shrub-Steppe (n = 7)	0	1	6	0
Sparsely Vegetated Upland Types (n =29)	2	8	19	0
Sparsely Vegetated Upland – alpine only (n = 11)	2	6	3	0
Sparsely Vegetated Upland – non-alpine only (n = 18)	0	2	16	0
Subalpine-Montane Mesic Forests & Woodlands (n = 5)	0	1	4	0
Tidal/Coastal Wetlands (n = 0)	0	0	0	0
Upland Grasslands & Meadows (n = 14)	0	6	6	2
Upland Shrublands (n = 7)	0	0	6	1
Vernal Pools (n = 7)	0	1	6	0

species often occur in specialized habitats (such as alpine tundra and talus or peatlands) or have reduced genetic variability due to being reproductively isolated or from past founder effects.

- Rare plant species ranked as Extremely or Highly Vulnerable to climate change are strongly associated with alpine, peatland, and marsh or wet meadow ecological systems. For the sake of simplifying this analysis, the 90 ecological systems recognized for Washington by Rocchio and Crawford (2015) are aggregated into 17 categories based on their similarity (this classification follows the organizational scheme presented in the table of contents of Rocchio and Crawford's 2015 classification). Ten of the 14 plant species from alpine tundra ecological systems examined in Phases I and II are scored as Extremely or Highly Vulnerable (71%) (Table 6). Eight of 11 species (73%) from sparsely vegetated upland systems in alpine sites (talus and fell-fields) are also rated as Extremely or Highly Vulnerable. Eight of 16 peatland species (50%) and six of 14 upland grassland and meadow species (43%) are ranked as Extremely or Highly Vulnerable (Table 6).

- Data gaps may influence the final vulnerability scores. Nearly 70% of the species examined in this study scored as neutral for breeding systems or genetic variability, with most of these species ultimately rating as Moderately Vulnerable to climate change. Often these species lacked Washington-specific genetic diversity data but scored neutral due to their reproductive traits (such as out-crossing) that usually correlate with higher genetic variability. When local genetic data are available, species tend to rank as more vulnerable to climate change. For example, Soltis et al. (1997) documented very low levels of allozyme polymorphism in the Snake River endemic, *Lomatium serpentinum*, which contributed to this species ranking as Highly Vulnerable (Table 3, Appendix A). (Additional factors, such as expected high temperature increases in the Blue Mountains region, hydrological niche issues, poor dispersal, and documented range contraction, also contributed to this score.) Other local or regionally endemic species may be more prone to low genetic variability (Hamrick and Godt 1989) than is currently recognized and might score as more vulnerable to climate change once these data are available.

- More data are needed on the modeled distribution of rare species in response to current and projected future climates. Models are available for only four of 107 species in this study (3.7%). All four of these species are alpine taxa from the Olympic Mountains (*Arabis olympica*, *Astragalus australis* var. *cottonii*, *Micranthes tischii*, and *Veronica dissecta* ssp. *lanuginosa*) studied by Wershow and DeChaine (2018) and scored as Highly Vulnerable to climate change. Comparable modeling data are needed for rare species from other geographic areas of the state and might result in higher vulnerability scores, especially for narrow endemics presently classified as Moderately Vulnerable.

Future Directions

The 107 species that have been assessed with the CCVI protocol since 2019 represent 29% of the state's vascular plant species of conservation concern (Fertig 2021b). Although the species in Phases I and II were selected to represent a cross section of habitats, distribution, and rarity patterns, they are limited to a subset of species listed as Sensitive by the USFS or BLM or Threatened or Endangered by USFWS. Species of concern from habitats not found on National Forest or BLM lands are under-represented in this analysis. This is especially true for species from low-elevation forests west of the Cascade crest and grassland species of the Puget Trough and eastern Washington.

Completing CCVIs for the remaining unscored rare plant species should be a priority to verify some of the emerging patterns found in the cumulative dataset and to uncover new ones. For example, are species from the Okanogan Range and Blue Mountains really more sensitive to climate change than other areas, or is this result an artifact of incomplete sampling of species? Are some under-represented habitat and geographic areas, such as Puget Trough wet or dry prairies, more vulnerable to climate change than our results indicate? Are there other geographic areas that might be hot-spots of high risk species, such as the Wenatchee Mountains, Palouse grasslands, or Columbia River Gorge? Many other questions could be answered by applying CCVI work to a broader set of rare species.

Plant species of conservation concern make up just 14% of the 2635 native vascular plant species in Washington. Thus the 107 completed CCVIs represent only 4% of the state's total native vascular flora. It remains unknown how the projected responses of rare plant species to climate change might differ from that of more widespread or common taxa. Due to their limited distribution, low population size, and specialized habitat requirements, rare species do tend to be more sensitive to the climatic and life history variables employed in the CCVI model. It would be informative to apply CCVI methods to a stratified random sample of more common species (chosen to represent a cross section of ecological systems and geographic distributions) to compare results with rare species. Will common species from habitats identified at risk from climate change (such as alpine, peatland, or groundwater-dependent wetlands) be more prone to score as Extremely or Highly Vulnerable, like rare species? Or will life history factors, such as higher genetic diversity, better dispersal ability, or lower vulnerability to competition, make common species less vulnerable? Information from common species would help put the results of analyses of rare species in clearer perspective.

Acknowledgements

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Literature Cited

Anacker, B.L., M. Gogol-Prokurat, K. Leidholm, and S. Schoenig. 2013. Climate change vulnerability assessment of rare plants in California. Madroño 60(3): 193-210.

Caicco, S. 2012. Assessing vulnerability to climate change among the rarest plants of Nevada's Great Basin. Calochortiana 1:91-105. Available at: https://www.unps.org/Calochortiana/CalochortianaDec2012Num1.pdf

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Comer, P.J., J.C. Hak, M.S. Reid, S.L. Auer, K.A. Schulz, H.H. Hamilton, R.L. Smyth, and M.M. King. 2019. Habitat climate change vulnerability applied to major vegetation types of the western interior United States. Land 8 (108): 1-27. (doi:10.3390/land8070108).

Fertig, W. 2020. Climate Change Vulnerability Index reports for selected Washington State rare plant species. Natural Heritage Report 2020-04. Report prepared for US Forest Service, Region 6. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 423 pp.

Fertig, W. 2021a. Status of federally listed plant taxa in Washington state. Natural Heritage Report 2021-01. Report prepared for US Fish and Wildlife Service. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 107 pp.

Fertig, W. 2021b. 2021 Washington vascular plant species of conservation concern. Natural Heritage Program Report 2021-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 43 pp.

Glick, P., B.A. Stein, and N.A. Edelson, eds. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C. 168 pp.

Hamrick, J.L. and M.J.W. Godt. 1989. Allozyme diversity in plant species. Pp 43-63. In: Brown, A.H.D., M.T. Clegg, A.L. Kahler, and B.S. Weir, eds. Plant Population Genetics, Breeding and Genetic Resources. Sinauer, Sunderlin, MA.

[IPCC] Intergovernmental Panel on Climate Change. 2014. Climate change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri, and L.A. Meyer, eds.)]. IPCC, Geneva, Switzerland. 151 pp.

[ISSSSP] Interagency Special Status and Sensitive Species Program. 2019. Final OR/WA State Director's Special Status Species List, March 21, 2019. Available at: www.fs.fed.us/r6/sfpnw/issssp/agency-policy.

Kleinknecht, J., D. Wilderman, and W. Fertig. 2019. Climate change and connectivity review of site designs for established natural areas with federally listed plant species. Natural Heritage

Report 2019-06. Report prepared for US Fish and Wildlife Service. Washington Natural Heritage Program. Washington Department of Natural Resources, Olympia, WA. 90 pp.

Parmesan, C. and M.E. Hanley. 2015. Plants and climate change: Complexities and surprises. Annals of Botany 116: 849-864.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological Systems of Washington State. A Guide to Identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Soltis, P.S., D.E. Soltis, and T.L. Norvell. 1997. Genetic diversity in rare and widespread species of *Lomatium* (Apiaceae). Madroño 44(1): 59-73.

Still, S.M., A.L. Frances, A.C. Treher, and L. Oliver. 2015. Using two climate change vulnerability assessment methods to prioritize and manage rare plants: A case study. Natural Areas Journal 35(1)): 106-121.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M. Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Washington Natural Heritage Program 2021. Online Field Guide to the Rare Plants of Washington (https://fieldguide.mt.gov/wa). Accessed 15 December 2021.

Wershow, S.T. and E. DeChaine. 2018. Retreat to refugia: Severe habitat contraction projected for endemic alpine plants of the Olympic Peninsula. American Journal of Botany 105(4): 760-778.

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.

Young, B.E., N.S. Dubois, and E.L. Rowland. 2015. Using the climate change vulnerability index to inform adaptation planning: Lessons, innovations, and next steps. Wildlife Society Bulletin 39:174-181.

Appendix A. Climate Change Vulnerability Index reports for 55 Washington Rare Plant Species Assessed in Phase II

Climate Change Vulnerability Index Report

Allium constrictum (Constricted onion)

Date: 19 January 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G2G3/S2S3

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	82.4
	-0.028 to -0.050	17.6
	>-0.028	0

Section B: Indirect Exposure to Climate Change	**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: Sensitivity and Adaptive Capacity	
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	Greatly 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 others 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	Neutral
5a. Measured genetic diversity	Somewhat Increase

5b. Genetic bottlenecks	Somewhat Increase
5c. Reproductive system	Somewhat Increase/Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All 17 of the known occurrences of *Allium constrictum* in Washington (100%) are found in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

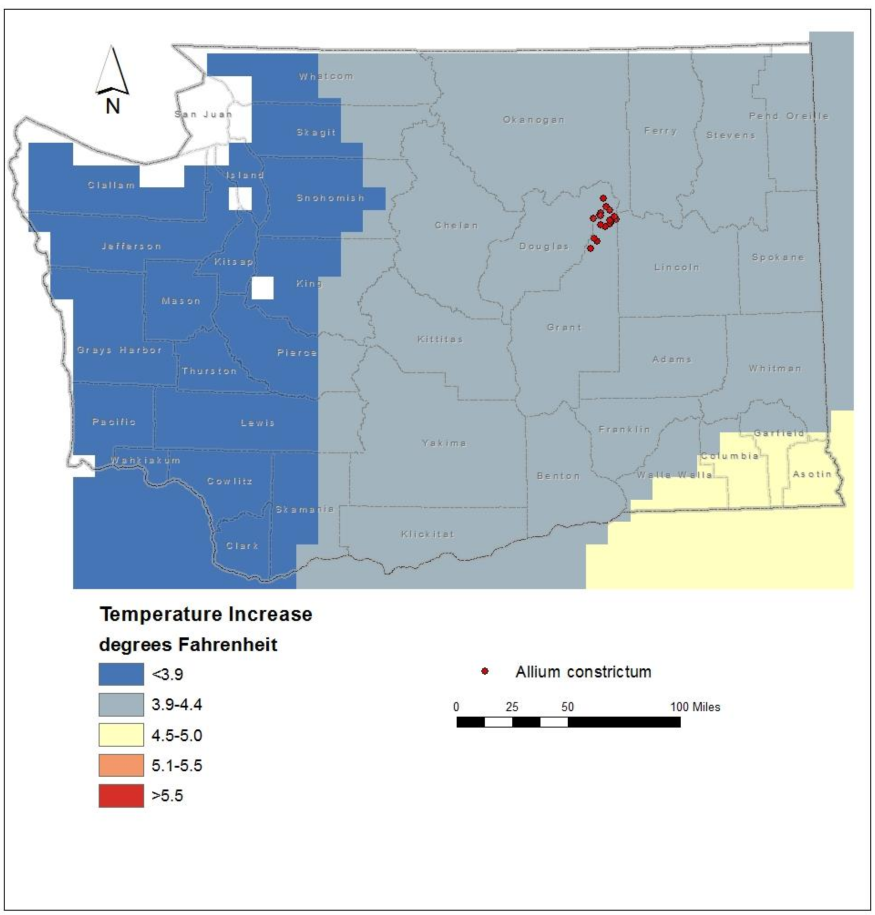

Figure 1. Exposure of *Allium constrictum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Fourteen of the 17 Washington occurrences of *Allium constrictum* (82.4%) 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). Three other occurrences (17.6%) are in areas with a projected decrease in the – 0.028 to – 0.050 range.

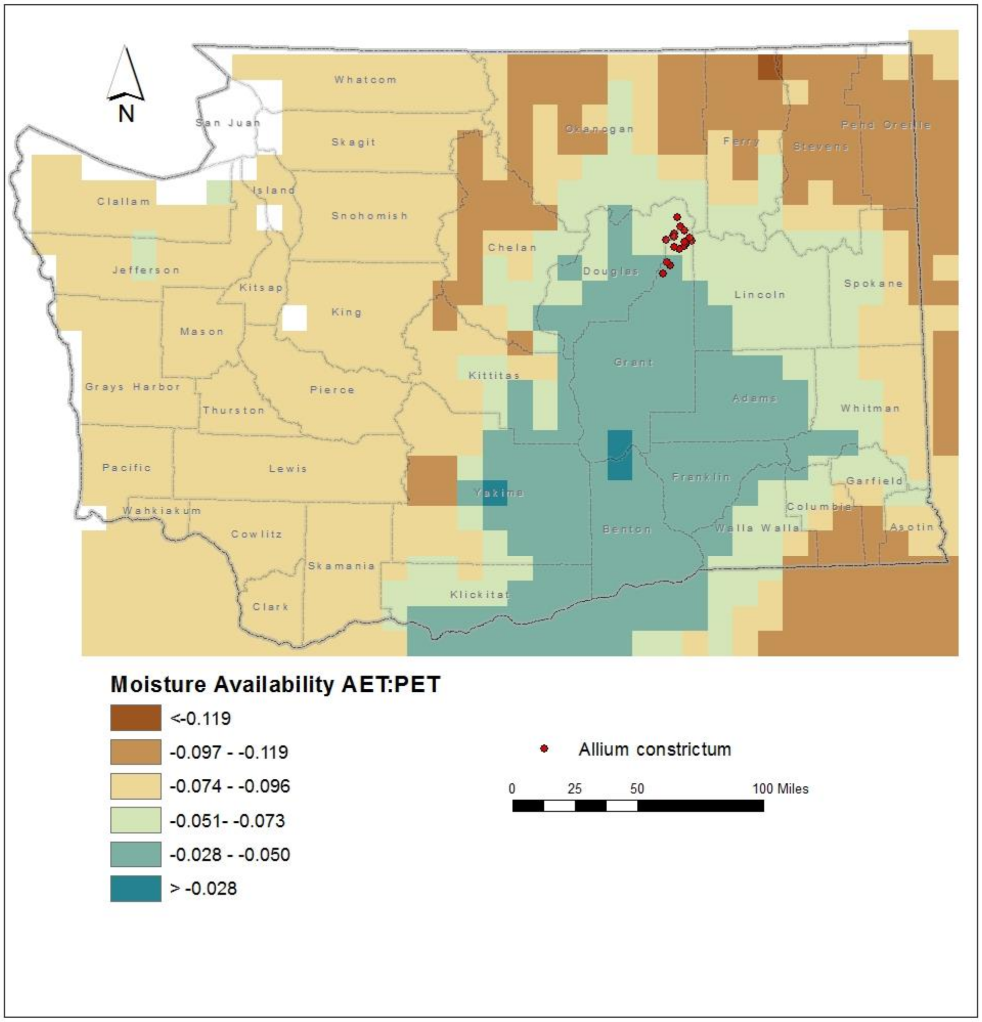

Figure 2. Exposure of *Allium constrictum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
All occurrences of *Allium constrictum* in Washington are found at elevations from 2070-2550 ft (630-780 m) and would not be inundated by sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Allium constrictum* occurs on the margins of vernal pools and moist flats or gentle slopes over thin basalt lithosols (Camp and Gamon 2011, Fertig & Kleinknecht 2020). This vegetation type is part of the Columbia Plateau Vernal Pool ecological system (Rocchio and Crawford 2015). Washington populations are separated by 0,5-3 miles (0.6-4.7 km). The entire range of the species is limited to an area of approximately 23 x 11 miles (37 x 18 km) (Camp and Gamon 2011). Vernal depressions are widely scattered through this area within a matrix of big sagebrush (*Artemisia tridentata*) and stiff sagebrush (*A. rigida*) scabland vegetation. The surrounding vegetation does not impose a significant barrier to gene flow.

B2b. Anthropogenic barriers: Neutral.
Allium constrictum occurs primarily on rangelands managed for grazing with relatively few roads or other developments to impede gene flow.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Allium constrictum reproduces by seed formed in dry capsules. The smooth seeds lack any structures such as barbs, hooks, parachutes, or wings to facilitate transportation by animals. Seeds are relatively small and could be carried short distances by strong winds, but are more likely to be passively dispersed within 1000 meters of the parent plant.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of known *Allium constrictum* occurrences in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 17 of the Washington occurrences (100%) are found in areas that have experienced average (57.1-77˚F) temperature variation in the past 50 years. According to Young et al. (2016) these populations are at neutral vulnerability to climate change.

C2aii. Physiological thermal niche: Neutral.
Allium constrictum occurrences in Washington are found in ephemeral wetlands and vernal pools that are not cold air drainages and would be neutral for climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
All 17 of the Washington occurrences (100%) of *Allium constrictum* (Figure 4) are found in areas that have averaged 11-20 inches (255-508 mm) of precipitation variation in the past 50 years and are considered at somewhat increased risk from climate change by Young et al. (2016).

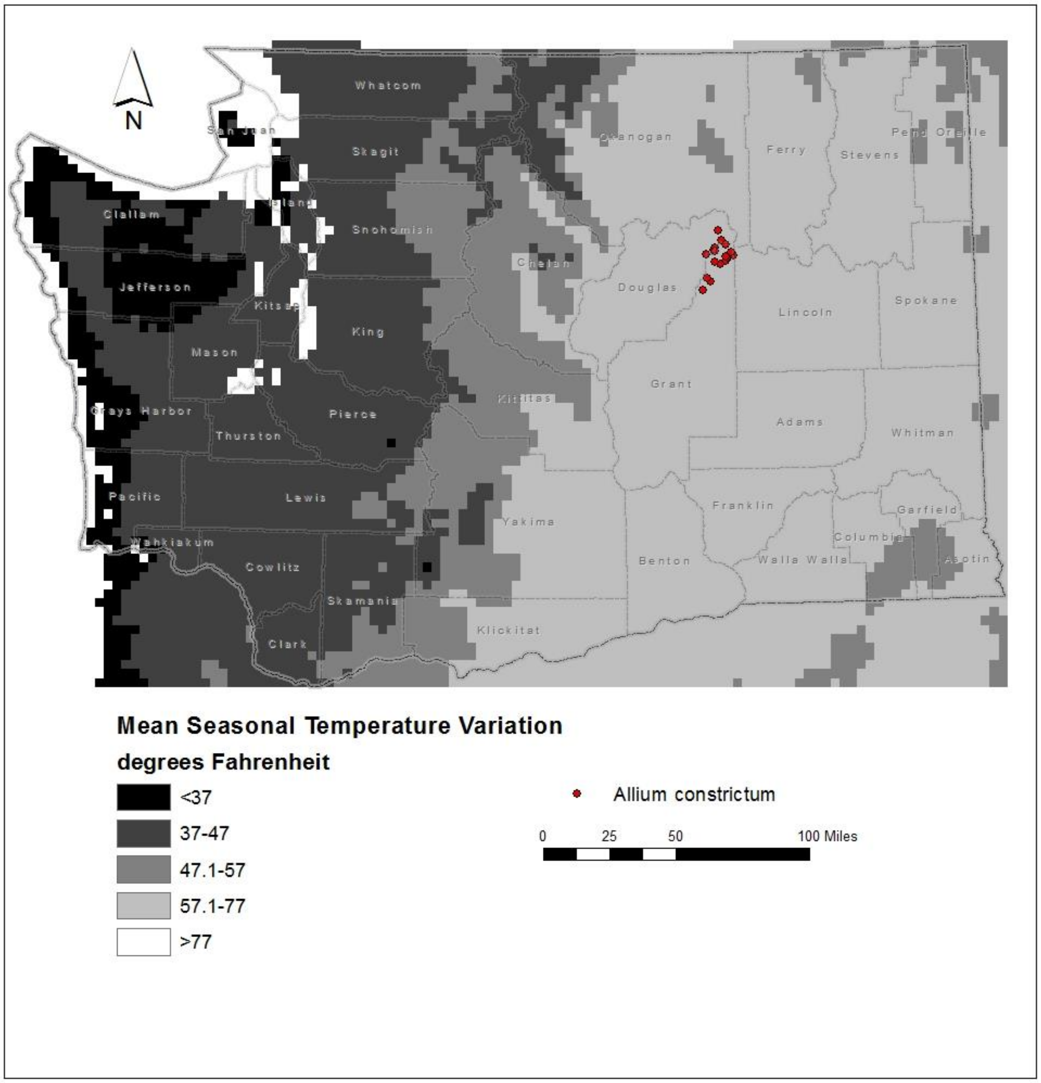

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Allium constrictum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
Allium constrictum is limited to vernal pools and thin lithosol habitats that are dependent on winter or spring snow or rain (and not groundwater) as a water source. These areas are impacted by drought in the summer. Changes in the timing or amount of precipitation in the growing season would likely alter the community structure of these ephemeral wetlands (Rocchio and Ramm-Granberg 2017). Increased drought in the growing season could lead to conversion of this ecological system to the sparsely vegetated Intermountain Basins Cliff and Canyon type.

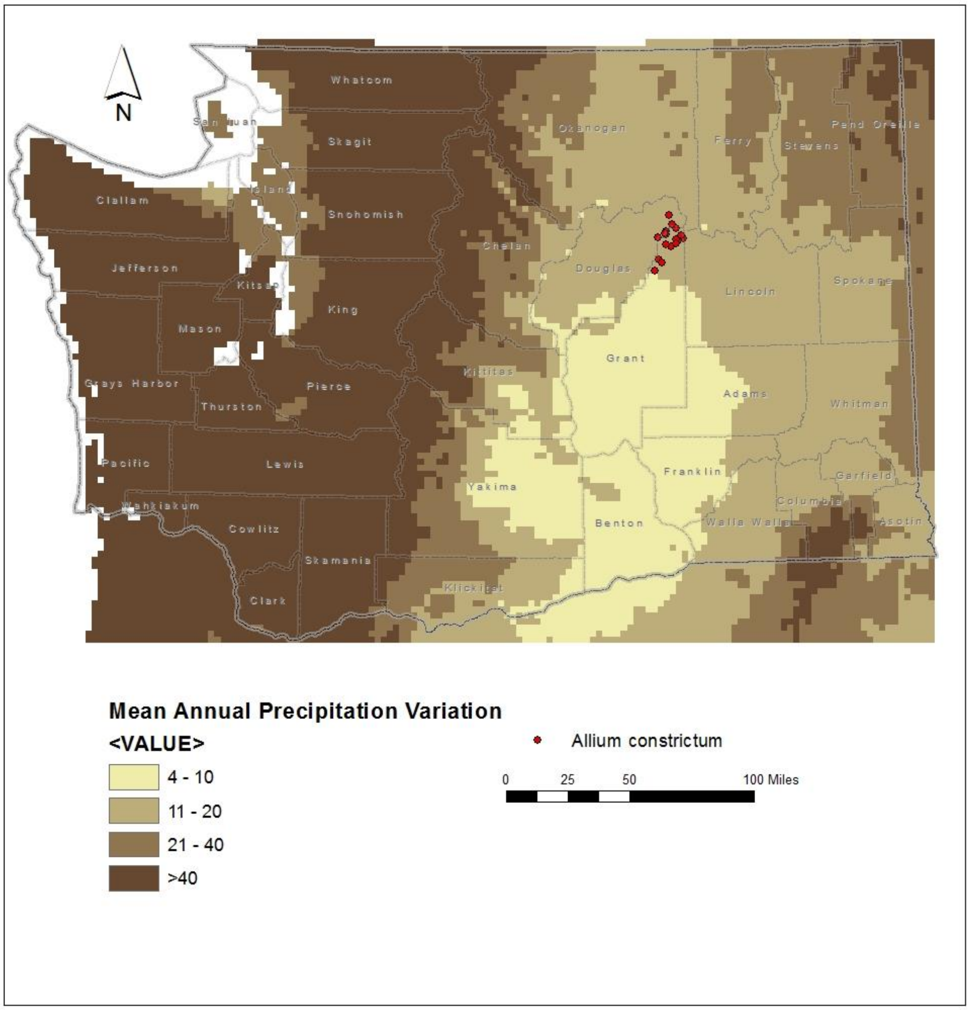

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Allium constrictum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2c. Dependence on a specific disturbance regime: Neutral.
This species is not dependent on periodic and unpredictable disturbances to maintain its vernal pool habitat on basalt outcrops (although regular summer drought does prevent these areas from converting to other wetland ecological systems associated with perennial water sources). Increased disturbances from drought and more frequent wildfire would likely affect the sagebrush scabland matrix in which its vernal pool habitat is embedded (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral
In Washington, *Allium constrictum* is found in basin areas that receive relatively little snowfall (though vernal depressions would likely accumulate any blowing snow).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
All of the Washington occurrences of *Allium constrictum* are found in shallow depressions or flats on outcrops of Miocene-age basalts of the Priest Rapids Member of the Wanapum basalt (Washington Division of Geology and Earth Resources 2016). While this geologic formation is widespread in the Columbia Plateau of central Washington, the vernal pool depressions are far less common and often widely scattered. The distribution of these geologic features is probably an important factor limiting the range of this species.

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal pool and rock outcrop habitat occupied by this species is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
McNeal (1994) reports that the pollinators of *Allium constrictum* are not known, but are probably solitary and social bees (including *Apis mellifera*) and other insects. If multiple insect species are capable of pollination, this factor could be scored as Neutral.

C4d. Dependence on other species for propagule dispersal: Neutral.
Dispersal of *Allium* seed is primarily passive and the small seeds can be spread by wind or gravity (McNeal 1994). Dispersal distances are probably short.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Current rates of livestock grazing is not considered a significant threat to *Allium constrictum* (Barrett and Sprague 1985; Camp and Gamon 2011). *Allium* flowers and leaves are palatable, and underground bulbs are also consumed by fossorial mammals, but whether natural herbivory is a limiting factor for *A. constrictum* is not known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The vernal pool habitat of *Allium constrictum* is vulnerable to invasion by native or introduced plant species adapted to drier conditions if changes in the amount or timing of winter/spring precipitation are altered due to climate change (Rocchio and Ramm-Granberg 2015).

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

C5a. Measured genetic variation: Somewhat Increase.
Rieseberg et al. (1987) conducted a genetic analysis of *Allium douglasii* and related taxa (at the time considered varieties, but now recognized as separate species), including *A. constrictum* (*A. douglasii* var. *constrictum*). Isozyme data suggest that *A. constrictum* is probably recently derived from *A. columbianum*, an endemic of vernal wetlands in Spokane County, western Idaho, and western Montana. *Allium constrictum* possesses a less diverse genome than *A. columbianum*, suggesting it evolved from a peripheral population that became reproductively isolated, possibly related to Pleistocene flooding events. The relatively low genetic diversity within *A. constrictum* makes it somewhat more vulnerable to impacts of climate change.

C5b. Genetic bottlenecks: Somewhat Increase.
Genetic data from Rieseberg et al. (1987) suggest that *Allium constrictum* evolved from a peripheral occurrence of *A. columbianum* and has since diverged somewhat due to reproductive isolation. The founder population, thus, may have been relatively small, suggesting an initial genetic bottleneck.

C5c. Reproductive System: Somewhat Increase/Neutral.
Allium species generally are outcrossers and have non-specialized pollinators. Due to its recent origin, *A. constrictum* may have lower than average levels of genetic diversity and at least two unique allozymes distinct from related onion species (Rieseberg et al. 1987).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on WNHP and Consortium of Pacific Northwest Herbaria records, no changes have been detected in phenology in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The range of *Allium constrictum* has not been altered in recent years due to impacts from climate change.

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.

References

Barrett, J.A. and N. Sprague. 1985. *Allium douglasii* Hook. var. *constrictum* Mingrone & Ownbey status report. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. 42 pp. + app.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

McNeal, D.W. 1994. Report on *Allium*. Columbia Basin Scientific Assessment Project. University of the Pacific, Stockton, CA. 21 pp.

Rieseberg, L.H., P.M. Peterson, D.E. Soltis, and C.R. Annable. 1987. Genetic divergence and isozyme number variation among four varieties of *Allium douglasii* (Alliaceae). American Journal of Botany 74(11): 1614-1624.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Anemone patens var. *multifida* (Pasqueflower)

Date: 3 March 2021 Synonym: *Pulsatilla nuttalliana*

Assessor: Walter Fertig, 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: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		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		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 others species to generate required habitat		Neutral/Somewhat Increase
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		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		Somewhat Increase

5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All 4 of the accepted extant and historical occurrences of *Anemone patens* var. *multifida* in Washington (100%) occur in areas with a projected temperature increase of 3.9-

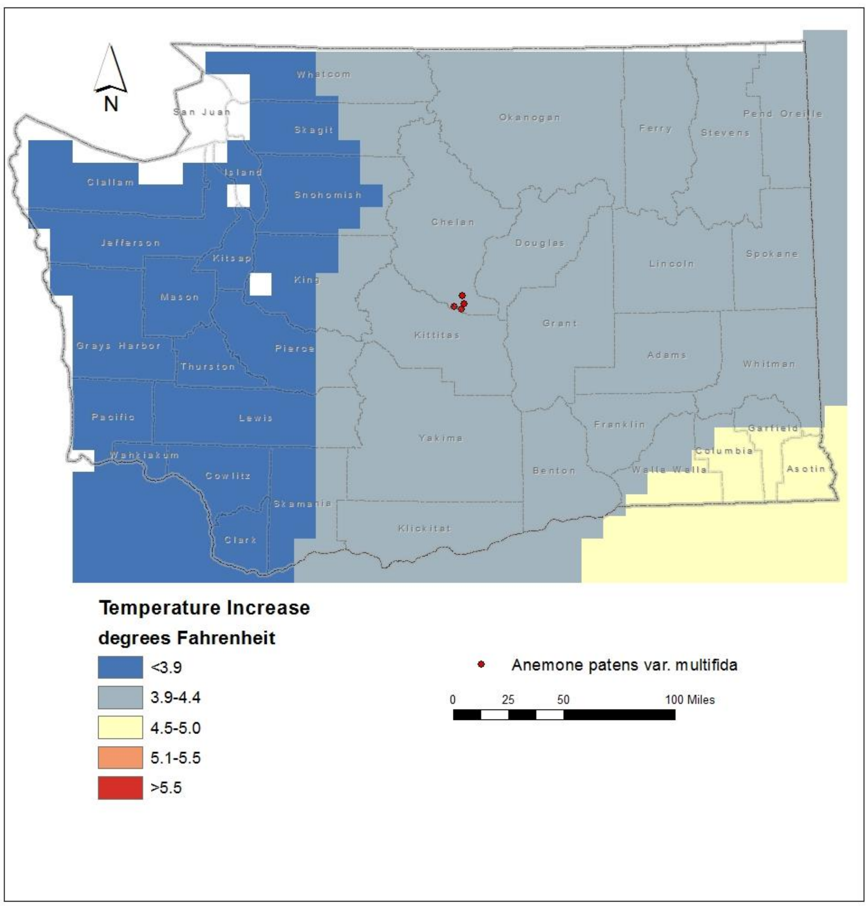

Figure 1. Exposure of *Anemone patens* var. *multifida* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

4.4 ˚ F (Figure 1). Previous reports from Okanogan and Whatcom County are based on misidentifications (Fertig and Kleinknecht 2020) and are excluded from this analysis.

A2. Hamon AET:PET Moisture Metric: The four occurrences (100%) of *Anemone patens* var. *multifida* 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).

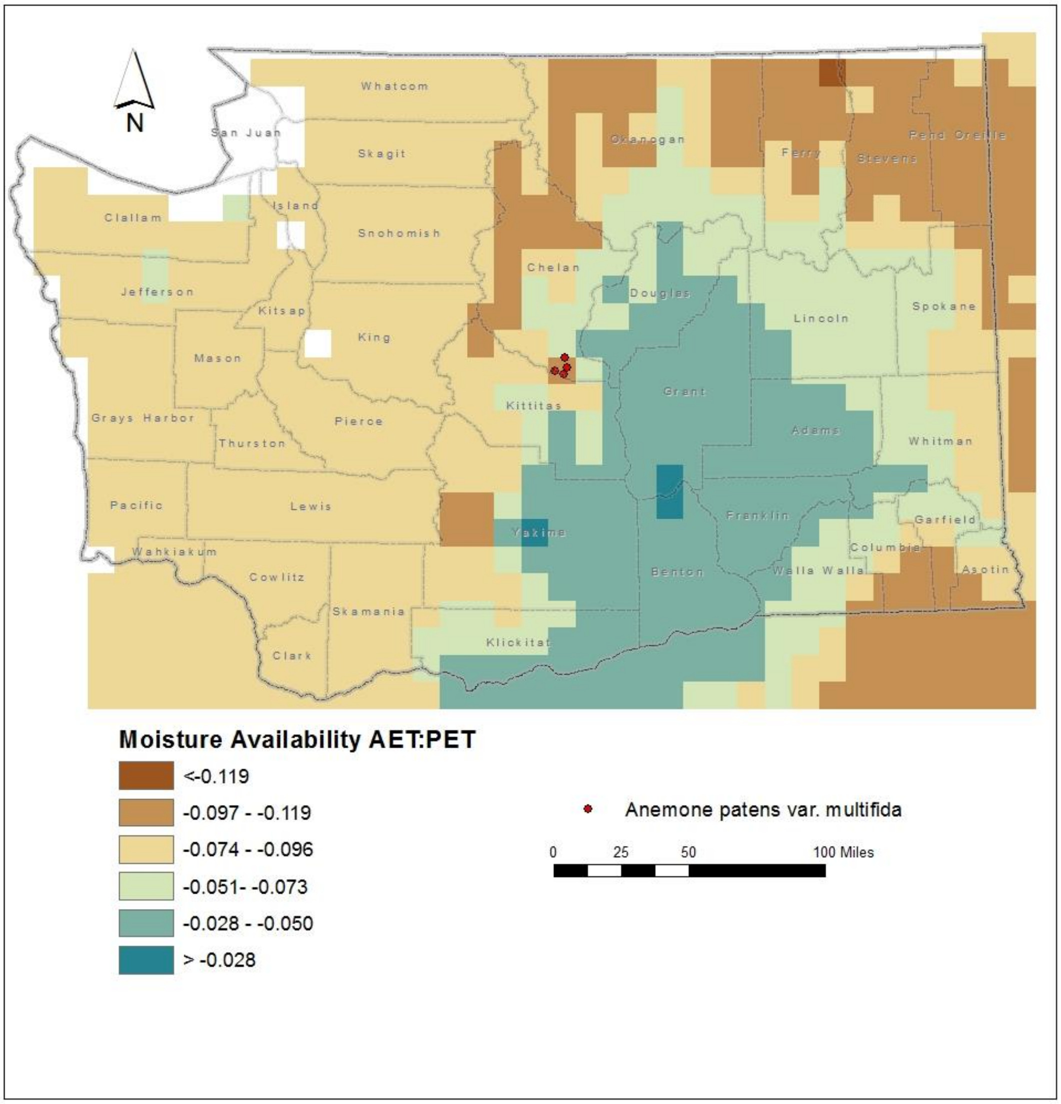

Figure 2. Exposure of *Anemone patens* var. *multifida* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Anemone patens* var. *multifida* are found at 3360-6600 feet (1025-2010 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Anemone patens* var. *multifida* occurs primarily on rocky basalt or sandstone talus slopes and meadows bordered by montane forests of *Pinus ponderosa* and *Pseudotsuga menziesii*. Reports from alpine habitats (Camp and Gamon 2011) were based on misidentifications. This species' habitat is part of the Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest ecological system (Rocchio and Crawford 2015). Populations are only 2.4-3.8 air miles (4-6 km) apart, but separated by canyons with unoccupied and unsuitable habitat. The proximity of the sites allows for some gene exchange between them. Topographic barriers could present a hurdle for migration of this species northward under projected climate change scenarios.

B2b. Anthropogenic barriers: Somewhat Increase.
The montane to subalpine ridge habitat of *Anemone patens* var. *multifida* in Washington is bisected by natural barriers (canyons and unsuitable forest habitat) and by human infrastructure, such as roads, agricultural fields, timber harvest areas, and rural inhabitations. Both natural and anthropogenic barriers are likely to constrain future migration.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Anemone patens var. *multifida* produces ball-like heads of nut-like achene fruits, each surmounted by a feathery style that helps disperse the individual achenes by wind. In theory, fruits could be dispersed over long distances, but studies in Germany found that 90% of fruits dispersed in the immediate vicinity of the maternal plant and only 0.05% were carried more than 100m away, perhaps abetted by secondary dispersal by insects carrying fruits once they landed on the ground (Röder and Kiehl 2006).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Anemone patens* var. *multifida* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All four of the known occurrences in the state (100%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The montane talus meadow and forest habitat of *Anemone patens* var. *multifida* is within cold air drainages on mountain slopes and would have somewhat increased vulnerability to warming temperatures from climate change.

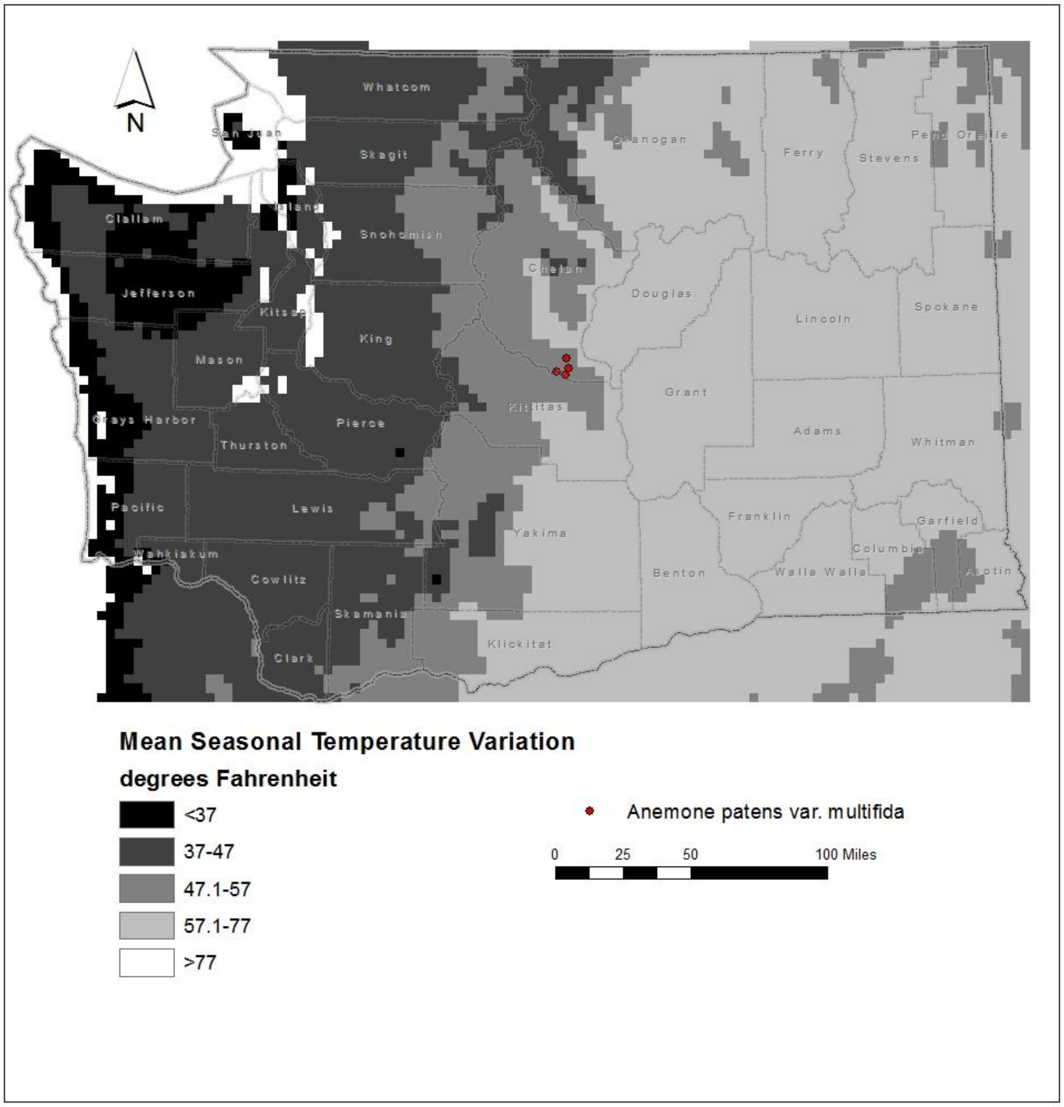

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Anemone patens* var. *multifida* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Anemone patens* var. *multifida* in Washington (100%) are found in areas that have experienced average precipitation variation in the past 50 years (20 -40 inches/508-1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

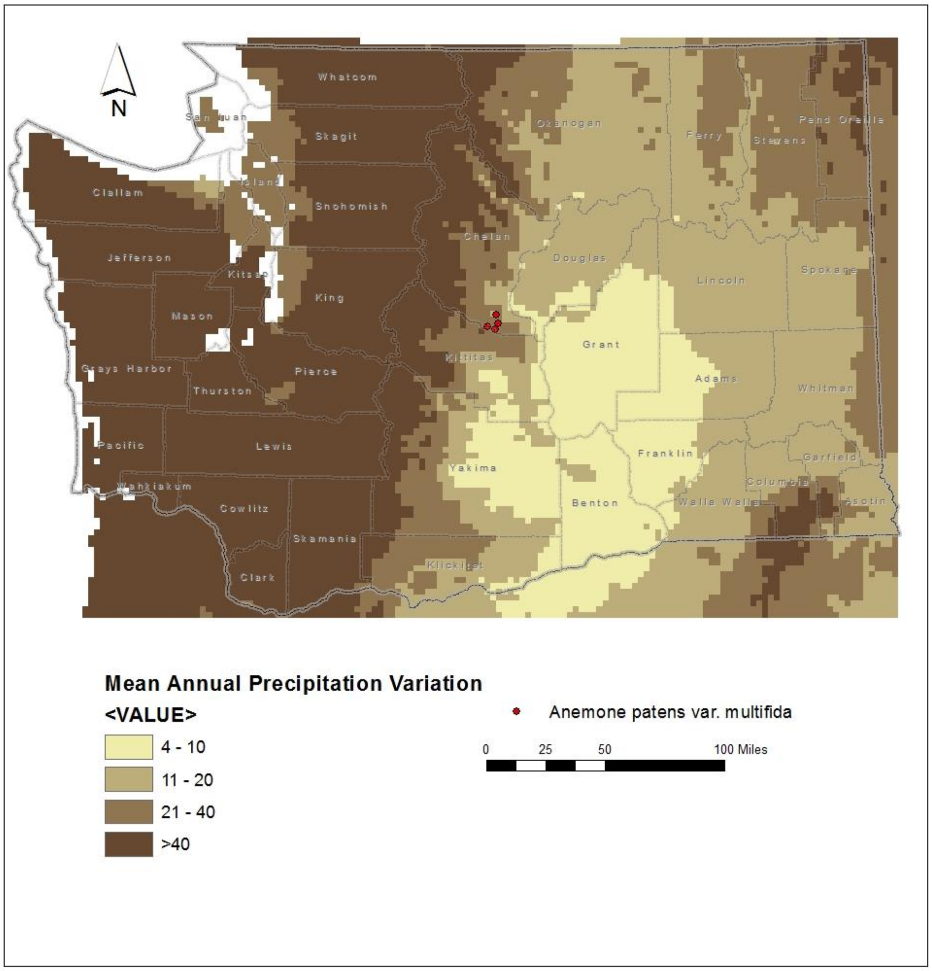

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Anemone patens* var. *multifida* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species relies on winter snow and summer precipitation for the majority of its annual water budget. 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 *Anemone patens* var. *multifida* more prone to drought and wildfire, favoring conversion to drier grasslands (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Under future climate change scenarios, montane meadow/forest habitats are likely to become drier and more prone to wildfire and outbreaks of mountain pine beetle. This increase in

disturbance could favor the shift to drier grasslands and invasion of non-native weedy species (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Populations of *Anemone patens* var. *multifida* in Washington are found in montane areas of the Eastern Cascades with moderate to high snowfall. Rocky meadow areas occupied by this species may have reduced snow cover due to wind or drifting, allowing this species to flower earlier than other native forbs (Bock and Peterson 1975). Reductions in the amount of snowpack or in the timing of melting due to increased temperatures in the future could impact meadow/conifer forest ecotone communities through reductions in available moisture or increased fire frequency or severity (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Anemone patens var. *multifida* is associated with the Tertiary Swauk Formation and Quaternary landslide deposits. The Swauk Formation consists of interbedded sandstone and mudstone deposited as stream outwash and is found primarily in the Wenatchee Mountains (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral/Somewhat Increase.
The montane talus and meadow habitat occupied by *Anemone patens* var. *multifida* is maintained largely by natural abiotic conditions, such as fire, snow deposition, and drought, but vegetation density and height may also be controlled by herbivory of native ungulates, rodents, and insects.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
In Colorado, Bock and Peterson (1975) observed pollination of *Anemone patens* var. *multifida* by honeybees (*Apis mellifera*), andrenid bees (*Andrena* spp.), bumblebees (*Bombus* spp.) and syrphid flies. The precise pollinators in Washington are not known.

C4d. Dependence on other species for propagule dispersal: Neutral.
The achene fruits of *Anemone patens* var. *multifida* have a persistent, feathery style to aid in dispersal by wind. Secondary dispersal by insects may be important for spreading seed once it lands on the ground.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Populations may be threatened by livestock grazing (Fertig and Kleinknecht 2020), although studies in Europe suggest that grazing and other management activities to maintain meadow and forest edge habitats are necessary for long-term persistence of the species (Szczecińska et al. 2016).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Studies in Alberta found that *Anemone patens* var. *multifida* experienced a negative population growth rate in prairie habitats that became dominated by introduced smooth brome (*Bromus inermis*) but increased over time in native prairie (Williams and Crone 2006). In Europe, where *A. patens* var. *patens* is endangered, populations are declining due to increased competition

with perennial grasses and mosses in places where cattle grazing has been removed and strict fire control policies have been enacted (Szczecińska et al. 2016).

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

C5a. Measured genetic variation: Somewhat Increase.
Washington populations of *Anemone patens* var. *multifida* are disjunct by 250 miles (400 km) from their nearest congeners in southeastern British Columbia. The Washington occurrences are probably genetically distinct from other populations in the Rocky Mountains due to inbreeding, genetic drift, or founder effects. Research in central Europe has shown that widely isolated populations of *A. patens* have reduced genetic diversity and high levels of inbreeding, which is likely a factor in its steep decline (Szczecińska et al. 2016). Genetic data are currently not available for Washington populations.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Anemone patens var. *multifida* produces large, open, showy flowers that are pollinated by a variety of early spring generalist bees and syrphid flies. Flowers are protogynous (with stigmas being receptive before pollen is shed) to promote outcrossing, but is also capable of selfing if pollinators are unavailable. Seed germination rates are comparable under out-crossing and selfing (Bock and Peterson 1975).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Anemone patens* var. *multifida* has not changed its typical blooming time in the past 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Anemone patens* var. *multifida* in Washington since it was first documented in the state in 1925.

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

References

Bock, J.H. and S.J. Peterson. 1975. Reproductive biology of *Pulsatilla patens* (Ranunculaceae) American Midland Naturalist 94(2): 476-478.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, Washington Department of Natural Resources, Olympia, WA. 173 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Röder, D. and K. Kiehl. 2006. Population structure and population dynamic of *Pulsatilla patens* (L.) Mill. In relation to vegetation characteristics. Flora – Morphology, Distribution, Functional Ecology of Plants 201(6): 499-507.

Szczecińska, M., G. Sramko, K. Wolosz, and J. Sawicki. 2016. Genetic diversity and population structure of the rare and endangered plant species *Pulsatilla patens* (L.) Mill. in East Central Europe. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0151730

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Williams, J.L. and E.E. Crone. 2006. The impact of invasive grasses on the population of *Anemone patens*, a long-lived native forb. Ecology 87(12): 3200-3208.

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

Arabis olympica (Olympic rockcress)

Date: 18 October 2021 | Synonym: *A. furcata* var. *olympica*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: GH/SH

Index Result: Highly Vulnerable. | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
4a. Dependence on others 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		Unknown
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		Increase

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
D1. Documented response to recent climate change	Somewhat Increase
D2. Modeled future (2050) change in population or range size	Increase
D3. Overlap of modeled future (2050) range with current range	Neutral
D4. Occurrence of protected areas in modeled future (2050) distribution	Neutral

Section A: Exposure to Local Climate Change

A1. Temperature: The six historical occurrences of *Arabis olympica* in Washington (100%) are found in areas with a projected temperature increase of < 3.9˚ F (Figure 1).

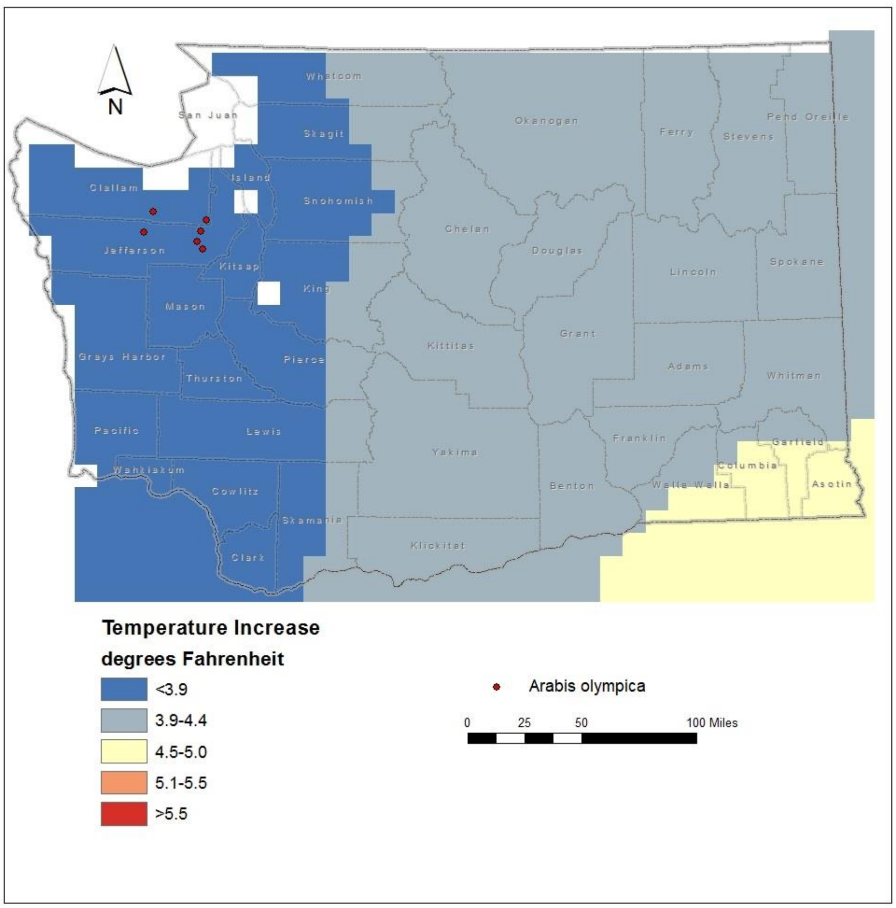

Figure 1. Exposure of *Arabis olympica* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All six historical occurrences of *Arabis olympica* (100%) 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).

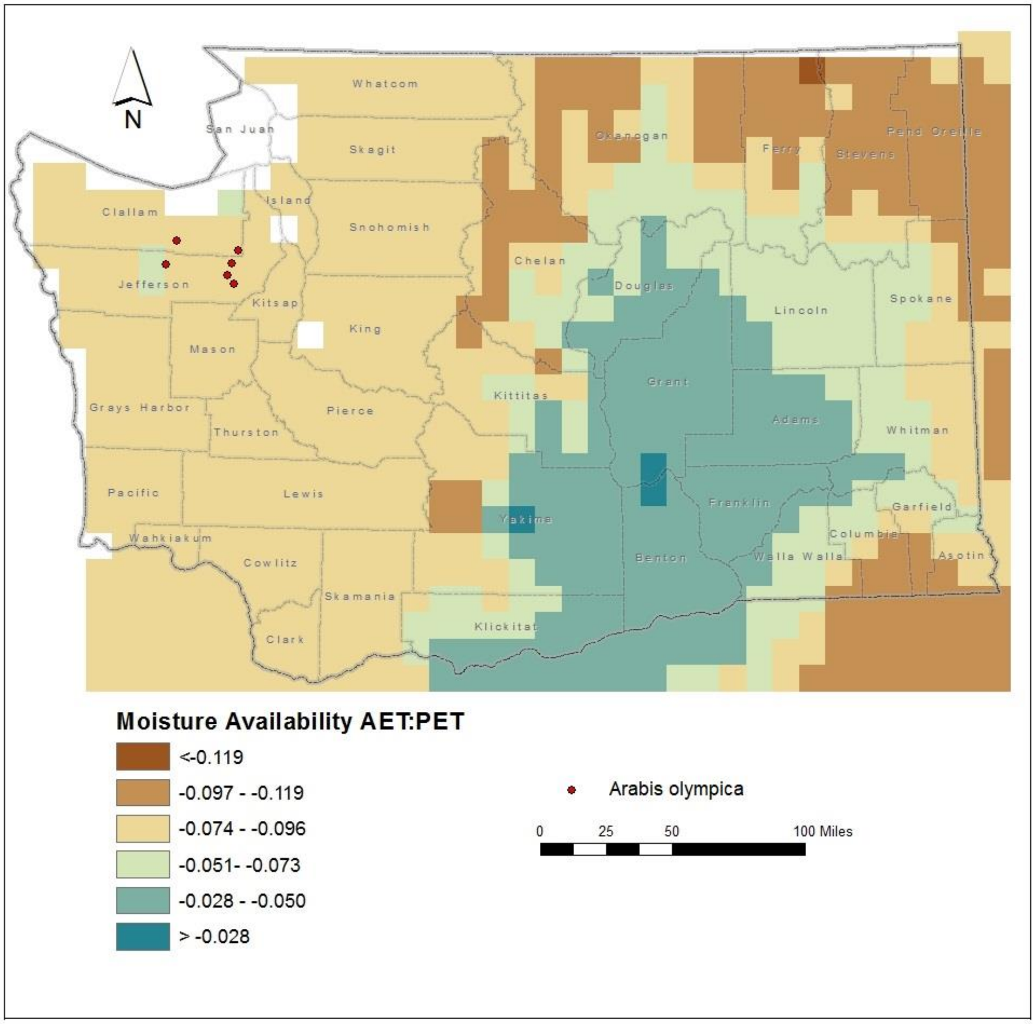

Figure 2. Exposure of *Arabis olympica* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Arabis olympica* are found at 3000-4495 feet (915-1370 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
Arabis olympica is endemic to the northeastern Olympic Range in Washington, where it is found in subalpine to alpine dry rocky meadows and turf areas amid rock outcrops (Buckingham et al. 1995; Fertig 2020; Washington Natural Heritage Program 2021). These habitats are a component of the North Pacific Alpine & Subalpine Dry Grassland and North Pacific Dry & Mesic Alpine Dwarf-Shrubland, Fell-Field & Meadow ecological systems (Rocchio and Crawford 2015). The entire global range of *A. olympica* is restricted to an area of 20 x 30 miles (33 x 46 km). Individual occurrences are separated by 5.5-20 miles (9-32 km) and occur on ridge systems isolated by deep valleys and unsuitable forested habitat. The Olympic Range is also disjunct from other alpine mountain ranges north and east of the Salish Sea/Puget Sound, making potential migration more difficult.

B2b. Anthropogenic barriers: Neutral.
The range of *Arabis olympica* is primarily at or above treeline in Olympic National Park and The Brothers and Buckhorn wilderness areas of Olympic National Forest. These sites have some hiking trails but otherwise the human footprint is negligible and does not present an additional barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Arabis olympica produces numerous, small, flattened seeds with a narrow wing within a dry, dehiscent fruit (Al-Shehbaz 2010). Seeds are released passively and may spread by gravity or strong winds. Dispersal distances are probably moderate (about 1000 m).

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Arabis olympica* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Five of the six occurrences (83.3%) are found in areas that have experienced very small (<37˚F/20.8˚C) temperature variation during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). One other occurrence (16.7%) is from an area with small (37-47˚F/20.8-26.3˚C) temperature variation over the same period and is at increased vulnerability to climate change.

C2aii. Physiological thermal niche: Increase.
The range of *Arabis olympica* is restricted to alpine and subalpine areas exposed to high winds and cold winter temperatures. These areas are projected to become warmer due to climate change (Rocchio and Ramm-Granberg 2017).

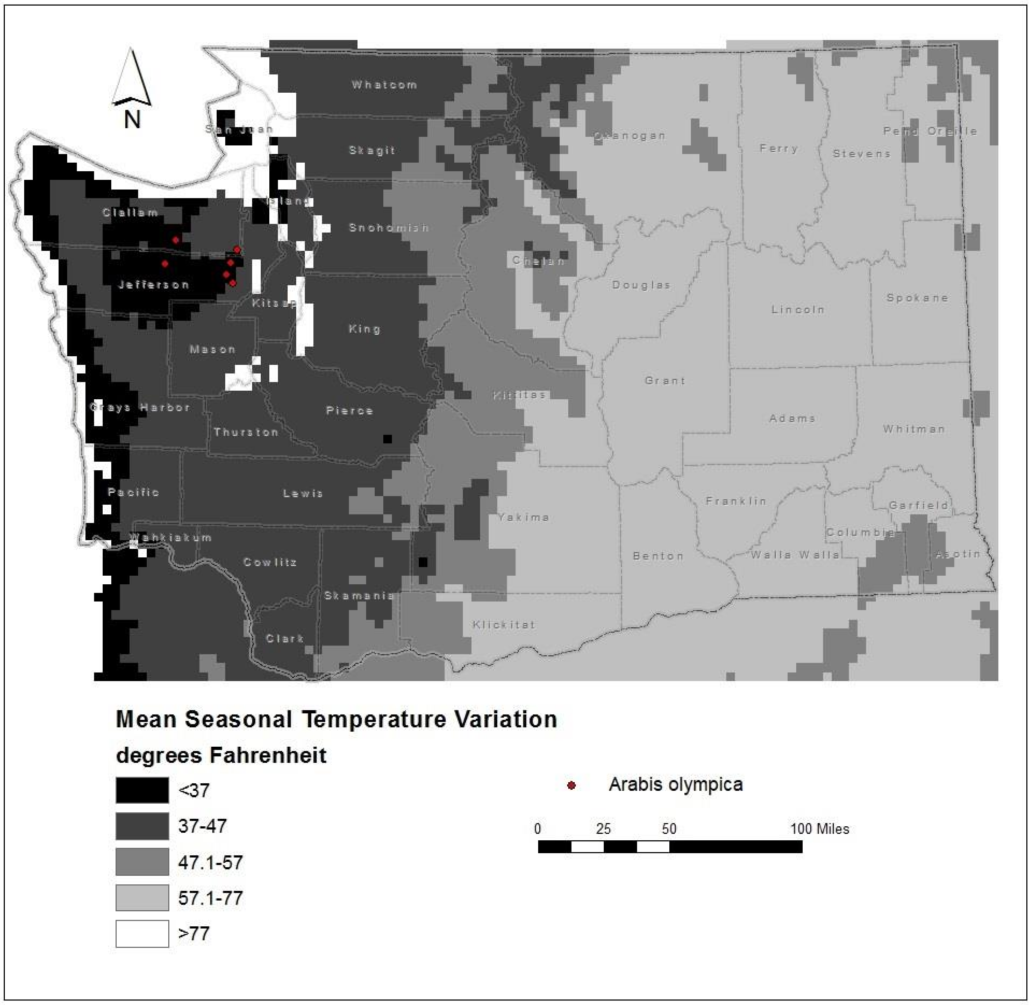

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Arabis olympica* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All six of the historical occurrences of *Arabis olympica* in Washington (100%) are found in areas that have experienced greater than average (>40 inches/1016 mm) of precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these areas are at neutral vulnerability to climate change.

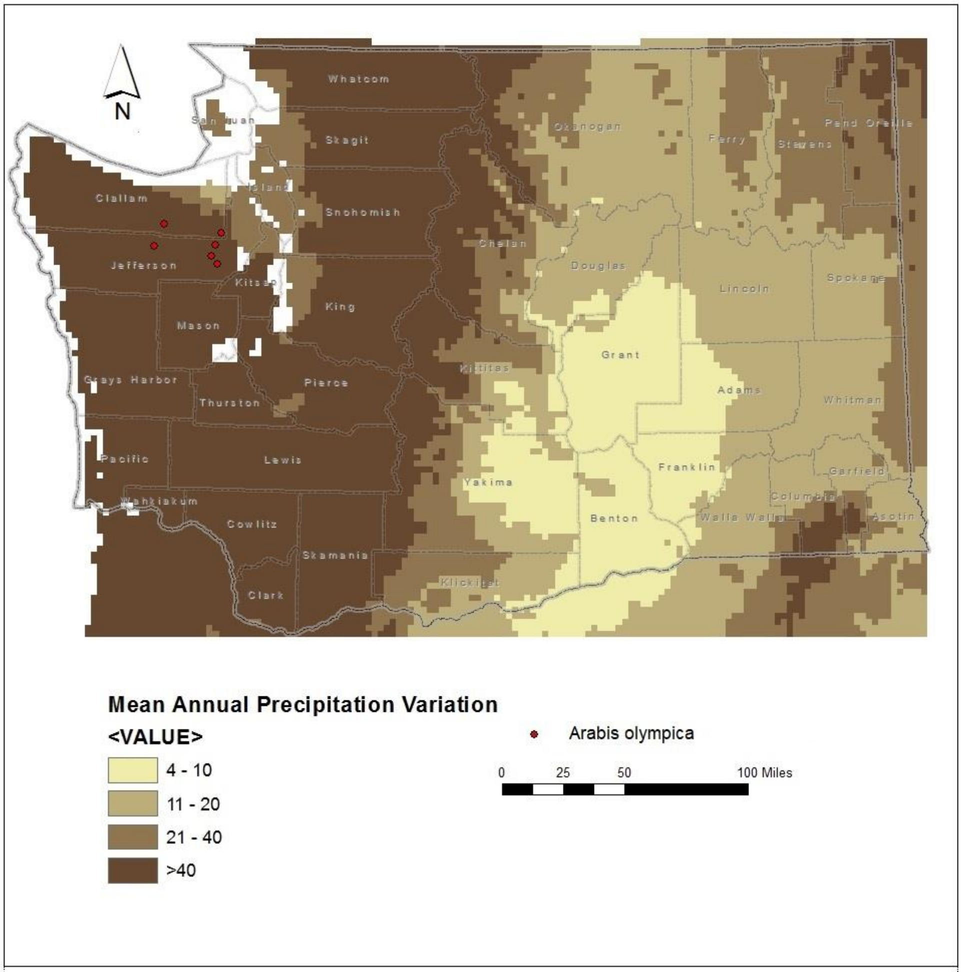

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Arabis olympica* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Arabis olympica occurs primarily in dry to moist alpine or subalpine meadows or rocky areas that are dependent on adequate snowmelt or summer precipitation for their moisture requirements. Increased temperatures from climate change are likely to alter the timing of snowmelt, leading to earlier runoff (Rocchio and Ramm-Granberg 2017). The amount and timing of summer precipitation is also likely to change, making these habitats drier and more vulnerable to invasion by lower elevation dry meadow species.

C2c. Dependence on a specific disturbance regime: Neutral.
The open, alpine to subalpine, meadow and rock outcrop habitat of *Arabis olympica* is maintained by a short growing season, high winds, and late-lying snow that prevent tree species from becoming established. Increased temperatures and changes in precipitation patterns could result in shifts in vegetation towards forest or drier meadow species and make these areas more vulnerable to wildfire (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The Olympic Mountains average over 10 meters (400 inches) of snow. The alpine and subalpine areas inhabited by *Arabis olympica* are on open ridges or slopes where snow may be exposed to wind and sun and less likely to accumulate late into the summer, making the local microenvironment drier than surrounding areas. Changes in the amount of snow, or timing of its melting (Rocchio and Ramm-Granberg 2017), will likely have an important impact on the persistence of this species.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Arabis olympica is found primarily on outcrops of the Eocene-age Crescent Formation, a basalt layer found mostly along the eastern and northern rim of the Olympic Range. One occurrence is associated with Oligocene-Miocene marine sediments (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The open alpine-subalpine meadow and rocky ridge habitat of *Arabis olympica* is mostly maintained by abiotic processes, such as snow distribution and how it is influenced by wind and melting temperatures, rather than by other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Arabis olympica* are not known. Other *Arabis* and related *Boechera* species are pollinated by a variety of insects, including honey bees (*Apis*), solitary bees (*Bombus*), bee flies (*Bombylius*), butterflies, and wasps (Hamilton and Mitchell-Olds 1994).

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Arabis olympica* dehisce when dry to release seeds passively by gravity or wind. The seeds are flat and have narrow wings to facilitate dispersal by wind. Secondary transport by animals may occur, but probably is insignificant.

C4e. Sensitivity to pathogens or natural enemies: Unknown.
Impacts from pathogens are not documented. *Arabis olympica* may be susceptible to herbivory by insects, rodents, or hoofed animals, including introduced mountain goats (*Oreamnos americanus*), but impacts are poorly documented.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Arabis olympica occurs mostly in dry alpine or subalpine meadows or rocky ridges. Under projected future climate change, these sites are likely to be warmer and have a longer growing season (Rocchio and Ramm-Granberg 2017), which may allow subalpine species to expand their

range or increase the cover of other alpine competitors. Herbivory or trampling by introduced mountain goats is a threat to many Olympic alpine plant species (Schreiner et al. 1994).

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

C5a. Measured genetic variation: Unknown.
Basic information on the ploidy level or population genetics of *Arabis olympica* are not known (Koch et al. 2010), although the species is inferred to be closely related to *Arabis furcata* based on morphological traits (Al-Shehbaz 2010, Rollins 1941).

C5b. Genetic bottlenecks: Unknown.
During the Pleistocene, populations of *Arabis olympica* could have been restricted to unglaciated refugia and had limited gene exchange with other populations or increased inbreeding.

C5c. Reproductive System: Increase.
According to Al-Shehbaz (2010), the few available herbarium specimens of *Arabis olympica* all have immature seeds. While this could be a factor of under-sampling, it might also reflect reproductive bottlenecks related to past hybridization, poor pollination success, or severe inbreeding. Species of *Arabis* and *Boechera* (formerly included in *Arabis*) exhibit a wide variety of breeding systems, including obligate outcrossing, limited autogamy (selfing), and apomixis (producing seed without fertilization) (Rollins 1941). Research is needed on the reproductive system and ploidy of *Arabis olympica* to determine whether these are factors in its rarity.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on Washington Natural Heritage Program data, no significant changes in the phenology of *Arabis olympica* populations have been detected.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase.
No populations of *Arabis olympica* have been observed since 1980 and attempts to relocate two historical occurrences in 2015 and 2016 were unsuccessful. Many historical records have vague locality details, and this species is small and cryptic, so it can be easy to overlook. Populations may also be in significant decline, and its range has become more constricted. Wershow and DeChaine (2018) did not include this species in their study of climate change impacts on alpine endemics of the Olympic Range, in part because they were unable to relocate any populations (Wershow notes from Rare Care survey in 2016).

D2. Modeled future (2050) change in population or range size: Increase.
Wershow and DeChaine (2018) modeled the projected future habitat of five Olympic alpine endemics that overlap the range of *Arabis olympica* and found that 85-99% of their current habitat would no longer be suitable by 2080 due to rising temperatures and reduced moisture availability.

D3. Overlap of modeled future (2050) range with current range: Neutral.
Based on the projected future range of other alpine endemic plants found in similar habitats in the Olympic Mountains (Wershow and Dechaine 2018), the range of *Arabis olympica* is expected to contract rather than shift in distribution.

D4. Occurrence of protected areas in modeled future (2050) distribution: Neutral.
Despite the likely contraction of potential suitable habitat due to climate change, the entire range of *Arabis olympica* will still be restricted to Olympic National Park.

References

Al-Shehbaz, I.A. 2010. *Arabis*. Pp 257-266. In: Flora of North America Editorial Committee. Flora of North America North of Mexico. Volume 7: Magnoliophyta: Salicaceae to Brassicaceae. Oxford University Press, New York. 797 pp.

Buckingham, N.M., E.G. Schriener, T.N. Kaye, J.E. Burger, and E.L. Tisch. 1995. Flora of the Olympic Peninsula. Northwest Interpretive Association, Seattle, WA.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Hamilton, M.B. and T. Mitchell-Olds. 1994. The mating system and relative performance of selfed and outcrossed progeny in *Arabis fecunda* (Brassicaceae). American Journal of Botany 81(10): 1252-1256.

Koch, M.A., R. Kral, C. Kiefer, and I.A, Al-Shehbaz. 2010. Colonizing the American continent: Systematics of the genus *Arabis* in North America (Brassicaceae). American Journal of Botany 97(6): 1040-1057.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Rollins, R.C. 1941. A monographic study of *Arabis* in western North America. Rhodora 43: 289-325.

Schreiner, E.G., M.B. Gracz, T.N. Kaye, A. Woodward, and N.M. Buckingham. 1994. Effects of mountain goats on rare plants. Pp. 173-188. In: Houston, D.B., E.G. Schreiner, and B.B. Moorhead, eds. Mountain goats in Olympic National Park: Biology and management of an introduced species. Scientific Monograph NPS/NROLYM/NRSM-94/25. US Department of Interior, National Park Service.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Arabis olympica*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=arabis%20olympica). Accessed 18 October 2021.

Wershow and E. DeChaine. 2018. Retreat to refugia: Severe habitat contraction projected for endemic alpine plants of the Olympic Peninsula. American Journal of Botany 105(4): 760-778.

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

Arcteranthis cooleyae (Cooley's buttercup)

Date: 25 October 2021 Synonym: *Ranunculus cooleyae*

Assessor: Walter Fertig, 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: Local Climate	**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	25
	<3.9° F (2.2°C) warmer	75
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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase/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 others 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		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: Documented or Modeled Response	
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: Three of the four occurrences of *Arcteranthis cooleyae* in Washington (75%) occur in areas with a projected temperature increase of <3.9˚ F (Figure 1). One other population (25%) is from an area with a projected temperature increase of 3.9-4.4˚ F.

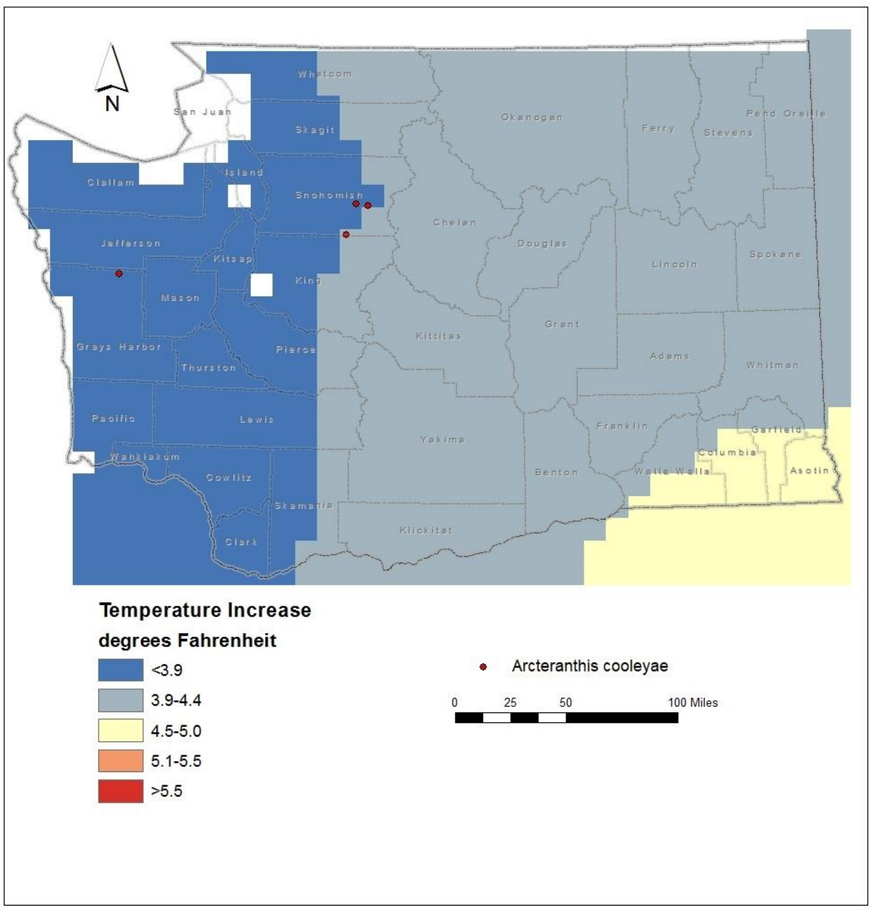

Figure 1. Exposure of *Arcteranthis cooleyae* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All of the known Washington occurrences of *Arcteranthis cooleyae* (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 -0.096 (Figure 2).

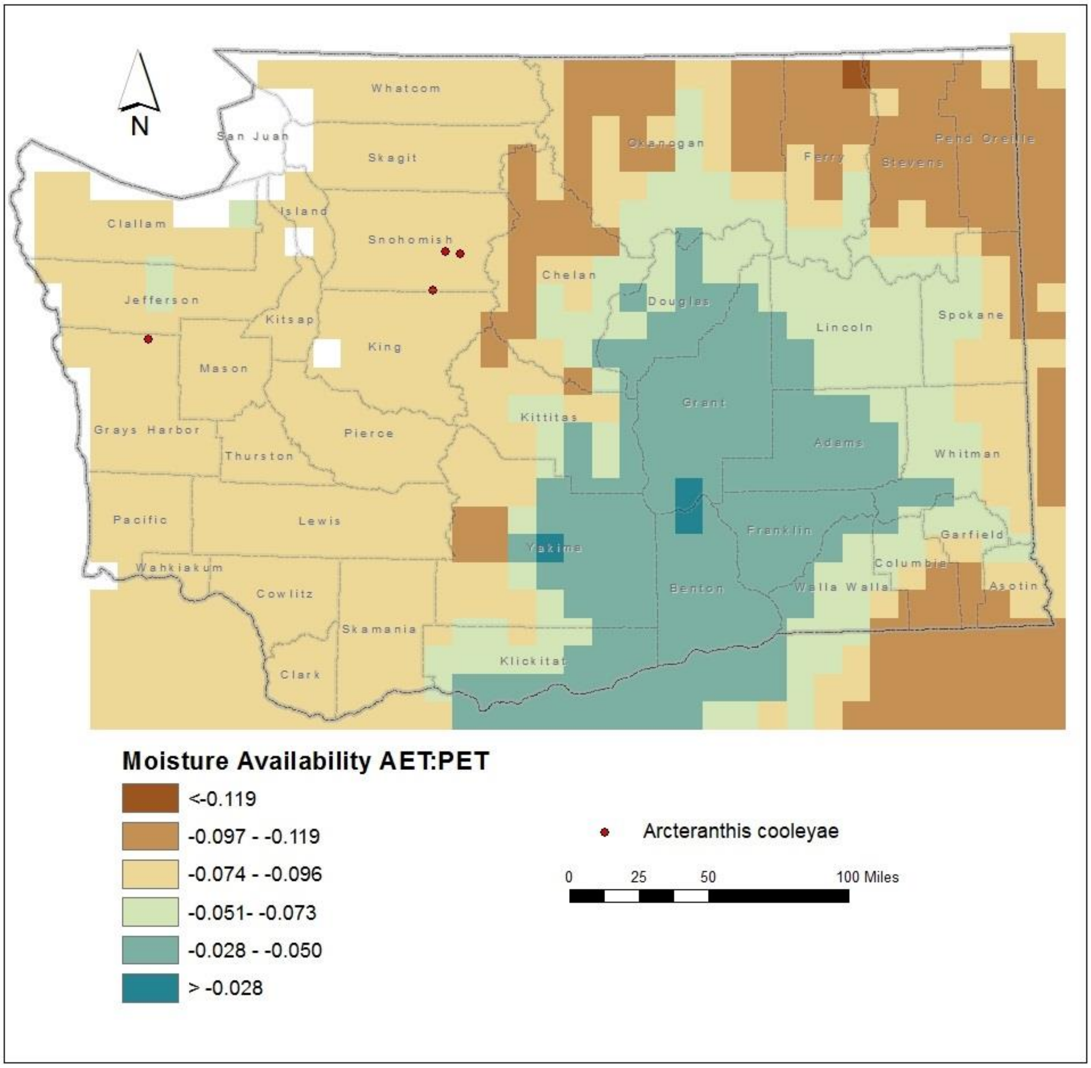

Figure 2. Exposure of *Arcteranthis cooleyae* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Arcteranthis cooleyae* are found at 2500-6000 feet (760-1830 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Arcteranthis cooleyae* is found at the base of cliffs on talus or fine gravel and sand, or on stream outlets and the edges of receding snowbanks, often on shady, north-facing slopes (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is a component of the North Pacific Alpine & Subalpine Bedrock & Scree ecological system (Rocchio and Crawford 2015). Individual populations are separated by 5-14.5 miles (7.6-23 km) in the North Cascades, with one disjunct population in the Olympic Range isolated by 103 miles (166 km). Large areas of unsuitable habitat exist between occurrences and dispersal is restricted by natural barriers.

B2b. Anthropogenic barriers: Neutral.
The range of *Arcteranthis cooleyae* in Washington is restricted to National Forest lands surrounded by human infrastructure, including roads, cities, and areas managed for silviculture or agriculture. Natural barriers, however, are more significant obstacles to dispersal than anthropogenic ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase/Increase.
Each flower of *Arcteranthis cooleyae* produces a ball-like cluster of 70-100 one-seeded achenes. Each achene has a persistent, hooked beak that can potentially latch on to animals for long distance dispersal. Scherff et al. (1994) found that dispersal of another beaked-fruited alpine buttercup (*Ranunculus adoneus*) averaged only 15-25 cm from the parent plant based on gravity and secondary dispersal by animals. Average dispersal distances for *A. cooleyae* may be similarly short, but with infrequent long-distance transport possible by birds or large-bodied mammals.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Arcteranthis cooleyae* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Two of the four known occurrences (50%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased risk from climate change (Young et al. 2016). One population (25%) is from an area with small temperature variation (37-47˚F/20.8-26.3˚C) over the same period and is at increased risk from climate change. One other occurrence in the Olympic Range (25%) is from an area with very small (>37˚F/20.8˚C) temperature variation during the last 50 years and is at greatly increased risk from climate change (Young et al. 2016).

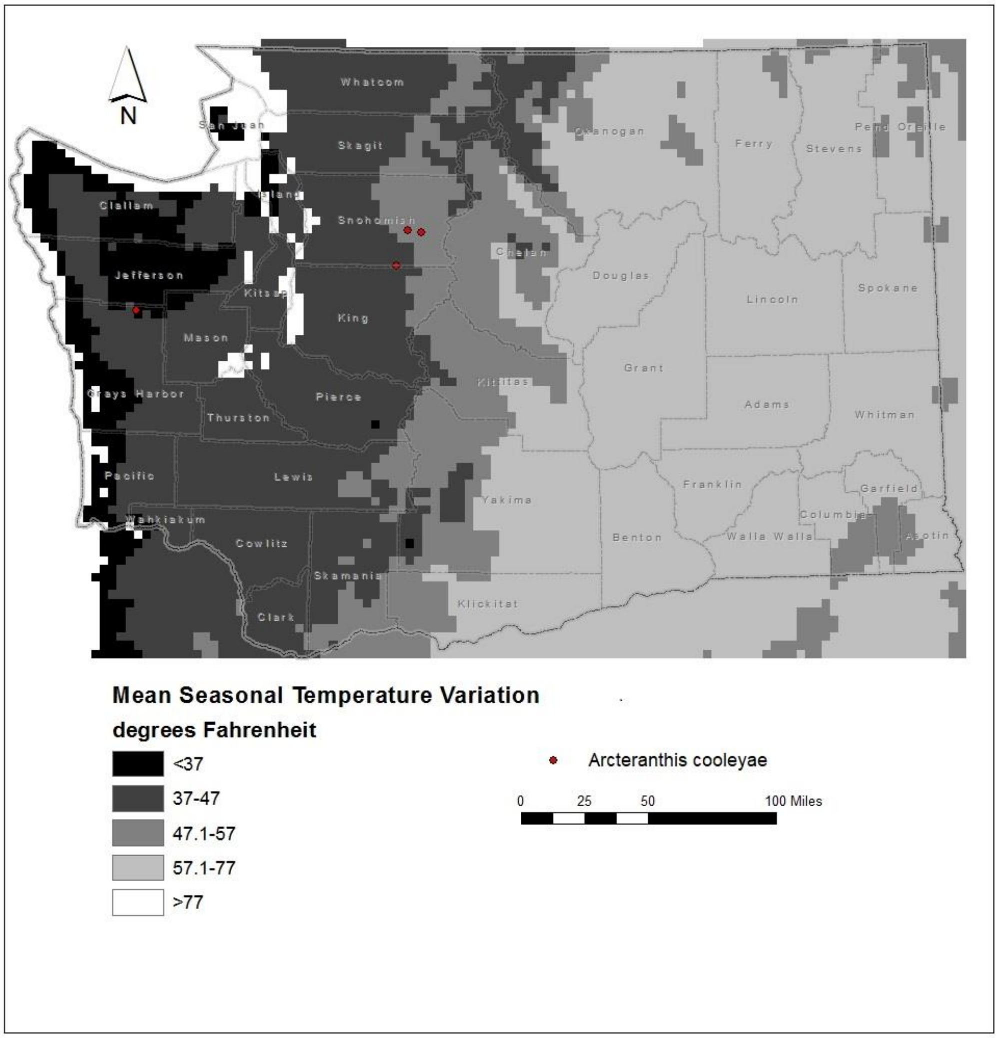

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Arcteranthis cooleyae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
In Washington, populations of *Arcteranthis cooleyae* are associated with subalpine, north-facing cliffs and talus slopes that are often shaded and in cold-air drainages. Under projected climate change, these cool microsites are likely to become warmer.

C2bi. Historical hydrological niche: Neutral.
All populations of *Arcteranthis cooleyae* in Washington (100%) are found in areas that have experienced greater than average (>40 inches/1016 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at neutral vulnerability from climate change.

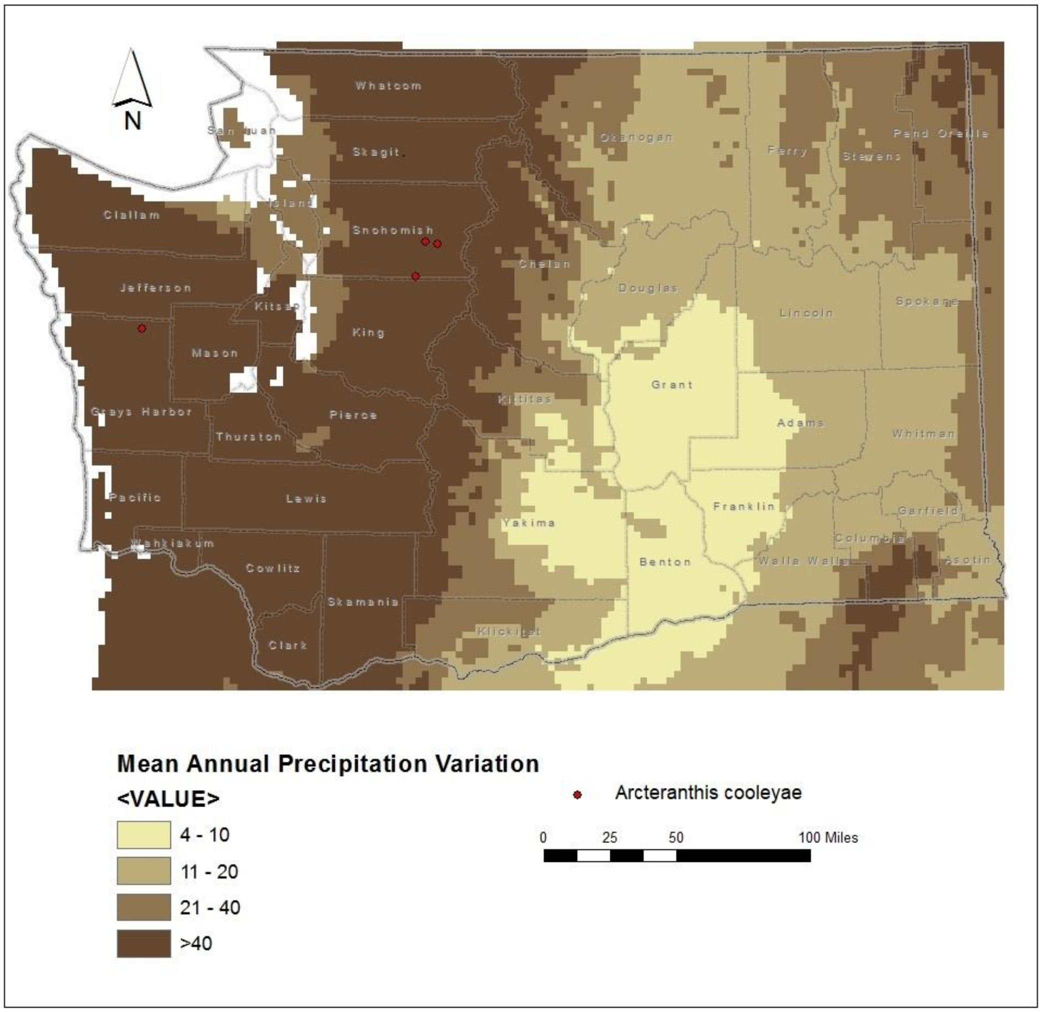

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Arcteranthis cooleyae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species occurs in shady cliff and talus sites that are not associated with perennial water sources or a high water table. *Arcteranthis cooleyae* is dependent on adequate winter snow and spring/summer rainfall for its moisture needs. Changes in the timing or amount of precipitation or snowmelt due to climate change and higher temperatures could extend the growing season and result in more soil development, making these barren cliff sites more suitable for forest vegetation (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Arcteranthis cooleyae occurs on barren cliffs and talus slopes that are maintained by natural weathering processes and facilitated by cool climatic conditions and high winds that reduce soil formation and keep plant density low. Additional periodic disturbances are not required to maintain this habitat.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Arcteranthis cooleyae* in Washington occur in area of high snow accumulation. Reduction in the amount of snow, conversion of snow to rain, or changes in the timing of snowmelt would potentially alter the amount of moisture available for this species under projected climate change (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
In the Olympic Mountains, *Arcteranthis cooleyae* is restricted to basalts of the Eocene-age Crescent Formation that rings the southern, eastern, and northeastern core of the range. Populations from the Cascades are associated with the Eocene volcanic Barlow Pass Formation and the Index Batholith (Washington Division of Geology and Earth Resources 2016). None of these geologic formations is particularly widespread in Washington, which may contribute to the rarity of *A. cooleyae* in the state.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Arcteranthis cooleyae* is maintained by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Arcteranthis cooleyae* in Washington are poorly known. Like other buttercups (*Ranunculus* and segregate genera *Beckwithia*, *Ficaria*, and *Halerpestes*) the cup-like flowers and ample nectar reward of *A. cooleyae* flowers probably attract a variety of generalist pollinators, which might include bees, butterflies, and flies.

C4d. Dependence on other species for propagule dispersal: Neutral.
Arcteranthis cooleyae produces numerous 1-seeded fruits (achenes) that have a small hook at the tip. Dispersal is primarily passive (gravity), but fruits can be secondarily moved by seed-caching animals or if the hooks get attached to fur or feathers. It is not dependent on a single animal species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Due to its remote cliff habitat, *Arcteranthis cooleyae* receives minimal impacts from livestock or ungulate 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.
Rocky microsites occupied by *Arcteranthis cooleyae* are not especially vulnerable to competition from other native or introduced plant species.

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability of Washington populations of *Arcteranthis cooleyae*. Recent genetic and morphologic studies indicate that *Arcteranthis* is more closely related to *Trautvetteria caroliniensis* than to other species of *Ranunculus*, in which it was once included (Emadzade et al. 2010).

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Arcteranthis cooleyae produces perfect flowers and is presumed to be an out-crosser with normal levels of genetic variation across all populations. Washington occurrences are at the extreme southern end of the species' range and might be expected to have lower overall genetic diversity due to inbreeding or founder effects.

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 in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Although one population of *Arcteranthis cooleyae* has not been relocated since the early 1960s, the range of the species in the state has not decreased significantly.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Emadzade, K., C. Lehnebach, P. Lockhart, and E. Hörandl. 2010. A molecular phylogeny, morphology and classification of genera of Ranunculeae (Ranunculaceae). Taxon 59(3): 809-828.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife.

Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Scherff, E.J., C. Galen, and M.L. Stanton. 1994. Seed dispersal, seedling survival and habitat affinity in a snowbed plant: limits to the distribution of the snow buttercup, *Ranunculus adoneus*. Oikos 69: 405-413.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Arcteranthis cooleyae*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=arcteranthis%20cooleyae). Accessed 26 October 2021.

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

Astragalus arrectus (Palouse milkvetch)

Date: 2 September 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G2G4/S2

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	46.7
	-0.051 to -0.073	53.3
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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		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: Documented or Modeled Response	
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: All 15 confirmed occurrences of *Astragalus arrectus* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). Erroneous or

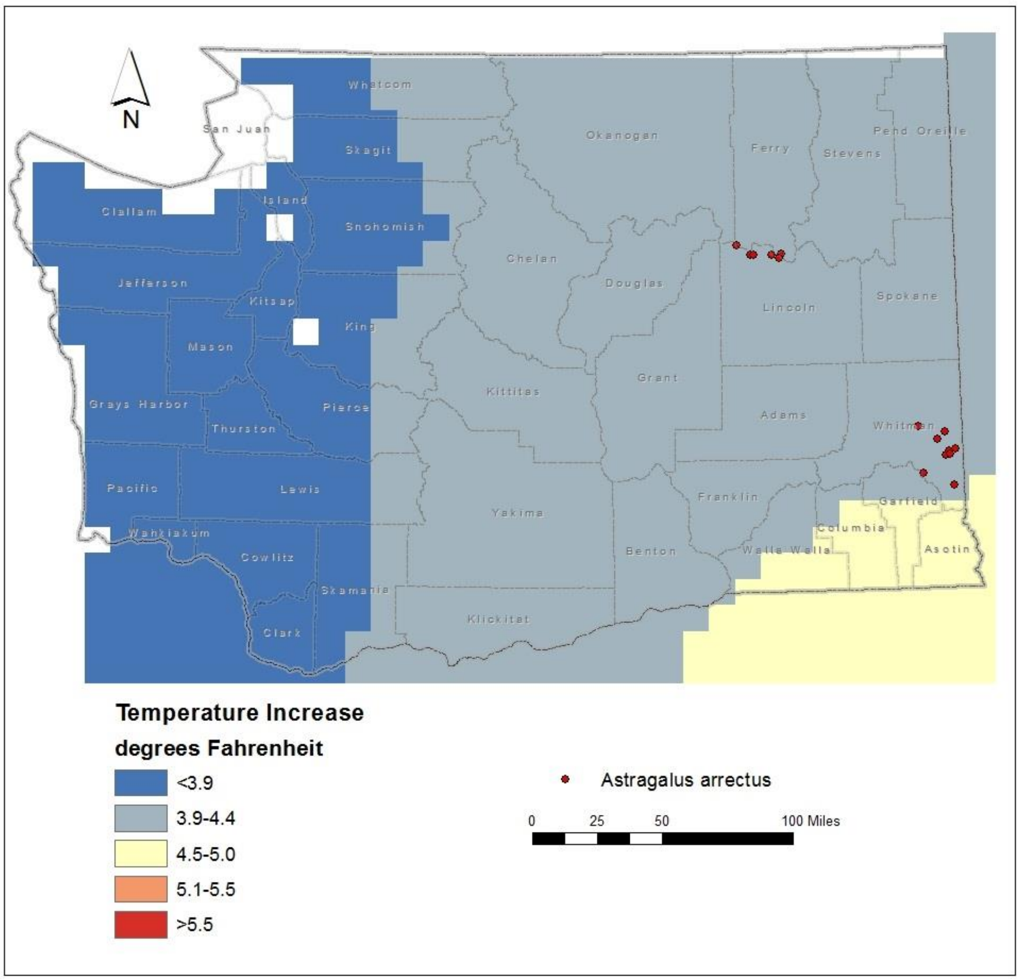

Figure 1. Exposure of *Astragalus arrectus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

unconfirmed records from Chelan, Kittitas, and Klickitat counties (Fertig and Kleinknecht 2020) were not used in this analysis.

A2. Hamon AET:PET Moisture Metric: Eight of the 15 verified occurrences of *Astragalus arrectus* (53.3%) 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 other 7 occurrences are from areas with a projected decrease from -0.074 to -0.096.

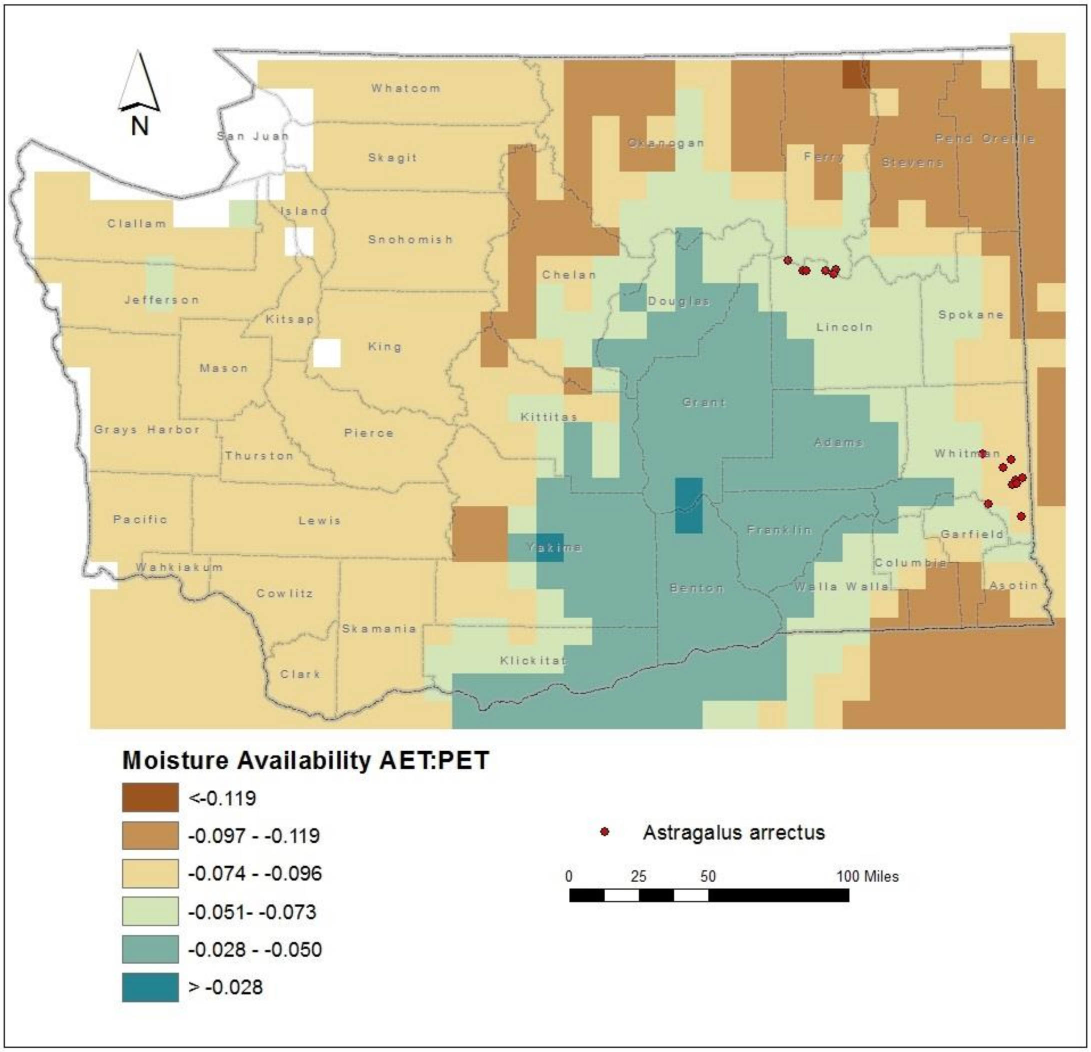

Figure 2. Exposure of *Astragalus arrectus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Astragalus arrectus* are found at 1000-2900 feet (300-880 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Astragalus arrectus* is found on grassy hillsides, sagebrush flats, river bluffs, and grassy or shrub-dominated openings in *Pinus ponderosa* and *Pseudotsuga menziesii* woods (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is a component of the Columbia Basin Foothill and Canyon Dry Grassland, Columbia Basin Palouse Prairie, and Northern Rocky Mountain Ponderosa Pine Woodland and Savanna ecological systems (Rocchio and Crawford 2015). Verified populations in Washington occur in two disjunct areas along the Columbia River in northern Lincoln County and the Palouse region of southeastern Whitman County. These main population centers are separated by 84 miles (135 km). Within these areas, individual occurrences are within 1.2-9 miles (1.9-14 km) of each other. Natural barriers of unsuitable habitat are significant between the two population centers, but are less of an impediment to dispersal within the population centers.

B2b. Anthropogenic barriers: Somewhat Increase.
In Whitman County, the pre-settlement Palouse Prairie habitat of *Astragalus arrectus* has become highly fragmented in the past 150 years due to agricultural development, growth of cities and towns, and an extensive road network. These present a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Astragalus arrectus produces 15-33 flowers per inflorescence and each mature fruit can produce 18-26 seeds. The fruit pods are leathery at maturity and split open to release the seeds passively (Barneby 1964). The seeds do not possess any wings, barbs, or hooks to promote dispersal by wind or animals. Dispersal is primarily by gravity and perhaps secondarily by insects or rodents, but distances are probably relatively short (no more than 100 m).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Astragalus arrectus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 15 accepted occurrences (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

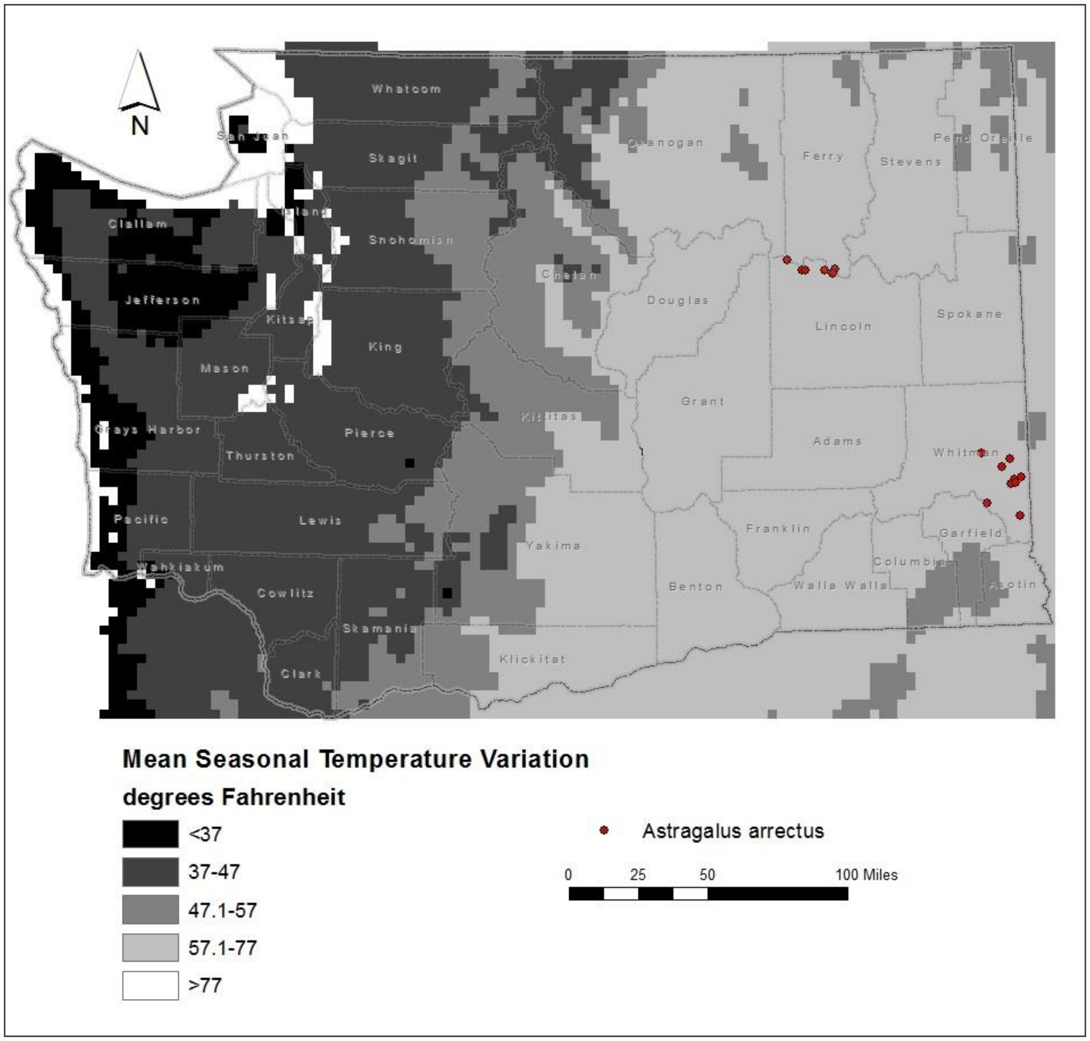

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus arrectus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The grassland and open Ponderosa pine woodland habitats of *Astragalus arrectus* are not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Eight of the 15 occurrences of *Astragalus arrectus* in Washington (53.3%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these areas are at somewhat increased vulnerability to climate change. The other 7 occurrences (46.7%) are from areas with average precipitation variation (>20 inches/508 mm) over the same time period and are at neutral vulnerability.

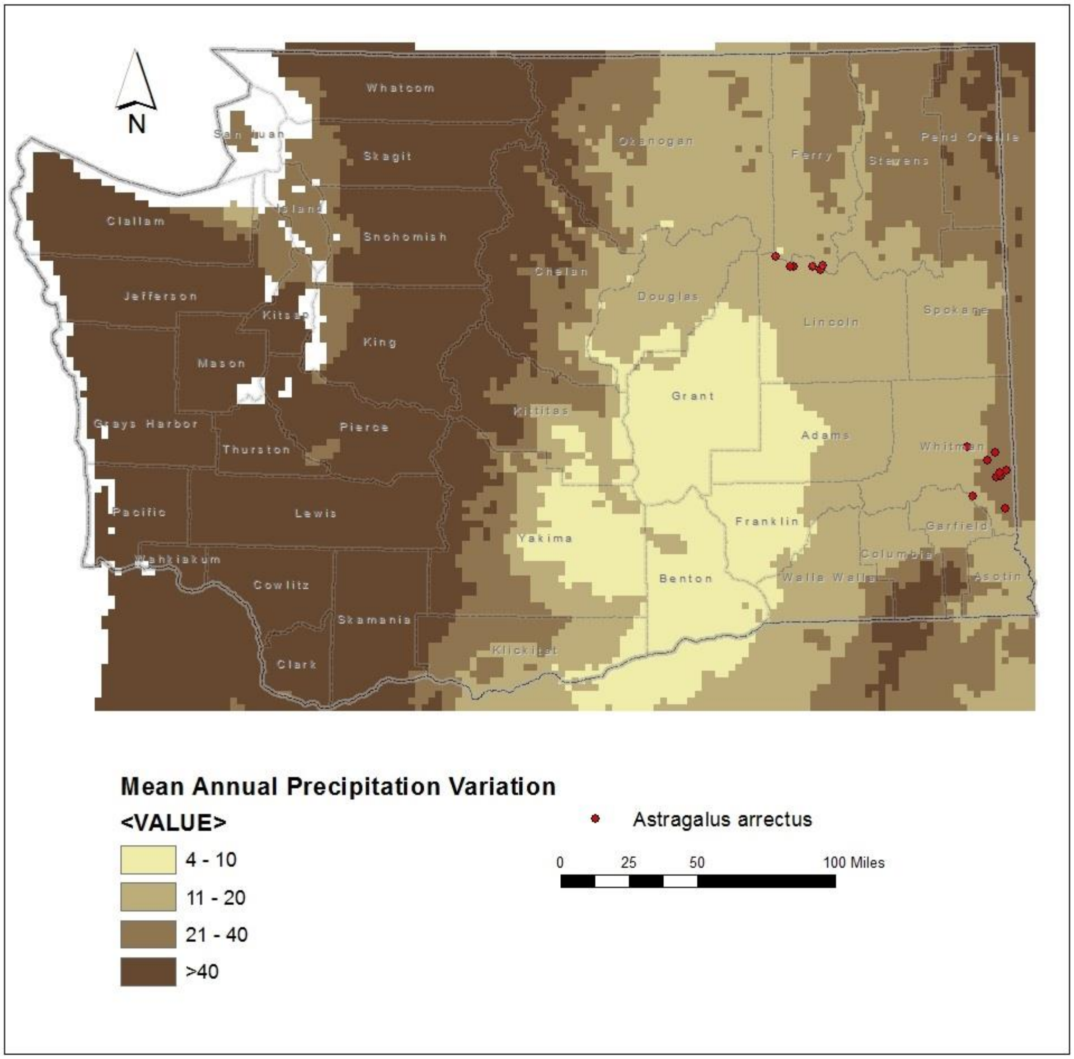

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus arrectus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on adequate precipitation for its moisture requirements, because its habitat is typically not associated with springs, streams, or a high water table. The Columbia Basin Foothills and Canyon Dry Grassland and Columbia Basin Palouse Prairie ecological systems are vulnerable to higher temperatures resulting in summer drought and changes in the timing or amount of precipitation (including extreme precipitation events that would accelerate erosion of steep slopes). Increased frequency and severity of fire could alter the composition of native grassland communities towards dominance by weedy annuals (Rocchio and Ramm-Granberg 2017). Northern Rocky Mountain Ponderosa Pine Woodland and Savanna sites are also vulnerable to the effects of drought on increased fire frequency or insect outbreaks that could result in a shift towards steppe vegetation (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Astragalus arrectus may be dependent on infrequent low-intensity wildfire to reduce encroachment from shrub species and to maintain open grassland habitat. Increased drought and reduced summer precipitation, however, could make wildfires too frequent and result in replacement of native perennial bunchgrasses with annual introduced grasses (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is low over the range of *Astragalus arrectus* in the Palouse grasslands of Whitman County and along the Columbia River in Lincoln County and is a small component of the plant's annual water budget.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Whitman County, *Astragalus arrectus* is primarily associated with Quaternary loess deposits, which are widespread in southeastern Washington. Occurrences in Lincoln County are found mostly on glaciolacustrine and outburst flood deposits or Grande Ronde Basalt along the Columbia River and tributary canyons (Washington Division of Geology and Earth Resources 2016). These substrates and geological features are also relatively widespread in the state.

C4a. Dependence on other species to generate required habitat: Neutral
Browsing by ungulates, rodents, and insects that impedes the spread of shrubs would help maintain the open grasslands and understory of Ponderosa pine woodlands occupied by *Astragalus arrectus,* although drought and infrequent fire probably are more significant.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Astragalus arrectus* are not known, but other *Astragalus* species are pollinated by bumblebees (*Bombus*) or other bees. A recent survey of bees of the Palouse region found higher than expected bee richness, but did not focus on pollinators of specific plant taxa (Rhoades et al. 2017).

C4d. Dependence on other species for propagule dispersal: Neutral.
The pods of *Astragalus arrectus* dehisce when dry to release seeds passively. These seeds lack wings, barbs, or hooks for dispersal by wind or animals. Dispersal distances are probably relatively short.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Herbivory by livestock has been identified as a potential threat (Camp and Gamon 2011), although most *Astragalus* species are toxic and only utilized when other forage is not available.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Astragalus arrectus occurs in patches of remnant grasslands and open Ponderosa pine woodlands. Adjacent areas have mostly been converted to crop agriculture. Disturbance from farming and wildfire make these areas susceptible to invasion by introduced weed species (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Astragalus arrectus* in Washington. Other species in subsection *Arrecti* have base chromosome counts of n = 11 or 12 (Spellenberg 1976). The populations along the Columbia River in Lincoln County are somewhat disjunct from the core range of the species in southeastern Washington and adjacent Idaho and might be expected to have lower genetic diversity due to founder effects or reproductive isolation.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Astragalus arrectus is assumed to be an outcrosser, rather than self-pollinated. Presumably, genetic variation is average rangewide, compared to other species, but no studies have been done for confirmation. Isolated occurrences, like those in Lincoln County, WA, may have lower genetic diversity.

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, the flowering period for *Astragalus arrectus* in Washington has shifted to earlier spring (mid April through early June) in the past 50 years, compared to early July in the late 1800s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Several occurrences from southeastern Washington are historical and potentially extirpated due to habitat conversion to agriculture or urbanization (Fertig and Kleinknecht 2020). Whether the range has contracted due to climate change is not known.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Rhoades, P., T. Griswold, H. Ikerd, L. Waits, N.A. Bosque-Perez, and S.D. Eigenbrode. 2017. The native bee fauna of the Palouse Prairie (Hymenoptera: Apoidea). Journal of Melittology 66:1-20.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Spellenberg, R. 1976. Chromosome numbers and their cytotaxonomic significance for North American *Astragalus* (Fabaceae). Taxon 25(4): 463-476.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Astragalus arrectus*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=astragalus%20arrectus). Accessed 19 September 2021.

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

Astragalus arthuri (Arthur's milkvetch)

Date: 16 March 2021

Assessor: Walter Fertig, 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: Local Climate	**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	15.8
	-0.074 to -0.096	84.2
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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		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: Documented or Modeled Response	
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: The 19 extant and historical occurrences of *Astragalus arthuri* in Washington (100%) occur in an area with a projected temperature increase of 4.5-5.0˚ F (Figure 1).

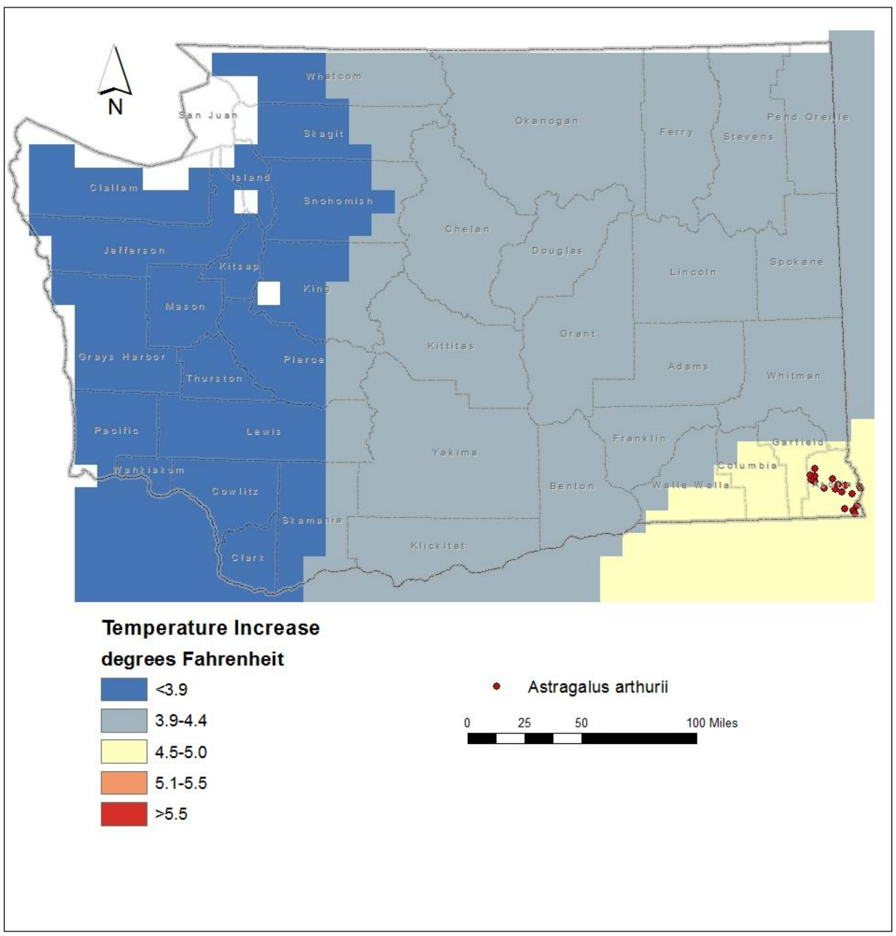

Figure 1. Exposure of *Astragalus arthuri* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Sixteen of the 19 occurrences of *Astragalus arthuri* (84.2%) 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). The other three occurrences (15.8%) are from areas with a projected decrease in available moisture of -0.097 to -0.119.

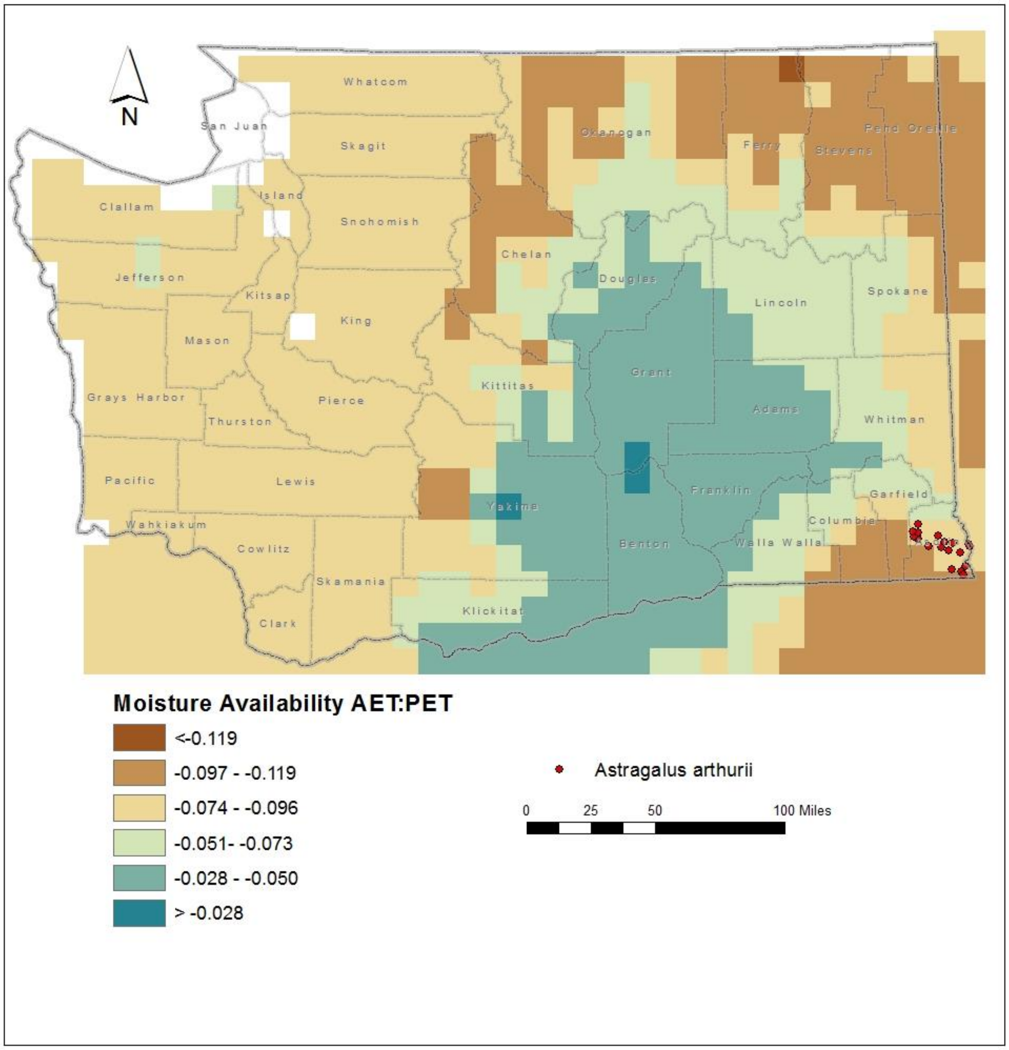

Figure 2. Exposure of *Astragalus arthuri* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Astragalus arthuri* are found at 800-3900 feet (245-1200 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Astragalus arthuri* is found on dry grassy hills and rocky meadows on basalt dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*) and Sandberg bluegrass (*Poa secunda*) (Camp and Gamon 2011; Fertig and Kleinknecht 2020). This habitat is a component of the Columbia Basin Foothill and Canyon Dry Grassland ecological system (Rocchio and Crawford 2015). Washington populations occur mostly on ridges and are separated from other populations by distances of 1-6.6 miles (1.9-11 km). The intervening unoccupied valley bottom habitat creates a barrier to dispersal or migration.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Astragalus arthuri* in Washington is bisected by roads and agricultural fields that form a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Astragalus arthuri produces 5-20 flowers per inflorescence and each mature fruit contains 18-30 seeds that are released passively by dehiscence of the legume pod (Barneby 1964). The seeds do not possess any wings, barbs, or hooks to promote dispersal by wind or animals. Dispersal is primarily by gravity and perhaps secondarily by insects or rodents, but the total distance is probably relatively short (no more than 100 m).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Astragalus arthuri* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Twelve of the 19 occurrences (63.2%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). The other 7 occurrences (36.8%) are from areas with slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation and are at somewhat increased risk from climate change Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
The Columbia Basin Foothill and Canyon Dry Grassland habitat of *Astragalus arthuri* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

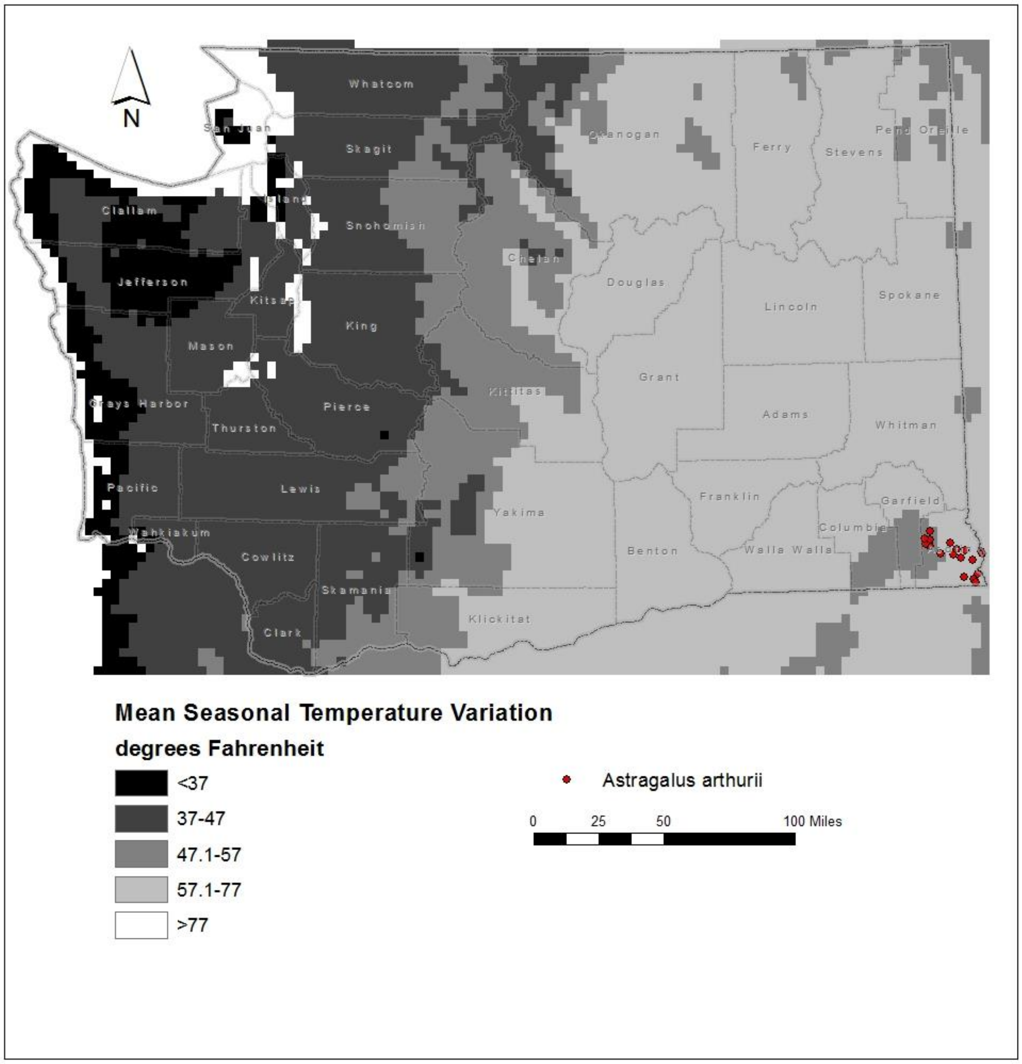

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus arthuri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Eleven of the 19 occurrence of *Astragalus arthuri* in Washington (57.9%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) of precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these areas are at somewhat increased vulnerability to climate change. Eight other populations occur in areas with average precipitation variation (21-40 inches/508-1016 mm) over the same period and are at neutral vulnerability to climate change.

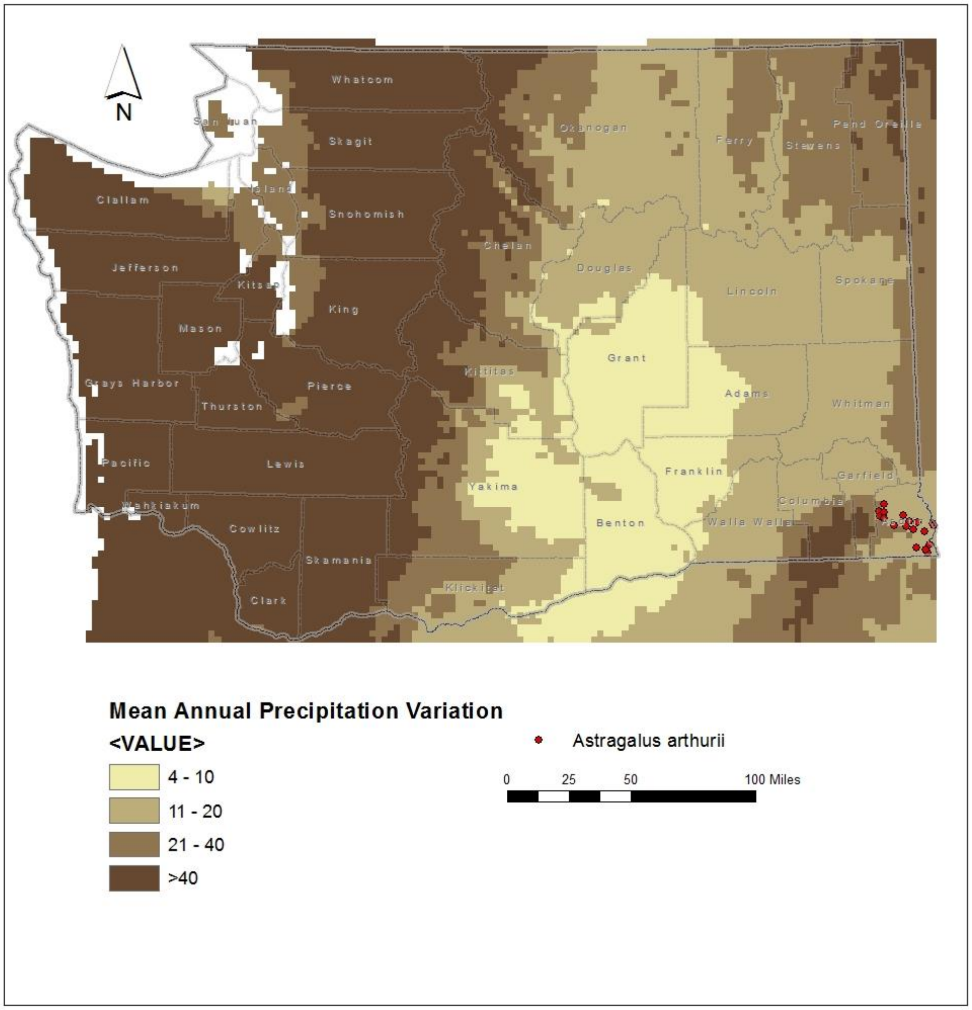

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus arthuri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent primarily on adequate precipitation for its moisture requirements, because its habitat is typically not associated with springs, streams, or a high water table. The Columbia Basin Foothills and Canyon Dry Grassland ecological system is vulnerable to changes in the timing or amount of precipitation, including extreme precipitation events that could accelerate erosion of steep slopes. Changes in precipitation, coupled with increases in temperature, could result in more frequent and severe drought and an increase in fire frequency (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Astragalus arthuri is dependent on infrequent wildfire to reduce encroachment from less fire-adapted shrub species and to maintain open grassland habitat. Natural fire frequency is thought to be less than 20 years (Rocchio and Crawford 2015). Increased drought and reduced summer precipitation, however, might make wildfires too frequent and result in replacement of native perennial bunchgrass with annual introduced grasses (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is relatively low over the range of *Astragalus arthuri* in the eastern foothills of the Blue Mountains in southeastern Washington and a small component of its annual water budget.

C3. Restricted to uncommon landscape/geological features: Neutral.
Astragalus arthuri is found on outcrops of the Saddle Mountain and Grande Ronde basalts, which are widespread in the Blue Mountains and elsewhere in eastern Washington (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
Browsing by ungulates, rodents, and insects that would impede shrub cover would help maintain the rocky grasslands occupied by *Astragalus arthuri,* although drought and infrequent fire probably are more significant.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Astragalus arthuri* are not known, but other *Astragalus* species are usually pollinated by bees.

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Astragalus arthuri* dehisce when dry to release seeds passively. These seeds lack wings, barbs, or hooks for dispersal by wind or animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Most *Astragalus* species are unpalatable or toxic to herbivores due to the presence of indolizidine alkaloids, aliphatic nitro compounds, or selenium in their tissues (Rios and Waterman 1997). Although some populations of *A. arthuri* are found in areas grazed by cattle and horses (Camp and Gamon 2011), herbivory is probably not a significant threat (Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Astragalus arthuri occurs in grassland slopes that burn infrequently. Under projected future climate change, these areas 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).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Astragalus arthuri* in Washington. Head (1957) reported the chromosome number of *A. arthuri* to be 2*n* = 24.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Astragalus arthuri is presumed to be an outcrosser, rather than self-pollinated. Presumably, genetic variation is average, compared to other species, but no studies have been done for confirmation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no significant changes in the phenology of *Astragalus arthuri* populations in Washington have been detected over the past 90 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Four of the 19 occurrences of *Astragalus arthuri* in Washington are historical and have not been relocated since 1981 (Fertig and Kleinknecht 2020). These populations are mostly on private lands that could be impacted by development, conversion to agriculture, or herbicides (Camp and Gamon 2011). No occurrences are known to be directly lost due to impacts from recent climate change.

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

References

Barneby, R. 1964. Atlas of North American *Astragalus*. Memoirs of the New York Botanical Garden 13:1-1188.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Department of Natural Resources, Olympia, WA. 173 pp.

Head, S.C. 1957. Mitotic chromosome studies in the genus *Astragalus*. Madroño 14(3): 95-106.

Rios, J-L. and P.G. Waterman. 1997. A review of the pharmacology and toxicology of *Astragalus*. Phytotherapy Research 11(6): 411-418.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Astragalus australis var. *cottonii* (Cotton's milkvetch)

Date: 1 February 2021

Synonym: *A. australis* var. *olympicus*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G5T2Q/S2

Index Result: Highly Vulnerable.

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		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		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on others 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		Somewhat Increase

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat Increase
D2. Modeled future (2050) change in population or range size	Increase
D3. Overlap of modeled future (2050) range with current range	Neutral
D4. Occurrence of protected areas in modeled future (2050) distribution	Neutral

Section A: Exposure to Local Climate Change

A1. Temperature: All eight of the occurrences of *Astragalus australis* var. *cottonii* in Washington (100%) are found in areas with a projected temperature increase of < 3.9° F (Figure 1).

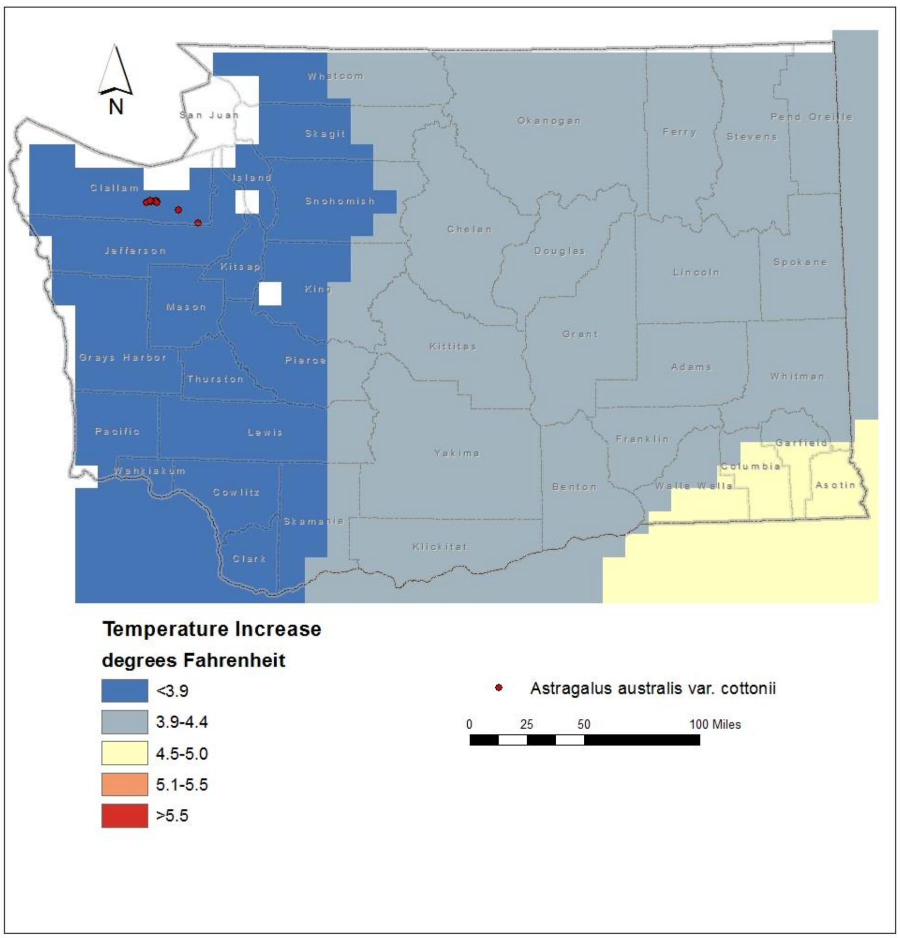

Figure 1. Exposure of *Astragalus australis* var. *cottonii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The eight occurrences of *Astragalus australis* var. *cottonii* (100%) 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).

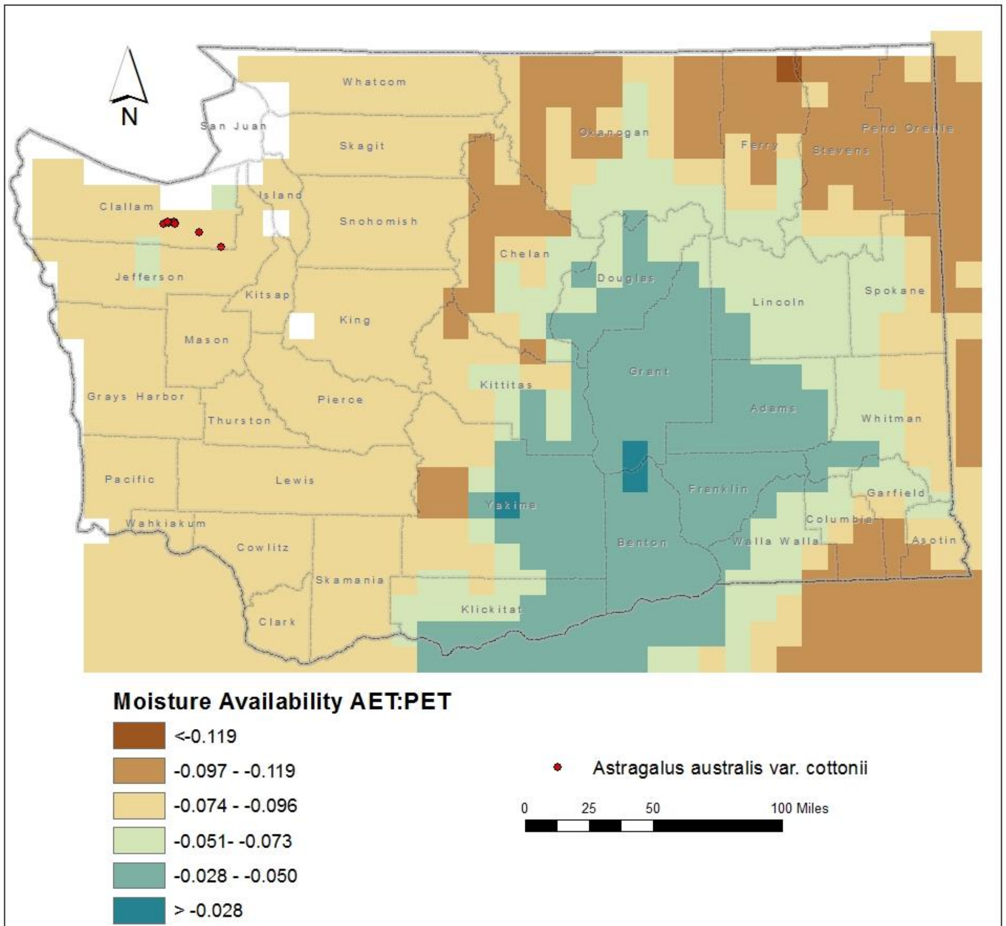

Figure 2. Exposure of *Astragalus australis* var. *cottonii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Astragalus australis* var. *cottonii* are found at 4800-6000 feet (1460-1830 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
Astragalus australis var. *cottonii* is endemic to the northeastern Olympic Range in Washington, where it is found in sparsely vegetated cushion plant or meadow communities on unstable scree slopes and ridges, often associated with limestone. Most sites are on southern or western exposures (Kaye 1989). Occasionally, plants are associated with rock outcrops, nearly barren slopes, or small clusters of trees. These habitats are a component of the North Pacific Alpine and Subalpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). The entire range of var. *cottonii* is restricted to an area of 10 x 20 miles (6 x 12 km) (Camp and Gamon 2011). Individual occurrences are naturally separated by valleys between alpine ridges, which create 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 range of *Astragalus australis* var. *cottonii* in Washington is primarily above treeline in Olympic National Park and Olympic National Forest. These areas have some hiking trails but otherwise the human footprint is small and does not present a significant barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Astragalus australis var. *cottonii* plants produce an average of 20 inflorescences, 314 flowers, 56 fruits, and 154 seeds (Kaye 1999). Seeds are released passively from the dry legume pod after it has dehisced from the infructescence. The inflated pods potentially could be transported short distances by high winds. Dispersal distances are probably relatively short (well under 100 m).

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Astragalus australis* var. *cottonii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the eight known occurrences (87.5%) are found in areas that have experienced very small (<37˚F/20.8˚C) temperature variation during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). One other occurrence is from an area with small (37-47˚F/20.8-26.3˚C) temperature variation over the same time period and is at increased vulnerability to climate change.

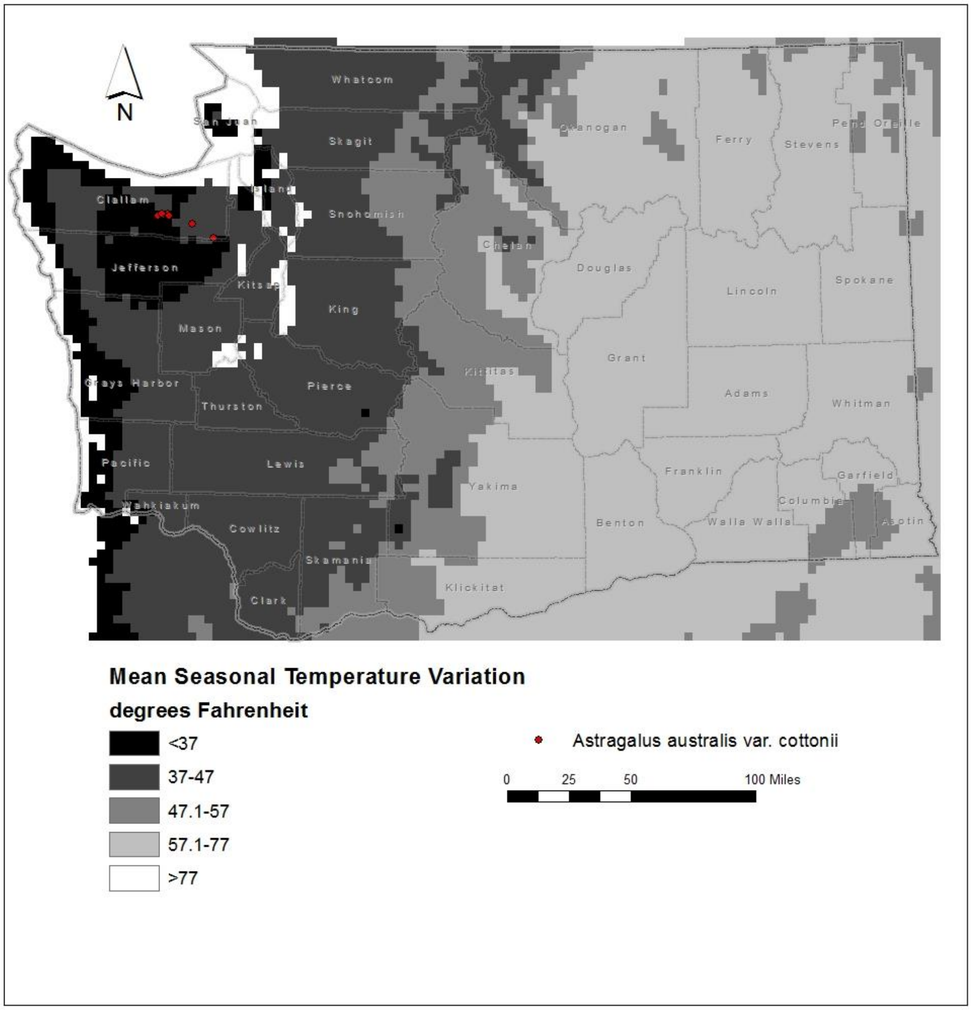

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus australis* var. *cottonii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The range of *Astragalus australis* var. *cottonii* is restricted to alpine areas exposed to high winds and cold winter temperatures. Most populations occur on south-facing slopes that are warmer than adjacent slopes. Increased temperatures could extend the growing season (Rocchio and Ramm-Granberg 2017), but might also put this species under increased moisture stress. Kaye (1999) showed that drought stress was a factor in the abortion of ovules and overall reduction of seed set in this species. A prolonged growing season could favor other plant species expanding into the habitat of *A. australis* var. *cottonii* and lead to increased competition for space and resources.

C2bi. Historical hydrological niche: Neutral.
All eight of the occurrences of *Astragalus australis* var. *cottonii* in Washington (100%) are found in areas that have experienced greater than average (>40 inches/1016 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these areas are at neutral vulnerability to climate change.

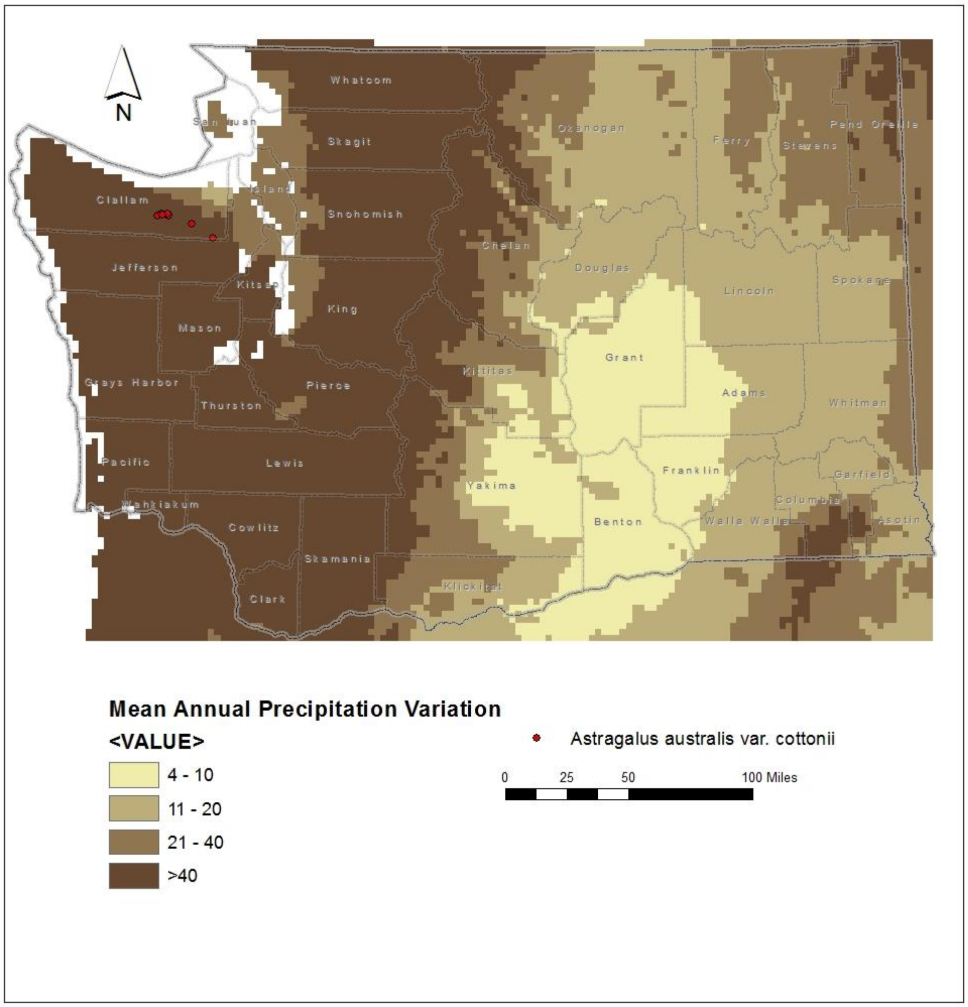

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus australis* var. *cottonii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Kaye (1989) found that *Astragalus australis* var. *cottonii* occurs primarily on drier, south and west-facing slopes with unstable soils where snowpacks do not persist. Increased temperatures from climate change are likely to change the timing of snowmelt, leading to earlier runoff

(Rocchio and Ramm-Granberg 2017). Changes in the timing or amount of summer precipitation could have negative impacts on development of ovules in fruit pods, which is currently a factor contributing to reduced seed production (Kaye 1999).

C2c. Dependence on a specific disturbance regime: Neutral.
Astragalus australis var. *cottonii* may depend on frost heaving or landslides to maintain its sparsely vegetated barren rocky slope habitat. These natural processes could be reduced if total vegetation cover were to increase in response to warming conditions and a longer growing season in the alpine zone (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The Olympic Mountains average over 10 meters (400 inches) of snow. The alpine areas inhabited by *Astragalus australis* var. *cottonii* are on open or steep slopes where snow is more exposed to wind and sun and less likely to accumulate late into the summer, making the local microenvironment droughtier than surrounding areas.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Astragalus australis var. *cottonii* is restricted to steep, barren, high elevation calcareous substrates derived from uplifted sea floor sediments (Kaye 1989, Washington Division of Geology and Earth Resources 2016). The distribution of these sites is limited within the northeastern Olympics.

C4a. Dependence on other species to generate required habitat: Neutral.
The barren slope and sparsely vegetated conditions favored by this species are maintained in part by natural processes, such as landslides and wind erosion. Feral mountain goats (*Oreamnos americanus*) released in the Olympic Mountains in the 1920s may have contributed to the creation of barren sites through herbivory, trampling, or dust wallows (Schreiner et al. 1994).

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase.
Kaye (1989) observed potential pollination of *Astragalus australis* var. *cottonii* flowers by three species of bumblebee (*Bombus appositus, B. bifarius nearcticus*, and *B. occidentalis occidentalis*), and three species of solitary bee (*Anthidium tenuiflorae, Megachile melanophaea calogaster*, and *Osmia* sp.). In any given population, however, no more than three pollinator species were present, and there was little overlap in pollinators present at sites on the east and west ends of its range. *Astragalus australis* var. *cottonii* is self-compatible, though with reduced seed production (Kaye 1999). Fruit set averages 25% and is limited in part by pollinator availability, adequate resources (especially summer moisture) for seed development, and seed predation (Kaye 1999).

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Astragalus australis* var. *cottonii* dehisce when dry to release seeds passively by gravity or wind. These seeds lack wings, barbs, or hooks for dispersal by wind or animals. Dispersal distances are probably relatively short.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Reproduction can be impacted by loss of seeds to predation by weevil larvae (*Tychius* sp). Rates of seed predation ranged from 28.4-60.9% over two years at two study sites in the Olympics (Kaye 1999). Introduced mountain goats have been observed grazing on *Astragalus australis* var. *cottonii,* as well as trampling and wallowing in *Astragalus* habitat. Grazing by mountain goats was observed on 72% of individual *A. australis* var. *cottonii* plants in study plots, with 76-100% of the plants consumed (Schreiner et al. 1994). The National Park Service and WA Department of Fish and Wildlife are actively working to cull or translocate mountain goats with the ultimate goal of eliminating them from the Olympic Range (Harris et al. 2019).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Astragalus australis var. *cottonii* occurs mostly in sparsely vegetated scree slopes and open alpine meadows. Kaye (1989) found that the cover and density of *A. australis* var. *cottonii* was negatively correlated with density and cover of other plant species in stable meadow sites. Populations on barren, steep, unstable talus were less affected by competition. This species is probably a poor competitor but can persist in less optimal sites where other plant species are less adapted. Under projected future climate change, the alpine habitats of *A. australis* var. *cottonii* are likely to be warmer and have a longer growing season (Rocchio and Ramm-Granberg 2017), which may allow subalpine species to expand their range or increase the cover of other alpine plants, resulting in increased competition. Herbivory or trampling by introduced mountain goats has been identified as a potential threat (Schreiner et al. 1994).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Astragalus australis* var. *cottonii* in Washington.

C5b. Genetic bottlenecks: Unknown.
Small populations of *Astragalus australis* var. *cottonii* may have been restricted to unglaciated refugia within the Olympic Mountains during the Pleistocene and subjected to genetic bottlenecks (Buckingham et al. 1995), but corroborating genetic data are not available.

C5c. Reproductive System: Somewhat Increase.
Astragalus australis var. *cottonii* is capable of self-pollination, but is primarily an outcrosser pollinated by bees. Kaye (1989) observed different bee pollinators at study sites in the east and west ends of the species' range, with no overlap, suggesting that pollen dispersal within its range may be limited. The geographic isolation of var. *cottonii* (perhaps due to its persistence in glacial refugia) has likely resulted in genetic diversification from other varieties of *A. australis* found in the Rocky Mountains from SW British Columbia and Alberta to Utah and Wyoming.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on Washington Natural Heritage Program data, no significant changes in the phenology of *Astragalus australis* var. *cottonii* populations have been detected over the past 20 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
The overall abundance and range of *Astragalus australis* var. *cottonii* appears to be stable since the late 1980s (4000-4400 individuals in 8 occurrences in four main clusters; Kaye 1989; Fertig 2020). One occurrence has not been relocated since 1981 and is now considered historical. Short term monitoring studies in the late 1980s documented a decline in density at some sites that may be more attributable to mountain goat herbivory than climate change (Schreiner et al. 1994).

D2. Modeled future (2050) change in population or range size: Increase.
Populations of *Campanula piperi* and *Viola flettii* overlap with *Astragalus australis* var. *cottonii* in the northeastern Olympic Range (Kaye 1989). Wershow and DeChaine (2018) modeled the projected future habitat of *C. piperi, V. flettii*, and three other Olympic alpine endemics and found that 85-99% of their current habitat would no longer be suitable by 2080 due to rising temperatures and reduced moisture availability.

D3. Overlap of modeled future (2050) range with current range: Neutral.
Based on the projected future range of other alpine endemic plants found in similar habitats in the Olympic Mountains (Wershow and Dechaine 2018), the range of *Astragalus australis* var. *cottonii* is expected to contract rather than shift in distribution.

D4. Occurrence of protected areas in modeled future (2050) distribution: Neutral.
Despite the likely contraction of potential suitable habitat due to climate change, the entire range of *Astragalus australis* var. *cottonii* will still be restricted to Olympic National Park.

References

Buckingham, N.M., E.G. Schriener, T.N. Kaye, J.E. Burger, and E.L. Tisch. 1995. Flora of the Olympic Peninsula. Northwest Interpretive Association, Seattle, WA.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Harris, R., P. Happe, and B. Murphie. 2019. Olympic National Park Mountain goat removal and translocation to the North Cascades. Progress Report II. Washington Department of Fish and Wildlife Report 02110.

Kaye, T.N. 1989. Autecology, reproductive ecology, and demography of *Astragalus australis* var. *olympicus* (Fabaceae). Master's thesis, Oregon State University, Department of Botany, Corvallis, OR. 114 pp.

Kaye, T.N. 1999. From flowering to dispersal: Reproductive ecology of an endemic plant, *Astragalus australis* var. *olympicus* (Fabaceae). American Journal of Botany 86(9): 1248-1256.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Schreiner, E.G., M.B. Gracz, T.N. Kaye, A. Woodward, and N.M. Buckingham. 1994. Effects of mountain goats on rare plants. Pp. 173-188. In: Houston, D.B., E.G. Schreiner, and B.B. Moorhead, eds. Mountain goats in Olympic National Park: Biology and management of an introduced species. Scientific Monograph NPS/NROLYM/NRSM-94/25. US Department of Interior, National Park Service.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Wershow and E. DeChaine. 2018. Retreat to refugia: Severe habitat contraction projected for endemic alpine plants of the Olympic Peninsula. American Journal of Botany 105(4): 760-778.

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

Astragalus microcystis (Least bladdery milkvetch)

Date: 22 August 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S2

Index Result: Moderately Vulnerable Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	88.9
	<3.9° F (2.2°C) warmer	11.1
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	74.1
	-0.074 to - 0.096	14.8
	-0.051 to - 0.073	11.1
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral/Somewhat 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/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/Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
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: Twenty-four occurrences of *Astragalus microcystis* in northeastern Washington (88.9%) are found in areas with a projected temperature increase of 3.9-4.4° F

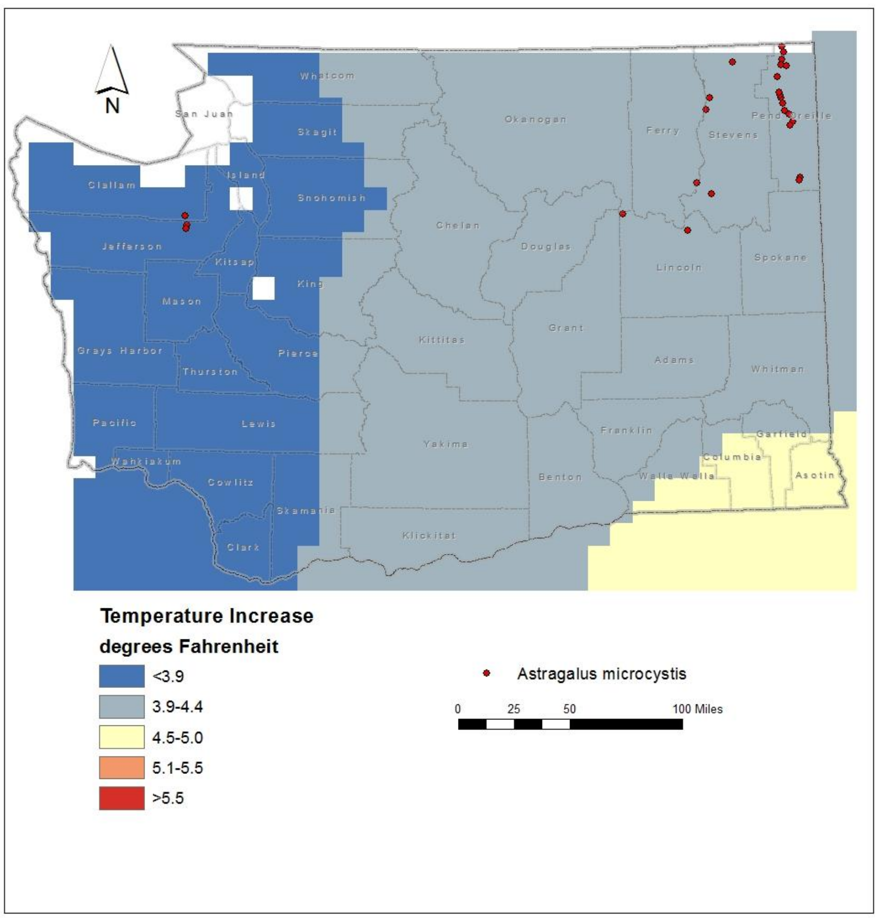

Figure 1. Exposure of *Astragalus microcystis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

(Figure 1). Three other occurrences from the Olympic Mountains (10.1%) are from areas with a projected temperature increase of < 3.9˚ F.

A2. Hamon AET:PET Moisture Metric: Twenty of the 27 occurrences (74.1%) of *Astragalus microcystis* 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). Four populations (14.8%), including all those from the Olympic Range, are from

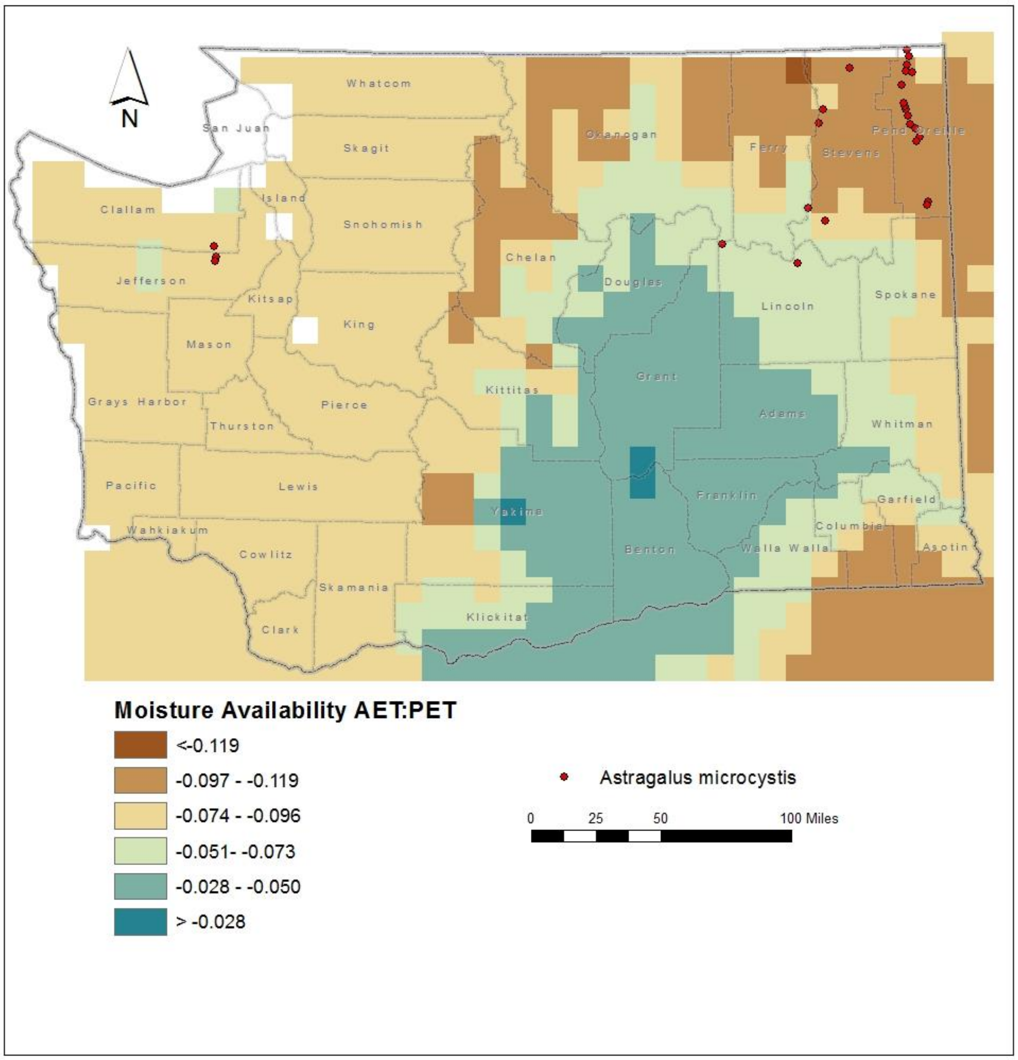

Figure 2. Exposure of *Astragalus microcystis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

areas with a projected decrease of -0.074 to -0.096 (14.8%). Three occurrences (11.1%) from the Columbia Plateau are from areas with a projected decrease of -0.051 to -0.073 (Figure 2).

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Astragalus microcystis* are found at 1900-6300 feet (580-2000 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Populations of *Astragalus microcystis* in northeastern Washington occur primarily on steep to flat gravelly or sandy riverbanks, islands, roadcuts, or terrace openings (Camp and Gamon 2011). Most of these occurrences are associated with the Columbia or Pend Oreille rivers. These sites are part of the Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland ecological system (Rocchio and Crawford 2015). Disjunct populations from the Olympic Range are found in sparsely vegetated alpine or upper subalpine cushion plant communities on dry, gravelly soils (Camp and Gamon 2011). These populations are part of the North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field and Meadow ecological system (Rocchio and Crawford 2015). Individual populations are separated by 1-29 miles (2.6-47 km) in northeastern Washington and 1.6-4.4 miles (3-6.8 km) in the Olympic Range. Natural barriers are relatively unimportant along river corridors in northeastern Washington or along ridgelines in the Olympic Mountains, but are more significant between watersheds or across mountain valleys. The populations in the Olympics are separated by 194 miles (310 km) of unsuitable habitat from those along the Columbia River and tributaries in eastern Washington.

B2b. Anthropogenic barriers: Neutral.
The alpine habitat of *Astragalus microcystis* in the Olympic Range is relatively unimpacted by human activities, other than summer recreation. Populations in northeastern Washington are found in naturally disturbed sites along rivers and occasionally in human-impacted sites (roadsides and a quarry) that have conditions comparable to its native habitat.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Astragalus microcystis produces 6-8 seeds per fruit. The fruits are papery and inflated at maturity, which may aid in dispersal. Barneby (1964) postulated that populations along the Pend Oreille and other tributaries of the Columbia River may have been transported by water from the core range of the species along the Continental Divide. Disjunct occurrences in the Olympic Mountains are likely due to chance, long distance dispersal events. Average dispersal distances are probably between 100-1,000 meters.

C2ai. Historical thermal niche: Neutral/Somewhat Increase.
Figure 3 depicts the distribution of *Astragalus microcystis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All

24 occurrences from northeastern Washington (88.9% of the state total) are found in areas that have experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). Two occurrences from the Olympic Range are from areas with very small temperature variation (<37 ˚F/20.8˚C) during the same period and are at greatly increased vulnerability. One other population from the Olympic Range has experienced small temperature variation (37-47˚F/20.8-26.3˚C) and is at increased vulnerability to climate change. This variable is scored as Neutral/Somewhat Increase to capture the variation in vulnerability across the species' range in Washington.

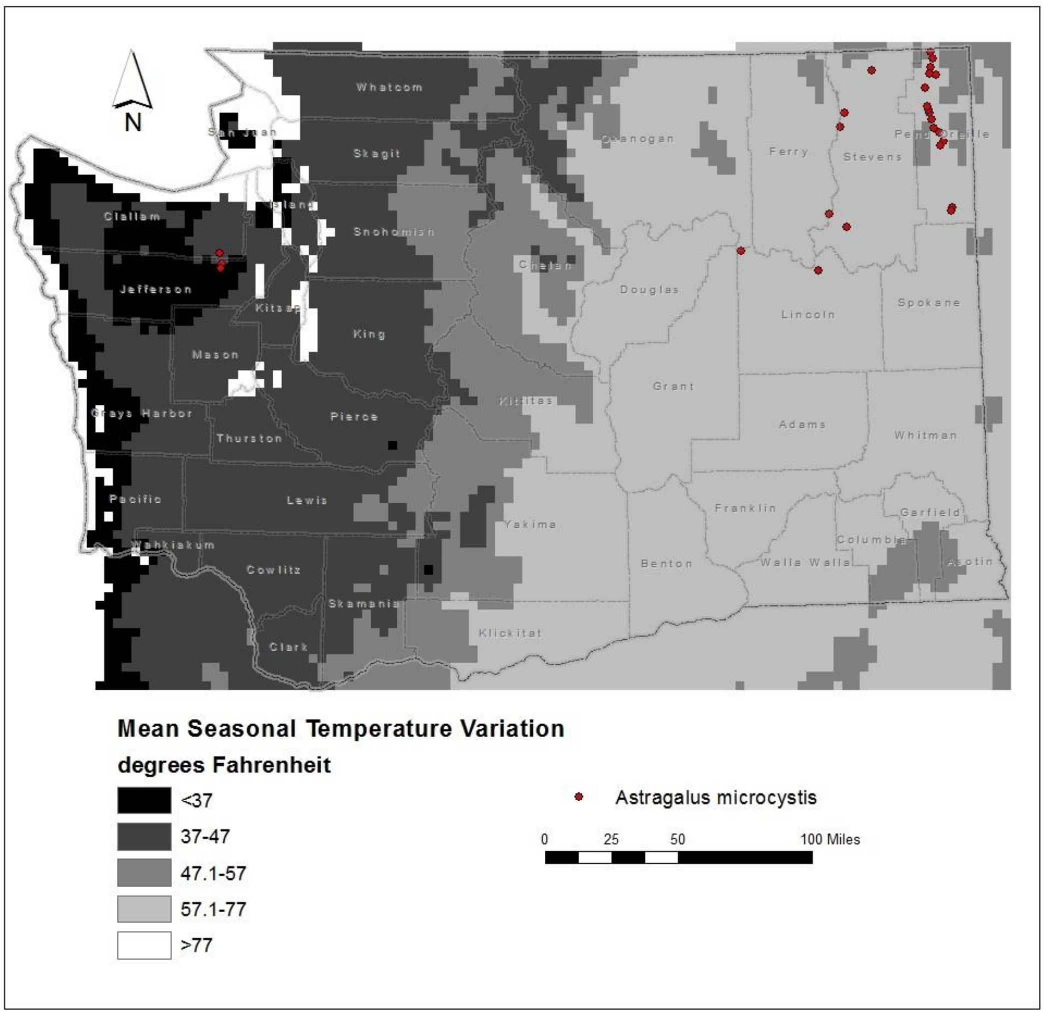

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus microcystis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase/Increase.
Populations of *Astragalus microcystis* from alpine habitats in the Olympic Mountains are entirely within a cold climate zone during the flowering season and are highly vulnerable to temperature increase from climate change. Other populations from lower elevation sites in northeastern Washington are found in cold air drainages in river bottoms that are locally cooler microhabitats and somewhat vulnerable to temperature increases.

C2bi. Historical hydrological niche: Neutral.
Twenty-three populations of *Astragalus microcystis* in Washington (85.2%) are found in areas that have experienced average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm) (Figure 4). According to Young et al. (2016), these occurrences are

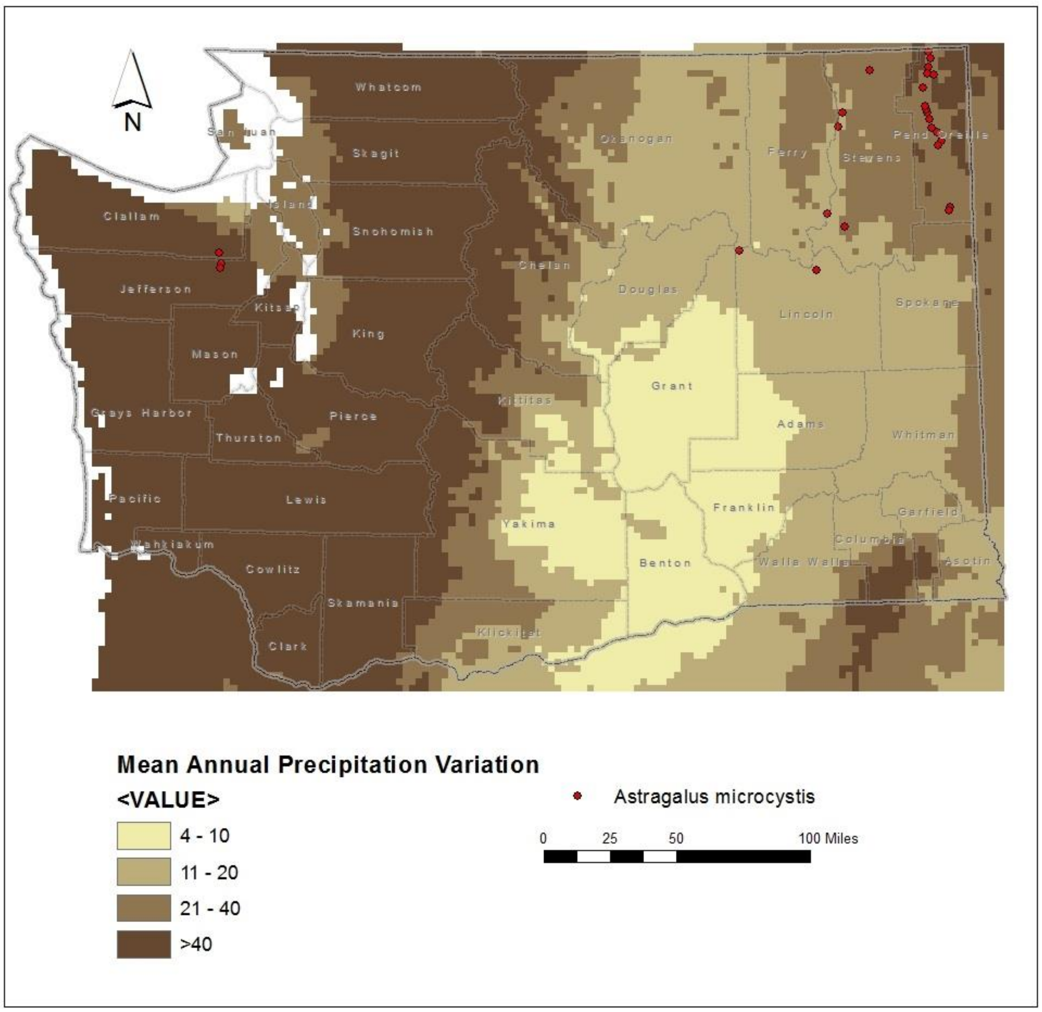

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus microcystis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

Neutral for climate change. Four other occurrences from northeastern Washington (14.8%) are from areas with slightly lower average (11-20 inches/255-508 mm) precipitation variation and are at somewhat increased vulnerability to climate change.

C2bii. Physiological hydrological niche: Somewhat Increase/Increase.
Populations from the Olympic Mountains are found on drier slopes where snow drifts may not persist. Increased temperatures from climate change are likely to alter the timing of snowmelt, potentially making these sites even drier (Rocchio and Ramm-Granberg 2017). Low elevation occurrences along gravelly riverbanks in northeastern Washington could be impacted by shifts in seasonal flooding patterns related to changes in the amount of precipitation or timing of mountain snow runoff related to climate change. Lower summer stream flows due to lower precipitation or higher temperatures are also a potential impact of climate change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
In northeastern Washington, *Astragalus microcystis* occurs in naturally disturbed sandy and gravel terraces along rivers and in some human-altered sites, such as roadsides and quarries. Other populations from the Olympic Mountains are found in sparsely vegetated cushion plant communities with dry, rocky soil exposed to natural disturbances, such as high winds and erosion. Across its range, disturbance patterns are not likely to be altered by climate change.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Astragalus microcystis* from the Olympic Mountains of Washington are found on alpine ridgecrests in cushion plant communities where snow accumulation may be low due to blowing wind. Reduced snowpack due to climate change, however, would further decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017). Other populations from eastern Washington at lower elevations along the Columbia and Pend Oreille rivers may be impacted from reduced stream flows resulting from decreased snowpack in the Okanogan Plateau or Canadian Rockies.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
Most occurrences of *Astragalus microcystis* along the Columbia and Pend Oreille rivers are found on alluvial deposits of gravel or sand (Washington Division of Geology and Earth Resources 2016). This geologic feature is widespread in northeastern Washington. Populations in the Olympic Mountains are strongly correlated with limestone (Camp and Gamon 2011) which is limited primarily to the northeastern part of the range.

C4a. Dependence on other species to generate required habitat: Neutral
The river terrace and alpine cushion plant communities occupied by *Astragalus microcystis* are maintained largely by natural abiotic processes. Feral mountain goats may contribute to habitat disturbance in the Olympic Mountains.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Astragalus microcystis* are poorly documented. Documented pollinators of other *Astragalus* species in north-central Washington include bumblebees (*Bombus*) and mason bees (*Osmia*) (Wilson et al. 2010).

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Astragalus microcystis* are papery and bladdery for dispersal by wind or potentially by water (Barneby 1964). The fruits dehisce when dry to release seeds passively by gravity or wind. These seeds lack wings, barbs, or hooks for secondary dispersal by wind or animals. Average dispersal distances are probably relatively short.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from herbivory or pathogens appear to be low in eastern Washington. Populations in the Olympic Mountains could be affected by trampling by introduced mountain goats (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Disturbed river terrace and bank habitats in eastern Washington could be impacted by invasion of non-native weed species competing for available space and nutrients. Trampling by introduced mountain goats and associated erosion is a potential threat in the Olympic Mountains (Camp and Gamon 2011).

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

C5a. Measured genetic variation: Unknown.
Not known.

C5b. Genetic bottlenecks: Unknown.
Not known. The disjunct populations from the Olympic Range might be expected to have lower genetic diversity than those from eastern Washington due to founder effects or inbreeding.

C5c. Reproductive System: Neutral.
Many *Astragalus* species are capable of self-pollination, but most reproduce by outcrossing. The reproductive biology of *A. microcystis* is poorly known, but is assumed to have neutral impacts from climate change.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Astragalus microcystis* has not significantly altered its typical blooming time since the 1890s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Astragalus microcystis* in Washington since it was first discovered in the state in 1860.

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

References

Barneby, R.C. 1964. Atlas of North American *Astragalus*. Memoirs of the New York Botanical Garden 13:1-1188.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Wilson, J.S., L.E. Wilson, L.D. Loftis, and T. Griswold. 2010. The montane bee fauna of north central Washington, USA, with floral associations. Western North American Naturalist 70(2): 198-207.

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

Astragalus misellus var. *pauper* (Pauper milkvetch)

Date: 6 December 2021 Synonym: *Astragalus howellii* var. *pauper*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5T3/S2

Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	17.6
	-0.028 to -0.050	82.4
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat 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 17 of the extant and historical occurrences of *Astragalus misellus* var. *pauper* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

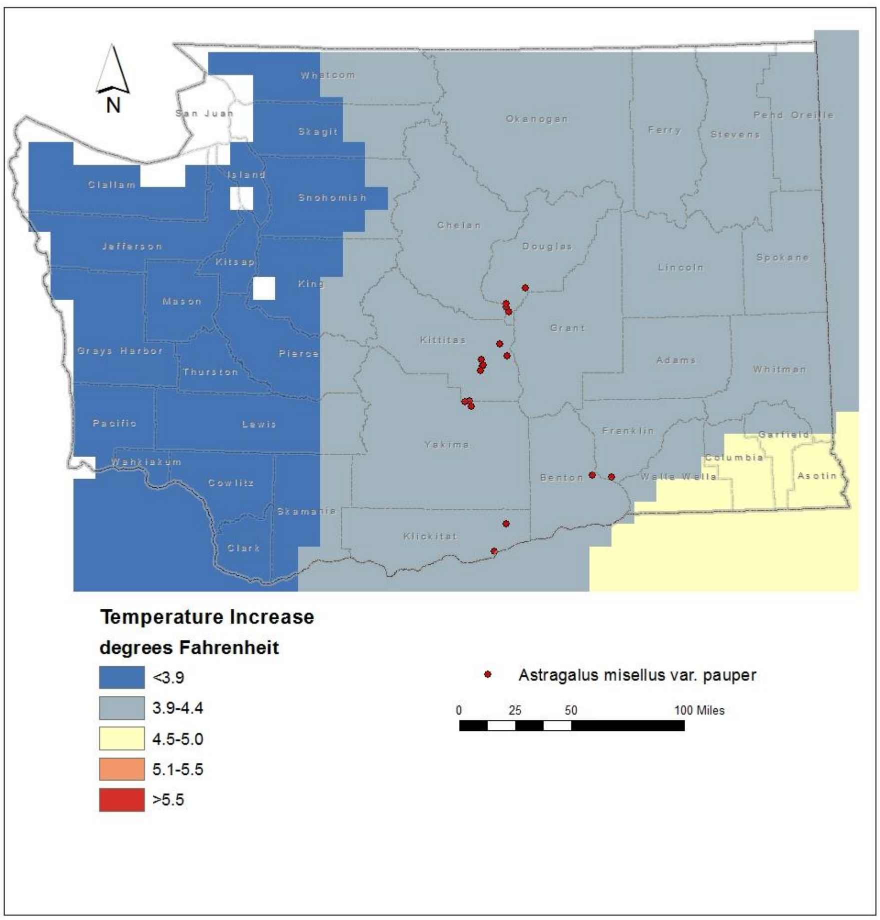

Figure 1. Exposure of *Astragalus misellus* var. *pauper* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Fourteen of the 17 occurrences (82.4%) of *Astragalus misellus* var. *pauper* 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). Three other occurrences (17.6%) are from areas with projected decrease of -0.051 to -0.073.

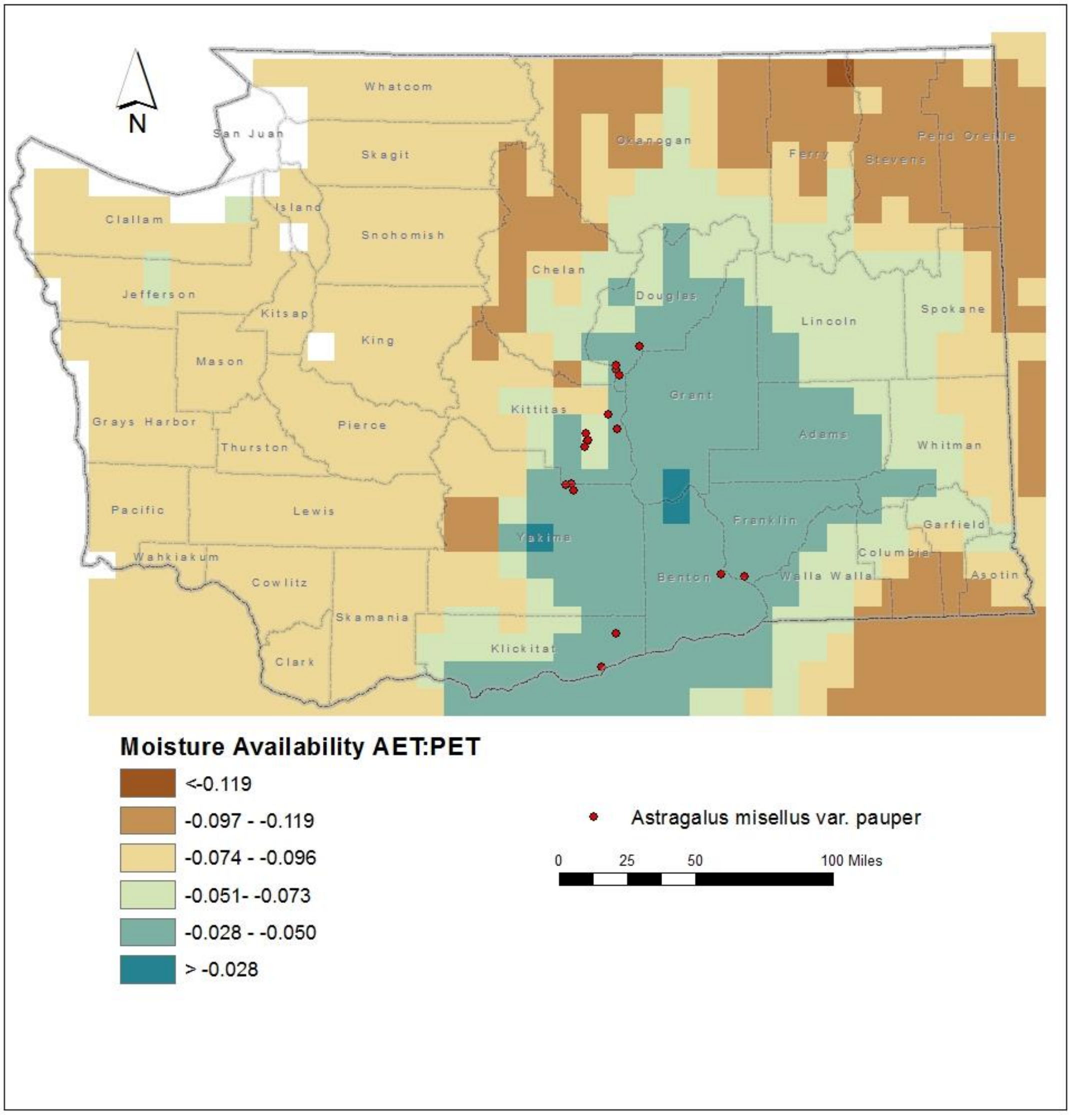

Figure 2. Exposure of *Astragalus misellus* var. *pauper* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Astragalus misellus* var. *pauper* are found at 500-3280 feet (150-1000 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Astragalus misellus var. *pauper* occurs primarily on ridgetops and gentle upper slopes in big sagebrush (*Artemisia tridentata*) or stiff sagebrush (*A. rigida*) communities with bluebunch wheatgrass (*Pseudoroegneria spicata*) and Sandberg's bluegrass (*Poa secunda*) (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the Intermountain Basin Big Sagebrush Steppe ecological system (Rocchio and Crawford 2015). Populations may be isolated from each other by 1.4 -54 miles (2-86 km). Extensive areas of potential habitat are present along ridges on the west bank of the Columbia River, with populations separated by canyons or valleys. The Columbia River may have historically provided a conduit for dispersal downstream, but may also create a barrier to movement across the river.

B2b. Anthropogenic barriers: Somewhat Increase.
The ridgetop habitat of *Astragalus misellus* var. *pauper* is embedded within an anthropogenic landscape of agricultural development, which creates a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Astragalus misellus var. *pauper* produces dry fruits (legumes) that dehisce at maturity along two sutures to release seeds passively by gravity. Individual seeds are large and lack wings, barbs, hooks, or other features to enhance their dispersal by wind or animals. Secondary movement of seeds by insects or rodents may occur after seeds are shed, but total dispersal distance is probably limited to less than 100 m. Occasional long distance dispersal by floodwaters of the Columbia River may explain disjunct occurrences downstream of the core of the species range in Douglas and Kittitas counties.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Astragalus misellus* var. *pauper* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 17 of the known occurrences in the state (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
The foothill big sagebrush steppe habitat of *Astragalus misellus* var. *pauper* is not associated with cold air drainage in the growing season and would have neutral vulnerability to climate change.

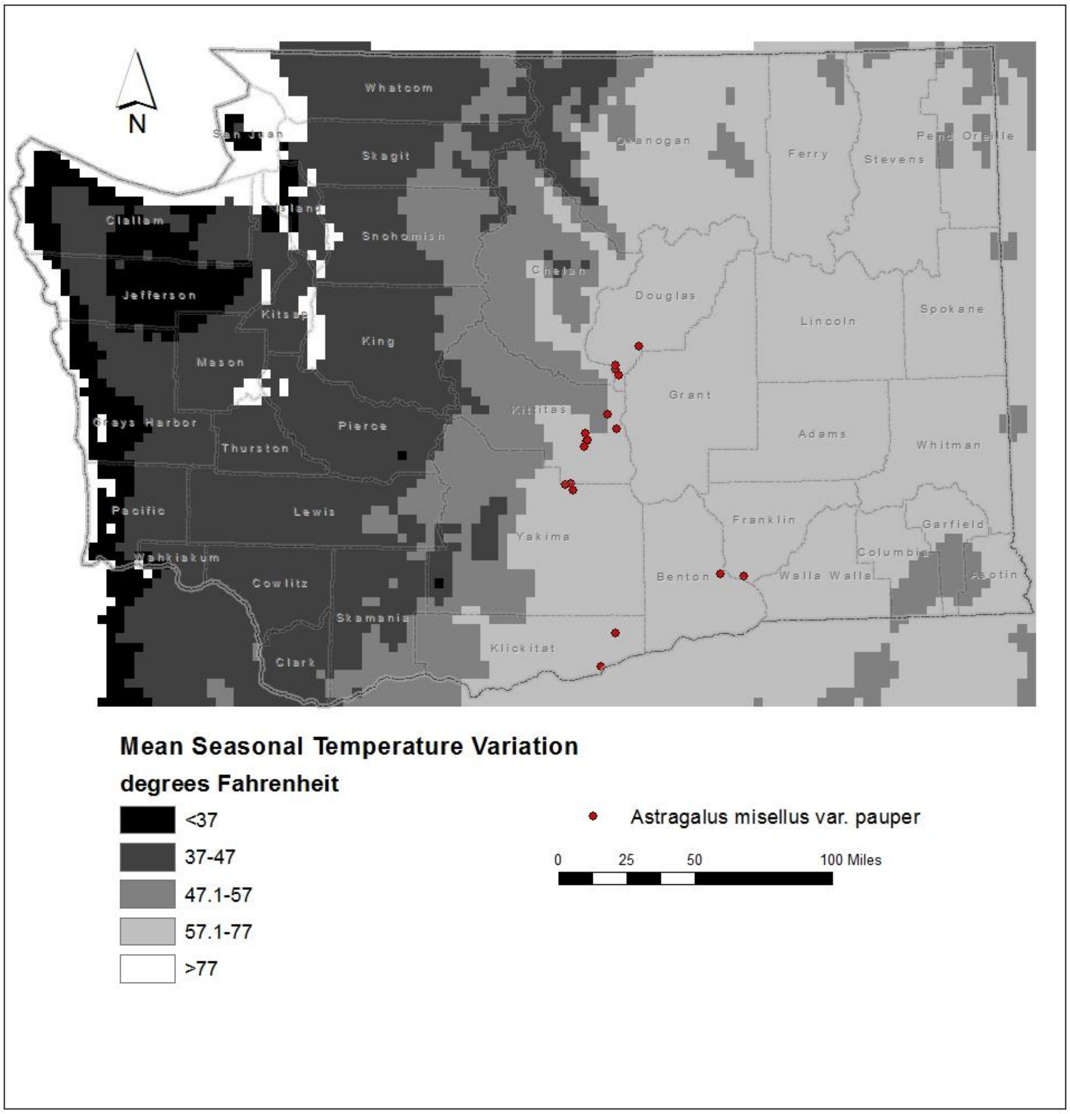

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus misellus* var. *pauper* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Increase.
Thirteen of the 17 populations of *Astragalus misellus* var. *pauper* in Washington (76.5%) are found in areas that have experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at increased vulnerability from climate change. Four other occurrences (23.5%) are from areas with slightly lower than average precipitation variation (11-20 inches/255-508 mm) during the same period and are at slightly increased risk from climate change.

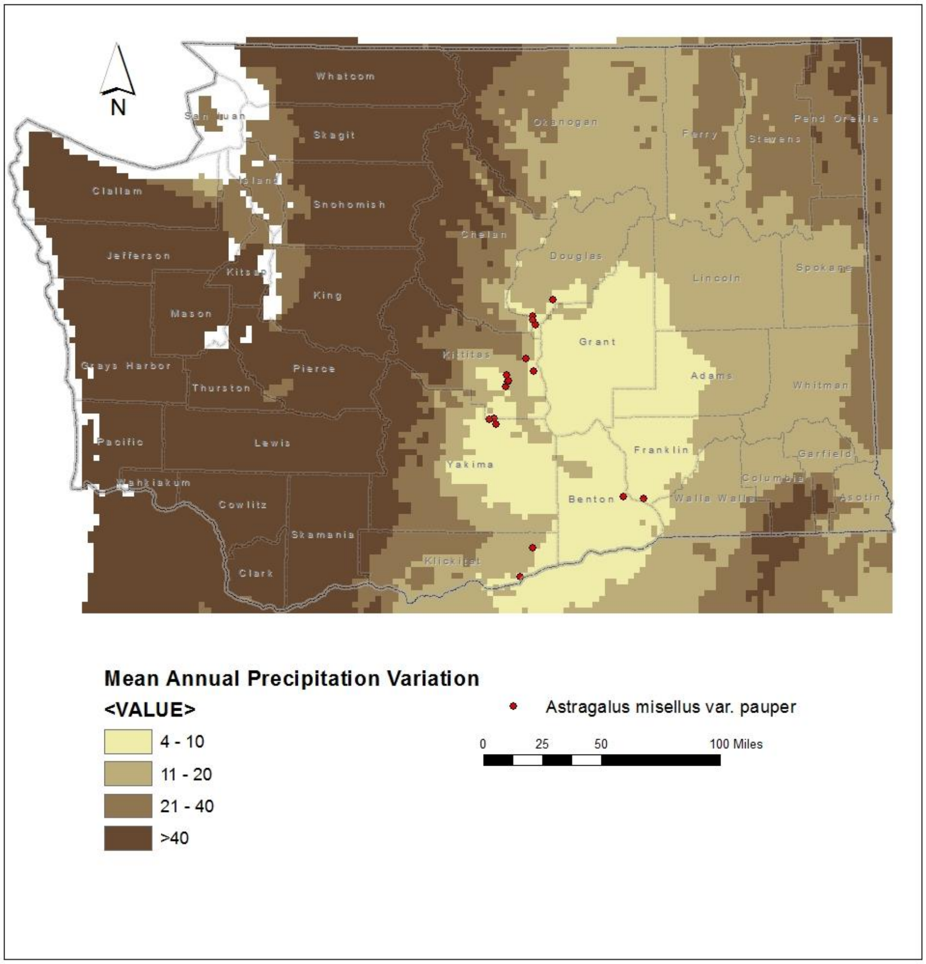

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus misellus* var. *pauper* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is primarily dependent on adequate precipitation to meet its moisture requirements since its habitat is mostly not associated with springs, streams, or a high water table. Its Intermountain Basins Big Sagebrush Steppe habitat is vulnerable to changes in the amount or timing of precipitation. Coupled with projected increases in temperature, these habitats are likely to have more severe drought and increased fire frequency in the future (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Astragalus misellus var. *pauper* occurs in sagebrush grassland sites that burned sporadically and patchily in the past. Increased drought and reduced summer precipitation are likely to

increase the frequency and intensity of wildfire, which in turn could result in a shift in vegetation towards invasive annuals or more fire-resilient grasslands (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Astragalus misellus var. *pauper* occurs in dry foothills of the Columbia Plateau that receive low amounts of winter snow.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
In Kittitas County, *Astragalus misellus* var. *pauper* is found primarily on Tertiary sedimentary rocks of the Ellensburg Formation. Other populations near the Columbia River are associated with various Miocene basalts (Saddle Mountain, Wanapum, and Grande Ronde basalts) or Quaternary alluvium. The Ellensburg Formation has a restricted distribution in the foothills between the East Cascades and the Columbia River, but the other formations are widespread in eastern Washington (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
Drought and fire are probably the primary drivers for generating the sagebrush steppe habitat of this species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Astragalus misellus* var. *pauper* are not known, but other *Astragalus* species are usually pollinated by bees.

C4d. Dependence on other species for propagule dispersal: Neutral.
The pod-like fruits of *Astragalus misellus* var. *pauper* split open at maturity to passively release seeds. The seeds lack structure to facilitate their movement by animals, though foraging species may transport seed short distances to cache them.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Most *Astragalus* species are toxic to grazing animals and not readily used as forage.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The sagebrush grassland habitat of *Astragalus misellus* var. *pauper* is likely to become drier and more prone to wildfire under project climate change. Vegetation may shift towards dominance by perennial grasses or invasive annuals and result in greater competition for space and resources (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Astragalus misellus* var. *pauper*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Astragalus misellus var. *pauper* appears to be an outcrosser, rather than self-pollinated. Presumably, genetic variation is average, though no research has been done to compare its genetic variability with its close relative, *A. howellii* of Oregon. Both have been considered varieties of the same species (*A. howellii*) based on morphological characters (Isely 1983).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Astragalus misellus* var. *pauper* has not changed its typical blooming time since the 1890s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
Populations of *Astragalus misellus* var. *pauper* from the vicinity of the Columbia River near the confluence of the Snake River are all historical and have not been observed since 1950. These occurrences may be extirpated due to habitat loss in the Tri-Cities area. Impacts from climate change on the habitat suitability of these sites are not known.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Isely, D. 1983. New combinations and two new varieties in *Astragalus, Orophaca*, and *Oxytropis* (Leguminosae). Systematic Botany 8(4): 420-426.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Astragalus misellus* var. *pauper*. In: Field Guide to the Rare Plants of Washington.

(https://fieldguide.mt.gov/wa/?species=astragalus%20misellus%20var.%20pauper). Accessed 6 December 2021.

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

Carex circinata (Coiled sedge)

Date: 17 March 2021

Assessor: Walter Fertig, 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: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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 others species to generate required habitat		Neutral/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/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: Documented or Modeled Response	
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: All four of the extant and historical occurrences of *Carex circinata* in Washington occur in areas with a projected temperature increase of < 3.9° F (Figure 1). One vague, historical report from Elmer ("Olympic Mountains, Clallam County") has not been included in this assessment.

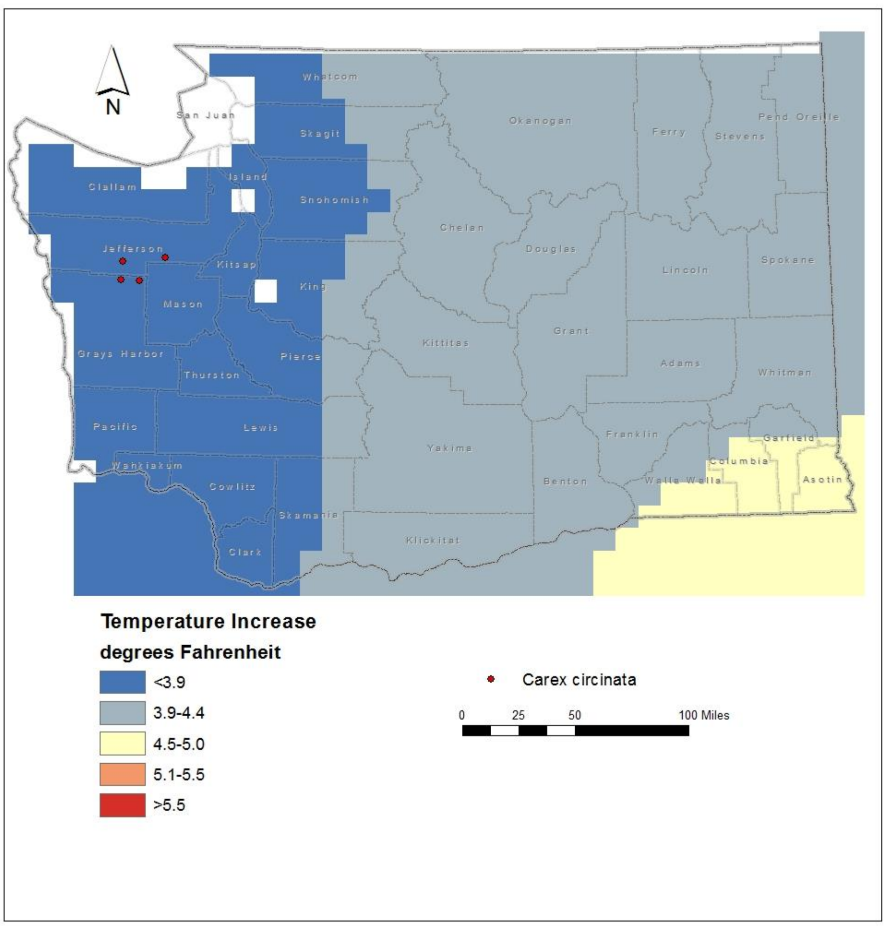

Figure 1. Exposure of *Carex circinata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four of the occurrences (100%) of *Carex circinata* 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).

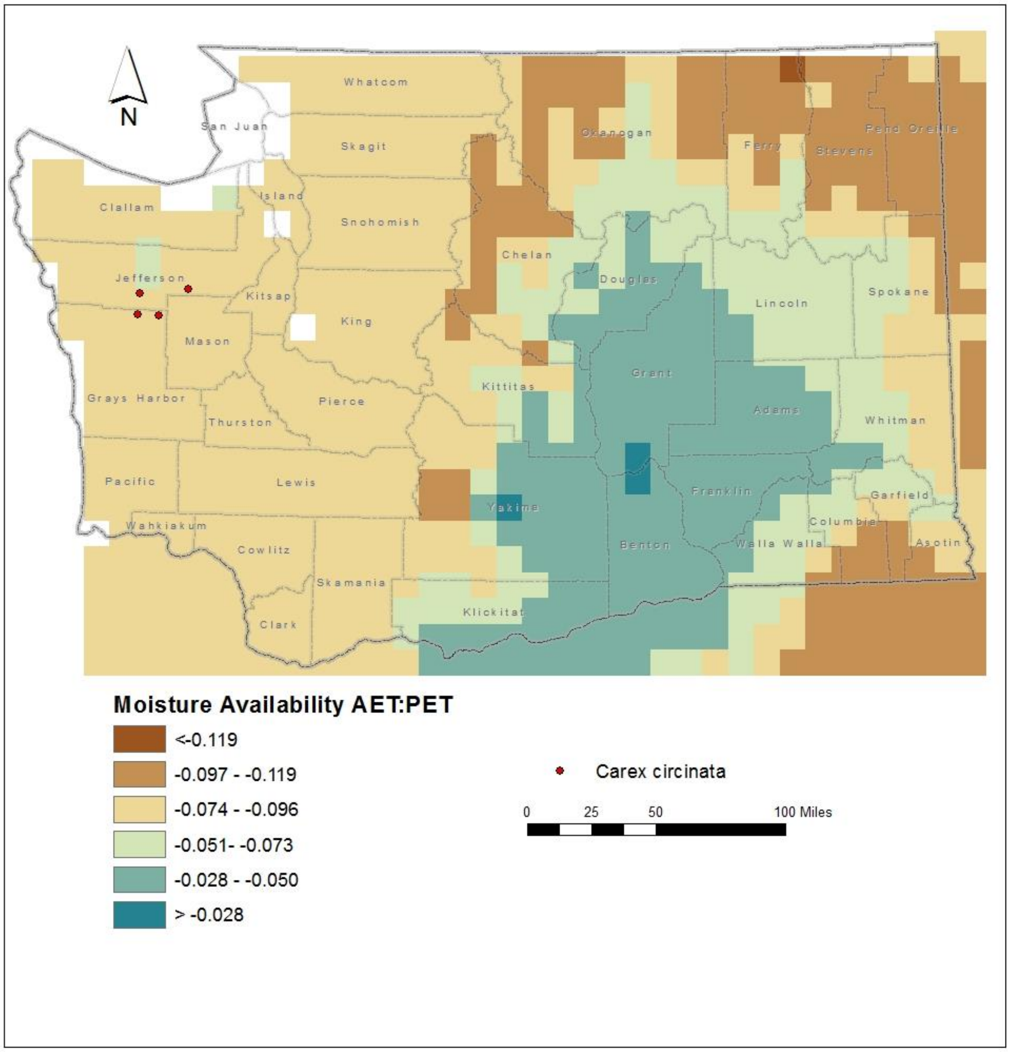

Figure 2. Exposure of *Carex circinata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex circinata* are found at 3120-4700 feet (950-1430 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Carex circinata occurs on barren, north-facing basalt cliffs, talus slopes, and moist meadows and streambanks on loamy, moss-rich soils surrounded by Alaska yellow cedar (*Callitropsis nootkatensis*), mountain hemlock (*Tsuga mertensiana*) and western hemlock (*T. heterophylla*). (Camp and Gamon 2011; Wilson et al. 2014). Some of the meadow sites appear to be former ponds that have become infilled by sediment through plant succession (WNHP records). The habitats occupied by *C. circinata* are part of the North Pacific Montane Massive Bedrock, Cliff & Talus and Temperate Pacific Subalpine-Montane Wet Meadow ecological systems (Rocchio and Crawford 2015). Populations are separated by 8-15 miles (12.5-24 km). The distribution of barren cliffs and open wet meadows is patchy within the matrix of montane to subalpine conifer forests in the southern Olympic Mountains. Forested areas provide a barrier to dispersal and potential migration of this species.

B2b. Anthropogenic barriers: Neutral.
Most of the habitat of *Carex circinata* in Washington is within Olympic National Park and the Colonel Bob Wilderness Area of Olympic National Forest in areas with limited roads or other human infrastructure to impede dispersal or migration.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Carex circinata produces dry, 1-seeded fruits that are lightweight and proportionally much longer than wide (Wilson et al. 2018), making them aerodynamically suitable for limited wind dispersal. Fruits might also be spread short distances by moving water and foraging animals. Average dispersal distances are probably short (<1000 m).

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Carex circinata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All four of the known occurrences in the state (100%) are found in areas that have experienced very small temperature variation (<37°F/20.8°C) during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Increase.
Most populations of *Carex circinata* in Washington are associated with wet meadows and wetlands associated with cold air drainage and would be vulnerable to changes in habitat quality and species composition associated with rising temperatures.

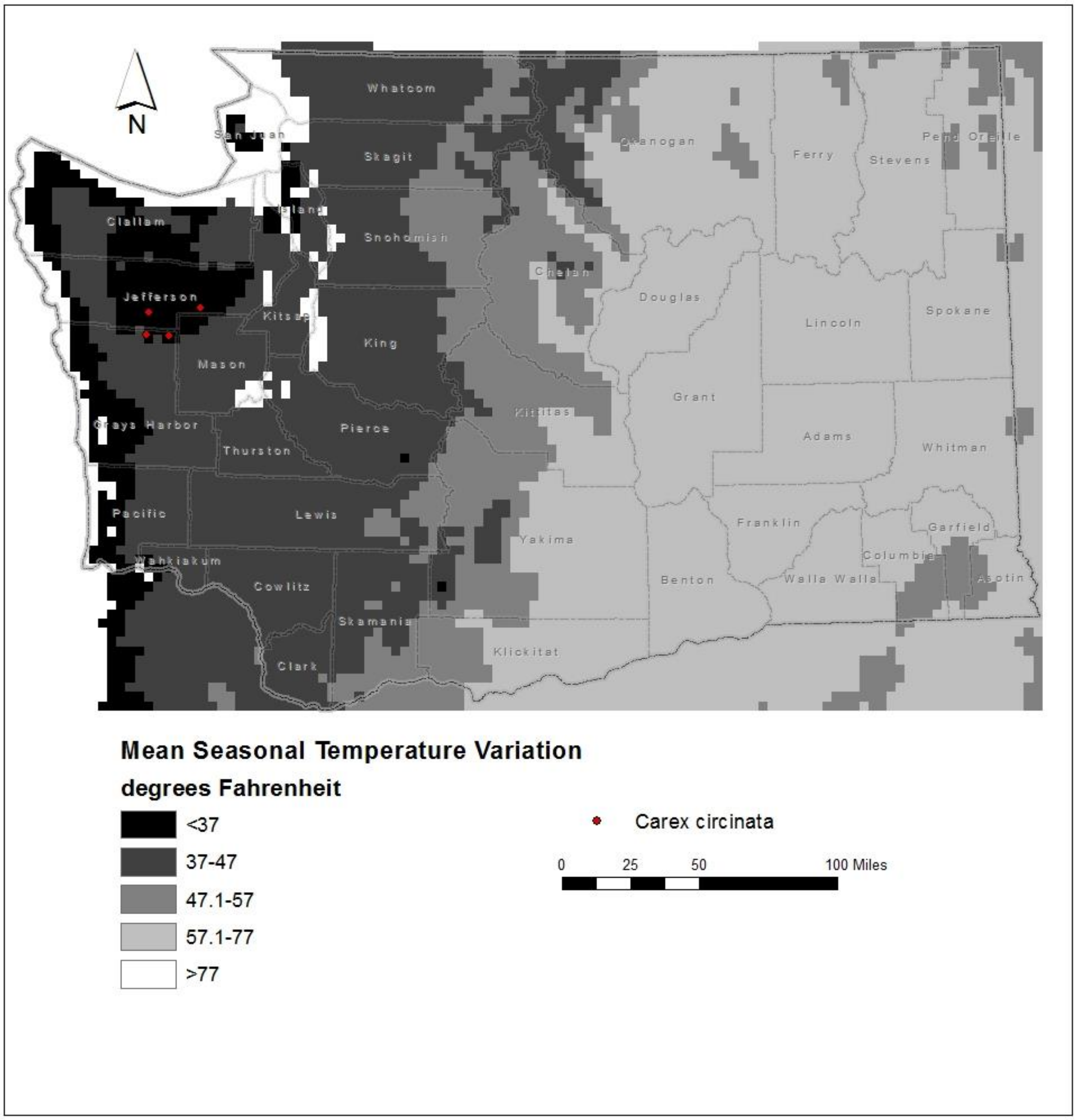

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex circinata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.

All four of the known populations of *Carex circinata* in Washington (100%) are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

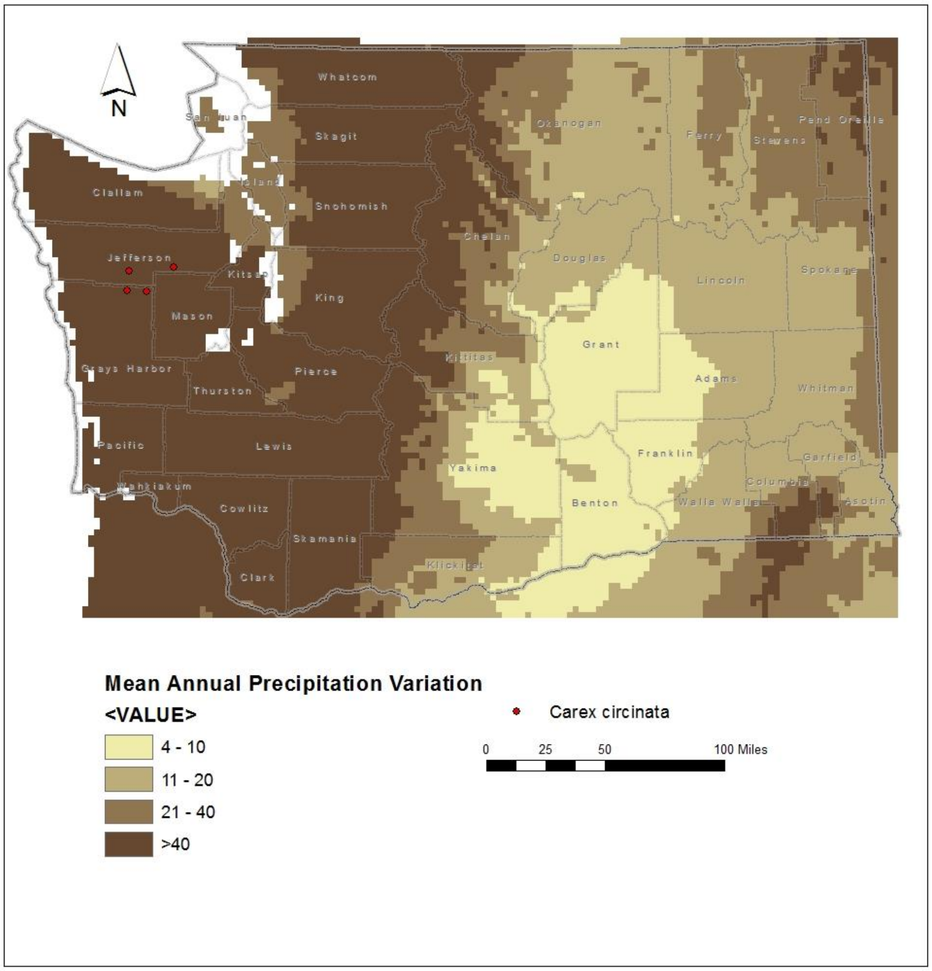

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex circinata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Populations of *Carex circinata* from wet meadows are dependent on groundwater fed by snowmelt and perennial streams. Decreases in the amount of snow and timing of its melting and increases in summer temperatures and drought that could result in permanent lowering of water tables and invasion by forest and dry meadow plant species (Rocchio and Ramm-Granberg 2017). Bedrock cliff occurrences are found in areas without a high water table and are more dependent on precipitation for moisture.

C2c. Dependence on a specific disturbance regime: Neutral.
The sparse vegetative cover in bedrock cliff populations of *Carex circinata* is maintained mostly by natural processes, such as rock fall, short growing seasons (due to long lasting snow or cold

temperatures) and poor soil development. Increased temperatures could make these sites more hospitable for establishment of competing tree, shrub, or forb species (Rocchio and Ramm-Granberg 2017). Wet meadow populations are currently not susceptible to fire or other 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).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Carex circinata* in Washington are found on subalpine ridgecrests and wet meadows in areas of extremely high snowfall. Reductions in the amount of snow and timing of spring melt related to climate change could result in drier conditions in summer that would lower the water table and favor invasion of forest or dry meadow species (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
One population of *Carex circinata* is found on outcrops of pillowed basalt lava and breccia of the Crescent Formation, which occurs along the southern and eastern flank of the Olympic Mountains. Other populations (all from meadow sites) occur on Miocene-Eocene age marine sedimentary rocks that comprise the central core of the Olympics (Washington Division of Geology and Earth Resources 2016). There formations are dispersed widely in the Olympic Peninsula.

C4a. Dependence on other species to generate required habitat: Neutral/Somewhat Increase.
Rock outcrop sites are not dependent on other species to be maintained. 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 circinata, 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: Neutral.
Grazing or disease have not been identified as significant threats to this species.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to the barren rock outcrop and subalpine wet meadow habitat of *Carex circinata*. Reductions in the water table or increased summer drought and temperatures from climate change could result in replacement of wet meadow species by forest or dry meadow plants and increase competition for *C. circinata* (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Genetic data are not available for Washington populations of *Carex circinata*. These occurrences are at least 200 km from their closest neighbors in Vancouver Island and southeastern British Columbia and are likely to be genetically distinct (and perhaps have lower variability) due to genetic drift or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Carex circinata is a wind-pollinated, obligate outcrosser (flowers are unisexual, with staminate flowers borne above the pistillate flowers in a single, spike-like inflorescence). The species as a whole would be expected to have at least average genetic variability. Washington populations are disjunct from those in southern British Columbia by at least 200 km and so probably have lower genetic variability or diversity due to reproductive isolation, genetic drift, or founder effects, but data are not available for confirmation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Carex circinata* has not changed its typical blooming time since the 1930s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Historically, the range of *Carex circinata* has been advancing northward following the retreat of glacial ice sheets, leaving behind scattered populations in the Olympic Range and mountains in British Columbia (Wilson et al. 2018). One Washington population has not been relocated since 1937 and is considered historical. Whether the population has been lost due to succession, disturbance, or climate change is not known.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Wilson, B.L., R.E. Brainerd, D. Lytjen, B. Newhouse, and N. Otting. 2014. Field Guide to the Sedges of the Pacific Northwest, second edition. Oregon State University Press, Corvallis, OR. 432 pp.

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

Carex heteroneura (Smooth-fruited sedge)

Date: 14 September 2021 | Synonym: *C. heteroneura* var. *epapillosa*

Assessor: Walter Fertig, 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: Local Climate	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	91.7
	-0.074 to -0.096	8.3
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
4a. Dependence on others 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		Somewhat Increase

5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat 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 24 of the occurrences of *Carex heteroneura* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

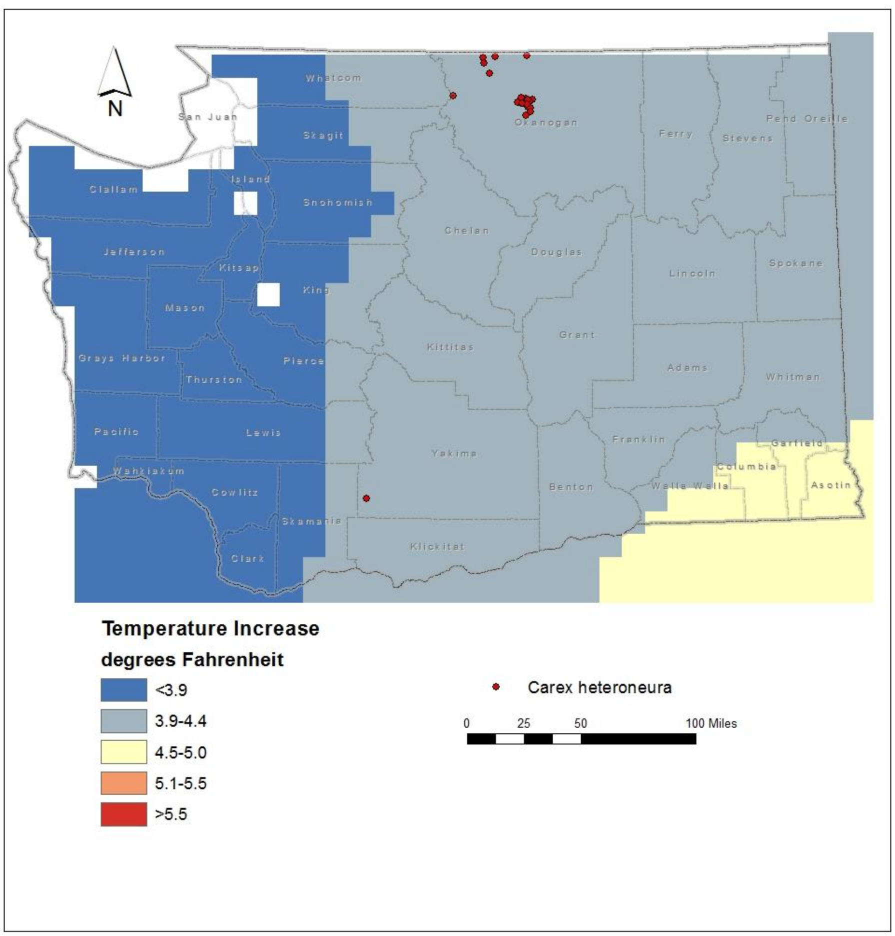

Figure 1. Exposure of *Carex heteroneura* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Twenty-two of the 24 occurrences (91.7%) of *Carex heteroneura* 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 other populations (8.3%) are from areas with a projected decrease of -0.074 to -0.096.

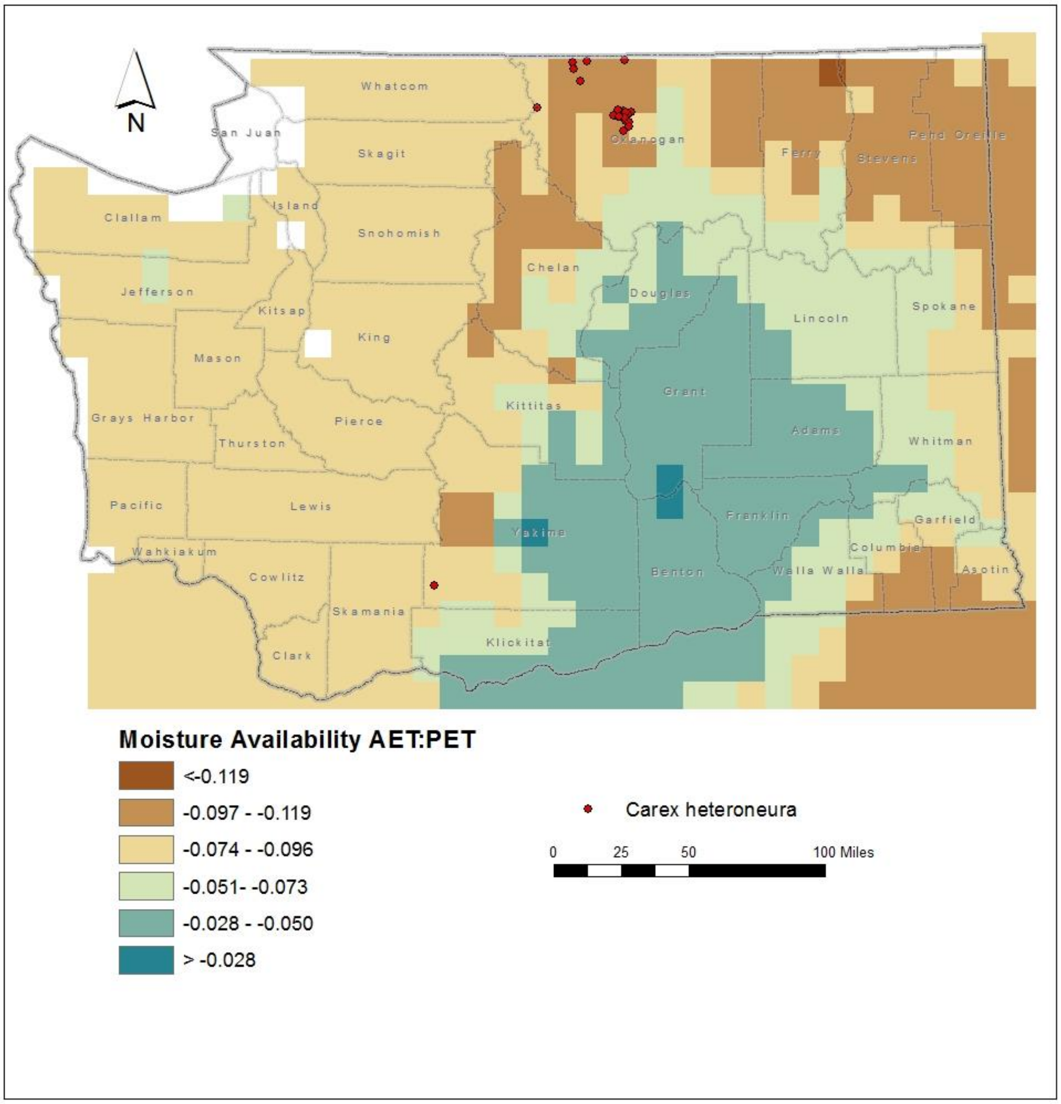

Figure 2. Exposure of *Carex heteroneura* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex heteroneura* are found at 5300-7900 feet (1615-2405 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Carex heteroneura occurs primarily in moist to mesic subalpine meadows and margins of streams, lakes, and seeps. It may also be associated with steep, rocky talus slopes (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Rocky Mountain Alpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). Most populations in the mountains of northern Washington are found within 0.6-18.5 miles (1-30 km) of each other, but a disjunct (and historical) occurrence in the Mount Adams area is separated by 180 miles (288 km). Natural barriers include mountain ridges and valleys, but are probably a minor impediment to dispersal in northern Washington. The isolated Yakima County population is separated by unoccupied and unsuitable habitat.

B2b. Anthropogenic barriers: Neutral.
Much of the subalpine habitat of *Carex heteroneura* in Washington is found along drainages in wilderness areas or backcountry sites with relatively few anthropogenic features aside from limited areas with trails, roads, and logging. Human-induced barriers are relatively minor.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Carex heteroneura produces 1-seeded dry fruits contained within winged sac-like perigynia that are passively dispersed by gravity, water, or high winds, mostly within a short distance of the parent plant (< 1000 m). Under rare circumstances, the perigynia are capable of longer-distance dispersal, which may account for disjunct occurrences, such as at Mount Adams (Biek and McDougall 2007).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Carex heteroneura* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eighteen of the 24 known occurrences in the state (75%) are found in areas that have experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016). The six other occurrences (25%) are from areas that have had a small variation (37-47°F/20.8-26.3°C) in temperature over the same period and are at increased vulnerability to climate change.

C2aii. Physiological thermal niche: Increase.
The subalpine meadow, streamside, and talus habitat of *Carex heteroneura* occurs in areas with cold air drainage in the flowering season and is vulnerable to temperature increases from climate change.

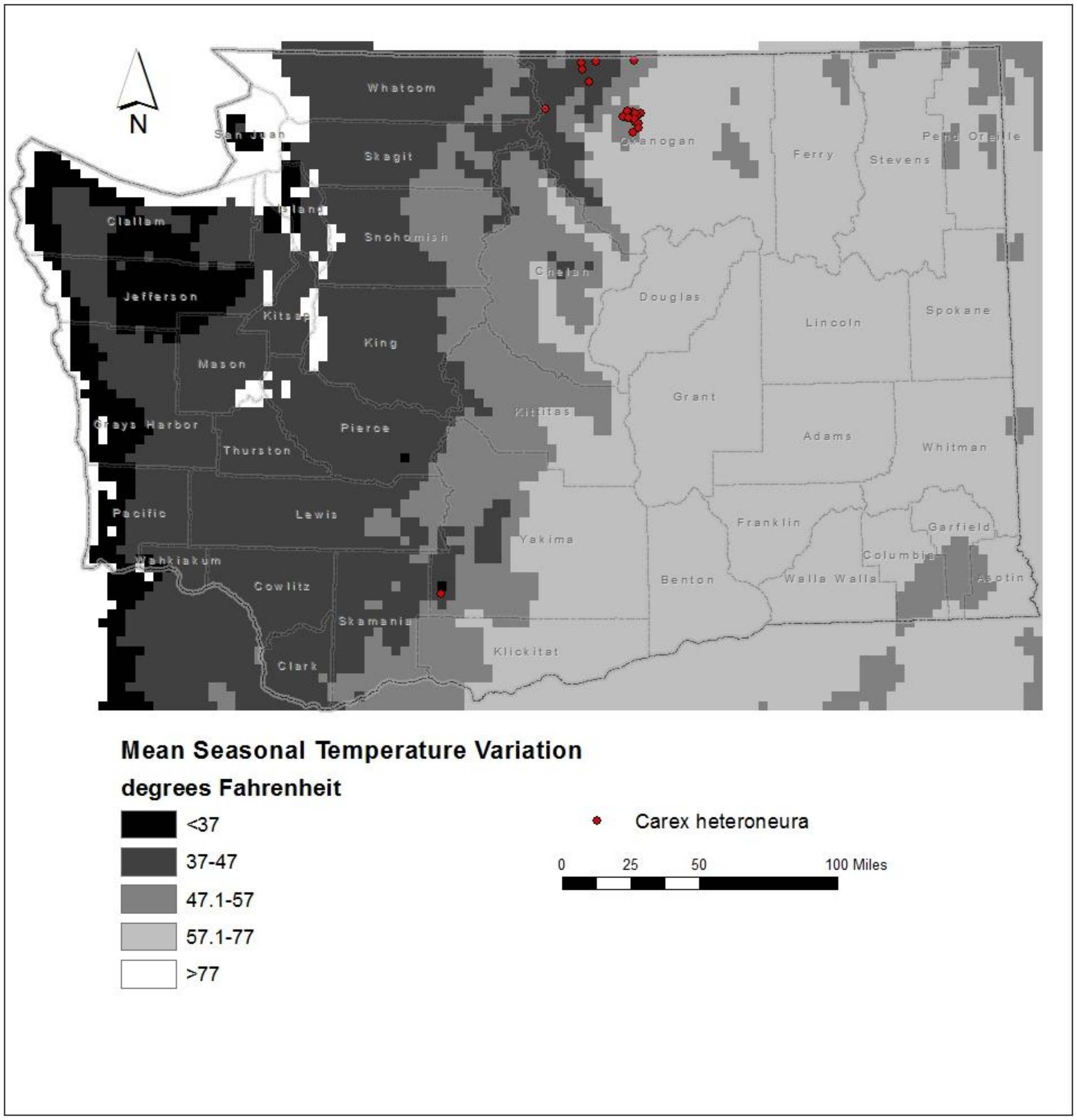

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex heteroneura* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Carex heteroneura* in Washington (100%) are found in areas that have experienced average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

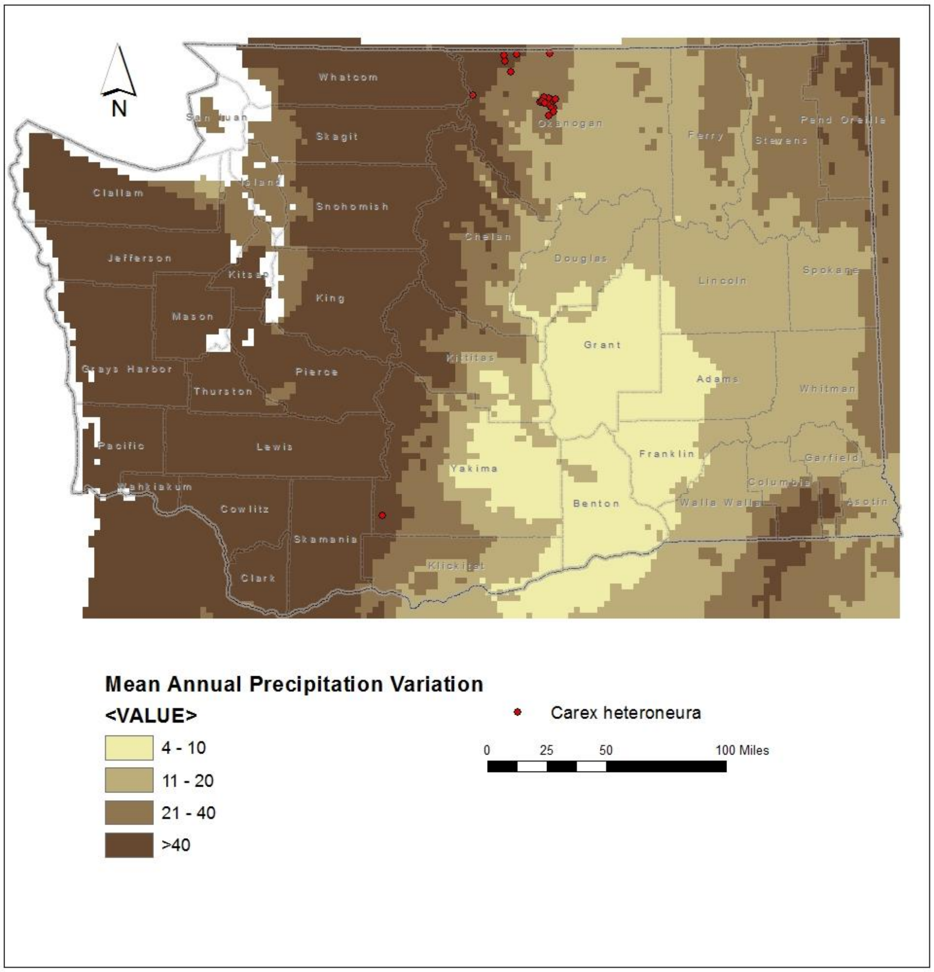

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex heteroneura* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Habitats occupied by *Carex heteroneura* 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.
Carex heteroneura occurs in subalpine wet meadows, streamsides, and talus slopes that are maintained primarily from groundwater discharge and snowmelt, rather than natural

disturbances (Rocchio and Crawford 2015). Under projected climate change, these areas could become drier and more fire-prone in the future (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Carex heteroneura* in Washington are found in subalpine wet meadows, streamsides, and talus areas fed by groundwater or snowmelt. 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).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Carex heteroneura is found on a variety of geologic substrates, including the Tiffany Mountain gneiss, Doe Mountain tonalite, marine sediments of the Hart's Pass Formation, and other gneiss and tonalite formations. In the Mount Adams area, it was historically found on andesite (Washington Division of Geology and Earth Resources 2016). Many of these geologic types are relatively uncommon in northern Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The subalpine wet meadow, streamside, and talus habitat occupied by *Carex heteroneura* is maintained largely by natural abiotic conditions, although influenced by browsing and grazing.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Carex species are entirely wind pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral.
Dispersal of fruits is predominantly passive by gravity or high winds. Secondary dispersal over short distances may occur by insects or rodents.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species could be impacted by grazing, though other graminoids are probably preferred forage.

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 harsh environmental conditions of the subalpine zone. Under projected climate change, competition could increase as wet meadows become drier and species composition shifts (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Somewhat Increase.
No information is available on genetic diversity of Washington occurrences. Wilson et al. (2008) suggest that the high degree of local variability in floral morphology (which has resulted in a complicated taxonomic history) may be a result of the lack of gene flow between different mountain ranges. Washington populations of *Carex heteroneura* are near the northern edge of

the species range and are somewhat isolated from those in British Columbia and Oregon, which could result in reduced genetic variability due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate out-crosser, *Carex heteroneura* would be expected to have reasonably high genetic variability. Washington populations are found near the edge of its global range, so are likely to possess lower levels of genetic diversity due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Carex heteroneura* has not changed its typical blooming time.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
The disjunct occurrence in the Mount Adams area has not been relocated since 1906 and may be extirpated. As a consequence, the extent of this species' range in Washington has contracted. Whether this is due to habitat loss, over-grazing, or climate change is not known.

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

References

Biek, D. and S. McDougall. 2007. The Flora of Mount Adams, Washington. Sound Books, Seattle, WA. 474 pp.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Natural Heritage Program. 2021 -. *Carex heteroneura*. In: Online Field Guide to the Rare Plants of Washington (https://fieldguide.mt.gov/wa/?species=carex%20heteroneura). Accessed 28 September 2021.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Wilson, B.L., R.E. Brainerd, D. Lytjen, B. Newhouse, and N. Otting. 2014. Field Guide to the Sedges of the Pacific Northwest, second edition. Oregon State University Press, Corvallis, OR. 432 pp.

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

Carex pauciflora (Few-flowered sedge)

Date: 18 March 2021

Assessor: Walter Fertig, 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: Local Climate	**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	25
	<3.9° F (2.2°C) warmer	75
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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase/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		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others species to generate required habitat		Neutral/Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral/Somewhat Increase
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	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: Fifteen of the 20 extant and historical occurrences of *Carex pauciflora* in Washington (75%) occur in areas with a projected temperature increase of <3.9˚ F (Figure 1).

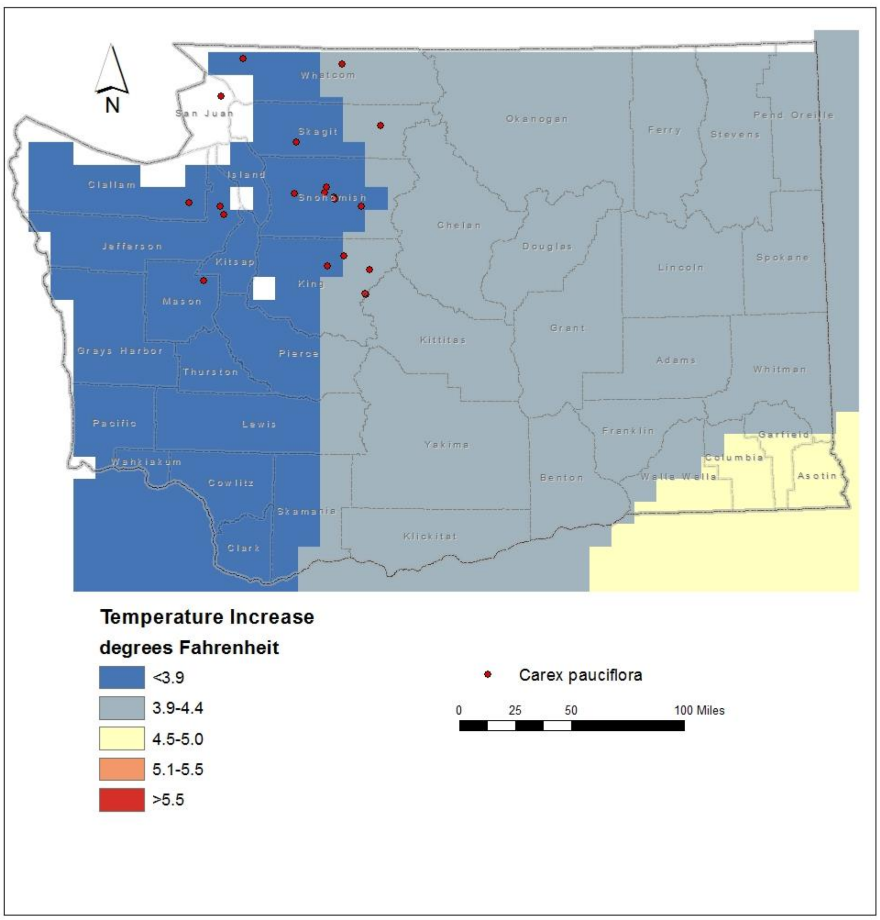

Figure 1. Exposure of *Carex pauciflora* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

Five other populations (25%) are from areas with projected temperature increases of 3.9-4.4˚ F.

A2. Hamon AET:PET Moisture Metric: All 20 of the occurrences of *Carex pauciflora* 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 -0.096 (Figure 2).

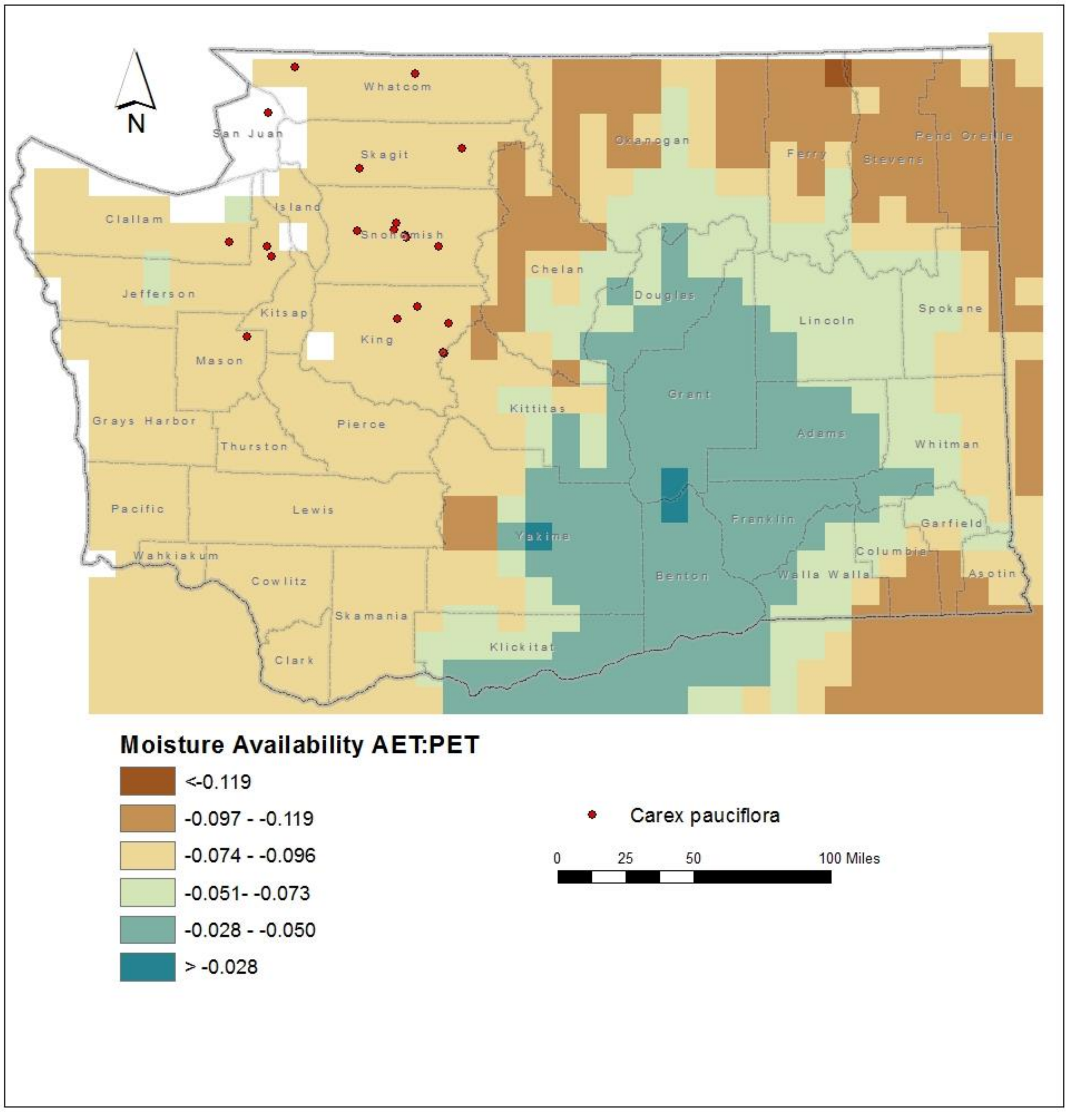

Figure 2. Exposure of *Carex pauciflora* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex pauciflora* are found at 250-4550 feet (75-1390 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Carex pauciflora occurs primarily on moss mats in sphagnum bogs and peatlands on islands, lakeshores, and benches embedded within western hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), alpine laurel (*Kalmia microphylla*) and bog Labrador tea (*Rhododendron groenlandicum*) communities (Camp and Gamon 2011; Wilson et al. 2018). This habitat is part of the North Pacific Bog and Fen ecological system (Rocchio and Crawford 2015). Populations are separated from each other by 0.5-44 miles (1.2-69 km). 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.
Populations of *Carex pauciflora* in Washington are primarily found in high elevation areas of the Olympic and northern Cascade mountains (at least 7 populations are in designated protected areas). Some populations may be near roads or timber harvesting areas, but otherwise are less impacted by human infrastructure than most lowland plant species. 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.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase/Increase.
Carex pauciflora produces 2-6 one-seeded dry fruits per inflorescence. At maturity, the dagger-shaped perigynia (a bladdery sac enclosing the achene fruit) are deflexed downward due to overgrowth of spongy cells at the base of each perigynium and the sterile scale that normally subtends the perigynium is shed. A passing animal that brushes the fruiting spike causes the perigynium to spring upwards, compressing the spongy tissue and forcibly discharging the perigynium 1-2 feet (Hutton 1976; Wilson et al. 2018). Once dehisced, the perigynium and achene may be secondarily transported by wind, water, or animals, although the total distance dispersed is probably less than 100m.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Carex pauciflora* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Fifteen of the 20 known occurrences in the state (75%) are found in areas that have experienced small temperature variation (37-47˚F/20.8-26.3˚C) during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016). The other five occurrences (25%) have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation over the same period and are at somewhat increased vulnerability to climate change.

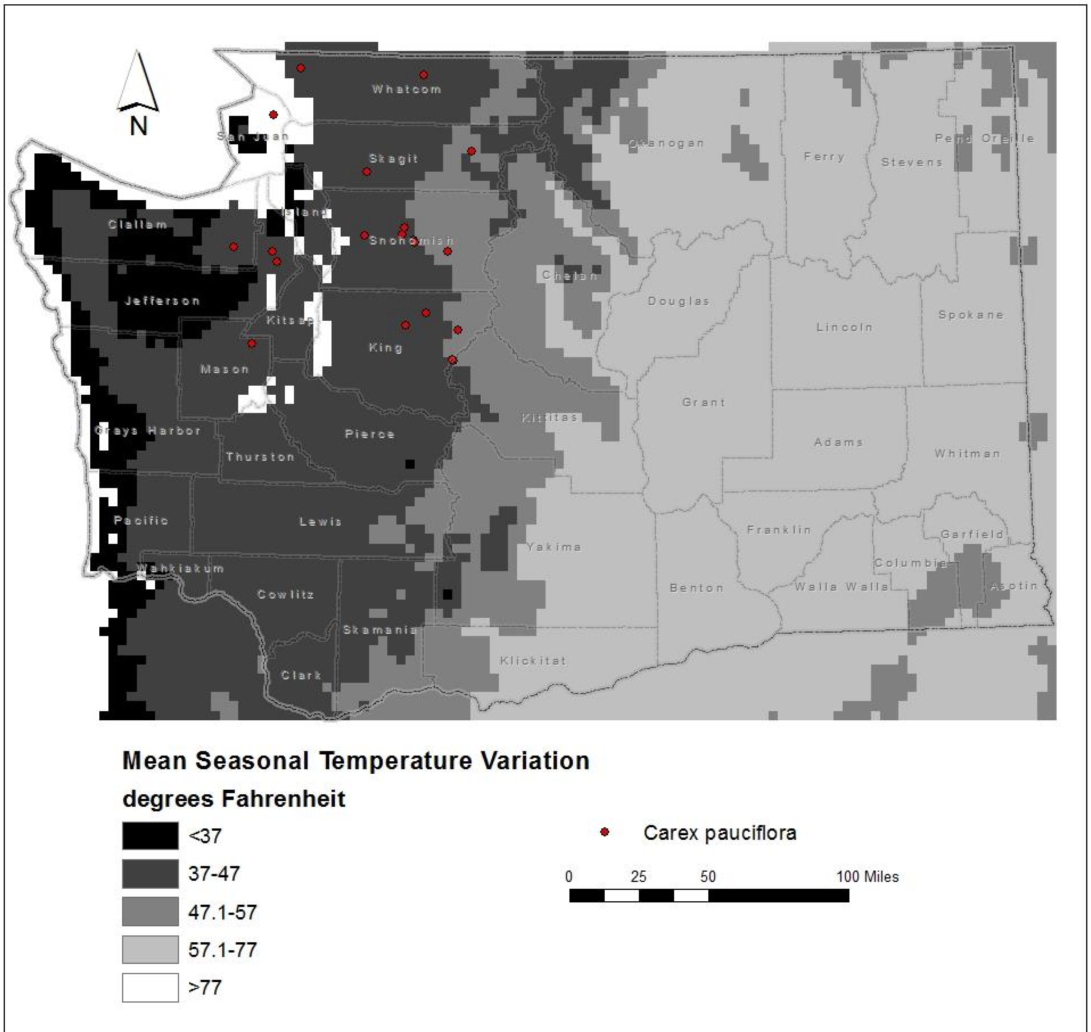

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex pauciflora* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The bog and peatland habitat of *Carex pauciflora* is often associated with cold air drainage sites in montane settings and are cooler than the surrounding matrix vegetation.

C2bi. Historical hydrological niche: Neutral.
Sixteen of the 20 populations of *Carex pauciflora* in Washington (80%) are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40

inches/1016 mm) (Figure 4). The other four populations (20%) are from areas with average precipitation variation (20-40 inches/508-1016 mm). According to Young et al. (2016), all of the Washington occurrences are neutral for climate change.

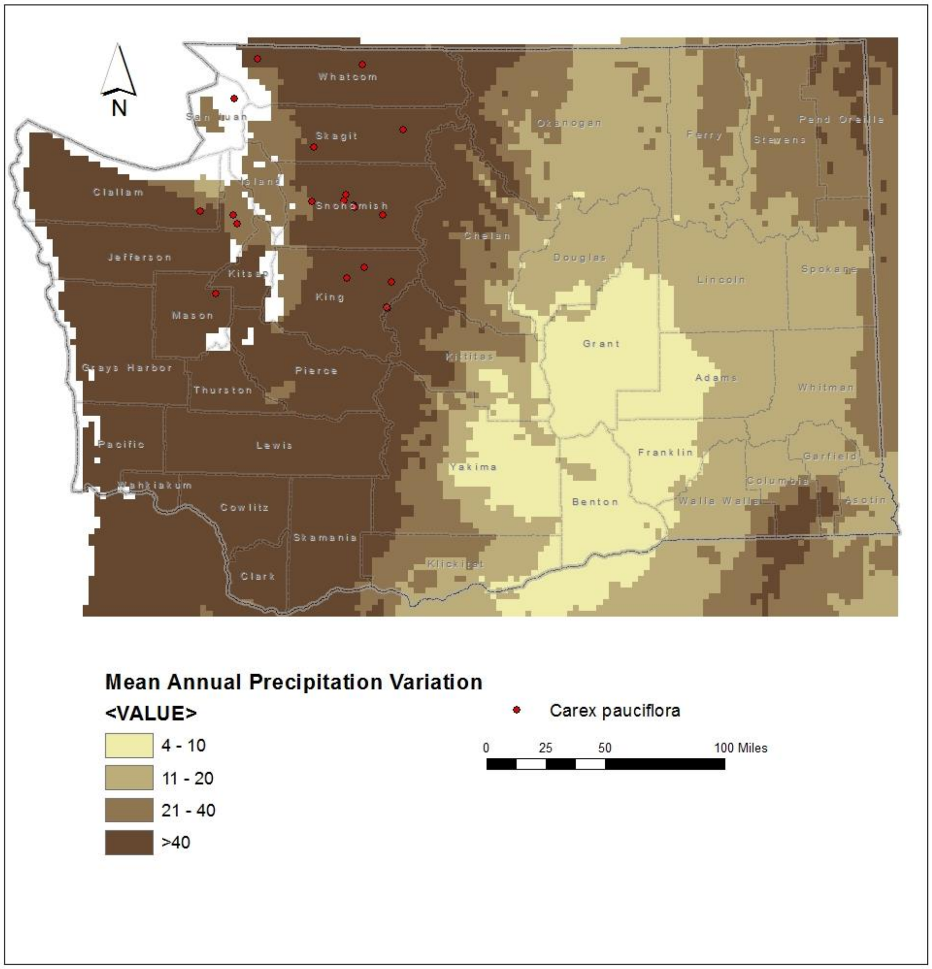

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex pauciflora* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
The peatland habitat of *Carex pauciflora* is dependent on adequate year-round moisture (particularly from groundwater). 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 that in turn would facilitate the transition from bog to wet meadow vegetation (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Carex pauciflora is not dependent on disturbance to maintain its peatland habitat.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Carex pauciflora* in Washington are found in areas of the Olympic and northern Cascade mountains with very high snowfall. Melting snow is a significant contributor to ground water that sustains many peatlands. Warming temperatures could result in a shift from snow to more winter rainfall in western Washington. A reduction in overall snowpack could result in less water being available in summer and a lowering of the water table. In turn, drier conditions could promote increased decay of peat or shifts in the dominance of plant species to those adapted to wet meadows (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Carex pauciflora is found primarily on peat soils over Quaternary alluvium and Pleistocene glacial drift. Some populations in the Cascade Range occur on granodiorite outcrops of the Snoqualmie batholith or Barlow Pass volcanics. Most of these geologic types are widespread in the Cascade and Olympic ranges of northwestern Washington (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral/Somewhat Increase.
One *Carex pauciflora* population in Skagit County appears to have been maintained in part by past beaver (*Castor canadensis*) activity (WNHP records). Whether beaver dams are maintaining high water tables at other peatland occurrences of *C. pauciflora* has not been documented.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Carex pauciflora is entirely wind pollinated and not dependent on animals for pollination.

C4d. Dependence on other species for propagule dispersal: Neutral/Somewhat Increase.
Perigynia of *Carex pauciflora* are ejected from the fruiting heads by being disturbed by passing animals and may be secondarily transported on muddy fur or feet. Otherwise, dispersal is primarily passive (gravity, wind, and flowing water).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Grazing is not considered a significant threat to this species (Wilson et al. 2018).

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to acidic bog environments. Potential shifts in vegetation from peatland to wet meadow that could result from persistently lowered water tables from climate change would increase competition from plant species adapted to drier conditions (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability in *Carex pauciflora* populations in Washington. Populations in the state are at the southern edge of the species' range, and so might have lower genetic diversity due to genetic drift or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Carex pauciflora is a wind-pollinated, obligate outcrosser and would be expected to have at least average genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Carex pauciflora* has not changed its typical blooming time since the 1890s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Carex pauciflora* in Washington in the last century. Wilson et al. (2018) state that some populations in Washington seem to be declining. Abundance data from WNHP records suggest most populations are locally abundant (often being a community dominant) and relatively stable, although two populations may be historical or extirpated. Whether these occurrences have disappeared due to habitat loss or climate change is not known.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Hutton, E.E. 1976. Dissemination of perigynia in *Carex pauciflora*. Castanea 41(4): 346-348.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Wilson, B.L., R.E. Brainerd, D. Lytjen, B. Newhouse, and N. Otting. 2014. Field Guide to the Sedges of the Pacific Northwest, second edition. Oregon State University Press, Corvallis, OR. 432 pp.

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

Carex vallicola (Valley sedge)

Date: 10 September 2021

Assessor: Walter Fertig, 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: Local Climate	**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	27.8
	-0.074 to - 0.096	61.1
	-0.051 to - 0.073	11.1
	-0.028 to -0.050	0
	>-0.028	0

Section B: Indirect Exposure to Climate Change	**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: Sensitivity and Adaptive Capacity	
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	Increase
2d. Dependence on ice or snow-covered habitats	Somewhat Increase
3. Restricted to uncommon landscape/geological features	Neutral
4a. Dependence on others 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	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All 18 of the known occurrences of *Carex vallicola* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

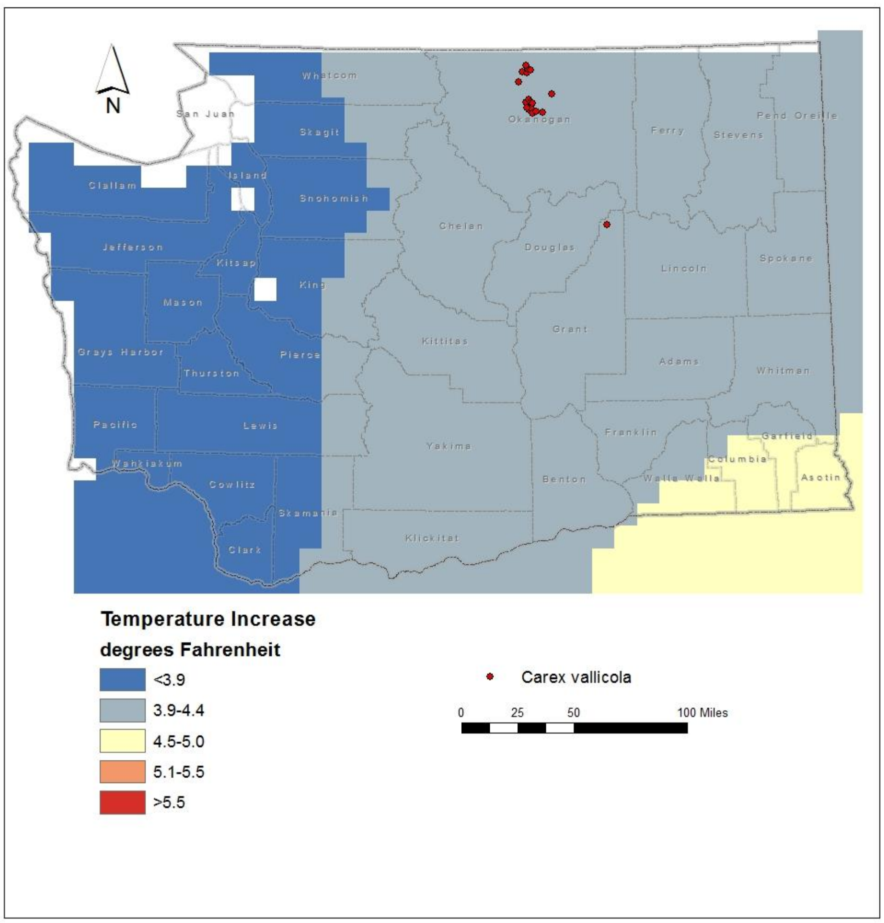

Figure 1. Exposure of *Carex vallicola* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Eleven of the 18 occurrences (61.1%) of *Carex vallicola* 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). Another five populations are from areas with a projected decrease of -0.097 to -0.119 (27.8%). Two other occurrences have a projected decrease of -0.051 to -0.073 (11.1%) (Figure 2).

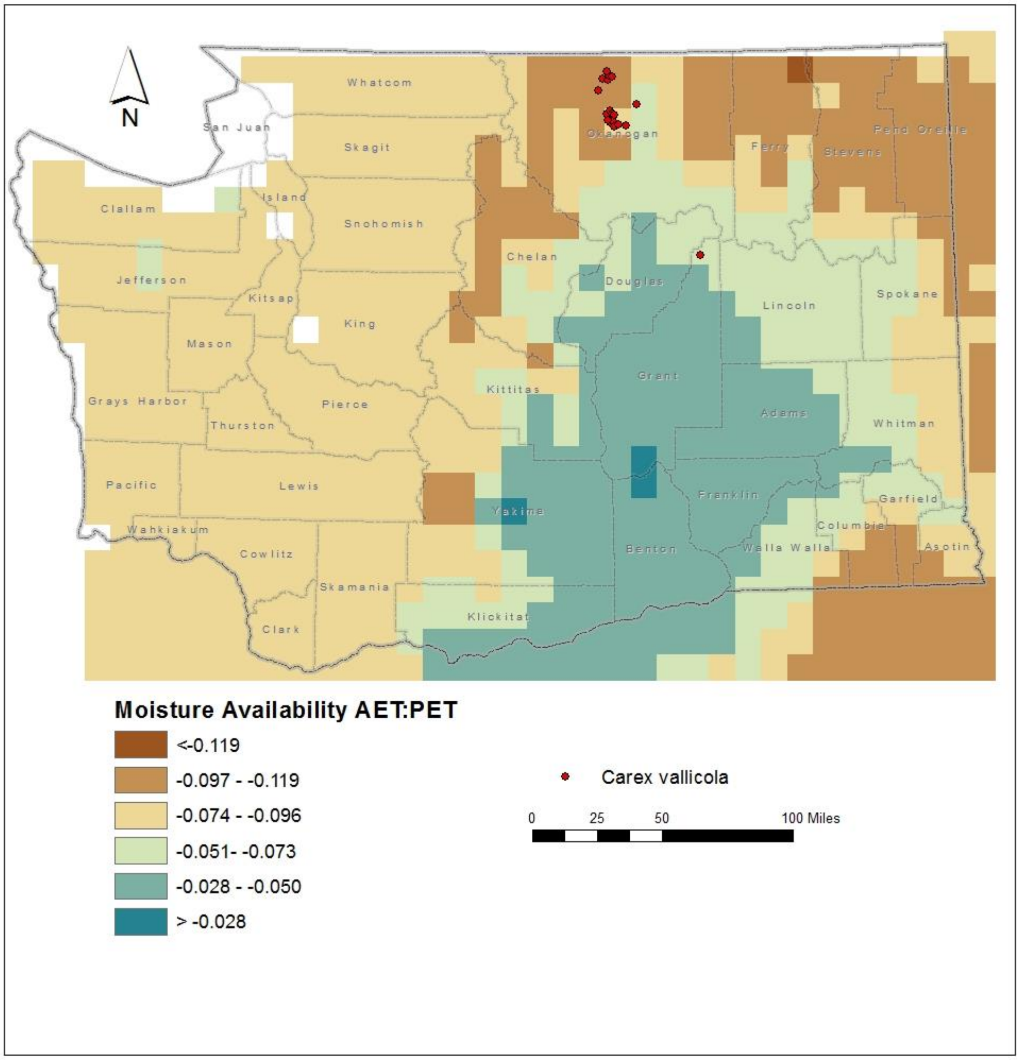

Figure 2. Exposure of *Carex vallicola* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex vallicola* are found at 2000-6800 feet (610-2075 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Carex vallicola occurs primarily in dry thickets, open forests of Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*), or sagebrush meadows. Although it often occurs in moist microsites, it is an upland, rather than a wetland sedge species (Camp and Gamon 2011; Washington Natural Heritage Program 2021; Wilson et al. 2008). This habitat is part of the Inter-Mountain Basin Sagebrush Steppe and Northern Rocky Mountain Subalpine-Upper Montane Grassland ecological systems (Rocchio and Crawford 2015). Most populations in Washington occur within 0.8-8 miles (1.3-14 km) of each other in the Okanogan Plateau, but one disjunct occurrence from Grant County is 57.5 miles (92 km) away. Populations are separated by ridges or valleys that offer small barriers to dispersal. The one disjunct site is isolated by extensive areas of unsuitable habitat.

B2b. Anthropogenic barriers: Somewhat Increase.
The low elevation sagebrush meadow and open conifer forest habitat of *Carex vallicola* in northern Washington is intersected by roads, farmland, logged areas, and other examples of human infrastructure that create a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Carex vallicola produces 1-seeded dry fruits contained within winged sac-like perigynia. These are passively dispersed by gravity, water, or high winds, mostly within a short distance of the parent plant (< 1000 m). Under rare circumstances, the perigynia are capable of longer-distance dispersal.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Carex vallicola* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Thirteen of the 18 known occurrences in the state (72.2%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variations during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). The 5 other populations (27.8%) have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) variation in temperature over the same period and are at somewhat increased vulnerability to climate change.

C2aii. Physiological thermal niche: Somewhat Increase.
The dry meadow, conifer forest, and sagebrush habitats of *Carex vallicola* are often in valleys that would have colder air drainage than surrounding slopes or exposed areas.

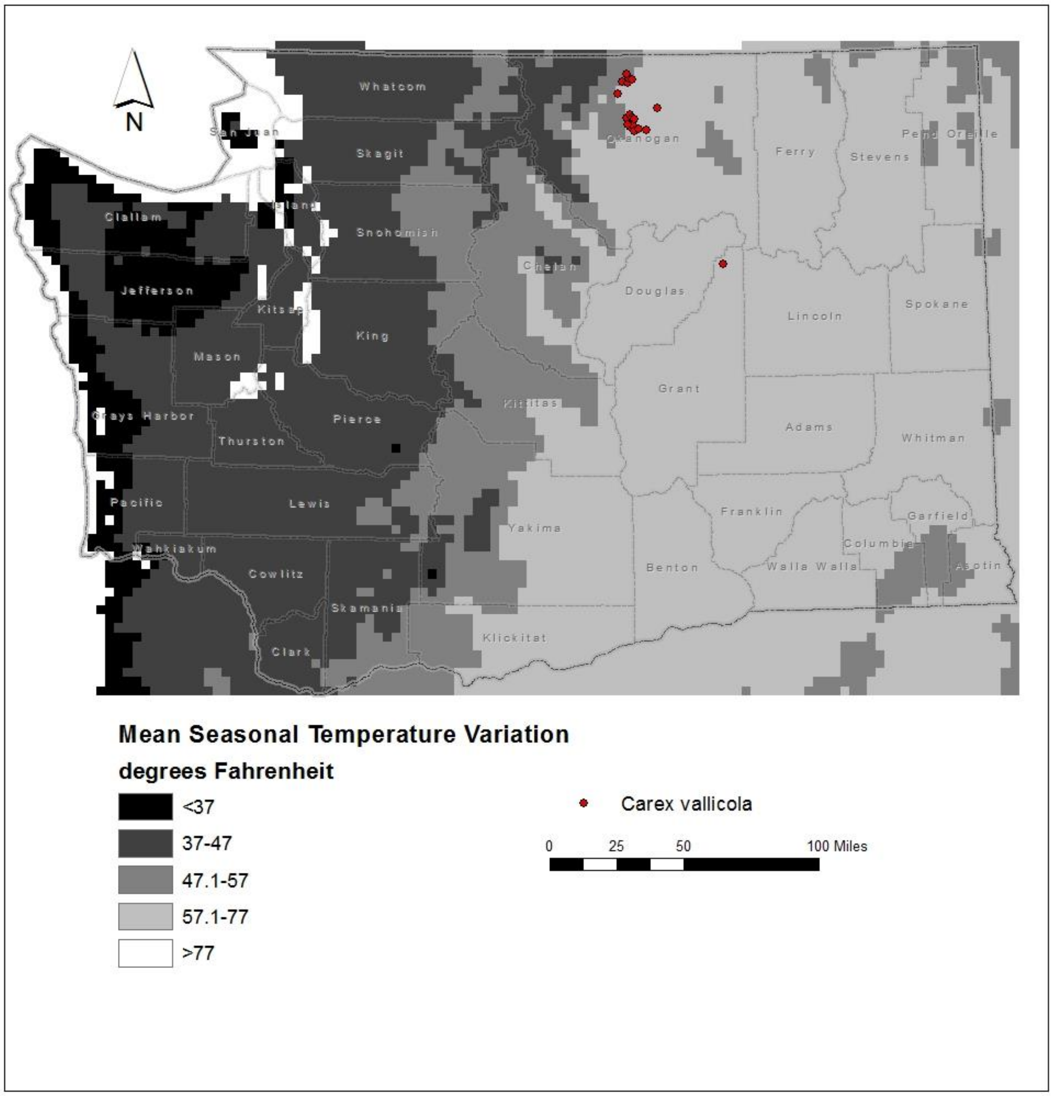

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex vallicola* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Ten of the 18 populations of *Carex vallicola* in Washington (55.6%) are found in areas that have experienced slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm) (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability to climate change. Eight other occurrences (44.4%) are from areas with average precipitation variation (21-40 inches/508-1016 mm) in the same period and are at neutral risk from climate change.

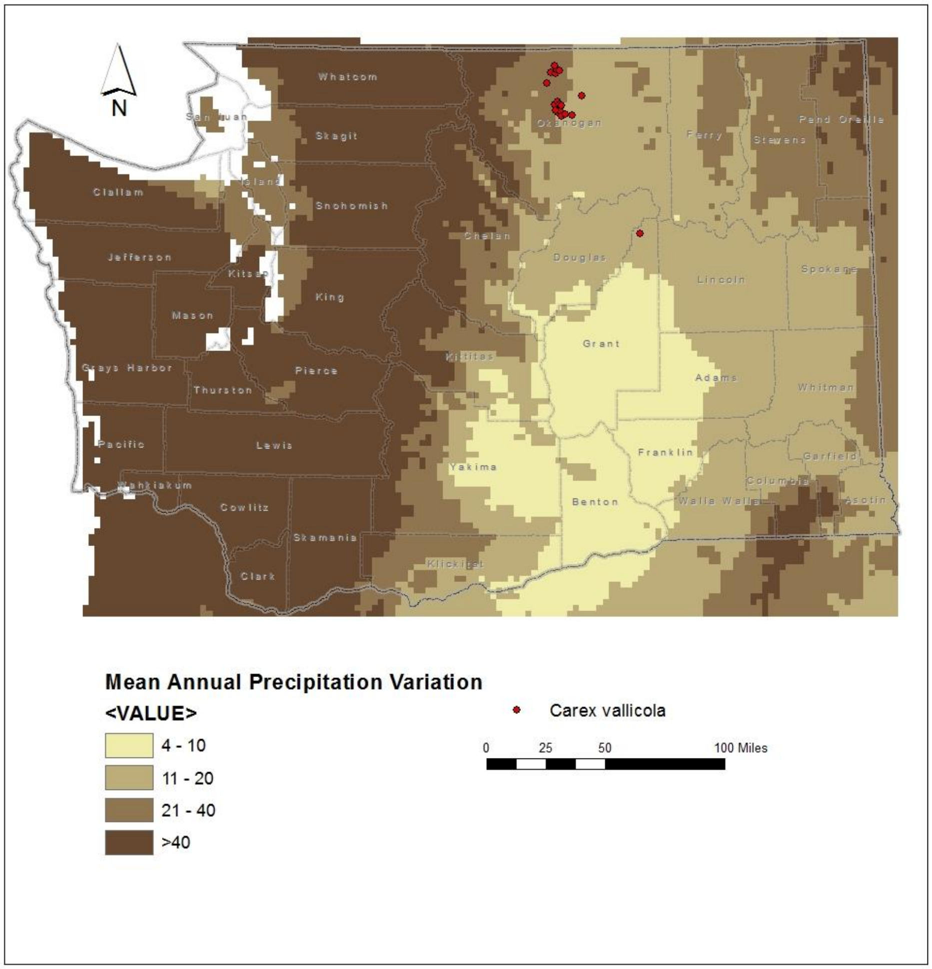

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex vallicola* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The dry meadow, lower montane conifer forest, and sagebrush grassland habitats of *Carex vallicola* are usually not associated with perennial water sources or a high water table and so are sensitive to reductions in snowpack or precipitation. Higher temperatures and drought make these habitats more vulnerable to wildfire (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Increase.
The dry meadow habitats of *Carex vallicola* may be maintained by periodic low-intensity fire. Under climate change, this community and other sagebrush and lower montane conifer woodland habitats used by this species are likely to experience more frequent or higher intensity wildfires that could result in shifts in species composition towards herbaceous or weedy annual species (Rocchio and Crawford 2015, Rocchio and Ramm-Granberg 2017). Fire suppression, by

contrast, could increase the density of woody vegetation, making these sites more vulnerable to catastrophic wildfire.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Carex vallicola* in Washington are found mostly in lower montane meadows, sagebrush steppe, and conifer forests with moderate snowfall. Changes in the amount of snow or in the timing of melt due to climate change are likely to make these habitats drier and more susceptible to fire or displacement by non-native species (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
In the Okanogan region, *Carex vallicola* is found primarily on outcrops of heterogeneous metamorphic and igneous rocks of the Tiffany and Conconully complexes or felsic intrusives of the Cathedral Batholith. These formations are relatively widespread in western Okanogan County. The disjunct Grant County occurrence is on the widespread Grande Ronde Basalt (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The dry meadow, sagebrush, and open conifer woodland habitats occupied by *Carex vallicola* are partly maintained by grazing (Rocchio and Crawford 2015), but are mostly the product of natural abiotic conditions or disturbance history.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Carex species are entirely wind pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral.
Dispersal of fruits is predominantly passive by gravity or high winds. Secondary dispersal over short distances may occur by insects or rodents.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Carex vallicola is palatable to livestock and native grazers and decreases when heavily utilized (Wilson et al. 2008).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Habitats occupied by *Carex vallicola* are already vulnerable to invasion by non-native species following disturbance. These areas are likely to be even more vulnerable to competition from weedy species if fire frequency or intensity increases with climate change (Rocchio and Ramm-Granberg 2017). Loss of sagebrush or conifer cover following wildfire, or drought-induced mortality in meadows, could lead to increased competition with other plant species better adapted to drier conditions.

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

C5a. Measured genetic variation: Unknown.
Genetic data are not available from Washington populations.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Carex vallicola is a wind-pollinated, obligate out-crosser to be an obligate outcrosser. Washington populations are near the northern edge of the species' range and are somewhat disjunct from occurrences in northern British Columbia, eastern Oregon and southern Idaho, and so might be expected to have lower genetic diversity due to founder effects or inbreeding.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Carex vallicola* has not changed its typical blooming time.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Carex vallicola* in Washington since it was first discovered in the state in the 1930s.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021 -. *Carex vallicola*. In: Online Field Guide to the Rare Plants of Washington (https://fieldguide.mt.gov/wa/?species=carex%20vallicola). Accessed 29 September 2021.

Wilson, B.L., R.E. Brainerd, D. Lytjen, B. Newhouse, and N. Otting. 2014. Field Guide to the Sedges of the Pacific Northwest, second edition. Oregon State University Press, Corvallis, OR. 432 pp.

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

Castilleja cryptantha (Obscure paintbrush)

Date: 27 September 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington		Heritage Rank: G2G3/S2S3

Index Result: Highly Vulnerable		Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		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/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on others 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	Increase
6. Phenological response to changing seasonal and precipitation dynamics	Somewhat Increase
Section D: Documented or Modeled Response	
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: All 22 of the occurrences of *Castilleja cryptantha* in Washington (100%) are from areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

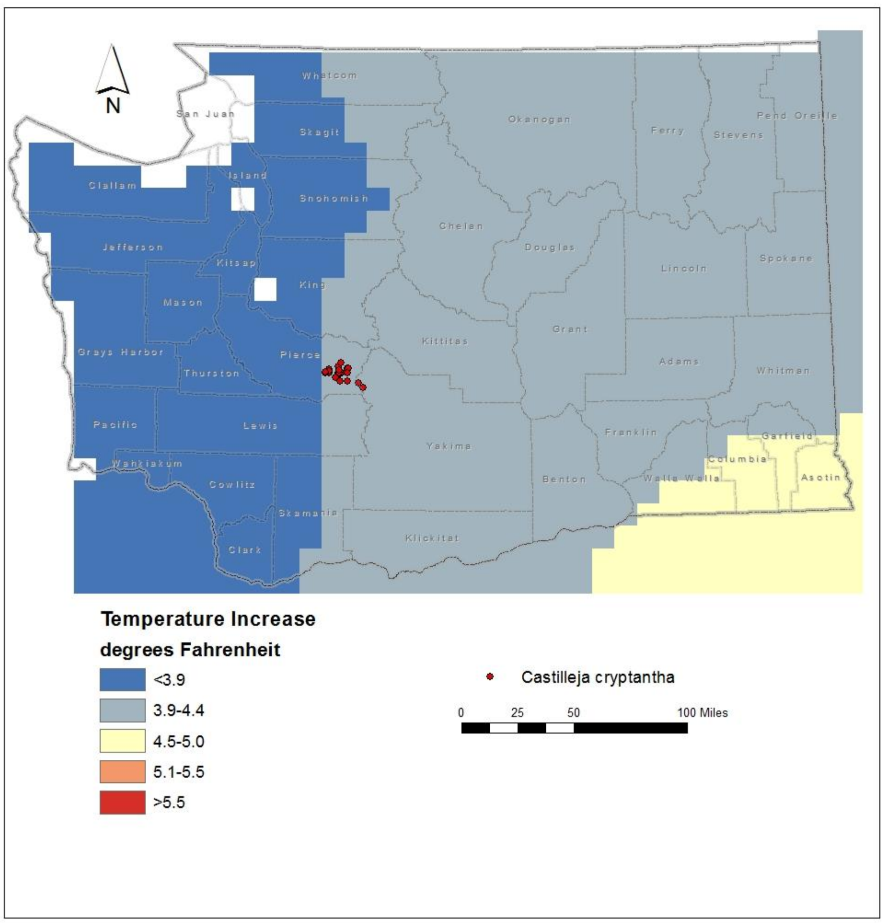

Figure 1. Exposure of *Castilleja cryptantha* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The 22 occurrences of *Castilleja cryptantha* 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 -0.096 (Figure 2).

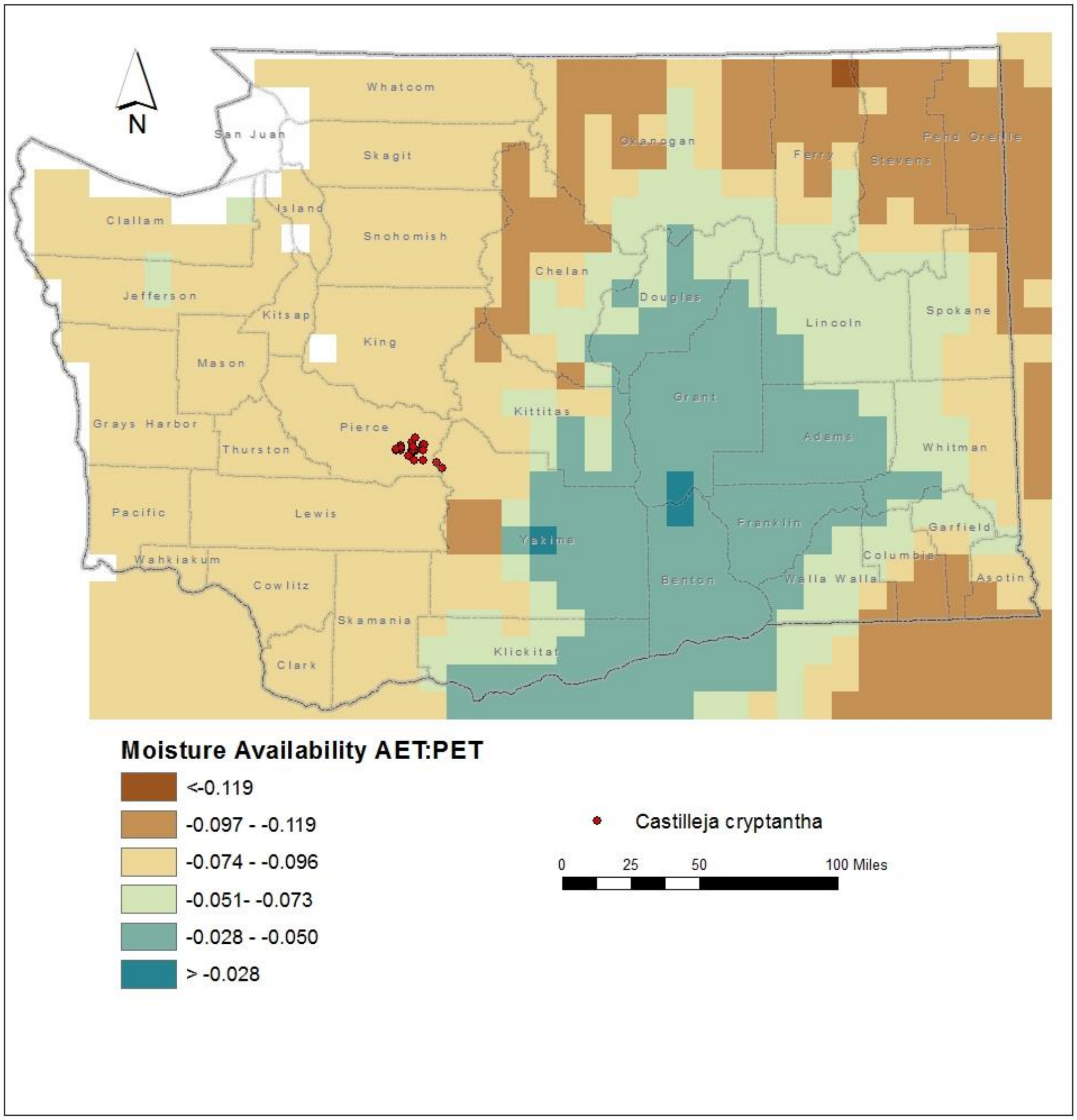

Figure 2. Exposure of *Castilleja cryptantha* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Castilleja cryptantha* are found at 4860-6760 feet (1480-2060 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Castilleja cryptantha occurs in grassy subalpine meadow flats and the edges of small alpine lakes and stream channels with poorly developed soils and dense cover of low shrubs and sedges (Camp and Gamon 2011, Egger et al. 2019). This habitat is part of the Northern Rocky Mountain Subalpine-Upper Montane Grassland ecological system (Rocchio and Crawford 2015). Populations are separated by 0.5-4.6 miles (0.6-7.4 km) of unoccupied valley habitat, which provides a barrier to propagule dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Castilleja cryptantha* in Mount Rainier National Park is partially bisected by paved roads that are mostly located in unoccupied or unsuitable habitat. Most of the habitat of this species is not impacted directly by human infrastructure.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Castilleja cryptantha produces numerous, small seeds within a dry capsule fruit that splits open at maturity. Seeds are passively dispersed by gravity, high winds, or secondarily by foraging animals. The seeds lack hooks, barbs, wings, or feathery structures to aid with dispersal. Average dispersal distances are probably short (less than 100 m).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Castilleja cryptantha* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Nineteen of the 22 known occurrences in the state (86.4%) are found in areas that have experienced small (37-47˚F/20.8-26.3˚C) temperature variation during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016). Two occurrences on the east side of the Cascades crest are from areas with slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the same period and are considered at somewhat increased vulnerability. One population on the slopes of Mount Rainier is from an area with very small temperature variation (<37˚F/20.8˚C) over the last 50 years and is considered at greatly increased risk from climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Greatly Increase.
The subalpine meadow and streamside habitat of *Castilleja cryptantha* is entirely within a cold climate zone during the flowering season and highly vulnerable to temperature increase from climate change.

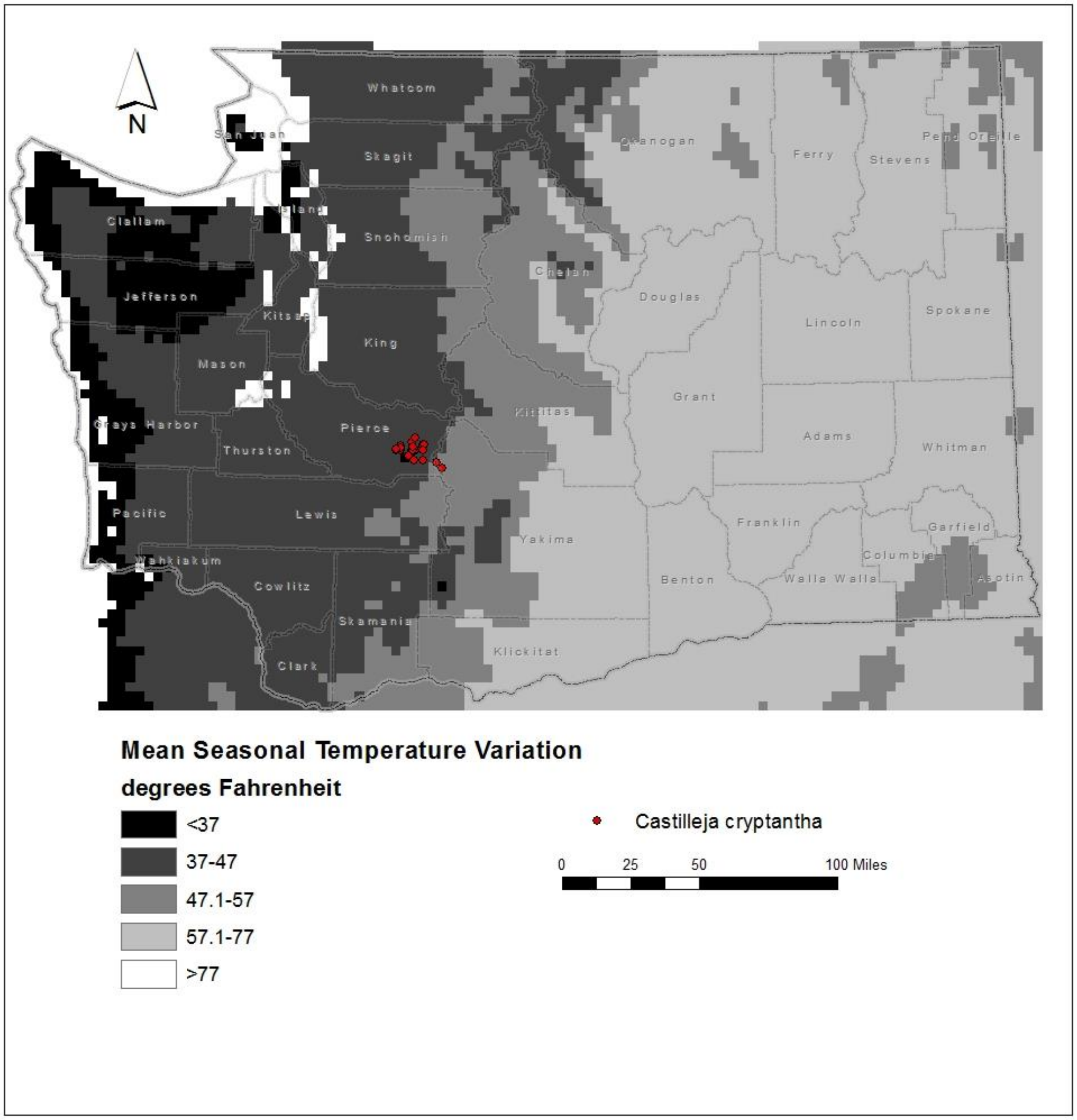

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Castilleja cryptantha* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Castilleja cryptantha* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

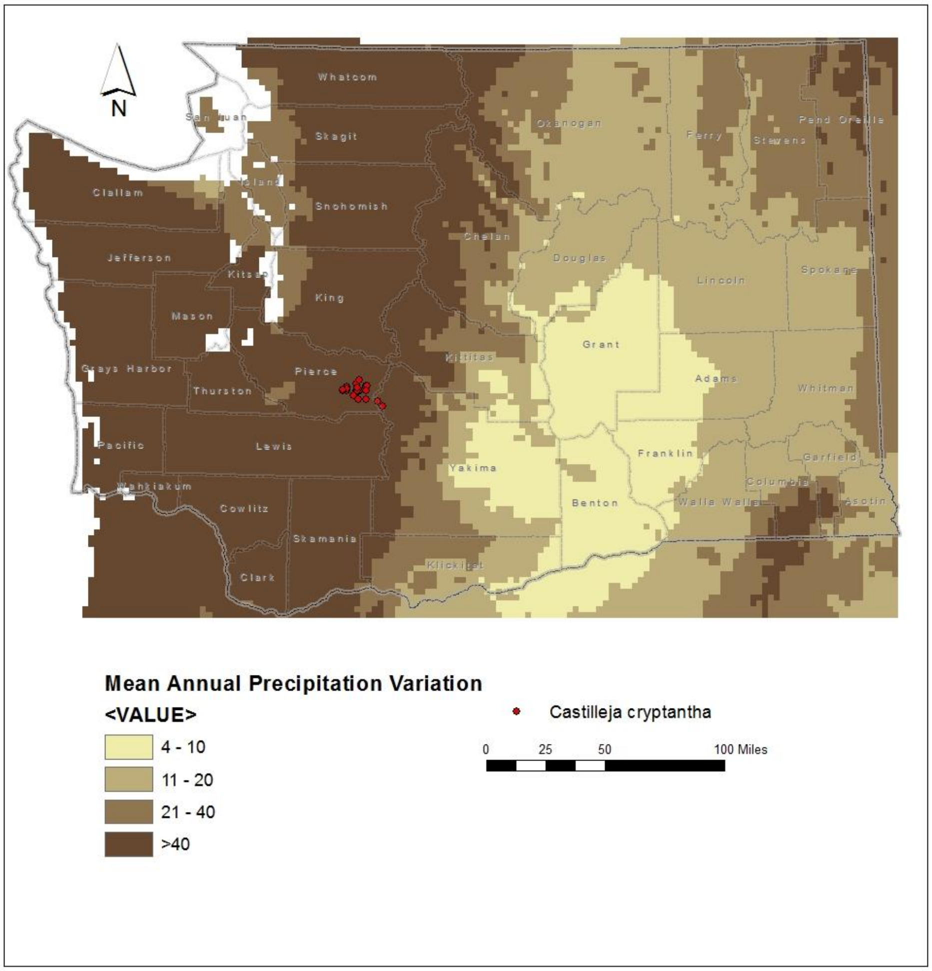

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Castilleja cryptantha* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The subalpine meadow and streamside habitat of *Castilleja cryptantha* is dependent on adequate amounts of winter snow and spring/summer rainfall. 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 conversion to drier grasslands (Rocchio and Ramm-Granberg 2017). Invasion of meadow sites by conifers could be countered by drier conditions or increased vulnerability to wildfire.

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase.
Castilleja cryptantha occurs in subalpine meadow and streamside habitats that are dominated by shrubs and herbaceous plants. These habitats are largely maintained by precipitation and

edaphic factors, more than natural disturbance patterns. Under future climate change scenarios, these sites could become more susceptible to wildfire associated with drought or higher temperatures (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Castilleja cryptantha* in Washington are found in subalpine meadows and 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 (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Castilleja cryptantha is found primarily on pumice and volcaniclastic rocks of the Oligocene Ohanapecosh Formation. Populations also occur on Quaternary age Mount Rainier andesite and Holocene glacial till (Washington Division of Geology and Earth Resources 2016). These outcrops are largely found in the vicinity of Mount Rainier, and may account for the small geographic extent of the species.

C4a. Dependence on other species to generate required habitat: Neutral.
The subalpine meadow and brushy streamside habitat of *Castilleja cryptantha* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Neutral.
Unlike most paintbrush species, *Castilleja cryptantha* is predominantly self-pollinated (Duffield 1972; Egger et al. 2019). Duffield (1972) conducted experiments with caged plants at Mount Rainier and observed high fruit production in *C. cryptantha* when pollinators were excluded. This species has stigmas that barely exceed the anthers and never project beyond the corolla or calyx, as in cross-pollinated *Castilleja* species (Duffield 1972; Egger et al. 2019). Since it is not dependent on other species for pollination, *C. cryptantha* has neutral vulnerability to pollinator loss related to climate change.

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry capsule fruits of *Castilleja cryptantha* split open at maturity to passively release numerous small seeds that spread primarily by gravity or wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Camp and Gamon (2011) suggested this species might be impacted by elk trampling. Threats from pathogens or herbivory have not been reported.

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 high in the subalpine meadow and streamside habitat occupied by *Castilleja cryptantha*. 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).

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

C5a. Measured genetic variation: Unknown.
Egger (2015) reported a chromosome count of $n = 12$ for *Castilleja cryptantha*. Overall genetic diversity is not known, but is probably lower than expected due to its self-pollination breeding system (see section C5c below).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Increase.
Castilleja cryptantha apparently reproduces mostly by self-pollination (Duffield 1972, Egger et al. 2019). As a result, the species is likely to have very low genetic diversity, making it more vulnerable to impacts of rapidly changing climate (Young et al. 2016).

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), the flowering period of *Castilleja cryptantha* now starts in late June, rather than July to late August in older records. Reports of flowering in May are based on misidentified specimens.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Castilleja cryptantha* in Washington since it was first discovered in the state in the 1902.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Duffield, W.J. 1972. Pollination ecology of *Castilleja* in Mount Rainier National Park. Ohio Journal of Science 72(2): 110-114.

Egger, J.M. 2015. New chromosome counts for selected species of North American *Castilleja* (Orobanchaceae). Phytoneuron 2015-32: 1-5.

Egger, J.M., P.F. Zika, B.L. Wilson, R.E. Brainerd, and N. Otting. 2019. *Castilleja*. Pp 565-665. In: Flora of North America Editorial Committee. Flora of North America North of Mexico.

Volume 17. Magnoliophyta: Tetrachondraceae to Orobanchceae. Oxford University Press, New York. 737 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Castilleja cryptantha*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=castilleja%20cryptantha). Accessed 27 September 2021.

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

Chaenactis thompsonii (Thompson's chaenactis)

Date: 2 March 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G3/S3

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	22.2
	-0.074 to - 0.096	61.1
	-0.051 to - 0.073	16.7
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral/Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C: Sensitivity and Adaptive Capacity		
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		Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
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: All 18 of the extant and historical occurrences of *Chaenactis thompsonii* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure

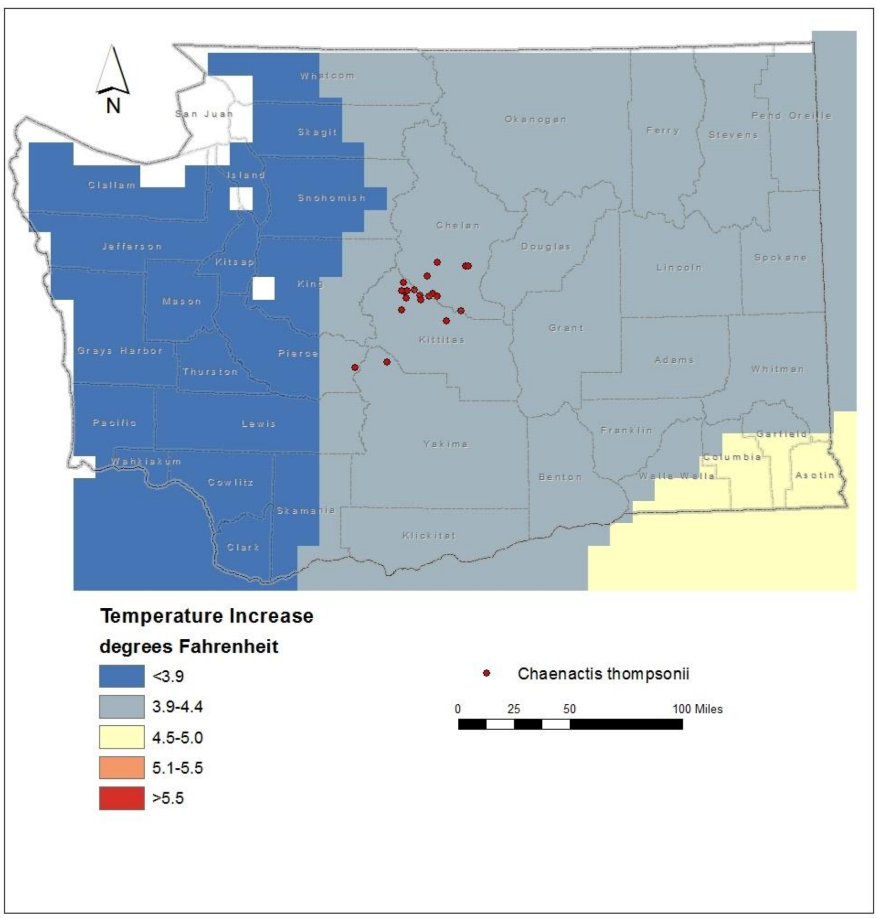

Figure 1. Exposure of *Chaenactis thompsonii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

1). A population reported from Whatcom County (Camp and Gamon 2011) is now known to be misidentified (Fertig and Kleinknecht 2020) and is excluded from this assessment.

A2. Hamon AET:PET Moisture Metric: Eleven of the 18 occurrences (61.1%) of *Chaenactis thompsonii* 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). Three populations (16.7%) are in areas with a projected decrease of -0.051 to -0.073. Four other populations (22.2%) are from areas with a projected decrease of -0.097 to -0.119 (Figure 2).

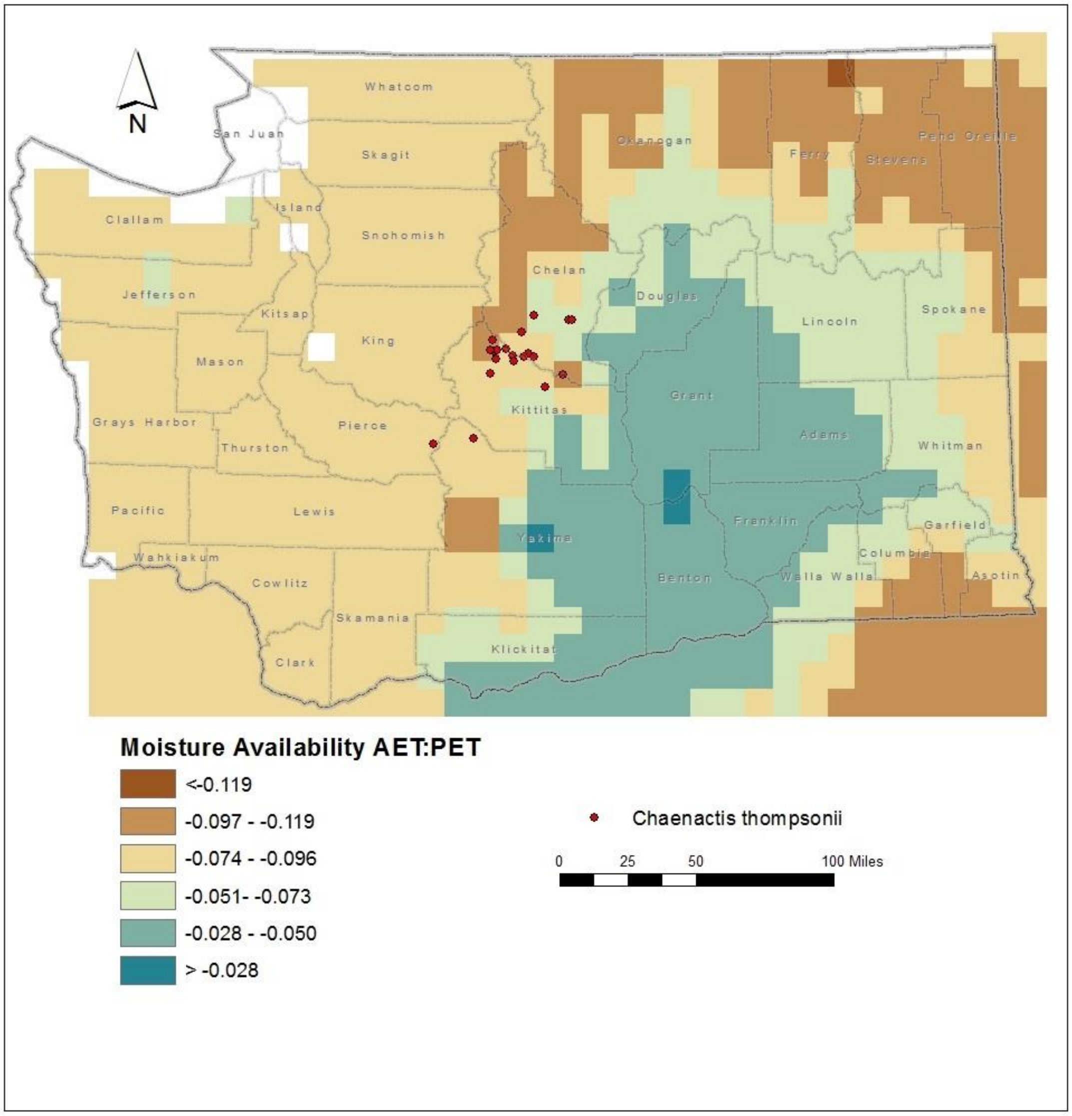

Figure 2. Exposure of *Chaenactis thompsonii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Chaenactis thompsonii* are found at 2900-7000 feet (880-2130 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral/Somewhat Increase.
Chaenactis thompsonii occurs primarily on dry, rocky subalpine to alpine slopes and ridges derived from serpentine bedrock (Camp and Gamon 2011). This habitat is part of the North Pacific Serpentine Barren ecological system (Rocchio and Crawford 2015). Populations are separated from each other by 0.7-24 miles (1.4-39 km) of unoccupied and unsuitable forested habitat. Many of these populations are 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 due to the lack of additional serpentine habitat beyond the Wenatchee Range.

B2b. Anthropogenic barriers: Neutral.
The subalpine and alpine habitat of *Chaenactis thompsonii* in Washington is located entirely on National Forest lands in the Wenatchee Range and vicinity. Although there are some roads and trails within this range, dispersal is probably not limited due to anthropogenic impacts.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Chaenactis thompsonii produces numerous, dry achenes topped by 10-16 transparent scales that may assist with dispersal by the wind. Dispersal distances may vary, but the species has the potential for dispersal of 100-1000 m from the parent plant.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Chaenactis thompsonii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seventeen of the 18 known occurrences in the state (94.4%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016). One other occurrence (5.6%) is from an area with small variation (37-47˚F/20.8-26.3˚C) in temperature over the same period and is at increased vulnerability to climate change. The identity of this occurrence (from Pierce County) has not been confirmed.

C2aii. Physiological thermal niche: Increase.
The alpine to subalpine serpentine talus habitat of *Chaenactis thompsonii* is primarily within a cold climate zone during the flowering season and highly vulnerable to temperature increase from climate change.

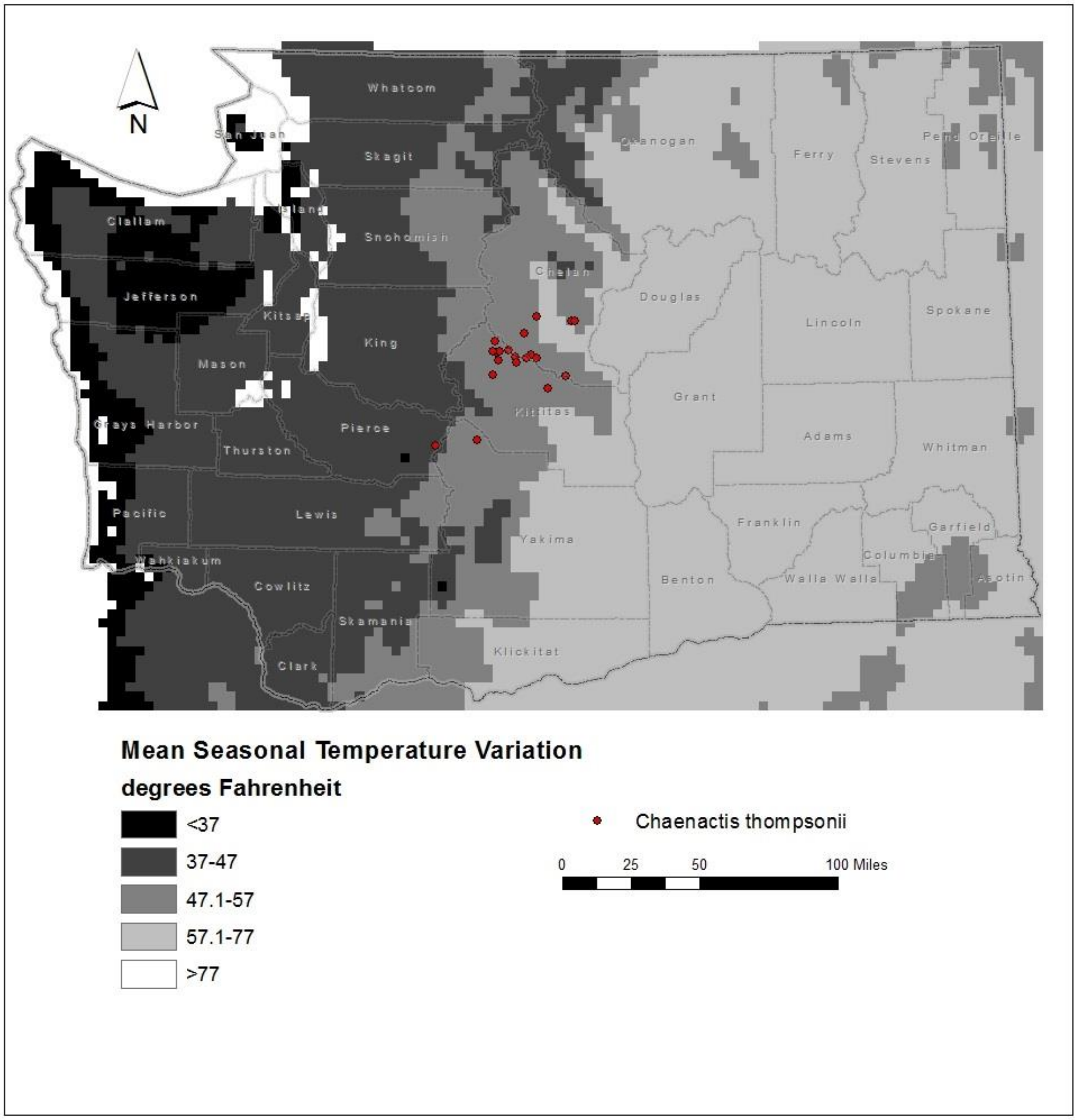

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Chaenactis thompsonii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
Sixteen of the 18 populations of *Chaenactis thompsonii* in Washington (88.9%) are found in areas that have experienced average precipitation variation in the past 50 years (20-40 inches/508-1016 mm) (Figure 4). Two other occurrences (11.1%) are from areas with greater than average precipitation variation (> 40 inches/1016 mm). According to Young et al. (2016), all of these occurrences are neutral for climate change.

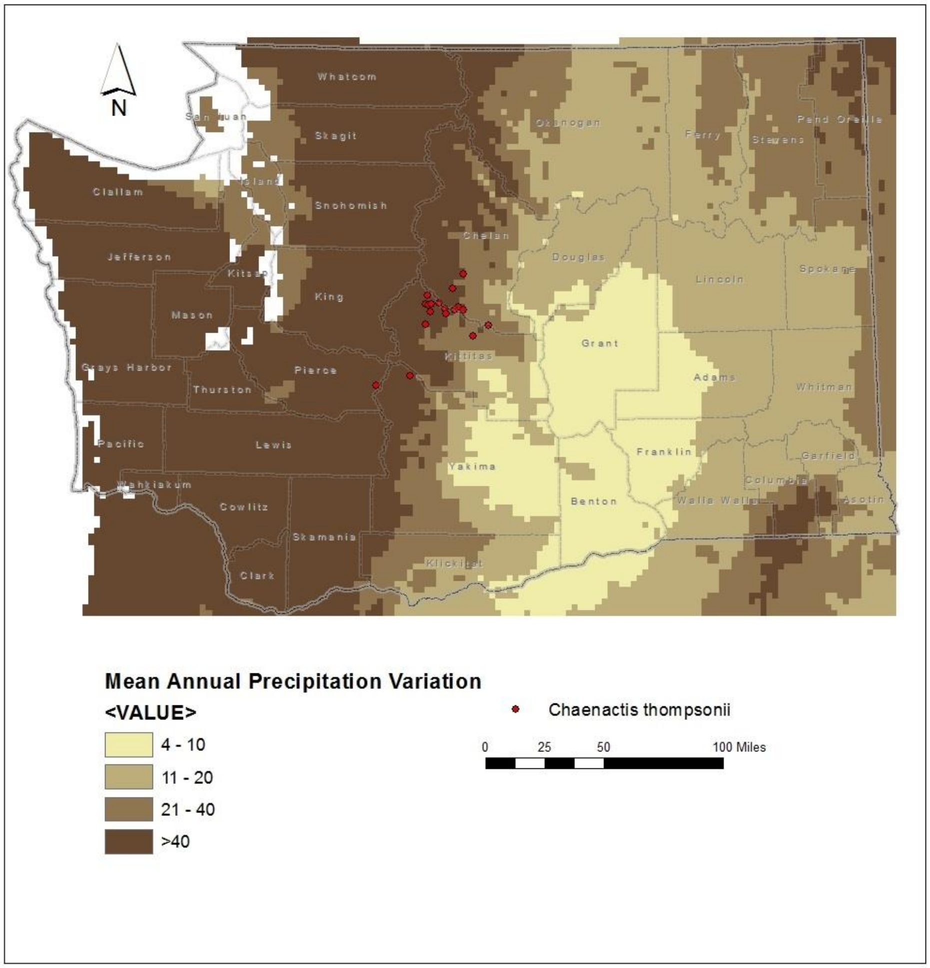

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Chaenactis thompsonii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is found in upland areas without perennial streams or a high water table. It is dependent on winter snowfall and summer precipitation for its moisture needs and so is potentially vulnerable to changes in the timing and amount of snow and rain.

C2c. Dependence on a specific disturbance regime: Neutral.
Chaenactis thompsonii occurs on rocky, barren slopes of serpentine soils in alpine and subalpine sites that may be prone to higher winds than adjacent forested areas. Other than occasional rock fall, these are largely undisturbed sites. Wildfire is uncommon within this habitat due to lack of vegetative cover and fuel, although fire has recently occurred in nearby forested areas.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Populations of *Chaenactis thompsonii* are found on subalpine and alpine ridgecrests and talus slopes associated with winter snow accumulation, though the areas may be free of snow due to evaporation or wind during the growing season. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Chaenactis thompsonii is restricted to serpentine outcrops in the Wenatchee Mountains and vicinity (Washington Division of Geology and Earth Resources 2016). Serpentine is a metamorphic formation derived from igneous peridotite and diorite and weathers to soils high in magnesium, nickel, and chromium but low in calcium, nitrogen, and phosphorus (Kruckeberg 1969). These soils support a suite of uncommon and localized endemic species that are often poor competitors or absent from adjacent sites.

C4a. Dependence on other species to generate required habitat: Neutral.
The subalpine and alpine serpentine rocky slope habitat occupied by *Chaenactis thompsonii* is maintained primarily by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The precise pollinators of *Chaenactis thompsonii*, are not known. Its close relative, *C. douglasii,* is pollinated by common, generalist bee species (Cane et al. 2012).

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits of *Chaenactis thompsonii* have a scale-like pappus that likely facilitates dispersal by wind. Fruits might be secondarily transported and cached short distances by insects or rodents.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
This species is not known to be impacted by pathogens or herbivory (Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Neutral.
At present, competition from non-native species is minimal due to the harsh growing conditions of its serpentine habitat. 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.
Does not require an interspecific interaction.

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Chaenactis thompsonii*. The related species, *C. douglasii*, which occurs widely across western North America, may be a diploid, tetraploid, or hexaploid. A diploid variant formerly recognized as *C. ramosa* occurs in the Wenatchee Range and has been considered intermediate between *C. thompsonii* and *C. douglasii* (Cronquist 1955). *Chaenactis ramosa* is now treated as a synonym of *C. douglasii* var. *douglasii* (Morefield 2006).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Chaenactis thompsonii, like other *Chaenactis* species, appears to be an obligate outcrosser without specialized pollinators. Though dispersal may be limited due to habitat suitability, it is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), the phenology of *Chaenactis thompsonii* has not changed significantly in the past 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Chaenactis thompsonii* in Washington in the last 50 years.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Cane, J.H., B. Love, and K. Swoboda. 2012. Breeding biology and bee guild of Douglas' dustymaiden, *Chaenactis douglasii* (Asteraceae, Helenieae). Western North American Naturalist 72(4): 563-568.

Cronquist, A. 1955. Part 5: Compositae. In: C.L. Hitchcock, A. Cronquist, M. Ownbey, and J.W. Thompson. Vascular Plants of the Pacific Northwest. University of Washington Press, Seattle. 343 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program. Washington Department of Natural Resources, Olympia, WA. 173 pp.

Kruckeberg, A.R. 1969. Soil diversity and the distribution of plants, with examples from western North America. Madroño 20(3): 129-154.

Morefield, J.D. 2006. *Chaenactis*. Pp. 400-414. Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 20+ vols. New York and Oxford. Vol. 21: Magnoliophyta: Asteridae, part 8: Asteraceae, part 3. 616 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Cicuta bulbifera (Bulb-bearing water-hemlock)

Date: January 28, 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5/S2S3

Index Result: Moderately Vulnerable. | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	82.6
	<3.9° F (2.2°C) warmer	17.4
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	73.9
	-0.074 to - 0.096	26.1
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral/Somewhat Increase
2ai Change in historical thermal niche		Neutral
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		Neutral/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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: Documented or Modeled Response	
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: Nineteen of the 23 known occurrences of *Cicuta bulbifera* in Washington (82.6%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). Another four populations (17.4%) are from areas with a projected increase <3.9° F.

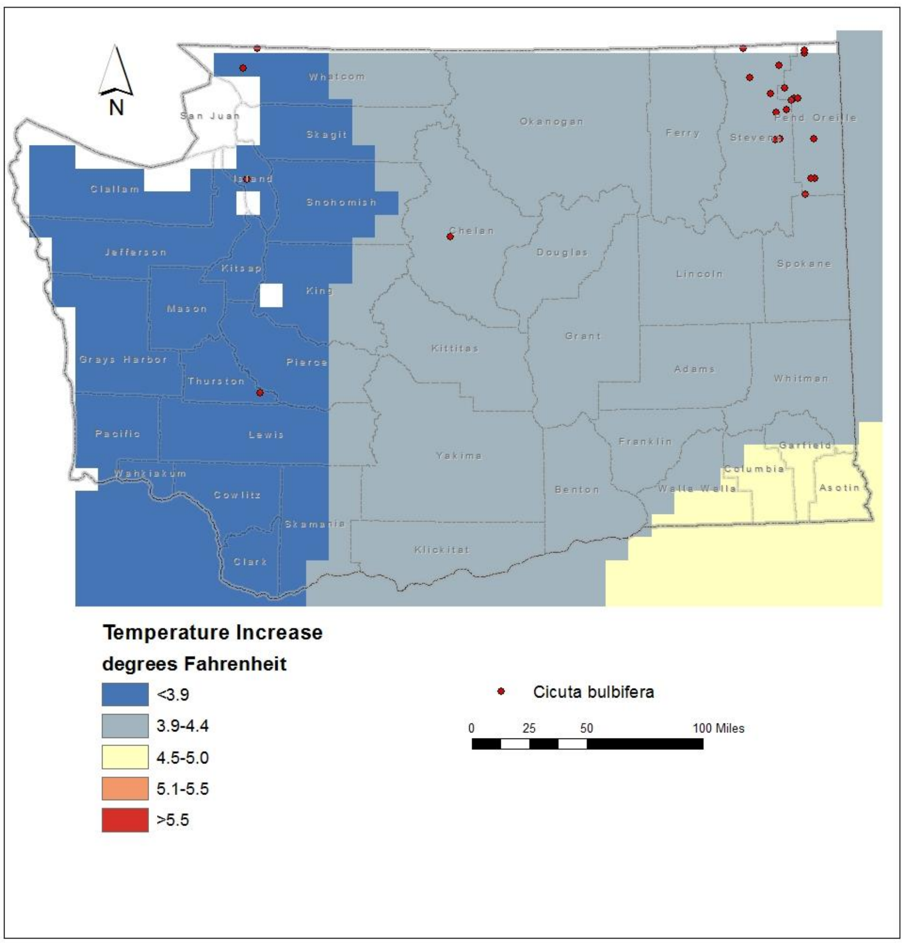

Figure 1. Exposure of *Cicuta bulbifera* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Seventeen of the 23 occurrences of *Cicuta bulbifera* (73.9%) 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 six occurrences (26.1) are in the range of -0.074 to -0.096.

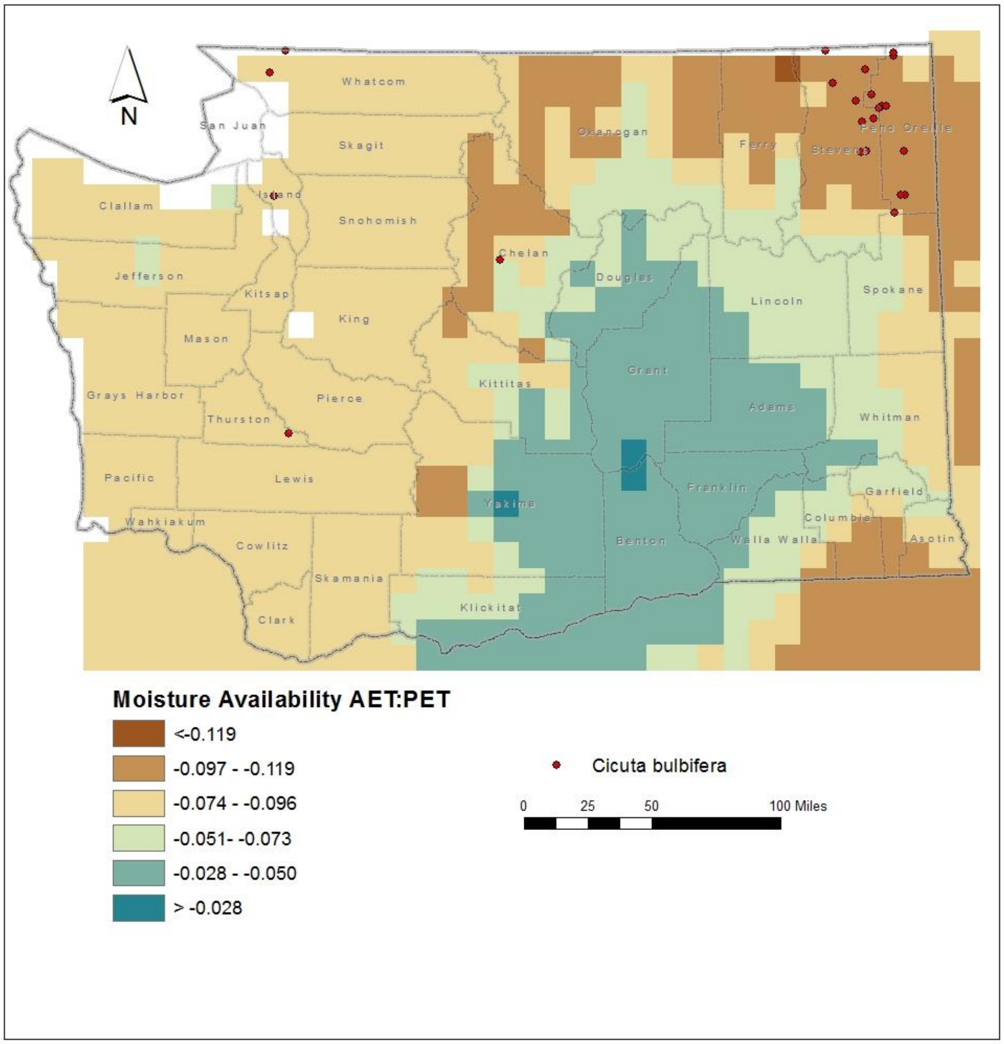

Figure 2. Exposure of *Cicuta bulbifera* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Cicuta bulbifera* are found at 20-3700 feet (6-1130 m). All of the populations (except one historical occurrence on Whidbey Island) are located well above the areas likely to be inundated by rising sea levels or impacted by increased storm surges.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Cicuta bulbifera* is found on mud, saturated mucky silt, or occasionally peat-rich soils along the margins of lakes and ponds (rarely streams) in openings surrounded by dense wetland shrub thickets or swampy coniferous forests. (Camp and Gamon 2011). Some populations are also found on floating mats of densely compacted vegetation and soil at the edge of dense *Phalaris arundinacea* and *Typha* stands (Fertig 2018). These habitats are components of the North American Arid West Emergent Marsh, North Pacific Bog and Fen, and Rocky Mountain Subalpine-Montane Fen ecological systems (Rocchio and Crawford 2015). Washington occurrences are separated by distances of 1.4-145 miles (2-235 km). Most populations are isolated by barriers of unsuitable matrix forest vegetation that are likely to impede dispersal or migration.

B2b. Anthropogenic barriers: Neutral.
The range of *Cicuta bulbifera* in Washington is primarily influenced by its dependence on widely scattered areas of specialized habitat that are naturally isolated. While the human imprint is significant in much of this area, anthropogenic factors are less likely to constrain dispersal than natural ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral/Somewhat Increase.
Cicuta bulbifera produces small, compound umbels of white flowers which rarely mature into fruits. If present, the fruit is a schizocarp that splits into two 1-seeded segments (Lee and Downie 2006). Reproduction occurs primarily by seed-like asexual bulbils (or bulblets) produced in the axils of upper stem leaves. Fruits and bulbils are dispersed passively by water, wind, or mud encrusted on aquatic birds or mammals. Limited dispersal may also be possible from ingestion and defecation by raccoons (Hewitt and Miyanishi 1997). Average dispersal distances are probably short (<1000 meters), although longer transport would be possible by birds.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Cicuta bulbifera* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eighteen of the 23 known occurrences (78.3%) from Chelan, Stevens, and Pend Oreille counties are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). One occurrence from northern Stevens County near the Canadian border has experienced slightly lower than average temperature variation (47.1-57˚F/26.3-31.8˚C) during the same

period and is at somewhat increased vulnerability from climate change. Three populations from the Puget Trough have had small temperature variation (37-47˚F/20.8-26.3˚C) in the past 50 years and are at increased vulnerability. One historical population from Whidbey Island has experienced very small (<37˚F/20.8˚C) temperature variation and is at greatly increased vulnerability from climate change (Young et al. 2016).

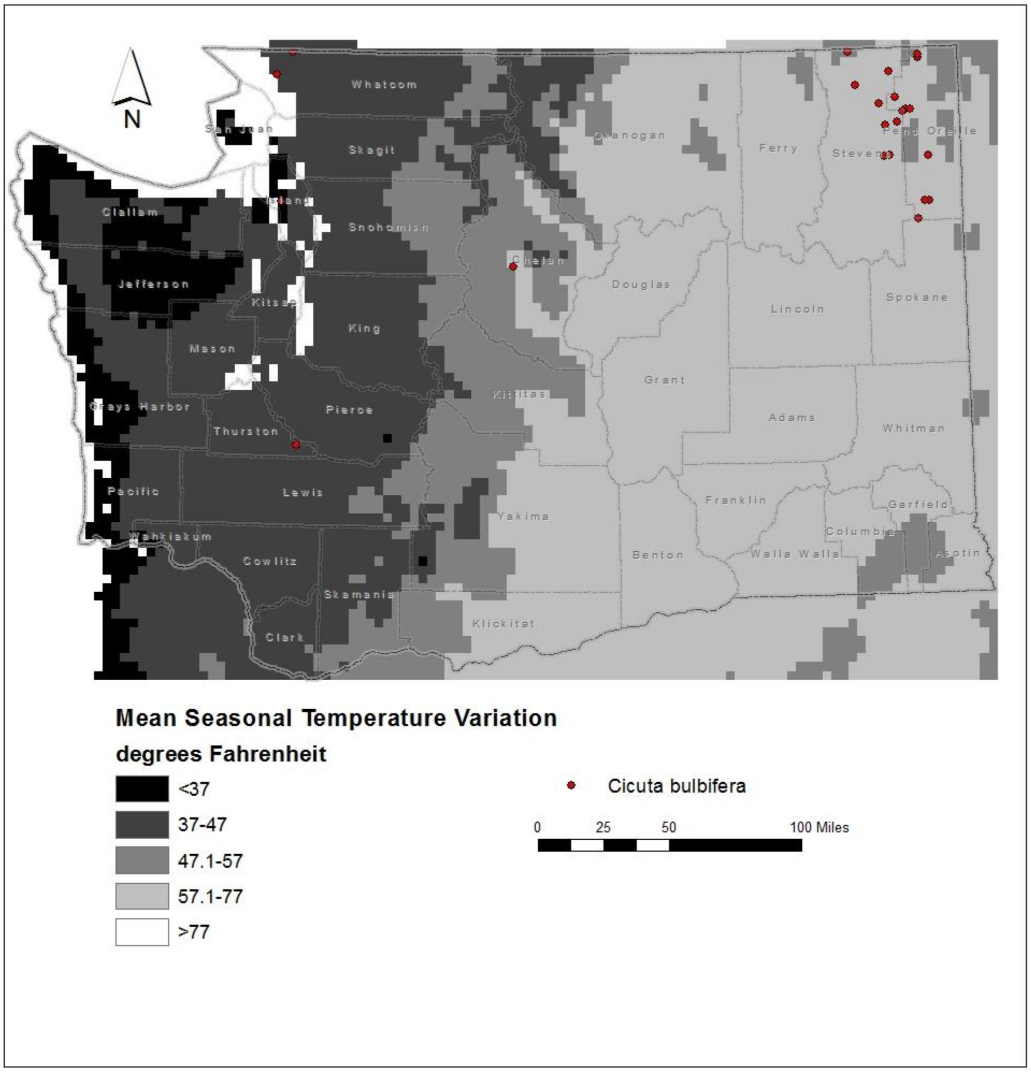

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cicuta bulbifera* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
Populations of *Cicuta bulbifera* from Washington are typically found along ponds or lakes in valleys that are cooler microsites than the surrounding matrix vegetation. Such areas would be at increased vulnerability from climate change.

C2bi. Historical hydrological niche: Neutral.
All 23 of the known occurrences of *Cicuta bulbifera* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 mm) of precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these areas are at neutral vulnerability to climate change.

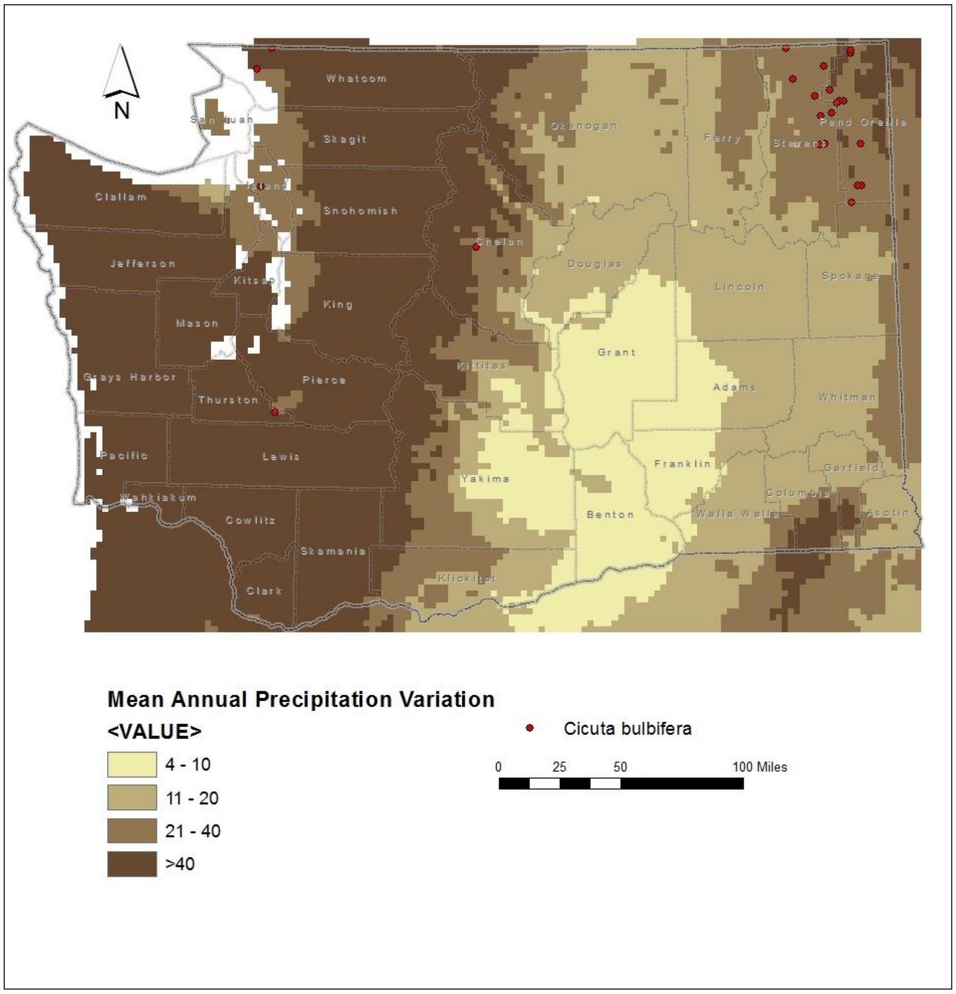

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cicuta bulbifera* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Most populations of *Cicuta bulbifera* in Washington are associated with muddy shores of small ponds and lakes with marsh vegetation. Sites in the North American Arid West Emergent Marsh ecological system are vulnerable to increased temperatures, decreased precipitation,

increased drought, and increased flooding that is predicted to occur due to climate change (Rocchio and Ramm-Granberg 2017). These habitats could be at risk of being converted to wet meadows. Populations associated with peatlands in the North Pacific Bog and Fen/Rocky Mountain Subalpine-Montane Fen ecological systems are more dependent on groundwater than precipitation for adequate moisture and so could be adversely affected by decreased snowpack and drops in the water table due to climate change. These sites might be at risk of being converted to forested wetlands due to tree encroachment, or have changes in water chemistry (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
This species is not dependent on disturbance to maintain its wetland habitat

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Snowpack is moderate over much of the range of *Cicuta bulbifera* in the mountains of northeastern Washington and east slopes of the Cascades. Reduced snowfall would negatively impact fen populations that are dependent on groundwater recharged by melting snow. Populations in the Puget Trough area experience low levels of snow but high amounts of winter rain.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Washington, *Cicuta bulbifera* is found mostly in ponds and small lakes associated with Fraser-age (Pleistocene) glacial drift material or Holocene lacustrine deposits (Washington Division of Geology and Earth Resources 2016). These geological substrates are scattered but widespread in the Puget Trough of western Washington and the northeastern corner of the state.

C4a. Dependence on other species to generate required habitat: Neutral.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
The specific pollinators of *Cicuta bulbifera* are not known, but in general members of the Apiaceae have unspecialized flowers pollinated by a wide variety of insects. Other *Cicuta* species are reported to be pollinated by bees and flies (Mulligan and Munro 1981). Reproduction in *C. bulbifera* is predominantly by asexual bulbils, and so the species is not dependent on animal pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits are rarely produced in *Cicuta bulbifera* due to an absence of flowers or their early abortion, which may be due to infertility from past hybridization. If present, the fruits split into two 1-seeded dry mericarps at maturity. The fruits lack barbs, bristles, wings, or other structures to aid in dispersal. Movement can occur by passive means from flowing water, or on mud attached to animals. Asexual bulbils (bulblets) are the primary reproductive/dispersal units and are fruit-like in appearance, but also lack ornamentation to facilitate transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Members of the genus *Cicuta* are the most poisonous group of vascular plants in North America. Of the 3-4 recognized species, *C. bulbifera* is the least virulent, but can still be toxic to livestock and other herbivores (Lee and Downie 2006). There is a report of *C. bulbifera* sprouting from

raccoon scat, suggesting that herbivory can occur and ingestion might be a means of limited dispersal (Hewitt and Miyanishi 1997).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Several *Cicuta bulbifera* populations in western Washington are threatened by competition from invasive wetland weeds, such as reed canarygrass (*Phalaris arundinacea*) and purple loosestrife (*Lythrum salicaria*) (Fertig 2018). 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).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Cicuta bulbifera* in Washington. This species is a diploid and has chromosomes intermediate in size between *C. maculata* and *C. virosa*, leading some researchers to suggest it may be of ancient hybrid origin and persisting (and spreading) primarily by asexual bulbils (Lee and Downie 2006, McNeil 2020).

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Somewhat Increase
Cicuta bulbifera is presumed to be an outcrosser, rather than self-pollinated. If the species is of hybrid origin and reproduces primarily by asexual bulbils, it would be expected to have lower than average overall genetic variability due to a reduction in outcrossing from sexual reproduction (Lee and Downie 2006).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no significant changes in the phenology of *Cicuta bulbifera* populations in Washington have been detected over the past 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Twenty-two of the 23 occurrences in Washington are extant. Trend data are available for 13 occurrences, most of which have stable to slightly increasing numbers (Fertig 2018).

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. 2018. Rare plant survey of the Lake Terrell Wildlife Area. Natural Heritage Report 2018-08. Washington Natural Heritage Program, Washington Department of Natural Resources, Olympia, WA. 15 pp.

Hewitt, N. and K. Miyanishi. 1997. The role of mammals in maintaining plant species richness in a floating Typha marsh in southern Ontario. Biodiversity and Conservation 6: 1085-1102.

Lee, C-S. and S.R. Downie. 2006. Phylogenetic relationships within *Cicuta* (Apiaceae tribe Oenantheae) inferred from nuclear rDNA ITS and cpDNA sequence data. Canadian Journal Botany 84:453-468.

McNeil, R.P. 2020. *Cicuta*. pp. 93-95. In: Flora of Oregon Volume 2: Dicots A-F. Meyers, S.C., T. Jaster, K.E. Mitchell, T. Harvey, and L.K. Hardison, eds. Botanical Research Institute of Texas Press, Fort Worth, TX. 861 pp.

Mulligan, G.A. and D.B. Munro. 1981. The biology of Canadian weeds. 48. *Cicuta maculata* L., *C. douglasii* (DC.) Coult. & Rose and *C. virosa* L. Canadian Journal Plant Science 61:93-105.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Coptis aspleniifolia (Spleenwort-leaved goldthread)

Date: 29 October 2021

Assessor: Walter Fertig, 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: Local Climate	**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	14.3
	<3.9° F (2.2°C) warmer	85.7
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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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/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: Documented or Modeled Response	
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: Six of the 7 occurrences of *Coptis aspleniifolia* in Washington (85.7%) occur in areas with a projected temperature increase of < 3.9˚ F (Figure 1). One other population (14.3%) is from an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

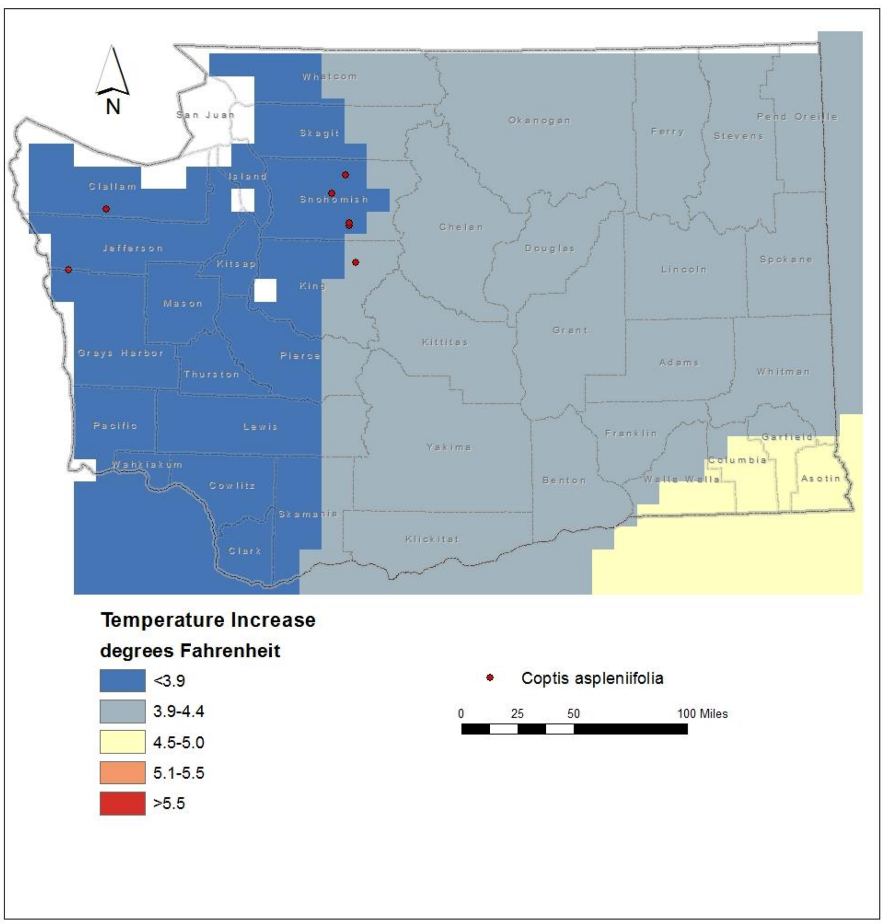

Figure 1. Exposure of *Coptis aspleniifolia* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 7 occurrences (100%) of *Coptis aspleniifolia* 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).

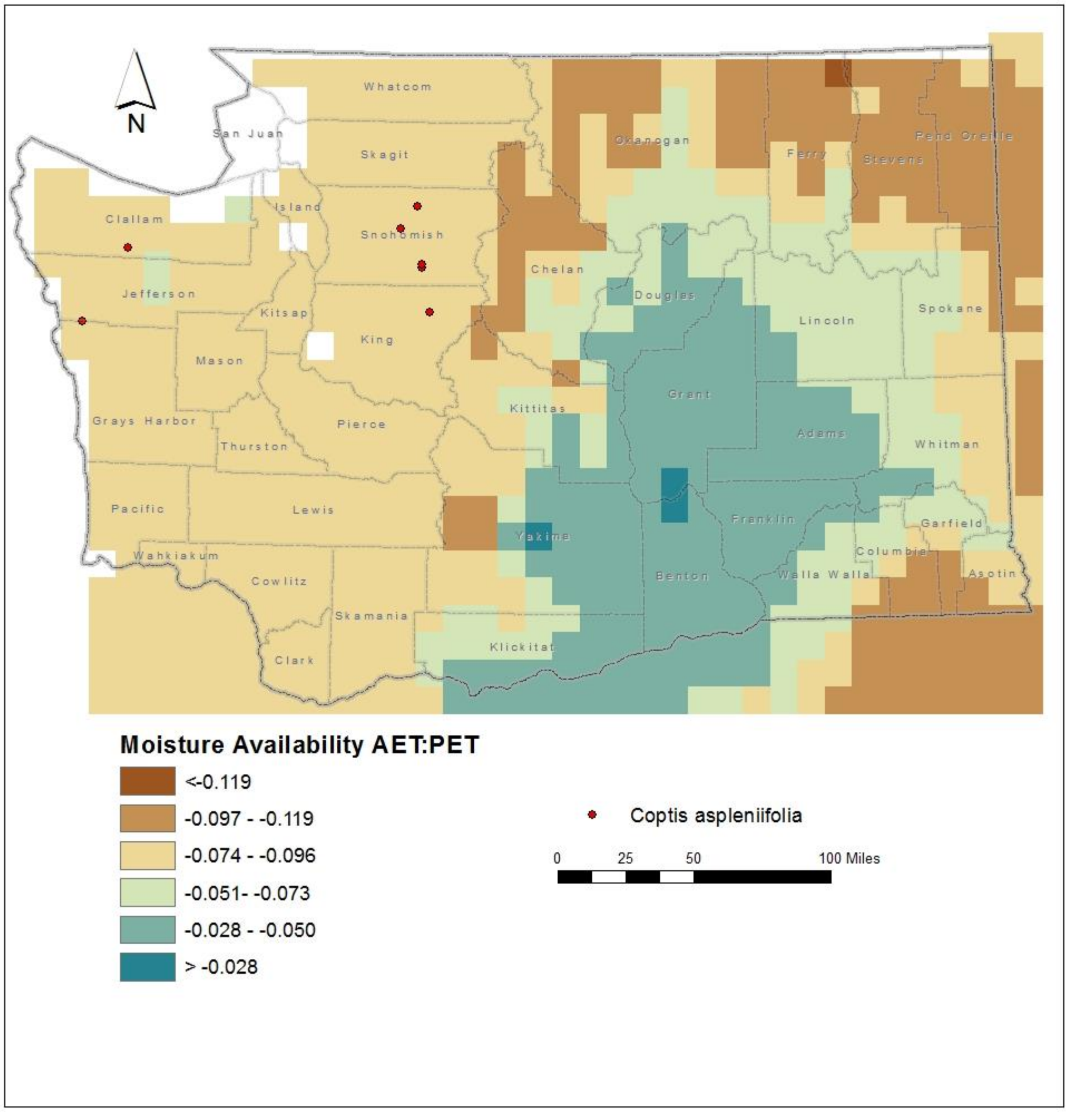

Figure 2. Exposure of *Coptis aspleniifolia* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Coptis aspleniifolia* are found at 100-3040 feet (30-930 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Coptis aspleniifolia* occurs primarily in moist depressions, streambanks, or shady lower slopes in old growth forested wetlands of western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) or silver fir (*Abies amabilis*) (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the North Pacific Lowland Riparian Forest & Shrubland and North Pacific Mesic Western Hemlock-Silver Fir Forest ecological systems (Rocchio and Crawford 2015). Populations within the North Cascades and Olympic Mountains are isolated by 1.7-30 miles (50 km) of potential (though patchy) habitat. These two main population centers are separated from each other by 100 miles (161 km) of mostly unsuitable habitat, which includes the Puget Sound, Puget Trough, and the Seattle-Tacoma metropolitan area. Dispersal between the two mountain ranges is probably minimal due to a lack of potential habitat.

B2b. Anthropogenic barriers: Neutral.
The montane forest wetland habitat of *Coptis aspleniifolia* in Washington is restricted to the western Olympic Range and Northern Cascades. Intervening sites include extensive areas of human development in the greater Seattle-Tacoma metropolitan area and second growth forested lands in montane foothills and valleys. These anthropogenic barriers are similar to those already in place due to a lack of intervening natural habitat.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Coptis aspleniifolia produces 6-10 dry fruits (follicles) per flower head that split open along the upper side at maturity to expose 5-10 seeds. The fruit acts as a “splash cup” in which the impact of raindrops landing on the fruit causes seeds to bounce short distances (up to 1 m) (Pojar 1974, Willson and Anderson 2007). Secondary dispersal by foraging insects or rodents may transport seeds further, though likely less than 100 m.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Coptis aspleniifolia* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”). Four of the 7 known occurrences in the state (57.1%) are found in areas that have experienced small (37-47˚F/20.8-26.3˚C) temperature variation during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016). Two occurrences (28.6%) are from areas that have had very small variation in temperature (<37˚F/20.8˚C) over the same period and are at greatly increased vulnerability to climate change. One other occurrence (14.3%) is from an area with slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation and is at somewhat increased vulnerability to climate change.

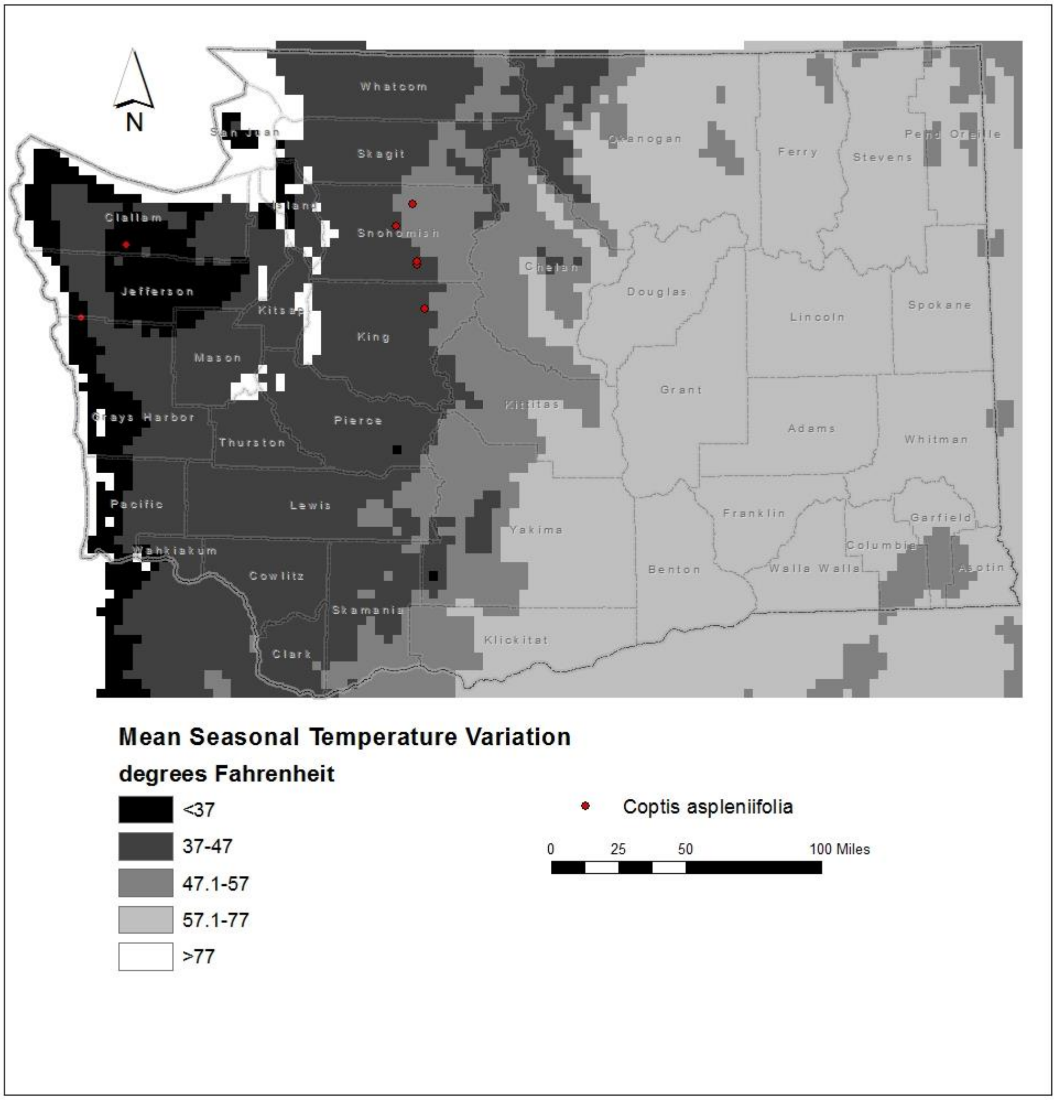

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Coptis aspleniifolia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Populations of *Coptis aspleniifolia* in Washington are found mostly along streambanks or lower slopes of forested areas that have cold air drainage during the growing season and could be adversely impacted by warming temperatures.

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Coptis aspleniifolia* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016

mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

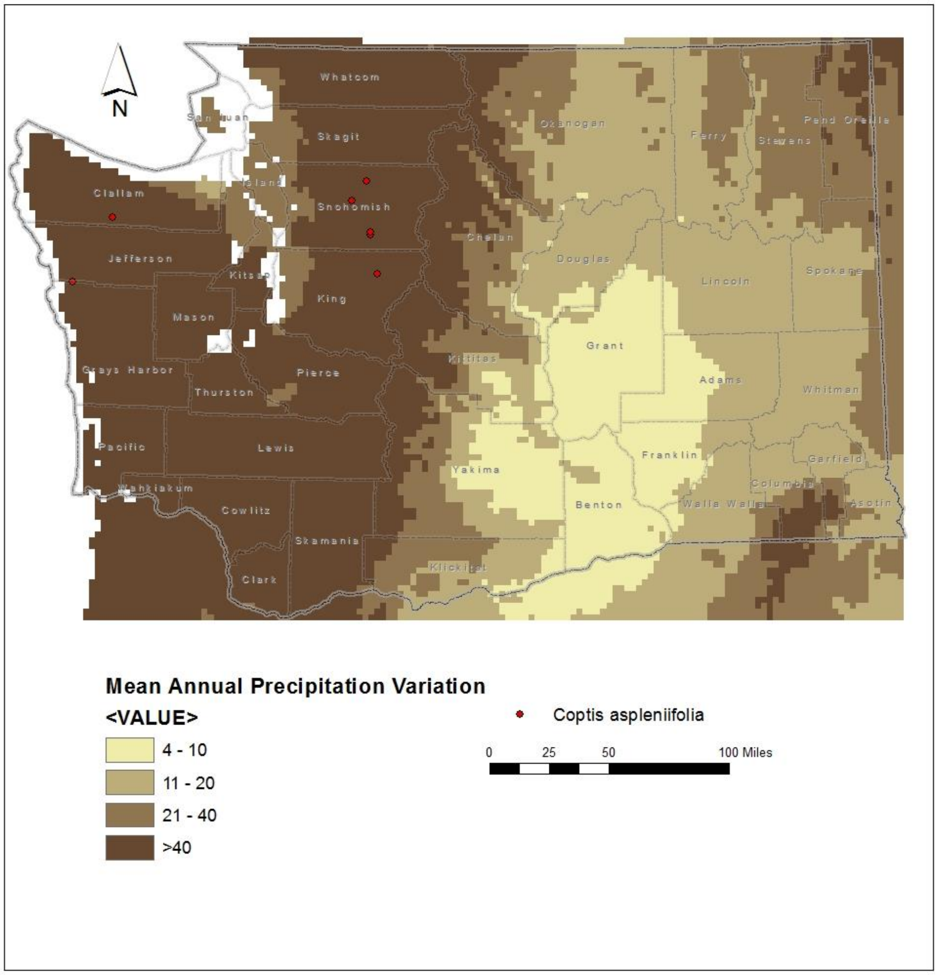

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Coptis aspleniifolia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is found in habitats with a high water table or associated with perennial water sources. Under project climate change, North Pacific Lowland Riparian Forest and Shrubland sites are likely to experience more drought or lower base flows during the summer due to changes in the amount or timing of precipitation. Streamside 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: Neutral.
Some *Coptis aspleniifolia* occurrences in the North Cascades are found in old avalanche chutes or areas where wind throw has created small light gaps. Otherwise, the species does not depend on disturbance events to maintain its swampy forest habitat (Fuentes 2004). Future climate change that would increase drought, lower water tables, and make forest areas more prone to wildfire would be detrimental to these habitats (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Populations of *Coptis aspleniifolia* occur in mountain foothill areas that receive moderate amounts of snow or high levels of winter rainfall. Streamside habitats could be negatively impacted by reduction in the amount of snow at higher elevations or changes in the timing of snowmelt (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
In the Olympic Peninsula, *Coptis aspleniifolia* is found on outcrops of the Western Olympics lithic assemblage (Oligocene-Eocene marine sedimentary rocks) or glacial outwash and alluvium. Populations from the North Cascades are associated with Cretaceous-Jurassic age marine metasedimentary rocks and granodiorite batholiths (Washington Division of Geology and Earth Resources 2016). These are relatively widespread geologic substrates in the mountains of western Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The montane and foothill swamp forest habitat occupied by *Coptis aspleniifolia* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Based on studies in Alaska, *Coptis aspleniifolia* is visited by a variety of potential pollinators, including at least 8 families of small flies (Diptera) bees (Hymenoptera) and beetles (Coleoptera) (Willson and Anderson 2007).

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds are dispersed primarily through passive means, facilitated by heavy rainfall (Pojar 1974; Willson and Anderson 2007).

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Coptis aspleniifolia is browsed by deer (Fuentes 2004) and herbivory is a potential threat to its persistence in Washington (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Coptis aspleniifolia is often found in areas with thick cover of mosses. Competition from other vascular plant species is usually low. Changes in the amount of precipitation or streamflow under projected climate change could reduce the area of swampy forest sites and make them drier and prone to invasion by species adapted to less saturated soils (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No data are available on the genetic diversity of *Coptis aspleniifolia* populations in Washington. Being at the southern edge of its range, Washington populations are likely to have lower overall genetic variation due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Coptis aspleniifolia produces three types of flowers (all staminate, protandrous with stamens maturing before pistils, and protogynous with pistils maturing before stamens) to promote outcrossing (Willson and Anderson 2007). This reproductive system is usually associated with average levels of genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Coptis aspleniifolia* has not changed its typical blooming time.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Coptis aspleniifolia* in Washington since it was first recorded in the state in 1965 (earlier reports are based on misidentified specimens).

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fuentes, T.L. 2004. Conservation Assessment for *Coptis aspleniifolia* Salisb. USDA Bureau of Land Management, Oregon and Washington. (https://www.blm.gov/or/plans/surveyandmanage/files/ca-va-coptis-asplenifolia-2005-03-07.pdf).

Pojar, J. 1974. Reproductive dynamics of four plant communities of southwestern British Columbia. Canadian Journal of Botany 52(8): 1819-1834.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021. *Coptis aspleniifolia*. In: Online Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=coptis%20aspleniifolia). Accessed 29 October 2021.

Willson, M.F. and E.M. Anderson. 2007. Natural history of fern-leaf goldthread (*Coptis aspleniifolia*) in Juneau, Alaska. Northwest Science 81(2): 163-165.

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

Cryptantha rostellata (Beaked cryptantha)

Date: 12 March 2021

Assessor: Walter Fertig, 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: Local Climate	**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	29.4
	3.9-4.4° F (2.2-2.4°C) warmer	70.6
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	5.9
	-0.074 to -0.096	11.8
	-0.051 to -0.073	17.6
	-0.028 to -0.050	64.7
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Neutral
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
4a. Dependence on others 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		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: Documented or Modeled Response	
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: Twelve of the 17 extant and historical occurrences of *Cryptantha rostellata* in Washington (70.6%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure

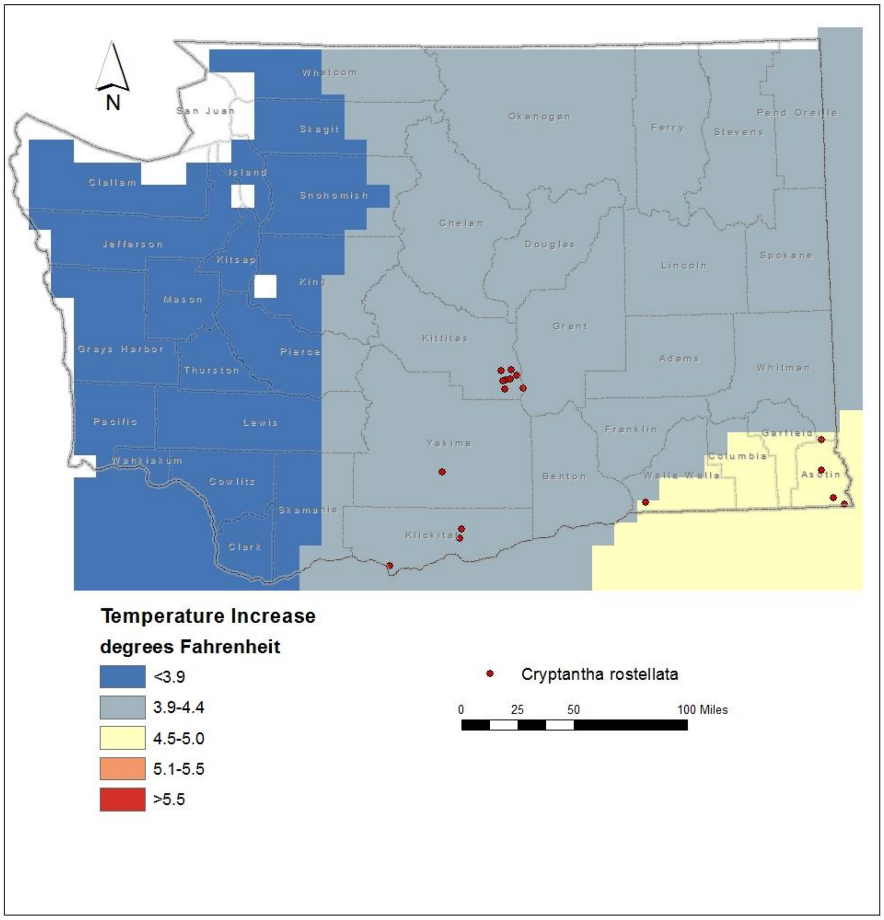

Figure 1. Exposure of *Cryptantha rostellata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

1). The remaining five occurrences (29.4%) are from areas with a projected temperature increase of 4.5-5° F.

A2. Hamon AET:PET Moisture Metric: Eleven of the 17 occurrences (64.7%) of *Cryptantha rostellata* in Washington (all from the Columbia Plateau) 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). Three populations (17.6%) are

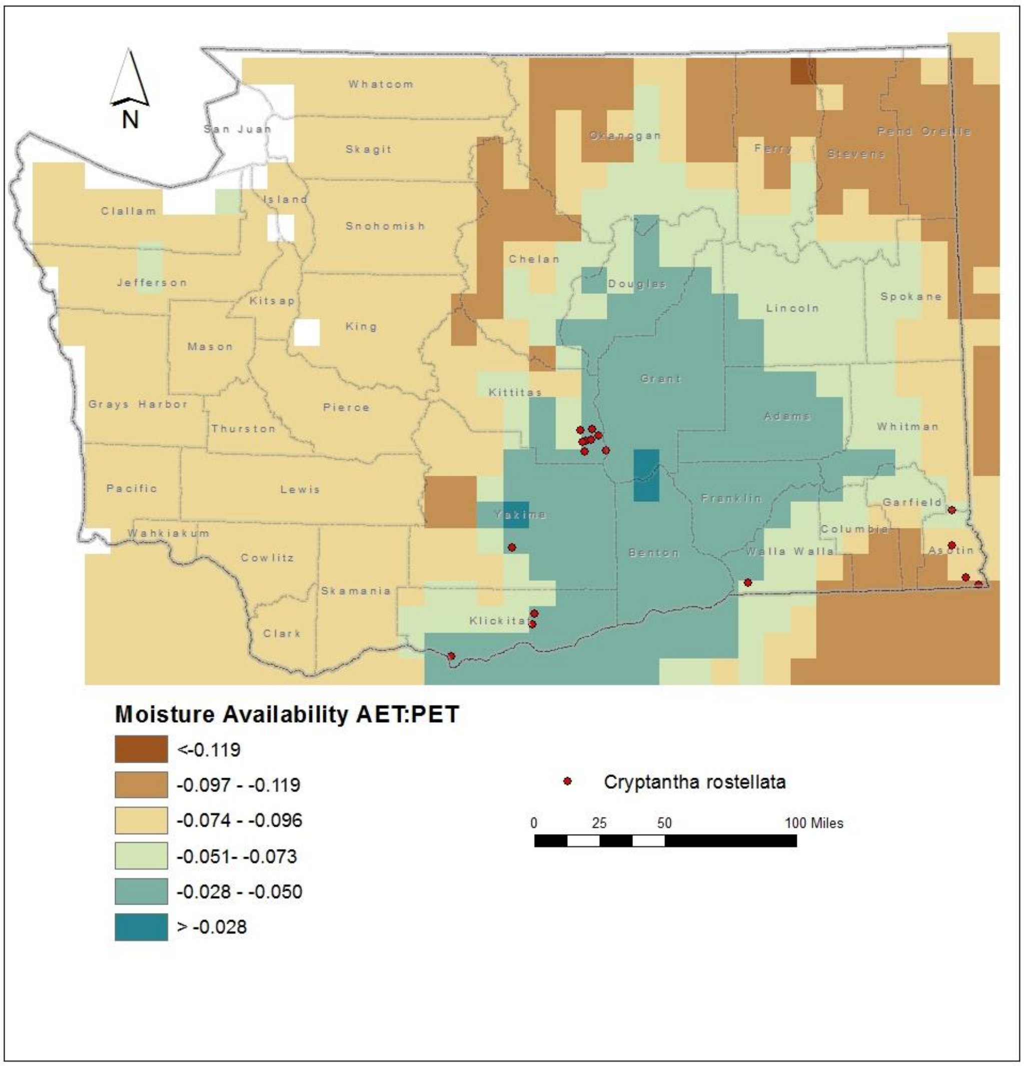

Figure 2. Exposure of *Cryptantha rostellata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

from areas in the range of -0.051 to -0.073. Two occurrences (11.8%) from the foothills of the Blue Mountains have a projected decrease in available moisture of -0.074 to -0.096. One final occurrence from the Blue Mountains (5.9%) is in the range of -0.097 to -0.119.

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Cryptantha rostellata* are found at 600-2900 feet (180-880 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Cryptantha rostellata occurs primarily on dry, rocky slopes and canyon bottoms associated with coarse gravel, cobbles, silt, and sand in big sagebrush (*Artemisia tridentata*) and stiff sagebrush (*A. rigida*) shrublands (Camp and Gamon 2011; Salstrom 1996). This habitat is part of the Columbia Basin Palouse Prairie and Columbia Plateau Scabland Shrubland ecological systems (Rocchio and Crawford 2015). Populations are separated by distances of 1.2-82 miles (2-130 km). Gaps in the distribution of the species reflect natural discontinuities in the availability of suitable habitat that present a barrier to range expansion or future migration.

B2b. Anthropogenic barriers: Somewhat Increase.
The scabland and shrub habitat of *Cryptantha rostellata* in Washington is naturally patchy but also dissected by roads, agricultural fields, rangelands, and other human infrastructure that present an additional barrier to dispersal or migration.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Cryptantha rostellata produces one hard, 1-seeded nutlet per flower. Nutlets are smooth and lack wings, feathery plumes, or other structures for wind dispersal. The calyx surrounding the nutlet has bristly, curved hairs that can adhere to animals for potential transport. Average dispersal distances are probably relatively short (less than 1000 meters).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Cryptantha rostellata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 17 of the known occurrences in the state (100%) are found in areas that have experienced average (57.1-77°F/31.8-43.0°C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
The scabland and rocky slope habitat of *Cryptantha rostellata* is not associated with cool air drainage or cold microhabitats.

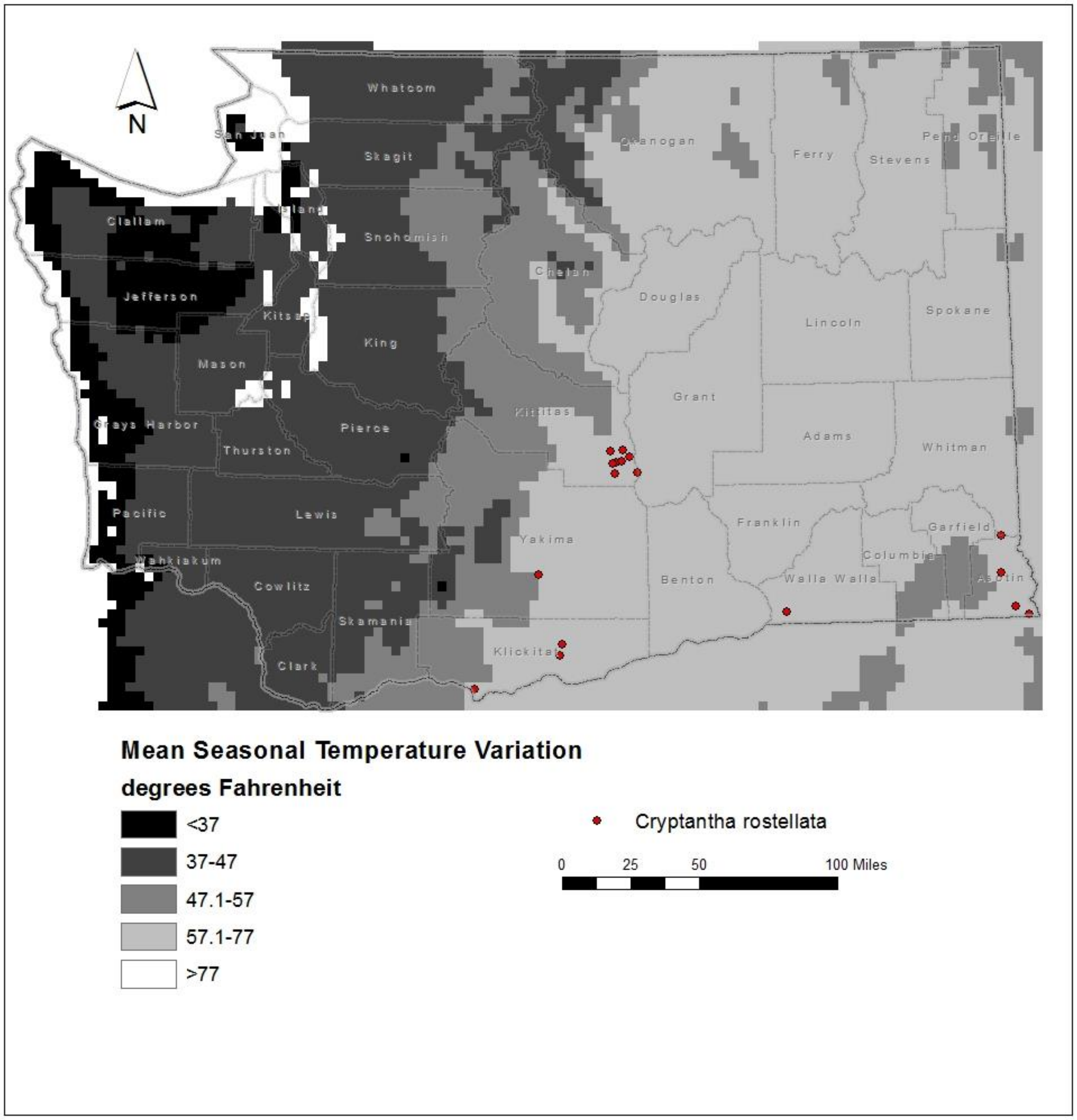

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cryptantha rostellata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Fifteen of the 17 known populations of *Cryptantha rostellata* in Washington (88.2%) are found in areas that have experienced slightly lower than average variation in the past 50 years (11-20 inches/255-508 mm) (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability to climate change. The other two populations (11.8%) are from areas with small precipitation variation (4-10 inches/100-254 mm) during the same period and are considered at increased vulnerability.

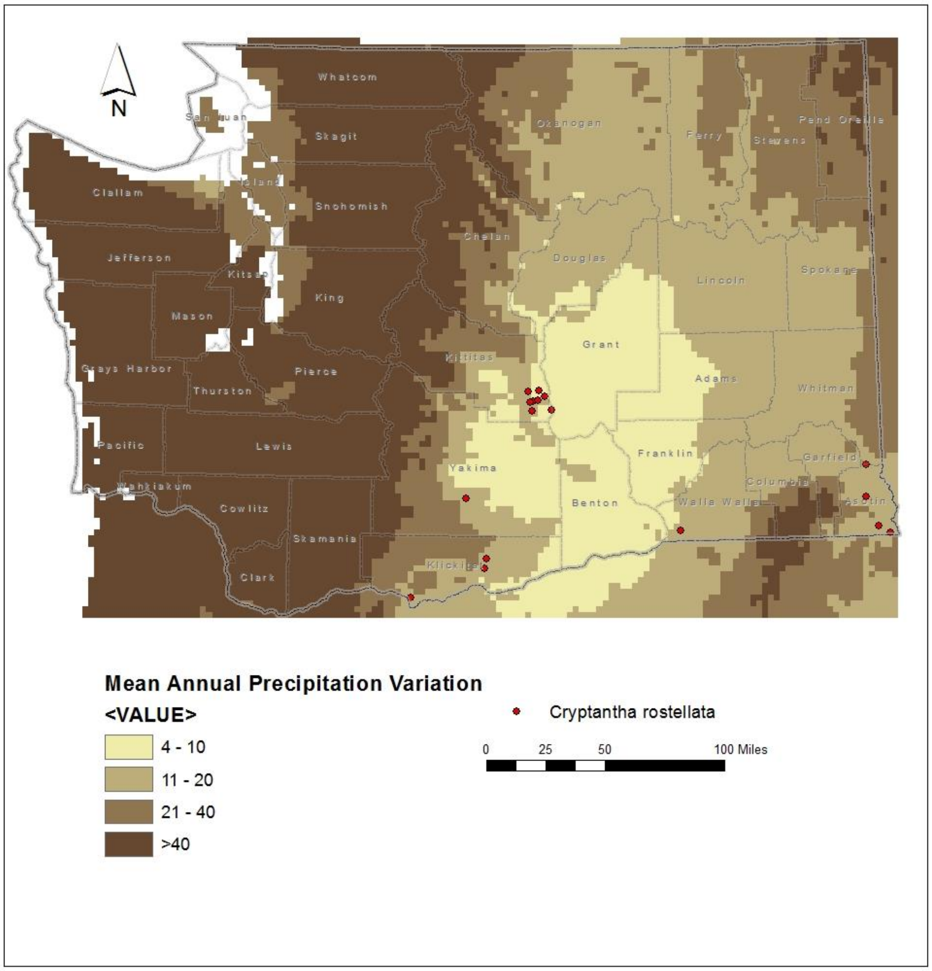

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cryptantha rostellata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a strongly seasonal hydrologic regime or specific wetland habitats. Under projected climate change, the rocky slope and sagebrush scabland habitats occupied by *Cryptantha rostellata* are likely to become even more drought prone due to increased temperatures and changes in the amount and timing of precipitation. Coupled with human disturbance, these areas may become invaded by non-native annual weed species and more vulnerable to wildfire (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase.
Cryptantha rostellata occurs on sparsely vegetated rocky slopes and valley bottoms and big sagebrush and stiff sagebrush shrub communities. Historically, these sites had infrequent

wildfire due to the paucity of fuels. With climate change, these areas may become invaded by non-native annual plant species that may make the sites more prone to wildfire that could alter the species composition of native plant communities, especially those dominated by sagebrush species (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
The populations of *Cryptantha rostellata* in Washington are found in low elevation basin or foothill areas with low winter snow cover.

C3. Restricted to uncommon landscape/geological features: Neutral.
Cryptantha rostellata is found primarily on rocky slopes and valley bottoms on a variety of soil texture types derived primarily from basalt bedrock types (such as the Grande Ronde and Wanapum basalts) that are widely distributed across the state (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The rocky slope and canyon bottom and sagebrush habitat of *Cryptantha rostellata* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The exact pollinators of *Cryptantha rostellata* in Washington are poorly known. Other annual *Cryptantha* species with small flowers (1-2 mm wide) may be pollinated by flies and mosquitos.

C4d. Dependence on other species for propagule dispersal: Neutral.
Individual nutlets lack ornamentation to promote dispersal by wind or animals. Fruits that remain within the bristly calyx could be transported on the fur of a variety of animal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. As an annual, this species is probably not abundant enough most years to be a significant food source for most herbivores. Impacts from grazing are low.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The barren rocky and sagebrush habitat of *Cryptantha rostellata* is vulnerable to invasion by non-native annuals, such as cheatgrass. Competition is likely to increase under predicted future climate change in response to increased drought, temperatures, and fire frequency, which may result in the conversion of sagebrush habitats to annual grasslands (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic diversity of Washington populations.

C5b. Genetic bottlenecks: Unknown.

Not known.

C5c. Reproductive System: Neutral.
Cryptantha rostellata, like other small-flowered annual *Cryptantha* species, may produce two types of flowers: open, chasmogamous flowers that produce seed from cross-pollination, and smaller, closed, self-fertilizing, cleistogamous flowers in which seed matures without cross-pollination (Simpson and Hasenstab 2009). This adaptation helps ensure that at least some seed is produced each year depending on climate conditions or availability of pollinators. This species is likely to have average genetic variability, but studies to confirm this have not been conducted.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Cryptantha rostellata* has not changed its typical blooming time since the late 1800s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
At least three occurrences of *Cryptantha rostellata* in Washington are historical (not relocated in the last 40 years) (Fertig and Kleinknecht 2020). These populations may be extirpated due to habitat loss rather than climate change.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Salstrom, D. 1996. Report on the status of *Cryptantha rostellata* Greene. Washington Natural

Heritage Program, Department of Natural Resources, Olympia, WA. 24 pp.

Simpson, M.G. and K.E. Hasenstab. 2009. *Cryptantha* of southern California. Crossosoma 35(1):1-59.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Dactylorhiza viridis (Long-bract frog orchid)

Date: 20 October 2021

Synonym: *Coeloglossum viride* var. *virescens*

Assessor: Walter Fertig, 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: Local Climate	**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	85.7
	-0.074 to -0.096	14.3
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0

Section B: Indirect Exposure to Climate Change	**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: Sensitivity and Adaptive Capacity	
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	Somewhat Increase
2bii. Changes in physiological hydrological niche	Increase
2c. Dependence on specific disturbance regime	Somewhat Increase
2d. Dependence on ice or snow-covered habitats	Somewhat Increase
3. Restricted to uncommon landscape/geological features	Neutral
4a. Dependence on others 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	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	Unknown

5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All seven of the extant and historical occurrences of *Dactylorhiza viridis* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

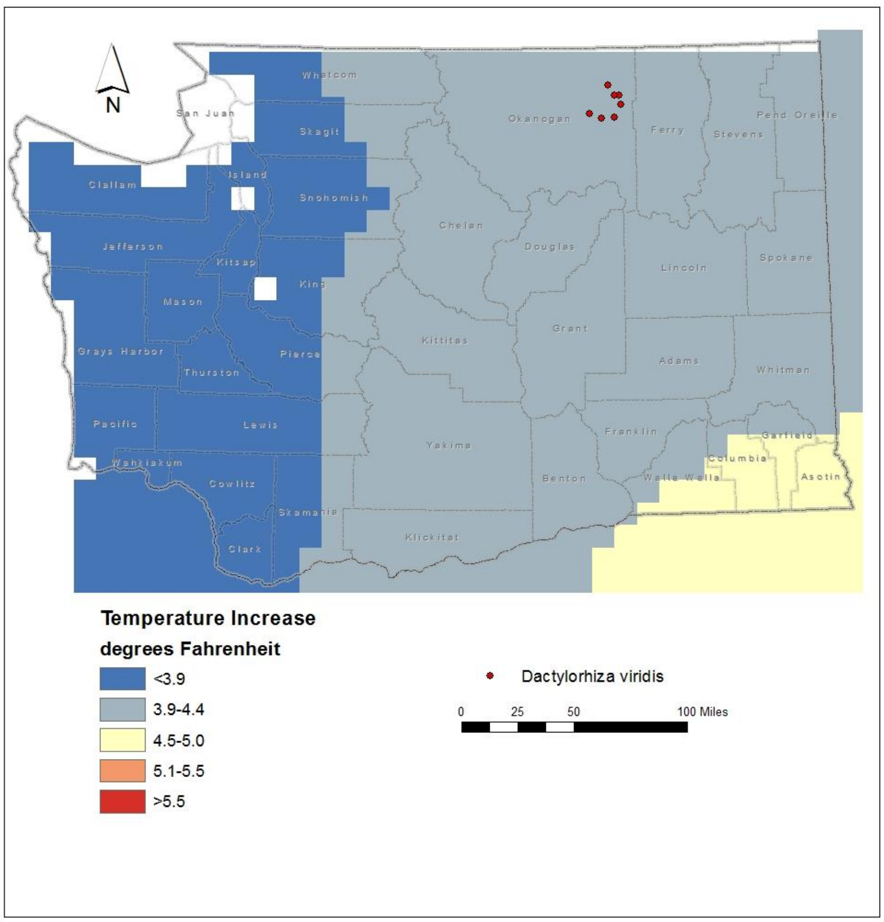

Figure 1. Exposure of *Dactylorhiza viridis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the 7 occurrences (85.7%) of *Dactylorhiza viridis* 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 other population (14.3%) is from an area with projected decrease of -0.074 to -0.096.

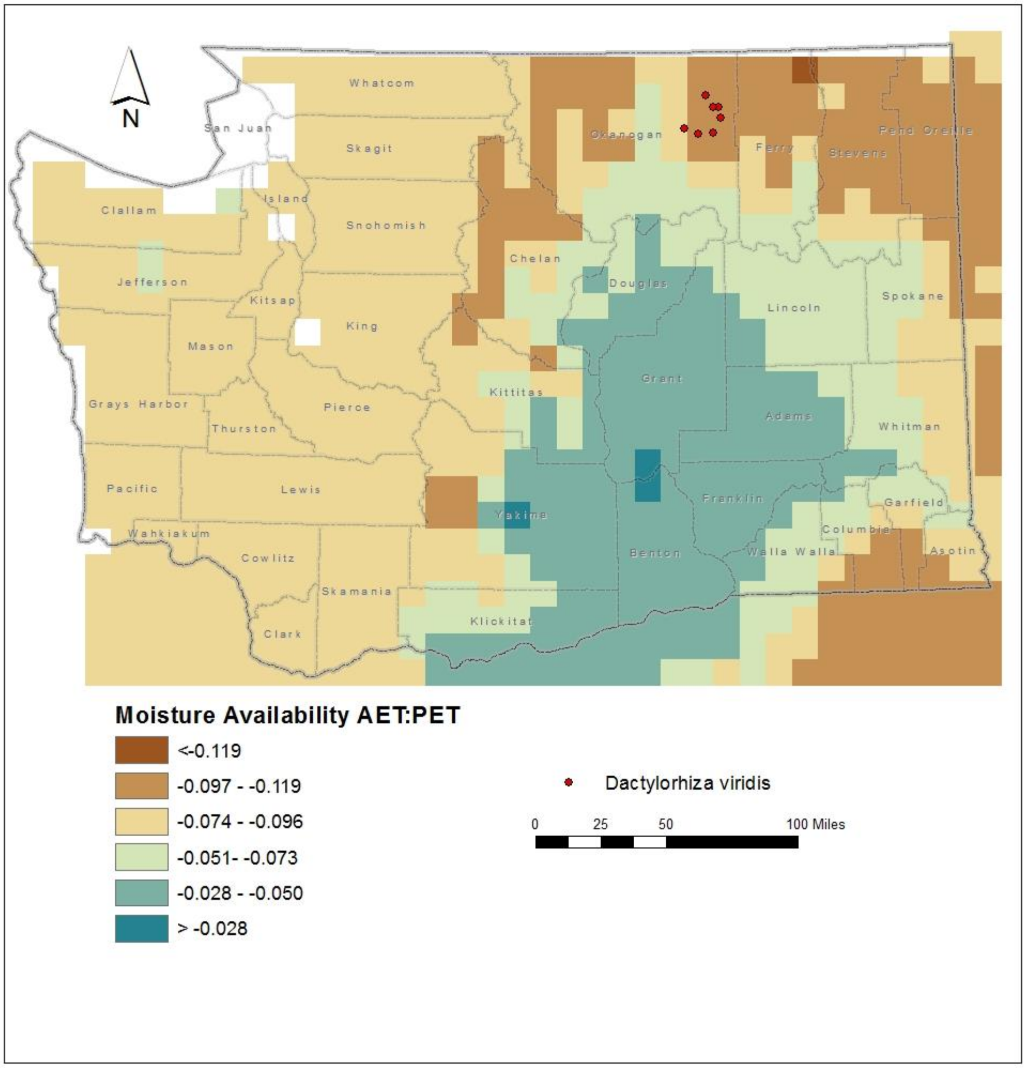

Figure 2. Exposure of *Dactylorhiza viridis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Dactylorhiza viridis* are found at 3840-4400 feet (1170-1340 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Dactylorhiza viridis* is found mostly in seasonally moist depressions or midslopes in recently thinned or burned Douglas-fir (*Pseudotsuga menziesii*) forests with aspen (*Populus tremuloides*), reedgrass (*Calamagrostis*), and snowberry (*Symphoricarpos*) (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest ecological system (Rocchio and Crawford 2015). The entire range of this species in Washington is contained within an area of 15 square miles, with individual occurrences isolated by 2-6.5 miles (3.5-10 km). Populations are separated by broad valleys and areas of dense forest which may impede dispersal.

B2b. Anthropogenic barriers: Neutral.
The forested habitat of *Dactylorhiza viridis* in northern Washington is located on low elevation National Forest lands actively managed for timber production and interspersed with private lands used for livestock, farming, and forestry. This human footprint may reduce long-distance dispersal, but is less significant at the local scale than natural topographic barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Dactylorhiza viridis produces 1400-2300 tiny seeds per pod (Tatarenko et al. 2020). These are released passively by dehiscence of the dried fruit capsule, with seeds spreading primarily by wind. Dispersal distances vary from a few meters to potentially long distances (over 1 km). Germination success beyond local populations is probably quite low if mycorrhizal fungi symbionts are not available in the soil (Tatarenko et al 2020).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Dactylorhiza viridis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Six of the 7 known occurrences in the state (85.7%) are found in areas that have experienced average (57.1-77˚F/31.8-4.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). One other population (14.3%) is from an area with slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation over the same period and is considered at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
In Washington, *Dactylorhiza viridis* occurs in low-lying areas and midslopes of partially open conifer forests that are in cold air drainages that create somewhat cooler microhabitat conditions. These areas could be impacted by increased temperatures or reduction of forest

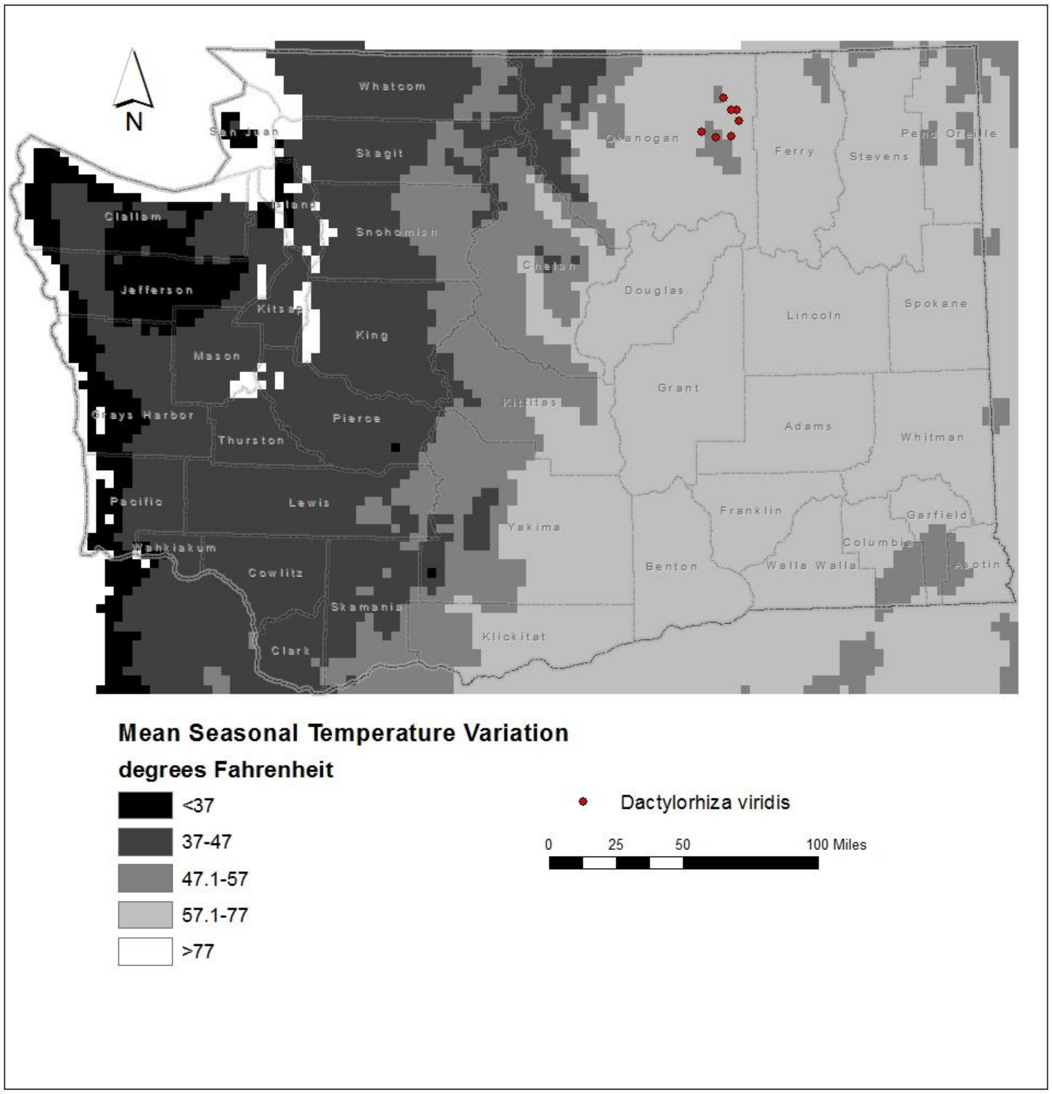

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Dactylorhiza viridis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

cover from increased wildfire expected from future climate change (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Somewhat Increase.
Four of the seven populations of *Dactylorhiza viridis* in Washington (57.1%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016) these occurrences are

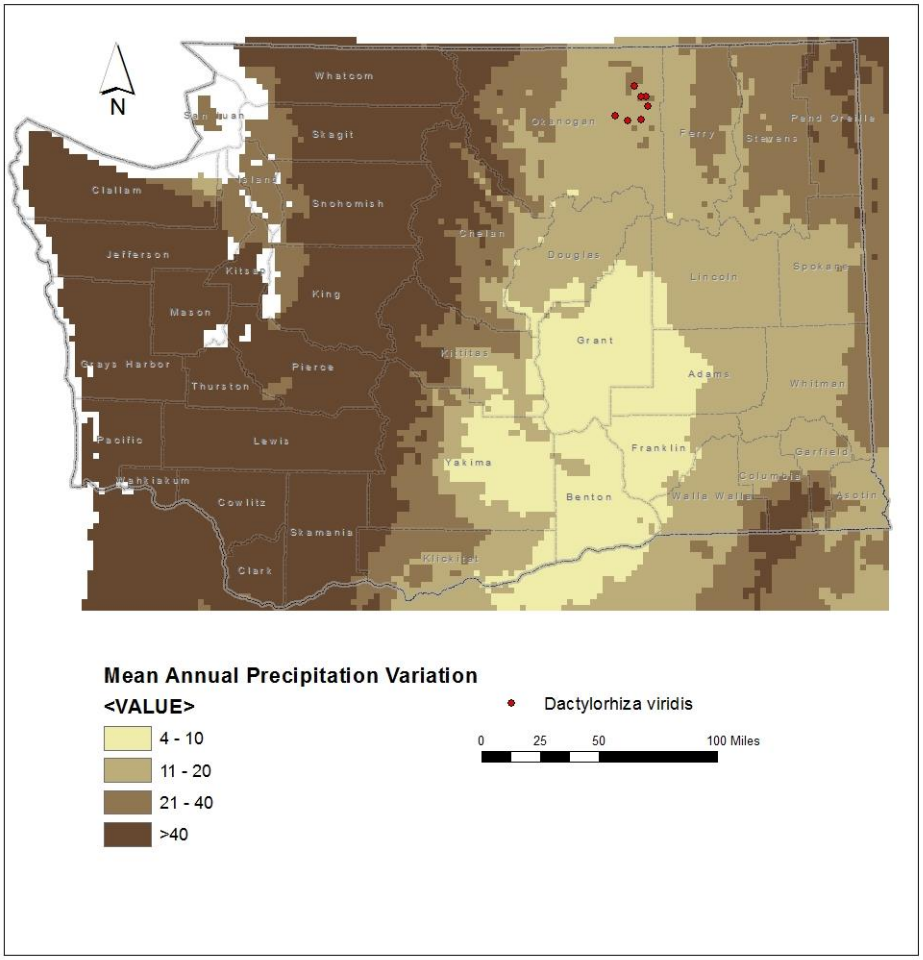

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Dactylorhiza viridis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

at slightly increased vulnerability to climate change. Three other populations (42.9%) are from areas with average variation in precipitation (20-40 inches/508-1116 mm) over the same period and are at neutral vulnerability.

C2bii. Physiological hydrological niche: Increase.
This species is dependent on seasonally moist conditions during the growing season that are enhanced by local snow deposition and adequate spring and summer precipitation. Reductions in the amount or timing of precipitation and warmer temperatures are likely to increase drought, insect outbreaks, and stand-replacing wildfires that could result in changes from Douglas-fir forests to shrublands or dry meadows (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Dactylorhiza viridis populations in Washington occur in small depression and slopes in openings in Douglas-fir forests. These openings may be maintained naturally through periodic, low-intensity wildfire. Recent management actions to thin forests or do controlled burns for silviculture may mimic these natural disturbances. Future climate change in these communities is likely to result in drier and hotter conditions that might promote larger scale, stand-replacing wildfires (Rocchio and Ramm-Granberg) that would be detrimental to *D. viridis*.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Dactylorhiza viridis* in Washington are found in lower elevation montane forested areas on the east side of the Cascades that receive moderate amounts of winter snow accumulation. Snow deposition in depressions and lee slopes may be important for ensuring adequate moisture in microhabitats occupied by *D. viridis*. Reduction in the amount of snowfall or in the timing of its melting due to climate change (Rocchio and Ramm-Granberg 2017) could be detrimental to this species.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Washington, *Dactylorhiza viridis* is known only from depressions and mountain slopes of Pleistocene Continental glacial drift. This geologic layer is found widely in the Okanogan Plateau.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat of *Dactylorhiza viridis* is maintained primarily by natural, abiotic processes and not by other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Dactylorhiza viridis* in Washington are not known. In Europe, this species is pollinated by beetles, bees, and wasps (Tatarenko et al. 2020) and by ants in alpine habitats (Claessens and Seifert 2017). *D. viridis* is unusual among orchids in taking 20 to 30 minutes to successfully bend the pollen-bearing pollinium structure of their flowers and adhere the sticky pollen mass to a pollinator (other orchids typically complete this in a matter of seconds) (Claessens and Seifert 2017).

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds of *Dactylorhiza viridis* are minute and readily wind dispersed.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Impacts from pathogens are not known. *Dactylorhiza viridis* is palatable and the species could be susceptible to grazing (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Populations of *Dactylorhiza viridis* in England are believed to be declining due to competition for space and nutrients from other plant species in open meadow habitats (Fay 2015). Under projected climate change, increasing temperatures and drier conditions could increase the frequency of wildfire and convert forest sites occupied by this species to dry meadows (Rocchio and Ramm-Granberg 2017).
C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase.

Successful germination of *Dactylorhiza viridis* seed is dependent on the presence of specific mycorrhizal fungi species in the soil (Tatarenko et al. 2020).

C5a. Measured genetic variation: Unknown.
Research on the genetic variability of *Dactylorhiza viridis* in Washington has not been conducted. In Eurasia, genetic variation in this species is high across the continent (Pillon et al. 2006). Being at the southern edge of its range in North America, Washington populations might be expected to have lower overall genetic variability due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Dactylorhiza viridis is an obligate outcrosser and is probably not limited by pollinators or dispersal, so is presumed to have at least average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
The flowering period for *Dactylorhiza viridis* has not changed in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Dactylorhiza viridis* in Washington since it was first discovered in the state in 1998.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Claessens, J. and B. Seifert. 2017. Significant ant pollination in two orchid species in the Alps an adaptation to the climate of the alpine zone? Tuexenia 37: 363-374.

Fay, M.F. 2015. British and Irish orchids in a changing world. Curtis's Botanical Magazine 32(1): 3-23.

Pillon, Y., M.F. Fay, A.B. Shipunov, and M.W. Chase. 2006. Species diversity versus phylogenetic diversity: A practical study in the taxonomically difficult genus *Dactylorhiza* (Orchidaceae). Biological Conservation 129: 4-13.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Tatarenko, I., M. Dodd, H. Wallace, G. Bellamy, and A. Fleckney. 2020. Protecting small populations of rare species. Case study of *Dactylorhiza viridis* (Orchidaceae) in Fanott Woods and Meadows SSSI, Bedfordshire, UK. Nature Conservation Research. 2020.5(Suppl.1). https://dx.doi.org/10.24189/ncr.2020.028

Washington Natural Heritage Program. 2021-. *Dactylorhiza viridis*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=dactylorhiza%20viridis). Accessed 20 October 2021.

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

Damasonium californicum (Fringed water-plantain)

Date: 19 October 2021 Synonym: *Machaerocarpus californicus*

Assessor: Walter Fertig, 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: Local Climate	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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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: Documented or Modeled Response	
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: The three confirmed occurrences of *Damasonium californicum* in Washington (100%) all occur near the Columbia River in Klickitat County in areas with a

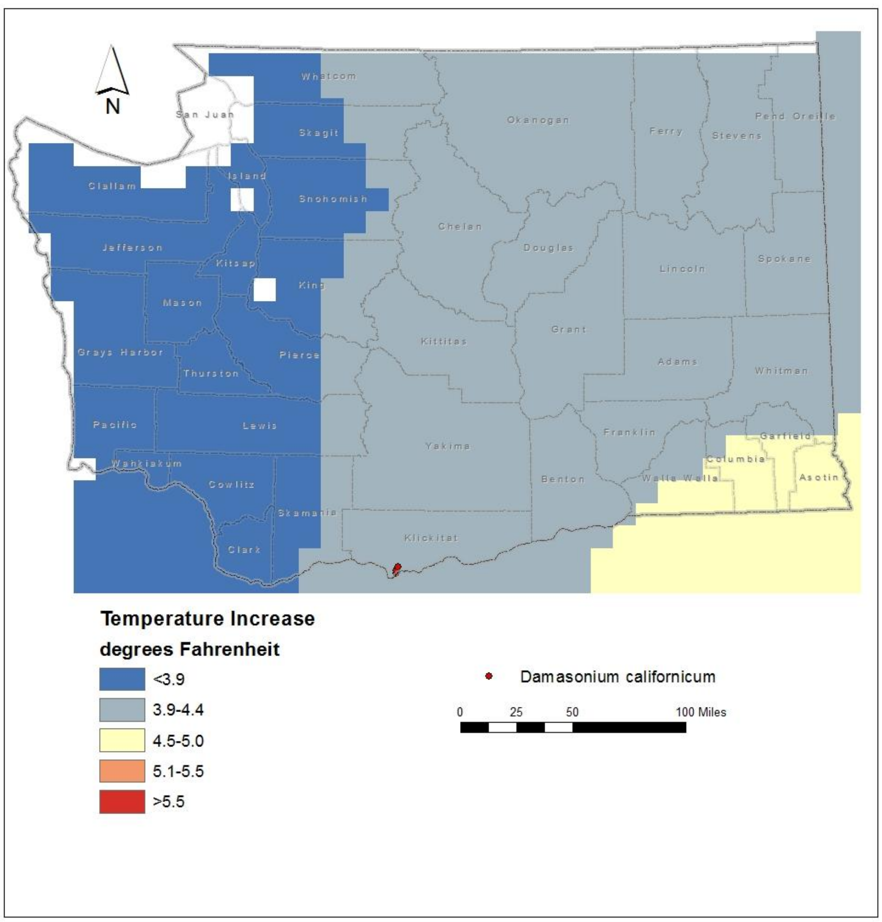

Figure 1. Exposure of *Damasonium californicum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

projected temperature increase of 3.9-4.4° F (Figure 1). Additional reports from Okanogan and Pierce counties need confirmation and are not included in this analysis.

A2. Hamon AET:PET Moisture Metric: All of the occurrences of *Damasonium californicum* 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 -0.028 to -0.050 (Figure 2).

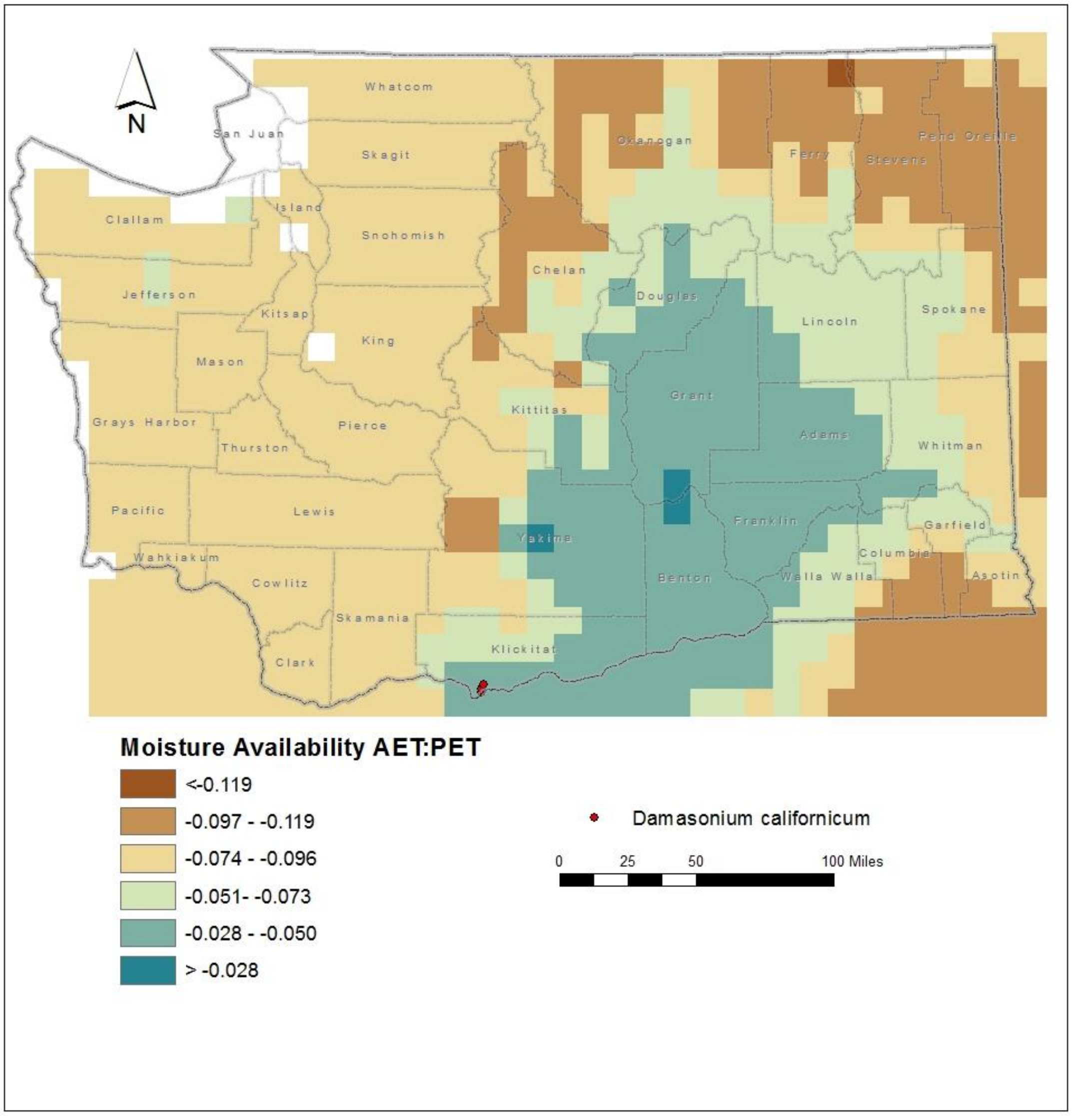

Figure 2. Exposure of *Damasonium californicum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Damasonium californicum* are found at 200-235 feet (60-72 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Damasonium californicum* occurs in shallow, mud-lined ponds in depressions in basalt bedrock associated with *Erythranthe guttata* (yellow monkeyflower), *Veronica* (veronica), *Juncus* (rush), *Alisma plantago-aquatica* (European water-plantain), *Downingia yina* (showy downingia), and *Ranunculus aquatilis* (white water crowfoot) (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the North American Arid West Emergent Marsh ecological system (Rocchio and Crawford 2015). Populations in Klickitat County are isolated from each other by 1-2 miles (1.5-3.3 km) of unoccupied and unsuitable upland habitat that creates a partial barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Damasonium californicum* in Washington is bisected by roads and other human infrastructure, but dispersal is more constrained by the naturally patchy distribution of suitable shallow pond habitat.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Damasonium californicum produces star-like whorls of flat, 1-seeded achenes, each with a long, pointed beak. Fruits may be transported by water or stuck to fur or feathers of animals. Dispersal distances may vary, but the species has the potential for moderate to long-distance dispersal (over 1 km) via animal vectors.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Damasonium californicum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All three occurrences in the state (100%) are found in areas that have experienced average (57.1-77°F/31.8-43.0°C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The shallow pond habitat of *Damasonium californicum* is associated with depressions in basalt bedrock that may be a cold air drainage. The proximity of these sites to the Columbia River may also expose them to strong winds that have a cooling effect. These sites are likely to be impacted by temperature increases associated with climate change.

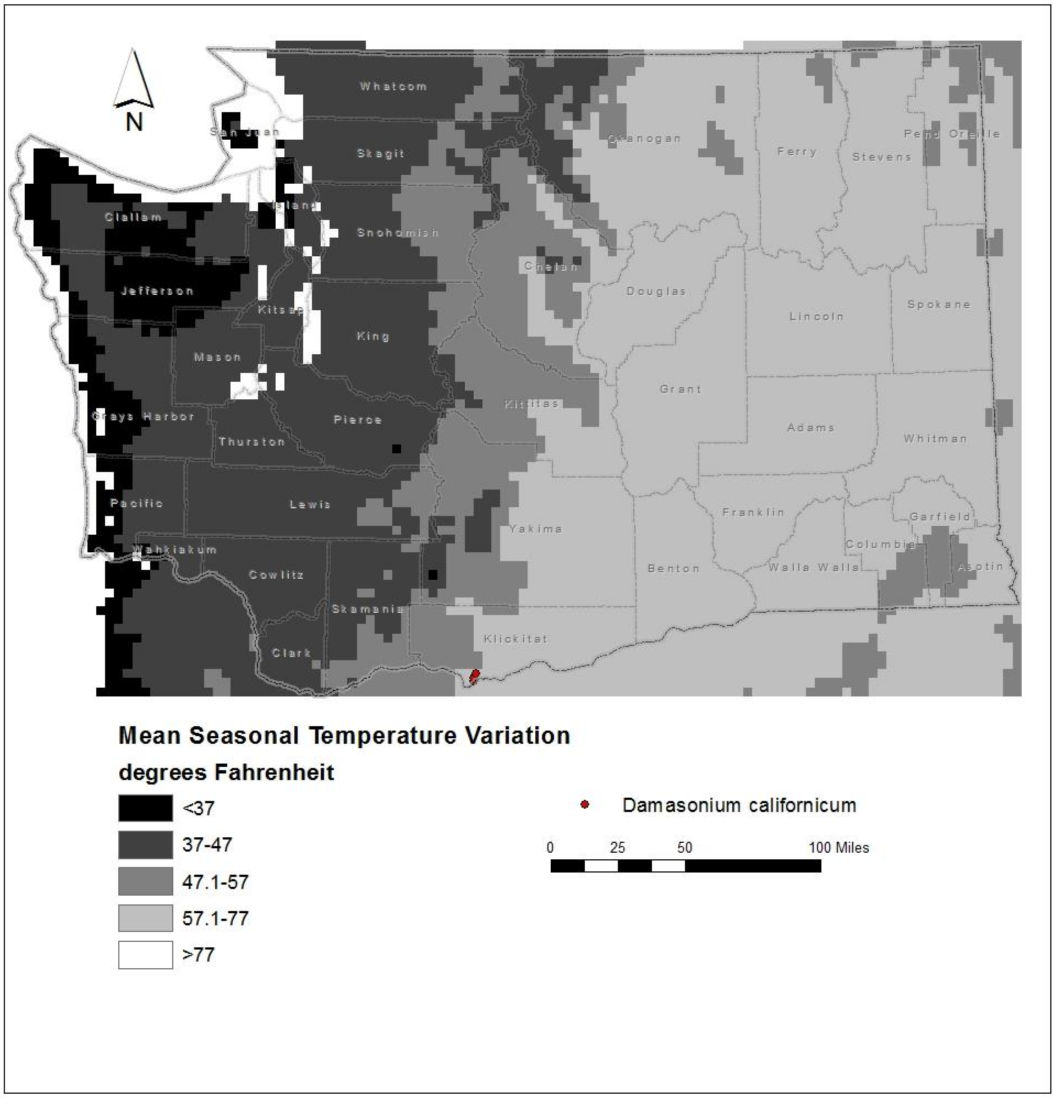

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Damasonium californicum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
All of the known populations of *Damasonium californicum* in Washington (100%) are found in areas that have experienced slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm) (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability from climate change.

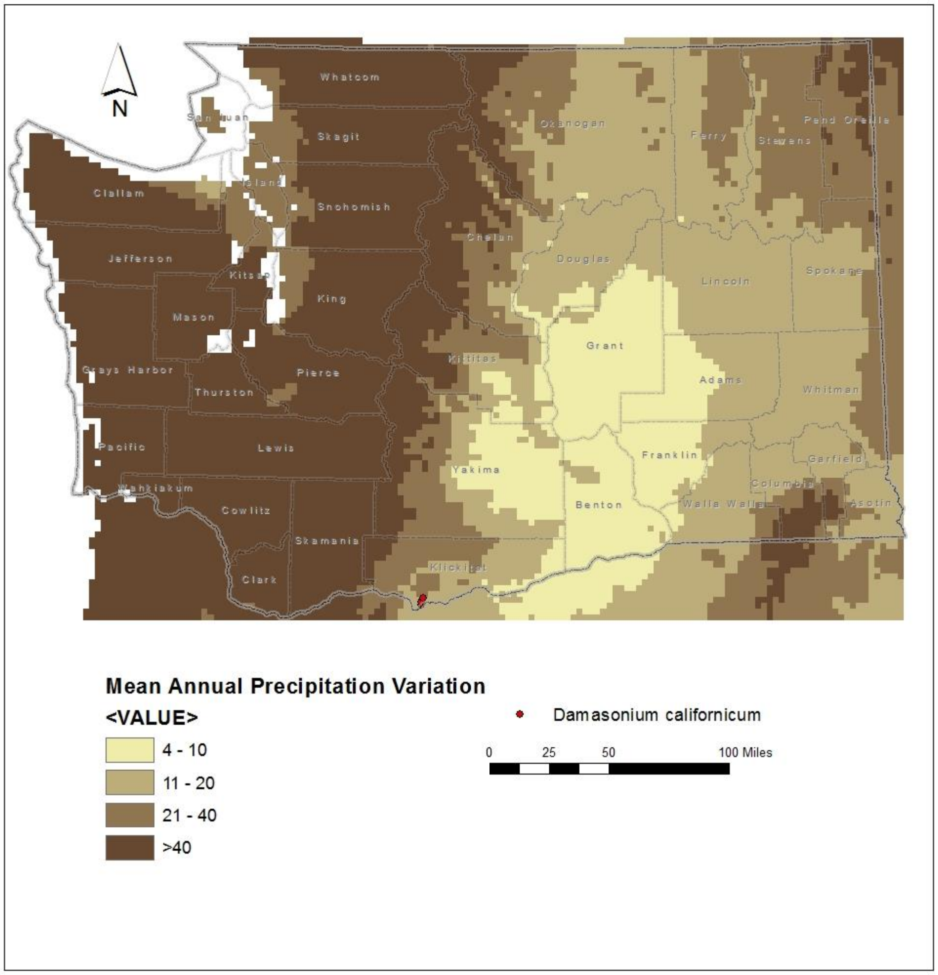

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Damasonium californicum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
This species occurs in shallow ponds underlain by basalt bedrock that are maintained by precipitation and a high water table. Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought and result in a conversion from marsh to wet meadow vegetation (Rocchio and Ramm-Granberg 2017). Groundwater-dependent marshes are also vulnerable if changes in snow deposition or timing of snowmelt reduce water availability in the growing season.

C2c. Dependence on a specific disturbance regime: Neutral.
Damasonium californicum occurs in shallow ponds underlain by basalt bedrock. These sites are maintained by sufficient precipitation and groundwater that keeps soils sufficiently saturated to prevent encroachment by species adapted to drier conditions (such as wet meadows

or forests). These sites are not dependent on episodic disturbances, such as fire, though they may benefit from periodic drought to prevent shrubs from being established.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
The populations of *Damasonium californicum* in Washington are found in areas with relatively low snow accumulation and mild winter temperatures. Reduced snowpack within the watershed could reduce the amount of groundwater available, which in turn could facilitate conversion of marshlands to wet meadows (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Damasonium californicum is found primarily in depressions within the Frenchman Springs Member of the Wanapum Basalt, a formation that is widespread in the Columbia Plateau (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The shallow pond habitat occupied by *Damasonium californicum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
The specific pollinators of *Damasonium californicum* are poorly known. Vuille (1987) has suggested that moths or other nocturnal insects may be attracted to the white flowers for pollination. Les (2020) notes that *D. californicum* is pollinated by a variety of insects.

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits have a sharp, pointed beak that may stick into fur or feathers for transport. The fruits are also flattened and might adhere to animals on mud.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Foliage and fruits may be eaten by waterfowl (Les 2020), but this is not considered a significant threat.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
At least one occurrence of *Damasonium californicum* in Washington has high cover of the *Phalaris arundinacea* (reed canary grass), an invasive species. Changes in water availability due to drought, reduced precipitation, or lowered water tables, are likely to result in the conversion of this habitat to meadows, which will lead to increased competition from other native and introduced plant species (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Genetic variability is poorly known. *Damasonium* species from Europe have a base chromosome number of $x = 7$, but no counts have been completed for *D. californicum* (Les 2020).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Damasonium californicum is strongly protandrous (stamens mature before the pistils) to promote outcrossing and thus probably has high genetic variability over its full range (Vuille 1987). Populations in Washington occur at the northern limit of the species' range and might be expected to have lower overall genetic variability due to inbreeding, genetic drift, or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Damasonium californicum* has not changed its typical blooming time in the last 40 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Damasonium californicum was first documented in Washington in 1981 (although an unconfirmed, vegetative specimen was collected in Pierce County in 1973). Of the three verified occurrences, one has not been relocated in the last 20 years despite several attempts. If this population is extirpated, it may be due to habitat destruction rather than a drying climate.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Les, D.H. 2020. Aquatic Monocotyledons of North America: Ecology, Life History, and Systematics. CRC Press, Boca Raton, FL. 185 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Vuille, F-L. 1987. Reproductive biology of the genus *Damasonium* (Alismataceae). Plant Systematics and Evolution 157: 63-71.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Damasonium californicum*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=damasonium%20californicum). Accessed 19 October 2021.

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

Dendrolycopodium dendroideum (Treelike clubmoss)

Date: 11 October 2021

Synonym: *Lycopodium dendroideum*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G5/S2

Index Result: Moderately Vulnerable

Confidence: High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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
	<3.9° F (2.2°C) warmer	16.7
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	22.2
	-0.074 to - 0.096	77.8
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral/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/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Not Applicable
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/Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: Fifteen of the 18 occurrences of *Dendrolycopodium dendroideum* in Washington (83.3%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure

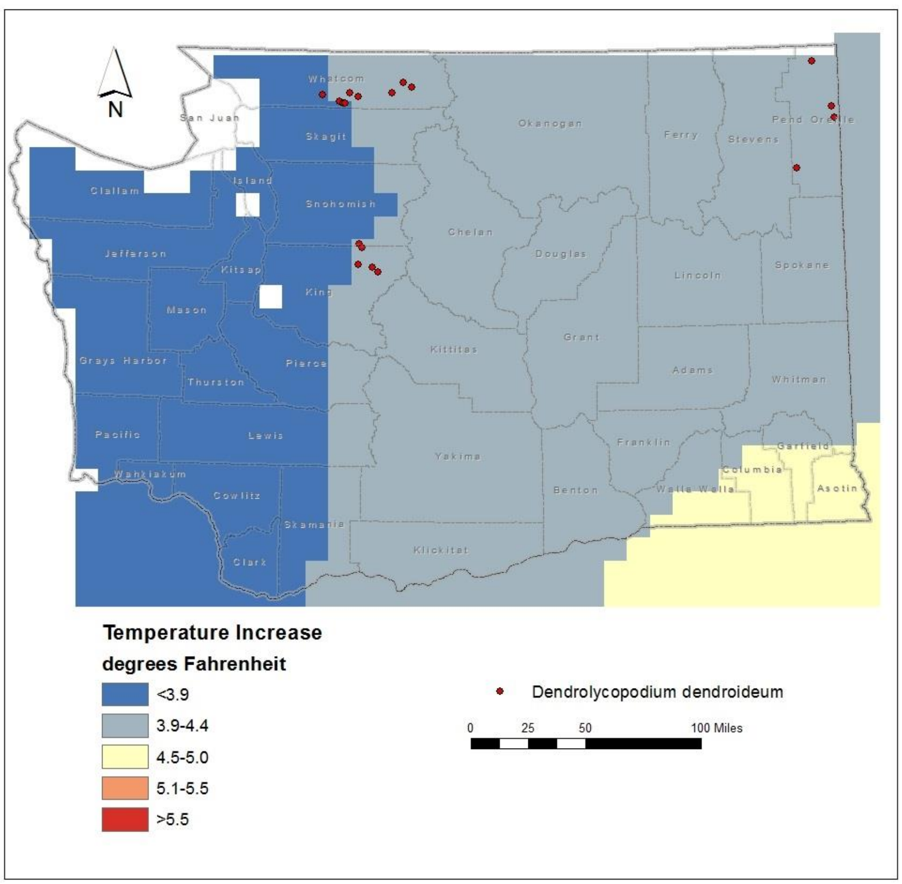

Figure 1. Exposure of *Dendrolycopodium dendroideum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

1). Three other populations (16.7%) are from areas with a projected temperature increase of < 3.9˚ F.

A2. Hamon AET:PET Moisture Metric: Fourteen of the 18 occurrences (77.8%) of *Dendrolycopodium dendroideum* 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). Four other populations (22.2%) are from areas with a predicted decrease of -0.097 to -0.119.

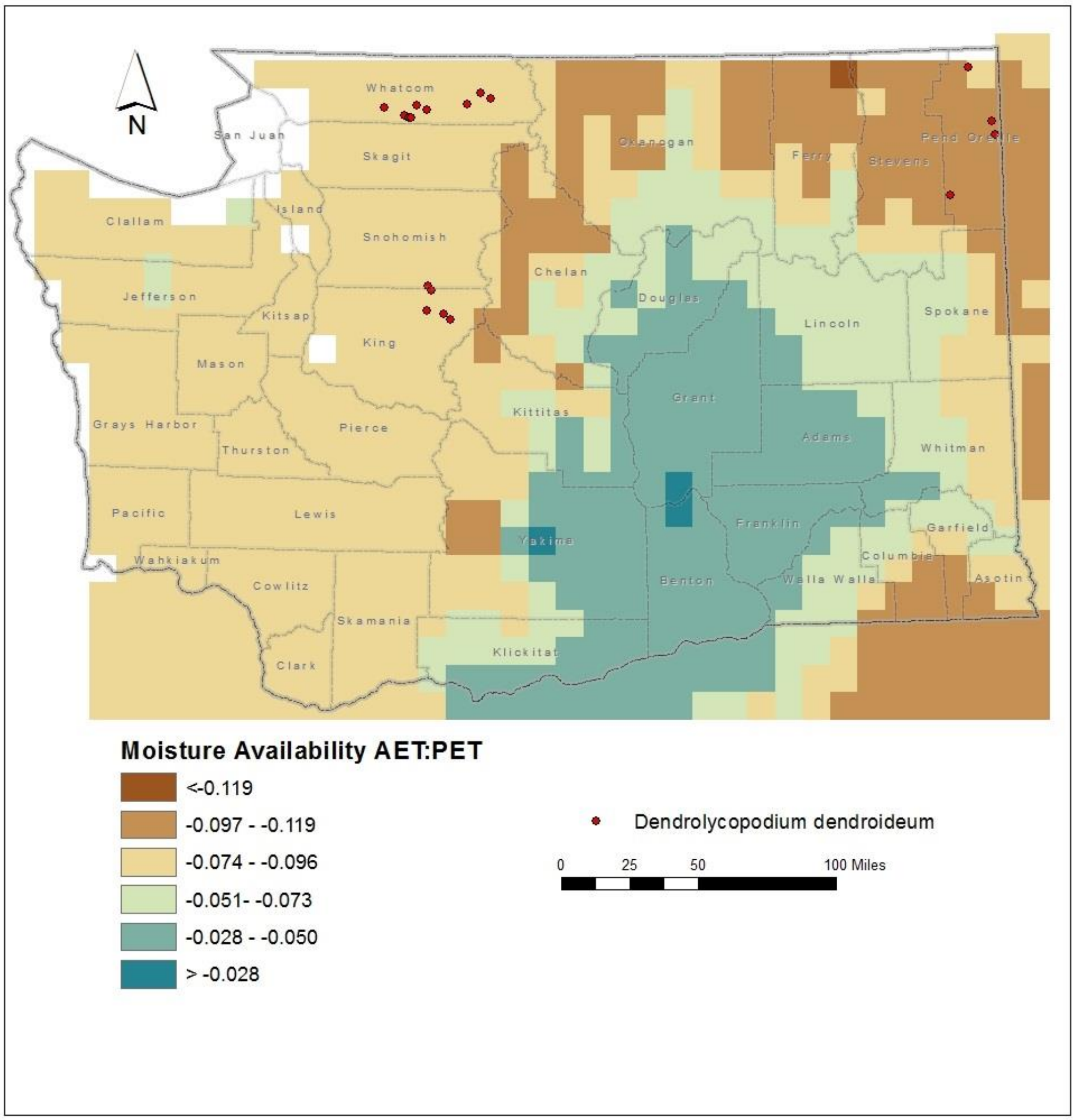

Figure 2. Exposure of *Dendrolycopodium dendroideum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Dendrolycopodium dendroideum* are found at 800-3650 feet (240-1110 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Dendrolycopodium dendroideum occurs mostly on mossy, rock outcrops and boulder fields at the edge of conifer forests dominated by western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*), Pacific silver fir (*Abies amabilis*), or Engelmann spruce (*Picea engelmannii*) (Camp and Gamon 2011; Washington Natural Heritage Program 2021). These habitats are part of the North Pacific Massive Bedrock, Cliff, & Talus; Rocky Mountain Cliff, Canyon, & Massive Bedrock; and Rocky Mountain Subalpine Mesic Spruce-Fir Forest & Woodland ecological systems (Rocchio and Crawford 2015). Populations are mostly isolated from each other by 1-26 miles (1.6-44 km), but are separated by up to 187 miles (300 km) between the North Cascades and Canadian Rockies. This species disperses by tiny wind-borne spores which may have reduced mobility within densely forested areas.

B2b. Anthropogenic barriers: Neutral.
The habitat of *Dendrolycopodium dendroideum* in northern Washington is entirely within National Forest or National Park lands where direct human impacts are primarily roads, trails, logging, and livestock grazing. Anthropogenic barriers are probably no more significant than natural ones for impacting dispersal of this species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral/Somewhat Increase.
Dendrolycopodium dendroideum, 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. Sporophyte plants produce large numbers of tiny, seed-like spores that are capable of long-distance dispersal by wind. Spores germinate to form gametophyte plants which reproduce sexually by gametes (sessile eggs retained within the plant and motile sperm that require moist surfaces to travel very short distances for fertilization). Sporophyte plants are produced from fertilized eggs within their parent gametophyte plant, and thus are incapable of further dispersal. Overall, dispersal by spores is not limiting, but the survival of sporophyte plants is strongly tied to gametophytes being able to survive in suitable microhabitats.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Dendrolycopodium dendroideum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eleven of the 18 occurrences in the state (61.1%) are found in areas that have experienced small variation in temperature (37-47˚F/20.8-26.3˚C) during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016). Six populations (33.3%) are from areas with slightly lower than average temperature variation (47.1-57˚F/26.3-

31.8˚C) over the same period and are at somewhat increased vulnerability to climate change. One other occurrence (5.6%) is from an area with average temperature variation (57.1-77˚F/31.8-43.0˚C) and is at neutral vulnerability to climate change (Young et al. 2016).

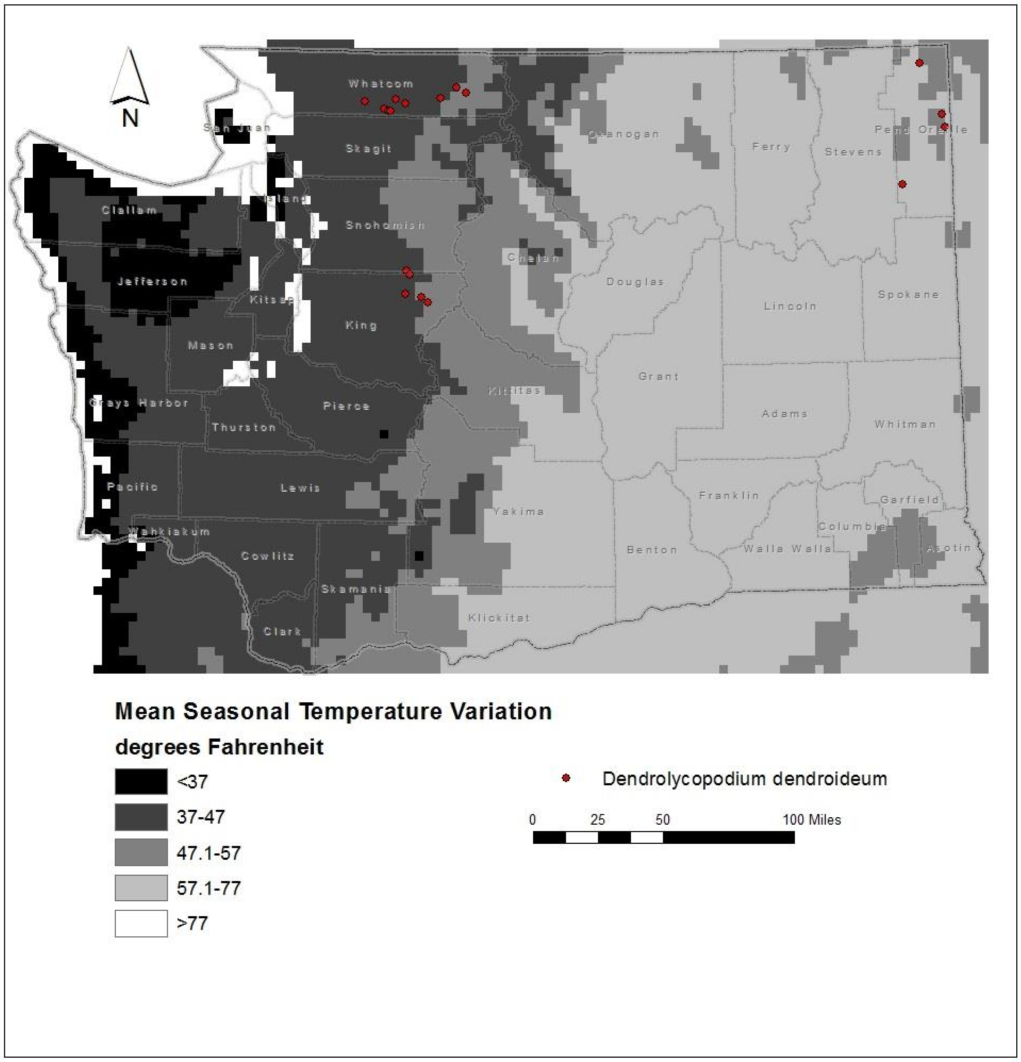

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Dendrolycopodium dendroideum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The forested rock outcrop and boulder field habitat of *Dendrolycopodium dendroideum* is often associated with cold air drainages that could be adversely impacted by warming temperatures (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
All of the populations of *Dendrolycopodium dendroideum* in Washington (100%) are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

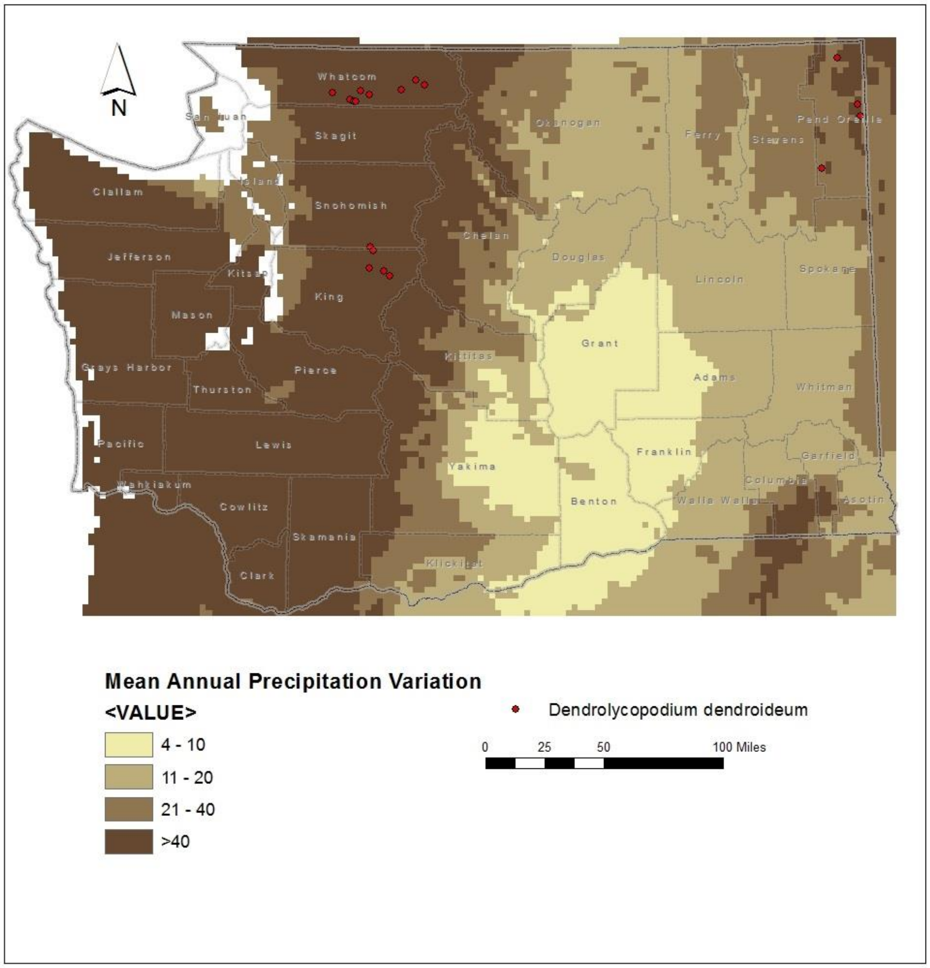

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Dendrolycopodium dendroideum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on adequate winter snowfall and spring/summer precipitation to maintain its forested habitat and mossy microhabitat. Projected climate change is likely to make these areas warmer and drier and more prone to wildfire (Rocchio and Ramm-Granberg 2017) which would make rocky sites less shaded and less suitable for *Dendrolycopodium*

dendroideum. Lycophytes and ferns of mesic environments are often poorly adapted for drought and vulnerable to drying and warming conditions (Link-Perez and Laffan 2018).

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase.
Dendrolycopodium dendroideum occurs on bedrock and boulder fields within forested areas and is not dependent on periodic disturbance to maintain its habitat. Under predicted future climate change, these forested sites could be more vulnerable to wildfire due to increased drought and reduced precipitation (Rocchio and Ramm-Granberg 2017). Newly opened rock outcrop sites could become too dry to sustain this species or be invaded by competing plant species.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Populations of *Dendrolycopodium dendroideum* in Washington are found in montane areas with moderate to high amounts of snow. Changes in the quantity of snow or the timing of snowmelt under future climate scenarios could impact the persistence of this species by making its microhabitat drier and making forests more prone to wildfire (Rocchio and Ramm-Granberg 2017)

C3. Restricted to uncommon landscape/geological features: Neutral.
Dendrolycopodium dendroideum is found primarily on basalt outcrops that are widespread in the mountains of northern Washington (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 *Dendrolycopodium dendroideum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Not applicable.
The sporophyte generation of *Dendrolycopodium dendroideum* 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 *Dendrolycopodium dendroideum* do not require animal species for assistance in dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Dendrolycopodium dendroideum is not an edible species and is not known to be attacked by pathogens.

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. 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).

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

C5a. Measured genetic variation: Unknown.
Petlewski (2020) examined genetic diversity across the range of *Dendrolycopodium dendroideum* and found distinct genotypes from northwestern and northeastern North America and eastern Asia (which may represent an undescribed taxon). Data are lacking for genetic diversity within and between populations of *D. dendroideum* in Washington. Since the species is near the southern edge of its range in Washington, it may have lower overall genetic diversity in the state due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral/Somewhat Increase.
Dendrolycopodium dendroideum has a complex life history involving an alternation between diploid spore-producing sporophytes (the familiar form of the species) and minute, gamete-producing haploid gametophytes. While spores are capable of long-distance dispersal, gametes are not and so genetic variability could be constrained in populations at the edge of the species' range, like those in Washington.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
The timing of reproduction in *Dendrolycopodium dendroideum* has not been altered in response to climate change.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Dendrolycopodium dendroideum* has not changed significantly in Washington since it was first discovered in the state in 1909.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Link-Perez, M.A. and S.W. Laffan. 2018. Fern and lycophyte diversity in the Pacific Northwest: Patterns and predictors. Journal of Systematics and Evolution 56(5): 498-522.

Petlewski, A.R. 2020. Exploring Lycopodiaceae endophytes, *Dendrolycopodium* systematics, and the future of fern model systems. Master's Thesis, Cornell University, Ithaca, NY. 94 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Dendrolycopodium dendroideum*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=dendrolycopodium%20dendroideum). Accessed 11 October 2021.

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

Draba cana (Lanceleaved draba)

Date: 14 September 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S1

Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	80
	<3.9° F (2.2°C) warmer	20
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: Indirect Exposure to Climate Change		**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 B: Indirect Exposure to Climate Change		
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		Somewhat Increase
4a. Dependence on others 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		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	Neutral/Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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 the five occurrences of *Draba cana* in Washington (80%) are found in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). One historical population from Clallam County (20%) is from an area with a projected temperature increase of <3.9˚ F.

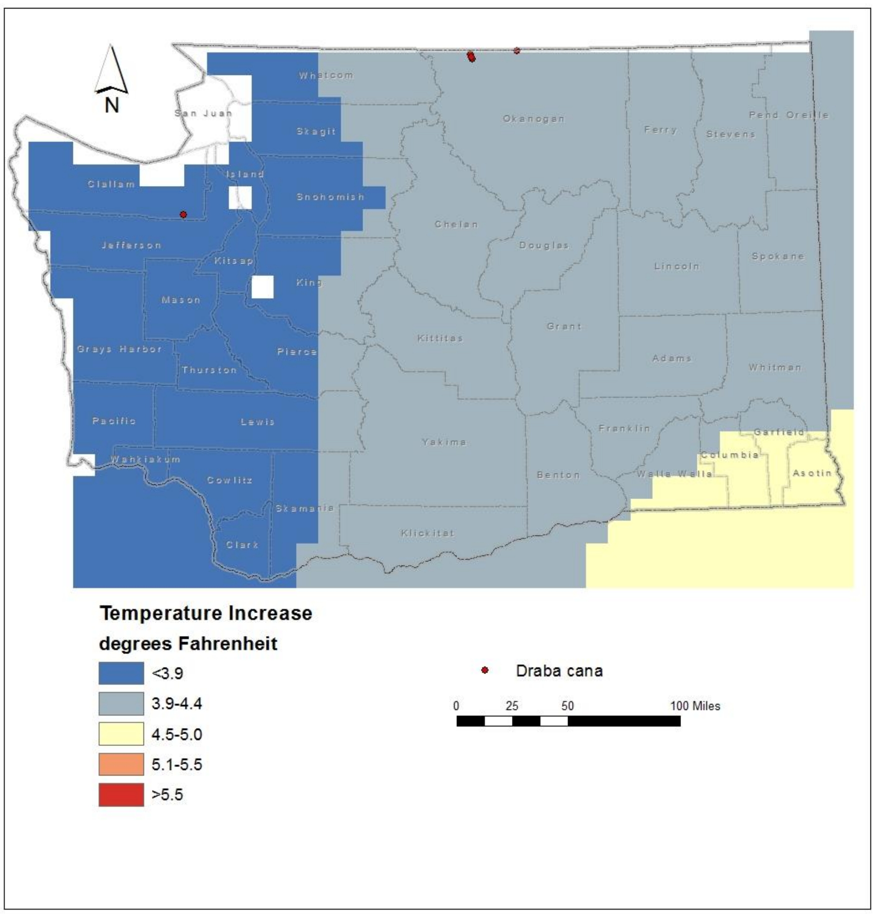

Figure 1. Exposure of *Draba cana* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the five occurrences (80%) of *Draba cana* 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 additional historical population (20%) is from an area with a projected decrease of -0.074 to -0.096.

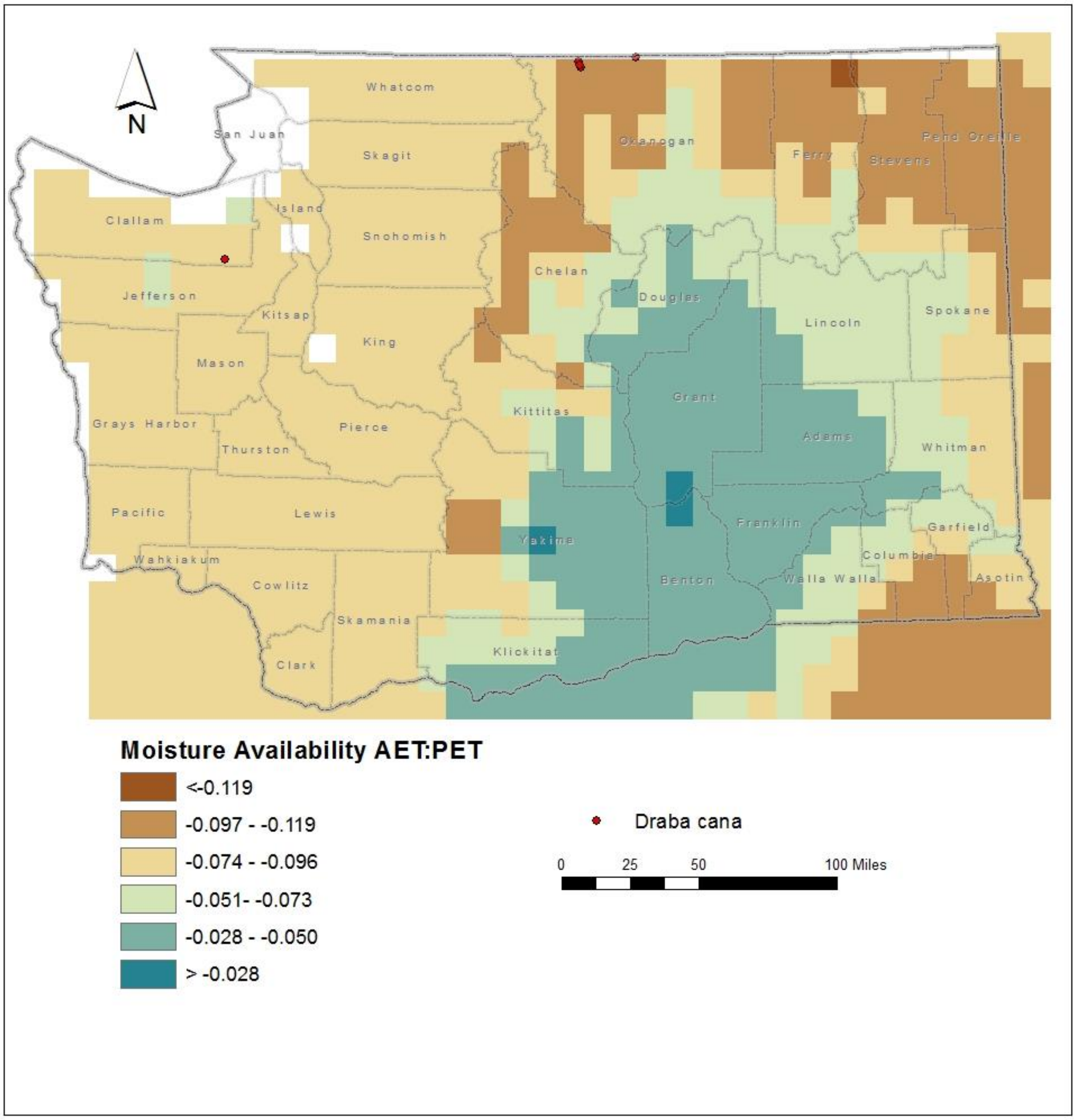

Figure 2. Exposure of *Draba cana* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Draba cana* are found at 5900-7800 feet (1800-2375 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Draba cana occurs on dry, rocky, south-facing alpine or upper subalpine slopes on sandy-loam soils in cushion plant or dry meadow communities (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Rocky Mountain Alpine Bedrock and Scree and Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems (Rocchio and Crawford 2015). Populations in the Okanogan Plateau of north-central Washington are separated from each other by 0.8-20 miles (1.5-32 km) of unoccupied and unsuitable habitat in valleys or broad basins. A single historical occurrence in the Olympic Range is disjunct by 145 miles (235 km) of mostly unsuitable habitat that presents a significant barrier to gene flow.

B2b. Anthropogenic barriers: Neutral.
The alpine and subalpine habitat of *Draba cana* in Washington is located primarily on high peaks in the Okanogan Plateau and in the northeast Olympic Range. These areas are mostly unimpacted by human development and barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Draba cana produces 20-50 small seeds (each 0.6-1 mm wide) in dry silicle fruits that dehisce at maturity to release the seeds passively (Hitchcock and Cronquist 1964). The seeds lack wings, hooks, barbs, or other structures to facilitate dispersal by animals, but due to their small size could be transported by strong winds up to 1,000 meters. Secondary dispersal by foraging animals once seeds land on the ground is also possible.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Draba cana* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the five known occurrences in the state (80%) are found in areas that have experienced small variation (37-47˚F/20.8-26.3˚C) in temperature in the past 50 years and are considered at increased vulnerability to climate change. One population (20%) is from an area of slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation over the same period and is at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Increase.
The subalpine and alpine rocky ridge, cushion plant, and dry meadow habitat of *Draba cana* is exposed to high winds and cold temperatures during the flowering season and highly vulnerable to temperature increases from climate change.

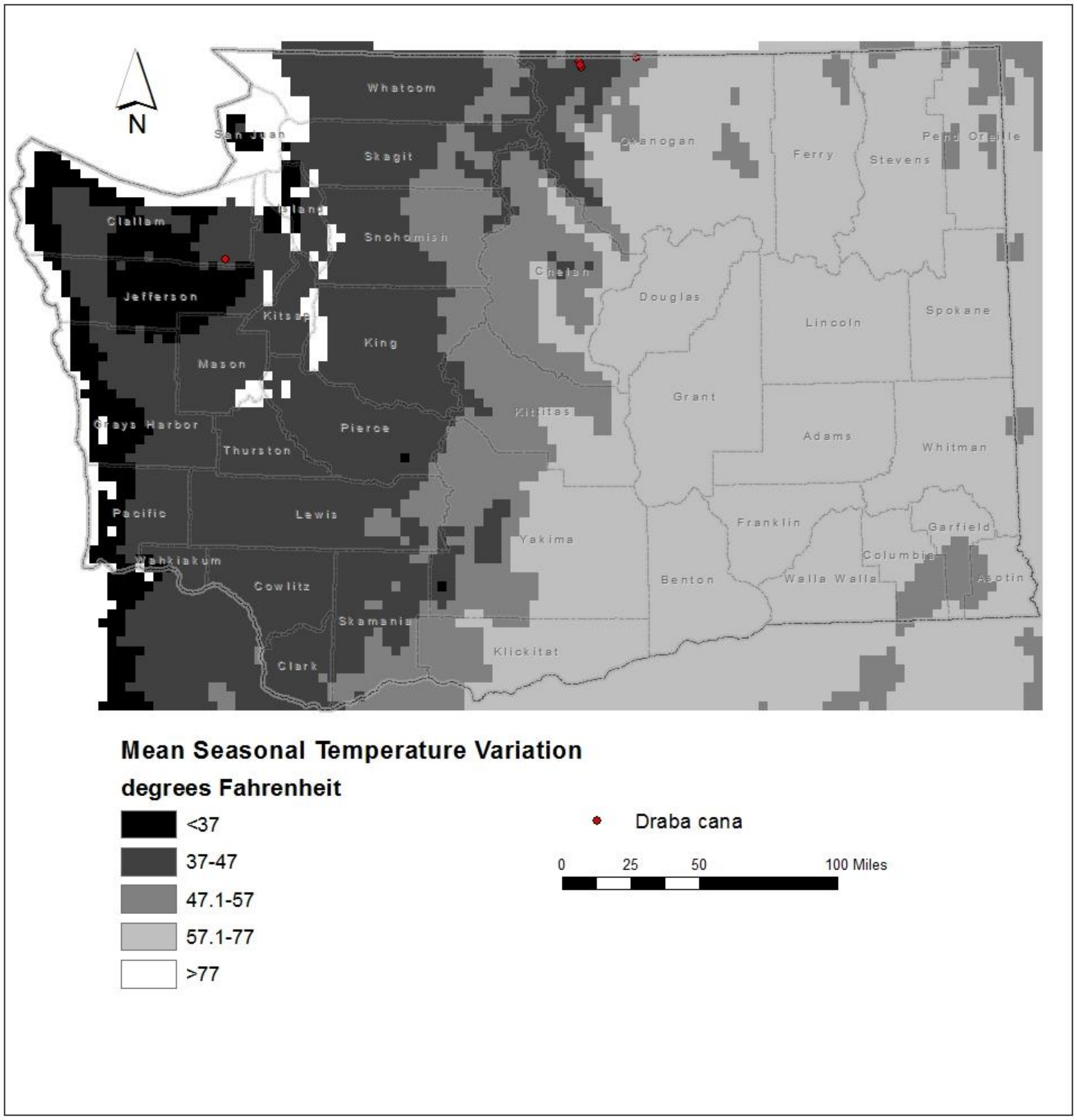

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Draba cana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Draba cana* in Washington are found in areas that have experienced average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

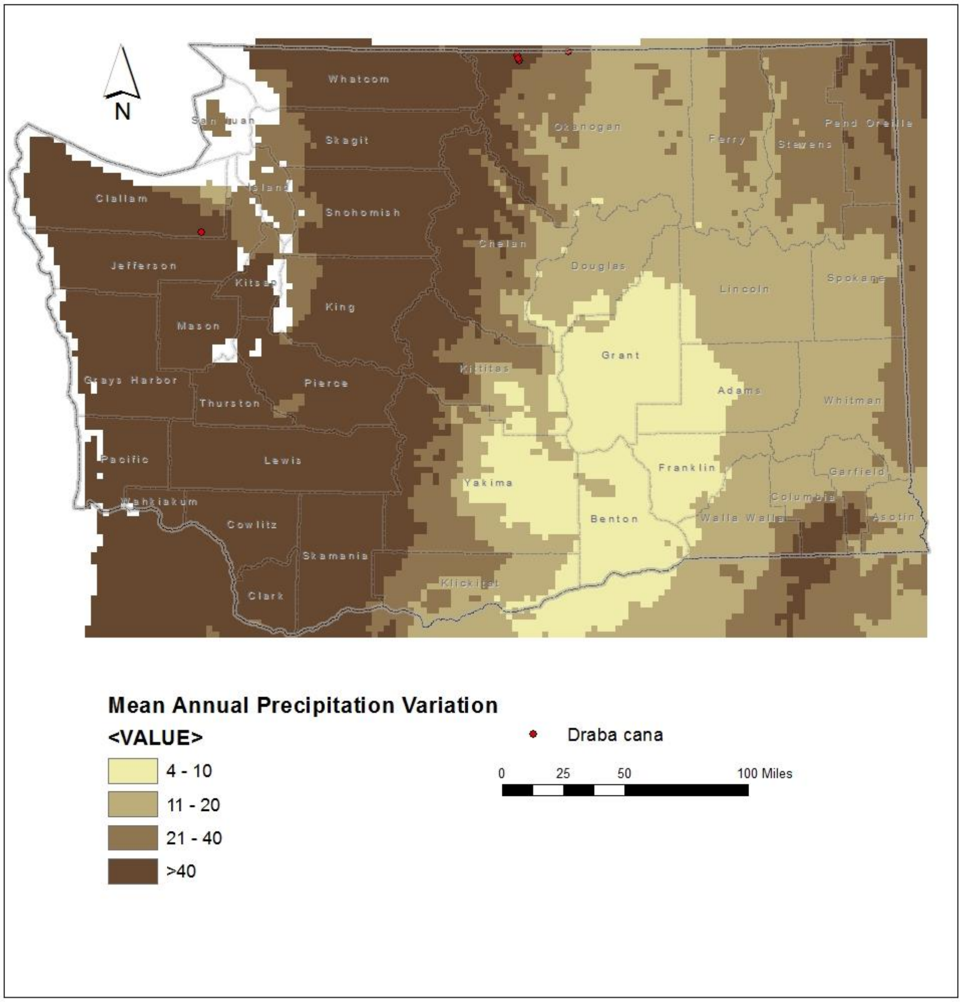

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Draba cana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is found in habitats that are not associated with perennial water sources or a high water table and so is dependent on winter snow and summer precipitation for its moisture needs. It would be vulnerable to changes in the timing or amount of snow and rainfall or snowmelt due to warming conditions (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Draba cana occurs in alpine or subalpine rock crevices, cushion plant communities, or dry meadows subjected to high winds. Other than occasional rock fall, these are largely undisturbed sites at present. Under future climate change scenarios, these sites could become 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).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Draba cana* in Washington are found on rocky alpine or subalpine slopes, dry meadows, or cushion plant communities associated with high winter snow accumulation, although the areas may be free of snow due to evaporation or wind during the growing season. Reduction in the amount of snow or timing of its melt due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
In the Okanogan Plateau, *Draba cana* is found primarily on outcrops of pre-Jurassic granodiorite gneiss of the Quartz Mountain area and tonalitic gneiss of Tillman Mountain. Both of these outcrops are mostly found near the Canadian border. In the Olympic Mountains, *D. cana* is known from Eocene-age uplifted marine sediments found mostly ringing the north and eastern slopes of the range (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
The alpine talus and tundra habitat occupied by *Draba cana* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Draba cana* are not known. Self-pollination is common among arctic and alpine species of *Draba* (Brochmann 1992) and may occur in *D. cana*.

C4d. Dependence on other species for propagule dispersal: Neutral.
The small, light-weight seeds of *Draba cana* are released passively and spread by high winds or gravity. Insects or rodents may transport seeds secondarily once they fall on the ground.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to the harsh environmental conditions of the alpine and upper subalpine zones. With warmer and drier conditions under projected climate change, competition could increase from lower elevation plant species that are able to expand their range into formerly unsuitable alpine habitats (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Beilstein and Windham (2003) documented that *Draba cana* is a tetraploid with a chromosome count of $2n = 32$. No data are available on genetic variability of Washington populations.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral/Somewhat Increase.
The reproductive biology of *Draba cana* is poorly known. Many arctic and alpine *Draba* taxa reproduce by agamospermy in which fertile seeds are produced without pollination (Brochmann 1992). Due to a lack of genetic intermixing, these species would be expected to have low genetic diversity. Washington populations of *Draba cana* are isolated from other U.S. occurrences in the Rocky Mountains and near the edge of the species' range in Canada and thus likely have lower genetic variability due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on Washington Natural Heritage Program element occurrence data, *Draba cana* has not changed its typical blooming time in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
Two of the five documented populations of *Draba cana* in Washington are historical and have not been relocated since the mid 1970s and early 1980s (including the disjunct occurrence from the Olympic Range). Whether these populations are extirpated or have gone undetected is not known. If extirpated, the cause of mortality is not known.

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

References

Beilstein, M.A. and M.D. Windham. 2003. A phylogenetic analysis of western North American *Draba* (Brassicaceae) based on nuclear ribosomal DNA sequences from the ITS region. Systematic Botany 28(3): 584-592.

Brochmann, C. 1992. Reproductive strategies of diploid and polyploid populations of arctic *Draba* (Brassicaceae). Plant Systematics and Evolution 185: 55-83.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Hitchcock, C.L. and A. Cronquist. 1964. Part 2: Salicaceae to Saxifragaceae. In: C.L. Hitchcock, A. Cronquist, M. Ownbey, and J.W. Thompson, eds. Vascular Plants of the Pacific Northwest. University of Washington Press, Seattle, WA. 597 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021. *Draba cana*. In: Online Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=draba%20cana). Accessed 4 October 2021.

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

Draba taylorii (Taylor's draba)

Date: 8 March 2021

Synonym: *Draba taylori* (orthographic variant)

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G1G2/S1

Index Result: Highly Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change	**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: Sensitivity and Adaptive Capacity	
1. Dispersal and movements	Increase/Somewhat Increase
2ai Change in historical thermal niche	Somewhat 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	Increase
3. Restricted to uncommon landscape/geological features	Somewhat Increase
4a. Dependence on others 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	Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: Both occurrences of *Draba taylorii* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

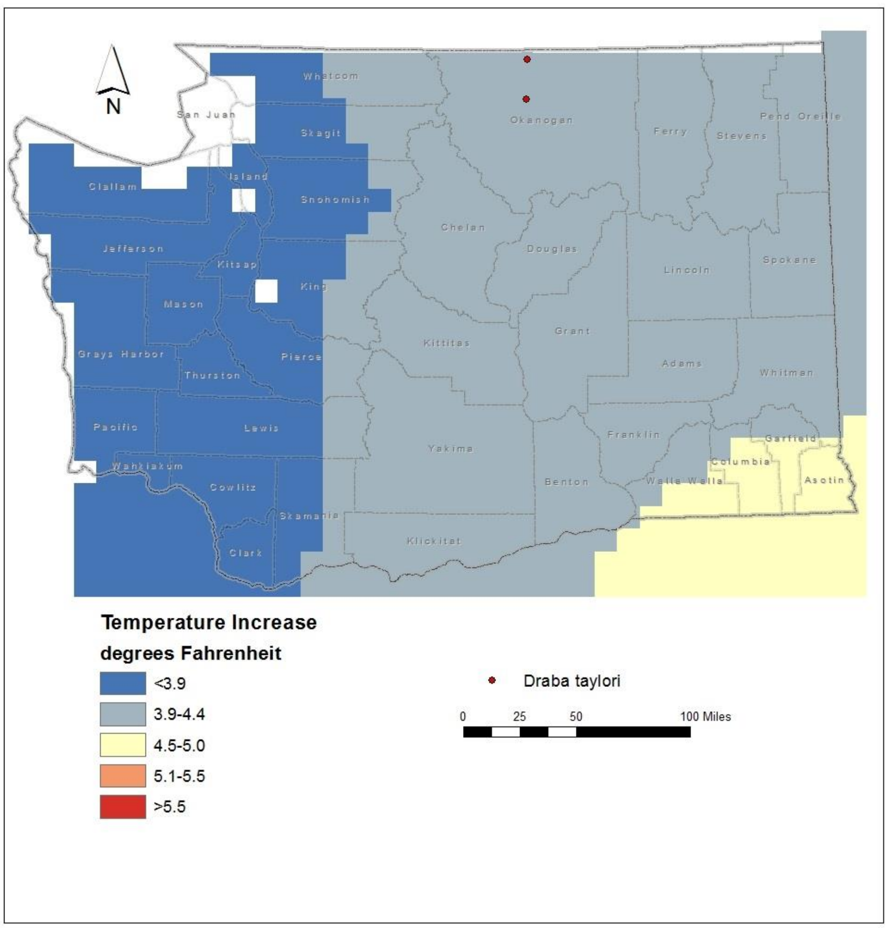

Figure 1. Exposure of *Draba taylorii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The two occurrences of *Draba taylorii* 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 -0.097 to -0.119 (Figure 2).

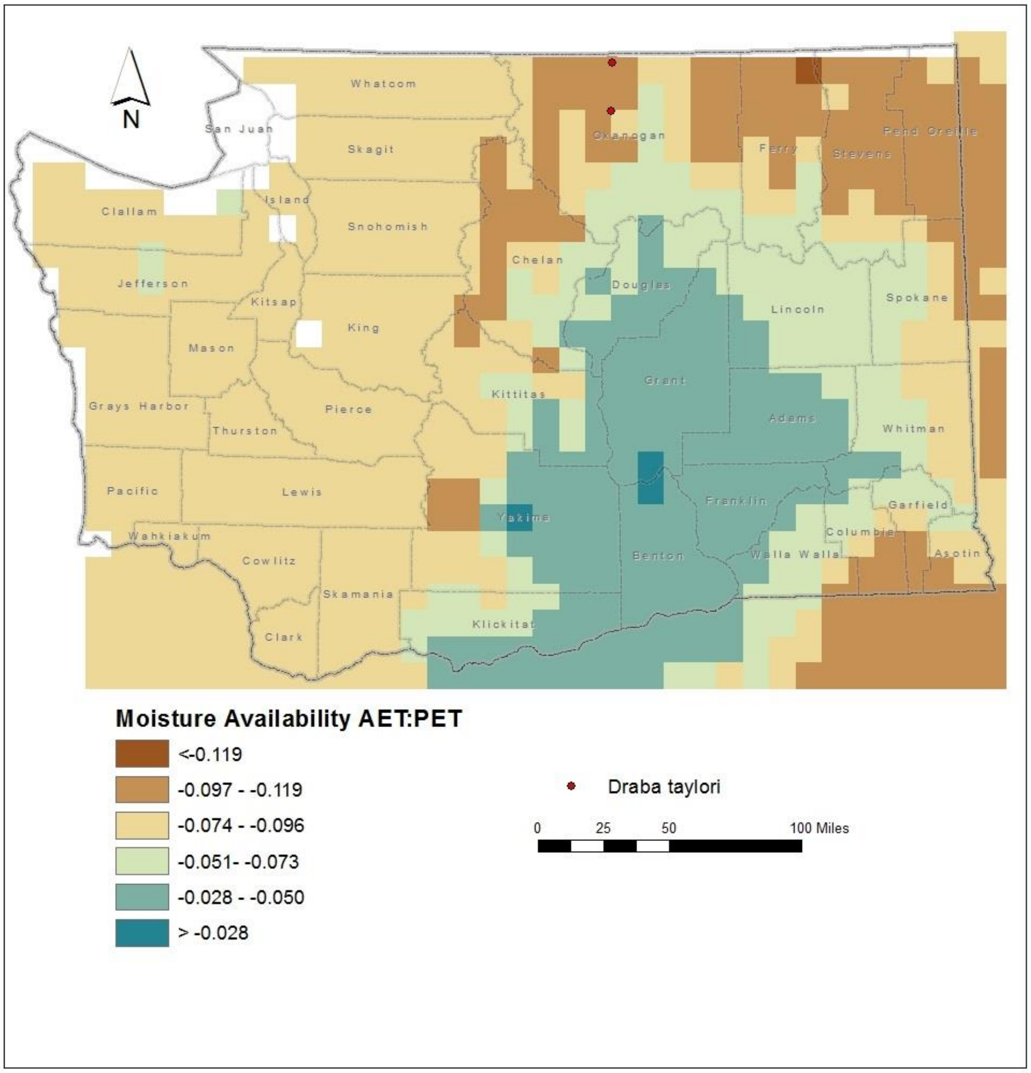

Figure 2. Exposure of *Draba taylorii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Draba taylorii* are found at 7910-7980 feet (2410-2435 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Draba taylorii occurs on east and southwest-facing rims and flat summits of gneiss and metagabbro bedrock in upper subalpine fellfield and turf communities of Engelmann sedge (*Carex engelmannii*), northern single-spike sedge (*C. scirpoidea*), Drummond's rush (*Juncus drummondii*), Spike oatgrass (*Trisetum spicatum*), alpine sandwort (*Cherleria obtuisloba*), blueleaf cinquefoil (*Potentilla glaucophylla*), and spotted saxifrage (*Saxifraga austromontana*) (Fertig 2020). This habitat is part of the Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological system (Rocchio and Crawford 2015). The Washington populations are separated from each other by 21 miles (35 km) of mostly unoccupied and unsuitable habitat. The full range of the species may not yet be known, since it is recently described and probably under-collected. Natural barriers may be sufficient to restrict gene flow between populations and impede future migration.

B2b. Anthropogenic barriers: Neutral.
The subalpine/alpine habitat of *Draba taylorii* in Washington is located primarily within wilderness areas and sparsely developed areas in the Okanogan Range. Some roads and scattered ranches and homesites are present, but do not present a significant barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase/Somewhat Increase.
Draba taylorii produces infructescences of 2-4 dry, silicle fruits with 6-10 smooth, wingless seeds 1-1.3 mm long (Al-Shehbaz and Mulligan 2013). These seeds are probably dispersed short distances by high winds or secondarily by insects or rodents once they land on the ground. Average dispersal distances are not known, but are likely to be less than 100 m from the parent plant, with longer dispersal possible under rare conditions, such as extreme weather events with high winds.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Draba taylorii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Both known occurrences in the state (100%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016).

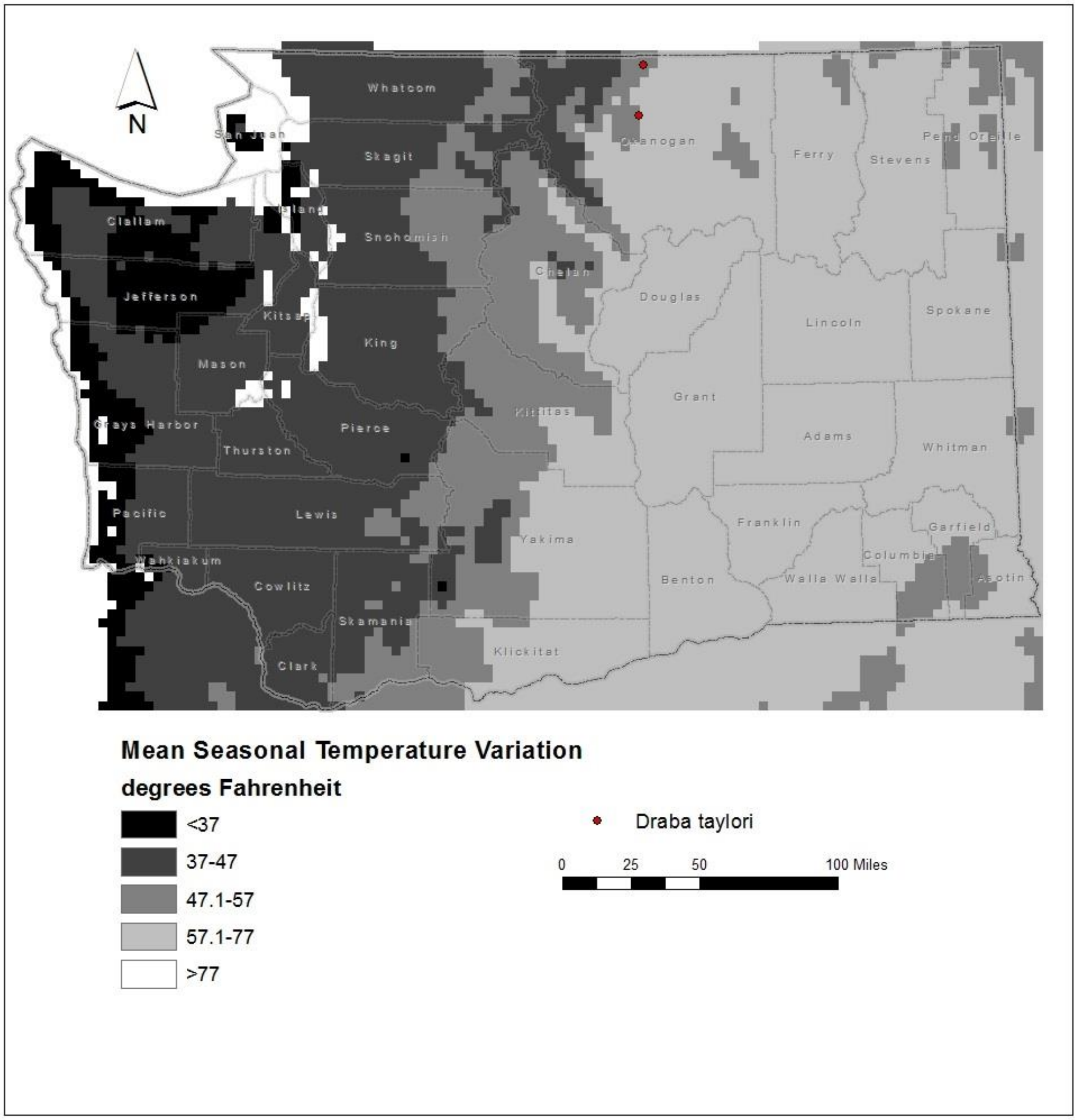

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Draba taylorii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Greatly Increase.
The subalpine rock and ledge habitat of *Draba taylorii* is exposed to high winds and cold temperatures throughout the growing season and is highly vulnerable to temperature increases due to climate change.

C2bi. Historical hydrological niche: Neutral.
Both of the known populations of *Draba taylorii* in Washington (100%) are from areas that have experienced average precipitation variation in the past 50 years (20-40 inches/508-1016

mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

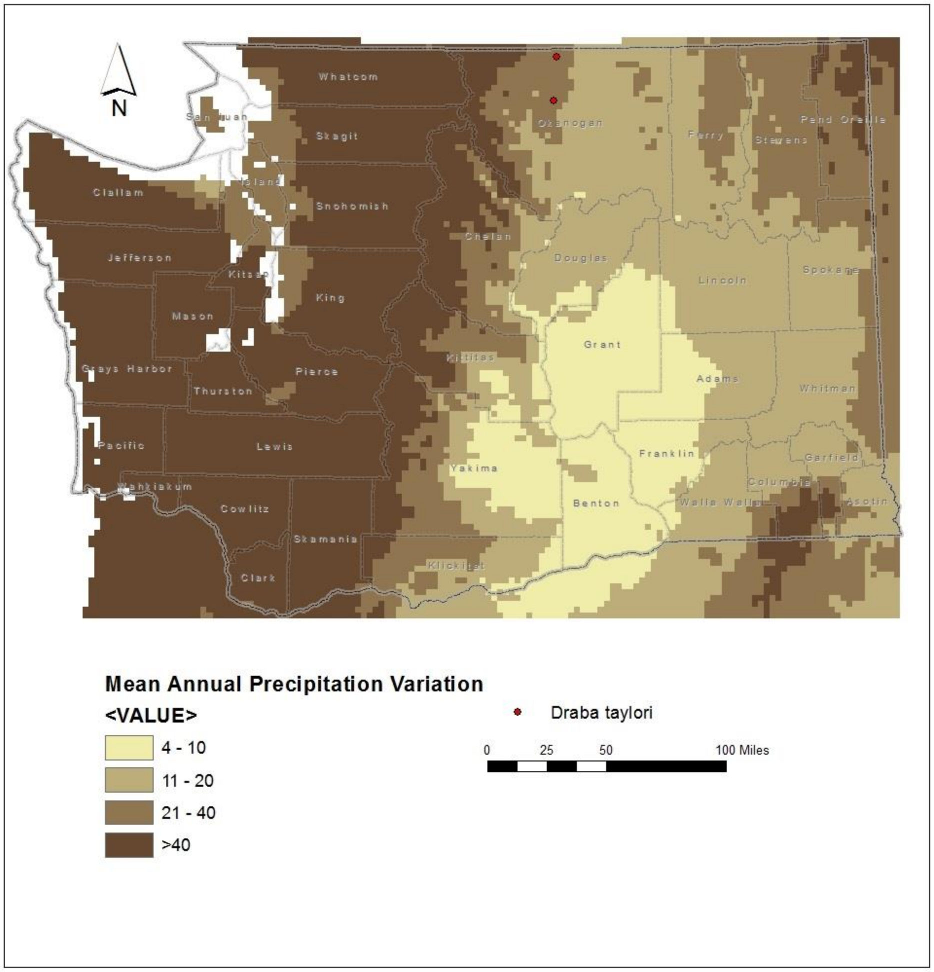

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Draba taylorii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on winter snow and summer precipitation for meeting its moisture needs, as it is not associated with wetlands or soils with a high water table. As such, it could 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: Neutral.
Draba taylorii occurs in upper subalpine ledge and rock outcrop habitats that are subject to high winds and occasional rock fall.

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Draba taylorii* in Washington are found on upper subalpine ridgecrests and rocky ledges in areas of moderate to high snowfall. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017)

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Draba taylorii is found on outcrops of gneiss and metagabbro in the Okanogan Mountains (Washington Division of Geology and Earth Resources 2016). These rock types are of limited distribution in Washington outside of the Okanogan Range.

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus and tundra habitat occupied by *Draba taylorii* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Based on its small flower size and sterile anthers, *Draba taylorii* appears to be an apomictic species capable of producing fertile seed without pollination (Al-Shehbaz and Mulligan 2013; Hitchcock and Cronquist 2018).

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds of *Draba taylorii* are small and light weight and are probably dispersed by wind. Insects or rodents might transport seeds short distances and cache them for later consumption. *Draba taylorii* is probably not dependent for dispersal by a specific animal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Currently, competition from non-native species is low, as few introduced plants are adapted to the harsh environmental conditions of the upper subalpine zone and cover of native species is low. Under projected climate change, competition could increase if lower elevation plant species are able to expand their range into formerly uninhabitable habitat (Rocchio and Ramm-Granberg 2017) due to longer growing seasons and increases in primary productivity resulting in more soil formation (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Not known.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Increase.
Al-Shehbaz and Mulligan (2013) consider *Draba taylorii* to be an apomictic species based on it not producing fertile pollen. Apomixis is a form of asexual reproduction in which fertile ovules are produced without pollination (also called agamospermy) and is common in the genus *Draba*, particularly for species from northern latitudes or of hybrid or polyploid origin (Al-Shehbaz et al. 2010, Brochmann 1992). Due to the lack of genetic intermixing, apomictic species tend to have low genetic diversity. Studies of the genetic variability and chromosome number have not been conducted for *D. taylorii* (Al-Shehbaz and Mulligan 2013).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Draba taylorii* has not changed its typical blooming time since the 1930s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Draba taylorii* is poorly known since it was only described as a new species in 2013. One population discovered in 1933 was relocated in 2018.

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

References

Al-Shehbaz, I.A. and G.A. Mulligan. 2013. New or noteworthy species of *Draba* (Brassicaceae) from Canada and Alaska. Harvard Papers in Botany 18(2): 101-124.

Al-Shehbaz, I.A., M.D. Windham, and R. Elven. 2010. *Draba*. Pp. 269-347. In: Flora of North America Editorial Committee. Flora of North America North of Mexico. Volume 7 Magnoliophyta: Salicaceae to Brassicaceae. Oxford University Press, New York. 797 pp.

Brochmann, C. 1992. Reproductive strategies of diploid and polyploid populations of arctic *Draba* (Brassicaceae). Plant Systematics and Evolution 185: 55-83.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, Washington Department of Natural Resources, Olympia, WA. 97 pp.

Hitchcock, C.L. and A. Cronquist. 2018. Flora of the Pacific Northwest, an illustrated manual, second edition. Edited by D.E. Giblin, B.S. Legler, P.F. Zika, and R.G. Olmstead. University of Washington Press and Burke Museum of Natural History and Culture, Seattle, WA. 882 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021. *Draba taylorii*. In: Online Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=draba%20taylorii). Accessed 4 October 2021.

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

Erigeron aliceae (Alice's fleabane)

Date: 12 October 2021

Assessor: Walter Fertig, 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: Local Climate	**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	81.8
	-0.051 to - 0.073	18.2
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral
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		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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: Documented or Modeled Response	
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: All 11 of the extant and historical occurrences of *Erigeron aliceae* in Washington (100%) occur in areas with a projected temperature increase of <3.9° F (Figure 1).

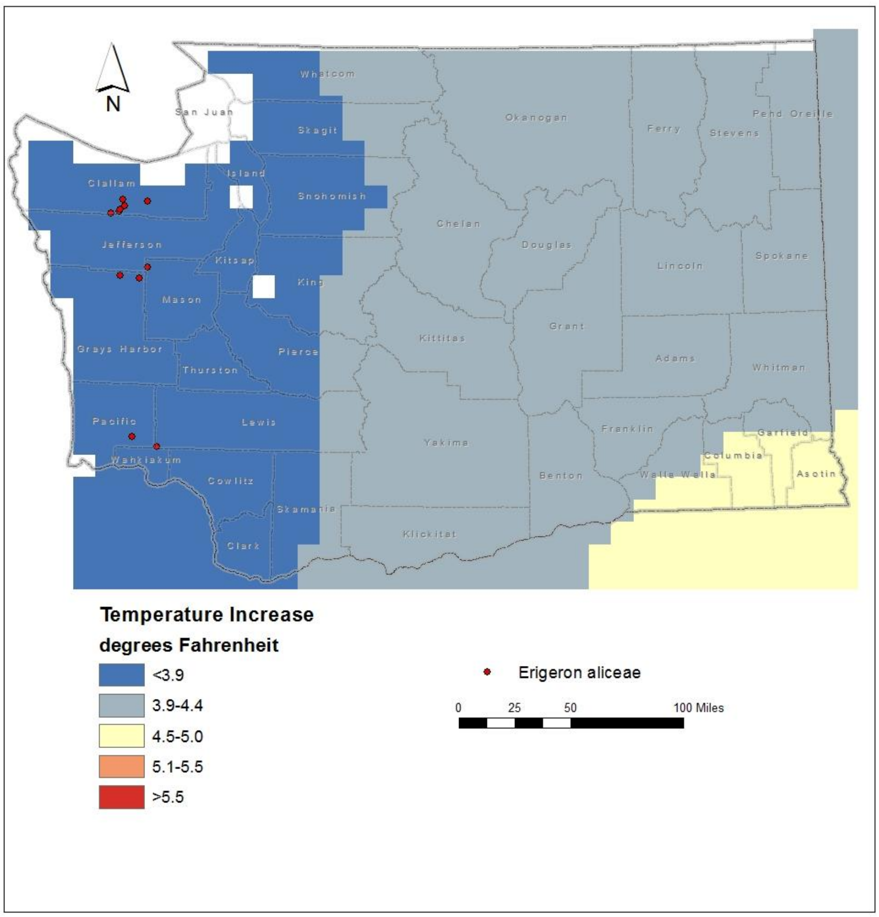

Figure 1. Exposure of *Erigeron aliceae* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

Two additional reports from Ferry and Yakima counties in eastern Washington have not been verified and are excluded from this assessment.

A2. Hamon AET:PET Moisture Metric: Nine of the 11 occurrences (81.8%) of *Erigeron aliceae* 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 other two occurrences (18.2%) are in areas with a projected decrease of -0.051 to -0.073 (Figure 2).

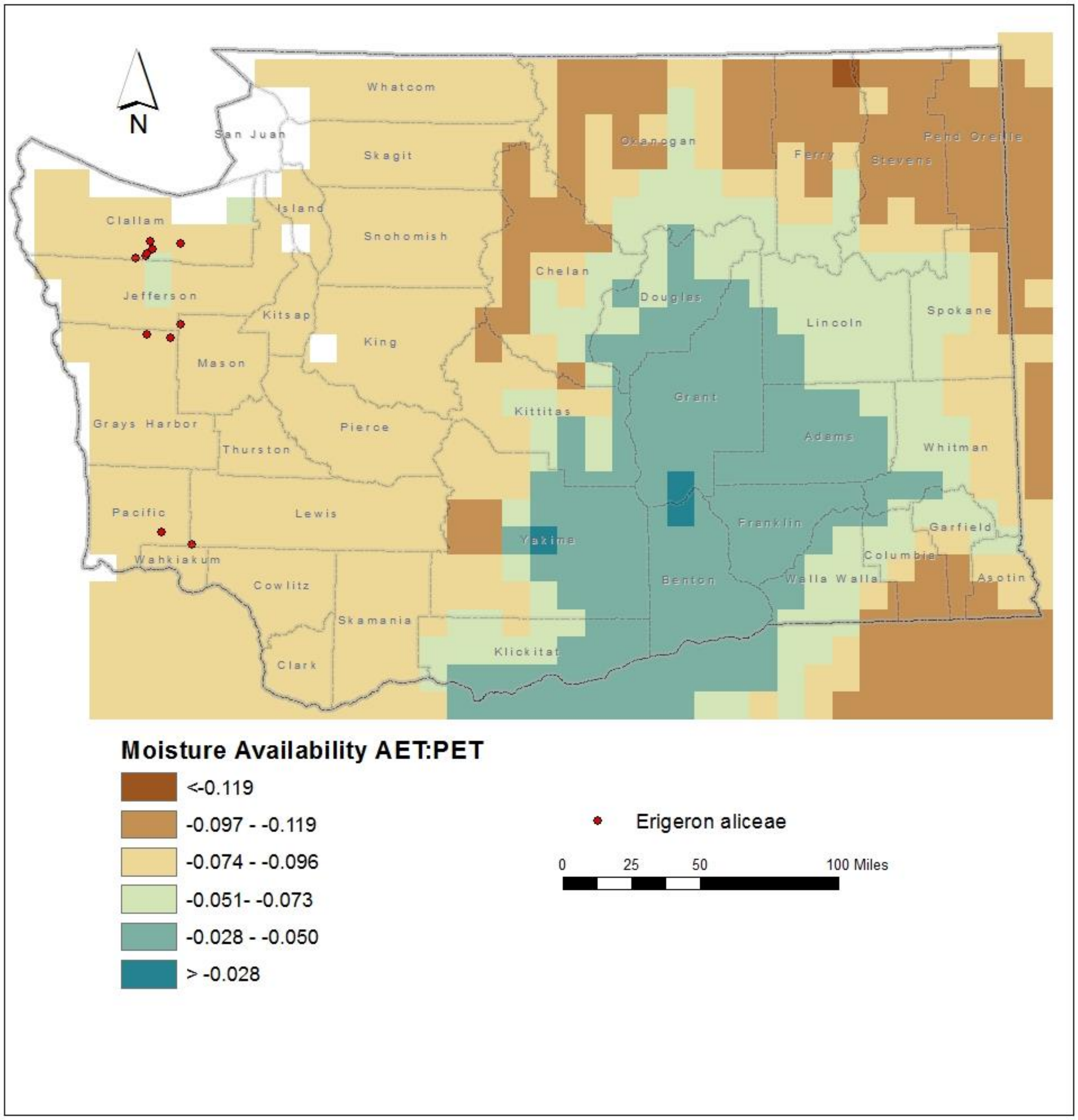

Figure 2. Exposure of *Erigeron aliceae* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Erigeron aliceae* are found at 2600-5475 feet (790-1670 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Erigeron aliceae populations in Washington are found primarily in subalpine meadows and rocky talus slopes or streamsides in forested areas (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the North Pacific Alpine & Subalpine Dry Grassland and North Pacific Montane Massive Bedrock, Cliff, & Talus ecological systems (Rocchio and Crawford 2015). Populations may be isolated from each other by 1-70 miles (1.8-112 km) of unoccupied lowland habitat between the Olympic Range and the Willapa Hills.

B2b. Anthropogenic barriers: Somewhat Increase.
Most of the subalpine habitat of *Erigeron aliceae* in the Olympic Range is found in high elevation National Park or Wilderness lands with a minimal human imprint. Areas between the Olympics and Willapa Hills populations are a patchwork of second growth logged forests and other human infrastructure that may reduce dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Erigeron aliceae produces numerous, small, one-seeded dry fruits (cypselae), each topped by a pappus of 18-32 hair-like bristles that are adapted for dispersal by the wind. Dispersal distances may vary, but the species has the potential for moderate to long-distance dispersal (over 1 km).

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Erigeron aliceae* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the 11 known occurrences in the state (63.6%) are found in areas that have experienced very small temperature variation (<37˚F/20.8˚C) during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). The four other occurrences (36.4%) are from areas that have had a small variation (37-47˚F/20.8-26.3˚C) in temperature over the same period and are at increased vulnerability to climate change.

C2aii. Physiological thermal niche: Increase.
The subalpine meadow and exposed rocky talus habitat of *Erigeron aliceae* is entirely within a cold climate zone during the flowering season and vulnerable to increased temperatures from climate change.

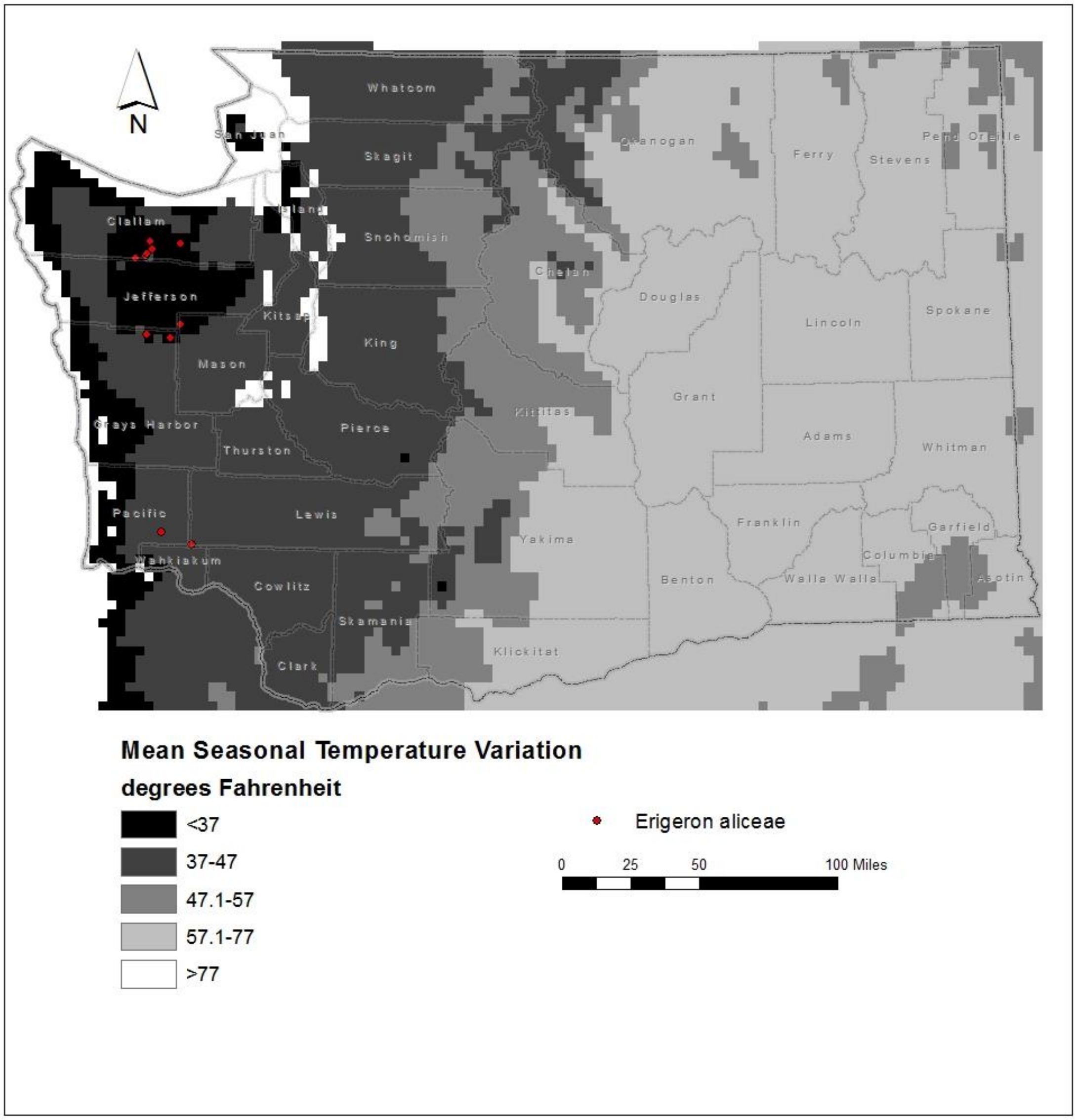

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Erigeron aliceae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Erigeron aliceae* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

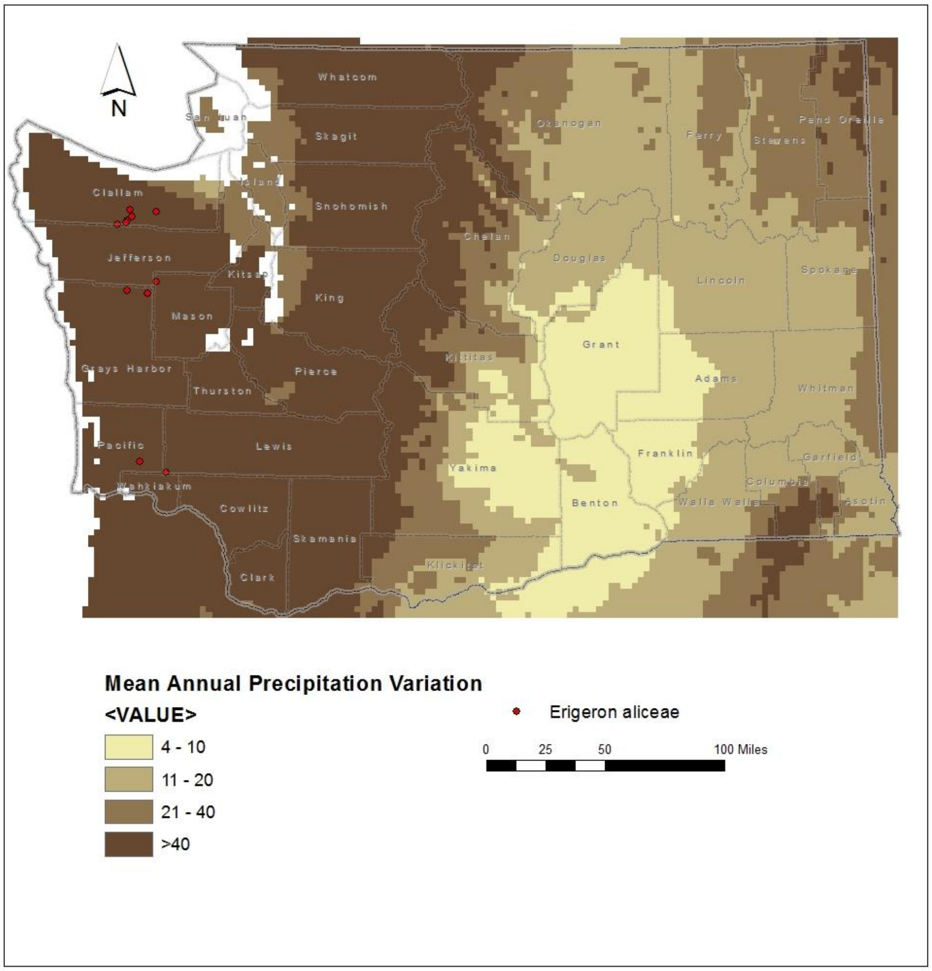

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Erigeron aliceae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Some populations of this species are associated with perennial water sources, but others are dependent on adequate winter snowpack or rainfall during the growing season. Changes in the amount or timing or precipitation or snowmelt could impact the persistence of *Erigeron aliceae* in meadow or talus sites.

C2c. Dependence on a specific disturbance regime: Neutral.
Erigeron aliceae occurs in subalpine meadows, talus, and forested streambanks. Open sites may be exposed to strong winds. Fire is infrequent in these high elevation habitats (Rocchio and Ramm-Granberg 2017). Soil characteristics and snowmelt dynamics may be the key drivers in maintaining these systems, rather than disturbance.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Erigeron aliceae* in the Olympic Range are associated with high winter snow accumulation. Reduced snowpack due to climate change, or changes in the timing of snowmelt, could decrease the amount of moisture available during the growing season (Rocchio and Ramm-Granberg 2017) and favor plant species adapted to drier conditions. Populations from the Willapa Hills are less dependent on winter snow, but occur in areas of high winter rainfall.

C3. Restricted to uncommon landscape/geological features: Neutral.
Erigeron aliceae is found primarily on uplifted Eocene or Oligocene-age marine sediments that are relatively widespread in the Olympic Range and Willapa Hills (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
The subalpine meadow and talus habitat of *Erigeron aliceae* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Erigeron aliceae, like most composites, is pollinated by generalist insect pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Erigeron aliceae* have a pappus of hair-like bristles for dispersal by wind, and thus are not dependent on animal species for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species may be vulnerable to grazing or trampling by introduced mountain goats in the Olympic Range (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Under projected climate change, the subalpine meadow and talus habitat of *Erigeron aliceae* could become drier during the growing season due to changes in the amount or timing of snowmelt or summer rainfall, favoring native and introduced plant species adapted to drier conditions (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
The genetic diversity within and between populations of *Erigeron aliceae* in Washington is not known. Molecular analysis of *E. aliceae* has focused mostly on deducing its relationship with other *Erigeron* taxa. Noyes (2000) found a relationship with species in Section *Asteroidea* (such as *E. eatonii* or *E. corymbosus*), whereas Nesom (2008) found stronger morphological similarities with other tall, leafy, aster-like species of Section *Fruticosus* (such as *E. glacialis*, *E. formosissimus*, and *E. howellii*). Being at the north end of its range, Washington populations of *E. aliceae* might be expected to have less overall genetic diversity due to limits on gene flow or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Erigeron aliceae is an obligate outcrosser and is not limited by pollinators or dispersal, so is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), no changes have occurred in the blooming period of *Erigeron aliceae* (June through August) in 90 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Erigeron aliceae* in Washington since it was first discovered in the state in the 1930s.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Nesom, G.L. 2008. Classification of Subtribe Conyzinae (Asteraceae: Astereae). Lundellia 2008(11): 8-38.

Noyes, R.D. 2000. Biogeographical and evolutionary insights on *Erigeron* and allies (Asteraceae) from ITS sequence data. Plant Systematics and Evolution 220:93-114.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Erigeron aliceae*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=erigeron%20aliceae). Accessed 12 October 2021.

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

Erigeron basalticus (Basalt daisy)

Date: 22 January 2019

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G2/S2

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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		Increase
4a. Dependence on others 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
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Neutral
5b. Genetic bottlenecks		Unknown

5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All six of the known occurrences of *Erigeron basalticus* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

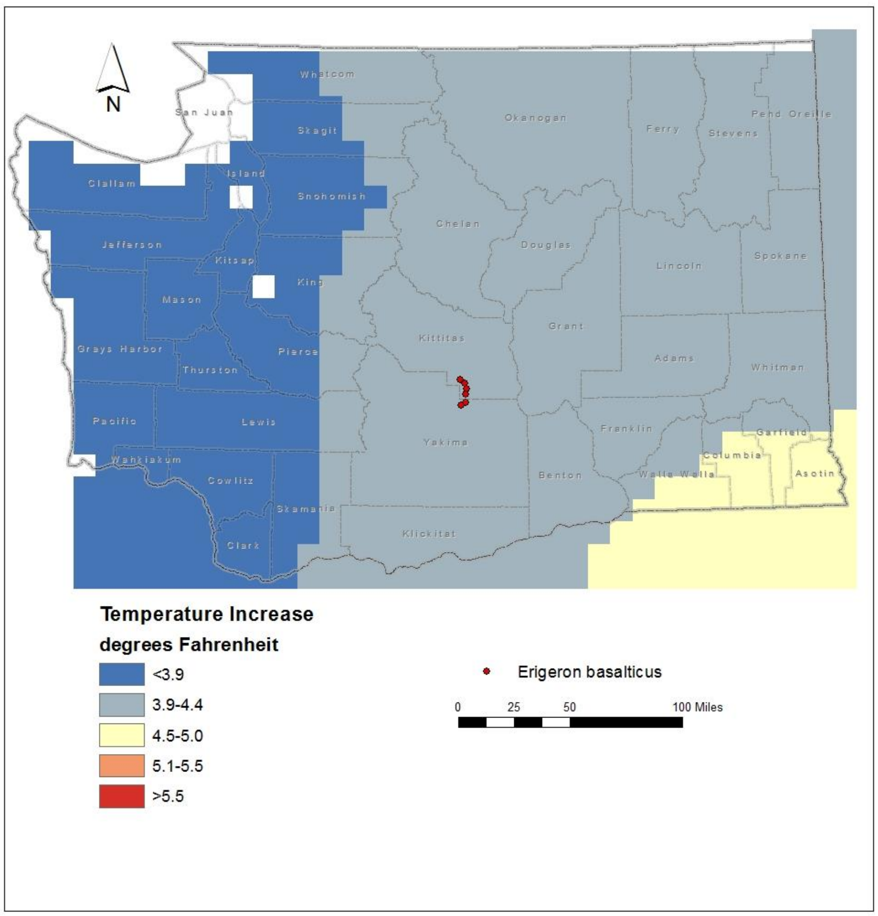

Figure 1. Exposure of *Erigeron basalticus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The six Washington occurrences of *Erigeron basalticus* (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 --0.028 to -0.050 (Figure 2).

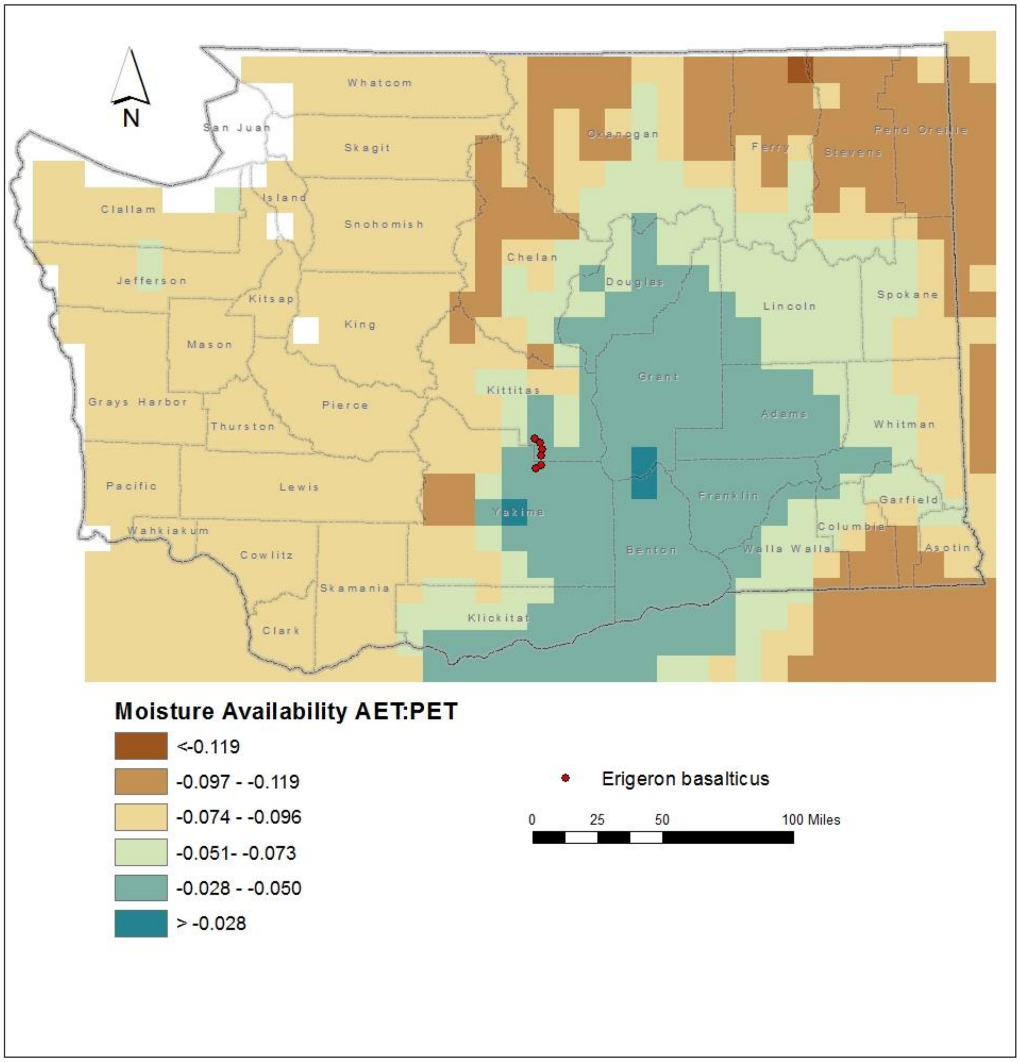

Figure 2. Exposure of *Erigeron basalticus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.

Washington occurrences of *Erigeron basalticus* are found at 1200-1500 feet (380-460 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Erigeron basalticus* is found in crevices in columnar basalt cliffs and basalt roadsides on east, west, and north-facing cliffs (Camp and Gamon 2011, Fertig 2020, Gamon 1998). This habitat is part of the Inter-Mountain Basins Cliff and Canyon ecological system (Rocchio and Crawford 2015). Individual populations are separated by 0.37-2.5 miles (0.5-4 km). The entire range of the species is restricted to a 3 x 11 mile area (4.5 x 17 km). Intervening lowland habitat is unsuitable, and the Yakima River bisects these populations, but probably does not impose a significant barrier to dispersal or gene flow.

B2b. Anthropogenic barriers: Neutral.
The range of *Erigeron basalticus* in Washington is constrained by the distribution of appropriate basalt cliff habitat in the Yakima River Canyon and Selah Creek areas. Washington State Highway 821 follows the Yakima River and Interstate 82 bisects the eastern edge of the population. These and bottomland agricultural lands present minor barriers to dispersal or gene flow.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity
C1. Dispersal and movements: Neutral.
Erigeron basalticus produces numerous small one-seeded achenes topped by a feathery pappus that are adapted for dispersal by wind. Dispersal distances will vary depending on prevailing weather conditions, but fruits have the potential for moderate to long-distance dispersal (over 1 km).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Erigeron basalticus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All six of the known occurrences (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral risk from climate change.

C2aii. Physiological thermal niche: Somewhat Increase.
Erigeron basalticus tends to occur in crevices and somewhat sheltered north, east, and west facing cliffs where temperature conditions are moderated by shade.

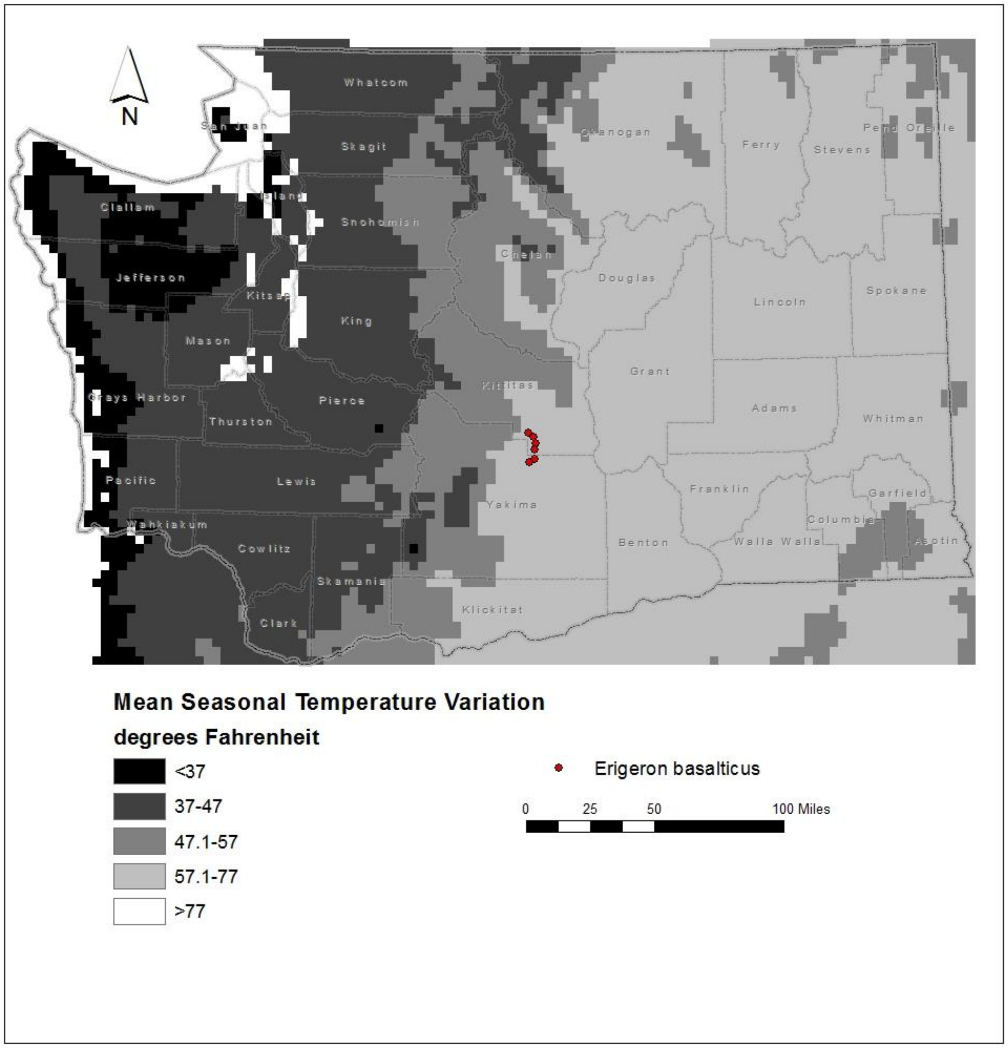

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Erigeron basalticus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Increase.
Four of the six occurrences of *Erigeron basalticus* in Washington (66.7%) are found in areas that have experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at increased vulnerability from climate change. Two other populations (33.3%) are from areas with slightly lower than average precipitation variation (11-20 inches/255-508 mm) over the same period and are at somewhat increased vulnerability.

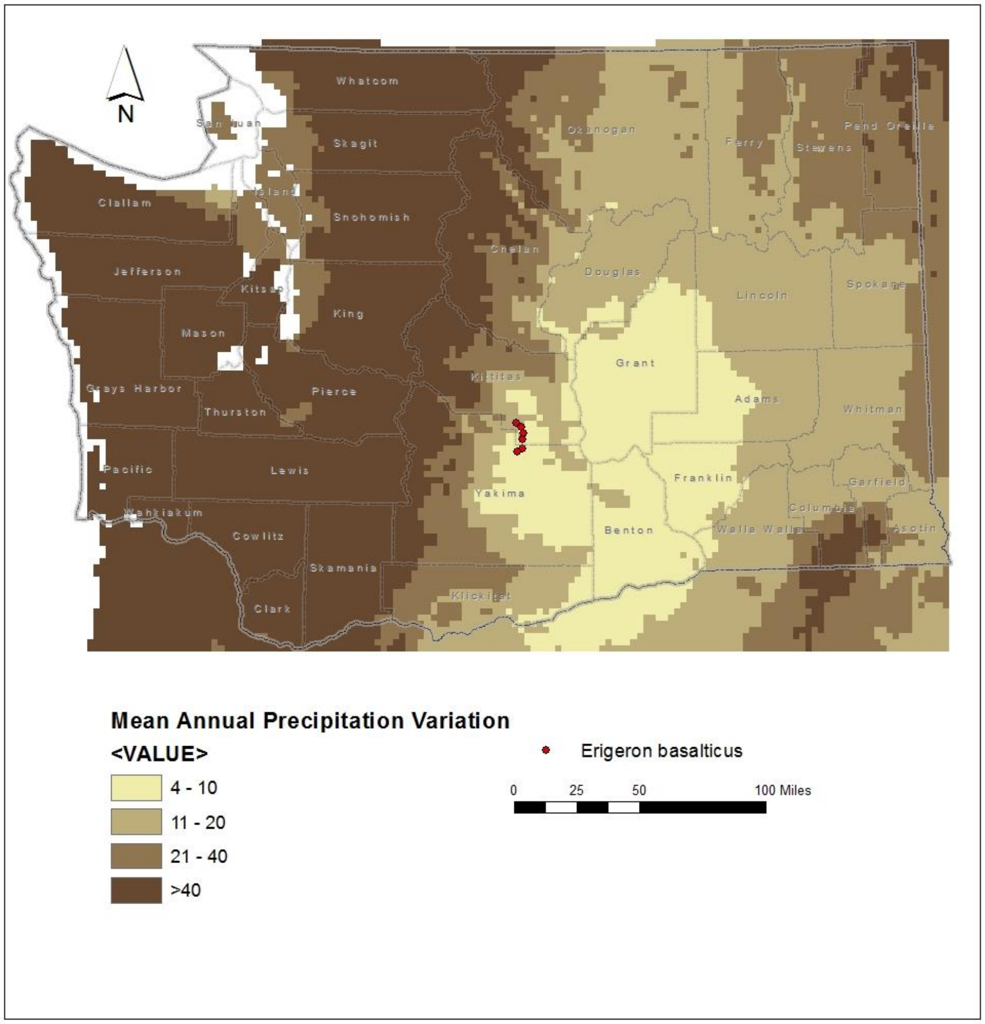

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Erigeron basalticus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
This species is dependent on precipitation and winter snow for its moisture requirements, because its habitat is not associated with springs, streams, or groundwater. At one occurrence, additional water comes from irrigation runoff from an orchard located above the cliff habitat (Petrina 2011). The Inter-Mountain Basins Cliff and Canyon ecological system is vulnerable to changes in the timing or amount of precipitation and increases in temperature (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Erigeron basalticus is not dependent on periodic disturbances to maintain its basalt cliff habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral.
In Washington, *Erigeron basalticus* occurs in areas of low to moderate snow accumulation. These populations are probably more adversely affected by changes in the timing and volume of rainfall due to projected climate change (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Erigeron basalticus is restricted to the Yakima Basalt Formation (Fertig 2020; Gamon 1998, Washington Division of Geology and Earth Resources 2016). This formation is related to the widespread Columbia River Basalt Group, but is restricted to cliffs in Yakima Canyon between Ellensburg and Yakima (Mackin 1961).

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Erigeron basalticus* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Somewhat Increase.
Petrina (2011) determined that *Erigeron basalticus* is primarily self-incompatible and pollinated by insects from at least 13 genera. At least 89% of observed insect visits were by species of Diptera (flies) in the genus *Mythicomyia* and Hymenoptera (bees and wasps) in the genera *Geron, Colletes,* and *Augochlora* (Petrina 2011). Mythicomyid flies are numerous but quite small and perhaps are ineffectual pollinators (Petrina 2011). The relatively low diversity of pollinators and irregular visitation (impacted by weather, pesticide drift, and number of flowering heads; Petrina 2011) makes *Erigeron basalticus* somewhat more vulnerable than more common Asteraceae species with generalist pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Erigeron fruits have a feathery pappus and are readily dispersed by wind, and thus not dependent on animal species for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
In her study of its reproductive biology, Petrina (2011) observed that 14 of 60 tagged flowering heads of *Erigeron basalticus* (23%) were infected by fungi or eaten by herbivores. Due to its remote cliff habitat, *Erigeron basalticus* receives minimal impacts from livestock or ungulate grazing. Overall impacts are probably low.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Rocky microsites occupied by *Erigeron basalticus* are not especially vulnerable to competition from other native or introduced plant species.

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

C5a. Measured genetic variation: Neutral.
No genetic data are available for *Erigeron basalticus* populations.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Erigeron basalticus produces perfect flowers that are pollinated by flies, wasps, and bees. Self-pollination is low (Petrina 2011).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on data from the Consortium of Pacific Northwest herbaria website, no major changes have been observed in phenology in the last 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Erigeron basalticus* has not changed notably in the last 50 years.

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

References
Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Gamon, J. 1998. Report on the status of *Erigeron basalticus* Hoover. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. 23 pp. + app.

Mackin, J.H. 1961. A stratigraphic section in the Yakima Basalt and the Ellensburg Formation in south-central Washington. Division of Mines and Geology. Report of Investigations No. 19. Washington Department of Conservation, Olympia, WA.

Petrina, D. 2011. Pollination of Basalt daisy (*Erigeron basalticus*: Asteraceae). Master's Thesis. Central Washington University, Ellensburg, WA. All Master's Theses. 1476. https://digitalcommons.cwu.edu/etd/1476.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series

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http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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Climate Change Vulnerability Index Report

Eritrichium argenteum (Pale alpine forget-me-not)

Date: 10 March 2021 Synonym: *E. nanum* var. *elongatum*

Assessor: Walter Fertig, 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: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat 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		Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on others 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		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 B: Indirect Exposure to Climate Change	
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: The single known occurrence of *Eritrichium argenteum* in Washington (100%) occurs in an area with a projected temperature increase of 3.9-4.4° F (Figure 1). Reports from Benton and Walla Walla counties are based on misidentifications and are excluded.

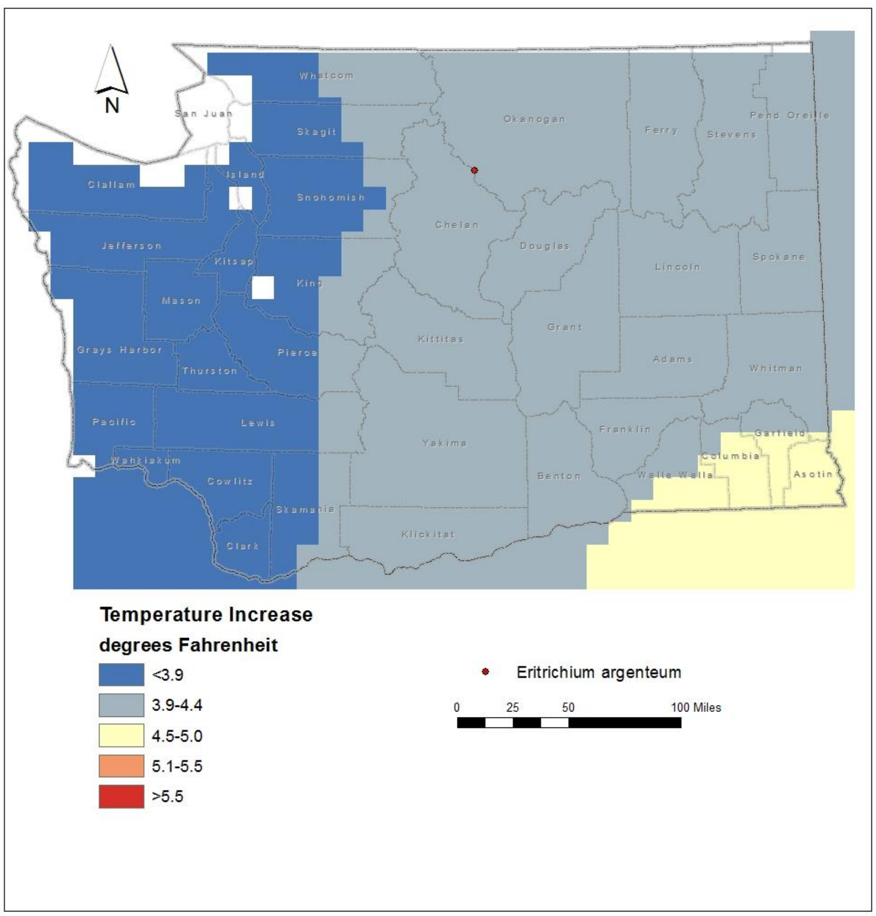

Figure 1. Exposure of *Eritrichium argenteum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Eritrichium argenteum* in Washington (100%) 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).

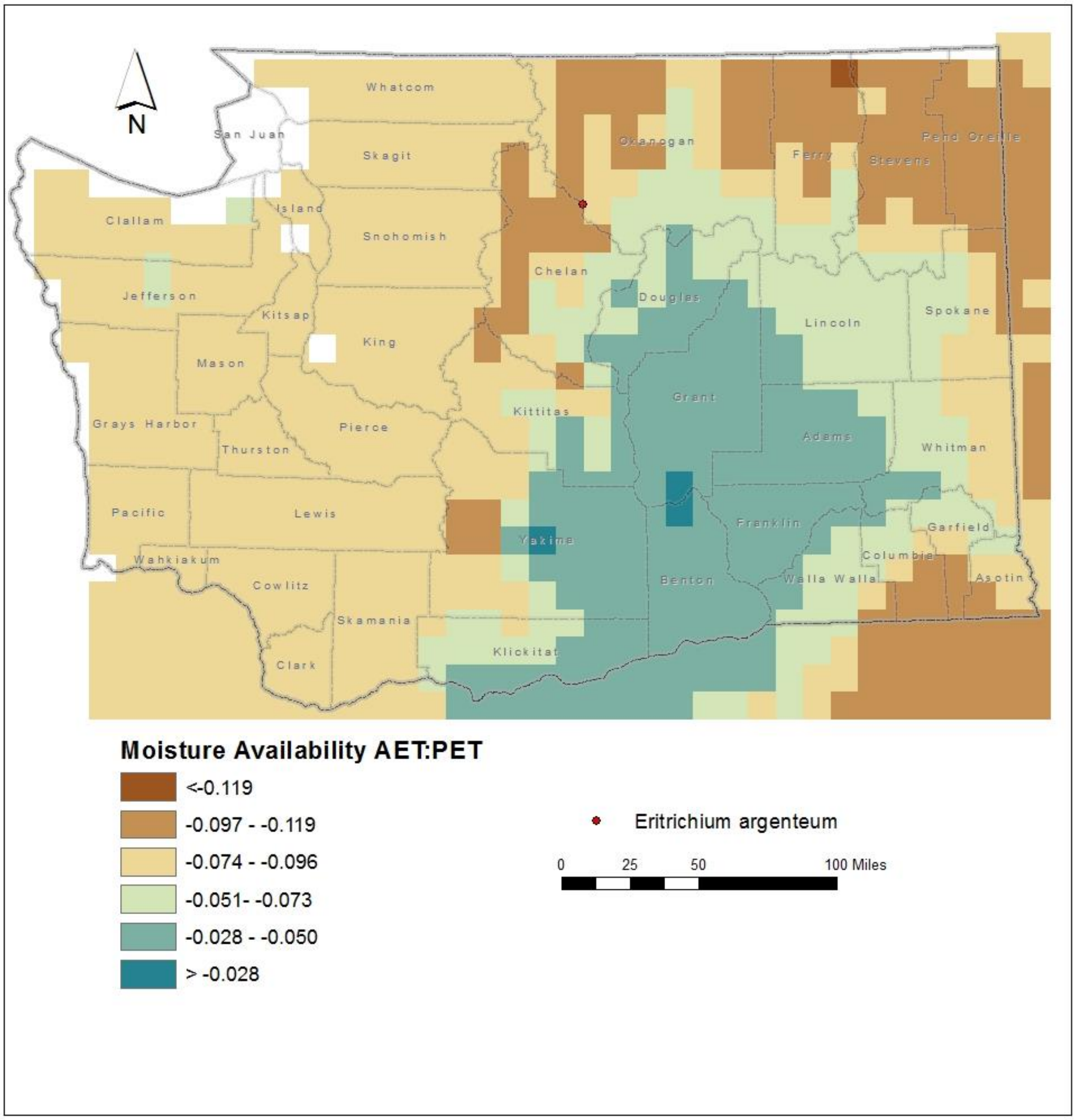

Figure 2. Exposure of *Eritrichium argenteum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrence of *Eritrichium argenteum* is found at 7300-8300 feet (2200-2600 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
Eritrichium argenteum occurs on rocky alpine slopes in a cushion plant community with dwarf, stunted shrubs (Camp and Gamon 2011; Fertig and Kleinknecht 2020). This habitat is part of the Rocky Mountain Alpine Dwarf-Shrubland, Fell-field, and Turf ecological system (Rocchio and Crawford 2015). Additional habitat may occur on high ridges of the Northern Cascades, but overall is limited in Washington. Natural barriers of unsuitable habitat at lower elevations are likely to restrict dispersal and migration to new areas under climate change.

B2b. Anthropogenic barriers: Neutral.
The alpine habitat of *Eritrichium argenteum* in Washington is restricted to the Chelan-Sawtooth Wilderness Area and is relatively unimpacted by human activities and barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Eritrichium argenteum produces one to four 1-seeded nutlets per flower. The nutlets are smooth and four-sided and lack structures to promote dispersal by wind. Genetic studies in Europe of *E. nanum* (a sister species) indicates that long distance dispersal is exceptionally rare (Stehlik et al. 2002). Dispersal probably depends on gravity and secondary movement by small mammals, and is likely to average less than 100 m.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Eritrichium argenteum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The single state population (100%) is from an area that has experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and is at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Greatly Increase.
The alpine talus and tundra habitat of *Eritrichium argenteum* is entirely within a cold climate zone during the flowering season and is highly vulnerable to temperature increase from climate change.

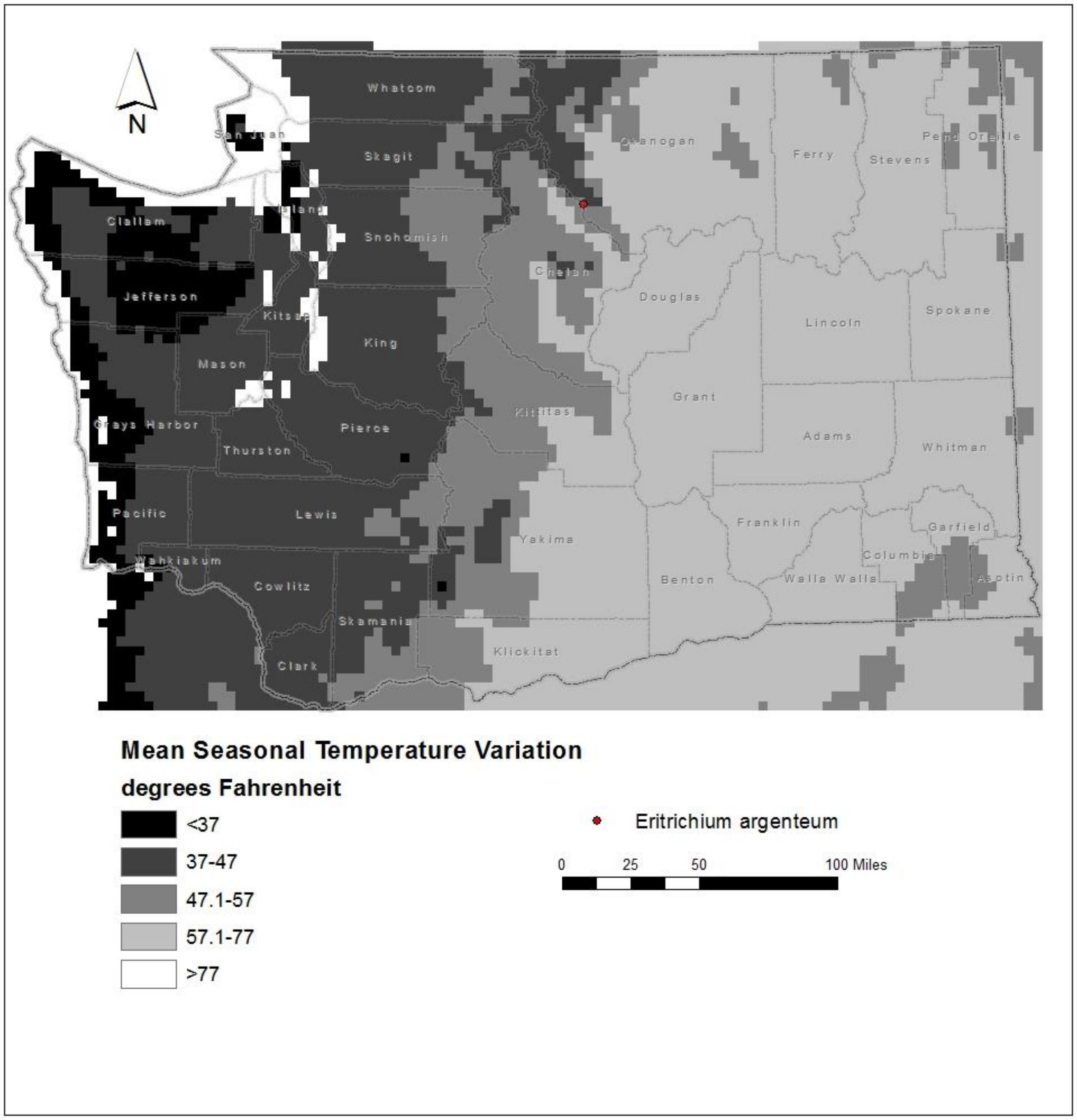

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Eritrichium argenteum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
The single known population of *Eritrichium argenteum* in Washington is found in an area that has experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), this occurrence is at neutral vulnerability from climate change.

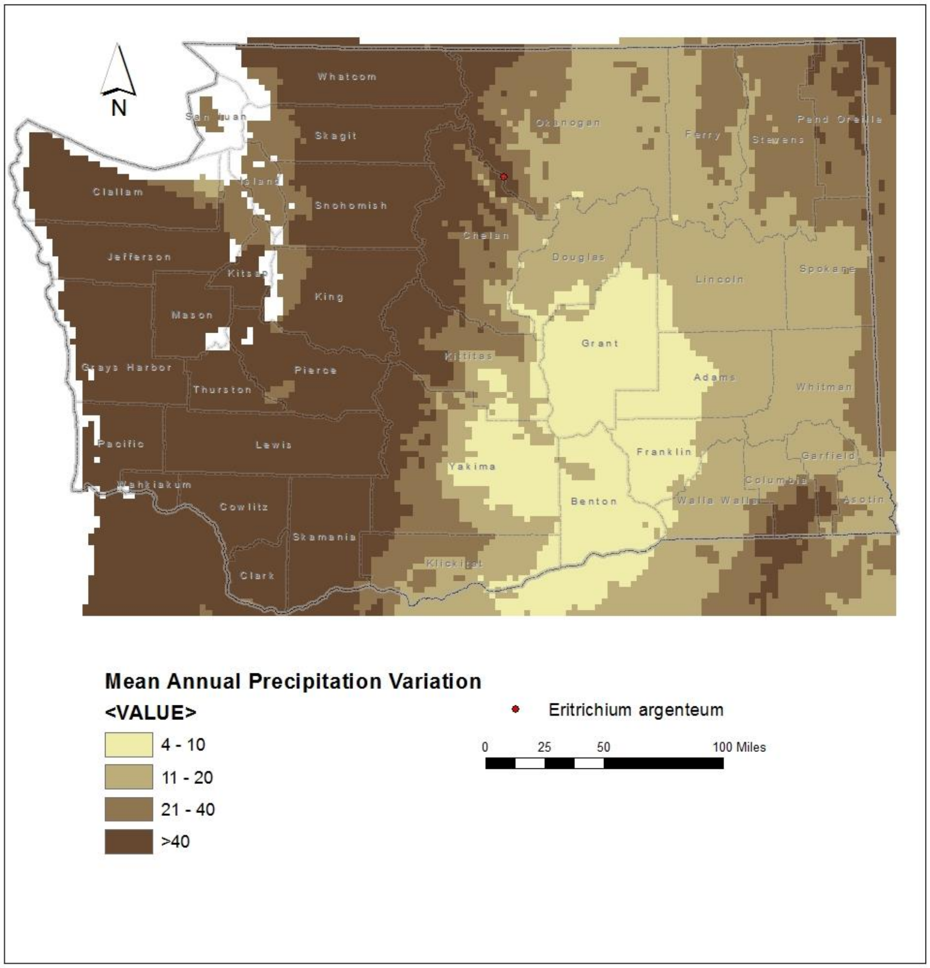

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Eritrichium argenteum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on winter snow and summer precipitation for meeting its moisture needs, as it is not associated with wetlands or soils with a high water table. As such, it could be vulnerable to changes in the timing or amount of snow and rainfall (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Eritrichium argenteum occurs in alpine talus, scree, and turf habitats that are subject to high winds. Other than occasional rock fall, these are largely undisturbed sites at present.

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Eritrichium argenteum* in Washington are found on alpine ridgecrests and talus slopes/tundra associated with winter snow accumulation, though the areas may be free of snow due to evaporation or drifting during the growing season. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Eritrichium argenteum is found on granite outcrops of the Oval Peak batholith, an uncommon geologic formation in the East Cascades and Okanogan Mountains of Washington (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus and tundra habitat occupied by *Eritrichium argenteum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Studies in Europe indicate that closely related *Eritrichium nanum* is pollinated primarily by several fly species in the families Anthomyiidae and Muscidae and less commonly by bees (*Andrena* sp.) (Zoller et al. 2002). The specific pollinators of *E. argenteum* in Washington are not known.

C4d. Dependence on other species for propagule dispersal: Neutral.
The hard, nutlet fruits of *Eritrichium argenteum* lack any wings, hairs, or other structures to aid in dispersal by wind, water, or animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
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 become 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: Neutral.
Does not require an interspecific interaction.

C5a. Measured genetic variation: Unknown.
Genetic variability has not been tested in Washington material. Since the single Washington population is disjunct from occurrences in northern British Columbia, Idaho, and northeastern Oregon, it probably has a more homogeneous genome due to genetic drift or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Somewhat Increase.
The sister species *Eritrichium nanum* from Europe is an outcrosser with flowers that can be protandrus (stamens mature before the stigmas in the same flower) or protogynous (stigmas mature before the stamens) (Zoller et al. 2002). Genetic studies of isolated and disjunct populations in the Alps found that they were associated with genetic haplotypes, suggesting they had persisted in unglaciated refugia with minimal gene flow since the Pleistocene (Stehlik et al. 2002). Washington populations are also disjunct and likely to have reduced genetic variability due to inbreeding depression, genetic drift, or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on observation reports from WNHP and herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Eritrichium argenteum* has not changed its typical blooming time since the 1960s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Eritrichium argenteum* in Washington since it was first discovered in the state in the 1960.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, Washington Department of Natural Resources, Olympia, WA. 173 pp.

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Stehlik, I., F.R. Blattner, R. Holderegger, and K. Bachmann. 2002. Nunatak survival of the high alpine plant *Eritrichium nanum* (L.) Gaudin in the central Alps during the ice ages. Molecular Ecology 11(10): 2027-2036.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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.

Zoller, H., H. Lenzin, and A. Erhardt. 2002. Pollination and breeding system of *Eritrichium nanum* (Boraginaceae). Plant Systematics and Evolution 233: 1-14.

Climate Change Vulnerability Index Report

Eryngium petiolatum (Oregon coyote-thistle)

Date: 16 February 2021

Assessor: Walter Fertig, 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: Local Climate	**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
	<3.9° F (2.2°C) warmer	66.7
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	66.7
	-0.051 to - 0.073	22.2
	-0.028 to -0.050	11.1
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
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: Six of the nine extant occurrences of *Eryngium petiolatum* in Washington (66.7%) are found in areas with a projected temperature increase of <3.9° F (Figure 1). Three other populations (33.3%) are from areas with a projected temperature increase of 3.9-4.4° F.

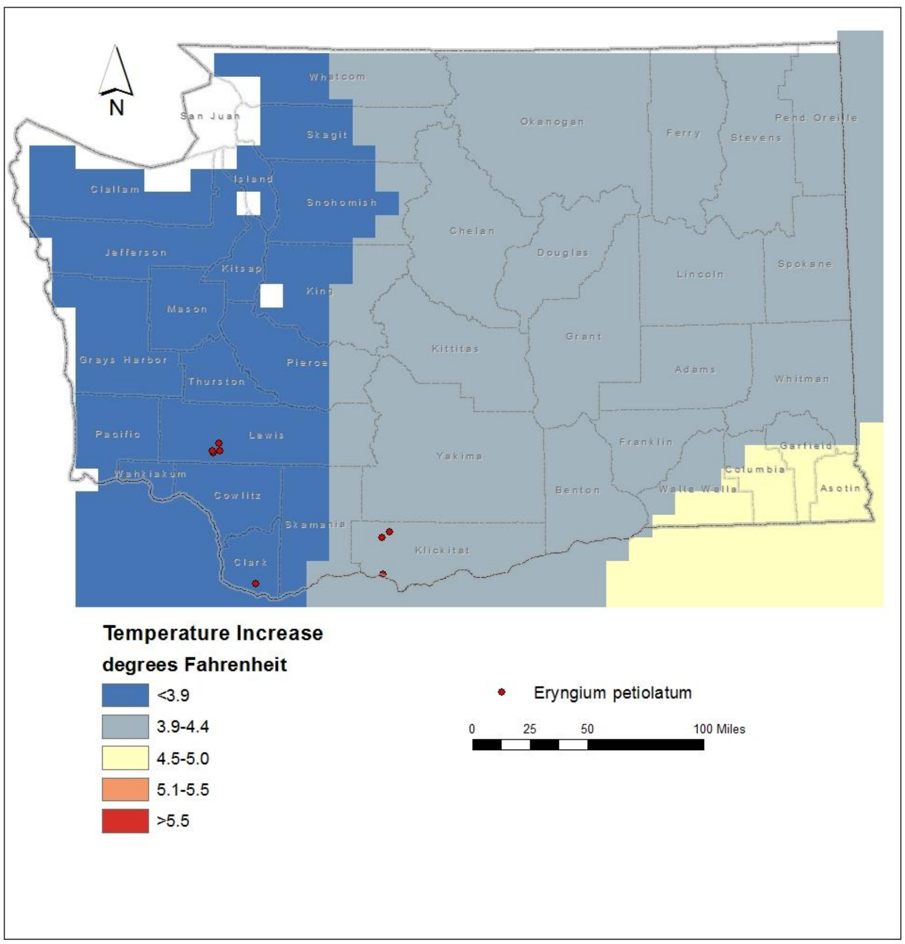

Figure 1. Exposure of *Eryngium petiolatum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the 9 occurrences of *Eryngium petiolatum* (66.7%) in western 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). Two populations from NW Klickitat County (22.2%) are from areas with a projected decrease in moisture in the range of -0.051 to -0.073. One other occurrence in SW Klickitat County (11.1%) has a projected decrease in moisture of -0.028 to -0.050.

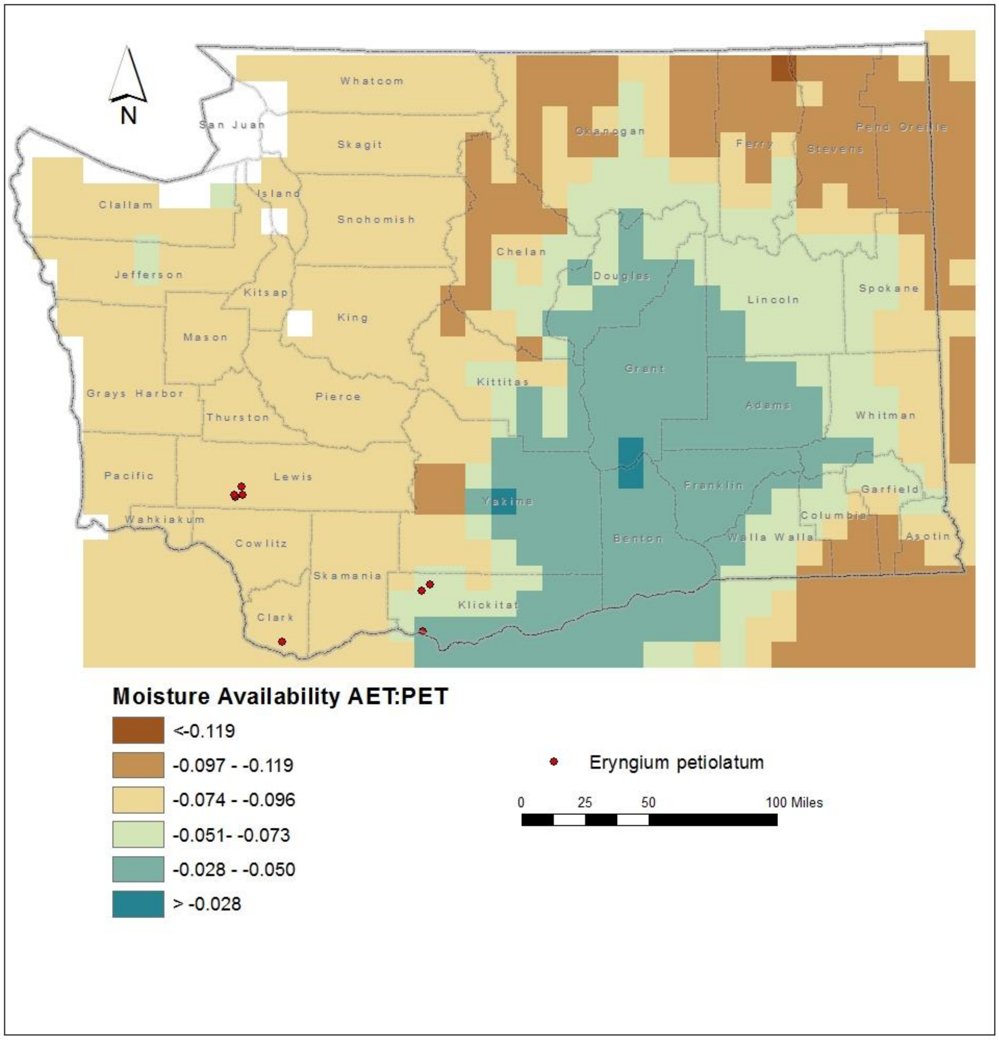

Figure 2. Exposure of *Eryngium petiolatum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Eryngium petiolatum* are found at 180-1850 feet (55-560 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Eryngium petiolatum* is found in seasonally wet meadows and shores of vernal ponds dominated by herbaceous and graminoid species (Camp and Gamon 2011). Sites may be flat or consist of swales or ditches and have alkali or organic-rich soils. Populations occur in areas that may be flooded or saturated in winter and spring, but become dry by mid summer (Fertig and Kleinknecht 2020). These occurrences conform to the Rocky Mountain Alpine-Montane Wet Meadow and Willamette Valley Wet Prairie ecological systems (Rocchio and Crawford 2015). Washington populations are found in three main clusters in southern Lewis Couty, Clark County east of Vancouver, and western Klickitat County. Occurrences are separated by distances of 0.3 to 54 miles (0.5-89 km) with large areas of unsuitable habitat between population clusters. Dispersal between populations is naturally restricted by unsuitable forest and dry prairie matrix habitat between occurrences.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Eryngium petiolatum* in Washington is bisected by roads, farmland, and human infrastructure that contributes to a fragmented landscape matrix. Areas of suitable habitat for this species, however, are naturally limited to sites that favor winter/spring flooding and summer drying. Historically, many of these areas have been converted to agricultural use through plowing and changes in hydrology (Camp and Gamon 2011).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Eryngium petiolatum produces numerous flowers in a compact, thistle-like capitate inflorescence subtended by spine-tipped bracts. Individual fruits are ovoid, 1-2 mm long, and covered by tapering scales (Camp and Gamon 2011). At maturity, fruits split into two 1-seeded segments. The scaly covering of the fruits can catch onto the fur of mammals or feathers of birds. Birds could spread some fruits well over 1 km from the parent plant.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Eryngium petiolatum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Six of the 9 known occurrences in Washington (66.7%) are found in areas that have experienced small temperature variation (37-47˚F/20.8-26.3˚C) during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016). Three other populations (33.3%) have slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the same period and are at somewhat increased vulnerability.

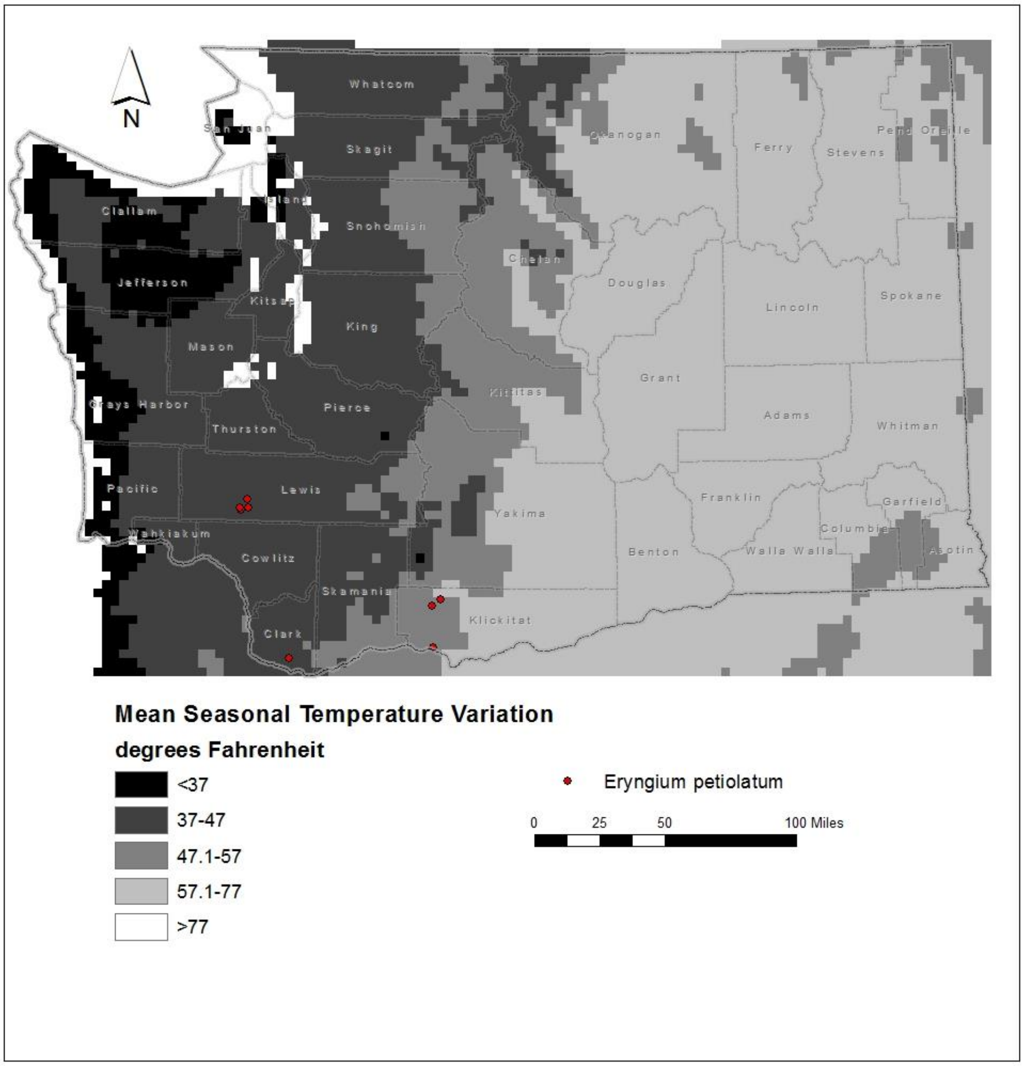

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Eryngium petiolatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The wetland habitats of *Eryngium petiolatum* are often associated with cold air drainage during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
Six of the 9 occurrences of *Eryngium petiolatum* in Washington (66.7%) are found in areas that have experienced average (21-40 inches/508-1016 mm) precipitation variation in the past 50 years (Figure 4). The other three occurrences (33.3%) are from areas with greater than average precipitation variation (>40 inches/1016 mm) during the same period. According to Young et al. (2016), these areas are all at neutral vulnerability to climate change.

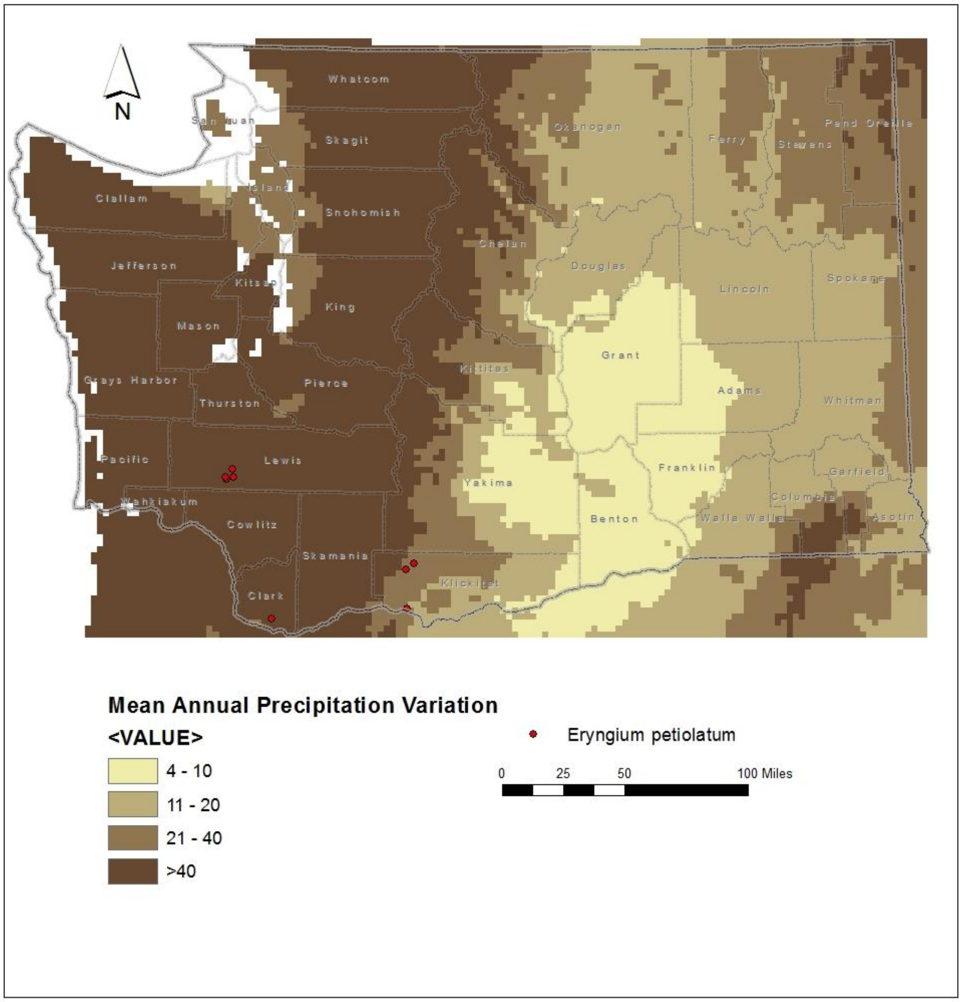

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Eryngium petiolatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.

Populations of *Eryngium petiolatum* in Washington occur in seasonally wet meadows dominated by graminoids that become dry in the summer. Such communities are vulnerable to changes in the timing of precipitation, especially in sites that are not fed by perennial springs. Populations from the east side of the Cascades Changes may be vulnerable to changes in hydrology, such as a drop in the water table, associated with long-term drought. This could result in the conversion of seasonally wet meadows to dry meadows dominated by upland plant species (Rocchio and Ramm-Granberg 2017). In the Puget Trough region, populations could be vulnerable to greater flooding in winter and increased drought in summer, which could result in shifts to marshland or dry meadow communities. Summer drought could make meadow sites more prone to wildfire and subsequent invasion by weedy species (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Eryngium petiolatum is dependent on a specific hydrological environment (high water table from winter/spring precipitation and summer drought) to maintain its graminoid-dominated meadow habitat. Wildfire, which could be enhanced by summer drought, may play a role in keeping these sites from becoming invaded by shrub species (Rocchio and Ramm-Granberg 2017). Climate change may actually increase the frequency of wildfire.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Snowpack is low within the range of *Eryngium petiolatum* in the Puget Trough but is moderate to high along the east slope of the Cascades east of Mount Adams. Changes in the amount of snowfall, or in the timing of snow melt, can have ramifications for wet meadow sites that are dependent on springs or underground recharge enhanced by snowpack (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
Eryngium petiolatum occurs primarily on Quaternary alluvium and glacial flood deposits that are widely distributed in the Willamette Valley and on the east side of Mount Adams (Washington Division of Geology and Earth Resources 2016). The geologic setting for the species is not restricted, although precise hydrological conditions that contribute to winter/spring flooding and summer drying may be uncommon.

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal conditions of wet meadows inhabited by *Eryngium petiolatum* are maintained primarily by hydrological factors (timing and amount of rainfall and snowpack), topographic drainage patterns, or wildfire to maintain moist grasslands with low shrub cover, rather than by herbivory by wildlife.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Eryngium petiolatum has showy heads of white flowers and is presumed to be an outcrosser. The exact pollinators of this species in Washington are not known. *Eryngium yuccifolium*, a related species from the Great Plains, is pollinated by a variety of insect species, including small bees, bumblebees, flies, wasps, butterflies, and moths (Molano-Flores 2001). Members of the Apiaceae family have unspecialized flowers and tend to be pollinated by a wide diversity of species.

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry fruits of *Eryngium petiolatum* split into two 1-seeded segments at maturity, each covered with scales that can attach to the fur or feathers of a variety of vertebrate species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. The leaves and flower heads of *Eryngium petiolatum* have spiny tips and margins, protecting them from herbivory by large browsers. Herbivory has been identified as a potential threat (Camp and Gamon 2011), though is likely to be of less

significance than habitat loss through changes in hydrology, conversion to agriculture, residential development, or competition from invasive weeds (Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Eryngium petiolatum occurs in moist meadow sites that become dry in the summer. These areas could be vulnerable to invasion by annual weed species under conditions of prolonged drought and increased wildfire (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Eryngium petiolatum* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Eryngium petiolatum is presumed to be an outcrosser, rather than self-pollinated. In the related species, *E. yuccifolium*, stamens mature before the stigmas become receptive within the same flower, making individuals "temporally dioecious" and promoting outcrossing (Molano-Flores 2001). Presumably, genetic variation is average, compared to other species, but no studies have been done for confirmation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no significant changes in the phenology of *Eryngium petiolatum* populations in Washington have been detected over the past 20 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Trend data are lacking for most occurrences of *Eryngium petiolatum*. Most populations contain 25-200 plnts, but at least two have 10,000-22,000 individuals (Engler and Stutte 2010; Fertig and Kleinknecht 2020). At present, state populations appear to be stable, though historically trends are likely to be downward due to widespread habitat loss.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Engler, J.D. and A. Stutte. 2010. 2010 Status of Oregon coyote-thistle (*Eryngium petiolatum*

Hook.), Conboy Lake National Wildlife Refuge, Klickitat County, Washington. US Fish and Wildlife Service. 8 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Molano-Flores, B. 2001. Reproductive biology of *Eryngium yuccifolium* (Apiaceae), a prairie species. Journal of the Torrey Botanical Society. 128(1): 1-6.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Erythranthe pulsiferae (Pulsifer's monkeyflower)

Date: 20 October 2021 Synonym: *Mimulus pulsiferae*

Assessor: Walter Fertig, 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: Local Climate	**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	90
	<3.9° F (2.2°C) warmer	10
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	10
	-0.074 to - 0.096	30
	-0.051 to - 0.073	50
	-0.028 to -0.050	10
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral/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		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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		Neutral
5a. Measured genetic diversity		Unknown

5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral/Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Somewhat Increase
Section D: Documented or Modeled Response	
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: Nine of the 10 extant and historical occurrences of *Erythranthe pulsiferae* in Washington (90%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). This includes one disjunct and historical population from Okanogan County that needs

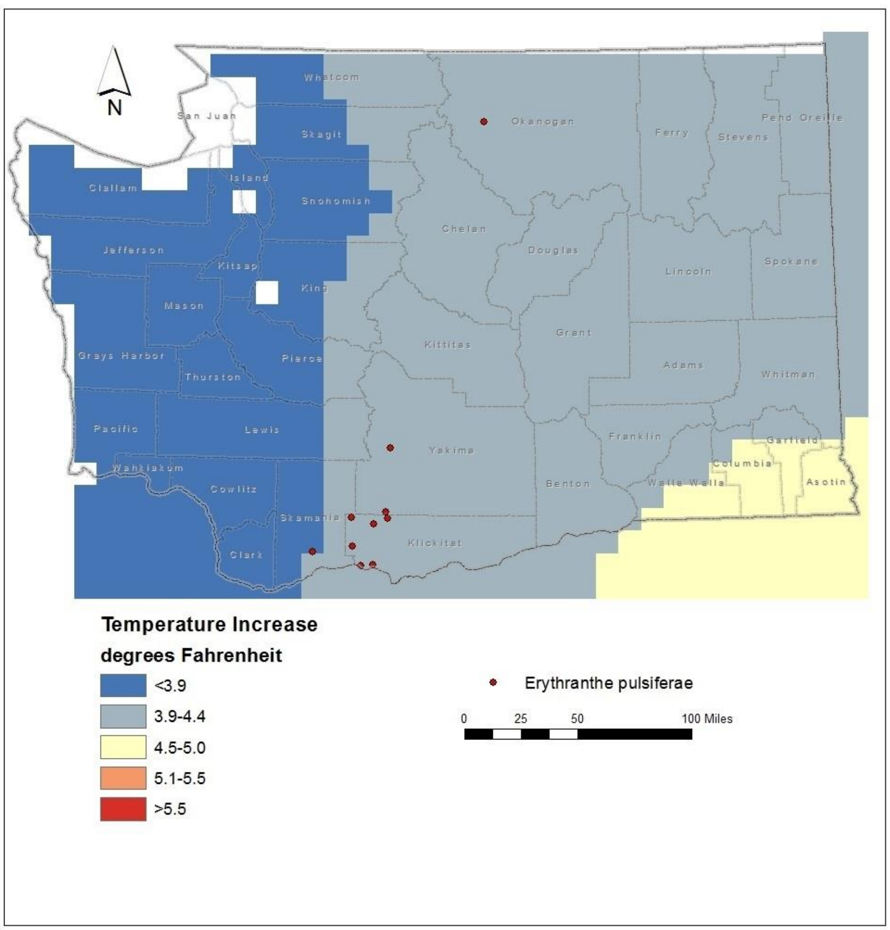

Figure 1. Exposure of *Erythranthe pulsiferae* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

confirmation. One other occurrence (10%) from the Columbia River is from an area with a projected temperature of <3.9° F (Figure 1).

A2. Hamon AET:PET Moisture Metric: Five of the 10 occurrences (50%) of *Erythranthe pulsiferae* 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). Three occurrences (30%) are in areas with a projected decrease of -0.074 to -0.096. One historical population (10%) is from an area with a predicted decrease of -0.097 to -0.119. One other occurrence (10%) is from an area with a projected decrease of -0.028 to -0.050 (Figure 2).

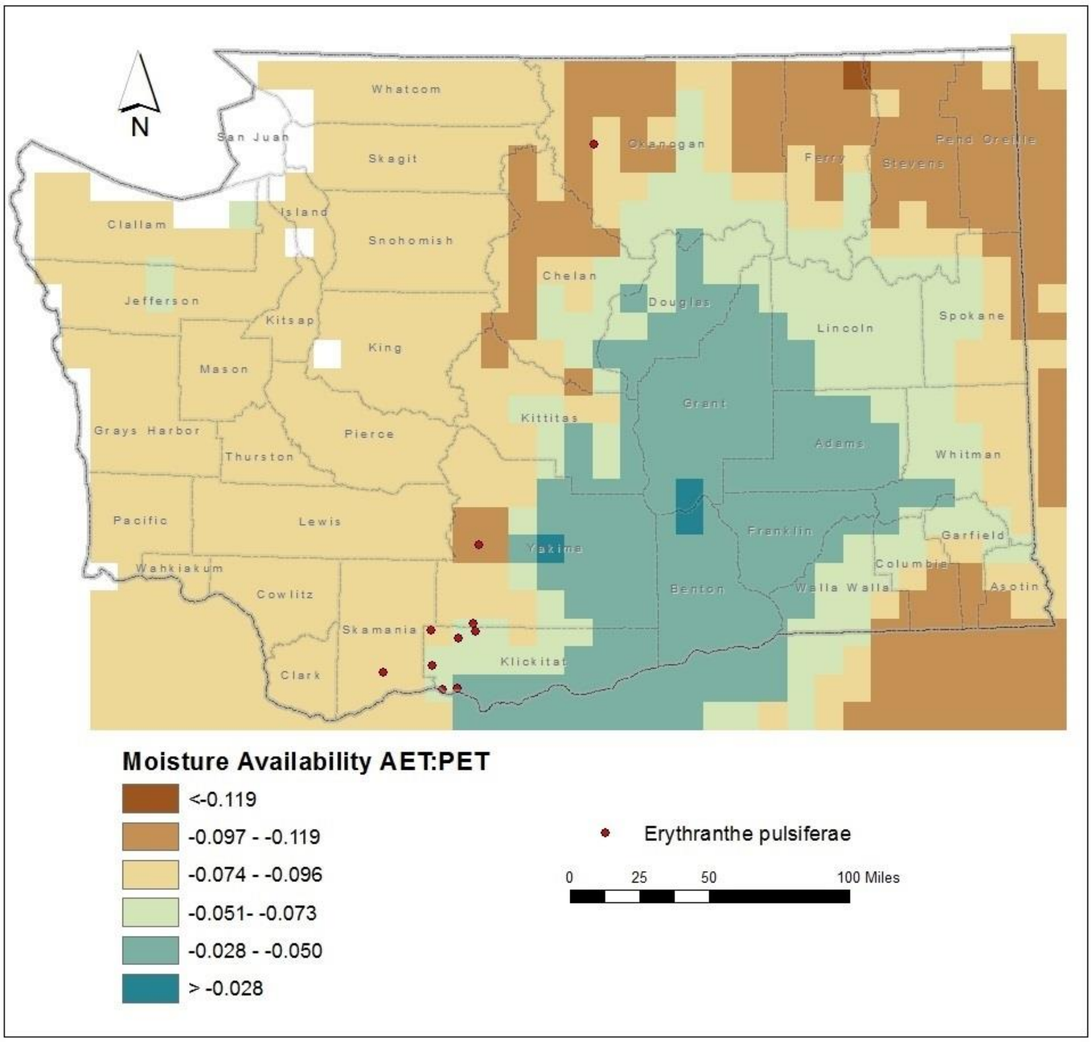

Figure 2. Exposure of *Erythranthe pulsiferae* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Erythranthe pulsiferae* are found at 1580-4000 feet (480-1220 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Erythranthe pulsiferae occurs primarily in seasonally wet or moist meadows, gravelly streambanks, or openings in ponderosa pine (*Pinus ponderosa*), Oregon white oak (*Quercus garryana*) or Douglas-fir (*Pseudotsuga menziesii*) woods (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the Rocky Mountain Alpine-Montane Wet Meadow and Temperate Pacific Subalpine-Montane Wet Meadow ecological systems (Rocchio and Crawford 2015). Populations may be isolated from each other by 3.1-148 miles (5.1-238 km) of unsuitable habitat that presents a barrier to dispersal. (This distance is reduced to 26 miles [44 km] if the historical and questionable population from Okanogan County is excluded.)

B2b. Anthropogenic barriers: Neutral.
The historical range of *Erythranthe pulsiferae* in Washington is strongly influenced by roads, cities, farmland, rangeland, and other large-scale anthropogenic influences, but dispersal may be more limited by available habitat and natural barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral/Somewhat Increase.
Erythranthe pulsiferae 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. Dispersal may be by gravity, strong winds, flowing water, or secondary transport by insects or rodents caching seeds. Most seeds probably fall within a short range of their parent, but some could stick to mud on waterfowl and be transported longer distances.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Erythranthe pulsiferae* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the 10 known occurrences in the state (70%) are found in areas that have experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016). The three other occurrences (30%) are from areas that have had average variation (57.1-77°F/31.8-43.0°C) in temperature over the same period and are at neutral vulnerability to climate change.

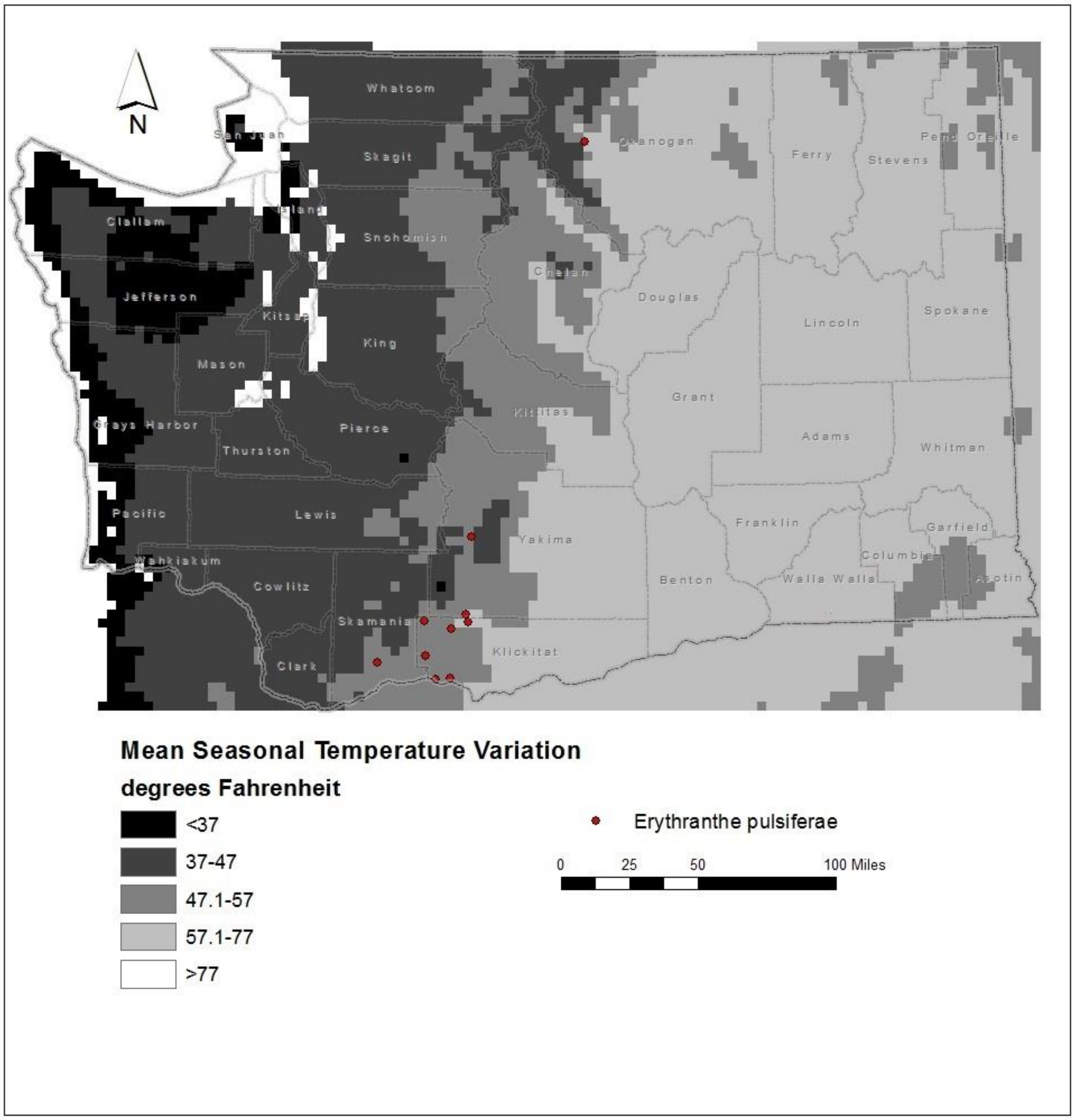

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Erythranthe pulsiferae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The seasonally moist meadows, rocky streambanks, or forest openings occupied by *Erythranthe pulsiferae* are found primarily in narrow drainage bottoms subject to cold air drainage. These habitats could be adversely impacted by predicted warming temperatures from climate change.

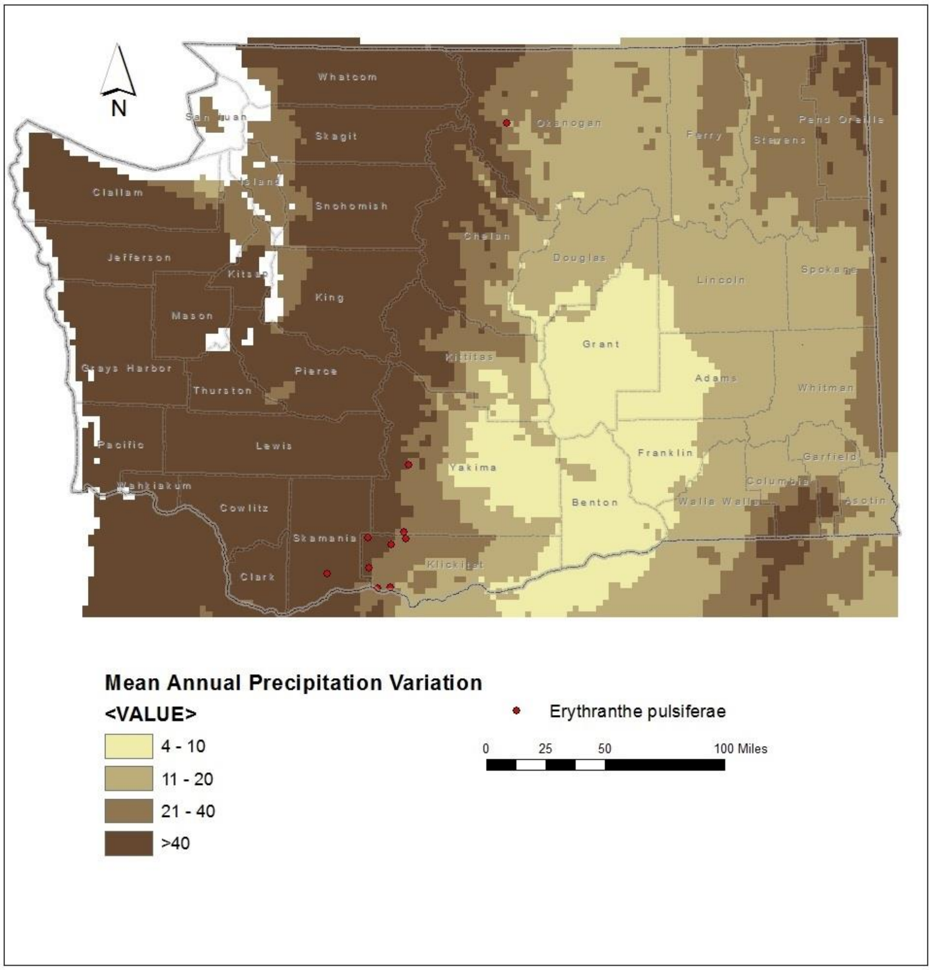

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Erythranthe pulsiferae* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All 10 of the extant and historical populations of *Erythranthe pulsiferae* in Washington (100%) are found in areas that have experienced average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

C2bii. Physiological hydrological niche: Increase.
Erythranthe pulsiferae occurs in seasonally wet meadows, rocky streambanks, and openings in conifer forests and relies on late-lying snow, high water tables, or adequate spring and summer precipitation to maintain necessary moisture levels. Under projected climate change, these habitats are likely to have increased summer temperatures, more variability in the amount and timing of rainfall, changes in the amount and timing of snowmelt, reduced soil moisture, and

higher risk of wildfire (Rocchio and Ramm-Granberg 2017). These changes could shift existing moist meadow or forest habitat to drier meadows inhabited by a new suite of plant species.

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Erythranthe pulsiferae occurs wet meadows and openings in conifer forests. Meadow sites may be maintained by adequate moisture from melting snow and groundwater recharge or summer precipitation. Landform patterns (depressions) are important in retaining moisture on the landscape. Populations in forest openings may rely on periodic low-intensity fire or wind-throw to create or maintain these conditions. The frequency or magnitude of these disturbances could increase under warming conditions (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
The populations of *Erythranthe pulsiferae* in Washington are found in low elevation mountain and foothill valleys or drainages that receive low to moderate amounts of snow. Patterns of snow deposition (such as drifting in low-lying areas) may be important to augment the annual water budget for some occurrences. Changes in the amount or timing of snowmelt could have a negative impact on the recharge of groundwater (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Erythranthe pulsiferae occurs primarily on Quaternary alluvium and basalts derived from the Wanapum and Grande Ronde formations (Washington Division of Geology and Earth Resources 2016). These substrates occur widely in eastern Washington. Local topographic relief, such as depressions, may be an important microhabitat feature for this species, but are also widespread on the landscape.

C4a. Dependence on other species to generate required habitat: Neutral
The wet meadow, streamside, and forest habitat occupied by *Erythranthe pulsiferae* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Erythranthe pulsiferae* are not known. Yellow-flowered species of *Erythranthe* (formerly *Mimulus*) with large flowers are primarily pollinated by various species of bees, mostly from the genus *Bombus* or *Apis* (Bodbyl Roels and Kelly 2011). Smaller-flowered *Erythranthe* species (like *E. pulsiferae*) may be insect pollinated and autogamous (capable of self pollination) (Meinke 1992).

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds of *Erythranthe pulsiferae* may be dispersed by gravity, strong winds, flowing water, or in mud on waterfowl.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is probably not negatively impacted by herbivory.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The lower montane wet meadow, rocky streamside, and conifer forest habitats of *Erythranthe pulsiferae* are potentially impacted by competition from introduced plant species today, and will continue to be affected under warming or drying conditions in the future, especially if these result in conversion of sites to drier meadows (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Genetic research on *Erythranthe pulsiferae* has focused primarily on assessing its taxonomic relationships with other *Erythranthe* species and not its population-level genetic differentiation. Whittall (1999) found that *E. pulsiferae* is more closely related to other species of the *E. moschata* complex centered in the Sierra Nevada of California than morphologically similar species endemic to the Columbia or Snake rivers (such as *E. washingtonensis*, *E. patula*, and *E. ampliata*).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral/Somewhat Increase.
The flowers of *Erythranthe pulsiferae* have paired anthers located at the same level as the stigma, allowing for self-pollination (autogamy) (Nesom 2012). Selfing generally results in lower overall genetic diversity within populations, but can increase diversity between populations. Washington populations are at the northern edge of its range and are more likely to have lower overall genetic diversity due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Erythranthe pulsiferae* may be flowering earlier (late April-late May) than it did in the 1880s-1930s (June-July or September).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The range of *Erythranthe pulsiferae* within Washington has thought to have contracted significantly since the 1930s based on the historical populations reported from southeast Washington in the Columbia Plateau ecoregion (Fertig and Kleinknecht 2020). Recent inspection of the herbarium records that were the basis of these reports indicates that these were misidentifications. One historical occurrence in Okanogan County also needs confirmation. If it is also erroneous, the range of this species remains largely the same as it was historically.

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

References

Bodbyl Roels, S.A. and J.K. Kelly. 2011. Rapid evolution caused by pollinator loss in *Mimulus guttatus*. Evolution: International Journal of Organic Evolution 65(9): 2541-2552.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Meinke, R.J. 1992. Systematic and reproductive studies of Mimulus (Scrophulariaceae) in the Pacific Northwest: Implications for conservation biology. PhD thesis, Oregon State University, Corvallis, OR. 151 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Erythranthe pulsiferae*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=erythranthe%20pulsiferae). Accessed 20 October 2021.

Whittall, J.B. 1999. A molecular phylogeny for the *Mimulus moschatus* alliance (Scrophulariaceae) and its conservation implications. Master's thesis, Oregon State University, Corvallis, OR. 87 pp.

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

Gentiana douglasiana (Swamp gentian)

Date: 25 October 2021

Assessor: Walter Fertig, 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: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Greatly Increase
2aii. Change in physiological thermal niche		Greatly Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral/Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
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: Nine of the 10 extant and historical occurrences of *Gentiana douglasiana* in western Washington (90%) occur in areas with a projected temperature increase of < 3.9° F

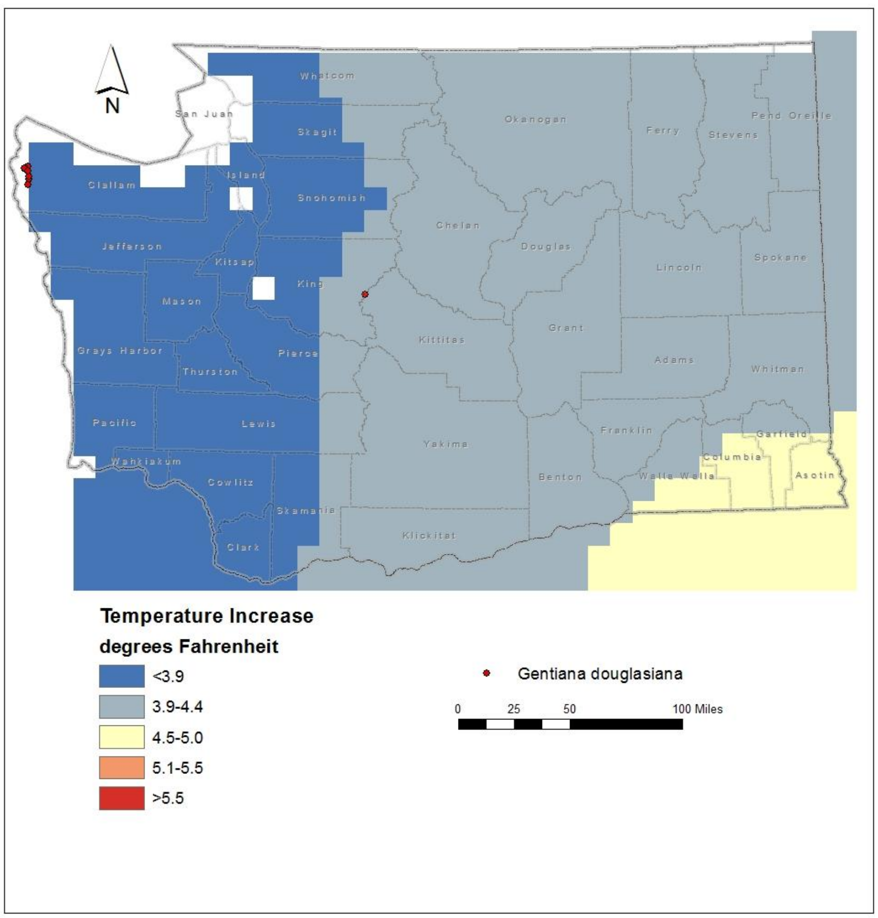

Figure 1. Exposure of *Gentiana douglasiana* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

(Figure 1). One population (10%) from the Cascade Range is from an area with a projected temperature increase of 3.9-4.4°.

A2. Hamon AET:PET Moisture Metric: All ten of the occurrences (100%) of *Gentiana douglasiana* 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).

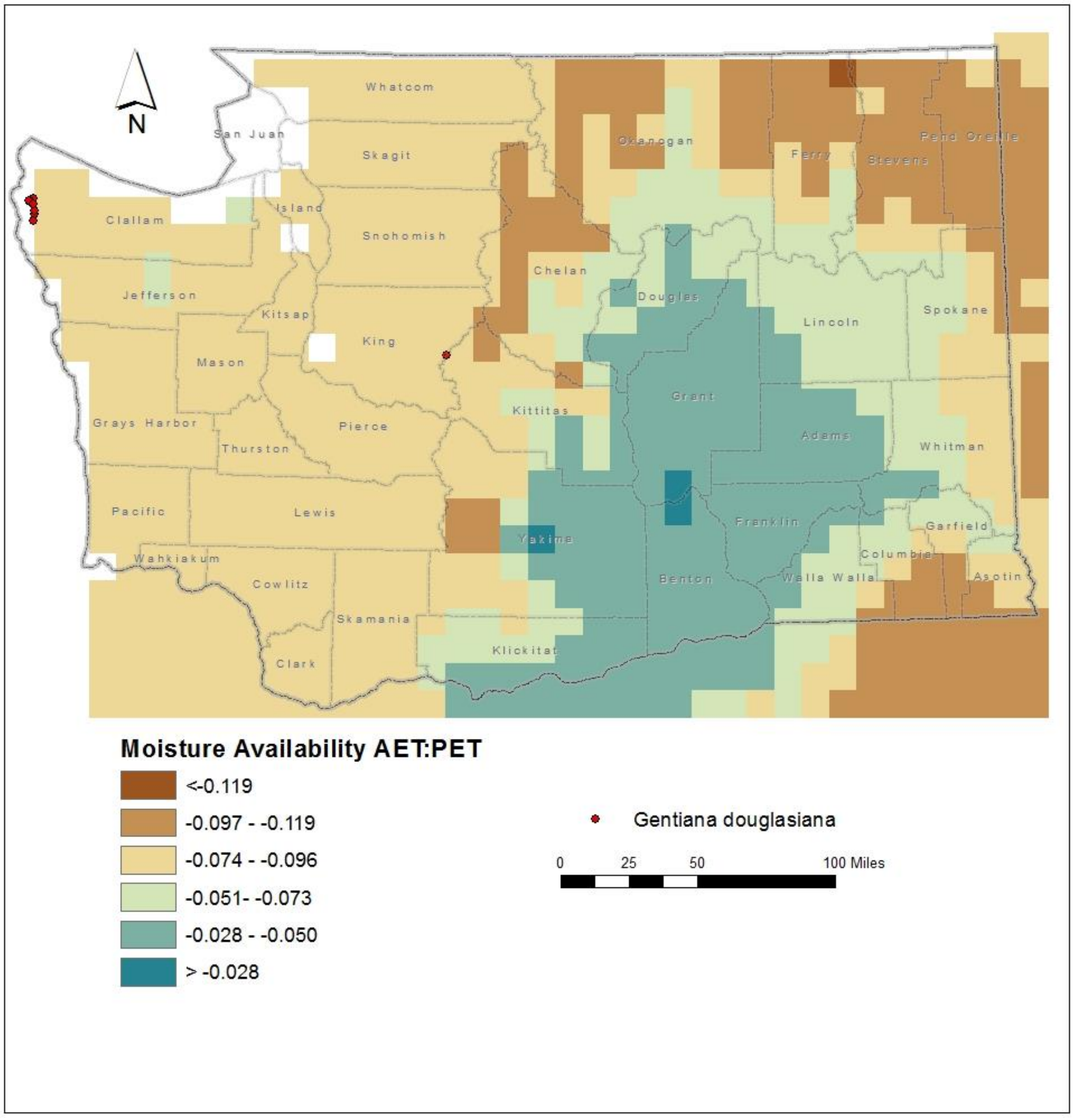

Figure 2. Exposure of *Gentiana douglasiana* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Gentiana douglasiana* from the Pacific Coast are found at 20-240 feet (5-75 m) and one occurrence from the Cascade Range is at 2920-3050 feet (890-930 m). These sites would not be inundated by projected sea level rise of 0.5-2 m by 2100 (Young et al. 2016).

B2a. Natural barriers: Somewhat Increase.
In the Olympic Peninsula, *Gentiana douglasiana* occurs in bogs and wet meadows ('prairies') dominated by sweetgale (*Myrica gale*), bog Labrador tea (*Rhododendron groenlandicum*), sedges (*Carex livida* and others), cranberry (*Vaccinium oxycoccos*), and sphagnum moss (*Sphagnum* spp.) in openings in western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) forests. The population from Snoqualmie Pass is from a sloping bog surrounded by conifer forest (Camp and Gamon 2011, Washington Natural Heritage Program 2021). These habitats are part of the North Pacific Bog & Fen and Rocky Mountain Subalpine-Montane Fen ecological systems (Rocchio and Crawford 2015). Populations in the Olympic Peninsula are separated by 0.6-2.5 miles (0.8-4 km). The disjunct population in the Snoqualmie Pass area is isolated by 157 miles (253 km) of mostly unsuitable habitat. Natural barriers and the patchy distribution of bog and fen habitats restrict dispersal of this species.

B2b. Anthropogenic barriers: Neutral.
The bog and fen habitat of *Gentiana douglasiana* in western Washington is naturally constrained by suitable environmental and topographic factors. Although extensive areas between the northwest Olympic Peninsula and Snoqualmie Pass have been altered by human activities, most of these areas are not suitable habitat. Anthropogenic barriers are less significant for this species than natural ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Gentiana douglasiana produces dry capsule fruits that split open at maturity to release numerous seeds. The fruits are flattened and wing-margined and might be capable of dispersal by water. Individual seeds are small and lack wings, barbs, hooks, or feathery hairs to facilitate dispersal by animals or wind. Dispersal distances are probably relatively short, though occasional long-distance dispersal on mud on birds or large mammals may explain large range disjunctions.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Gentiana douglasiana* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Nine of the 10 occurrences in the state (90%) are found in areas that have experienced very small (<37°F/20.8°C) temperature variation during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). One other occurrence (10%) is

from an area with small variation (37-47˚F/20.8-26.3˚C) in temperature over the same period and is at increased vulnerability to climate change.

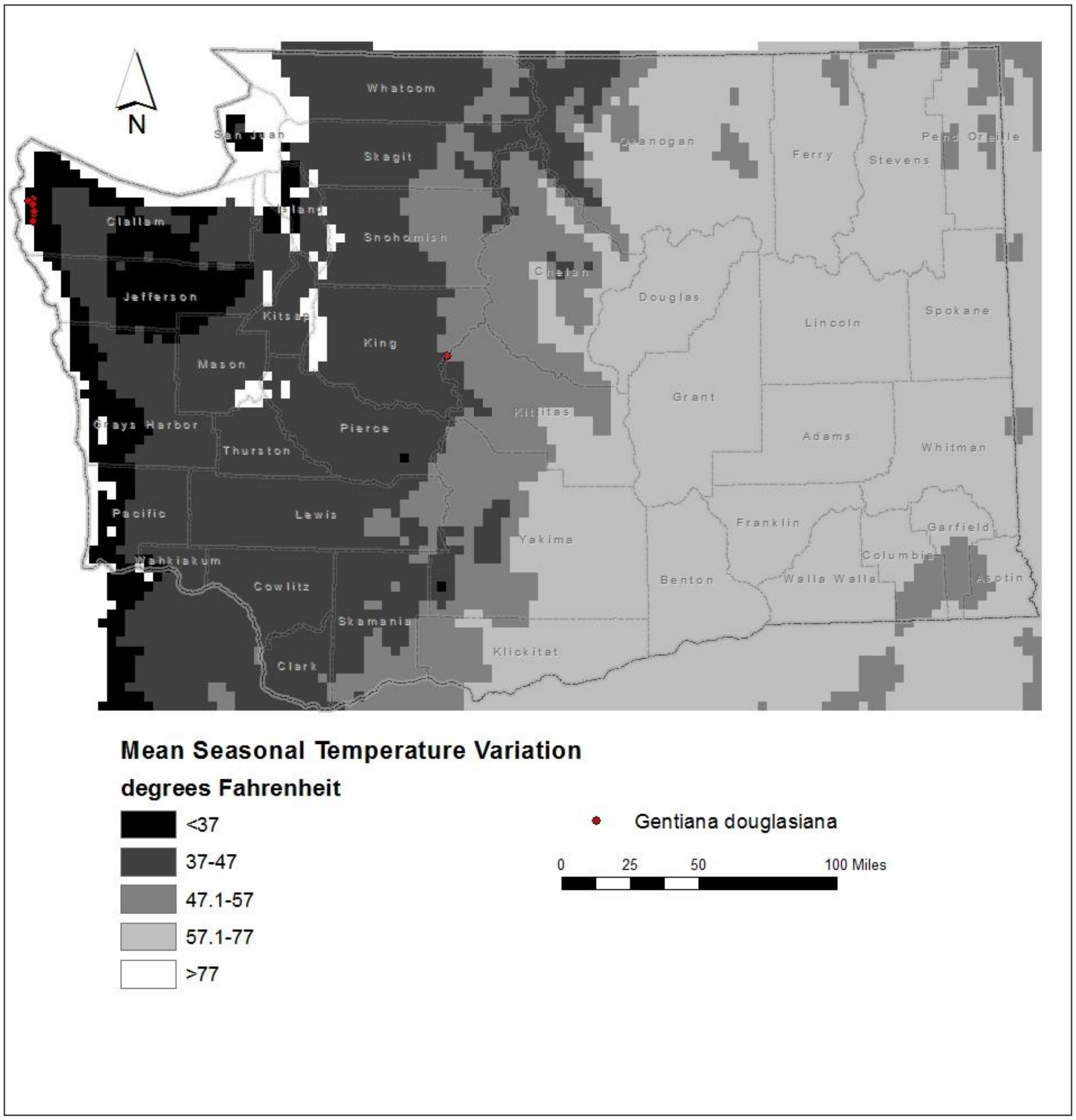

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Gentiana douglasiana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Greatly Increase.
The coastal bog and montane fen habitats of *Gentiana douglasiana* in Washington are associated with cold air drainages and would be negatively impacted by increasing temperatures from climate change.

C2bi. Historical hydrological niche: Neutral.
All of the populations of *Gentiana douglasiana* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

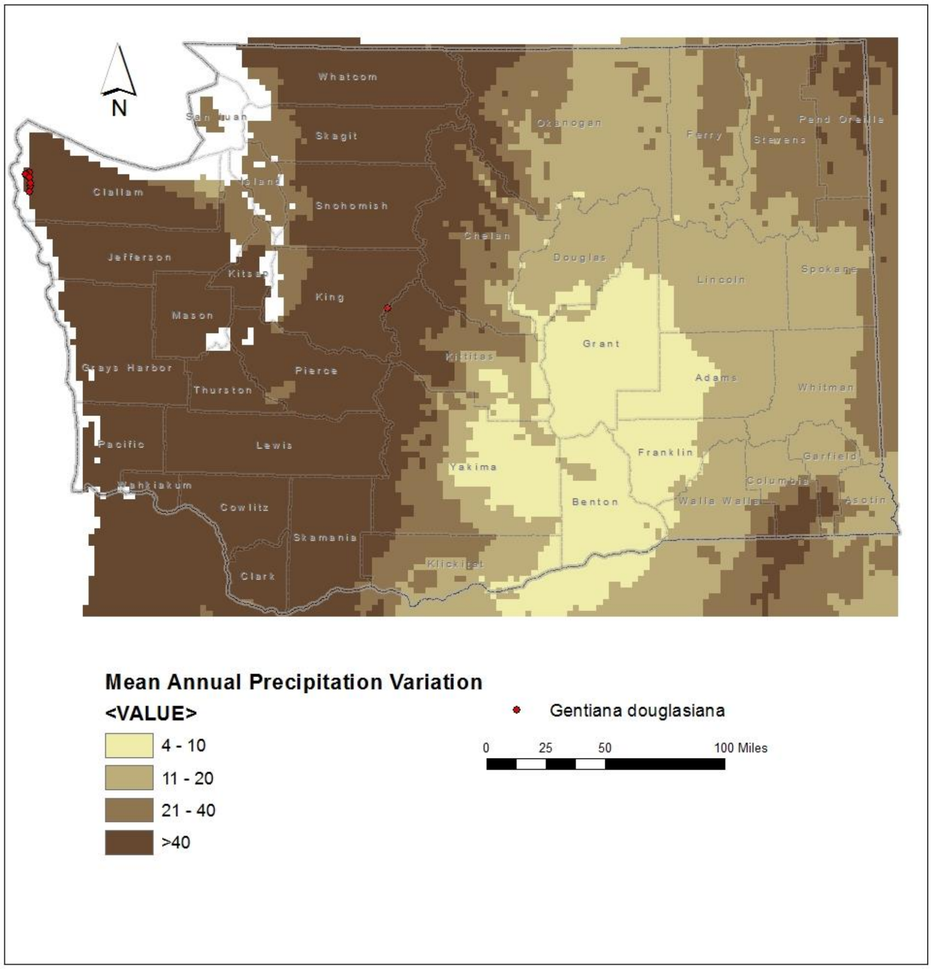

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Gentiana douglasiana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species is strongly dependent on precipitation and groundwater (along with cool temperatures) to maintain a high water table necessary for accumulation of peat. Reductions in the amount of precipitation and increased temperatures could shift the balance from peat accumulation to peat decomposition in coastal bog areas, accelerating their conversion to wet meadow habitats, or favoring encroachment by conifer forests (Rocchio and Ramm-Granberg

2017). These areas are also strongly influenced by coastal fog (Rocchio and Crawford 2015). In the Snoqualmie Pass area, a reduction in the amount of snow or shift from snow to rainfall would accelerate the loss of peat and shifts from fen to other wetland types (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Gentiana douglasiana occurs in coastal bog and montane fen habitats in Washington found in openings in conifer forests. These areas are maintained by high water tables fed by groundwater and augmented by rainfall or melting snow. Historically, fire was utilized by indigenous cultures to keep coastal prairie wetlands more open for game habitat and to promote edible plants (Anderson 2009). These fires could have prevented encroachment of conifer species from adjacent forests.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Gentiana douglasiana* in the Cascade Range are found in areas with high snowfall. Changes in the amount of snow, the timing of its melting, or shifts from snow to rain due to warming temperatures, would adversely affect the amount of groundwater recharge in fen habitats (Rocchio and Ramm-Granberg 2017). Coastal populations primarily receive winter rain due to their proximity to the Pacific Ocean and are not dependent on groundwater recharge from snow.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
Gentiana douglasiana populations from the northwest Olympic Peninsula occur on Quaternary continental glacial drift of the Vashon Strade. The occurrence from the Snoqualmie Pass area is on alpine glacial drift of Fraser-age (Washington Division of Geology and Earth Resources 2016). These geologic types are relatively widespread in western 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 more limited features on the landscape (Rocchio and Crawford 2015).

C4a. Dependence on other species to generate required habitat: Neutral.
The coastal bog and montane fen habitat of *Gentiana douglasiana* is 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: Unknown.
The specific pollinators of *Gentiana douglasiana* are poorly known, though the rare Makah copper butterfly (*Lycaena mariposa charlottensis*), is known to use *G. douglasiana* as a nectar source and thus would likely be a pollinator (Pyle 2002). Additional pollinators might include other butterfly species or bees.

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Gentiana douglasiana* are dry capsules that split open at maturity to passively release small seeds. Dispersal of seeds is mostly by water or gravity, but could be augmented by animals caching seed or transporting seed in mud on feathers or feet. This species is not dependent on a specific animal vector, so is ranked neutral.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species does not appear to be an important forage species.

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 coastal bogs and montane fens. This could change under projected climate change, as higher temperatures, reduced precipitation, and more frequent drought are likely to shift these sites from accumulating peat to losing organic material from increased decomposition. Resulting changes in soil moisture could shift these communities to wet meadows or conifer 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.
Gentiana douglasiana is the main nectar source for the rare Makah copper butterfly (*Lycaena mariposa charlottensis*), a rare species in Washington and potential pollinator (Jordan 2011, Pyle 2002).

C5a. Measured genetic variation: Unknown.
Research has not been done on the genetic variability of Washington populations of *Gentiana douglasiana*. Being at the far southern end of its range, and isolated from the nearest populations on Vancouver Island, *G. douglasiana* populations in Washington may have lower overall genetic variability due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Gentiana douglasiana appears to be an obligate outcrosser and is likely to have average genetic variation. Isolated populations in Washington are likely to have reduced genetic variability from those in British Columbia and Alaska due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Gentiana douglasiana* has not changed its typical blooming time since the 1920s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Gentiana douglasiana* in Washington since it was first scientifically documented in the state in 1925.

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

References

Anderson, M.K. 2009. The Ozette Prairies of Olympic National Park: Their former indigenous uses and management. Final Report to Olympic National Park. National Plant Data Center, USDA Natural Resources Conservation Service, University of California, Davis. 158 pp.

Banner, A., J. Pojar, and G.E. Rouse. 1983. Postglacial paleoecology and successional relationships of a bog woodland near Prince Rupert, British Columbia. Canadian Journal of Forest Research 13(5): 938-947.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Foltz Jordan, S. 2011. Species Fact Sheet: *Lycaena mariposa charlottensis* (Makah Copper). https://www.fs.fed.us/r6/sfpnw/issssp/species-index/fauna-invertebrates.shtml.

Pyle, M. 2002. The Butterflies of Cascadia. Seattle Audubon Society, Seattle, WA. 420 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Gentiana douglasiana*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=gentiana%20douglasiana). Accessed 22 October 2021.

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

Geum rossii var. *depressum* (Ross's avens)

Date: 11 March 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5T1/S1

Index Result: Highly Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	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	80
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Somewhat 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		Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on others 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		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	Neutral/Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
D1. Documented response to recent climate change	Somewhat 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: The five extant and historical occurrences of *Geum rossii* var. *depressum* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

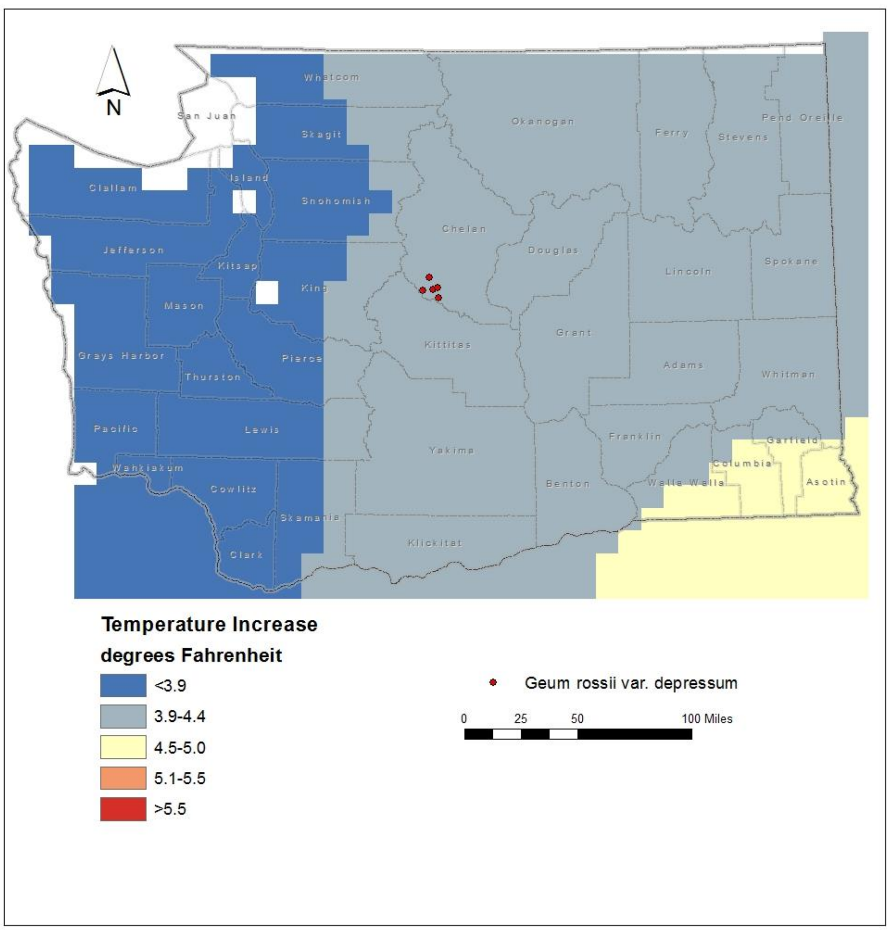

Figure 1. Exposure of *Geum rossii* var. *depressum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the five occurrences (80%) of *Geum rossii* var. *depressum* 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). One of the five populations (20%) is from an area with a projected decrease of -0.097 to -0.119.

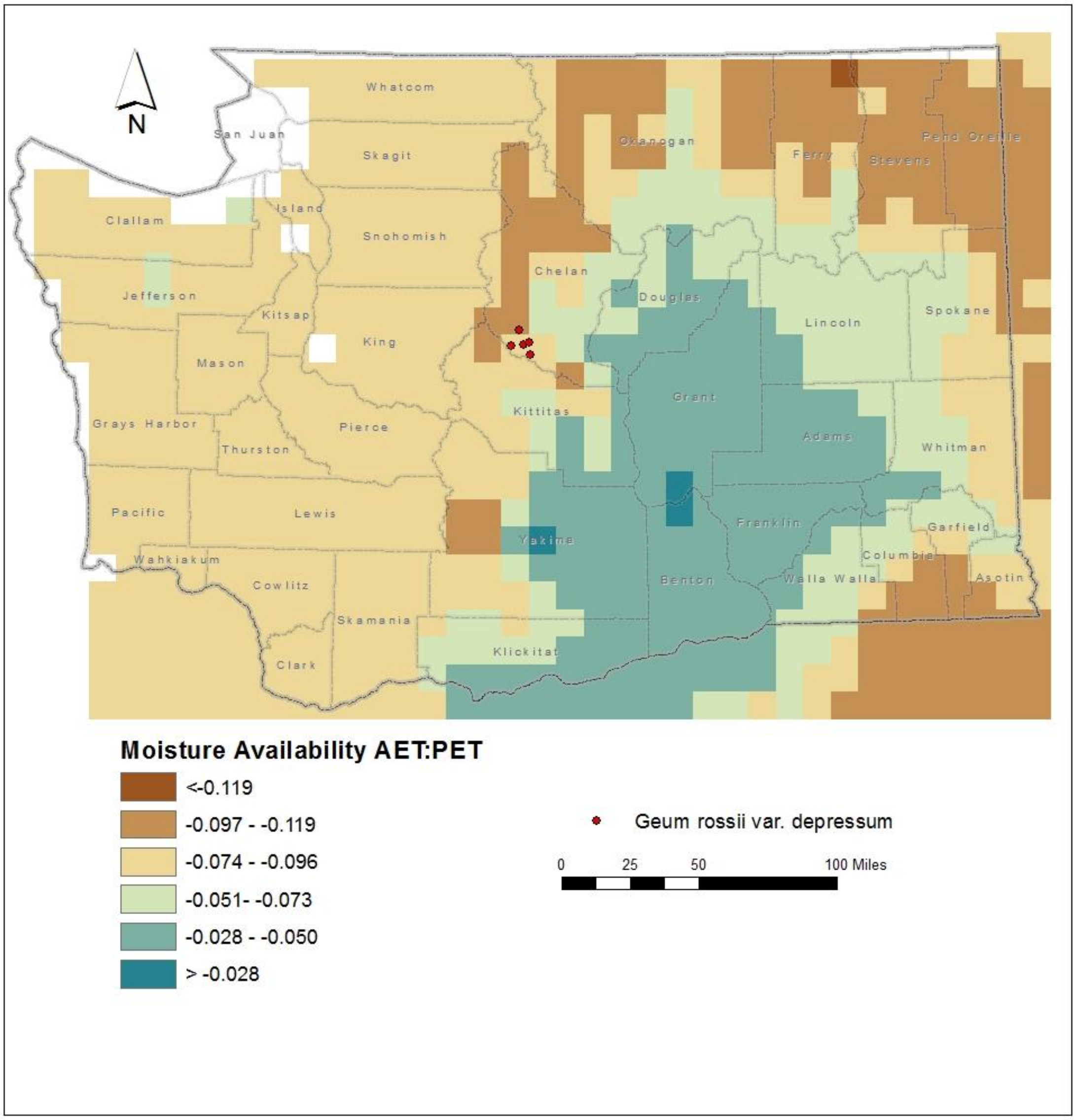

Figure 2. Exposure of *Geum rossii* var. *depressum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Geum rossii* var. *depressum* are found at 6700-8400 feet (2040-2560 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Geum rossii var. *depressum* occurs in alpine talus slopes, rock ledges, and cliffs of granite, quartz, and occasionally serpentine (Camp and Gamon 2011; Fertig 2020). This habitat is part of the North Pacific Serpentine Barren and Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological systems (Rocchio and Crawford 2015). Populations are found on separate ridges or peaks isolated by 1.3-6 miles (6-10 km) of unoccupied and unsuitable habitat. The natural heterogeneity of available habitat forms a barrier to propagule dispersal and future migration.

B2b. Anthropogenic barriers: Neutral.
Four of the populations of *Geum rossii* var. *depressum* in Washington are found in wilderness or special interest areas with a minimal human footprint. The alpine summits inhabited by the species are surrounded by anthropogenic infrastructure in surrounding valley bottoms, but these areas are already a natural barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Geum rossii var. *depressum* produces hairy, spindle-shaped, one-seeded achenes that lack structures associated with wind dispersal. Spence and Shaw (1983) suggested that pikas (*Ochotona princeps*) may disperse whole fruiting stalks of *Geum rossii* in the Wyoming Tetons as they gather and dry leaf material in hay piles for later storage and consumption in winter. Dispersal by gravity and small animals (rodents, lagomorphs) may account for short distance dispersal of fruits or fruiting stems of less than 25 m (the maximum foraging distance for pikas; Huntly et al. 1986).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Geum rossii* var. *depressum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All five of the known occurrences in the state (100%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Greatly Increase.
The alpine talus habitat of *Geum rossii* var. *depressum* is entirely within a cold climate zone during the flowering season and is highly vulnerable to temperature increases from climate change.

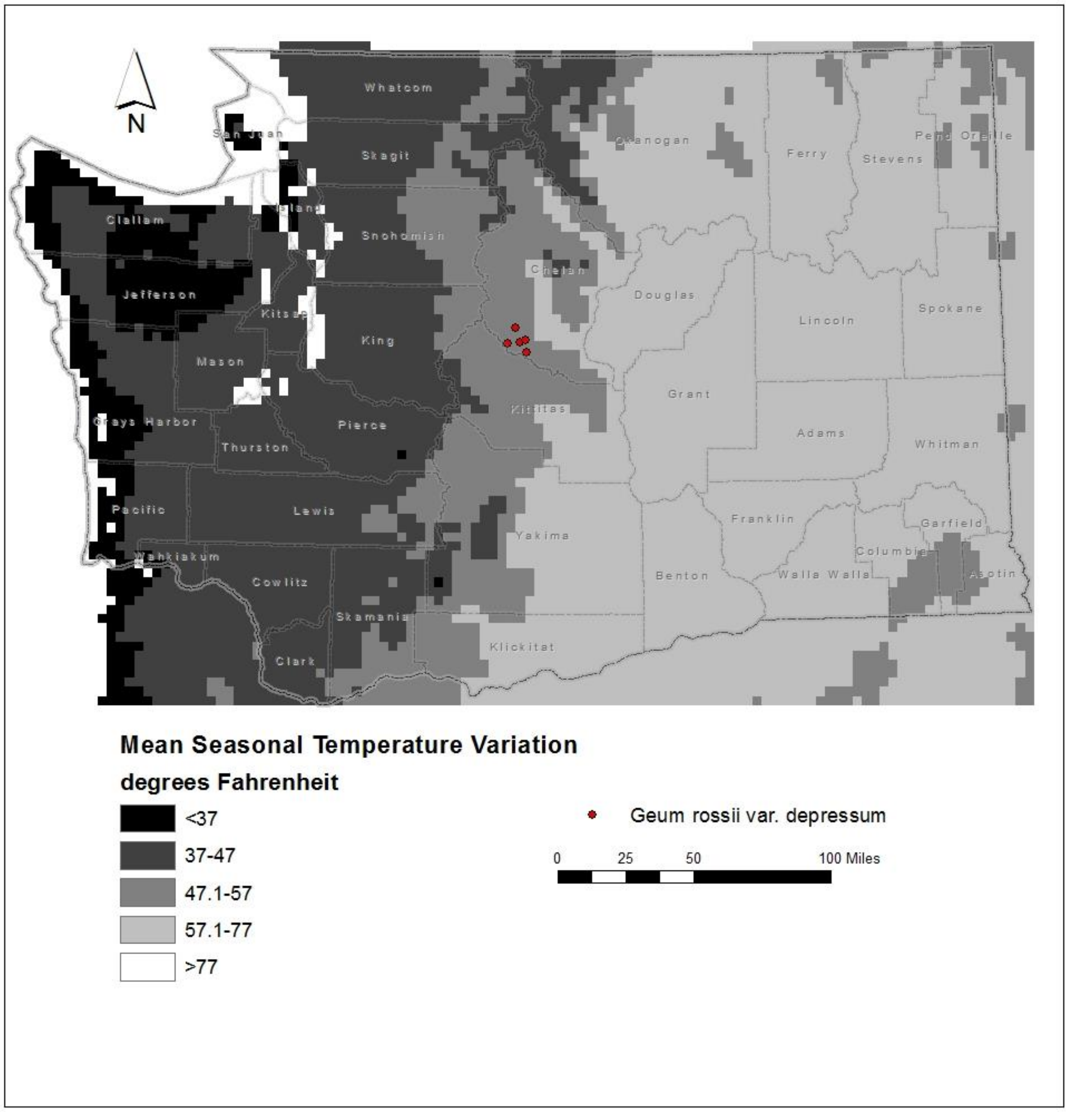

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Geum rossii* var. *depressum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Geum rossii* var. *depressum* in Washington (100%) are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

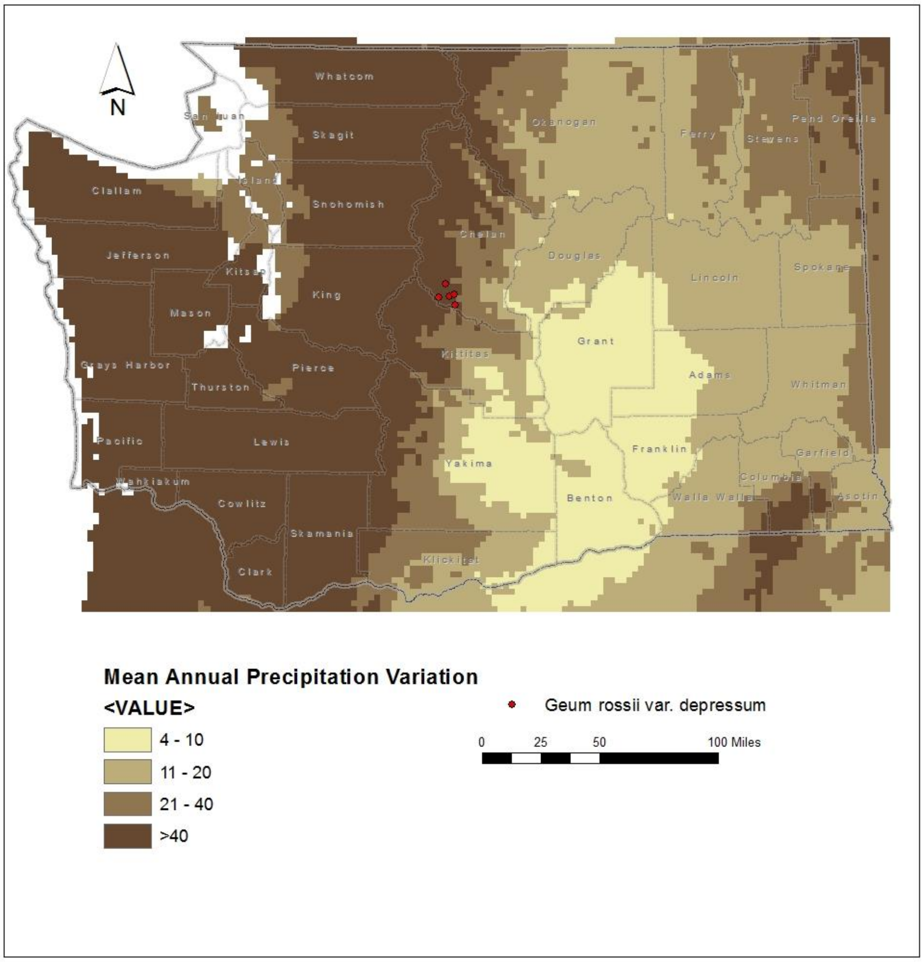

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Geum rossii* var. *depressum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on winter snow and summer precipitation for meeting its moisture needs, as populations are not associated with perennial wetlands or soils with a high water table. It could be vulnerable to changes in the timing or amount of snow and rainfall and earlier snowmelt related to warming temperatures (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Geum rossii var. *depressum* occurs in alpine talus and rock outcrop habitats that are subject to high winds. Other than occasional rock fall, these are largely undisturbed sites at present.

C2d. Dependence on ice or snow-cover habitats: Increase.
Populations of *Geum rossii* var. *depressum* in Washington are found on alpine talus slopes and ridgecrests associated with winter snow accumulation, though the areas may be free of snow due to evaporation or wind during the growing season. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Geum rossii var. *depressum* is found primarily on outcrops of the Mount Stuart Batholith (a pluton of gabbro, granite, and quartz diorite) (Washington Division of Geology and Earth Resources 2016). One historical population is also found on serpentine (Fertig 2020). These formations are uncommon in the East Cascades.

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus habitat occupied by *Geum rossii* var. *depressum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Geum rossii has moderately large, bright yellow, cup-shaped flowers with numerous stamens and is likely pollinated by a variety of bees, flies, and butterflies. The specific pollinators of var. *depressum* in Washington are not known.

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry achene fruits are dispersed by gravity or secondarily by insects, rodents, or pikas.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Overall herbivory appears to be low.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Presently, 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 periodic rock fall. Under projected climate change, competition could increase if lower elevation plant species are able to expand their range into formerly uninhabitable habitat (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Geum rossii occurs from Alaska to Nunavut, south to northern British Columbia and in the Rocky Mountains from central Idaho and southwestern Montana to Nevada, Arizona and New Mexico with a disjunct population in the Wenatchee Mountains of north-central Washington. These three main population centers have been recognized as separate taxa, with var. *rossii* present in Alaska and Canada, var. *turbinatum* in the Rocky Mountains, and var. *depressum* endemic to Washington. These varieties differ in calyx color and venation, petal length, and leaf pubescence (Hitchcock and Cronquist 1961). Rohrer (2015) and Hitchcock and Cronquist

(2018) no longer recognize these varieties as taxonomically distinct. Surprisingly little genetic research has been done on the species, despite chromosome counts showing a range from 2*n* = 56 to 70 (Löve et al. 1971). Genetic data are lacking for Washington populations.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral/Somewhat Increase.
Geum rossii var. *depressum* has floral characteristics suggesting it is an outcrosser and likely to have normal genetic variability across its range. The isolated populations in Washington probably have reduced genetic diversity, however, due to genetic drift or founder effects.

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 *Geum rossii* var. *depressum* has not changed significantly in the last 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase.
Two occurrences of *Geum rossii* var. *depressum* in Washington are historical (not relocated in the last 40 years) and a third was not relocated in a recent site visit. The decline of these populations could be associated with climate change.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Hitchcock, C.L. and A. Cronquist. 1961. Part 3: Saxifragaceae to Ericaceae. Pp. 1-614. In: C.L. Hitchcock, A. Cronquist, M. Ownbey, and J.W. Thompson, eds. Vascular Plants of the Pacific Northwest. University of Washington Press, Seattle, WA.

Hitchcock, C.L. and A. Cronquist. 2018. Flora of the Pacific Northwest, an illustrated manual, second edition. Edited by D.E. Giblin, B.S. Legler, P.F. Zika, and R.G. Olmstead. University of Washington Press and Burke Museum of Natural History and Culture, Seattle, WA. 882 pp.

Huntly, N.J., A.T. Smith, and B.L. Ivins. 1986. Foraging behavior of the pika (*Ochotona princeps*), with comparisons of grazing versus haying. Journal of Mammalogy 67(1): 139-148.

Löve, Á., D. Löve, and B.M. Kapoor. 1971. Cytotaxonomy of a century of Rocky Mountain orophytes. Arctic and Alpine Research 3(2): 139-165.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Rohrer, J.R. 2015. *Geum*. Pp. 58-70. In: Flora of North America Editorial Committee. Flora of North America North of Mexico. Volume 9 Magnoliophyta: Picramniaceae to Rosaceae. Oxford University Press, New York. 713 pp.

Spence, J.R. and R.J. Shaw. 1983. Observations on alpine vegetation near Schoolroom Glacier, Teton Range, Wyoming. Great Basin Naturalist 43(3): 483-491.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Hackelia hispida var. *disjuncta* (Disjunct sagebrush stickseed)

Date: 2 November 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G4T3/S3

Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Unknown
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/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: Documented or Modeled Response	
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: All 19 of the extant and historical occurrences of *Hackelia hispida* var. *disjuncta* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4 ˚ F (Figure 1). Two historical reports from Chelan and Kittitas counties are excluded because

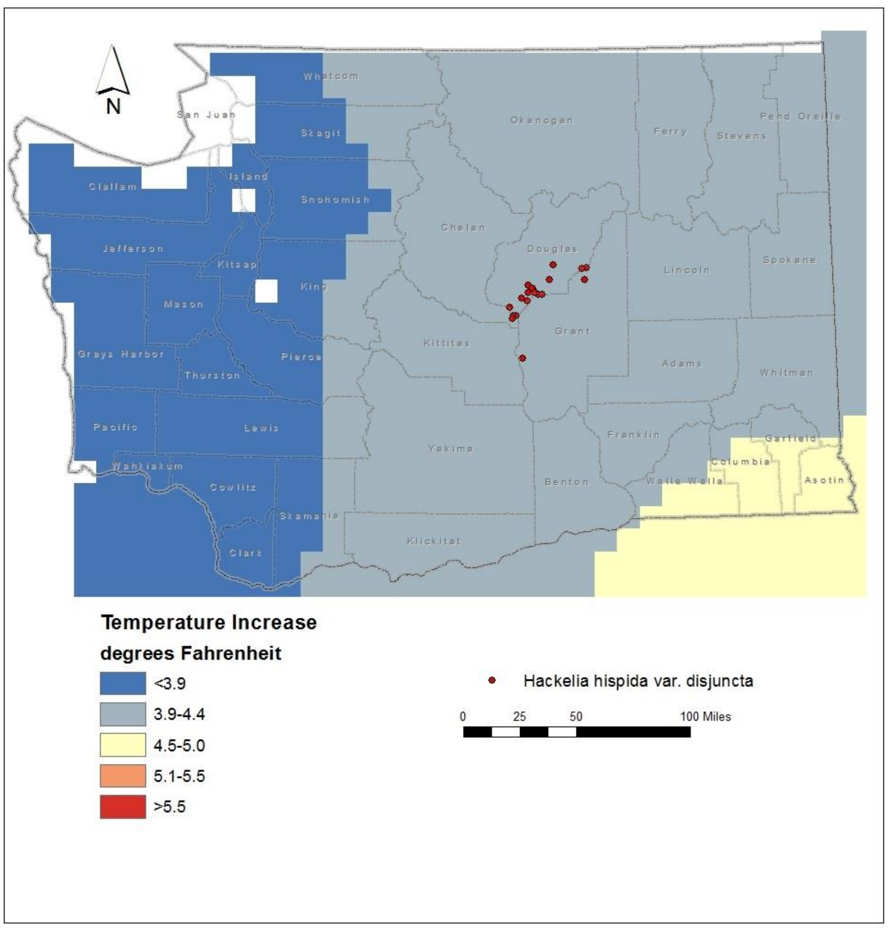

Figure 1. Exposure of *Hackelia hispida* var. *disjuncta* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

they have recently been determined to be misidentified specimens of *Hackelia diffusa* var. *arida*.

A2. Hamon AET:PET Moisture Metric: All of the 19 recognized occurrences (100%) of *Hackelia hispida* var. *disjuncta* 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).

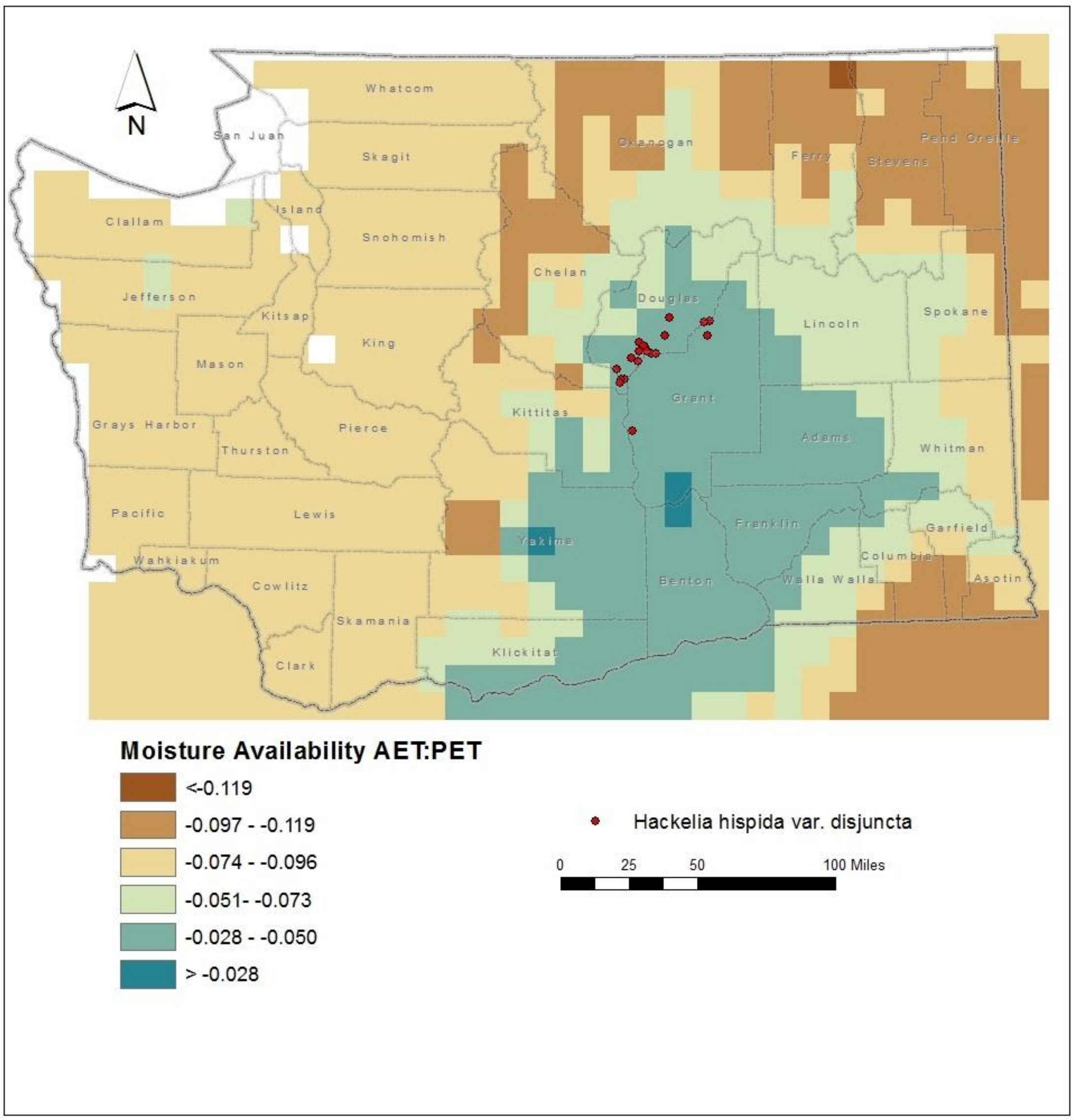

Figure 2. Exposure of *Hackelia hispida* var. *disjuncta* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Hackelia hispida* var. *disjuncta* are found at 1000-2140 feet (300-650 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Hackelia hispida var. *disjuncta* occurs in sparsely vegetated, dry, rocky basalt talus and cliffs (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Inter-Mountain Basin Cliff & Canyon ecological system (Rocchio and Crawford 2015). Populations are separated from each other by 1-18 miles (1.5-29 km) and nearly confined to Moses Coulee and its tributary canyons. Additional habitat exists in other dry canyons in central Washington, but this species may be dispersal limited, or these sites are already occupied by related *Hackelia* species with a similar ecological niche. Carr (1974) suggested that large scale flooding events during the Pleistocene could have wiped out satellite populations of this species in other areas of central Washington.

B2b. Anthropogenic barriers: Neutral.
The rocky basalt talus habitat of *Hackelia hispida* var. *disjuncta* occurs in numerous coulees and canyons in central Washington. Some populations are associated with railroad banks and other human disturbances. The range of this species appears to be naturally constrained by poor dispersal or competition with other *Hackelia* species, rather than human influences, such as agricultural developments and roads. Carr (1974) speculates that human disturbance along roadcuts might actually create a new avenue for increased dispersal of *Hackelia* species.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Hackelia hispida var. *disjuncta* produces 4-parted hard nutlets with a rim of short prickles that allow the fruits to be transported on the fur of mammals. Dispersal distances are thus dependent on the home range of ungulates, rodents, or rabbits, which may be limited to less than 1,000 meters. Longer-distance dispersal is possible, but probably rare, as reflected in the limited natural range of the species.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Hackelia hispida* var. *disjuncta* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 19 known occurrences in the state (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
The basalt cliff and boulder talus habitat of *Hackelia hispida* var. *disjuncta* is often on southerly exposures or otherwise exposed to high temperatures, especially in summer. These site characteristics are not likely to be impacted by projected future climate change.

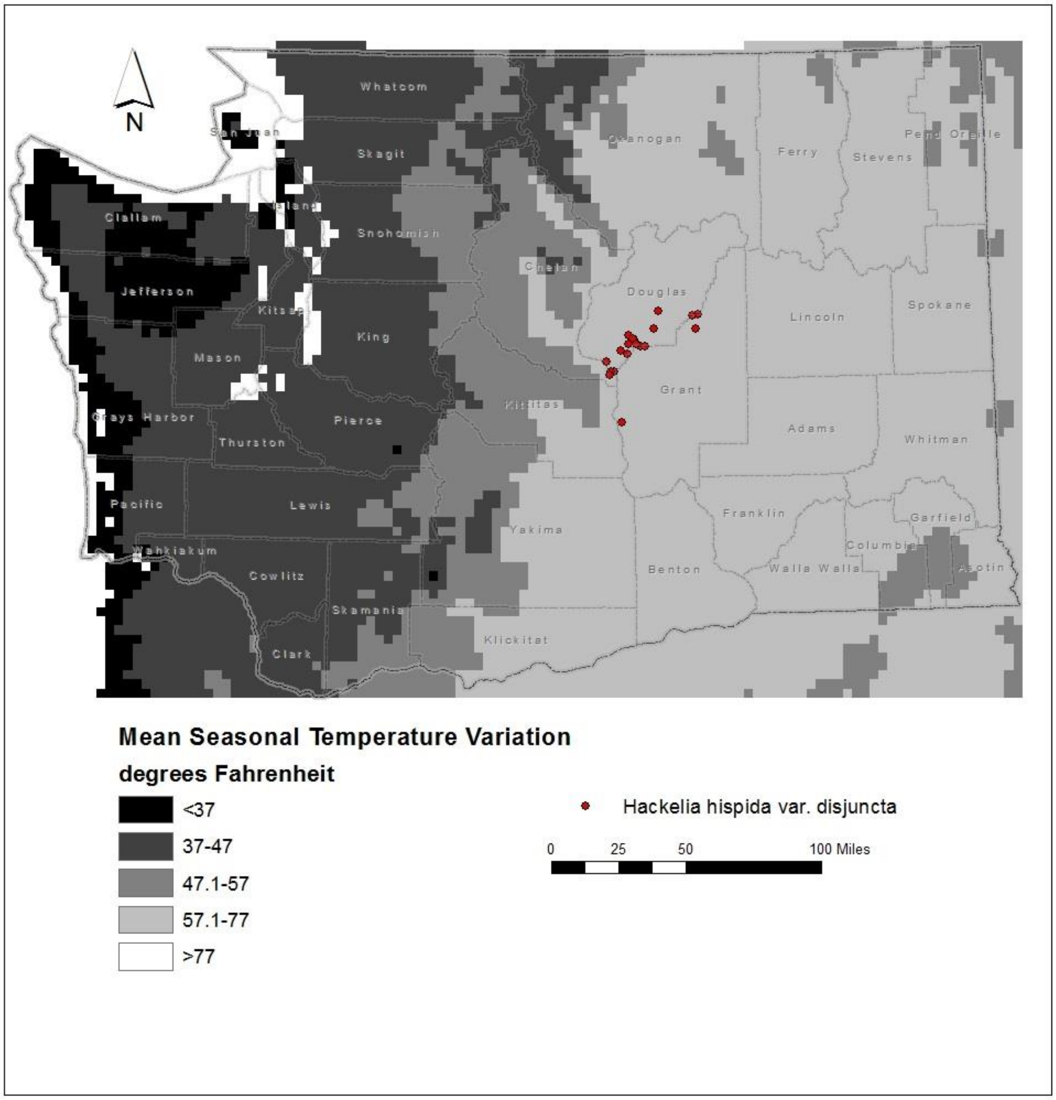

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Hackelia hispida* var. *disjuncta* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Increase.
Sixteen of the 19 populations of *Hackelia hispida* var. *disjuncta* in Washington (84.2%) are found in areas that have experienced small precipitation variation in the past 50 years (4-10 inches/100-254 mm) (Figure 4). According to Young et al. (2016), these occurrences are at increased vulnerability from climate change. Three other occurrences (15.8%) are from areas with slightly lower than average (11-20 inches/255-508 mm) precipitation variation over the same period and are at somewhat increased risk from climate change.

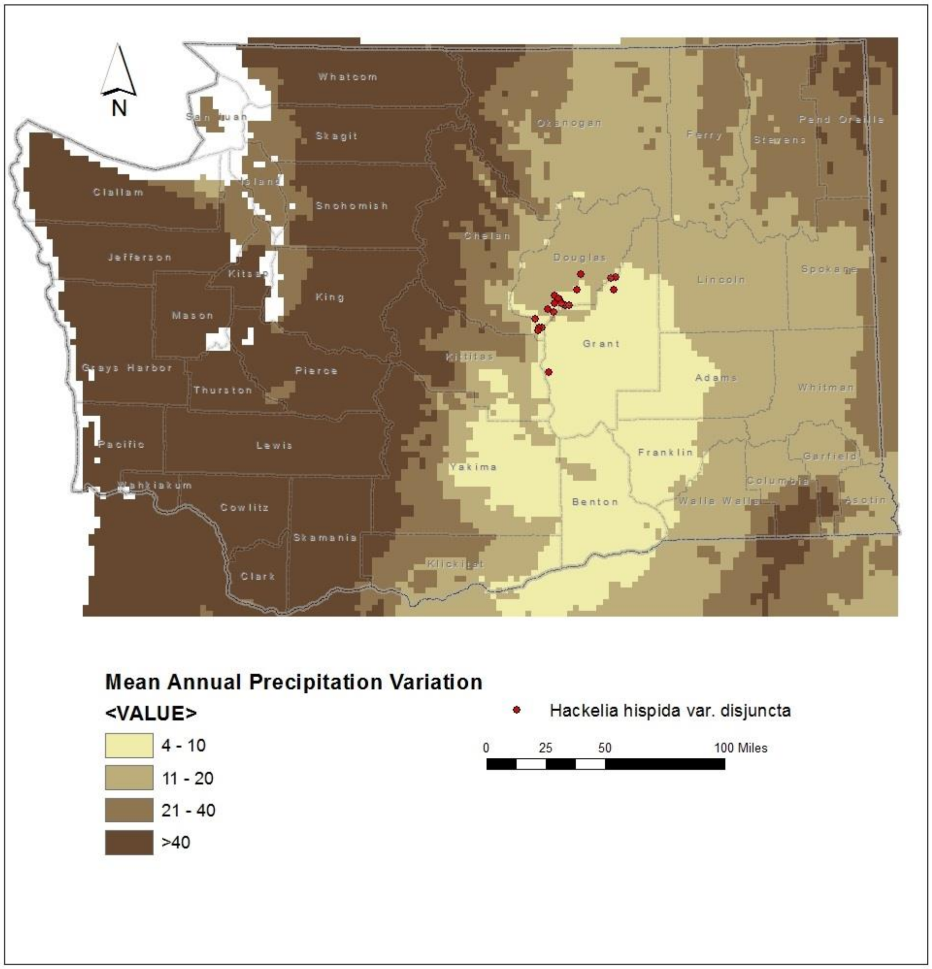

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Hackelia hispida* var. *disjuncta* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is not associated with perennial water sources or a high water table. Changes in the amount and timing of precipitation and increases in temperature are likely to make basalt cliff and talus habitat drier in the future and could shift dominance from vascular plants to lichens (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Hackelia hispida var. *disjuncta* occurs in basalt cliff and talus habitats in dry canyons. These areas have naturally low vegetation cover and infrequent fires due to the paucity of fuels (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
The populations of *Hackelia hispida* var. *disjuncta* in Washington are found in low elevation areas that receive small amounts of snow and are not dependent on regeneration of groundwater from melting snow.

C3. Restricted to uncommon landscape/geological features: Neutral.
Hackelia hispida var. *disjuncta* is found on cliffs and large rock talus of the Miocene-age Grande Ronde Basalt and Quaternary alluvium (Washington Division of Geology and Earth Resources 2016). These outcrops are widespread in central Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The basalt cliff and talus habitat occupied by *Hackelia hispida* var. *disjuncta* is maintained by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Hackelia hispida* var. *disjuncta* are not known. Other *Hackelia* species are pollinated primarily by flies (families Tachinidae, Syrphidae, and Bombyliidae) and bees (families Halictidae and Megachilidae) and less frequently by butterflies (Carr 1974).

C4d. Dependence on other species for propagule dispersal: Somewhat Increase.
The nutlet fruits of *Hackelia hispida* var. *disjuncta* have marginal prickles that can adhere to the fur of mammal species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to the harsh environmental conditions of basalt cliffs and talus. Under projected climate change, these habitats may become even drier, which may shift dominance to lichens over vascular plants (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Carr (1974) sampled five populations of *Hackelia hispida* var. *disjuncta* and determined the chromosome number to be $2n = 48$, making the taxon a tetraploid. Additional data on genetic variability is not known.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Hackelia species have perfect flowers in which the stamens and pistils mature at different times (dichogamy) to promote out-crossing (Carr 1974; Gentry and Carr 1976). Most obligate

outcrossing species have at least moderate levels of genetic diversity. *Hackelia hispida* var. *disjuncta* is disjunct from var. *hispida* of the Snake River drainage and has diverged morphologically and presumably genetically.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral. Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Hackelia hispida* var. *disjuncta* has not changed its typical blooming time since it was first discovered in the 1930s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Hackelia hispida* var. *disjuncta* in Washington in recent years.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Carr, R.L. 1974. A taxonomic study in the genus *Hackelia* in western North America. Doctoral Dissertation, Oregon State University, Corvallis, OR.

Gentry, J.L., Jr. and R.L. Carr. 1976. A revision of the genus *Hackelia* (Boraginaceae) in North America, north of Mexico. Memoirs New York Botanical Garden 26(1): 121-227.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021. *Hackelia hispida* var. *disjuncta*. In: Online Field Guide to the Rare Plants of Washington.

(https://fieldguide.mt.gov/wa/?species=hackelia%20hispida%20var.%20disjuncta). Accessed 2 November 2021.

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 uncialis (Howell's rush)

Date: 7 September 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G3G4/S2

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	91.7
	-0.028 to -0.050	8.3
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral/Somewhat Increase
2bi. Changes in historical hydrological niche		Somewhat Increase
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		Increase
4a. Dependence on others 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: Documented or Modeled Response	
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: All 12 known occurrences of *Juncus uncialis* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

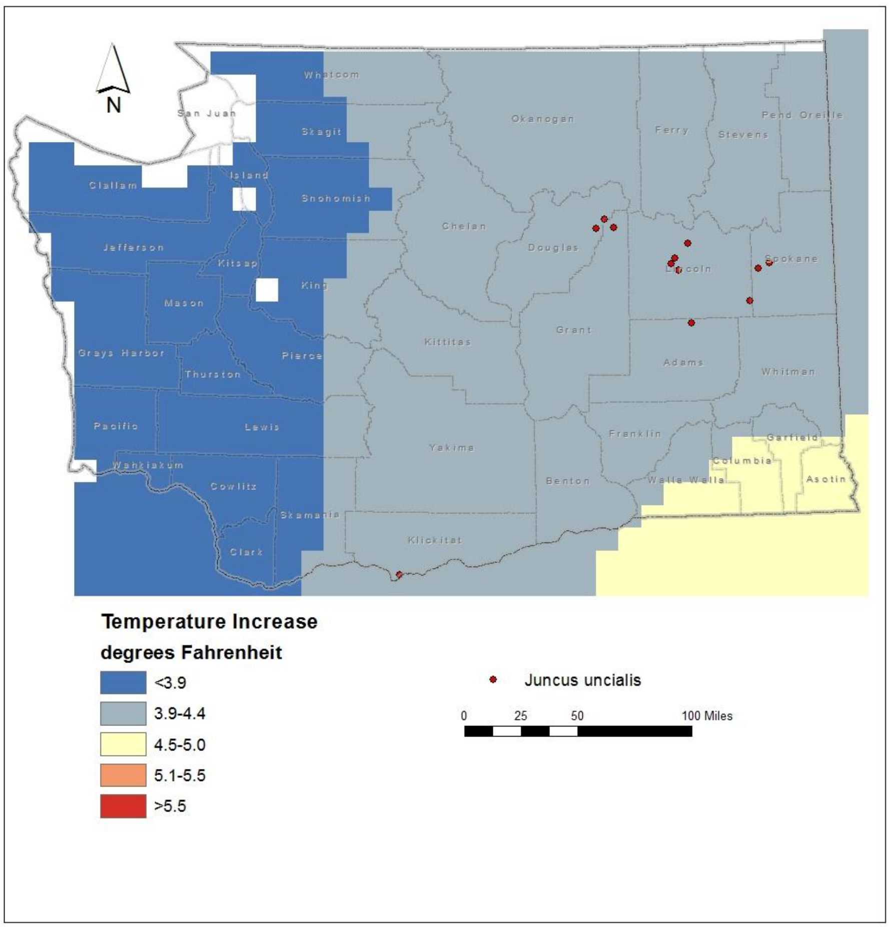

Figure 1. Exposure of *Juncus uncialis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Eleven of the 12 Washington occurrences of *Juncus uncialis* (91.7%) 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). One other population (8.3%) is from an area with a projected decrease of -0.028 to -0.050.

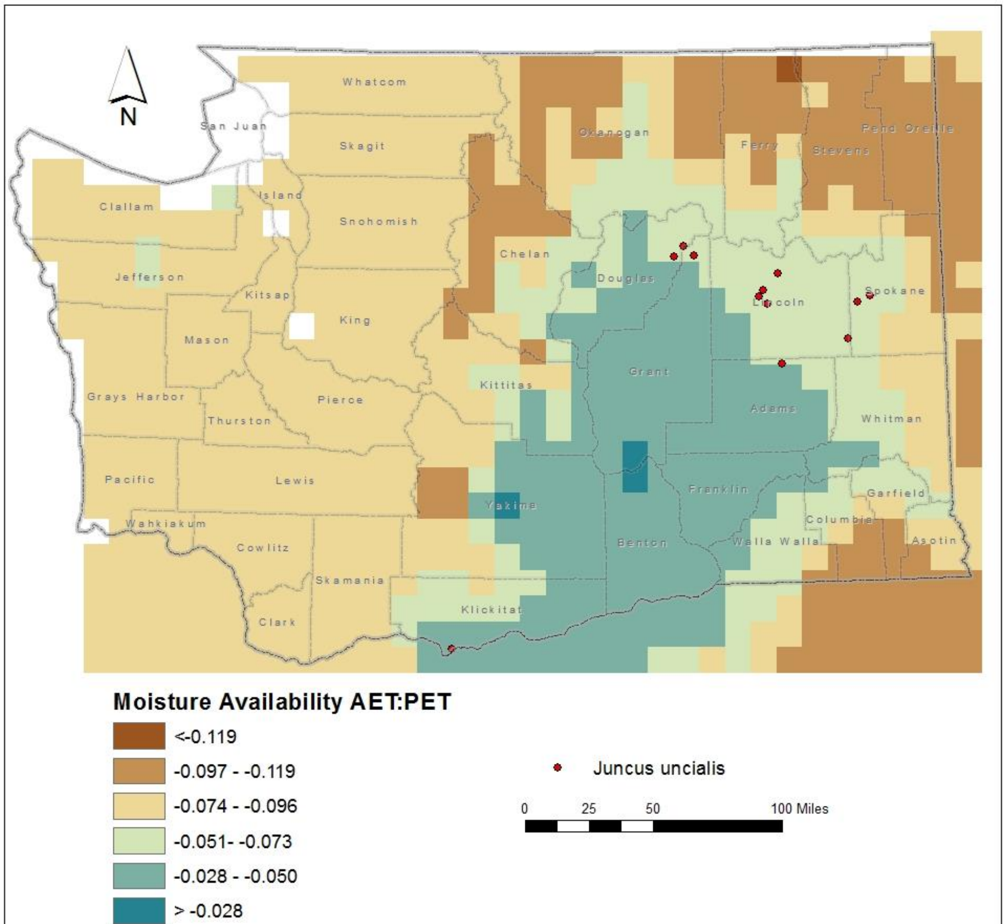

Figure 2. Exposure of *Juncus uncialis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Juncus uncialis* are found at 300-2500 feet (90-760 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
In Washington, *Juncus uncialis* is mostly associated with vernal pools and the edges of small ponds within channeled scablands (Camp and Gamon 2011, Fertig and Kleinknecht 2020). One site in Klickitat County is in a vernal pool on basalt tablelands in the Columbia River Gorge. These sites are components of the Columbia Basin Vernal Pool and Modoc Basalt Flow Vernal Pool ecological systems (Rocchio and Crawford 2015). Populations from eastern Washington are separated by 3-29 miles (4.7-47 km). A gap of 170 miles (274 km) exists between the populations from eastern Washington and Klickitat County (although populations also occur across the Columbia River in Wasco County, Oregon). 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.
The range of *Juncus uncialis* is naturally fragmented. Historically, some vernal pool habitat has been lost to human impacts, but overall anthropogenic barriers are less significant than natural ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Juncus uncialis produces dry capsules containing up to 140 seeds that are 0.4 mm long or less (Ertter 1986). These tiny seeds may be dispersed short distances through the air, or longer distances by flowing water or attached to feathers or muddy feet of waterfowl. While most seeds probably travel short distances from their parent, the potential for medium to long-distance travel (over 1 km) suggests that this factor should be scored as neutral.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Juncus uncialis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 12 occurrences (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change.

C2aii. Physiological thermal niche: Neutral/Somewhat Increase.
The vernal pool habitat occupied by *Juncus uncialis* is not associated with cold air drainage during the growing season. Shallow vernal pools would be vulnerable to long-term persistent drought exacerbated by increased temperatures (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Somewhat Increase.
All 12 populations of *Juncus uncialis* in Washington (100%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability from climate change.

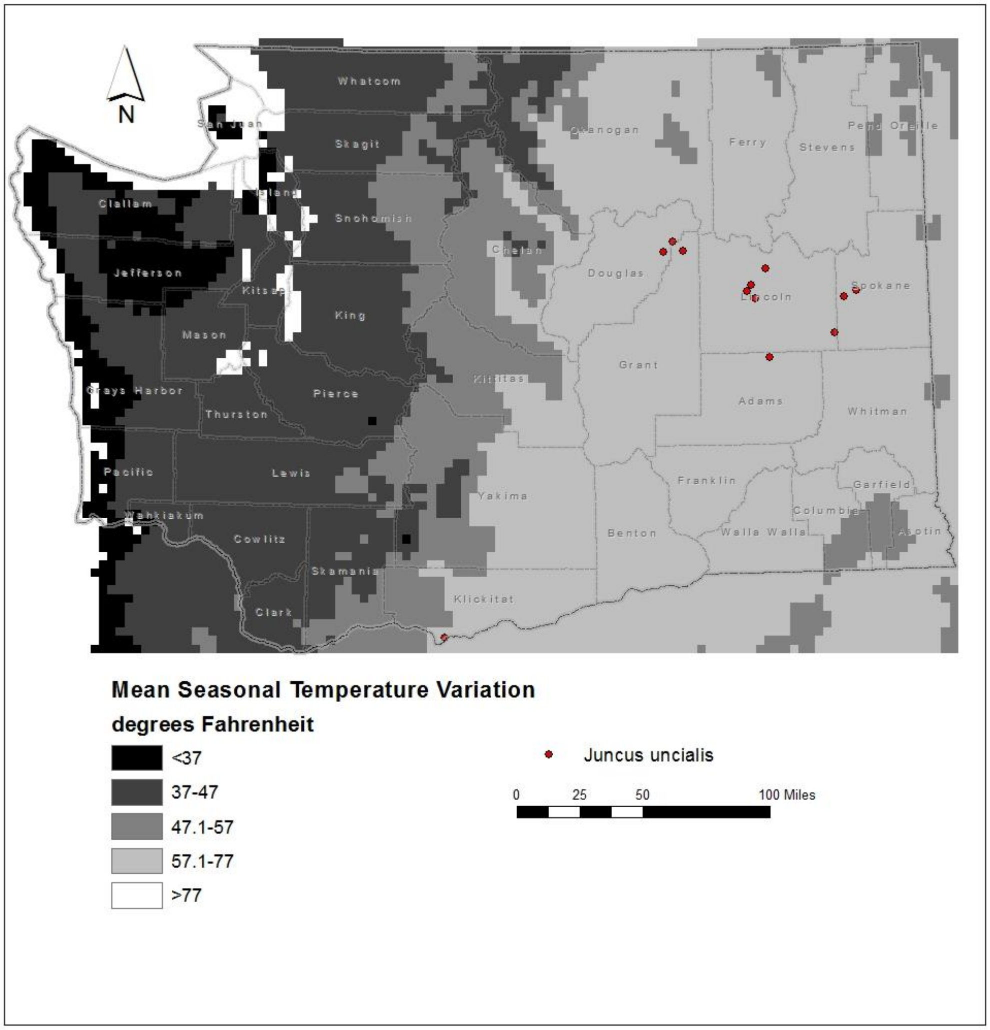

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Juncus uncialis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
Juncus uncialis is dependent on winter and early spring precipitation and snow melt followed by drought to maintain its specialized vernal pool habitat. It is especially vulnerable to changes in the timing or amount of precipitation or snowmelt (Rocchio and Ramm-Granberg 2017). Potentially higher amounts of precipitation in winter could be offset by higher temperatures and greater evapotranspiration in spring. Unpredictable climatic events could also be significant on this annual species which must rely on a seed bank to persist through unfavorable years.

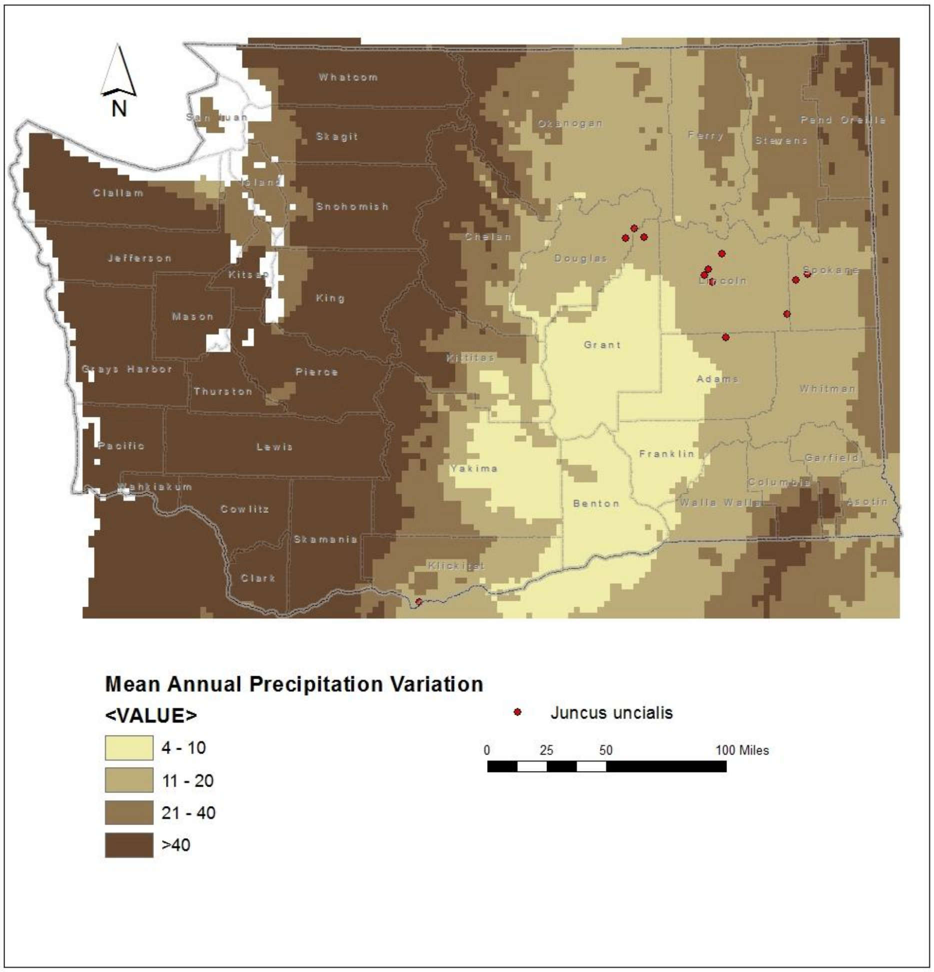

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Juncus uncialis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2c. Dependence on a specific disturbance regime: Neutral.
Juncus uncialis is not dependent on disturbance to maintain its vernal pool habitat. It would, however, be detrimentally impacted by increased summer temperatures, drought, or decreased snowpack that could lead to a shift to other plant communities or invasive annuals (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Although *Juncus uncialis* occurs in areas with moderate winter snowfall, reductions in snowpack or changes in the timing of snow melt could reduce the amount of available water in

its vernal pool habitat, favoring the transition of these sites to less mesic community types (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Juncus uncialis is found on Miocene-age Wanapum Basalt beds found widely across the channeled scablands or eastern Washington and the Columbia River Gorge (Washington Division of Geology and Earth Resources 2016). While this geologic formation is common, 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 a habitat specialist.

C4a. Dependence on other species to generate required habitat: Neutral
The vernal pool habitat occupied by *Juncus uncialis* is maintained by natural abiotic processes and geological conditions, rather than interactions with other species.

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Neutral.
Juncus uncialis, like other members of the genus *Juncus*, is presumed to be primarily wind-pollinated. Recent research suggests that some *Juncus* species can be insect pollinated and capable of selfing too (Huang et al. 2013).

C4d. Dependence on other species for propagule dispersal: Neutral.
Juncus uncialis seeds are tiny and well-suited for dispersal by air, water, or on muddy feathers, feet, or fur of animals. It is not dependent on any single species of animal for dispersal, and so this factor is scored as neutral.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. *Juncus uncialis* is edible for wildlife and grazing is cited as a potential threat (Camp and Gamon 2011; Fertig and Kleinknecht 2020). Whether climate change would exacerbate these threats is poorly known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Juncus uncialis could be sensitive to competition from other plant species (particularly invasive, non-native annual grasses) if its vernal pool habitat is converted to upland vegetation due to climate change (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Data are not available on the genetic diversity of this species. *Juncus uncialis* is known to have a base chromosome number of $n = 16$ (Ertter 1986).

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Juncus uncialis is presumed to be an outcrosser and primarily wind pollinated suggesting that genetic variability should be average to high rangewide. Populations from eastern Washington are at the northern edge of the species' range and somewhat disjunct from other occurrences along the lower Columbia River and might have lower total diversity due to founder effects or inbreeding.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on information from WNHP records and specimens in the Consortium of Pacific Northwest Herbaria, no changes have been detected in phenology in the past 40 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The range of this species in Washington has not changed significantly since it was first documented in the state in 1983.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Ertter, B. 1986. The *Juncus triformis* complex. Memoirs of the New York Botanical Garden 39:1-90.

Fertig, W. and J. Kleinknecht 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Huang, S-Q, Y-Z. Xiong, and S.C.H. Barrett. 2013. Experimental evidence of insect pollination in Juncaceae, a primarily wind-pollinated family. International Journal Plant Sciences 174(9): 1219-1228.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Juncus uncialis*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=juncus%20uncialis). Accessed 10 September 2021.

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

Leptosiphon bolanderi (Bolander's linanthus)

Date: 5 October 2021 | Synonym: *Linanthus bakeri, Linanthus bolanderi*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G4G5/S2

Index Result: Less Vulnerable | Confidence: Low

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	88.9
	-0.028 to -0.050	11.1
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral/Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral/Somewhat Increase
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/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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: Documented or Modeled Response	
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: All 9 of the extant and historical occurrences of *Leptosiphon bolanderi* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

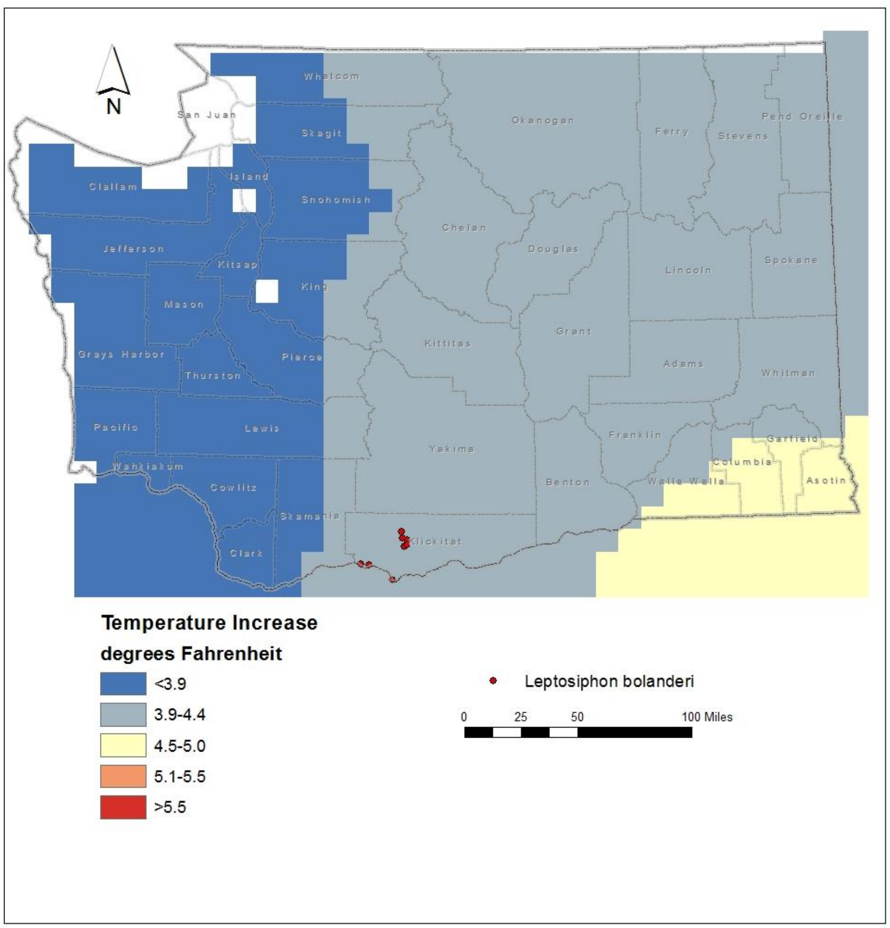

Figure 1. Exposure of *Leptosiphon bolanderi* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Eight of the 9 occurrences (88.9%) of *Leptosiphon bolanderi* 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). One other population (11.1%) is from an area with a projected decrease of -0.028 to -0.050.

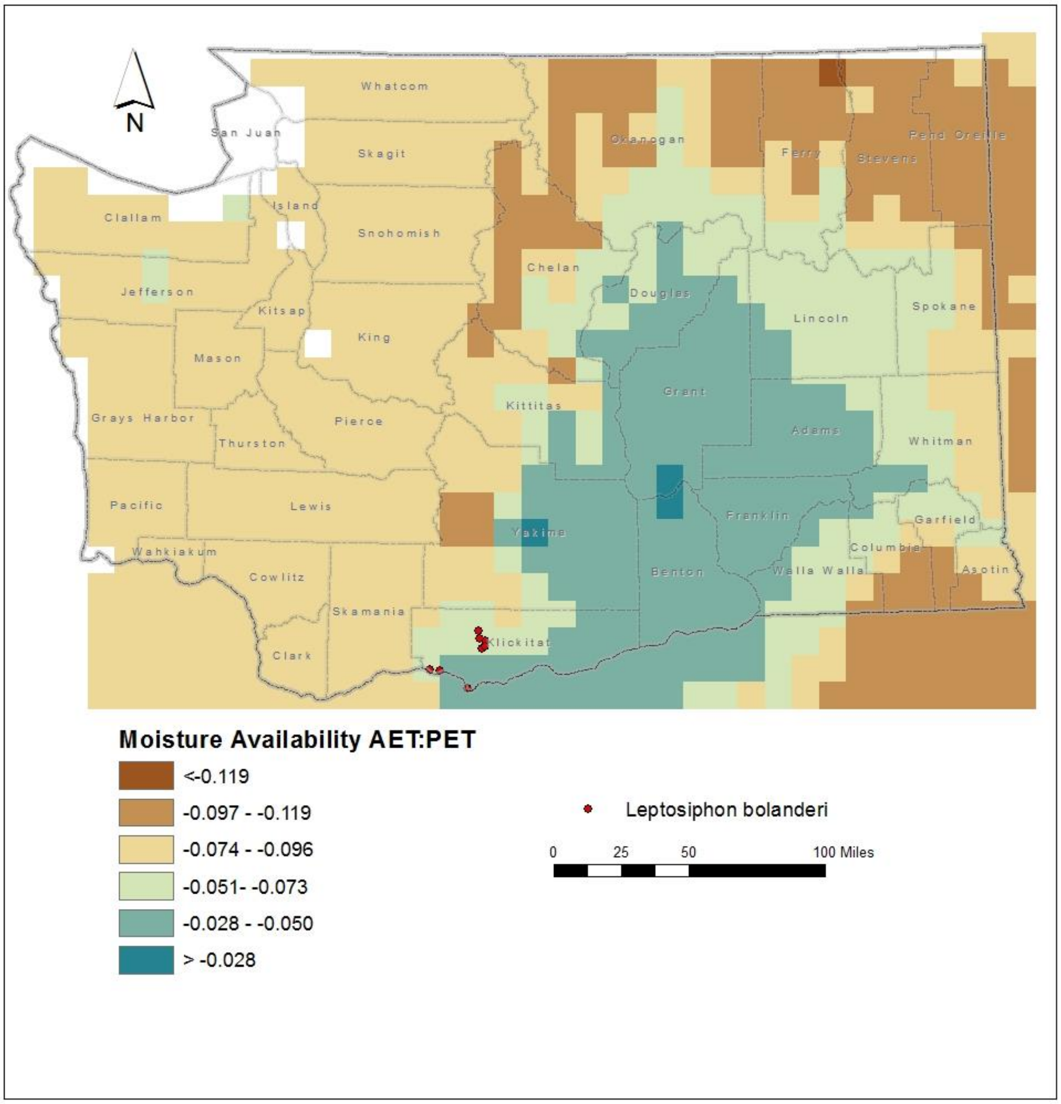

Figure 2. Exposure of *Leptosiphon bolanderi* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Leptosiphon bolanderi* are found at 850-1800 feet (260-550 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Leptosiphon bolanderi occurs primarily on dry, partially vegetated rocky areas with bare mineral soil in openings in Oregon white oak (*Quercus garryana*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) communities (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the East Cascades Oak-Ponderosa Pine Forest & Woodland ecological system (Rocchio and Crawford 2015). Populations are separated from each other by 1.5-17.5 miles (2.5-28 km). There are natural, topographic barriers between the main concentrations of populations along the upper Klickitat River Canyon and the Columbia River that may limit overland dispersal.

B2b. Anthropogenic barriers: Neutral.
This species is adapted to sparsely vegetated, bare soil areas within Oregon white oak/ponderosa pine habitat. Human activities over the past 150 years have increased the amount of disturbed habitat in Klickitat County and created potential new conduits for dispersal along roads or across deforested areas, but has not seemed to increase the spread of *Leptosiphon bolnderi*.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral/Somewhat Increase.
Leptosiphon bolanderi produces numerous, small seeds within dry capsule fruits that split open to release the seeds passively at maturity. Dispersal distances may vary from short (less than 100 m) to 1000 m or more, depending on whether the seed becomes wet and mucilaginous (sticky-gooey), allowing them to become fastened to animals (Moran 1977).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Leptosiphon bolanderi* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the 9 known occurrences in the state (77.8%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). Two of nine populations (22.2%) have had slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the same period and are considered at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral/Somewhat Increase.
The sparsely vegetated openings within oak-ponderosa pine woodland habitat of *Leptosiphon bolanderi* may be on exposed ridges or in topographic depressions. The latter sites are cooler

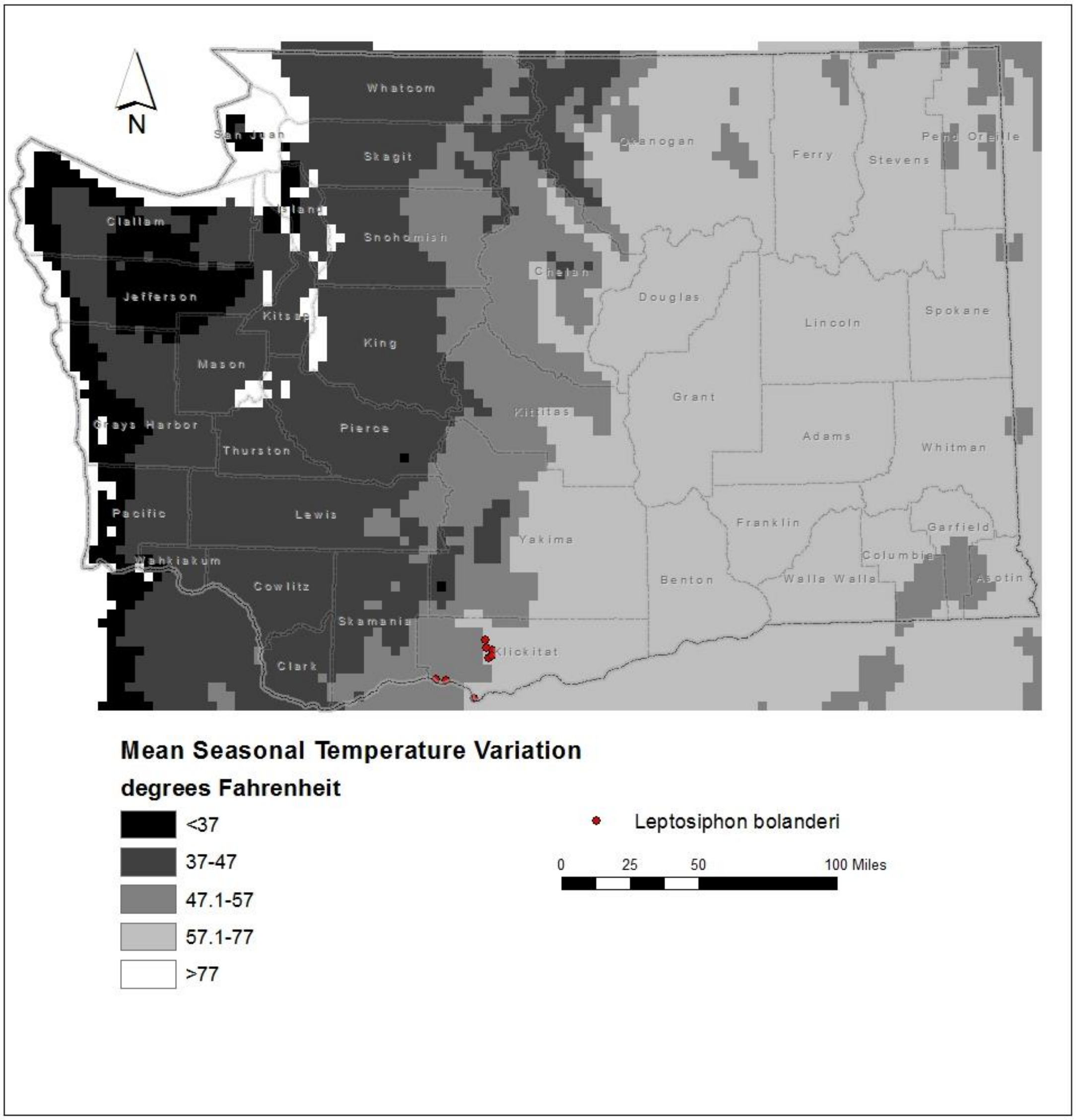

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Leptosiphon bolanderi* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

microsites during the flowering season and could be impacted by increasing temperatures from climate change.

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Leptosiphon bolanderi* in Washington are found in areas that have experienced average precipitation variation in the past 50 years (20-40 inches/508-1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

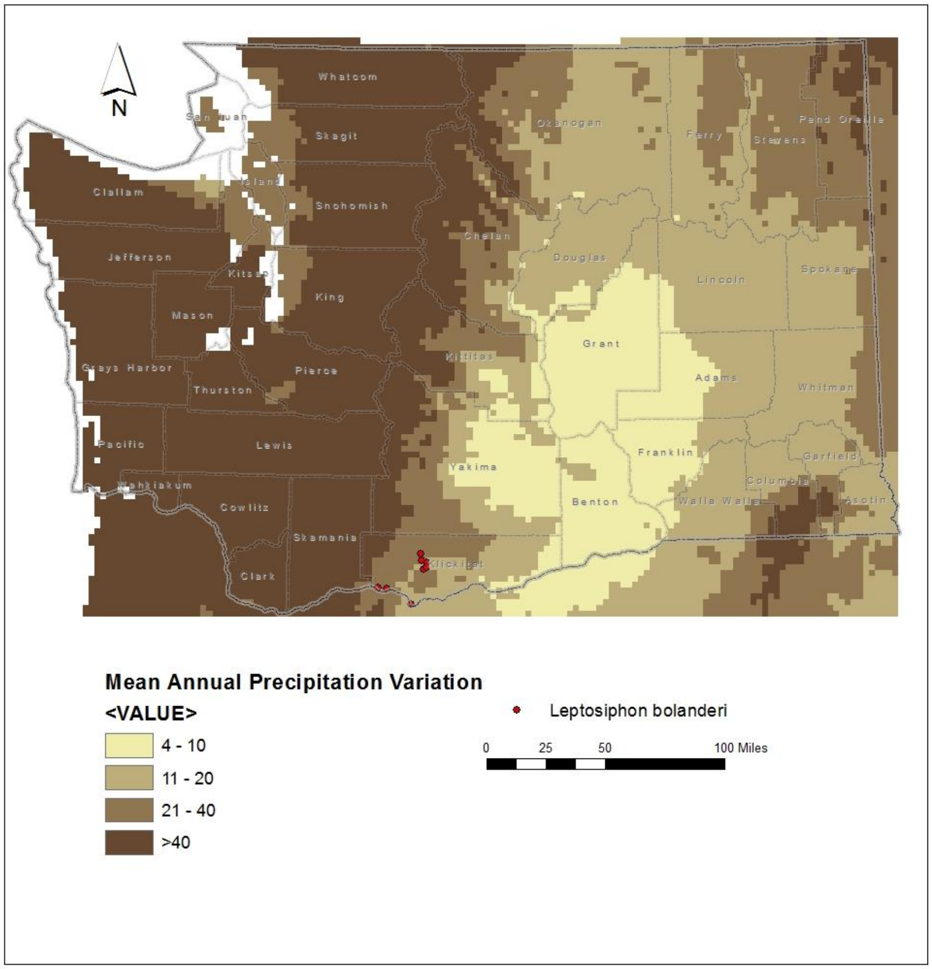

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Leptosiphon bolanderi* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species occurs in partially barren openings associated with Oregon white oak and ponderosa pine that are not associated with perennial water sources or a high water table. Reduction in precipitation or warmer temperatures leading to more frequent or prolonged drought are likely to increase the fire frequency in this ecological system and result in a shift from mixed pine and oak to oak dominance, or more open habitat (Rocchio and Ramm-Granberg 2017). Disturbance from fire and drought may actually increase the amount of habitat available for *Leptosiphon bolanderi*, but this positive effect could be countered by increased competition with invasive, weedy annuals.

C2c. Dependence on a specific disturbance regime: Neutral.
Leptosiphon bolanderi occurs in sparsely vegetated and rocky openings in dry Oregon white oak/ponderosa pine woodlands. Natural or anthropogenic disturbances, including fire, may be neutral to beneficial in creating or maintaining these open and early seral conditions. Projected climate change is likely to make these areas drier, hotter, and more prone to wildfire and insect outbreaks that may negatively impact oaks (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
The populations of *Leptosiphon bolanderi* in Washington are found in low elevation foothill areas of the eastern Cascades and Columbia River that receive relatively low amounts of snow. Annuals, like *Leptosiphon bolanderi*, may have better flower or seed production, however, following wetter winters.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Washington, *Leptosiphon bolanderi* is found mostly on soils derived from Wanapum or Grande Ronde basalt and Quaternary alluvium, all of which are widespread within its range (Washington Division of Geology and Earth Resources 2016). Populations from California may be associated with serpentine soils which often have specialized floras adapted to low levels of nitrogen, phosphorus, and potassium and high amounts of heavy metals, like cobalt, chromium, and nickel (Hitchcock et al. 1959). Serpentine is uncommon in Washington, being known primarily from islands in the Salish Sea and the Wenatchee Mountains, both areas where *L. bolanderi* has not been documented.

C4a. Dependence on other species to generate required habitat: Neutral
The open, rocky habitat of *Leptosiphon bolanderi* is created and maintained largely by natural abiotic conditions, such as fire or drought, but may be enhanced by grazing or soil disturbance by burrowing animals.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Leptosiphon bolanderi has small, white to pink flowers (6-8 mm long) that may be pollinated by small insects. Like other small-flowered *Leptosiphon* species, it is also likely capable of self-pollination (Goodwillie 1999).

C4d. Dependence on other species for propagule dispersal: Neutral.
The small seeds of *Leptosiphon bolanderi* may disperse passively by wind or be carried on the surface of animals (including waterfowl) after the seed coat has been wetted and become sticky. It is not dependent on a single species for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The open, rocky, partially barren habitat of *Leptosiphon bolanderi* is prone to invasion by annual weedy species that may compete for space or resources. Climate change is likely to make its habitat drier, hotter, and more vulnerable to wildfire and may hasten the spread of non-native competitors (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Studies of the genetic diversity within and between Washington populations of *Leptosiphon bolanderi* have not been done.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Somewhat Increase.
Leptosiphon bolanderi has a mixed mating system involving both outcrossing and potential self-pollination. As a result, it may have lower genetic variability overall than might be expected, but more variability between populations.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Leptosiphon bolanderi* has not changed its typical blooming time since the 1880s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Two historical populations along the Columbia River have not been relocated and may be extirpated due to habitat loss from development. Impacts from climate change does not appear to have altered the distribution of this species.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Goodwillie, C. 1999. Multiple origins of self-compatibility in *Linanthus* section *Leptosiphon* (Polemoniaceae): Phylogenetic evidence from Internal-Transcribed-Spacer sequence data. Evolution 53(5): 1387-1395.

Hitchcock, C.L., A. Cronquist, and M. Ownbey. 1959. Part 4: Ericaceae through Campanulaceae. In: C.L. Hitchcock, A. Cronquist, M. Ownbey, and J.W. Thompson, eds. Vascular Plants of the Pacific Northwest. University of Washington Press, Seattle, WA. 510 pp.

Moran, R. 1977. New or renovated Polemoniaceae from Baja California, Mexico (*Ipomopsis*, *Linanthus, Navarretia*). Madroño 24(3): 141-159.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Leptosiphon bolanderi*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=leptosiphon%20bolanderi). Accessed 5 October 2021.

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

Lomatium knokei (Knoke's desert-parsley)

Date: 5 October 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G1/S1

Index Result: Highly Vulnerable | Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	100
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		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/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on others species to generate required habitat		Neutral/Somewhat Increase
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		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: Documented or Modeled Response	
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: The single occurrence of *Lomatium knokei* in Washington (100%) occurs in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

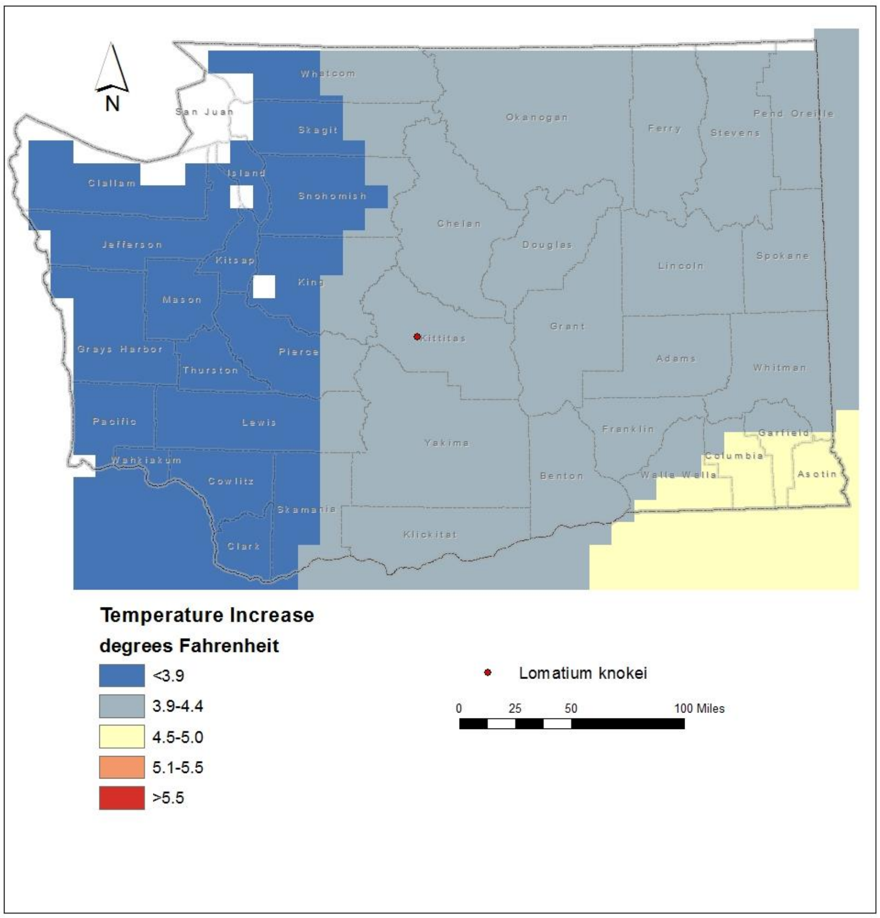

Figure 1. Exposure of *Lomatium knokei* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single Washington occurrence of *Lomatium knokei* (100%) 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 -0.051 to -0.073 (Figure 2).

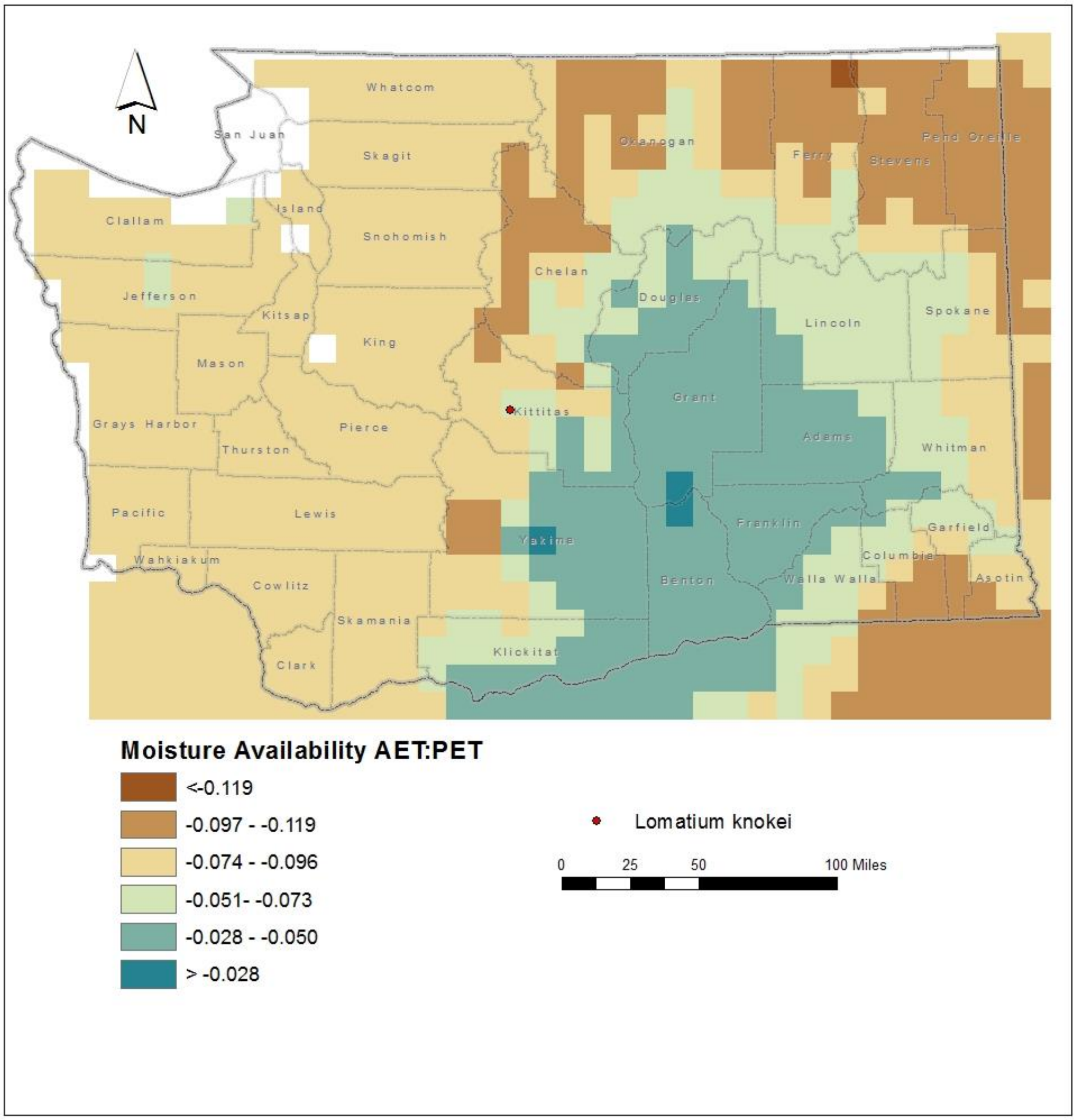

Figure 2. Exposure of *Lomatium knokei* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Lomatium knokei* are found at 3940-3985 feet (1200-1215 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Lomatium knokei* is found in seasonally wet depressions in forb-rich mountain meadows surrounded by Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*) and lodgepole pine (*Pinus contorta* var. *latifolia*) forests (Darrach 2014; Fertig 2020; Washington Natural Heritage Program 2021). This habitat is a component of the Rocky Mountain Alpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015. Additional areas of suitable potential habitat in the East Cascades are separated by dense forests or broad valleys which present a barrier to seed dispersal.

B2b. Anthropogenic barriers: Neutral.
The limited range of *Lomatium knokei* is bisected by roads, including one through the core of its main subpopulation. These disturbances may create some of the rutted depression habitat in which this species grows. Dispersal is probably more constrained by large blocks of unsuitable forest or dry valleys that isolate areas of seasonal wetland habitat.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitivity and Adaptive Capacity

C1. Dispersal and movements: Increase.
Lomatium knokei produces dry, flattened, elliptical fruits (schizocarps) that split at maturity into two one-seeded segments. Each fruit segment has a narrow, membranous wing along the margins to facilitate dispersal by wind. Other structures, such as hooks, barbs, or rough hairs for attachment to animals are not present. In general, *Lomatium* species have poor dispersal ability (less than 100 meters) which may account for their unusually high degree of endemism in western North America (Marisco and Hellman 2009).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Lomatium knokei* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The single occurrence (100%) is found in an area that has experienced slightly lower than average temperature variation (47.1-57°F/26.3-31.8°C) during the past 50 years and is considered at somewhat increased risk from climate change (Young et al. 2016).

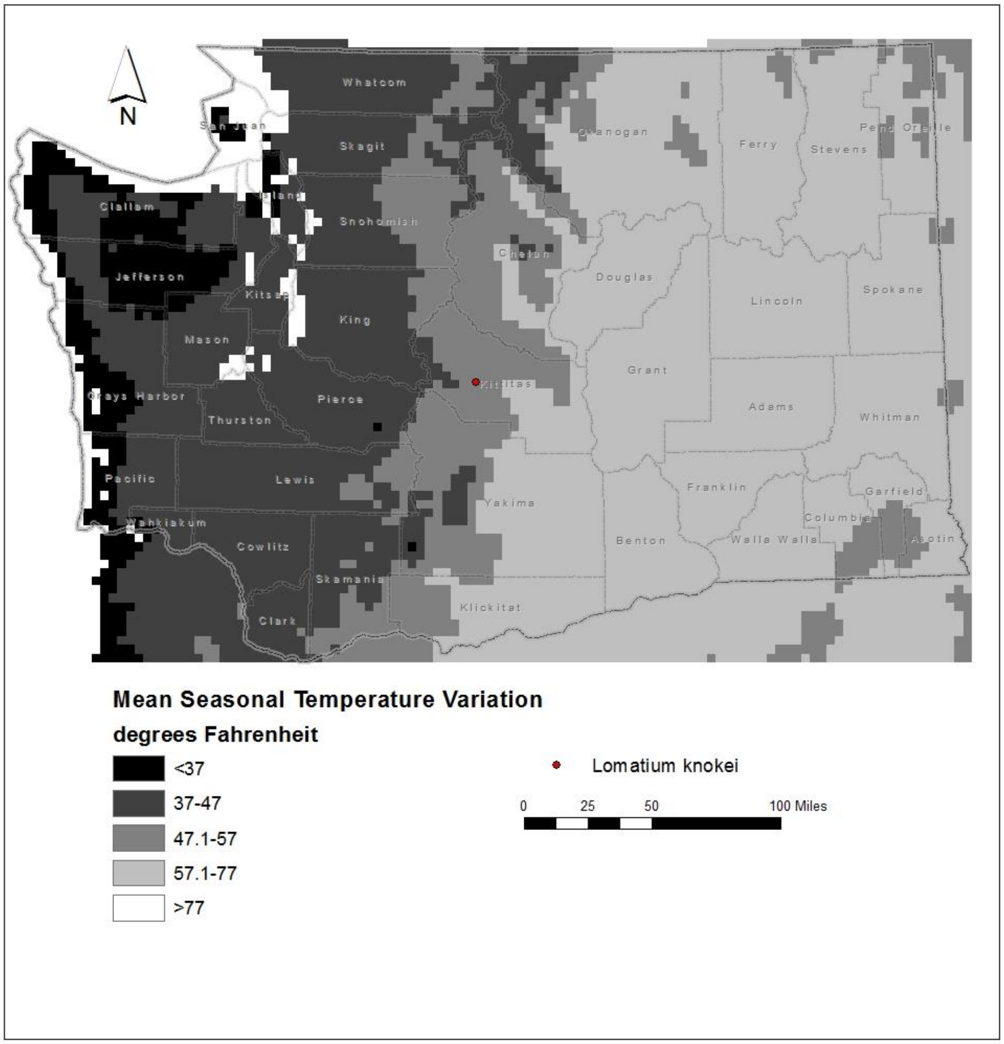

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium knokei* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The seasonally wet montane meadow areas inhabited by *Lomatium knokei* are associated with cold air drainage during the growing season and could be vulnerable to increased temperatures associated with climate change.

C2bi. Historical hydrological niche: Neutral.
The single known population of *Lomatium knokei* in Washington (100%) is found in an area that has experienced greater than average (>40 inches/1016 mm) precipitation variation in the past 50 years (Figure 4) and is at neutral vulnerability from climate change (Young et al. 2016).

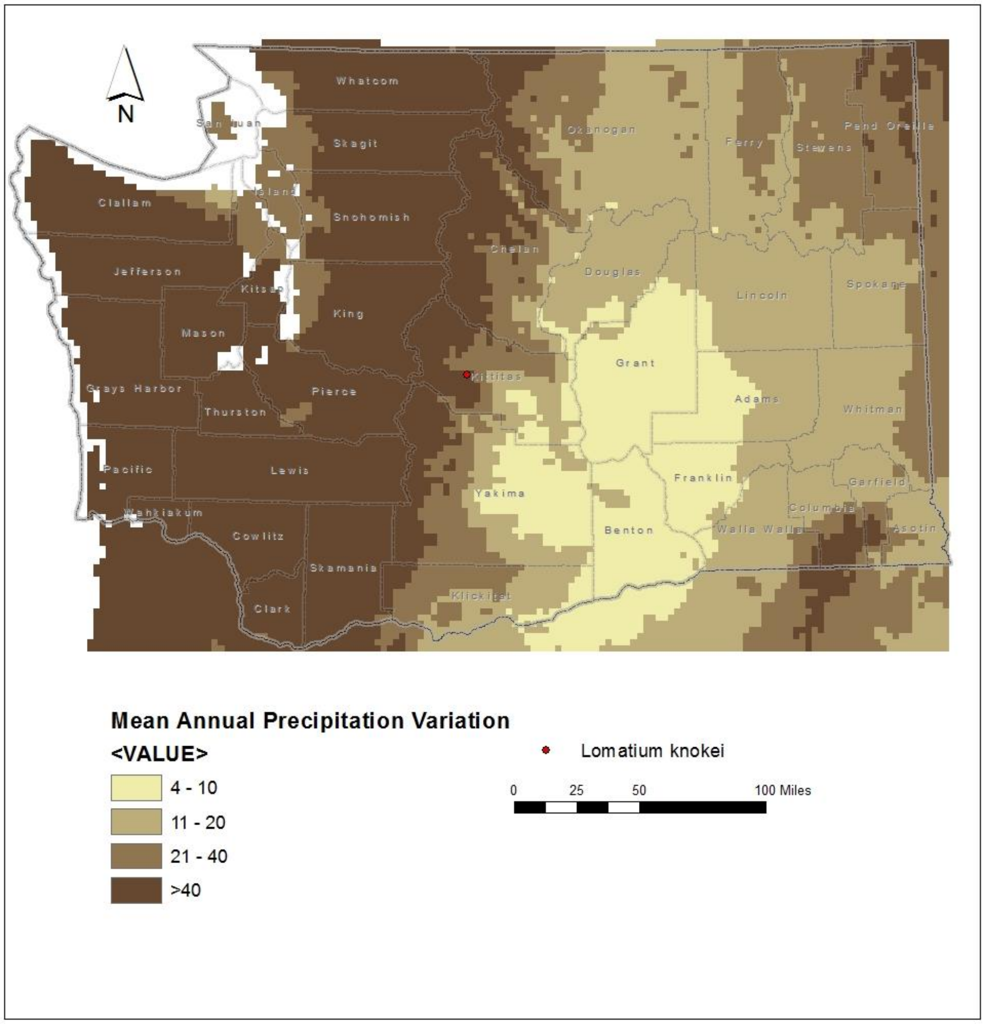

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium knokei* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Lomatium knokei is found in seasonally wet depressions in clay-rich soils in montane meadows. These sites do not appear to be associated with springs, but rather represent low spots in the landscape where snow drifts or spring melt-water accumulates. Changes in the amount of snowfall and the timing of snowmelt resulting from warmer temperatures could have significant impacts on *Lomatium knokei* and its habitat (Darrach 2014). Decreases in summer precipitation and rising temperatures could also affect these meadow sites by favoring the spread of more drought-tolerant herbaceous species, or encroachment by trees and shrubs (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase.
Lomatium knokei is found in low depressions that may be formed by erosion or wallowing by elk or deer. These depressions may also be associated with ruts from dirt roads. Periodic wildfire may be important in keeping meadow sites open and free from encroachment by woody species. Wildfire is likely to increase in the future due to summer drought and reduced precipitation (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Lomatium knokei occurs in areas of moderate accumulation of snow. Drifting or late-melting snow is an important source of spring moisture during the flowering and fruiting period of *L. knokei* (Darrach 2014).

C3. Restricted to uncommon landscape/geological features: Increase.
Lomatium knokei is restricted to the Hakker soil series which is a seasonally wetted, fine-grained clay-loam (Darrach 2014) derived from colluvium and basalt bedrock of the Grande Ronde Basalt (Washington Division of Geology and Earth Resources 2016). The Hakker series is not widespread in the mountains south of Cle Elum. This species may also be dependent on a landscape feature (depressions that are seasonally wet) that is not widespread.

C4a. Dependence on other species to generate required habitat: Neutral/Somewhat Increase.
The seasonally flooded depressions within montane meadows occupied by *Lomatium knokei* may be formed or maintained by wallowing ungulates.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Lomatium knokei* are not known, but other tuberous *Lomatium* species are pollinated by solitary bees, syrphid flies, tachinid flies, muscid flies, bee flies, and beetles (Schlessman 1982).

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Lomatium knokei* are dispersed primarily by wind, gravity, or other passive means. The species is not dependent on animals for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Darrach (2014) noted that *Lomatium knokei* is sometimes infested with aphids and gall-forming insects, which may be an important source of herbivory.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The seasonally wet depressions occupied by *Lomatium knokei* could be vulnerable to invasion by competing native or introduced species under prolonged periods of drought (Rocchio and Ramm-Granberg 2017). This species appears to be absent or sparse in adjacent meadow areas with dense cover of other herbaceous species.

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

C5a. Measured genetic variation: Unknown.
Data are not available on genetic diversity within *Lomatium knokei*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Lomatium knokei is andromonoecious and produces compound umbels with individual umbellets comprised of all staminate flowers or a mix of staminate and pistillate flowers (and some perfect flowers) (Darrach 2014). Occasional plants may also be monoecious. The presence of separate gendered flowers that mature at different times promotes outcrossing and leads to higher genetic variability (Schlessman 1982).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Onset of flowering in *Lomatium knokei* appears to be tied to the melting of mountain snow, which may vary from early April to mid May. The timing of flowering has not changed significantly, however, since the species was first documented in 2002 (Darrach 2014).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Lomatium knokei was first recognized in 2002 and was not formally described as a new species until 2014 (Darrach 2014). To date, it is known only from 3 small patches within a single population in the mountains south of Cle Elum, Washington (Fertig 2020). Searches of other potential seasonal wetland sites in the vicinity have not located any additional populations. Due to the paucity of baseline data, no inferences can be made about impacts of climate change to this species since its discovery.

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

References

Darrach, M.E. 2014. *Lomatium knokei* (Apiaceae), a new, narrowly endemic species from Washington state. Phytoneuron 2014-108:1-12.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Marsico, T.D. and J.J. Hellman. 2009. Dispersal limitation inferred from an experimental translocation of *Lomatium* (Apiaceae) species outside their geographic ranges. Oikos 118:1783-1792.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Schlessman, M.A. 1982. Expression of andromonoecy and pollination of tuberous *Lomatium*s (Umbelliferae). Systematic Botany 7(2): 134-149.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Lomatium knokei*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=lomatium%20knokei). Accessed 28 September 2021.

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

Lomatium lithosolamans (Hoover's biscuitroot)

Date: 18 September 2021

Synonym = *Tauschia hooveri*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G2G3/S2S3

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	38.7
	-0.028 to -0.050	61.3
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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/Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat 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 31 occurrences of *Lomatium lithosolamans* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). Two recent reports from

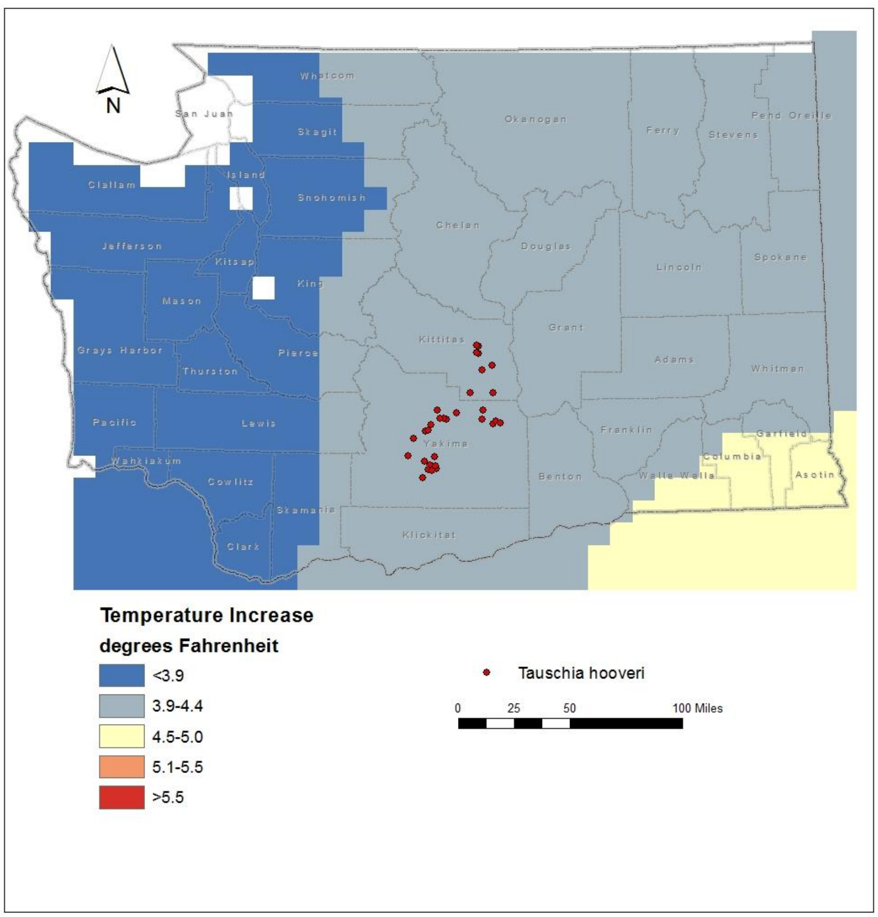

Figure 1. Exposure of *Lomatium lithosolamans* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

high elevations in the East Cascades need confirmation and have not been included in this analysis.

A2. Hamon AET:PET Moisture Metric: Nineteen of the 31 Washington occurrences of *Lomatium lithosolamans* (61.3%) 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). The other 12 populations (38.7%) occur in areas with a projected decrease in available moisture of -0.051 to – 0.073.

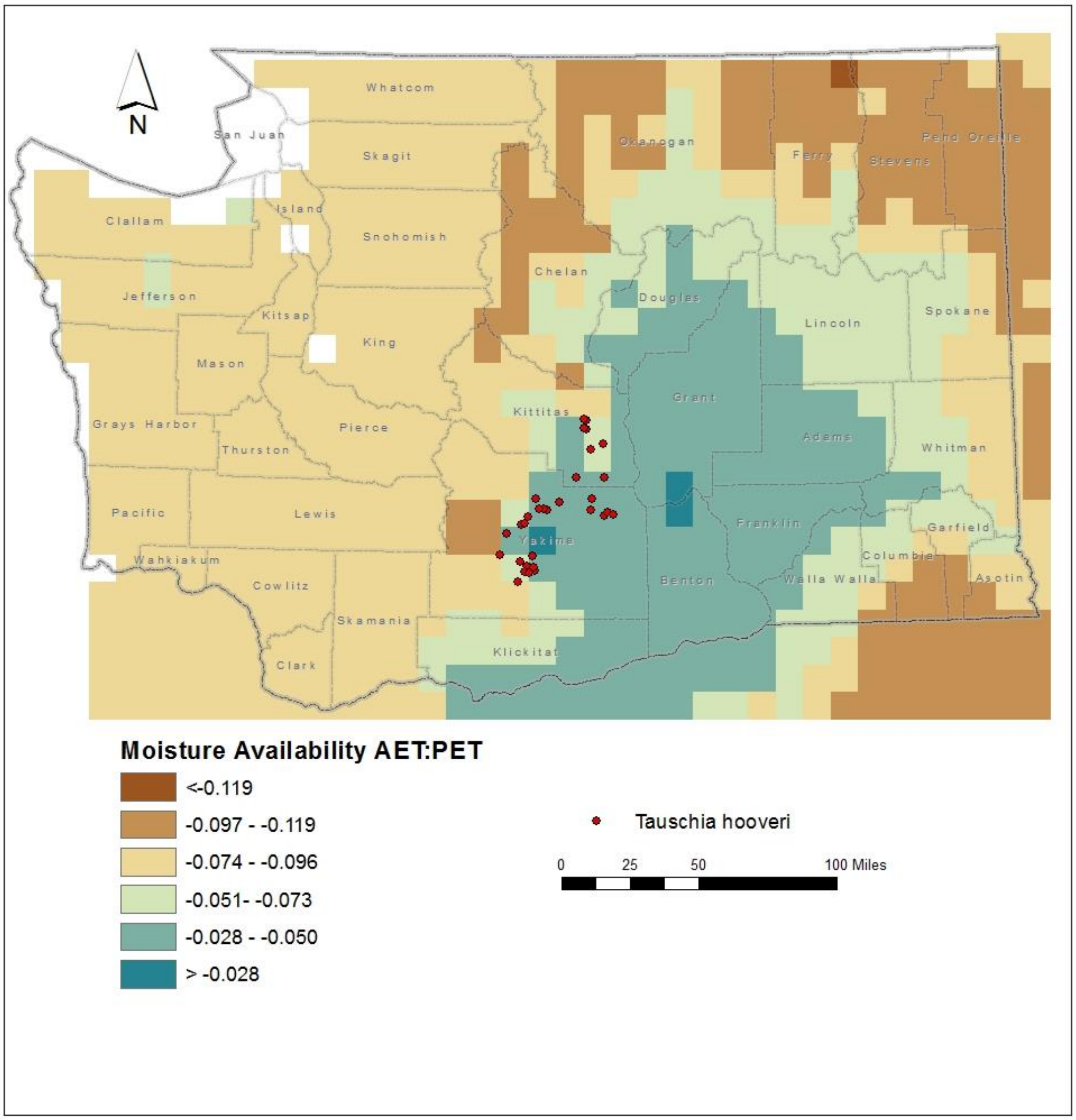

Figure 2. Exposure of *Lomatium lithosolamans* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Lomatium lithosolamans* are found at 1300-4000 feet (400-1220 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Lomatium lithosolamans* is found on well-drained basalt lithosols in mostly flat, shrub steppe habitats dominated by stiff sagebrush (*Artemisia rigida*) and Sandberg's bluegrass (*Poa secunda*) (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is a component of the Columbia Plateau Scabland Shrubland ecological system (Rocchio and Crawford 2015). Individual populations are separated by 2.1-18 km (1.2-11 miles) and restricted to an area of approximately 24 x 105 km (15 x 65 miles) (Camp and Gamon 2011). Potential habitat is intersected by drainages and ridges that present a moderate physical barrier to dispersal.

B2b. Anthropogenic barriers: Somewhat Increase.
Much of the range of *Lomatium lithosolamans* in Washington has been converted to agriculture (especially grazing) or human development, resulting in a fragmented distribution. As a result, there is less opportunity for genetic exchange between populations along the east slope of the Cascades and those in eastern Kittitas and Yakima counties. Nearly one-third of all known occurrences are historical, suggesting the range may be contracting.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitivity and Adaptive Capacity

C1. Dispersal and movements: Increase.
Lomatium lithosolamans produces dry, linear-oblong fruits (schizocarps) that split at maturity into two one-seeded segments. Each fruit segment has slightly raised ribs but otherwise lack structures such as hooks, barbs, or wings for attachment to animals or to catch air currents. In general, *Lomatium* species have poor dispersal ability (less than 100 meters) which may account for their unusually high degree of endemism in western North America (Marisco and Hellman 2009).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Lomatium lithosolamans* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Twenty-six of the 31 known occurrences (83.9%) are found in areas of the Columbia Basin that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral risk from climate change (Young et al. 2016). Seven of these 26 populations are historical. The other five occurrences in the state (16.1%) are from areas on the east slope of the Cascades with a slightly lower than average temperature variation (47.1-57˚F/26.3-31.8˚C) during the same period and are at somewhat increased vulnerability to climate change. Three of these occurrences are also historical.

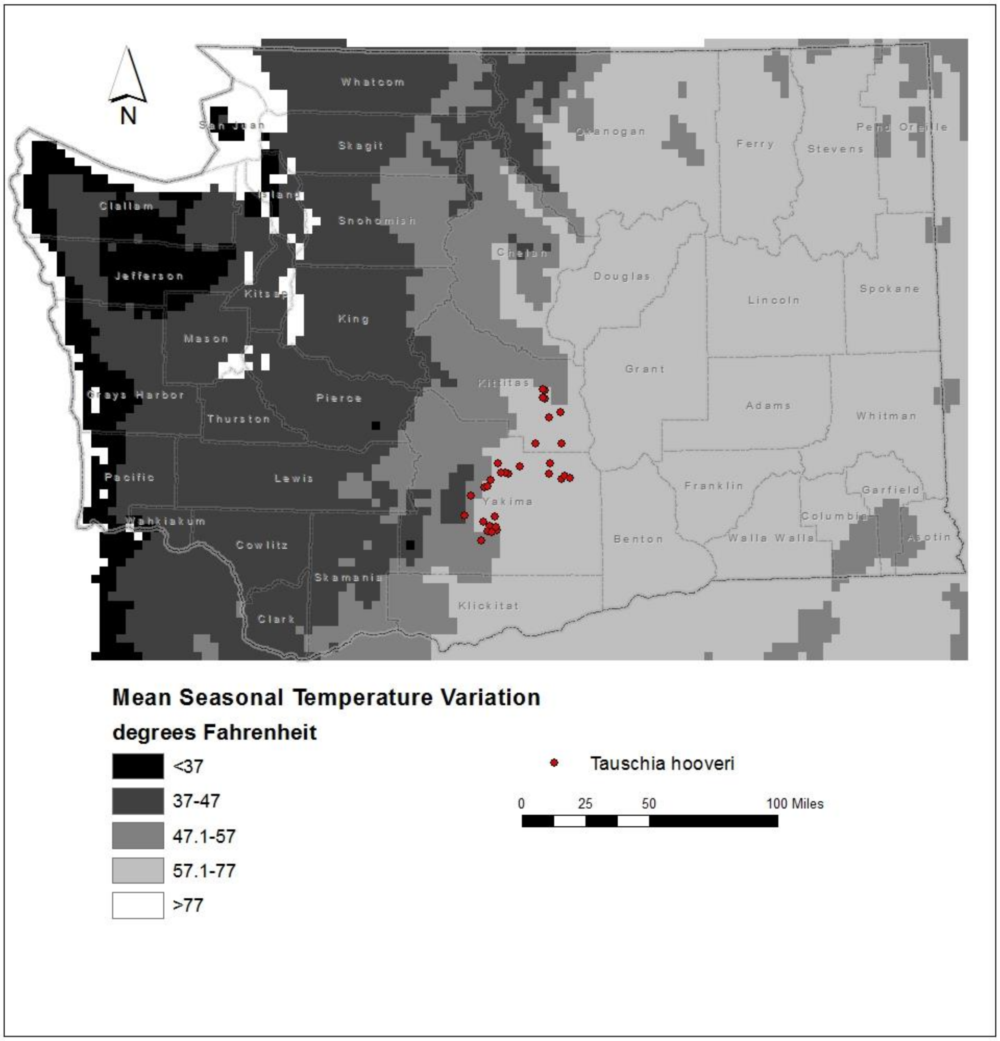

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium lithosolamans* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The lithosol flats inhabited by *Lomatium lithosolamans* are not associated with cold air drainage during the growing season and have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Sixteen of the 31 populations of *Lomatium lithosolamans* in Washington (51.6%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability from climate change. Eleven occurrences

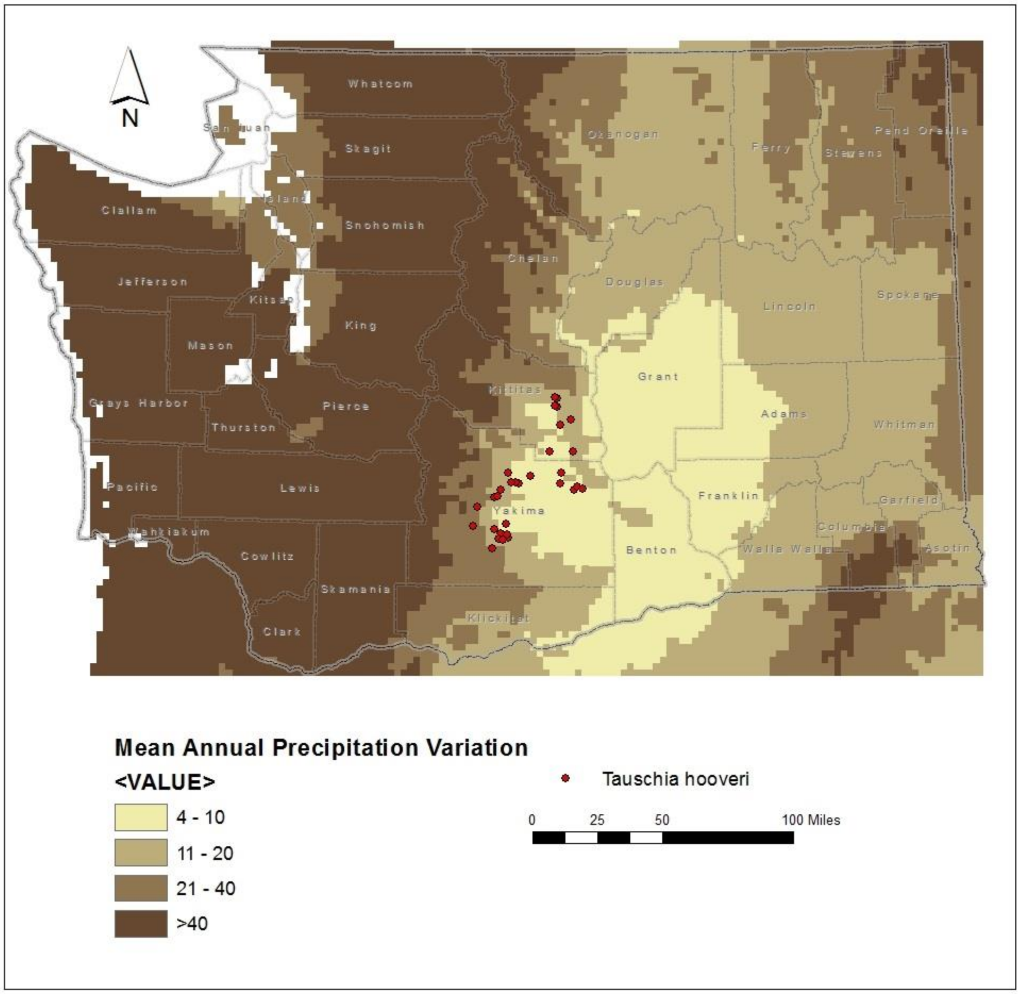

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium lithosolamans* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

(35.5%) are from areas that have had small precipitation variation (4-10 inches/100-254 mm) during the same period and are considered at increased vulnerability (Young et al. 2016). Four populations from the east slope of the Cascades (12.9%) are from areas with average precipitation variation (20-40 inches/508-1016 mm) and are at neutral vulnerability (Figure 4).

C2bii. Physiological hydrological niche: Increase.
This species is dependent on precipitation and winter snow for its moisture requirements, because its habitat is not associated with springs, streams, or groundwater. The Columbia Plateau Scabland Shrubland ecological system is vulnerable to changes in the timing or amount

of precipitation and increases in temperature that could lead to longer periods of drought (Rocchio and Ramm-Granberg 2017). Drought could result in a shift to more non-native annual species and increase fire frequency, which historically would have been low due to a lack of continuous fuel.

C2c. Dependence on a specific disturbance regime: Neutral.
Lomatium lithosolamans is not dependent on periodic disturbances to maintain its sparsely vegetated lithosol habitat. The species could, however, be negatively impacted by increased summer temperatures, drought, or decreased precipitation that might favor the establishment of annual plants and make sites more vulnerable to wildfire (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Lomatium lithosolamans occurs in areas of low accumulation of snow. These populations are more influenced by reduction in the timing and volume of rainfall (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
Lomatium lithosolamans is found mostly on Miocene-age outcrops of the Grande Ronde and Wanapum Basalt (Washington Division of Geology and Earth Resources 2016). These formations are widely distributed in the Columbia Basin. It is strongly associated with level areas of shallow lithosols, which are mostly found at the toe of the eastern Cascades and western rim of the Columbia Basin in Yakima and Kittitas County (these are covered by Quaternary fill over much of the basin). Additional outcrops occur to the south in Yakima County, where this species is replaced by other tuberous *Lomatium* taxa. The small global range of *L. lithosolamans* is strongly correlated with the distribution of suitable substrates.

C4a. Dependence on other species to generate required habitat: Neutral.
The lithosol habitat of *Lomatium lithosolamans* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Lomatium lithosolamans* are not known, but other tuberous *Lomatium* species are pollinated by solitary bees, syrphid flies, tachinid flies, muscid flies, bee flies, and beetles (Schlessman 1982).

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Lomatium lithosolamans* are dispersed primarily by wind, gravity, or other passive means. The species is not dependent on animals for transport.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. The species could be impacted by livestock grazing and trampling, though the plant's short stature and limited time above ground (it starts flowering in early March, sets fruit by mid-April, and senesces by the end of April) reduces its exposure.

C4f. Sensitivity to competition from native or non-native species: Neutral.
The shallow, rocky lithosol soils occupied by *Lomatium lithosolamans* are not especially vulnerable to competition from other native plant species. Introduced annual weeds could become more common under projected hotter and drier conditions in the future and compete for space and resources (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Data are not available on genetic diversity within *Lomatium lithosolamans*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Lomatium lithosolamans may be similar to other tuberous *Lomatium* species in being andromonoecious, with hermaphroditic and functionally staminate flowers produced in different parts of the same inflorescence and maturing at different times to promote outcrossing and higher genetic variability (Schlessman 1982).

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 of low elevation populations in recent years. Some recent records from high in the East Cascades were flowering and fruiting in July, but these reports may represent another species.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
The present distribution of *Lomatium lithosolamans* has contracted during the past 40 years, with 10 of 31 populations considered historical (32.3%). This includes most of the occurrences from the east slope of the Cascades and many from the Yakama Nation. Whether these populations are extirpated or in need of revisiting is not known. If the populations are extirpated, the cause may be habitat loss due to agricultural development, although perhaps influenced by climate change.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Marsico, T.D. and J.J. Hellman. 2009. Dispersal limitation inferred from an experimental translocation of *Lomatium* (Apiaceae) species outside their geographic ranges. Oikos 118:1783-1792.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Schlessman, M.A. 1982. Expression of andromonoecy and pollination of tuberous *Lomatium*s (Umbelliferae). Systematic Botany 7(2): 134-149.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Lomatium lithosolamans*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=lomatium%20lithosolamans). Accessed 28 September 2021.

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

Lomatium serpentinum (Snake Canyon biscuitroot)

Date: 22 November 2021

Assessor: Walter Fertig, 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: Local Climate	**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	76.9
	3.9-4.4° F (2.2-2.4°C) warmer	23.1
	<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	61.5
	-0.051 to -0.073	23.1
	-0.028 to -0.050	15.4
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase/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
4a. Dependence on others 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		Neutral/Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Increase
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat 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: Ten of the 13 occurrences of *Lomatium serpentinum* in southeastern Washington (76.9%) occur in areas with a projected temperature increase of 4.5-5.0˚ F (Figure

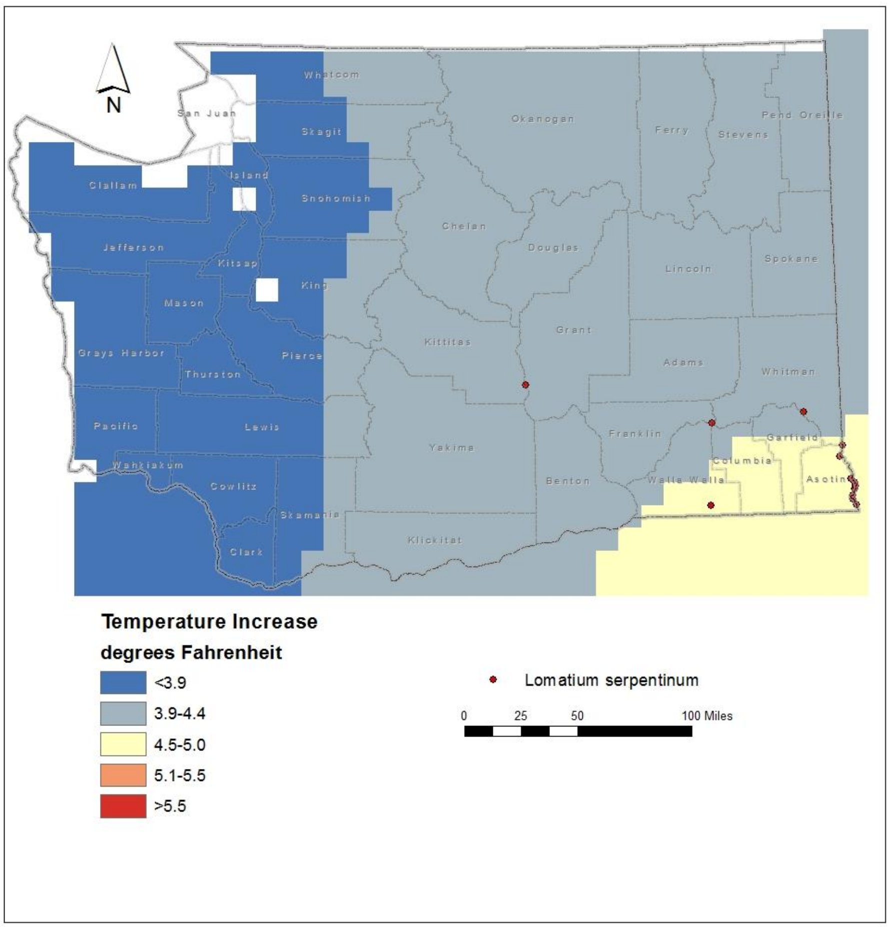

Figure 1. Exposure of *Lomatium serpentinum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

1). Three historical records (23.1%) from the Columbia Plateau are from areas with a predicted increased of 3.9-4.4° F (Figure 1). A questionable recent report from the East Cascades in Yakima County is excluded from this analysis.

A2. Hamon AET:PET Moisture Metric: Eight of 13 Washington occurrences of *Lomatium serpentinum* (61.5%) 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). Three historical occurrences (23.1%) are from areas with a predicted decrease in the range of -0.051 to -0.073. Two other historical occurrences (15.4%) are from areas with a projected decrease of -0.028 to -0.050 (Figure 2).

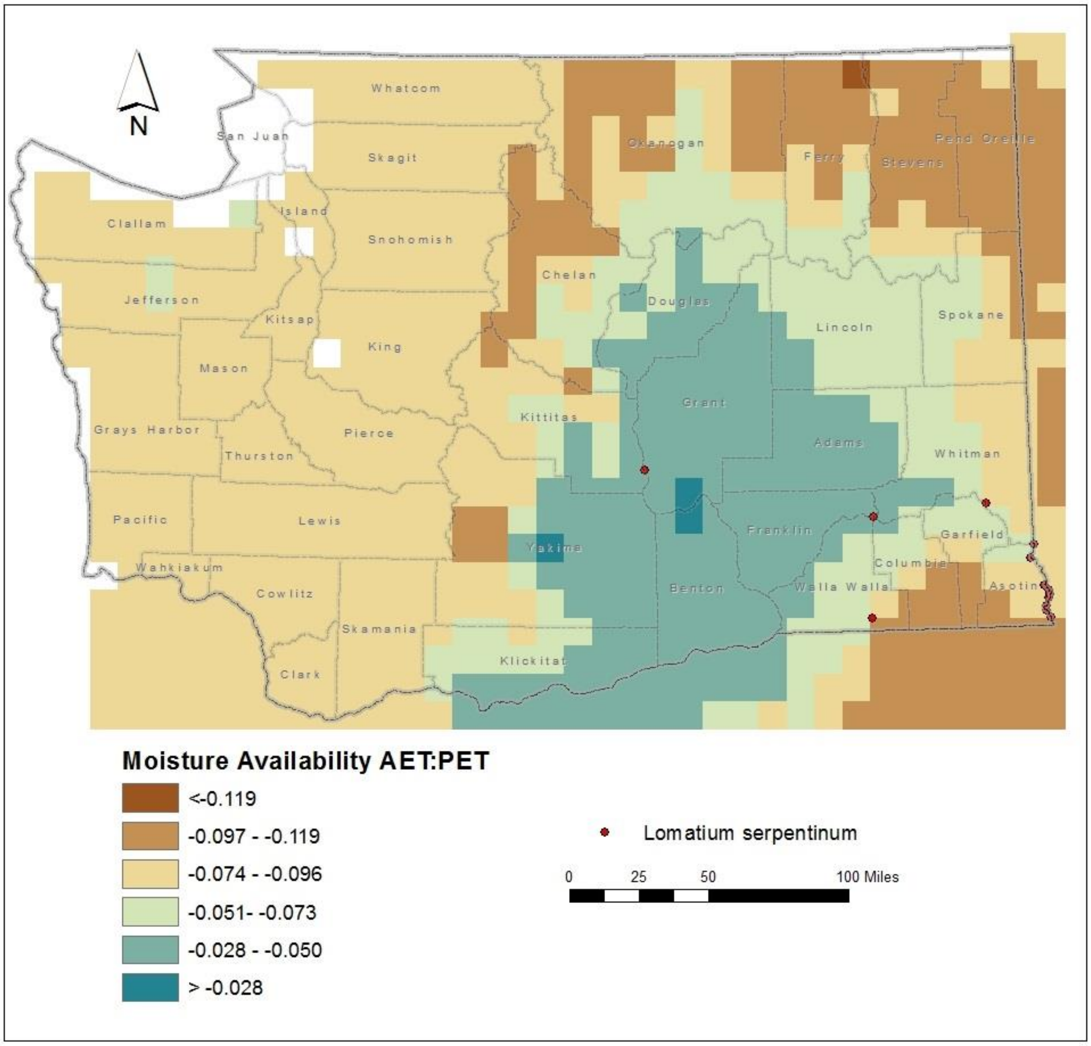

Figure 2. Exposure of *Lomatium serpentinum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Lomatium serpentinum* are found at 750-1200 feet (230-365 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Lomatium serpentinum* is found in rock crevices, basalt ledges, and talus along river channels (above the high water zone) and old floodplains (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is a component of the Intermountain Basin Cliff and Canyon ecological system (Rocchio and Crawford 2015). Individual populations are separated by 1.2-83 miles 2.6-133 km). Potential habitat may occur along the Snake and Columbia rivers and their main tributaries, but is unlikely to be present in areas between. The river corridors provide a potential route for dispersal, but intervening upland areas present a barrier.

B2b. Anthropogenic barriers: Somewhat Increase.
Much of the riverbank habitat of *Lomatium serpentinum* in Washington has been altered by construction of reservoirs downstream of Clarkston or conversion to agricultural lands (Camp and Gamon 2011), which now present a significant barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitivity and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase/Increase.
Lomatium serpentinum produces dry, oblong fruits (schizocarps) that split at maturity into two one-seeded segments. Each fruit segment has slightly raised ribs on the surface and broad, membranous wings along the margins. The winged fruits could travel short distances by wind. Fruit segments might also travel longer distances by water. Most *Lomatium* species have poor dispersal ability (less than 100 meters) which may account for their unusually high degree of endemism in western North America (Marisco and Hellman 2009).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Lomatium serpentinum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 13 extant and historical occurrences (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral risk from climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The river channel habitat of *Lomatium serpentinum* is a cold air drainage during the early spring growing season. Higher temperatures from projected climate change could make these sites warmer than they are presently.

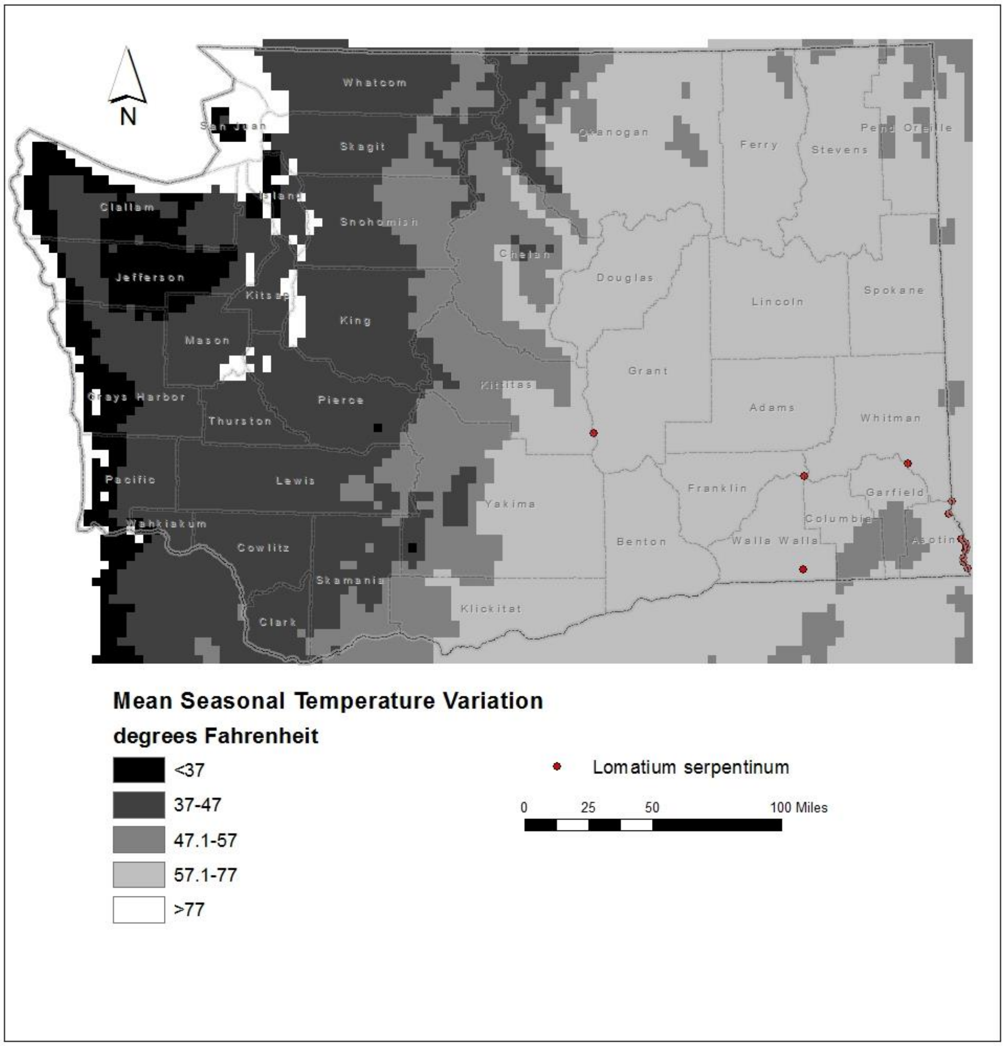

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium serpentinum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Twelve of the 13 populations of *Lomatium serpentinum* in Washington (92.3%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability from climate change. One historical occurrence from central Washington is from an area with small precipitation changes (4-10 inches/100-254 mm) over the same period and is at increased risk from climate change.

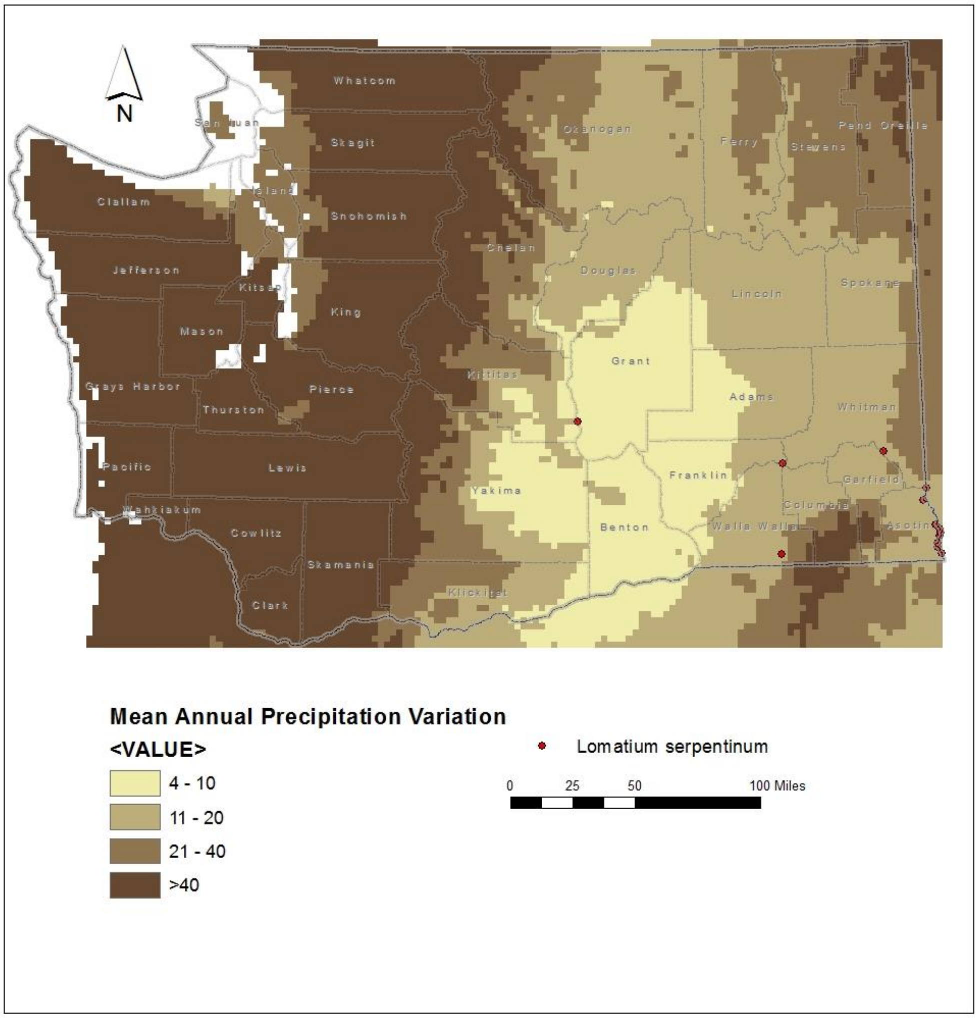

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium serpentinum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species occurs in sparsely vegetated basalt talus, boulders, and rock outcrops above the high water zone of rivers in eastern Washington. Rising temperatures associated with projected climate change could affect water levels, especially during summer. Changes in the amount or timing of precipitation could also make these sites drier, resulting in a shift in dominance from vascular plants to more drought-resistant lichens (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Lomatium serpentinum may be dependent on periodic disturbances, such as flooding, to maintain its sparsely vegetated basalt ledge, boulder, and talus habitat in river valleys. Reduction in precipitation or upstream snowmelt and increases in temperature could reduce total water flows or the intensity of spring flooding events. In the absence of disturbance, total plant cover of shrubs, trees, and herbaceous species is likely to increase and displace species adapted to low competition (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Lomatium serpentinum occurs in areas of low accumulation of snow. Reduced snowpack or changes in the timing of snowmelt in the montane headwaters of the Snake River would result in lower flow levels and reduced disturbance (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Lomatium serpentinum is restricted to Miocene-age outcrops of the Grande Ronde and Wanapum Basalt (Washington Division of Geology and Earth Resources 2016). One population has also been reported from limestone substrates in extreme southeast Washington, a formation limited to the Lime Hill area. These formations are widely distributed in the Columbia Basin. Reports from granite substrates (Soltis et al. 1997) are probably erroneous.

C4a. Dependence on other species to generate required habitat: Neutral.
The riverine volcanic bedrock, boulder, and talus habitat of *Lomatium serpentinum* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Lomatium serpentinum* are not known. Other *Lomatium* species are pollinated by a variety of solitary bees, syrphid flies, tachinid flies, muscid flies, bee flies, and beetles (Schlessman 1982).

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Lomatium serpentinum* are dispersed primarily by wind, gravity, water, or other passive means. 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 rocky habitat, this species is not easily grazed by livestock or large ungulates. Impacts from smaller herbivores (insects and rodents) are poorly known, but probably low.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
The rocky sites occupied by *Lomatium serpentinum* have low vegetative cover, which may be maintained in part by periodic disturbance by flooding along the Snake or Columbia rivers. Under projected climate change, river flows may be reduced and the timing or severity of floods may be changed, making basalt boulder and talus areas more susceptible to competition from trees, shrubs, or herbaceous species. Long term drought conditions, however, may shift species dominance on rock sites from vascular plants to hardier lichens (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Increase.
Soltis et al. (1997) sampled the genetic variability of *Lomatium serpentinum* and several other rare and common *Lomatium* species. They found that the rare species (*L. serpentinum, L. rollinsii,* and *L. laevigatum* – all edaphic endemics in the Snake and Columbia River drainages) maintained very low levels of allozymic polymorphism within and between populations, while widespread species (*L. dissectum, L. grayi*, and *L. triternatum*) had significantly higher genetic variability. The low variability of *L. serpentinum* may be attributed to its recent evolutionary origin, which has not allowed sufficient time for new mutations to accumulate (Soltis et al. 1997).

C5b. Genetic bottlenecks: Unknown.
Soltis et al. (1997) suggest that past genetic bottlenecks could contribute to the low overall genetic diversity of *Lomatium serpentinum* and other Snake and Columbia River endemic *Lomatium* species.

C5c. Reproductive System: Neutral.
Like many other *Lomatium* species, *L. serpentinum* is probably primarily an outcrosser due to andromonoecy (hermaphroditic and functionally staminate flowers produced in different parts of the same inflorescence and maturing at different times) (Schlessman 1982).

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 documented in Washington in the 1920s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
The present distribution of *Lomatium serpentinum* has contracted significantly during the past 40 years, with 8 of 13 populations considered historical (61.5%). This includes all of the known occurrences from the Columbia River and the lower reaches of the Snake River (outside of Asotin County) (Washington Natural Heritage Program 2021). If the populations are extirpated, the cause may be habitat loss due to reservoir and agricultural development, although perhaps influenced by climate change.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Marsico, T.D. and J.J. Hellman. 2009. Dispersal limitation inferred from an experimental translocation of *Lomatium* (Apiaceae) species outside their geographic ranges. Oikos 118:1783-1792.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Schlessman, M.A. 1982. Expression of andromonoecy and pollination of tuberous *Lomatium*s (Umbelliferae). Systematic Botany 7(2): 134-149.

Soltis, P.S., D.E. Soltis, and T.L. Norvell. 1997. Genetic diversity in rare and widespread species of *Lomatium* (Apiaceae). Madroño 44(1): 59-73.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Lomatium serpentinum*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=lomatium%20serpentinum). Accessed 22 November 2021.

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

Luzula arcuata ssp. *unalaschcensis* (Curved woodrush)

Date: 19 November 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5T4T5/S1

Index Result: Highly Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	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	33.3
	-0.074 to -0.096	66.7
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Greatly Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral/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		Somewhat Increase
4a. Dependence on others 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: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat 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 six of the extant and historical occurrences of *Luzula arcuata* ssp. *unalaschcensis* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

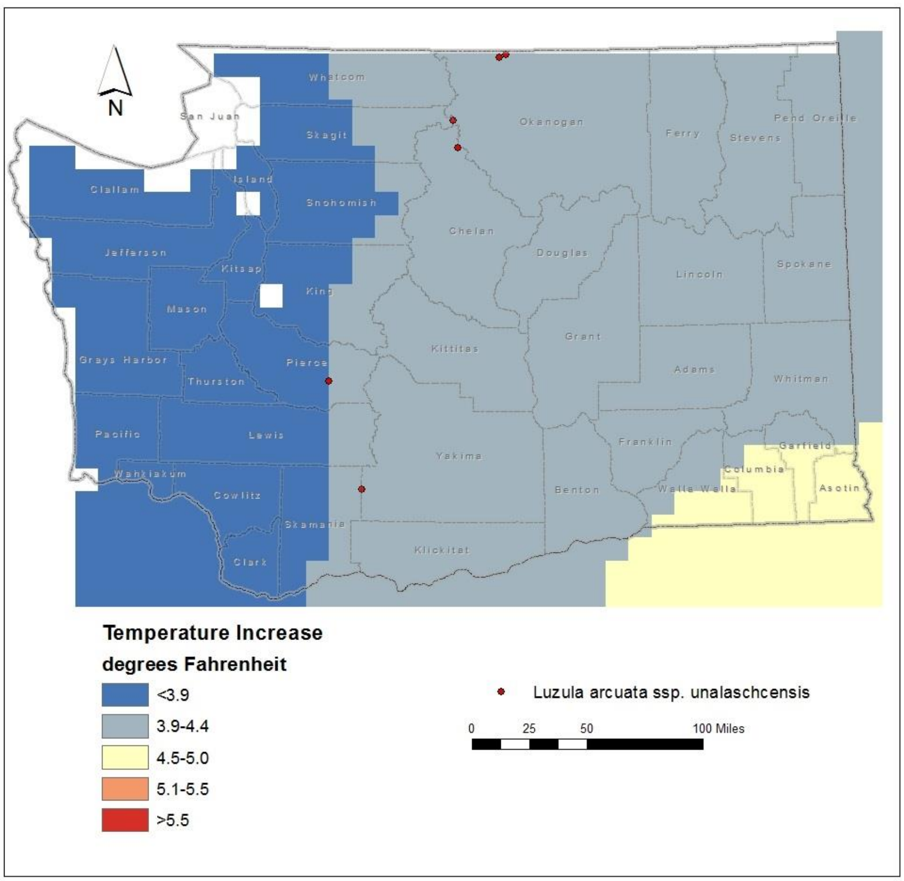

Figure 1. Exposure of *Luzula arcuata* ssp. *unalaschcensis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the 6 occurrences (66.7%) of *Luzula arcuata* ssp. *unalaschcensis* 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 other two occurrences (33.3%) are from areas with a projected decrease of -0.097 to -0.119.

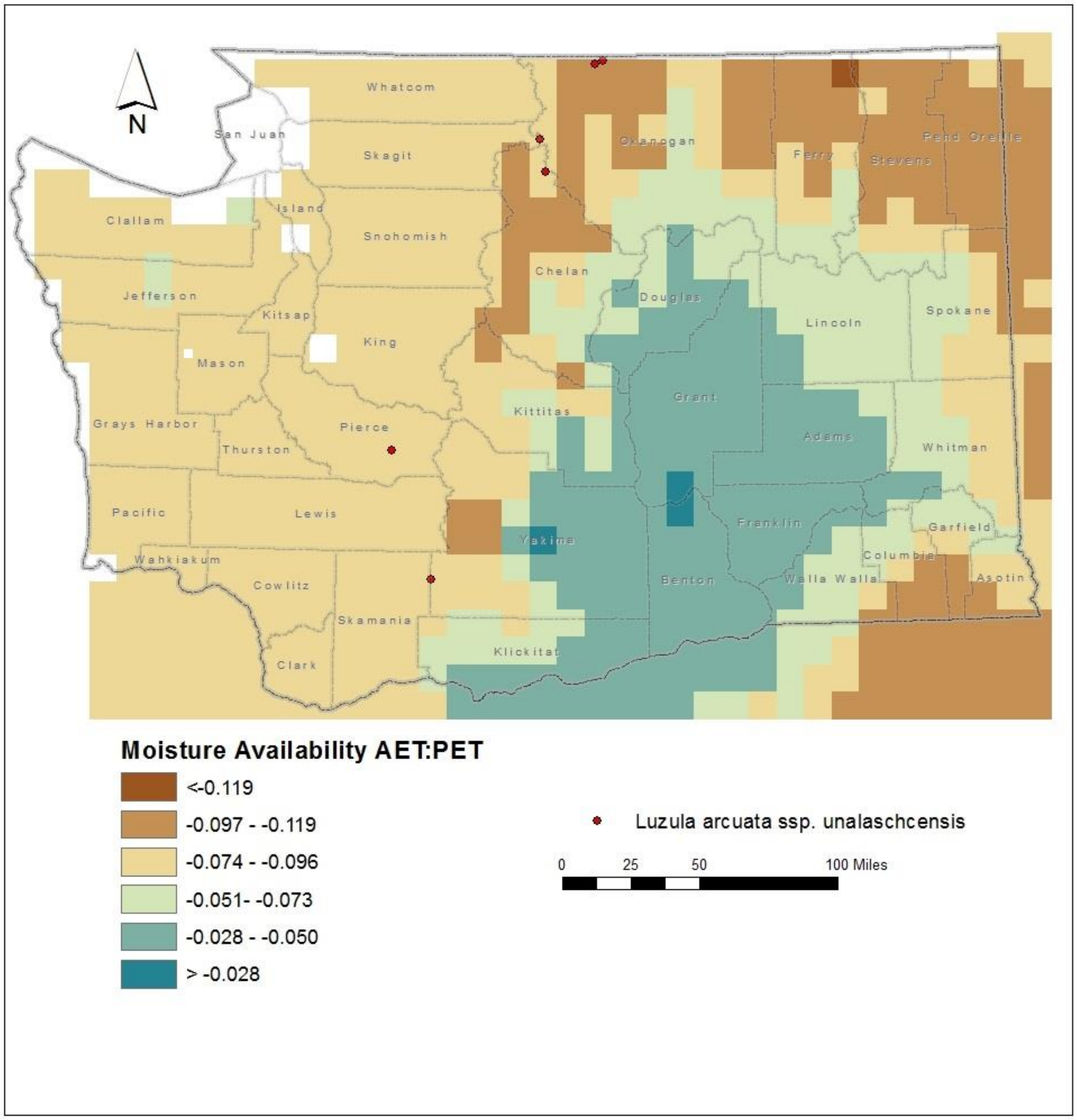

Figure 2. Exposure of *Luzula arcuata* ssp. *unalaschcensis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Luzula arcuata* ssp. *unalaschcensis* are found at 7040-8230 feet (2145-2510 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Luzula arcuata ssp. *unalaschcensis* occurs primarily in alpine to subalpine moraines, turf meadows, rocky ridges, and bare patches of soil associated with snowfields (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the Rocky Mountain Alpine Bedrock & Scree and Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, & Turf ecological systems (Rocchio and Crawford 2015). Populations may be isolated from each other by 2.7-116 miles (5.2-186 km) of unoccupied habitat, most of which is probably unsuitable. This species is small and could be over-looked, so additional alpine habitat may be present along the crest of the Cascades, but alpine areas themselves are isolated by unsuitable lower elevation forest and valley sites that would provide a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The alpine habitat of *Luzula arcuata* ssp. *unalaschcensis* in Washington is naturally patchy and mostly associated with designated wilderness (Mt. Adams and Pasaysten wilderness areas) and national parks with minimal human footprints.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Luzula arcuata ssp. *unalaschcensis* produces 8-15 dense clusters of flowers per plant, with each cluster containing 3-5 flowers. Individual flowers produce 3 seeds with a few small hairs at one end. These seeds are released passively and may spread by wind or gravity. Many *Luzula* species have a nutrient-rich appendage (caruncle) that may entice insects or rodents to transport and cache seeds (Swab 2000), although the caruncle appears to be poorly developed in this species. Average dispersal distances are probably short (<1000 m) though occasional, long-distance movement by wind likely occurs.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Luzula arcuata* ssp. *unalaschcensis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 6 of the known occurrences in the state (100%) are found in areas that have experienced small variation (37-47˚F/20.8-26.3˚C) in temperature during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Greatly Increase.
The alpine talus and tundra habitat of *Luzula arcuata* ssp. *unalaschcensis* is entirely within a cold climate zone during the flowering season and highly vulnerable to temperature increase from climate change.

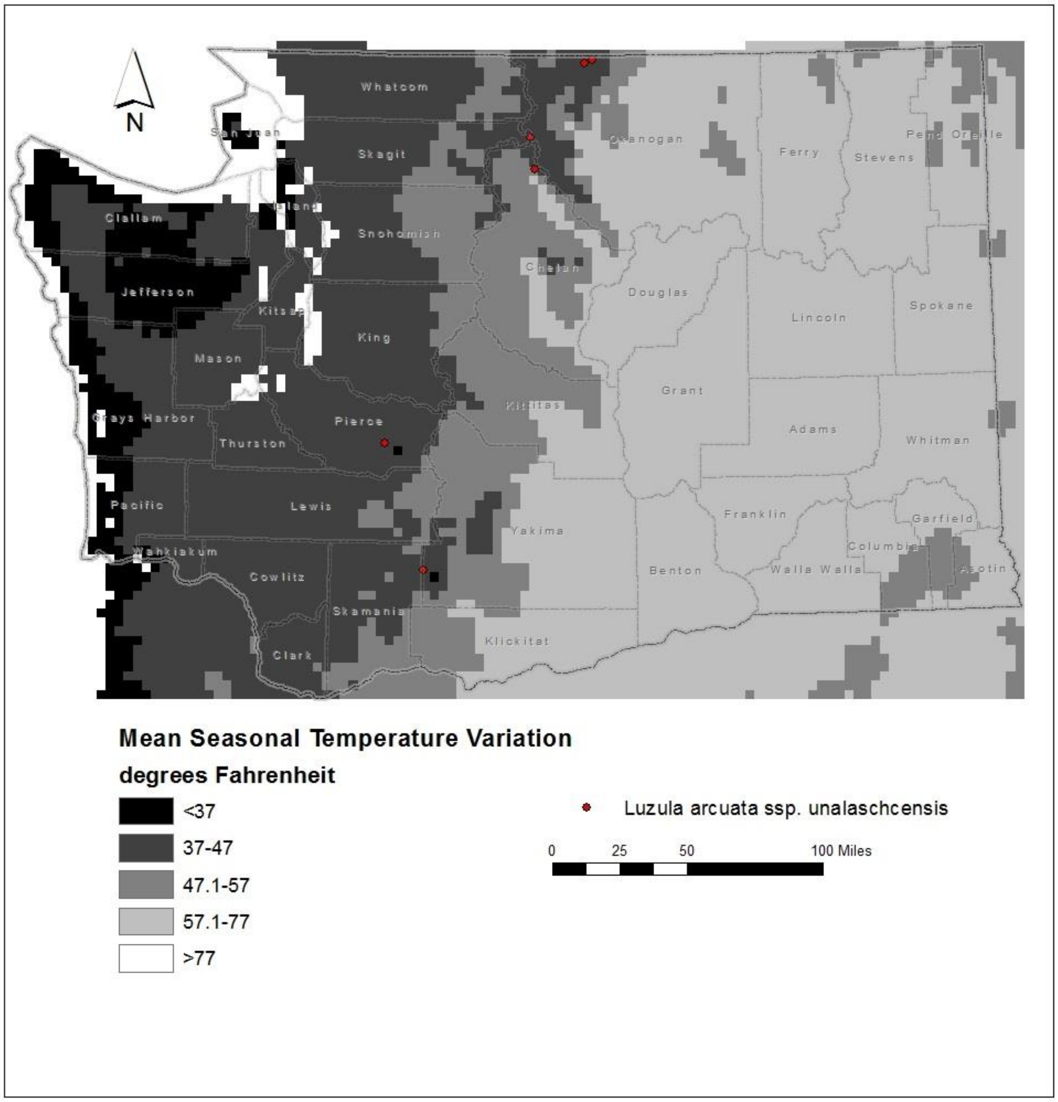

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Luzula arcuata* ssp. *unalaschcensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Luzula arcuata* ssp. *unalaschcensis* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

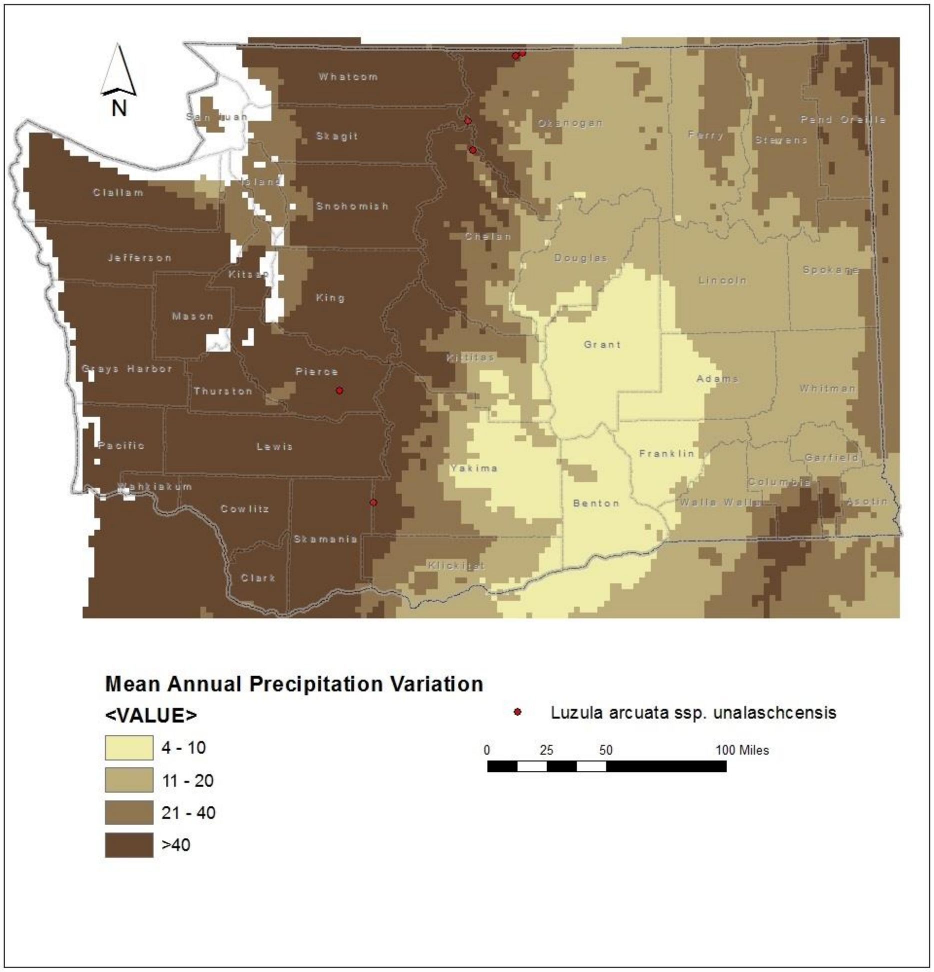

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Luzula arcuata* ssp. *unalaschcensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral/Somewhat Increase.
This species is probably more dependent on adequate winter snowpack and timing of snowmelt (see section C2d below) than on spring or summer precipitation for its moisture requirements. Increased temperatures could reduce the amount and timing of precipitation, however, making alpine sites more suitable for lower elevation shrubs, trees, and herbaceous species to become established (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
In Norway, *Luzula arcuata* is an early successional species that can colonize recently exposed areas following the retreat of glaciers (Robbins and Matthews 2009). Washington populations

are adapted to sites that are subjected to high winds that may restrict the accumulation of soil or the establishment of taller plant species from lower elevations.

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Luzula arcuata ssp. unalaschcensis* in Washington are mostly found in alpine ridges, talus slopes, or turf meadows associated with high winter snow accumulation. 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: Somewhat Increase.
Luzula arcuata ssp. *unalaschcensis* is found on a variety of geologic substrates in the Cascade Range and Okanogan Plateau, including the Golden Horn and Cathedral batholiths, Fifes Peak and Mount Adams andesites, and Bald Mountain tonalite (Washington Division of Geology and Earth Resources 2016). These granitic and volcanic formations are often of limited distribution, and may account for the few records of this species in Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus and turf meadow habitat occupied by *Luzula arcuata* ssp. *unalaschcensis* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Luzula arcuata ssp. *unalaschcensis*, like most other brown-flowered *Luzula* species, is primarily wind-pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds produced by *Luzula arcuata* ssp. *unalaschcensis* have a few short hairs on one end to facilitate wind dispersal. Unlike many other species of *Luzula*, *L. arcuata* ssp. *unalaschcensis* appears to lack a nutritious caruncle (an outgrowth of the seed coat) that may attract insects or rodents to feed on or cache the seeds (Swab 2000). Secondary dispersal by animals is still possible, but *L. arcuata* probably does not depend entirely on one or a few species for seed dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

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 harsh environmental conditions of the alpine zone. Under projected climate change, competition could increase if lower elevation plant species are able to expand their range into formerly unsuitable habitat (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No data are available on the genetic diversity of Washington populations. Dawe (1979) found ssp. *unalaschcensis* to be a hexaploid (2*n* = 36) based on samples from Russia, Alaska, and Alberta. By contrast, ssp. *arcuata* from Eurasia can be a hexaploid, septaploid (2*n* = 42) or octoploid (2*n* = 48). Purported hybrids have been reported from Alaska between *L. arcuata* ssp. *unalaschcensis* and *L. confusa* (Dawe 1979). Hybrids are not known from Washington.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Luzula arcuata ssp. *unalaschcensis* appears to be an obligate outcrosser and is not limited by pollinators or dispersal, so is presumed to have average genetic variation. Washington populations, being located at the far southern edge of its geographic range, are likely to have lower overall genetic diversity due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Luzula arcuata* ssp. *unalaschcensis* has not changed its typical blooming time since it was first reported in the state in 1919.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
One population from Mount Rainier National Park has not been relocated since 1919 (Biek 2000) and may be extirpated. Otherwise, no major changes have been detected in the distribution of *Luzula arcuata* ssp. *unalaschcensis* in Washington.

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

References

Biek, D. 2000. Flora of Mount Rainier National Park. Oregon State University Press, Corvallis, OR. 506 pp.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Dawe, J.C. 1979. Cytotaxonomy and cytogeography of selected arctic and boreal Alaskan vascular plant taxa. Master's thesis, University of Alaska, Fairbanks, AK. 167 pp.

Robbins, J.A. and J.A. Matthews. 2009. Pioneer vegetation on glacier forelands in southern Norway: Emerging communities? Journal of Vegetation Science 20: 889-902.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Swab, J.C. 2000. *Luzula*. pp. 255-267. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. Volume 22. Magnoliophyta: Alismatidae, Arecidae, Commelinidae (in part), and Zingiberidae. 352 pp.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Luzula arcuata ssp. unalaschcensis*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=luzula%20arcuata%20ssp.%20unalaschcensis). Accessed 19 November 2021.

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

Micranthes tischii (Olympic saxifrage)

Date: 17 November 2021 Synonym: *Saxifraga tischii*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G2/S1?

Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	87.5
	-0.051 to -0.073	12.5
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Greatly 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		Increase
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
D1. Documented response to recent climate change	Somewhat Increase
D2. Modeled future (2050) change in population or range size	Increase
D3. Overlap of modeled future (2050) range with current range	Neutral
D4. Occurrence of protected areas in modeled future (2050) distribution	Neutral

Section A: Exposure to Local Climate Change

A1. Temperature: All 8 of the extant and historical occurrences of *Micranthes tischii* from the Olympic Range in Washington (100%) occur in areas with a projected temperature increase

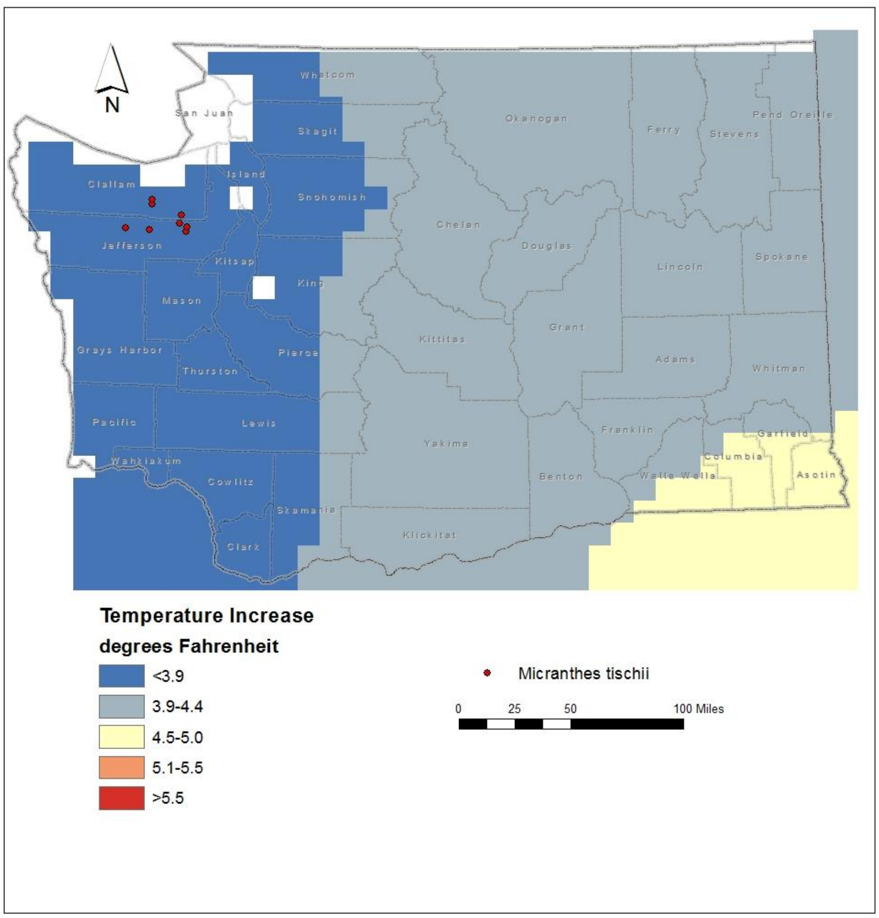

Figure 1. Exposure of *Micranthes tischii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

< 3.9˚ F (Figure 1). An additional report from Okanogan County may be a related species and is not included in this analysis.

A2. Hamon AET:PET Moisture Metric: Seven of the 8 occurrences (87.5%) of *Micranthes tischii* 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). One other population (12.5%) is from an area with a projected decrease from -0.051 to -0.073.

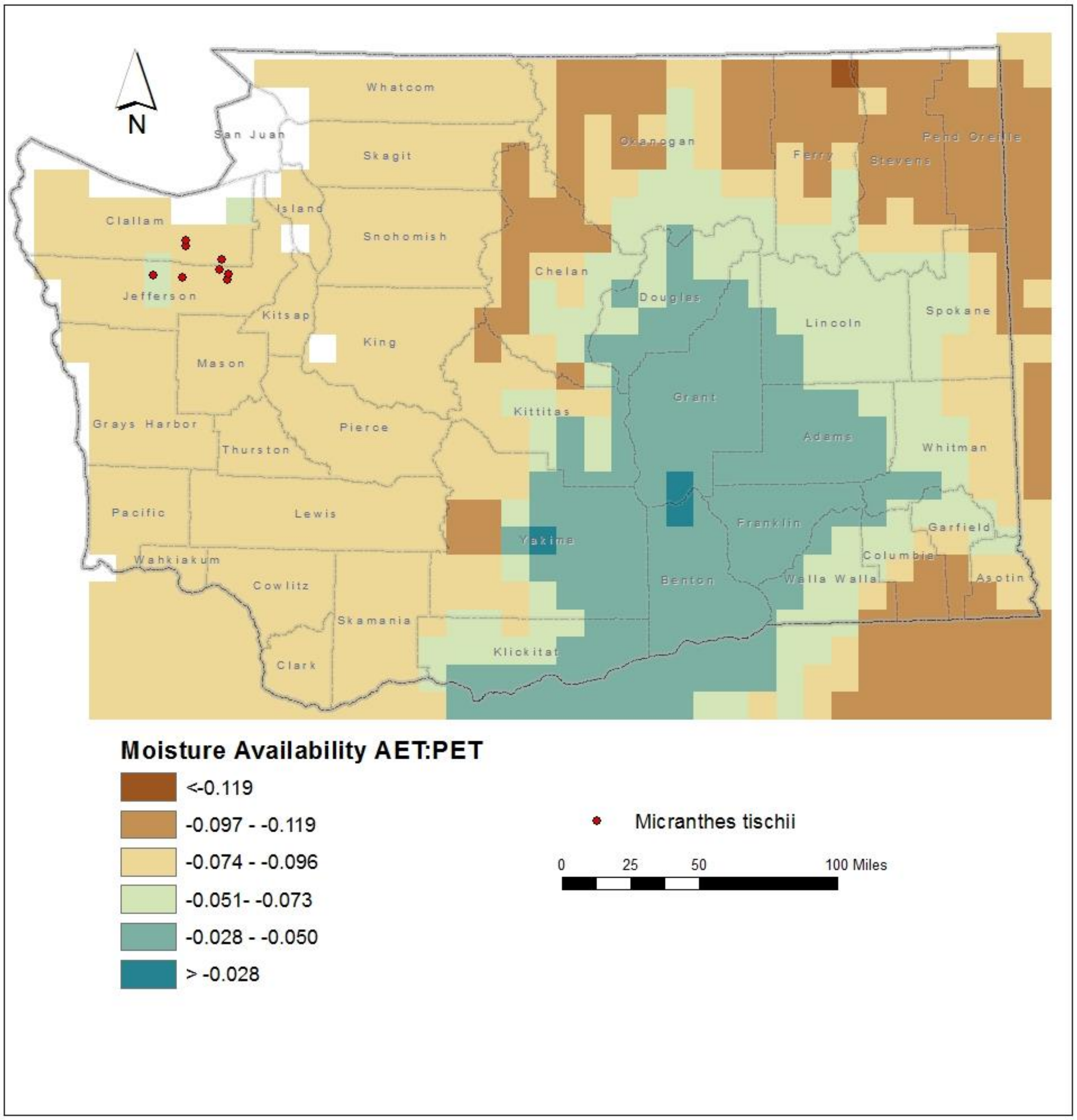

Figure 2. Exposure of *Micranthes tischii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Micranthes tischii* are found at 4500-6500 feet (1370-1980 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Micranthes tischii occurs primarily on cool, shady basalt ledges, basalt or sandstone scree slopes, and thin-soiled depressions below alpine snowbanks in the Olympic Range (Skelly 1988, Washington Natural Heritage Program 2021). This habitat is part of the North Pacific Alpine & Subalpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). Populations are on peaks and ridgelines separated by 2.3-11.2 miles (3.8-18.2 km) of unoccupied and unsuitable river valley and lower elevation forested habitat that present a barrier to propagule dispersal. The Olympic Mountains are disjunct from other alpine mountain ranges to the north and east of the Salish Sea and Puget Sound in the Pacific Northwest, making potential migration more difficult.

B2b. Anthropogenic barriers: Neutral.
The range of *Micranthes tischii* in Washington is restricted to Olympic National Park and the Buckhorn Wilderness Area of Olympic National Forest (Fertig 2020). These areas have some hiking trails but otherwise receive minimal direct impacts from humans to limit dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Micranthes tischii produces dry, follicle-like fruits that split at maturity to passively release small seeds. The seeds lack hairs, spines, hooks, barbs, wings, or other features to facilitate dispersal by wind or for attaching to animal vectors. Dispersal distances are reported as small for European species of *Micranthes* (Alsos et al. 2012) and probably average less than 100 meters. Young et al. (2016) and Alsos et al. (2012) rate species with this dispersal distance as having increased vulnerability to climate change.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Micranthes tischii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the 8 known occurrences in the state (87.5%) are found in areas that have experienced very small (<37°F/20.8°C) temperature variation during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). One other occurrence (12.5%) is from an area with small temperature variation (37-47°F/20.8-26.3°C) over the same period and is at increased vulnerability to climate change.

C2aii. Physiological thermal niche: Greatly Increase.
Micranthes tischii is restricted to alpine scree slopes and shaded ledges entirely within a cold climate zone during the flowering season and are highly vulnerable to temperature increases from climate change.

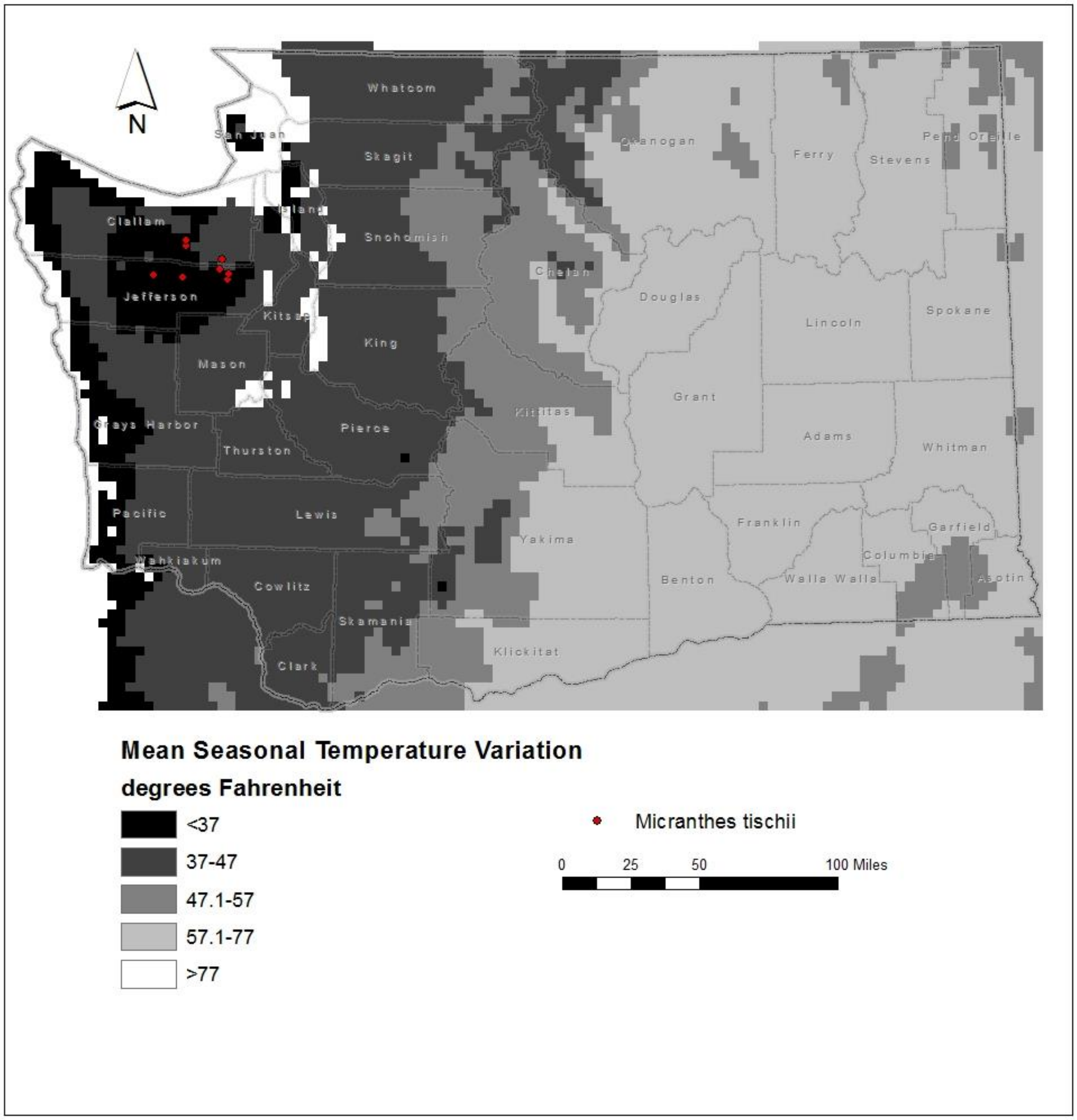

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Micranthes tischii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Micranthes tischii* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

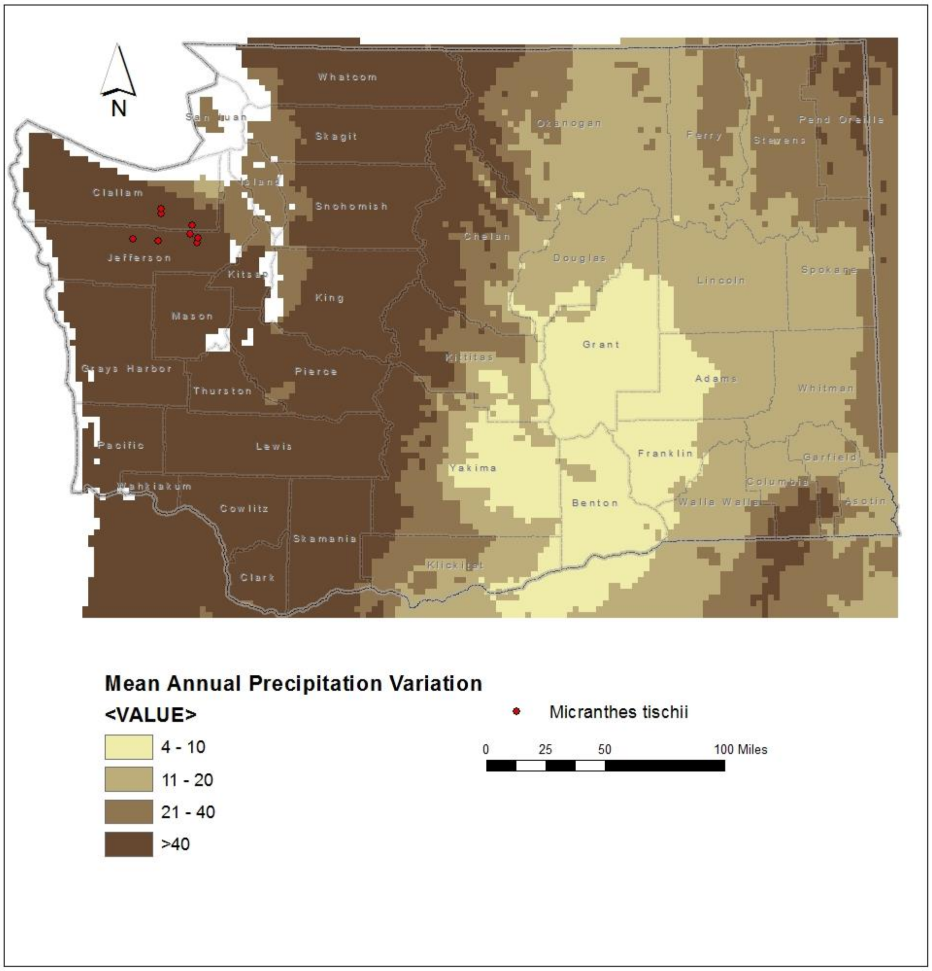

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Micranthes tischii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Micranthes tischii occurs in shady, cool, basalt ledges, or exposed scree slopes below snowdrifts. It is strongly reliant on adequate snowpack and the timing of snowmelt to provide sufficient moisture during the growing season (see C2d below). Increasing temperatures could shift snow to winter rain or lead to earlier snowmelt and runoff in the alpine zone (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
The alpine cliff and scree habitat of *Micranthes tischii* is maintained by a short growing season, high winds that scours fine soil, and late-lying snowdrifts that prevent tree species from becoming established. Increased temperatures could eventually make these areas more suitable

to invasion by meadow species from lower elevations as rock weathers and soil accumulates. Climate change could increase the area available to this species, however, as formerly glaciated areas melt and convert to alpine bedrock and scree habitat (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The Olympic Mountains average over 10 meters (400 inches) of snow each winter. The alpine cliff and scree habitat of *Micranthes tischii* is often located below late-lying snowbanks (Washington Natural Heritage Program 2021). This species is dependent on high volumes of snow and predictable snowmelt for its moisture requirements during the growing season. Changes in the amount of snowpack or timing of snowmelt resulting from climate change is likely to have a significant negative impact on *M. tischii* (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Micranthes tischii is found primarily on outcrops of Oligocene to Eocene-aged marine sedimentary rocks (mostly thin to medium-bedded shale or sandstone). This geologic type forms the core of the Olympic Range, but is otherwise uncommon in Washington. Two occurrences in the eastern Olympics are associated with the Eocene-age Crescent Basalt, which is limited to the northern and eastern rim of the range (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus and cliff habitat occupied by *Micranthes tischii* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Micranthes tischii* are not known. Related species of *Saxifraga* and *Micranthes* are pollinated by a variety of small bees, wasps, and flies (Soltis 2007).

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Micranthes tischii* split open at maturity to release seeds passively by gravity. Secondary dispersal may occur by rodents or insects collecting seeds for food, but *M. tischii* is not reliant on other species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
This species is not known to be impacted by pathogens or herbivory.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Wendy Gibble has observed lower elevation *Micranthes* species moving uphill into the alpine zone occupied by *M. tischii* (Fertig 2020). Other lower elevation plant species may also be able to invade alpine cliff and scree habitats in the future under projected warmer conditions, increasing competition for space and nutrients (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No data are available on the genetic diversity of populations of *Micranthes tischii*. Studies of related alpine species in Europe suggest that genetic diversity is likely to decrease in the future if ranges shrink due to climate change (Alsos et al. 2012).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Micranthes tischii appears to be an obligate outcrosser and is not limited by pollinators or dispersal, so is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Micranthes tischii* has not changed its typical blooming time since it was first collected in the early 1900s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase.
Four of the known occurrences of *Micranthes tischii* in Washington are historical and have not been relocated since 1976 and are considered historical. Whether these populations have been overlooked or are extirpated is not known. The potential contraction of its range may be due to climate change rather than habitat loss, as all populations are from protected areas.

D2. Modeled future (2050) change in population or range size: Increase.
Wershow and DeChaine (2018) did not include this species in their study of climate change impacts on alpine endemics of the Olympic Range, but found that taxa from similar habitats were likely to lose 85-99% of their available habitat by 2080.

D3. Overlap of modeled future (2050) range with current range: Neutral.
Based on the projected future range modeling of other alpine endemic plant species of the Olympic Range (Wershow and DeChaine 2018), the range of *Micranthes tischii* is likely to contract rather than shift in distribution northward in the future.

D4. Occurrence of protected areas in modeled future (2050) distribution: Neutral.
Despite the predicted contraction of potential habitat due to climate change, the entire range of *Micranthes tischii* in Washington will still be restricted to Olympic National Park and the Buckhorn Wilderness Area of Olympic National Forest.

References

Alsos, I.G., D. Ehrich, W. Thuiller, P.B. Eidersen, A. Tribsch, P. Schönswetter, C. Lagaye, P. Taberlet, and C. Brochmann. 2012. Genetic consequences of climate change for northern plants. Proceedings of the Royal Society B 279: 2042-2051.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Skelly, R.J. 1988. A new species of *Saxifraga* (Saxifragaceae) from the Olympic Mountains, Washington, and Vancouver Island, British Columbia. Madroño 35(2): 126-131.

Soltis, D.E. 2007. Saxifragaceae: A taxonomic treatment. Pp. 418-435. In: Kubitzki, K., ed. The Families and Genera of Vascular Plants. Vol. 9. Flowering Plants Eudicots. Springer, Berlin. 509 pp.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Micranthes tischii*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=micranthes%20tischii). Accessed 17 November 2021.

Wershow, S.T. and E,G, DeChaine. 2018. Retreat to refugia: Severe habitat contraction projected for endemic alpine plants of the Olympic Peninsula. American Journal of Botany 105(4): 760-778.

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

Myosurus alopecuroides (Foxtail mousetail)

Date: 19 November 2021 Synonym: *Myosurus clavicaulis*

Assessor: Walter Fertig, 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: Local Climate	**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	14.3
	-0.051 to -0.073	42.9
	-0.028 to -0.050	35.7
	>-0.028	7.1
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral/Somewhat Increase
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Greatly 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		Increase
4a. Dependence on others 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: Documented or Modeled Response	
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: All 14 of the known occurrences of *Myosurus alopecuroides* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

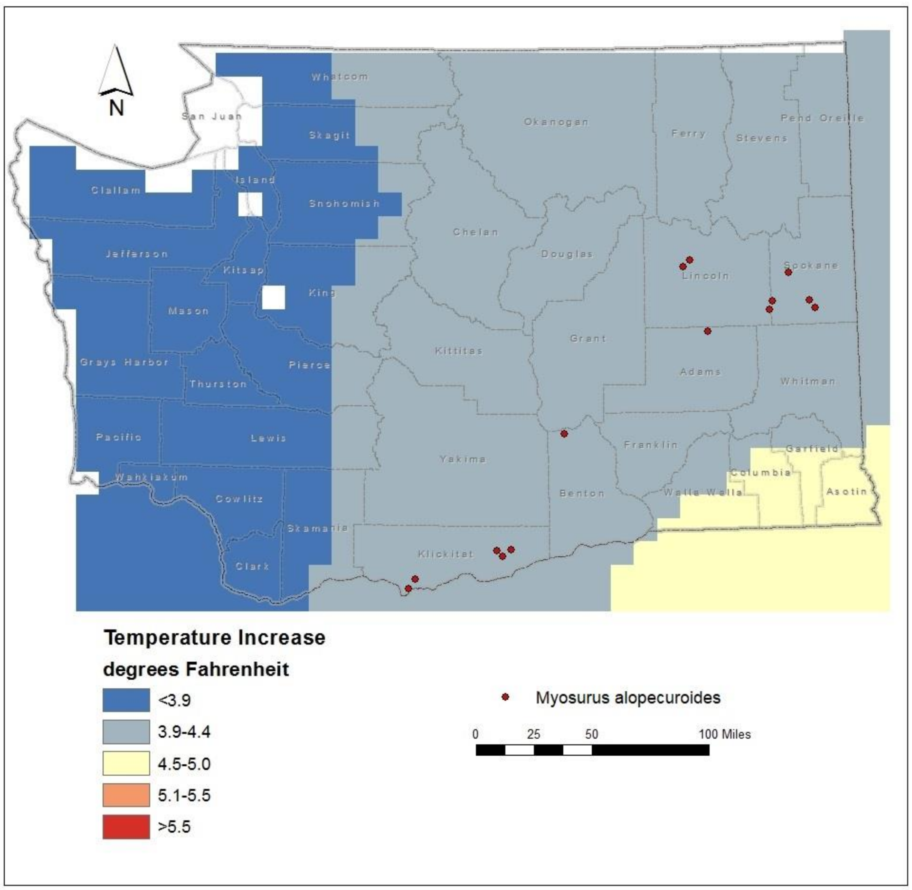

Figure 1. Exposure of *Myosurus alopecuroides* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the 14 occurrences of *Myosurus alopecuroides* (42.9%) in eastern 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). Five occurrences from Klickitat County (35.7%) have a projected decrease of -0.028 to -0.050. Two populations from Spokane County (14.3%) are from areas with a projected decrease of -0.074 to -0.096. One occurrence (7.1%) from the central Columbia Plateau has a projected decrease of > -0.028 (Figure 2).

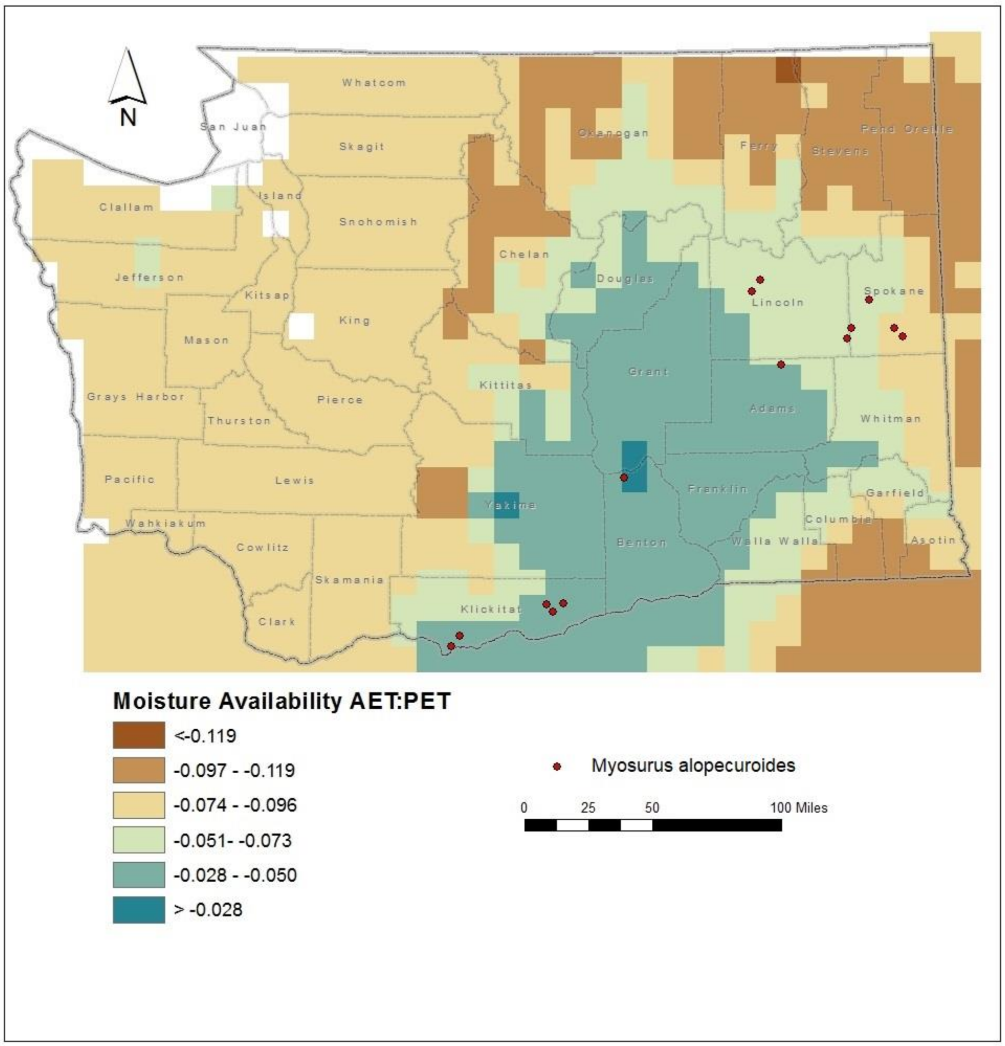

Figure 2. Exposure of *Myosurus alopecuroides* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Myosurus alopecuroides* are found at 250-2500 feet (75-760 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Myosurus alopecuroides* is restricted to sparsely vegetated shallow vernal pools over clay that are flooded in spring and become dry and desiccated in summer (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the Columbia Plateau Vernal Pool and Modoc Basalt Flow Vernal Pool ecological systems (Rocchio and Crawford 2015). Populations are separated by 1.6-56 miles (2.3-90 km) of unoccupied and unsuitable habitat. Vernal pools are specialized landscape features embedded within a matrix of sagebrush steppe and scablands in eastern Washington that provide a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The vernal pool habitat of *Myosurus alopecuroides* is widely scattered and naturally sparse. Although much of the matrix landscape in which these vernal sites are embedded has been converted to agriculture, human impacts in these areas do not impose a greater impediment to migration than natural barriers.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Myosurus alopecuroides produces numerous, small, one-seeded, achene fruits that have a short, pointed beak. Fruits can become attached to mud on waterfowl or embedded in the fur or feathers of animals for long-distance transport. Carlquist (1983) notes that the related species, *Myosurus apetalus*, has a bipolar geographic range (western North America and southern Argentina) that is likely the result of long-distance dispersal mediated by migrating birds. Fruits may also disperse through water. Dispersal in *M. alopecuroides* is probably constrained by the availability of suitable habitat (other vernal pools).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Myosurus alopecuroides* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 14 of the known occurrences (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral/Somewhat Increase.
The ephemeral wetland and vernal pool habitat of *Myosurus alopecuroides* 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 (Rocchio and Ramm-Granberg 2017).

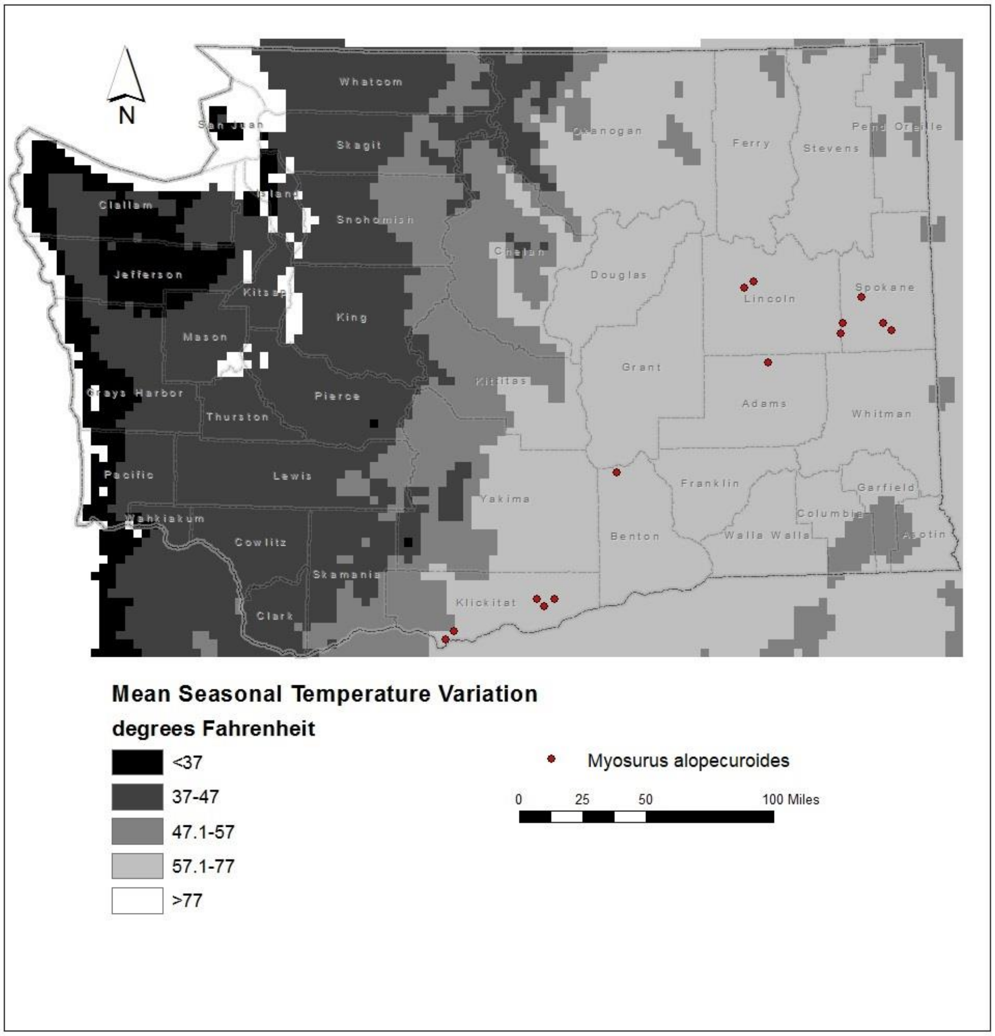

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Myosurus alopecuroides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Thirteen of the 14 populations of *Myosurus alopecuroides* in Washington (92.9%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability to climate change. One population from the central Columbia Plateau is from an area with small precipitation variation (4-10 inches/100-254 mm) over the same period and is at increased risk from climate change.

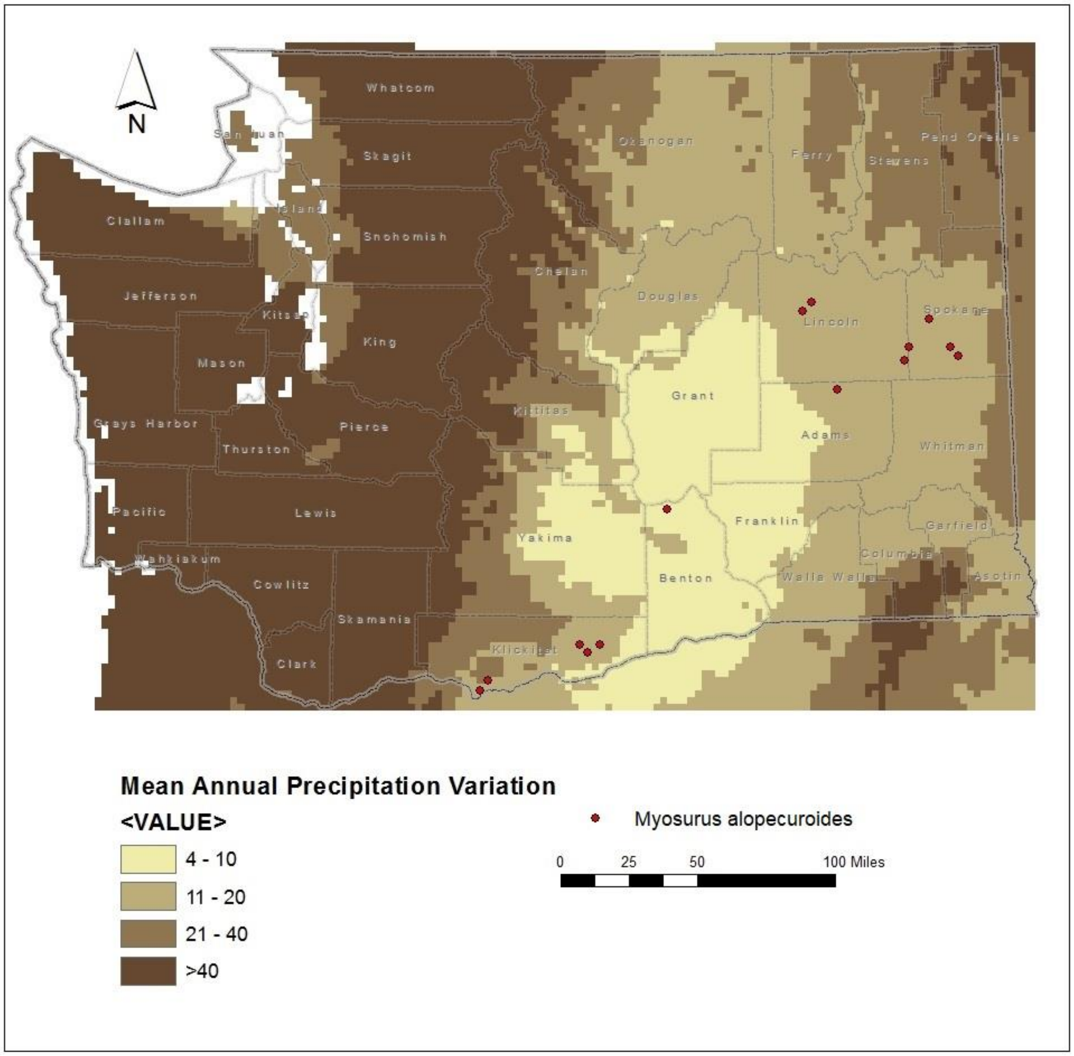

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Myosurus alopecuroides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species is strongly dependent on winter and early spring precipitation followed by summer drought to maintain its ephemeral vernal pool habitat. Under projected future climate change, winter precipitation is expected to increase, but this is likely to be offset by greater evapotranspiration from higher spring and summer temperatures (Rocchio and Ramm-Granberg 2017). Too much additional precipitation could result in permanent inundation of pools and replacement of the current flora with annuals or perennials adapted to wetter conditions. Likewise, higher rates of evapotranspiration relative to precipitation could allow

invasion by weedy upland species or conversion to drier upland plant communities (Rocchio and Ramm-Granberg 2017). Increasingly unpredictable climatic events could also be significant on this annual species that relies on a seed bank to persist through unfavorable years.

C2c. Dependence on a specific disturbance regime: Neutral.
Myosurus alopecuroides is not dependent on periodic disturbances to maintain its scabland and basalt tableland vernal pool habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Most of the range of *Myosurus alopecuroides* in Washington is within areas with low winter snowfall, and thus drifting snow or snowmelt is a relatively minor component of the plant's annual water budget. A few populations in western Klickitat and Spokane counties are located in the transition zone towards higher elevation mountains and may receive more snow or runoff. Changes in the amount of snow or timing of its melt could affect hydrological conditions in these vernal pools (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Myosurus alopecuroides is restricted to shallow depressions with poor drainage in Miocene basalt beds that are deep enough to be flooded in winter and early spring, but shallow enough to become dry in late spring or summer. This species is associated with the Wanapum Basalt, which is widespread across the Columbia Plateau (Washington Division of Geology and Earth Resources 2016). Sites with the exact microsite characteristics, however, are much less widespread and may limit the ability of this species to expand its range, or constrain its response to changing hydrologic conditions due to climate change (Rocchio and Ramm-Granberg 2017).

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal wetland habitat occupied by *Myosurus alopecuroides* is maintained by natural abiotic processes and geologic conditions, rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Myosurus alopecuroides and other vernal pool species of *Myosurus* are adapted for self-pollination but also capable of out-crossing and hybridization (Stone 1959). Pollen becomes viable while flowers are still in the bud to ensure some self-fertilization. As the flower receptacle grows and elongates it can push past the reflexed sepals to expose unpollinated pistils. *Myosurus* flowers produce a small amount of nectar to attract insects that can pollinate the exposed pistils (Stone 1959). The specific pollinators of *M. alopecuroides* are not known, but based on the small size of the flowers are likely to be gnats, flies, mosquitoes, or other small Dipterans.

C4d. Dependence on other species for propagule dispersal: Neutral.
The one-seeded fruits of *Myosurus alopecuroides* may be dispersed by water, gravity, or attached to animals in mud or caught in fur or feathers by the pointed beak of the achene. *M. alopecuroides* fruits can be dispersed by a wide variety of animal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. The low stature of this species suggests it is not a significant forage species for most grazing animals, although flowers and fruits could be consumed by rodents or insects. Impacts from natural herbivory are probably low.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Myosurus alopecuroides could be sensitive to competition from other plant species (especially non-native invasive annuals) if its specialized wetland habitat were completely dried out due to climate change (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Data are not available on genetic diversity of *Myosurus alopecuroides* occurrences in Washington. Stone (1959) hypothesized that *M. alopecuroides* is of hybrid origin between *M. sessilis* and *M. minimus* (both 2*n* = 16) where they occur in sympatry in central California (Whittemore 1997).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Somewhat Increase.
Genetic diversity in Washington populations of *Myosurus alopecuroides* may be lower than expected due to the prevalence of self-pollination and the hybrid origin of the species (which could reduce fecundity). Being at the northern edge of the species' range, Washington occurrences may also have lower diversity due to founder effects or genetic drift.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website and WNHP data, *Myosurus alopecuroides* populations in Washington have not changed their flowering season since first being documented in the state in 1997 (Beck and Caplow 2006).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No significant changes have been documented in the distribution of *Myosurus alopecuroides* in Washington in the past 30 years.

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

References

Beck, K.A. and F.E. Caplow. 2006. Additions to the vascular flora of Washington from a biodiversity study on the Hanford Nuclear Reservation. Madroño 53(1): 36-45.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Carlquist, S.C. 1983. Intercontinental dispersal. Sonderbande des Naturwissenschaftlichen Vereins in Hamburg. 7: 37-47. (http://sherwincarlquist.com/pdf/Intercontinental-Dispersal_1983.pdf).

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Stone, D.E. 1959. A unique balanced breeding system in the vernal pool mouse-tails. Evolution 13(2): 151-174.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Myosurus alopecuroides*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=myosurus%20alopecuroides). Accessed 19 November 2021.

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

Orthocarpus bracteosus (Rosy owl's-clover)

Date: 11 February 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G3?/S2

Index Result: Highly Vulnerable. | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	76.9
	<3.9° F (2.2°C) warmer	23.1
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	46.2
	-0.051 to - 0.073	53.8
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral/Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		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/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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		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: Documented or Modeled Response	
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: Ten extant occurrences of *Orthocarpus bracteosus* in Washington (76.9%) are found in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). Three other historical populations (23.1%) are from areas with a projected temperature <3.9° F.

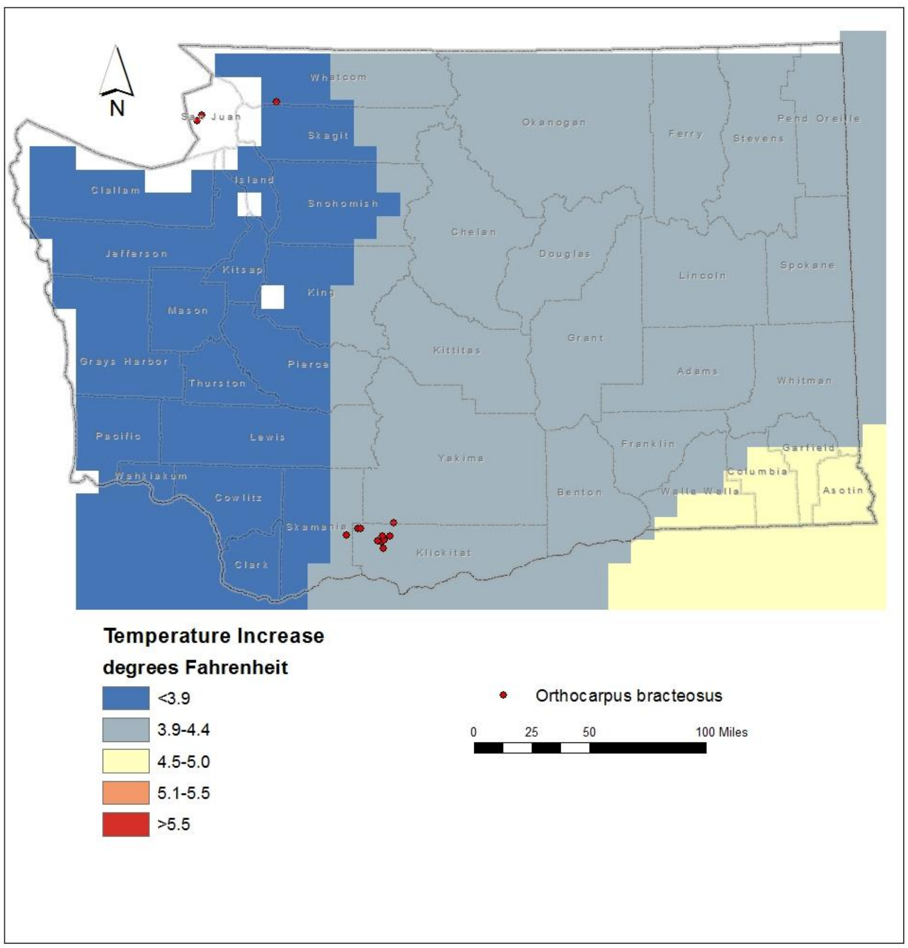

Figure 1. Exposure of *Orthocarpus bracteosus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Seven of the 13 occurrences of *Orthocarpus bracteosus* (53.8%) 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 other six populations (including three historical records from NW Washington) are from areas with a projected decrease in moisture in the range of -0.074 to -0.096 (46.2%).

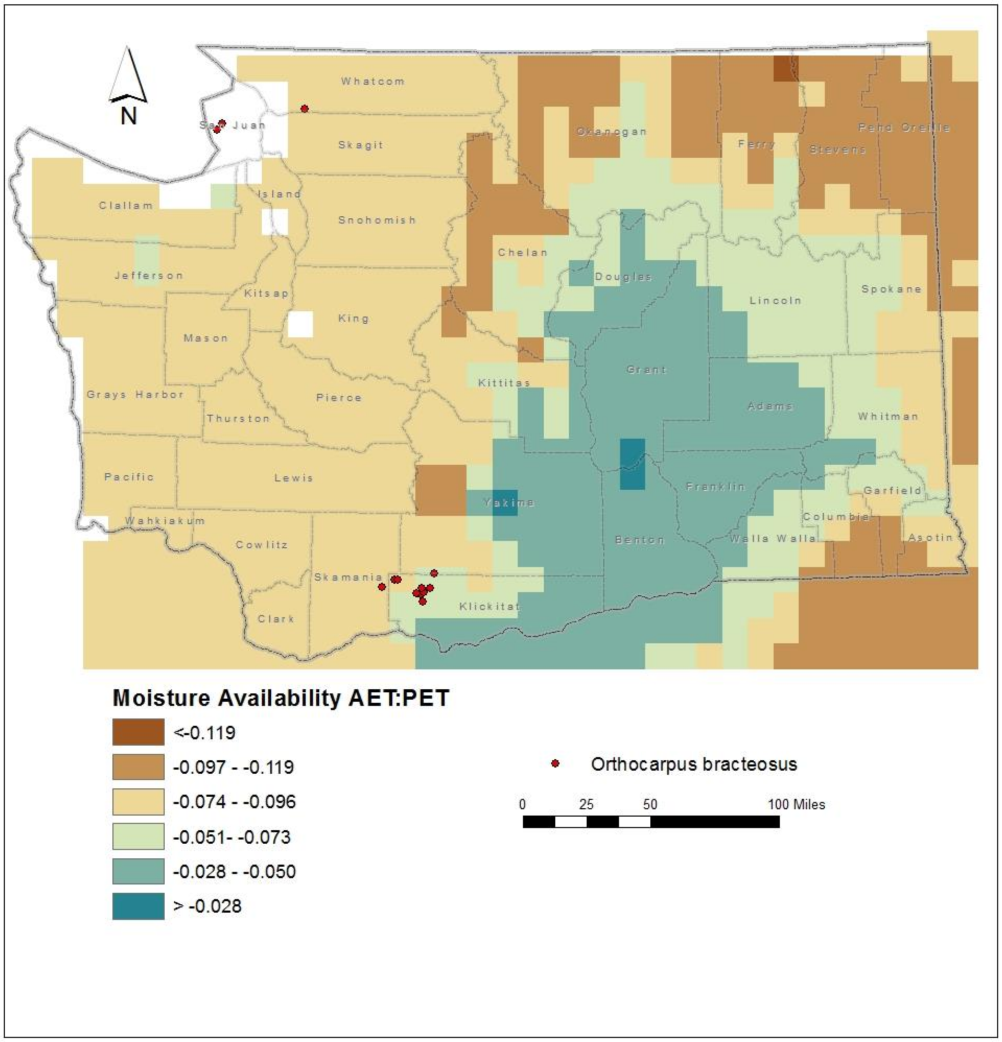

Figure 2. Exposure of *Orthocarpus bracteosus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Orthocarpus bracteosus* are found at 80-3000 feet (25-1000 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Orthocarpus bracteosus* is found in moist meadows that may be seasonally flooded in the winter or spring before becoming drier in the summer. These areas are dominated by grasses and herbaceous species, rather than shrubs (Camp and Gamon 2011; Fertig and Kleinknecht 2020). Some populations occur in depressions or channels. Populations on the east slope of the Cascade Mountains conform to the Rocky Mountain Alpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). Historical occurrences from the Puget Trough and San Juan Islands were found on lakeshores that fit the Temperate Pacific Subalpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). The single extant occurrence in Canada from Trial Island is associated with vernal pools and would conform to the North Pacific Hardpan Vernal Pool ecological system (COSEWIC 2004). Over a dozen historical occurrences are known from the Willamette Valley of western Oregon and probably belonged to the Willamette Valley Wet Prairie ecological system (Rocchio and Crawford 2015).

Washington populations are separated by distances of 1.2 to 187 miles (2-300 km) with large areas of unsuitable habitat between population clusters in the southern Cascades and northern Puget Trough. Dispersal between populations is naturally restricted by oceanic barriers (for the San Juan Islands) or unsuitable forest matrix habitat between occurrences in the Cascades.

B2b. Anthropogenic barriers: Neutral/Somewhat Increase.
The range of *Orthocarpus bracteosus* in Washington is bisected by roads, farmland, and human infrastructure that contributes to a fragmented landscape matrix. Areas of suitable habitat for this species, however, are naturally limited to sites that favor winter/spring flooding and summer drying. Natural factors are likely to be more significant to limiting dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Orthocarpus bracteosus produces numerous, showy flowers in a dense spike-like inflorescence. Fruit capsules contain 10-15 seeds that are 18-25 mm long with reticulate markings, but lack hooks, hairs, or other appendages to facilitate dispersal by wind or animals. Seeds are released passively when the dry capsule splits open at maturity. Chuang and Heckard (1983) suggested that the reticulations on the seed coat coupled with the light weight of the seed improved their aerodynamic qualities for wind dispersal. The reticulations might also trap air and increase the seed's buoyancy (COSEWIC). Most seed probably falls close to their parent (<100 m) (Chuang and Heckard 1983).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Orthocarpus bracteosus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Nine of the 13 known occurrences in Washington (69.2%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016). Two historical populations from the San Juan Islands (15.4%) have very small temperature variation (<37˚F/20.8˚C) during the same period and are at greatly increased vulnerability. The historical Whatcom County occurrence (7.7% of the state's populations) has experienced small (37-47˚F/20.8-26.3˚C) temperature variation in the past 50 years and is

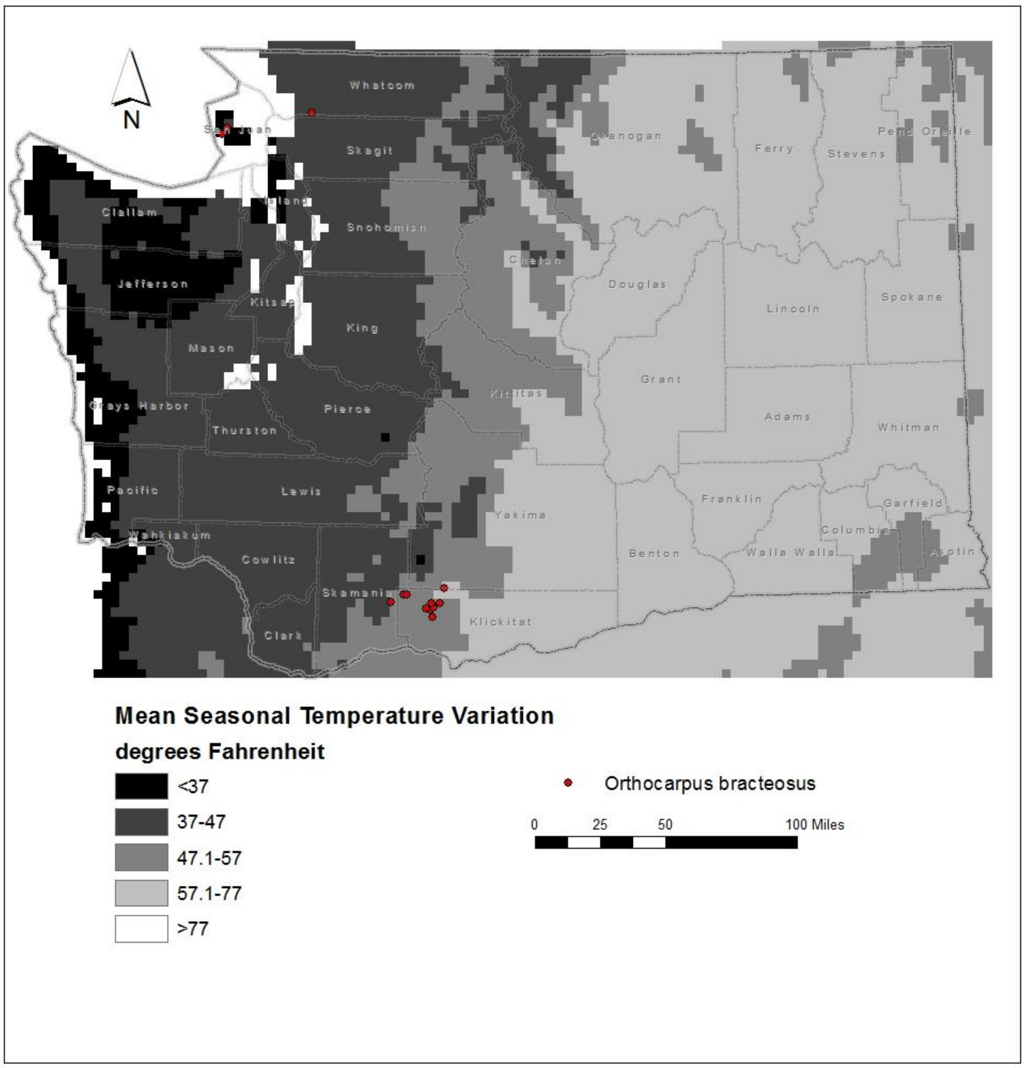

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Orthocarpus bracteosus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

rated at increased vulnerability from climate change. Lastly, one occurrence (7.7%) has experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) in the last 50 years and would have neutral impacts (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The wetland habitats of *Orthocarpus bracteosus* are often associated with cold air drainage during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
Nine of the 13 occurences of *Orthocarpus bracteosus* in Washington (69.2%) are found in areas that have experienced average (21-40 inches/508-1016 mm) precipitation variation in the past 50 years (Figure 4). The other four occurrences (30.8%) are from areas with greater than

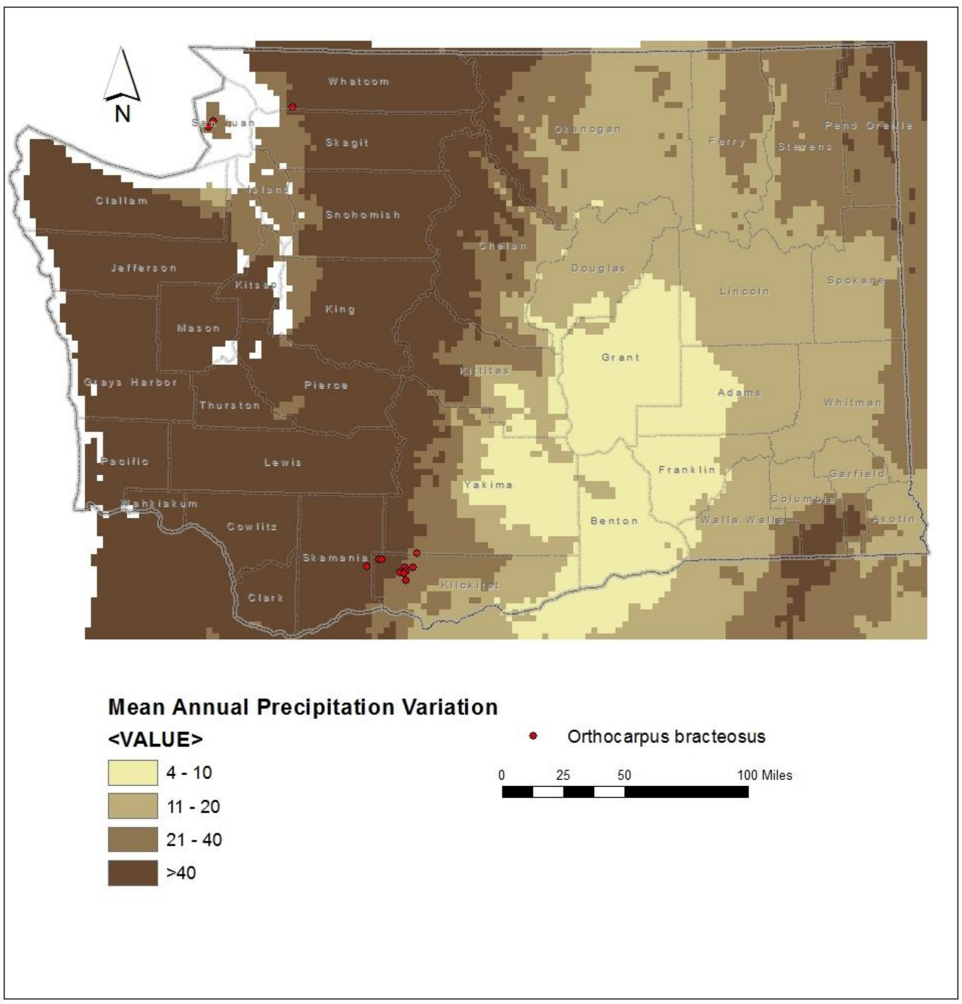

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Orthocarpus bracteosus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

average precipitation variation (>40 inches/1016 mm) during the same time period. According to Young et al. (2016), these areas are all at neutral vulnerability to climate change.

C2bii. Physiological hydrological niche: Increase.
Extant occurrences of *Orthocarpus bracteosus* in Washington occur in seasonally wet meadows dominated by graminoids that become dry in the summer. Such communities are vulnerable to changes in the timing of precipitation, especially in sites that are not fed by perennial springs. Hydrological changes, such as a drop in the water table, associated with long-term drought could result in the conversion of seasonally wet meadows to dry meadows dominated by upland plant species (Rocchio and Ramm-Granberg 2017). Historical populations in the Puget Trough region were associated with lakeshores and could be impacted by changes in the timing of precipitation or increased drought. Open meadow sites could be maintained, however, by increased wildfire resulting from drought and reduced precipitation, preventing these areas from converting to shrublands (Rocchio and Ramm-Granberg 2017). In Canada, *O. bracteosus* is known from hardpan vernal pool sites that are dependent on precipitation for adequate spring moisture conditions, and so would be vulnerable to extended drought or changes in the timing or amount of rainfall.

C2c. Dependence on a specific disturbance regime: Neutral.
Orthocarpus bracteosus is dependent on a specific hydrological environment (high water table from winter/spring precipitation and summer drought) to maintain its graminoid-dominated meadow habitat. Wildfire, which could be enhanced by summer drought, may play a role in keeping these sites from becoming invaded by shrub species (Rocchio and Ramm-Granberg 2017). Climate change may actually increase the frequency of wildfire.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Snowpack is low within the range of *Orthocarpus bracteosus* in the Puget Trough and San Juan Islands, but is moderate to high along the east slope of the Cascades near Mount Adams. Changes in the amount of snowfall, or in the timing of snow melt, can have ramifications for wet meadow sites that are dependent on springs or underground recharge enhanced by snowpack (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
In the East Cascades of Washington, *Orthocarpus bracteosus* occurs primarily on Quaternary alluvium derived from volcanic parent material. These deposits are widespread in the vicinity of Mount Adams. The historical occurrences from northwestern Washington are found on soils derived from metasedimentary marine deposits found in the San Juan Islands and along the coast in the northern Puget Sound/Salish Sea area (Washington Division of Geology and Earth Resources 2016). The geologic setting for the species is not restricted, although precise hydrological conditions that contribute to winter/spring flooding and summer drying may be uncommon.

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal conditions of wet meadows inhabited by *Orthocarpus bracteosus* are maintained primarily by hydrological factors (timing and amount of rainfall and snowpack), topographic drainage patterns, or wildfire rather than herbivory by wildlife.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Orthocarpus bracteosus has showy pink-purple flowers and is presumed to be an obligate outcrosser, pollinated primarily by bees (COSEWIC 2004). The exact pollinators of this species in Washington are not known.

C4d. Dependence on other species for propagule dispersal: Neutral.
The capsules of *Orthocarpus bracteosus* dehisce when dry to release seeds passively. These seeds lack barbs or hooks associated with dispersal by animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Many *Orthocarpus* species contain secondary compounds, such as alkaloids, that reduce herbivory. Herbivory has been identified as a potential threat (Camp and Gamon 2011), though is likely to be of less significance than herbicide application, conversion of habitat to agriculture, or changes in hydrology.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Orthocarpus bracteosus occurs in moist meadow sites that become dry in the summer. These areas could be vulnerable to invasion by annual weed species under conditions of prolonged drought and increased wildfire (Rocchio and Ramm-Granberg 2017). Competition with invasive weeds is considered an important threat for Canadian populations (COSEWIC 2004).

C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase.
Orthocarpus bracteosus is a hemiparasite that produces its own food through photosynthesis but also forms haustorial connections to other plant hosts to obtain supplemental water, nutrients, or photosynthates. Other *Orthocarpus* species are known to partially parasitize members of the legume, grass, and sunflower families (Matthies 1997). This species does not appear to be restricted to particular hosts, at least in the Canadian Trial Islands (COSEWIC 2004). In Canada, *O. bracteosus* overlaps with a population of the endangered Taylor's checkerspot butterfly (*Euphydryas editha taylori*) but is not thought to be a significant food source or host species (COSEWIC 2004). These two species are not known to co-occur in the Puget Trough in Washington.

C5a. Measured genetic variation: Unknown.
Species in *Orthocarpus* section *Orthocarpus* are diploids with a chromosome count of $n = 14$, except for *O. bracteosus* which is $n = 15$ (Chuang and Heckard 1982). No genetic data are available for *Orthocarpus bracteosus* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Orthocarpus bracteosus is presumed to be an outcrosser, rather than self-pollinated. Presumably, genetic variation is average, compared to other species, but no studies have been done to confirm this. Due to founder effects or genetic drift, disjunct occurrenes (such as those in the San Juan Islands of Washington and British Columbia) might be expected to have lower genetic diversity than those in the core of its range in the eastern Cascades of Washington and central to southern Oregon.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no significant changes in the phenology of *Orthocarpus bracteosus* populations in Washington have been detected over the past 20 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
The three occurrences from the San Juan Islands and Puget Trough in northwestern Washington are all historical and have not been observed since 1923. These populations are from lakeshore areas and may be extirpated due to development, or have not been surveyed in recent years. Climate change is not known to be a factor in their disappearance. Other populations in the East Cascades Range may fluctuate greatly in abundance from year to year, perhaps following trends in annual precipitation (Fertig and Kleinknecht 2020). Such populations could be vulnerable to long term climate change.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Chuang, T.J. and L.R. Heckard. 1982. Chromosome numbers of *Orthocarpus* and related monotypic genera (Scrophulariaceae: Subtribe Castillejinae). Brittonia 34L89-101.

Chuang, T.J. and R.L. Heckard. 1983. Systematic significance of seed-surface features in *Orthocarpus* (Scrophulariaceae – Subtribe Castillejinae). American Journal of Botany 70(6): 877-890.

COSEWIC. 2004. COSEWIC assessment and status report on the rosy owl-clover *Orthocarpus bracteosus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 18 pp + app.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Matthies, D. 1997. Parasite-host interactions in *Castilleja* and *Orthocarpus*. Canadian Journal of Botany 75: 1252-1260.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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Climate Change Vulnerability Index Report

Pellaea breweri (Brewer's cliffbrake)

Date: 11 October 2021

Assessor: Walter Fertig, 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: Local Climate	**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	84.6
	<3.9° F (2.2°C) warmer	15.4
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	46.2
	-0.074 to - 0.096	53.8
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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 others species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Not Applicable
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/Somewhat Increase
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: Eleven of the 13 confirmed occurrences of *Pellaea breweri* in Washington (84.6%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). Two other

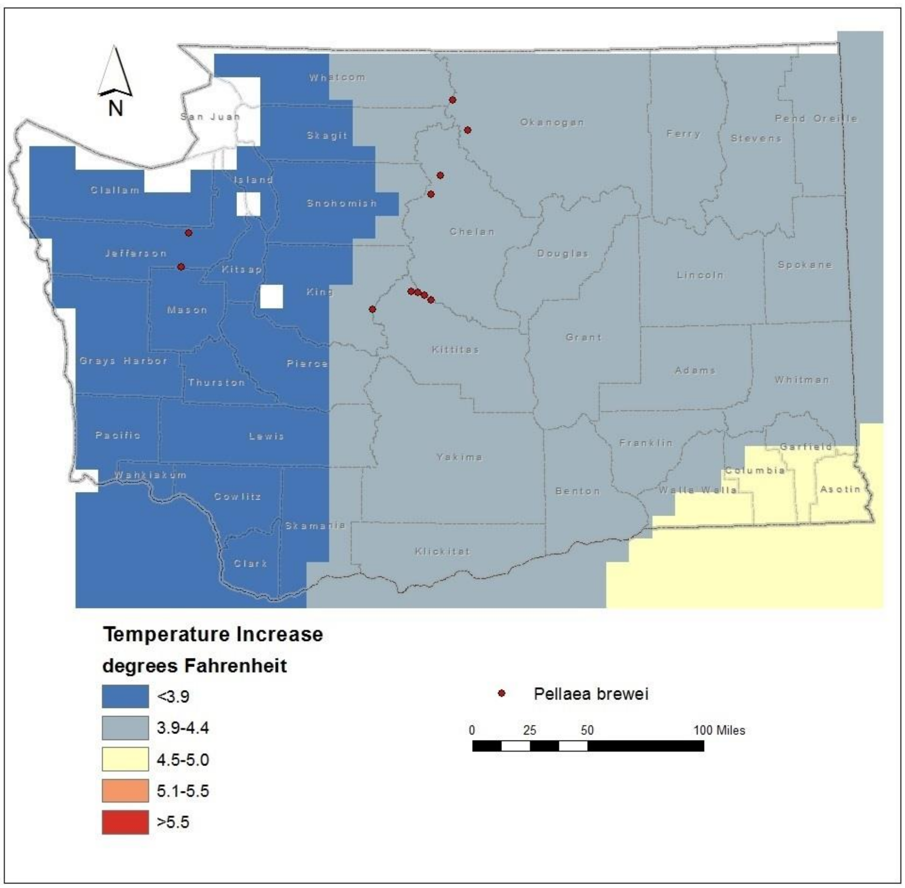

Figure 1. Exposure of *Pellaea breweri* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

populations (15.4%) are from areas with a projected temperature increase of < 3.9° F. A report from Stevens County has been excluded because it is a misidentification.

A2. Hamon AET:PET Moisture Metric: Seven of the 13 occurrences (53.8%) of *Pellaea breweri* 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). Six other populations (46.2%) are from areas with a predicted decrease of -0.097 to -0.119.

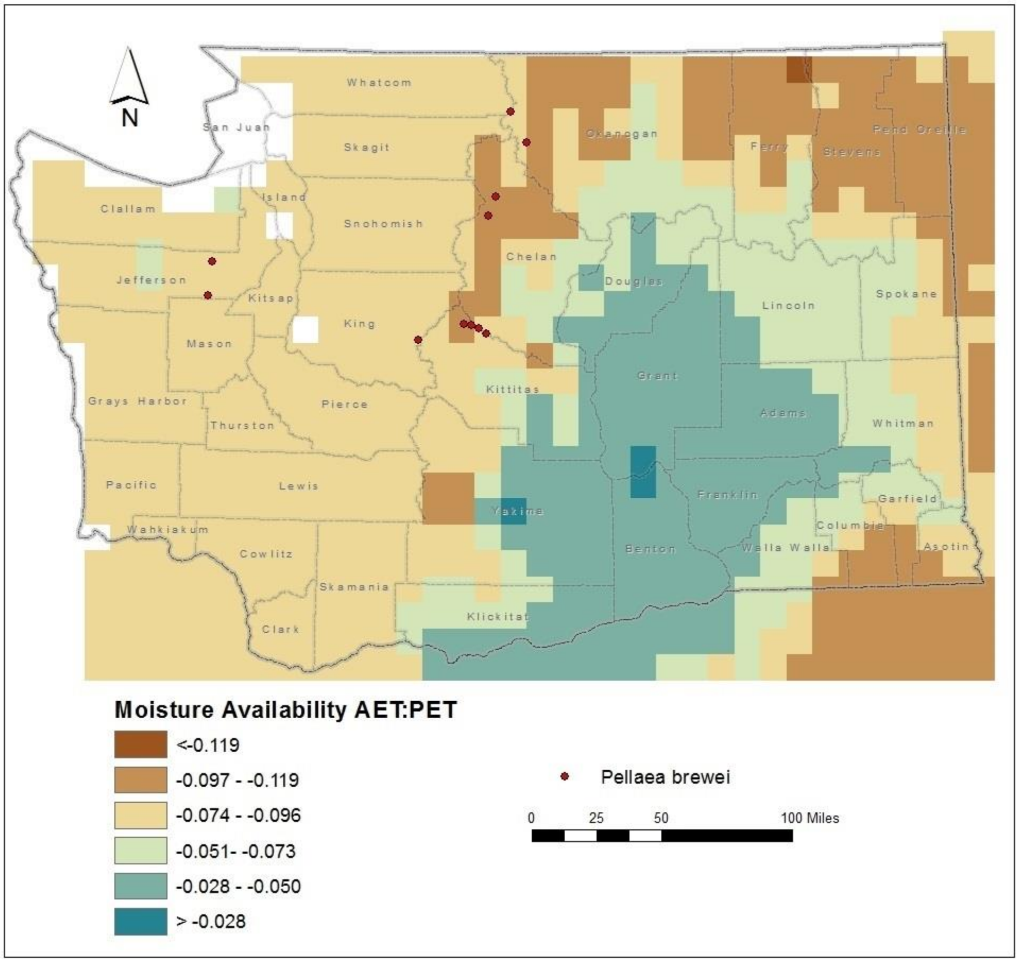

Figure 2. Exposure of *Pellaea breweri* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Pellaea breweri* are found at 4700-6700 feet (1430-2040 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Pellaea breweri* occurs in crevices and ledges of cliffs and talus slopes in glacial cirques and openings in montane to subalpine forests. It occurs on a variety of substrates, including basalt, sandstone, serpentine, granite, and marble (and limestone elsewhere in its range). Populations are often on southerly exposures but in shady microsites (Camp and Gamon 2011; Washington Natural Heritage Program 2021). These habitats are part of the North Pacific Alpine & Subalpine Bedrock & Scree and Rocky Mountain Alpine Bedrock & Scree ecological systems (Rocchio and Crawford 2015). Populations are separated by 1.3-102 miles (1.6-164 km) of unoccupied or unsuitable habitat.

B2b. Anthropogenic barriers: Neutral.
Most populations of *Pellaea breweri* in Washington are found on National Park or Forest Service Wilderness lands with relatively few direct human impacts to negatively affect dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Pellaea breweri, like other ferns and fern-allies, has a complex life cycle involving alternation of two distinct growth forms: the familiar sporophyte phase and a much-reduced gametophyte phase. Sporophyte plants produce large numbers of tiny, seed-like spores that are capable of long-distance dispersal by wind. Spores germinate to form gametophyte plants which reproduce sexually by gametes (sessile eggs retained within the plant and motile sperm that require moist surfaces to travel very short distances for fertilization). Sporophyte plants are produced from fertilized eggs within their parent gametophyte plant, and thus are incapable of further dispersal. Overall, dispersal by spores is not limiting, but the survival of sporophyte plants is strongly tied to gametophytes reaching and persisting in suitable microhabitats. The dependence on proper conditions for gametophyte survival makes ferns more vulnerable to dispersal bottlenecks.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Pellaea breweri* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eight of the 13 occurrences in the state (61.5%) are found in areas that have experienced slightly lower than average variation in temperature (47.1-57˚F/26.3-31.8˚C) during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016). Three populations (23.1%) have experienced small (37-47˚F/20.8-26.3˚C) temperature variation during the same period and are at increased vulnerability to climate change. Two other populations (15.4%) from the Olympic Range are from areas with very small (<37˚F/20.8˚C) temperature variation and are at greatly increased vulnerability to climate change (Young et al. 2016).

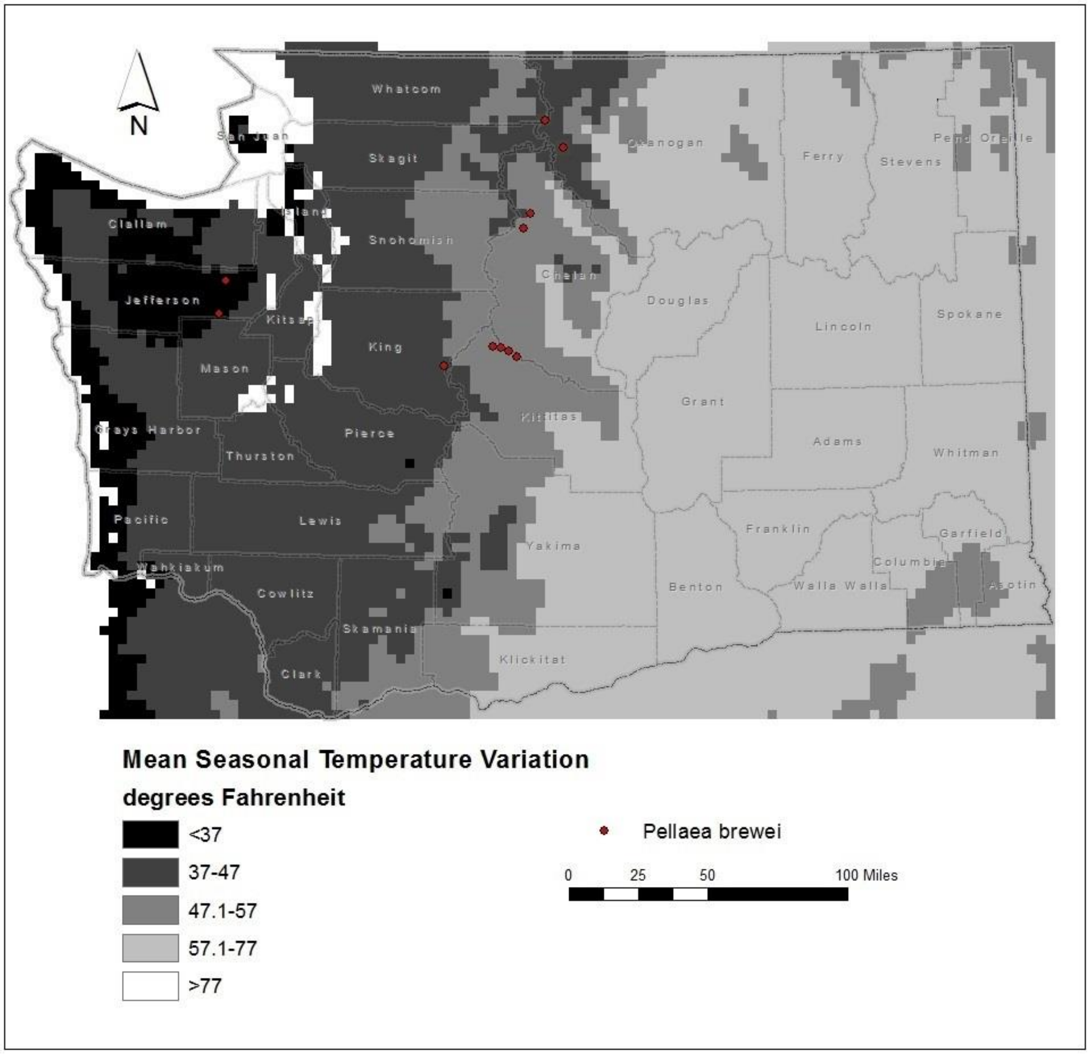

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Pellaea breweri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The rock outcrop and talus field habitat of *Pellaea breweri* occur at high elevations and may be associated with cold air drainages and would be adversely impacted by warming temperatures (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
All of the populations of *Pellaea breweri* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016

mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

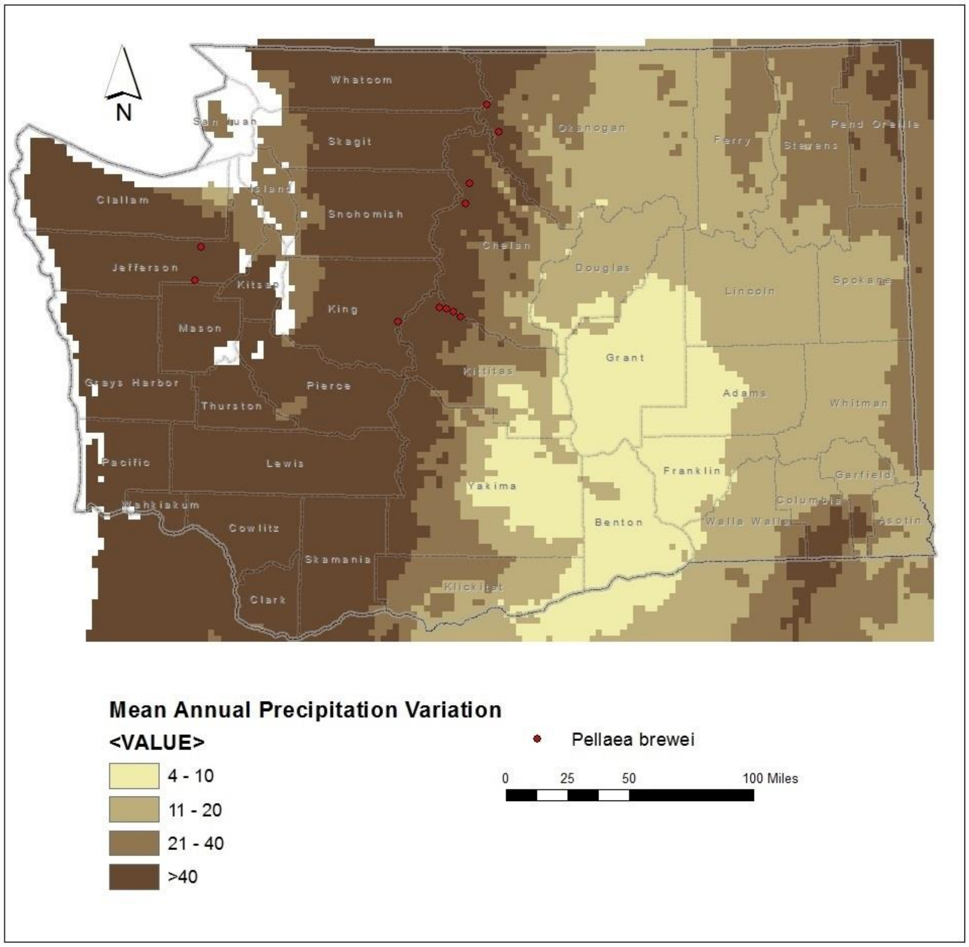

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Pellaea breweri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The high elevation rock outcrop habitat of *Pellaea breweri* is not associated with perennial water sources or a high water table. This species is dependent on adequate winter snowfall and spring/summer precipitation. Projected climate change is likely to make these areas warmer and extend the growing season, which over the long term will increase soil production and make these rocky sites more amenable to invasion by plants from lower elevations (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Pellaea breweri occurs on bedrock and boulder fields and is not dependent on periodic disturbance to maintain its habitat.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
In Washington, *Pellaea breweri* is found in montane to lower alpine areas with moderate to high amounts of snow. Changes in the quantity of snow or the timing of snowmelt under future climate scenarios could impact the persistence of this species by making its microhabitat too dry (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Pellaea breweri occurs on a variety of rock outcrops in the Olympic and North Cascades mountains, including serpentine, basalt, sandstone, granite, and marble (Washington Natural Heritage Program 2021). Formations include the Crescent basalt, Naches, Swauk, Ingalls, Goat Creek, and Harts Pass formations (Washington Division of Geology and Earth Resources 2016). Many of these outcrops occur widely in central Washington and the Olympic Peninsula.

C4a. Dependence on other species to generate required habitat: Neutral.
The rock outcrop and talus habitat occupied by *Pellaea breweri* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Not applicable.
The sporophyte generation of *Pellaea breweri* 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 breweri* do not require animal species for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Pellaea breweri is not an edible species and is not known to be attacked by pathogens.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Currently, competition from non-native species is minor, as few introduced plants are adapted to the extreme climatic conditions of alpine and subalpine cliffs and boulder fields. Under future climate change, warmer temperatures could extend the growing season, making these areas more susceptible to invasion by annual introduced species 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: Neutral.
Does not require an interspecific interaction.

C5a. Measured genetic variation: Unknown.
Data are lacking on the genetic diversity within and between populations of *Pellaea breweri* in Washington. This species is at the northern edge of its range in Washington and so may have lower overall genetic diversity in the state due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral/Somewhat Increase.
Pellaea breweri is a sexual diploid and does not reproduce by apogamy (Tryon and Britton 1958). Like other ferns, it has a complex life history involving an alternation between diploid spore-producing sporophytes (the familiar form of the species) and minute, gamete-producing haploid gametophytes. While spores are capable of long-distance dispersal, gametes are not and so genetic variability could be constrained in populations at the edge of the species' range, like those in Washington.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
The timing of reproduction in *Pellaea breweri* has not been altered in response to climate change.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Pellaea breweri* has not changed significantly in Washington since it was first discovered in the state in 1932.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Tryon, A.F. and D.M. Britton. 1958. Cytotaxonomic studies on the fern genus *Pellaea*. Evolution 12(2): 137-145.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Pellaea breweri*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=pellaea%20breweri). Accessed 13 October 2021.

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

Penstemon eriantherus var. *whitedii* (Whited's fuzzytongue beardtongue)

Date: 6 December 2021

Assessor: Walter Fertig, WA Nat. Heritage Program

Geographic Area: Washington

Heritage Rank: G4G5T2/S2

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	8.7
	-0.051 to -0.073	47.8
	-0.028 to -0.050	43.5
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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 others 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		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: Documented or Modeled Response	
D1. Documented response to recent climate change	Neutral/Somewhat 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 23 of the extant and historical occurrences of *Penstemon eriantherus* var. *whitedii* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1). The Spokane County population falls outside the traditionally-defined range of var.

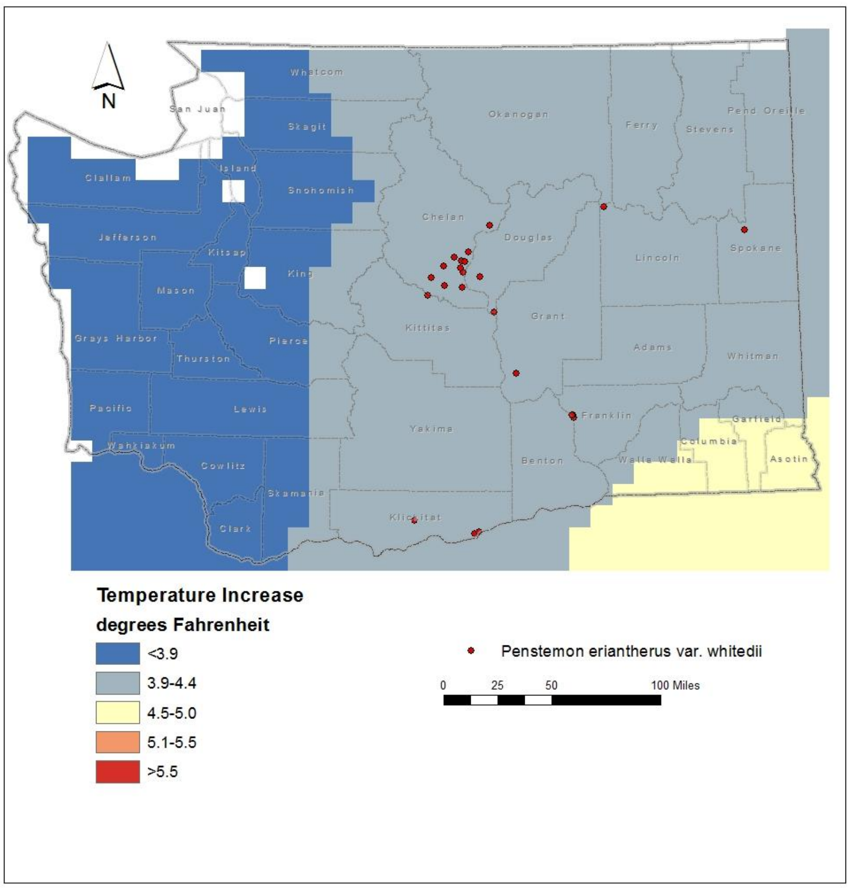

Figure 1. Exposure of *Penstemon eriantherus* var. *whitedii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

whitedii and within the range of var. *eriantherus*, but is included in this analysis (Freeman 2019).

A2. Hamon AET:PET Moisture Metric: Eleven of the 23 historical and extant occurrences of *Penstemon eriantherus* var. *whitedii* in Washington (47.8%) 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). Ten populations (43.5%) are

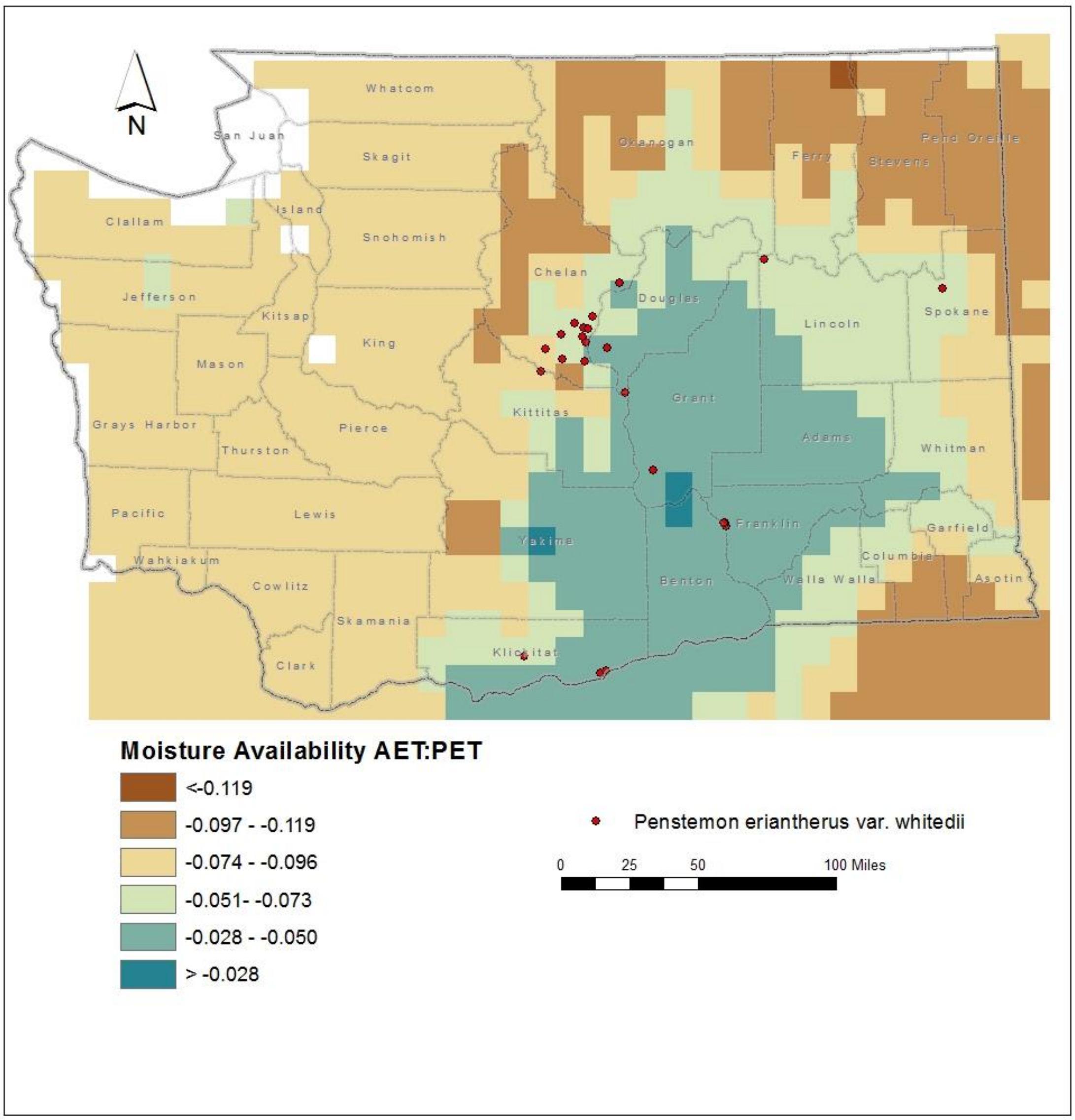

Figure 2. Exposure of *Penstemon eriantherus* var. *whitedii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

from areas with a projected decrease of -0.028 to -0.050. Two other occurrences (8.7%) are from areas with a projected decrease of -0.074 to -0.096 (Figure 2).

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Penstemon eriantherus* var. *whitedii* are found at 500-4000 feet (150-1220 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Penstemon eriantherus var. *whitedii* occurs primarily on dry, rocky slopes or cut banks of small canyons and ridgetops in the foothills of the East Cascades and Columbia Basin in communities of antelope bitterbrush (*Purshia tridentata*), rubber rabbitbrush (*Ericameria nauseosa*), big sagebrush (*Artemisia tridentata*) or open ponderosa pine (*Pinus ponderosa*). These sites are often sparsely vegetated or being actively eroded and may be associated with caliche fragments, basalt rubble, or granite, sandstone, or volcanic talus (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the Intermountain Basin Cliff & Canyon; Intermountain Basin Semi-Desert Shrub-Steppe; and Rocky Mountain Cliff, Canyon & Massive Bedrock ecological systems (Rocchio and Crawford 2015). Populations are separated by 1.1-67 miles (1,8-108 km) of unoccupied and unsuitable habitat that presents a barrier to dispersal and gene flow.

B2b. Anthropogenic barriers: Somewhat Increase.
The foothill canyon and ridge habitat of *Penstemon eriantherus* var. *whitedii* in eastern Washington is naturally sporadic but also fragmented by human impacts, such as agriculture, roads, and human habitations that are likely to limit dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Penstemon eriantherus var. *whitedii* produces many-seeded dry capsule fruits that split open at maturity to release the seeds passively by gravity or high winds. Seeds on the ground may be secondarily distributed short distances by insects or small mammals. Average dispersal distances are probably relatively short (100-1000 meters).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Penstemon eriantherus* var. *whitedii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Sixteen of the 23 known occurrences in the state (69.6%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). Seven other occurrences (30.4%) are from areas that have had slightly lower than average variation (47.1-57˚F/26.3-31.8˚C) in temperature over the same period and are at somewhat increased vulnerability to climate change.

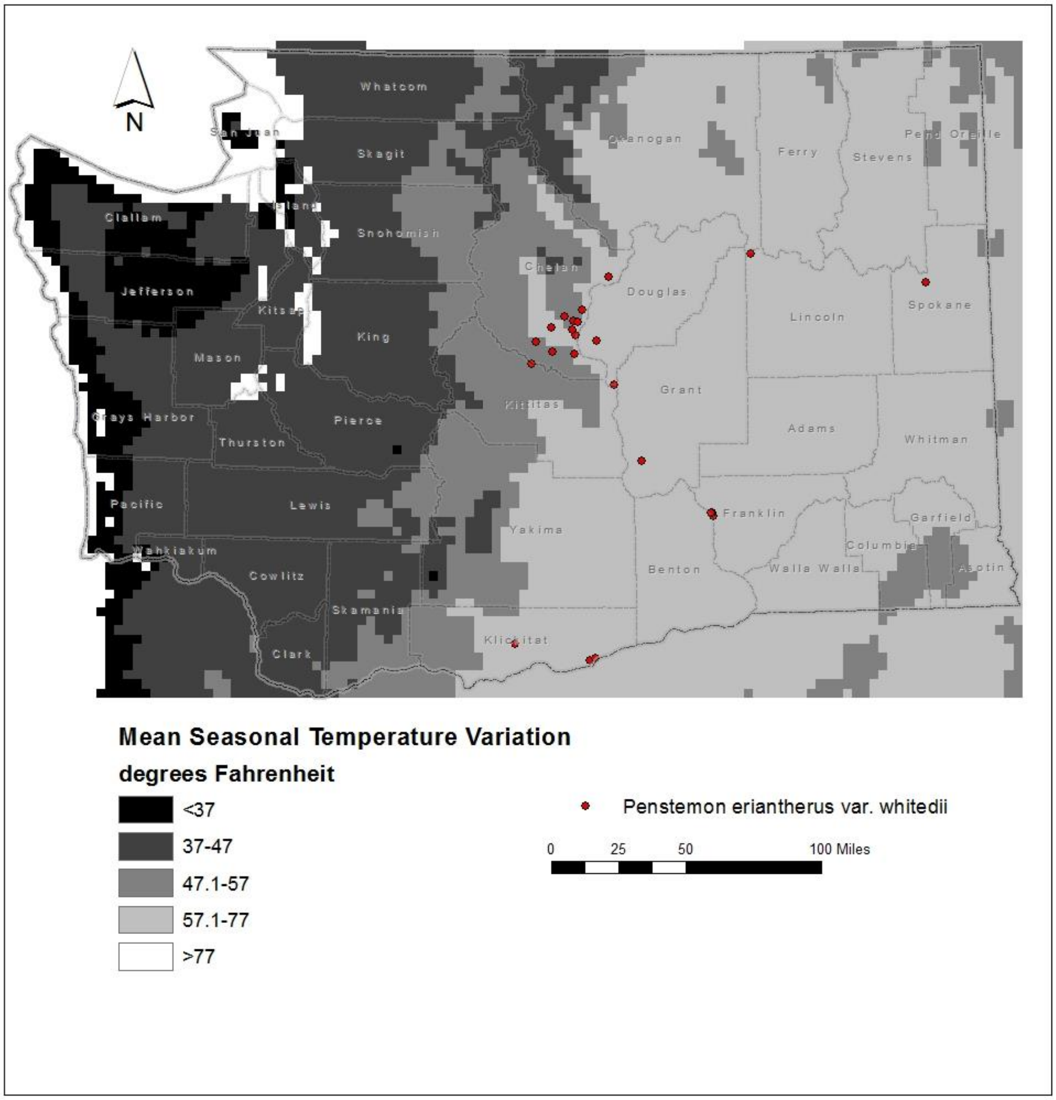

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Penstemon eriantherus* var. *whitedii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The sagebrush/bitterbrush canyon and ridgetop habitat of *Penstemon eriantherus* var. *whitedii* may be exposed to cold air drainage early in the growing season, making these sites somewhat vulnerable to long-term increases in temperature related to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Ten of the 23 known populations of *Penstemon eriantherus* var. *whitedii* in Washington (43.5%) are found in areas that have experienced slightly lower than average precipitation

variation in the past 50 years (>20 inches/508 mm) (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased risk from climate change. Seven occurrences from the central Columbia Plateau (30.4%) are in areas with small (4-10 inches/100-254 mm) variation in precipitation over the same period and are at increased vulnerability due to projected climate change. Six populations in the foothills of the Cascades (26.1%) are from areas with average precipitation variation (21-40 inches/508-1016 mm) over the past 50 years and are at neutral vulnerability (Young et al. 2016).

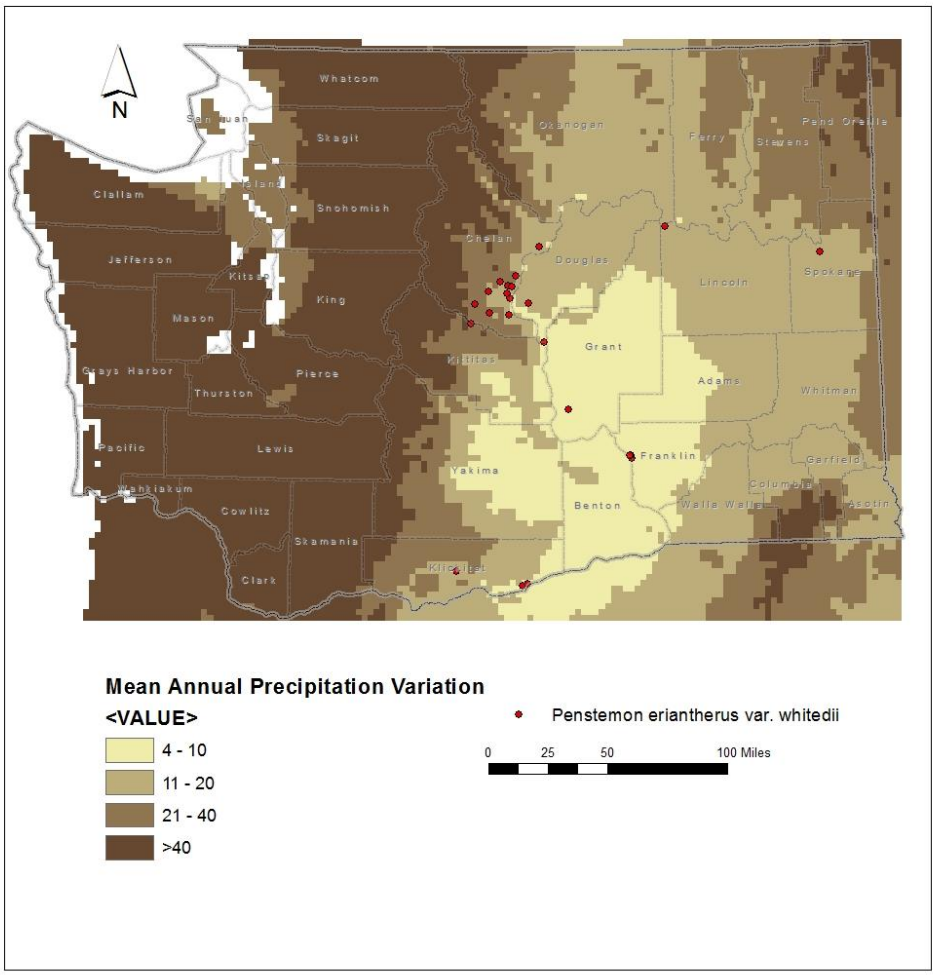

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Penstemon eriantherus* var. *whitedii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is not associated with perennial water sources or high water tables and is dependent on spring precipitation or winter snow for much of its moisture needs during the growing

season. Changes in the amount or timing of precipitation and increased temperatures from projected future climate change are likely to exacerbate drought conditions in semi-desert scrub and grassland habitats of eastern Washington (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Penstemon eriantherus var. *whitedii* often occurs on actively-eroding slopes or road banks, where it may have an advantage over later seral species adapted to more stable conditions. Under drier conditions, these semi-barren sites could shift to dominance by lichens. Changes in precipitation could also result in increased cover of other herbaceous plants and ultimately greater risk from wildfire (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
The populations of *Penstemon eriantherus* var. *whitedii* in Washington are found in foothills and low elevation ridges in the East Cascades and Columbia Plateau that receive relatively low quantities of snow. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff in these areas (Rocchio and Ramm-Granberg 2017). Populations from the central Columbia Plateau receive low amounts of snow and would largely be unaffected by changes in the quantity or timing of snowmelt.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
Penstemon eriantherus var. *whitedii* occurs on a variety of geologic substrates. In the Wenatchee Mountains and vicinity, it is mostly associated with the Swakane biotite (gneiss) and Chumstick Formation (granitic sandstone), with at least one population found on serpentine talus. Along the Hanford Reach of the Columbia, this species is found on the Ringold Formation, a white caliche-rich sandstone. Elsewhere, it is found on talus derived from the Miocene-age Grande Ronde Basalt or Quaternary alluvium (Washington Division of Geology and Earth Resources 2016). Several of these formations are of limited distribution (Swakane, Chumstick, and Ringold), while others are widespread in eastern Washington. Soil testing might indicate that this species has more restricted geologic requirements than presently known.

C4a. Dependence on other species to generate required habitat: Neutral.
The foothill talus and rock outcrop habitat occupied by *Penstemon eriantherus* var. *whitedii* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Penstemon eriantherus has medium to large lavender, blue, or purple flowers with an inflated (ampliate) corolla and large, bushy staminode (Freeman 2019). *Penstemon* species with this syndrome of characters tend to be pollinated by medium to large-sized bumblebees, such as the genus *Bombus* (Montana Natural Heritage Program 2021, Wilson et al. 2004). The specific pollinators of var. *whitedii* have not been reported.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seed dispersal in *Penstemon* is passive, with small seeds spreading by gravity or high winds once the dry fruit capsule is ripe and splits open. The genus is not dependent on animals for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
No impacts from pathogens are known. This species is not an important forage plant for wildlife or livestock.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Vegetation cover is low in many of the talus habitats occupied by this species. Warmer, wetter winters projected in the future could negatively impact some native shrub taxa in semi-desert shrub steppe sites occupied by *Penstemon eriantherus* var. *whitedii*, resulting in a shift towards perennial grassland communities (Rocchio and Ramm-Granberg 2017). Increased cover of annual species following disturbance or altered fire regimes could also result in more competition (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Not known. Broderick (2010) assessed the genetic variability of 104 of the 270 *Penstemon* taxa in North America and used *P. eriantherus* var. *redactus,* an endemic of the Snake River Basin in Oregon, Idaho, and Montana, as a stand-in for *P. eriantherus*. Var. *redactus* is a diploid ($2n = 16$) and had one of the largest genomes of all sampled diploid taxa, despite its small geographic range (Broderick 2010). This finding is somewhat counter-intuitive, as small geographic ranges and isolation are often correlated with low genetic diversity (Hamrick and Godt 1989). Three other varieties of *P. eriantherus* also have relatively narrow geographic ranges (vars. *argillosus*, *cleburnei*, and *whitedii*), while diploid var. *eriantherus* is widespread from southern Canada and northeastern Washington to North Dakota and Colorado. Genetic diversity might be expected to be low in var. *whitedii* due to its geographic isolation (though it may be enhanced from potential gene exchange with var. *eriantherus* in northeast Washington).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Penstemon eriantherus var. *whitedii* produces relatively large flowers that are insect pollinated. It is presumed to be an outcrosser and should have at least average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Penstemon eriantherus* var. *whitedii* has historically flowered from early May to early June. In the last 20 years, the species has been observed flowering in the last week of April.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral/Somewhat Increase.
At least 5 populations of *Penstemon eriantherus* var. *whitedii* in Washington are historical and have not been relocated since 1981. These occurrences may be extirpated or just have not been

revisited. One historical occurrence from the East Cascades in Klickitat County may be a misidentified record.

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

References

Broderick, S.R. 2010. An examination of the DNA content, taxonomy and phylogeny of *Penstemon* (Plantaginaceae). Master's Thesis, Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT. 51 pp.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Freeman, C. 2019. *Penstemon*. Pp. 82-255. In: Flora of North America Editorial Committee. Flora of North America North of Mexico. Volume 17. Magnoliophyta: Tetrachondraceae to Orobanchaceae. Oxford University Press, New York. 737 pp.

Hamrick, J.L. and M.J.W. Godt. 1989. Allozyme diversity in plant species. Pp 43-63. In: Brown, A.H.D., M.T. Clegg, A.L. Kahler, and B.S. Weir, eds. Plant Population Genetics, Breeding and Genetic Resources. Sinauer, Sunderlin, MA.

Montana Natural Heritage Program. 2021. Fuzzy-tongue Penstemon – *Penstemon eriantherus*. Montana Field Guide. (https://FieldGuide.mt.gov/speciesDetail.aspx?elcode=PDSCR1L270). Accessed 3 December 2021.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Penstemon eriantherus* var. *whitedii*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=penstemon%20eriantherus%20var.%20whitedii). Accessed 29 November 2021.

Wilson, P., M.C. Castellanos, J.N. Hogie, J.D. Thomson, and W.S. Armbruster. 2004. A multivariate search for pollination syndromes among penstemon. Oikos 104: 345-361.

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

Petrophytum caespitosum ssp. *caespitosum* (Rocky Mountain rockmat)

Date: 27 September 2021 | Assessor: Walter Fertig, WA Nat. Heritage Program

Geographic Area: Washington | Heritage Rank: G5T3T5/S1

Index Result: Highly Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on others 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: Documented or Modeled Response	
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: The single occurrence of *Petrophytum caespitosum* ssp. *caespitosum* in Washington (100%) occurs in an area with a projected temperature increase of 4.5-5.0° F (Figure 1).

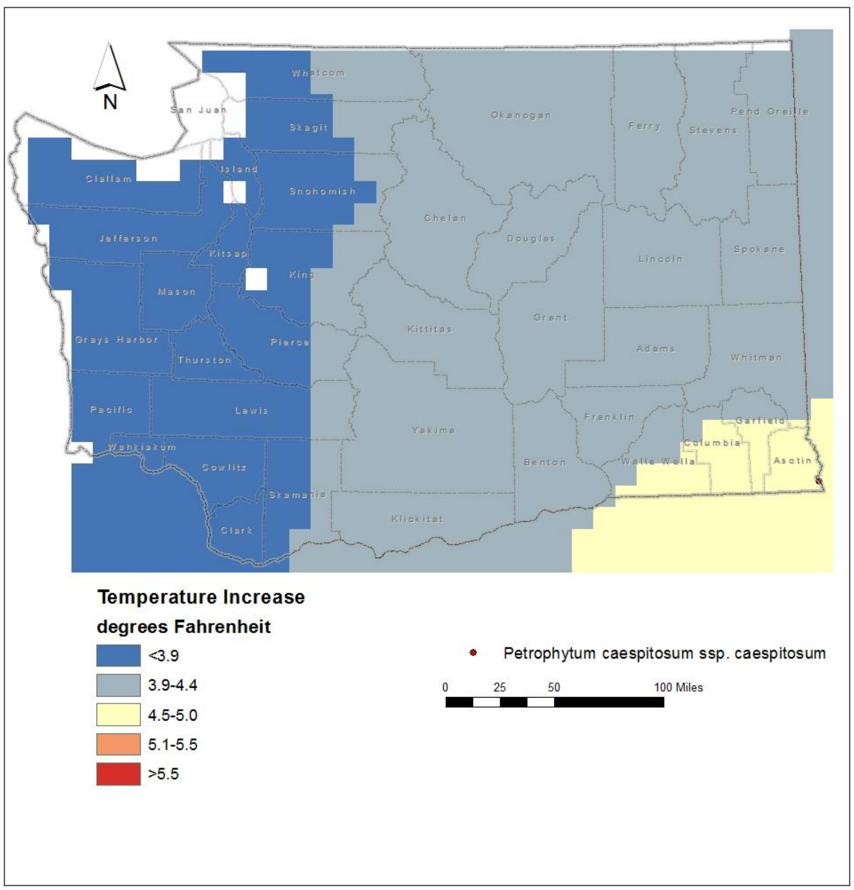

Figure 1. Exposure of *Petrophytum caespitosum* ssp. *caespitosum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The one Washington occurrence of *Petrophytum caespitosum* ssp. *caespitosum* (100%) 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).

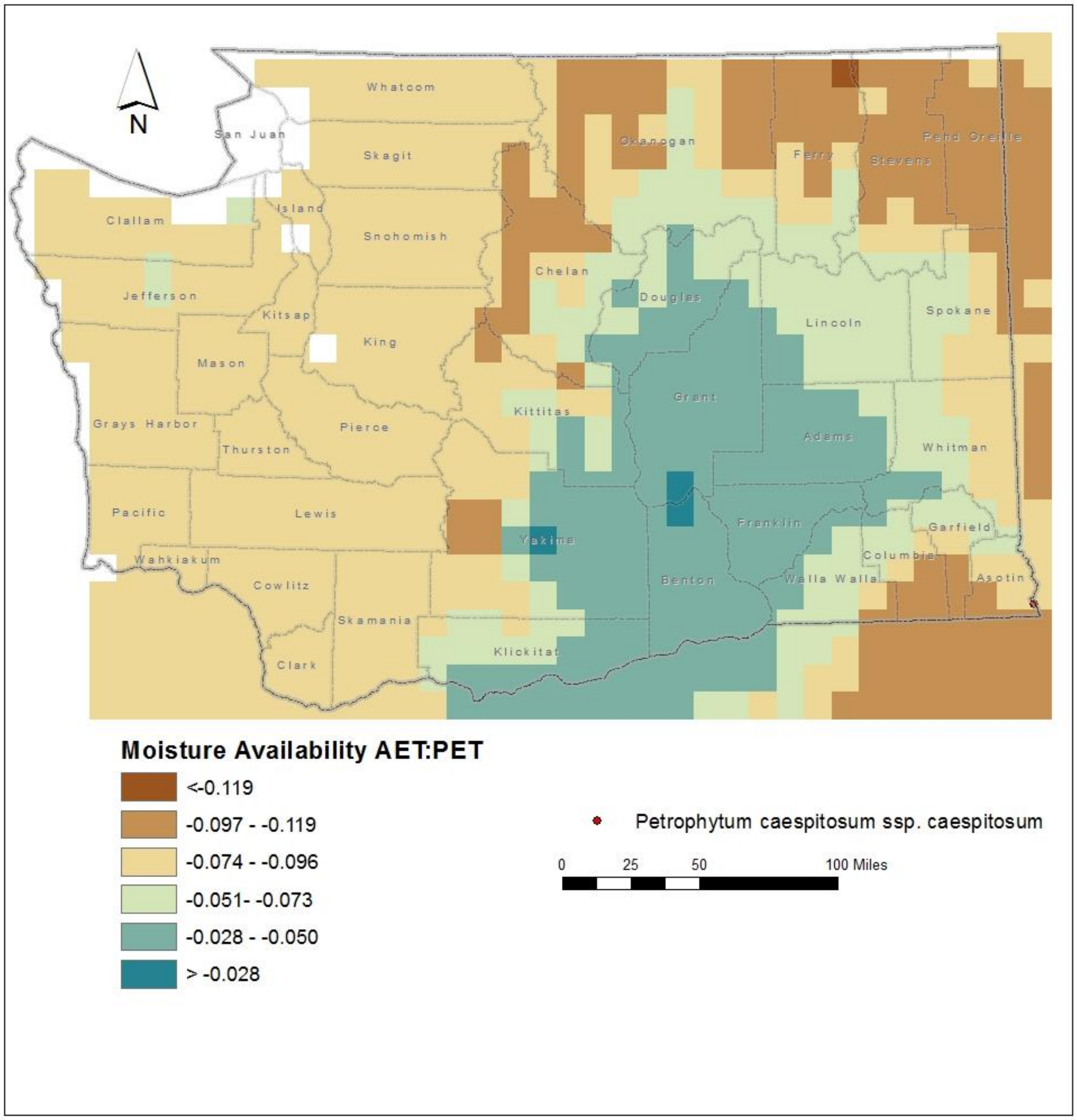

Figure 2. Exposure of *Petrophytum caespitosum* ssp. *caespitosum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
In Washington, *Petrophytum caespitosum* ssp. *caespitosum* occurs at 2200 feet (670 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
The single Washington population of *Petrophytum caespitosum* ssp. *caespitosum* is found on ledges and faces of hard, dry, limestone cliffs near the mouth of the Grande Ronde and Snake rivers (Camp and Gamon 2011). This habitat is a component of the Inter-Mountain Basins Cliff and Canyon ecological system (Rocchio and Crawford 2015). The Washington occurrence is disjunct from the nearest population in Idaho by 46 miles (75 km) of unoccupied and unsuitable habitat. Deep canyons in the Blue Mountains area provide an effective barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
Human impacts are relatively minor within the occupied range of *Petrophytum caespitosum* ssp. *caespitosum* in southeastern Washington and present less of an obstacle to dispersal than natural barriers, such as the Snake River and its many tributary canyons.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Petrophytum caespitosum ssp. *caespitosum* produces 1-2 seeded dry follicle fruits that split open at maturity to release the seeds passively by gravity or wind. Average dispersal distances are probably relatively short (100-1000 meters).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Petrophytum caespitosum* ssp. *caespitosum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The single Washington occurrence (100%) is found in an area that has experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and is considered at neutral risk from climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The microsites within the limestone cliffs occupied by *Petrophytum caespitosum* ssp. *caespitosum* may be associated with cool, shaded conditions during the growing season and would have somewhat increased vulnerability to climate change.

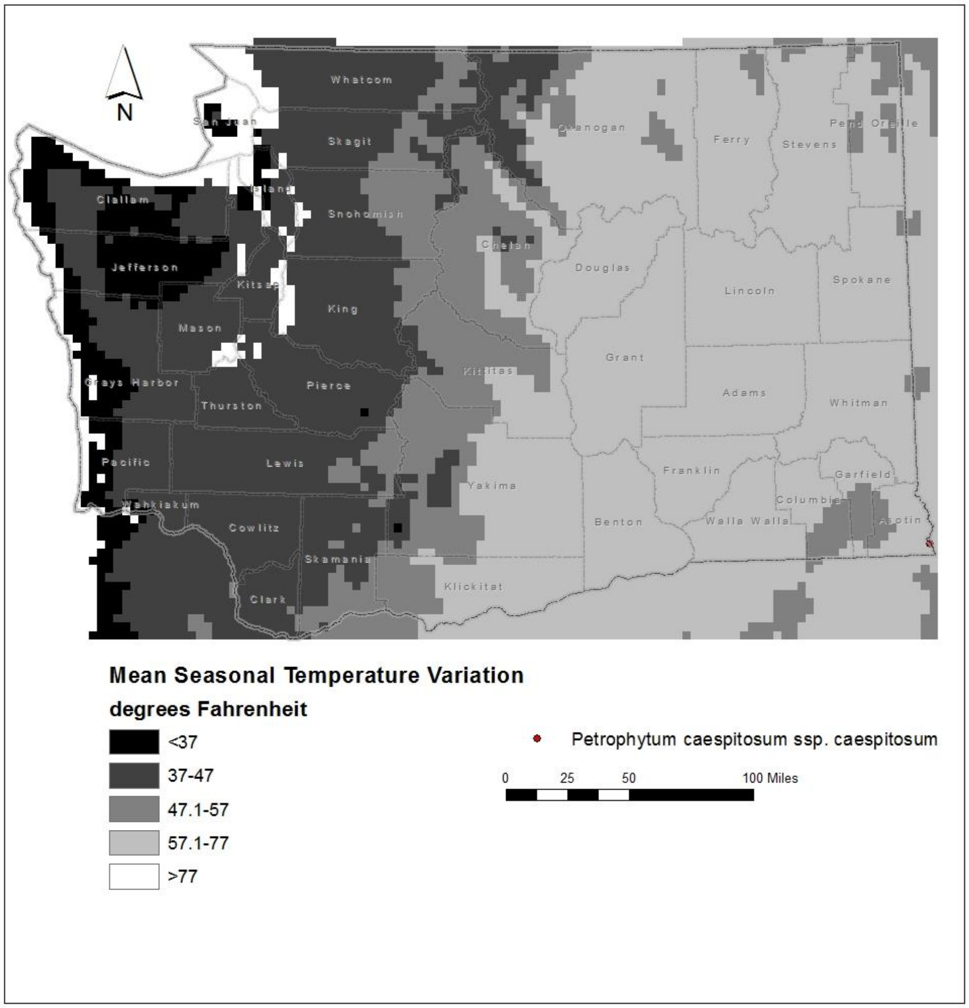

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Petrophytum caespitosum* ssp. *caespitosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
The single population of *Petrophytum caespitosum* ssp. *caespitosum* in Washington (100%) is found in an area that has experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these sites are at somewhat increased vulnerability from climate change.

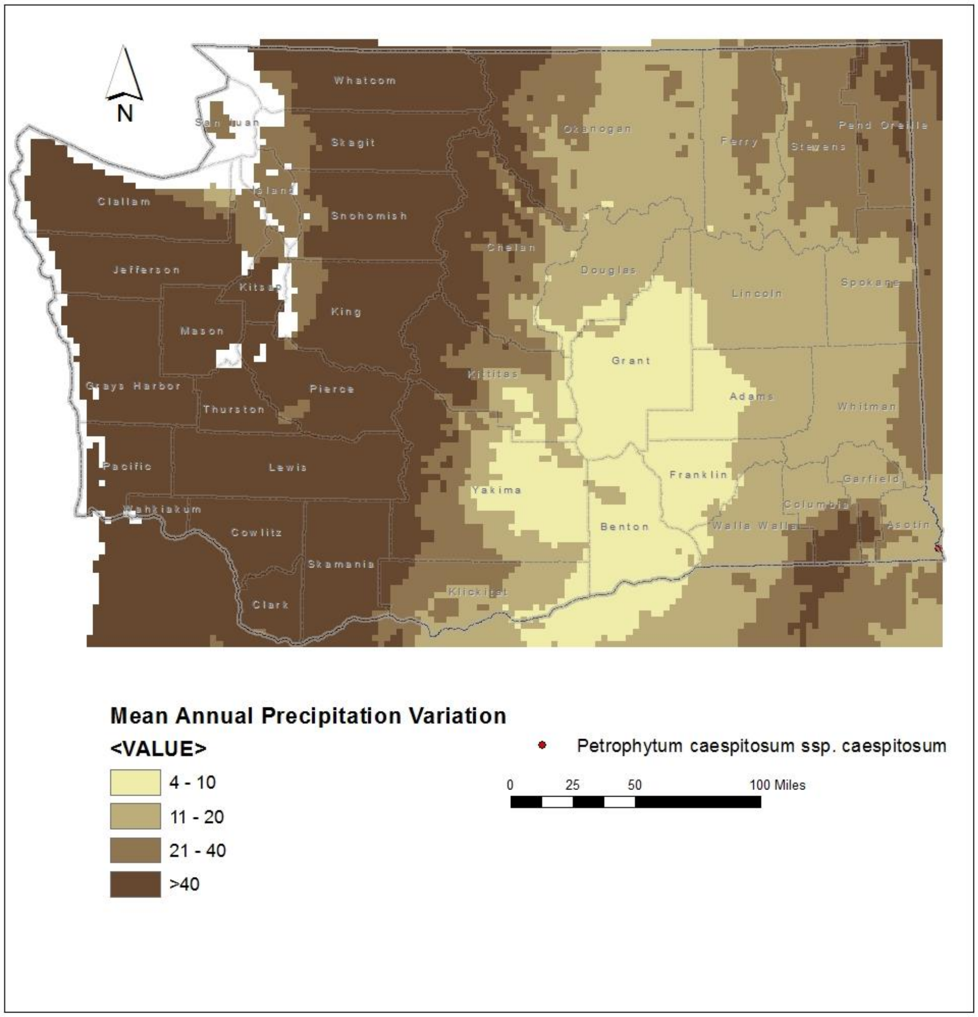

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Petrophytum caespitosum ssp. caespitosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on precipitation and winter snow for its moisture requirements, because its habitat is not associated with springs, streams, or groundwater. The Inter-Mountain Basins Cliff and Canyon ecological system is vulnerable to changes in the timing or amount of precipitation and increases in temperature that could favor the replacement of perennial cushion plants in rock ledges with lichens or annual grasses (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Petrophytum caespitosum ssp. *caespitosum* is not dependent on periodic disturbances to maintain its montane cliff habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased precipitation that might favor conversion of this habitat to lichens or annual plants (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
In Washington, *Petrophytum caespitosum* ssp. *caespitosum* occurs in an area of moderate accumulation of snow. It is probably more adversely affected by reduction in changes in the timing and volume of rainfall due to projected climate change (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
The population of *Petrophytum caespitosum* ssp. *caespitosum* in Washington is found primarily on the Martin Bridge Limestone, a Triassic age metasedimentary formation, and the Doyle Creek Formation, a Triassic metasedimentary and metavolcanic layer (Washington Division of Geology and Earth Resources 2016). The species occurs mostly on hard cliffs rather than more erodible, softer limestones in the Lime Hill area (Curtis Björk, specimen label data, Consortium of Pacific Northwest Herbaria [https://www.pnwherbaria.org/index.php]). Limestone outcrops are uncommon in Washington, having mostly been buried by volcanic material.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Petrophytum caespitosum* ssp. *caespitosum* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Petrophytum caespitosum ssp. *caespitosum* has relatively unspecialized flowers. Based on its sticky pollen, this and related taxa in the tribe Spiraeeae (Rosaceae) are mostly pollinated by several families of bees (Song et al. 2017).

C4d. Dependence on other species for propagule dispersal: Neutral.
Seed dispersal in *Petrophytum* is passive, with small seeds spreading by gravity or high winds once the dry fruit capsule is ripe and splits open. Animals may secondarily translocate fallen seed, but are not the primary dispersal agent.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Due to its cliff habitat, *Petrophytum caespitosum* ssp. *caespitosum* receives minimal impacts from livestock or ungulate grazing.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Rocky microsites occupied by *Petrophytum caespitosum* ssp. *caespitosum* are not especially vulnerable to competition from other native plant species. Rock ledges could become more susceptible to colonization by annual weedy plants under projected drier conditions in the future (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Genetic data are not available for the Washington population. Drysdale (1968) and McArthur and Sanderson (1985) documented a chromosome count of $n = 18$ for *Petrophytum caespitosum*. Genetic data are not available rangewide. Drysdale (1968) conducted a detailed morphologic analysis of specimens across the west (not including Washington) that suggests there is high genetic variability for the entire species. The Washington population likely contains a subset of the overall genetic diversity of the species due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
No data are available for the Washington population.

C5c. Reproductive System: Somewhat Increase.
Petrophytum caespitosum ssp. *caespitosum* produces perfect flowers that are pollinated by bees. The Washington population is disjunct from the nearest occurrences in central Idaho and likely has a fraction of the genetic variability of the species rangewide due to founder effects or inbreeding.

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 in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Petrophytum caespitosum* ssp. *caespitosum* has not changed notably since it was discovered in Washington in 1999.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Drysdale, F.R. 1968. An experimental study of variation within and between populations of *Petrophytum caespitosum* (Nutt.) Rydb. with emphasis on numerical techniques. Master of Science thesis, Department of Botany, Utah State University, Logan, UT. 71 pp.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

McArthur, E.D. and S.C. Sanderson. 1985. A cytotaxonomic contribution to the western North American rosaceous flora. Madroño 32(1): 24-28.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Song, J., M. Oak, H. Roh, and S. Hong. 2017. Morphology of pollen and orbicules in the tribe Spiraeeae (Rosaceae) and its systematic implications. Grana 2017. http://dx.doi.org/10.1080/00173134.2016/1274334.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Petrophytum caespitosum* ssp. *caespitosum*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=petrophytum%20caespitosum%20ssp.%20caespitosum). Accessed 27 September 2021.

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

Phacelia lenta (Sticky phacelia)

Date: 10 February 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G2?/S2?

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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 others 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		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/Somewhat Increase

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All nine of the occurrences of *Phacelia lenta* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

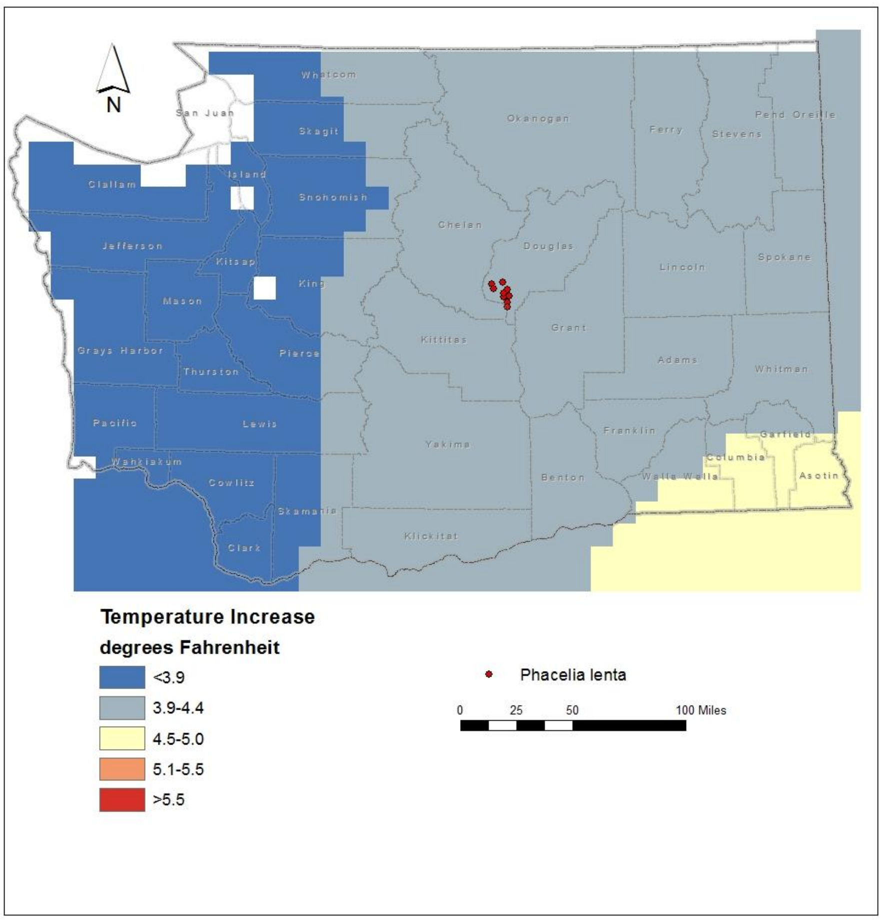

Figure 1. Exposure of *Phacelia lenta* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All nine Washington occurrences of *Phacelia lenta* (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 --0.028 to -0.050 (Figure 2).

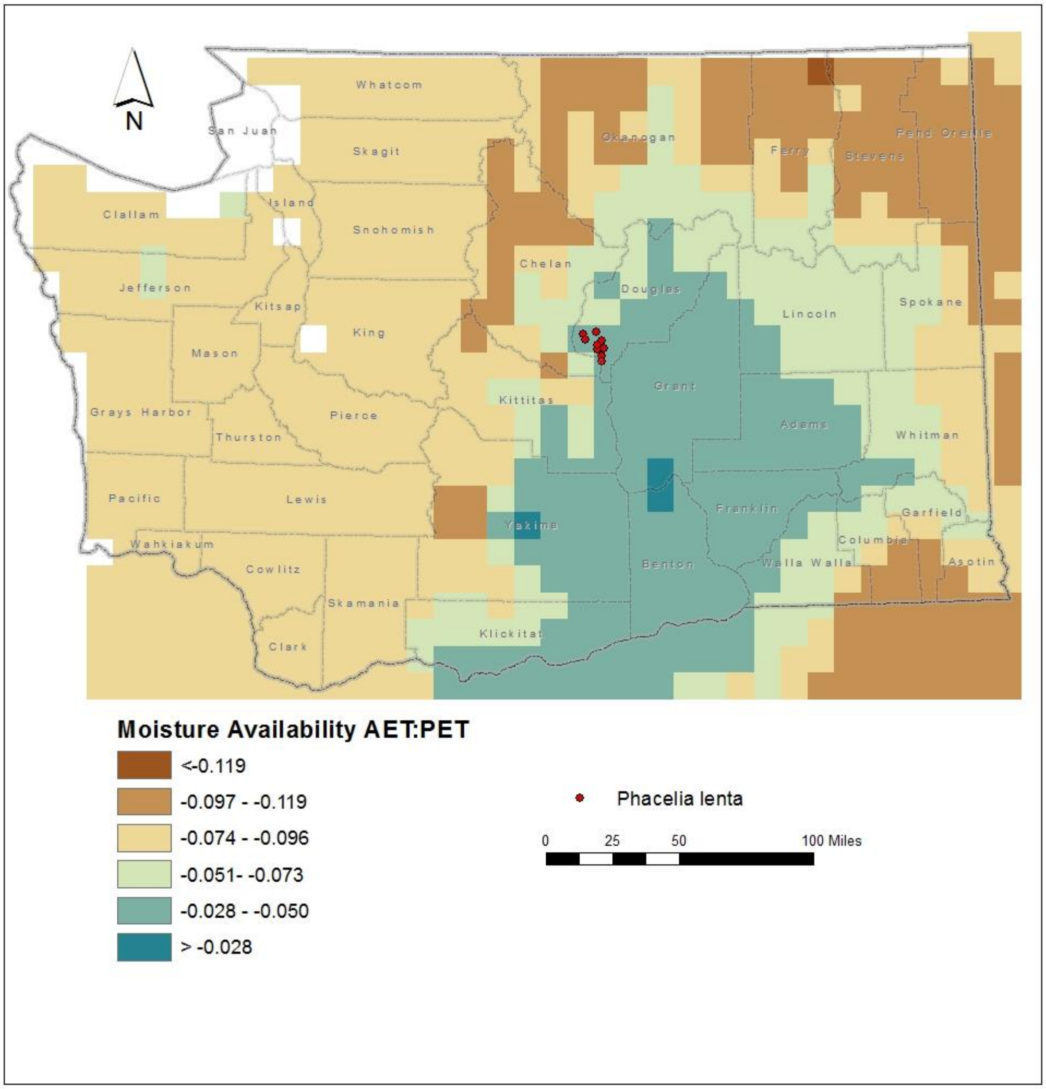

Figure 2. Exposure of *Phacelia lenta* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Phacelia lenta* are found at 1300-3400 feet (400-1040 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Phacelia lenta* is found on sparsely vegetated basalt cliff faces on north or west-facing slopes separated from other cliff sites by steep canyons (Camp and Gamon 2011; Fertig 2020). This habitat is a component of the Inter-Mountain Basins Cliff and Canyon ecological system (Rocchio and Crawford 2015). Individual populations are separated by 0.4-3.5 miles (0.75-5.7 km) and restricted to an area of 8 x 12 miles (13 x 19 km) (Camp and Gamon 2011; Gamon 1986). Ridgetops above the basalt cliffs and intervening canyons are unsuitable habitat for this species, and present a natural barrier to dispersal. Potential basalt cliff habitat elsewhere in the Columbia Plateau may be too isolated for ready dispersal.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Phacelia lenta* in Washington is restricted to steep cliffs of basalt along the east side of the Columbia River. These sites are naturally patchy, but are further isolated by roads and agricultural fields on ridgetops that are likely restrict seed dispersal or spread of existing populations.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitivity and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Phacelia lenta produces numerous small seeds that are finely reticulated on the surface. The seeds are released passively following dehiscence of the dry fruit capsule. Seeds are likely dispersed by gravity or strong winds. Average dispersal distances are probably relatively short (100-1000 meters).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Phacelia lenta* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All nine of the known occurrences (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral risk from climate change.

C2aii. Physiological thermal niche: Somewhat Increase.
The west and north-facing ledges and crevices within the basalt cliffs inhabited by *Phacelia lenta* are often associated with cool, shaded conditions during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Seven of the populations of *Phacelia lenta* in Washington (77.8%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability from climate change. Two other occurrences (22.2%) are from areas that have had small precipitation variation (4-10 inches/100-254 mm) during the same period and are considered at increased vulnerability (Young et al. 2016).

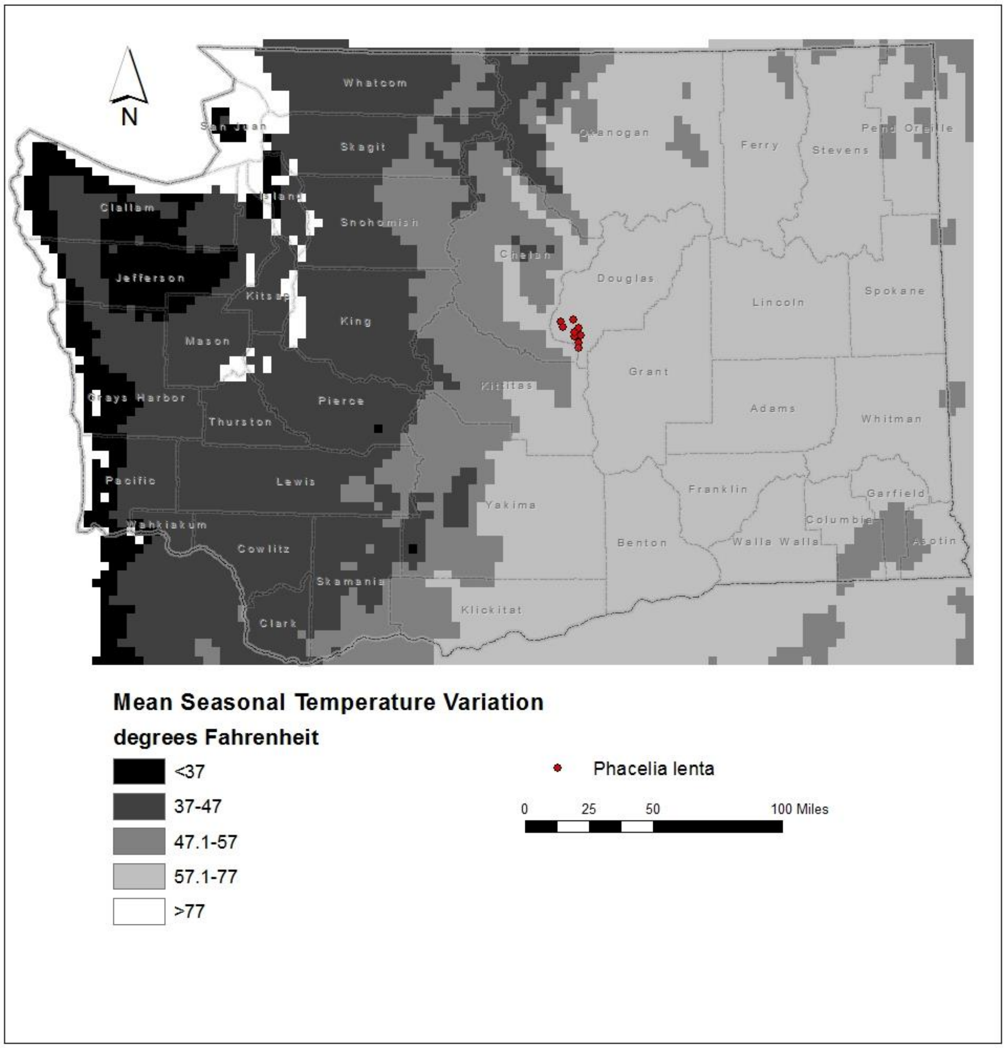

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Phacelia lenta* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
This species is dependent on precipitation and winter snow for its moisture requirements, because its habitat is not associated with springs, streams, or groundwater. The Inter-Mountain Basins Cliff and Canyon ecological system is vulnerable to changes in the timing or amount of precipitation and increases in temperature (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Phacelia lenta is not dependent on periodic disturbances to maintain its cliff and talus habitat. The species could, however, be detrimentally affected by increased summer temperatures,

drought, or decreased precipitation that might favor the establishment of lichens or annual plants in cliff crevices (Rocchio and Ramm-Granberg 2017).

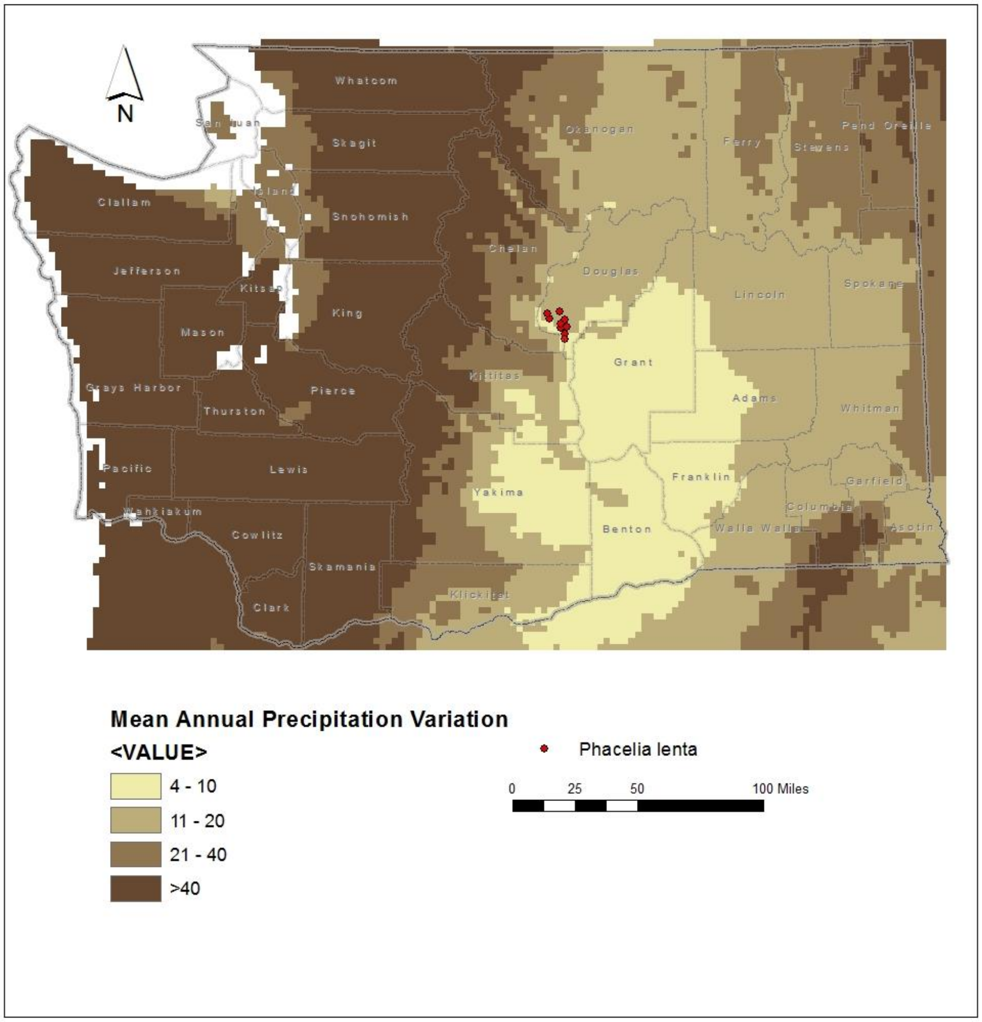

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Phacelia lenta* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2d. Dependence on ice or snow-cover habitats: Neutral.
Phacelia lenta occurs in areas of low accumulation of snow. These populations are probably more adversely affected by reduction in changes in the timing and volume of rainfall due to projected climate change (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Phacelia lenta is restricted to Miocene-age columnar basalt cliffs and talus slopes of the Grande Ronde Basalt. Occupied habitat is found within the Upper flows, Hammond, and Keane Ranch subunits (Washington Division of Geology and Earth Resources 2016). The latter subunits have a relatively restricted distribution in central Washington and may have some chemical differences from other Grande Ronde basalt layers (Tabor et al. 1982).

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Phacelia lenta* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Phacelia lenta* are not known, but related *Phacelia* species are pollinated by a variety of bee species and some are considered important plants for supporting pollinators in agricultural settings (Gilbert 2003). Like other related species in the *P. franklinii* group, *P. lenta* has flowers that produce nectar and have long-exserted stamens to attract insect pollinators and promote outcrossing (Gillett 1960). The diversity of pollinators may be threatened by insecticide drift from nearby agricultural fields (Fertig and Kleinknecht 2020, Gamon 1986).

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds of *Phacelia* are small, dry, and strongly ornamented with ridges, papillae, or indentations that resemble corrugations in cardboard. These surface features may help facilitate dispersal of seed by wind, but are not likely to adhere to animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Due to its steep cliff habitat, *Phacelia lenta* receives minimal impacts from livestock or ungulate grazing (Fertig 2020).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Rocky microsites occupied by *Phacelia lenta* are not especially vulnerable to competition from other native or introduced plant species.

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

C5a. Measured genetic variation: Unknown.
Data are not available on genetic diversity within *Phacelia lenta*. Gillett (1960) found that other species in the *P. franklinii* group had a base chromosome count of $n = 11$ and were diploids, except for one tetraploid species from Alaska. *P. lenta* material was not available at the time of this study, however (the species was known only from the original type collection from 1883 until it was rediscovered in 1981 [Alverson 1982]).

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral/Somewhat Increase.
Based on its floral morphology (showy flowers, prominent nectar production, exserted anthers), *Phacelia lenta* is probably an obligate outcrosser. Due to its restricted range, it may have less genetic diversity than more widespread species. Whether *P. lenta* was formerly wide-ranging but now has a more limited distribution (Alverson 1982), or is a recently evolved species with the potential to expand its range but is dispersal limited, is not known. Genetic data on within- and between-population variability is a high research priority (Fertig 2020).

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 in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Phacelia lenta* has not changed notably in the last 50 years.

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

References

Alverson, E. 1982. The rediscovery of *Phacelia lenta*. Douglasia 6(2): 1.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. 2020. Potential federal candidate plant species of Washington. Natural Heritage Report 2020-01. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 97 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Gamon, J. 1986. Report on the status of *Phacelia lenta* St. John. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. 38 pp. + app.

Gilbert, L. 2003. *Phacelia tanacetifolia*: A brief overview of a potentially useful insectary plant and cover crop. Small Farm Success Progject. Fact Sheet Number 2a. Initiative for Future Agriculture and Food Systems – US Department of Agriculture.

Gillett, G.W. 1960. A systematic treatment of the *Phacelia franklinii* group. Rhodora 62(740): 205-222.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Tabor, R.W., R.B. Waitt, Jr., V.A. Frizzell, Jr., D.A. Swanson, G.R. Byerly, and R.D. Bentley. 1982. Geologic Map of the Wenatchee 1:100,000 Quadrangle, Central Washington. Department of the Interior, US Geological Survey. 3 pp.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Polemonium viscosum (Sticky sky-pilot)

Date: 20 September 2021

Assessor: Walter Fertig, 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: Local Climate	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	69.2
	-0.074 to -0.096	30.8
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0

Section B: Indirect Exposure to Climate Change	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: Sensitivity and Adaptive Capacity	
1. Dispersal and movements	Increase
2ai Change in historical thermal niche	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	Increase
3. Restricted to uncommon landscape/geological features	Increase
4a. Dependence on others 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	Somewhat Increase
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: Documented or Modeled Response	
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 extant and historical occurrences of *Polemonium viscosum* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

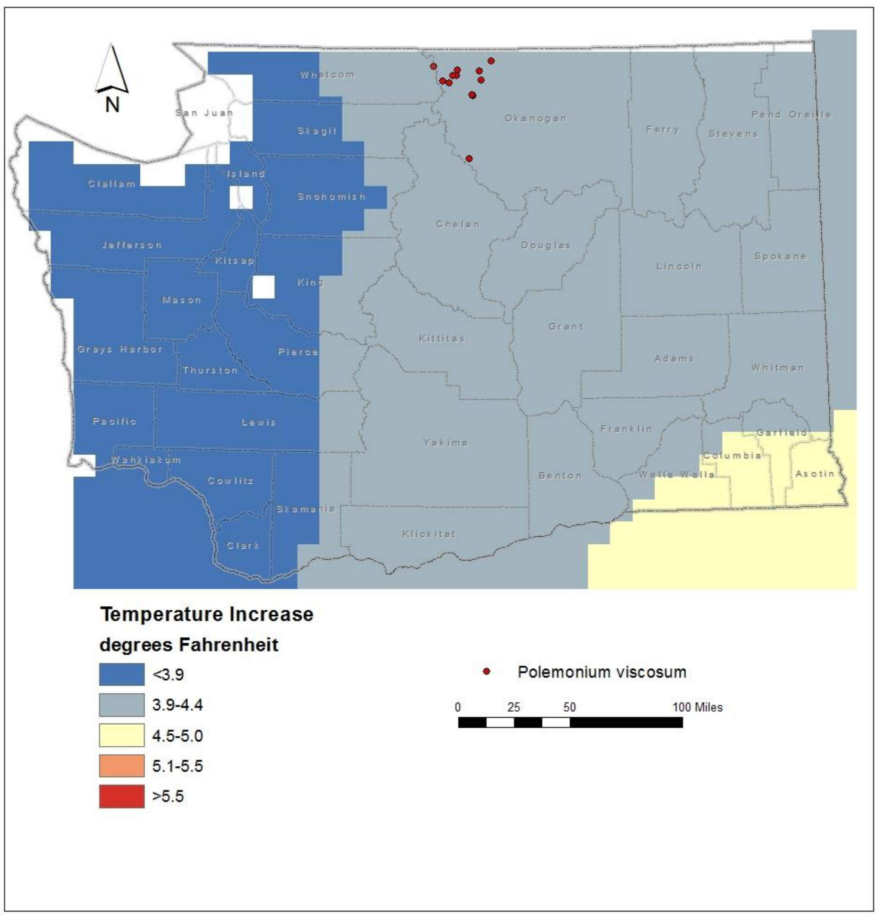

Figure 1. Exposure of *Polemonium viscosum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Nine of the 13 occurrences (69.2%) of *Polemonium viscosum* 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). Four other populations (30.8%) are from areas with a projected decrease of -0.074 to -0.096.

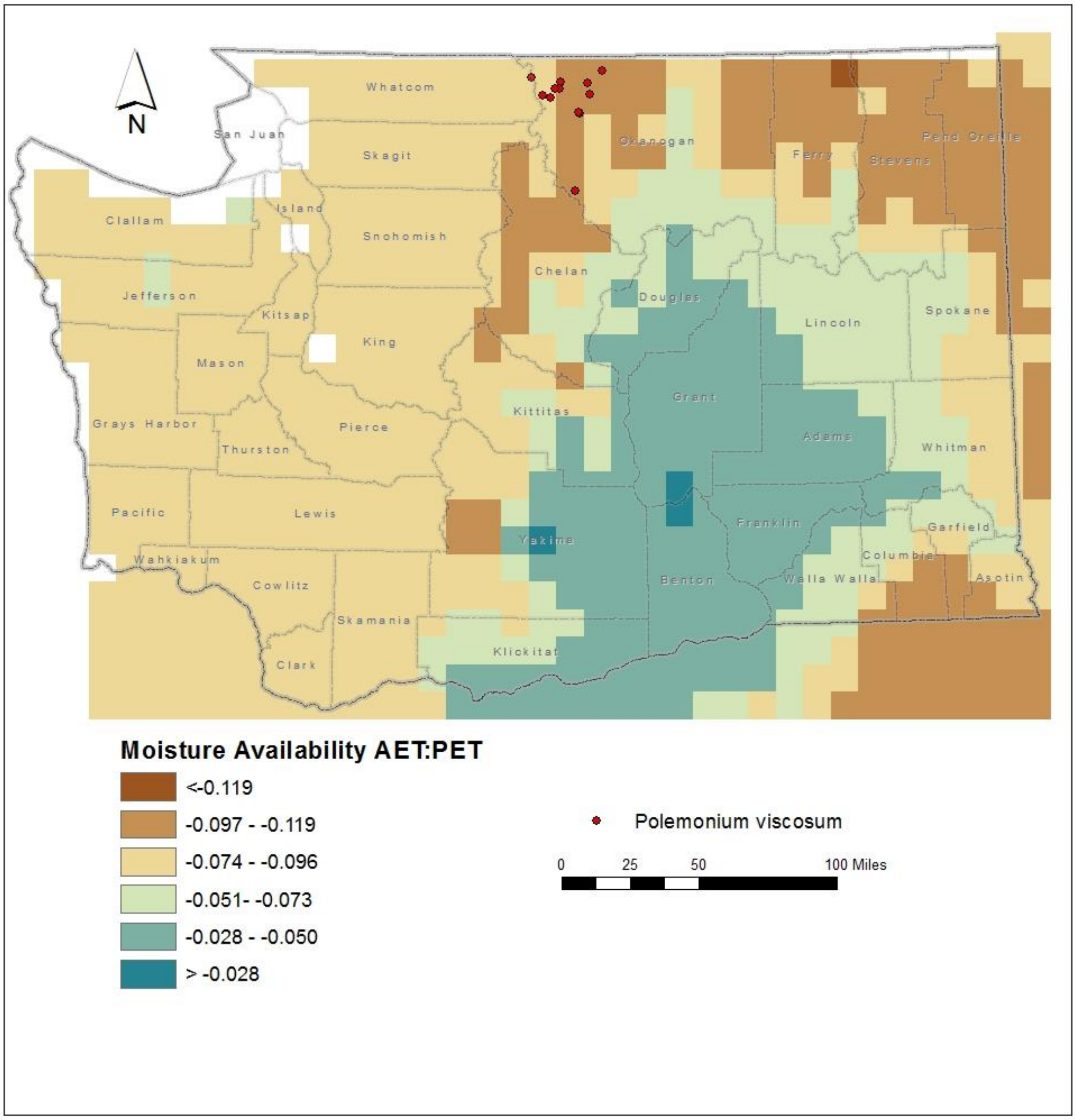

Figure 2. Exposure of *Polemonium viscosum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Polemonium viscosum* are found at 6350-8200 feet (1935-2500 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Polemonium viscosum occurs in crevices and protected microsites in alpine talus, fellfield, and sandy-gravelly slopes, often below recently melted snow (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Rocky Mountain Alpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). Populations are found on separate ridges or peaks isolated by 1.3-28 miles (2.5-45 km) of unoccupied and unsuitable habitat. The natural heterogeneity of available habitat forms a barrier to dispersal and future migration.

B2b. Anthropogenic barriers: Neutral.
Eight populations of *Polemonium viscosum* in Washington are found in wilderness areas with a minimal human footprint. The alpine summits inhabited by the species are surrounded by anthropogenic infrastructure in adjacent lowlands, but these areas are already a natural barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Polemonium viscosum produces 2-12 seeds in dry capsule fruits that split open at maturity to passively release the seed (Newport 1989). The seeds are dispersed primarily by gravity and perhaps secondarily by animals. Average dispersal distances are probably small (<100 meters).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Polemonium viscosum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 13 of the known occurrences in the state (100%) are found in areas that have experienced small (37-47°F/20.8-26.3°C) temperature variation during the past 50 years and are considered at increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Greatly Increase.
The alpine talus habitat of *Polemonium viscosum* is entirely within a cold climate zone during the flowering season and highly vulnerable to temperature increase from climate change.

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Polemonium viscosum* in Washington are found in areas that have experienced greater than average precipitation variation in the past 50 years (>40 inches/1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

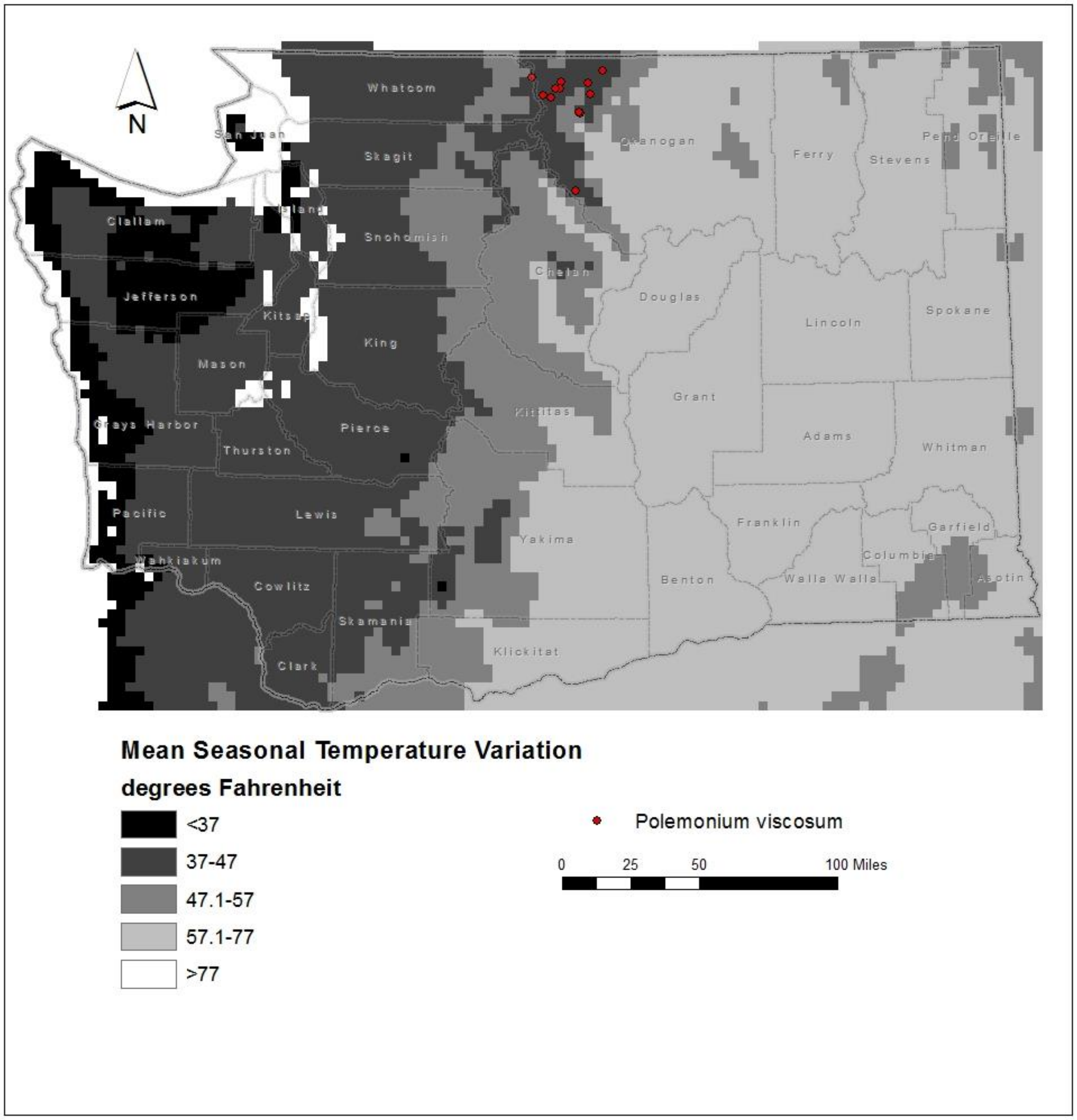

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Polemonium viscosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on winter snow and summer precipitation for meeting its moisture needs, as populations are not associated with perennial wetlands or soils with a high water table. It could be vulnerable to changes in the timing or amount of snow and rainfall and earlier snowmelt related to warming temperatures (Rocchio and Ramm-Granberg 2017). Increased temperatures would extend the growing season and accelerate soil formation, allowing for increased vegetation cover and long-term displacement of existing species with those adapted to meadow conditions.

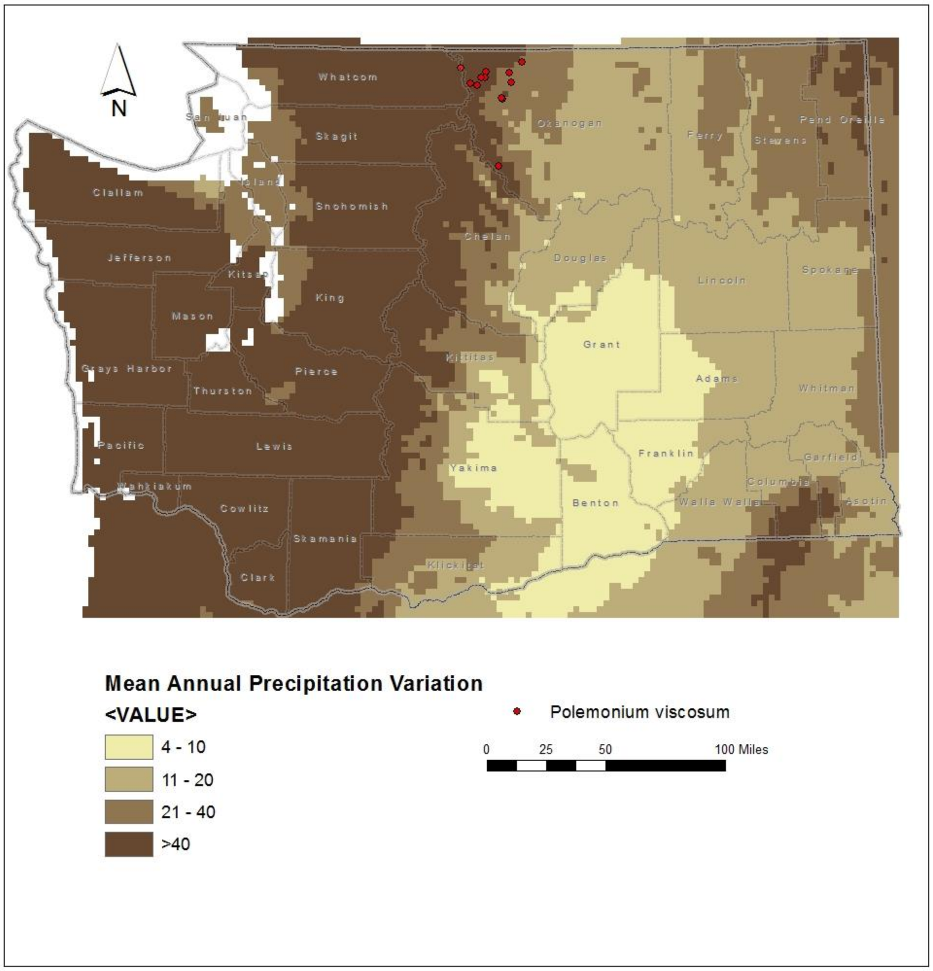

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Polemonium viscosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2c. Dependence on a specific disturbance regime: Neutral.
Polemonium viscosum occurs in alpine talus and rock outcrop habitats that are subjected to high winds. Other than occasional rock fall, these sites are largely undisturbed at present.

C2d. Dependence on ice or snow-cover habitats: Increase.
Populations of *Polemonium viscosum* in Washington are found on alpine talus slopes and ridgecrests associated with high winter snow accumulation. Reduced snowpack due to climate change, or changes in the timing of snowmelt, would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Polemonium viscosum is found primarily on outcrops of Cretaceous marine sedimentary rock (including the Winthrop Sandstone, Goat Creek, and Harts Pass formations) or intrusions of Eocene granodiorite and Paleocene tonalite (Oval Peak batholith) (Washington Division of Geology and Earth Resources 2016). These formations occupy a limited area in western Okanogan County south of the Canadian border and may account for the small range of *P. viscosum* in Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus habitat occupied by *Polemonium viscosum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Increase.
Polemonium viscosum has large, tubular, purple to blue flowers that attract a variety of insect pollinators, including bumblebees (*Bombus*), solitary bees, syrphid flies, anthomyiid flies, and muscid flies (Galen 1985). Bumblebees, however, are the most effective pollinators due to their size and faithfulness to visiting *Polemonium* flowers, whereas other insect species are more generalist pollinators with low floral fidelity. Studies in Colorado have found that the golden-belted bumblebee (*Bombus kirbiellus*) is the primary pollinator of *P. viscosum*. In Washington, *B. kirbiellus* is ranked S1 (critically imperiled), which may factor into the rarity of *P. viscosum* in the state (NatureServe 2021).

Polemonium viscosum is noteworthy in producing flowers with two distinct odors (either in different individuals or on the same plant). Sweet-smelling flowers preferentially attract bumblebees, while skunky-smelling flowers (with the odor produced by sticky glands on the sepals) function to deter herbivory by ants, which can cause damage to stigmas and ovaries and reduce seed set (Galen and Cuba 2007, Galen and Kevan 1983).

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds of *Polemonium viscosum* are released passively through the dehiscence of dry fruit capsules and rely on gravity or high winds for dispersal (although secondary movement by foraging animals may also occur).

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Impacts from pathogens are not known. Overall herbivory on the sticky-glandular foliage appears to be low. Floral damage by nectar-feeding ants can result in significant reductions in seed production (Galen 1983) and has resulted in the evolution of different flower shapes and scents in *Polemonium viscosum* in response (Galen 1985).

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
The harsh growing conditions and few sites for seedling establishment keep vegetation cover low in the alpine talus and fellfield habitat occupied by *Polemonium viscosum*. Competition with invasive non-native plants is also minimal. Under projected climate change, competition with native and introduced plant species could increase if lower elevation species are able to expand their range due to milder and longer growing seasons or increased soil development (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral.
Does not require an interspecific interaction, other than pollinators.

C5a. Measured genetic variation: Unknown.
In Colorado, Galen et al. (1991) found genetic differentiation and morphologic differences at two ends of a population cline, suggesting local adaptation was important in creating ecotypic variation. Similar studies have not been done in Washington. Based on the isolation of Washington populations, it is likely that they have lower overall genetic diversity than occurrences from the central and southern Rocky Mountains.

C5b. Genetic bottlenecks: Unknown.
Washington populations of *Polemonium viscosum* are geographically isolated from the core of the species' range in the central and southern Rocky Mountains (northeast Oregon to southwest Montana, south to northern Arizona and New Mexico). If Washington occurrences arose via long distance dispersal, they would be expected to have lower genetic diversity due to founder effects or inbreeding.

C5c. Reproductive System: Somewhat Increase.
Polemonium viscosum is an obligate outcrosser with little self-compatibility (Galen and Kevan 1980). These characteristics are associated with normal genetic variability. The isolated populations in Washington probably have reduced genetic diversity, however, due to genetic drift or founder effects.

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 *Polemonium viscosum* has not changed significantly in the last 100 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
Two occurrences of *Polemonium viscosum* in Washington are historical (not relocated in the last 40 years). Whether this potential range contraction is due to climate change is not known.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Galen, C. 1983. The effects of nectar thieving ants on seedset in floral scent morphs of *Polemonium viscosum*. Oikos 41:245-249.

Galen, C. 1985. The smell of success. Natural History 94(7): 28-35.

Galen, C, and J. Cuba. 2007. Down the tube: Pollinators, predators, and the evolution of flower shape in the alpine skypilot, *Polemonium viscosum*. Evolution 55(10): 1963-1971.

Galen, C. and P.G. Kevan. 1980. Scent and color, floral polymorphisms and pollination biology in *Polemonium viscosum* Nutt. American Midland Naturalist 104(2): 281-289.

Galen, C. and P. Kevan. 1983. Bumblebee foraging and floral scent dimorphism: *Bombus kirbyellus* Curtis (Hymenoptera: Apidae) and *Polemonium viscosum* Nutt. (Polemoniaceae). Canadian Journal of Botany 61:1207-1213.

Galen, C., J.S. Shore, and H. Deyoe. 1991. Ecotypic divergence in alpine *Polemonium viscosum*: Genetic structure, quantitative variation, and local adaptation. Evolution 45(5): 1218-1228.

NatureServe Explorer. 2021. *Bombus kirbiellus*. (https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.1028349/Bombus_kirbiellus). Accessed 24 September 2021.

Newport, M.E. 1989. A test for proximity-dependent outcrossing in the alpine skypilot, *Polemonium viscosum*. Evolution 43(5):1110-1113.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Polemonium viscosum*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=polemonium%20viscosum). Accessed 23 September 2021.

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

Ranunculus californicus (California buttercup)

Date: 9 February 2021

Assessor: Walter Fertig, 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: Local Climate	**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: Indirect Exposure to Climate Change		**Effect on Vulnerability**
1. Sea level rise		Somewhat Increase
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral/Somewhat Increase
3. Impacts from climate change mitigation		Somewhat Increase
Section C: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Greatly 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/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on others 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		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: Documented or Modeled Response	
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: All four of the confirmed occurrences of *Ranunculus californicus* in Washington (100%) are found in areas with a projected temperature increase of <3.9° F (Figure 1). At least 5 other island populations have been reported (Dunwiddie, no date), but each of

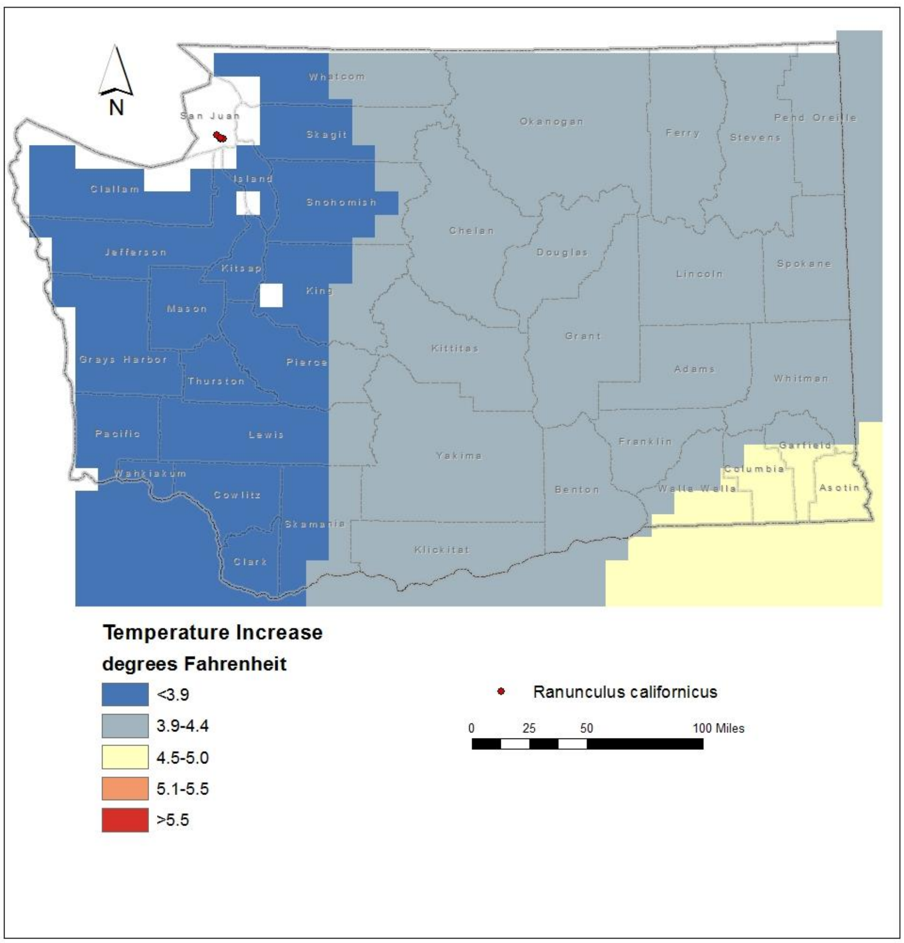

Figure 1. Exposure of *Ranunculus californicus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

these consists of hybrids between *R. californicus* and *R. occidentalis* and are excluded from this analysis. All of the Washington occurrences (including hybrids) are from the same small geographic area and have similar ecological conditions, and so leaving out hybrid populations will not alter the results of this assessment.

A2. Hamon AET:PET Moisture Metric: The four occurrences of *Ranunculus californicus* 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 -0.096 (Figure 2).

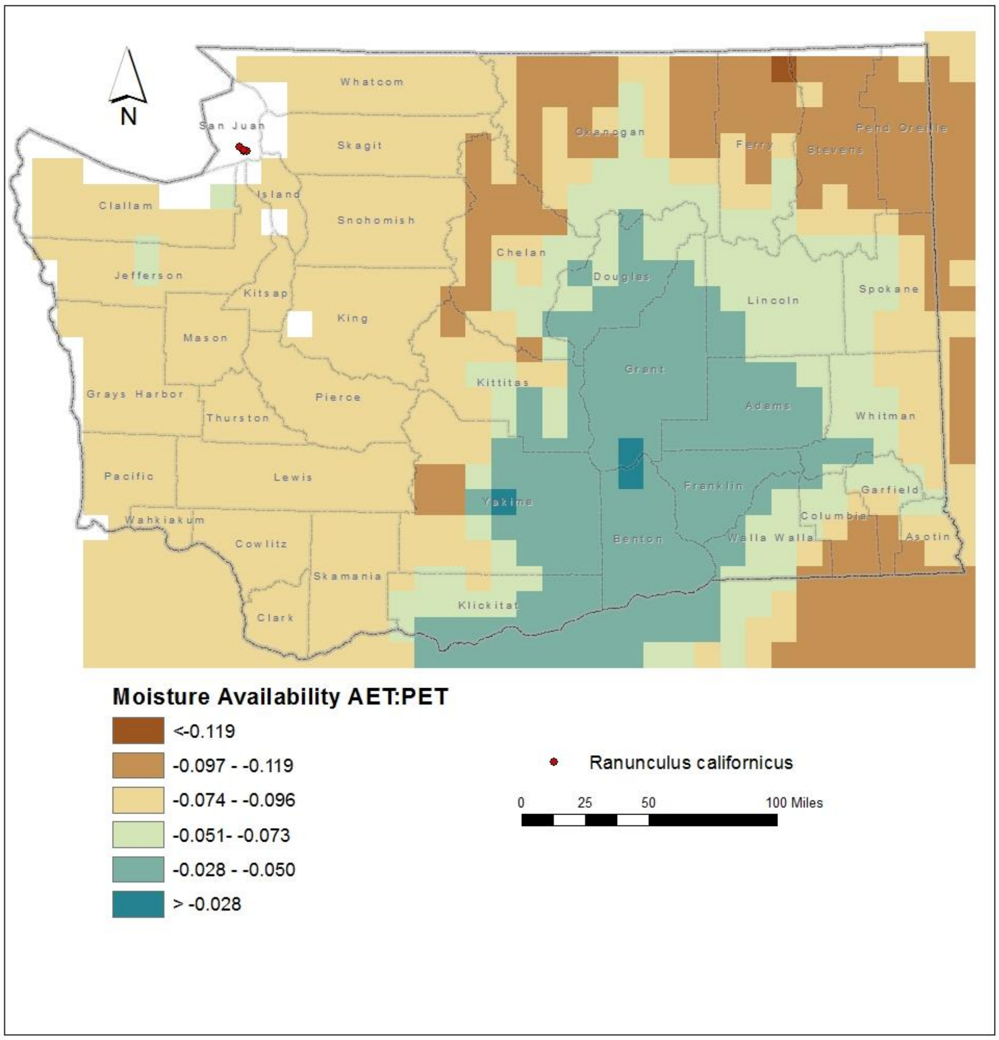

Figure 2. Exposure of *Ranunculus californicus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Somewhat Increase.
The Washington occurrences of *Ranunculus californicus* are found at 10-30 feet (3-9 m) and within 0.5 miles (0.8 km) of the Pacific Ocean on low-lying islands in the Salish Sea. Sea level is projected to rise by 0.5-2 m in the current century (Young et al. 2016). While existing populations are high enough to escape sea level rise, they are low enough to experience additional storm surges or intrusions of salt water due to climate change.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Ranunculus californicus* is found mostly on coastal bluffs and dry grasslands on small islets (Camp and Gamon 2011). These sites conform to the North Pacific Hypermaritime Shrub and Herbaceous Headland and Willamette Valley Upland Prairie and Savanna ecological systems (Rocchio and Crawford 2015). Individual occurrences are isolated by distances of 0.6-1.6 miles (0.8-2.6 km) and occur on separate islands. Dispersal to other islands or the mainland is limited due to expanses of inhospitable ocean habitat.

B2b. Anthropogenic barriers: Neutral/Somewhat Increase.
The small islets inhabited by *Ranunculus californicus* in Washington are naturally isolated, but have a small human footprint. Anthropogenic barriers from roads, farms, and homesites, are more pervasive on the larger islands of the San Juan chain and on the mainland. Whether this species occurred more widely in the San Juan Islands or the coast of the Puget Sound in the past is not known, and some authors have suggested the Washington populations may have been introduced* (Whittemore 1997). At present, human-influenced barriers are minor (neutral) within occupied habitat, but could significantly constrain migration to new sites in the future (somewhat increase).

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase.
The island bluff habitat of *Ranunculus californicus* could be vulnerable to impacts from construction of sea walls or other structures to protect shoreline homes.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Ranunculus californicus produces clusters of flattened, one-seeded achenes. Each fruit has a short, stout beak that can catch on the fur or feathers of animals. Dispersal by birds could

Ranunculus californicus was first reported in the San Juan Islands in 1978, prompting Whittemore (1997) to suggest the populations were recently established through human introduction, since early collectors missed the species. Whittemore further suggested that introductions were the result of "maritime trade between Victoria and San Francisco" which also resulted in other California coastal species being translocated. COSEWIC (2008) and Dunwiddie no date) cite five facts in considering *R. californicus* to be native in Washington and British Columbia: (1) the islands inhabited by *R. californicus* were poorly botanized until recently; (2) these islands are not along major trade routes and retain relatively undisturbed habitats; (3) this species is not otherwise known from weedy sites at major ports; (4) a suite of native, coastal disjunct species is found in the San Juan Islands; and (5) the islands are actually not that isolated from the nearest occurrences of *R. californicus* on islands in the Columbia River in Oregon. The British Columbia and Washington state natural heritage programs recognize *R. californicus* as native and a species of conservation concern.

potentially spread fruits well over 1 km from the parent plant. Due to the isolation of the San Juan Islands, however, dispersal to the mainland is probably rare and unpredictable.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Ranunculus californicus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All four occurrences (100%) are found in coastal areas that have experienced very small temperature variation (<37˚F/20.8˚C) during the past 50 years and are considered to be at greatly increased vulnerability to climate change (Young et al. 2016).

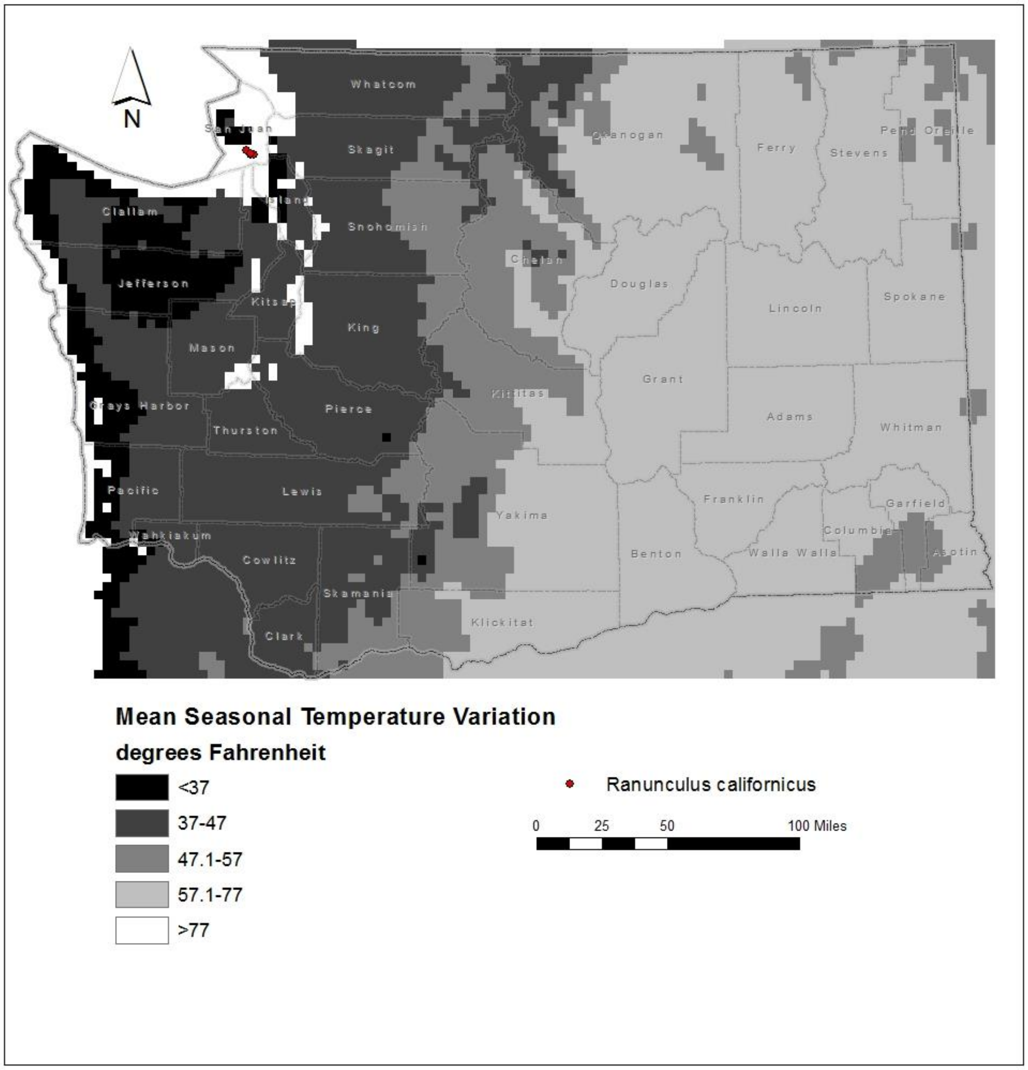

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Ranunculus californicus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The San Juan Islands in Washington and Canada have milder temperatures than nearby inland locations due to the moderating effect of the ocean as a heat sink and warm off-shore currents (COSEWIC 2008). This condition has a neutral impact on climate change vulnerability.

C2bi. Historical hydrological niche: Neutral.
The four occurrences of *Ranunculus californicus* in Washington (100%) have experienced average (21-40 inches/533-1016 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), all of these populations are at neutral vulnerability to climate change.

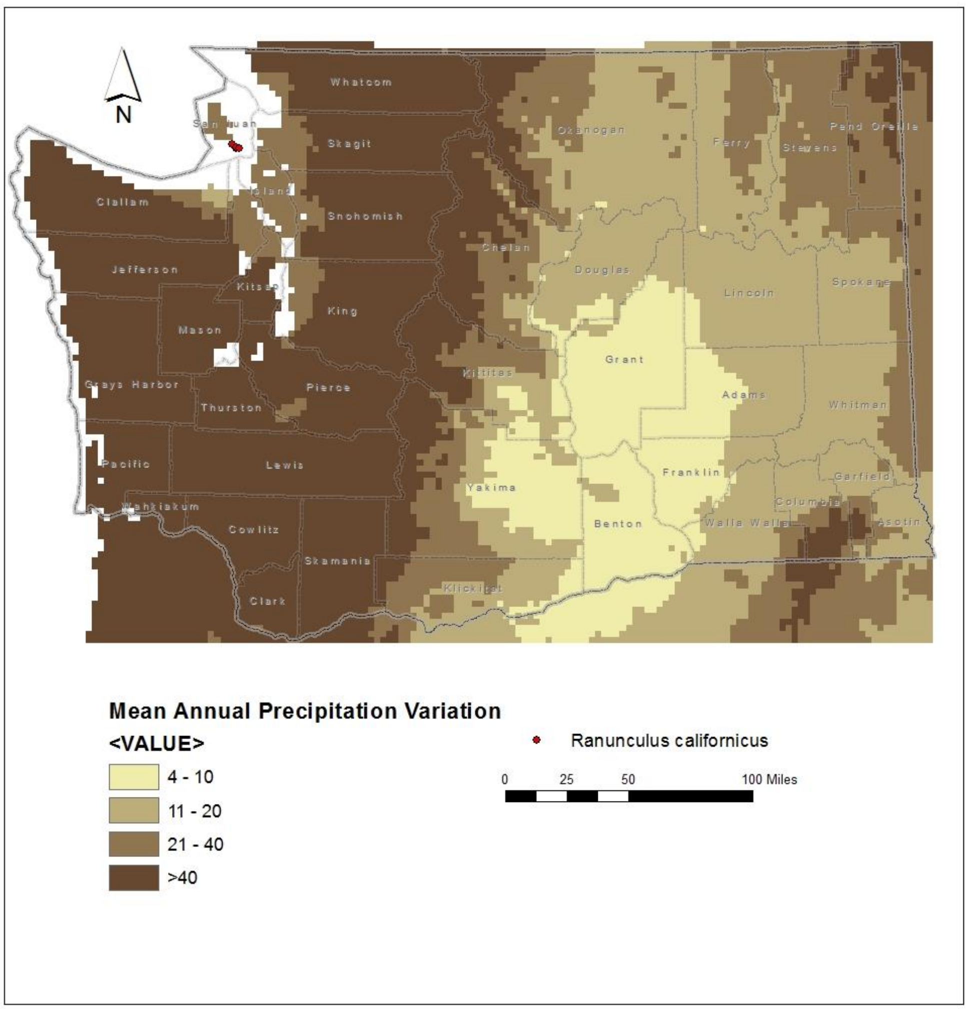

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Ranunculus californicus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Ranunculus californicus populations in the San Juan Islands depend on precipitation for moisture, as their habitat is not associated with springs or streams. Supplemental moisture comes from coastal fog in fall and winter (COSEWIC 2008). The proximity of populations to the coast makes them susceptible to saltwater intrusion during storm events or because of sea level rise (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase.
Ranunculus californicus populations in Washington are found on small, low-lying islands that are influenced by winter storms and erosion events. Drought conditions in summer may have been important historically for maintaining grassland communities with wildfire. Climate change may actually increase the frequency of winter storm surges and erosion that would maintain early seral conditions (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowfall is low over the range of *Ranunculus californicus* in Washington and a minimal component of its annual water budget.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
In Washington, *Ranunculus californicus* is found on rocky slopes and bluffs of metamorphic sandstone and schist of the Cretaceous-Jurassic Constitution Formation (Washington Division of Geology and Earth Resources 2016). This marine sedimentary formation is restricted to portions of Orcas, San Juan, Shaw, and southern Lopez Islands and adjacent small islets in the San Juan archipelago (Logan 2003).

C4a. Dependence on other species to generate required habitat: Neutral.
The coastal meadow habitat of *Ranunculus californicus* is primarily maintained by abiotic factors, including exposure to drying winds, summer drought stress, and winter infiltration creating waterlogged soils in the spring that restricts encroachment of woody vegetation. Unlike mainland sites, herbivores are scarce on small islets in Canada, and do not appear to be significant in maintaining open habitats (COSEWIC 2008). Dunwiddie (no date) observed heavy deer browse on one islet in the Washington San Juans close to Lopez Island.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Ranunculus californicus is primarily pollinated by bees (COSEWIC 2008), but may also be pollinated by flies and thrips. Specific pollinators in Washington are not known.

C4d. Dependence on other species for propagule dispersal: Neutral.
The one-seeded achene fruits of *Ranunculus californicus* are flattened and have a short, curved beak at the tip. These fruits can be dispersed on the fur of mammals or feathers of birds. Dispersal within populations is not likely to be limiting. Long-distance dispersal (across the ocean to other islands or the mainland), however, may be limited to wide-ranging birds and is probably infrequent.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Observations in Canada suggest little impact to this species from herbivory (COSEWIC 2008).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Populations of *Ranunculus californicus* in Canada are threatened by competition from invasive plants (COSEWIC 2008). Canadian and Washington occurrences are also impacted by hybridization with the closely related *Ranunculus occidentalis*. Hybrids may have the floral traits of *R. californicus* (characterized by more than 5 narrow petals) and long fruit beaks found in typical *R. occidentalis* (Dunwiddie, no date). At least four islands in Washington consist of populations that are likely hybrids between the two species (Dunwiddie, no date).

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

C5a. Measured genetic variation: Unknown.
Ranunculus californicus is a diploid with a chromosome count of $2n = 28$. It is known to hybridize with *R. occidentalis*. Hybrids are morphologically intermediate between both parents and have reduced fertility, with only 50% of pollen viable and ovules producing seed (Brayshaw 1989). Genetic data are not available for *R. californicus* in Washington. Due to the isolation of island populations in Canada and western Washington, it is likely that genetic intermixing between these sites and others along the coast of Oregon and California is infrequent, and the original populations that reached these sites likely represented a small subset of the full genome of the species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Somewhat Increase.
Ranunculus californicus is presumed to be an outcrosser, rather than self-pollinated. As noted in section C5a (above) genetic diversity is probably low in isolated Washington and Canadian populations due to founder effects and poor dispersal, but genetic studies have not been undertaken (Dunwiddie, no date). Hybridization with *R. occidentalis* is present in at least 5 Washington populations and possibly other mainland sites (COSEWIC 2008) and threatens to swamp out unique *californicus* genes.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no significant changes in the phenology of *Ranunculus californicus* have been detected over the past 20 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Abundance data in Washington are difficult to interpret because of the presence of hybrids in several populations. Genetically pure *Ranunculus californicus* occurrences range in size from several hundred to several thousand individuals. Populations appear to be stable at present.

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

References

Brayshaw, T.C. 1989. Buttercups, waterlilies, and their relatives (the Order Ranales) in British Columbia. Royal British Columbia Museum Memoir 1. Victoria.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

COSEWIC. 2008. COSEWIC assessment and status report on the California buttercup *Ranunculus californicus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 24 pp + app.

Dunwiddie, P.W. no date (2019?). Summary of an assessment of *Ranunculus californicus* in the San Juan Islands. Unpublished report, on file, WA Natural Heritage Program. 8 pp.

Logan, R.L. 2003. Geologic map of the Washington portion of the Roche Harbor 1:100,000 quadrangle. Washington Division of Geology and Earth Resources. Open File Report 2003-17.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Whittemore, A.T. 1997. *Ranunculus*. Pp. 88-135. In: Flora of North America Editorial Committee. Flora of North America North of Mexico. Volume 3 Magnoliophyta: Magnoliidae and Hamamelidae. Oxford University Press, New York. 590 pp.

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 cereum var. *colubrinum* (Snake wax currant)

Date: 1 November 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5T3/S1

Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	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	14.3
	-0.074 to -0.096	85.7
	-0.051 to -0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral/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		Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral/Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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		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: Documented or Modeled Response	
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: All 7 of the extant and historical occurrences of *Ribes cereum* var. *colubrinum* in Washington (100%) occur in areas with a projected temperature increase of 4.5-5.0° F (Figure 1).

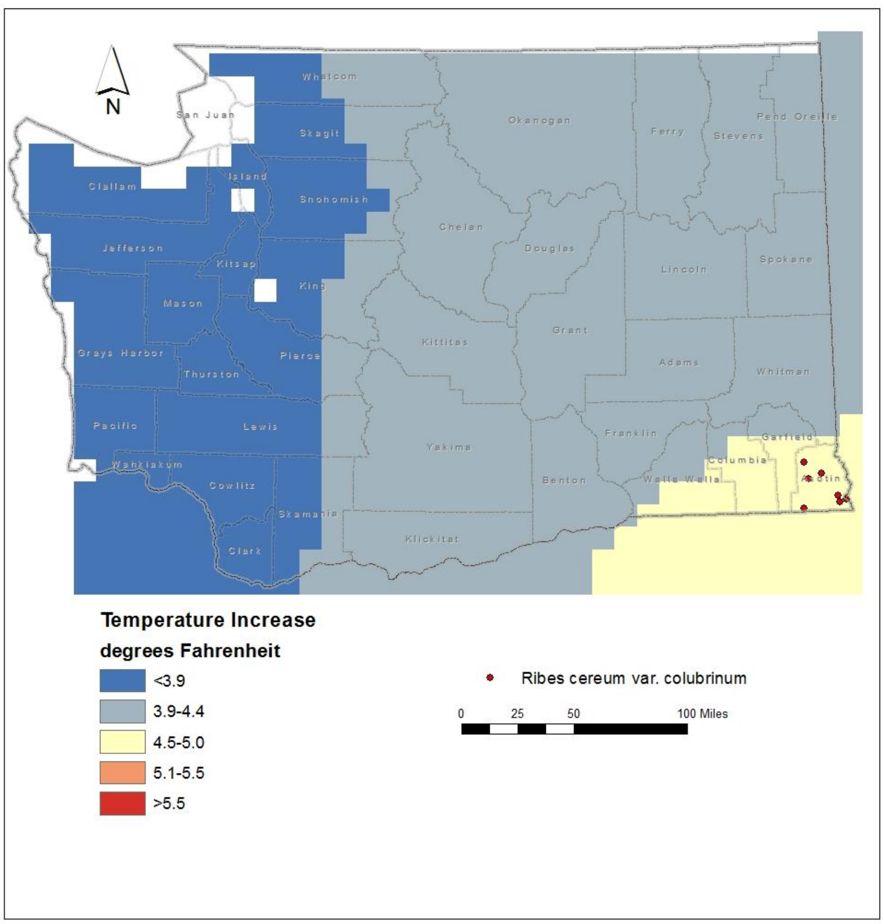

Figure 1. Exposure of *Ribes cereum* var. *colubrinum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the 7 occurrences (85.7%) of *Ribes cereum* var. *colubrinum* 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). One other population (14.3%) is from an area with projected decrease of -0.097 to -0.119

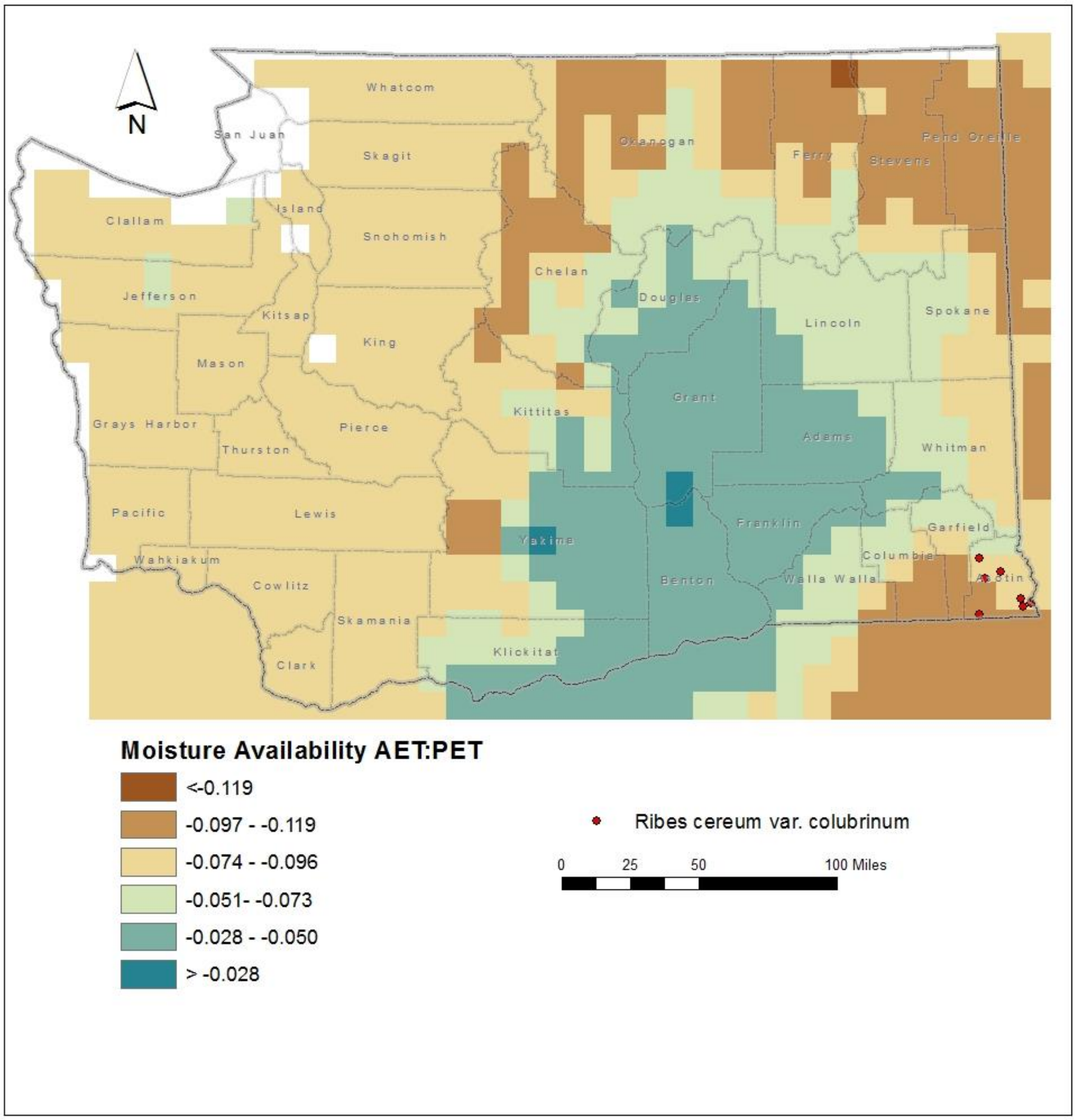

Figure 2. Exposure of *Ribes cereum* var. *colubrinum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Ribes cereum* var. *colubrinum* are found at 1000-3300 feet (300-1000 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Ribes cereum var. *colubrinum* occurs in dry, rocky canyon slopes or terraces along streams within tall shrub communities (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Columbia Basin Foothill & Canyon Dry Grassland and Rocky Mountain Subalpine-Montane Mesic Meadow ecological systems (Rocchio and Crawford 2015). Populations may be separated from each other by 3-13 miles (4.5-21 km). Drier ridges with conifer forest or Palouse grassland habitats may provide an effective barrier to dispersal between drainage basins.

B2b. Anthropogenic barriers: Somewhat Increase.
The rocky canyon and streamside shrub habitat of *Ribes cereum* var. *colubrinum* in the foothills of the Blue Mountains in southeastern Washington is bisected by agricultural lands that may provide a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral/Somewhat Increase.
Ribes cereum var. *colubrinum* produces red to orange, many-seeded, fleshy berries that are eaten by a wide variety of bird and animal species. 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.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Ribes cereum* var. *colubrinum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Five of the 7 occurrences in the state (71.4%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016). The other two occurrences (28.6%) are from areas that have had slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation over the same period and are at somewhat increased vulnerability to climate change.

C2aii. Physiological thermal niche: Somewhat Increase.
Most occurrences of *Ribes cereum* var. *colubrinum* in Washington are found in shaded, rocky draws or narrow canyons that have a cooler microclimate than surrounding areas.

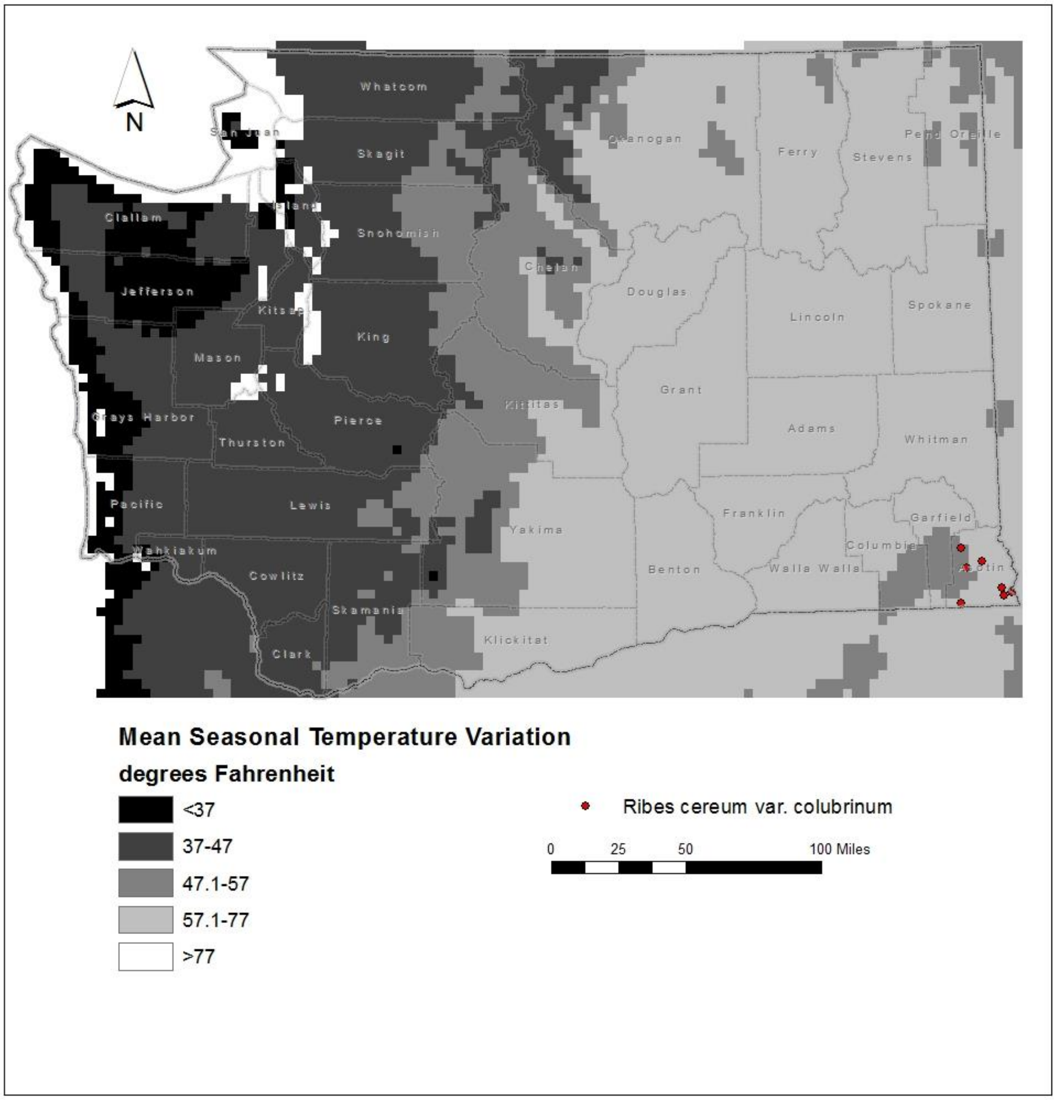

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Ribes cereum* var. *colubrinum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
All of the known populations of *Ribes cereum* var. *colubrinum* in Washington are found in areas that have experienced slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm) (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability from climate change.

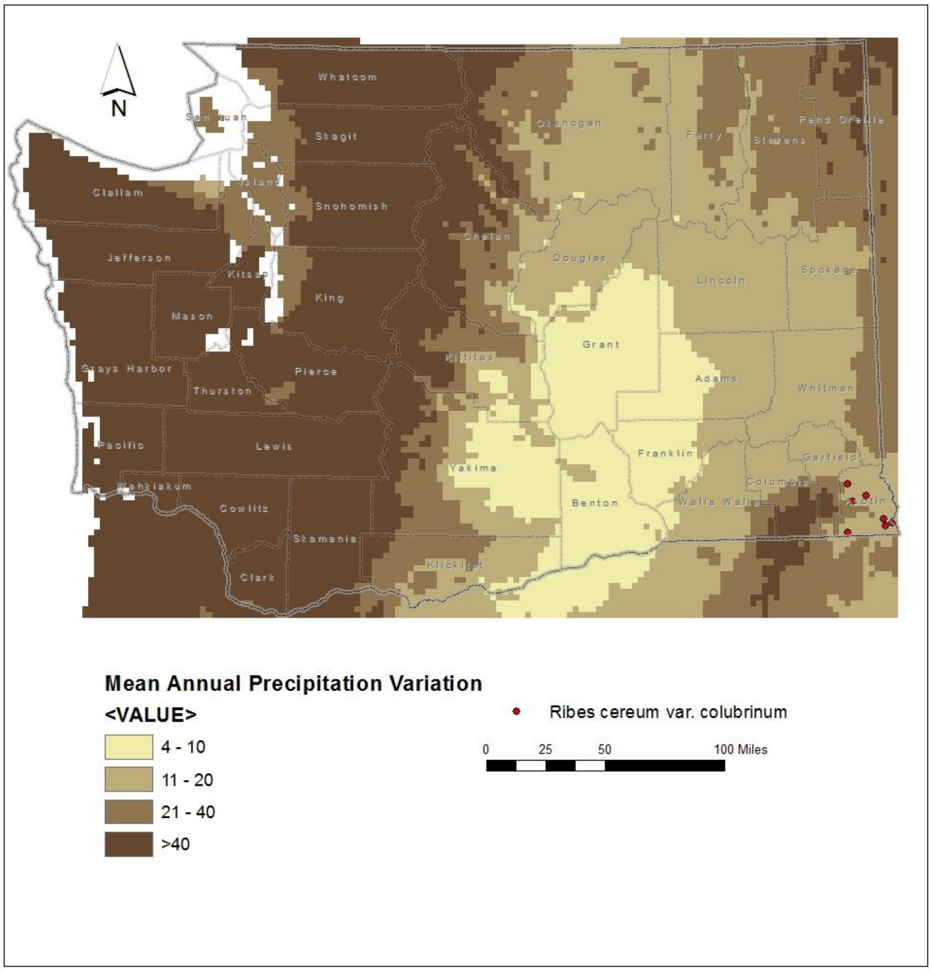

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Ribes cereum* var. *colubrinum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Populations of *Ribes cereum* var. *colubrinum* occur on stream terraces with a high water table. Water flows are dependent on recharge from melting snow at higher elevations or on seasonal precipitation. Projected climate change is likely to reduce the amount of snow and timing of melting and reduce or alter the timing of spring/summer rainfall, which in turn could make foothills stream areas more prone to drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Ribes cereum var. *colubrinum* occurs in rocky canyons and shaded stream terraces where natural disturbances are relatively low. Under projected climate change, these areas are likely to become warmer, drier, and more vulnerable to frequent wildfire, which could convert

streamside shrublands to open vegetation with more invasive weed species (Rocchio and Ramm-Granberg 2017). Studies in Colorado, however, suggest that *Ribes cereum* responds to low-intensity wildfire during the non-flowering season with increased growth (Young and Bailey 1975).

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Most of the range of *Ribes cereum* var. *colubrinum* in Washington is in foothill areas that receive moderate amounts of winter snow. These areas may be influenced by adjacent highlands that receive more snow. Changes in the amount of snow and the timing of snowmelt could have deleterious effects on riparian vegetation in shady canyon sites dependent on recharge of subsurface flows (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Ribes cereum var. *colubrinum* is found almost entirely in canyons carved from Miocene-age Grande Ronde Basalt, a common geologic formation in the Blue Mountains and foothills. Some occurrences are also found on Quaternary alluvium derived from basalt (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral
The basalt canyon and shady stream terrace habitat occupied by *Ribes cereum* var. *colubrinum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Across its range in western North America, *Ribes cereum* is pollinated by a large number of bumblebee species (*Bombus*). The specific pollinators of var. *colubrinum* are not known.

C4d. Dependence on other species for propagule dispersal: Neutral.
The edible berries produced by *Ribes cereum* var. *colubrinum* are eaten and dispersed by a wide variety of bird and mammal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species may be browsed by ungulates, rabbits, or rodents, but is not threatened because of these uses.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Predicted climate change is likely to make the canyon streamside thicket habitat of *Ribes cereum* var. *colubrinum* drier, warmer, and more vulnerable to wildfire in the future (Rocchio and Ramm-Granberg 2017), making these sites susceptible to increased competition from invasive weeds and other species adapted to drier conditions.

C4g. Forms part of an interspecific interaction not covered above: Neutral.
Ribes cereum is an alternate host for *Cronartium ribicola*, the invasive fungus that causes white pine blister rust in some species of pine (*Pinus*).

C5a. Measured genetic variation: Unknown.
The genetic diversity within and between populations of *Ribes cereum* var. *colubrinum* is not known.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Ribes cereum var. *colubrinum* is presumed to be an obligate outcrosser and is not limited by pollinators or dispersal, so is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Ribes cereum* var. *colubrinum* has not changed its typical blooming time since the 1920s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Ribes cereum* var. *colubrinum* in Washington since it was first discovered in the state in the 1920s.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Ribes cereum* var. *colubrinum*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=ribes%20cereum%20var.%20colubrinum). Accessed 1 November 2021.

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.

Young, D.L. and J.A. Bailey. 1975. Effects of fire and mechanical treatment on *Cercocarpus montanus* and *Ribes cereum*. Journal of Range Management 28(6): 495-497.

Climate Change Vulnerability Index Report

Sabulina nuttallii var. *fragilis* (Nuttall's sandwort)

Date: 23 November 2021 Synonym: *Minuartia nuttallii* var. *fragilis*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5T4/S1

Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		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 others 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		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: Documented or Modeled Response	
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: All 4 of the occurrences of *Sabulina nuttallii* var. *fragilis* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

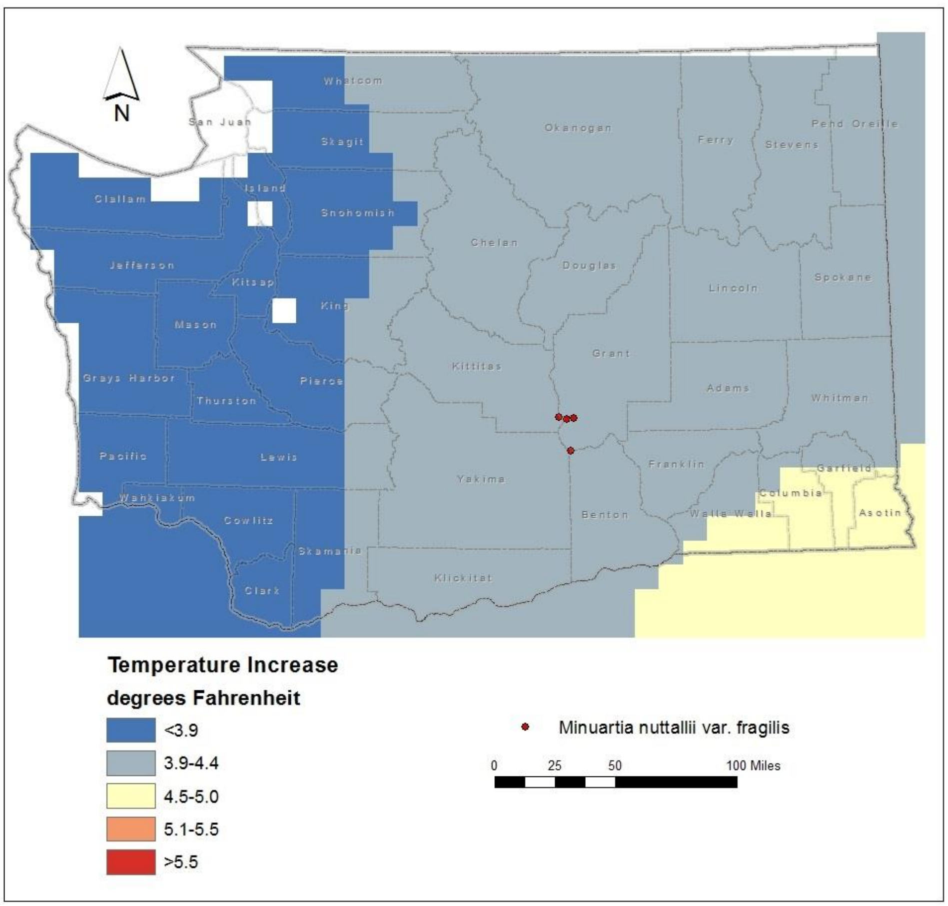

Figure 1. Exposure of *Sabulina nuttallii* var. *fragilis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four occurrences of *Sabulina nuttallii* var. *fragilis* 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 -0.028 to -0.050 (Figure 2).

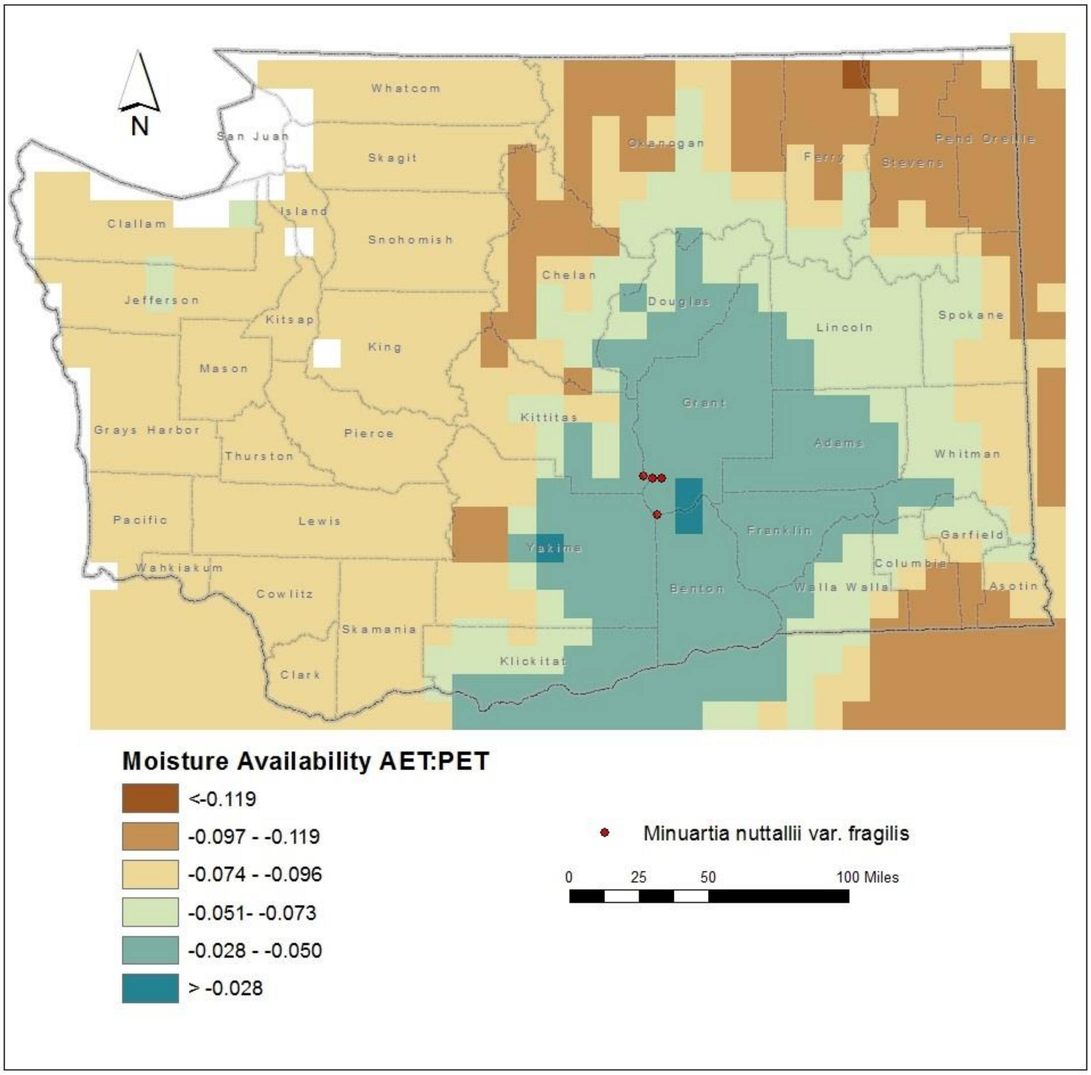

Figure 2. Exposure of *Sabulina nuttallii* var. *fragilis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Sabulina nuttallii* var. *fragilis* are found at 520-2350 feet (160-715 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Sabulina nuttallii* var. *fragilis* occurs primarily on steep, often north-facing, slopes of basalt talus (sometimes with intermixed sand) of desert ridges (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Intermountain Basin Cliff & Canyon ecological system (Rocchio and Crawford 2015). The entire range of var. *fragilis* in Washington is restricted to an area of 7 x 15 miles (11 x 24 km) with individual populations separated by 1.9-13.5 miles (3.2-21.4 km). Additional potential habitat is present in desert ridges of the central Columbia Plateau, but dispersal may be constrained by unsuitable habitat in intervening valleys.

B2b. Anthropogenic barriers: Somewhat Increase.
The desert ridge habitat of *Sabulina nuttallii* var. *fragilis* in Washington is embedded within an anthropogenic landscape used for human habitation and agriculture that present a barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Sabulina nuttallii var. *fragilis* produces numerous dry capsule fruits that split open along 3 sutures at maturity to passively release 1-3 seeds covered by low, bump-like tubercles (Rabeler et al. 2005). These seeds could be dispersed relatively short distances by high winds. Seeds that fall to the ground near the parent plant may be secondarily dispersed by seed-caching insects or rodents. Inflorescences of var. *fragilis* are also quite brittle and could be dispersed by wind as a unit, like a tumbleweed. Average dispersal distances are probably short (<1000 m), though rare, long-distance events are likely.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Sabulina nuttallii* var. *fragilis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All four of the known occurrences in the state (100%) are found in areas that have experienced average (57.1-77°F/31.8-43.0°C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
The basalt talus habitat of *Sabulina nuttallii* var. *fragilis* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

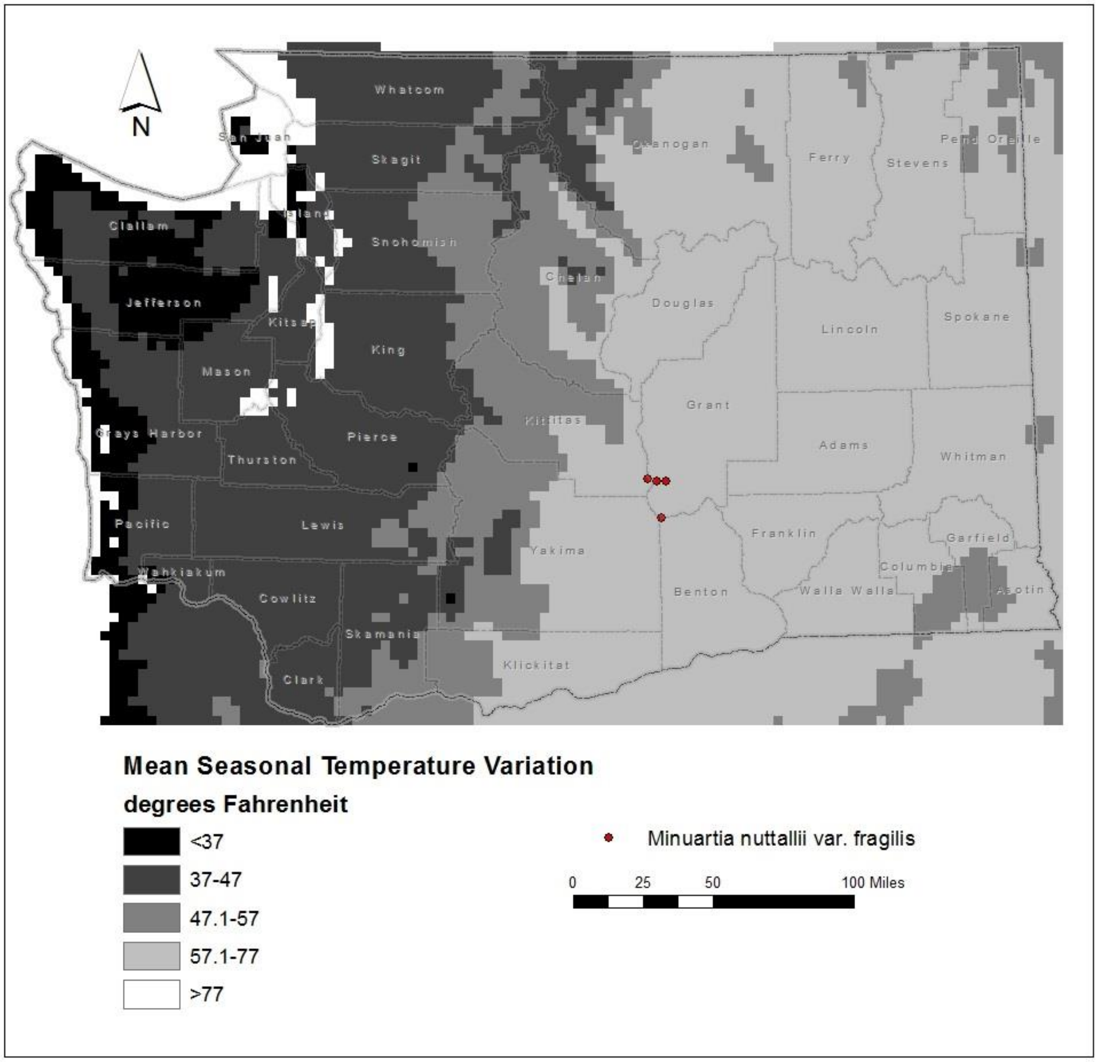

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Sabulina nuttallii* var. *fragilis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Increase.
All of the known populations of *Sabulina nuttallii* var. *fragilis* in Washington are found in areas that have experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at increased vulnerability to climate change.

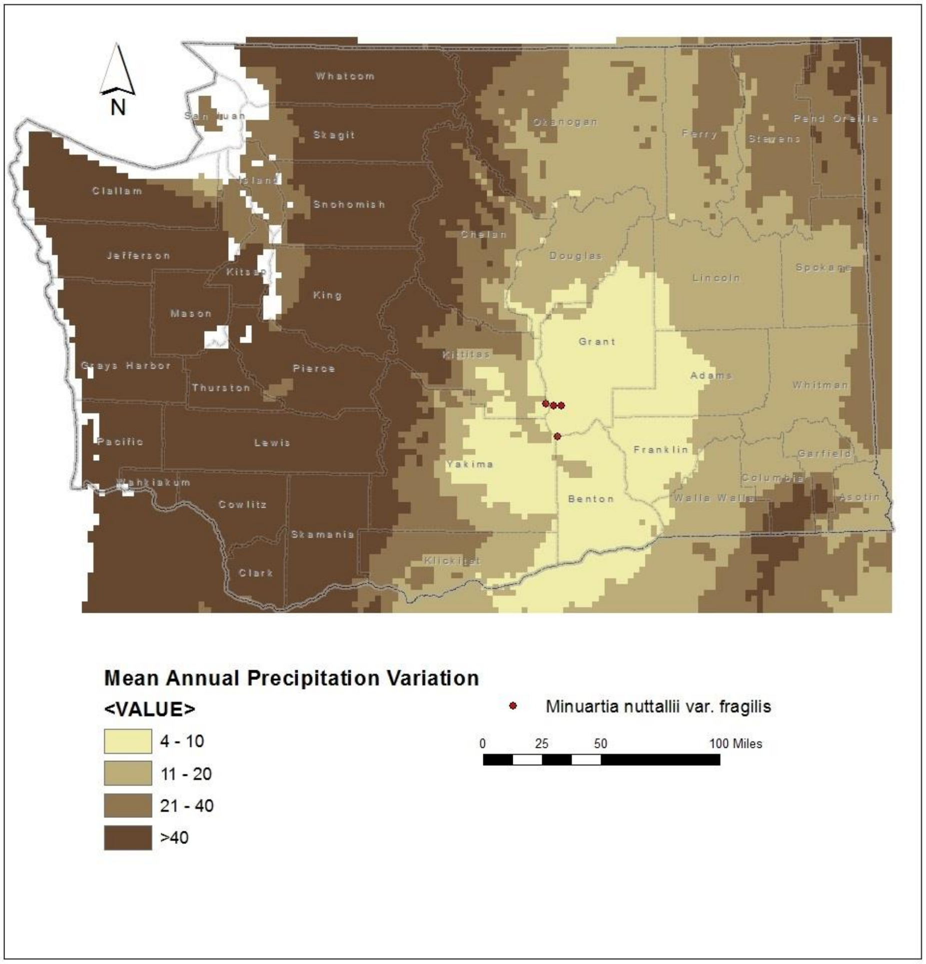

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Sabulina nuttallii* var. *fragilis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
This species is dependent on precipitation and winter snow for its moisture requirements because its habitat is not associated with perennial water sources or a high water table. The Intermountain Basins Cliff and Canyon ecological system is vulnerable to changes in the timing or amount of precipitation and increases in temperature that make these sites more drought-prone (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Sabulina nuttallii var. *fragilis* occurs in sparsely vegetated desert talus sites subjected to high winds. Historically, these sites had relatively low cover and probably burned infrequently.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The populations of *Sabulina nuttallii* var. *fragilis* in Washington are found in areas of the central Columbia Plateau that receive low amounts of winter snow. Some drifting snow may accumulate in talus areas and recharge ground water, providing a short-term hydrologic boost in early spring. Overall, this species is probably more dependent on winter or spring rainfall.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Washington, *Sabulina nuttallii* var. *fragilis* is found on steep talus slopes of reddish-brown basalt talus derived from the middle Miocene Grande Ronde basalt (Washington Division of Geology and Earth Resources 2016). Some sites contain wind-blown sand from adjacent dune fields, or are associated with Quaternary-age landslide deposits. The Grande Ronde basalt is widely distributed in central and eastern Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The desert basalt talus habitat occupied by *Sabulina nuttallii* var. *fragilis* is maintained by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Sabulina nuttallii* var. *fragilis* are not known. Many *Sabulina* species possess floral nectaries to attract a variety of insect pollinators, including flies, bees, and butterflies (Rabeler et al. 2005).

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds of *Sabulina nuttallii* var. *fragilis* 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 prickly foliage of this taxon probably reduced herbivory from ungulates and livestock, but not smaller grazers (insects or rodents). Impacts from grazing is probably low (Washington Natural Heritage Program 2021).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Sabulina nuttallii var. *fragilis* occurs in sparsely vegetated steep talus slopes where competition from other plant species is naturally low. 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).

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

C5a. Measured genetic variation: Unknown.
There is no published research on genetic diversity of var. *fragilis*. Hartman (1971) found *Sabulina nuttallii* (as *Arenaria nuttallii*) to be a tetraploid with $2n = 36$ chromosomes. Washington populations of var. *fragilis* are disjunct from the closest occurrences in central Oregon and might have reduced genetic diversity due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Sabulina nuttallii var. *fragilis* appears to be an obligate outcrosser and is not limited by pollinators, so is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Sabulina nuttallii* var. *fragilis* has not changed its typical blooming time in the last 40 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No changes have been detected in the distribution of *Sabulina nuttallii* var. *fragilis* in Washington since it was first discovered in the state in 1984.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Hartman, R.L. 1971. Chromosome numbers in Caryophyllaceae from Wyoming and adjacent states. Bulletin Torrey Botanical Club 98(5): 276-280.

Rabeler, R.K., R.L. Hartman, and F.H. Utech. 2005. *Minuartia*. Pp. 116-136. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 20+ vols. New York and Oxford. Vol. 5: Magnoliophyta: Caryophyllidae, part 2. 656 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Sabulina nuttallii* var. *fragilis*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=sabulina%20nuttallii%20var.%20fragilis). Accessed 23 November 2021.

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

Salix maccalliana (MacCalla's willow)

Date: 16 November 2021

Assessor: Walter Fertig, 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: Local Climate	**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	66.7
	-0.074 to - 0.096	0
	-0.051 to - 0.073	33.3
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
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 others 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: Documented or Modeled Response	
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: All 3 of the known occurrences of *Salix maccalliana* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

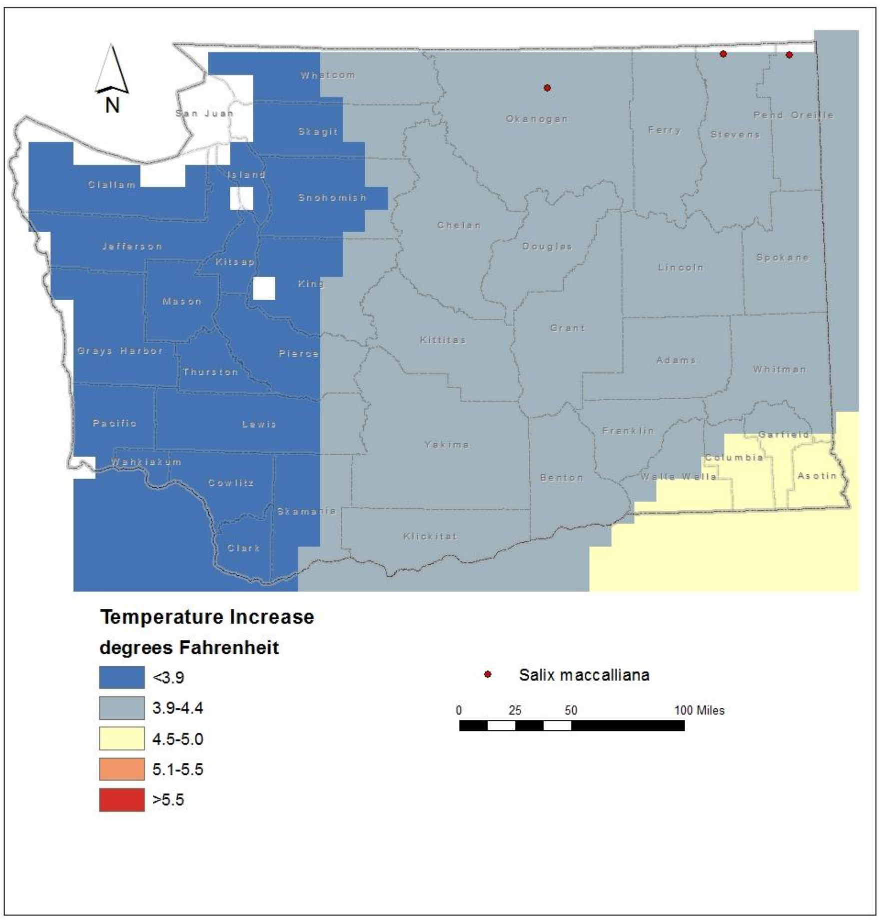

Figure 1. Exposure of *Salix maccalliana* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the three occurrences (66.7%) of *Salix maccalliana* 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 other population (33.3%) is from an area with a projected decrease of -0.051 to -0.073.

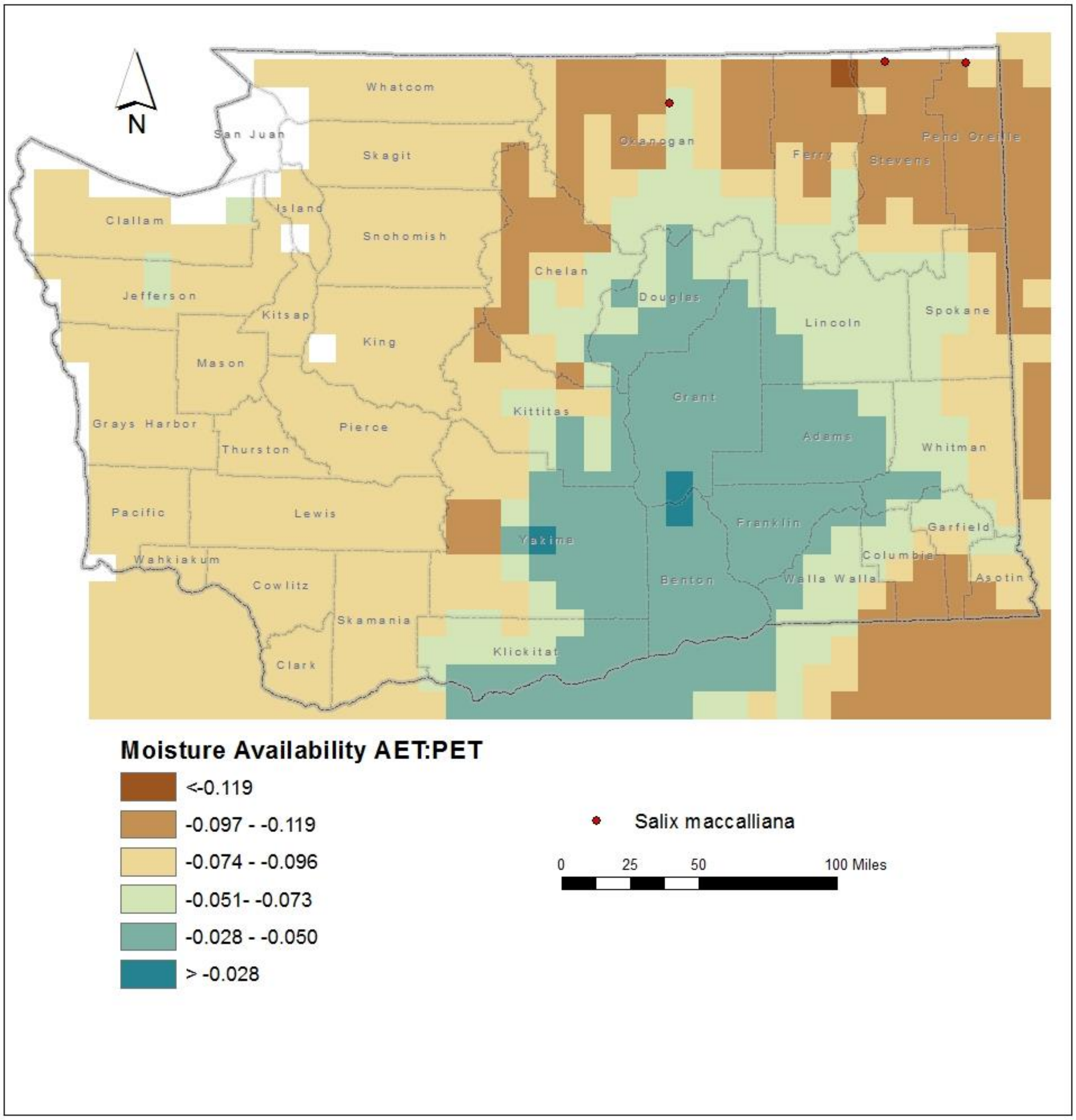

Figure 2. Exposure of *Salix maccalliana* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Salix maccalliana* are found at 1500-3000 feet (460-915 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Salix maccalliana occurs on peaty soils of raised hummocks in fens, swamps, and marshes. At least one population is from a former cedar swamp converted to an open fen by fire (Camp and Gamon 2011; Washington Natural Heritage Program 2021). This habitat is part of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio and Crawford 2015). Populations are separated from each other by 29-79 miles (46-127 km) of unoccupied and mostly unsuitable habitat that creates a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The fen habitat of *Salix maccalliana* in Washington is naturally uncommon and widely scattered within a matrix of natural and human-influenced lands. Anthropogenic activities, however, are less significant than natural impediments to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Salix maccalliana produces numerous, many-seeded dry capsule fruits. Individual seeds are small and have a tuft of hairs to facilitate wind dispersal. While typical dispersal distances are probably short, some seeds are capable of moving over 1 km. Willow seeds are also able to disperse by water and can remain floating for several days (Argus 2010). Dispersal may be limited by the availability of suitable habitat for germination and survival of seedlings.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Salix maccalliana* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All three known occurrences in the state (100%) are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Increase.
The fen habitat of *Salix maccalliana* in Washington is associated with pockets of cold air drainage in mountain foothills and would be adversely impacted by increasing temperatures from climate change.

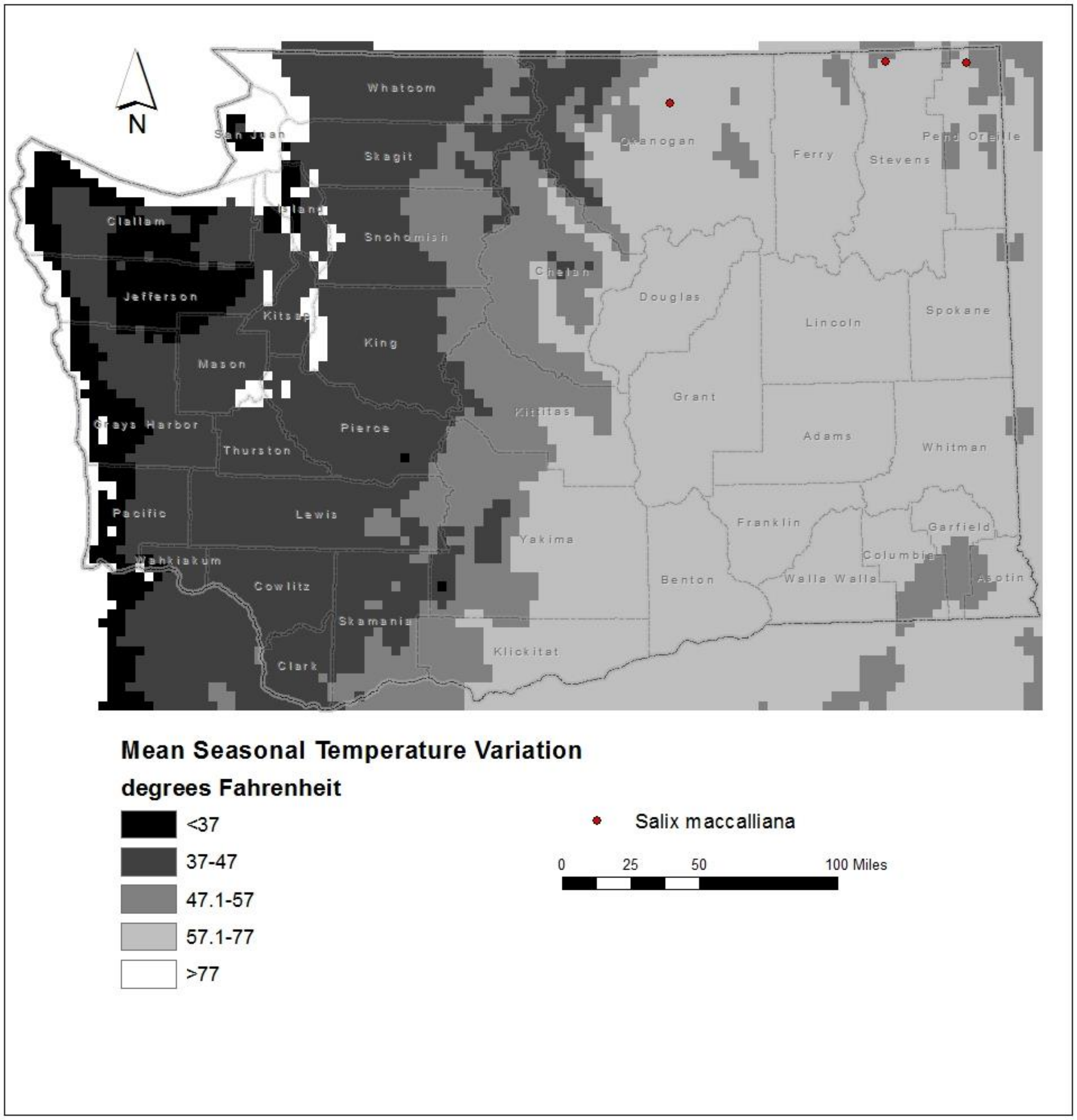

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Salix maccalliana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
Two of the three populations of *Salix maccalliana* in northeastern Washington (66.7%) are found in areas that have experienced average precipitation variation in the past 50 years (21-40 inches/508-1016 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change. The Okanogan County occurrence (33.3%) is from an area with slightly lower than average (11-20 inches/255-508 mm) precipitation variation over the same period and is at slightly increased risk from climate change.

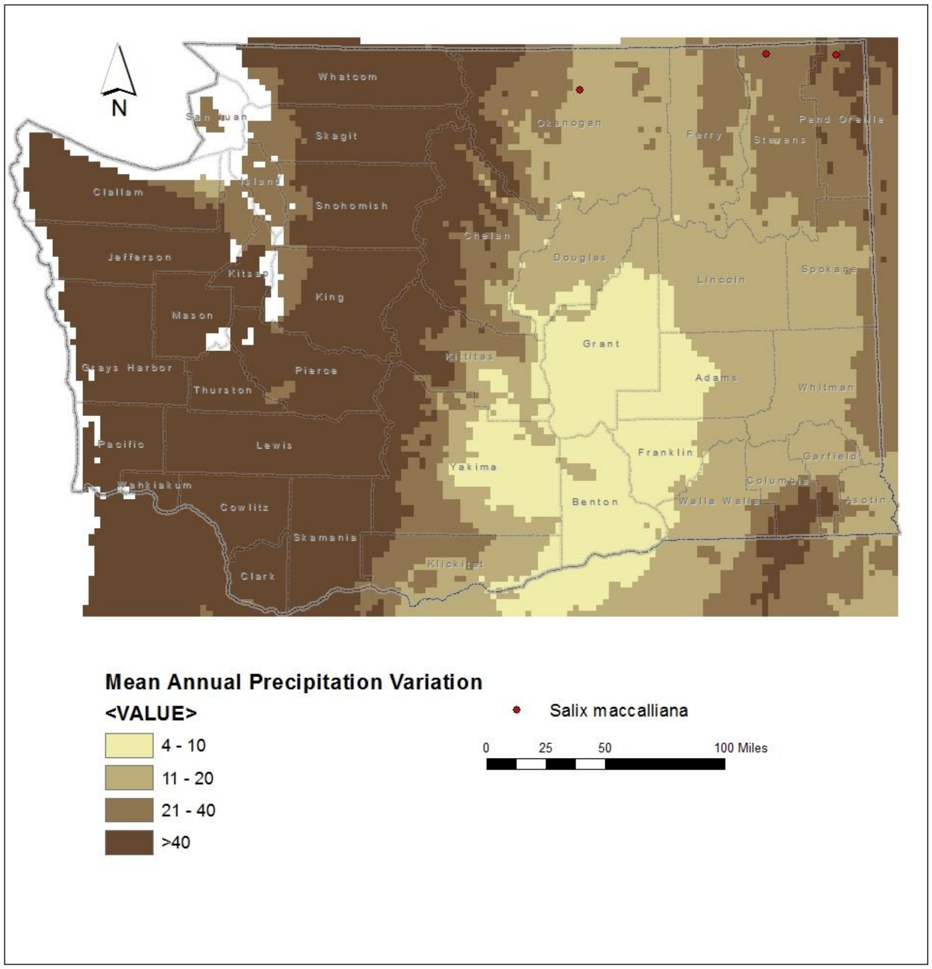

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Salix maccalliana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The fen habitats occupied by *Salix maccalliana* are dependent on groundwater, and thus more reliant on adequate moisture from melting snow than summer rainfall (Rocchio and Ramm-Granberg 2017). Reduction in the timing and amount of precipitation and increased temperatures and drought would make these fen sites more vulnerable to climate change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Salix maccalliana is not dependent on periodic disturbances to maintain its montane peatland habitat. The species could be impacted by increased summer temperatures, drought, or reduced

snowpack that could favor conversion of fen habitats to swamp forest or wet meadows or lead to increased fire frequency (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
Salix maccalliana is found in mountainous areas of northern and northeastern Washington that receive high amounts of winter snowfall. Fen wetlands occupied by this species are dependent on groundwater recharged by melting snow (Rocchio and Ramm-Granberg 2017). Reduction in the amount of snow or timing of its melt could lead to shifts in the dominance of fen species or invasion of plants adapted to wet meadow or swamp forest environments.

C3. Restricted to uncommon landscape/geological features: Increase.
Salix maccalliana is found on Quaternary glacial drift derived from granodiorite (Loomis Pluton) or limestone (Metaline Formation) (Washington Division of Geology and Earth Resources 2016). The parent formations are of limited distribution in Washington. Landscape features associated with fens may also be sporadic, contributing to the overall rarity of the species in the state.

C4a. Dependence on other species to generate required habitat: Neutral
The fen habitat occupied by *Salix maccalliana* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Salix inflorescences lack showy petals or sepals and are capable of wind pollination. Flowers also produce nectar and floral scents to attract insect pollinators, such as flies, bees, and butterflies.

C4d. Dependence on other species for propagule dispersal: Neutral.
Willow seeds are small and have a tuft of wavy hairs for dispersal by wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Sensitivity from pathogens is not known. Willows can be important browse species for a number of native species, including ungulates, rodents, and insects. Heavy browsing is a threat to many rare willow species, but the effects on *Salix maccalliana* are poorly documented.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Salix maccalliana could be impacted by competition from invading plant species if its fen habitat is converted to wet meadows or swamp forests due to future drought or reduced snowpack because of climate change (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Genetic variability within Washington occurrences is poorly known. *Salix maccalliana* has the highest chromosome number of any species in the genus *Salix* with a $2n$ count of 190 or 228 (making it a decaploid or dodecaploid with $x = 19$) (Argus 2010). This species is probably of

hybrid origin, incorporating genomes from at least two subgenera, making it difficult to place phylogenetically (Argus 2010; Lauron-Moreau et al. 2015). Large genomes from hybridization are typically associated with high genetic diversity. Washington populations of *S. maccalliana*, are located at the southern edge of the species' overall range, and might be expected to have somewhat lower overall genetic diversity than populations at the core of its range.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Salix maccalliana is an obligate outcrosser and is not limited by pollinators or dispersal, so is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Salix maccalliana* has not changed its typical blooming time since the 1980s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Salix maccalliana* in Washington since it was first documented in the state in the early 1980s.

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

References

Argus, G.W. 2010. *Salix*, pp 23-162. In: Flora of North America Editorial Committee. Flora of North America North of Mexico. Volume 7 Magnoliophyta: Salicaceae to Brassicaceae. Oxford University Press, New York. 797 pp.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Lauron-Moreau, A., F.E. Pitre, G.W. Argus, M. Labrecque, and L. Brouillet. 2015. Phylogenetic relationships of American willows (*Salix* L., Salicaceae). PLOS One 10(9): e0138963. https://doi.org/10.1371/journal.pone.0138963

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021. *Salix maccalliana*. In: Online Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=salix%20maccalliana). Accessed 4 November 2021.

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

Sanicula arctopoides (Bear's-foot sanicle)

Date: 12 January 2021

Assessor: Walter Fertig, 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: Local Climate	**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: Indirect Exposure to Climate Change		**Effect on Vulnerability**
1. Sea level rise		Increase
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Somewhat Increase
Section C: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Greatly 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/Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on others 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: Documented or Modeled Response	
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: All ten of the confirmed occurrences of *Sanicula arctopoides* in Washington (100%) occur in areas with a projected temperature increase of <3.9° F (Figure 1). Two additional reports have been excluded. One is an historical record from "near Ilwaco" collected

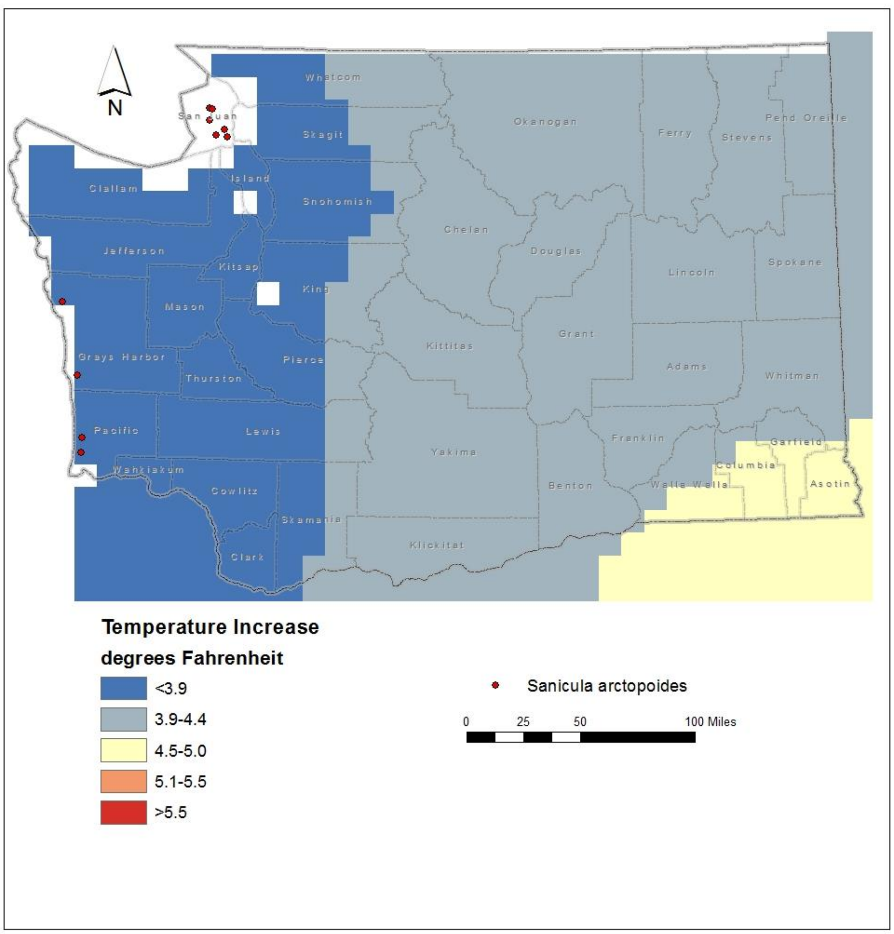

Figure 1. Exposure of *Sanicula arctopoides* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

in 1952 which has not been confirmed. The second is an iNaturalist image attributed to Cathlamet, Wahkiakum County, but with an error radius of 2500 km. (https://www.inaturalist.org/observations/21671598). The cited locality is not within the expected range of the species, and so is excluded until more precise data are available.

A2. Hamon AET:PET Moisture Metric: The ten occurrences of *Sanicula arctopoides* 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 -0.096 (Figure 2).

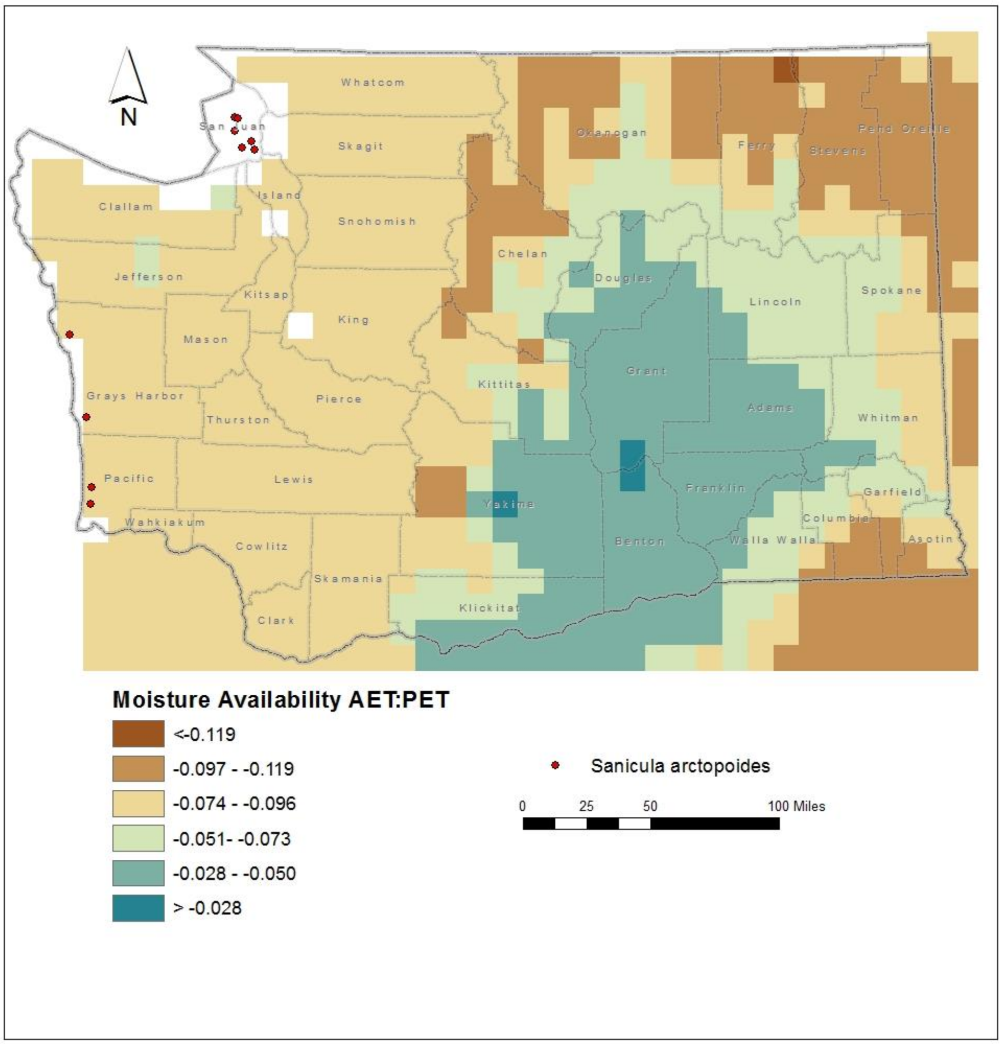

Figure 2. Exposure of *Sanicula arctopoides* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Increase.
The Washington occurrences of *Sanicula arctopoides* are found at 4-65 feet (1-20 m) and are typically within 0.5 miles (0.8 km) of the Pacific Ocean or on low-lying islands in the Salish Sea. Sea level is projected to rise by 0.5-2 m in the current century (Young et al. 2016) and could inundate at least one occurrence. At least half of the known occurrences would be impacted by storm surges or intrusions of salt water due to their proximity to the ocean and low elevation.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Sanicula arctopoides* is found mostly on coastal bluffs and grassy sand dunes near the ocean and on small islands off the coast. It has also been reported from shallow soil over bedrock and old fields at the edge of forests just above the high tide line (Camp and Gamon 2011, WNHP records). These sites conform to the North Pacific Maritime Coastal Sand Dune and Strand and North Pacific Coastal Cliff and Bluff ecological systems (Rocchio and Crawford 2015). In Canada, this species is found in Oregon white oak ecosystems on the southeast coast of Vancouver Island (COSEWIC 2015) that are analogous to the North Pacific Oak Woodland ecological system in the Puget Sound area of Washington. Individual occurrences are separated by distances of 4-100 miles (100-160 km). Potential shoreline habitat of this species is naturally patchy and occurrences may be isolated due to large blocks of unsuitable upland habitat and expanses of ocean. Migration in response to climate change will likely be somewhat limited due to these natural obstacles.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Sanicula arctopoides* in Washington is naturally patchy, but loss of habitat has also occurred in the past 120 years due to development of shoreline sites for homes and roads. Habitat has also been lost due to efforts to manage shifting dunes and from invasion of competing vegetation. Future dispersal of this species will be constrained due to the large human footprint on coastal habitats that are already naturally fragmented.

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase.
The coastal bluff and shifting dune habitats of *Sanicula arctopoides* could be vulnerable to impacts from construction of sea walls or other structures to protect shoreline homes.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Sanicula arctopoides produces compact umbels of dry, schizocarp fruits that split at maturity into pairs of one-seeded segments. The fruits are covered by stout, hooked bristles that catch on the fur or feathers of animals. Dried fruitstalks that break off the plant may also disperse seeds over short distances in the manner of a "tumbleweed" (COSEWIC 2015). Dispersal by birds could potentially spread fruits well over 1 km from the parent plant. Matt Fairbarns (in COSEWIC 2015), however, observed poor dispersal over short distances in seemingly suitable habitat within Canadian populations.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Sanicula arctopoides* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All ten occurrences (100%) are found in coastal areas that have experienced very small temperature variation (<37˚F/20.8˚C) during the past 50 years and are considered to be at greatly increased vulnerability to climate change (Young et al. 2016).

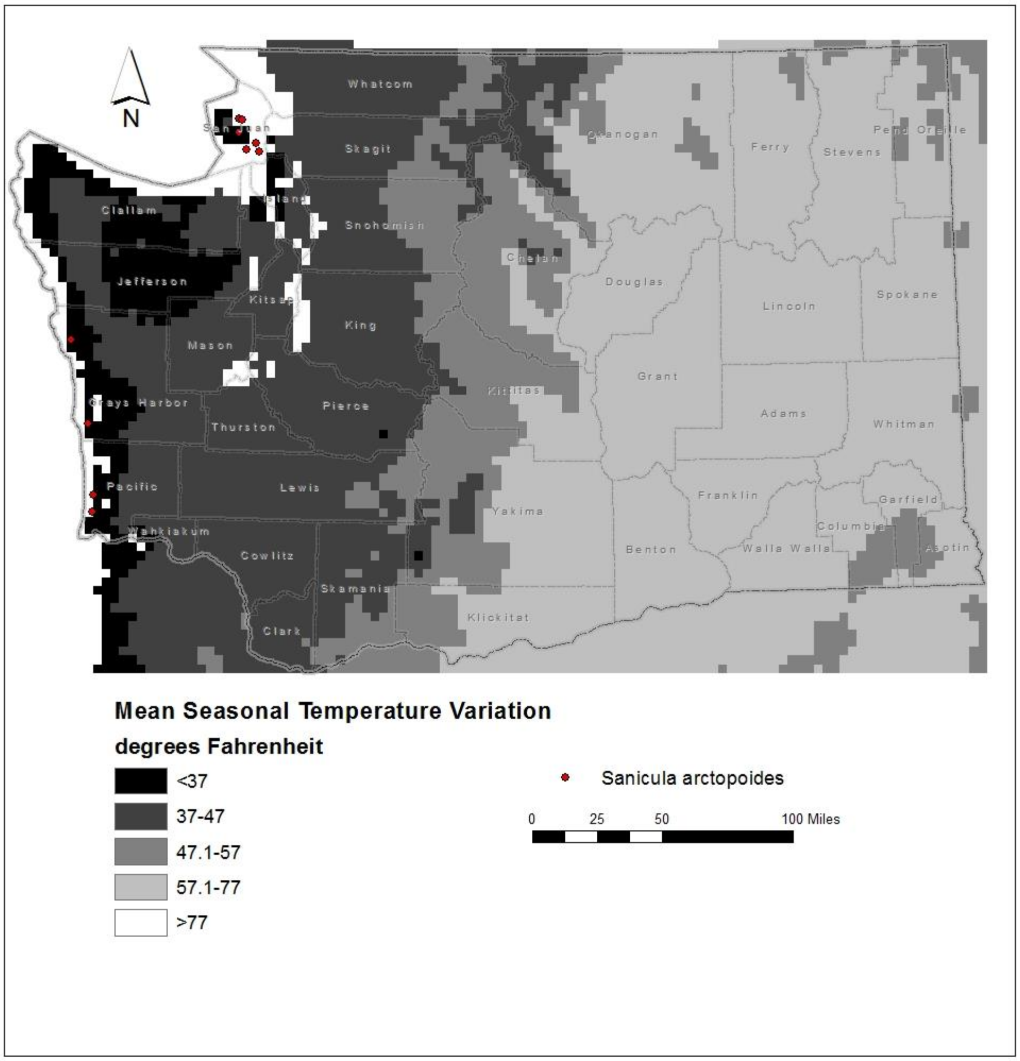

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Sanicula arctopoides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The Pacific Ocean coast and San Juan Islands tend to have milder temperatures than nearby inland locations due to the moderating effect of the ocean as a heat sink. This condition has a neutral impact on climate change vulnerability.

C2bi. Historical hydrological niche: Neutral.
The six occurrences of *Sanicula arctopoides* in the San Juan Islands (60% of the state's occurrences) have experienced average (21-40 inches/533-1016 mm) precipitation variation in the past 50 years (Figure 4). The other four occurrences along the Pacific Coast (40%) have experienced greater than average precipitation variation (>40 inches/1016 mm) in the same time period. According to Young et al. (2016), all of these populations are at neutral vulnerability to climate change.

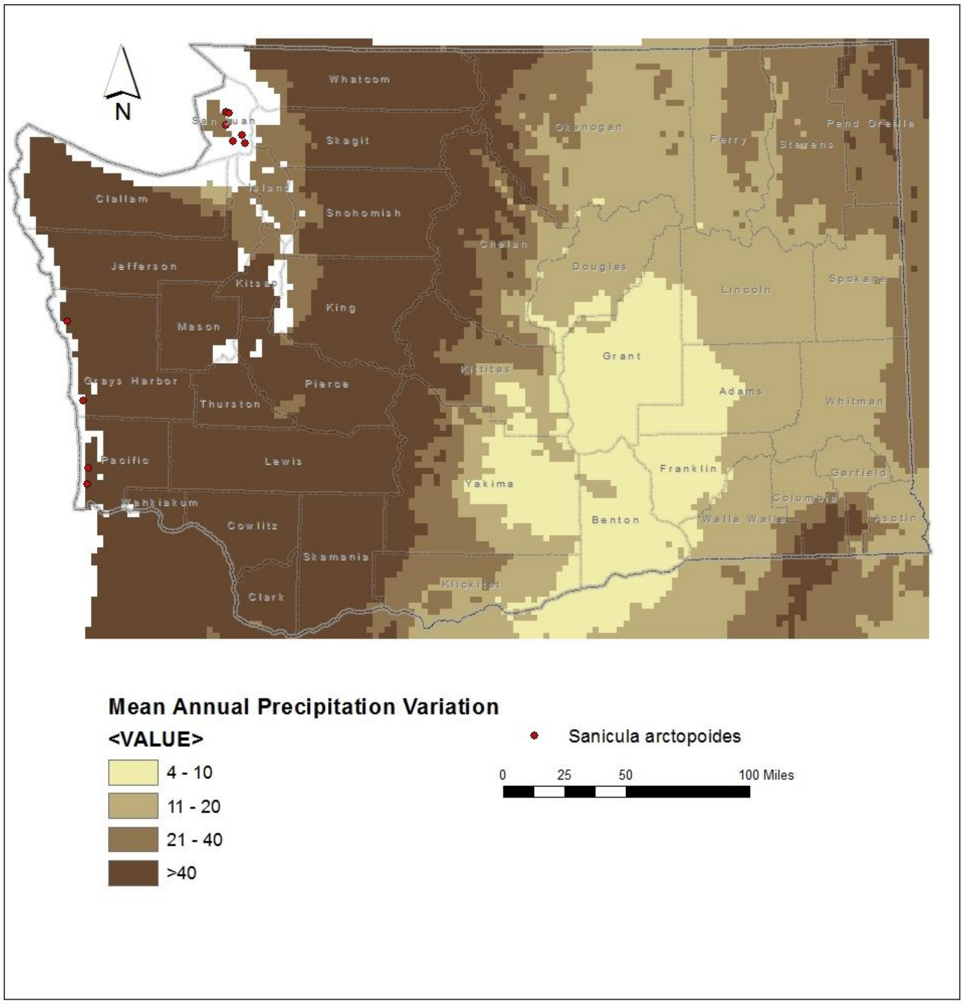

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Sanicula arctopoides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent primarily on adequate precipitation for its moisture requirements, because its habitat is typically not associated with springs or streams and soils are prone to

seasonal drought. The proximity of populations to the coast also makes them susceptible to saltwater intrusion during storm events or because of sea level rise (Rocchio and Ramm-Granberg 2017). The North Pacific Maritime Coastal Sand Dune and Strand and North Pacific Coastal Cliff and Bluff ecological systems are somewhat vulnerable to enhanced erosion from increased winter storm events. While dune sites are maintained by wind erosion, the stability of cliffs and bluffs can be decreased due to extreme weather events (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral/Somewhat Increase.
Sanicula arctopoides populations in shifting sand dune habitats along the Pacific Coast are dependent on frequent disturbance to prevent sites from becoming stabilized by meadow or woodland vegetation. Climate change may actually increase the frequency of winter storm surges and erosion that would maintain early seral conditions. These positive benefits, however, may be offset by human efforts to protect against erosion through construction (sea walls). Coastal bluff and cliff populations and those in the San Juan Islands associated with shallow soils over bedrock could be negatively impacted by increased erosion from winter storms (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is low over the range of *Sanicula arctopoides* in Washington and a minimal component of its annual water budget.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Sanicula arctopoides is restricted to shifting sand dunes along the Pacific Coast or thin soils over basalt on maritime islands (Washington Division of Geology and Earth Resources 2016). While these rock types are not intrinsically rare, the landscape conditions under which they have formed is uncommon.

C4a. Dependence on other species to generate required habitat: Neutral.
While herbivory by ungulates, rodents, and insects can reduce invasive vegetative cover that is stabilizing dunes, frequent disturbance by wind is a more significant factor in maintaining shifting dune habitats for Pacific coast populations of *Sanicula arctopoides*.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
The specific pollinators of *Sanicula arctopoides* are poorly known in Washington. In general, members of the Apiaceae are visited by a variety of generalist pollinators, including bees, flies, and beetles.

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Sanicula arctopoides* are covered in stout hooks designed to adhere to fur or feathers of a wide variety of bird or mammal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Lowenberg (1994) documented that herbivory by deer early in the flowering season did not result in a loss of seed production due to compensatory flowering, but late season herbivory could reduce seed set by up to 52%. Grazing by Canada

geese is a growing threat on the Gulf Islands of Canada (COSEWIC 2015) and potentially in the San Juan archipelago in Washington (Peter Dunwiddie, personal communication 2021).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Populations of *Sanicula arctopoides* in shifting sand dune habitats are negatively impacted by competition from invading grassland or forest species and resulting stabilization of the dune environment.

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for *Sanicula arctopoides* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Sanicula arctopoides is presumed to be an outcrosser, rather than self-pollinated. Presumably, genetic variation is average, compared to other species, but no studies have been done for confirmation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website and monitoring studies in Canada (COSEWIC 2015), no significant changes in the phenology of *Sanicula arctopoides* have been detected over the past 20 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Abundance data are lacking for most occurrences of *Sanicula arctopoides* in Washington. At least three populations have not been relocated since 1981 and are considered historical. The only population with long term monitoring data in the state has experienced a 50% decline since 1982. Much of this decrease has been attributed to changes in vegetation cover and competition (WNHP records), rather than climate change.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

COSEWIC. 2015. COSEWIC assessment and status report on the Bear's-foot Sanicle *Sanicula arctopoides* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa 35 pp.

Lowenberg, G. 1994. Effects of floral herbivory on maternal reproduction in *Sanicula arctopoides* (Apiaceae). Ecology 75:359-369.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Silene seeleyi (Seely's catchfly)

Date: 15 October 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G3/S3

Index Result: Moderately Vulnerable Confidence: High

Climate Change Vulnerability Index Scores

Section A: Local Climate	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	18.75
	-0.074 to -0.096	62.5
	-0.051 to -0.073	18.75
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		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 others 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		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	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All 14 of the extant and historical occurrences of *Silene seelyi* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

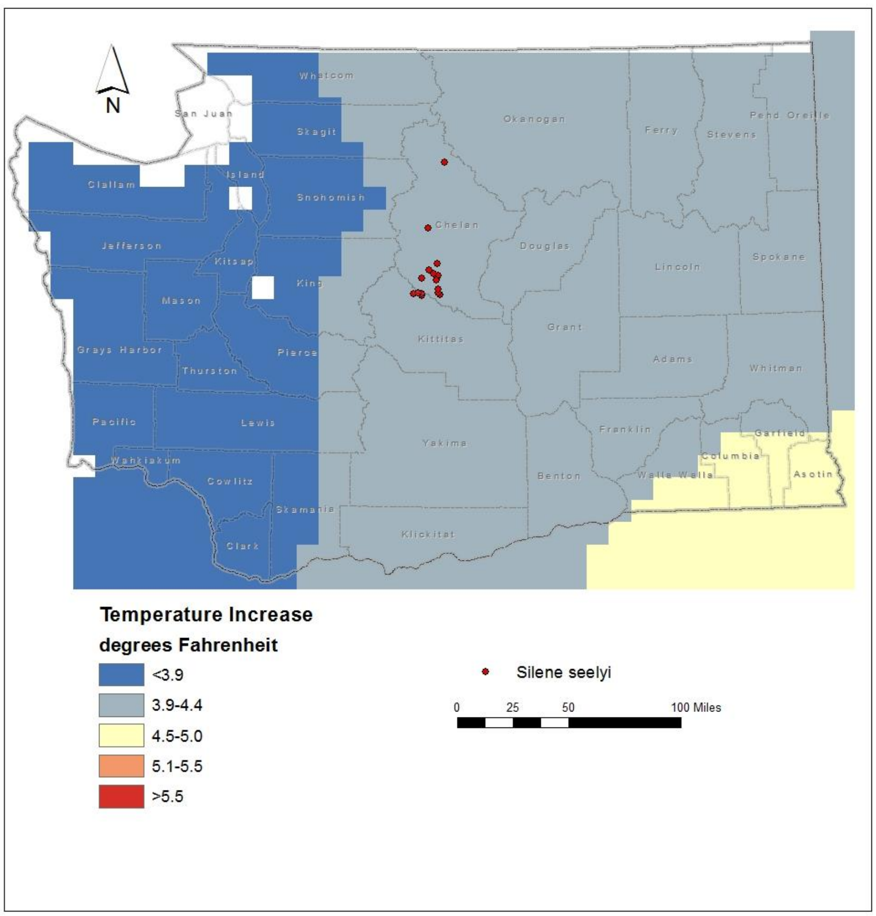

Figure 1. Exposure of *Silene seelyi* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Ten of the 16 occurrences (62.5%) of *Silene seelyi* 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). Three populations (18.75%) are from areas with a projected decrease of -0.051 to -0.073 and three others (18.75%) have a projected decreases of -0.097 to -0.119 (Figure 2).

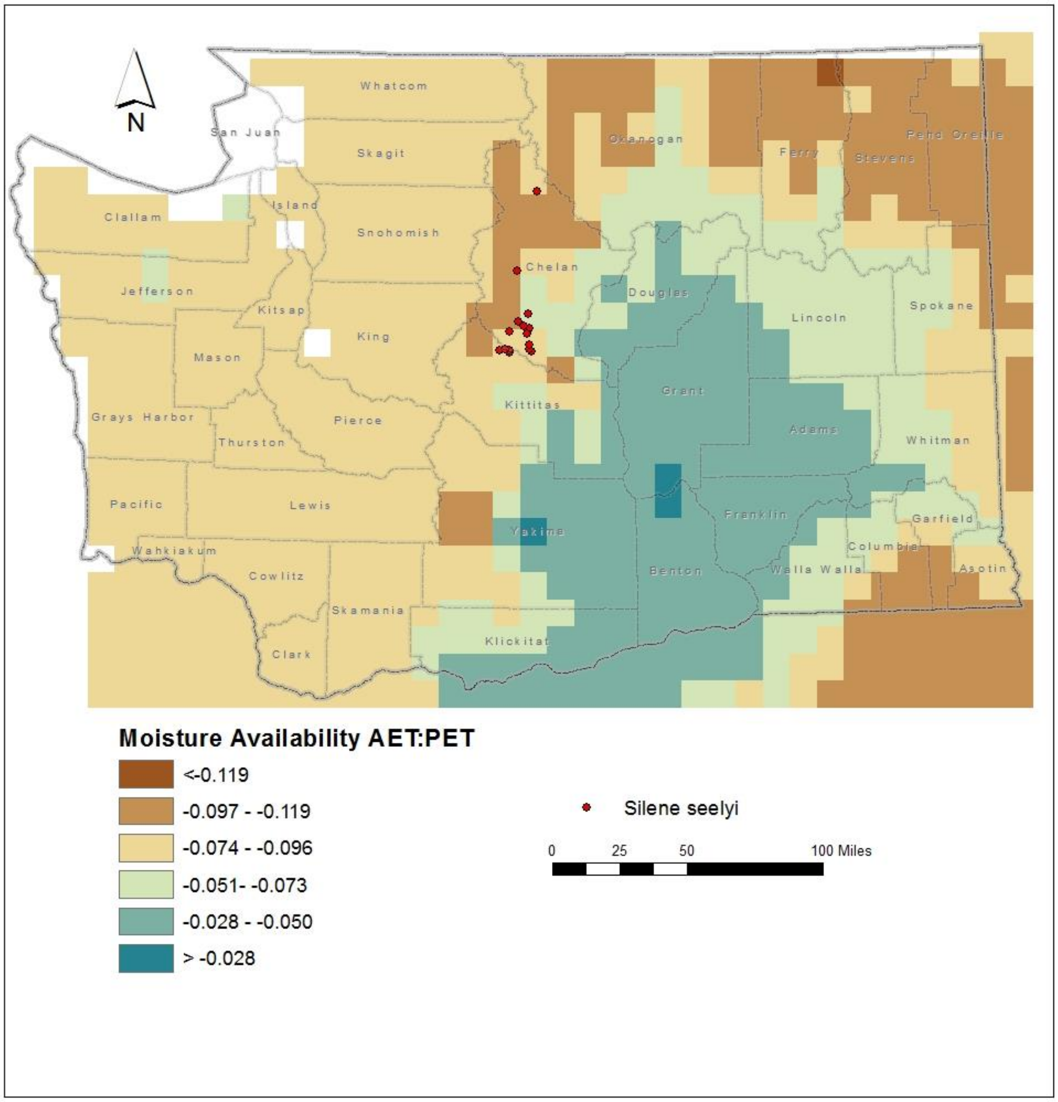

Figure 2. Exposure of *Silene seelyi* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Silene seelyi* are found at 1120-6300 feet (340-1920 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Silene seelyi occurs primarily in shady crevices of cliffs, rock outcrops, and boulder fields with thin soil and sparse vegetation within Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) forests (Camp and Gamon 2011, Washington Natural Heritage Program 2021). This habitat is part of the North Pacific Serpentine Barren and Rocky Mountain Cliff, Canyon, & Massive Bedrock ecological systems (Rocchio and Crawford 2015). The entire range of the species is restricted to an area of 12 x 60 miles (20 x 98 km), with populations separated by 0.8-30 miles (1.3-49 km). Available habitat is patchy throughout its range, with populations isolated by narrow canyons or expanses of forest. Natural barriers represent an impediment to dispersal.

B2b. Anthropogenic barriers: Neutral.
The rock outcrop and talus habitat of *Silene seelyi* is located in National Forest lands managed primarily for multiple use, including recreation and forestry. The rugged terrain inhabited by the species largely protects it from most direct human impacts. Anthropogenic barriers are minor relative to natural ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Silene seelyi produces numerous, small seeds within a dry capsule fruit that splits open at maturity along 6 sutures to release the seeds passively. Seeds are flattened but lack wings, hooks, or feathery hairs for dispersal by animals or wind. Dispersal distances are probably 10-100 m.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Silene seelyi* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 16 known occurrences in the state (100%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Increase.
Silene seelyi is found primarily in shaded crevices of boulders and rock outcrops (often on north-facing aspects) within narrow canyons that have cold air drainage. These microhabitats are at increased susceptibility to climate change.

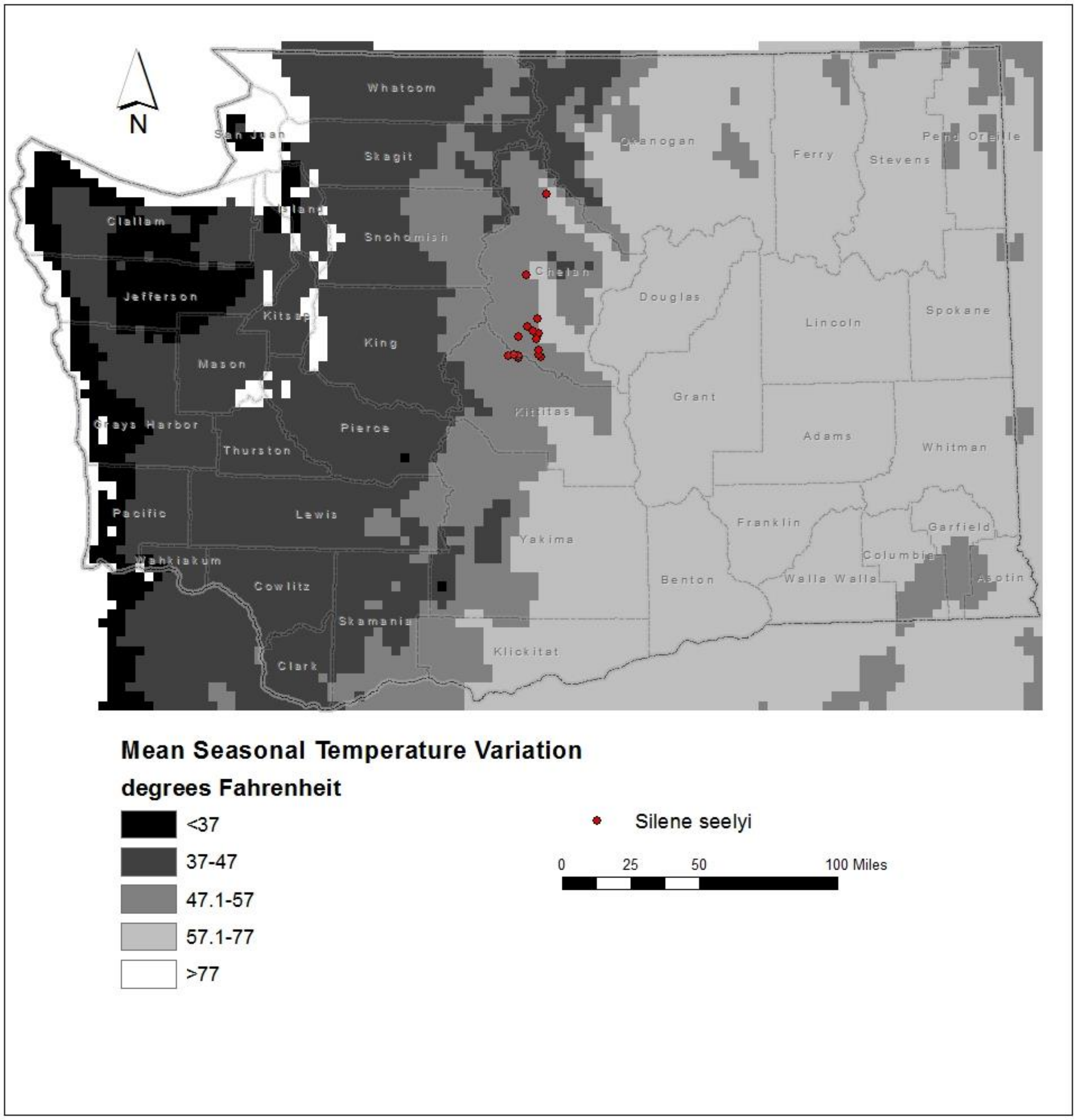

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Silene seelyi* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Silene seelyi* are found in areas that have experienced average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm) (Figure 4). According to Young et al. (2016), these occurrences are neutral for climate change.

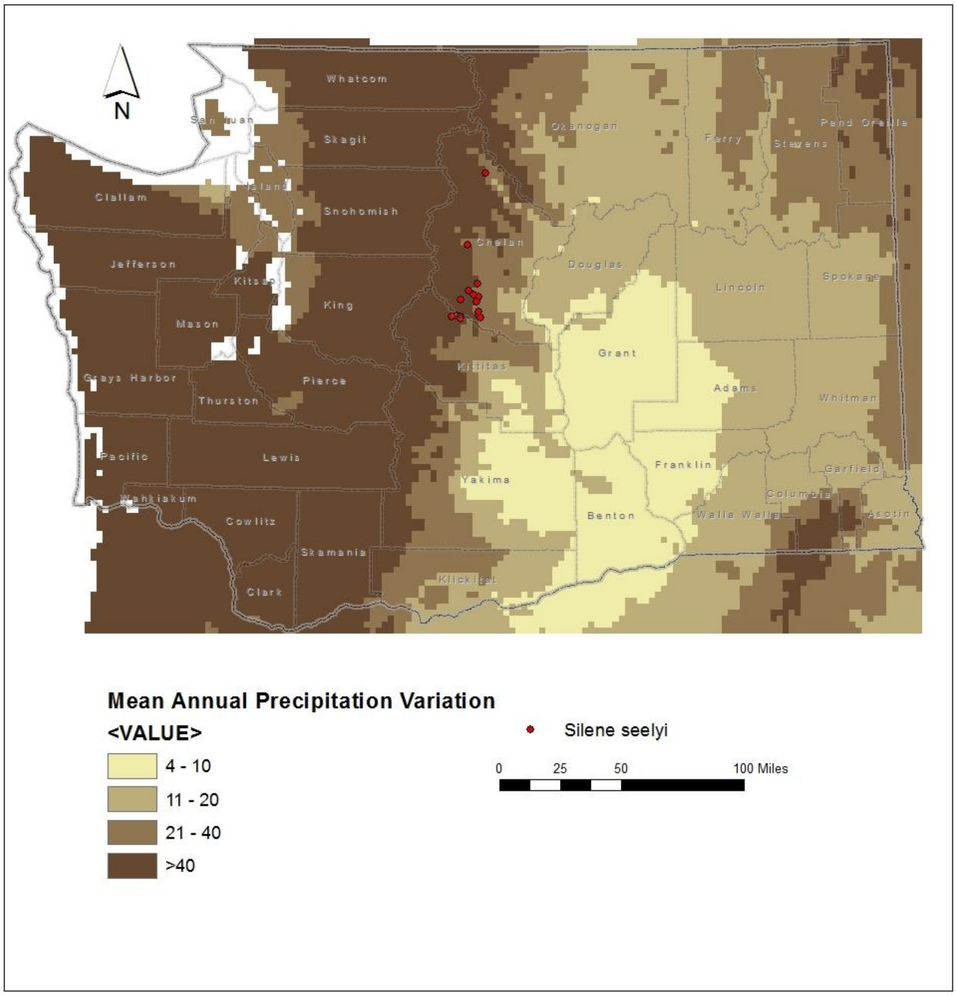

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Silene seelyi* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is not associated with perennial water features or a high water table, and is dependent on winter snow and spring/summer rain for its moisture needs. Changes in the timing or amount of precipitation could result in drying of its rock outcrop habitat and make surrounding forests more prone to wildfire (Rocchio and Ramm-Granberg 2017), reducing shade and making cliff microsites drier.

C2c. Dependence on a specific disturbance regime: Neutral.
Silene seelyi occurs in montane cliffs and rock outcrops subject to periodic rockfall due to erosion, earthquakes, freeze-thaw activity, and vegetation growth. These are natural processes that are unlikely to be altered by projected climate change.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Populations of *Silene seelyi* are found in shady mountain canyons that receive high amounts of winter snow and ice. Water infiltrating cracks and crevices in rock outcrops 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: Somewhat Increase.
Silene seelyi is found on a variety of geologic substrates, including serpentine (Ingalls complex), basalt (Mt Stuart Batholith), gneiss (Skagit Formation), fluvial sediments (Swauk Formation), and Quaternary landslides (Washington Division of Geology and Earth Resources 2016). Several of these formations are restricted to the Wenatchee Mountains and vicinity. This species may be more dependent on the presence of exposed rock than its mineralogy or chemistry.

C4a. Dependence on other species to generate required habitat: Neutral
The rock outcrop habitat occupied by *Silene seelyi* is maintained by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Silene seeleyi* are not known. Having dark red to purplish flowers, *S. seelyi* might be hummingbird pollinated, as are other red-flowered *Silene* species (Reynolds et al. 2009). Flowers may also be white, which would attract a variety of insect pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds of *Silene seelyi* are released passively and may disperse by gravity or short distances by strong winds. Secondary, short-distance, dispersal may be possible by insects or rodents collecting seeds.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known, but probably not a limiting factor. Herbivory appears to be insignificant.

C4f. Sensitivity to competition from native or non-native species: Neutral/Somewhat Increase.
Under present conditions, competition from non-native species is minor, as few introduced plants are adapted to bare, shady surfaces of cliffs or talus. Under projected climate change, competition from invasive weeds could increase if these rocky sites become 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.
Does not require an interspecific interaction.

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Silene seelyi is a diploid (*n* = 12) (Popp and Oxelman 2007) and appears to be an obligate outcrosser. Kruckeberg (1961) conducted hybridization experiments in greenhouse settings and found *S. seelyi* to be capable of hybridizing and producing some fertile F1 progeny with the related tetraploid *S. menziesii* and diploid *S. williamsii* (native to Alaska and NW Canada). *Silene menziesii* occurs widely across Washington and western North America, but does not co-occur with *S. seelyi* in the Wenatchee Mountains, suggesting that any gene flow in nature is unlikely.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Silene seelyi* has not changed its typical blooming time over the past 90 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No major changes have been detected in the distribution of *Silene seelyi* in Washington since it was first discovered in the state in 1932.

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

References

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Kruckeberg, A.R. 1961. Artificial crosses of western North American *Silene*s. Brittonia 13(4): 305-333.

Popp, M. and B. Oxelman. 2007. Origin and evolution of North American polyploidy *Silene* (Caryophyllaceae). American Journal of Botany 94(3): 330-349.

Reynolds, R.J., M.J. Westbrook, A.S. Rohde, J.M. Cridland, C.B. Fenster, and M.R. Dudash. 2009. Pollinator specialization and pollination syndromes of three related North American *Silene*. Ecology 90(8): 2077-2087.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Erigeron aliceae*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=silene%20seelyi). Accessed 15 October 2021.

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

Spartina pectinata (Prairie cordgrass)

Date: 27 October 2021 Synonym: *Sporobolus michauxianus*

Assessor: Walter Fertig, 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: Local Climate	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	30.8
	3.9-4.4° F (2.2-2.4°C) warmer	69.2
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	38.5
	-0.074 to -0.096	7.6
	-0.051 to - 0.073	15.4
	-0.028 to -0.050	38.5
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
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		Somewhat Increase
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Increase
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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: Documented or Modeled Response	
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: Ten of the 13 occurrences of *Spartina pectinata* in Washington (69.2%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). Three other populations (30.8%) are from areas in southeast Washington with a projected temperature increase of 4.5-5.0˚ F.

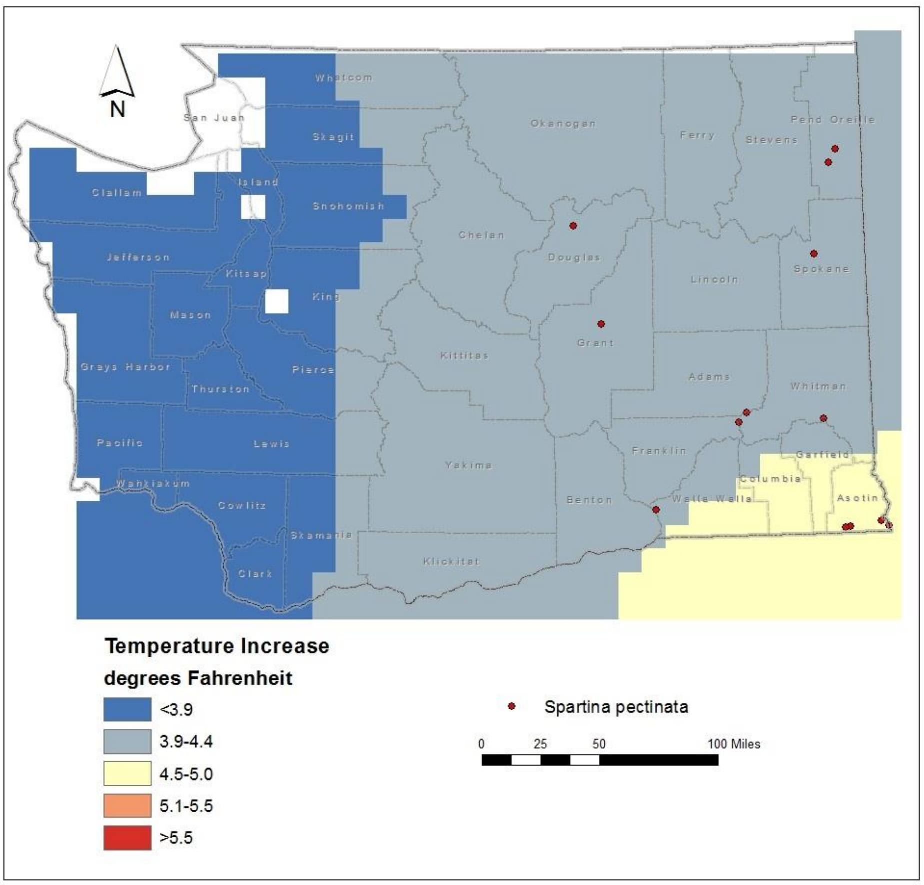

Figure 1. Exposure of *Spartina pectinata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Five of the 13 occurrences of *Spartina pectinata* (38.5%) in the Blue Mountains and Canadian Rockies 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 population in southeast Washington (7.6%) is found in an area of projected decrease in available moisture of -0.074 to -0.096. Two occurrences (15.4%) from eastern Washington are from areas with a projected decrease of -0.051 to -0.073. Five other populations from the central Columbia Plateau (38.5%) are from areas with a projected decrease in moisture of -0.028 to -0.050 (Figure 2).

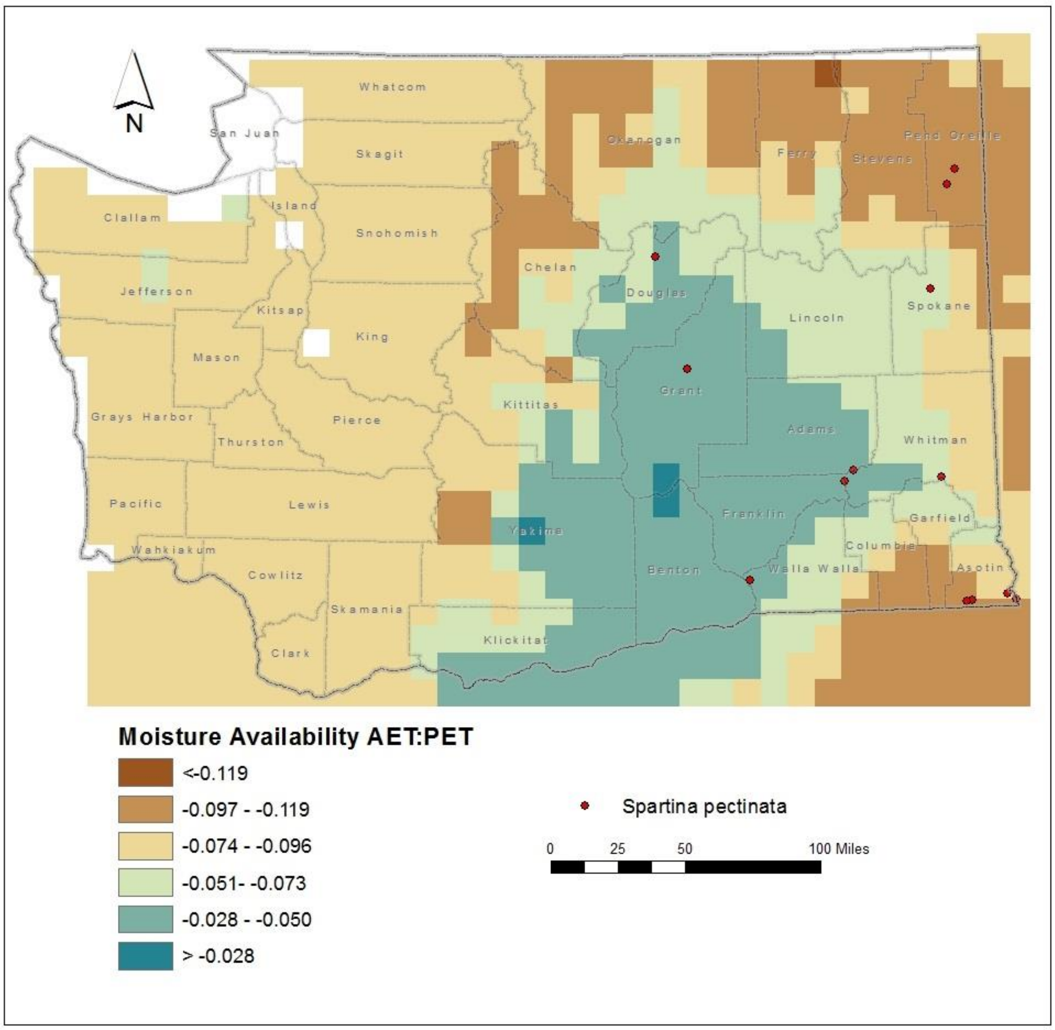

Figure 2. Exposure of *Spartina pectinata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Spartina pectinata* are found at 335-2080 feet (103-630 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Spartina pectinata* is found on sandy or silty bars or rocky terraces along riverbanks, sloughs, wet meadows on the margins of lakes, or alkaline flats and cattail-bulrush thickets bordering rivers (Camp and Gamon 2011; Washington Natural Heritage Program 2021). These habitats correspond with the North American Arid West Emergent Marsh and Northern Columbia Plateau Basalt Pothole Ponds ecological systems (Rocchio and Crawford 2015). Populations are separated by 4-102 miles (6.2-165 km). Most populations in Washington are associated with rivers or ponds and are naturally isolated by intervening uplands that present a barrier to dispersal between watersheds.

B2b. Anthropogenic barriers: Neutral.
The range of *Spartina pectinata* is fragmented by human infrastructure, including dams, farms, roads, and cities. Dispersal across the human landscape is probably less significant than natural barriers to dispersal associated with river drainages and isolated ponds and lakes.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
The inflorescence of *Spartina pectinata* is a panicle bearing numerous 1-flowered spikelets consisting of a long-awned upper glume and unawned lemma and palea surrounding the 1-seeded fruit (caryopsis). At maturity, spikelets are shed as a single unit, with the awned glume potentially catching on the fur or feathers of animals for dispersal. Fruits may also be spread passively by gravity, strong winds, or water, potentially over long distances in riverine habitats. The majority of reproduction, however, is vegetative, as fertile caryopses are often not produced (Barkworth 2003).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Spartina pectinata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All of the known occurrences in the state (100%) are found in areas that have experienced average (57.1-77°F/31.8-43.0°C) temperature variation during the past 50 years and are considered at neutral vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The riverbank, pond, and slough habitat of *Spartina pectinata* in eastern Washington may be associated with cold soils and cool air drainage. These areas could be adversely affected by warmer temperatures in the future.

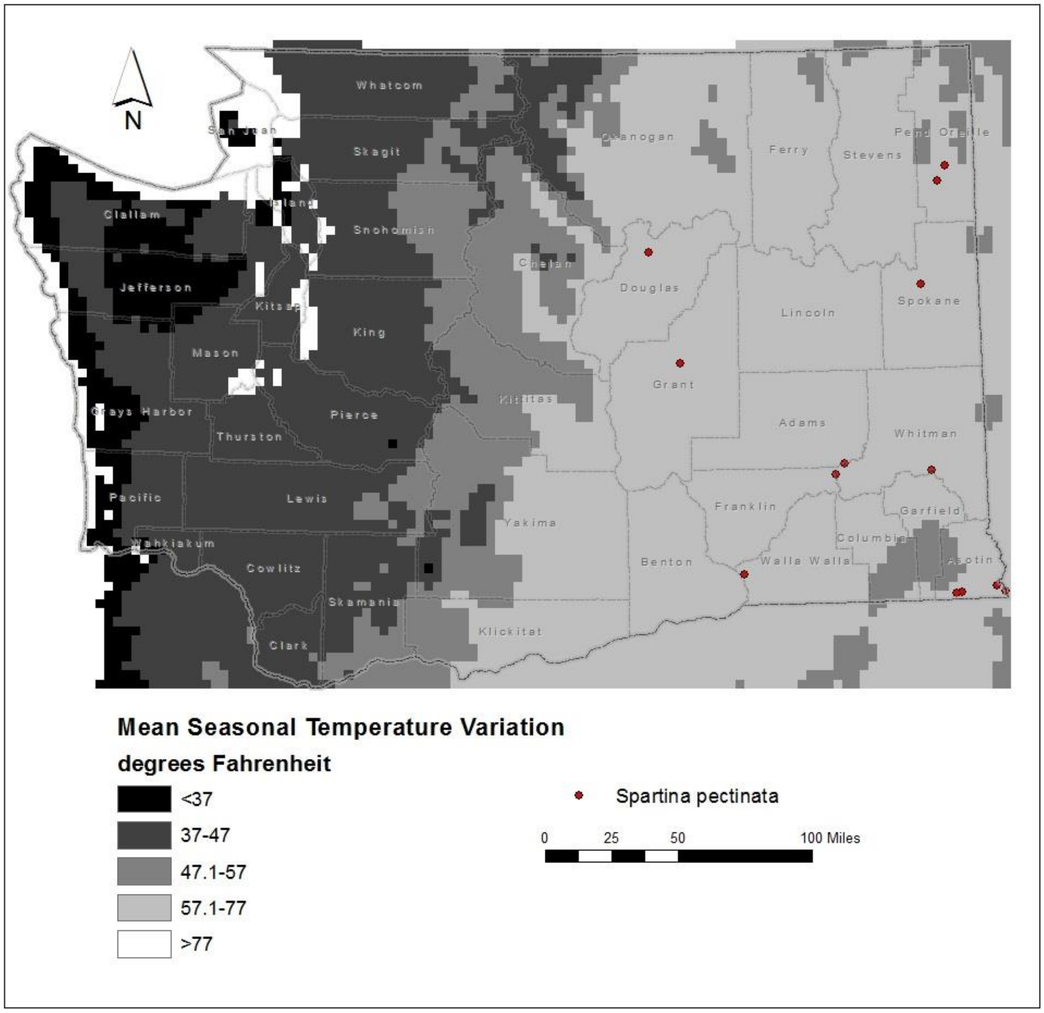

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Spartina pectinata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Nine of the 13 populations of *Spartina pectinata* in Washington (69.2%) are found in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at somewhat increased vulnerability to climate change. Two occurrences from the central Columbia Plateau (15.4%) are from areas with small variation in precipitation over the same period (4-10 inches/100-254 mm) and are at increased risk from climate change. Two other populations from northeastern Washington (15.4%) are from areas with average (21-40

inches/508-1016 mm) precipitation variation and are at neutral vulnerability to climate change (Young et al. 2016).

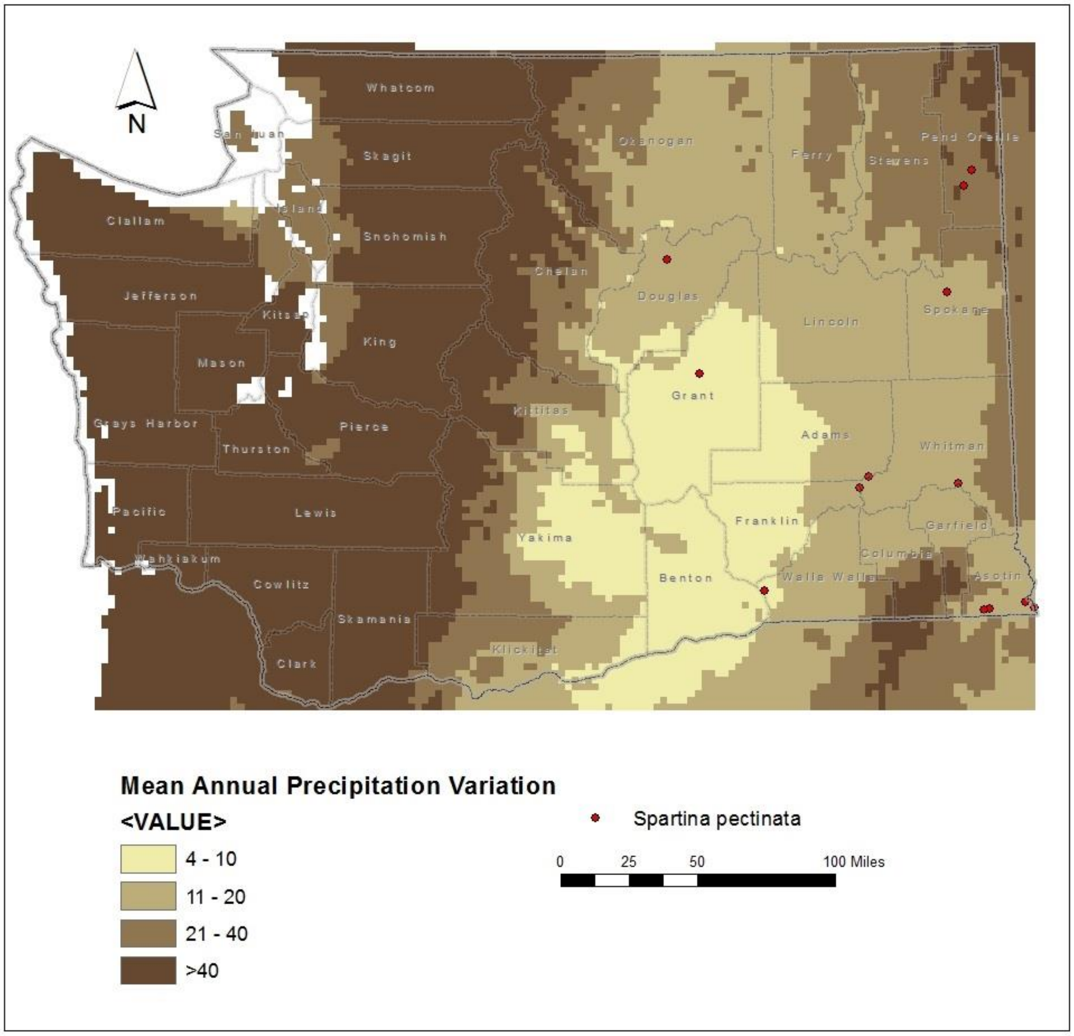

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Spartina pectinata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
Populations of *Spartina pectinata* along rivers are associated with seasonal flooding which may be important in preventing shore sites from shifting towards wet meadow or aquatic habitats. River and pond shore populations may also be vulnerable to changes in the amount or timing or precipitation (including snowmelt upstream) and increased temperatures that would exacerbate

drought (Rocchio and Ramm-Granberg 2017). Lowered water tables could result in shifts from emergent marsh vegetation to wet meadows or riparian shrub or forest systems (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Increase.
Most populations of *Spartina pectinata* in Washington are associated with periodic disturbance from annual flooding along the shores of large rivers or ponds. 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: Somewhat Increase.
Most of the areas in eastern Washington where *Spartina pectinata* grows has relatively low winter snowfall. Reductions in the amount of snow or timing of snowmelt in mountainous areas at the head of drainages could make downstream *S. pectinata* habitat drier in the future. In many areas, however, existing dams regulate seasonal high water flows and make snowmelt flooding less significant.

C3. Restricted to uncommon landscape/geological features: Neutral.
Washington populations of *Spartina pectinata* are mostly found on Quaternary alluvium or soils derived from Grande Ronde basalt (Washington Division of Geology and Earth Resources 2016). Both of these geologic types are widespread in the eastern half of the state.

C4a. Dependence on other species to generate required habitat: Neutral.
The emergent marsh habitat of *Spartina pectinata* is maintained primarily by hydrologic factors, rather than other species.

C4b. Dietary versatility: Not applicable for plants

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

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Spartina pectinata* are dispersed as part of an entire spikelet (consisting of an awned glume and a single floret). The awn helps adhere the spikelet to passing animals. Fruits might also be dispersed by flowing water or on mud on waterfowl. *S. pectinata* is not limited to a single seed vector species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. *Spartina pectinata* is not a preferred forage species for livestock or native herbivores because of its coarse foliage, hard culms, and wet habitat (Walkup 1991).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Spartina pectinata is sensitive to competition from some invasive plant species (Camp and Gamon 2011). 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 of riparian shrublands or woodlands (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
No genetic data are available for Washington populations. *Spartina pectinata* is a polyploid with three cytotypes: tetraploid (4*x* = 40), hexaploid (6*x* = 60) and octoploid (8*x* = 80) (Graves et a. 2016). Studies in the Midwest have detected high genome sizes between populations (Kim et al. 2010). Populations from Washington and the Pacific Northwest are somewhat disjunct from the core of the species' range (Barkworth 2003) and are likely to have less genetic diversity due to genetic drift or founder effects.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Range-wide, *Spartina pectinata* has high genetic diversity due to its ability to cross-pollinate over long distances and its multiple ploidy levels (see section C5a).

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 changes have been detected in phenology in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Three populations of *Spartina pectinata* in Washington have not been relocated in more than 40 years and are historical or possibly extirpated. Across the Northwest, the range of this species has decreased due to habitat destruction (Roché et al. 2019).

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

References

Barkworth, M.E. 2003. *Spartina*. Pp.240-250. In: Barkworth, M.E., K.M. Capels, S. Long, and M.B. Piep, eds. Flora of North America North of Mexico. Volume 25 Magnoliophyta: Commelinidae (in part): Poaceae, part 2. Oxford University Press, New York. 783 pp.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Graves, H., A.L. Rayburn, J.L. Gonzalez-Hernandez, G. Nah, D-S. Kim, and D.K. Lee. 2016. Validating DNA polymorphisms using KASP assay in prairie cordgrass (*Spartina pectinata* Link) populations in the U.S. Frontiers Plant Science 6 (1271): 1-12. doi:10.3389/fpls.2015.01271

Kim, S., A. Lane Rayburn, and D.K. Lee. 2010. Genome size and chromosome analyses in prairie cordgrass. Crop Science 50(6): 2277-2282.

Roché, C.T., R.E. Brainerd, B.L. Wilson, N. Otting, and R.C Korfhage. 2019. Field Guide to the Grasses of Oregon and Washington. Oregon State University Press, Corvallis, OR. 460 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Walkup, C.J. 1991. *Spartina pectinata*. In: Fire Effects Information System (FEIS). US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (https://www.fs.fed.us/database/feis/plants/graminoid/spapec/all.html). Accessed 27 October 2021.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021-. *Spartina pectinata*. In: Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=spartina%20pectinata). Accessed 26 October 2021.

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

Trillium albidum ssp. *parviflorum* (Small-flowered trillium)

Date: 28 February 2021

Synonyms: *Trillium parviflorum*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G4G5T2T3/S2S3

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change	**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: Sensitivity and Adaptive Capacity	
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	Neutral
4a. Dependence on others species to generate required habitat	Neutral
4b. Dietary versatility	Not Applicable
4c. Pollinator versatility	Neutral
4d. Dependence on other species for propagule dispersal	Neutral/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	Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
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: All 48 of the occurrences of *Trillium albidum* ssp. *parviflorum* in Washington (100%) occur in areas with a projected temperature increase of <3.9° F (Figure 1).

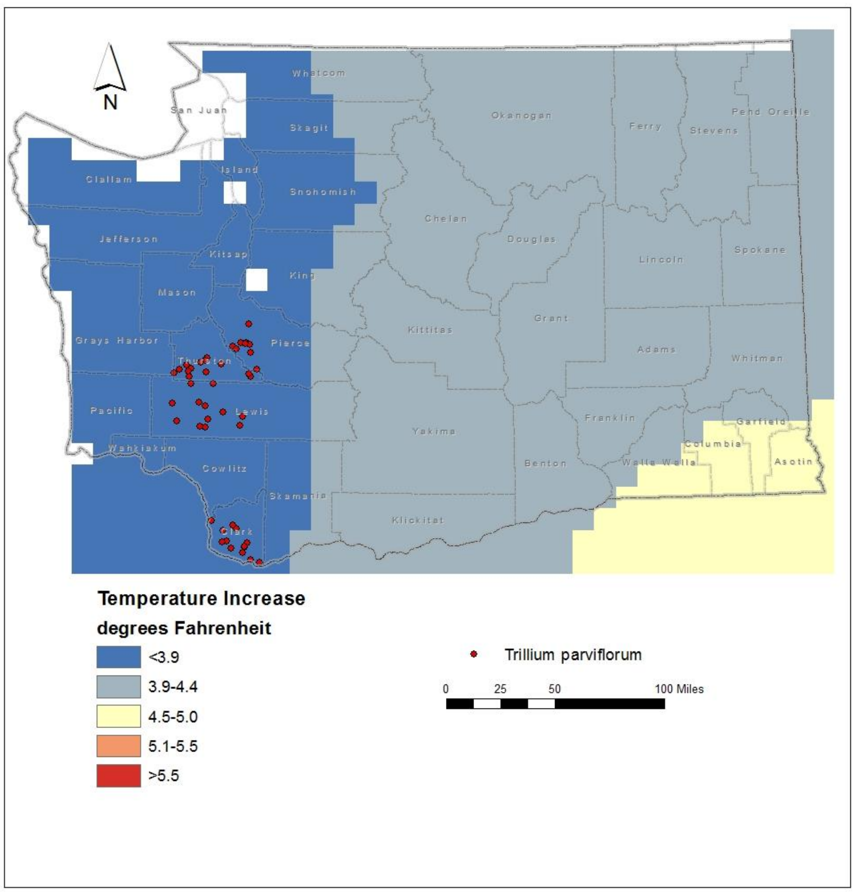

Figure 1. Exposure of *Trillium albidum* ssp. *parviflorum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 48 of the Washington occurrences of *Trillium albidum* ssp. *parviflorum* (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 -0.096 (Figure 2).

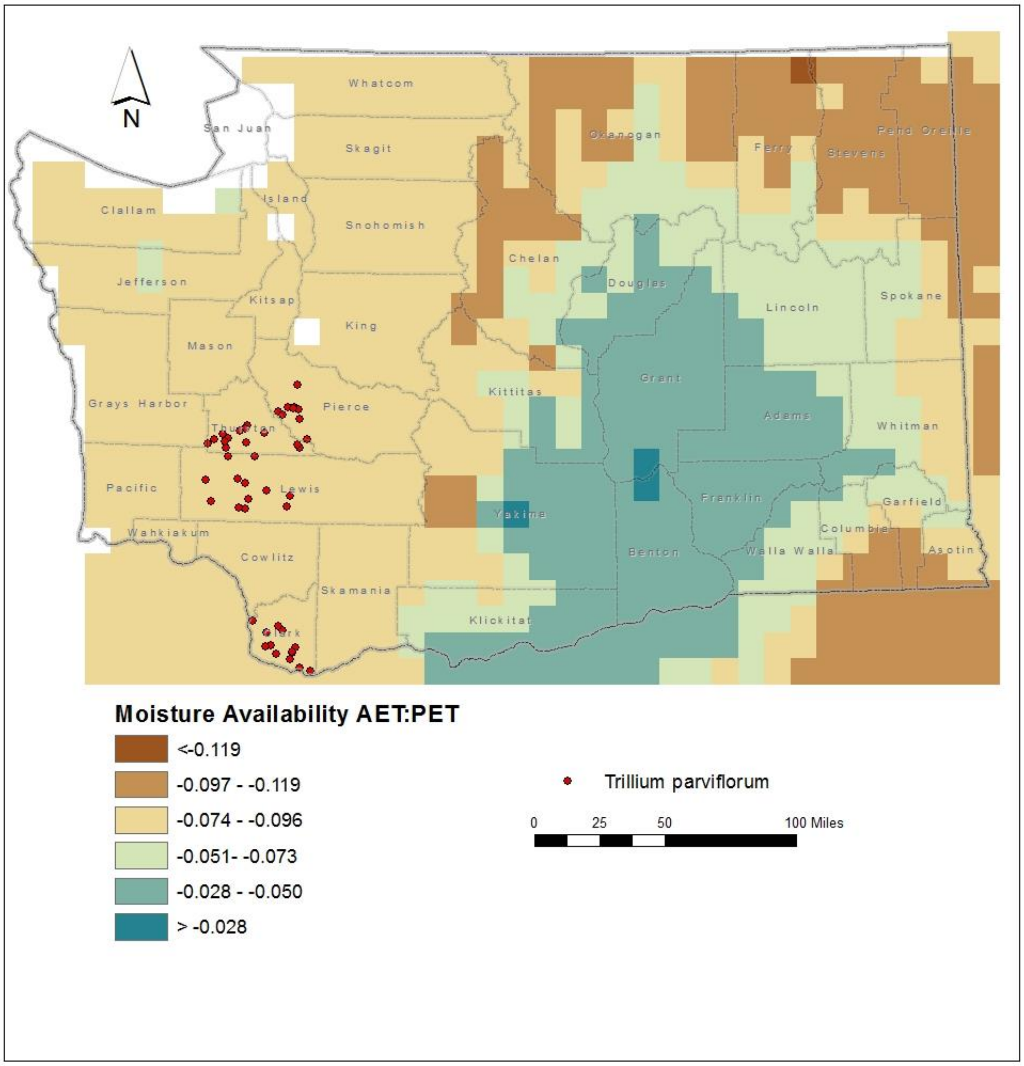

Figure 2. Exposure of *Trillium albidum* ssp. *parviflorum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Trillium albidum* ssp. *parviflorum* are found at 25-700 feet (8-215 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Trillium albidum* ssp. *parviflorum* is found in moist, shady Oregon white oak (*Quercus garryana*) and Oregon ash (*Fraxinus latifolia*) forests on alluvial soils along streams or in low areas that may be periodically flooded in winter (Camp and Gamon 2011). Populations may also occur in moist prairie grasslands bordering deciduous forests. These habitats are a component of the North Pacific Lowland Riparian Forest and Shrubland and Willamette Valley Wet Prairie ecological systems (Rocchio and Crawford 2015). Individual populations are separated by 0.6-68 km (0.3-42 miles). Populations are embedded within a matrix of upland forest, prairie, and urbanized landscapes that create a barrier for long-distance dispersal between population clusters in the South Puget Sound (Thurston, Lewis, and Pierce counties) and southern Puget Trough/Vancouver area (Clark County).

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Trillium albidum* ssp. *parviflorum* in Washington has become increasingly fragmented through the conversion of mesic oak-ash woodlands and prairie to agriculture, roads, and urbanization. These anthropogenic barriers probably impose a more significant constraint on seed dispersal by insects within Washington, but natural barriers (such as the Columbia River) may be more significant over larger geographic areas (Bledsoe 1993).

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Trillium albidum ssp. *parviflorum* produces a fleshy capsule with many seeds. *Trillium* species produce lipid or protein-rich structures called elaiosomes on their seeds that provide food for ants or wasps. These insects may transport the seeds short distances to their nests. New seedlings of *Trillium ovatum* and other species tend to be found close to mature *Trillium* plants, suggesting that dispersal failed, or the insects ate the elaisomes on site without moving the seed (Mesler and Lu 1983). Researchers in eastern North America have suggested that deer may feed on *Trillium* fruits and transport seeds more than 3 km before defecating them. Otherwise, the seeds of *Trillium* appear to have limited ability for dispersal over 100 meters.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Trillium albidum* ssp. *parviflorum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 48 of the known occurrences (100%) are found in areas that have experienced small (37-47˚F/20.8-26.3˚C) temperature variation during the past 50 years and are considered at increased risk from climate change.

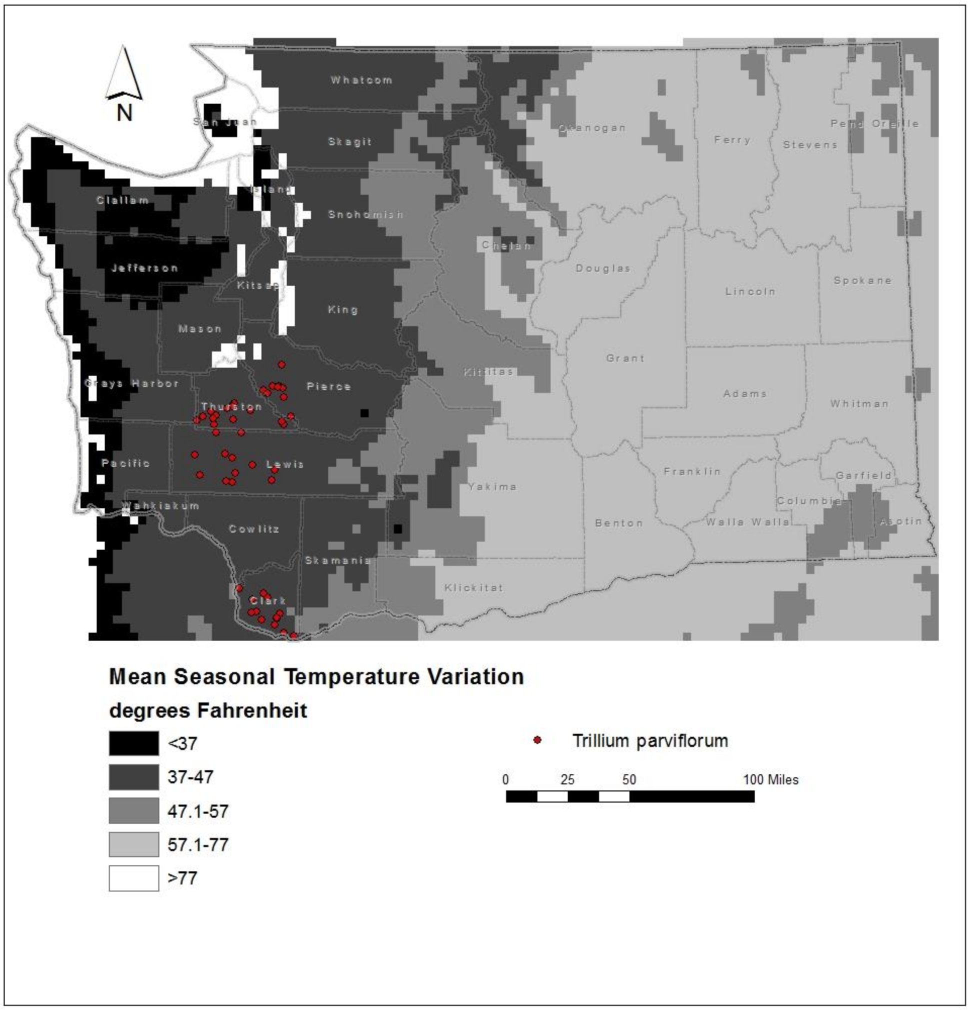

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Trillium albidum ssp. parviflorum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The microsites occupied by *Trillium albidum* ssp. *parviflorum* are often associated with cool, shaded conditions and seasonally flooded soils in winter and early spring. These sites would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
Forty-six of the 48 populations of *Trillium albidum* ssp. *parviflorum* in Washington (95.8%) are found in areas that have experienced greater than average (>40 inches/1016 mm) precipitation variation in the past 50 years (Figure 4). Two other occurrences (4.2%) are from areas with

average precipitation variation during the same period. According to Young et al. (2016), all of these occurrences are at neutral vulnerability from climate change.

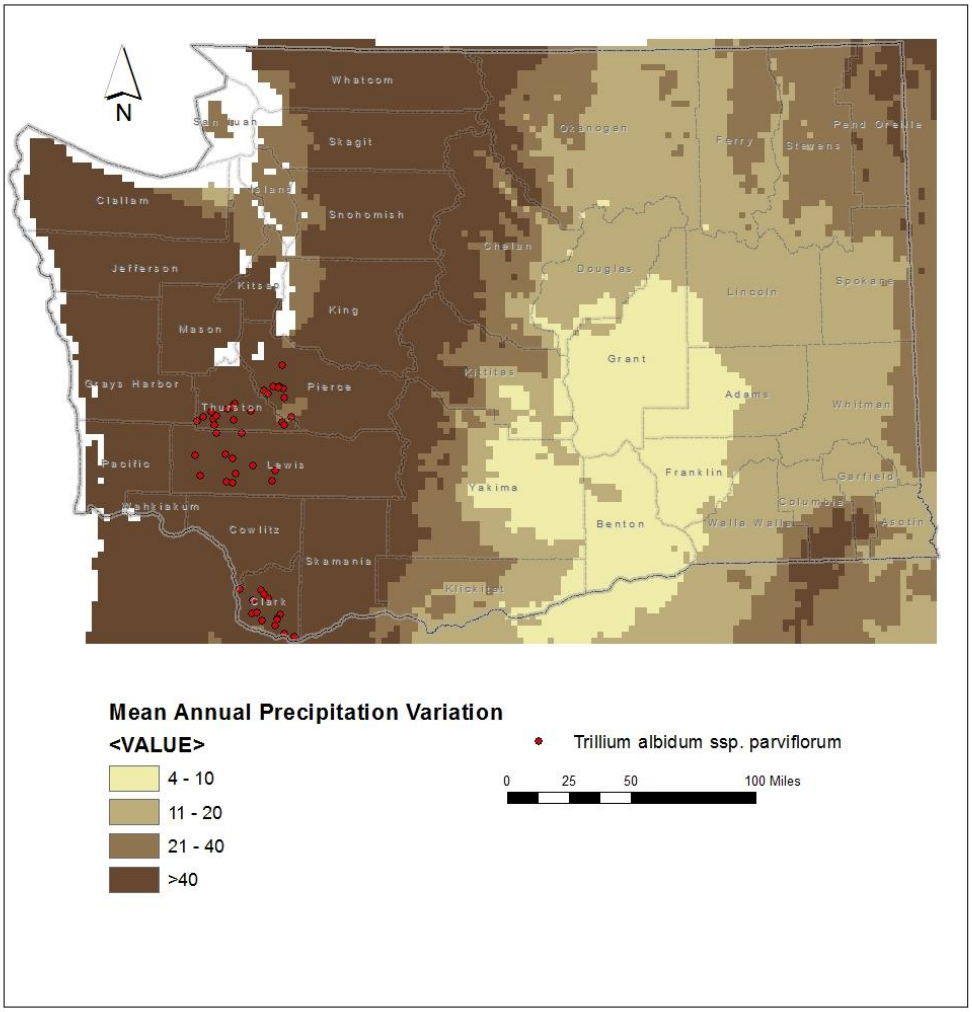

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Trillium albidum* ssp. *parviflorum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The riparian forest habitat occupied by *Trillium albidum* ssp. *parviflorum* is primarily dependent on precipitation, but could be impacted by early snowmelt in headwater streams. More severe winter storms or early season flooding could change channel sedimentation or erosion, resulting in a narrower riparian corridor. Decreased summer precipitation could shift these communities to drier forests and increased fire frequency could covert forests to wet meadows (Rocchio and Ramm-Granberg 2017). Willamette Valley wet prairie sites could

expand due to higher winter precipitation creating more water-logged soils, but a decrease in summer rainfall or increased temperature and drought could result in changes in species composition towards more xeric meadows (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Trillium albidum ssp. *parviflorum* is more dependent on adequate precipitation than natural disturbances to maintain its wet forest and prairie/forest ecotone habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The range of *Trillium albidum* ssp. *parviflorum* in lowland valleys of western Washington receives relatively low amounts of snow in winter (though very high winter rainfall). Populations along perennial streams in the Puget Trough could be indirectly affected by changes in the timing of snowmelt runoff from mountain headwaters, leading to earlier flooding events and earlier onset of lower summer flows (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
In the South Puget Sound area, *Trillium albidum* ssp. *parviflorum* is found primarily on Fraser-age Pleistocene glacial till. At the south end of the Puget Trough in Clark County, populations are mostly associated with Missoula glacial flood deposits (Washington Division of Geology and Earth Resources 2016). Both formations are relatively widespread in the valleys of western Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Trillium albidum* ssp. *parviflorum* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Trillium albidum ssp. *parviflorum* has a sweet floral scent, similar to cloves (Bledsoe 1993). The aroma, in conjunction with the open flowers, suggest pollination by a variety of unspecialized pollinators (Soukup 1980).

C4d. Dependence on other species for propagule dispersal: Neutral/Somewhat Increase.
Trillium seeds are dispersed primarily by ants feeding on oil-rich bodies (elaiosomes) on the seed (Bledsoe 1993, Mesler and Lu 1983). Yellowjackets and deer have also been observed transporting seed of eastern *Trillium* species (Vellend et al. 2003; Zettler et al. 2001). *Trillium albidum* ssp. *parviflorum* is dependent on animals for seed dispersal, but the number of potential seed vector species is not known.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Thomas and Carey (1996) observed seed predation on plants monitored at Fort Lewis, but otherwise impacts from herbivory appear to be low.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Forested wetland sites in western Washington are vulnerable to invasion by reed canarygrass (*Phalaris arundinacea*) and other non-native species.

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

C5a. Measured genetic variation: Somewhat Increase.
Trillium albidum ssp. *parviflorum* populations from Washington are genetically similar to each other, suggesting a period of inbreeding (Bledsoe 1993). The Washington occurrences also contain one unique karyotype and are missing another genetic marker typical of populations from southern Oregon. Overall, the Washington populations have somewhat less genetic variability than other occurrences found across the range of *T. albidum* (Bledsoe 1993).

C5b. Genetic bottlenecks: Unknown.
The genetic similarity of Washington populations may be the result of past inbreeding that could have been the result of a genetic bottleneck (Bledsoe 1993).

C5c. Reproductive System: Neutral.
Trillium albidum ssp. *parviflorum* is an outcrosser with relatively large and showy flowers pollinated by insects. Data from Bledsoe (1993) indicate that Washington populations have a largely homozygous genome and lack some diagnostic chromosome markers found in southern Oregon populations. Bledsoe (1993) suggested that the genetic and morphologic characters of *T. parviflorum* overlapped enough with *T. albidum* to suggest that the former should be treated as a subspecies, rather than a full species as originally proposed by Soukup (1980).

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 in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
The distribution of *Trillium albidum* ssp. *parviflorum* has not changed notably in the last 50 years.

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

References

Bledsoe, K.E. 1993. Morphological and cytological variation in *Trillium albidum* Freeman (Liliaceae). Master's Thesis, Oregon State University, Corvallis, OR. 65 pp.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Mesler, M.R. and K.L. Lu. 1983. Seed dispersal of *Trillium ovatum* (Liliaceae) in second-growth redwood forests. American Journal of Botany 70(10): 1460-1467.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Soukup, V.G. 1980. A new *Trillium* (Liliaceae) from the northwestern United States. Brittonia 3(3): 330-333.

Thomas, T.B. and A.B. Carey. 1996. Endangered, threatened, and sensitive plants of Fort Lewis, Washington: Distribution, mapping, and management recommendations for species conservation. Northwest Science 70(2): 148-163.

Vellend, M., J.A. Myers, S. Gardescu, and P.L. Marks. 2003. Dispersal of *Trillium* seeds by deer: Implications for long-distance migration of forest herbs. Ecology 84(4): 1067-1072.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.
http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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.

Zettler, J.A., T.P. Spira, and C.R. Allen. 2001. Yellowjackets (*Vespula* spp.) disperse *Trillium* (spp.) seeds in eastern North America. American Midland Naturalist 146(2): 444-446.

Climate Change Vulnerability Index Report

Utricularia intermedia (Flat-leaved bladderwort)

Date: 18 February 2021

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington   Heritage Rank: G5/S2S3

Index Result: Moderately Vulnerable   Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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	38.5
	<3.9° F (2.2°C) warmer	61.5
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	7.7
	-0.074 to - 0.096	84.6
	-0.051 to - 0.073	7.7
	-0.028 to -0.050	0
	>-0.028	0
Section B: Indirect Exposure to Climate Change		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral/Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		Neutral/Somewhat Increase
2ai Change in historical thermal niche		Increase/Greatly 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		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others 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		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: Documented or Modeled Response	
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: Eight of the 13 occurrences of *Utricularia intermedia* in Washington (61.5%) occur in areas with a projected temperature increase of <3.9˚ F (Figure 1). The other 5 occurrences (38.5%) are from areas with a projected temperature of 3.9-4.4˚ F.

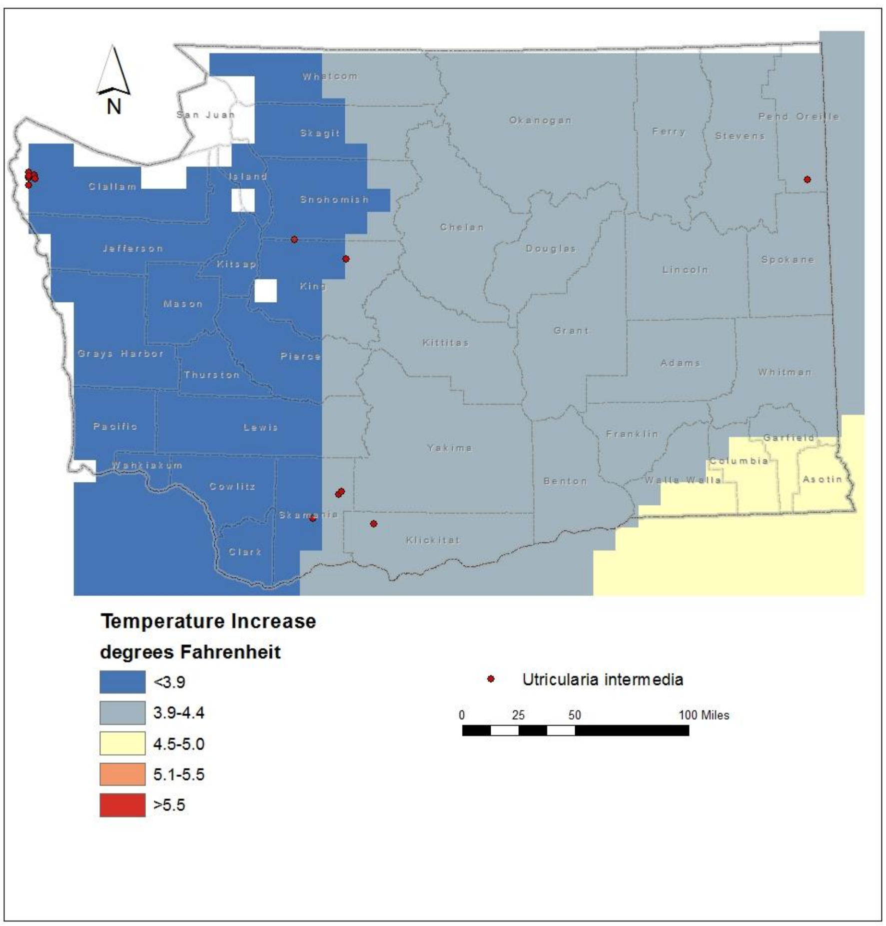

Figure 1. Exposure of *Utricularia intermedia* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Eleven of the 13 occurrences of *Utricularia intermedia* (84.6%) in western 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). One historical occurrence (7.7%) from Klickitat County is from an area with a projected decrease in moisture of -0.051 to -0.073. One other population from NE Washington (7.7%) is from an area with a projected decrease of -0.097 to -0.119.

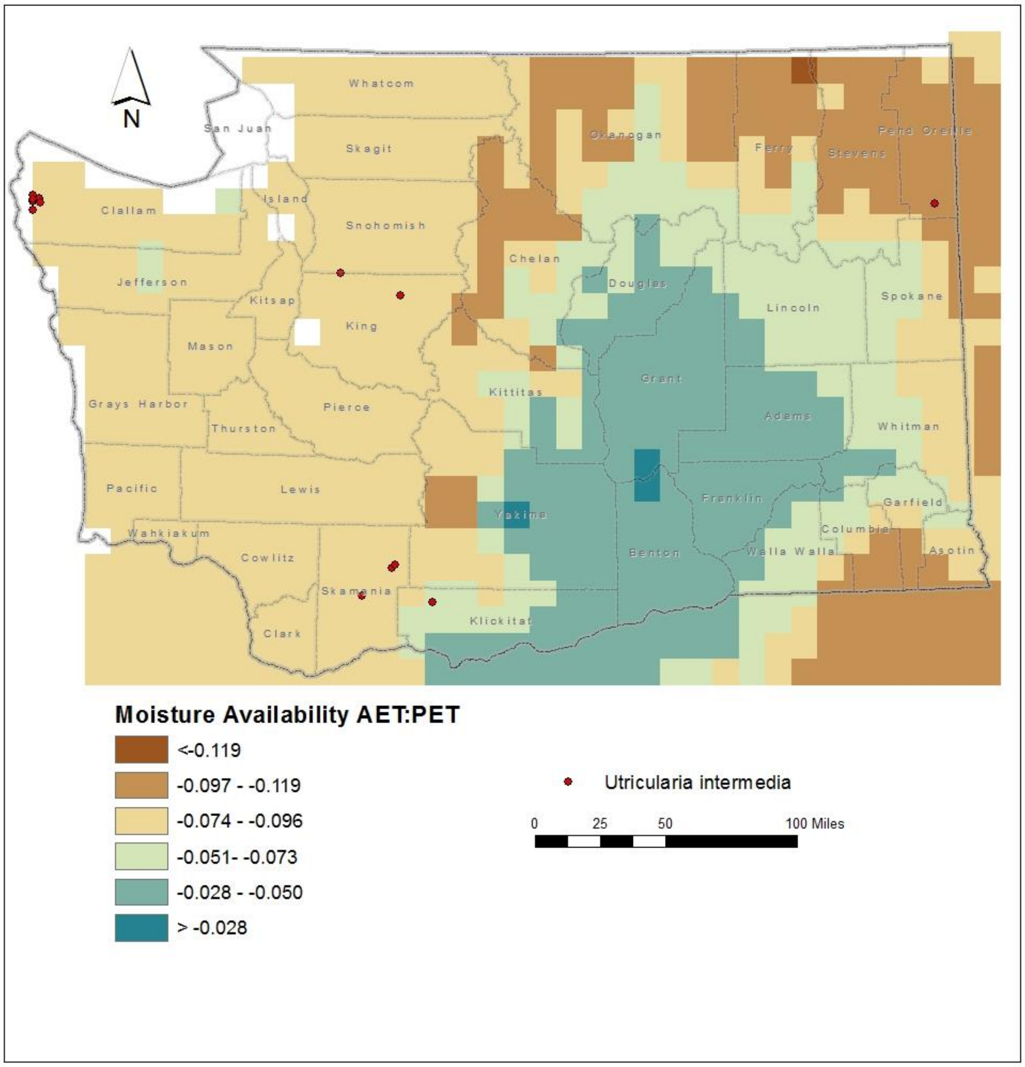

Figure 2. Exposure of *Utricularia intermedia* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Utricularia intermedia* are found at 10-4100 feet (3-1300 m) and would not be inundated by projected sea level rise. At least six occurrences are found along the shores of Lake Ozette (elevation 10 feet) on the Olympic Peninsula, 1.3-4 miles east of the Pacific Ocean. These populations could be vulnerable to storm surges or severe weather related to climate change.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Utricularia intermedia* is an emergent aquatic species found in shallow ponds, lakeshores, fens, and flooded marshes (Camp and Gamon 2011, Fertig & Kleinknecht 2020). These habitats are a component of the North American Arid West Emergent Marsh, Rocky Mountain Subalpine-Montane Fen, and Temperate Pacific Freshwater Aquatic Bed ecological systems (Rocchio and Crawford 2015). Individual populations are separated by 3-332 km (2-205 miles). Most of the matrix vegetation between occurrences is unsuitable and presents a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral/Somewhat Increase.
The range of *Utricularia intermedia* in Washington is associated with small ponds, lakes, fens and marshes. Populations are widely scattered and isolated, largely due to natural barriers. The human footprint from roads and commercial or agricultural development, has also fragmented the landscape and is an impediment to dispersal, though probably of lesser significance than natural factors.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral/Somewhat Increase.
Like other aquatic species of *Utricularia, U. intermedia* produces numerous, small seeds within dry fruiting capsules. These seeds lack ornamentation, such as spines, or hooks to attach to animals. Seed could be transported long distances in mud on the feet of waterfowl. In lakes or ponds, seeds could also be distributed by water (Neid 2006). This species also produces asexual, bud-like, vegetative structures called turions that can be transported by water or aquatic birds in the same manner as seeds (Adamec 2020). Most dispersal is probably within less than 1000 m of the parent plant, but birds could transport some seeds or turions over many kilometers, accounting for the patchy and disjunct range of *U. intermedia* in the state.

C2ai. Historical thermal niche: Increase/Greatly Increase.
Figure 3 depicts the distribution of *Utricularia intermedia* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Six of the 13 known occurrences (46.1%) from Washington are found in areas that have experienced very small (<37˚F/20.8˚C) temperature variation during the past 50 years and are considered at greatly increased risk from climate change (Young et al. 2016). Five occurrences from the Cascade Range (38.5%) are from areas with small temperature variation (37-47˚F/20.8-26.3˚C) over the same period and are at increased vulnerability. One historical occurrence from

Klickitat County (7.7%) has experienced slightly lower than average temperature variation (47.1-57˚F/26.3-31.8˚C) and has somewhat increased vulnerability. One occurrence from northeast Washington (7.7%) has had average (57.1-77˚F/31.8-43.0˚C) temperature variation over the last 50 years and is at neutral risk from climate change (Young et al. 2016).

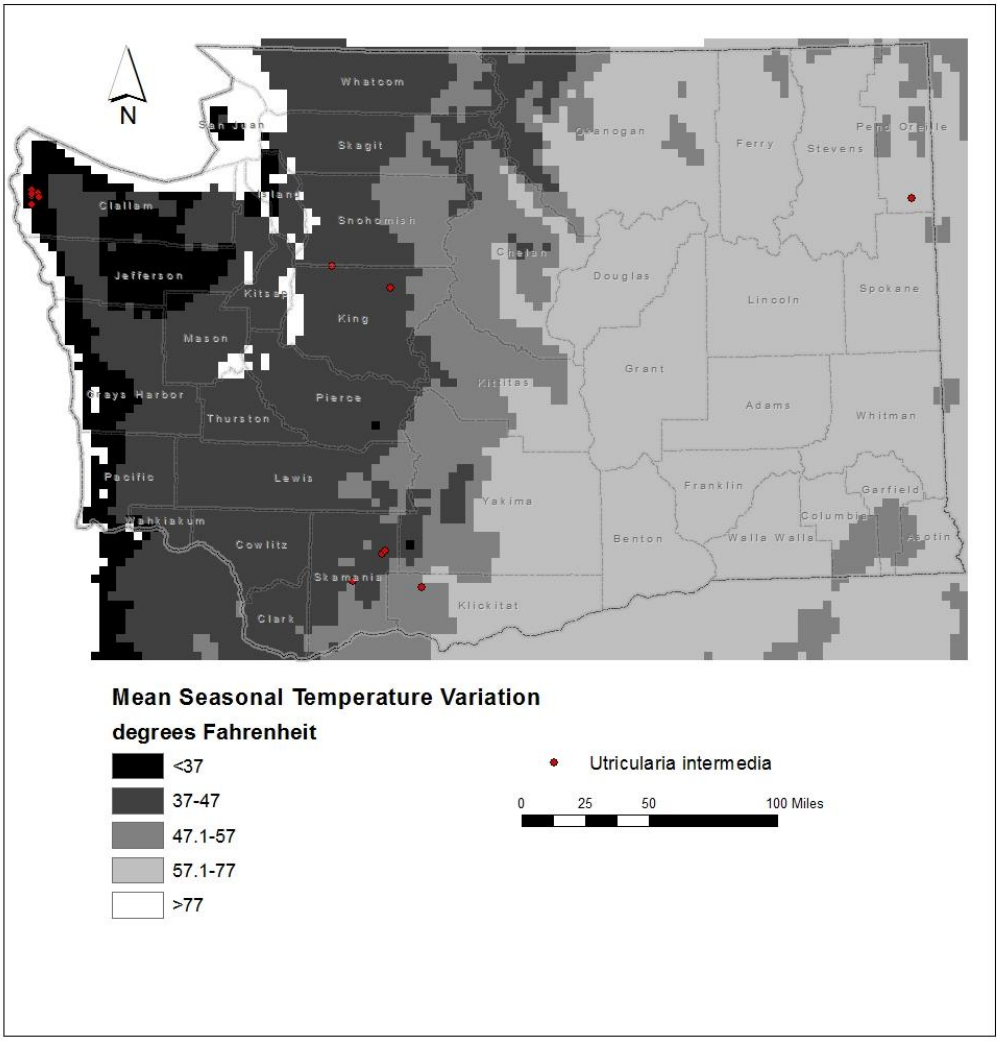

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Utricularia intermedia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The pond, lake, fen, and marsh sites occupied by *Utricularia intermedia* are often associated with cool, shaded conditions or cold air drainage during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
Eleven of the 13 occurences of *Utricularia intermedia* in Washington (84.6%) are found in areas that have experienced greater than average precipitation variation (>40 inches/1016 mm) in the past 50 years (Figure 4). Two other populations (15.4%) are from areas with average (21-40 inches/508-1016 mm) precipitation variation in the same period. According to Young et al. (2016), all of these areas in Washington are at neutral vulnerability to climate change.

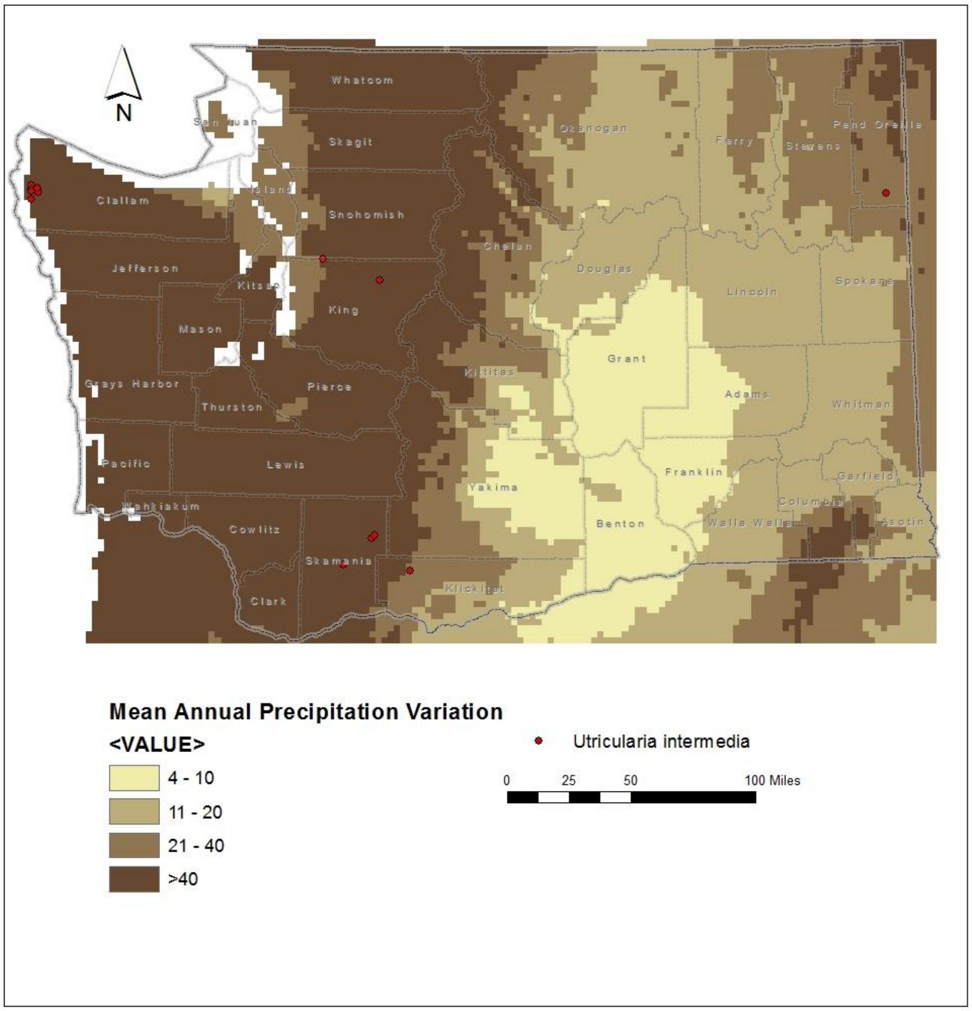

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Utricularia intermedia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Populations of *Utricularia intermedia* from western Washington associated with lakeshores in the Temperate Pacific Freshwater Aquatic Bed ecological system 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. These sites could also be adversely affected by increases in water temperature (Rocchio and Ramm-Granberg 2017). 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 (Rocchio and Ramm-Granberg 2017). The occurrence from northeastern Washington from 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).

C2c. Dependence on a specific disturbance regime: Neutral.
Utricularia intermedia is not dependent on periodic disturbances to maintain its pond, lake, marsh, and fen habitat.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
With the exception of occurrences found along Lake Ozette, the occurrences of *Utricularia intermedia* in Washington occur in areas of moderate to high snowfall. A reduction in overall snowpack or change in the timing of snowmelt would make wetland populations dependent on groundwater recharge more vulnerable to future climate change (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Utricularia intermedia is found in small ponds, lakes, marshes, and fens in the Olympic Peninsula, Cascades, and Canadian Rockies in northeast Washington. Populations in the Olympics and northern Cascades are found primarily on Quaternary alluvium or lacustrine deposits associated with glacial activity. Occurrences from the southern Cascades east of Mount Adams are associated with Quaternary volcanic flows. The single fen occurrence in northeast Washington is found on peat over Missoula Lake flood deposits (Washington Division of Geology and Earth Resources 2016). Except for the fen site, the other geologic settings where *U. intermedia* occur are widespread in the state.

C4a. Dependence on other species to generate required habitat: Neutral.
The habitat occupied by *Utricularia intermedia* is maintained primarily by natural abiotic processes rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Utricularia intermedia has showy flowers with nectar rewards adapted for insect pollination by flies or bees (Adamec 2020). The exact pollinators in Washington are not known,

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds and turions of *Utricularia* species may be dispersed by water within ponds and lakes, or more widely on mud-encrusted birds or mammals (Neid 2006). Dispersal is not limited to a particular animal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Grazing is not considered a significant threat (Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Wetland sites inhabited by *Utricularia intermedia* are vulnerable to competition from reed canarygrass (*Phalaris arundinacea*) (Fertig and Kleinknecht 2020).

C4g. Forms part of an interspecific interaction not covered above: Neutral.
Utricularia intermedia is a carnivorous plant that supplements its photosynthetic production of sugars with capturing and dissolving minute aquatic invertebrates in specialized bladders dispersed among its leaves. The number of potential invertebrate species available as food sources, however, is not limiting.

C5a. Measured genetic variation: Unknown.
Genetic data are not available for Washington occurrences of *Utricularia intermedia*. Studies in Europe have found the genome size of *Utricularia* species to be unusually small relative to other vascular plants (Adamec 2020). Based on genetic data, pollen fertility, and seed viability, *U. intermedia* is thought to be one of the parental taxa of *U. ochroleuca*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Utricularia intermedia produces large, showy flowers that provide a nectar reward for pollinators in a tube-like spur at the back of the corolla. The combination of floral traits and production of fertile pollen strongly suggests this species is primarily insect pollinated (Beretta et al. 2014). This species is presumed to have average genetic diversity based on its outcrossing reproductive strategy.

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 in recent years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Two of the 13 known occurrences of *Utricularia intermedia* are historical and have not been relocated since 1981. Overall, the range of the species in Washington has not changed notably in the last 50 years.

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

References

Adamec, L. 2020. Biological flora of Central Europe: *Utricularia intermedia* Hayne, *U. ochroleuca* R.W. Hartm., *U. stygia* Thor and *U. bremii* Heer ex Kölliker. Perspectives on Plant Ecology, Evolution and Systematics 44 (2020): 1-20.

Beretta, M., G. Rodondi, L. Adamec, and C. Andreis. 2014. Pollen morphology of European bladderworts (*Utricularia* L., Lentibulariaceae). Review of Paleobotany and Palynology 205: 22-30.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Fertig, W. and J. Kleinknecht. 2020. Conservation status and protection needs of priority plant species in the Columbia Plateau and East Cascades ecoregions. Natural Heritage Report 2020-02. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 173 pp.

Neid, S.L. 2006. *Utricularia minor* L. (lesser bladderwort): A technical conservation assessment. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO. 47 pp.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000 --GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

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

Veronica dissecta ssp. *lanuginosa* (Woolly kittentails)

Date: 30 September 2021 Synonym: *Synthyris lanuginosa*

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G4T2/S2

Index Result: Highly Vulnerable. Confidence: Very High

Climate Change Vulnerability Index Scores

Section A: Local Climate	**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: Indirect Exposure to Climate Change		**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: Sensitivity and Adaptive Capacity		
1. Dispersal and movements		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		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on others 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		Neutral
5a. Measured genetic diversity		Somewhat Increase
5b. Genetic bottlenecks		Neutral
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D: Documented or Modeled Response	
D1. Documented response to recent climate change	Somewhat Increase
D2. Modeled future (2050) change in population or range size	Increase
D3. Overlap of modeled future (2050) range with current range	Neutral
D4. Occurrence of protected areas in modeled future (2050) distribution	Neutral

Section A: Exposure to Local Climate Change

A1. Temperature: All ten of the occurrences of *Veronica dissecta* ssp. *lanuginosa* in Washington (100%) are found in areas with a projected temperature increase of < 3.9° F (Figure 1).

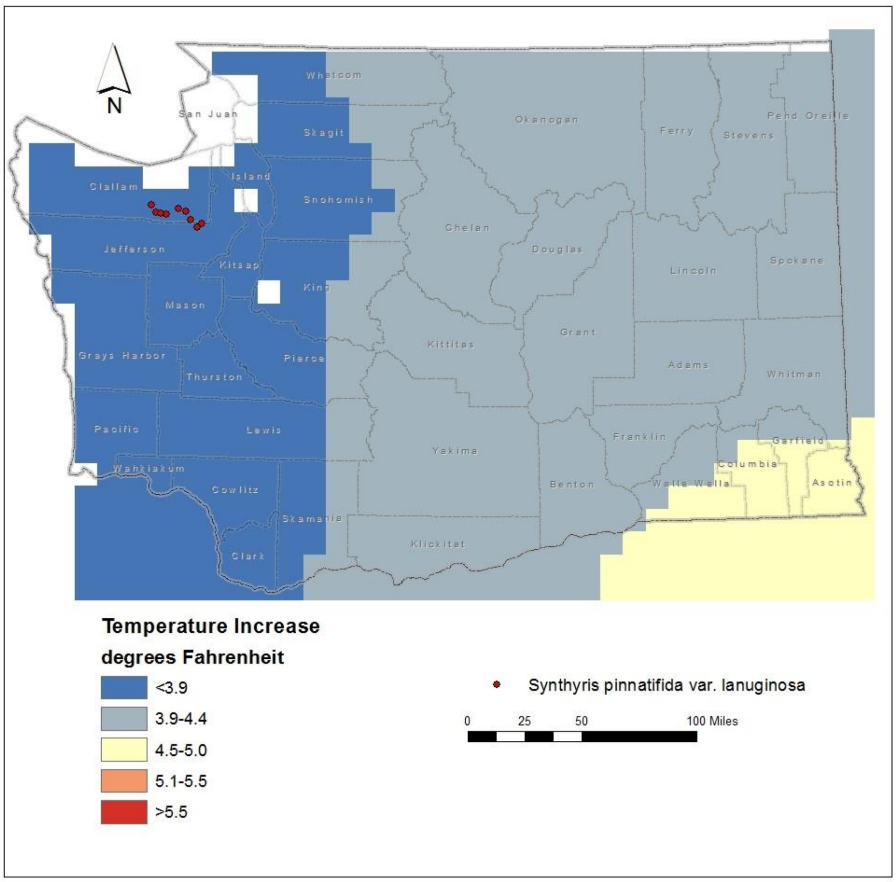

Figure 1. Exposure of *Veronica dissecta* ssp. *lanuginosa* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The ten occurrences of *Veronica dissecta* ssp. *lanuginosa* (100%) 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).

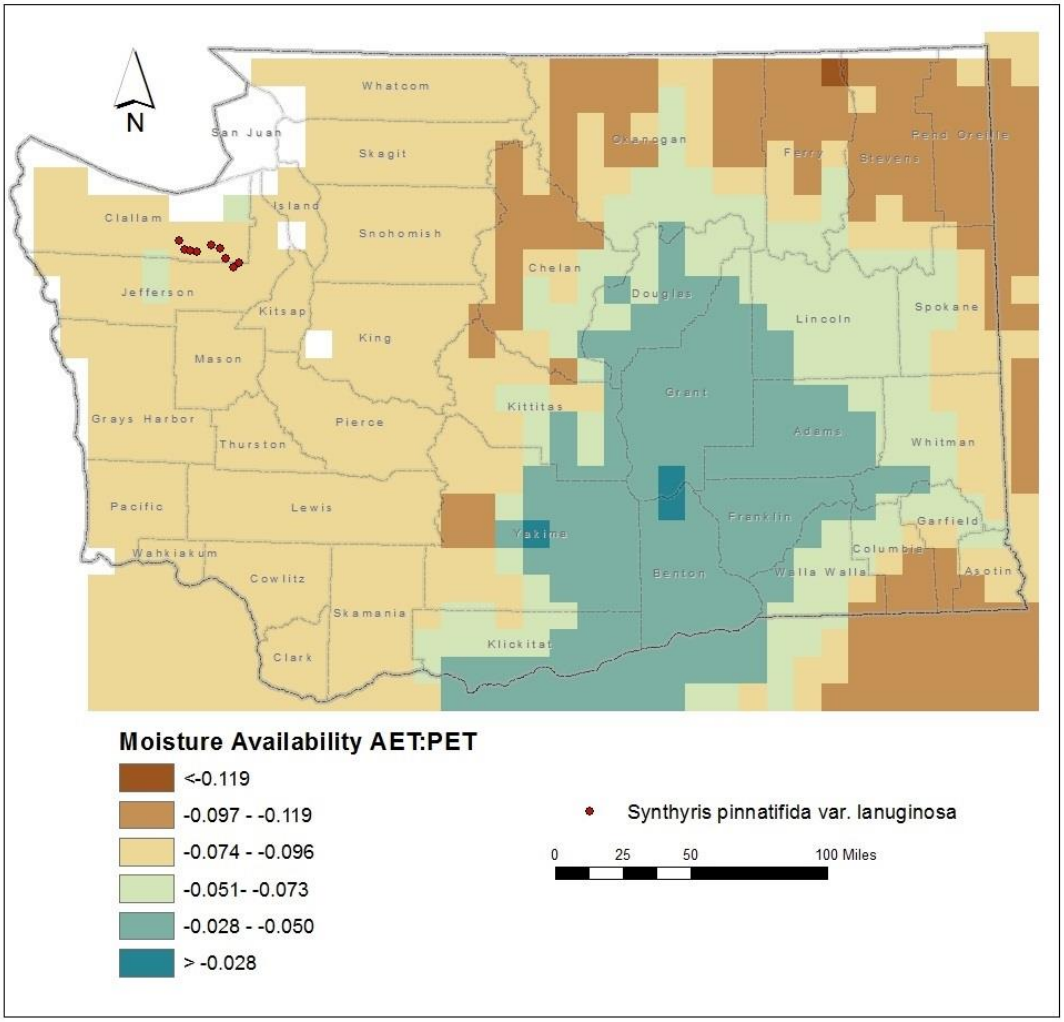

Figure 2. Exposure of *Veronica dissecta* ssp. *lanuginosa* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Veronica dissecta* ssp. *lanuginosa* are found at 4640-6900 feet (1415-2100 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
Veronica dissecta ssp. *lanuginosa* is endemic to the northeastern Olympic Range in Washington, where it is found in alpine cushion plant communities on south or southwest-facing rocky meadows, exposed fell-fields, or talus slopes (Camp and Gamon 2011; Wershow and DeChaine 2018). These habitats are a component of the North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field and Meadow ecological system (Rocchio and Crawford 2015). The entire range of this taxon is restricted to an area of 6 x 21 miles (10 x 33 km) (Washington Natural Heritage Program 2021). Individual occurrences are naturally separated by valleys between alpine ridges, which create a barrier to local dispersal and gene flow (Marlowe and Hufford 2008). The isolation of the Olympic Range also constrains potential migration to other alpine mountain ranges north and east of the Salish Sea/Puget Sound in Washington or British Columbia.

B2b. Anthropogenic barriers: Neutral.
The range of *Veronica dissecta* ssp. *lanuginosa* in Washington is primarily above treeline in Olympic National Park and Olympic National Forest. These areas have some hiking trails but the overall human footprint is small and does not present a significant barrier to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Veronica dissecta ssp. *lanuginosa* plants produce 10-30 flowers per raceme, with each fruit containing 10-16 seeds (Hufford 2019). At maturity, the dry fruit capsules split open to release seeds passively. The seeds lack wings, hooks, barbs, or other structures to facilitate dispersal by animals or wind. Average dispersal distances are probably relatively short (well under 100 m), though longer transport is possible from high winds.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Veronica dissecta* ssp. *lanuginosa* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the 10 known occurrences (70%) are found in areas that have experienced very small (<37˚F/20.8˚C) temperature variation during the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). Three other occurrences (30%) are from areas with small (37-47˚F/20.8-26.3˚C) temperature variation over the same time period and are at increased vulnerability to climate change.

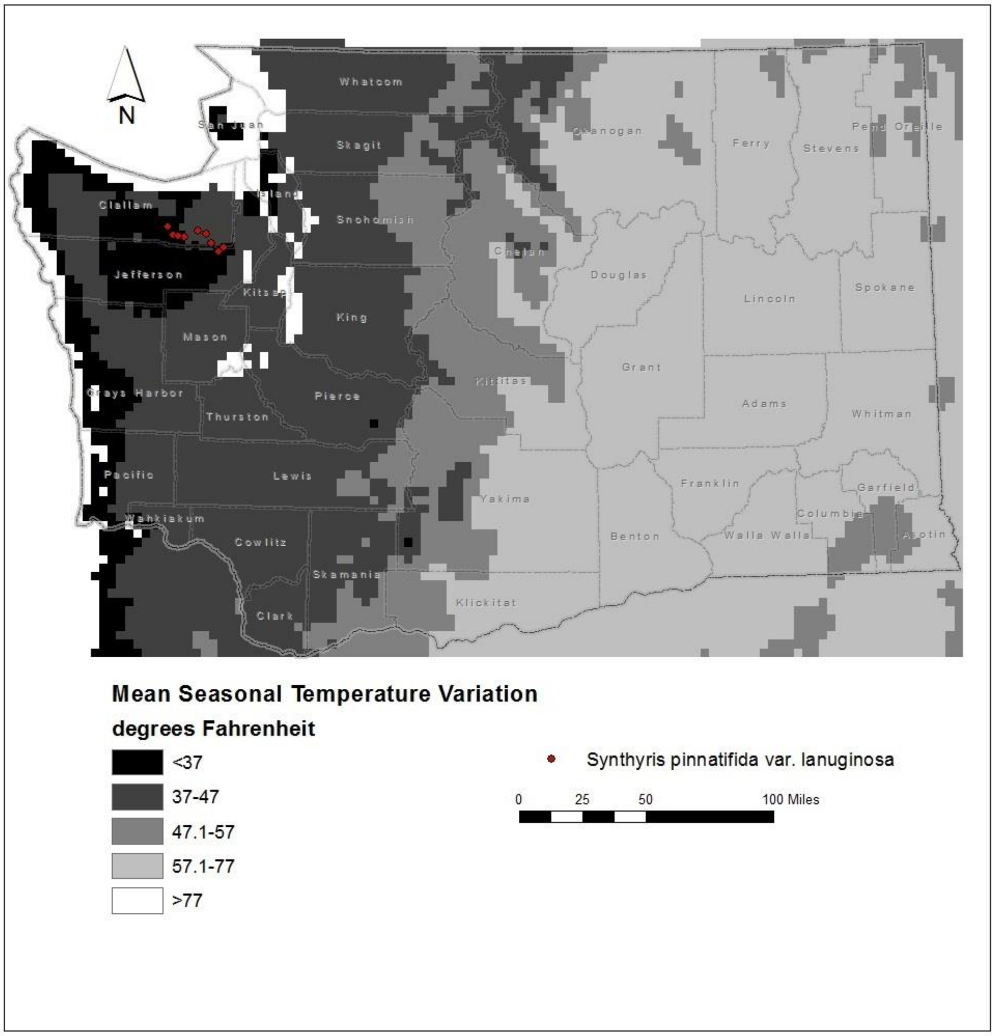

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Veronica dissecta* ssp. *lanuginosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The range of *Veronica dissecta* ssp. *lanuginosa* is restricted to alpine areas exposed to high winds and cold winter temperatures. Most populations occur on southerly slopes that provide a warmer microclimate than other exposures. Increased temperatures could extend the growing season (Rocchio and Ramm-Granberg 2017), but might also put this species under increased moisture stress. A prolonged growing season could favor other plant species expanding into the habitat of *V. dissecta* ssp. *lanuginosa* and lead to increased competition for space and resources.

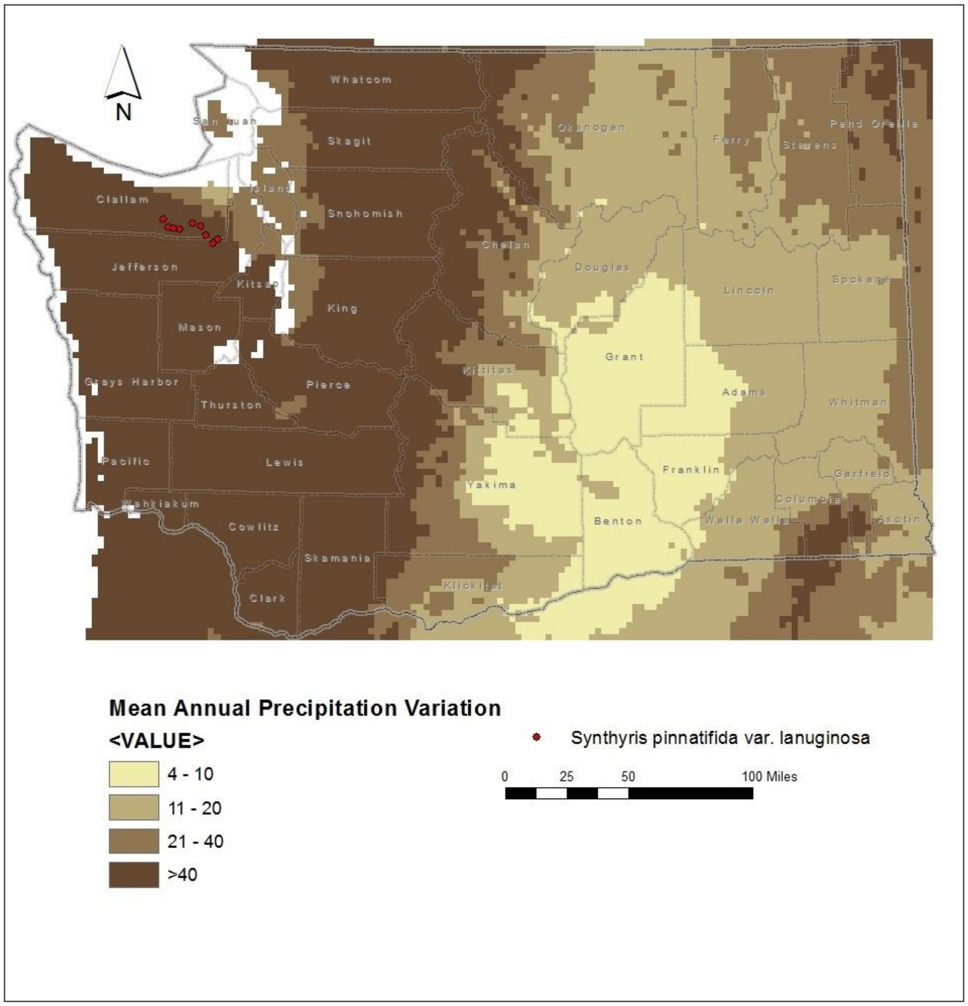

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Veronica dissecta* ssp. *lanuginosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All ten of the occurrences of *Veronica dissecta* ssp. *lanuginosa* in Washington (100%) are found in areas that have experienced greater than average (>40 inches/1016 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these areas are at neutral vulnerability to climate change.

C2bii. Physiological hydrological niche: Somewhat Increase.
Veronica dissecta ssp. *lanuginosa* occurs primarily on exposed south facing rocky slopes that are not associated with perennial streams or a high water table. The species depends on winter snowfall and summer precipitation for its water needs. Snowpacks are likely to be thinner on the wind-exposed slopes occupied by *V. dissecta* ssp. *lanuginosa* than on more protected slopes.

With climate change, the amount of snow may be reduced, or it will melt sooner in the spring. Increased temperatures from climate change are likely to change the timing of snowmelt, leading to earlier runoff (Rocchio and Ramm-Granberg 2017). Changes in the timing or amount of summer precipitation could also impact survival and reproduction of this species and favor competing plants adapted to drier conditions.

C2c. Dependence on a specific disturbance regime: Neutral.
The alpine cushion plant and fell-field habitat of *Veronica dissecta* ssp. *lanuginosa* is maintained by natural, abiotic processes (mostly climate-related) rather than periodic disturbances, such as fire or drought.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The Olympic Mountains average over 10 meters (400 inches) of snow. The alpine areas inhabited by *Veronica dissecta* ssp. *lanuginosa* are on open or steep slopes where snow is more exposed to wind and sun and less likely to accumulate late into the summer, making the local microenvironment drier than surrounding areas. Reductions in the amount of snow, or changes in the timing of snowmelt could make alpine cushion plant and fell-field habitats drier in the future and more prone to invasion by plants from lower elevations (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Veronica dissecta ssp. *lanuginosa* is restricted to alpine exposures of Oligocene and Eocene-age marine sediments (including thin bedded sandstones and shales) found in a semi-circular arc along the east side of the Olympic Mountains (Washington Division of Geology and Earth Resources 2016). Under future climate change, the amount of suitable substrate will become even more reduced as growing conditions become restricted to only the highest peaks in the northeast corner of the Olympics (Wershow and DeChaine 2018).

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine cushion plant and fell-field habitat of *Veronica dissecta* ssp. *lanuginosa* is maintained mostly by natural factors, such as low temperatures, high precipitation, southerly exposures, and high winds erosion, rather than activities of animal species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
The specific pollinators of *Veronica dissecta* ssp. *lanuginosa* are not known. Related *Synthyris* species (now placed in *Veronica*) are pollinated by halictid bees (Hufford and McMahon 2004).

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Veronica dissecta* ssp. *lanuginosa* dehisce when dry to release seeds passively by gravity or wind. These seeds lack wings, barbs, or hooks for dispersal by wind or animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Introduced mountain goats (*Oreamnos americanus*) have been reported grazing on *Veronica dissecta* ssp. *lanuginosa* at one site. Herbivory by other animals is not well documented.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Veronica dissecta ssp. *lanuginosa* occurs mostly in alpine cushion plant and fell-field communities which are likely to become warmer, drier, and have a longer growing season under projected climate change (Wershow and DeChaine 2018). These changes could facilitate spread of lower elevation plants into alpine habitats and increase competition for resources and space (Rocchio and Ramm-Granberg 2017). Herbivory or trampling by introduced mountain goats may be a potential threat (Schreiner et al. 1994).

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

C5a. Measured genetic variation: Somewhat Increase.
Marlowe and Hufford (2008) found relatively limited genetic diversity in *Veronica dissecta* ssp. *lanuginosa* (cited as *Synthyris lanuginosa* in their study) compared to its sister taxa, *Veronica canbyi* and *V. dissecta* (ssp. *dissecta*) from the northern Rocky Mountains of Montana and Idaho. The absence of shared haplotypes between *V. dissecta* ssp. *lanuginosa* and its closest relatives suggests that the event that isolated ssp. *lanuginosa* was not recent. A phylogeographic analysis of the *dissecta*-clade suggests that ssp. *lanuginosa* diverged approximately 7.55 million years ago (10.99-4.59 mya) through allopatric speciation (Hooker 2018).

C5b. Genetic bottlenecks: Neutral.
Small populations of *Veronica dissecta* ssp. *lanuginosa* may have been restricted to unglaciated refugia within the Olympic Mountains during the Pleistocene and subjected to genetic bottlenecks (Buckinhgam et al. 1995). Inter-population genetic variability was found to be greater than intra-population diversity by Marlowe and Hufford (2008).

C5c. Reproductive System: Neutral.
Veronica dissecta ssp. *lanuginosa* is primarily an out-crosser, but is capable of self-pollination if bees first visit older flowers near the base of the inflorescence that are functionally staminate and then work their way up the flower stalk to pollinate younger flowers that are functionally pistillate (protogynous) (Hufford and McMahon 2004).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on Washington Natural Heritage Program data, no significant changes in the phenology of *Veronica dissecta* ssp. *lanuginosa* populations have been detected over the past 90 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase.
Two occurrences of *Veronica dissecta* ssp. *lanuginosa* from Hurricane Ridge and Mount Angeles have not been relocated in more than 40 years and may be extirpated. The loss of these populations (both from the northwestern edge of its range) suggest that the overall range is contracting. Whether this is due primarily to climate change or is influenced by local events (trampling, over-collection, or herbivory) is not known. Both of these sites are well-visited within Olympic National Park, increasing the likelihood of impacts and detection (if the species was still present).

D2. Modeled future (2050) change in population or range size: Increase.
Wershow and DeChaine (2018) modeled the current and future distribution of *Veronica dissecta* ssp. *lanuginosa* and four other alpine endemics of the Olympic Range based on herbarium data, field sampling, and various environmental predictors, such as elevation, slope angle, aspect, topographic position, solar radiation, temperature and precipitation. *Veronica dissecta* ssp. *lanuginosa* had the most restricted predicted range and narrowest ecological niche of any species in the assessment and was projected to have a 99% reduction in its range, collapsing to the Mount Constance area.

D3. Overlap of modeled future (2050) range with current range: Neutral.
Based on its modeled future distribution under climate change, the range of *Veronica dissecta* ssp. *lanuginosa* is expected to contract by 99%, rather than shift in distribution to new, currently unoccupied habitat (Wershow and DeChaine 2018).

D4. Occurrence of protected areas in modeled future (2050) distribution: Neutral.
Despite the likely contraction of potential suitable habitat due to climate change, the entire range of *Veronica dissecta* ssp. *lanuginosa* will still be restricted to Olympic National Park and the Buckhorn Wilderness Area of Olympic National Forest.

References

Buckingham, N.M., E.G. Schriener, T.N. Kaye, J.E. Burger, and E.L. Tisch. 1995. Flora of the Olympic Peninsula. Northwest Interpretive Association, Seattle, WA.

Camp, P. and J.G. Gamon, eds. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle. 392 pp.

Hooker, M.A. 2018. Diversification and phylogeography of *Synthyris* (Plantaginaceae) in northwestern North America. Doctoral dissertation, School of Biological Sciences, Washington State University, Pullman, WA. 116 pp.

Hufford, L. D. 2019. *Synthyris*. Pp. 296-304. In: Flora of North America Editorial Committee. 1993-. Flora of North America North of Mexico. Volume 17 Magnoliophyta: Tetrachondraceae to Orobanchaceae. Oxford University Press, New York. 737 pp.

Hufford, L. and M. McMahon. 2004. Morphological evolution and systematics of *Synthyris* and *Besseya* (Veronicaceae): A phylogenetic analysis. Systematic Botany 29(3): 716-736.

Marlowe, K. and L. Hufford. 2008. Evolution of *Synthyris* sect. *Dissecta* (Plantaginaceae) on sky islands in the northern Rocky Mountains. American Journal of Botany 95(3): 381-392.

Rocchio, F.J. and R.C. Crawford. 2015. Ecological systems of Washington State. A guide to identification. Natural Heritage Report 2015-04. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 384 pp.

Rocchio F.J. and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment. Unpublished Report to the Washington Department of Fish and Wildlife. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Schreiner, E.G., M.B. Gracz, T.N. Kaye, A. Woodward, and N.M. Buckingham. 1994. Effects of mountain goats on rare plants. Pp. 173-188. In: Houston, D.B., E.G. Schreiner, and B.B. Moorhead, eds. Mountain goats in Olympic National Park: Biology and management of an introduced species. Scientific Monograph NPS/NROLYM/NRSM-94/25. US Department of Interior, National Park Service.

Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. 2021. *Synthyris lanuginosa*. In: Online Field Guide to the Rare Plants of Washington. (https://fieldguide.mt.gov/wa/?species=synthyris%20lanuginosa). Accessed 1 October 2021.

Wershow, S.T. and E. DeChaine. 2018. Retreat to refugia: Severe habitat contraction projected for endemic alpine plants of the Olympic Peninsula. American Journal of Botany 105(4): 760-778.

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.