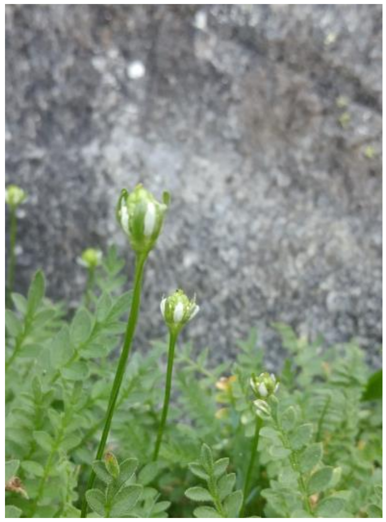
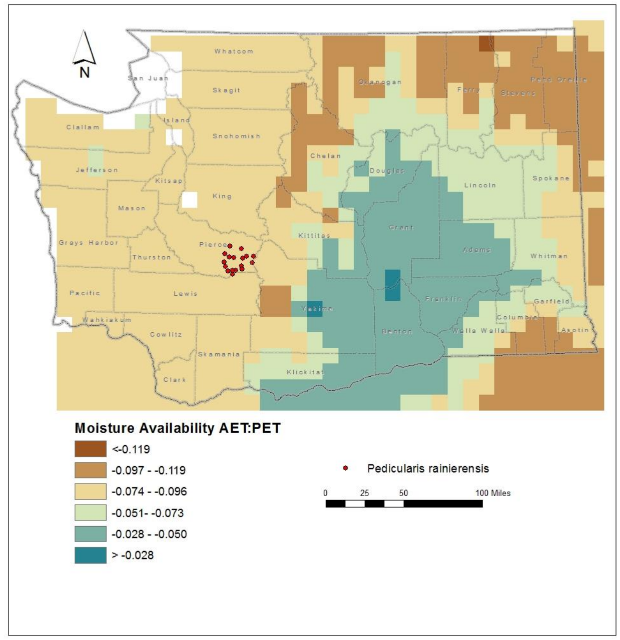
WASHINGTON NATURAL HERITAGE PROGRAM





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

Prepared for

US Forest Service, Region 6

Prepared by

Walter Fertig

August 18, 2020

Natural Heritage
Report 2020-04

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

Climate Change Vulnerability Index Reports for Selected Washington Rare Plant Species

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ON THE COVER: Kotzebue's grass-of-Parnassus (*Parnassia kotzebuei*) 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 seasonal 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 2007, Thomas et al. 2004). In order to develop conservation and mitigation strategies, it is imperative that researchers and managers be able to predict how vulnerable species might respond to current and future changes in climate (Glick et al. 2011).

The Climate Change Vulnerability Index (CCVI) was developed by NatureServe to assess how individual plant and animal species might react to projected climate change (Young et al. 2016). CCVI organizes information about species vulnerability into three components: (1) exposure to climate change within a particular assessment area; (2) inherent sensitivity to climate change; and (3) and capacity to adapt to change. A final CCVI score is derived from 29 indicators related to sensitivity to changes in temperature and precipitation, habitat specificity, and life history factors, such as dispersal ability, competition, pollination biology, and genetic diversity. The ranks and associated indicator scores can be used to identify and prioritize species that are most at risk of extirpation due to climate change and help land managers develop adaptation and mitigation strategies (Young et al. 2015).

In 2019, the Washington Natural Heritage Program (WNHP) received funding from the US Fish and Wildlife Service to apply CCVI protocols to four federally listed plant species as part of a project to better inform management of Washington State natural areas (Kleinknecht et al. 2019). WNHP also received funding from the US Forest Service (USFS) to apply the CCVI protocol to a subset of plant species listed as agency Sensitive (ISSSP 2019, WNHP 2019). The following report summarizes the results of the CCVI assessment for 47 rare Washington plant species (Appendix A) and includes recommendations for applying CCVI methods to additional taxa in the future.

Methods

Staff from the Interagency Special Status and Sensitive Species Program (ISSSSP) identified an initial set of 150 US Forest Service and Bureau of Land Management (BLM) Sensitive species for potential CCVI assessment. Due to funding constraints, only 47 CCVIs were completed (Table 1). These species were selected to represent a cross section of habitats and patterns of rarity (narrow endemics, regional endemics, disjuncts, and species at the edge of their range).

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 were developed of projected local temperature change, moisture availability (based on the ratio of actual to predicted evapotranspiration), historical thermal niche, and historical hydrological niche for each species by intersecting base map layers from NatureServe (www.natureserve.org/ccvi) 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), 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).

Individual factors were scored as Greatly Increase, Increase, Somewhat Increase, or Neutral based on the likely response of each target species to climate change 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 by the CCVI calculator and a confidence score given based on the number of criteria assessed. CCVI Index scores fall into five categories ranging from Extremely Vulneable to Less Vulnerable, depending on whether a species is likely to substantially decrease or become extirpated in the state by 2050 or is likely to be unimpacted by projected climate change (Young et al. 2016).

Results and Discussion

Each CCVI assessment is included in Appendix A. Of the 47 vascular plant species examined in this study, only one (*Kalmia procumbens*) scored as Extremely Vulnerable to climate change (Table 1). This alpine species from the North Cascades is extremely vulnerable due to its dependence on snow and ice and because of shifts in its historical and physiological niches (Table 2). *Kalmia procumbens* is unique among the species investigated in this study in being ranked as "historical" in Washington due to it last being observed in 1963. It is possible that it may be extirpated in the state, though whether this is due to climate impacts, loss of habitat, or other factors is not known.

Ten species in this study scored as Highly Vulnerable to climate change (Table 1). Five of these are alpine or subalpine talus, seep, or meadow species and four others are restricted to fen habitats in northeastern Washington. One species, *Astragalus asotinensis*, is a Palouse grassland species restricted to limestone substrates in extreme southeast Washington and adjacent Idaho. In general, species that scored as Highly Vulnerable occur in mesic sites that are susceptible to increased temperatures and reduced moisture availability in the future, have barriers to dispersal, are dependent on adequate snowpack for water recharge, are found on uncommon geologic or landform types, and have genetic diversity or reproductive issues (Table 2, Appendix A).

The majority of species assessed in this study (33 of 47) scored as Moderately Vulnerable to climate change (Table 1). One third of these species (11) are wetland plants found in fens, forested swamps, vernal pools, or montane streambanks that are dependent on snowpack or cooler temperatures (Table 2). Twelve others are predominantly found in low elevation shrub steppe, rock outcrop, or sand dune sites in eastern Washington that are already prone to high temperatures or low precipitation. Often these species are linked to uncommon landform or geologic substrates. Two narrow endemics restricted to rock outcrops are included in this group (*Oxytropis campestris* var. *wanapum* and *Petrophytum cinerascens*). The remaining species occur in alpine or subalpine meadows or forests where impacts from climate change are less immediate.

Only three species were ranked as Less Vulnerable to climate change (Table 1). These species tend to occur in a variety of unspecialized habitats or can occur in human-modified landscapes and are less impacted by projected changes in moisture availability or temperature than other taxa examined in this study (Table 2). None are dependent on snowpacks or restricted to uncommon geologic formations. One species (*Nicotiana attenuata*) may actually benefit from climate impacts (Appendix A).

A number of factors used in the CCVI were not informative in determining vulnerability for these 47 species, either because they applied to nearly every species (natural or anthropogenic barriers, dispersal limitations) or because they were employed infrequently (sea level rise, dependence on interspecific relationships). In many cases, data were not available on modeled current and future range, changes in distribution, or measured genetic variability. In other instances, factors such as dependence on pollinators and other species for dispersal, sensitivity to natural enemies, and competition were surprisingly unimportant for many of the species selected for this study. For example, only four of the 47 species studied were identified as being at risk due to low pollinator versatility (*Cypripedium parviflorum, Oxytropis campestris* var. *wanapum, Pedicularis rainierensis*, and *Petrophytum cinerascens*).

There does not appear to be a correlation between concentration of rare species and climate vulnerability in this study, however, this may be an artifact of the subsample of rare species selected. For example, six of the 11 taxa (55%) identified as extremely or highly vulnerable to climate change are from the Okanogan Plateau ecoregion in north-central Washington, though this region only contains 22% of the state's plant species of concern (WNHP 2019). In contrast, the two ecoregions with the greatest number of rare plant species in the state (Columbia Plateau and East Cascades, both with 37%) had only one species that scored as highly vulnerable (*Hackelia taylorii*), an alpine species from the Mount Stuart Region near the crest of the Cascades. Of the species assessed, low elevation, shrub steppe, rock outcrop, and vernal pool species of the Columbia Plateau consistently scored as moderately vulnerable, despite often being restricted to unusual geologic types, or occurring in areas where reduction in the timing and amount of precipitation are expected. These species all occur in areas that are already dry and where changes in these conditions are less pronounced than in montane and alpine regions of the state (they score on the dry spectrum of the Actual Evapotranspiration to Potential Evapotranspiration ratio; Young et al. 2016). Although arguably pre-adapted to aridity, these species may have upper limits to how much climatic change they can ultimately tolerate. In the case of edaphic endemics such as *Oxytropis campestris* var. *wanapum* and *Petrophyum cinerascens*, increased regional aridity may be of little consequence if they cannot migrate to new areas with similar soil and climate conditions in the future (Caicco 2012).

Presently WNHP tracks 365 Endangered, Threatened, and Sensitive plant species in Washington, of which 78 have been assessed using CCVI methods (Kleinknecht et al. 2019; (https://www.dnr.wa.gov/NHPclimatespecies). There are some significant gaps remaining in the representation of rare species from the Blue Mountains, Northwest Coast, North Cascades, and

Puget Trough ecoregions, and many of the state's rarest or more localized endemics have not yet been analyzed. Some ranking factors which did not seem significant for the subsample of species examined in this report may appear to be more important once a broader suite of species is assessed. A number of alpine taxa that are not currently tracked as species of concern (such as *Viola flettii* and other Olympic Mountain endemics) should be assessed with CCVI methods to determine if new conservation measures are necessary. With additional funding, WNHP could complete CCVI assessments for more of these species and post the reports on the program's website for the benefit of other researchers, land managers, and the general public. Additional funding would also provide opportunities to update existing CCVIs as new data become available. A complete set of CCVI reports for all of the state sensitive, threatened, and endangered plant species will be beneficial for prioritizing those species most in need of conservation, mitigation, or monitoring. It will also help managers identify specific geographic areas and community types that may be at high risk from climate change.

Acknowledgements

This project was funded by the US Forest Service, Region 6. Special thanks to Carol Hughes, Robert Huff, and Kelli Van Norman of ISSSSP for their interest and encouragement. Jake Kleinknecht of WNHP and Rebecca Niggemann of DNR's IT Department helped develop the base maps for each CCVI report. Joe Rocchio, John Gamon, Tynan Ramm-Granberg, and David Wilderman of WA DNR provided helpful comments on many draft CCVI reports.

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Table 1. Summary of Climate Change Vulnerability Index scores for 47 Washington rare plant taxa. WA Status: BS = BLM state Sensitive; FS = US Forest Service state Sensitive; WE = Washington State Endangered, WS = Washington State Sensitive; WT = Washington State Threatened (WNHP 2019).

Species (Common Name)	GRank	SRank	WA Status	CCVI Score
Allium campanulatum (Sierra onion)	G4	S1	BS, FS, WT	Less Vulnerable
Astragalus asotinensis (Asotin milkvetch)	G2	S1	BS, WE	Highly Vulnerable
Astragalus columbianus (Columbia milkvetch)	G2G3	S2S3	BS, WS	Moderately Vulnerable
Carex anthoxanthea (Yellow-flowered sedge)	G5	S1	BS, FS, WT	Moderately Vulnerable
Carex chordorrhiza (Cordroot sedge)	G5	S1	BS, FS, WT	Highly Vulnerable
Carex proposita (Smoky Mountain sedge)	G4	S2	BS, FS, WS	Moderately Vulnerable
Carex rostrata (Beaked sedge)	G5	S2	BS, FS, WS	Highly Vulnerable
Carex sychnocephala (Many-headed sedge)	G4	S2	BS, FS, WS	Moderately Vulnerable
Carex tenuiflora (Sparse-flowered sedge)	G5	S2	BS, FS, WS	Highly Vulnerable
Chrysolepis chrysophylla var. *chrysophylla* (Golden chinquapin)	G5T5	S2	BS, FS, WS	Moderately Vulnerable
Chrysosplenium tetrandrum (Northern golden-carpet)	G5	S2	BS, FS, WS	Moderately Vulnerable
Cryptantha leucophaea (Gray cryptantha)	G2G3	S2	BS, WT	Moderately Vulnerable
Cryptantha spiculifera (Snake River cryptantha)	G4?	S2S3	BS, WS	Moderately Vulnerable
Cypripedium parviflorum (Yellow lady's-slipper)	G5	S2	BS, FS, WS	Moderately Vulnerable
Erigeron salishii (Salish fleabane)	G3	S2	BS, FS, WS	Moderately Vulnerable
Eriophorum viridicarinatum (Green-keeled cottongrass)	G5	S2	BS, FS, WS	Moderately Vulnerable
Gaultheria hispidula (Creeping snowberry)	G5	S2	BS, FS, WS	Moderately Vulnerable
Hackelia taylorii (Taylor's stickseed)	G2	S2	FS, WT	Highly Vulnerable
Heterotheca oregona (Oregon goldenaster)	G4	S2	BS, FS, WS	Moderately Vulnerable

Species (Common Name)	GRank	SRank	WA Status	CCVI Score
Impatiens noli-tangere (Western jewelweed)	G4G5	S1	BS, FS, WT	Moderately Vulnerable
Juncus howellii (Howell's rush)	G4	S1	BS, FS, WT	Moderately Vulnerable
Kalmia procumbens (Alpine azalea)	G5	SH	BS, FS, WT	Extremely Vulnerable
Lomatium tuberosum (Hoover's desert-parsley)	G2G3	S2S3	BS, WS	Moderately Vulnerable
Muhlenbergia glomerata (Marsh muhly)	G5	S2	BS, FS, WS	Moderately Vulnerable
Navarretia tagetina (Marigold pincushion-plant)	G5	S1	BS, FS, WT	Moderately Vulnerable
Nicotiana attenuata (Coyote tobacco)	G4	S2	BS, FS, WS	Less Vulnerable
Oxytropis campestris var. *wanapum* (Wanapum crazyweed)	G5T1	S1	BS, WE	Moderately Vulnerable
Packera porteri (Porter's butterweed)	G4	S1	FS, WE	Highly Vulnerable
Parnassia kotzebuei (Kotzebue's grass-of-Parnassus)	G5	S1	BS, FS, WT	Highly Vulnerable
Pedicularis rainierensis (Mt. Rainier lousewort)	G2G3	S2S3	FS, WS	Highly Vulnerable
Pediocactus nigrispinus (Snowball cactus)	G4	S2	BS, WS	Moderately Vulnerable
Penstemon wilcoxii (Wilcox's beardtongue)	G4	S1	BS, FS, WT	Moderately Vulnerable
Petrophytum cinerascens (Chelan rockmat)	G1G2	S1S2	BS, FS, WE	Moderately Vulnerable
Polemonium carneum (Great polemonium)	G4	S2	BS, FS, WT	Less Vulnerable
Polyctenium fremontii (Fremont's combleaf)	G4	S1	BS, WT	Moderately Vulnerable
Pyrrocoma hirta var. *sonchifolia* (Sticky goldenweed)	G4G5T3	S2	BS, FS, WT	Moderately Vulnerable
Ranunculus populago (Mountain buttercup)	G4	S2	BS, FS, WS	Moderately Vulnerable
Rubus arcticus ssp. *acaulis* (Nagoonberry)	G5T5	S1	BS, FS, WT	Moderately Vulnerable
Salix candida (Hoary willow)	G5	S1	BS, FS, WT	Highly Vulnerable

Species (Common Name)	**GRank**	**SRank**	**WA Status**	**CCVI Score**
Salix glauca var. *villosa* (Glaucous willow)	G5T5?	S1S2	BS, FS, WS	Moderately Vulnerable
Salix pseudomonticola (False mountain willow)	G5	S1	BS, FS, WS	Moderately Vulnerable
Saxifraga cernua (Nodding saxifrage)	G5	S1	BS, FS, WS	Highly Vulnerable
Scribneria bolanderi (Scribner's grass)	G4	S1	BS, FS, WT	Moderately Vulnerable
Sericocarpus oregonensis ssp. *oregonensis* (Oregon white-topped aster)	G5TNR	S1	BS, FS, WT	Moderately Vulnerable
Swertia perennis (Swertia)	G5	S1	BS, FS, WT	Moderately Vulnerable
Thelypodium sagittatum ssp. *sagittatum* (Arrow thelypody)	G4T4	S1	BS, WT	Moderately Vulnerable
Vaccinium myrtilloides (Velvetleaf blueberry)	G5	S1	BS, FS, WT	Moderately Vulnerable

Table 2. Comparison of Selected Variables in Climate Change Vulnerability Index scores for 47 Washington rare plant taxa.

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 < -0.119 to -0.074) and "moister" (for values from -0.073 to > -0.028). 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**: Gr Inc: = Greatly Increased vulnerability; Inc = Increased vulnerability, Sl Inc: = Slightly 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	Sl Inc	Sl Inc	Neut	Neut	Neut	Neut	Neut	Neut
Astragalus asotinensis (Asotin milkvetch)	HV	Moister	Sl Inc	Neut	Neut	Sl Inc	Sl Inc	Neut	Inc	Neut
Astragalus columbianus (Columbia milkvetch)	MV	Drier	Sl Inc	Neut	Neut	Inc	Sl Inc	Neut	Neut	Neut
Carex anthoxanthea (Yellow-flowered sedge)	MV	Moister	Sl Inc	Gr Inc	Sl Inc	Neut	Sl Inc	Inc	Neut	Neut
Carex chordorrhiza (Cordroot sedge)	HV	Moister	Sl Inc	Inc	Sl Inc	Neut	Sl Inc	Inc	Neut	Neut
Carex proposita (Smoky Mountain sedge)	MV	Moister	Sl Inc	Sl Inc	Inc	Neut	Sl Inc	Inc	Neut	Neut
Carex rostrata (Beaked sedge)	HV	Moister	Sl Inc	Neut	Inc	Neut	Inc	Sl Inc/ Neut	Neut	Neut
Carex sychnocephala (Many-headed sedge)	MV	Drier	Sl Inc	Neut	Sl Inc	Sl Inc	Sl Inc	Sl Inc	Neut	Neut
Carex tenuiflora (Sparse-flowered sedge)	HV	Moister	Sl Inc	Sl Inc	Sl Inc	Neut	Inc	Sl Inc	Sl Inc	Neut
Chrysolepis chrysophylla var. *chrysophylla* (Golden chinquapin)	MV	Moister	Sl Inc	Inc	Neut	Neut	Neut	Neut	Neut	Sl Inc

Species (Common Name)	**CCVI Score**	**AET: PET***	**Dispers**	**Hist Therm N**	**Phys Therm N**	**Hist Hydr N**	**Phys Hydr N**	**Ice/ Snow**	**Geol**	**Genes**
Chrysosplenium tetrandrum (Northern golden-carpet)	MV	Moister	Sl Inc	Inc	Sl Inc	Neut	Sl Inc	Neut	Neut	Sl Inc
Cryptantha leucophaea (Gray cryptantha)	MV	Drier	Neut	Neut	Neut	Inc	Neut	Neut	Inc	Neut
Cryptantha spiculifera (Snake River cryptantha)	MV	Drier	Sl Inc	Neut	Neut	Sl Inc	Inc	Neut	Neut	Neut
Cypripedium parviflorum (Yellow lady's-slipper)	MV	Moister	Neut	Neut	Sl Inc	Sl Inc	Sl Inc	Sl Inc	Neut	Neut
Erigeron salishii (Salish fleabane)	MV	Moister	Neut	Sl Inc	Gr Inc	Neut	Neut	Sl Inc	Neut	Neut
Eriophorum viridicarinatum (Green-keeled cottongrass)	MV	Moister	Neut	Neut	Sl Inc	Neut	Neut	Sl Inc	Sl Inc	Neut
Gaultheria hispidula (Creeping snowberry)	MV	Moister	Sl Inc	Sl Inc/ Neut	Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Hackelia taylorii (Taylor's stickseed)	HV	Moister	Sl Inc	Sl Inc	Inc	Neut	Neut	Inc	Inc	Sl Inc
Heterotheca oregona (Oregon goldenaster)	MV	Moister	Neut	Sl Inc	Sl Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Impatiens noli-tangere (Western jewelweed)	MV	Moister	Inc	Inc	Sl Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Juncus howellii (Howell's rush)	MV	Moister	Neut	Sl Inc	Sl Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Kalmia procumbens (Alpine azalea)	EV	Moister	Sl Inc	Inc	Inc	Neut	Neut	Gr Inc	Neut	Sl Inc
Lomatium tuberosum (Hoover's desert-parsley)	MV	Drier	Inc	Neut	Neut	Inc	Inc	Neut	Sl Inc/ Neut	Neut

Species (Common Name)	CCVI Score	AET: PET*	Dispe rs	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Muhlenbergia glomerata (Marsh muhly)	MV	Moister	Neut	Neut	Sl Inc	Neut	Sl Inc	Inc	Neut	Neut
Navarretia tagetina (Marigold pincushion-plant)	MV	Drier	Neut	Sl Inc	Sl Inc/ Neut	Neut	Gr Inc	Sl Inc	Inc	Neut
Nicotiana attenuata (Coyote tobacco)	LV	Drier	Sl Inc	Neut	Neut	Sl Inc	Neut	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	Sl Inc	Sl Inc	Sl Inc
Parnassia kotzebuei (Kotzebue's grass-of-Parnassus)	HV	Moister	Sl Inc	Inc	Gr Inc	Neut	Sl Inc	Sl Inc	Sl Inc	Sl Inc/ Neut
Pedicularis rainierensis (Mt. Rainier lousewort)	HV	Moister	Sl Inc	Inc	Inc	Neut	Sl Inc	Inc	Sl Inc	Neut
Pediocactus nigrispinus (Snowball cactus)	MV	Drier	Sl Inc	Neut	Neut	Inc	Inc	Sl Inc/ Neut	Neut	Neut
Penstemon wilcoxii (Wilcox's beardtongue)	MV	Moister	Sl Inc	Neut	Sl Inc	Sl Inc/ Neut	Sl Inc	Sl Inc	Neut	Neut
Petrophytum cinerascens (Chelan rockmat)	MV	Drier	Sl Inc	Neut	Sl Inc	Sl Inc	Inc	Neut	Inc	Neut
Polemonium carneum (Great polemonium)	LV	Moister	Sl Inc	Inc	Neut	Neut	Neut	Neut	Neut	Neut
Polyctenium fremontii (Fremont's combleaf)	MV	Drier	Sl Inc	Neut	Neut	Sl Inc	Gr Inc	Neut	Sl Inc	Sl Inc/ Neut

Species (Common Name)	CCVI Score	AET: PET*	Dispers	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Pyrrocoma hirta var. *sonchifolia* (Sticky goldenweed)	MV	Moister	Neut	Sl Inc	Sl Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Ranunculus populago (Mountain buttercup)	MV	Moister	Sl Inc	Sl Inc	Sl Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Rubus arcticus ssp. *acaulis* (Nagoonberry)	MV	Moister	Neut	Sl Inc	Sl Inc	Neut	Sl Inc	Sl Inc	Neut	Sl Inc
Salix candida (Hoary willow)	HV	Moister	Neut	Neut	Gr Inc	Neut	Sl Inc	Inc	Sl Inc	Neut
Salix glauca var. *villosa* (Glaucous willow)	MV	Moister	Neut	Sl Inc	Inc	Neut	Sl Inc	Inc	Neut	Neut
Salix pseudomonticola (False mountain willow)	MV	Moister	Neut	Neut	Inc	Neut	Sl Inc	Inc	Sl Inc	Neut
Saxifraga cernua (Nodding saxifrage)	HV	Moister	Inc	Inc	Gr Inc	Neut	Sl Inc	Sl Inc	Neut	Neut
Scribneria bolanderi (Scribner's grass)	MV	Drier	Neut	Sl Inc	Sl Inc/ Neut	Neut	Gr Inc	Sl Inc	Unk	Neut
Sericocarpus oregonensis ssp. *oregonensis* (Oregon white-topped aster)	MV	Moister	Neut	Sl Inc	Neut	Neut	Neut	Neut	Neut	Neut
Swertia perennis (Swertia)	MV	Moister	Sl Inc	Sl Inc	Inc	Neut	Sl Inc	Sl Inc	Sl Inc	Neut
Thelypodium sagittatum ssp. *sagittatum* (Arrow thelypody)	MV	Drier	Sl Inc	Neut	Neut	Sl Inc	Inc	Neut	Sl Inc	Neut
Vaccinium myrtilloides (Velvetleaf blueberry)	MV	Moister	Neut	Neut	Inc	Sl Inc	Sl Inc	Sl Inc	Sl Inc	Neut

Appendix A. Climate Change Vulnerability Index reports for 47 Washington Rare Plant Species

Climate Change Vulnerability Index Report

Allium campanulatum (Sierra onion)

Date: 5 November 2019

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G4/S1

Index Result: Less Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	33.3
	3.9-4.4° F (2.2-2.4°C) warmer	66.7
	<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	33.3
	-0.051 to - 0.073	0
	-0.028 to -0.050	33.4
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Unknown
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
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	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Two of the three known occurrences of *Allium campanulatum* in Washington (66.7%) are found in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). The

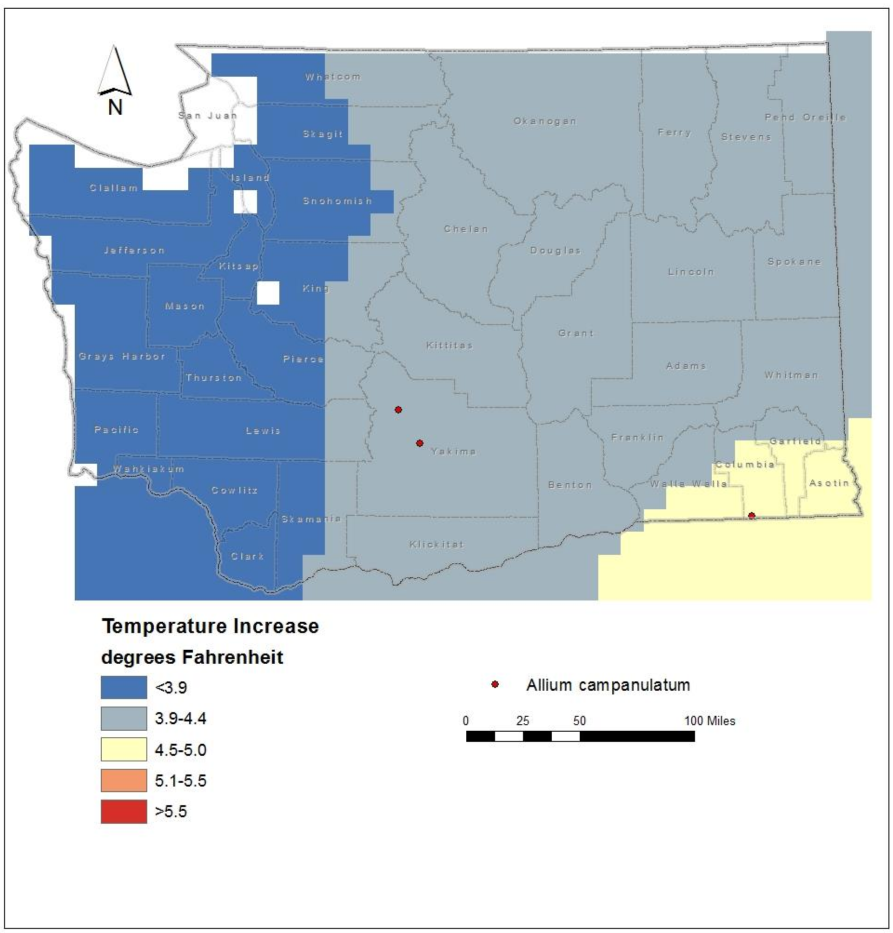

Figure 1. Exposure of *Allium campanulatum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

third occurrence from the Blue Mountains (33.3% of state occurrences) is in an area with a projected temperature increase of 4.5-5˚ F.

A2. Hamon AET:PET Moisture Metric: One third of the Washington occurrences of *Allium campanulatum* 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. One third of the occurrences are in areas with a projected decrease in the – 0.074 to – 0.096 range. The final one third are from areas with a projected decrease in the – 0.028 to – 0.050 range.

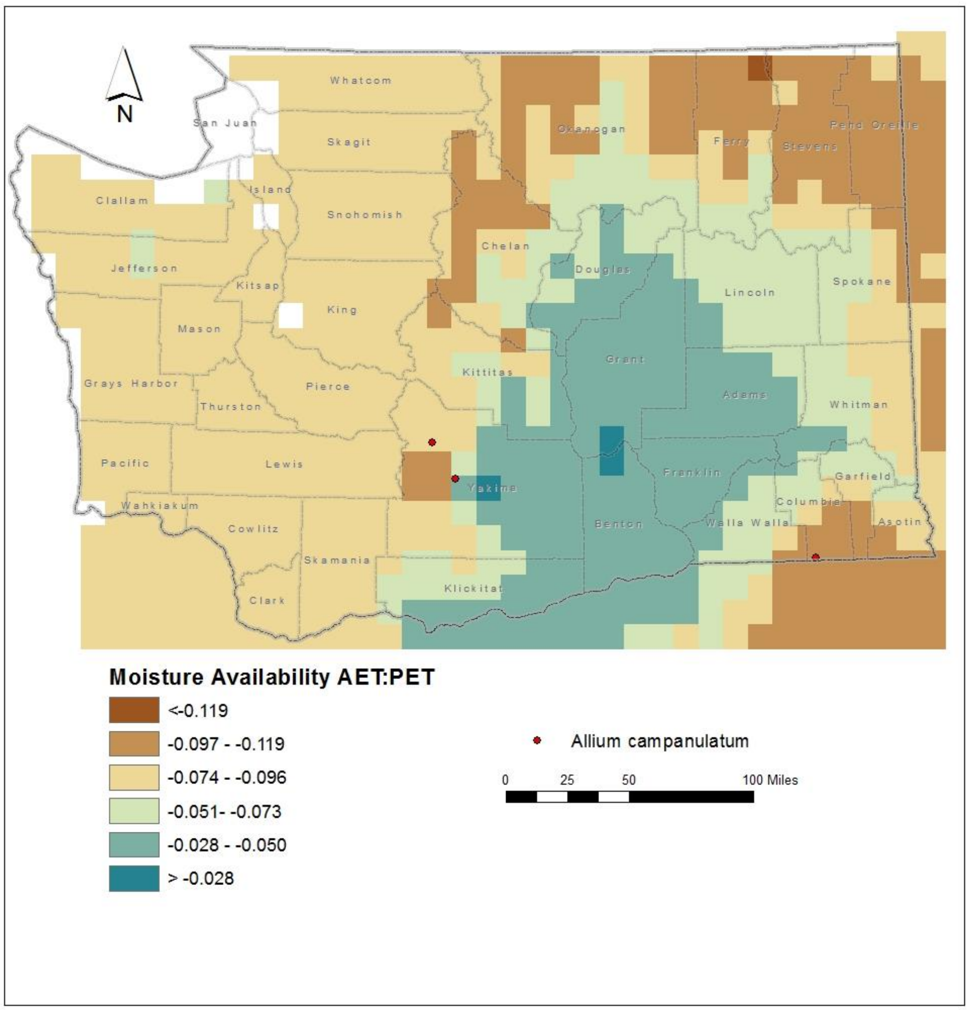

Figure 2. Exposure of *Allium campanulatum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
All occurrences of *Allium campanulatum* in Washington are found at elevations from 3200-6600 ft (975-2015 m) and would not be inundated by sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Allium campanulatum* occurs on thin, rocky or sandy soil of slopes and dry drainage channels or in dry, rocky meadows with sparse (10-25%) vegetative cover (Camp and Gamon 2011, WNHP records). This vegetation type is closest to the Northern Rocky Mountain Lower Montane, Foothills, and Valley Grassland ecological system (Rocchio and Crawford 2015), but represents a phase with lower vegetation cover and more exposed rocky soil. Washington populations are separated by 17-150 miles (27-240 km). The habitat occupied by this species may be relatively uncommon and widely scattered, presenting a potential barrier to dispersal for this species.

B2b. Anthropogenic barriers: Neutral.
Two of the known occurrences in Washington are bisected by two-track roads. Overall, the known range of this species in Washington is not strongly impacted by human development.

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 campanulatum reproduces by seed formed in dry capsules with no active dispersal mechanism, such as barbs, hooks, parachutes, or wings to be transported by animals or the wind. Seeds are relatively small and could possibly be carried short distances by strong winds, but more likely are passively dispersed within 1000 meters of the parent plant.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of known *Allium campanulatum* occurrences in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All three of the Washington occurrences (100%) are found in areas that have experienced slightly lower than average (47.1-57˚F) temperature variation in the past 50 years. According to Young et al. (2016) these populations are at somewhat increased vulnerability to climate change.

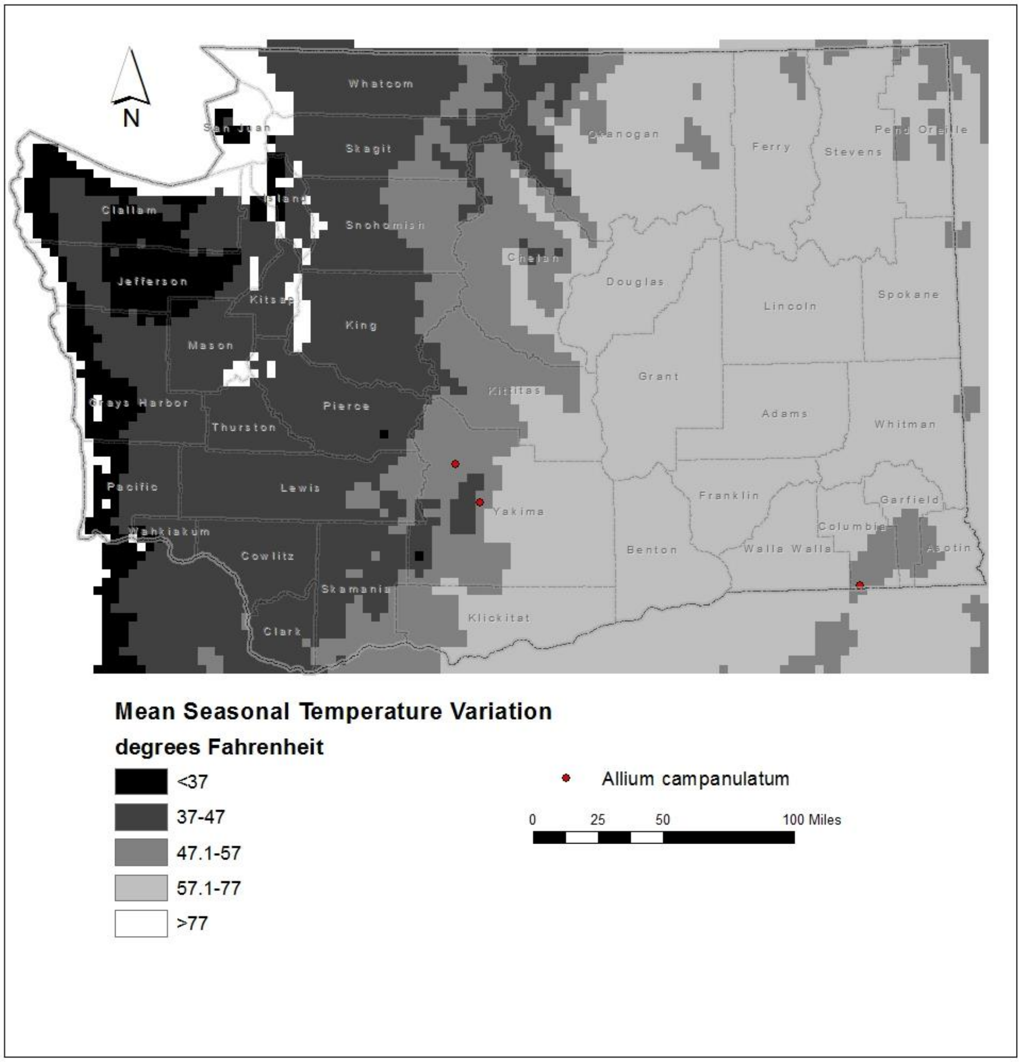

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Allium campanulatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
Allium campanulatum occurrences in Washington are mostly on openings in upper slopes in area that are not cold air drainages.

C2bi. Historical hydrological niche: Neutral.
All three of the Washington occurrences (100%) of *Allium campanulatum* (Figure 4) are found in areas that have averaged more than 20 inches (508 mm) of precipitation variation in the past 50 years and are ranked neutral for climate change by Young et al. (2016).

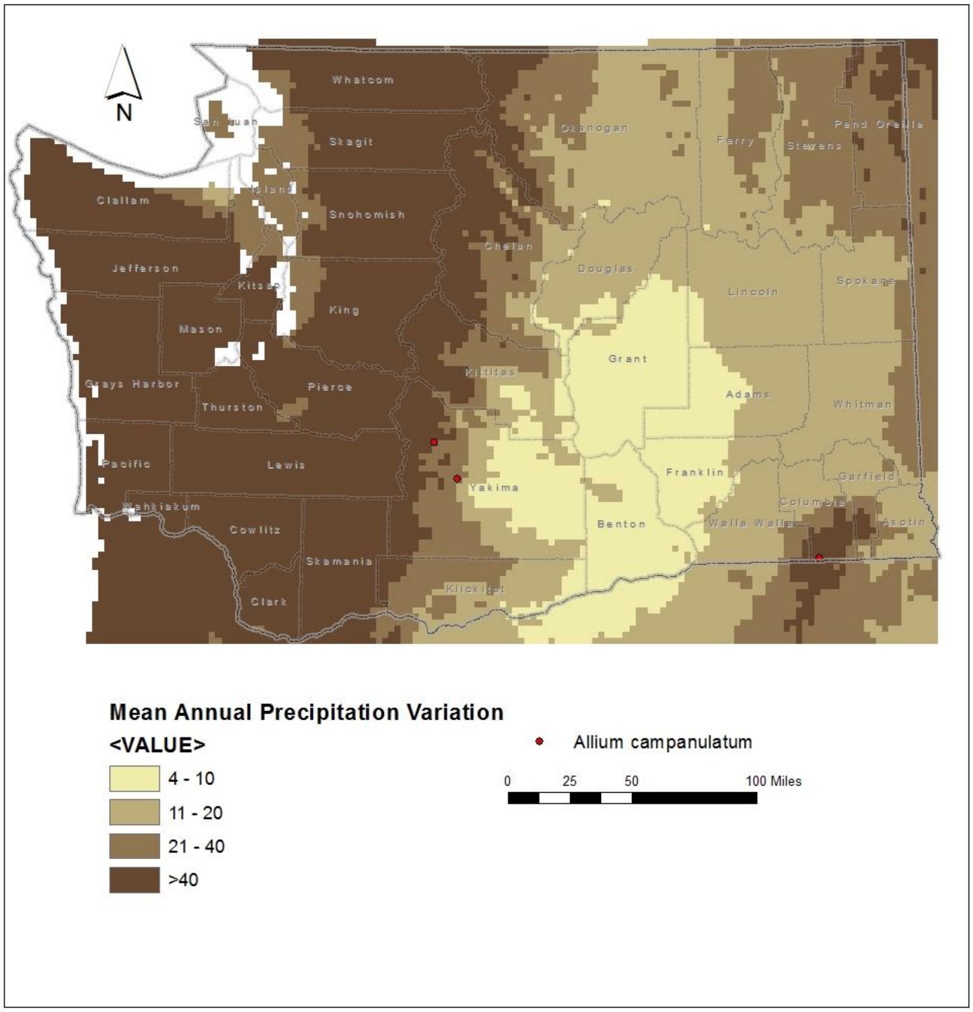

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Allium campanulatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
Allium campanulatum is not strongly associated with wetland habitats, and so is considered neutral for this factor.

C2c. Dependence on a specific disturbance regime: Unknown.
This species is found in sparsely vegetated, rocky sites on upper slopes or in dry drainages. These conditions may be maintained by erosion or exposure to wind. It is not known whether periodic disturbances are necessary to maintain this habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral
In Washington, *Allium campanulatum* is found in foothills areas that receive moderate amounts of snow, and so may not be impacted by reductions in snow cover predicted by climate change.

C3. Restricted to uncommon landscape/geological features: Neutral.
All of the Washington occurrences of *Allium campanulatum* are found on Miocene-age basalts and breccia tuff. Two of the populations are associated with the Grande Ronde Basalt. These geologic substrates are widespread in the state.

C4a. Dependence on other species to generate required habitat: Neutral.
The barren slope and sparse meadow habitat occupied by this species is not a consequence of ecosystem engineering by other organisms.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
McNeal (1994) reports that most western species of *Allium* are pollinated by native bees. The specific pollinators of *A. campanulatum* are not known.

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. Dispersal distances are probably short.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Livestock grazing has been identified as a potential threat to *Allium campanulatum* (Camp and Gamon 2011). One population in Yakima County is in an area with high gopher activity, though this disturbance might help maintain open habitats occupied by this species (WNHP records). *Allium* flowers and leaves are palatable, and underground bulbs are also consumed by fossorial mammals. Whether natural herbivory is a limiting factor in the survival of *A. campanulatum* is not known.

C4f. Sensitivity to competition from native or non-native species: Neutral.
The habitat of *Allium campanulatum* is mostly open and has low cover of introduced invasive weeds.

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability within or between Washington populations of *Allium campanulatum*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Allium species generally are outcrossers and have non-specialized pollinators. It is probable that the full species has at least average levels of genetic diversity, though disjunct and reproductively isolated populations in Washington might be expected to have less total genetic diversity and some unique markers (WNHP 2003).

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
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 campanulatum* 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

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

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Climate Change Vulnerability Index Report

Astragalus asotinensis (Asotin milkvetch)

Date: 23 March 2020

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	**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		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		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	
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 single occurrence of *Astragalus asotinensis* in Washington (100%) occurs in an area with a projected temperature increase of 4.5-5.0˚ F (Figure 1).

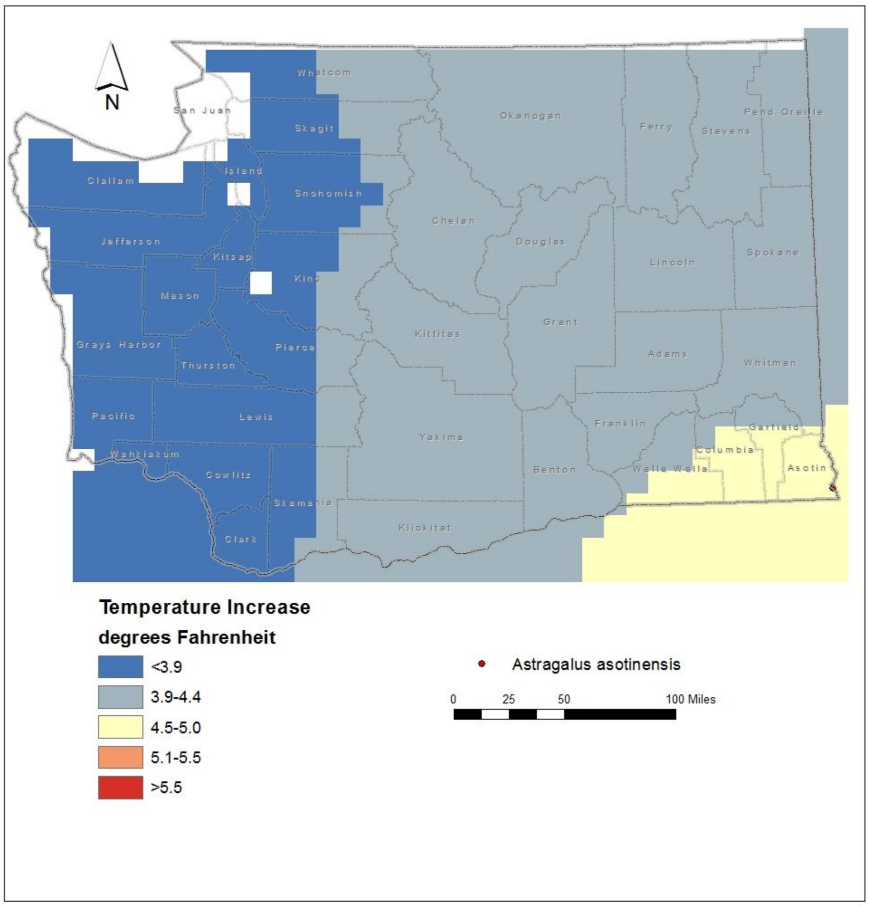

Figure 1. Exposure of *Astragalus asotinensis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Astragalus asotinensis* (100%) in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2).

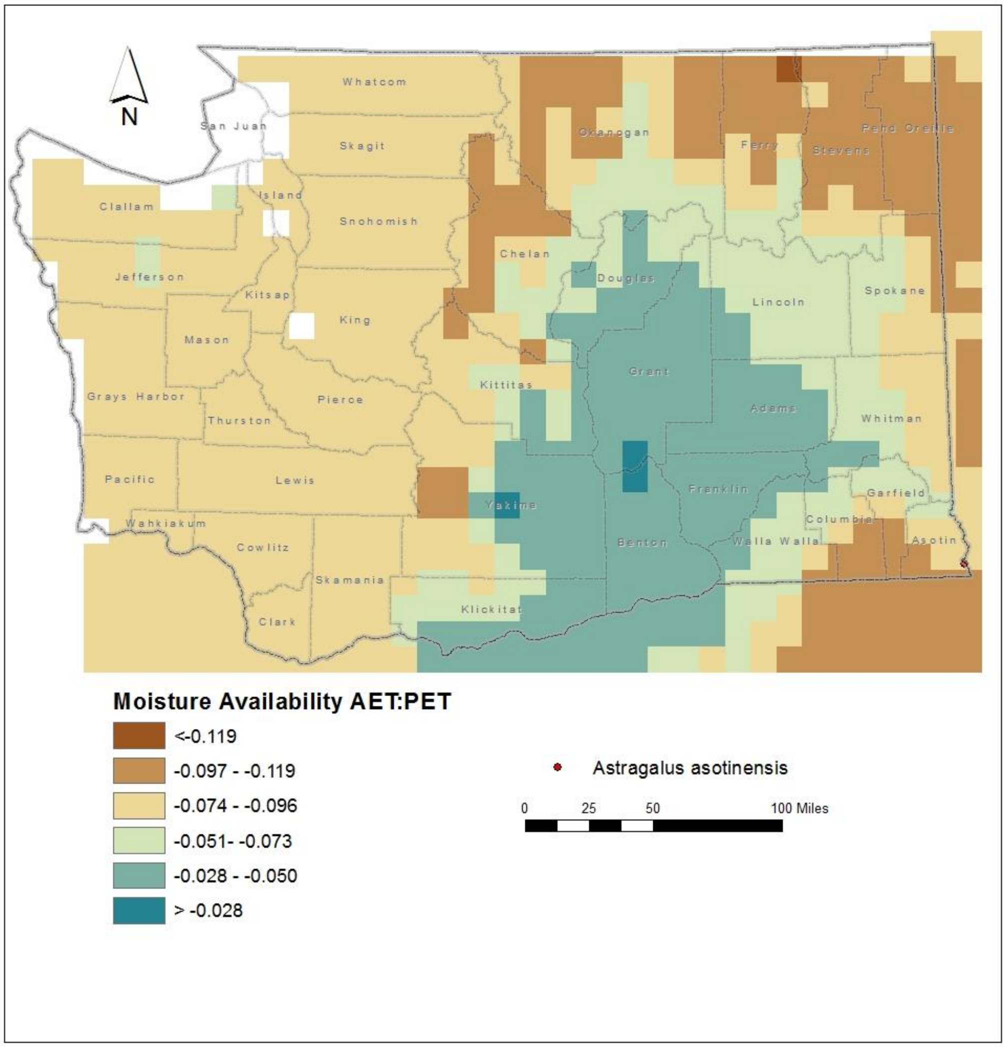

Figure 2. Exposure of *Astragalus asotinensis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrence of *Astragalus asotinensis* is found at 1300-3000 feet (400-900 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Astragalus asotinensis* is found on steep slopes in grasslands dominated by *Pseudoroegneria spicata* and *Festuca idahoensis* on ashy loess and limestone (Björk 2010, Camp and Gamon 2011, Fertig 2020). This habitat is a component of the Columbia Basin Foothill and Canyon Dry Grassland ecological system (Rocchio and Crawford 2015). The single occurrence in Washington covers about 300 acres and is isolated from populations in Idaho by the Snake River. Additional, unoccupied habitat in Washington has not been found (Björk 2010).

B2b. Anthropogenic barriers: Neutral.
The range of *Astragalus asotinensis* in Washington is bisected by old mining roads (now blocked by rockslides). These do not form 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: Somewhat Increase.
Astragalus asotinensis produces 7-20 flowers per inflorescence and each mature fruit contains 4-10 seeds that are released passively by dehiscence of the legume pod (Björk and Fishbein 2006). The seeds do not possess any wings, barbs, or hooks to promote dispersal by wind or animals. Dispersal distances are probably relatively short (no more than 100 m).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Astragalus asotinensis* 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 average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years and is considered at neutral vulnerability to climate change.

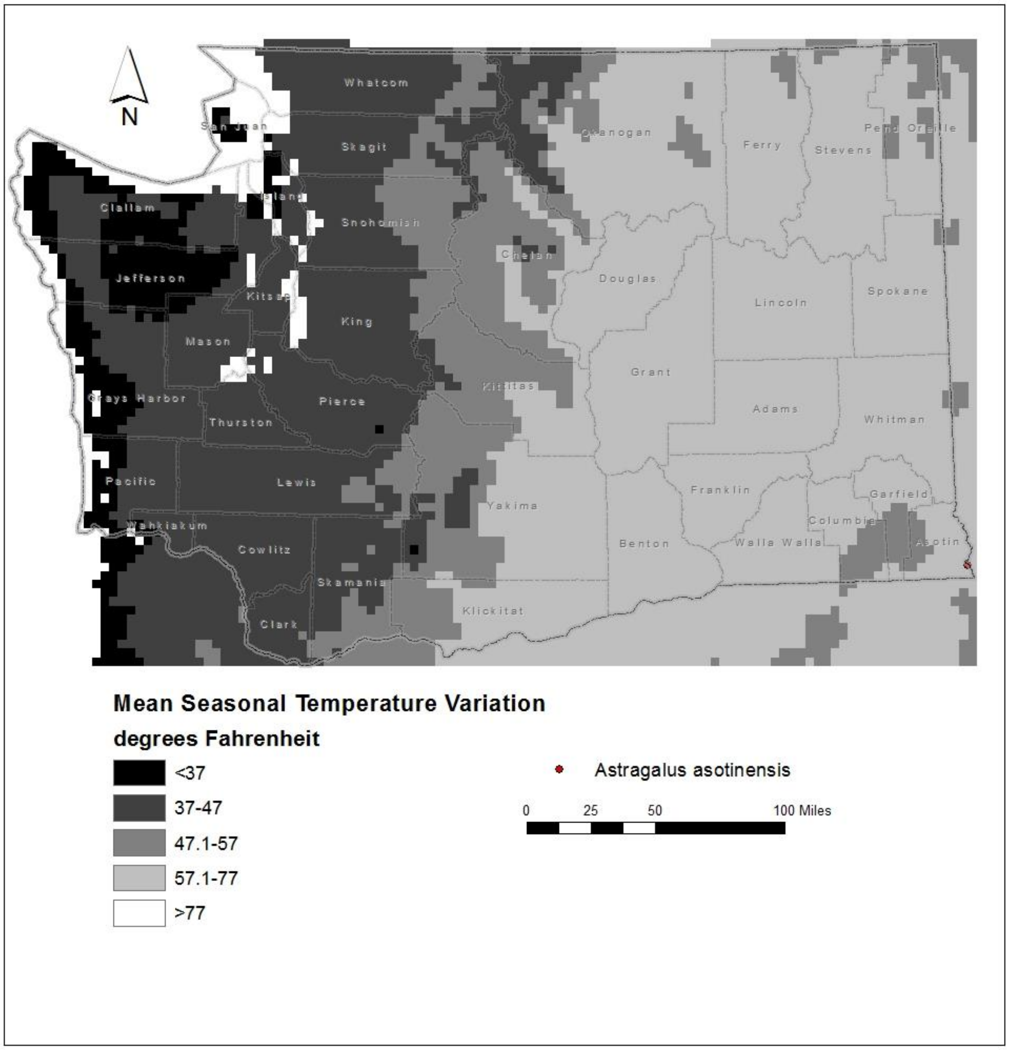

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus asotinensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

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

C2bi. Historical hydrological niche: Somewhat Increase.
The single occurrence of *Astragalus asotinensis* in Washington (100%) is found in an area that has 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.

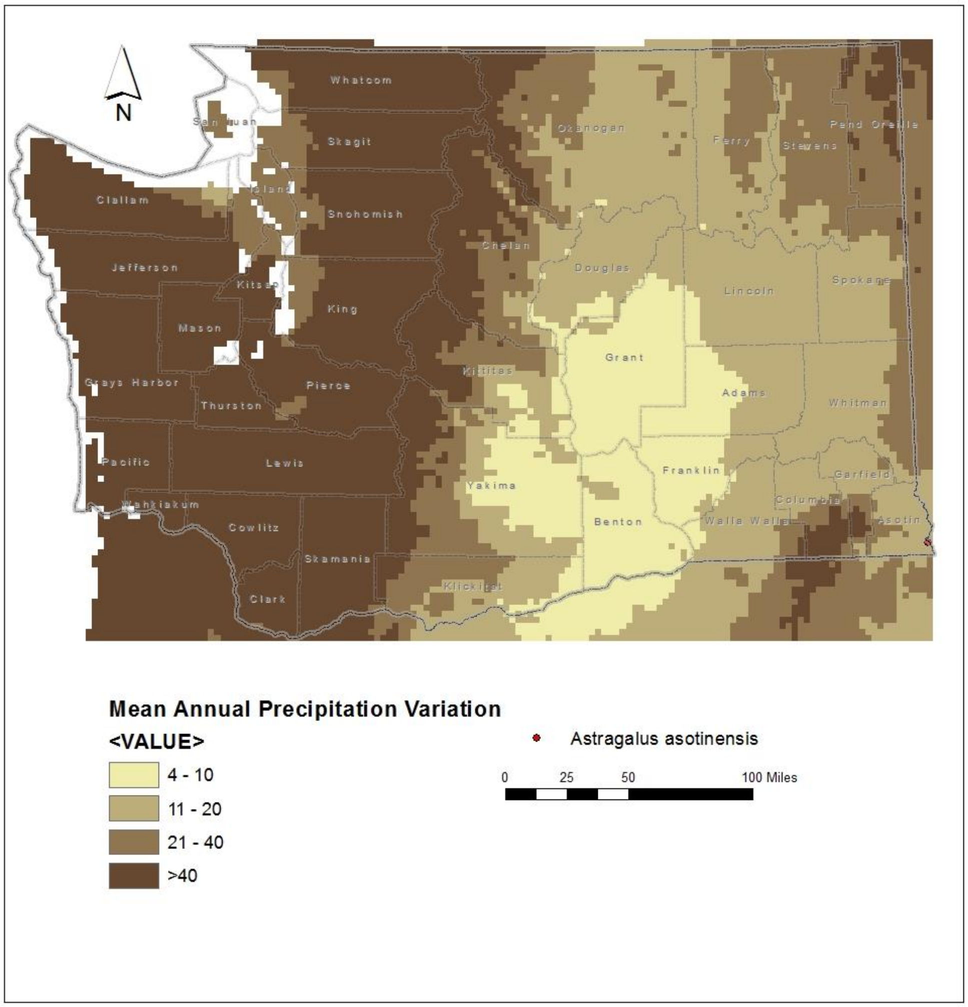

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus asotinensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

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 would accelerate erosion of steep slopes). This coupled with increases in temperature would 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 asotinensis is dependent on infrequent wildfire to reduce encroachment from less fire-adapted shrub species and to maintain open grassland habitat. 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 asotinensis* in the foothills of the Blue Mountains in southeastern Washington and a small component of its annual water budget.

C3. Restricted to uncommon landscape/geological features: Increase.
Astragalus asotinensis is restricted to limestone and shale outcrops of the Martin Bridge and Hurwal formations (called the Limekiln Formation in Björk and Fishbein 2006) on Lime Hill and adjacent ridges in Idaho near the confluence of the Columbia and Grande Ronde rivers (Björk 2010; Fertig 2020).

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 open grasslands occupied by *Astragalus asotinensis,* 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 asotinensis* are not known, but other *Astragalus* species are usually pollinated by bees or other insects.

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Astragalus asotinensis* 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 has not been identified as a significant threat (Fertig 2020).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Astragalus asotinensis 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 asotinensis* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Astragalus asotinensis 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 asotinensis* 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: Somewhat Increase.
The population declined by 80-90% from 2005 to 2010 (Björk 2010) but has apparently increased since then (Fertig 2020). The cause of the decline is poorly known, but could have been influenced by fire or drought 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

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Climate Change Vulnerability Index Report

Astragalus columbianus (Columbia milkvetch)

Date: 24 March 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	100
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		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
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	
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 20 occurrences of *Astragalus columbianus* in Washington (100%) occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

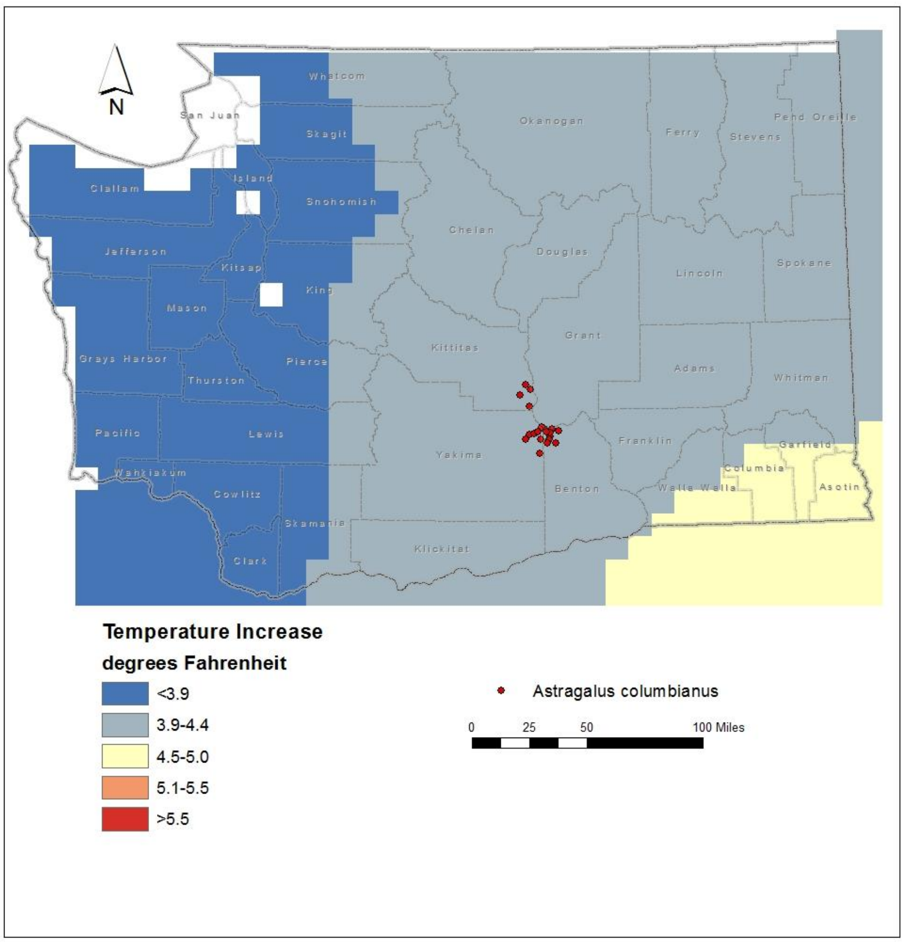

Figure 1. Exposure of *Astragalus columbianus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 20 of the occurrences of *Astragalus columbianus* (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 -0.028 to -0.050 (Figure 2).

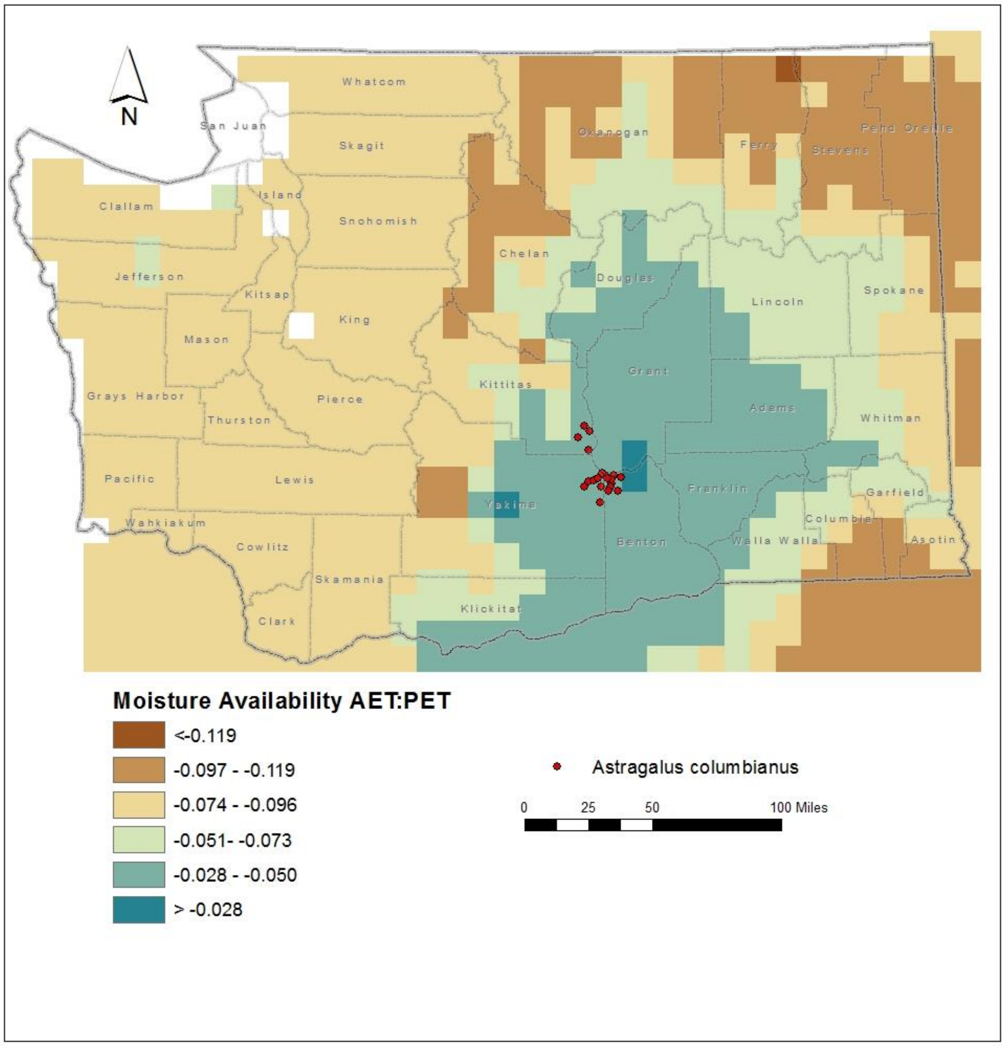

Figure 2. Exposure of *Astragalus columbianus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Astragalus columbianus* are found at 420-2320 feet (130-700 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Astragalus columbianus* is found in sagebrush steppe communities dominated by *Artemisia tridentata, Artemisia rigida*, *Poa secunda*, and *Pseudoroegneria spicata* on ridgecrests, slopes, riverbanks, and roadcuts with sandy, gravelly, or lithic loams (Camp and Gamon 2011, WNHP records). This habitat is a component of the Inter-Mountain Basins Big Sagebrush Steppe ecological system (Rocchio and Crawford 2015). The entire range of the species is limited to an area of 15 x 30 miles (25 x 50 km) with individual populations separated by less than 5 miles (8 km) (WNHP records). Historically, this habitat was probably more continuous prior to European settlement and there were relatively few barriers to dispersal

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Astragalus columbianus* in Washington is bisected by roads, agricultural fields, and industrial development and the formerly continuously distributed sagebrush steppe vegetation is now sufficiently fragmented to 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: Somewhat Increase.
The fruits of *Astragalus columbianus* are dry legumes that dehisce at maturity along two sutures to release seeds passively by gravity. Individual seeds lack wings, barbs, hooks or other adornments to enhance their dispersal by wind or animals. Dispersal distances are probably relatively short (no more than 100 m).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Astragalus columbianus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 20 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).

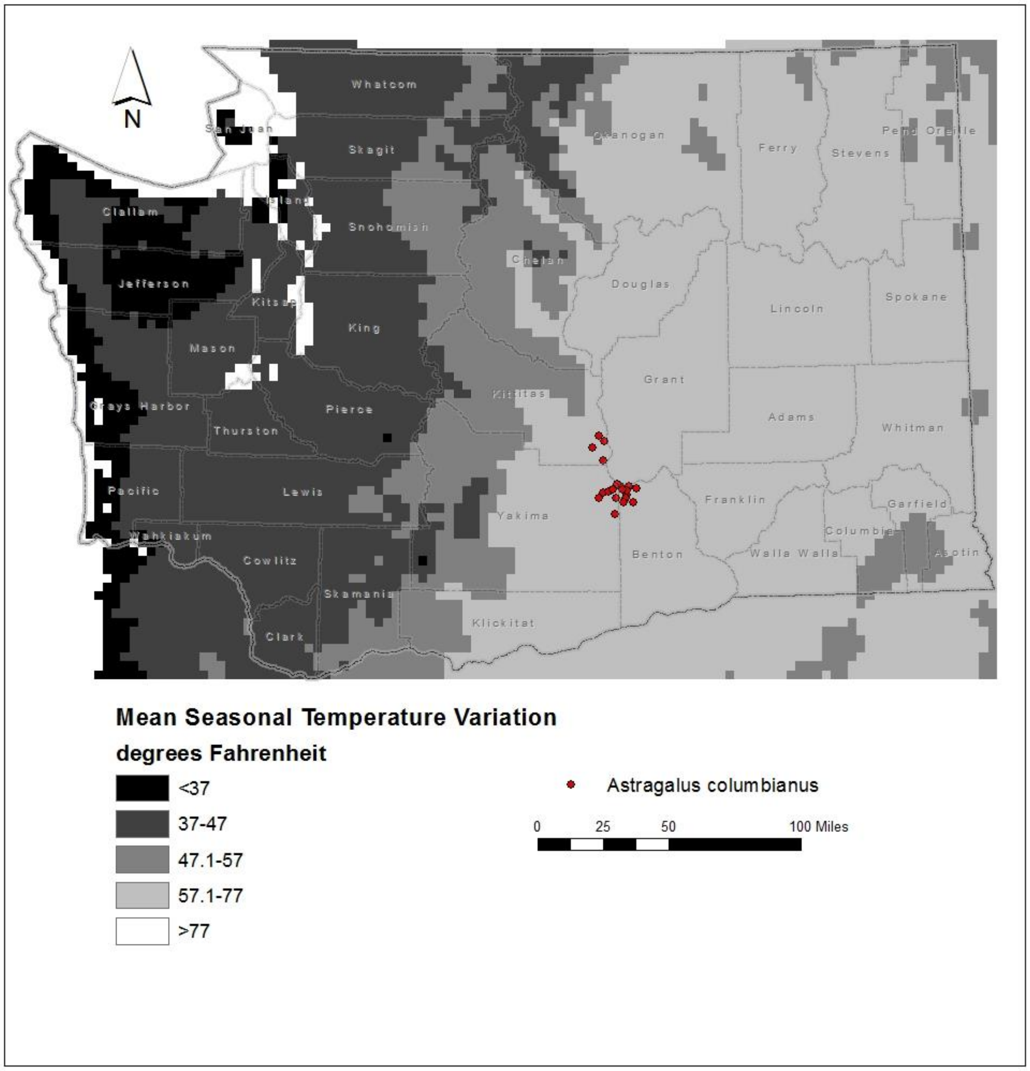

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Astragalus columbianus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The Inter-Mountain Basins Big Sagebrush Steppe habitat of *Astragalus columbianus* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Increase.
Seventeen of the 20 occurrences of *Astragalus columbianus* in Washington (85%) 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. The remaining three occurrences (15%) are from areas with a slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the same period and are at somewhat increased vulnerability to climate change.

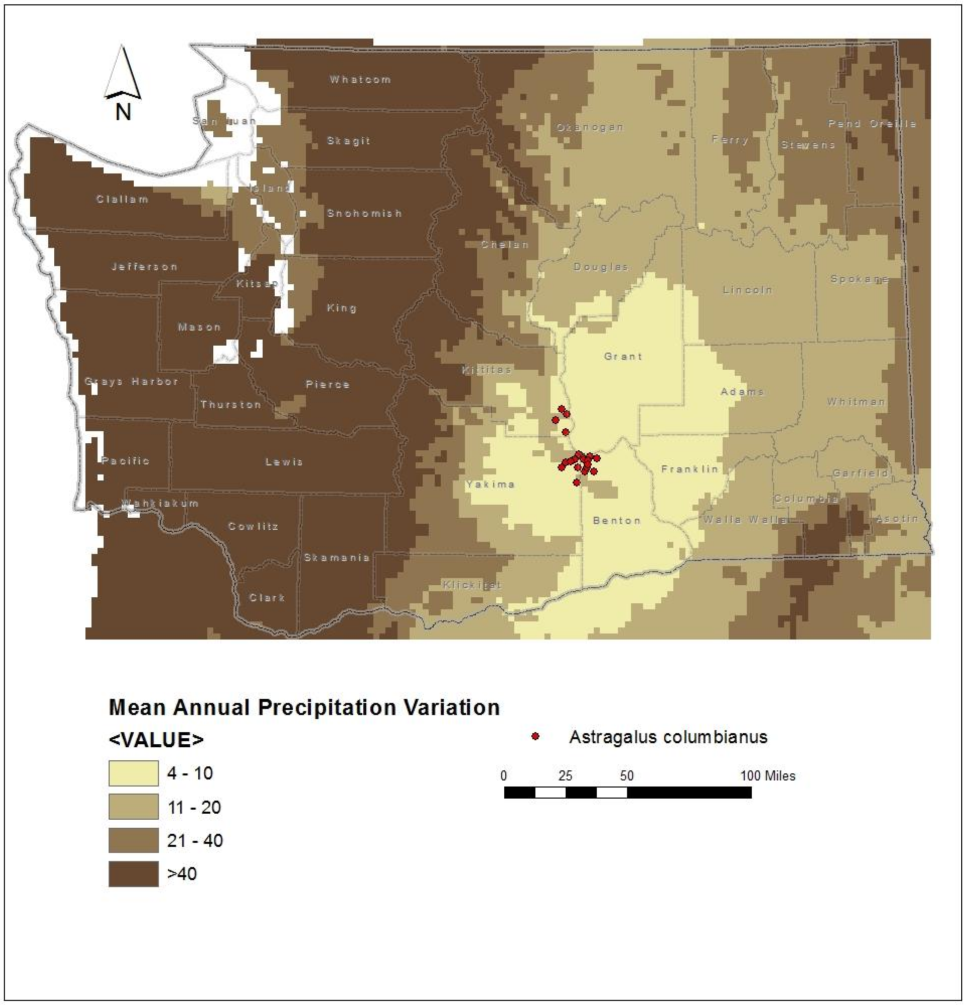

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Astragalus columbianus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is primarily dependent on adequate precipitation for its moisture requirements, because its habitat is typically not associated with springs, streams, or a high water table. The Inter-Mountain Basins Big Sagebrush Steppe ecological system is vulnerable to changes in the timing or amount of precipitation that coupled with increases in temperature would 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 columbianus is dependent on periodic, low-intensity wildfires to reduce encroachment from less fire-adapted shrub species and to maintain open grassland habitat. Long-term monitoring suggests that populations may be ephemeral and the species depends on freshly disturbed sites for population expansion (Camp and Gamon 2011). Increased drought and reduced summer precipitation, however, could make wildfires too frequent and result in replacement of native perennial bunchgrass with annual introduced grasses, such as cheatgrass (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is relatively low over the range of *Astragalus columbianus* in the Columbia Plateau of eastern Washington area and a minor component of its annual water budget.

C3. Restricted to uncommon landscape/geological features: Neutral.
Astragalus columbianus is found primarily on the Grande Ronde Basalt, which is a widespread Miocene-age deposit in central and eastern Washington.

C4a. Dependence on other species to generate required habitat: Neutral
Browsing by ungulates, rodents, and insects could help maintain open areas within big sagebrush steppe vegetation occupied by *Astragalus columbianus,* although drought and periodic low-intensity fire are probably more significant.

C4b. Dietary versatility: Not applicable for plants

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

C4d. Dependence on other species for propagule dispersal: Neutral.
The fruits of *Astragalus columbianus* 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 has not been identified as a significant threat (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase. *Astragalus columbianus* 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 columbianus* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Astragalus columbianus is 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 columbianus* populations in Washington have been detected over the past 40 years since the species was rediscovered (Sauer et al. 1979).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
This species had been thought to be extirpated, until it was rediscovered in the late 1970s. Its known range has increased in recent years due to more thorough survey effort. Long-term population trends are poorly known, as some of its former habitat was probably lost to development of fruit orchards (Camp and Gamon 2011).

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.

Sauer, R.H., J.D. Mastrogiuseppe, and R.H. Smookler. 1979. *Astragalus columbianus* (Leguminosae) – rediscovery of an "extinct" species. Brittonia 31(2): 261-264.

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 anthoxanthea (Yellow-flowered sedge)

Date: 1 November 2019

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Greatly Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		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		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	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: The single known occurrence of *Carex anthoxanthea* in Washington (100%) is found in an area with a projected temperature increase of less than 3.9˚F (Figure 1).

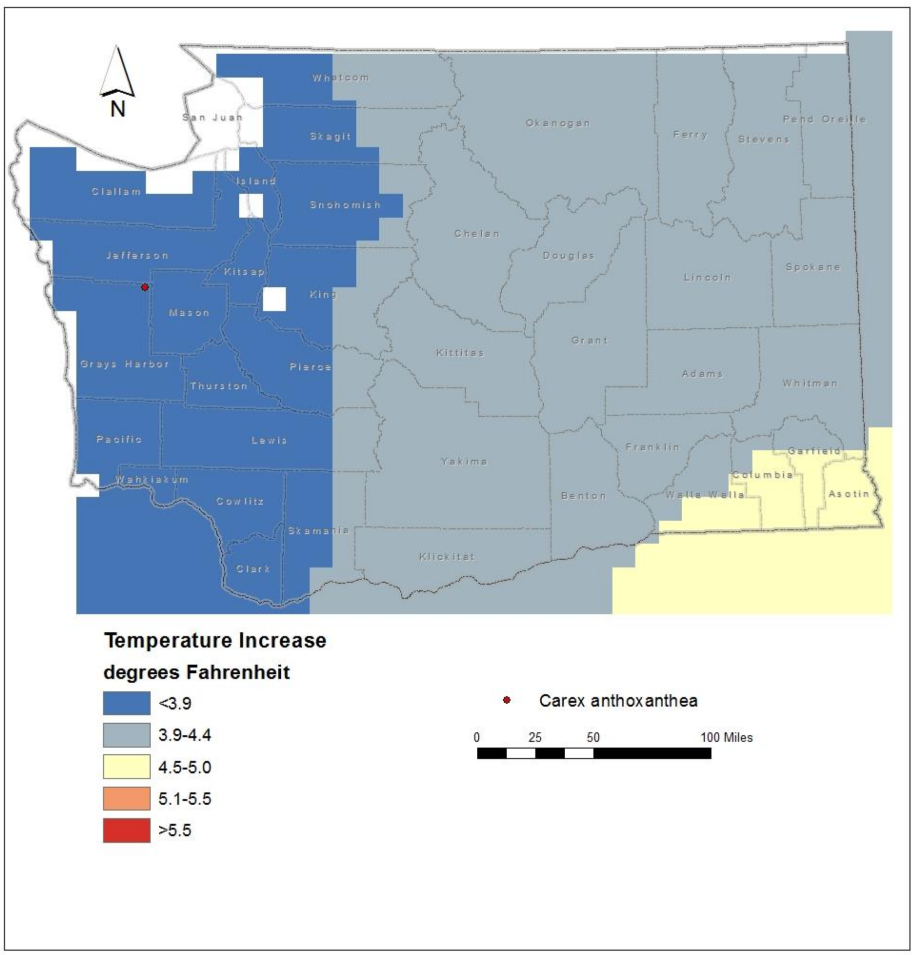

Figure 1. Exposure of *Carex anthoxanthea* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The sole occurrence of *Carex anthoxanthea* in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.0474 to -0.096 (Figure 2).

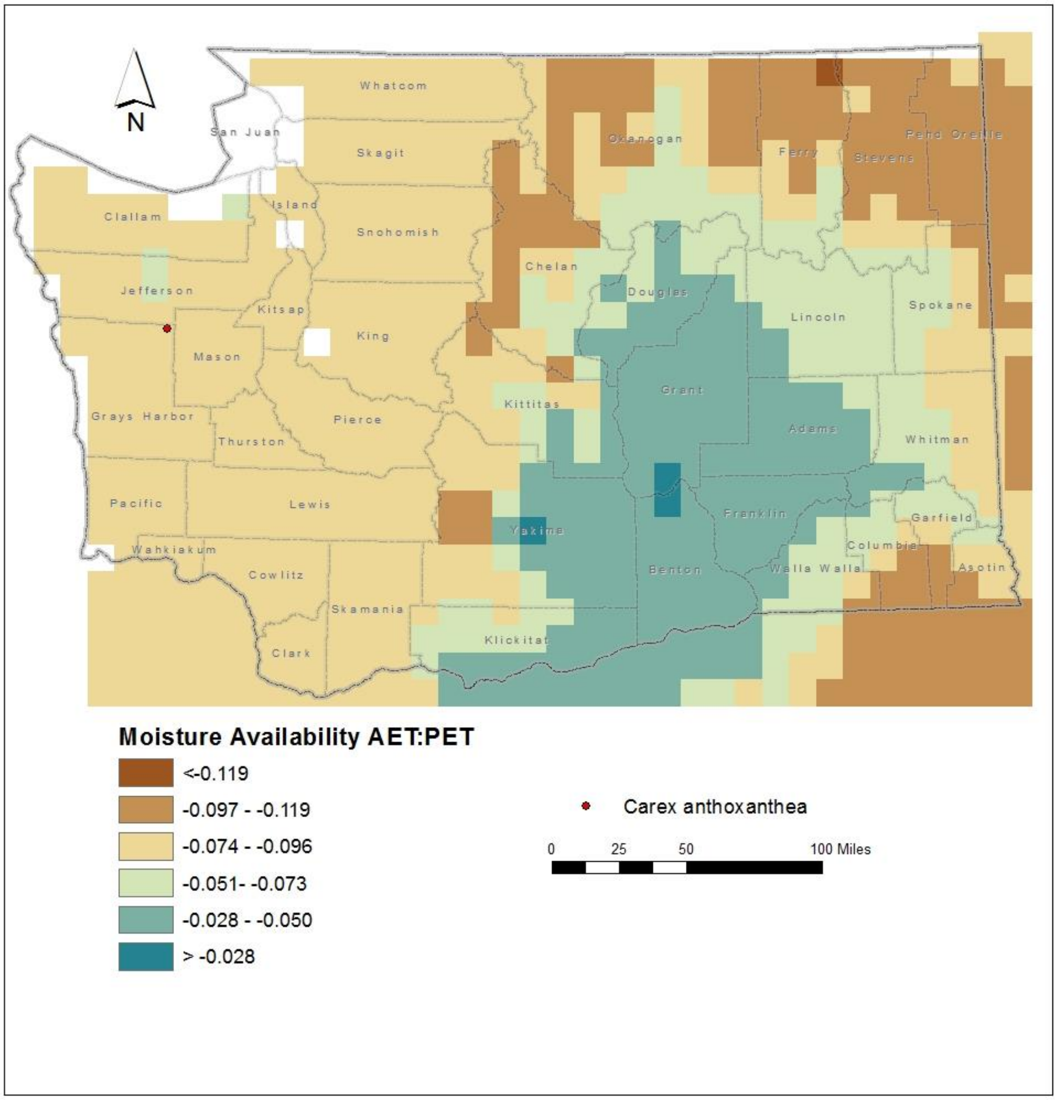

Figure 2. Exposure of *Carex anthoxanthea* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The entire range of *Carex anthoxanthea* in Washington is at or above 2800 ft (853 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Carex anthoxanthea* is found in wet seeps on cliffs, wet meadow fen complexes, and moist roadside ditches in mountainous areas of the Olympic Peninsula (Camp and Gamon 2011). This habitat conforms with the Temperate Pacific Subalpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). These habitats are scattered across the landscape, but barriers are not sufficient to prevent potential dispersal.

B2b. Anthropogenic barriers: Neutral.
Some subpopulations of *Carex anthoxanthea* in Washington are bounded by roads and could be impacted by culvert maintenance (Camp and Gamon 2011; Wilson et al. 2014). Seeps and wet areas in roadcuts also provide habitat, however, so net effects are probably neutral.

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 anthoxanthea produces 1-seeded dry fruits that are light weight and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Longer distance dispersal might occasionally be facilitated by the fruits adhering to mud on birds or mammals.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the distribution of *Carex anthoxanthea* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The range of the species is limited to an area that has experienced very small (<37˚F/20.8˚C) temperature variation during the past 50 years. It is considered to have greatly increased vulnerability under projected climate change (Young et al. 2016).

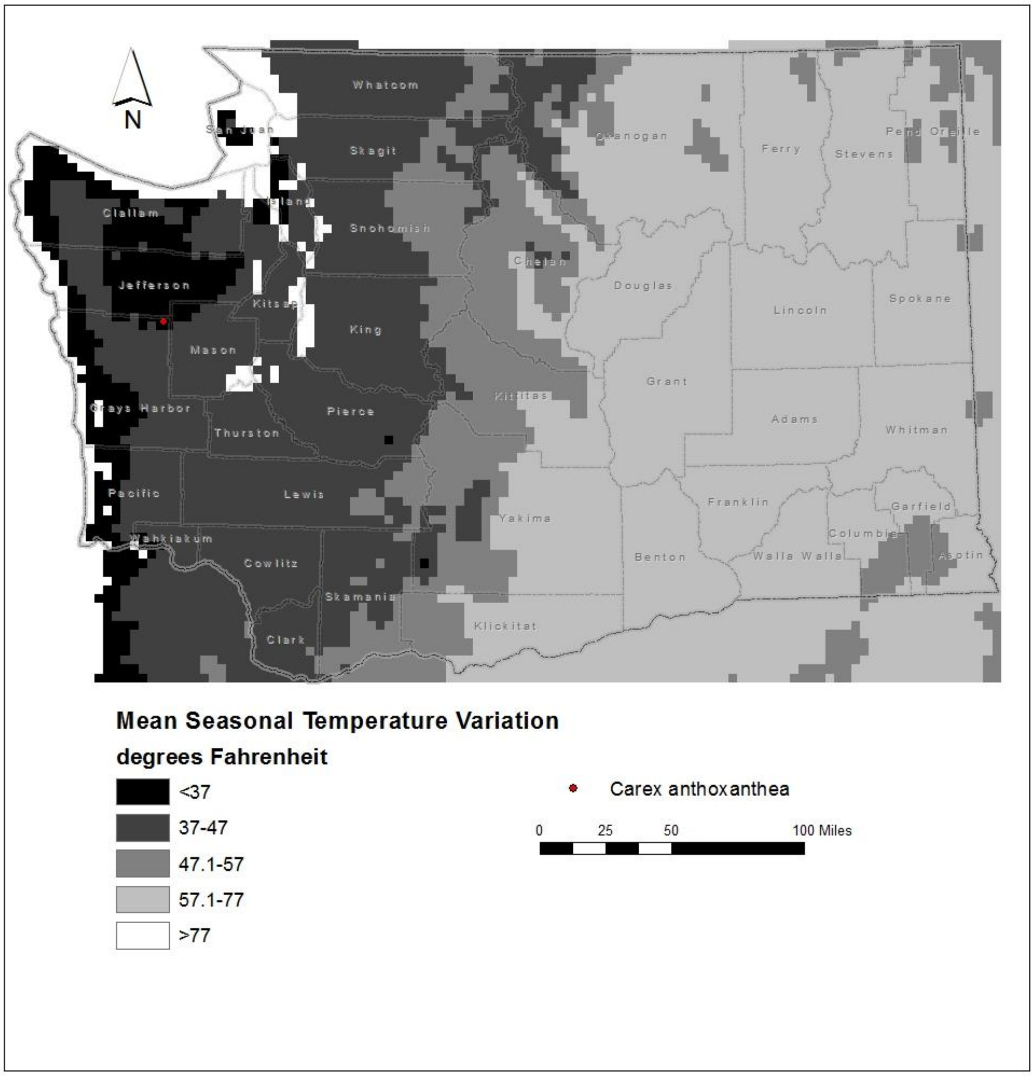

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex anthoxanthea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Several subpopulations of the single Washington occurrence of *Carex anthoxanthea* are found in wetlands associated with cool air drainages in mountain valleys.

C2bi. Historical hydrological niche: Neutral.
The entire range of *Carex anthoxanthea* in Washington occurs in areas that have experienced greater than average (>40 inches) precipitation variation in the past 50 years (Figure 4) and are considered neutral in terms of risk from climate change (Young et al. 2016).

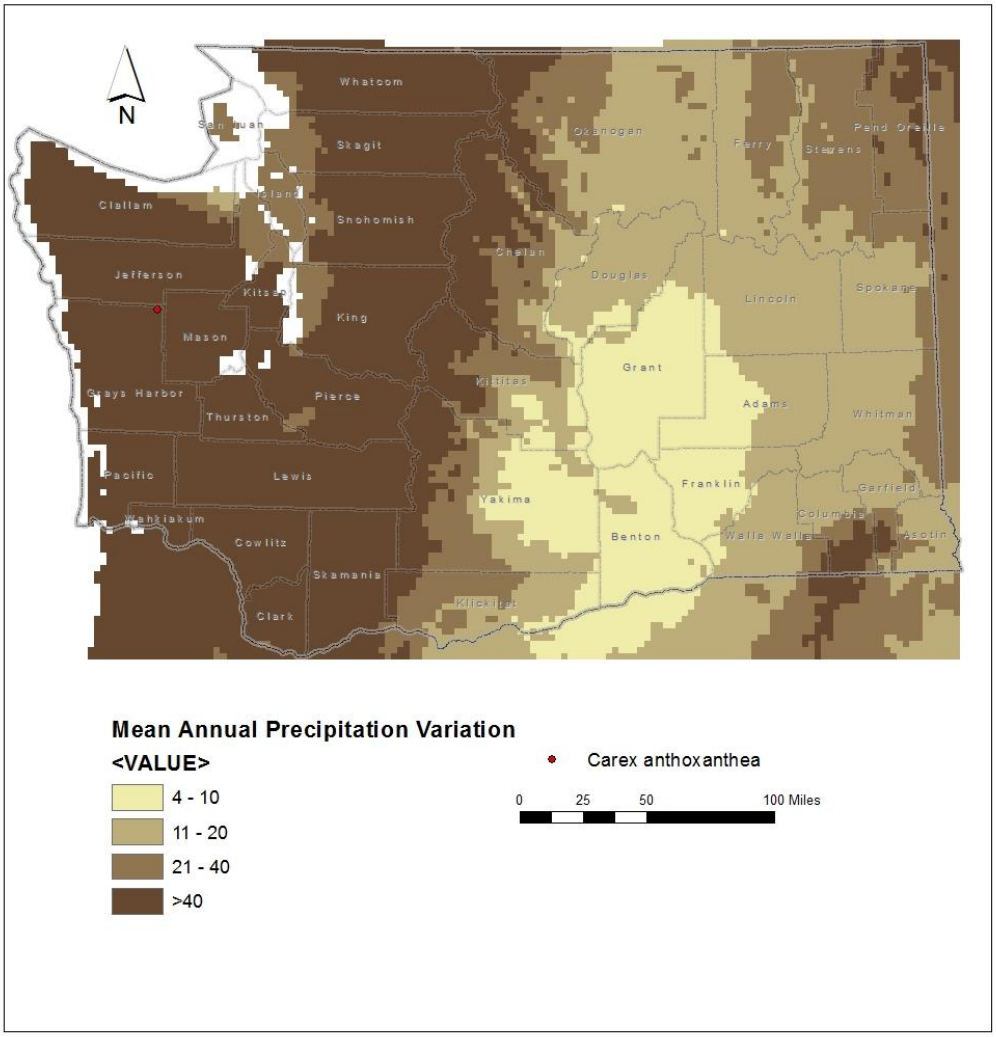

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex anthoxanthea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Carex anthoxanthea is dependent on wet seeps derived from groundwater (and ultimately from snowpack) that is augmented by spring and summer precipitation. Changes in the timing and amount of rainfall in the growing season or increases in temperature could convert montane wet meadows to drier meadows for forests (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: Increase.
In Washington, *Carex anthoxanthea* occurs in areas of high snowfall in the Olympic Mountains. Changes in the amount of snow accumulation or timing of snow melt could negatively impact groundwater-fed seeps and result in the conversion of wet meadows utilized by *C. anthoxanthea* to unsuitable dry meadows (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Washington populations of *Carex anthoxanthea* are found on cliffs and soils derived from Eocene-Paleocene marine clastic rock (lithic sandstone). This substrate is widespread in the Olympic Mountains.

C4a. Dependence on other species to generate required habitat: Neutral.
This species is not dependent on other species to maintain its seep-fed wet meadow habitat.

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 (gravity, water, high winds), but occasionally may abetted by animal vectors transporting fruit embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Grazing or disease has not been identified as a significant threat.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Carex anthoxanthea in Washington is sometimes found in densely vegetated wet meadows (Camp and Gamon 2011). Most competition for niche space is from other native species.

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability in the Washington occurrence. This population is the southern-most known occurrence, however, and might be expected to have lower genetic variation than populations closer to the core of the species' range.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate outcrosser, *Carex anthoxanthea* would be expected to have reasonably high genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
Changes in the onset of flowering or fruiting have not yet been detected in *Carex anthoxanthea*.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
No changes have been observed in the distribution of this species 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.

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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Carex chordorrhiza (Cordroot sedge)

Date: 4 November 2019

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		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		Unknown
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	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: The single known occurrence of *Carex chordorrhiza* in Washington is found in an area with a projected temperature increase of 3.9 to 4.4˚F (Figure 1).

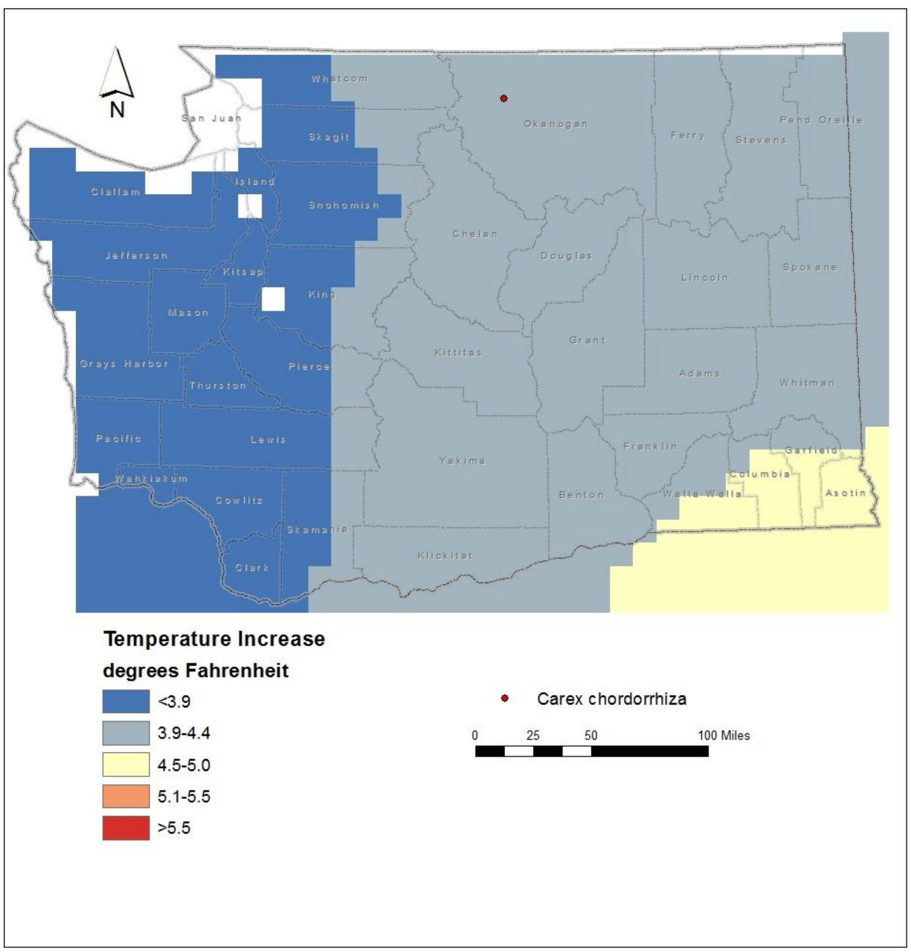

Figure 1. Exposure of *Carex chordorrhiza* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The sole occurrence of *Carex chordorrhiza* in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) of -0.097 to -0.119 (Figure 2).

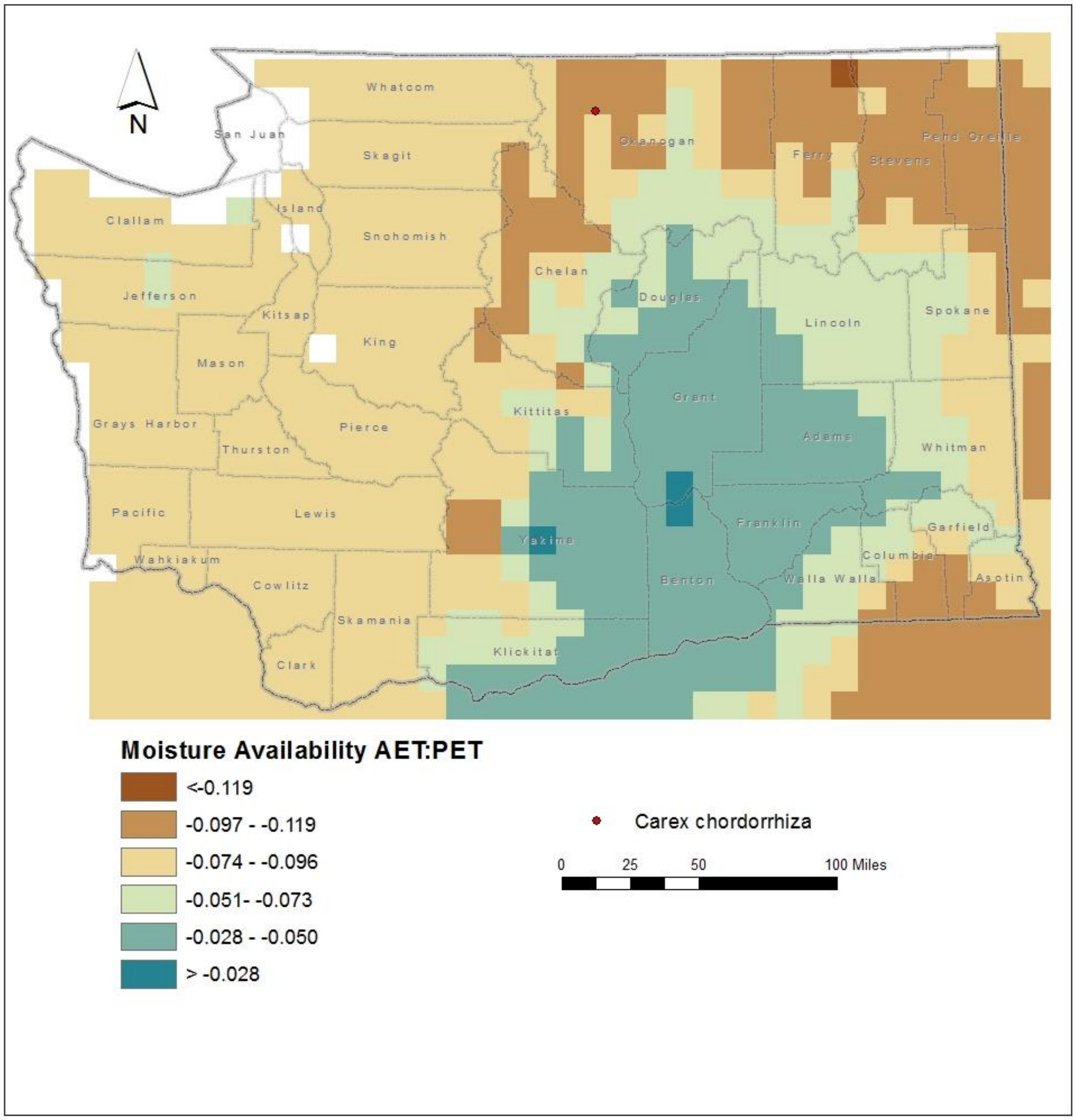

Figure 2. Exposure of *Carex chordorrhiza* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The entire range of *Carex chordorrhiza* in Washington is at 4520 ft (1380 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Carex chordorrhiza* is restricted to a rare rich fen community dominated by *Carex* and mosses other than *Sphagnum* in water 4 inches deep within a red cedar/willow community (Camp and Gamon 2011; Wilson et al. 2014). This habitat is part of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio and Crawford 2015). The surrounding matrix forested vegetation provides a barrier for natural dispersal.

B2b. Anthropogenic barriers: Neutral.
Although there are roads to the north and west of the single *Carex chordorrhiza* occurrence in Washington, they may not be restricting dispersal of this species. Populations of *C. chordorrhiza* from cultivated cranberry farms in Oregon are believed to have been introduced accidently by humans (Zika 2003), suggesting that this is an alternative dispersal pathway.

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 chordorrhiza produces 1-seeded dry fruits that are light weight and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Carex chordorrhiza* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The range of the species is limited to an area that has experienced small (37-47˚F/20.8-26.3˚C) temperature variation during the past 50 years. It is considered to have increased vulnerability under projected climate change (Young et al. 2016).

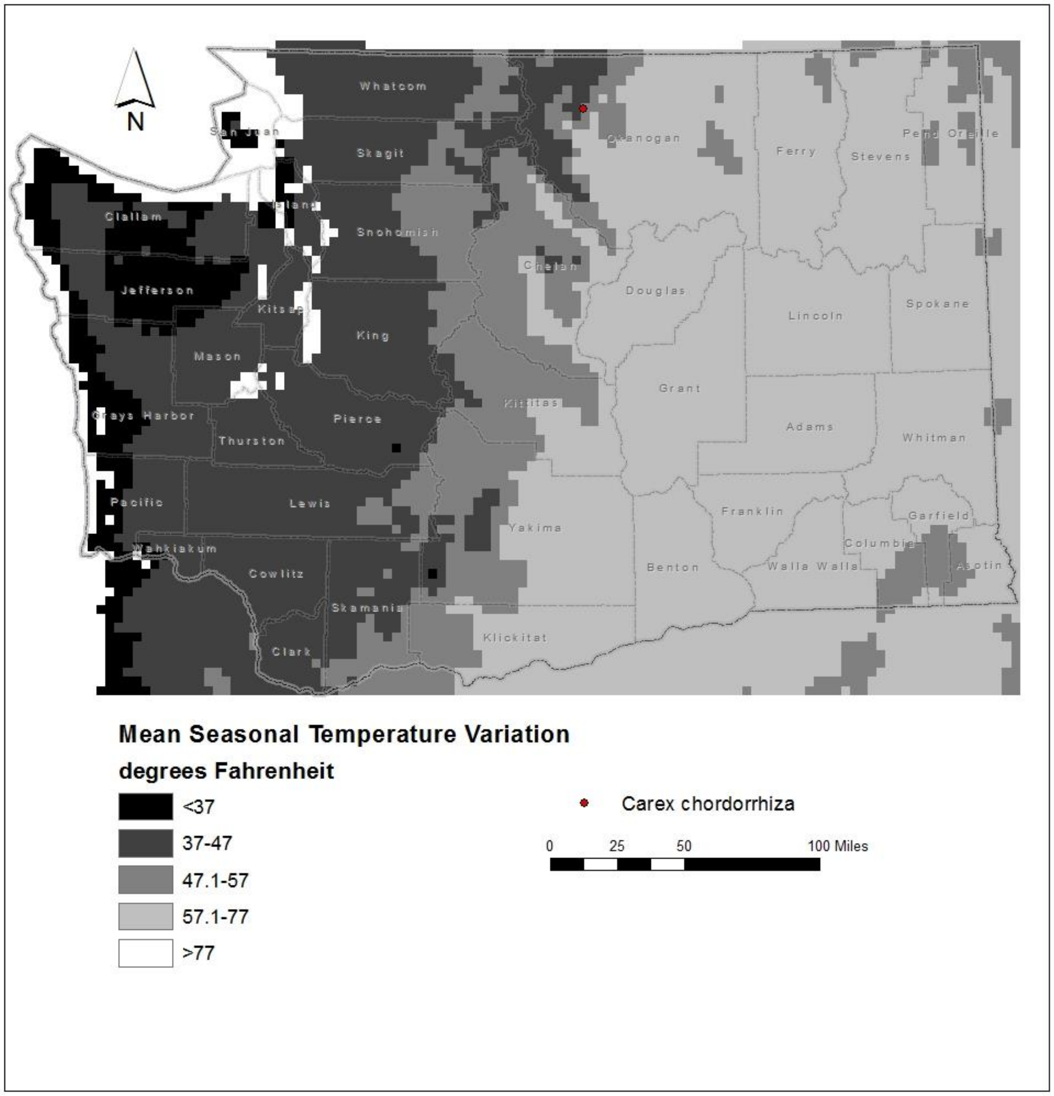

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex chordorrhiza* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The single Washington occurrence of *Carex chordorrhiza* is found in fens associated with cold air drainages in mountain valleys. These microhabitats are cooler than the general landscape matrix.

C2bi. Historical hydrological niche: Neutral.
The entire range of *Carex chordorrhiza* in Washington occurs in areas that have experienced average (21-40 inches) precipitation variation in the past 50 years (Figure 4) and are considered neutral in terms of risk from climate change (Young et al. 2016).

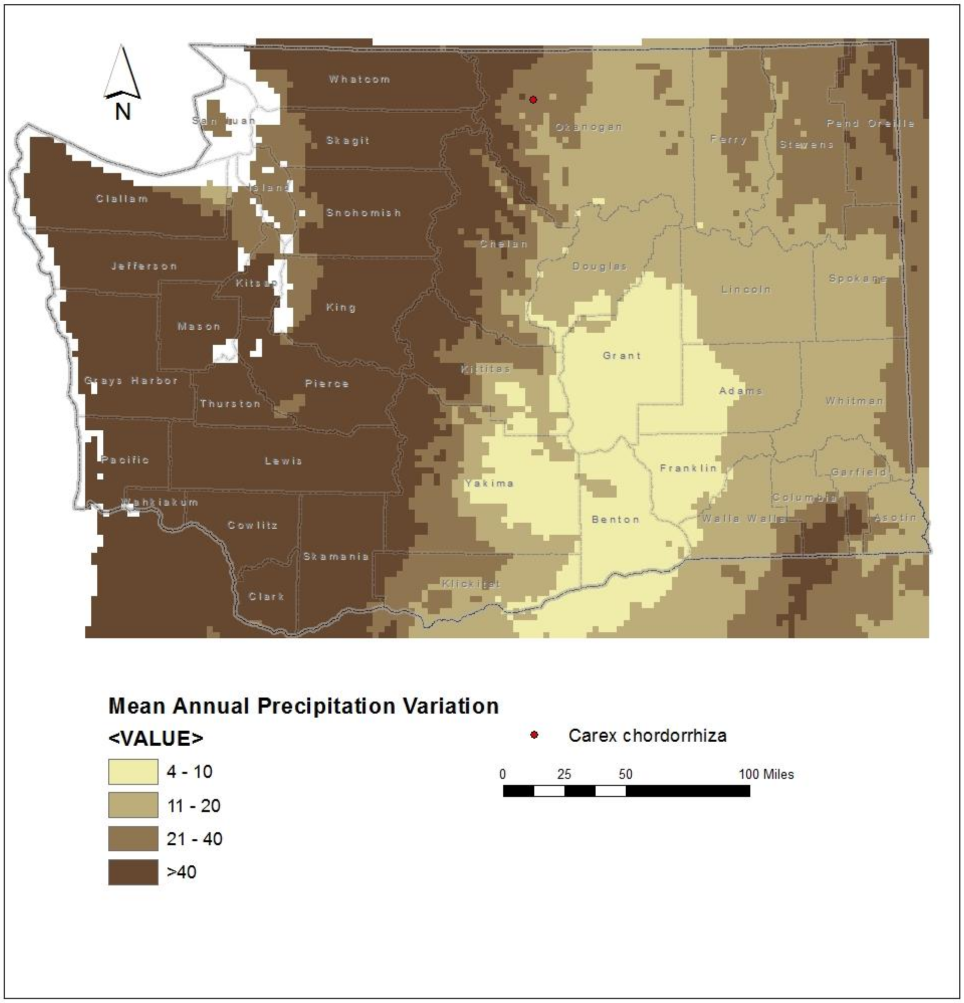

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex chordorrhiza* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Carex chordorrhiza is restricted to an unusual rich fen habitat dependent on adequate year-round moisture. Much of the moisture in this system is derived from groundwater, which is ultimately fed by snowpack. The yearly water balance is augmented by summer precipitation, which could be reduced under projected climate change. Increased summer temperatures and drought or changes in water chemistry could shift this vegetation type towards drier meadow conditions and make the site unsuitable for *C. chordorrhiza* (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: Increase.
In Washington, *Carex chordorrhiza* occurs in areas of moderate snowfall in the foothills of the Okanogan Mountains. Snowpack, however, is critical for maintaining groundwater supplies for fen wetlands (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow and timing of melting could have long-term negative impacts on this ecological system, changing fen conditions to mesic or dry meadows.

C3. Restricted to uncommon landscape/geological features: Neutral.
Washington populations of *Carex chordorrhiza* are found on glacial outwash and alluvium restricted to valley bottoms in the Okanogan Range. This feature is relatively widespread in northeastern Washington.

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

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 (gravity, water, high winds), but occasionally may also occur by animal vectors transporting fruits embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Grazing has been identified as a significant threat to Washington populations of *Carex chordorrhiza* (Camp and Gamon 2011; Wilson et al. 2014).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Carex chordorrhiza in Washington is found in rich fen habitats with low cover of non-native species. Competition with other native species is currently not a threat, but future changes in species composition due to climate change are unknown.

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability in the Washington occurrence. This population is the southern-most known native occurrences (some introduced populations are also found in Oregon [Wilson et al. 2014; Zika 2003]), however, and is disjunct from populations in south-central British Columbia. It might be expected to have lower genetic variation than populations closer to the core of the species' range.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate outcrosser, *Carex chordorrhiza* would be expected to have reasonably high genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown. Changes in the onset of flowering or fruiting have not yet been detected in *Carex chordorrhiza*.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No changes have been documented in the range of this species 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

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.

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Zika, P.F. 2003. Notes on the provenance of some eastern wetland species disjunct in western North America. Journal of the Torrey Botanical Society 130(1):43-46.

Climate Change Vulnerability Index Report

Carex proposita (Smoky Mountain sedge)

Date: 5 November 2019

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	**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	91
	<3.9° F (2.2°C) warmer	9
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	55
	-0.074 to - 0.096	45
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		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
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 11 known occurrences of *Carex proposita* in Washington (91%) are found in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). One other

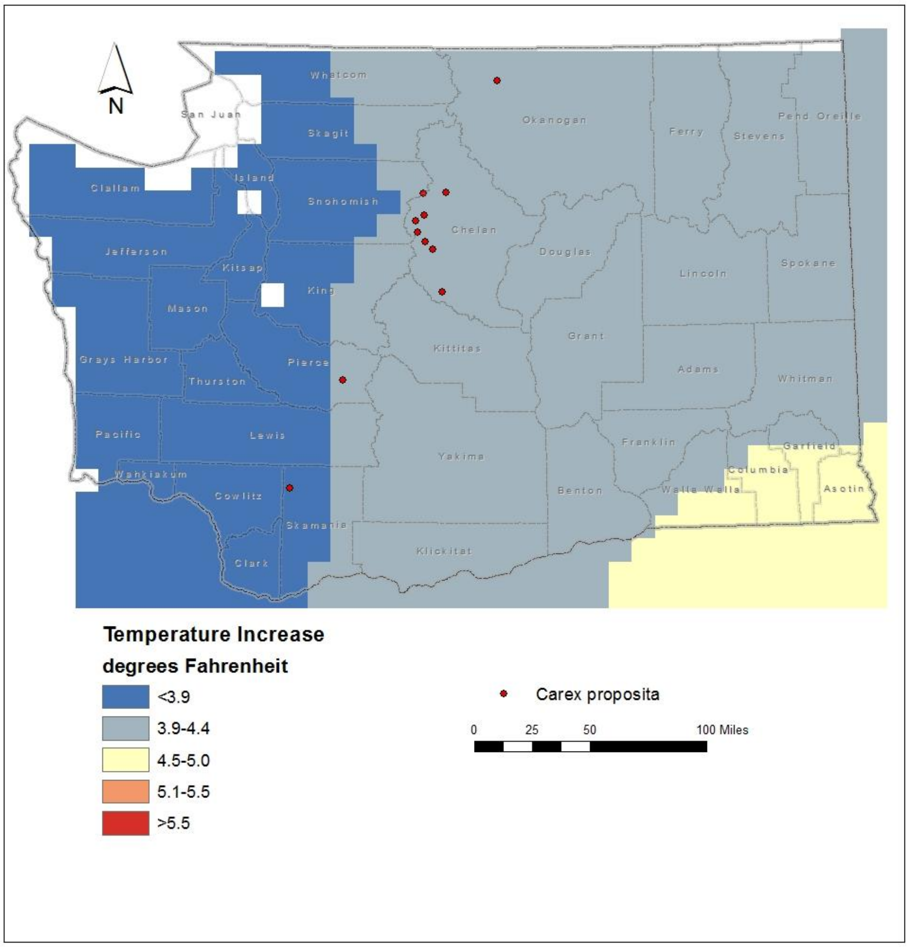

Figure 1. Exposure of *Carex proposita* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

population (9%) has a projected future temperature increase of < 3.9˚F. This assessment excludes some recent erroneous reports of *C. proposita* from NE Washington.

A2. Hamon AET:PET Moisture Metric: Six of 11 occurrences of *Carex proposita* (55%) 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 five occurrences (45%) are in the range from – 0.074 to -0.096.

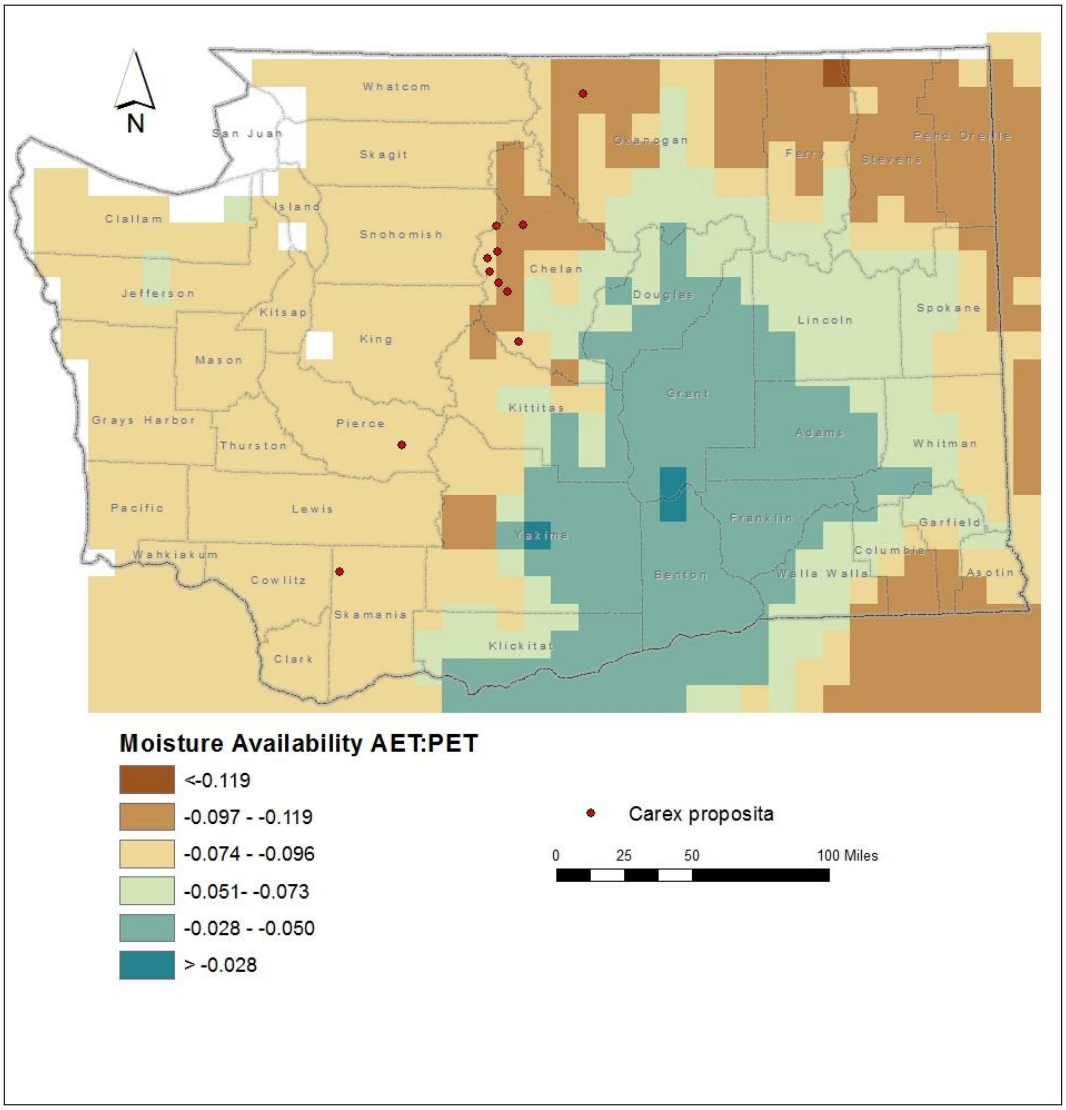

Figure 2. Exposure of *Carex proposita* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington populations of *Carex proposita* range in elevation from 1370-2450m (4500-8040 ft) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
In Washington, populations of *Carex proposita* are found in rocky alpine ridges, on granite talus, and dry meadows near lakes above tree line (Camp and Gamon 2011; Wilson et al. 2014). This habitat conforms to the North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow and Rocky Mountain Alpine Dwarf Shrubland, Fell-field, and Turf ecological systems (Rocchio and Crawford 2015). Washington populations are separated by distances of 4-68 miles (8-110 km). Along the crest of the northern Cascades, these habitats may be relatively continuous, but elsewhere in the state they are widely isolated by dissimilar forest and valley sites that would be a significant barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
Anthropogenic barriers, such as roads, agricultural developments, and urban areas exist at low elevations between populations of *Carex proposita*, but dispersal is primarily limited by natural barriers encircling high elevation occurrences.

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 proposita produces 1-seeded dry fruits contained within winged sac-like perigynia that are passively dispersed by gravity or high winds, mostly within a short distance of the parent plant (< 1000 m).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Carex proposita* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eight of the 11 known occurrences (73%) 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. These populations have somewhat increased vulnerability to climate change (Young et al. 2016). The other three occurrences (27%) are found in areas that have experienced small (37-47˚F/20.8-26.3˚C) temperature variation in the same time span and have increased vulnerability under projected climate change (Young et al. 2016).

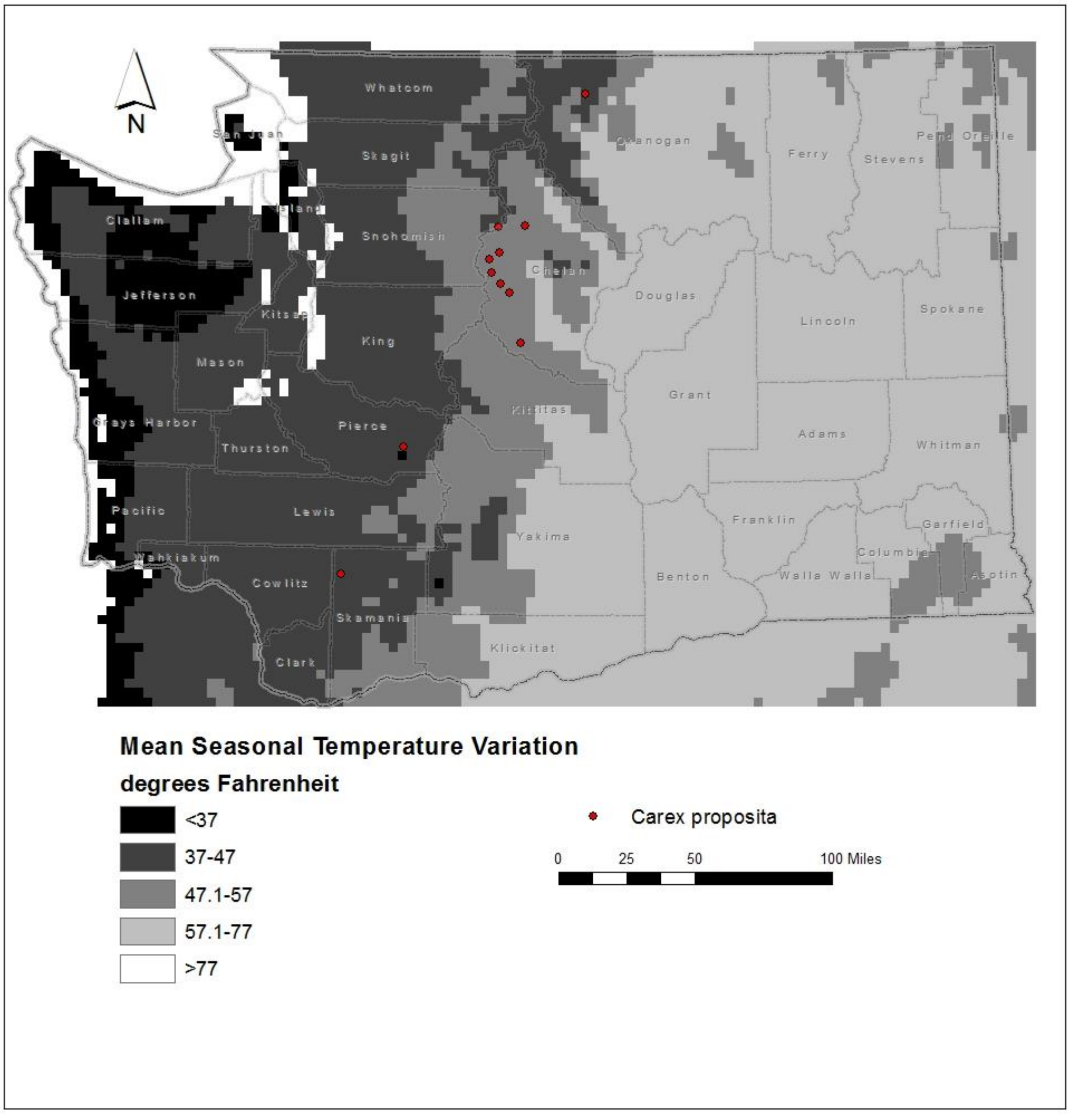

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex proposita* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
Carex proposita is found mostly at or above treeline in the alpine zone of Washington mountains in areas subjected to cool temperatures in the growing season.

C2bi. Historical hydrological niche: Neutral.
The entire range of *Carex proposita* in Washington occurs in areas that have experienced average or greater than average (>20 inches/508 mm) precipitation variation in the past 50 years (Figure 4) and is at neutral vulnerability from climate change (Young et al. 2016).

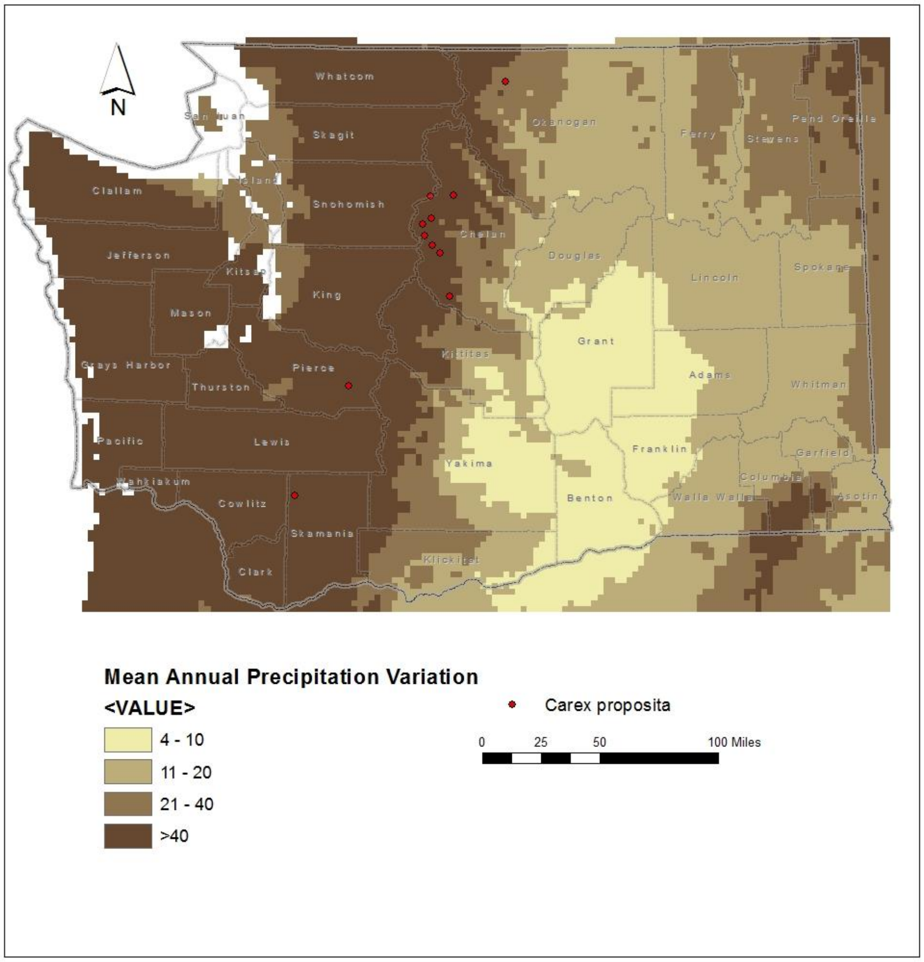

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex proposita* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
In Washington, *Carex proposita* occurs at high elevation rocky ridge and meadow sites that are dependent primarily on snow or summer rainfall for moisture. Changes in the timing of precipitation, or reduction in the amount, coupled with increases in temperature, would favor conversion of these communities to meadow communities currently found at lower elevations (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
The alpine meadow and talus habitat of this species is not dependent on periodic disturbances to be maintained.

C2d. Dependence on ice or snow-cover habitats: Increase.
Snowpack is a primary moisture source for this species in its treeline and alpine habitat, making it vulnerable to reduced snow cover and changes in the timing of snow melt under climate change scenarios (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Washington occurrences of *Carex proposita* are associated with pyroclastic volcanic rock or metamorphic quartz or gneiss batholiths. These are relatively widespread geologic types in the Cascade Range.

C4a. Dependence on other species to generate required habitat: Neutral.
The habitat of Carex proposita is maintained primarily by abiotic factors.

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 (gravity or high winds), but occasionally may occur by animal vectors, such as ants.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Grazing or disease has not been identified as a significant threat.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Non-native species are currently a minor component of the habitat of *Carex proposita*. Competition is relatively low in its rocky habitat.

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability in Washington. The species has an unusual global range consisting of three disjunct population centers: north-central Washington, southern Idaho and NW Wyoming, and east-central California. It is plausible that these populations are sufficiently isolated to reduce gene flow and are probably diverging genetically, but more research is needed.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate out-crosser, *Carex proposita* would be expected to have reasonably high genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Significant changes in the onset of flowering or fruiting have not yet been detected in this species in Washington.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral
Although some individual populations of *Carex proposita* (such as Mount Rainier) have not been relocated since the 1930s, the overall range of the species has not contracted in Washington. Historical occurrences could be extirpated or no attempt has been made to relocate them.

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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Carex rostrata (Beaked sedge)

Date: 5 November 2019

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		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		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: The entire range of *Carex rostrata* (considered here in the narrow sense and excluding *C. utriculata*, which occurs commonly throughout Washington [Reznicek 1985, 1997])

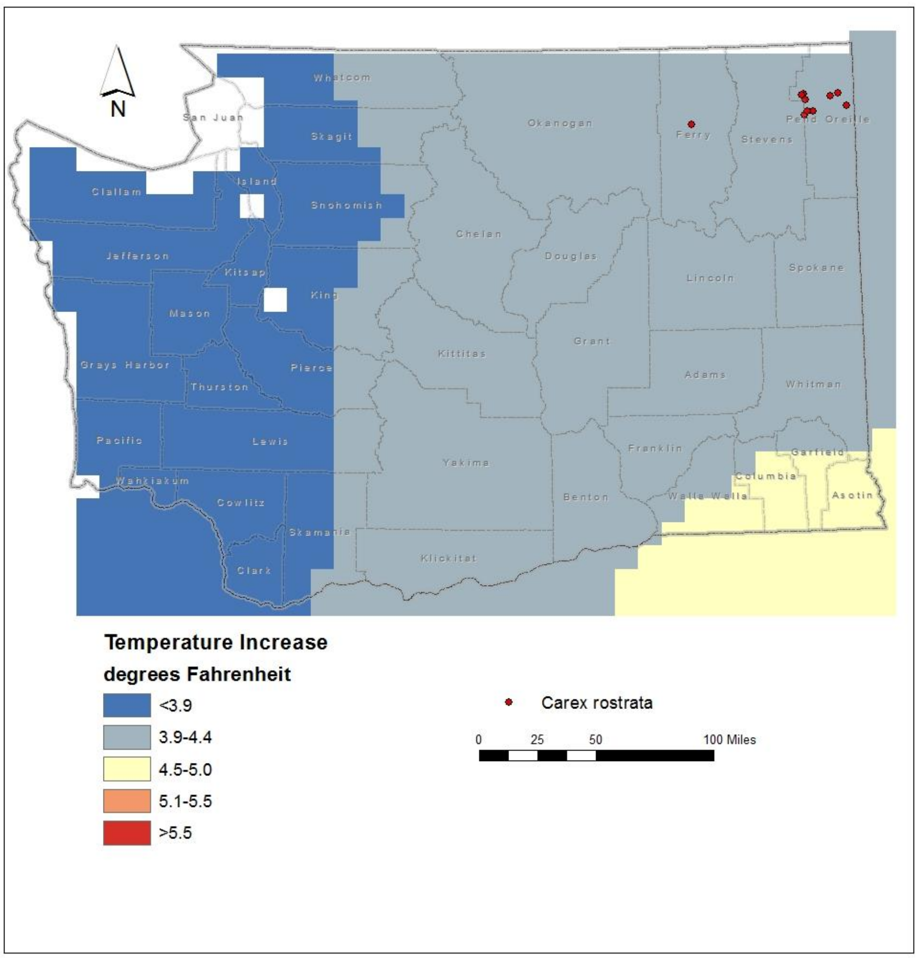

Figure 1. Exposure of *Carex rostrata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

is found within the area of the state with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

A2. Hamon AET:PET Moisture Metric: In Washington, all confirmed occurrences of *Carex rostrata* 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).

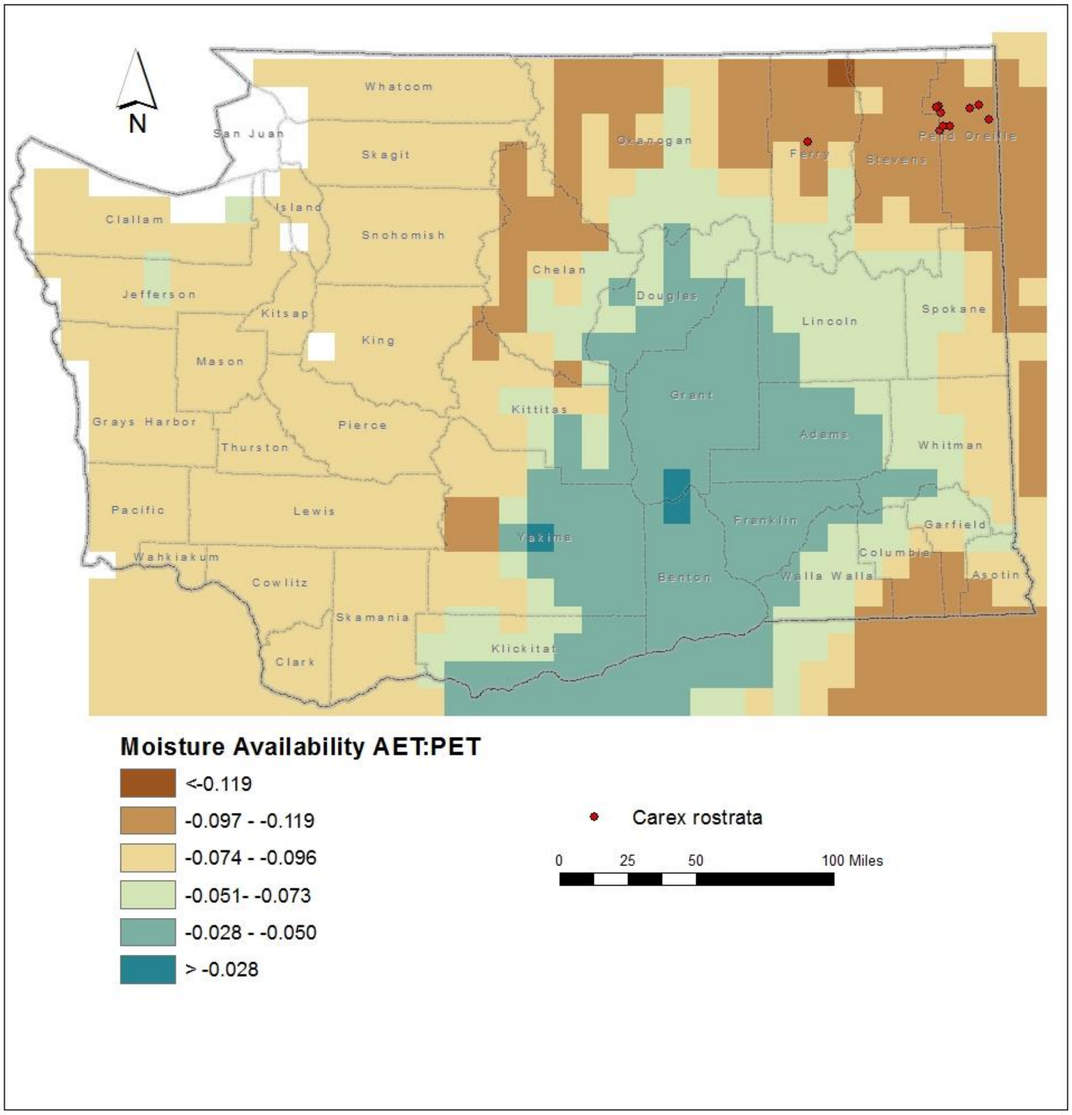

Figure 2. Exposure of *Carex rostrata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex rostrata* are found at elevations of 3200-5120 ft (975-1560 m) (Camp and Gamon 2011) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Carex rostrata* is found in fens or floating mats of peat (*Sphagnum*) along lakes and streams (Camp and Gamon 2011; Kovalchik and Mastrogiuseppe 1991; Wilson et al. 2014). These wetlands are part of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio and Crawford 2015). Populations in northeastern Washington are separated by 1.3-10 miles (2-15.5 km). Occupied habitat is patchy and embedded in a matrix of unsuitable forest habitat, which creates a barrier for dispersal.

B2b. Anthropogenic barriers: Somewhat Increase.
The habitat of *Carex rostrata* in NE Washington is bisected by paved highways and gravel Forest Service roads, agricultural lands, sites managed for forestry, and residential areas.

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 rostrata produces 1-seeded dry fruits within a beaked, sac-like perigynium that is lightweight and passively dispersed by gravity, high winds, or water. Most dispersal probably occurs within less than 1000 m of the parent plant. Longer distance dispersal is facilitated by fruits adhering to mud on birds or mammals.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Carex rostrata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Thirty percent of the Washington occurrences 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. These populations are considered to have somewhat increased vulnerability under projected climate change (Young et al. 2016). The remaining 70% of known *C. rostrata* occurrences in the state are from areas with average (57.1-77˚F/31.8 – 43.0˚C) temperature variation over the same historic period and are ranked as neutral for climate change impacts. Since the majority of Washington populations are in the latter category, the species is ranked neutral for the whole state.

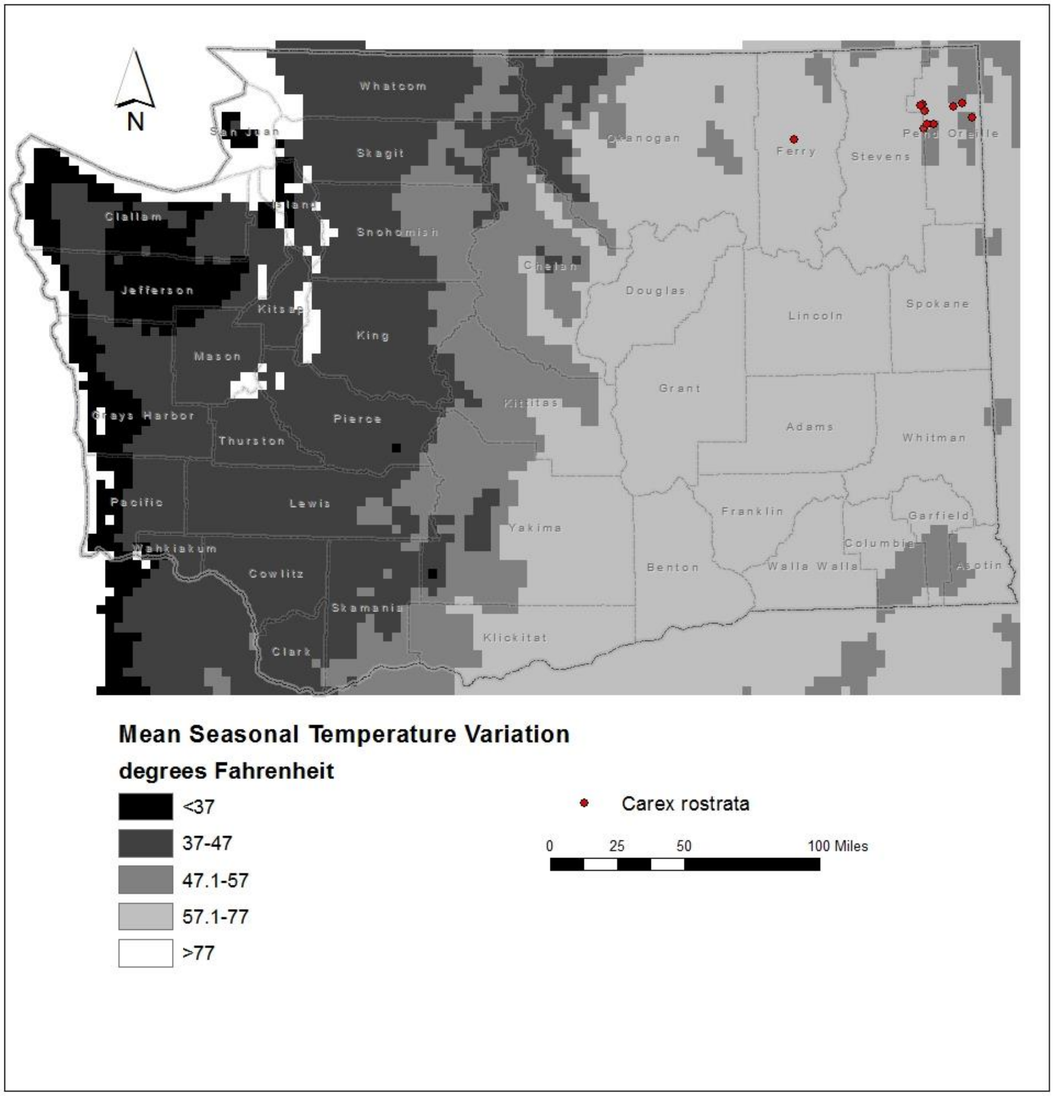

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex rostrata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
More than half of the Washington occurrences of *Carex rostrata* are found in cold air drainages in valley bottoms and fen depressions that are cooler microsites than the matrix vegetation, and so potentially at increased risk from climate change.

C2bi. Historical hydrological niche: Neutral.
The entire range of *Carex rostrata* in Washington is found in areas that have experienced average (>20 inches) or greater than average (>40 inches) precipitation variation in the past 50

years (Figure 4). These populations are considered neutral in terms of risk from climate change by Young et al. (2016).

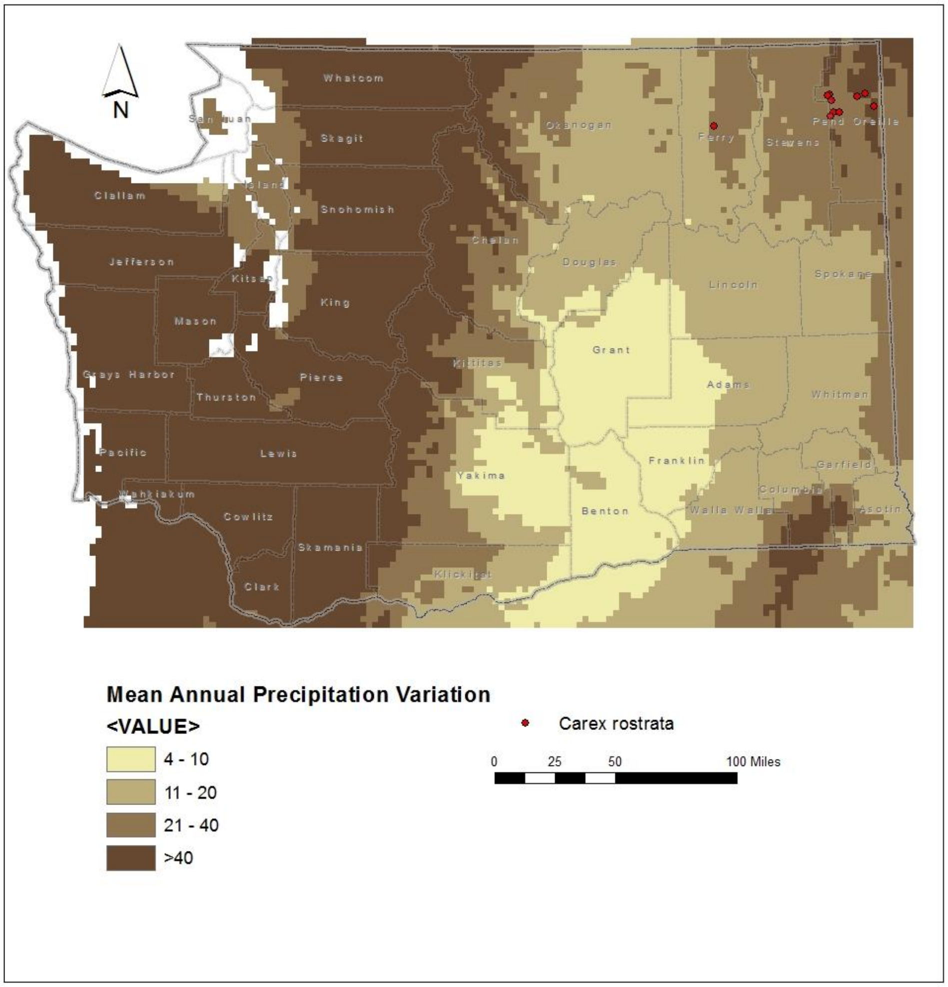

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex rostrata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Carex rostrata populations in Washington are dependent on a very specific wetland ecological system (fen with floating *Sphagnum* mats) in which water chemistry may be extremely important. These habitats are also dependent on groundwater and can be negatively impacted by decreased snow accumulation. Changes in the timing and amount of precipitation and increasing temperatures could shift these communities towards drier wet meadows (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
The habitat of *Carex rostrata* in northeast Washington is not characterized by exceptionally high amounts of ice or snow, but reduced snowpack could impact groundwater recharge (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Some *Carex rostrata* occurrences in Washington are associated with areas of glacial drift, which is relatively widespread in NE Washington. Water chemistry, however, may be important for this species.

C4a. Dependence on other species to generate required habitat: Neutral.
Some wet meadows occupied by *Carex rostrata* in NE Washington are associated with old beaver dams and ponds.

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 (gravity, water, high winds), but occasionally may also occur by animal vectors transporting fruit embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Carex rostrata is palatable and grazed by livestock, which has been identified as a threat at some sites (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Carex rostrata is often locally dominant within its specialized habitat.

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

C5a. Measured genetic variation: Neutral.
Ford et al. (1993) studied genetic variation among species in *Carex* Section *Vesicariae* and found significant variability within and between populations of *Carex rostrata* and *C. utriculata*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate outcrosser, *Carex rostrata* would be expected to have reasonably high genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
Significant changes in the onset of flowering or fruiting have not been detected in *Carex rostrata*.

Section D: Documented or Modeled Response to Climate Change

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.

References

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Climate Change Vulnerability Index Report

Carex sychnocephala (Many-headed sedge)

Date: 1 April 2020

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	**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	15.4
	-0.074 to - 0.096	15.4
	-0.051 to - 0.073	69.2
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others species to generate required habitat		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown

5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	
Section D	Neutral
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: All 13 known occurrences of *Carex sychnocephala* in Washington are found in areas with a projected temperature increase of 3.9-4.4˚F (Figure 1).

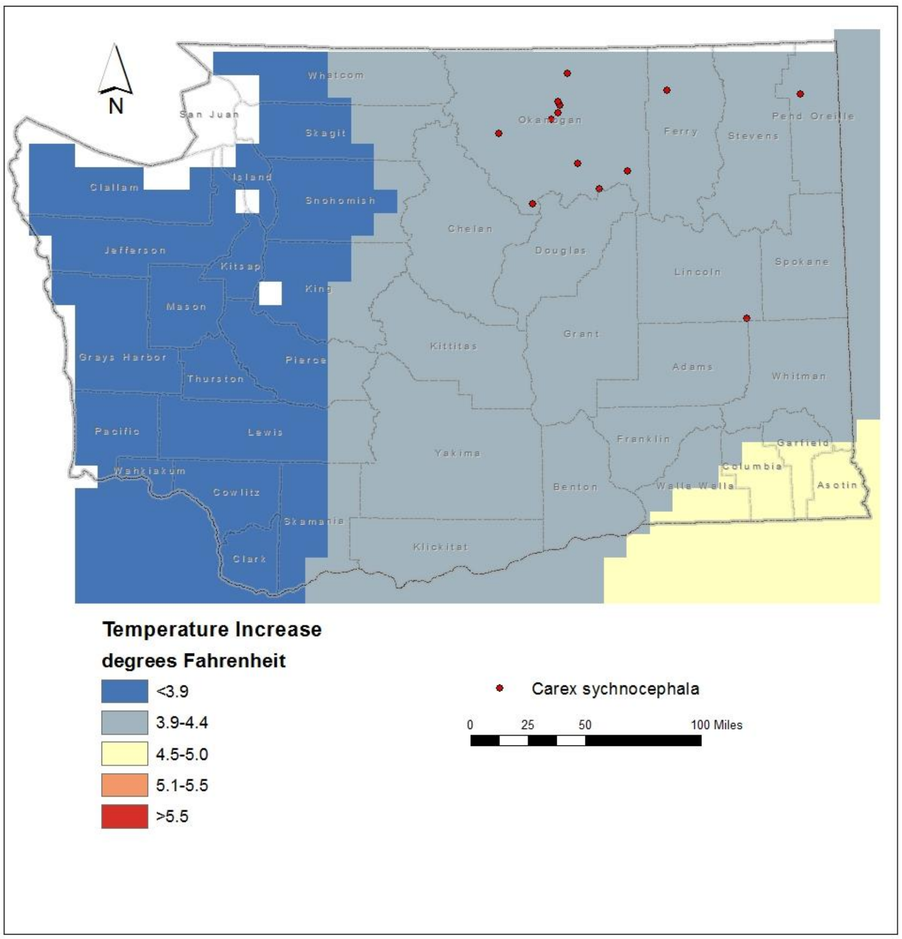

Figure 1. Exposure of *Carex sychnocephala* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Nine of the 13 occurrences of *Carex sychnocephala* in Washington (69.2%) 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). Two populations (15.4%) are from areas with a projected decrease in available moisture between -0.074 to -0.096 and two others (15.4%) are from areas with a predicted decrease of -0.097 to -0.119 (Figure 2).

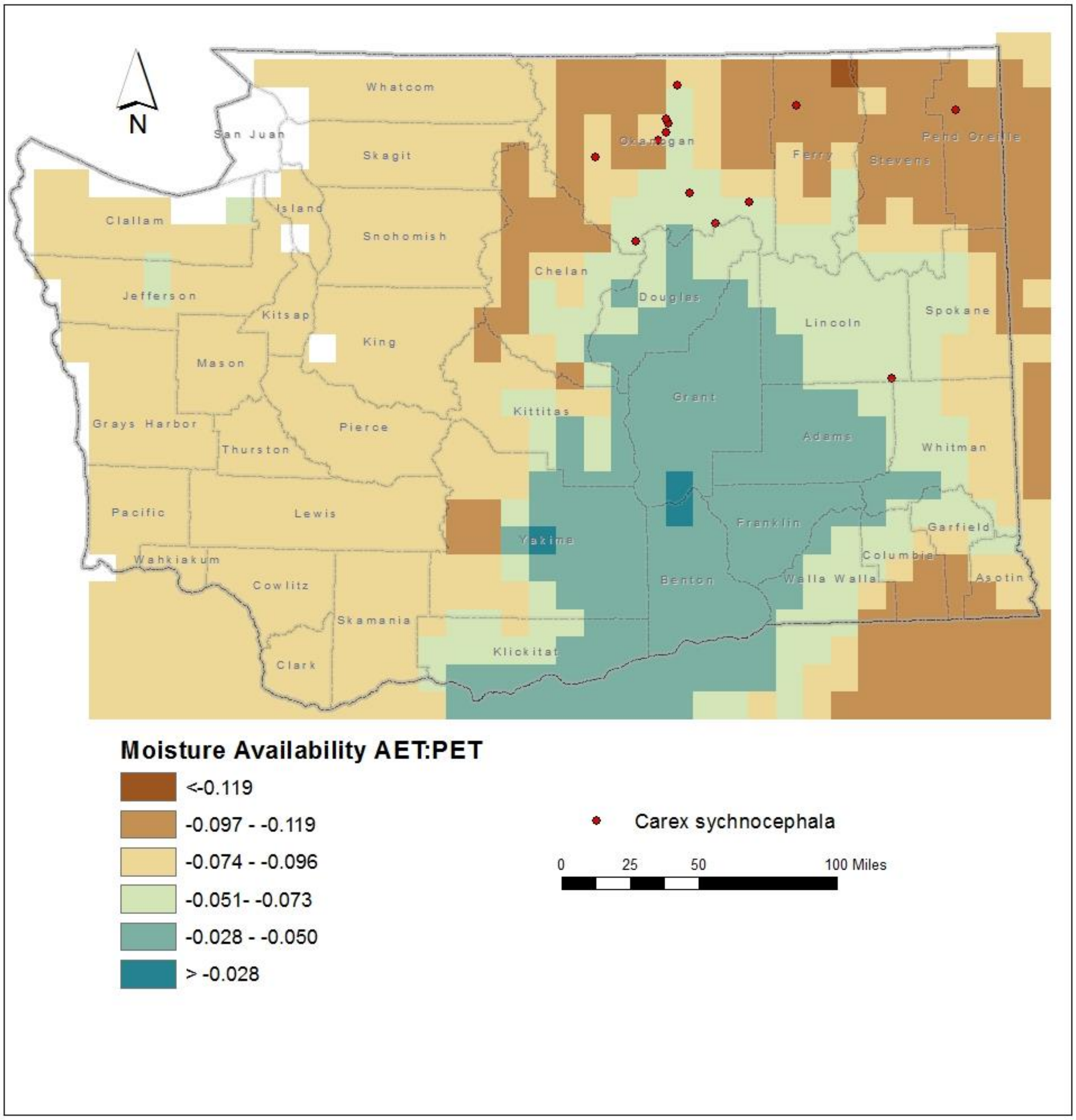

Figure 2. Exposure of *Carex sychnocephala* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The entire range of *Carex sychnocephala* in Washington is at or above 1170-3400 ft (360-1040 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Carex sychnocephala* is found in moist depressions, marshy areas, and shores of small lakes and ponds on rocky, silty, or sandy soils (Camp and Gamon 2011, Wilson et al. 2014, WNHP records). Some occurrences on basalt bedrock are associated with ephemeral wetlands that become dry by late summer. Populations may be found in openings within forests or in sagebrush steppe. Shoreline habitats may have dense cover of Reed canarygrass (*Phalaris arundinacea*), bulrushes (*Scirpus* or *Schoenoplectus* spp), or other sedges. The habitat of most populations in Washington conforms with the North American Arid West Emergent Marsh ecological system, though a few associated with ephemeral basalt ponds might be better classified as Northern Columbia Plateau Basalt Pothole Ponds (Rocchio and Crawford 2015). Washington populations are separated by 1.7-85 miles (3-125 km) and isolated by large areas of unsuitable habitat.

B2b. Anthropogenic barriers: Neutral.
Most populations of *Carex sychnocephala* in Washington occur within a matrix of agricultural development, roads, and other human developments, but the distribution of this species is more strongly influenced by the availability of natural 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.
Carex sychnocephala produces 1-seeded dry fruits (achenes) that are light weight and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Longer distance dispersal might occasionally be facilitated by the fruits adhering to mud on birds or mammals.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Carex sychnocephala* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 13 of the known occurrences are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years. The species is considered to have neutral vulnerability under projected climate change (Young et al. 2016).

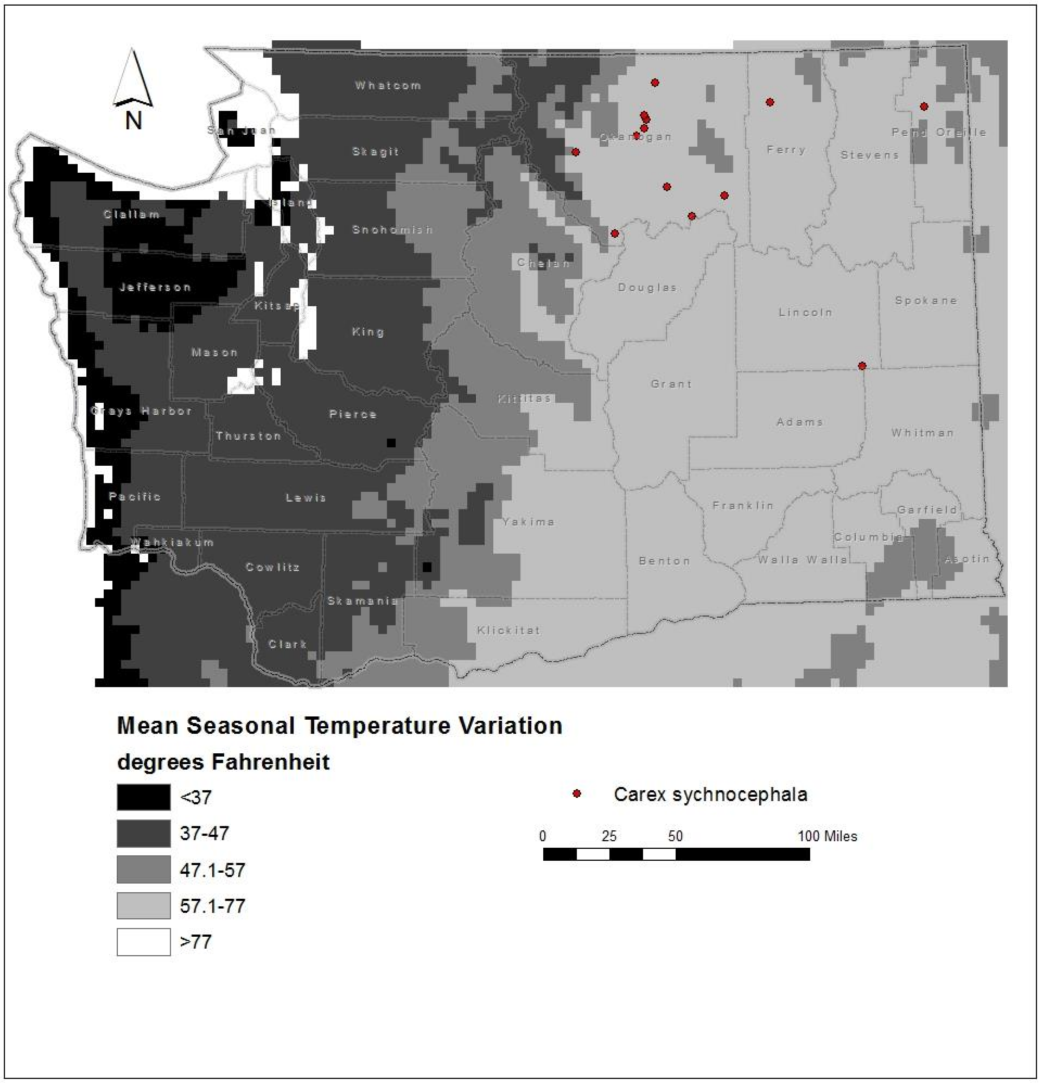

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex sychnocephala* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Populations of *Carex sychnocephala* in Washington are found in depressions, lake shores, and wetlands associated with cool air drainages, often within mountain valleys. These microhabitats are cooler than the general landscape matrix.

C2bi. Historical hydrological niche: Somewhat Increase.
Ten of the 13 known occurrences of *Carex sychnocephala* in Washington (76.9%) occur in areas that have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation in the past 50 years (Figure 4) and are considered to be at somewhat increased risk from climate change (Young et al. 2016). Three other populations (23.1%) have experienced average or greater than average (>20 inches/508 mm) precipitation variation over the same period and are at neutral risk from climate change.

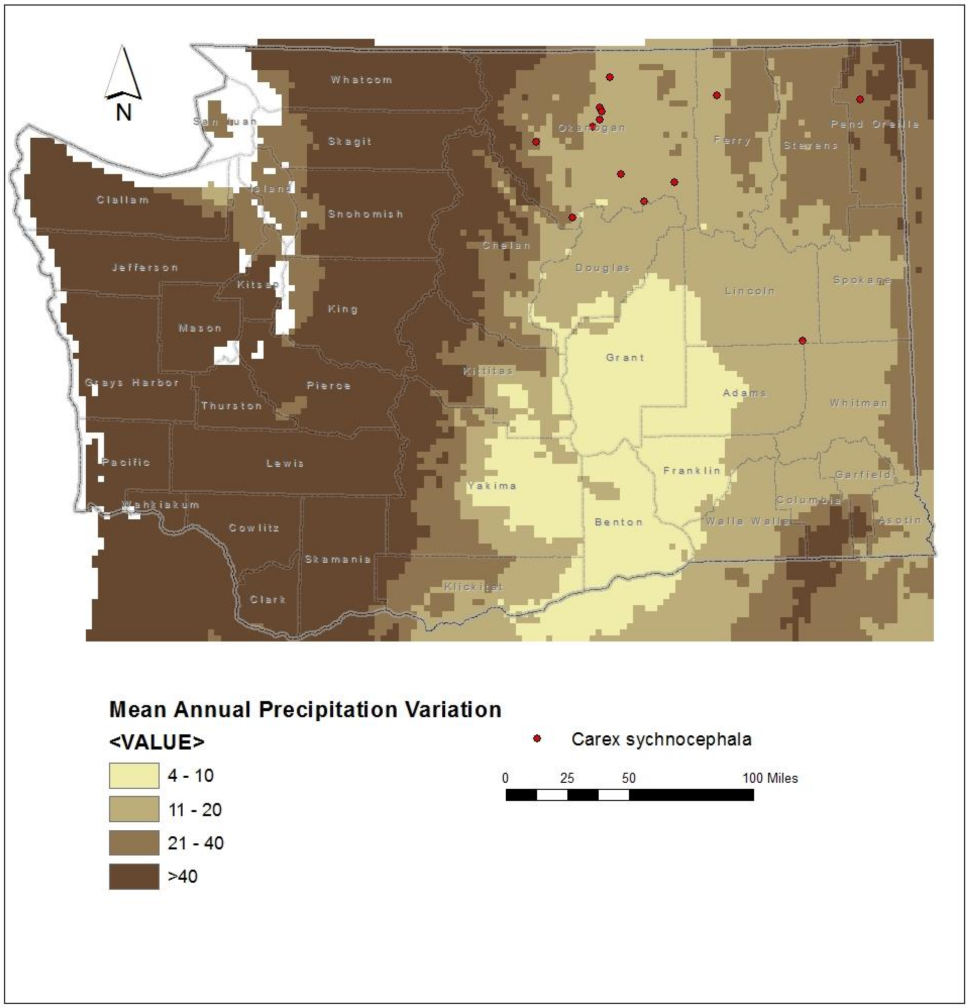

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex sychnocephala* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The marsh, pond, and lakeshore habitat of *Carex sychnocephala* is dependent on adequate surface moisture. It would be negatively impacted by changes in the amount and timing of spring and summer precipitation and increased temperatures that would exacerbate drought

conditions. Some occurrences may also be dependent on groundwater that is influenced by snowpack (see C2d below). Drying conditions could favor transition of some sites to wet meadows (Rocchio and Ramm-Granberg 2017). Summer drought also helps maintain some populations in ephemeral wetlands (Wilson et al. 2014), but changes in precipitation timing might make these areas prone to longer periods of flooding.

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: Somewhat Increase.
Some occurrences of *Carex sychnocephala* in the Okanogan Mountains are in areas of relatively high snowfall and may depend on recharge of groundwater through snowmelt to maintain appropriate hydrological conditions.

C3. Restricted to uncommon landscape/geological features: Neutral.
Washington populations of *Carex sychnocephala* are found in a variety of widespread geological formations, including the Priest Rapids member of the Wanapum Basalt, Palmer Mountain Greenstone, O'Brien Creek Formation, Conconully granodiorite, and various Pleistocene geolacustrine deposits. The species is usually found in naturally occurring depressions or lakeshores formed by geomorphic processes.

C4a. Dependence on other species to generate required habitat: Somewhat Increase.
Herbivory of marsh vegetation (especially competing graminoids) may help maintain partially open lakeshore habitat for *Carex sychnocephala*.

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 (gravity, water, high winds), but occasionally may occur by animal vectors transporting fruit embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
No impacts from pathogens are known. The species can withstand moderate grazing or trampling (Wilson et al. 2014), but may decline with heavy grazing.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Carex sychnocephala in Washington is sometimes found in densely vegetated wet meadows (Camp and Gamon 2011) and at one site has declined due to competition with reed canarygrass (WNHP records).

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability in the state. Washington populations are near the southern edge of the species' range and might be expected to have lower genetic variation than populations closer to the core of its range.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate outcrosser, *Carex sychnocephala* would be expected to have reasonably high genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on records from the Consortium of Pacific Northwest Herbaria website, no significant changes have occurred in the onset of flowering or fruiting in *Carex sychnocephala* in the past 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase
Four of the 13 known occurrences of this species in Washington have not been relocated in recent surveys (since 2000) and may have become extirpated. Whether this is due to local factors, such as competition with exotic plants, development, loss of water, over-grazing, or climate impacts is poorly 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.

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 tenuiflora (Sparse-flowered sedge)

Date: 8 November 2019

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		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		Unknown
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	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: all seven of the known occurrences of *Carex tenuiflora* in Washington are found in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

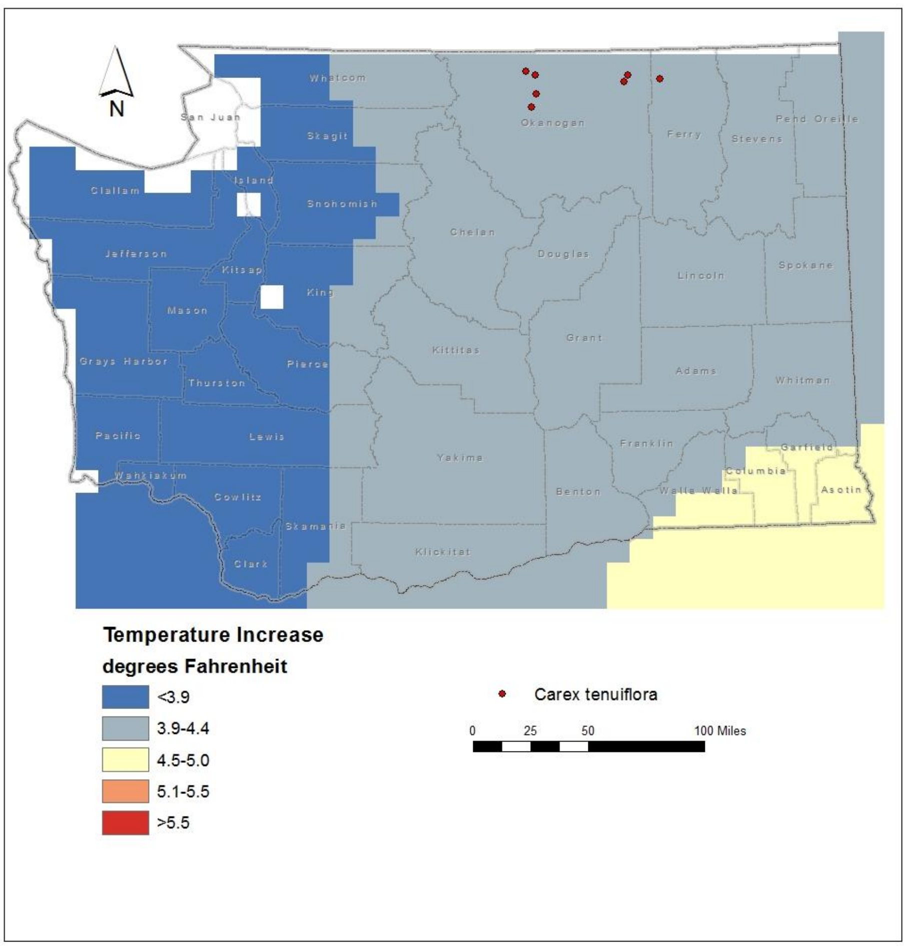

Figure 1. Exposure of *Carex tenuiflora* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All Washington occurrences of *Carex tenuiflora* 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).

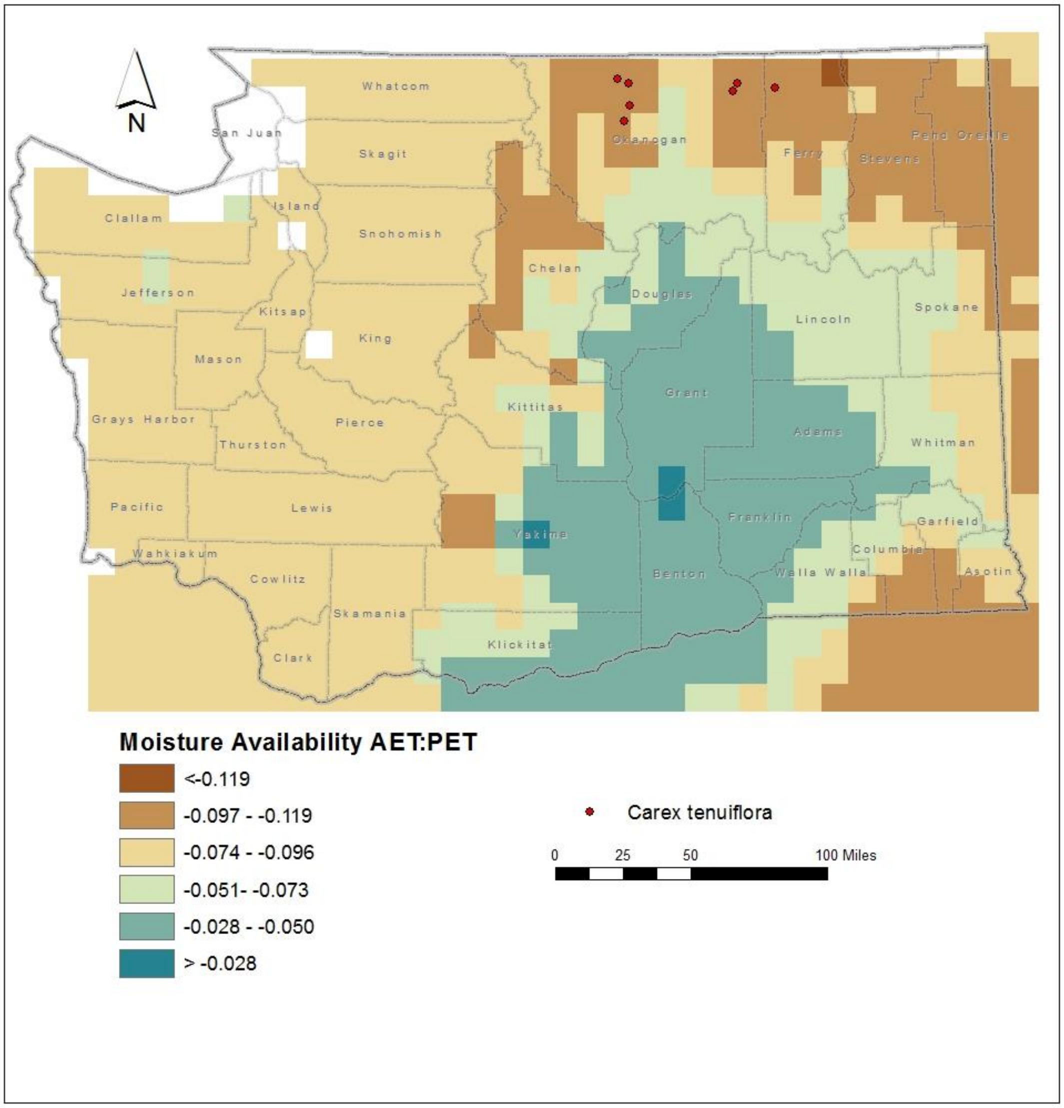

Figure 2. Exposure of *Carex tenuiflora* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex tenuiflora* are found at 1660-6250 ft (595-1905 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Carex tenuiflora is restricted to intermediate to rich calcareous fens found in glacial basins, the margins of beaver ponds, and small wetlands on relatively level topography within a matrix of forest (WNHP element occurrence records; Camp and Gamon 2011; Wilson et al. 2014). These habitats correspond to the Rocky Mountain Subalpine-Montane ecological system (Rocchio and Crawford 2015). Washington populations are separated by 3.5 to 38 miles (4.7-61 km), reflecting the scattered and isolated distribution of fen habitat in the eastern portion of the state.

B2b. Anthropogenic barriers: Neutral.
Most populations of *Carex tenuiflora* in Washington are found in mountainous areas with relatively few roads or other human imprints.

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 tenuiflora produces 1-seeded dry fruits enclosed in bladder-like sacs that are lightweight and passively dispersed by gravity, high winds, or running water. Dispersal is probably mostly within a short distance of the parent plant (<1000m). Longer distance dispersal might occasionally be facilitated by fruits adhering to mud on birds or mammals.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Carex tenuiflora* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the seven Washington occurrences (57%) 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. These populations are considered to have somewhat increased vulnerability under projected climate change (Young et al. 2016). Three of the seven state populations (43%) are from areas with average (57.1-77˚F/31.8 – 43.0˚C) temperature variation over the same historic period and are ranked as Neutral for climate change impacts. Since the majority of Washington populations are in the former category, the species is ranked as "Somewhat Increased" vulnerability for the whole state.

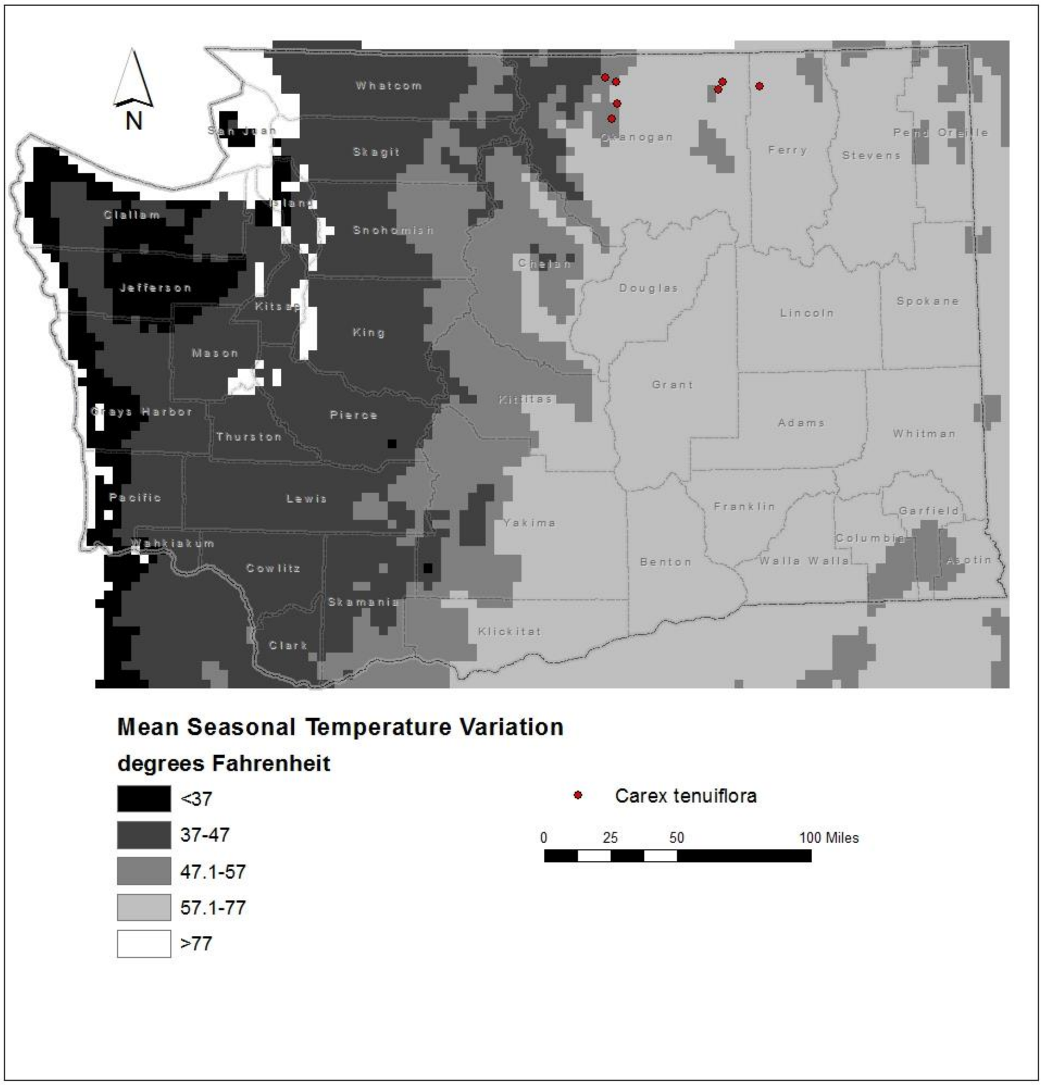

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex tenuiflora* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Washington occurrences of *Carex tenuiflora* are found mostly in cold air drainages in montane valleys that are cooler than the surrounding matrix vegetation or landforms.

C2bi. Historical hydrological niche: Neutral.
Six of the seven known occurrences of *Carex tenuiflora* in Washington (86%) are found in areas that have experienced average (20 inches/508 mm) precipitation variation in the past 50 years. These areas have neutral impacts from climate change according to Young et al. (2016). One Washington occurrence is from an area with slightly lower than average (11-20 inches/255-508

mm) precipitation variation and are considered at Somewhat Increased vulnerability to climate change.

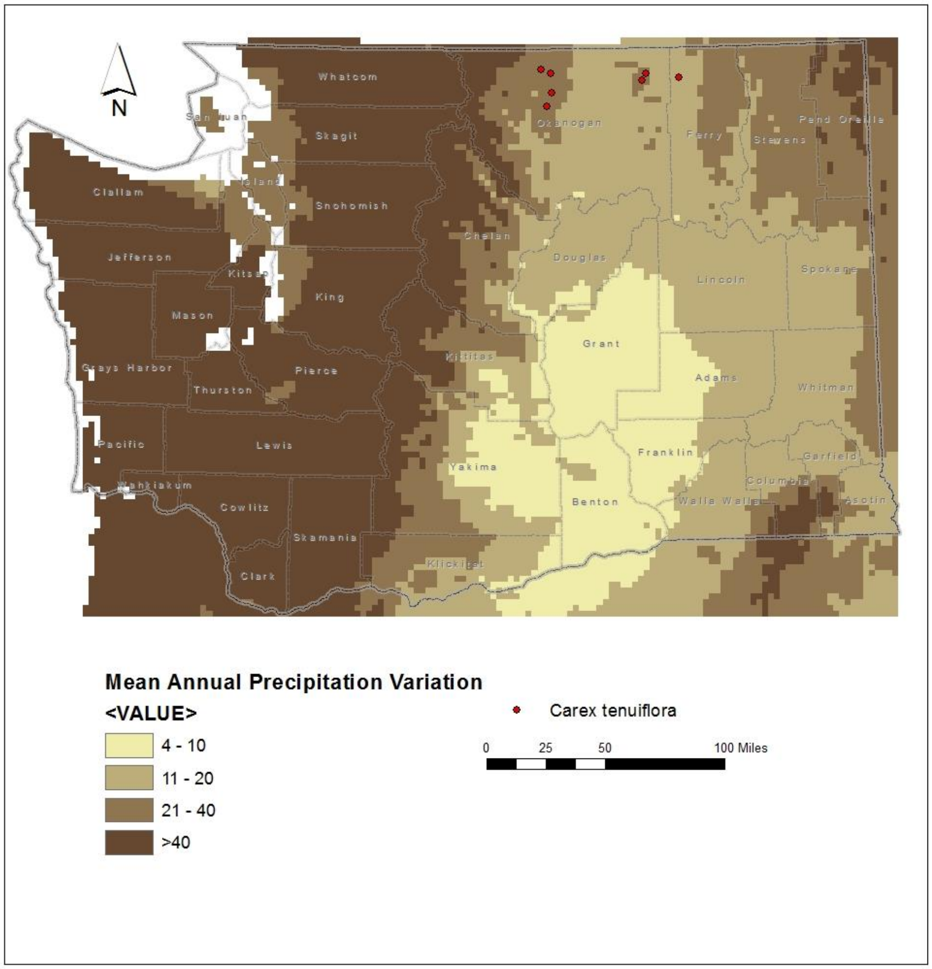

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Carex tenuiflora* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Carex tenuiflora is restricted to fens dependent on adequate year-round moisture (especially from groundwater). It is vulnerable to changes in water availability, especially from reduced snowpack, under projected climate change scenarios. Changes in the timing and amount of precipitation and increasing temperatures could convert fen habitats to drier wet meadows (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: Somewhat Increase.
In Washington, *Carex tenuiflora* is found in areas of moderate snowfall in the foothills of the Okanogan and Kettle mountains and might be adversely impacted by ant climate-related decrease in snowfall or spring melting of the snowpack (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Carex tenuiflora is restricted to fens in glacial depression or relatively flat drainage bottoms in the mountains, often associated with acidic intrusive soils within uplifted volcanic batholiths.

C4a. Dependence on other species to generate required habitat: Neutral.
At least one Washington occurrence is associated with a beaver dam that is raising the water table, potentially affecting the *Sphagnum* community with which *Carex tenuiflora* is associated. Other known *C. tenuiflora* occurrences are not dependent on animal ecosystem engineers.

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 (gravity, water, high winds), but occasionally may also occur by animal vectors transporting fruit embedded in mud.

C4e. Sensitivity to pathogens or natural enemies: Unknown.
Camp and Gamon (2011) cite livestock grazing as a potential threat. Impacts from native grazers currently or in the future are poorly known.

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

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

C5a. Measured genetic variation: Unknown.
No data are available on genetic variability in Washington. Populations in the state are at the southern edge of the species' range and would be expected to have lower overall genetic diversity.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
As a wind-pollinated, obligate outcrosser, *Carex tenuiflora* would be expected to have reasonably high genetic variability.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
No changes have been observed in the distribution of this species 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.

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.

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

Chrysolepis chrysophylla var. *chrysophylla* (Golden chinquapin)

Date: 30 January 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington   Heritage Rank: G5T5/S2

Index Result: Moderately Vulnerable   Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	35
	<3.9° F (2.2°C) warmer	65
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Somewhat Increase
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	
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 17 known occurrences of *Chrysolepis chrysophylla* var. *chrysophylla* in Washington (35%) occur in areas with a projected temperature increase of

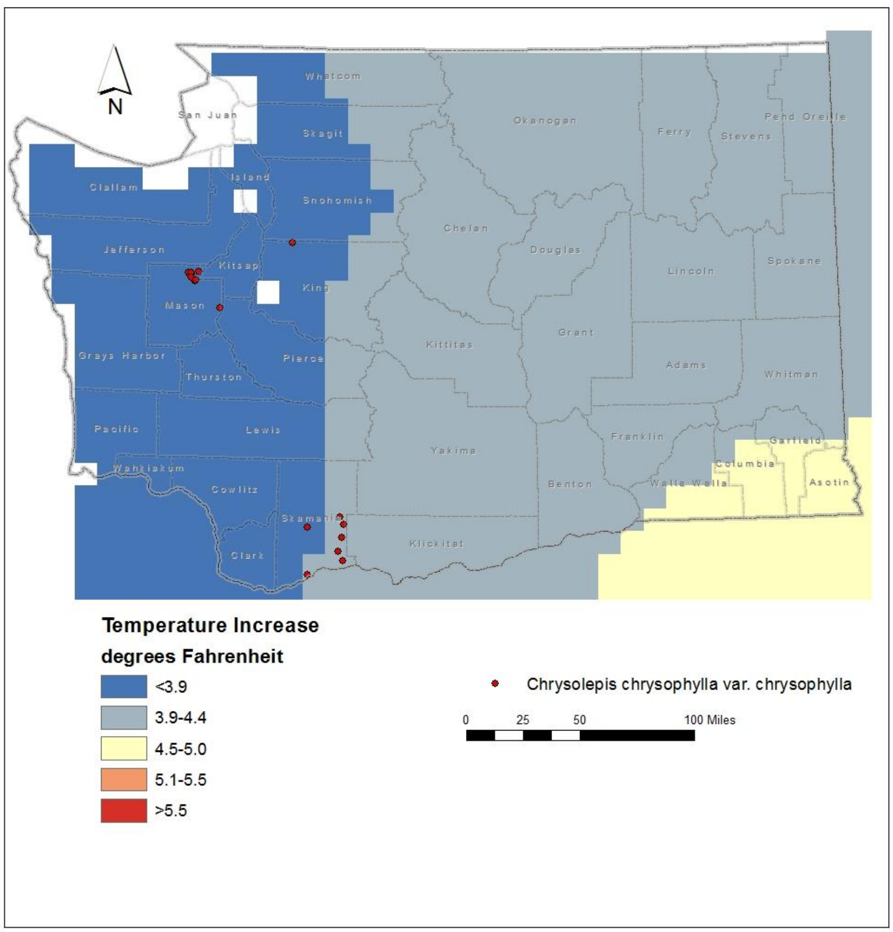

Figure 1. Exposure of *Chrysolepis chrysophylla* var. *chrysophylla* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

3.9-4.4° F (Figure 1). The other 11 occurrences (65%) are from areas with a predicted temperature increase of <3.9° F.

A2. Hamon AET:PET Moisture Metric: All Washington occurrences of *Chrysolepis chrysophylla* var. *chrysophylla* 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).

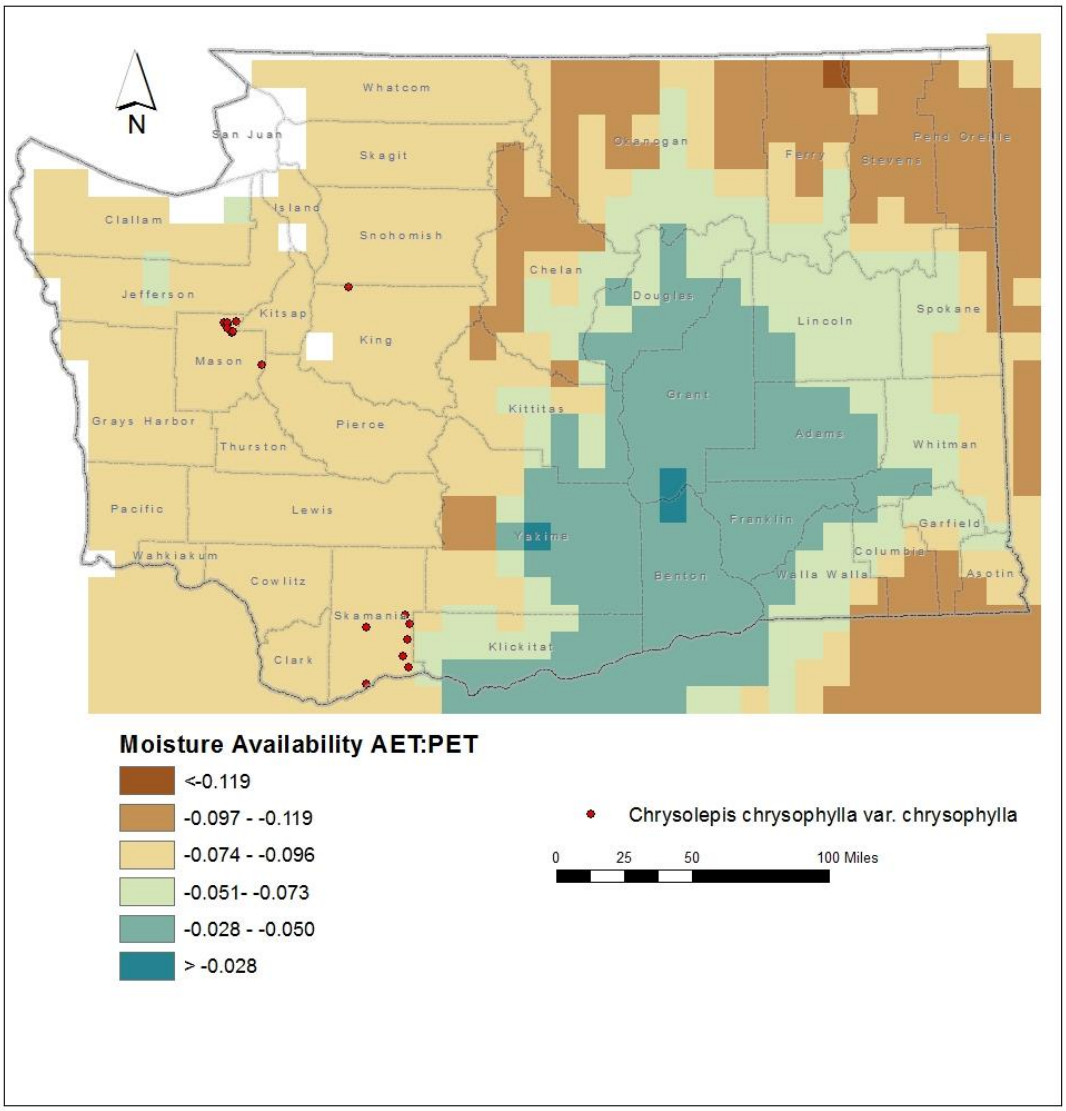

Figure 2. Exposure of *Chrysolepis chrysophylla* var. *chrysophylla* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Chrysolepis chrysophylla* var. *chrysophylla* are found at 50-3600 ft (15-1100 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Chrysolepis chrysophylla* var. *chrysophylla* occurs mostly in second growth Douglas-fir/mixed hardwood forests on droughty soils. It is found in two main areas of the state: the Olympic Peninsula/Hood Canal area in Mason County and the vicinity of Mount Adams in Skamania County (Kruckeberg 1980). Reports from King and Kitsap counties are recent human introductions. Populations from the Olympic Peninsula are found in the North Pacific Dry Douglas-fir Forest and Woodland ecological system, while those from the Mount Adams area are from the North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest ecological system (Rocchio and Crawford 2015). Kruckeberg (1980) noted few apparent physical, environmental, or climatic barriers to explain the disjunct populations in Mason County, though chance long-distance dispersal or periodic cold snaps/disease may account for its present isolated distribution.

B2b. Anthropogenic barriers: Neutral.
Extant occurrences of *Chrysolepis chrysophylla* var. *chrysophylla* in Washington are embedded within a matrix of paved and unpaved roads and areas that have been recently logged and second growth forest. The species is dispersal limited, but this is discussed separately.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Golden chinquapin produces 1-3 large, hard-shelled, one-seeded nuts surrounded by a spiny involucre. These fruits are dispersed passively by gravity or by seed predators, such as squirrels and pigeons (McKee 1990, Salstrom 1992).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Chrysolepis chrysophylla* var. *chrysophylla* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Five of the 17 known occurrences in the state (29%) 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. These populations have somewhat increased vulnerability under projected climate change (Young et al. 2016). The remaining 12 occurrences (71%) are found in areas that have experienced small (37-47˚F/20.8-26.3˚C) temperature variation in the same historic time period and are at increased vulnerability to climate change. Since the majority of Washington populations are in the latter group, this factor is scored "Increase" for the full species.

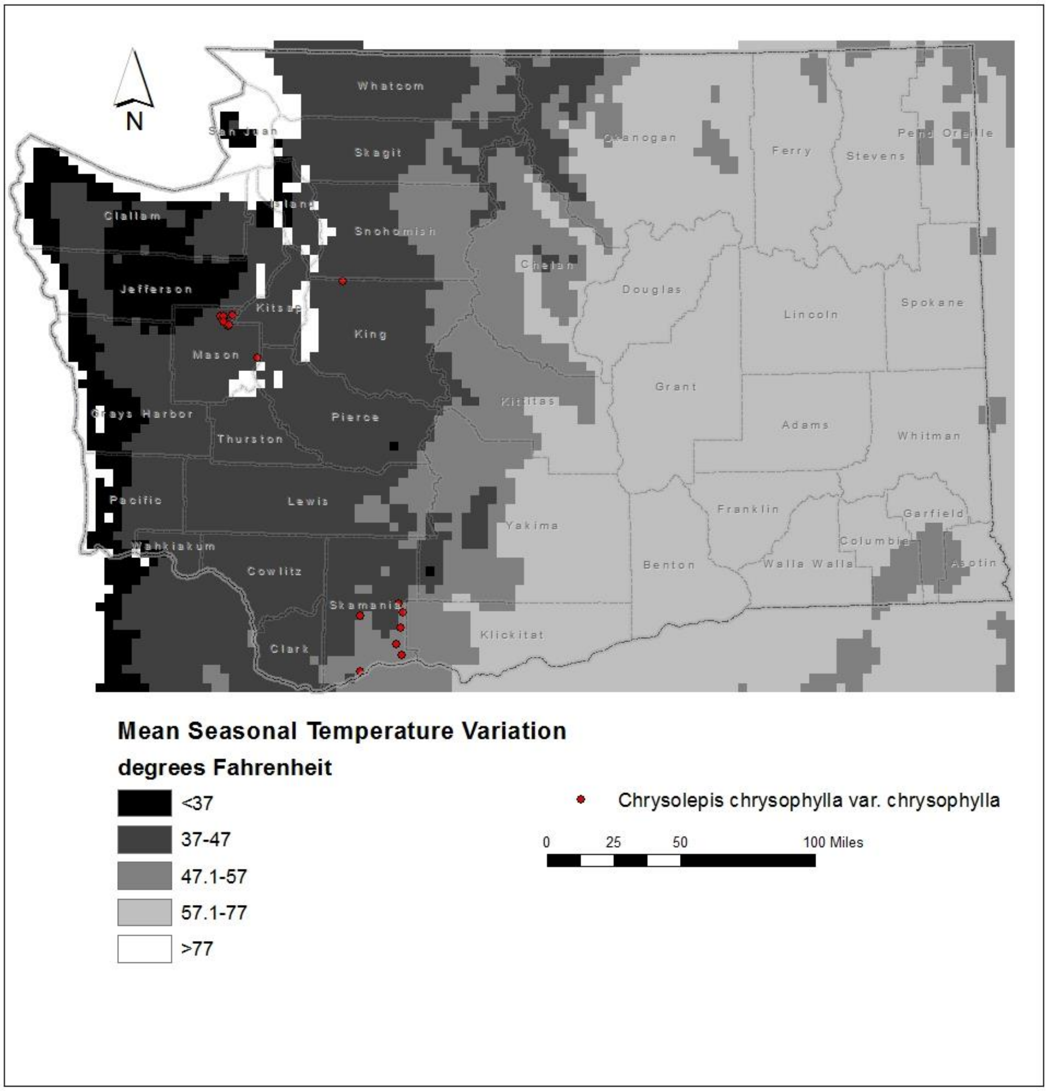

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Chrysolepis chrysophylla* var. *chrysophylla* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The low-elevation tree ecotype of *Chrysolepis chrysophylla* var. *chrysophylla* found in Washington is not dependent on cool environments like the high-elevation shrub ecotypes of the Oregon Cascades (McKee 1990).

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Chrysolepis chrysophylla* var. *chrysophylla* in Washington are found in areas that have experienced average or greater than average (>20 inches/508 mm)

precipitation variation in the past 50 years. According to Young et al. (2016), these occurrences are Neutral in terms of risk from climate change.

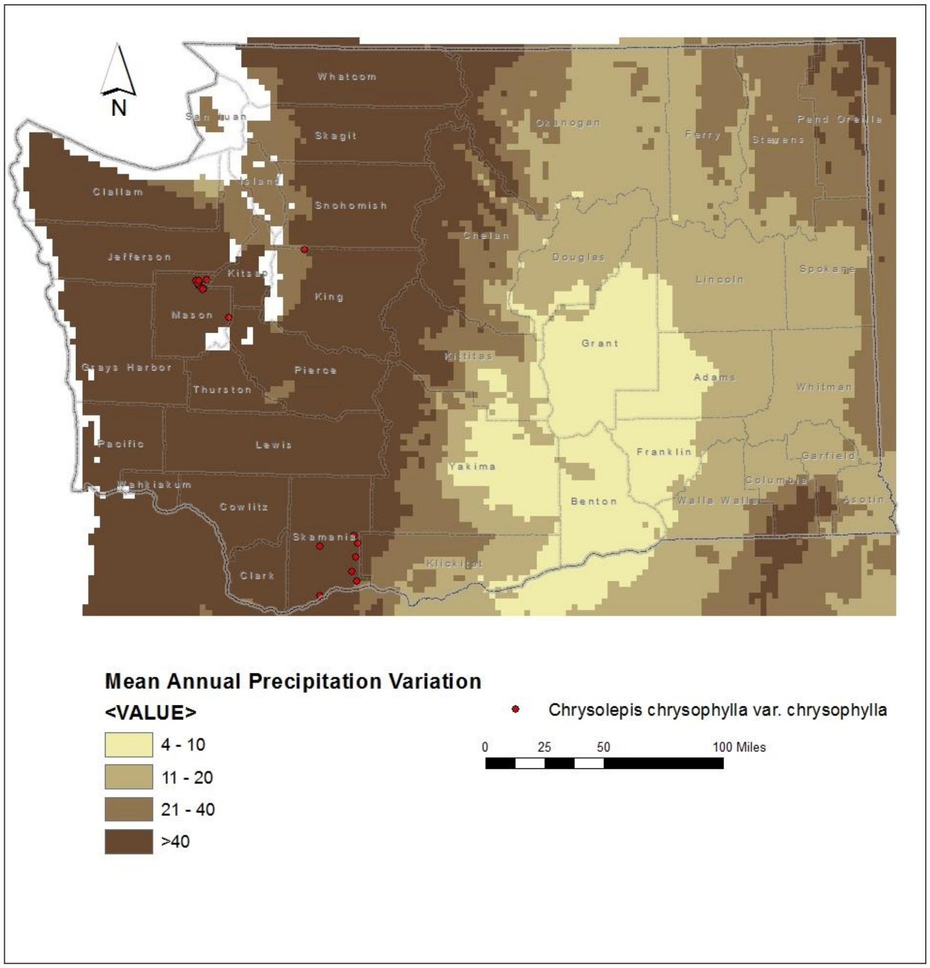

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Chrysolepis chrysophylla* var. *chrysophylla* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a specific aquatic or wetland habitat or a seasonal hydrologic regime.

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Seedling Golden chinquapins are somewhat shade intolerant and have better establishment success in sites without a dense understory (McKee 1990). Most populations in Washington are found at forest edges or in second growth forests, suggesting that it may be partly dependent on periodic disturbances (such as fire, wind-throw, or cutting) to create open conditions for

seedling establishment (McKee 1990). Projected climate change could result in increased drought and higher fire frequency and increased susceptibility to wind-throw in dry Douglas-fir forests (Rocchio and Ramm-Granberg 2017). Mature plants are able to re-sprout prolifically. McKee (1990) considered the tree-form of Golden chinquapin (the phase found in Washington) to be less shade tolerant than the shrub phase of Oregon and California, but to be intermediate in shade tolerance relative to other trees of the Northwest.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The Hood Canal populations occur at low elevations where ice and snow is not significant (relative to rainfall). Populations in the Mt. Adams area may be more dependent on winter precipitation, and could be considered to have somewhat increased vulnerability.

C3. Restricted to uncommon landscape/geological features: Neutral
Washington populations occur on flats or convex slopes on relatively infertile or droughty pumice, ash, or sandy soils (Salstrom 1992).

C4a. Dependence on other species to generate required habitat: Neutral
The second growth forest habitats occupied by Golden chinquapin are maintained by natural climatic phenomena (and enhanced by humans), but are largely not influenced by other animal species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Chrysolepis chrysophylla var. *chrysophylla* is predominantly wind-pollinated, though it can be pollinated by honeybees (McKee 1990).

C4d. Dependence on other species for propagule dispersal: Somewhat Increase.
Dispersal of *Chrysolepis* seeds is dependent on squirrels and pigeons (Salstrom 1992).

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
This species is vulnerable to heart-rot fungi (*Phellinus igniarius*) that can become established following scarring by wind-throw, large game animals, or mountain beaver (Salstrom 1992). Kruckeberg (1980) reported that populations in the Hood Canal area were partially defoliated and infected by ascomycete fungi (*Venturia* or *Didymella*). Several insect pests have been reported to reduce seed production or affect foliar cover in northern California (McKee 1990). McDonald (2008) suggests that establishment of this species by seed may be relatively uncommon due to high rates of seed predation by squirrels, insects, and birds.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
In droughty sites, Golden chinquapin may out-compete other forest species. In late seral conditions, it is susceptible to competition and poor recruitment. Some disturbance (wind-throw, fire, thinning) appears to be beneficial in maintaining populations (McKee 1990). These disturbances are likely to increase in dry Douglas-fir forest habitats under projected climate change (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase.
Chrysolepis chrysophylla is the only host for the rare golden hairstreak butterfly (*Habrodais grunus heri*) (Pyle 1989).

C5a. Measured genetic variation: Somewhat Increase.
Rangewide, *Chrysolepis chrysophylla* exhibits regional patterns of genetic divergence between northern and southern populations and between high elevation and lower elevation occurrences (Willyard et al. 2020 in press). The disjunct Olympic Peninsula/Hood Canal populations from Washington are also genetically distinct from other populations in the state and from those in Oregon and California. Willyard et al. (2020 in press) also note some minor morphological differences in the NW Washington populations and suggest that these plants may warrant taxonomic recognition. The genetic variability among different populations of Golden chinquapin is more similar to that found between species in the Fagaceae. Rangewide (and in the Mount Adams area of Washington), genetic diversity is relatively high and the vulnerability of the species is neutral. Lower genetic diversity and lower heterozygosity in the Olympic Peninsula/Hood Canal populations, however, suggest that these plants are at somewhat increased risk than the species as a whole (Willyard et al. 2020 in press). Because of the conservation significance of the disjunct Hood Canal populations, the statewide score is given as Somewhat Increase.

C5b. Genetic bottlenecks: Neutral (according to Young et al. 2016, this is not scored if C5a is not unknown).
The genetic distinctiveness of the Olympic Peninsula/Hood Canal populations may be due to founder effects if the population arose by long distance dispersal of one or a few individuals representing a small subset of the genetic variability of the full species. Conversely, it might also be due to long-term inbreeding depression if these populations were once connected with other breeding populations but are now isolated due to contraction of its range.

C5c. Reproductive System: Neutral.
Chrysolepis chrysophylla is a monoecious outcrosser and predominantly pollinated by wind. This reproductive system should promote more genetic homogenization across its range, except for instances (like the populations in the Olympic Peninsula/Hood Canal) that are reproductively isolated.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Changes in flowering or fruiting time for *Chrysolepis chrysophylla* in Washington have not been observed.

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 40 years since Kruckeberg (1980) published his paper on the distribution of *Chrysolepis chrysophylla* in Washington. Case et al. (2015) ranked the climate sensitivity of this species as moderate (score of 44) in their assessment of 195 northwestern bird, mammal, amphibian, reptile, and vascular plant 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

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Climate Change Vulnerability Index Report

Chrysosplenium tetrandrum (Northern golden-carpet)

Date: 31 January 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		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		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		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Somewhat Increase

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

Section A: Exposure to Local Climate Change

A1. Temperature: All seven of the known occurrences of *Chrysosplenium tetrandrum* in Washington occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

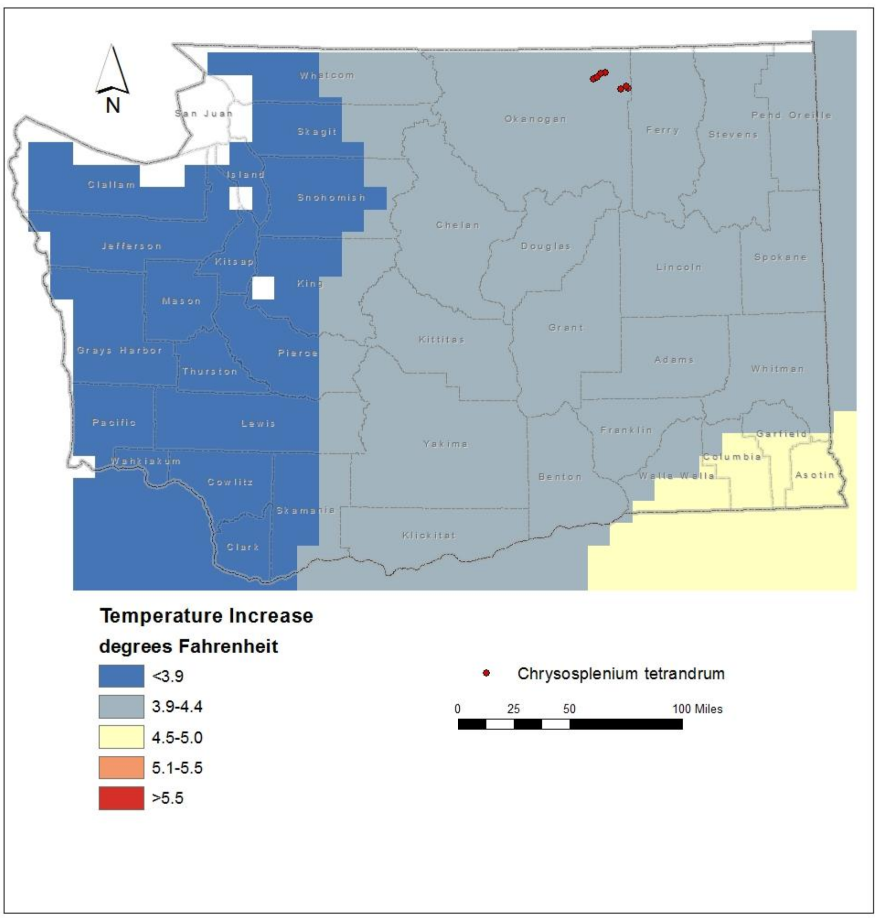

Figure 1. Exposure of *Chrysosplenium tetrandrum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All Washington occurrences of *Chrysosplenium tetrandrum* 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).

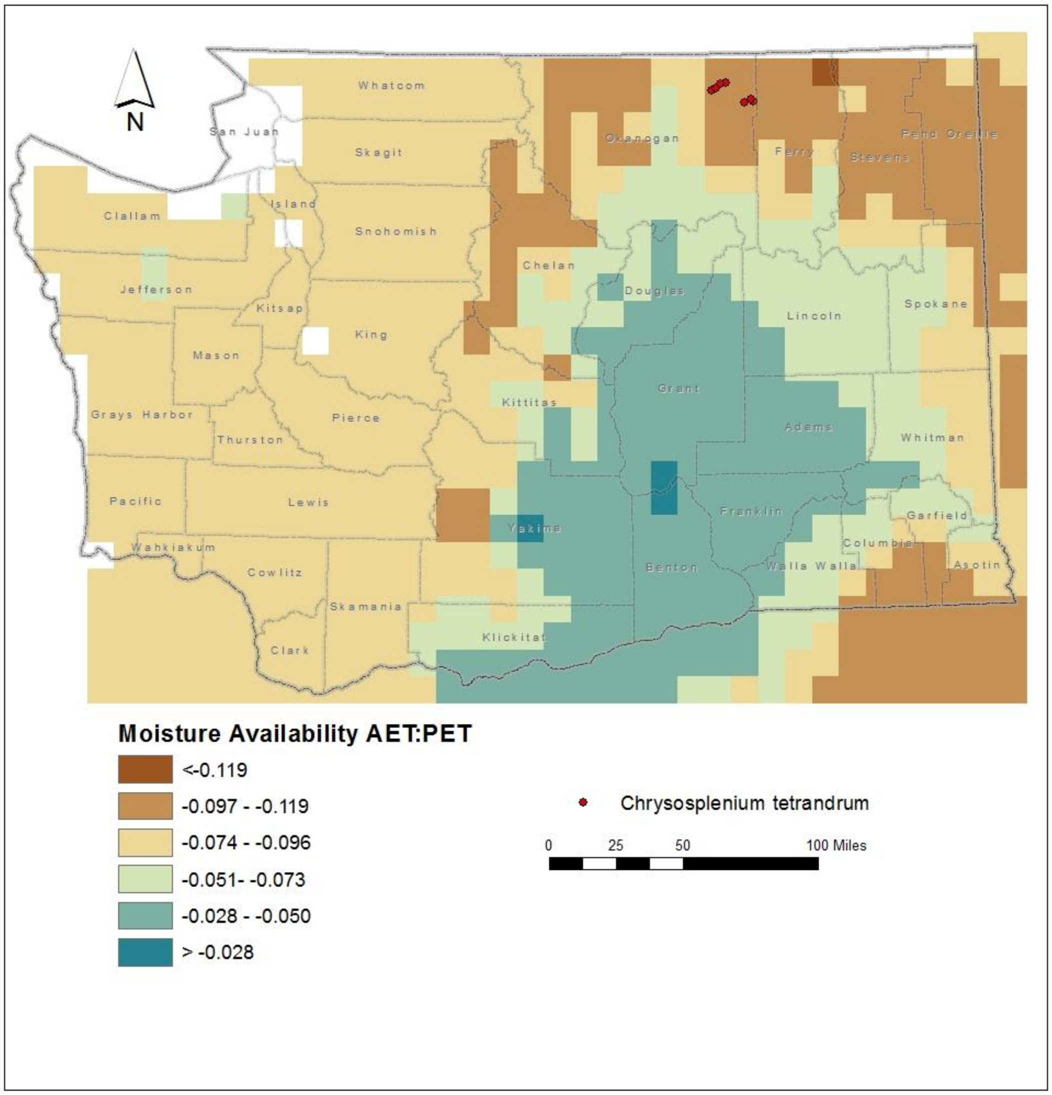

Figure 2. Exposure of *Chrysosplenium tetrandrum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Chrysosplenium tetrandrum* are found at 3500-4600 ft (1070-1400 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Chrysosplenium tetrandrum* occurs in densely vegetated creek bottoms and seeps associated with rock crevices, wet banks, or densely vegetated stream banks associated with Douglas-fir, Engelmann spruce, and alder (Camp and Gamon 2011). These sites are part of the Rocky Mountain Subalpine-Montane Riparian Woodland and Northern Rocky Mountain Conifer Swamp ecological systems (Rocchio and Crawford 2015). Washington populations are separated by 1-11 miles (1.6-17 km) and occur within a matrix of dry upland forest habitats that may be a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
Populations of *Chrysosplenium tetrandrum* in Washington are found in the Okanogan Plateau ecoregion at the headwaters of streams within National Forest lands, and are relatively unaffected by roads and other human 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.
Chrysosplenium tetrandrum produces numerous, small, plump seeds within a cup-shaped capsule that is fully open across its top at maturity. This shape is analogous to the "splash cup" or gemmae of spore-producing liverworts, such as *Marchantia*, in which spores are dispersed by the energy of raindrops splashing on the cup. Savile (1953) observed the splash cup syndrome as a method of short-distance seed dispersal in *Chrysosplenium tetrandrum* and species of *Mitella*. Once removed from the parent plant, the seeds of *Chrysosplenium* could be secondarily relocated by small animals (insects or rodents) or by flowing water along streams. Dispersal distances are probably short under most circumstances.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Chrysosplenium tetrandrum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Two of the seven known occurrences in the state 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. These populations have somewhat increased vulnerability under projected climate change (Young et al. 2016). The remaining five occurrences (71% of the state's population) are found in areas that have experienced small (37-47˚F/20.8-26.3˚C) temperature variation in the same historic time period and are at increased vulnerability to climate change. Since the majority of Washington populations are in the latter group, this factor is scored "Increase".

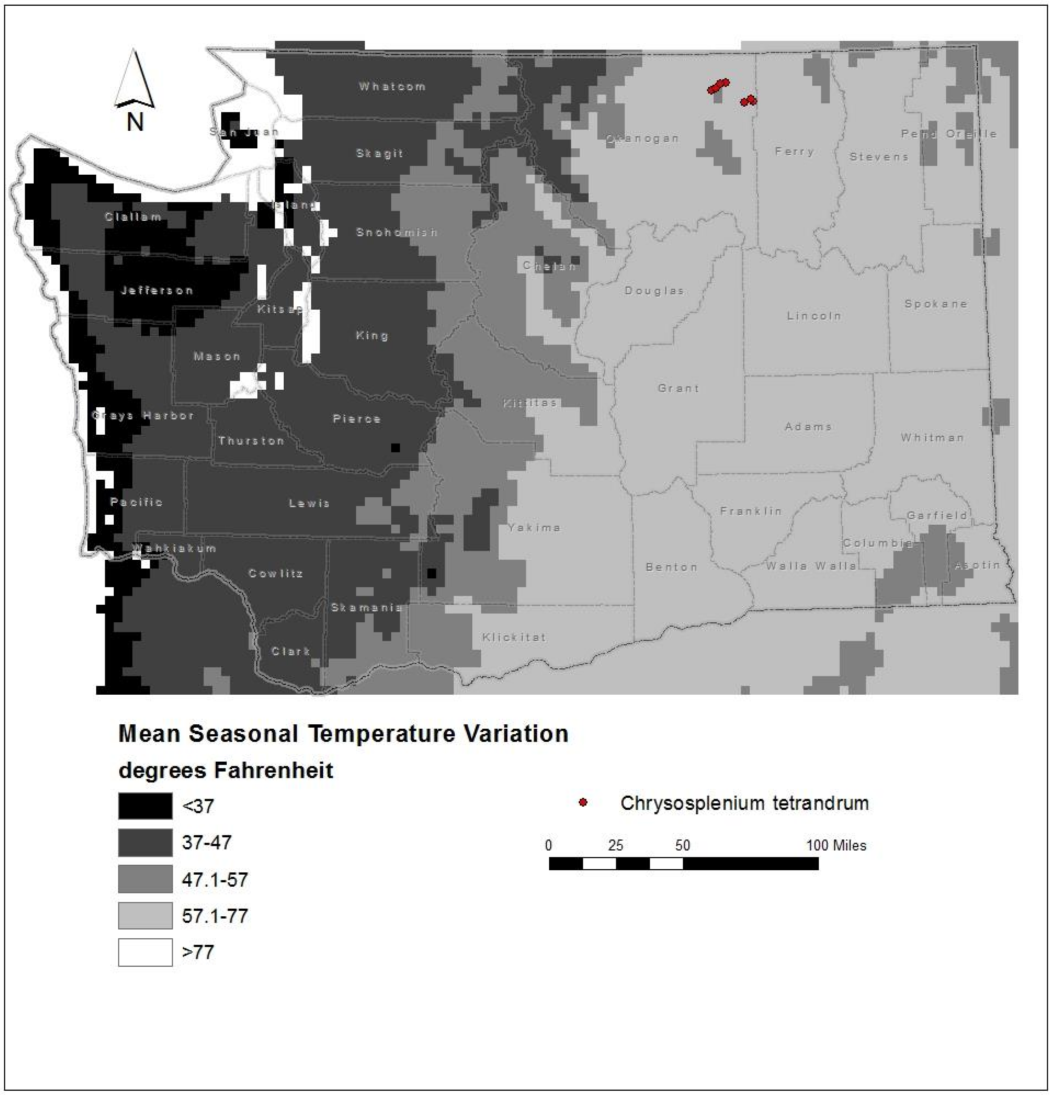

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Chrysosplenium tetrandrum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The montane stream habitat occupied by *Chrysosplenium tetrandrum* in Washington is associated with a moist microclimate that would be vulnerable to increased temperature and increased frequency of wildfire due to climate change Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Chrysosplenium tetrandrum* in Washington are found in areas that have experienced average or greater than average (>20 inches/508 mm) precipitation

variation in the past 50 years. According to Young et al. (2016), these occurrences are Neutral in terms of risk from climate change.

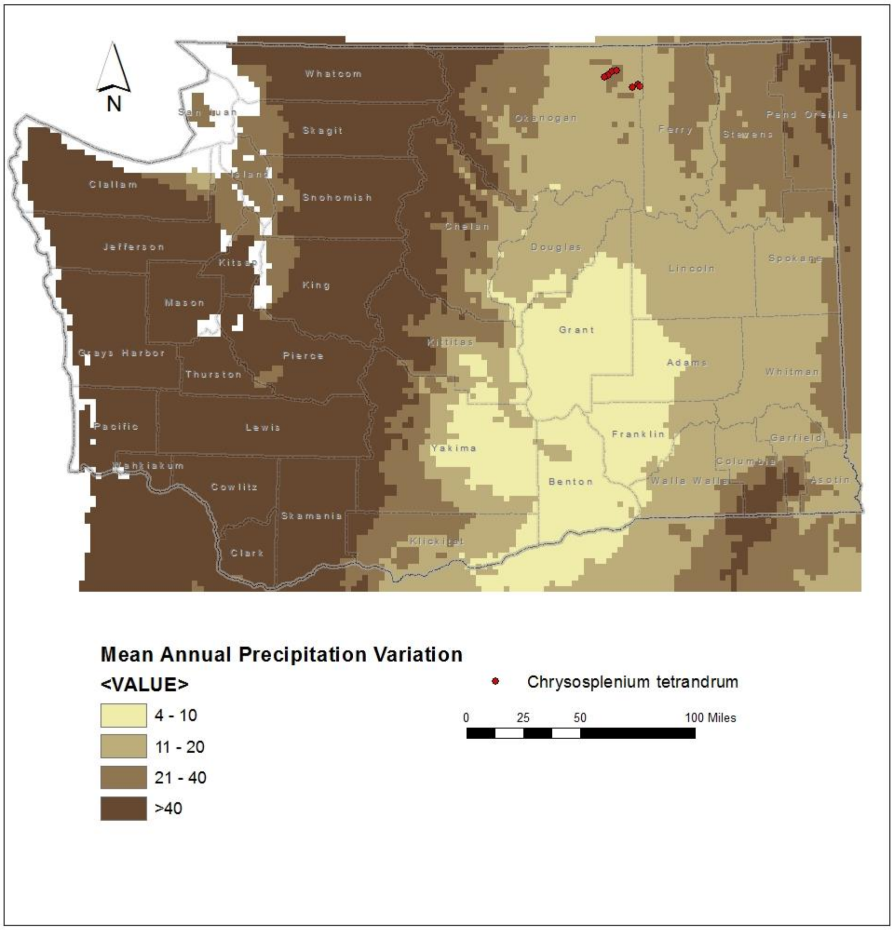

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Chrysosplenium tetrandrum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
In Washington, this species is restricted to mossy streambanks in montane conifer forests and wet rocky seeps and thus is dependent on the continuation of adequate moisture conditions. Under climate change, the timing and amount of precipitation, amount and duration of snowpack, stream flows, and spring discharge are all likely to decrease, making these sites more vulnerable to drought and wildfire (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Chrysosplenium tetrandrum is not adapted to disturbance and depends on forest cover to maintain cool, shady conditions in its wetland habitat. It would be negatively impacted by increased fire frequency or drought within its montane forest wetland habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Although the populations of *Chrysosplenium tetrandrum* in Washington all occur in areas of high snow accumulation, they are not directly associated with permanent snow or ice features. Reduced snowpack could affect regeneration of groundwater necessary for forested springs, and thus have a negative impact on some occurrences (Rocchio and Ramm-Granberg 2017). Across Alaska and Canada, this species is found in stream habitats in arctic and subarctic habitats and is dependent on adequate winter snow and ice cover.

C3. Restricted to uncommon landscape/geological features: Neutral
Washington populations occur on in stream drainages of low elevation mountains and are associated with the Mount Bonaparte Pluton and Klondike Mountain Formation. These geologic types are relatively widespread in the Okanogan Plateau.

C4a. Dependence on other species to generate required habitat: Neutral
The forest wetland habitat occupied by *Chrysosplenium tetrandrum* is maintained by natural climatic phenomena, and not strongly influenced by animal species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Chrysosplenium tetrandrum has been reported to be self-pollinated, though genetic data from Levsen and Mort (2009) suggest that some outcrossing is occurring to maintain homogenous levels of genetic diversity among Washington populations and those from British Columbia. The exact pollinator is not known, though the small size of the flowers suggest small, generalist insects such as gnats or mosquitos.

C4d. Dependence on other species for propagule dispersal: Neutral.
Dispersal of *Chrysosplenium* seeds is primarily by passive means (rain drops splashing on open capsules or gravity), abetted secondarily by flowing water or possibly by insects or rodents (Savile 1953).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Although probably edible, the low stature of this plant suggests it is not a common food source. No natural pathogens are known.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Not greatky impacted by competition from native or 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.
Levsen and Mort (2009) measured low genetic differentiation and diversity across populations of *Chrysosplenium tetrandrum* sampled in Alaska, British Columbia, and Washington, suggesting that these populations arose from a recent bottleneck event or range expansion following post-Pleistocene deglaciation. Higher diversity was observed in disjunct populations in Montana and Colorado, indicating long-term isolation.

C5b. Genetic bottlenecks: Not Scored (according to Young et al. 2016, this is scored only if C5a is unknown).
There is genetic evidence of a bottleneck in Washington, British Columbia, and Alaska populations of this species (Levsen and Mort 2009).

C5c. Reproductive System: Not Scored (according to Young et al. 2016, this is scored only if C5a and C5b are unknown).
Chrysosplenium tetrandrum is primarily self-pollinated, but genetic data suggest sufficient outcrossing also occurs to maintain relatively homogenous genetic diversity across most of its range.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Changes in flowering or fruiting time for *Chrysosplenium tetrandrum* in Washington have not been observed.

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 *Chrysosplenium tetrandrum* in Washington since it was first discovered in the state in 1934.

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

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Climate Change Vulnerability Index Report

Cryptantha leucophaea (Gray cryptantha)

Date: 3 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G2G3/S2

Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	2
	-0.028 to -0.050	96
	>-0.028	2
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
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		Neutral
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		Unknown
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	Somewhat Increase
Section D	
D1. Documented response to recent climate change	Neutral
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 45 of the extant and historical occurrences of *Cryptantha leucophaea* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

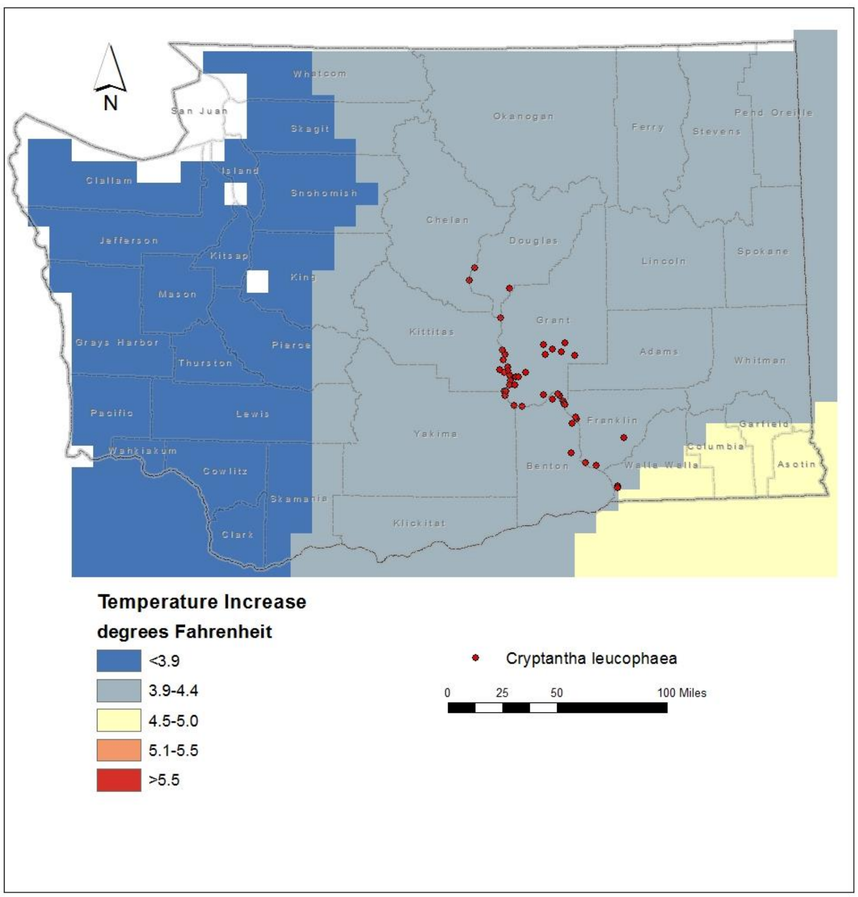

Figure 1. Exposure of *Cryptantha leucophaea* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: 96% of the Washington occurrences of *Cryptantha leucophaea* 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). Two percent of the occurrences are in areas with projected decrease of -0.051 to -0.073 and 2% are from areas with a projected decrease greater than -0.028.

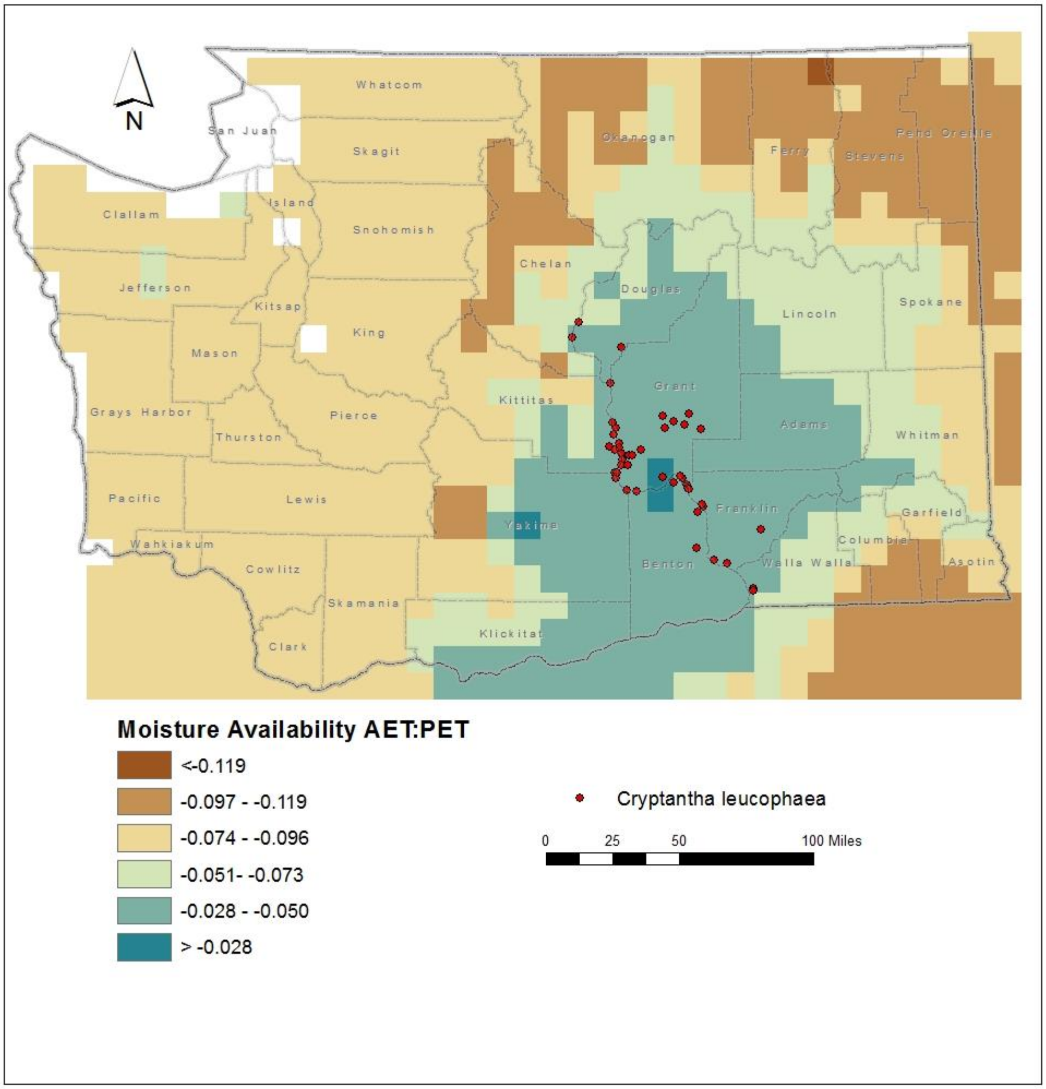

Figure 2. Exposure of *Cryptantha leucophaea* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Cryptantha leucophaea* are found at 300-2500 feet (90-760 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Cryptantha leucophaea occurs primarily in unstabilized sand dunes or other sandy areas associated with *Artemisia tridentata* or *Purshia tridentata* (Camp and Gamon 2011). This habitat is a component of the Inter-Mountain Basins Active and Stabilized Dune ecological system (Rocchio and Crawford 2015). Sand dunes occur within a matrix of upland sagebrush steppe and sparsely vegetated basalt communities paralleling the Columbia River in central and south-central Washington. Populations of *Cryptantha leucophaea* are separated by 1-23 miles (1.6-37 km). Although dunes tend to be patchy across the landscape, there is some connectivity between dunes along the Columbia River.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Cryptantha leuocophaea* in Washington has become further dissected by conversion of habitat to irrigated agriculture, road construction, and urbanization in the Richland-Pasco-Kennewick and Wenatchee areas. The reduction in extent of sand dunes and in the quality of habitat in-between these dunes will likely make it more difficult for this species to migrate in response to climate change.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
At maturity, *Cryptantha leucophaea* fruits split into 4 smooth nutlets. In many *Cryptantha* species, nutlets are roughened or have minute papillae that facilitate dispersal on the fur or feathers of animals. The small, smooth nutlets of *C. leucophaea* are less suited for animal dispersal, but may be small enough to be transported short distances by wind.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Cryptantha leuocophaea* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 45 of the known occurrences in the state are found in areas that have experienced average (57.1-77˚F/31.8-43.0˚C) temperature variation during the past 50 years. The vulnerability of these populations are considered "neutral" under projected climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
The basin sand dune habitat occupied by *Cryptantha leucophaea* in Washington is not associated with cool or cold environments or microhabitats. Higher temperatures, increased evapotranspiration, and increased wind speeds predicted from climate change could potentially prevent dunes from becoming stabilized by vegetation and actually sustain or create additional habitat for this species (Rocchio and Ramm-Granberg 2017).

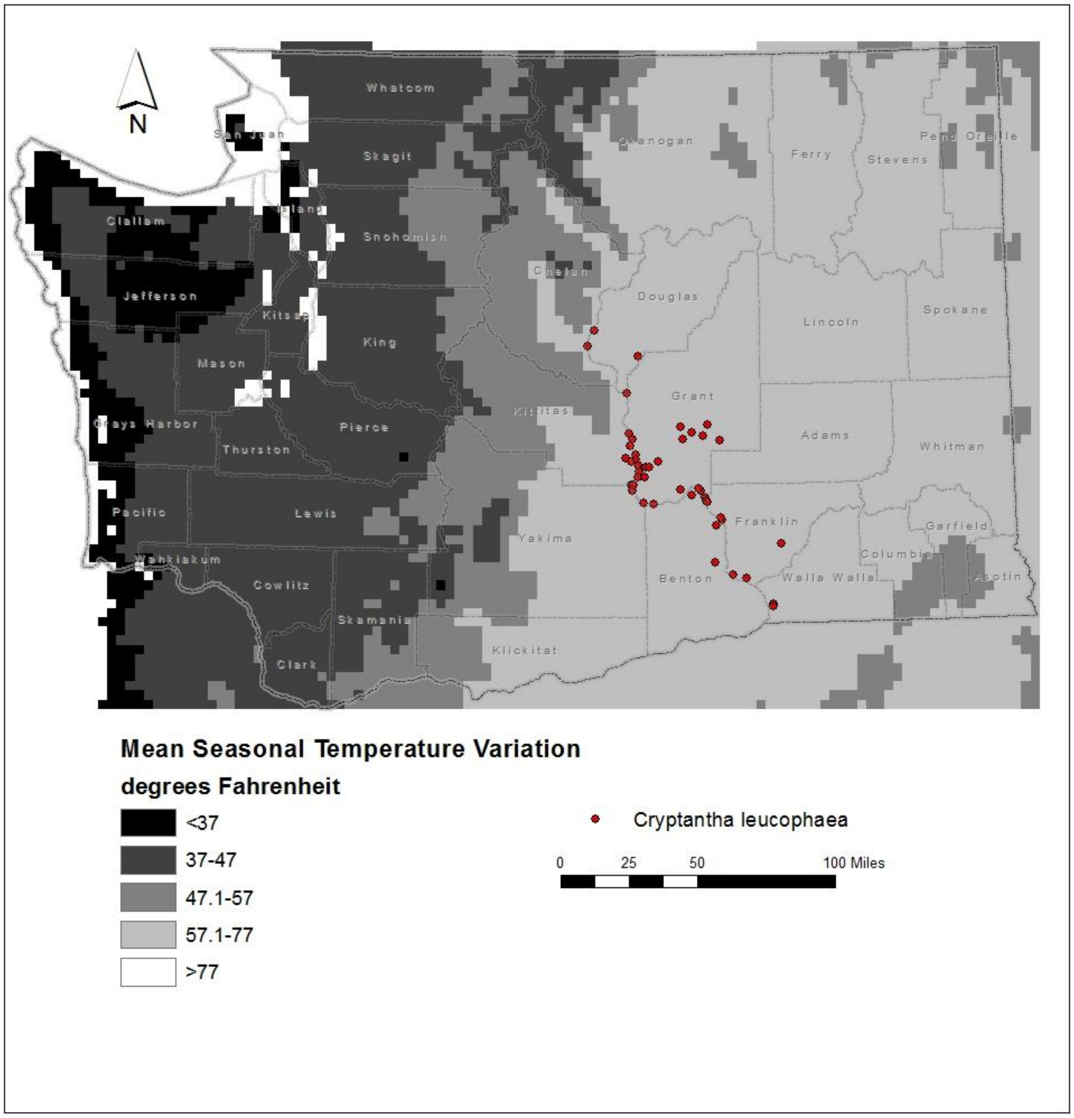

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cryptantha leucophaea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Increase.
All of the known populations of *Cryptantha leucophaea* in Washington 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.

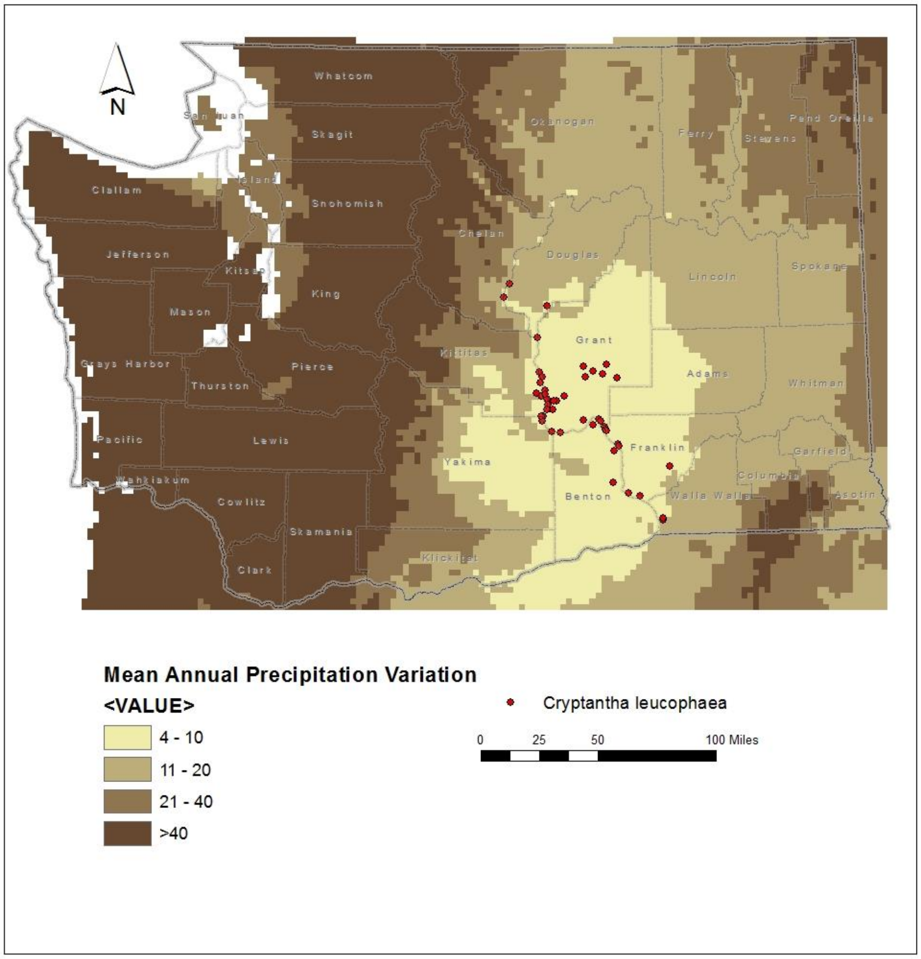

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cryptantha leucophaea* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a strongly seasonal hydrologic regime or specific wetland habitats. Under projected climate change, shifting sand dune habitats in central Washington might actually benefit from increased temperatures and drought conditions by reducing encroaching vegetation cover and spread of invasive weeds that can cause dunes to become stabilized (Rocchio and Ramm-Granberg 2017). Potential increases in winter precipitation would tend to favor the spread of competing plants, but this would likely be negated by higher temperatures and drought in the summer.

C2c. Dependence on a specific disturbance regime: Neutral.
Cryptantha leucophaea is adapted to shifting, unstabilized sand dunes that are maintained by periodic natural disturbances, such as wind erosion, drought, or fire (Rocchio and Ramm-Granberg 2017). While climate change is likely to increase the likelihood and severity of these disturbances, this could have a net positive effect on *Cryptantha leucophaea* by maintaining or creating additional unstabilized dune habitat, and so the factor is scored as neutral.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The populations of *Cryptantha leucophaea* in Washington all occur in areas of low snow accumulation and are not directly associated with permanent snow or ice features.

C3. Restricted to uncommon landscape/geological features: Increase.
Cryptantha leucophaea is restricted to a specific geologic type (shifting sand dunes) that is relatively uncommon in Washington. Climate change could have a positive impact on this species by reducing competing vegetation cover and keeping dunes from becoming stabilized or dominated with non-native weed species.

C4a. Dependence on other species to generate required habitat: Neutral
Dune habitats are largely influenced by wind or topographic features, although human-mediated disturbance (livestock grazing, dune recreation, climate change) could reduce vegetation cover.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Salstrom (1994) observed bumblebees on *Cryptantha leucophaea* inflorescences. In general, *Cryptantha* species are not pollinator-specific.

C4d. Dependence on other species for propagule dispersal: Unknown.
The nutlets of *Cryptantha leucophaea* are dry and smooth and lack any structures to enhance dispersal by animals (Salstrom 1994). The species may be more dependent on wind to spread its fruits.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
No pathogens are known to affect this species. Herbivory has not been identified as a significant threat (Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Populations of *Cryptantha leucophaea* can be threatened by competition from invasive annual weeds, such as cheatgrass, especially after wet winters or springs. Higher temperatures and increased drought related to climate change, however, might reduce invasive species cover in dune 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.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Cryptantha leucophaea has relatively large flowers and 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 on this species for confirmation.

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), *Cryptantha leucophaea* may be blooming about a week earlier (mid April-early June) than it did from the 1880s to 1980 (late April to early June).

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 *Cryptantha leuocophaea* in Washington since it was first discovered in the state in the 1820s.

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. 1994. Report on the status of *Cryptantha leucophaea* (Dougl.) Pays. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA.15 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

Cryptantha spiculifera (Snake River cryptantha)

Date: 16 March 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G4?/S2S3

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	3.5
	-0.051 to - 0.073	24.1
	-0.028 to -0.050	72.4
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on 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	Somewhat Increase
Section D	
D1. Documented response to recent climate change	Neutral
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: all 29 of the known occurrences of *Cryptantha spiculifera* in Washington (100%) occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

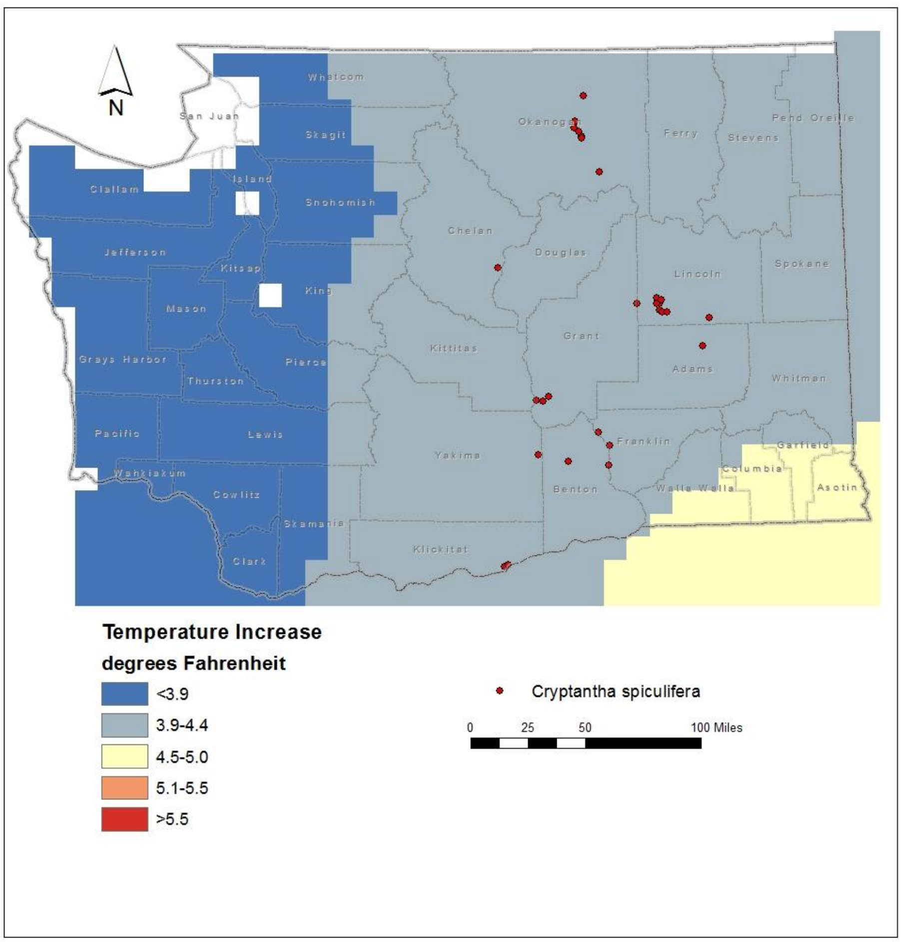

Figure 1. Exposure of *Cryptantha spiculifera* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Twenty-one of 29 occurrences of *Cryptantha spiculifera* (72.4%) 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). Seven of 29 populations (24.1%) occur in areas with a projected decrease in available moisture of -0.051 to -0.073. One population (3.5%) has a projected decrease of -0.074 to -0.096 (Figure 2).

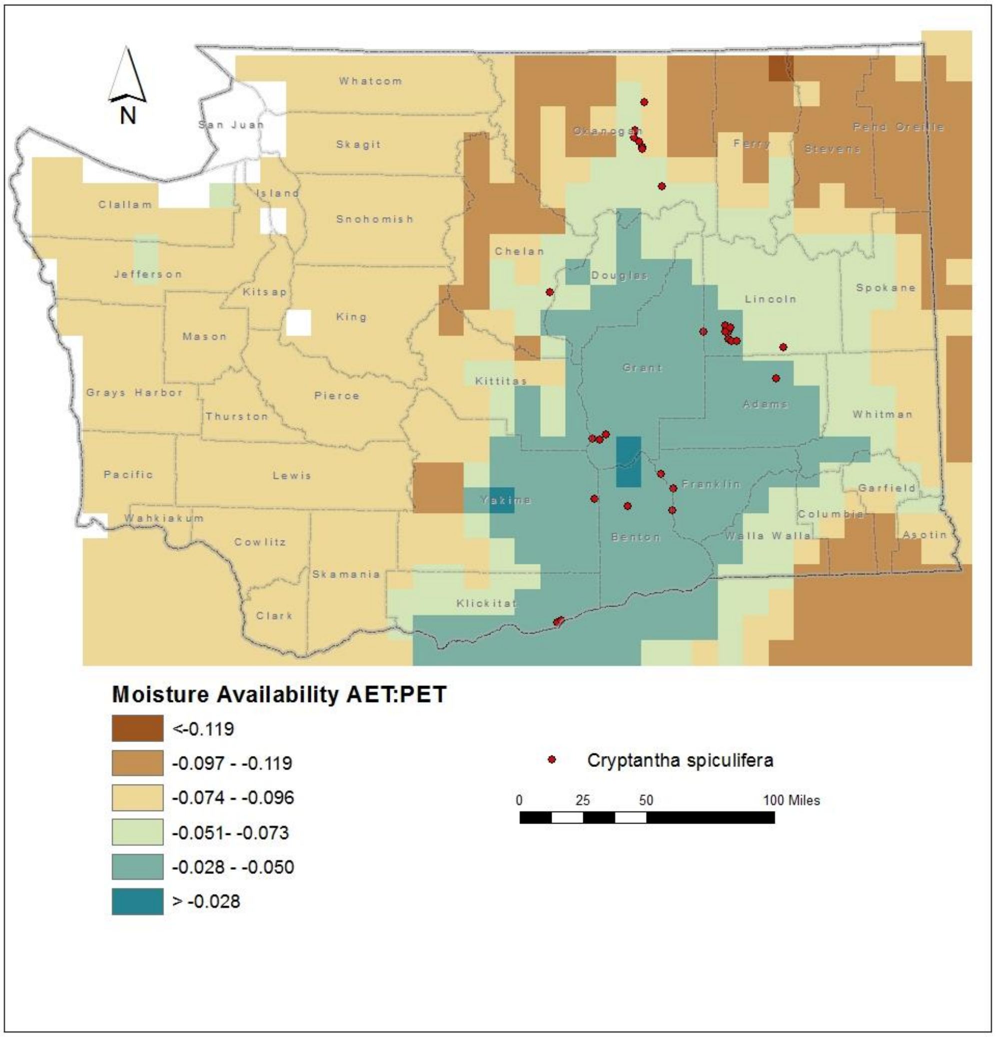

Figure 2. Exposure of *Cryptantha spiculifera* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Cryptantha spiculifera* are found at 450-3500 feet (140-1050 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral
In Washington, *Cryptantha spiculifera* is found in sparsely vegetated openings within desert grasslands and *Artemisia tridentata, A. rigida*, or *Salvia dorrii*-dominated shrub steppe on steep, unstable slopes or barren ridgecrests on basalt, alluvium, gravel, or white calcium carbonate caliche (Camp and Gamon 2011, Fertig and Kleinknecht 2020). This habitat is a component of the Inter-Mountain Basins Cliff and Canyon and the Inter-Mountain Basin Semi-Desert Shrub-Steppe ecological systems (Rocchio and Crawford 2015). Populations are separated by 0.5-60 miles (0.7-98 km) and are scattered within a matrix of sagebrush steppe, desert shrub, or grassland communities overlain by extensive areas of human development (roads, towns, and agricultural development). Anthropogenic barriers probably create more of an impediment to dispersal than natural barriers.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Cryptantha spiculifera* is bisected by human development, including roads, towns, and agricultural fields. These probably present more of an obstacle to dispersal 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: Somewhat Increase.
At maturity, *Cryptantha spiculifera* fruits split into 1 to 4 nutlets. The outer wall of each nutlet has low ridges and small tubercles that could help the fruit segments attach to small animals for dispersal. Nutlets are small enough to also be dispersed by strong winds or gravity. Average dispersal distances are probably less than 1 km.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Cryptantha spiculifera* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 29 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.

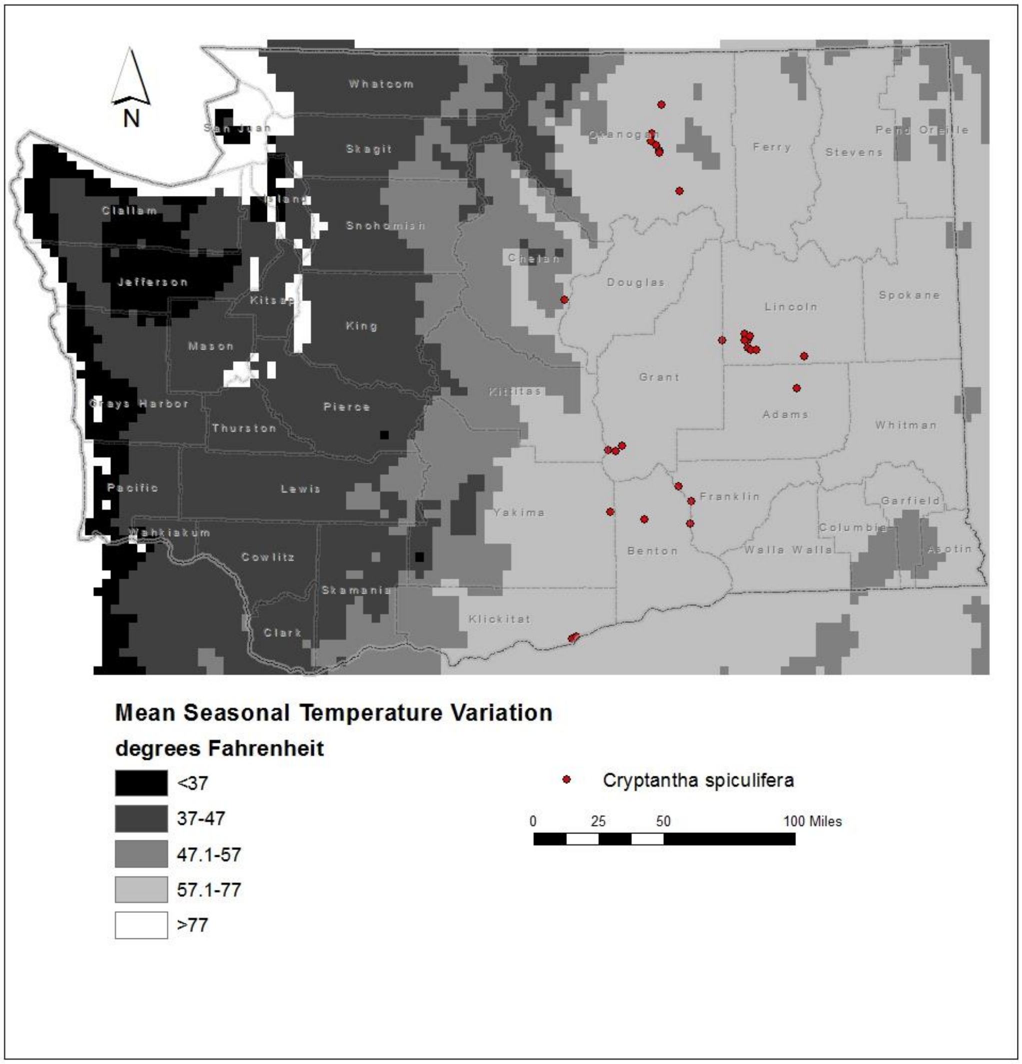

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cryptantha spiculifera* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The barren ridge and rocky slope habitat of *Cryptantha spiculifera* in the Columbia Plateau is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Nineteen of the 29 occurrences of *Cryptantha spiculifera* in Washington (65.5%) 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 occurrences are at somewhat increased vulnerability to climate change. The remaining 10 occurrences (34.5%) are from areas that have experienced small (4-10 inches/100-254 mm) of precipitation variation over the same period and are considered to be at increased vulnerability to climate change.

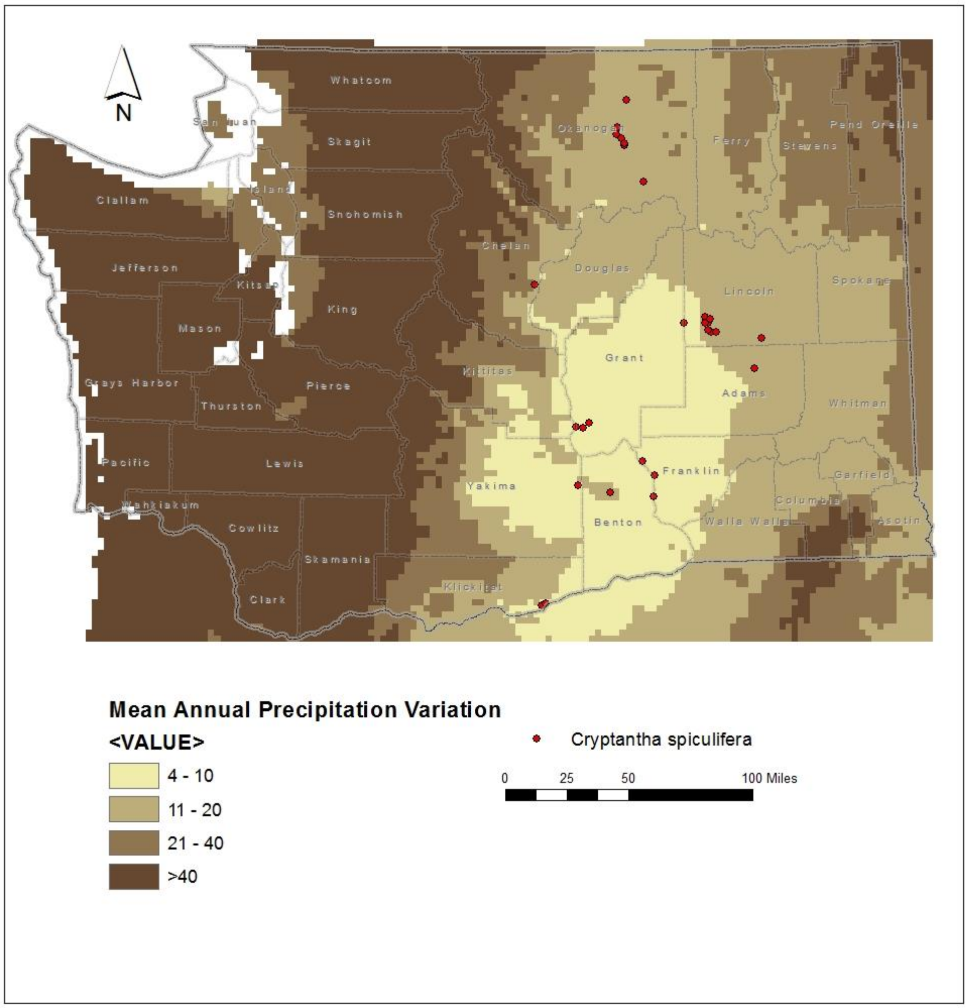

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cryptantha spiculifera* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

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 and Inter-Mountain Basin Semi-Desert Shrub-Steppe ecological systems are vulnerable to changes in the timing or amount of precipitation and increases in temperature, with resulting increases in fire frequency (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Cryptantha spiculifera is not dependent on periodic disturbances to maintain its barren shrub steppe habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased precipitation that would increase fire frequency and convert its habitat to annual grasslands dominated by introduced species (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is relatively low over most of the range of *Cryptantha spiculifera* in the Columbia Plateau of eastern Washington area and probably a minor component of its annual water budget.

C3. Restricted to uncommon landscape/geological features: Neutral.
Cryptantha spiculifera occurs primarily on barren ridgecrests or steep slopes of loose rock. It can grow on a variety of geologic substrates, including basalt lithosols, alluvium, gravel, sand, and calcium-carbonate caliche. Most of these rock types occur widely in the Columbia Plateau ecoregion.

C4a. Dependence on other species to generate required habitat: Neutral
The barren ridgetop and slope habitat occupied by *Cryptantha spiculifera* 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.
Cryptantha species are pollinated by bees, flies, and other insects and tend not to show high specificity.

C4d. Dependence on other species for propagule dispersal: Neutral.
The nutlets of *Cryptantha spiculifera* are probably dispersed passively by gravity or transported short distances by animals (which may be seed or fruit predators).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Herbivory has not been identified as a significant threat (Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Cryptantha spiculifera occurs in sparsely vegetated outcrops that currently have relatively low cover and competition from other species. Climate change could shift the composition to more annual plant species (Rocchio and Ramm-Granberg 2017), including some that could be invasive exotics.

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 *Cryptantha spiculifera* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Cryptantha spiculifera 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 on this species for confirmation.

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, *Cryptantha spiculifera* populations in Washington have been blooming from the last week of April to early June since at least the 1980s. Historical collections from 1893-1979 are from early May to early June.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Although three occurrences of this species are historical in Washington, significant changes in the distribution of *Cryptantha spiculifera* have not been documented.

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, 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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Cypripedium parviflorum (Yellow lady's slipper)

Date: 5 April 2020

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	**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	21.7
	-0.074 to - 0.096	43.5
	-0.051 to - 0.073	34.8
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		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		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
4g. Forms part of an interspecific interaction not covered above		Somewhat Increase
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 23 of the occurrences of *Cypripedium parviflorum* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

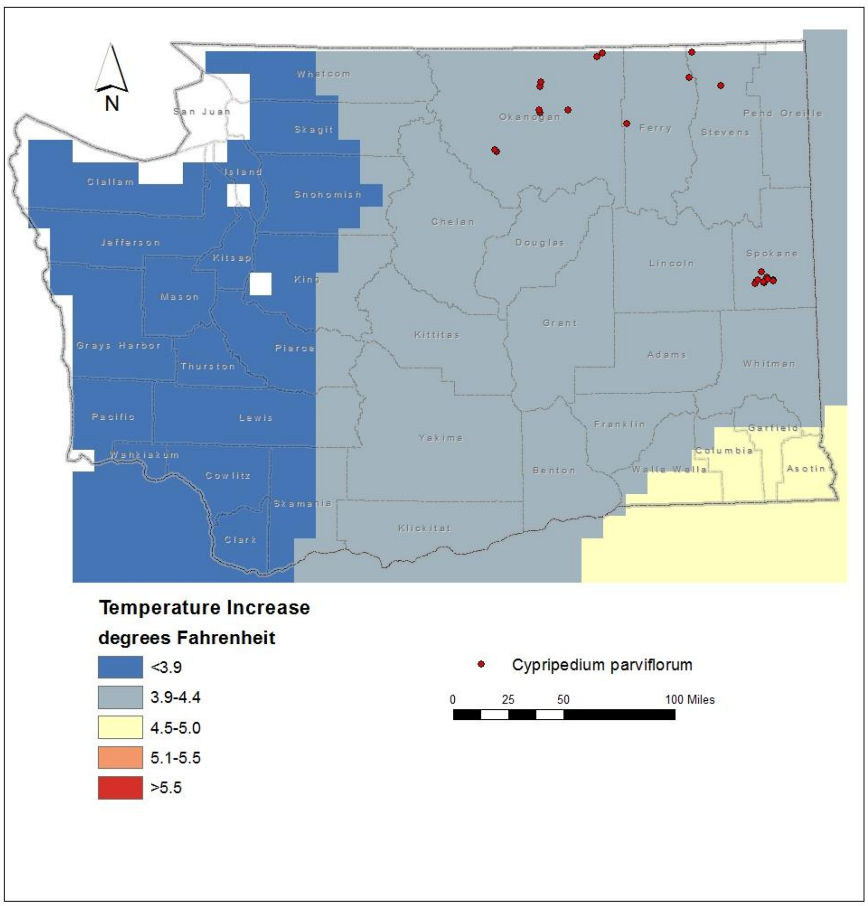

Figure 1. Exposure of *Cypripedium parviflorum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Five of the 23 extant and historical occurrences of *Cypripedium parviflorum* (21.7%) 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). Ten of 23 populations (43.5%) occur in areas with a projected decrease in the range of -0.074 to -0.096. Eight other occurrences (34.8%) are from areas with a projected decrease in available moisture of -0.051 to -0.073 (Figure 2).

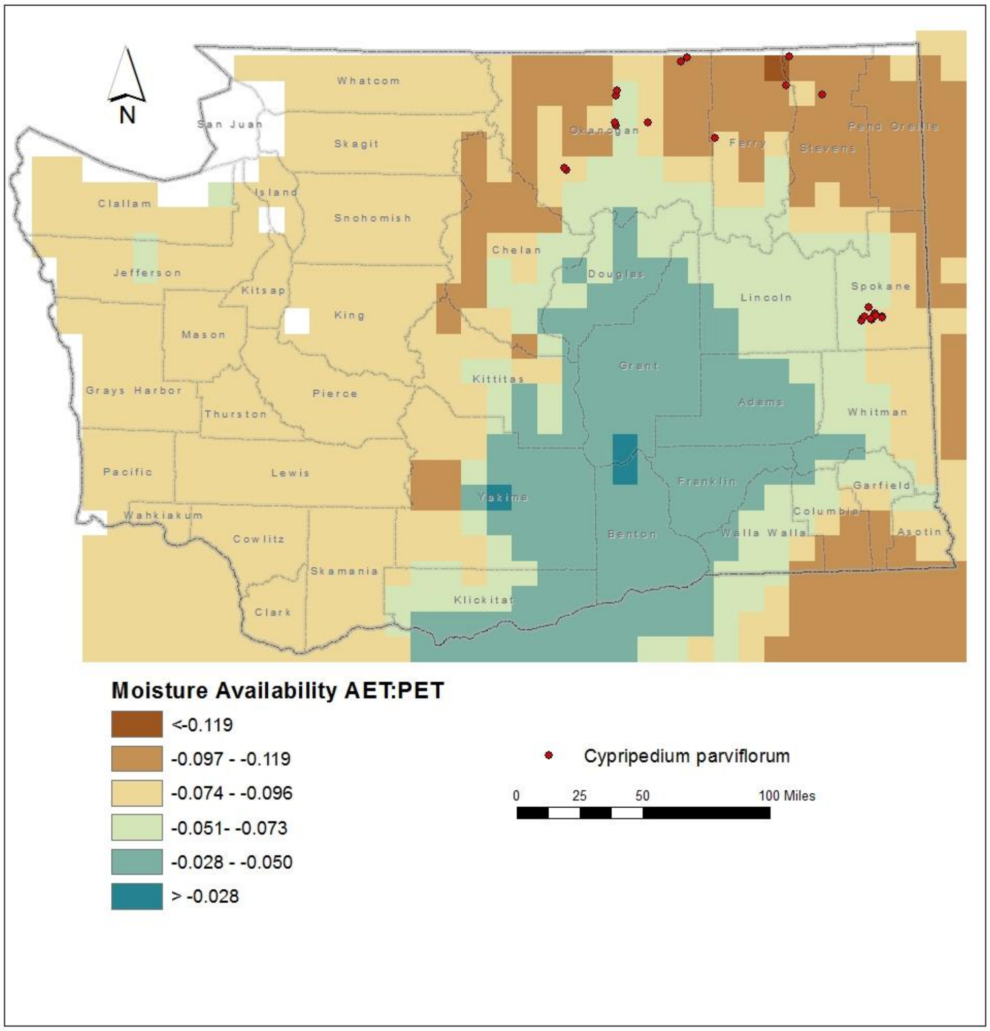

Figure 2. Exposure of *Cypripedium parviflorum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Cypripedium parviflorum* are found at 1800-3400 feet (550-1050 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Cypripedium parviflorum* occurs in grassy areas amid shrubs along the edge of beaver ponds, perennial or ephemeral scabland ponds, marshy areas, or forested swamps (Camp and Gamon 2011, WNHP records). Some populations on the Colville National Forest occur in areas with calcareous soils. Dominant shrub and tree species in wetlands occupied by *C. parviflorum* include *Pseudotsuga menziesii, Populus tremuloides, Thuja plicata, Picea engelmannii, Pinus ponderosa, Alnus, Salix*, and *Betula* (WNHP records). The shrub/marsh and swamp forest habitat utilized by this species conforms with the Rocky Mountain Subalpine-Montane Riparian Shrubland and Northern Rocky Mountain Conifer Swamp ecological systems (Rocchio and Crawford 2015). Washington occurrences are restricted to small patches of suitable habitat separated by distances of 1-90 miles (1.5-145 km). The natural patchiness of the populations and large extent of unsuitable habitat between them creates a barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Cypripedium parviflorum* is naturally fragmented. Human impacts on the landscape of northeastern Washington may exacerbate this condition, but overall are of less significance 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.
Cypripedium parviflorum produces numerous, miniscule seeds within dry capsules that split open at maturity to release seed passively. Dispersal is primarily by wind and seeds can travel over 100 km (Carlson and Fulkerson 2017).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Cypripedium parviflorum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 23 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. 2006).

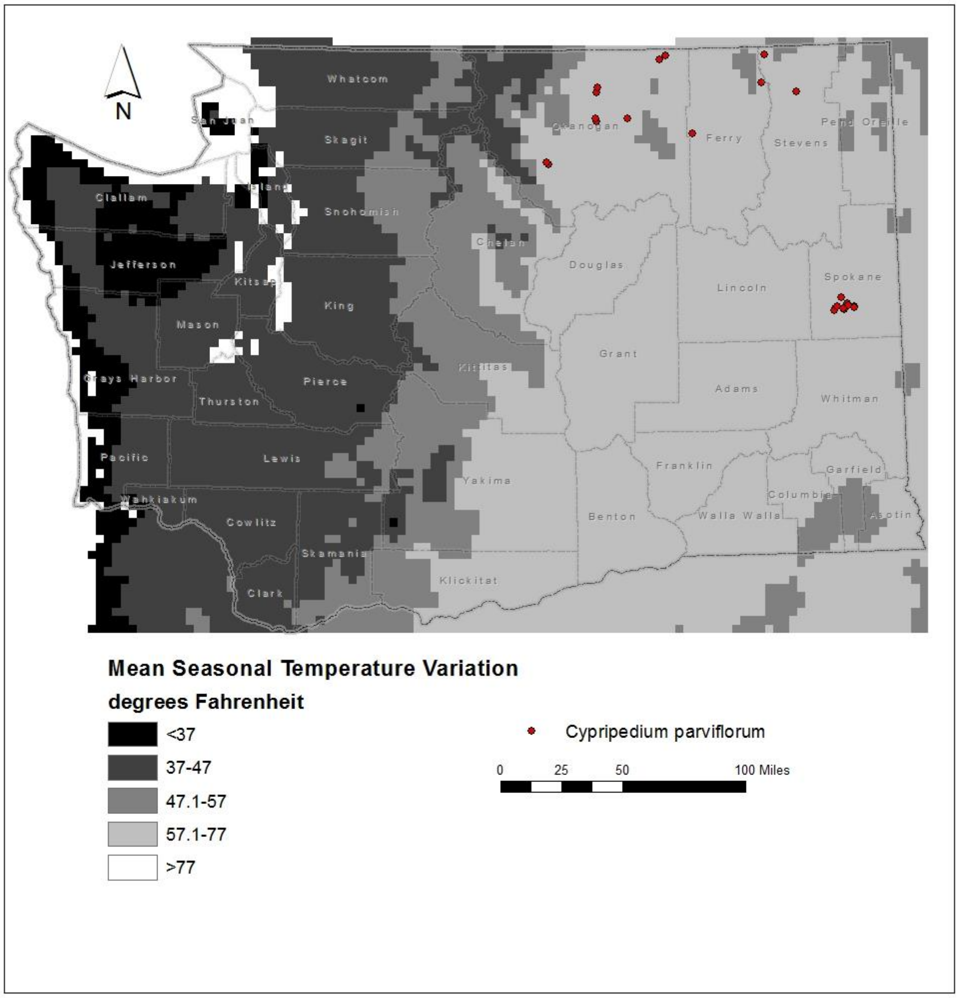

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Cypripedium parviflorum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Many populations of *Cypripedium parviflorum* are found in shady and cool microsites associated with swamp forests and shrubby marshlands and depressions. These sites are likely to be cold air drainages during the growing season and would have somewhat increased vulnerability to temperature changes associated with global warming.

C2bi. Historical hydrological niche: Somewhat Increase.

Twenty of the 23 populations of *Cypripedium parviflorum* in Washington (87%) 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. The other three populations from northeastern Washington have experienced average or greater than average (>20 inches/508 mm) precipitation variation over the same period and are at neutral vulnerability (Figure 4).

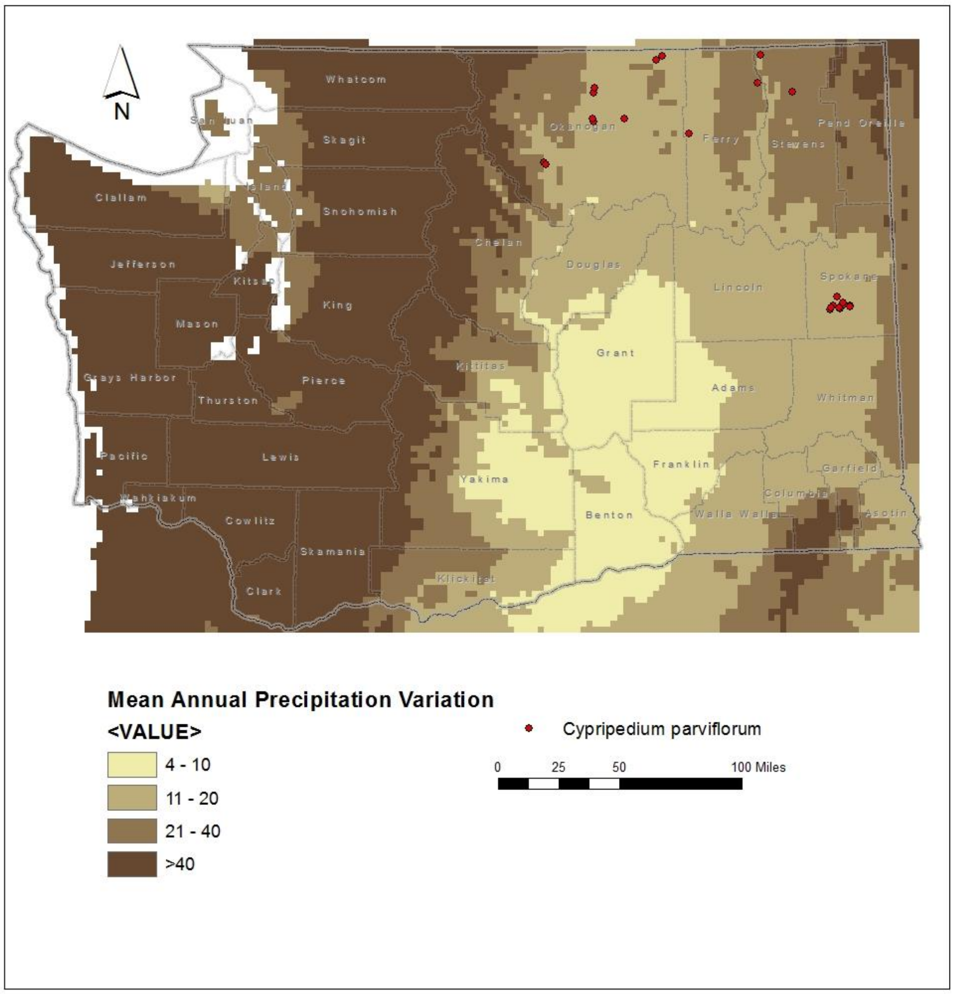

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Cypripedium parviflorum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is associated with forested swamps and marshy shrublands maintained by high water tables or seasonal flooding, both of which could be negatively impacted by projected higher temperatures in the summer or earlier melting of snowpacks in the spring (Rocchio and Ramm-Granberg 2017). See "Dependence on ice or snow-cover habitats" below.

C2c. Dependence on a specific disturbance regime: Neutral.
Cypripedium parviflorum occurs in swamp forest and marshy shrubland habitats that may be subjected to flooding in spring or late winter. These high flows may be important for maintaining adequate soil moisture into the summer (Rocchio and Ramm-Granberg 2017). Otherwise, these habitats are not adapted to disturbances, such as fire or wind-throw. Increase in temperature or reduction in precipitation could make these habitats more vulnerable to drought or fire and lead to conversion to more xeric shrublands or meadows.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Cypripedium parviflorum* in Washington are found in marshy shrublands and swamp forests where high water tables are maintained in part from snowmelt. Projected future changes in temperature could negatively impact the timing of snowmelt and result in less recharge of water in the spring, making these habitats more vulnerable to summer drought (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Populations of *Cypripedium parviflorum* in Washington occur on a variety of substrates. In the Spokane area, most occurrences are in scoured kettle ponds in the Priest Rapids Member of the Wanapum Basalt, a common formation in eastern Washington. Elsewhere in the state, populations are found on Pleistocene glacial drift, ultramafic intrusive formations, the Metaline limestone, Tonasket gneiss, and Loomis granodiorite. The variety of substrates suggest that geological features are not limiting the distribution of this species.

C4a. Dependence on other species to generate required habitat: Neutral.
The marshy shrubland and swamp forest habitat occupied by *Cypripedium parviflorum* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Increase.
Cypripedium parviflorum flowers are pollinated by small bees in the genus *Andraena* that are enticed to the showy slipper petal by a floral scent and then become trapped inside, able to escape only through a narrow opening at the back of the slipper below the sticky pollinaria. Bees loaded with pollen must then visit another *Cypripedium* flower and become trapped again to release their pollen load on a receptive stigma as they escape. Pollination rates and seed set are low for this and other *Cypripedium* species (Carlson and Fulkerson 2017). The complexity of pollination and few species of bees capable of being pollinators make this species have increased vulnerability to climate change.

C4d. Dependence on other species for propagule dispersal: Neutral.
The tiny seeds of *Cypripedium parviflorum* are dispersed long distances by wind and are not dependent on animals.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Impacts from pathogens are not known. This species is palatable and potentially vulnerable to grazing by livestock and other herbivores.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Competition from other plant species is not identified as a significant threat to C*ypripedium parviflorum* (Camp and Gamon 2011).

C4g. Forms part of an interspecific interaction not covered above: Somewhat Increase.
Cypripedium parviflorum seeds do not contain endosperm to provide nutrition for developing seedlings, and so mycorrhizal fungi symbionts are necessary for establishment of young plants (Carlson and Fulkerson 2017). High specificity to mycorrhizal fungi has been reported for other Cypripedium species (Shefferson et al. 2005).

C5a. Measured genetic variation: Unknown.
Data are not available on the genetic diversity of this species in Washington. In the eastern United States, Wallace and Case (2000) found significant differences in genetic variation across the range of *Cypripedium parviflorum*, particularly in regions that had been glaciated. The authors suggested that a refugium may have existed within the glacial region which served as the source for new populations in the southeastern US, or the southern populations have become spatially isolated and experienced genetic drift to account for their lower genetic diversity.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Cypripedium parviflorum reproduces sexually and is self-incompatible. The pollination syndrome of the species is complex (as noted in Section C4c) and strongly favors outcrossing. Seeds are small and easily dispersed long distances by wind. Wallace and Case (2000) found high rates of genetic variability across the range of the species in the eastern US, consistent with high dispersal, although isolated populations also showed evidence of reduced genetic diversity through genetic drift. Genetic data are not available for Washington populations, which may have slightly lower genetic diversity than expected because the state populations are at the edge of the species' full range and could be impacted by genetic drift or founder effects.

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 this species within Washington has not changed significantly 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.

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Climate Change Vulnerability Index Report

Erigeron salishii (Salish fleabane)

Date: 5 February 2020

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	**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	50
	-0.074 to - 0.096	50
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
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		Neutral
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	
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 of the extant and historical occurrences of *Erigeron salishii* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

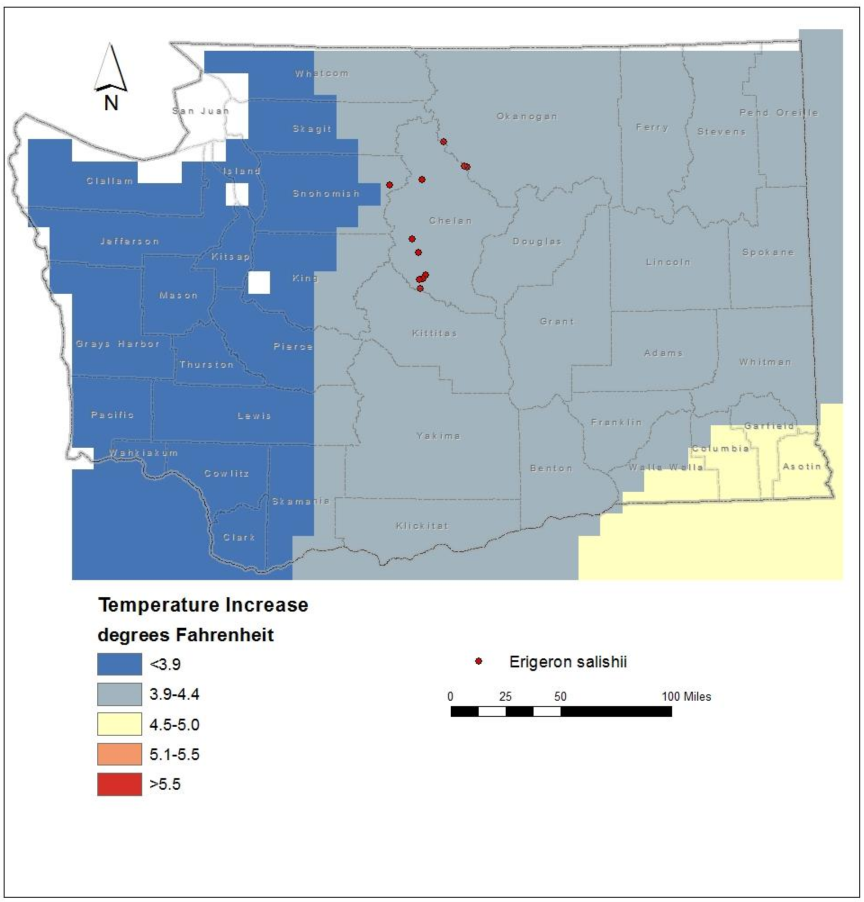

Figure 1. Exposure of *Erigeron salishii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the 12 occurrences (50%) of *Erigeron salishii* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other fifty percent of occurrences are in areas with projected decrease of -0.074 to -0.096.

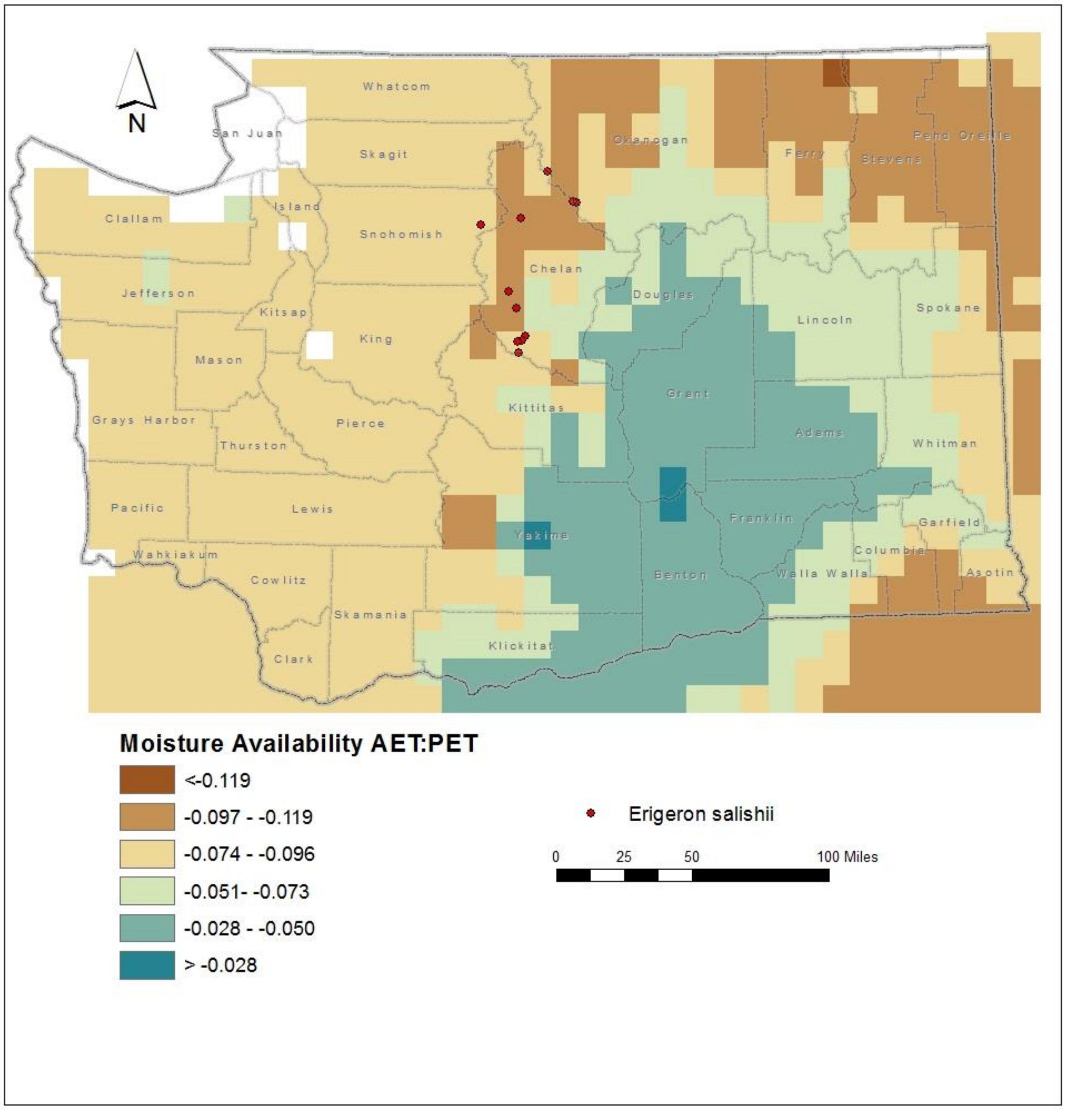

Figure 2. Exposure of *Erigeron salishii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Erigeron salishii* are found at 6600-9000 feet (2000-2800 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Erigeron salishii occurs primarily on dry, rocky talus slopes or ridgetops with granite, sand, or loess soils in the alpine zone (Camp and Gamon 2011). This habitat is part of the Rocky Mountain Alpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). Populations may be isolated from each other by 1.2-25 miles (2-40 km) of unoccupied and unsuitable habitat, although this distance is not a complete barrier to propagule dispersal.

B2b. Anthropogenic barriers: Neutral.
The alpine habitat of *Erigeron salishii* in Washington is located primarily along the crest of the East and North Cascades and is relatively 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: Neutral.
Erigeron salishii produces numerous, small achenes with a feathery pappus 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: Somewhat Increase.
Figure 3 depicts the distribution of *Erigeron salishii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Nine of the 12 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 three 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: Greatly Increase.
The alpine talus and tundra habitat of *Erigeron salishii* is entirely within a cold climate zone during the flowering season and highly vulnerable to temperature increase from climate change.

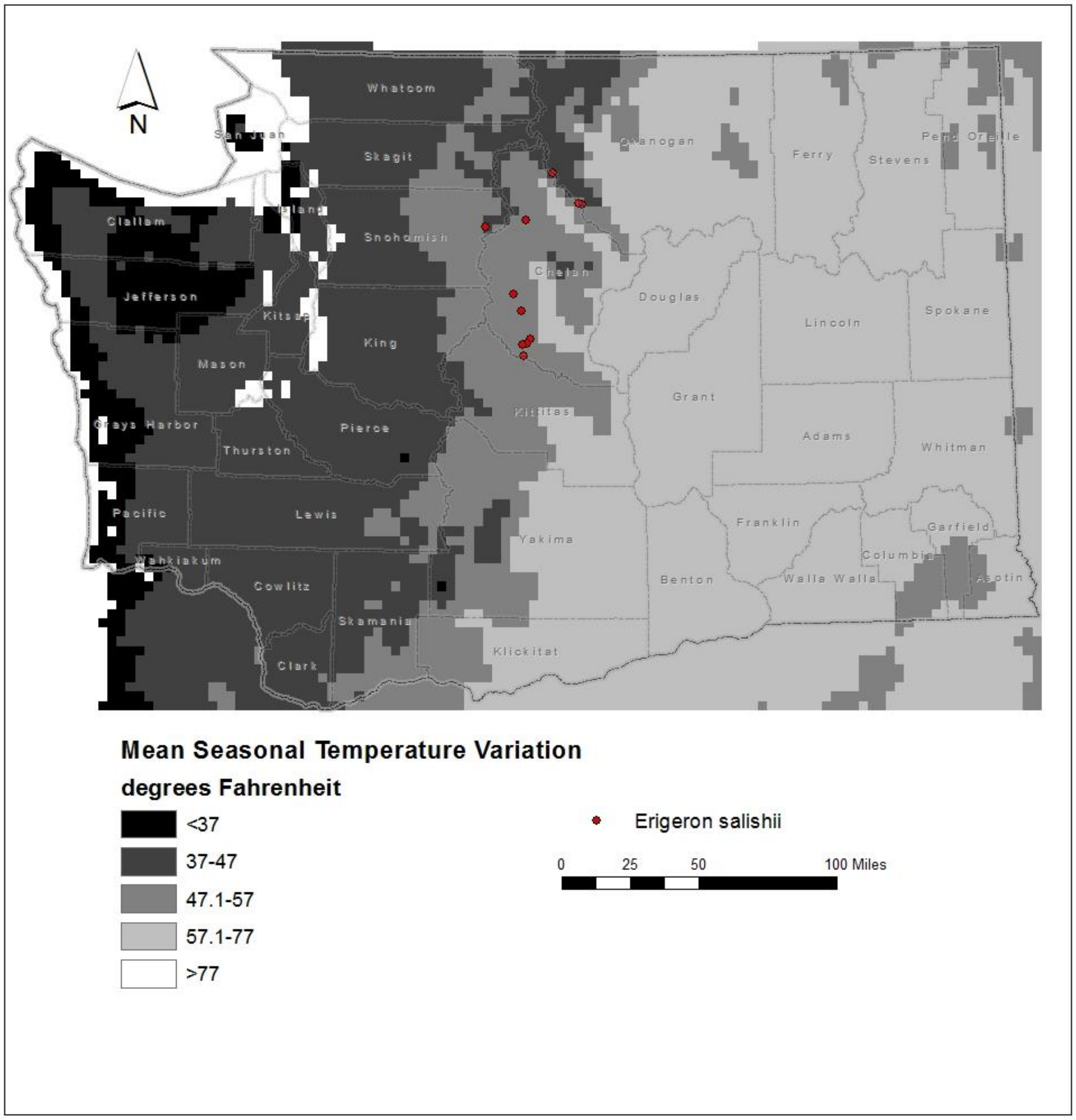

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Erigeron salishii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Erigeron salishii* 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.

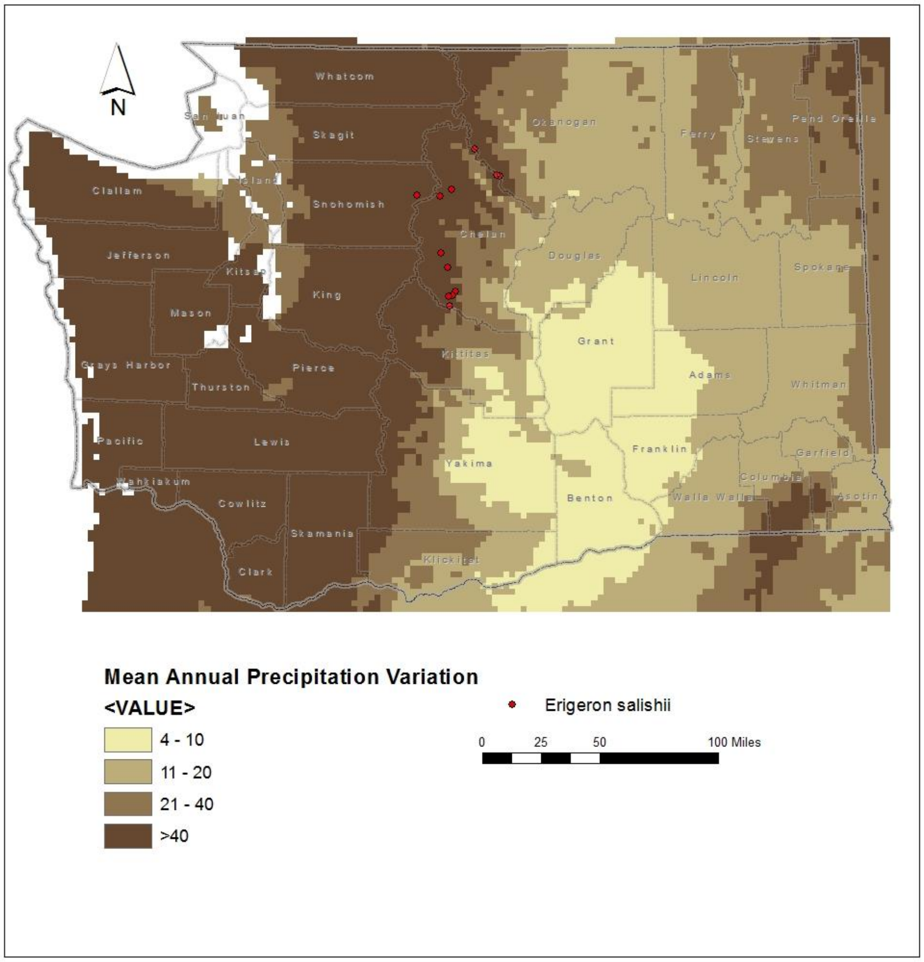

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Erigeron salishii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a strongly seasonal hydrologic regime or specific wetland habitats (but see "Dependence on ice or snow-cover habitats" below).

C2c. Dependence on a specific disturbance regime: Neutral.
Erigeron salishii occurs in alpine talus, scree, and tundra habitats that are subject 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: Somewhat Increase.
The populations of *Erigeron salishii* 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 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: Neutral.
Erigeron salishii is found primarily on outcrops of felsic tonalite, a rock type similar to granite diorite that is exposed at high elevations in the East Cascades and Okanogan mountains.

C4a. Dependence on other species to generate required habitat: Neutral
The alpine talus and tundra habitat occupied by *Erigeron salishii* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Erigeron salishii, like most composites, is pollinated by generalist insect pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits have a feathery pappus and are readily wind-dispersed, and thus are not dependent on animal 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.
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 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.
Not known. Douglas and Packer (1988) report that *Erigeron salishii* is a diploid (2n = 18), while its close relative, *Erigeron compositus* is a polyploid (2n = 54).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Erigeron salishii appears to be an obligate outcrosser and is not limited by pollinators or dispersal, so is presumed to have average genetic variation, though no research has been done to confirm this.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Erigeron salishii* 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 *Erigeron salishii* 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

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Douglas, G.W. and J.G. Packer. 1988. *Erigeron salishii*, a new *Erigeron* (Asteraceae) from British Columbia and Washington. Canadian Journal of Botany 66(3): 414-416.

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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.

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

Eriophorum viridicarinatum (Green keeled cottongrass)

Date: 10 February 2020

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	**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	92
	<3.9° F (2.2°C) warmer	8
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	77
	-0.074 to - 0.096	23
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		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		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 13 occurrences (92%) of *Eriophorum viridicarinatum* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). One population (8% of state total) is found in an area with a projected increase of <3.9˚ F

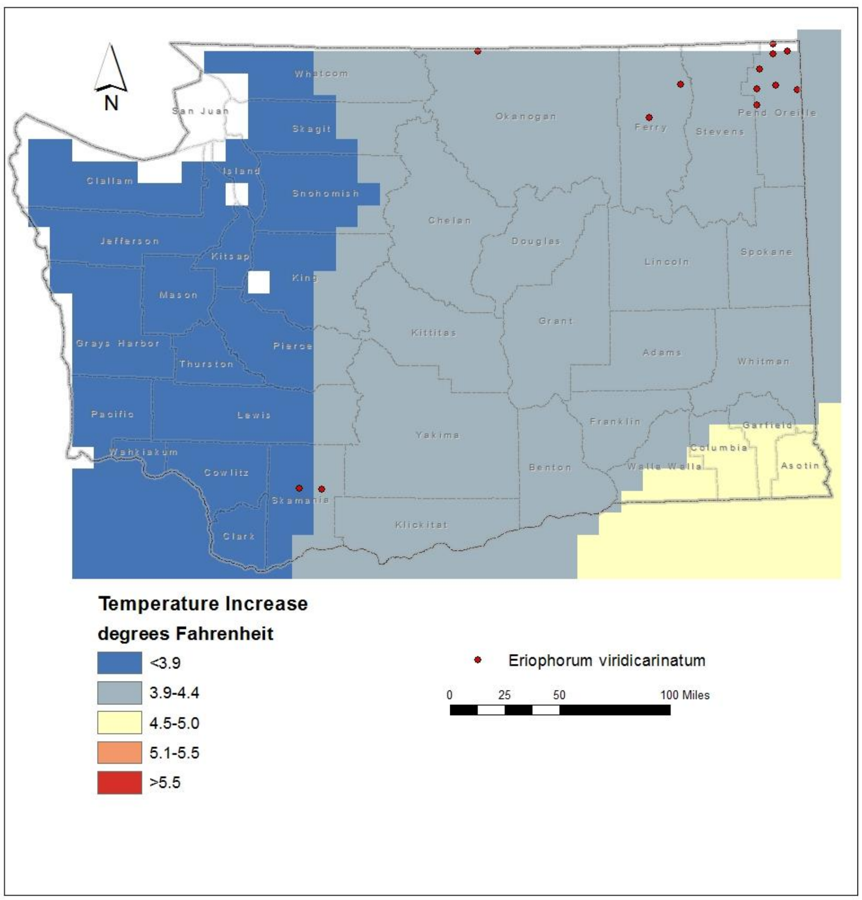

Figure 1. Exposure of *Eriophorum viridicarinatum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Ten of the 13 Washington occurrences of *Eriophorum viridicarinatum* (77%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other 23% of occurrences are in areas with projected decrease of -0.074 to -0.096.

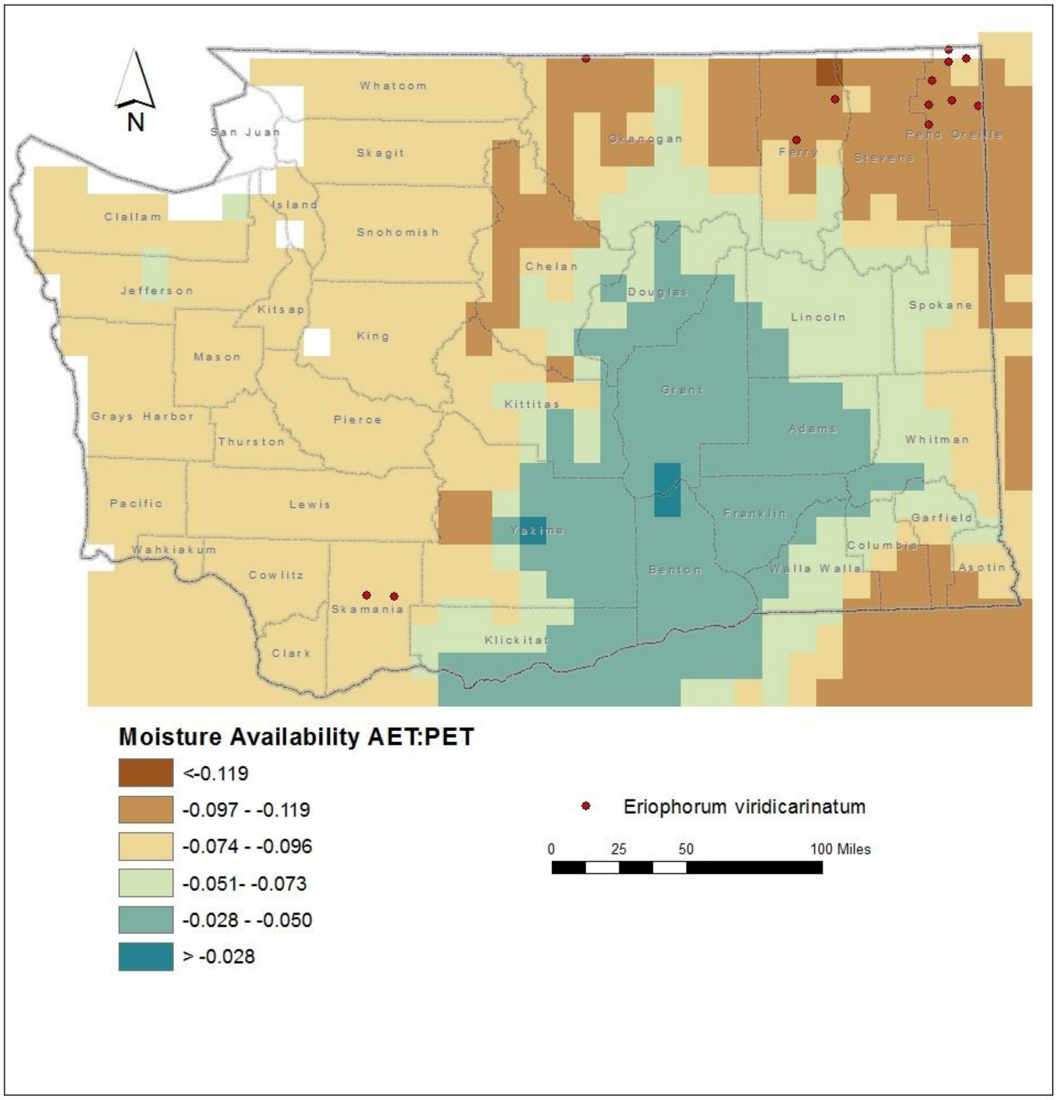

Figure 2. Exposure of *Eriophorum viridicarinatum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Eriophorum viridicarinatum* are found at 2120-6560 feet (650-2000 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Eriophorum viridicarinatum is an obligate wetland species found in cold calcareous fens, pond shores, and wet meadows, mostly in lower montane zones (Camp and Gamon 2011). A report from the Columbia Plateau southwest of Spokane was misidentified (Fertig and Kleinknecht 2020). Washington occurrences are part of the North Pacific Bog and Fen and Rocky Mountain Subalpine-Montane Fen ecological systems (Rocchio and Crawford 2015). Populations may be isolated from each other by 4-10 miles (7-16 km) or of unoccupied and unsuitable habitat. Large blocks of forested habitat may be a sufficient barrier to wind-dispersed pollen or seed.

B2b. Anthropogenic barriers: Neutral.
The wetland habitat of *Eriophorum viridicarinatum* in Washington is already naturally fragmented and isolated, so additional habitat fragmentation by human activities is of comparatively low significance.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Eriophorum viridicarinatum produces small achenes associated with tufts of long, feathery bristles that aid in dispersal by wind. The fruits might also be dispersed by flowing water. Although dispersal could be constrained by forests, the fruits probably can disperse over 1 km.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Eriophorum viridicarinatum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eight of the 13 known occurrences (62%) are found in areas that have experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) during the last 50 years and are considered neutral in terms of climate change vulnerability (Young et al. 2016). Three populations (23%) 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. Two other occurrences (15%) are from areas that have had a small temperature variation (37-47˚F/20.8-26.3˚C) in temperature over the same period and are considered to be at increased vulnerability. The species is scored as "Neutral" in vulnerability because the majority of occurrences fall in this category.

C2aii. Physiological thermal niche: Somewhat Increase.
The montane calcareous fen and wet meadow habitat of *Eriophorum viridicarinatum* is found primarily in areas of cold air drainage and would be somewhat vulnerable to temperature increase from climate change.

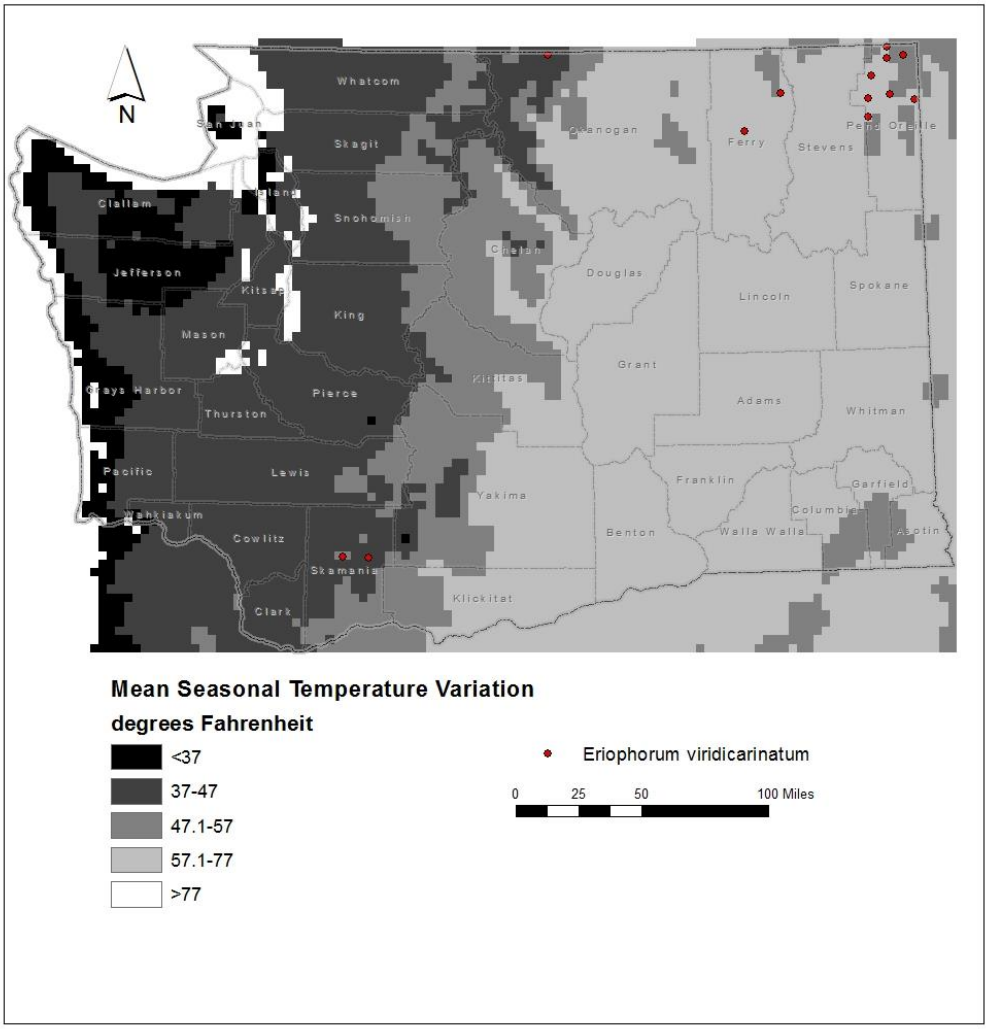

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Eriophorum viridicarinatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All 13 known populations of *Eriophorum viridicarinatum* in Washington (100%) are found in areas that have experienced average of greater than average (>20 inches/508 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.

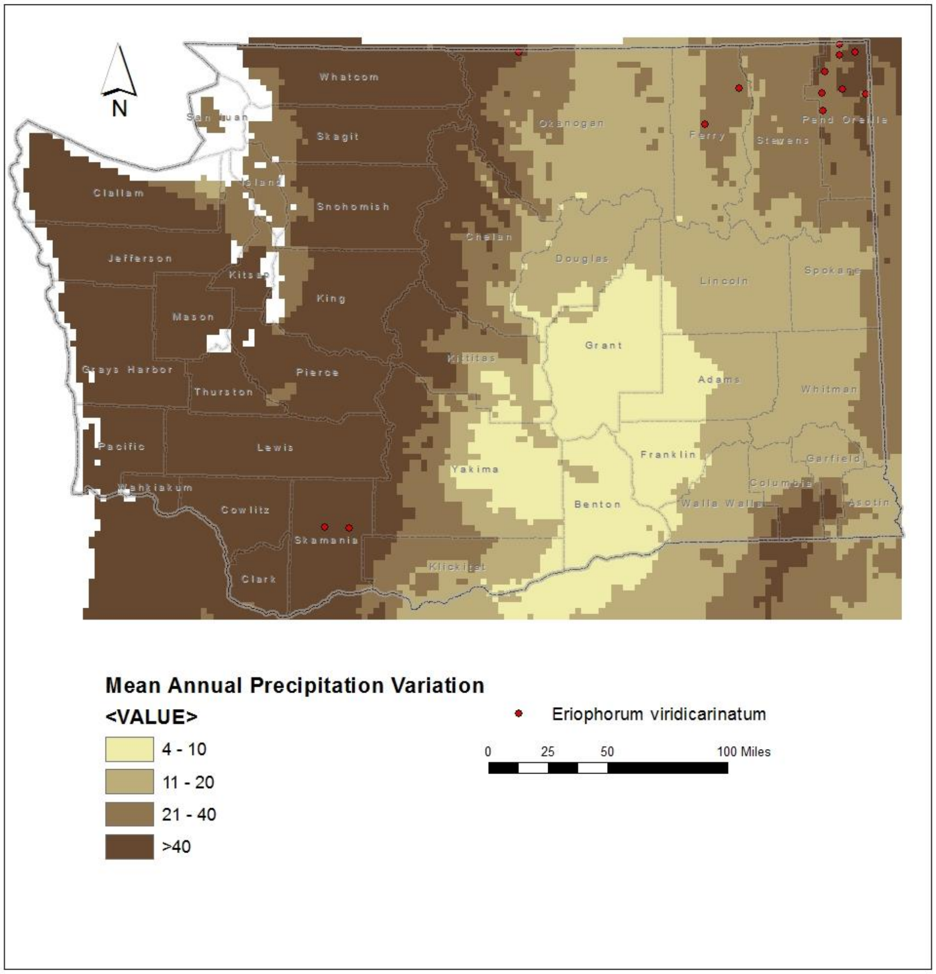

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Eriophorum viridicarinatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
The fen habitats of *Eriophorum viridicarinatum* are mostly associated with groundwater discharge, and in the short-term may be more resilient to reductions in available precipitations from climate change than rainwater-dependent wetlands (Rocchio and Ramm-Granberg 2017). Long-term, however, reduced snowpack and recharge of regional aquifers would make these habitats more vulnerable. For now, the score is Neutral, but long term might warrant “Somewhat Increased” (but see “Dependence on ice or snow-cover habitats” below).

C2c. Dependence on a specific disturbance regime: Neutral.
Eriophorum viridicarinatum occurs in fen and wet meadow habitats that are maintained by a high water table to prevent encroachment of forests, rather than on natural disturbance cycles. Prolonged drought that might reduce groundwater, or wildfire in surrounding forested habitat, could make these sites more prone to invasion by wetland plants adapted to less harsh environmental conditions (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Eriophorum viridicarinatum* in Washington occur in fen and wet meadow habitats maintained by groundwater in regional aquifers. Ultimately, these sites are dependent on adequate winter snowfall for recharge. Reduction in winter snow accumulation could have a long term negative impact on the hydrologic conditions necessary to maintain this habitat (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Eriophorum viridicarinatum is found in wetland sites with basic water chemistry often associated with calcareous bedrock, which is a relatively uncommon geologic type in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The fen and wet meadow habitat occupied by *Eriophorum viridicarinatum* is maintained by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Eriophorum viridicarinatum is wind-pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits are surrounded by tufts of cottony bristles that aid in dispersal by wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Palatable, but not thought to be threatened by grazing from native species (livestock grazing may be a localized impact).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Under present conditions, competition from non-native species is low, as few introduced plants are adapted to the harsh environmental conditions of calcareous fens. Under projected climate change, competition could increase if fen sites are converted to meadows due to a reduction in groundwater availability from prolonged drought or diminution of snow recharge (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 are no published studies specifically addressing the population genetics of this species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Eriophorum viridicarinatum is presumed to be an outcrosser and pollinated by wind, suggesting that rangewide genetic variability should be average. Isolated occurrences, such as those at the southern edge of its range (like Washington), might be expected to have lower overall diversity due to 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), *Eriophorum viridicarinatum* 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.
In 2009, *Eriophorum viridicarinatum* was first documented in the West Cascades ecoregion (Gifford Pinchot NF), though it is unknown whether this represents a range extension or imroved survey effort.

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.

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

Gaultheria hispidula (Creeping snowberry)

Date: 11 February 2020

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	**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	86
	-0.074 to - 0.096	14
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral/Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on 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		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: All seven of the known occurrences of *Gaultheria hispidula* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

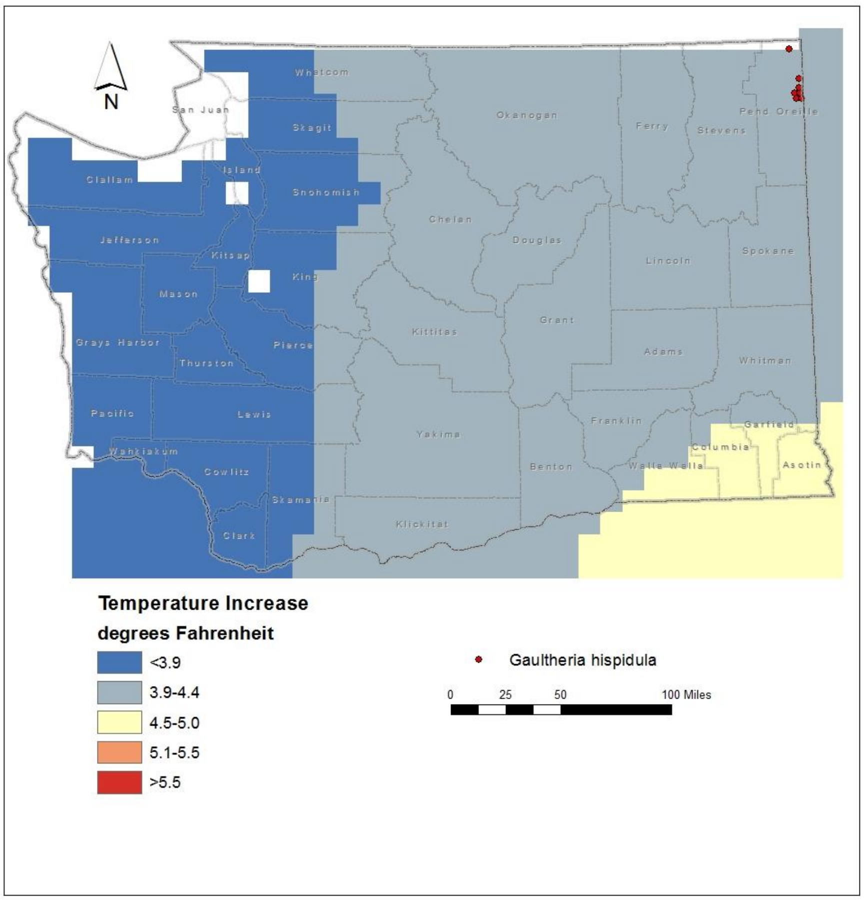

Figure 1. Exposure of *Gaultheria hispidula* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Six of the seven Washington occurrences of *Gaultheria hispidula* (86%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). One other occurrence (14%) is from an area with a projected decrease of -0.074 to -0.096.

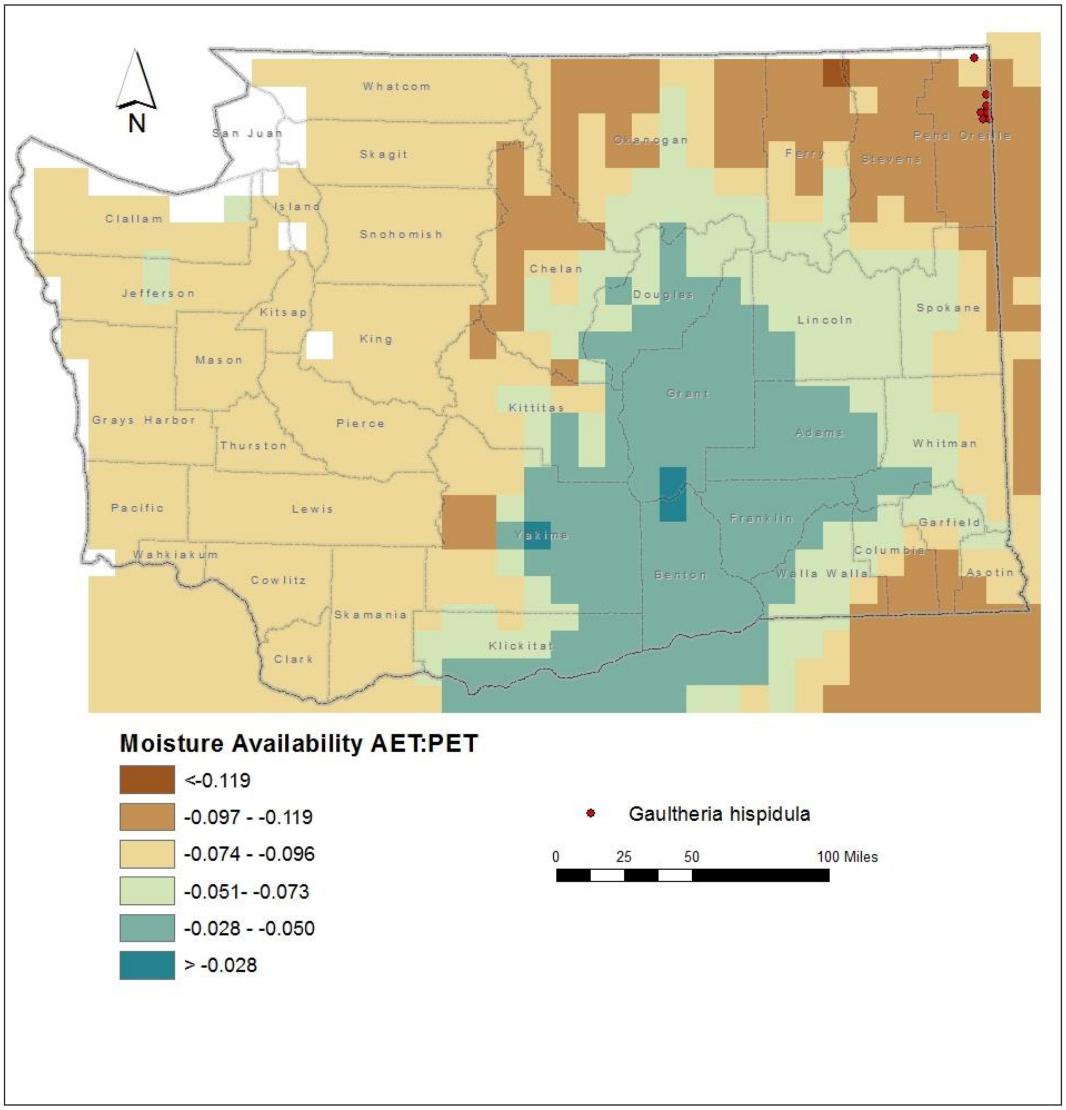

Figure 2. Exposure of *Gaultheria hispidula* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Gaultheria hispidula* are found at 2960-6470 feet (900-1160 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Gaultheria hispidula* is restricted to swamp forests in drainage bottoms dominated by *Thuja plicta* or *Picea engelmannii* with abundant *Sphagnum* in the understory and rotting logs (Camp and Gamon 2011, WNHP Biotics records). All of these records are from the Canadian Rockies ecoregion of northeastern Pend Oreille County. A report from the North Cascades in Snohomish County is based on a misidentified specimen of *Vaccinium oxycoccus* and is not included in this assessment. The habitat from northeastern Washington is part of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio and Crawford 2015). Populations often consist of numerous subpopulations scattered along a drainage within 1 km of each other. Other populations may be separated by 3.7-8 km (2.5-5 miles) of unoccupied habitat. The natural heterogeneity of suitable habitat and its presence within a matrix of unsuitable environments creates a natural barrier to pollen and seed dispersal.

B2b. Anthropogenic barriers: Neutral.
The *Sphagnum*-rich wet forest habitat of *Gaultheria hispidula* in Washington is already naturally patchy, so additional habitat fragmentation by human activities is a relatively minor impediment 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.
Gaultheria hispidula produces berry-like edible fruits (technically a dry many-seeded capsule enclosed by a juicy calyx). These are primarily dispersed by small rodents (mice or chipmunks) for relatively short distances (Hays 2001).

C2ai. Historical thermal niche: Neutral/Somewhat Increase
Figure 3 depicts the distribution of *Gaultheria hispidula* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the seven known occurrences (57%) are found in areas that have experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) during the last 50 years and are considered neutral in terms of climate change vulnerability (Young et al. 2016). Three populations (43%) 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.

C2aii. Physiological thermal niche: Increase.
The montane *Sphagnum*-rich swamp forest habitat of *Gaultheria hispidula* is restricted to areas of cold air drainage and would have increased vulnerability to temperature increase from climate change.

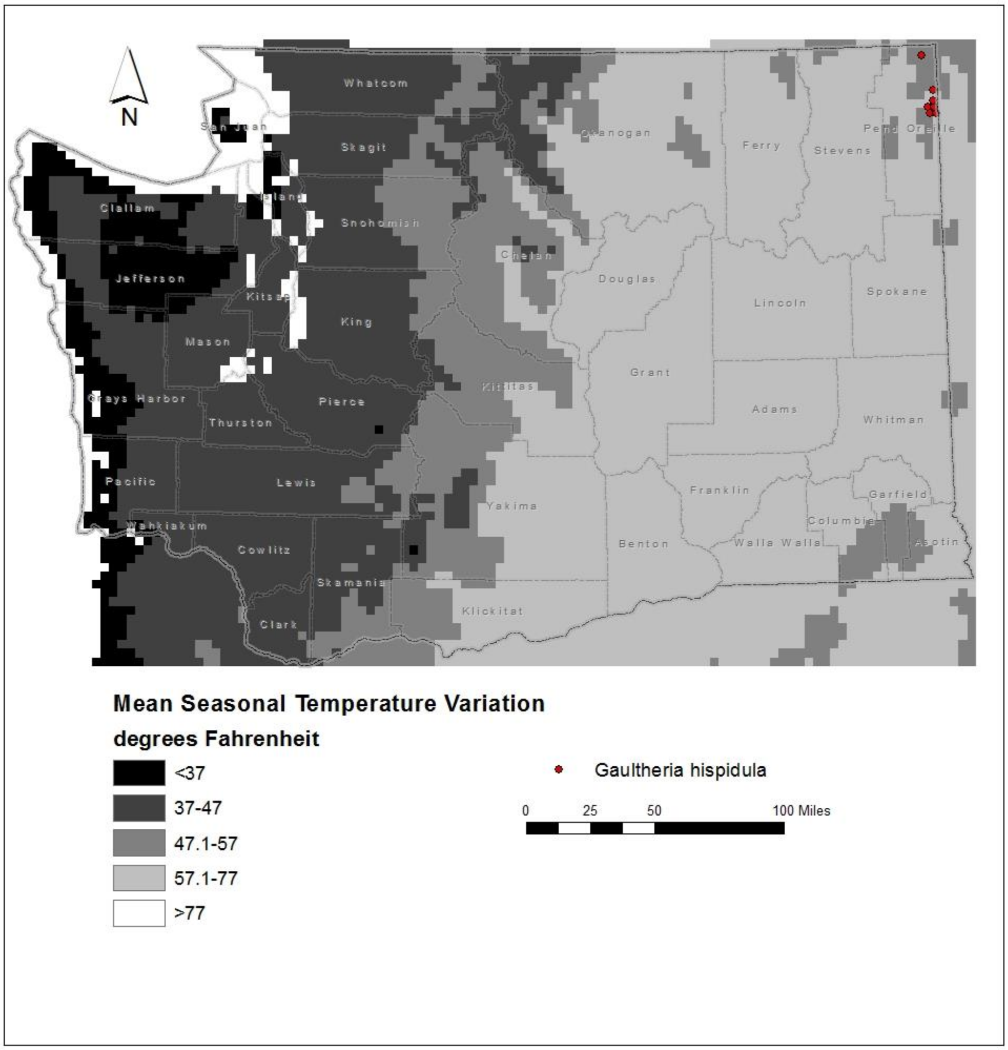

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Gaultheria hispidula* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All seven of the known populations of *Gaultheria hispidula* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 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.

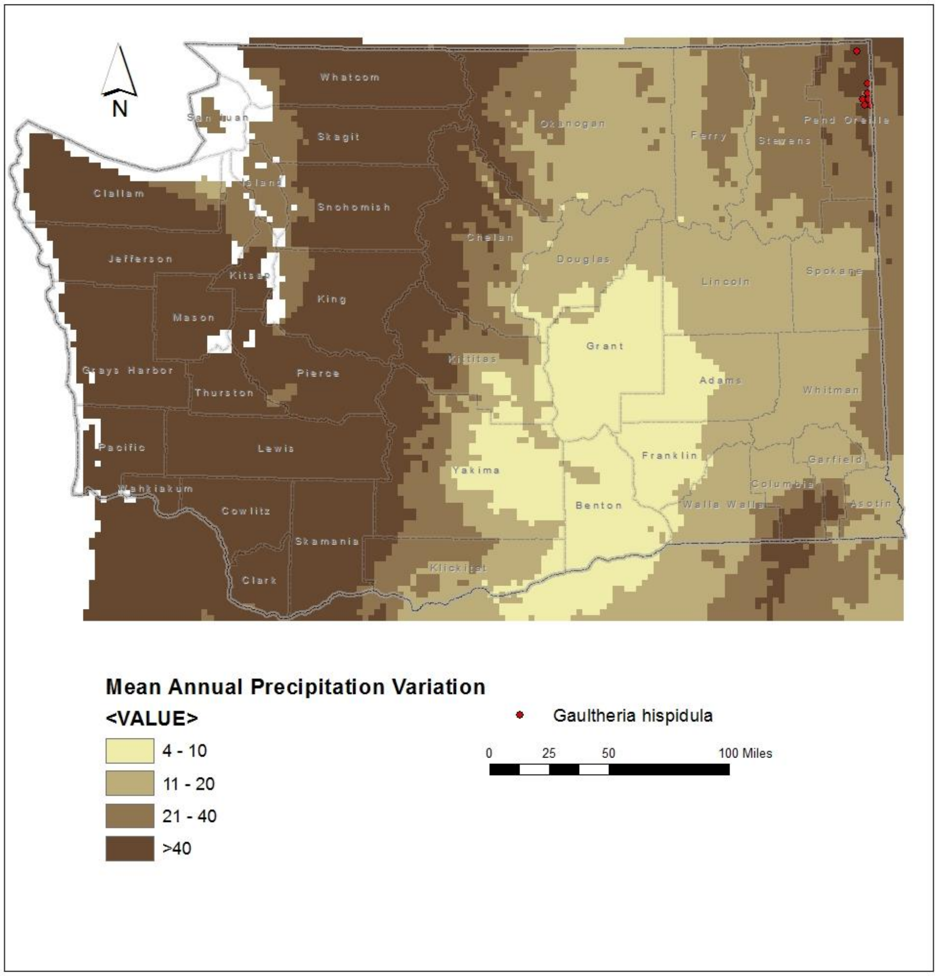

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Gaultheria hispidula* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The *Sphagnum*-rich swamp forest habitats of *Gaultheria hispidula* are associated with groundwater discharge that in turn is affected by snowpack and precipitation. In the face of projected climate change, extended summer drought would reduce the amount of moisture avaiable for the *Sphagnum* understory. Increased fire frequency would negatively impact

swamp forests and create open conditions, reducing habitat quality for this species (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Gaultheria hispidula occurs in *Sphagnum*-rich swamp forest habitats that are maintained by a high water table and are not adapted to frequent natural disturbance cycles. Prolonged drought that might reduce groundwater or increase wildfire in surrounding forested habitat could make these sites more prone to invasion by wetland plants adapted to less specific environmental conditions.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Gaultheria hispidula* in Washington occur in *Sphagnum*-rich swamp forest habitats maintained by groundwater in regional aquifers. Ultimately, these sites are dependent on adequate winter snowfall for recharge. Reduction in winter snow accumulation could have a long term negative impact on the hydrologic conditions necessary to maintain this habitat (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Gaultheria hispidula occurs on a variety of Quaternary glacial till formations that are relatively widespread. It is not directly associated with unusual topography.

C4a. Dependence on other species to generate required habitat: Neutral
The swamp forest habitat occupied by *Gaultheria hispidula* is maintained by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Gaultheria hispidula is probably self-sterile and pollinated by bumblebees, solitary bees, bee flies and syrphid flies (Hays 2001).

C4d. Dependence on other species for propagule dispersal: Neutral.
Dependent on several species of small mammals for dispersal (Hays 2001).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Palatable, but not thought to be threatened by grazing from native species (livestock grazing may be a localized impact).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Under present conditions, competition from non-native species is not limiting, as few introduced plants are adapted to the harsh environmental conditions of *Sphagnum*-dominated swamp forests. Under projected climate change, competition could increase if these sites are converted to drier meadows due to a reduction in groundwater availability from prolonged drought, reduced snow recharge, or 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.
There are no published studies specifically addressing the population genetics of this species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Gaultheria hispidula is presumed to be an outcrosser and pollinated by numerous species of bees and flies, suggesting that genetic variability should be average rangewide. Populations at the southern edge of its range (like Washington) might be expected to have lower overall diversity due to founder effects.

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 this species have occurred over the past 50 years.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No change in the distribution of this species in Washington has been documented.

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.

Hays, M. 2001. Conservation assessment for Creeping snowberry (*Gaultheria hispidula*). USDA Forest Service Eastern Region, Milwaukee, WI. 27 pp. (https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm91_054132.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.

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 taylorii (Taylor's stickseed)

Date: 11 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G2/S2

Index Result: Highly Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	50
	-0.074 to - 0.096	50
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Somewhat Increase
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		Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Somewhat Increase
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: All four of the known occurrences of *Hackelia taylorii* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4° F (Figure 1).

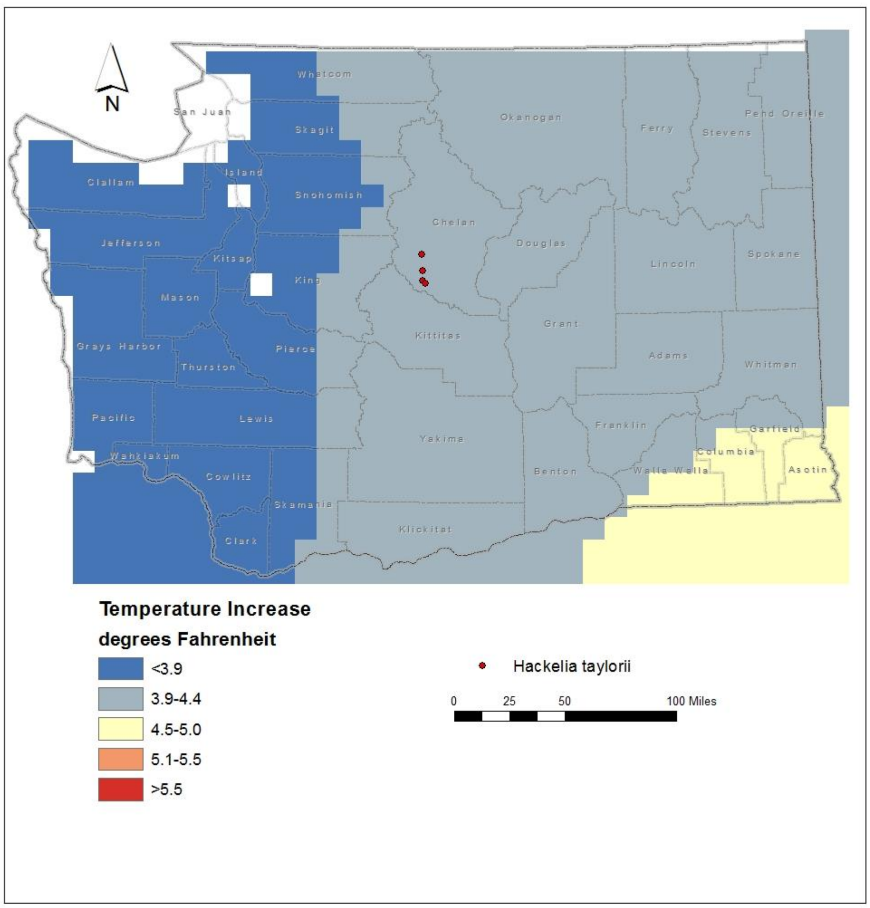

Figure 1. Exposure of *Hackelia taylorii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the four Washington occurrences of *Hackelia taylorii* (50%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other 50% of occurrences are in areas with projected decrease of -0.074 to -0.096.

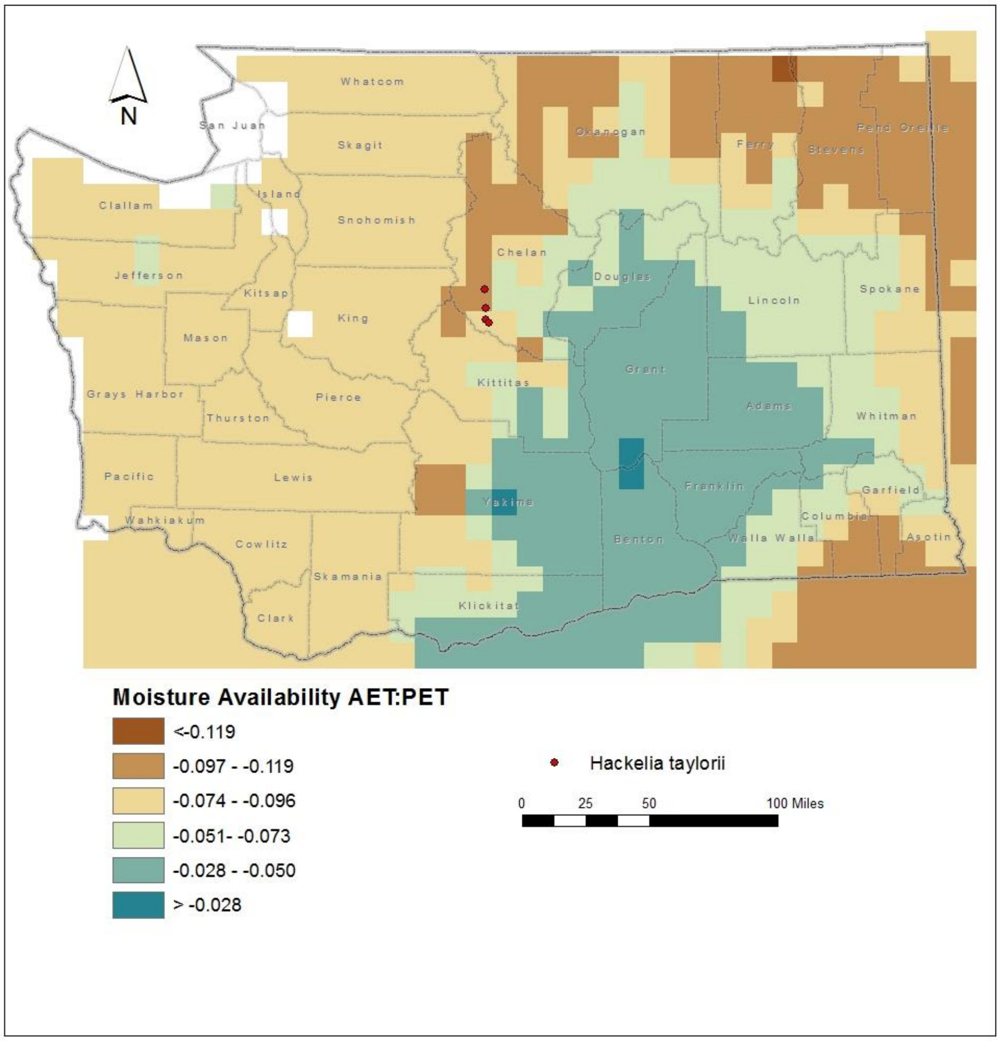

Figure 2. Exposure of *Hackelia taylorii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Hackelia taylorii* are found at 5900-7550 feet (1800-2300 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Hackelia taylorii* is found on steep, unstable, sparsely vegetated, subalpine to alpine sandy-gravely talus slopes derived from the Mount Stuart batholith (an intrusive gabbro, granite, and quartz diorite) (Camp and Gamon 2011, Fertig 2020, Harrod et al. 2013). This habitat is part of the Rocky Mountain Alpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). Individual populations occupy small areas and are separated from each other by 2-12 km (1.25-7.3 miles) of mostly unsuitable habitat. The natural heterogeneity of suitable habitat and its presence within a matrix of unsuitable environments creates a natural barrier to pollen and seed dispersal.

B2b. Anthropogenic barriers: Neutral.
The subalpine to alpine talus and cliff habitat of *Hackelia taylorii* in Washington is naturally dissected; human stressors that are dominant in more accessible lowland sites are far less prevalent here (Rocchio and Ramm-Granberg 2017).

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 taylorii produces 1-seeded nutlets with a rim of marginal prickles that facilitate dispersal on the fur or feathers of animals. These fruits could potentially travel more than 1 km if stuck to an animal. Observations of the closely related *Hackelia venusta* (which has similar fruits), suggest that most fruits are dropped close to the parent plant and may move downhill due to rock slides or erosion (Gamon 1997). Actual dispersal distance is probably less than 1 km in *H. taylorii*.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Hackelia taylorii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”). All of the known occurrences (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.

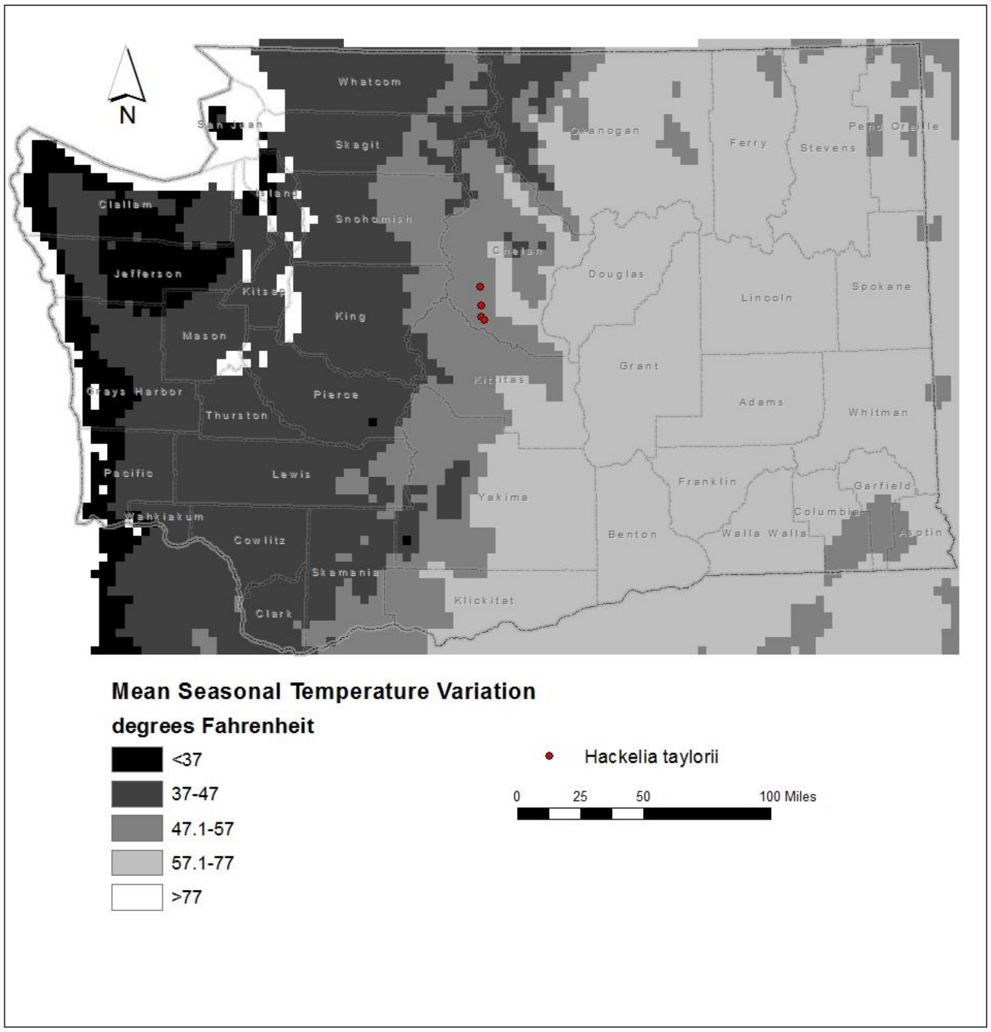

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Hackelia taylorii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The subalpine to alpine talus and cliff habitat of *Hackelia taylorii* is associated with cold temperatures during the growing season would have increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
All four of the known populations of *Hackelia taylorii* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 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.

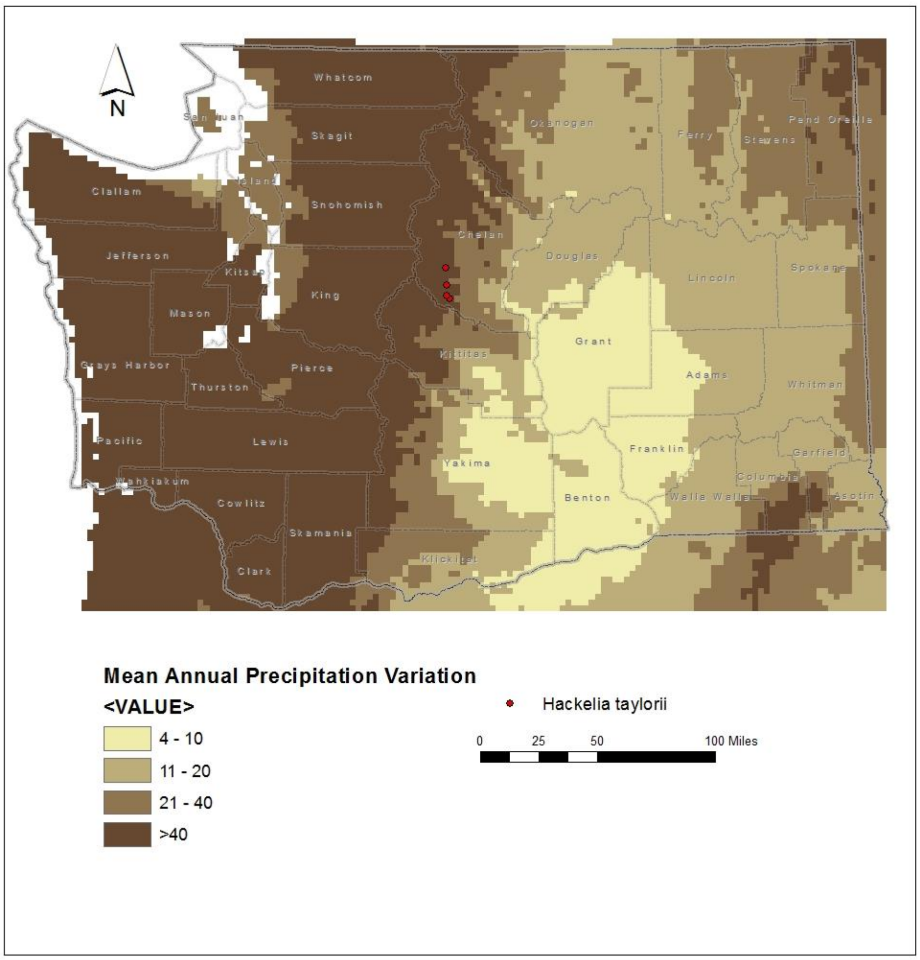

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Hackelia taylorii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
The subalpine to alpine rock talus and cliff habitat of *Hackelia taylorii* is not strongly associated with wetland habitats and scored as neutral (but see "Dependence on ice or snow-cover habitats" below).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Hackelia taylorii is found in unstable talus slopes and cliffs prone to rock fall. Arnett (2014) noted that one occurrence was nearly eliminated due to a large landslide. This sort of disturbance helps reduce competing vegetation cover. Under projected climate change, rock slide areas would become warmer and could potentially support more vegetation, ultimately creating more soil to stabilize slopes and alter the community structure to a subalpine turf community (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Hackelia taylorii* in Washington occur at high elevations in the subalpine and alpine zone and are largely dependent on precipitation or late-lying snowbanks for soil moisture. Increased summer temperatures or drought resulting from projected climate change would reduce the amount of moisture available during the growing season (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Hackelia taylorii is restricted to the Mount Stuart batholith, an intrusive gabbro, granite, and quartz diorite (Fertig 2020) and is found predominantly on steep slopes or cliffs.

C4a. Dependence on other species to generate required habitat: Neutral
The rock talus and cliff habitat occupied by *Hackelia taylorii* is maintained by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Hackelia venusta, the closest relative to *H. taylorii*, is capable of self pollination and outcrossing (Taylor 2008). The primary pollinators of *H. venusta* are generalist bees *Andrena nigrocaerulea* and *Protosmia rubifloris* and flies (*Eulonchus* and *Nicocles*) (Taylor 2008). These, or similar species, may also be the pollinators of *Hackelia taylorii*.

C4d. Dependence on other species for propagule dispersal: Somewhat Increase.
Hackelia taylori is dependent on small mammals or birds for long-distance dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known and the species does not appear to be significantly affected by herbivory.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Hackelia taylorii occurs in areas that are sparsely vegetated and has few native or introduced competitors under the current climate regime. Projected climate change could make its habitat more conducive for lower elevation meadow species to invade (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Somewhat Increase.
Hipkins et al. (2003) investigated isozyme variation between white and blue-flowered populations of *Hackelia venusta* (the blue-flowered phase is now recognized as *H. taylorii*) and related *Hackelia* species from Washington. They found average levels of genetic variability within the white-flowered ("true") *H. venusta* and somewhat lower variability in blue-flowered *H. taylorii* compared to *H. diffusa*, a more common species of central Washington. Hipkins et al. (2003) and Wendling and DeChaine (2011) found that isozyme and molecular ITS data did not show significant genetic differentiation between white and blue-flowered forms of *H. venusta*, though the two taxa are morphologically distinct and occur in different habitats (Harrod et al. 2013).

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Hackelia taylorii is presumed to be an outcrosser and pollinated by numerous species of bees and flies, suggesting that genetic variability should be average rangewide.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No change has been detected to date.

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

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Climate Change Vulnerability Index Report

Heterotheca oregona (Oregon goldenaster)

Date: 9April 2020

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	**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	75
	<3.9° F (2.2°C) warmer	25
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	6.25
	-0.028 to -0.050	6.25
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		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	
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 16 occurrences of *Heterotheca oregona* in Washington (75%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). The other four populations (25%) are from areas with a predicted temperature increase of <3.9˚ F.

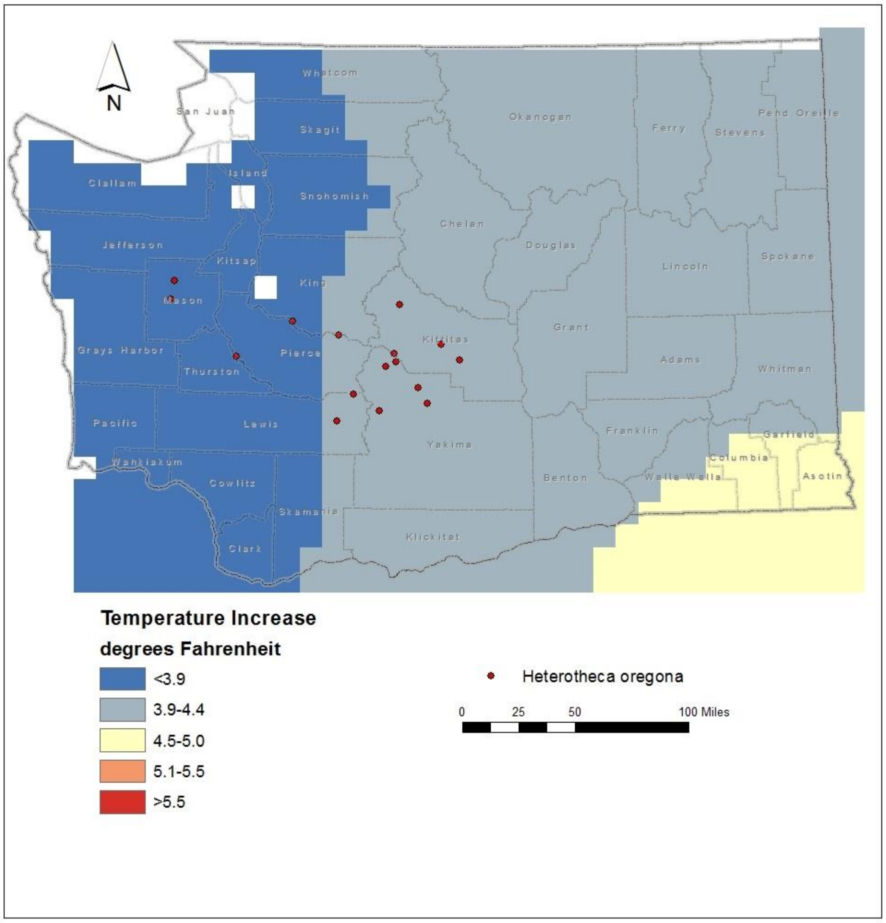

Figure 1. Exposure of *Heterotheca oregona* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Fourteen of the 16 occurrences of *Heterotheca oregona* (87.5%) 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 population (6.25%) is from an area with a projected decrease in the range of -0.051 to -0.073 and one other occurrence (6.25%) is from a site with a predicted decrease in available moisture of -0.028 to -0.050 (Figure 2).

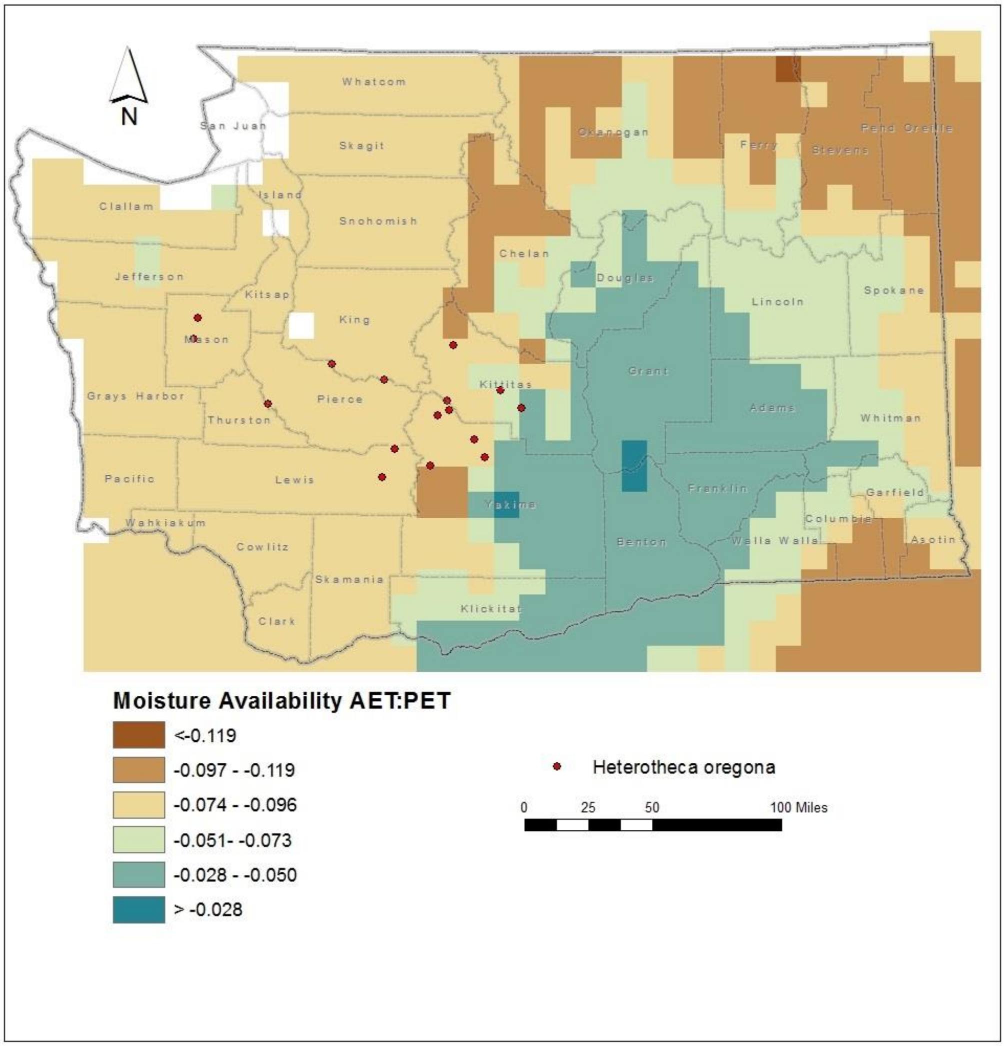

Figure 2. Exposure of *Heterotheca oregona* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Heterotheca oregona* are found at 90-2600 feet (30-800 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Heterotheca oregona* is found on riverbank terraces of smooth cobblestones and sand or gravel bars in sparsely vegetated openings with low shrubs, cottonwood saplings, and herbs amid more dense forest of Ponderosa pine or Douglas-fir (Camp and Gamon 2011, Fertig and Kleinknecht 2020). It is also occasionally found on steep gravel or sand bluffs above rivers and on gravelly roadsides. This habitat is an early seral component of the Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland ecological system (Rocchio and Crawford 2015). Washington populations are mostly restricted to small patches or narrow riparian strips separated from other populations by distances of 3-39 miles (5-63 km). The natural patchiness of the populations and large extents of unsuitable habitat between them creates a barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Heterotheca oregona* is naturally fragmented. Human impacts on the landscape of central and western Washington have exacerbated this condition, but overall are of less significance 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.
Heterotheca oregona produces numerous, flattened, single-seeded achenes topped by a double papppus of bristles that help transport the fruit by wind. Dispersal might also be possible by moving water. While many fruits fall close to their parent, some are capable of being dispersed more than 1 km.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Heterotheca oregona* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Ten of the 16 known occurrences in the state (62.5%) 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. 2006). Five occurrences (31.2%) are from areas that have had small (37-47˚F/20.8-26.3˚C) temperature variation over the same period and are at increased vulnerability. One population (6.3%) is from a site with average (57.1-77˚F/31.8-43.0˚C) temperature variation over the past 50 years (Table 3) and is at neutral risk from climate change (Young et al. 2016).

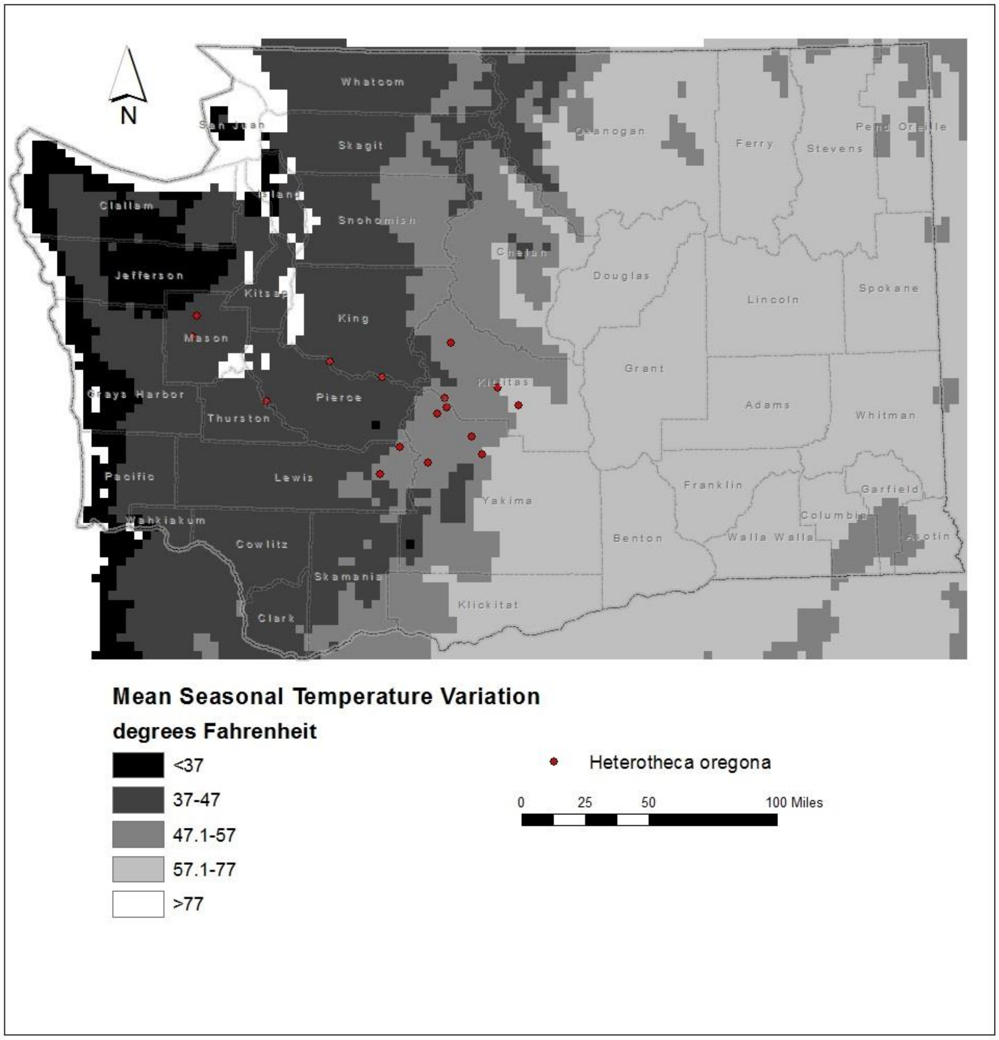

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Heterotheca oregona* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Most populations of *Heterotheca oregona* are found along foothills streams in areas of cold air drainage and would be at somewhat increased vulnerability to temperature changes associated with global warming.

C2bi. Historical hydrological niche: Neutral.
Thirteen of the 16 populations of *Heterotheca oregona* in Washington (81.3%) 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 occurrences are at neutral vulnerability to climate change. Two other populations (12.5%) have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation over the same period and are at somewhat increased vulnerability (Figure 4), while one occurrence (6.3%) has experienced small (4-10 inches/100-254 mm) precipitation variation and is at increased vulnerability.

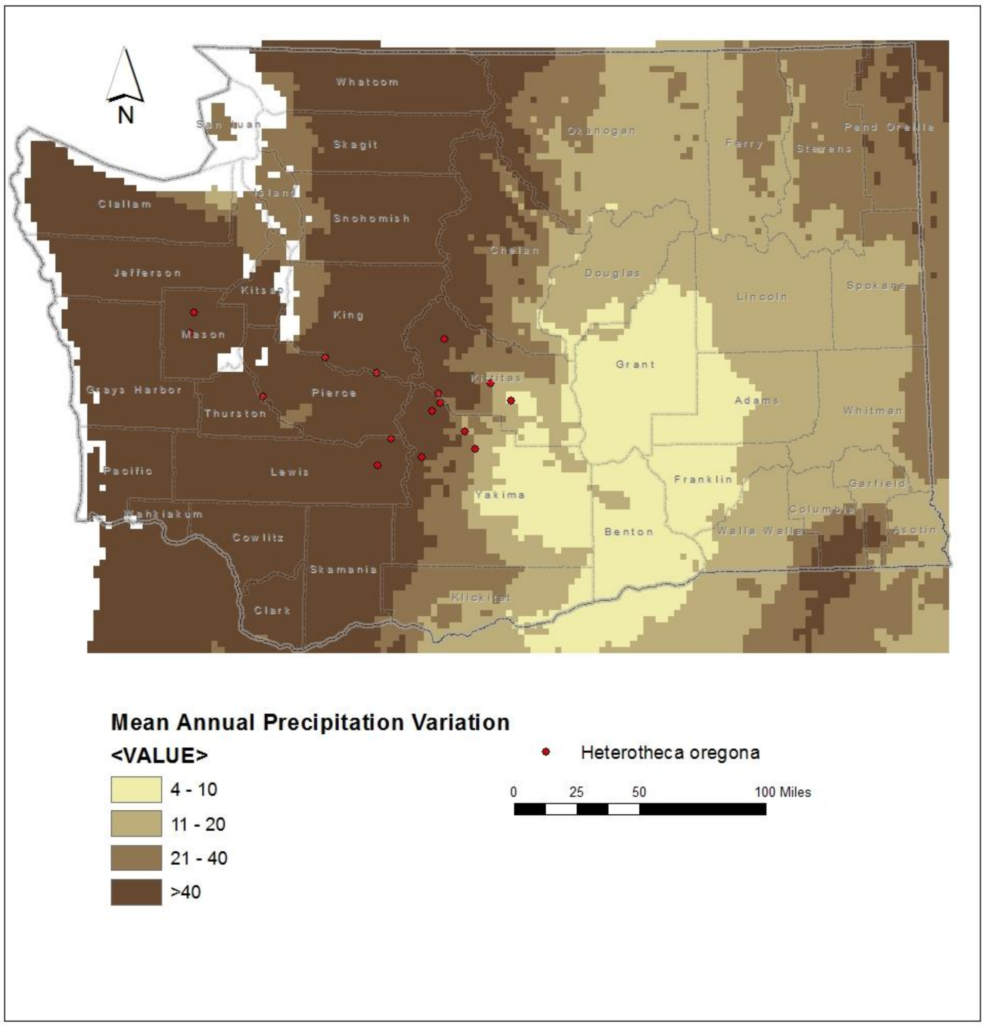

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Heterotheca oregona* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Heterotheca oregona populations occur along streams and rivers on low-lying cobblestone terraces that are seasonally flooded by meltwater. Changes in the timing of snowmelt or the amount of precipitation could make these sites drier in the future and subject to invasion of meadow or forest species (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Most populations of *Heterotheca oregona* in Washington occur on partly sand or cobble terraces along streams and rivers and are maintained by late winter or early spring flooding. These habitats are vulnerable to changes in the timing and magnitude of floods, which in turn is influenced by snowpack and timing of snowmelt. All of these factors are likely to be affected by warming temperatures (Rocchio and Ramm-Granberg 2017). A reduction in disturbance from flooding could result in increased tree cover or replacement of current riparian vegetation with species adapted to drier conditions.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Heterotheca oregona* in Washington occur in the lower montane and foothill zones of mountains and receive relatively low snowfall, but are tied to river systems fed by deeper snowfall at their headwaters at higher elevations. Reduction in snowpack or changes in the timing of snowmelt will impact flooding in the late winter and early spring that is important to maintain the plant's partially open river terrace habitat (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Populations of *Heterotheca oregona* in Washington occur primarily on Quaternary alluvium, glacial till, and landslide deposits. These features are widespread along smaller rivers and streams in the foothills of mountains across the state.

C4a. Dependence on other species to generate required habitat: Neutral.
The partly open sand and cobble terrace habitat occupied by *Heterotheca oregona* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Heterotheca oregona flowers are pollinated by a variety of insects including bees, wasps, and butterflies and reproduction is not limited by pollinator availability.

C4d. Dependence on other species for propagule dispersal: Neutral.
The small fruits of *Heterotheca oregona* have a feathery pappus and can be dispersed relatively long distances by wind or water. The species is not dependent on animals for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is not a preferred forage plant and does not appear to be adversely impacted by grazing.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
In the absence of annual flooding, competition from other plant species could become a significant threat to *Heterotheca oregona* populations along floodplain terraces (Fertig and Kleinknecht 2020).

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 in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Heterotheca oregona reproduces sexually and is an out-crosser. Genetic diversity is presumed to be average.

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 this species within Washington has not changed significantly 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.

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.

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Climate Change Vulnerability Index Report

Impatiens noli-tangere (Western jewelweed)

Date: 13 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G4G5/S1

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	14
	<3.9° F (2.2°C) warmer	86
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		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		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: Six of the seven occurrences of *Impatiens noli-tangere* in Washington (86%) occur in areas with a projected temperature increase of <3.9˚ F (Figure 1). One other population (excluding an historical record from Spokane County that has been found to be misidentified) occurs in an area with a predicted temperature increase of 3.9-4.4˚ F.

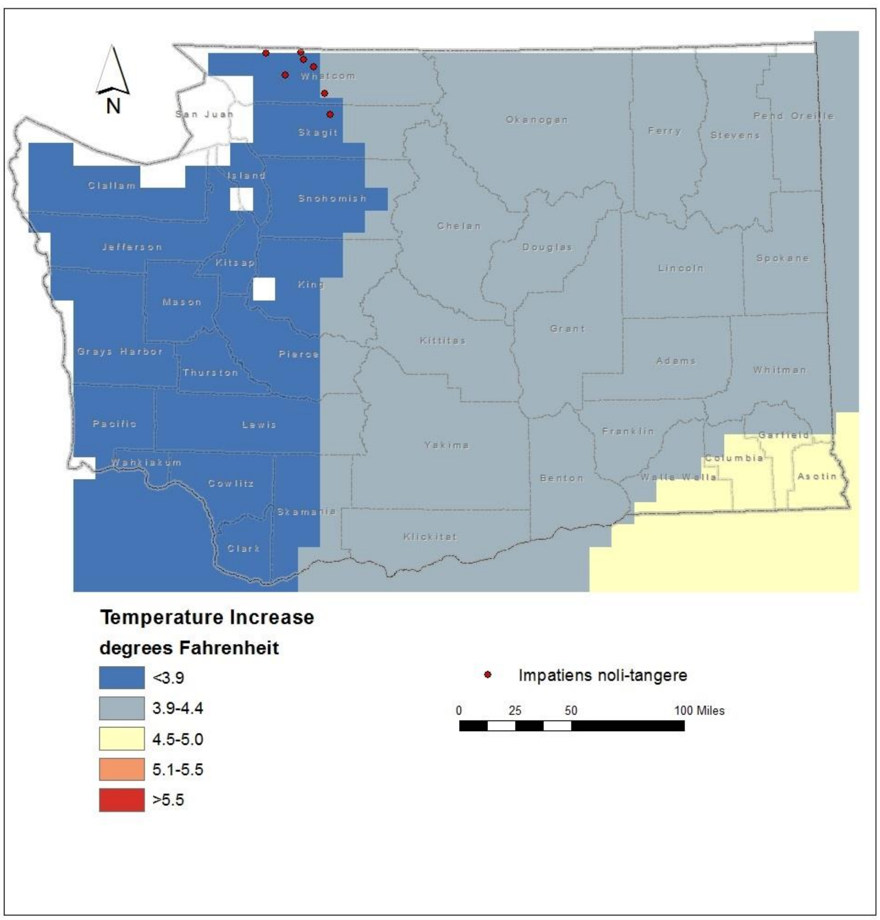

Figure 1. Exposure of *Impatiens noli-tangere* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All seven of the Washington occurrences of *Impatiens noli-tangere* (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).

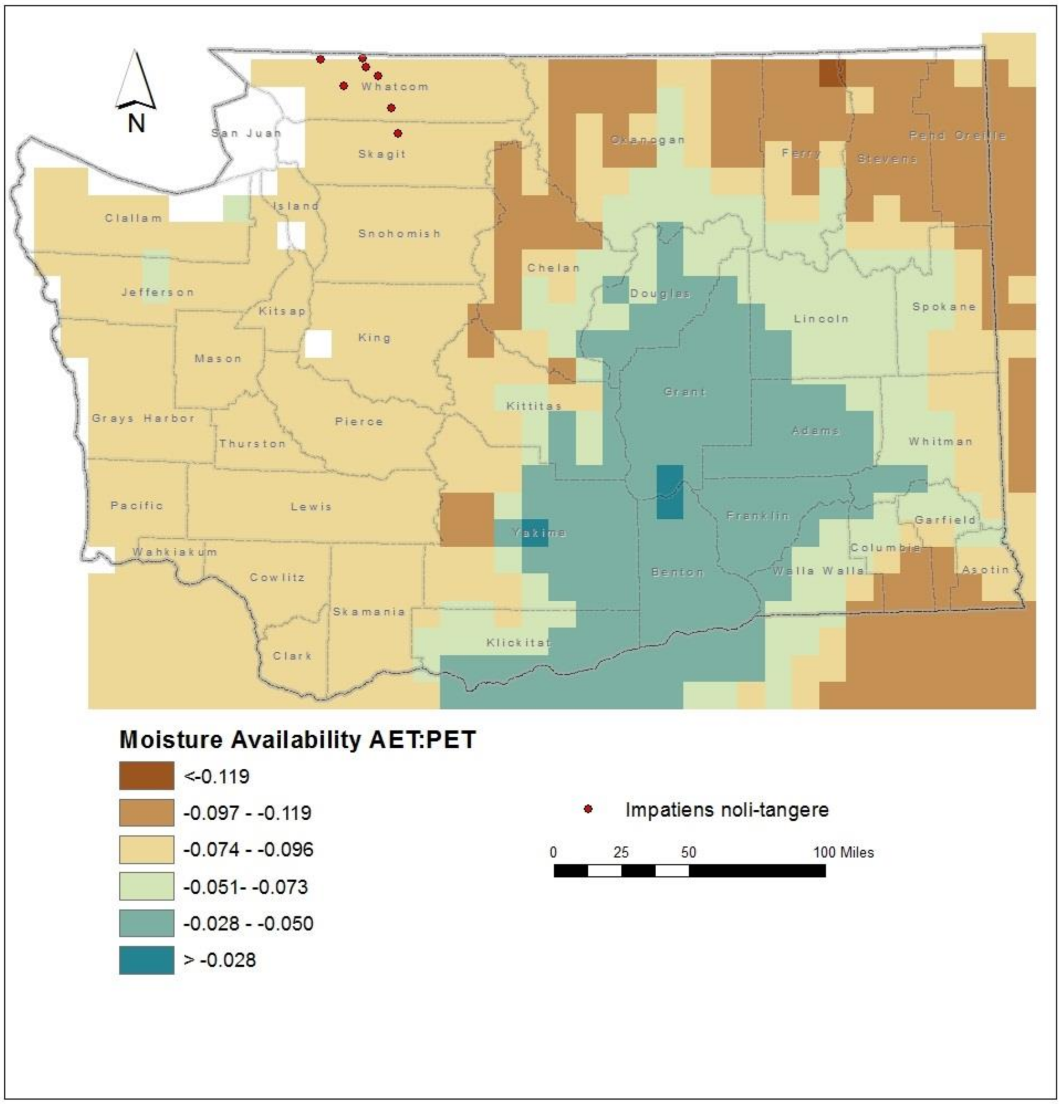

Figure 2. Exposure of *Impatiens noli-tangere* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Impatiens noli-tangere* are found at 400-1700 feet (120-520 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Impatiens noli-tangere* is found in shady, moist riparian forests and ditch banks (Camp and Gamon 2011, WNHP records). This habitat is a component of the North Pacific Lowland Riparian Forest and Shrubland ecological system (Rocchio and Crawford 2015). Individual populations occupy small areas and are separated from each other by 6-30 km (4-19 miles). This is a relatively widespread habitat type, so the discontinuities in distribution might be the result of insufficient survey effort or competition from related species. Based on available information, this factor is scored as neutral.

B2b. Anthropogenic barriers: Neutral.
The range of *Impatiens noli-tangere* in Washington is mostly in the foothills of the North Cascades and is moderately bisected by roads, forestry activities, and human habitations. Whether these anthropogenic impacts create a significant barrier for dispersal of this species is not well established.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Impatiens noli-tangere produces many-seeded fruits that are released explosively for distances of 2-3 meters by sudden dehiscence of the fruit wall (Hatcher 2003). Seeds produced by plants in streamside habitats may be secondarily transported by flowing water (Hatcher 2003). In Europe, *I. noli-tangere* often grows in association with ant mounds, suggesting that ants may help disperse seeds (Gorb and Gorb 2003). Hiratsuka and Inoue (1988) found that fruits produced by chasmogamous (open) flowers dispersed over larger distances than those from cleistogamous (closed) flowers. Average dispersal distances are probably relatively short, however (less than 100 meters).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Impatiens noli-tangere* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 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 vulnerability to climate change.

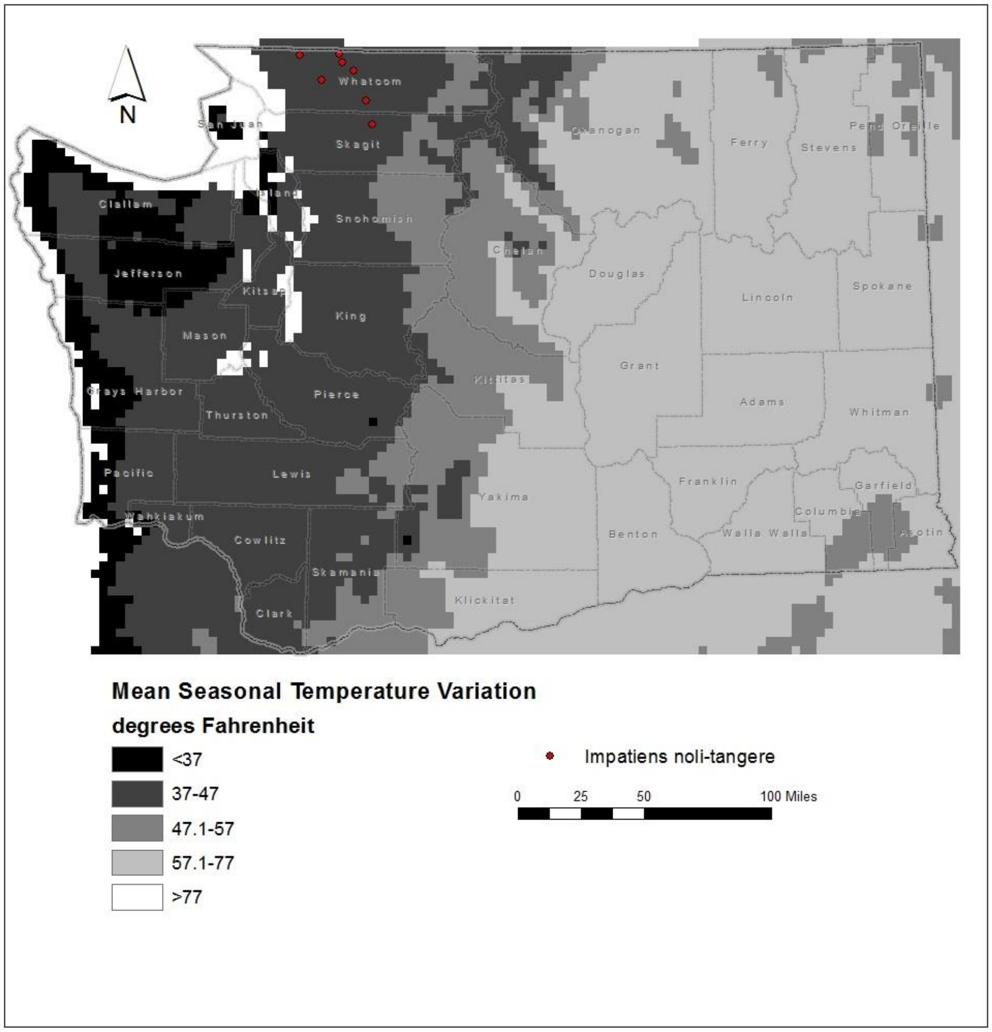

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Impatiens noli-tangere* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The foothills riparian forest habitat of *Impatiens noli-tangere* is associated with cool, shaded conditions during the growing season and would be potentially impacted by increased drought that would affect the width of riparian habitat (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
All seven of the known populations of *Impatiens noli-tangere* 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 occurrences are at neutral vulnerability from climate change.

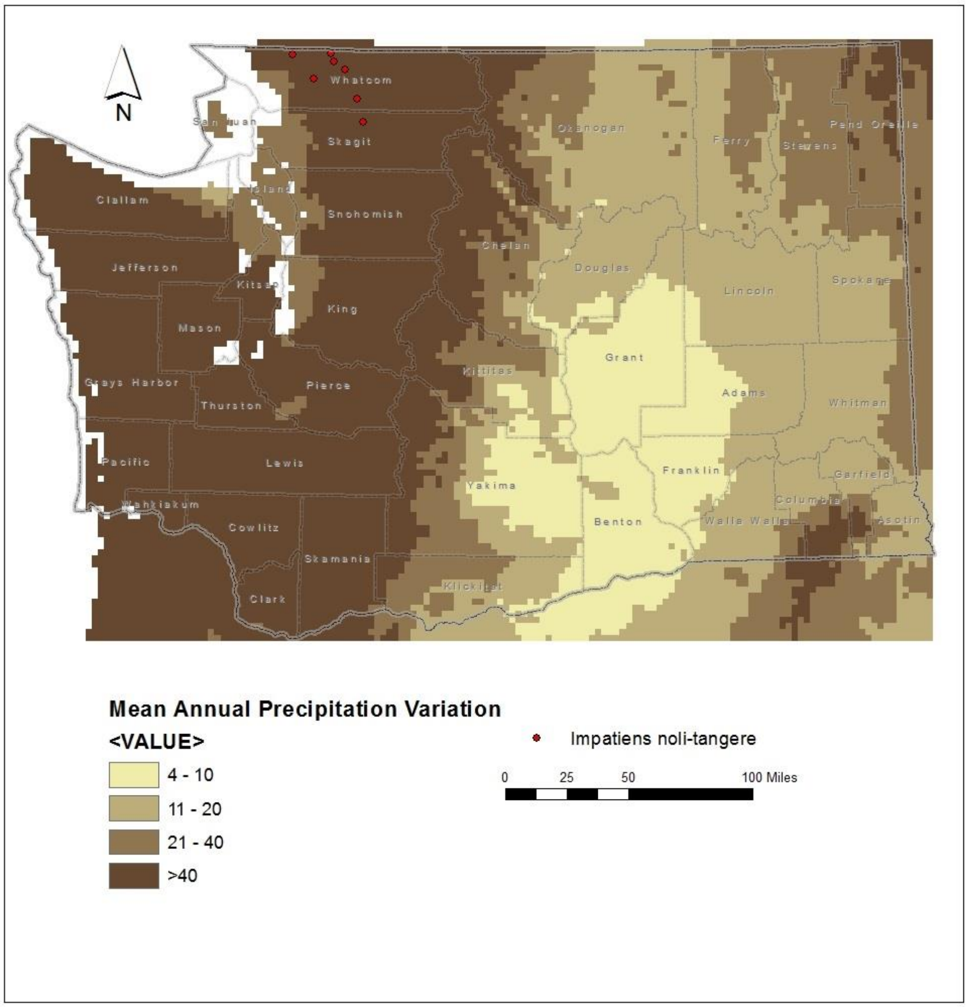

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Impatiens noli-tangere* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
As an annual species adapted to cool, moist, forested wetlands, *Impatiens noli-tangere* is somewhat vulnerable to seasonal fluctuations or long-term decreases in moisture availability. Changes in the onset and intensity of annual flooding from melted snowpack could impact the

condition of montane riparian habitats occupied by this species (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Impatiens noli-tangere is not dependent on periodic disturbances to maintain its riparian forest habitat. The species could, however, be detrimentally affected by loss of forest canopy due to wildfire, or long-term drought associated with potential climate change (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Impatiens noli-tangere* in Washington occur in lower montane riparian forest habitats that could be negatively impacted by earlier flooding due to decreased snowpack and reduction in base flow levels in summer (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Impatiens noli-tangere is found on a variety of Pleistocene glacial and tertiary sedimentary formations that are relatively widespread in northwestern Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Impatiens noli-tangere* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Hatcher (2003) observed that chasmogamous flowers of *Impatiens noli-tangere* in Europe are pollinated by at least 11 insect species. These include long-tongued bees (*Bombus*, Halictid bees) as well as vespid wasps and syrphid flies. Tokuda et al. (2015) found that *I. noli-tangere* and *I. textori* compete for the same pool of pollinators in forests in Japan and this competition can lead to reduced seed production. This species can also self-pollinate within unopened cleistogamous flowers.

C4d. Dependence on other species for propagule dispersal: Neutral.
Initial dispersal of seeds is done by mechanical means of the fruit pod itself (explosive discharge of the fruit wall, often triggered by light touch – thus the common name 'touch-me-not'). Secondary dispersal may be from water or potentially by ants (Gorb and Gorb 2003). Overall importance of animal dispersers is low and the factor is ranked neutral.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is edible to livestock and deer, though this does not appear to be a limiting factor to its persistence.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
In Europe, *Impatiens noli-tangere* can be sensitive to competition from other vegetation. Plants in open areas may respond favorably to increased light, but are impacted by drought (Hatcher 2003).

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

Does not require an interspecific interaction.

C5a. Measured genetic variation: Unknown.
Despite numerous studies on the pollination and dispersal of *Impatiens noli-tangere*, there appears to be limited data on its genetic diversity. Masuda and Yahara (1994) report that genetic diversity between populations may be high based on research in Japan where phenotypic differences were maintained in common garden trials.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Impatiens noli-tangere produces showy, open chasmogamous flowers that are functionally unisexual and self-sterile due to maturation of the anthers before the stigmas are receptive for pollen. Such a reproductive system promotes outcrossing and should result in relatively high genetic variability. Under stressful environmental conditions or late in the flowering season, *I. noli-tangere* can also produce cleistogamous flowers which do not open and are entirely self-pollinated. Cleistogamy ensures that some seed will be produced each year, which is important for an annual species that does not produce a large seed bank (Hatcher 2003).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No change has been detected to date.

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

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Climate Change Vulnerability Index Report

Juncus howellii (Howell's rush)

Date: 13 February 2020

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	**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
	-0.074 to - 0.096	67
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral/Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		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		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: All three of the known occurrences of *Juncus howellii* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). Several unconfirmed populations have been reported from the Blue Mountains of SE Washington,

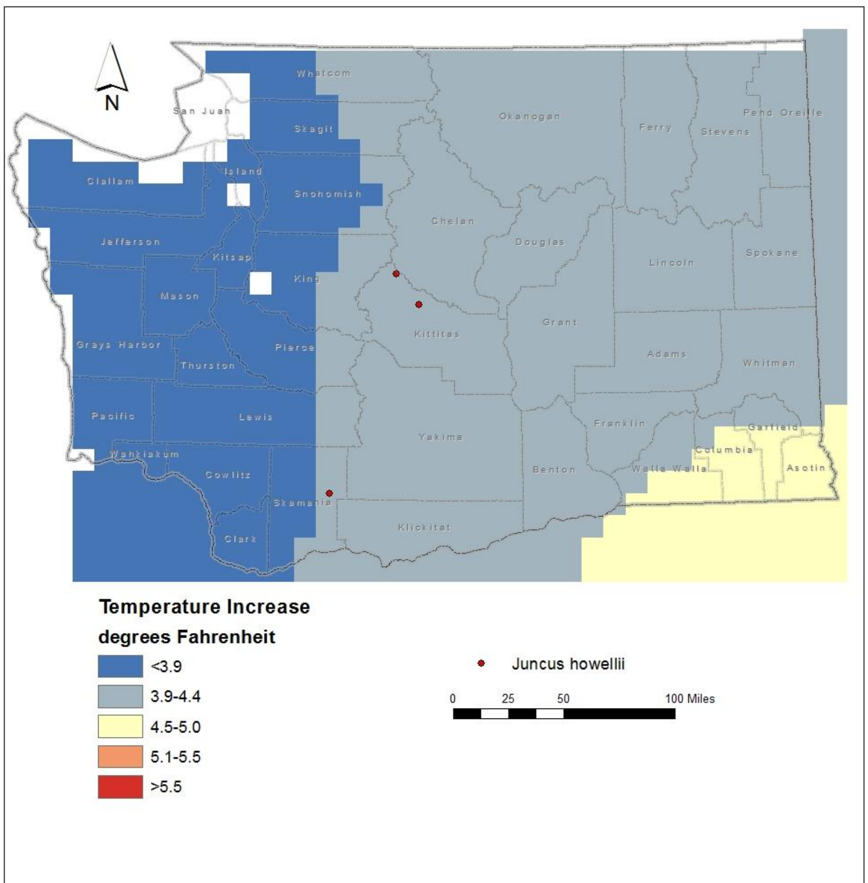

Figure 1. Exposure of *Juncus howellii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

within the area identified as having a projected temperature increase of 4.5-5.0˚ F, but are not included in this assessment. Other unverified (and probably erroneous) reports from Pierce and Whitman counties have also been excluded.

A2. Hamon AET:PET Moisture Metric: Two of the three confirmed Washington occurrences of *Juncus howellii* (67%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 to -0.096 (Figure 2). The other 33% of occurrences are in areas with projected decrease of -0.097 to -0.119. If accepted, populations from the Blue Mountains would fall in the latter range as well.

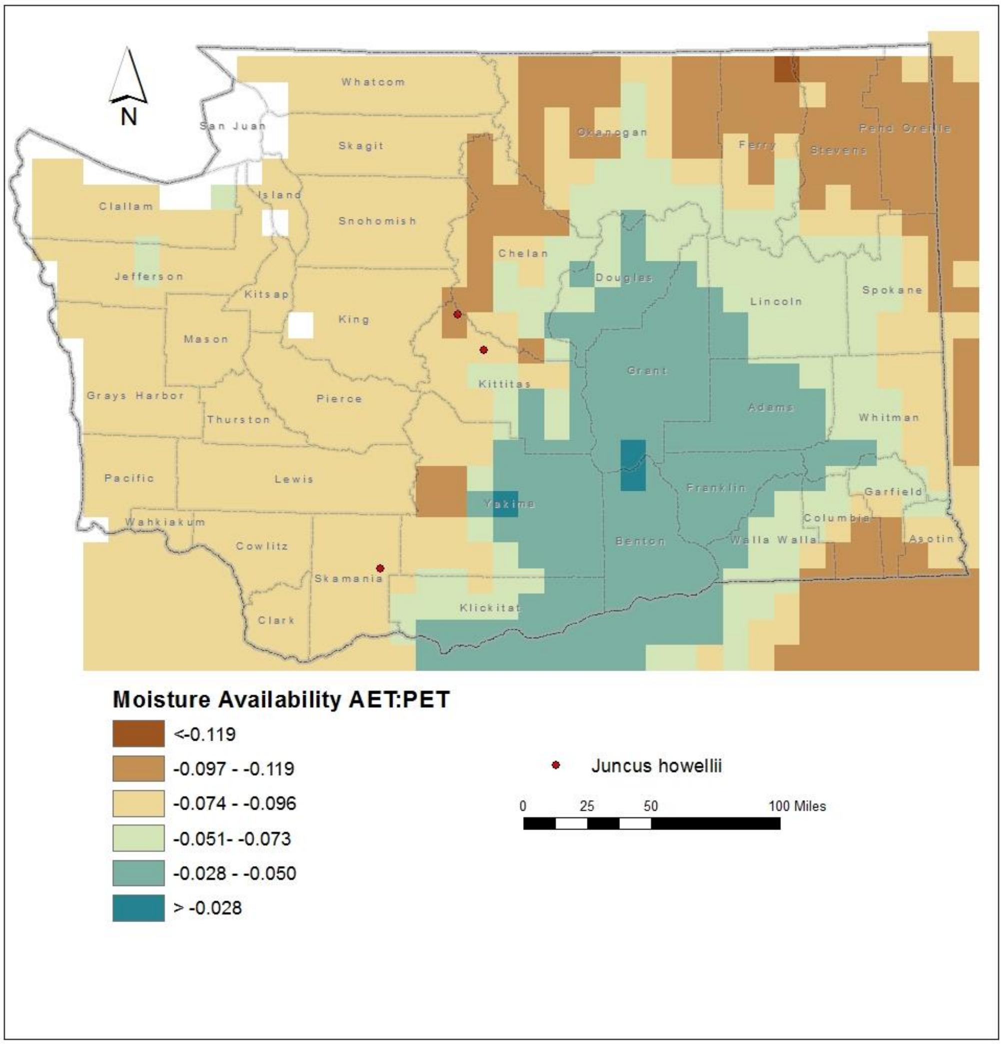

Figure 2. Exposure of *Juncus howellii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Juncus howellii* are found at 2590-3500 feet (790-1070 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral/Somewhat Increase.
In Washington, *Juncus howellii* is found in wet meadows, moist boulder areas below basalt cliffs, and sunny, damp roadsides and narrow riparian areas (Fertig and Kleinknecht 2020). These sites are a component of the Temperate Pacific Subalpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). Washington populations are separated by 17-94 miles (28-150 km). The large gap between known occurrences may be due to incomplete sampling, significant dispersal barriers, or site-specific adaptations.

B2b. Anthropogenic barriers: Neutral.
The wet meadow and riparian habitat of *Juncus howellii* is associated with mountainous areas of Washington, where the human footprint is less extensive than in lowland areas.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Juncus howellii produces dry capsules containing numerous, minute seeds with short tail-like appendages at both tips. These seeds are small enough to be dispersed short distances through the air, or longer distances by flowing water or attached to feathers or muddy feet of waterfowl. While many seeds may 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: Somewhat Increase.
Figure 3 depicts the distribution of *Juncus howellii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Two of the three confirmed occurrences (67%) 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. One of three occurrences (33%) is found in an area with small temperature variation (37-47˚F/20.8-26.3˚C) in the same period and is at increased vulnerability. This factor is scored as Somewhat Increase because the majority of occurrences fall in this category.

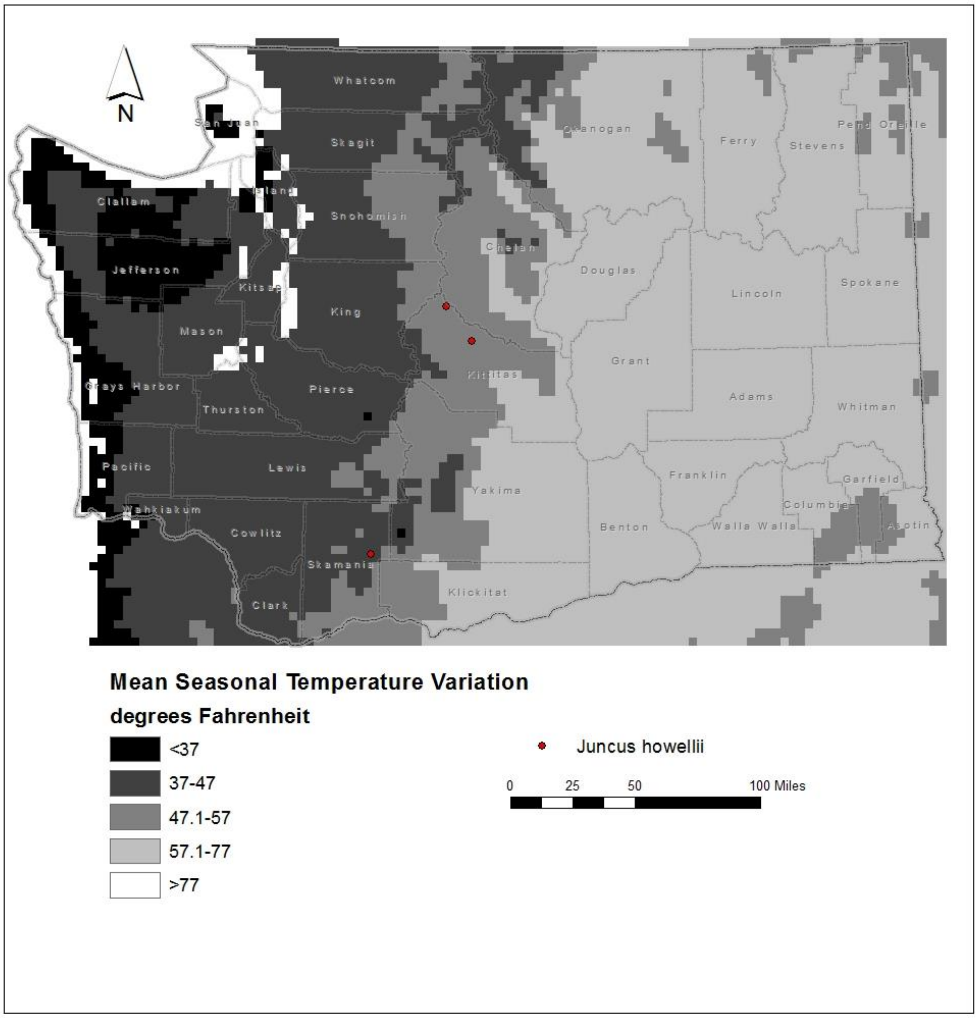

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Juncus howellii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The lower montane wetland habitat of *Juncus howellii* is associated with cool temperatures during the growing season and would be vulnerable to hotter temperatures predicted through climate change. Increased summer drought and increased susceptibility to wildfire would make wet meadow communities prone to shifts in species composition towards drier habitat types (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
All three confirmed populations of *Juncus howellii* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 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.

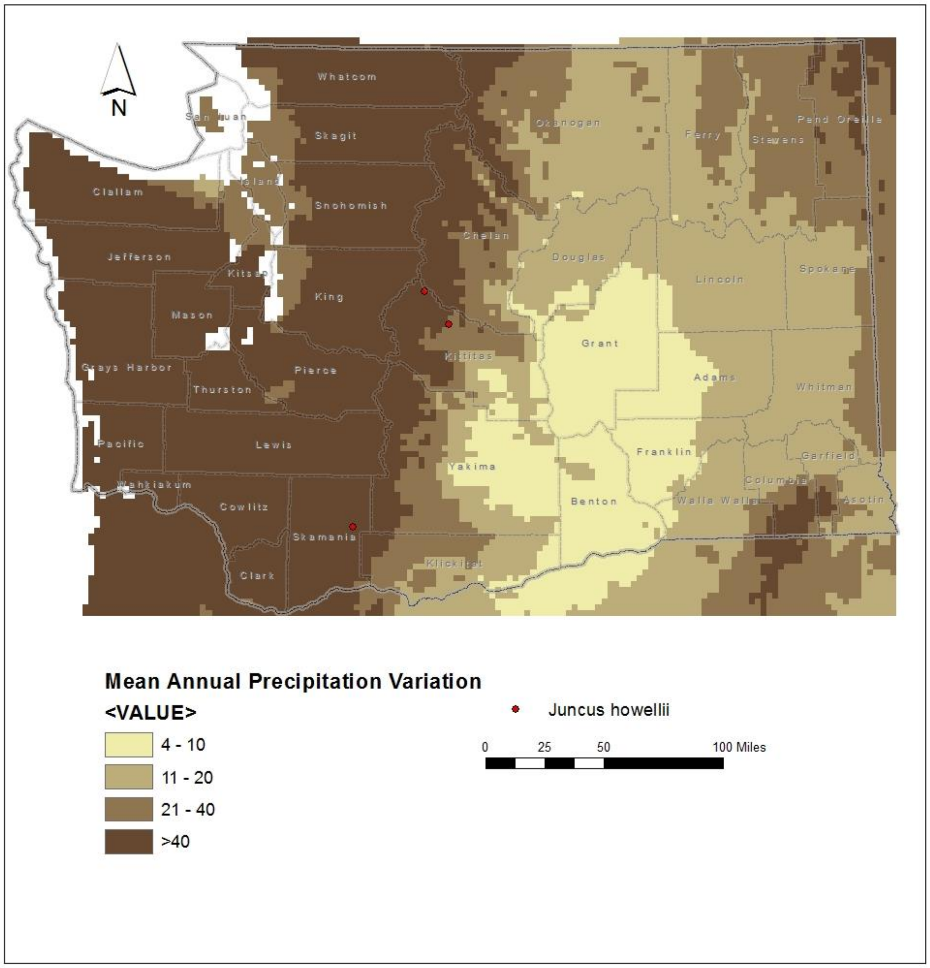

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Juncus howellii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The wet meadow and narrow streamside habitat of *Juncus howellii* may be impacted by shifts in timing and amount of precipitation, resulting in lowered stream flows and increased drought.

This could result in invasion of woody shrubs and trees or increased competition with dry meadow or invasive plant species (Rocchio and Ramm-Granberg 2017). See also "Dependence on ice or snow-cover habitats" below.

C2c. Dependence on a specific disturbance regime: Neutral.
Juncus howellii is found in moist meadows and narrow riparian corridors, with one occurrence also reported from a moist roadside. The disturbance from the roadside may be less critical for its presence than the open canopy created by the road. This species does not appear to be disturbance-dependent for its habitat and is scored as neutral.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Juncus howellii* in Washington occur in wet meadows and narrow streamsides in mountainous areas that may be dependent on late-lying snow for groundwater recharge, especially when droughty conditions arise in summer (Rocchio and Ramm-Granberg 2017). Reduction in the amount of snowpack, or changes in snowmelt patterns could make these habitats more drought-prone and less suitable for *J. howellii*.

C3. Restricted to uncommon landscape/geological features: Neutral.
Juncus howellii occurrences are not associated with any unusual geologic substrate or land form.

C4a. Dependence on other species to generate required habitat: Neutral
The wet meadow and riparian habitat occupied by *Juncus howellii* is maintained by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Juncus howellii, 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 howellii seeds are small and have tiny tail-like appendages for dispersal by air, water, or on feathers 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 howellii* is edible for wildlife and grazing is cited as a potential threat (Fertig and Kleinknecht 2020). Whether climate change would exacerbate these threats is not known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Projected climate change could make montane wet meadow habitats more susceptible to drought and invasion by dry meadow species (native and introduced) that could increase 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.
Data are not available on the genetic diversity of this species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Juncus howellii is presumed to be an outcrosser and primarily wind pollinated suggesting that genetic variability should be average to high rangewide. Washington populations are at the northern edge of the species' range and might have lower total diversity due to founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No change has been detected to date.

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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Kalmia procumbens (*Loiseluria procumbens*; Alpine azalea)

Date: 14 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G5/SH (formerly S1)

Index Result: Extremely Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Greatly 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		Somewhat Increase
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: Both of the known occurrences of *Kalmia procumbens* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

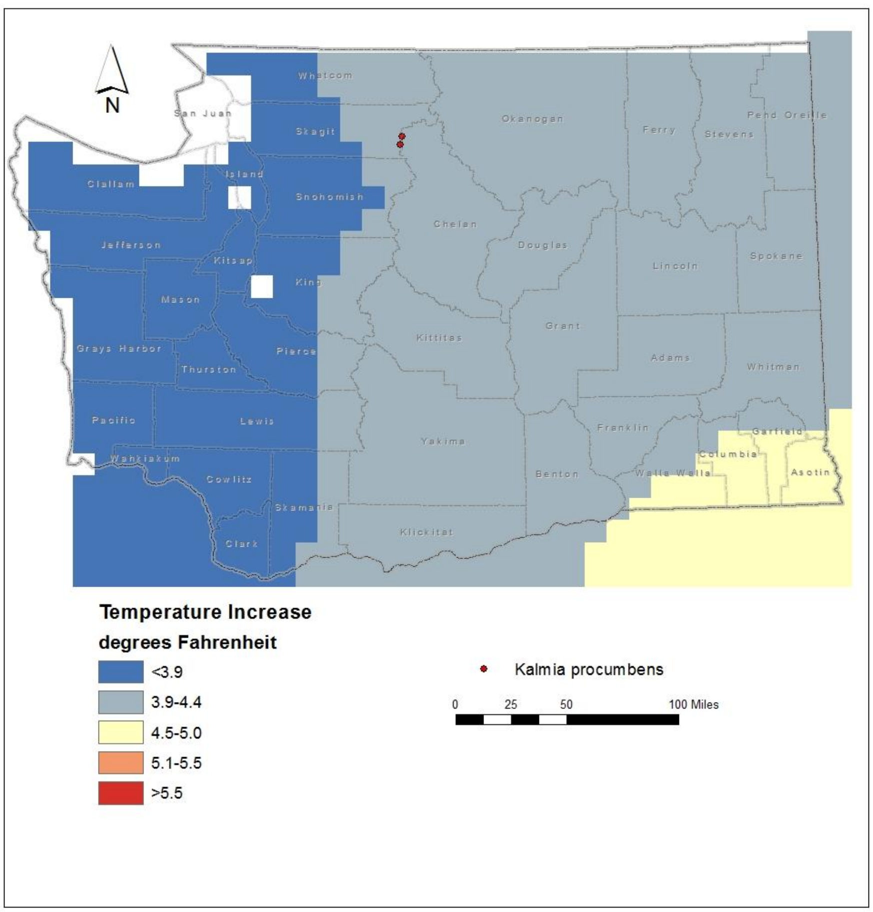

Figure 1. Exposure of *Kalmia procumbens* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The two occurrences of *Kalmia procumbens* (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).

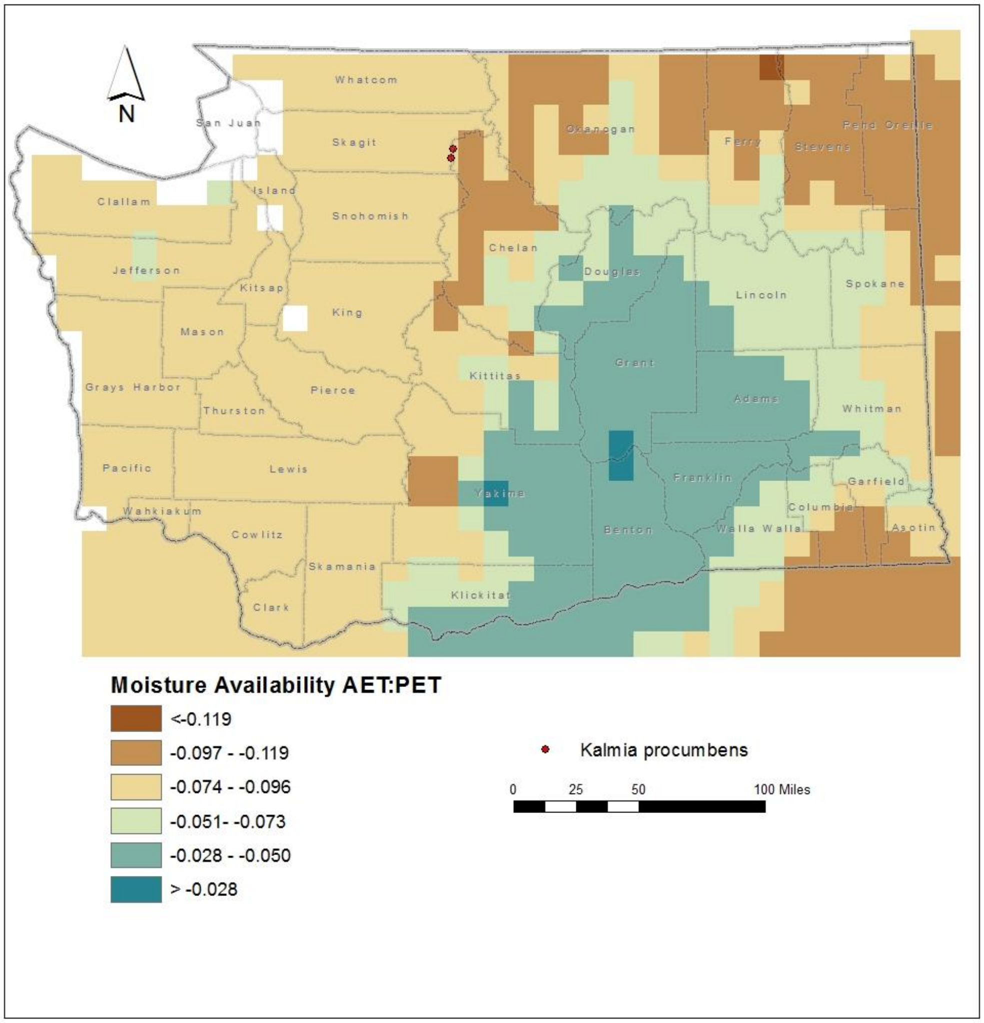

Figure 2. Exposure of *Kalmia procumbens* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Kalmia procumbens* are found at 6100-6550 feet (1800-2000 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Kalmia procumbens* is found in cold, subalpine or alpine heath tundra vegetation often near lakeshores (Camp and Gamon 2011, Hitchcock and Cronquist 2018, WNHP records). This habitat is intermediate between the Temperate Pacific Subalpine-Montane Wet Meadow and North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow ecological systems (Rocchio and Crawford 2015). Individual populations occupy small areas and are separated by 6 km (3.7 miles). Although relatively widespread in the Cascades, this habitat type is naturally discontinuous, with montane valleys and lowlands presenting a natural barrier to gene flow.

B2b. Anthropogenic barriers: Neutral.
The range of *Kalmia procumbens* in Washington is in the subalpine/alpine ecotone in the Northern Cascades along the Chelan/Skagit county line. This area receives little impact from human activities other than seasonal recreation.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Kalmia procumbens produces dry, capsule fruits containing 100-150 tiny, winged seeds. Seeds are released passively and are probably dispersed by wind. Average distances may be relatively short, but a small fraction of seed could disperse over hundreds of meters. Typical dispersal distance is probably less than 1 km, so this factor is scored as 'somewhat increase' following Young et al. (2016).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Kalmia procumbens* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Both of the known historical 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 vulnerability to climate change.

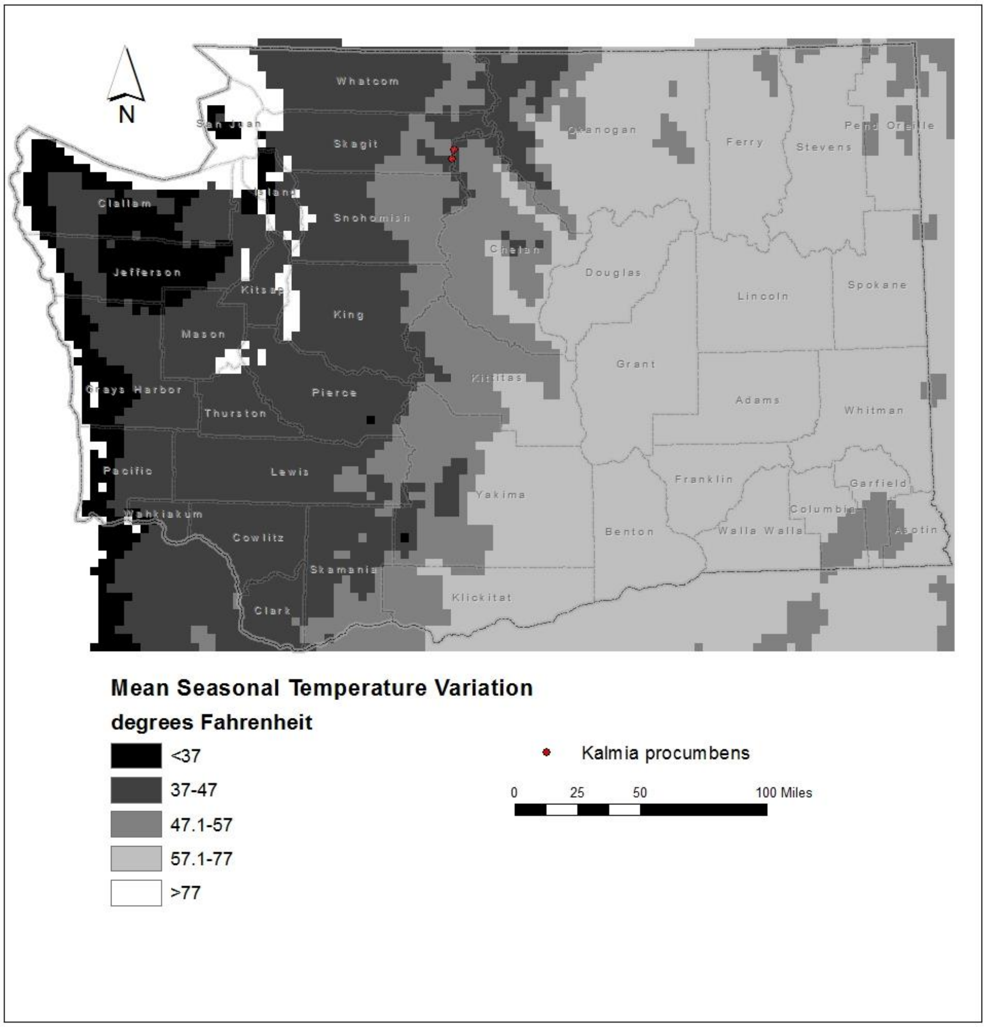

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Kalmia procumbens* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The subalpine/alpine heath habitat of *Kalmia procumbens* is associated with cold air drainage during the growing season and would have increased vulnerability to higher temperatures resulting from climate change.

C2bi. Historical hydrological niche: Neutral.
All of the historical populations of *Kalmia procumbens* 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 occurrences are at Neutral vulnerability from climate change.

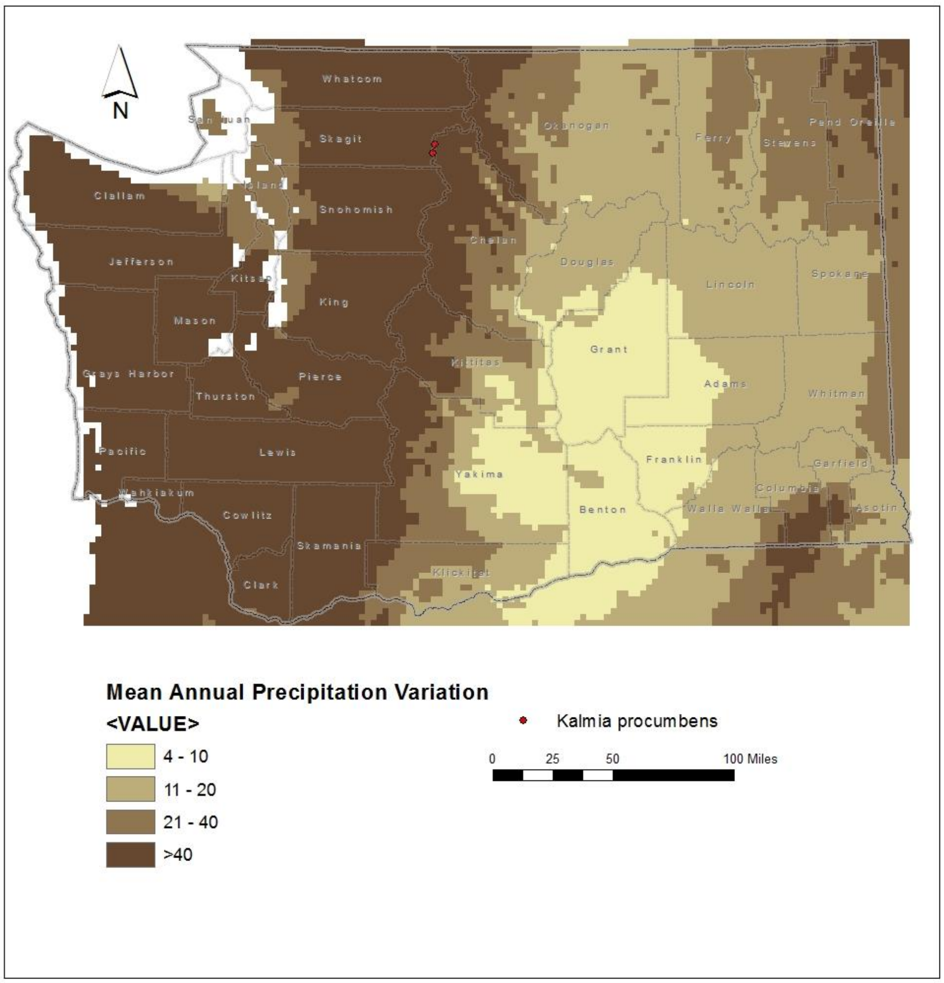

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Kalmia procumbens* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a strongly seasonal hydrologic regime or specific wetland habitats (but see “Dependence on ice or snow-cover habitats” below).

C2c. Dependence on a specific disturbance regime: Neutral.
Kalmia procumbens is not dependent on periodic disturbances to maintain its subalpine/alpine heath habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased snowpack that might favor conversion of this habitat to forest or meadows (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Greatly Increase.
The populations of *Kalmia procumbens* in Washington occur at the subalpine/alpine ecotone in heath-dominated habitats near small lakes. These sites are highly dependent on moisture from late-lying snowbanks (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow or timing of snowmelt could lead to shifts in the dominance of herbaceous species or invasion of trees or shrubs.

C3. Restricted to uncommon landscape/geological features: Neutral.
Kalmia procumbens is found on outcrops of Triassic-age gneiss, which is relatively widespread in the North Cascades Range.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Kalmia procumbens* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Gracie (2020) notes that the primary pollinators of *Kalmia procumbens* are bees. In Europe, pollination has also been recorded by flies and butterflies. *Kalmia procumbens* is atypical in the genus in not having the ripe anthers held under tension in small pockets in the corolla tube and triggered to release pollen explosively when an insect steps on the spring-loaded filaments. The diversity of available pollinators is poorly known in Washington, but is assumed to be broad enough to warrant "neutral" designation.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds are released passively by wind when the dry capsule fruits are mature and split open.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is low-growing and not readily grazed by livestock.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Kalmia procumbens can be sensitive to competition from other vegetation. Washington populations are sparse and difficult to observe amid dense patches of *Vaccinium deliciosum* and other heath species (Mary Fries, 1982 letter in WNHP files). Climate change is likely to increase competition from meadow species or invasive trees and shrubs if subalpine/alpine heath sites become drier or have reduced 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: Somewhat Increase.
Ikeda et al. (2017) examined the range-wide genetic diversity of *Kalmia procumbens* from northern Europe, NE Asia, Alaska, northern Canada, and the northeastern US to test hypotheses on the post-Pleistocene spread of this circumboreal arctic-alpine species. They found genetic differentiation between these population centers and evidence for secondary diversification between core arctic populations and outlying alpine ones. It is likely that the Washington occurrences, being at the southern periphery of the species range in western North America, have a reduced genome due to founder effects or limited gene flow with neighboring occurrences in southern British Columbia. Data are not available on the actual genetic diversity of Washington populations however, as neither has been relocated since 1963.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Kalmia procumbens produces showy, insect-pollinated flowers and is a functional out-crosser due to the maturation of the stigmas before the anthers (Gracie 2020).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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: Unknown.
Kalmia procumbens has not been relocated in Washington (despite at least three attempts) since first being discovered in the state in 1963. It is possible that the species may be extirpated, or has avoided detection at other sites. Whether its present status is the result of ongoing 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

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Climate Change Vulnerability Index Report

Lomatium tuberosum (Hoover's desert-parsley)

Date: 10 April 2020

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	**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	13.3
	-0.028 to -0.050	86.7
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		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	
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: All 15 of the occurrences of *Lomatium tuberosum* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

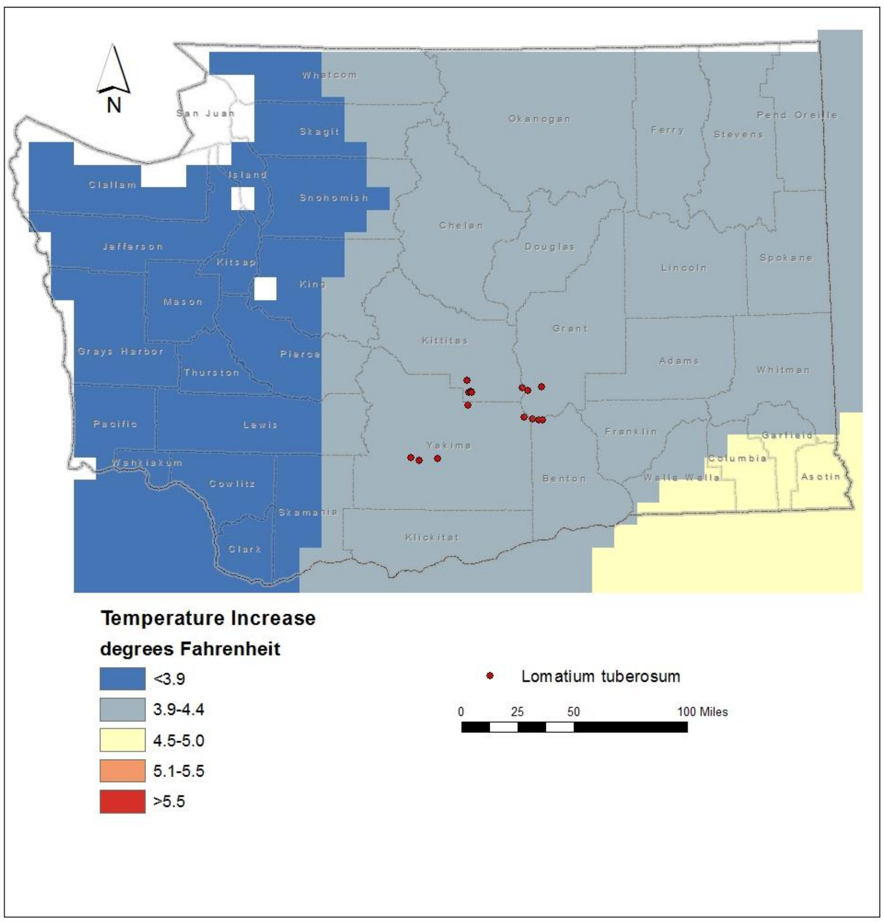

Figure 1. Exposure of *Lomatium tuberosum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Thirteen of the 15 occurrences of *Lomatium tuberosum* (86.7%) 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). Two populations (13.3%) are from areas with a projected decrease in the range of -0.051 to -0.073.

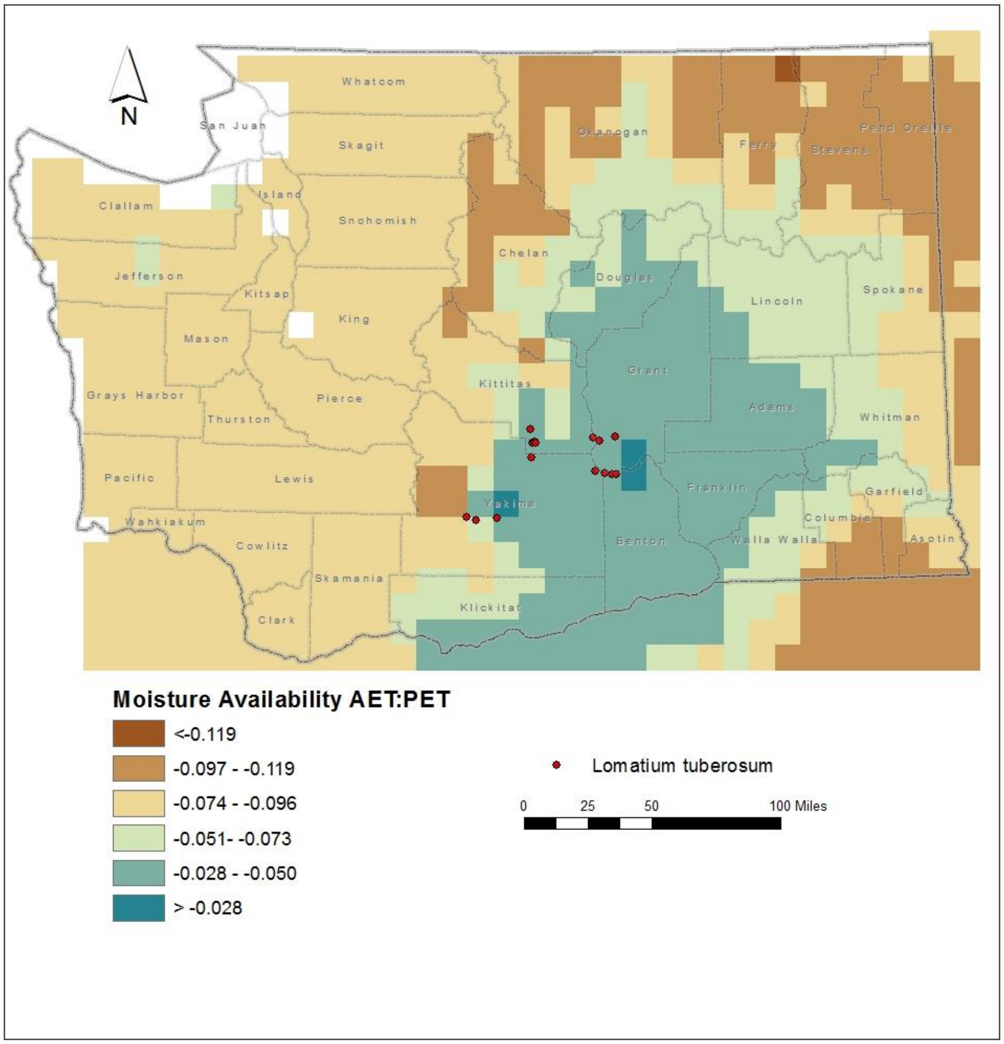

Figure 2. Exposure of *Lomatium tuberosum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Lomatium tuberosum* are found at 460-4000 feet (140-1220 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Lomatium tuberosum* occurs among loose basalt talus on slopes and ridgetops in sagebrush steppe dominated by *Artemisia rigida, Poa secunda*, and *Pseudoroegneria spicata* (Camp and Gamon 2011, Fertig and Kleinknecht 2020, Mastrogiuseppe et al. 1985). This habitat conforms with the Inter-Mountain Basins Cliff and Canyon ecological system (Rocchio and Crawford 2015). Washington populations often consist of a series of subpopulations separated by less than 0.1 miles. Other populations may be up to 27 miles (43 km) apart. The sparsely vegetated areas occupied by this species are isolated primarily by natural barriers.

B2b. Anthropogenic barriers: Neutral.
The range of *Lomatium tuberosum* is naturally fragmented. Human impacts on the landscape of central Washington have increased fragmentation, but overall are of less significance 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: Increase.
Lomatium tuberosum produces flattened fruits that dehisce into one-seeded segments with prominent raised wings on the dorsal surface. The wings might help with dispersal by wind. In general, *Lomatium* species have surprisingly poor dispersal (less than 100 m), which may account for their unusually high degree of endemism in the northwest (Marisco and Hellman 2009).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Lomatium tuberosum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Thirteen of the 15 occurrences (86.7%) 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 other populations (13.3%) 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.

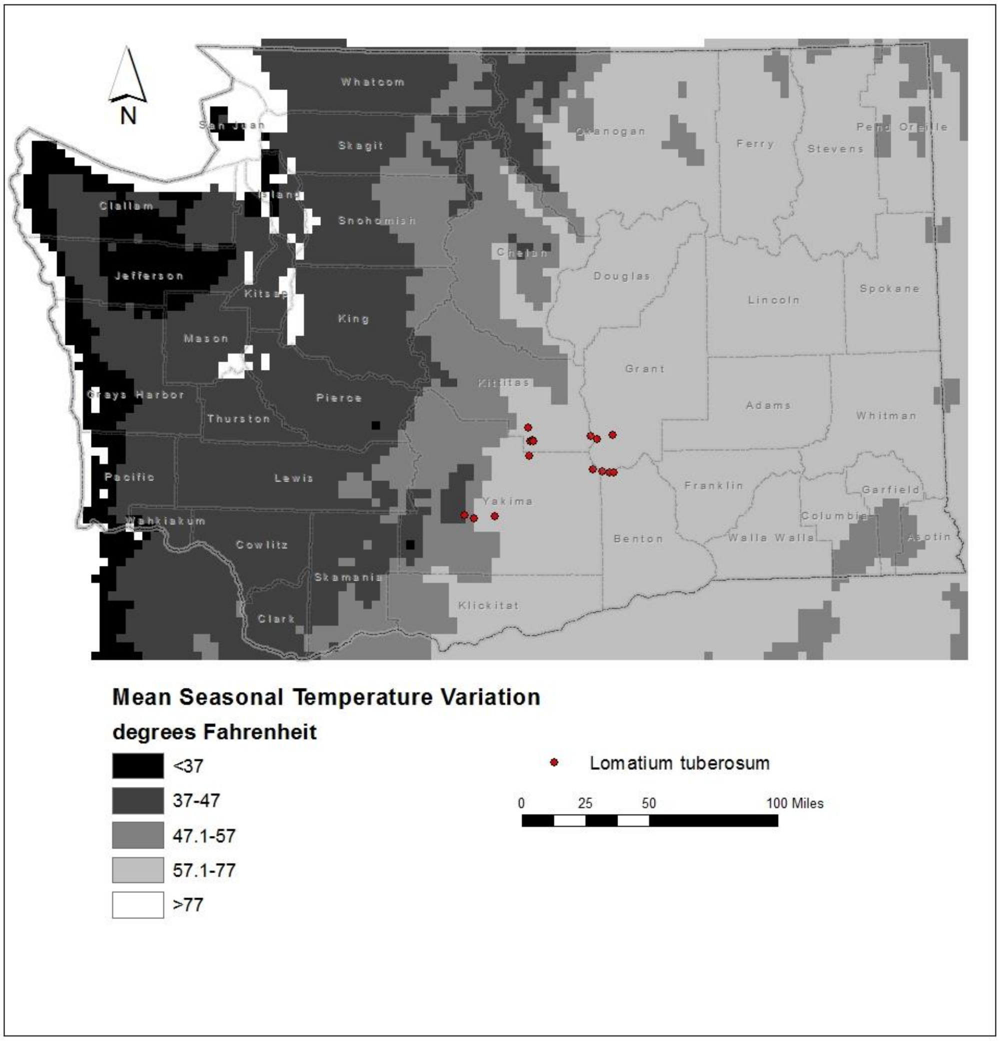

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Lomatium tuberosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The talus slope and ridge habitat of *Lomatium tuberosum* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Increase.
Eleven of the 15 populations of *Lomatium tuberosum* in Washington (73.3%) 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. Three other populations (20%) have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation over the same period and are at somewhat increased vulnerability (Figure 4), while one occurrence (6.7%) has experienced average (>20 inches/508 mm) precipitation variation and is at neutral vulnerability.

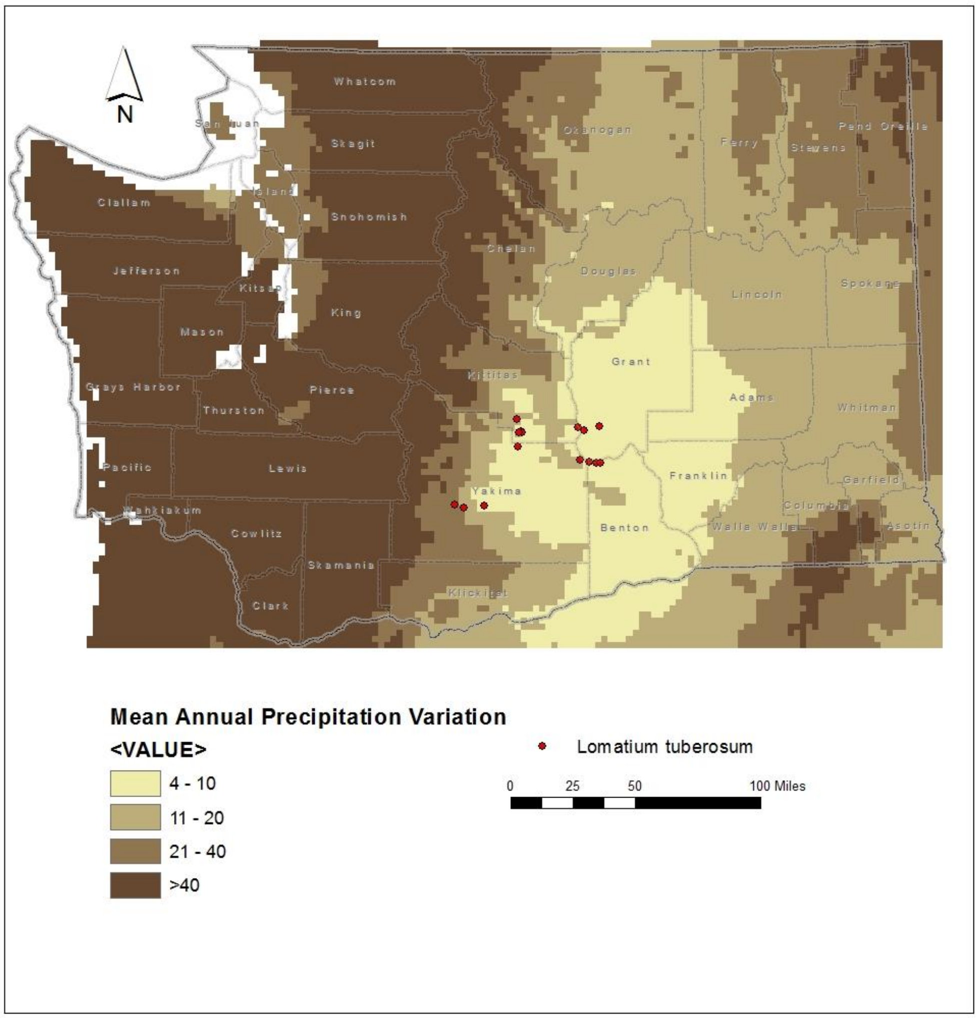

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Lomatium tuberosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Lomatium tuberosum populations occur on aridic basalt talus slopes and ridges in areas without springs, streams, or a high water table. These sites are dependent on winter snow and spring precipitation for a large proportion of their yearly water budget. Changes in the timing of snowmelt or the amount of precipitation could make these sites drier in the future and subject to displacement by lichens or invasive annuals (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Lomatium tuberosum occurs in areas that are sparsely vegetated due to unstable slopes, rock fall, and poor soil development. These areas are mostly not impacted by disturbances such as wildfire.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is low in the desert ridges and talus slopes occupied by *Lomatium tuberosum*. Drifting snow within talus, however, may help augment the annual water budget.

C3. Restricted to uncommon landscape/geological features: Neutral/Somewhat Increase.
Populations of *Lomatium tuberosum* occur primarily on outcrops of the Grande Ronde basalt and Quaternary alluvium, both common geologic formations in central Washington. The distribution of volcanic talus slopes is less widespread, and mostly restricted to east-west oriented ridge systems near the Columbia River.

C4a. Dependence on other species to generate required habitat: Neutral.
The cliff habitat occupied by *Lomatium tuberosum* 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: Unknown.
The exact pollinators of *Lomatium tuberosum* are not known, but other tuberous *Lomatium* species are pollinated by solitary bees, tachinid flies, syrphid flies, muscid flies, bee flies, and beetles (Schlessman 1982).

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruit dispersal in *Lomatium tuberosum* is probably by wind, gravity, or other passive means. The species is not dependent on animals for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species could be vulnerable to grazing, but actual use may be low due to the poor accessibility of its talus slope habitat (Fertig & Kleinknecht 2020, Mastroguiseppe et al. 1985).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Lomatium tuberosum occurs in sparsely vegetated talus slopes and ridgetops with low cover or competition from other plant species. Climate change could shift the species composition towards lichens or invasive annual 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.
Data are not available on the genetic diversity of this species in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Lomatium tuberosum is probably 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 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: Somewhat Increase.
The range of *Lomatium tuberosum* has contracted, with three disjunct occurrences from south-central Yakima County having not been relocated for more than 40 years and possibly extirpated. Whether this absence is due to climate change, local exploitation, or is an artifact of incomplete survey 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.

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Climate Change Vulnerability Index Report

Muhlenbergia glomerata (Marsh muhly)

Date: 18 February 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	75
	-0.074 to - 0.096	25
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		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		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		Somewhat Increase
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 eight of the known occurrences of *Muhlenbergia glomerata* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

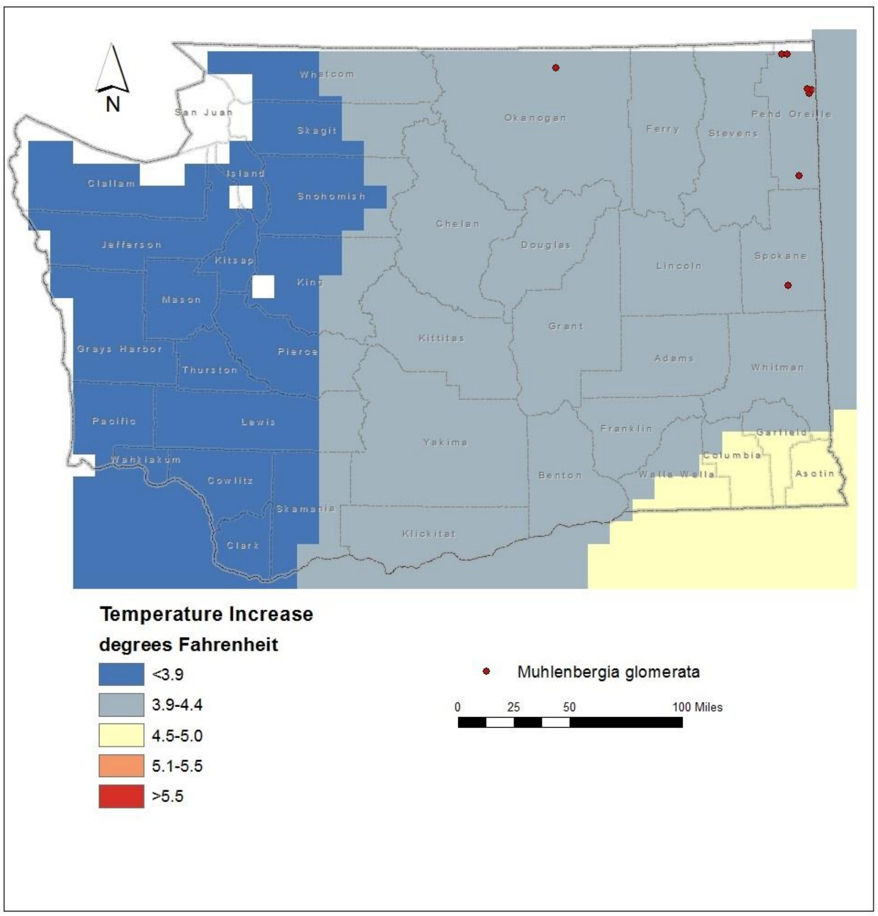

Figure 1. Exposure of *Muhlenbergia glomerata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the eight occurrences of *Muhlenbergia glomerata* (25%) 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 six occurrences (75%) are found in areas with a projected decrease in available moisture of – 0.097 to – 0.119.

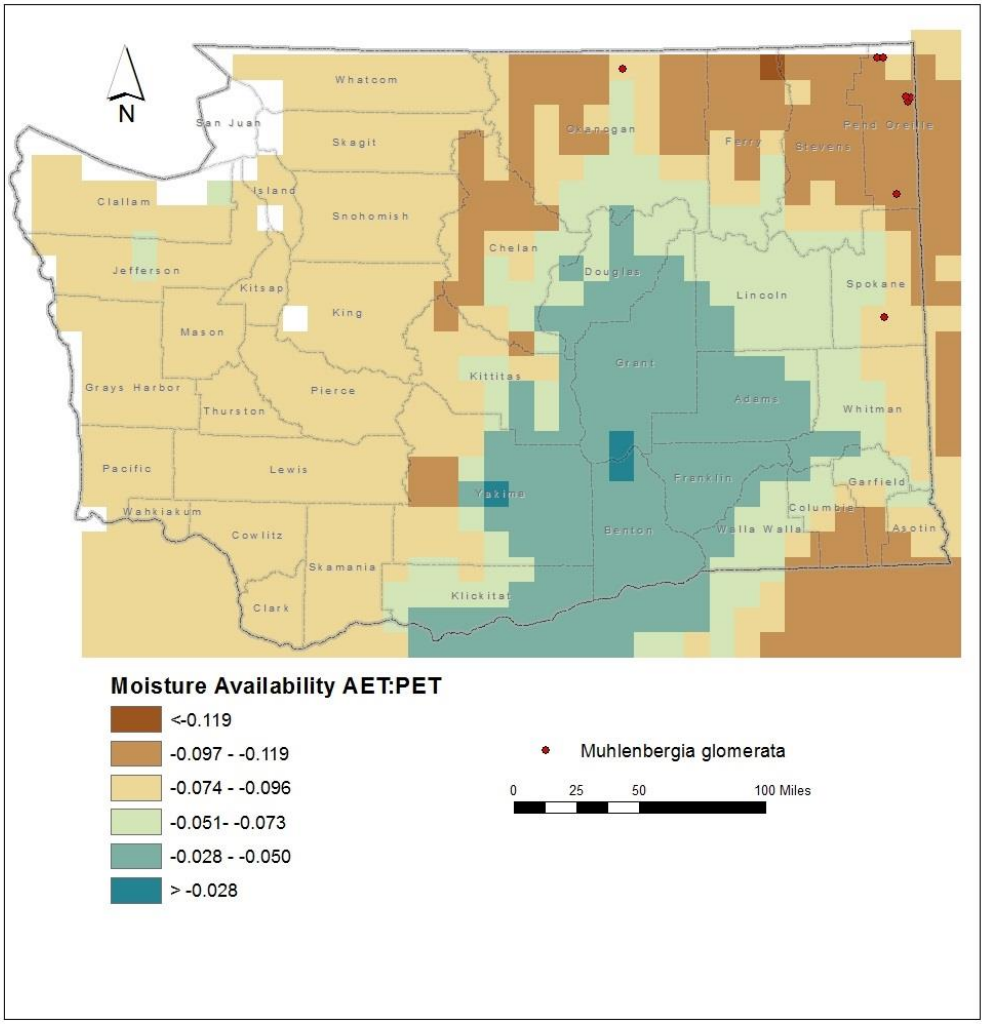

Figure 2. Exposure of *Muhlenbergia glomerata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Muhlenbergia glomerata* are found at 575-3600 feet (175-1100 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Muhlenbergia glomerata* is found in calcareous fens, marshy meadows, and banks of streams and ponds in mountains and valleys. Historically, the species was also found in a wet Palouse Prairie site near Spangle (Camp and Gamon 2011, WNHP records). These habitats are included within the Rocky Mountain Subalpine-Montane Fen and Rocky Mountain Alpine-Montane Wet Meadow ecological systems (Rocchio and Crawford 2015). *M. glomerata* is unusual for a fen species in having the water-conserving C_4 photosynthetic pathway and may be adapted to slightly drier microsites on hummocks formed by ants (Kublen and Sage 2003, Lesica and Kannowski 1998). Individual populations occupy small areas and are separated by 4-158 km (2.25-100 miles). These specialized habitats are naturally isolated from each other with mostly unsuitable habitat in-between.

B2b. Anthropogenic barriers: Neutral.
The range of *Muhlenbergia glomerata* is naturally fragmented. Human impacts on the landscape of northeastern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Muhlenbergia glomerata produces small, dry, one-seeded fruits (caryopses) with a tuft of hairs at the base that are readily dispersed by wind or small animals. Although average travel distances may be relatively short, the species is capable of long-distance dispersal of at least 1 km.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Muhlenbergia glomerata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All eight 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 to climate change.

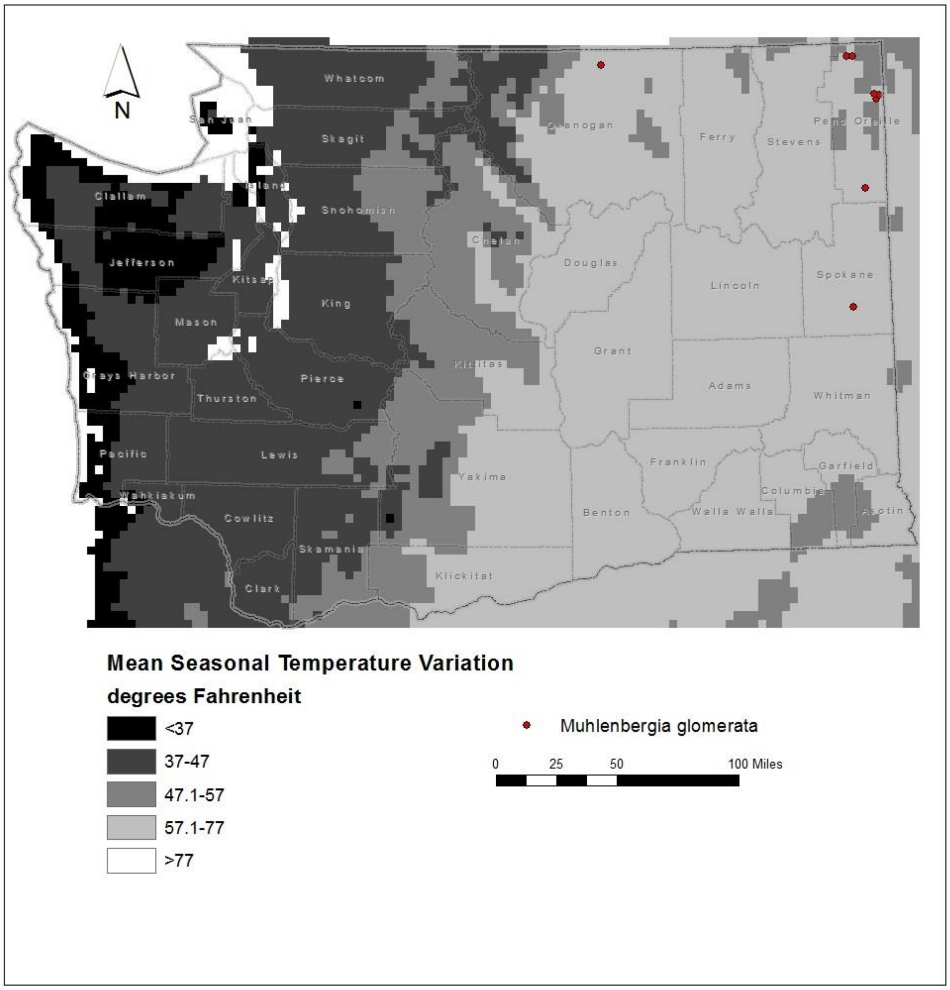

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Muhlenbergia glomerata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The fen and wet meadow habitat of *Muhlenbergia glomerata* is associated with cold air drainage during the growing season and would have increased vulnerability to rising temperatures from climate change. Increased drought and higher susceptibility to wildfire would make these habitats prone to conversion to drier forest or meadow habitats (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
Six of the eight populations of *Muhlenbergia glomerata* in Washington (75%) are found in areas that have experienced average or greater than average (>20 inches/508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at neutral vulnerability to climate change. Two of the eight occurrences (25%) are from areas that have experienced slightly lower than average (11-20 inches/255-508 mm) variation in precipitation over the same period and are considered at somewhat increased vulnerability.

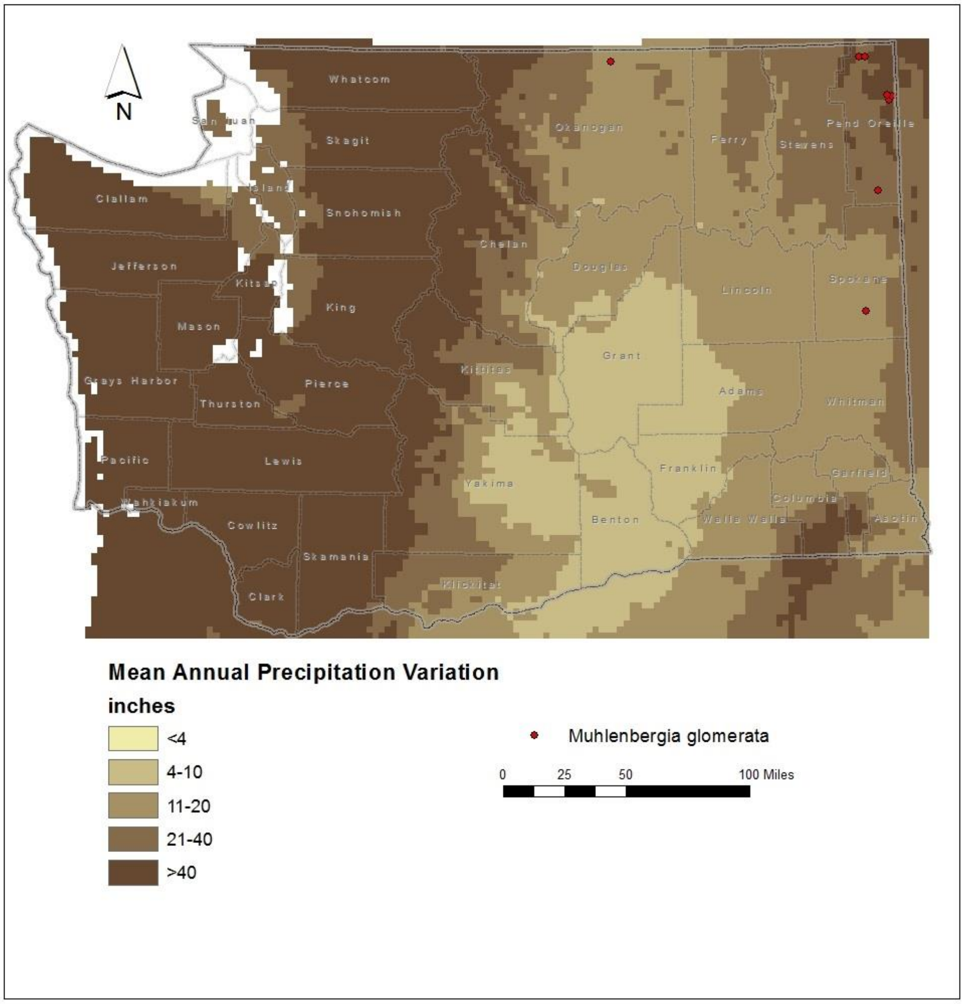

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Muhlenbergia glomerata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on a specific wetland habitat that is vulnerable to increased drought, changes in the timing or amount of precipitation, increased wildfire, or change in snowpack (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Muhlenbergia glomerata is not dependent on periodic disturbances to maintain its fen or wet meadow habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased snowpack that might favor conversion of this habitat to forest or meadows (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Muhlenbergia glomerata* in Washington are found mostly in montane wetlands that are dependent on snow for recharging groundwater. These sites are highly dependent on moisture from late-lying snowbanks (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow or when the snow melts could lead to shifts in the dominance of herbaceous species or invasion of trees or shrubs.

C3. Restricted to uncommon landscape/geological features: Neutral.
Muhlenbergia glomerata is found mostly on glacial drift deposits, which are widespread in northeastern Washington.

C4a. Dependence on other species to generate required habitat: Somewhat Increase
The wetland habitat occupied by *Muhlenbergia glomerata* is maintained primarily by natural abiotic processes. In Montana and Wyoming, *M. glomerata* is often associated with semi-dry hummocks formed by ant colonies (Fertig 1998; Lesica and Kannowski 1998). Similar relationships may be present in Washington.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Muhlenbergia glomerata is entirely wind-pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds are mostly dispersed passively by wind, but the short-awned lemmas of the florets might also facilitate dispersal by animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is not a preferred forage for livestock and may increase in early seral sites grazed by cattle (Hansen et al. 1995).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Muhlenbergia glomerata could be sensitive to competition from other plant species if its specialized wetland habitat became drier due to drought or reduced snowpack and water recharge under future 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.
Mitchell and Pohl (1966) report that *Muhlenbegia glomerata* is ordinarily a diploid and outcrosser, but that aneuploids have been documented that may persist through selfing, which is an unusual characteristic for a wind-pollinated grass species. The aneuploids may have also arisen from hybridization with *M. mexicana*, a species more typical of mesic rather than fen or wet meadow habitats. The aneuploids may be more adapted to drier conditions and might actually be favored under changing climatic conditions (Mitchell 1962, Mitchell and Pohl 1966). Population-level genetic data, however, are not available for Washington occurrences to infer genetic variability.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Muhlenbergia glomerata produces small, wind-pollinated flowers, which is typically associated with out-crossing and at least average genetic diversity (Young et al. 2016). Mitchell and Pohl (1966) have demonstrated that *M. glomerata* is capable of self-pollination. This and its scattered distribution across the west would suggest that local populations may be genetically diverging. In either situation, the reproductive system would be considered neutral for impacts from climate change.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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: Somewhat Increase.
Low elevation populations of *Muhlenbergia glomerata* in the Columbia Plateau have not been relocated in recent years and are probably extirpated. Whether this is due primarily to alteration of its wetland habitat or climate change is poorly known. These low elevation sites are no longer suitable habitat, however, and the species is unlikely to become re-established under present or anticipated future climatic conditions.

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

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Climate Change Vulnerability Index Report

Navarretia tagetina (Marigold pincushion-plant)

Date: 18 February 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	100
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral/Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		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	Somewhat Increase
Section D	
D1. Documented response to recent climate change	Neutral
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All three of the known occurrences of *Navarretia tagetina* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

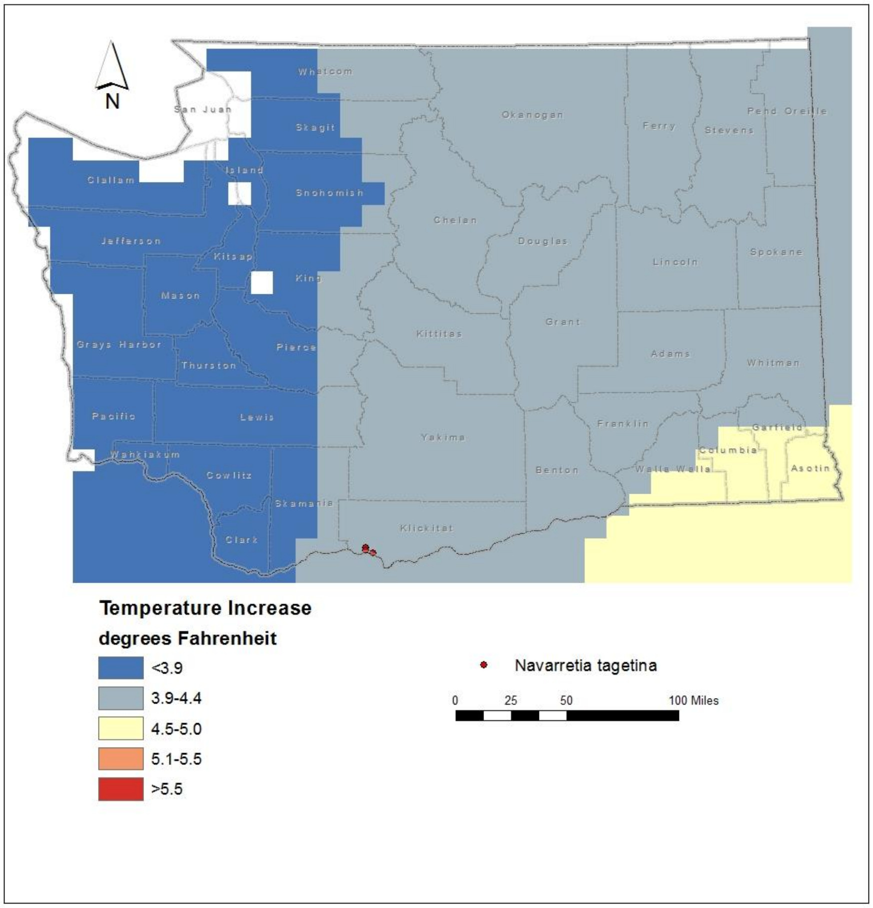

Figure 1. Exposure of *Navarretia tagetina* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All three of the occurrences of *Navarretia tagetina* (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 -0.028 to -0.050 (Figure 2).

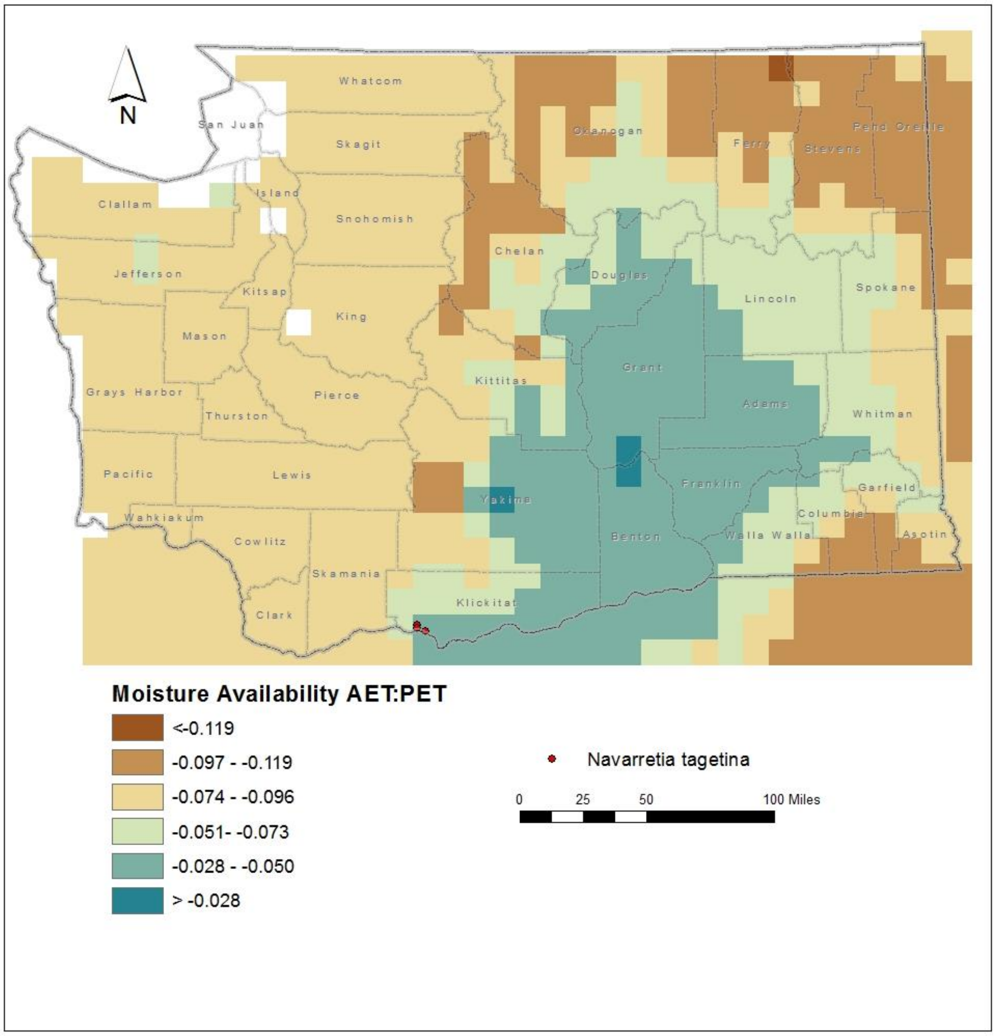

Figure 2. Exposure of *Navarretia tagetina* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Navarretia tagetina* are found at 250-450 feet (75-140 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Navarretia tagetina* is found in shallow vernal pools and stony washes in basalt scablands within grasslands or along the forest-grassland ecotone (Camp and Gamon 2011, WNHP records). These areas are characterized by shallow standing water or saturated soils in the spring, but are dry in summer (Alverson and Sheehan 1986). This habitat is part of the Modoc Basalt Flow Vernal Pool ecological system (Rocchio and Crawford 2015). All of the known occurrences (2 historic and 1 extant) are located within 5.4 km (3.5 miles) of each other in the Columbia River Gorge. These sites are embedded within a matrix of unsuitable habitat.

B2b. Anthropogenic barriers: Neutral.
The range of *Navarretia tagetina* is naturally fragmented. Human impacts in southern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Navarretia tagetina has indehiscent capsule fruits with numerous small seeds. After heavy rains, fibers on the seed surface uptake moisture to swell and break the fruit wall, allowing the seeds to be released (Spencer and Rieseberg 1998). *Navarretia* seeds become mucilaginous when wetted and can be transported long distances (or at least to other ephemeral wetlands) by waterfowl. Although average travel distances may be relatively short, the species is capable of dispersal of at least 1 km.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Navarretia tagetina* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All three of the known occurrences (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.

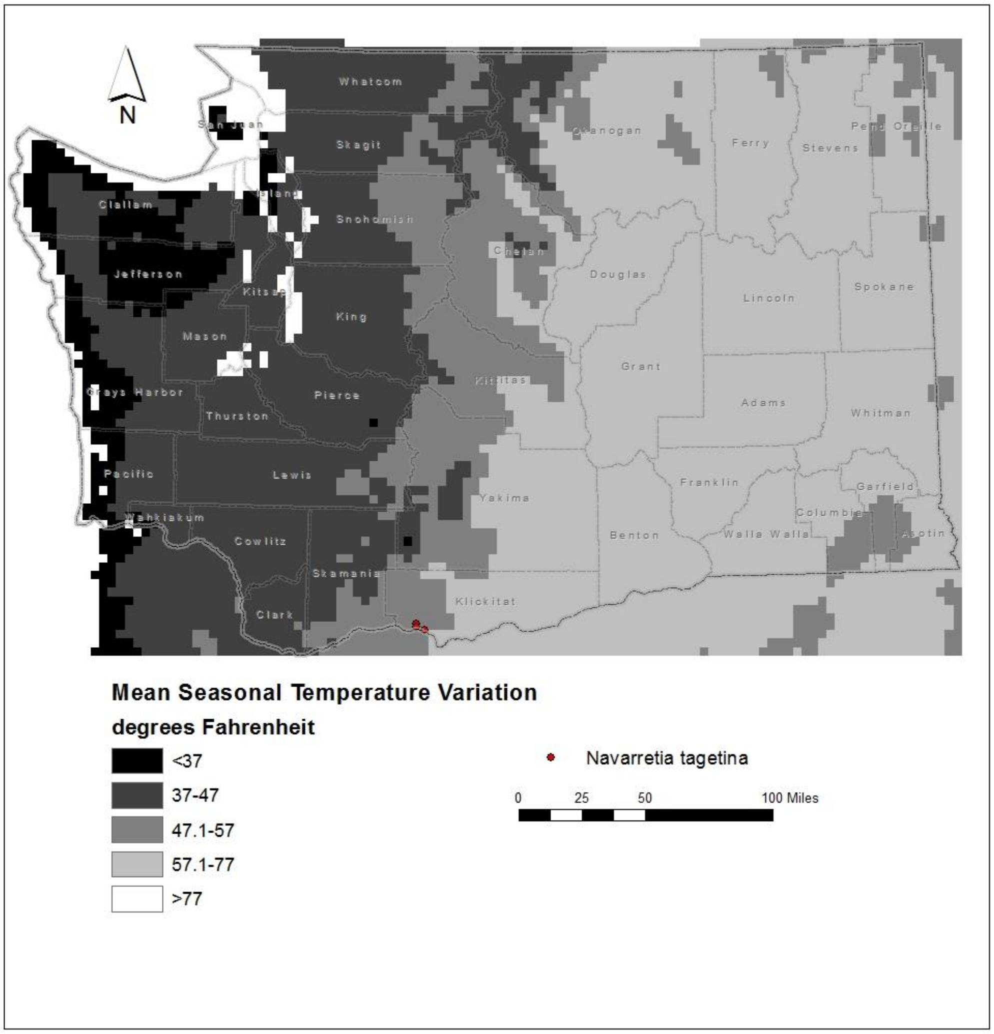

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Navarretia tagetina* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral/Somewhat Increase.
The ephemeral wetland and vernal pool habitat of *Navarretia tagetina* is not associated with cold air drainage during the growing season. These shallow wetlands would be vulnerable to long-term persistent drought (Rocchio and Ramm-Granberg 2017).

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

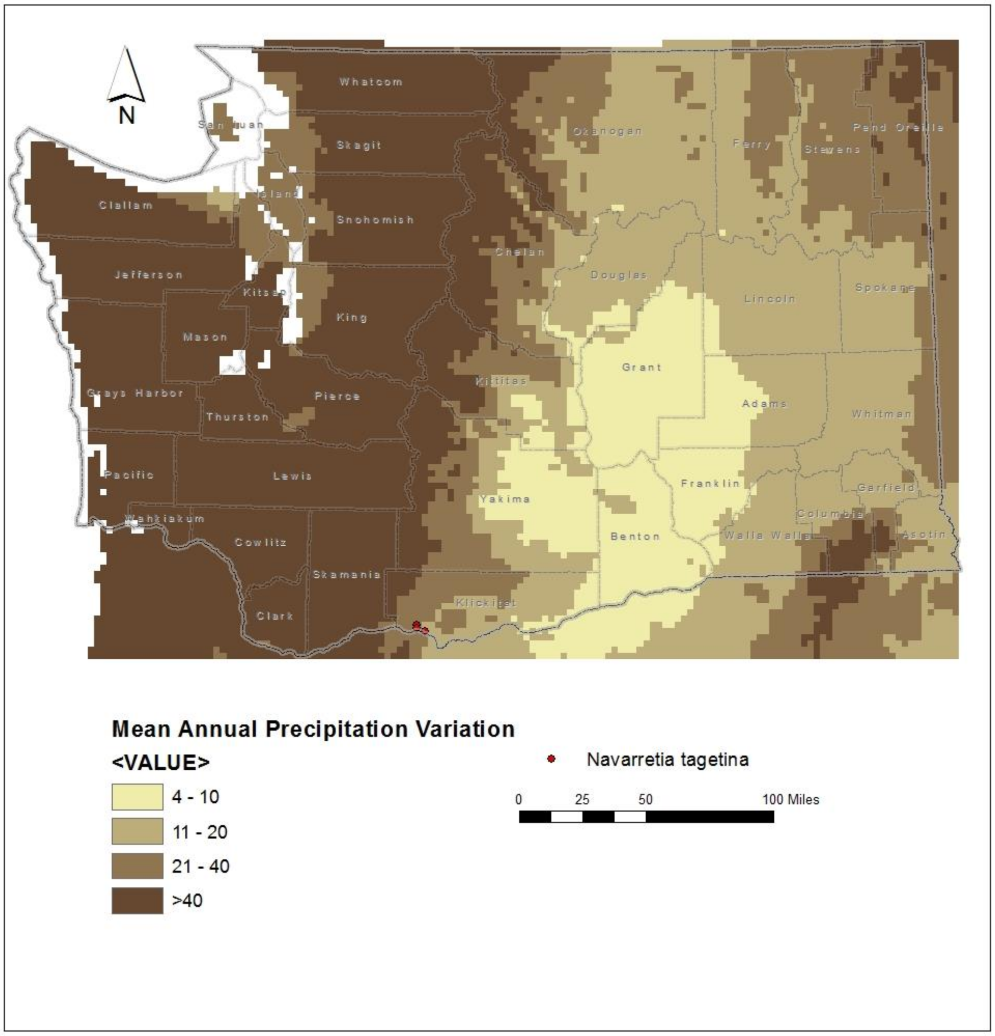

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Navarretia tagetina* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species is dependent on episodic winter and early spring precipitation and snow melt followed by severe drought to maintain its specialized vernal wetland habitat. It is especially vulnerable to changes in the amount and timing of precipitation (Rocchio and Ramm-Granberg 2017). Potentially higher amounts of precipitation in winter could be offset by higher temperatures and greater evapotranspiration. Unpredictable climatic events could also be significant on this annual species which must rely on a seed bank to persist through unfavorable years.

C2c. Dependence on a specific disturbance regime: Neutral.
Navarretia tagetina is not dependent on periodic disturbances to maintain its scabland vernal pool habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased snowpack that might favor conversion of this habitat to sparsely vegetated scablands, or make it more susceptible to competition from invasive annual weeds (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Reduced snowpack or changes in snow melt are a threat to many scabland vernal pool communities in the Columbia Plateau Columbia River Gorge (Rocchio and Ramm-Granberg 2017). Increased drought would favor transition to sparsely vegetated scabland communities.

C3. Restricted to uncommon landscape/geological features: Increase.
Navarretia tagetina is restricted to shallow depressions 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. Although basalt outcrops are widespread in the Columbia River Gorge, sites with the specific microsite qualities required by this species are much less common.

C4a. Dependence on other species to generate required habitat: Neutral
The vernal wetland habitat occupied by *Navarretia tagetina* 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.
Navarretia tagetina is presumed to be pollinated by small insects (Alverson and Sheehan 1986). Other *Navarretia* species from vernal pools are predominantly selfers, but *N. tagetina* is capable of outcrossing (Spencer and Rieseberg 1998).

C4d. Dependence on other species for propagule dispersal: Neutral.
The mucilaginous seeds of *Navarretia tagetina* are probably dispersed by sticking to the feet or feathers of waterfowl. It is probably not limited by the number of potential seed vector species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Whether this species is grazed by livestock is poorly known (Alverson and Sheehan 1986), but given its low stature and spiny foliage, it may not be widely consumed.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Navarretia tagetina could be sensitive to competition from other plant species (especially non-native invasive annuals) if its specialized wetland habitat became 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.
Spencer and Rieseberg (1998) used pollen to ovule ratios to infer that *Navarretia tagetina* is probably a facultative selfer but also capable of outcrossing. This would suggest that genetic variation between populations should be somewhat less than within isolated occurrences maintained by selfing. No genetic data are available on actual variability within or between populations in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Navarretia tagetina probably has average genetic diversity across populations due to its ability to outcross as well as self-pollinate. Washington populations are located at the northern edge of the species range and may have less genetic diversity than occurrences from Oregon or California due to founder effects or genetic drift (Alverson and Sheehan 1986)

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, *Navarretia tagetina* populations in Washington appear to be flowering slightly later in the past 30 years (June 7-July 24) than in the 1920s when the species was first documented in the state (May 12-27).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Significant changes in the distribution of *Navarretia tagetina* have not been documented. Although two of the three known occurrences in Washington are historical, they are from the same general location as the extant population. Their disappearance could be an artifact of incomplete surveys (both are from private lands) or a consequence of development.

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

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Alverson, E. and M. Sheehan. 1986. Status report on *Navarretia tagetina*. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA.

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Climate Change Vulnerability Index Report

Nicotiana attenuata (Coyote tobacco)

Date: 13 April 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G4/S2

Index Result: Less Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	2.6
	-0.051 to - 0.073	15.4
	-0.028 to -0.050	79.4
	>-0.028	2.6
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on 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/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	
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: All 39 of the extant and historical occurrences of *Nicotiana attenuata* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

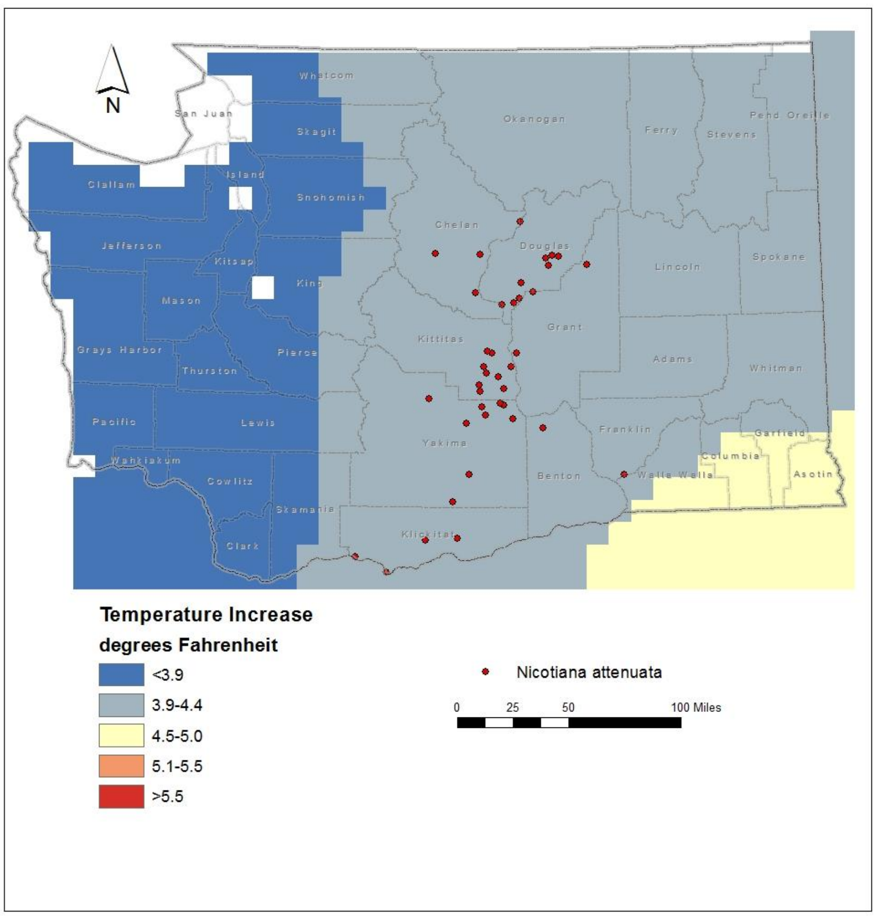

Figure 1. Exposure of *Nicotiana attenuata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Thirty-one of the 39 occurrences of *Nicotiana attenuata* (79.4%) 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). Six populations (15.4%) are from areas with a projected decrease in the range of -0.051 to -0.073. One occurrence (2.6%) is from an area with a predicted decrease in the range of -0.074 to -0.096 and one other (2.6%) has a projected decrease of > -0.028 (Figure 2).

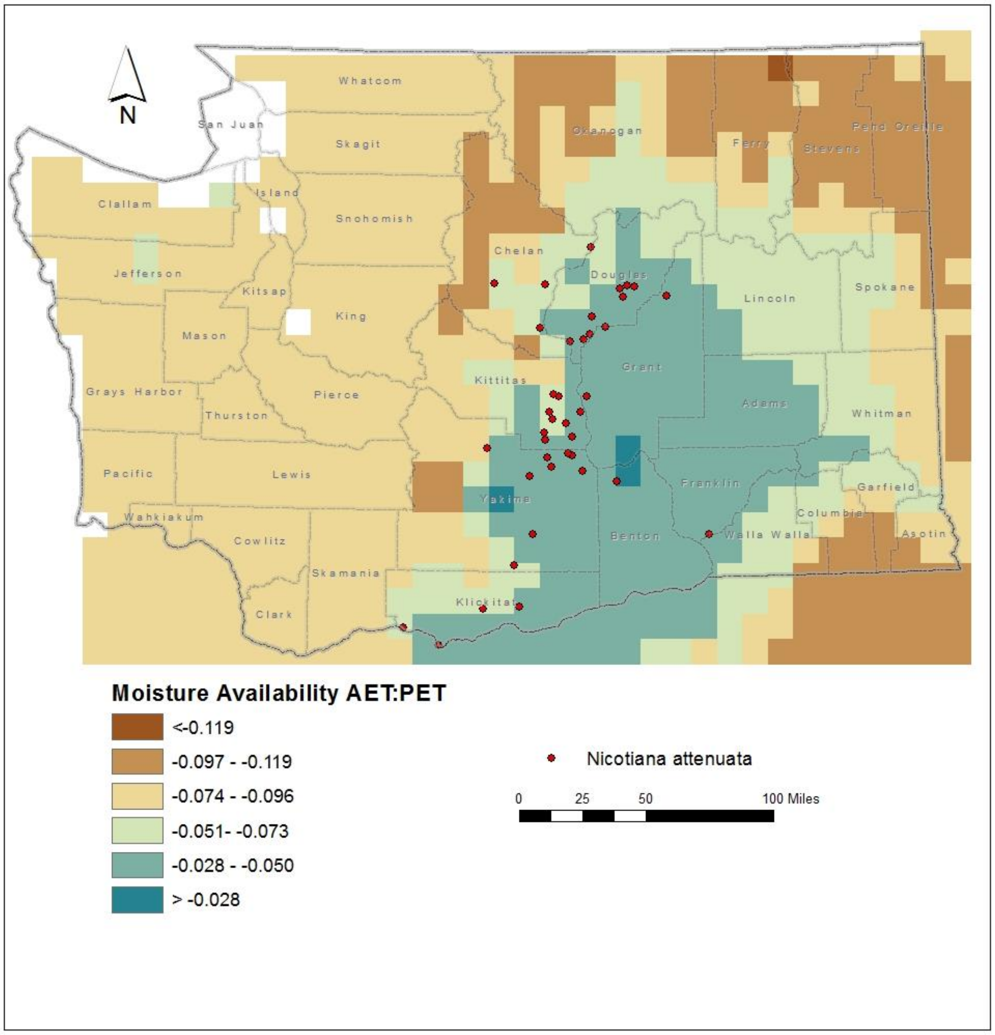

Figure 2. Exposure of *Nicotiana attenuata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Nicotiana attenuata* are found at 320-2640 feet (100-800 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Nicotiana attenuata* occurs in open or disturbed areas within big sagebrush (*Artemisia tridentata*) communities on sandy bottoms, rocky washes, or roadsides (Camp and Gamon 2011, Fertig and Kleinknecht 2020). This species is strongly associated with fire and may remain abundant up to three years following wildfire, and then persist for 30-150 years in the seedbank until the next fire (Preston and Baldwin 1999). The habitat occupied by *N. attenuata* conforms with the Inter-Mountain Basins Wash and Inter-Mountain Basins Big Sagebrush Steppe ecological systems (Rocchio and Crawford 2015). Washington populations often consist of a series of subpopulations separated by less than 0.1 miles. Other populations may be up to 22 miles (35 km) apart. Potential habitat for this species is relatively widespread in central Washington but fragmented by natural and anthropogenic barriers. Of the two, natural barriers may be more important, as anthropogenic disturbances may actually increase habitat along disturbed roadsides (areas that historically would not have been suitable).

B2b. Anthropogenic barriers: Neutral.
The range of *Nicotiana attenuata* is naturally fragmented. Human impacts on the landscape of have contributed to this condition, but overall may be of less significance because anthropogenic disturbances have created open conditions along roadsides favorable to this early seral 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.
Nicotiana attenuata produces numerous small, unornamented seeds in dry fruit capsules that split open to release the seeds passively by wind or gravity. Dispersal distances are probably variable, with most seed landing near the parent plant, and some seed traveling 100-1000m. Once dispersed, long-term seed dormancy and persistence of the seedbank may be critical for establishing populations after wildfire (Preston and Baldwin 1999).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Nicotiana attenuata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Thirty-four of the 39 occurrences (87.2%) 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). Five other populations (12.8%) 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.

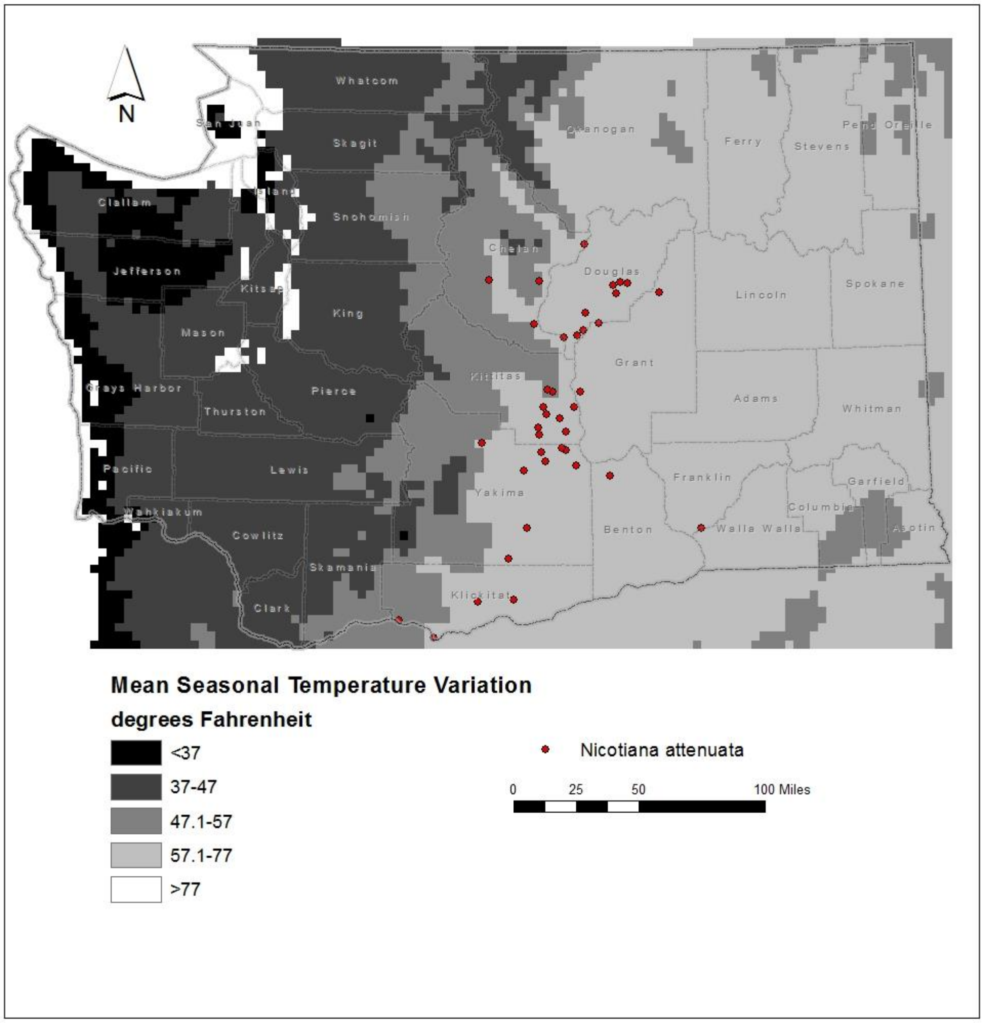

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Nicotiana attenuata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The disturbed sagebrush habitat of *Nicotiana attenuata* in central Washington is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Twenty-three of the 39 populations of *Nicotiana attenuata* in Washington (59%) 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. Thirteen populations (33.3%) have experienced small (4-10 inches/100-254 mm) precipitation variation over the same period and are at increased vulnerability (Figure 4). Three other occurrences (7.7%) have experienced average (>20 inches/508 mm) precipitation variation and are at neutral vulnerability.

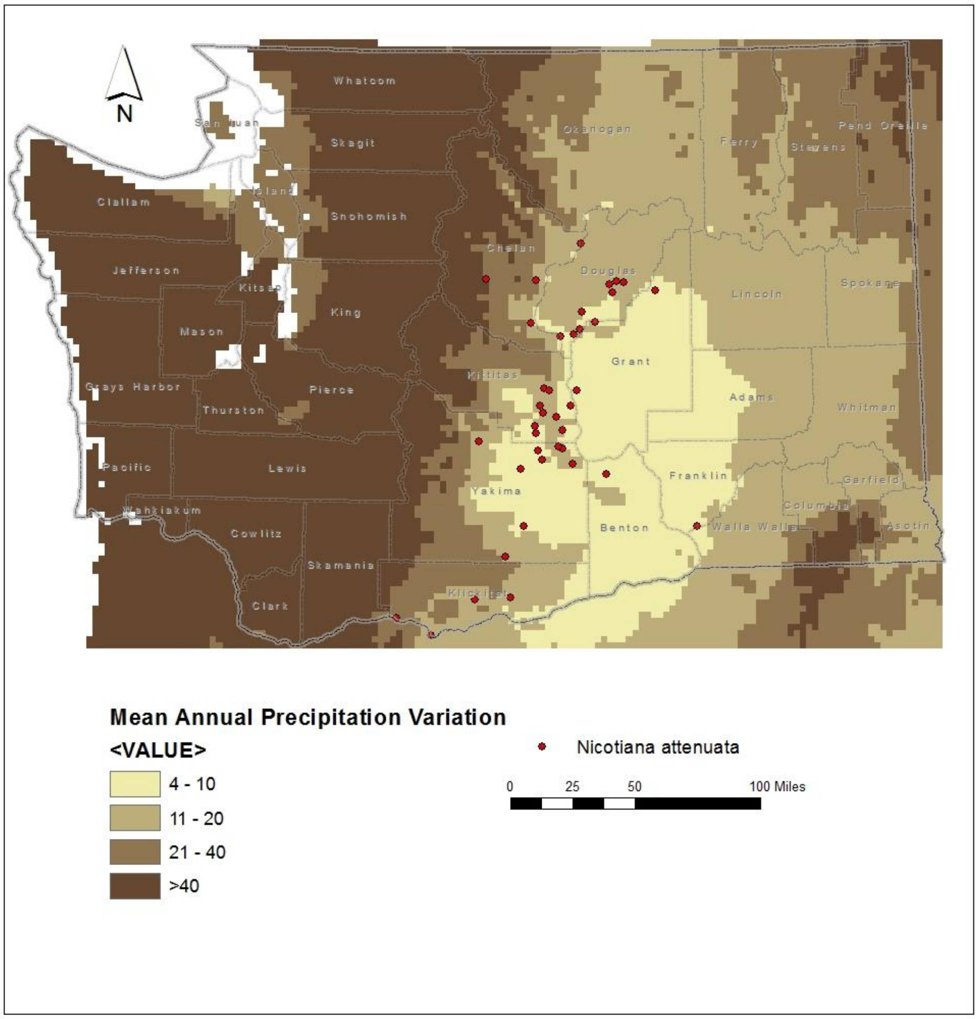

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Nicotiana attenuata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
Nicotiana attenuata populations occur in disturbed openings in Big sagebrush steppe and seasonally dry wash bottoms. These areas are dependent on spring and summer precipitation and could be impacted by changes in the timing and amount of rainfall and higher temperatures, which in turn could make the habitats more prone to wildfire (Rocchio and Ramm-Granberg 2017). As *N. attenuata* is adapted to wildfire for seed germination and short-term abundance (before leaving more seed in the seedbank for future disturbances; Preston and Baldwin 1999), this species might actually benefit from projected climate change.

C2c. Dependence on a specific disturbance regime: Neutral.
Nicotiana attenuata is positively associated with periodic wildfires to create suitable open habitat and requires chemicals in smoke to break seed dormancy (Preston and Baldwin 1999). In the absence of climate change, reduction in the frequency of fire would be considered a negative impact on this species. Increased drought and higher temperatures, however, are likely to increase the frequency of wildfire and could open up additional habitat for *N. attenuata*, provided there is a seedbank available in or near burned areas (augmentation by seeding might be beneficial in some areas as a conservation measure).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack is low in the areas occupied by *Nicotiana attenuata*.

C3. Restricted to uncommon landscape/geological features: Neutral.
Populations of *Nicotiana attenuata* occur primarily on outcrops of the Grande Ronde and Wanapum basalt and Quaternary alluvium, both common geologic formations in central Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The disturbed, open sagebrush habitat occupied by *Nicotiana attenuata* is maintained by natural abiotic processes (primarily fire), rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Nicotiana attenuata is self-fertile and is primarily self-pollinated, but it can also be pollinated by hawkmoths in the genera *Hyles* and *Manduca* (Sime and Baldwin 2003), which promotes out-crossing and increases genetic diversity.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seed dispersal in *Nicotiana attenuata* is probably by wind, gravity, or other passive means. The species is not dependent on animals for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. *Nicotiana attenuata* is consumed by at least 20 different herbivores, but the degree of herbivory varies depending on the plant's ability to rapidly produce anti-herbivory compounds, such as nicotine (Baldwin 2001).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase/Neutral. *Nicotiana attenuata* is most abundant in areas that are frequently disturbed by wildfire or human impacts, such as blading roads (Baldwin 2001; Fertig and Kleinknect 2020). In the absence of disturbance, it is quickly outcompeted by other native or introduced plant species, and may become absent from a site within three years (Preston and Baldwin 1999). Increased drought and higher temperatures due to climate change is likely to increase disturbances such as fire, which would potentially counteract effects of secondary succession (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: Neutral.
Data are not available on the genetic diversity of this species in Washington. Studies elsewhere in western North America have found relatively low genetic variation between populations (populations are homogeneous), but high genetic divergence within populations (Bahulikar et al. 2004). The authors attribute this to multiple generations of seeds being available in the seed bank and strong natural selection on cohorts of germinating plants following wildfire.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Nicotiana attenuata is primarily a selfer, but 3-24% of seed can be produced from pollination by hawkmoths (Sime and Baldwin 2003).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on WNHP and Consortium of Pacific Northwest Herbaria records, the flowering season of this species has not changed significantly since records were first available in the late 19th Century.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase.
The range of *Nicotiana attenuata* has contracted since the mid-20th Century, with populations in the foothills of the East Cascades and in southeastern Washington no longer extant (Gamon and Camp 2011; WNHP records, Consortium of Pacific Northwest Herbaria records).

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

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Climate Change Vulnerability Index Report

Oxytropis campestris var. *wanapum* (Wanapum crazyweed)

Date: 20 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5T1/S1

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	100
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Unknown (Neutral?)
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		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		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		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: The single occurrence of *Oxytropis campestris* var. *wanapum* in Washington (100%) occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

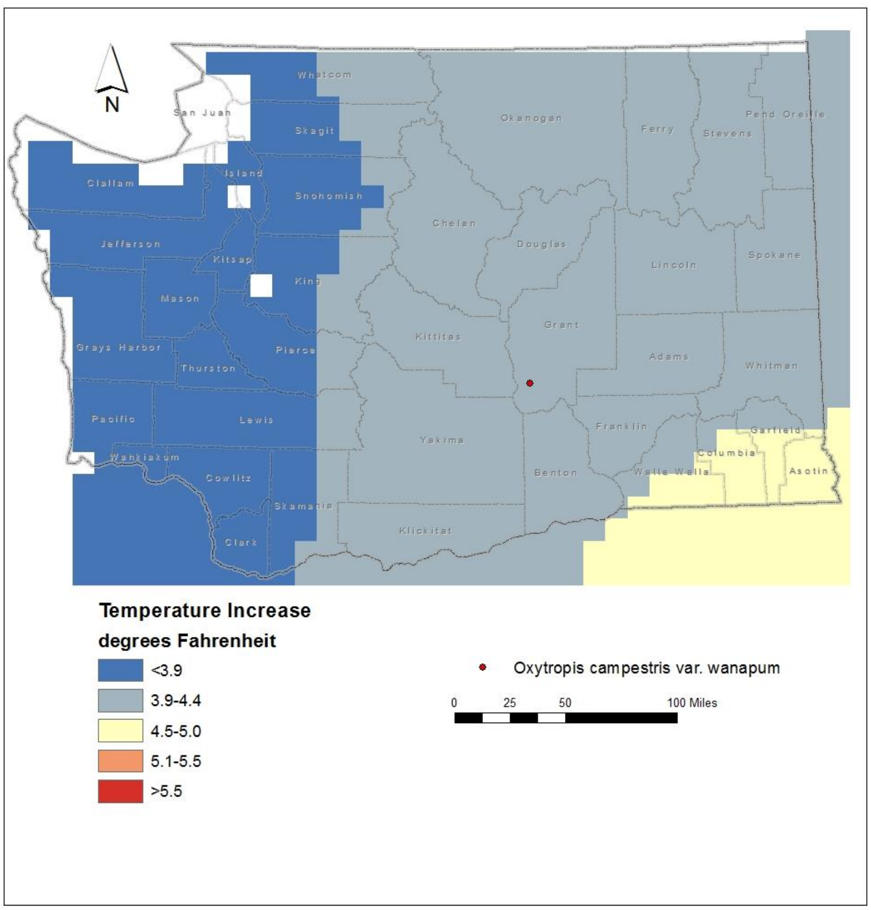

Figure 1. Exposure of *Oxytropis campestris var. wanapum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Oxytropis campestris* var. *wanapum* (100%) in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.028 to -0.050 (Figure 2).

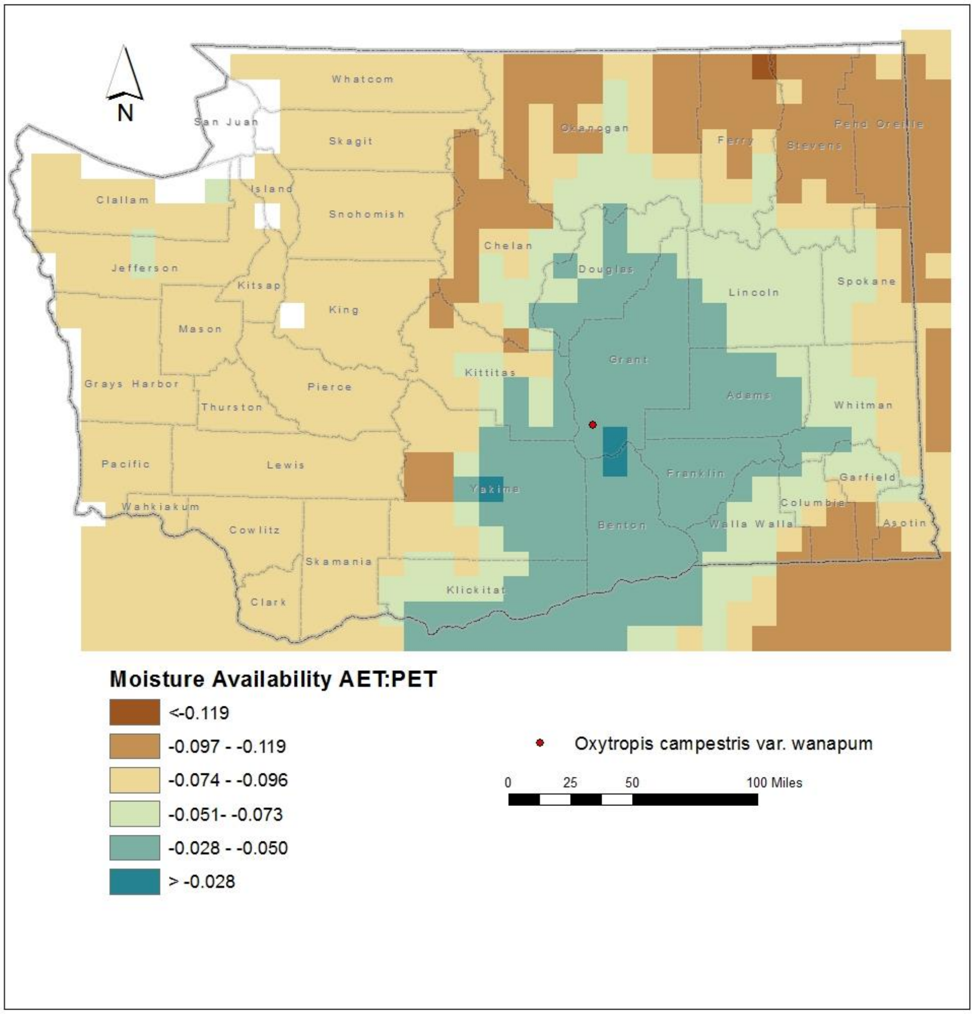

Figure 2. Exposure of *Oxytropis campestris var. wanapum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Oxytropis campestris* var. *wanapum* are found at 1800-2420 feet (550-740 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral?
In Washington, *Oxytropis campestris* var. *wanapum* is restricted to a community of *Ericameria nauseosa, Salvia dorrii*, and *Pseudoroegneria spicata* along a narrow band of whitish ashy mudstone or sandstone within thick deposits of brown basalt talus and bedrock near the summit of Saddle Mountain (Fertig 2020). This habitat is a component of the Inter-Mountain Basins Cliff and Canyon ecological system (Rocchio and Crawford 2015). The population extends discontinuously for about 4 1/2 miles. No other populations have been documented in central Washington, although potential habitat could exist on basalt ridges on the Yakima Training Center or Hanford Reservation to the south (Joyal 1990). These potential sites are separated by areas of unsuitable habitat. Whether the range of var. *wanapum* is constrained by its dispersal ability or lack of additional habitat is not known.

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Oxytropis campestris* var. *wanapum* is apparently restricted to Saddle Mountain, east of the Columbia River and Wanapum Dam. Human development surrounds much of this area and could restrict potential expansion or migration of the species beyond Saddle Mountain.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Oxytropis campestris var. *wanapum* produces 6 to 12 slightly inflated legume fruits with membranous-leathery walls. In other varieties of *O. campestris*, seeds are dehisced while the fruits are still attached to the infructescence or the entire fruit is the dispersal unit (Barneby 1989). Dispersal distances are probably relatively short (less than 100 meters) and depend on passive means (such as gravity) or movement by seed-caching animals. Genetic data from other varieties of *O. campestris* suggest limited gene flow between populations due to poor dispersal (Chung et al. 2004).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Oxytropis campestris* var. *wanapum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”). The single known 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 atneutral vulnerability to climate change.

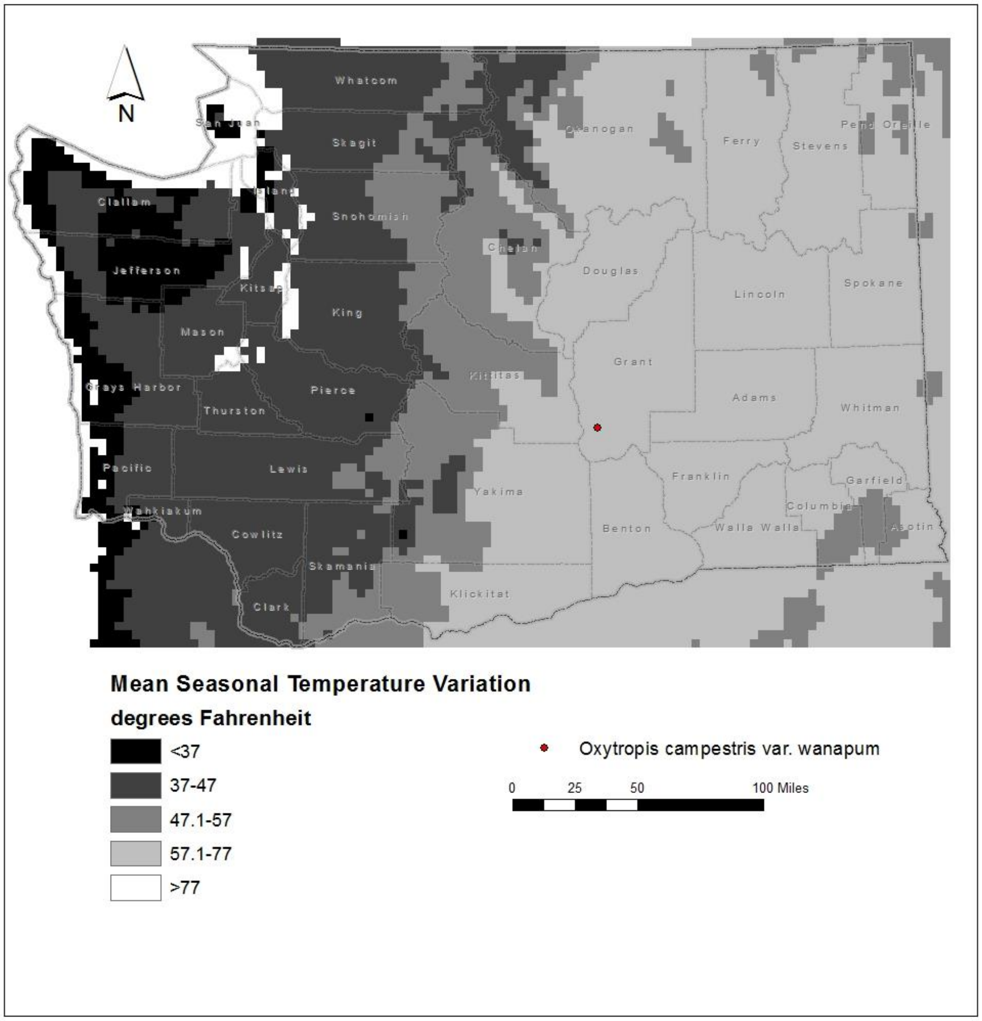

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Oxytropis campestris* var. *wanapum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The rock outcrop and habitat of *Oxytropis campestris* var. *wanapum* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Increase.
The single population of *Oxytropis campestris* var. *wanapum* in Washington (100%) is found in an area 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.

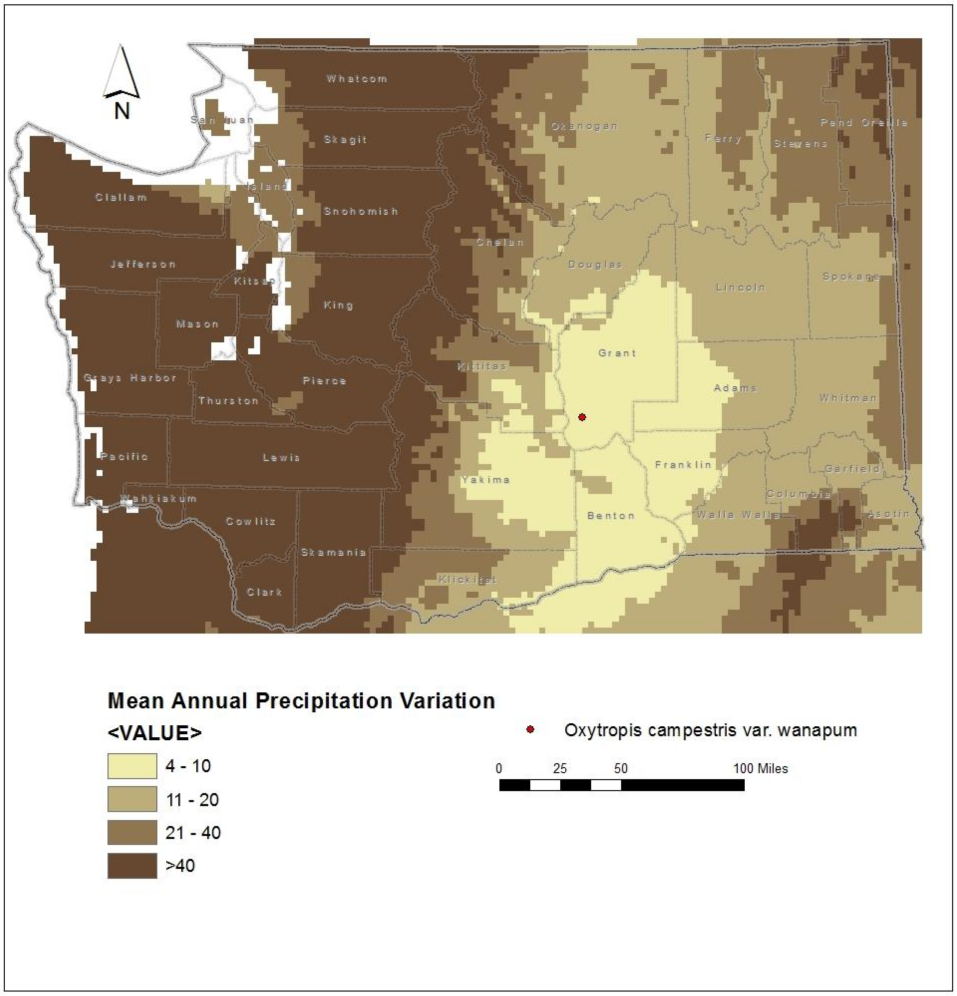

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Oxytropis campestris* var. *wanapum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

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.
Oxytropis campestris var. *wanapum* is not dependent on periodic disturbances to maintain its basin cliff and canyon 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.
Snowpack is low in the Saddle Mountain area, but infiltration of snowmelt water may be an important component of the annual water budget.

C3. Restricted to uncommon landscape/geological features: Increase.
Oxytropis campestris var. *wanapum* is restricted to a lens of whitish sandy soil derived from ashy sandstone embedded within thick beds of brown Wanapum Basalt. This geologic layer appears to be uncommon within the Columbia Plateau ecoregion, which may account for the limited range of var. *wanapum*.

C4a. Dependence on other species to generate required habitat: Neutral
The cliff habitat occupied by *Oxytropis campestris* var. *wanapum* 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: Somewhat Increase.
Joyal (1990) observed the metallic leaf-cutter bee *Osmia integra* visiting *Oxytropis campestris* var. *wanapum* inflorescences. No other pollinators are known. The diversity of insect pollinators may be adversely affected by insecticides used in nearby agricultural fields.

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds of *Oxytropis campestris* var. *wanapum* are probably dispersed passively by gravity or transported short distances by animals (which may be seed or fruit predators). The number of potential seed vector species is not known.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. *Oxytropis* species are generally of low palatability due to chemical defense compounds (at least for mammalian herbivores). Weevils (genus *Tychius*) are probably important fruit and seed predators (Joyal 1990).

C4f. Sensitivity to competition from native or non-native species: Neutral.
Oxytropis campestris var. *wanapum* occurs in sparsely vegetated outcrops that currently have relatively low cover and competition from other species. Climate change could shift the composition to more annual plant species, including some that could be invasive exotics (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 var. *wanapum*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral?
Other varieties of *Oxytropis campestris* are obligate outcrossers with low rates of self-pollination or apomixis (Chung et al. 2004). Genetic diversity is relatively high within and between populations of the edaphic endemic, *O. campestris* var. *chartacea* in Wisconsin and other varieties in the *O. campestris* complex (Chung et al. 2004). The degree of genetic divergence is not known for var. *wanapum*. Joyal (1990) suggested that this variety may be most closely allied with var. *columbiana* (an endemic of the upper Columbia River watershed in northern Washington and NW Montana), but no comparative genetic studies have been undertaken. The relatively isolated population of var. *wanapum* might have a reduced genome based on founder effects compared to other varieties.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no changes in the phenology of *Oxytropis campestris* var. *wanapum* populations in Washington have been detected.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Significant changes in the distribution of *Oxytropis campestris* var. *wanapum* have not been documented.

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

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Packera porteri (*Senecio porteri*; Porter's butterweed)

Date: 21 February 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Greatly 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		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		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Somewhat Increase

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 *Packera porteri* in Washington (100%) occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

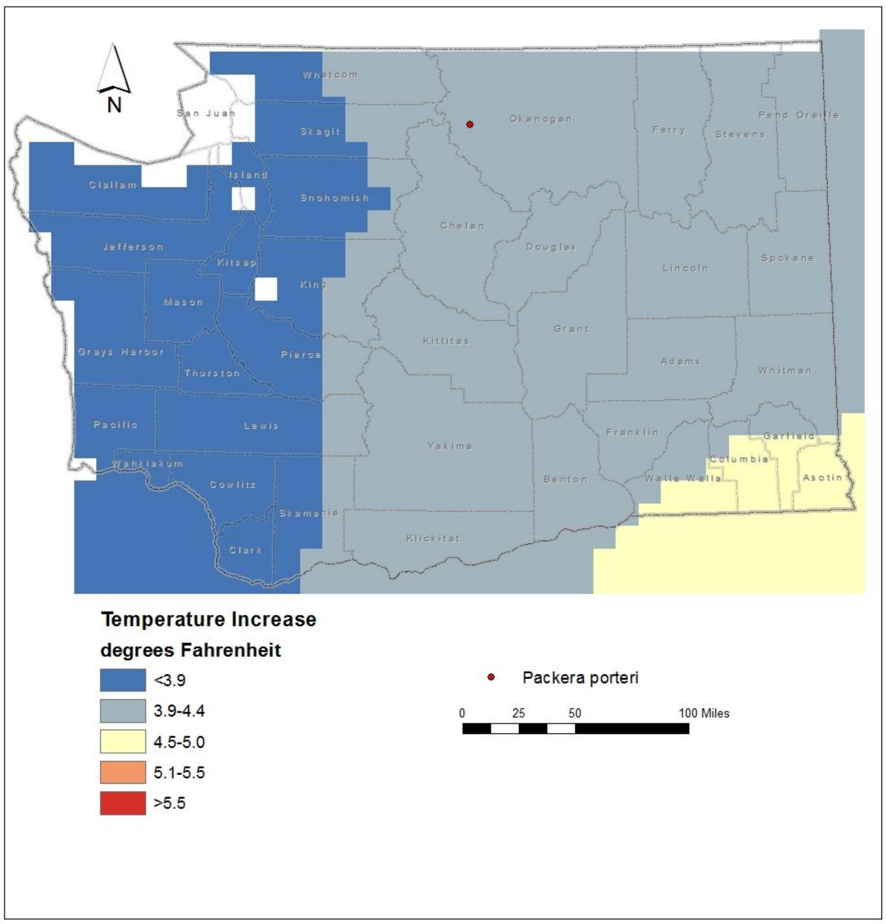

Figure 1. Exposure of *Packera porteri* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Packera porteri* (100%) in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

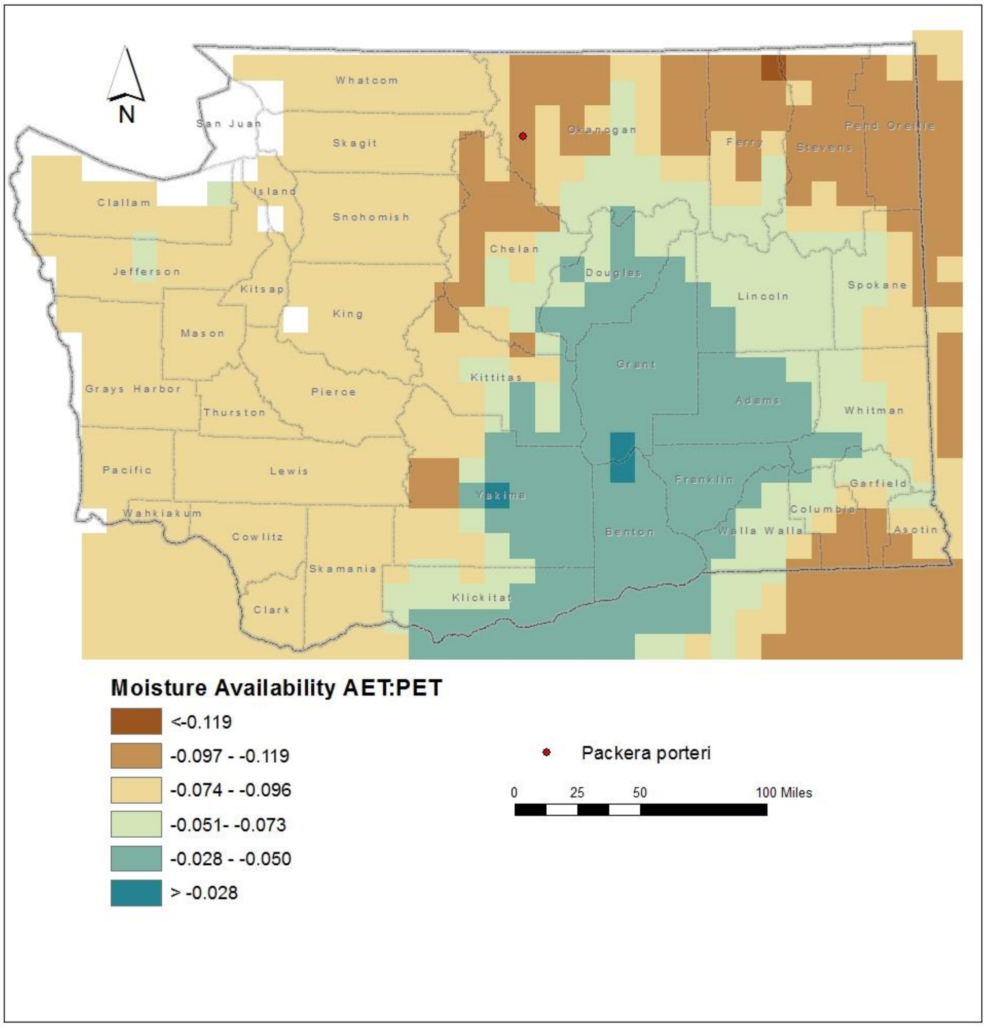

Figure 2. Exposure of *Packera porteri* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrence of *Packera porteri* is found at 7800 feet (2735 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Packera porteri* is found on lichen-covered volcanic bedrock of the Midnight Peak Formation and loose talus in an unglaciated nunatak with *Pinus albicaulis, Juniperus communis*, and *Penstemon davidsonii* (WNHP 2005, WNHP Biotics database). This habitat is a component of the Rocky Mountain Alpine Bedrock and Scree ecological system (Rocchio and Crawford 2015). Similar scree outcrops of the Midnight Peak Formation are scattered in the Okanogan Range, with areas of unsuitable habitat in between, creating a barrier to dispersal. The current distribution of *P. porteri* in Washington may be an artifact of under-sampling, as its alpine habitat is difficult to access and identification of *Packera* species can be tricky.

B2b. Anthropogenic barriers: Neutral.
Human impacts in the alpine and subalpine of the Okanogan range are limited and do not impose more of a barrier than already exists naturally (Rocchio and Ramm-Granberg 2017).

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Packera porteri produces numerous one-seeded achene fruits topped by feathery pappus bristles for ready dissemination by wind, potentially over distances of over 1 km in windy areas above tree line.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Packera porteri* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The single known occurrence (100%) is found in an area that has experienced small (37-47˚F/20.8-26.3˚C) temperature variation during the past 50 years and is considered at increased vulnerability to climate change.

C2aii. Physiological thermal niche: Greatly Increase.
The rock outcrop/nunatak habitat of *Packera porteri* is strongly correlated with cold air drainage during the growing season and would have greatly increased vulnerability to climate change.

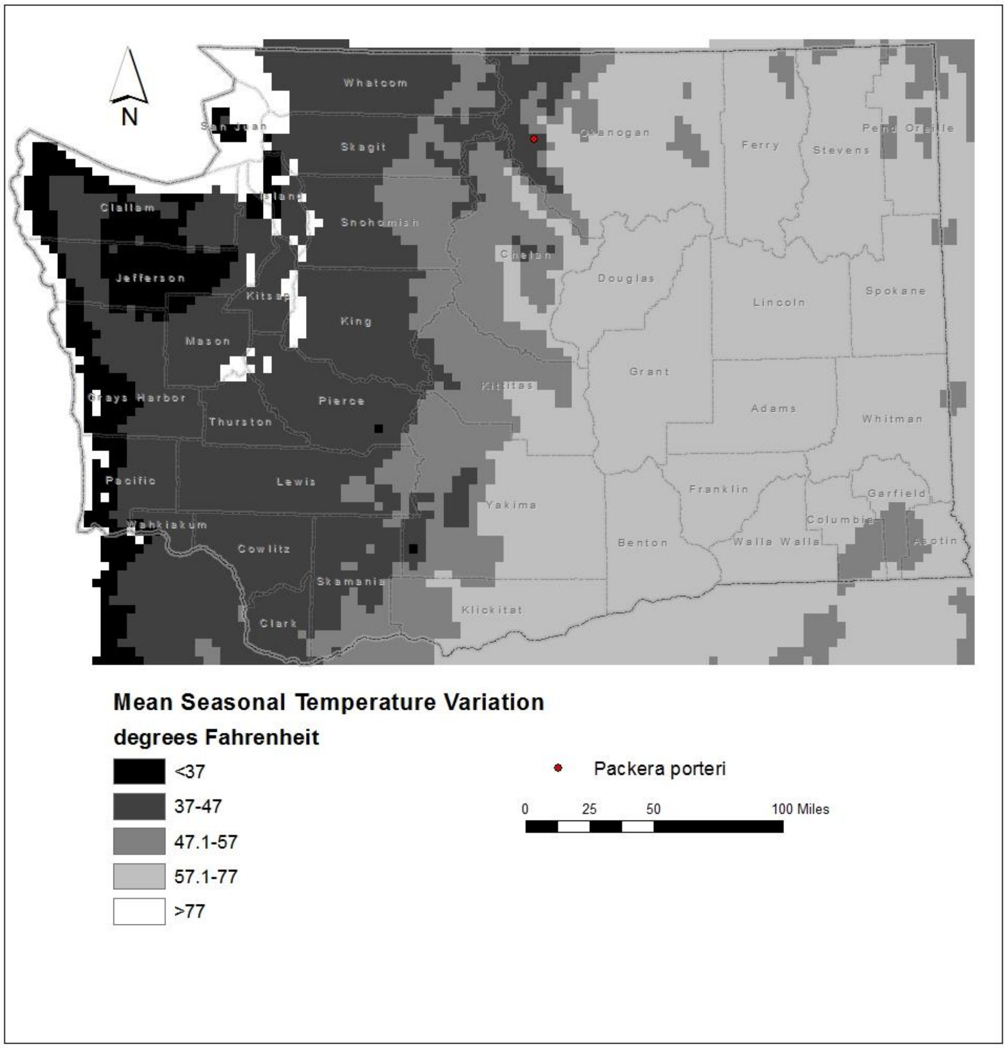

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Packera porteri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
The single population of *Packera porteri* in Washington (100%) is found in an area that has experienced average or greater than average (>20 inches/5080 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at neutral vulnerability to climate change.

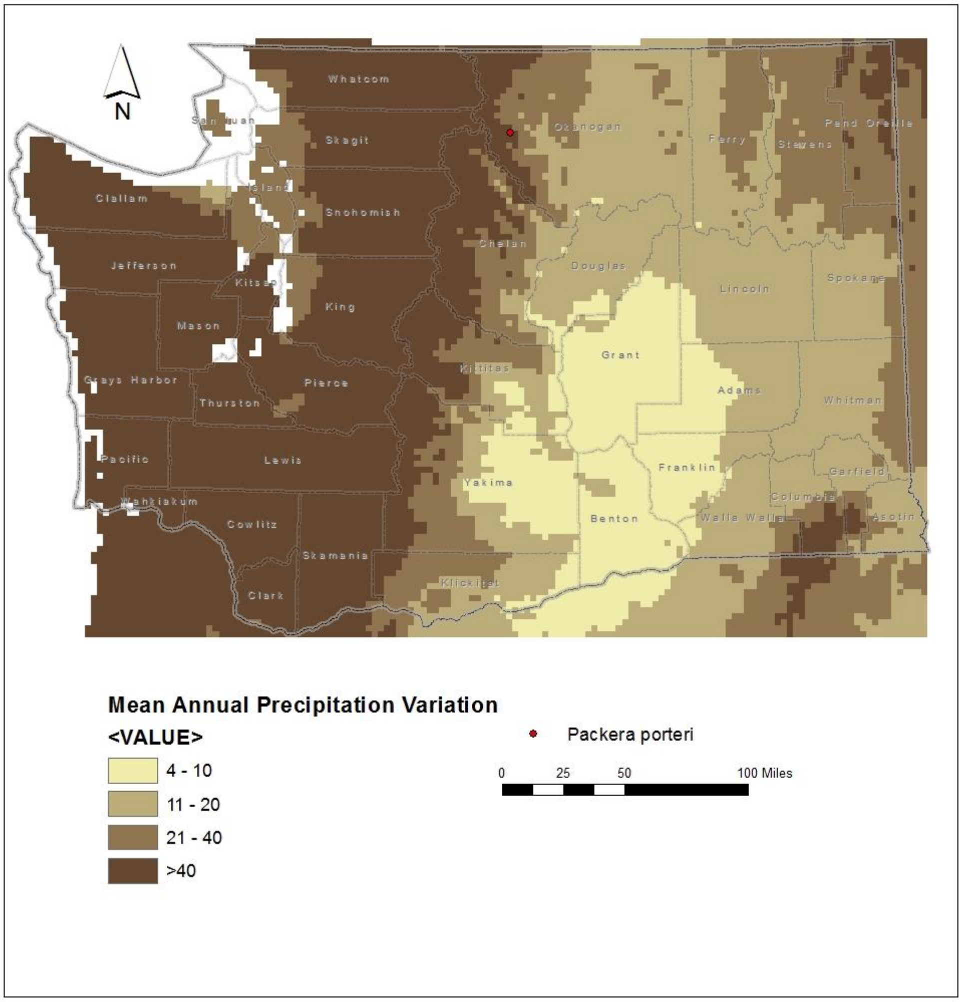

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Packera porteri* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a strongly seasonal hydrologic regime or specific wetland habitats (but see “Dependence on ice or snow-cover habitats” below).

C2c. Dependence on a specific disturbance regime: Neutral.
Packera porteri occurs in alpine talus and scree habitats that are subject 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: Somewhat Increase.
The population of *Packera porteri* in Washington is found in alpine talus slopes that accumulate snow in winter and are dependent on gradual thawing of snowfields for moisture in the growing season. Some areas, however, may be snow free due to wind. Reduced snowpack due to climate change would reduce the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Packera porteri is restricted to the Midnight Peak Formation, a type of volcanic basalt found sporadically in the Okanogan Range in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The alpine talus habitat occupied by *Packera porteri* 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.
The exact pollinators of *Packera porteri* have not been documented, but other *Packera* and *Senecio* species have unspecialized inflorescences that can be pollinated by a wide variety of insects, including bees, flies, butterflies, and beetles.

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds of *Packera porteri* are wind dispersed.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Under present conditions, competition from non-native species is minimal, 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.
No genetic data are available for *Packera porteri* populations from Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Somewhat Increase
Packera porteri is presumed to be an outcrosser with good dispersal ability by its small, wind-blown fruits. In theory, it should have average genetic diversity across its range. Populations in Washington and northeastern Oregon are significantly disjunct from the core range of the

species in the southern Rocky Mountains of Colorado (Trock 2003). These isolated occurrences probably have a subset of the species' full genome due to founder effects or inbreeding depression. As a result, genetic diversity in Washington is probably low and the species is at somewhat increased vulnerability to climate change in the state.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records from the Consortium of Pacific Northwest herbaria website, no changes in the phenology of *Packera porteri* populations in Washington have been detected.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
Significant changes in the distribution of *Packera porteri* have not been documented.

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

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Climate Change Vulnerability Index Report

Parnassia kotzebuei (Kotzebue's grass-of-Parnassus)

Date: 21 February 2020

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	**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	50
	-0.074 to - 0.096	50
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Greatly Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		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/Somewhat Increase

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

Section A: Exposure to Local Climate Change

A1. Temperature: All four extant and historical occurrences of *Parnassia kotzebuei* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

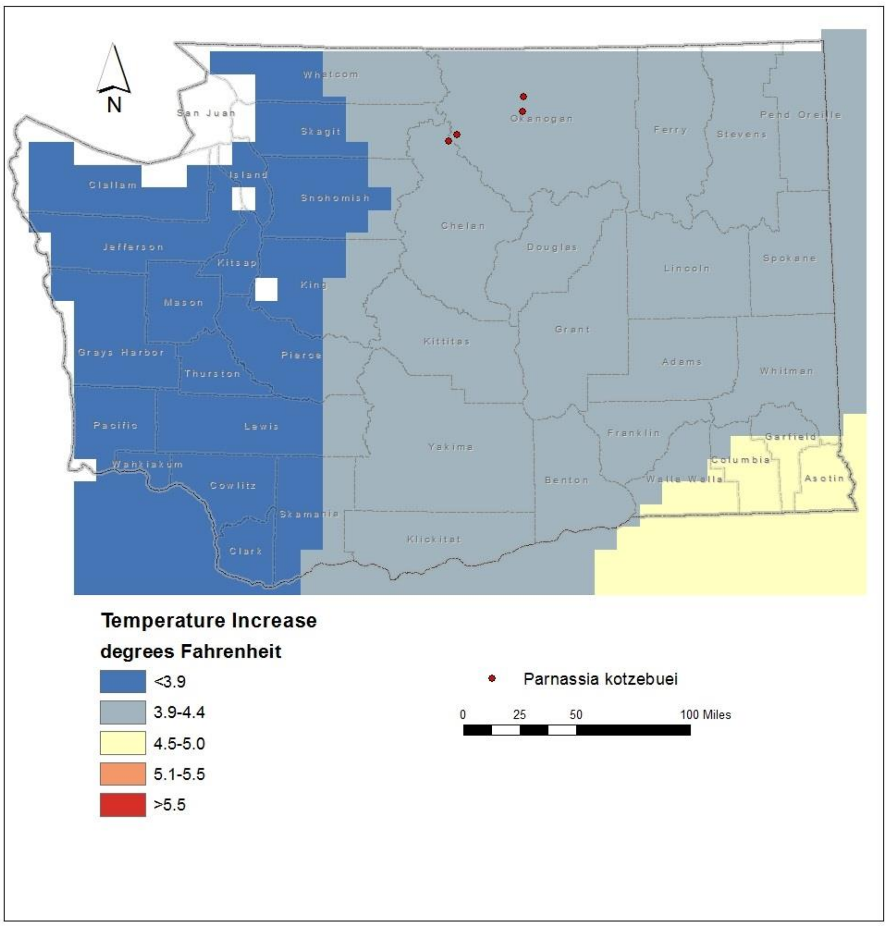

Figure 1. Exposure of *Parnassia kotzebuei* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the four occurrences of *Parnassia kotzebuei* (50%) in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). The other 50% of the state's occurrences are in areas with a projected decrease in AET:PET of – 0.074 to – 0.096.

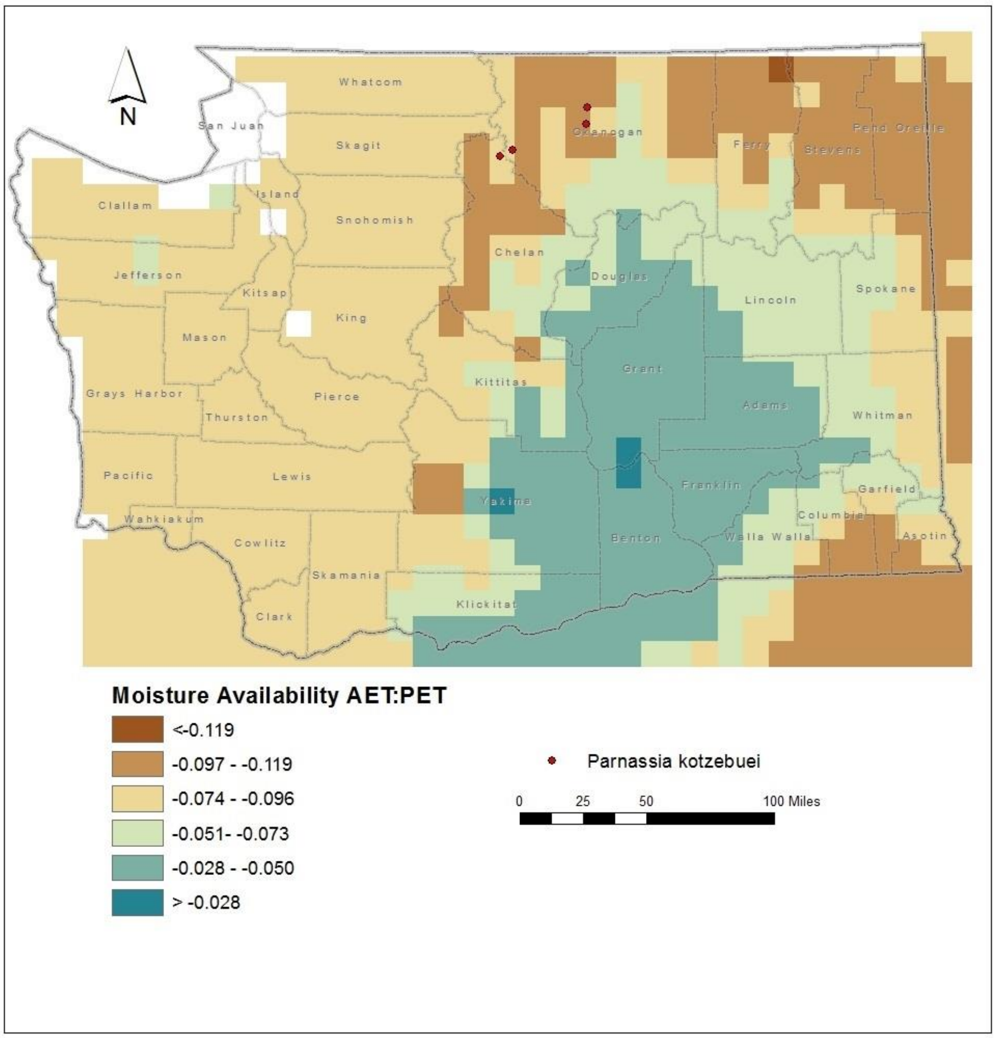

Figure 2. Exposure of *Parnassia kotzebuei* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The Washington occurrences of *Parnassia kotzebuei* are found at 4800-6700 feet (1460-2030 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Parnassia kotzebuei* is found on shady, moist, north-facing talus slopes or ledges of granitic or gneiss cliffs with high cover of moss and forbs but without shrubs or trees (Camp and Gamon 2011, Fertig and Kleinknecht 2020). These sites are mostly in the upper subalpine zone. This habitat is a component of the Rocky Mountain Alpine Dwarf Shrubland, Fell-Field, and Turf ecological system (Rocchio and Crawford 2015). Washington occurrences are separated by distances of 4.5-30 miles (7.4-49 km) and extensive areas of unsuitable habitat. The natural patchiness of the habitat creates a barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
Human impacts in the alpine and subalpine areas of the Okanogan Plateau and North Cascades are limited and do not impose a significant barrier.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Parnassia kotzebuei produces fruit capsules and numerous small seeds that lack any physical structures to assist with dissemination by wind or animals. Seeds are dispersed primarily by water, wind, and gravity (Spackman Panjabi and Anderson 2007). Dispersal distances are probably relatively short (less than 1000 m).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Parnassia kotzebuei* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Two extant occurrences (50%) 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. The other occurrences (one extant and one historical) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature change and would be at somewhat increased vulnerability to climate change (Young et al. 2016). Based on the greater number of extant populations being at increased risk, this factor is scored as such for the whole state.

C2aii. Physiological thermal niche: Greatly Increase.
The north-facing subalpine rock ledge habitat of *Parnassia kotzebuei* is strongly correlated with cold air drainage during the growing season and would have greatly increased vulnerability to climate change.

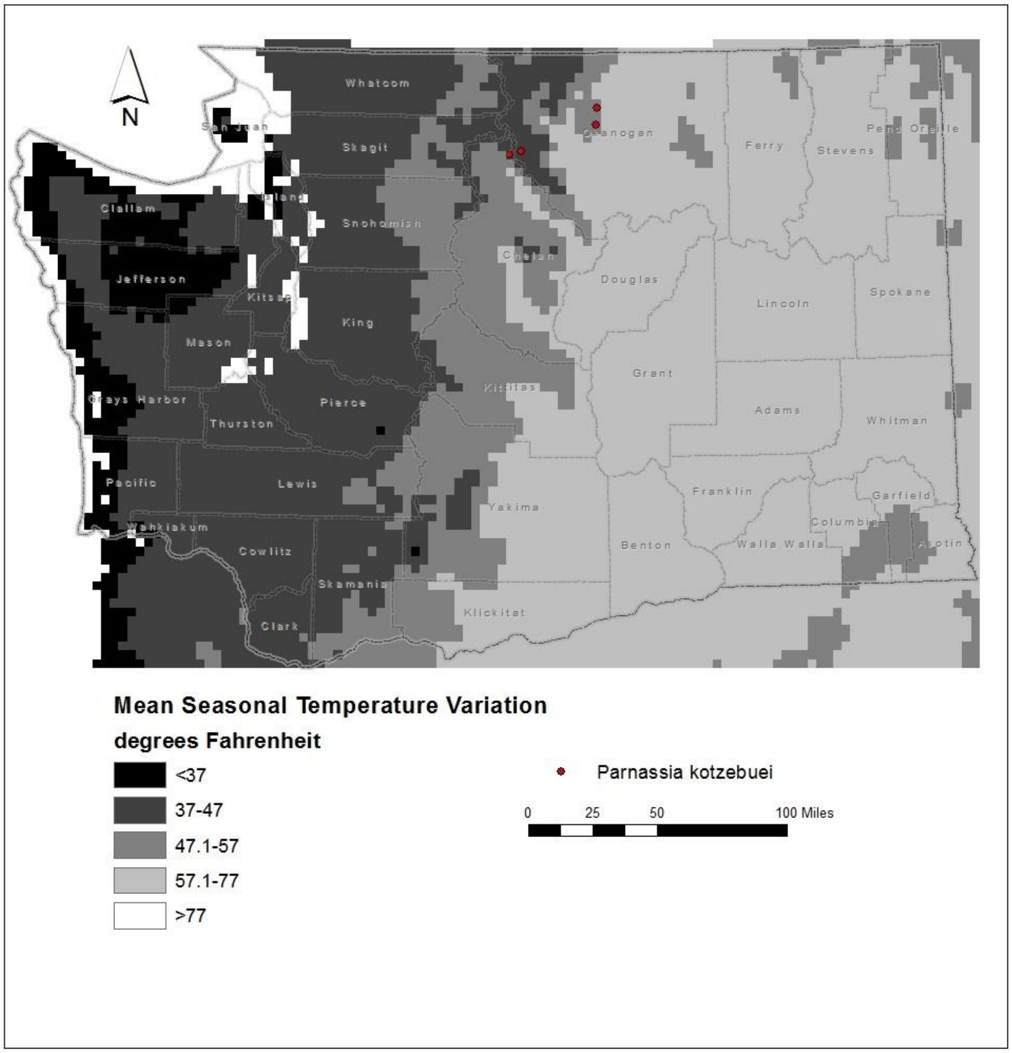

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Parnassia kotzebuei* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All four populations of *Parnassia kotzebuei* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/5080 mm) precipitation variation over the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at neutral vulnerability to climate change.

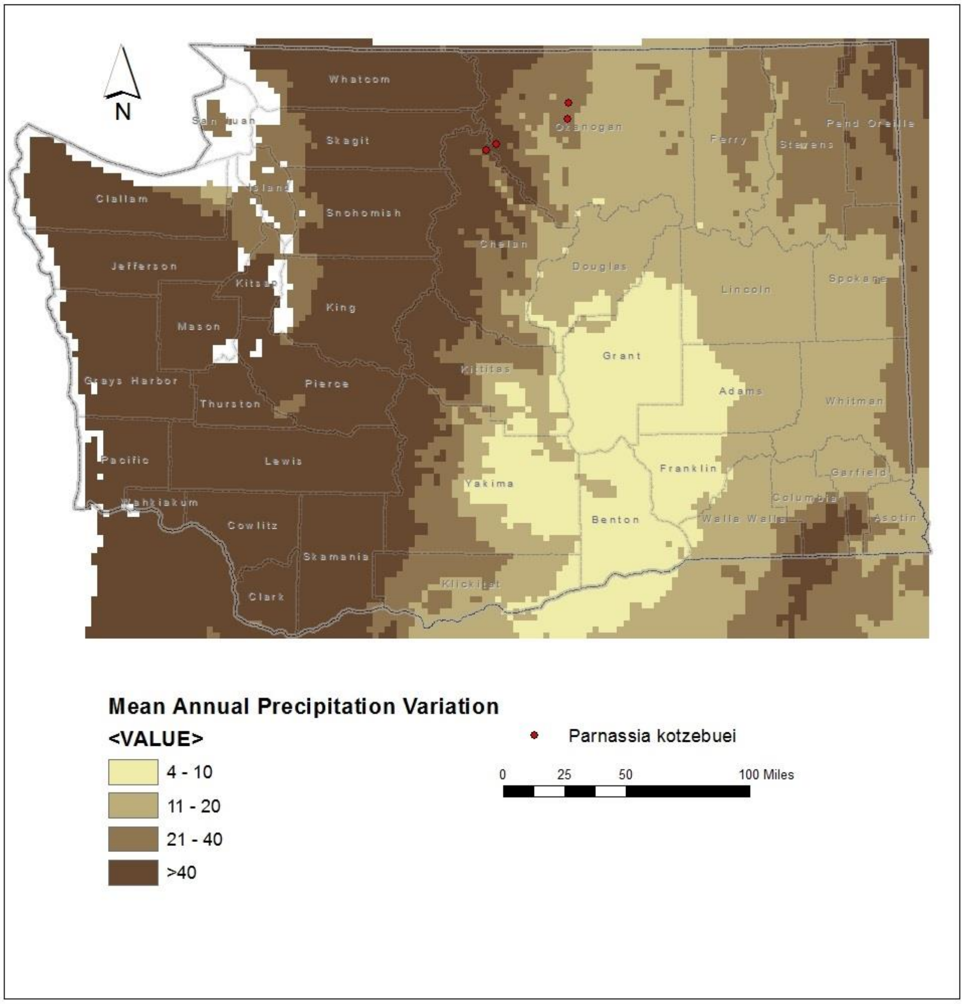

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Parnassia kotzebuei* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is often associated with small seeps that keep the habitat moist year round. The ultimate source of this moisture is precipitation and slow-melting snow. Changes in the amount and timing of precipitation could be detrimental to the habitat of *Parnassia kotzebuei*, allowing shrubs or dry meadow species to displace alpine talus and rock field taxa (Rocchio and Ramm-Granberg 2017). See "Dependence on ice or snow-cover habitats" below.

C2c. Dependence on a specific disturbance regime: Neutral.
Parnassia kotzebuei occurs in alpine rock ledge and scree habitats that are potentially subject 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: Somewhat Increase.
The populations of *Parnassia kotzebuei* in Washington are found in subalpine talus and cliff sites associated with springs and seeps that are derived from late-lying and slow-melting snow for moisture in the growing season. Reduced snowpack due to climate change would lessen the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Parnassia kotzebuei is found mostly on gneiss talus or cliff ledges on shady, north-facing aspects. Although the geologic substrate is widespread, the combination of rock type, aspect, and moist seeps is uncommon and widely scattered, accounting for the sporadic distribution of this species.

C4a. Dependence on other species to generate required habitat: Neutral
The subalpine talus/cliff habitat occupied by *Parnassia kotzebuei* 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.
The specific pollinators of *Parnassia kotzebuei* are not known, but related species of *Parnassia* are pollinated by flies, bees, and ants (Spackman Panjabi and Anderson 2007). *Parnassia* species are primarily outcrossers and protandrous (pollen ripens on the flower before the stigmas are fertile), but selfing is possible.

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds off *Parnassia kotzebuei* are primarily passively dispersed by wind, water, or gravity and are not dependent on animal species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. The cliff and talus habitat of *Parnassia kotzebuei* are difficult to access for domestic livestock, and threats from grazing are probably very low (Spackman Panjabi and Anderson 2007). Impacts from native grazers are poorly known, but probably low.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Under present conditions, competition from non-native species is minimal, as few introduced plants are adapted to the harsh environmental conditions of subalpine talus slopes and cliffs. 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.
No genetic data are available for *Parnassia kotzebuei* populations from Washington. Washington populations from Okanogan County have been recognized as a separate variety (var. *pumila*) distinguished from typical var. *kotzebuei* based on the shape of the staminodia (sterile stamens) in the flower and degree of venation of the petals (Hitchcock and Cronquist 1961). Var. *pumila* is not currently recognized as taxonomically distinct (Hitchcock and Cronquist 2018), and the genetic basis of the morphological differences have not been determined, but it is plausible that Washington populations have diverged from those in adjacent states and provinces.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral/Somewhat Increase
Parnassia kotzebuei is presumed to be an outcrosser with modest seed dispersal ability. Pollen vectors could potentially travel over 1 km (Spackman Panjabi and Anderson 2007). Populations in Washington and elsewhere in the Rocky Mountains are often widely scattered and isolated, suggesting that gene flow between occurrences is probably low and individual populations may have reduced genetic diversity due to inbreeding depression or the legacy of founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Based on herbarium records from 1978-2007 in the Consortium of Pacific Northwest herbaria website, *Parnassia kotzebuei* populations in Washington flower from late July to early August. Earlier records from 1939-1958 indicate flowering occurring from late June to mid July.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral?
Significant changes in the distribution of *Parnassia kotzebuei* have not been documented. One of the four known occurrences in Washington is considered historical (last found in 1980) and may be extirpated, as it has not been relocated in repeat visits by Rare Care volunteers from 2004-2018. The other three occurrences have all been relocated since 2004 (most recently in 2018) (Fertig and Kleinknecht 2020). Whether climate change or other factors are responsible for the loss of one population 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

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Climate Change Vulnerability Index Report

Pedicularis rainierensis (Mt. Rainier lousewort)

Date: 14 April 2020

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	**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	76.5
	<3.9° F (2.2°C) warmer	23.5
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		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/Somewhat Increase
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: Thirteen of the 17 occurrences of *Pedicularis rainierensis* in Washington (76.5%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). Four other occurrences (23.5%) are from areas with a projected temperature increase <3.9˚ F.

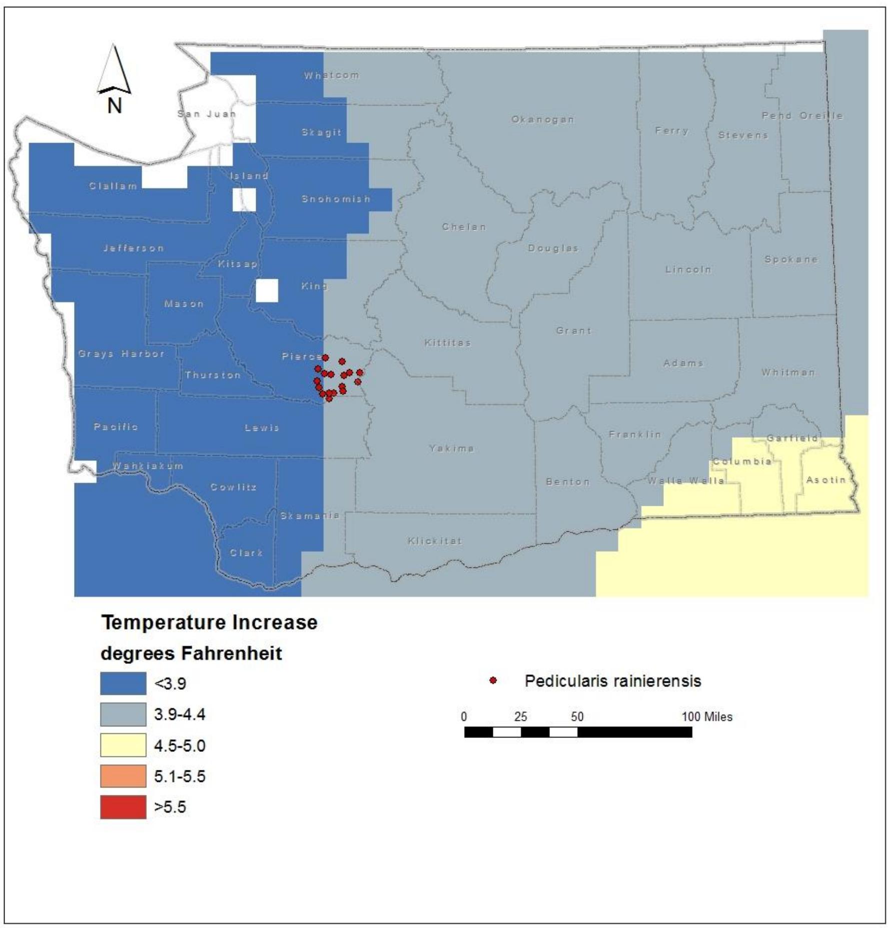

Figure 1. Exposure of *Pedicularis rainierensis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 17 of the occurrences of *Pedicularis rainierensis* (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).

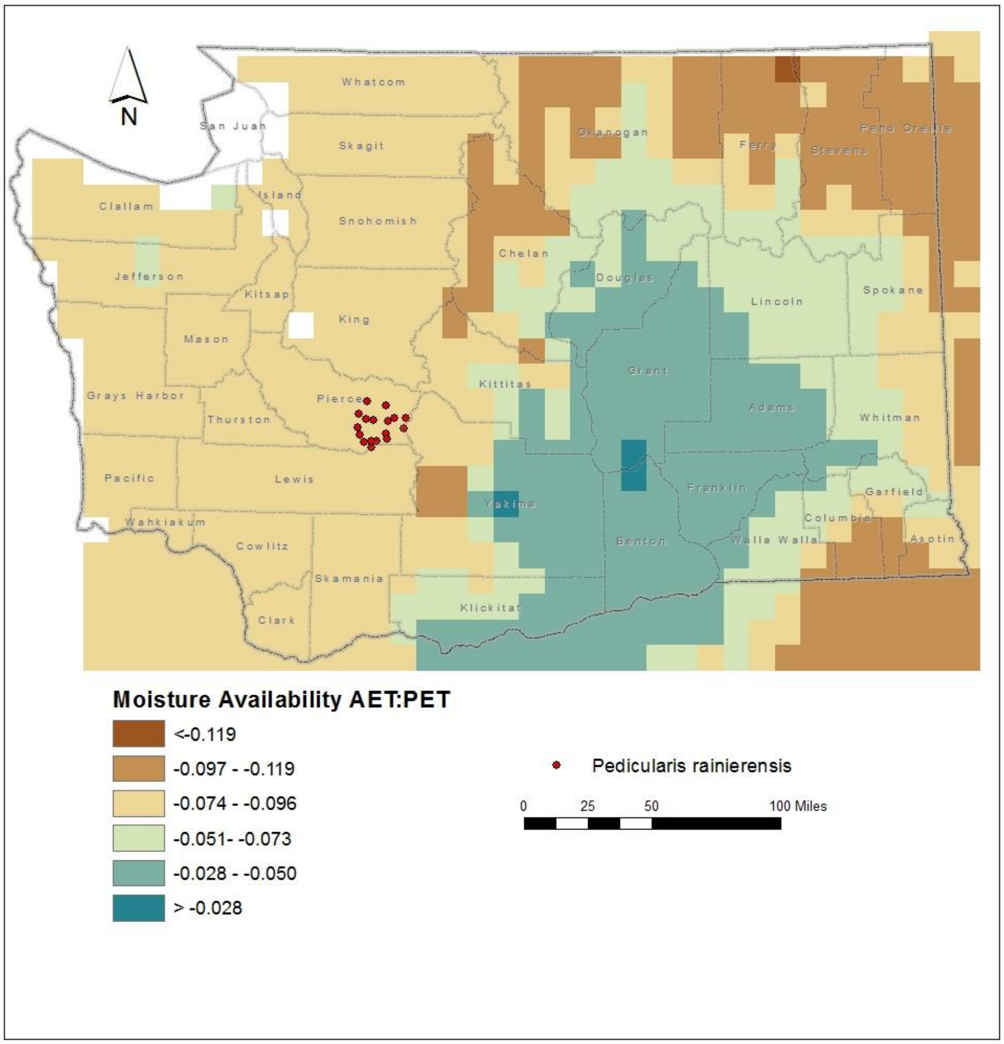

Figure 2. Exposure of *Pedicularis rainierensis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Pedicularis rainierensis* are found at 4800-6800 feet (1400-2100 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Pedicularis rainierensis* is found in subalpine or alpine moist meadows, rocky slopes, and openings in Subalpine fir and Mountain hemlock forests on deep loam, moist talus, or gravel on the slopes of Mount Rainier (Camp and Gamon 2011, Fertig and Kleinknecht 2020). This habitat most closely matches the North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field and Meadow ecological system (Rocchio and Crawford 2015). Washington occurrences often consist of a series of subpopulations separated by less than 0.1 miles. Other populations may be up to 6 miles (8.4 km) apart. Patches of suitable habitat are separated by extensive areas of subalpine forest and steep valleys that present a barrier to gene flow.

B2b. Anthropogenic barriers: Neutral.
The entire range of *Pedicularis rainierensis* is restricted to the slopes of Mount Rainier and vicinity. This area has few permanent anthropogenic barriers 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.
Pedicularis rainierensis produces dry, capsule fruits containing 20-25 small seeds that are dispersed passively by wind or gravity. Average distances may be relatively short, but a small fraction of seed could disperse over 100 meters.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Pedicularis rainierensis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 17 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 vulnerability to climate change (Young et al. 2016).

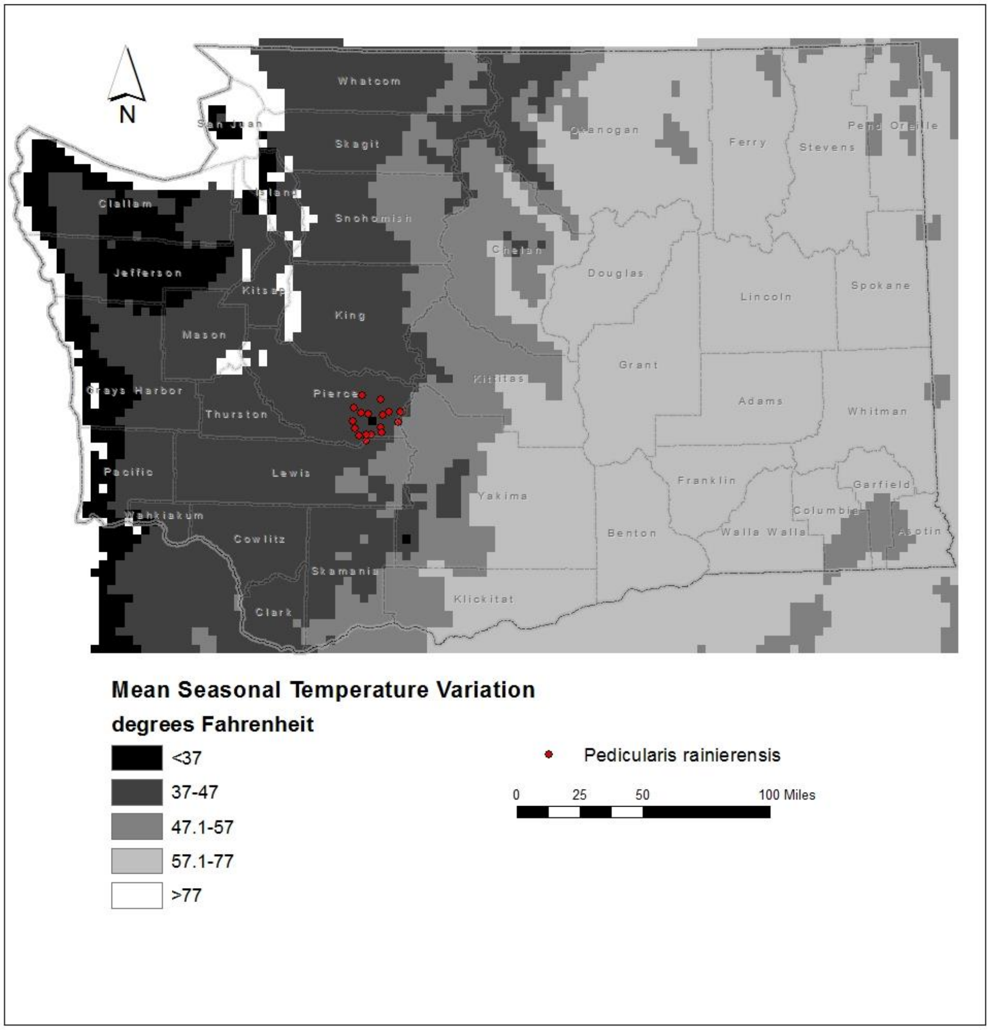

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Pedicularis rainierensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The subalpine/alpine meadow habitat of *Pedicularis rainierensis* is associated with cold air drainage during the growing season and would have increased vulnerability to temperature changes from climate change.

C2bi. Historical hydrological niche: Neutral.
All 17 of the populations of *Pedicularis rainierensis* in Washington (100%) are found in areas that have experienced greater than average (>20 inches/508 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.

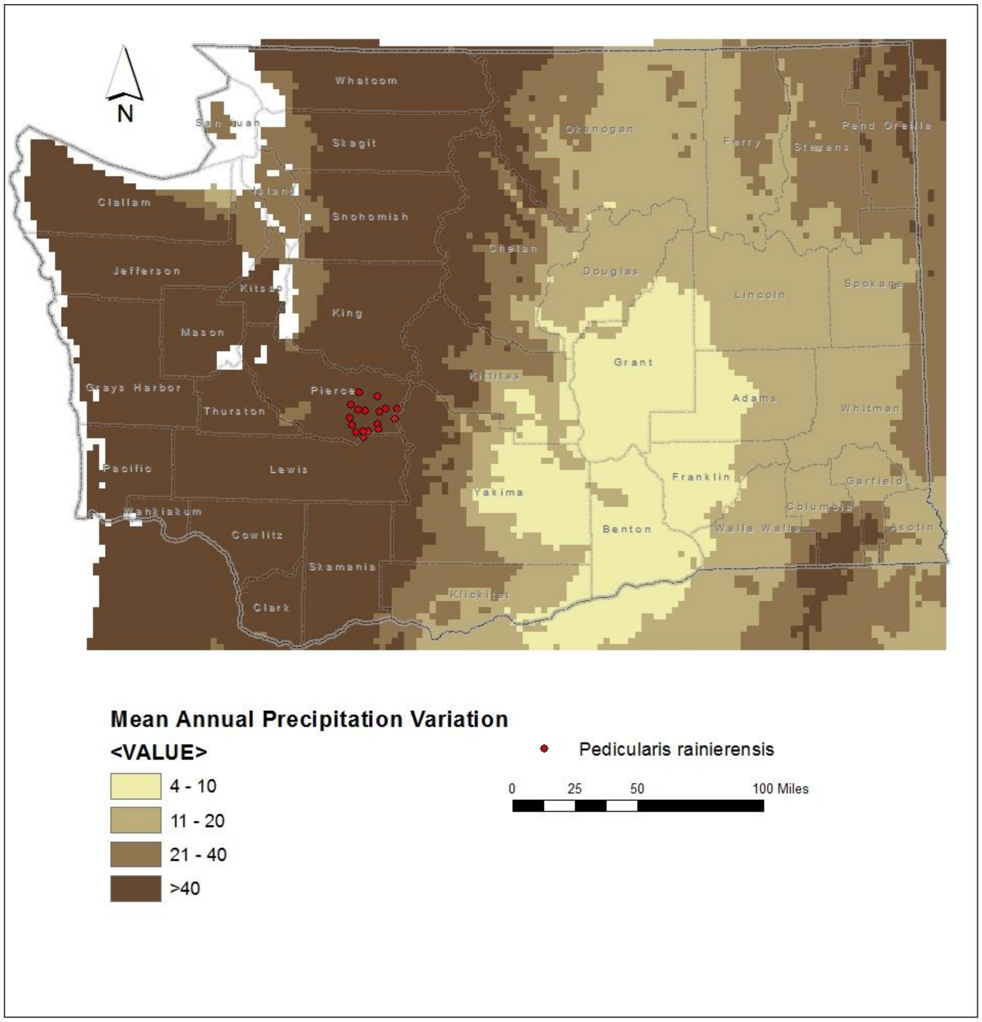

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Pedicularis rainierensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is dependent on adequate growing season moisture from melting snow and summer precipitation. Hotter temperatures and reductions in the amount and timing of summer rainfall and reduction in the amount of snowfall or the timing of snowmelt could disrupt growth and flowering of alpine and subalpine plant species or make mesic meadow sites more vulnerable to

displacement by conifer forest or drier meadows (Rocchio and Ramm-Granberg 2017). See also "Dependence of ice or snow-cover habitats below.

C2c. Dependence on a specific disturbance regime: Neutral.
Pedicularis rainierensis is not dependent on periodic disturbances to maintain its subalpine/alpine mesic meadow habitat.

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Pedicularis rainierensis* in Washington occur at the subalpine/alpine ecotone in moist meadows on the slopes of Mount Rainier. These sites are highly dependent on moisture from late-lying snowbanks (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow or the timing of snow melt could lead to shifts in the dominance of herbaceous species or invasion of trees or shrubs.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Pedicularis rainierensis is restricted to high elevation outcrops of Quaternary andesite, Holocene debris flows, and Miocene and Oligocene-age andesite and rhyolite deposits on the slopes of Mount Rainier. Similar deposits are found on Mount Adams but are otherwise not extensive in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Pedicularis rainierensis* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral/Somewhat Increase.
Macior (1973) observed five different bumblebee (*Bombus*) species pollinating *Pedicularis rainierensis*, although the majority of pollination was conducted by just three species (*Bombus bifarius, B. melanopygus,* and *B. occidentalis*). Pollination was done primarily by worker bees found inverted within the galea beak of the corolla or rarely by queens or workers collecting nectar and pollen in flight. Hummingbirds are also attracted to *P. rainierensis* for nectar (Macior 1973). Bee foraging behavior and fidelity to a particular *Pedicularis* species and differences in the timing of flowering traditionally helped prevent hybridization among the six native taxa of *Pedicularis* on Mount Rainier (Adams 1983, Macior 1973). More recently, hybrids between *P. rainierensis* and *P. bracteosa* have been found on Mount Rainier as the range of *P. bracteosa* has begun to move higher upslope (Fertig and Kleinknecht 2020). The long-term persistence of native *Bombus* species in light of climate change is poorly known.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds are released passively by wind when the dry capsule fruits are mature and split open.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Disease, trampling, and grazing by elk and marmots have been identified as potential threats (Camp and Gamon 2011, Fertig and Kleinknecht 2020).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Pedicularis rainierensis may be hybridizing with *P. bracteosa* where the two species now overlap on Mount Rainier and barriers to pollen exchange due to timing of flowering or pollinator behavior break down (Adams 1983, Macior 1973).   Climate change is likely to increase competition from meadow species or invasive trees and shrubs if subalpine/alpine wet meadow sites become drier or have reduced snowpack (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral.
Mulvey and Hansen (2011) found no evidence that *Pedicularis rainierensis* is a potential telial host for white pine blister rust (*Cronartium ribicola*) in whitebark pine in Mount Rainier National Park.

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

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Pedicularis rainierensis produces showy, insect-pollinated flowers and is an obligate outcrosser (Macior 1973). It is likely to have average genetic variability based on these life history parameters.

C6. Phenological response to changing seasonal and precipitation dynamics: Somewhat Increase.
Macior (1973) reported the flowering season for *Pedicularis rainierensis* at his study sites on Mount Rainier to be from July 22 to August 10. Since 1973, this species has been documented to flower as early as June 23 and as late as August 16 (Consortium of Pacific Northwest Herbaria database records).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Neutral.
No significant changes have been documented.

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

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Climate Change Vulnerability Index Report

Pediocactus nigrispinus (Snowball cactus)

Date: 18 April 2020

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	**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	5.55
	-0.051 to - 0.073	5.55
	-0.028 to -0.050	88.9
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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/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/Somewhat Increase
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 36 of the occurrences of *Pediocactus nigrispinus* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

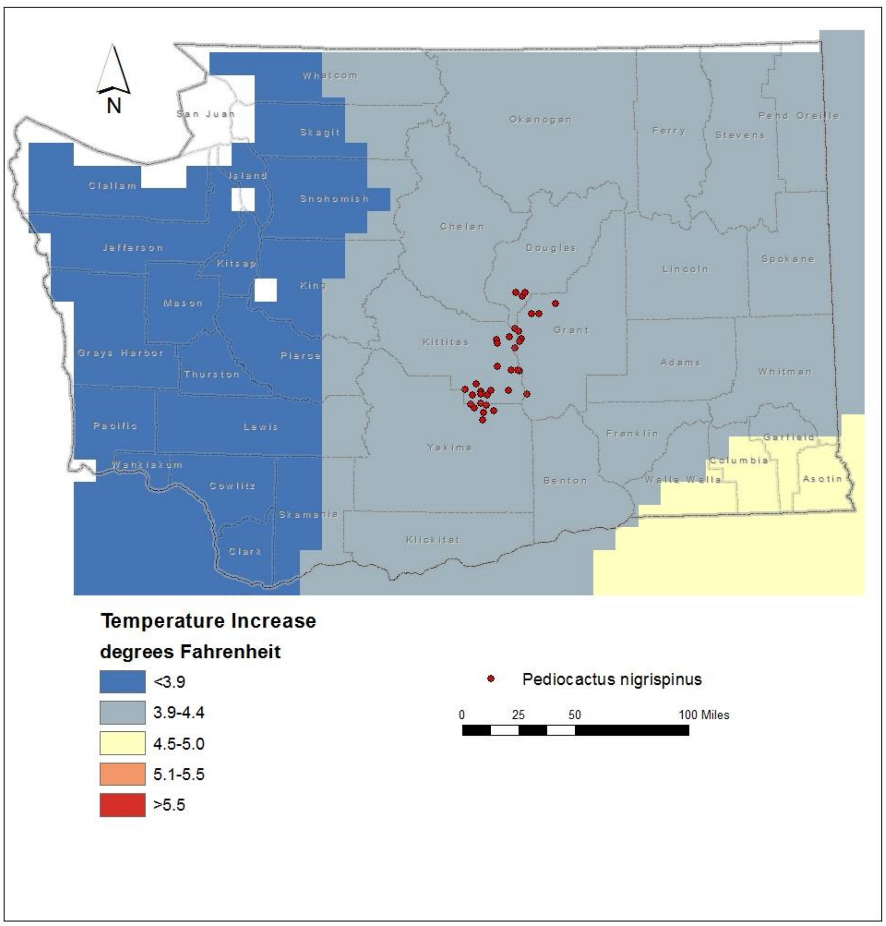

Figure 1. Exposure of *Pediocactus nigrispinus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Thirty-two of the 36 occurrences of *Pediocactus nigrispinus* (88.9%) 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 -0.028 to -0.050 (Figure 2). Two populations (5.55%) are from areas with a projected decrease in the range of -0.051 to -0.073 and two others (5.55%) are from areas with a predicted decrease of -0.074 to -0.096 (Figure 2).

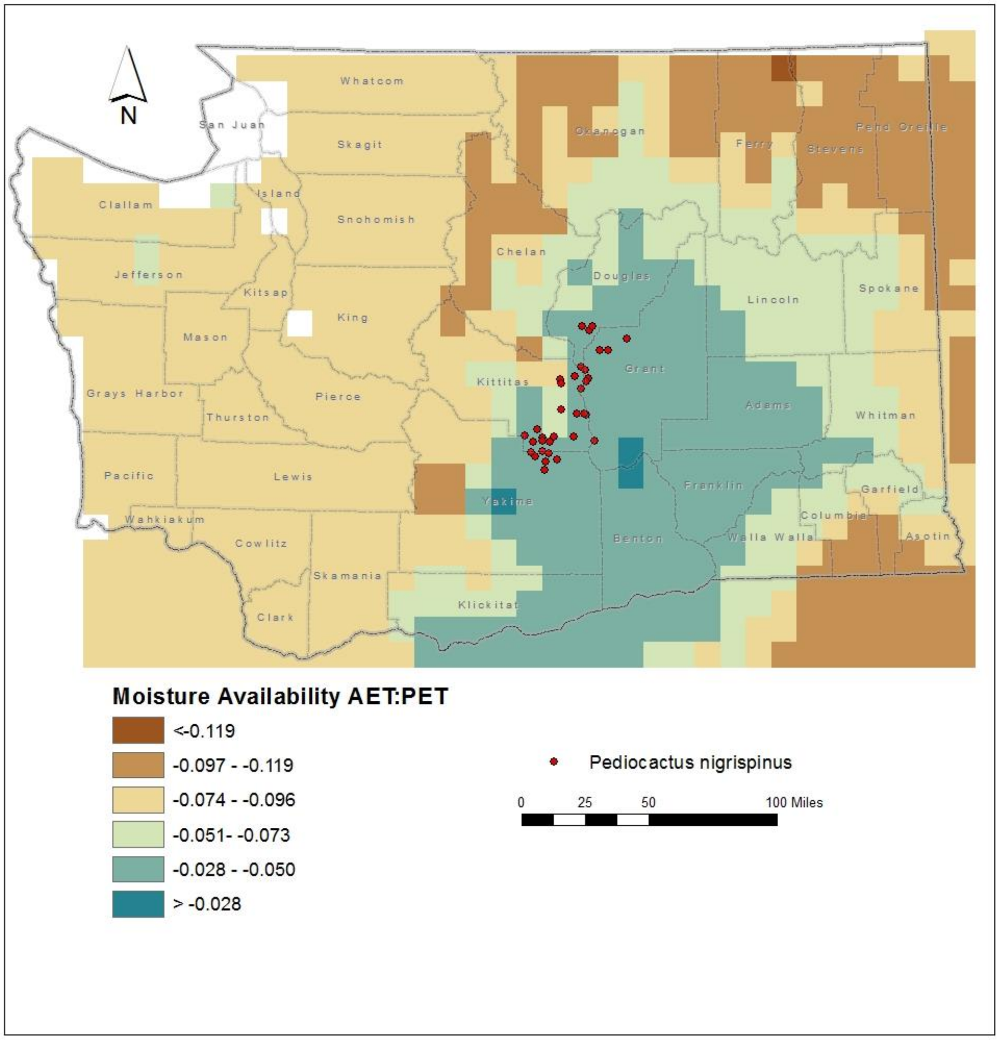

Figure 2. Exposure of *Pediocactus nigrispinus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Pediocactus nigrispinus* are found at 600-4000 feet (200-1200 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Pediocactus nigrispinus* occurs on basalt outcrops and slopes in scabland areas with thin soil or gravelly lithosols. These sites are usually dominated by *Artemisia rigida* or *Artemisia tridentata* with *Eriogonum thymoides, Poa secunda*, and *Pseudoroegneria spicata* (Bockelman 2020, Fertig and Kleinknecht 2020, WNHP 2005). This habitat conforms with the Columbia Plateau Scabland Shrubland ecological system (Rocchio and Crawford 2015). Washington populations often consist of a series of subpopulations separated by less than 0.1 miles. Other populations may be up to 8 miles (13 km) apart. The areas occupied by this species are isolated primarily by natural barriers.

B2b. Anthropogenic barriers: Neutral.
The range of *Pediocactus nigrispinus* is naturally fragmented. Human impacts on the landscape of central Washington have contributed to this condition, but overall are of less significance 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: Somewhat Increase.
Pediocactus nigrispinus produces berry-like fruits with multiple small seeds that are released passively as the fruit dries at maturity. Ants have been observed transporting seeds and storing them underground (Bockelmann 2020). Dispersal distances are probably relatively short (100-1000 m at most).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Pediocactus nigrispinus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Thirty-four of the 36 occurrences (94.4%) 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). Two other populations (5.6%) 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.

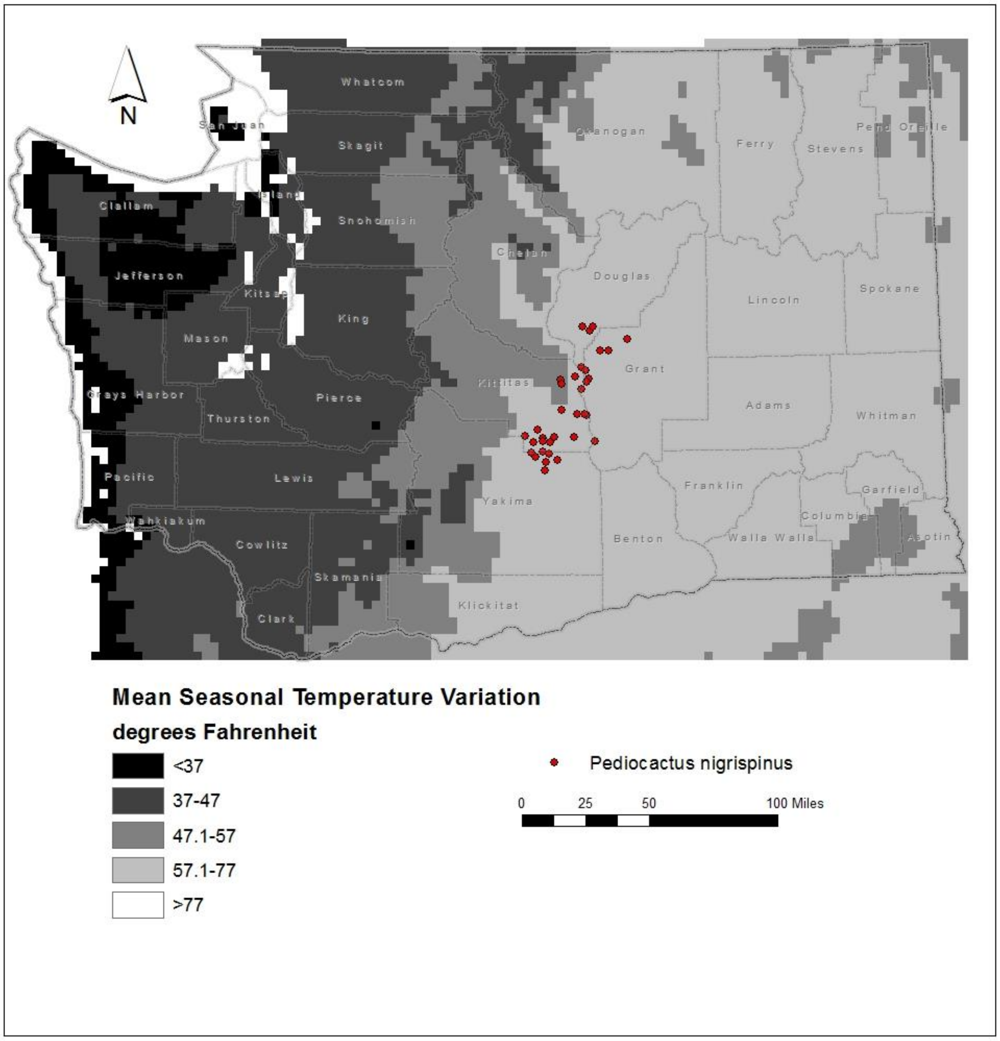

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Pediocactus nigrispinus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The basalt ridge and sagebrush steppe habitat of *Pediocactus nigrispinus* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Increase.
Twenty-five of the 36 populations of *Pediocactus nigrispinus* in Washington (69.4%) 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. Nine other populations (25%) have experienced slightly lower than average (11-20 inches/255-508 mm) precipitation variation over the same period and are at somewhat increased vulnerability (Figure 4), while two occurrences (5.6%) have experienced average (>20 inches/508 mm) precipitation variation and are at neutral vulnerability.

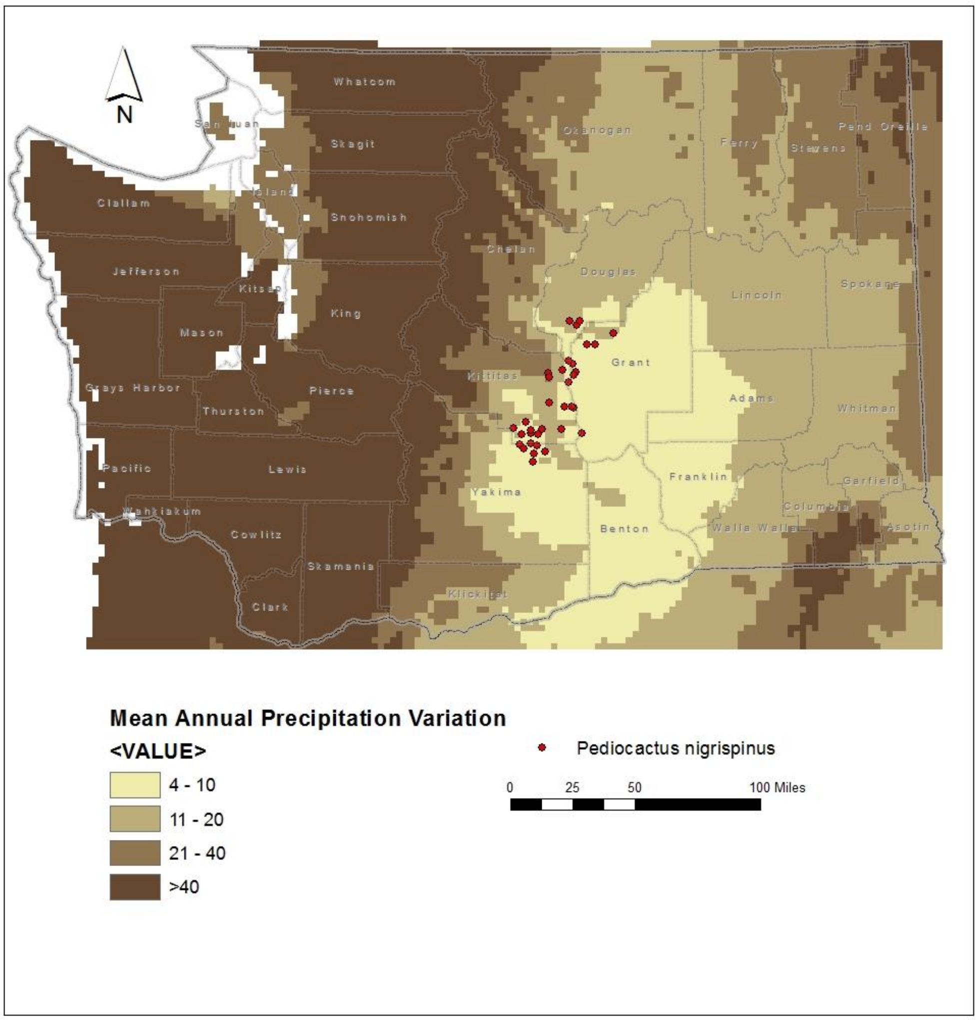

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Pediocactus nigrispinus* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Pediocactus nigrispinus populations occur on scabland lithosol ridges and slopes in areas without springs, streams, or a high water table. These sites are dependent on winter snow and fall and spring precipitation for a large proportion of their yearly water budget. Changes in the timing of snowmelt or the amount of precipitation could make these sites drier in the future and subject to displacement by lichens or invasive annuals (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Pediocactus nigrispinus occurs in areas that are sparsely vegetated due to shallow soils, freeze-thaw, and summer drought. These areas are not dependent on episodic disturbances, such as wildfire, for perpetuation.

C2d. Dependence on ice or snow-cover habitats: Neutral/Somewhat Increase.
Bockelman (2020) notes that *Pediocactus nigrispinus* tends to be most abundant in areas where winter snowdrifts are present and provide supplemental moisture in the spring after they melt. Overall, snow cover is low in this plant's habitat in central Washington.

C3. Restricted to uncommon landscape/geological features: Neutral.
Pediocactus nigrispinus occurs primarily on outcrops of the Miocene-age Grande Ronde and Wanapum basalt, Quaternary alluvium, and Pleistocene Lake Missoula flood deposits, all of which are common geologic formations in central Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The scabland shrubland habitat occupied by *Pediocactus nigrispinus* 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.
Pediocactus nigrispinus is pollinated primarily by small sweat bees (Bockelman 2020). The large flowers with numerous stamens are unspecialized and could potentially be pollinated by many insect species.

C4d. Dependence on other species for propagule dispersal: Neutral/Somewhat Increase.
Dried fruits of *Pediocactus nigrispinus* split open at maturity to release numerous small seeds. Dispersal can be augmented by ants, which carry seeds to their underground nests for food (some seeds are not eaten and become planted by the ants) (Bockelman 2020). Seed may also be transported passively by wind or gravity.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is not vulnerable to herbivory, but could be impacted by trampling.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Pediocactus nigrispinus occurs in sparsely vegetated lithosol ridges and slopes with low cover or competition from other plant species. Climate change and increased fire frequency could shift the species composition towards invasive annual 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.
Data are not available on the genetic diversity of this species in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Pediocactus nigrispinus is probably an obligate outcrosser and likely to have moderate amounts of genetic diversity. Washington populations are isolated from those in Oregon and Idaho and might be expected to be diverging genetically.

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: Somewhat Increase.
The range of *Pediocactus nigrispinus* has contracted, with three disjunct occurrences from south-central Yakima County not being relocated for more than 40 years and possibly extirpated. Whether this absence is due to climate change, local exploitation, or is an artifact of incomplete survey 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

Bockelman, R. 2020. *Pediocactus nigrispinus* – Washington's only ball cactus. Douglasia 44(1): 2.

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.

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[WNHP]. Washington Natural Heritage Program. 2005. Field Guide to Washington's Rare Plants 2005. Washington Natural Heritage Program and USDI Bureau of Land Management. (http://dnr.wa.gov/publications/amp_nh_isomin.pdf).

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 wilcoxii (Wilcox's beardtongue)

Date: 24 February 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	12.5
	3.9-4.4° F (2.2-2.4°C) warmer	75
	<3.9° F (2.2°C) warmer	12.5
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	25
	-0.074 to - 0.096	50
	-0.051 to - 0.073	25
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Somewhat Increase/Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase/Neutral
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		Neutral
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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: Six of the eight occurrences of *Penstemon wilcoxii* in Washington (75%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). One population (12.5%) occurs in an area with a predicted temperature increase of <3.9˚ F and one historical occurrence (12.5%) is from an area with a predicted temperature increase of 4.5-5.0˚ F.

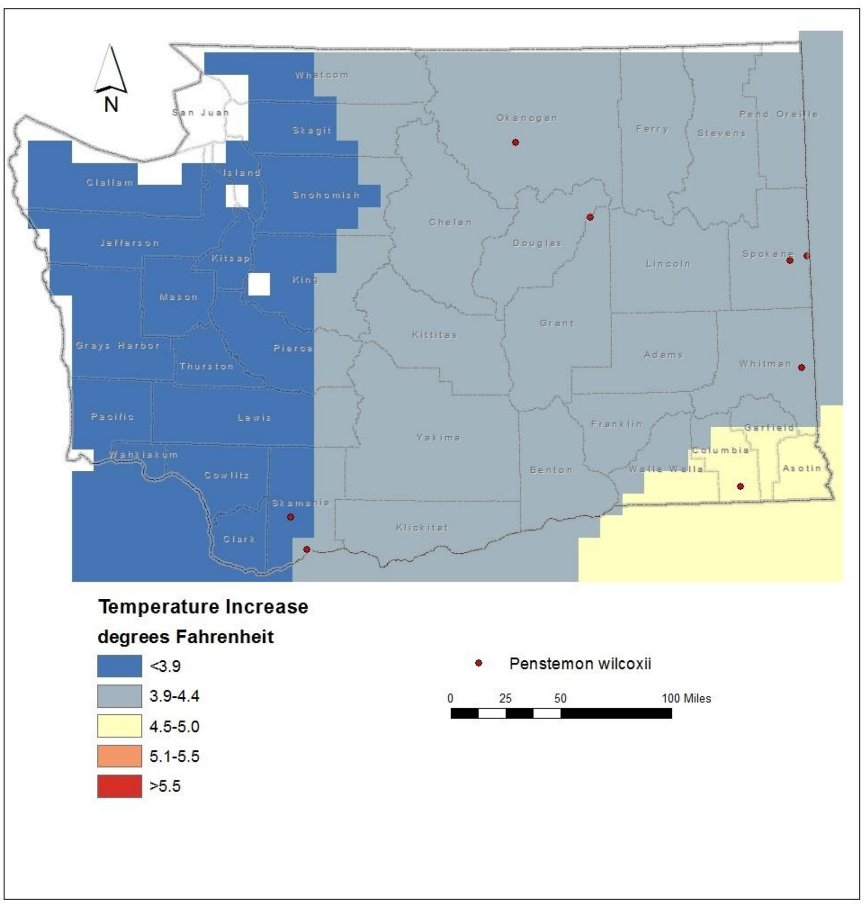

Figure 1. Exposure of *Penstemon wilcoxii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the eight Washington occurrences of *Penstemon wilcoxii* (50%) 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 occurrences (25%) are found in areas with a projected decrease in moisture of -0.097 to -0.119 and two others (25%) are from areas with a projected decrease of -0.051 to -0.073.

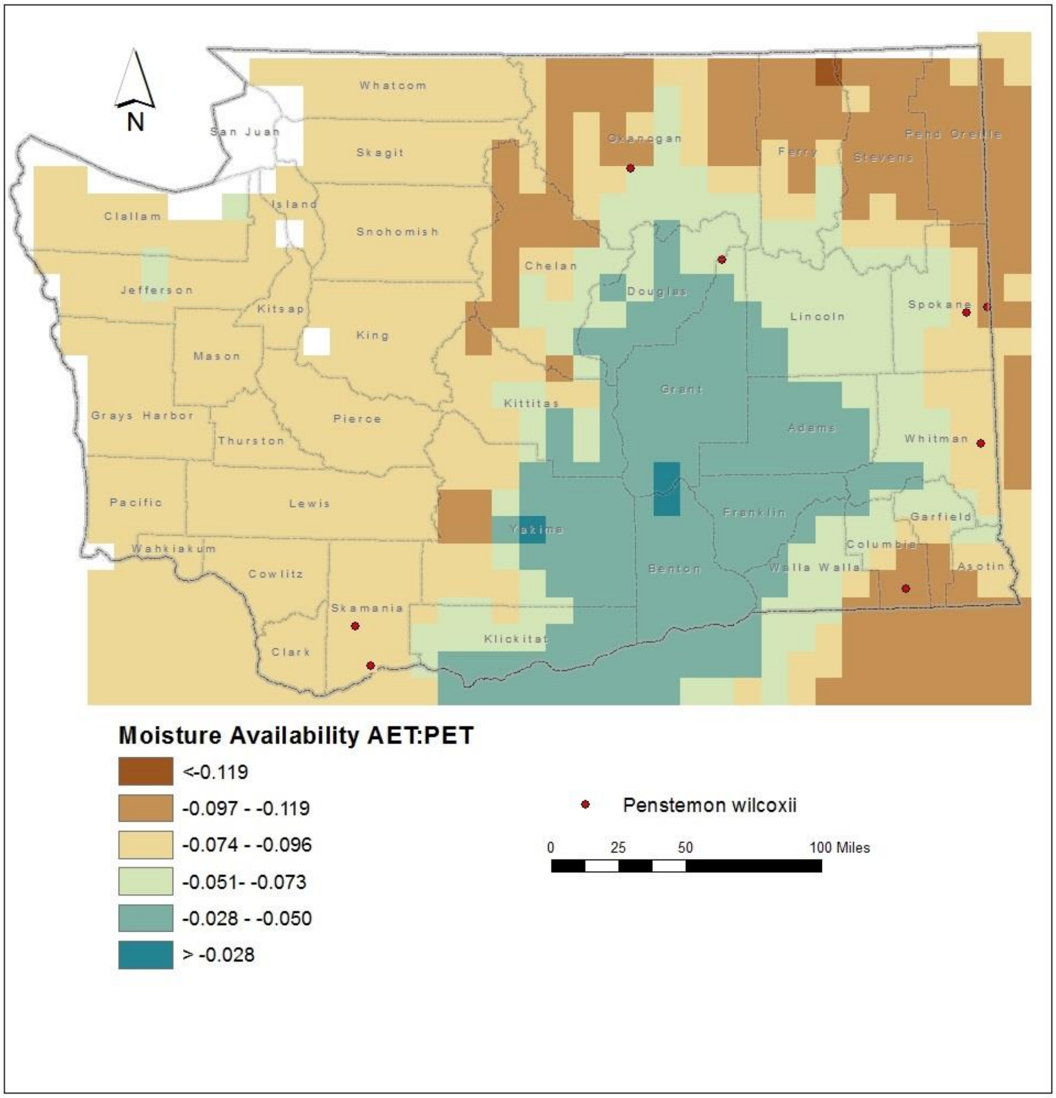

Figure 2. Exposure of *Penstemon wilcoxii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Penstemon wilcoxii* are found at 200-4200 feet (60-1280 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Penstemon wilcoxii* is found mostly on moist, shady, rocky sites or cliffs in conifer forests dominated by Douglas-fir or Ponderosa pine or shrublands (Camp and Gamon 2011, WNHP records). This habitat is most similar to the Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest ecological system (Rocchio and Crawford 2015). Individual populations occupy small areas and are separated from each other by 13-320 km (7.5-200 miles). The habitat is not specialized, and populations are widely scattered, suggesting that the species may be under-sampled or is rare for reasons besides lack of habitat (such as over-collection or hybridization with other species; Fertig and Kleinknecht 2020). Based on available information, this factor is scored as neutral.

B2b. Anthropogenic barriers: Neutral.
The range of *Penstemon wilcoxii* in Washington is scattered over much of the state in a variety of ecological settings in the Blue Mountains, Columbia Plateau, Okanogan Mountains, and West Cascades. Whether anthropogenic impacts create a significant barrier for dispersal of this species is not well documented.

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 wilcoxii produces many-seeded dry capsule fruits that split open at maturity to release the seeds passively by gravity or wind. Average dispersal distances are probably relatively short, however (100-1000 meters).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Penstemon wilcoxii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Five of the eight known occurrences (62.5%) 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). Two occurrences (25%) have experienced slightly lower than average (47.1-57˚ F/26.3-31.8˚C) temperature variation and would be at somewhat increased vulnerability. One population (12.5%) has experienced small temperature variation (37-47˚F/20.8-26.3˚C) during the last 50 years and is considered at increased vulnerability to climate change.

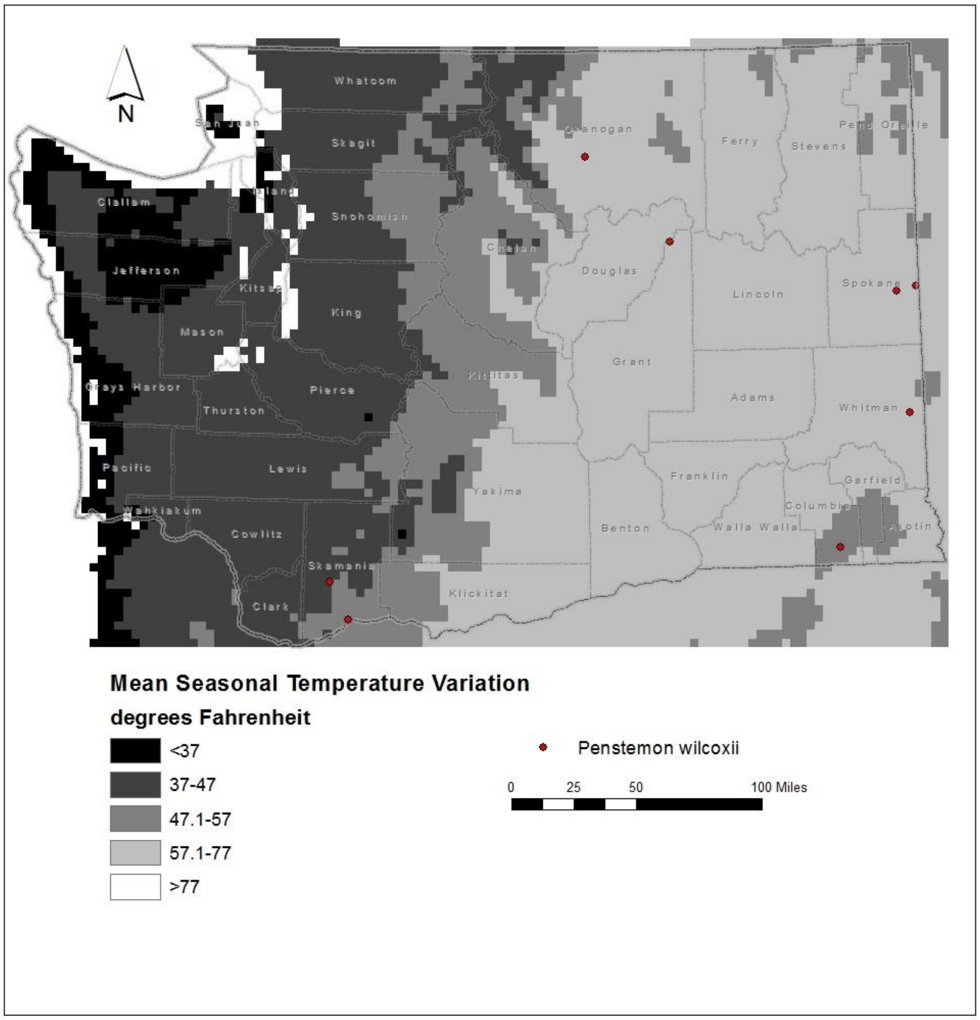

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Penstemon wilcoxii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The microsites within the montane conifer forest habitat occupied by *Penstemon wilcoxii* 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/Neutral.
Three of the eight populations of *Penstemon wilcoxii* in Washington (37.5%) 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. Five occurrences (62.5%) have experienced average or greater than average (>20 inches/508 mm) precipitation variation and are at neutral vulnerability from climate change.

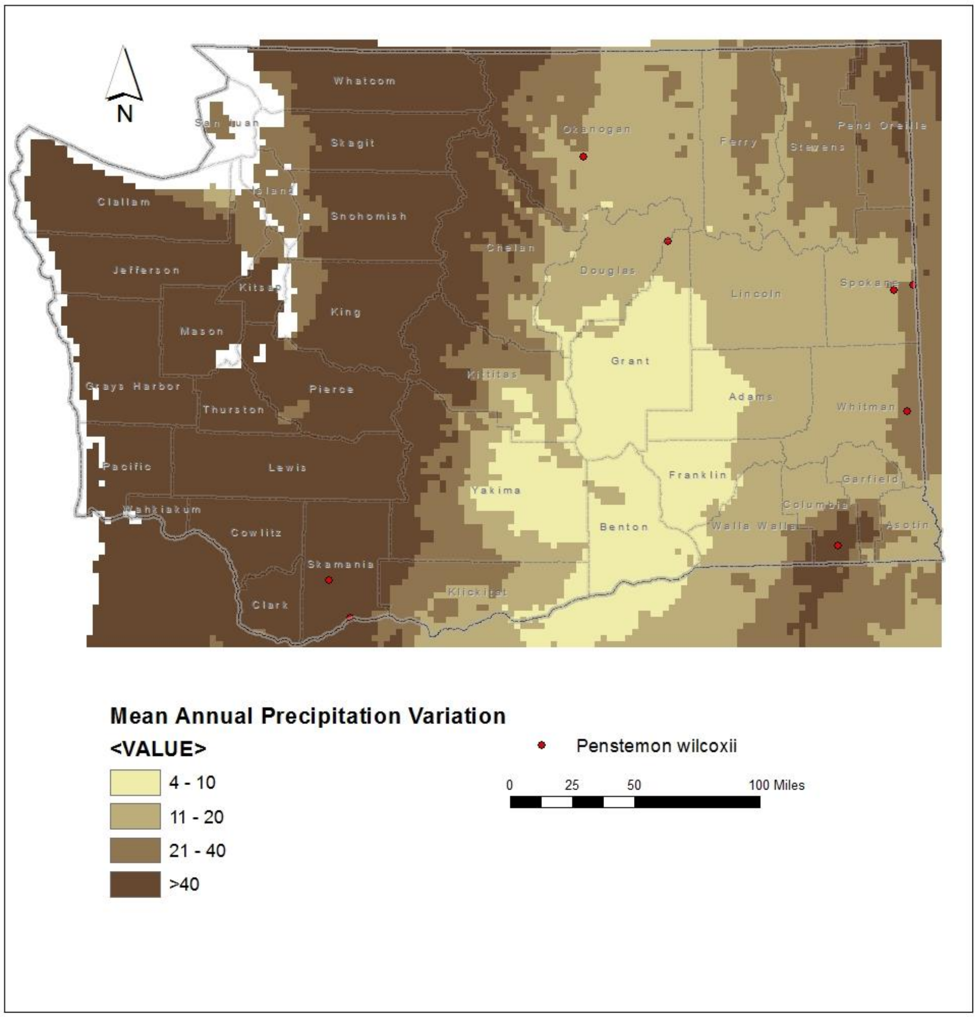

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Penstemon wilcoxii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase/Neutral.
Penstemon wilcoxii is not a wetland obligate or dependent on a seasonal hydrologic regime. Its dry-mesic montane mixed conifer forest habitat is vulnerable to drought, wildfire, and insect outbreaks due to increased temperature, and reduced snowpack (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Penstemon wilcoxii is not dependent on periodic disturbances to maintain its montane rocky forest habitat. The species could, however, be detrimentally affected by loss of forest canopy due to wildfire, or long-term drought associated with potential climate change (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
At least five of the populations of *Penstemon wilcoxii* in Washington (and all but one of the extant ones) occur in montane areas with at least moderate accumulations of snow. These populations could be adversely affected by reduction in snow cover or changes in the timing of snow melt due to projected climate change (Rocchio and Ram-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Penstemon wilcoxii is found on a variety of geologic substrates, including basalt, gneiss, and glacial deposits, none of which are uncommon in the state.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Penstemon wilcoxii* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Blue or bluish-purple flowered species of *Penstemon* are predominantly pollinated by bees. The size of the *Penstemon* flower and position of the sterile staminode is often correlated with the size of the bee species best suited to receive and deposit pollen. *P. wilcoxii* has intermediate sized flowers and should be adapted to pollination by a large number of medium-sized bees.

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.
Impacts from pathogens are not known. This species may be edible to livestock, ungulates, rodents, and insect grazers, but whether herbivory limits its distribution is not known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Rocky microsites occupied by *Penstemon wilcoxii* may not be especially vulnerable to competition from other native or introduced plant species. Changes to forest and shrub cover due to long-term drought or wildfire could make these sites more vulnerable to competition from more xeric-adapted 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: Neutral.
Broderick (2010) assessed the genetic variability of 104 of the 270 *Penstemon* taxa in North America and found that *P. wilcoxii* had the highest variation among samples of any species studied. This variation may be evidence of on-going differentiation of populations into subspecies (Broderick 2010).

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Penstemon wilcoxii produces showy flowers that are pollinated by bees and is an outcrosser.

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: Somewhat Increase.
Three occurrences in the Columbia Plateau and Blue Mountains are historical and possibly extirpated, suggesting a potential contraction of the species range in the past 40 years. Whether this is due to climate change or other factors is poorly 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

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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Petrophytum cinerascens (Chelan rockmat)

Date: 27 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G1G2/S1S2

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	60
	-0.028 to -0.050	40
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		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		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	
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 five of the occurrences of *Petrophytum cinerascens* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

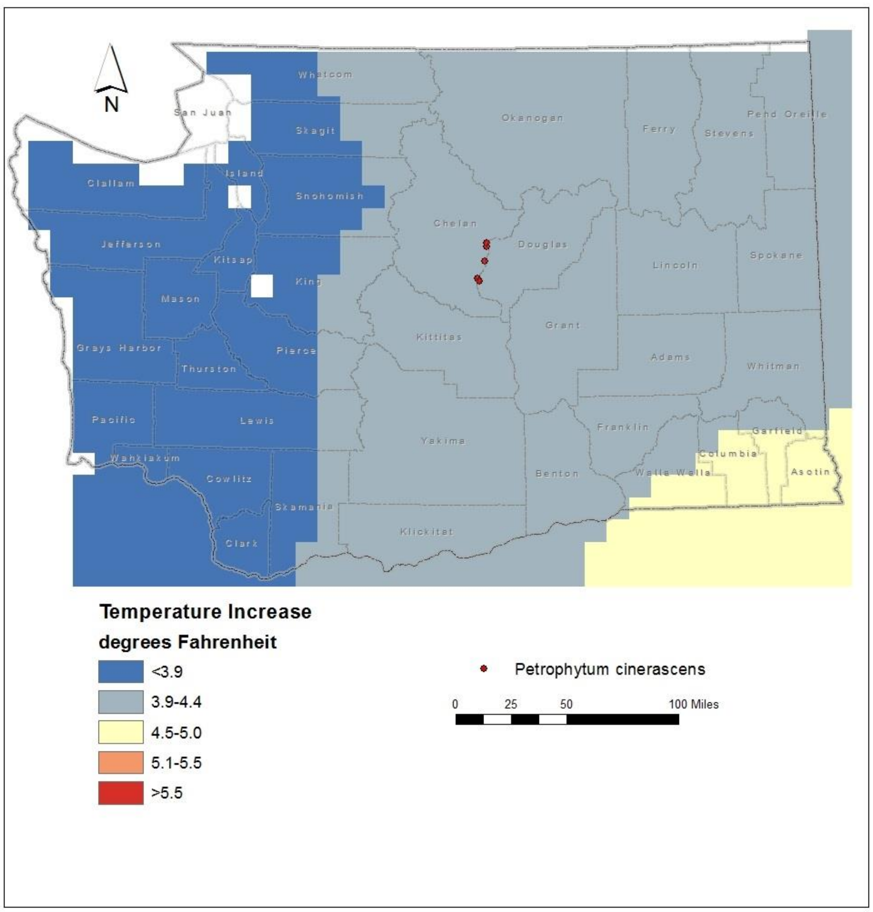

Figure 1. Exposure of *Petrophytum cinerascens* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Three of the five Washington occurrences of *Petrophytum cinerascens* (60%) 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). Two occurrences (40%) are found in areas with a projected decrease in moisture of -0.028 to -0.050.

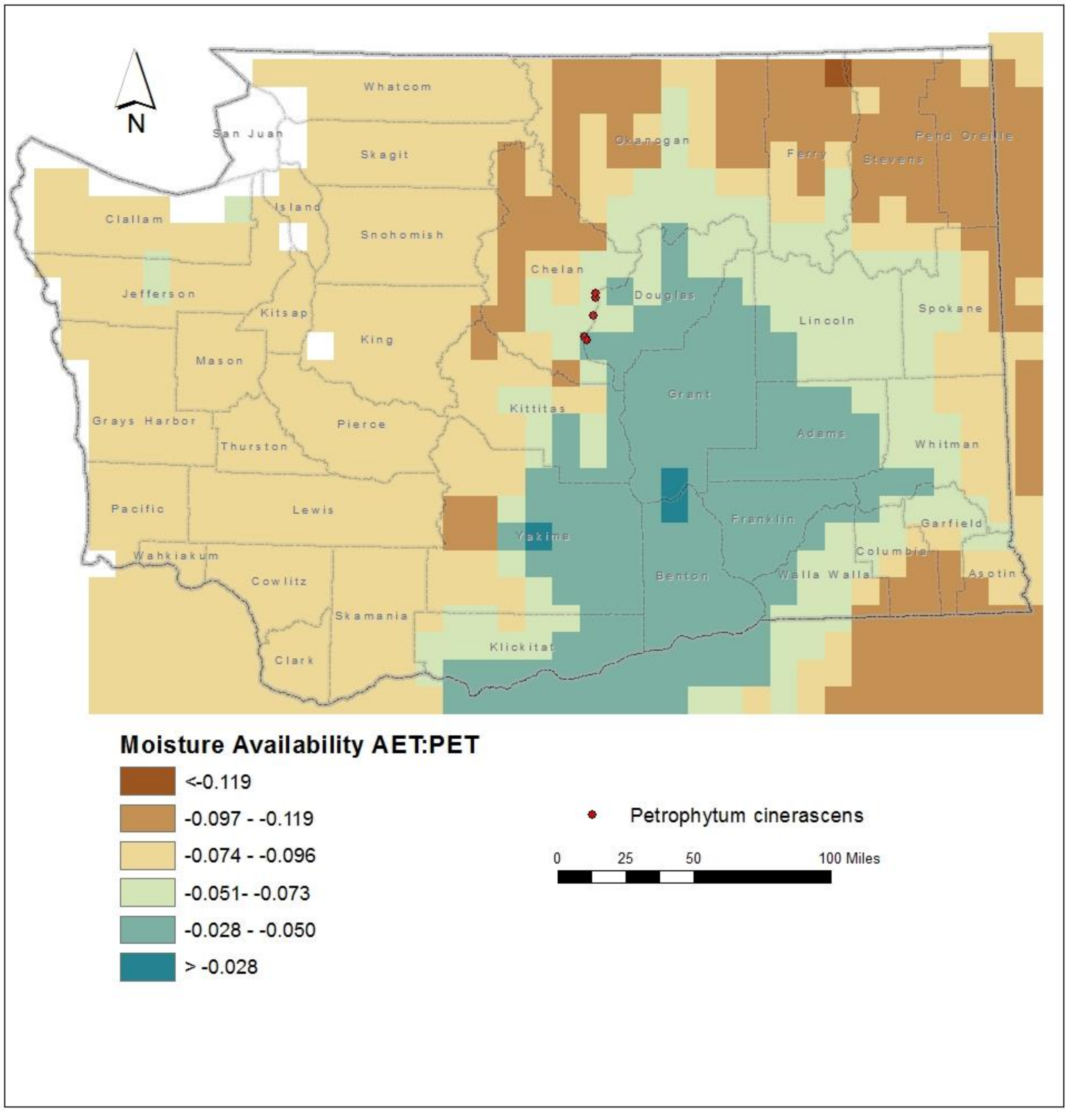

Figure 2. Exposure of *Petrophytum cinerascens* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Petrophytum cinerascens* are found at 800-1800 feet (240-550 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Petrophytum cinerascens* is found in ledges and exposed rock faces of east or west-facing cliffs of metamorphosed granitic or gneiss plutons (intrusions within the basalt matrix) along a 27 km (17 mile) stretch of the Columbia River near the Rocky Reach dam, north of Wenatchee (Camp and Gamon 2011, Fertig 2020, Gamon 1989). This habitat is a component of the Inter-Mountain Basins Cliff and Canyon ecological system (Rocchio and Crawford 2015). Individual populations are separated by 1.6-11 km (1-7 miles). Adjacent habitat (including south-facing gneiss cliffs) is unsuitable for this species and creates a barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Petrophytum cinerascens* in Washington is constrained by the distribution of appropriate granite and genies plutons along the Columbia River. The east side of these cliffs has a highway. Dispersal is probably more constrained by natural conditions, however, than human 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.
Petrophytum cinerascens produces 1-2 seeded dry capsule 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 cinerascens* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All five 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.

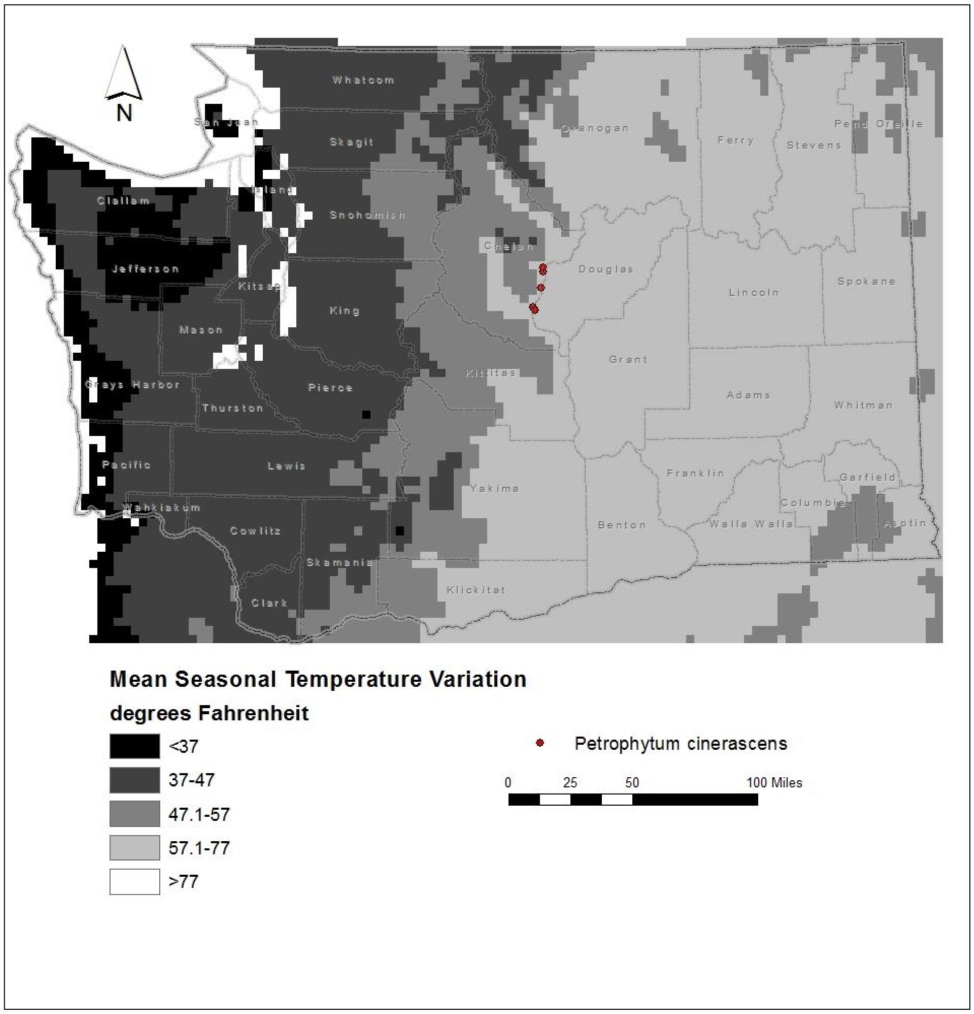

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Petrophytum cinerascens* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The microsites within the intrusive gneiss cliffs occupied by *Petrophytum cinerascens* are often associated with cool, shaded conditions during the growing season and would have somewhat increased vulnerability to climate change. Under experimental conditions, Moore et al. (1998) found that *P. cinerascens* was not be able to acclimate to increased temperatures and thus would be a very sensitive indicator of climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
All five of the populations of *Petrophytum cinerascens* 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.

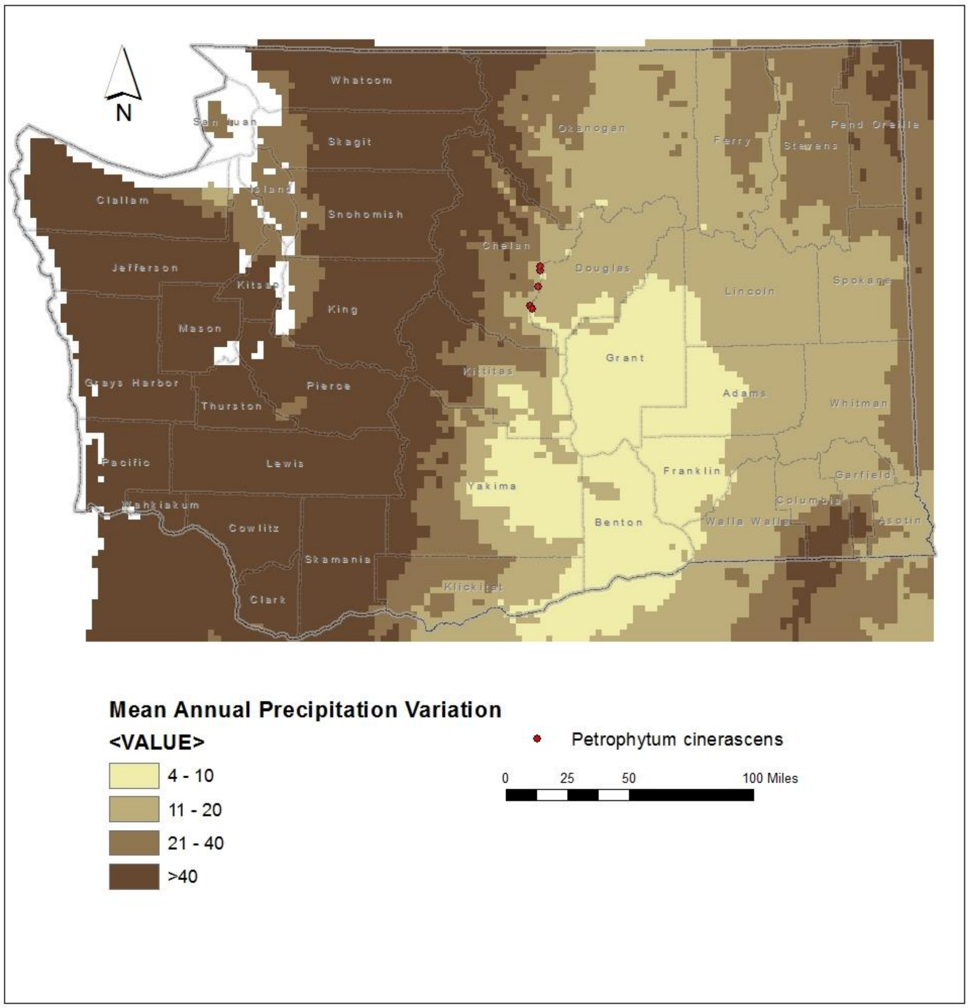

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Petrophytum cinerascens* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

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.
Petrophytum cinerascens is not dependent on periodic disturbances to maintain its montane rocky forest 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.
The five populations of *Petrophytum cinerascens* in Washington occur in an area of low to moderate accumulations 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 Ram-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Petrophytum cinerascens is restricted to two geologic formations of limited extent in central Washington: Swakane Biotite and Entiat Pluton. These are intrusive granitic or gneiss formations within a matrix of basalt. These rock outcrops do not readily weather into soil, and *P. cinerascens* is mostly restricted to cracks or narrow ledges (Gamon 1989).

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Petrophytum cinerascens* 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.
Petrophytum cinerascens has relatively unspecialized flowers. It is probably pollinated by bumblebees (Gamon 1989). The diversity of bee species may be threatened by insecticide drift from nearby agricultural fields.

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. The genus is not dependent on animals for dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Due to its remote cliff habitat, *Petrophytum cinerascens* receives minimal impacts from livestock or ungulate grazing. Gamon (1989) noted that stems were sometimes nipped off by an unknown herbivore. Possible grazers could be rodents or insects. Overall impacts are probably low.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Rocky microsites occupied by *Petrophytum cinerascens* 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.
Michael Windham observed relatively high genetic variability in one population of *Petrophytum cinerascens* based on electrophoretic research (Gamon 1989)

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Petrophytum cinerascens produces perfect flowers that are pollinated by bees. Self-pollination could be possible.

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 cinerascens* 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

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Climate Change Vulnerability Index Report

Polemonium carneum (Great polemonium)

Date: 24 April 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G4/S2

Index Result: Less Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase/Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase/Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Somewhat Increase/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	
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: All 17 occurrences of *Polemonium carneum* in Washington (100%) occur in areas with a projected temperature increase of < 3.9˚ F (Figure 1).

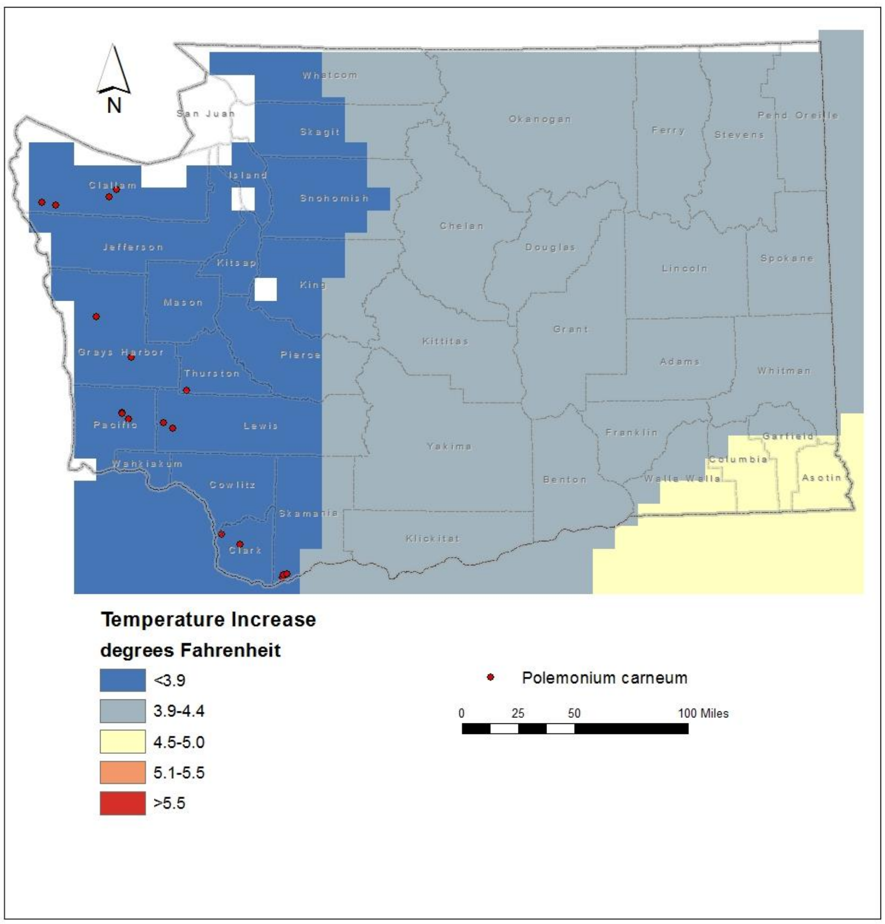

Figure 1. Exposure of *Polemonium carneum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 17 of the occurrences of *Polemonium carneum* (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).

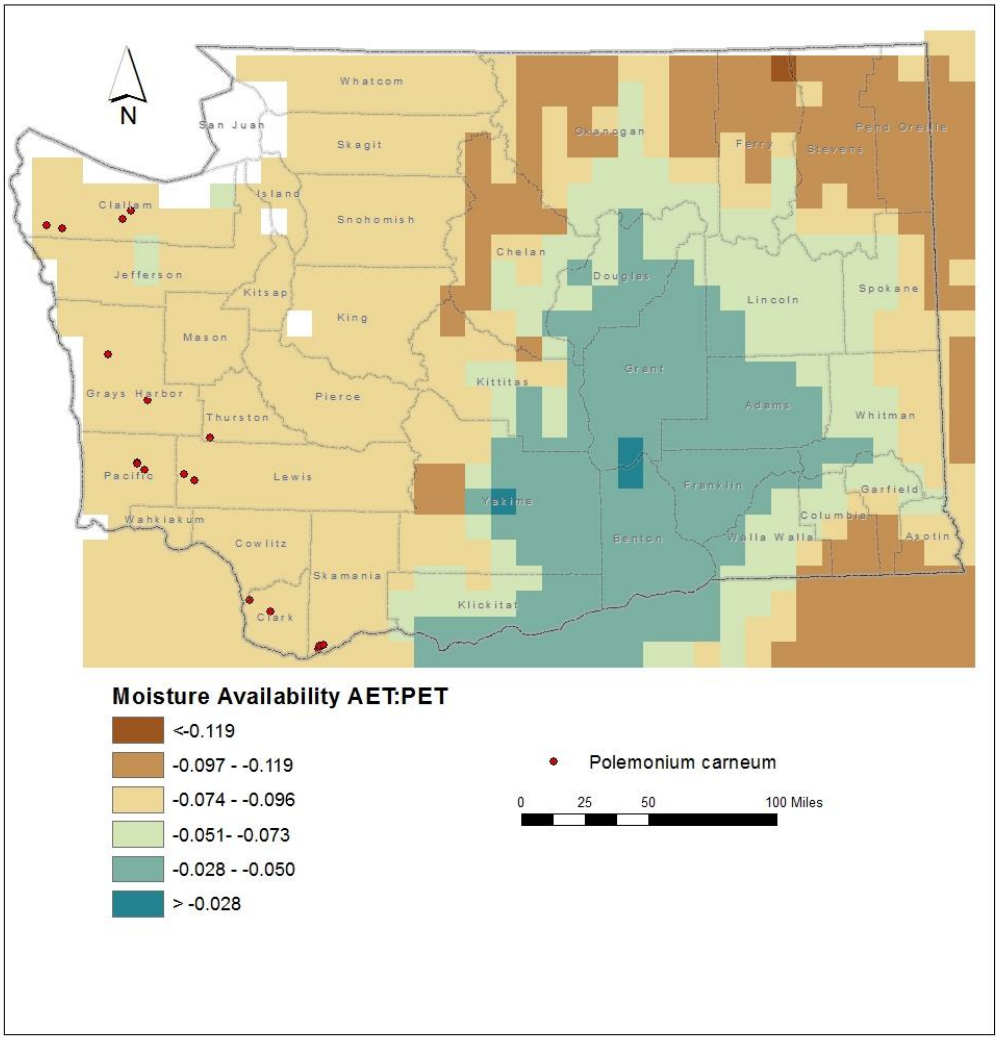

Figure 2. Exposure of *Polemonium carneum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Polemonium carneum* are found at 150-2000 feet (50-600 m) and would not be inundated by projected sea level rise. Some occurrences in Oregon on the Pacific Coast would be impacted by rising sea levels.

B2a. Natural barriers: Somewhat Increase/Neutral.
In Washington, *Polemonium carneum* is found in open areas in moist forests of Douglas-fir, meadows, and fencerows and in the ecotone between forests and prairies (Camp and Gamon 2011; WNHP records). These habitats probably represent early seral communities within disturbed North Pacific Dry Douglas-fir Forest and Woodland or North Pacific Maritime Dry-Mesic Douglas-fir-Western hemlock forest ecological systems or prairie/bald stands in the North Pacific Herbaceous Bald and Bluff and Willamette Valley Upland Prairie and Savanna ecological systems being invaded by Douglas-fir (Rocchio and Crawford 2015). Washington occurrences are separated by 2.5-52 miles (4-84 km). Patches of suitable habitat occur sporadically within a matrix of lowland forest, remnant prairie, and anthropogenic (agricultural, rural, and urban) environments. Barriers to gene flow are probably equally influenced by natural and human barriers.

B2b. Anthropogenic barriers: Somewhat Increase/Neutral
The range of *Polemonium carneum* in Washington is largely embedded within a matrix of second-growth natural habitats and human-modified landscapes, with gene flow equally restricted by natural and anthropogenic processes.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Polemonium carneum produces dry, capsule fruits with numerous seeds that are released passively. *Polemonium* seeds become mucilaginous and sticky when wet, so can be dispersed by animals, such as waterfowl. Dispersal distances are poorly known for *P. carneum*, but are likely in the range of 100-1000m.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Polemonium carneum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Ten of the 17 known occurrences (58.8%) 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). Three occurrences (17.7%) are from areas with very small (<37˚F/20.8˚C) temperature variation over the same period and are at greatly increased vulnerability to climate change. Four other populations are found in areas with slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation over the past 50 years and would be at somewhat increased vulnerability to climate change (Fgure 3, Young et al. 2016).

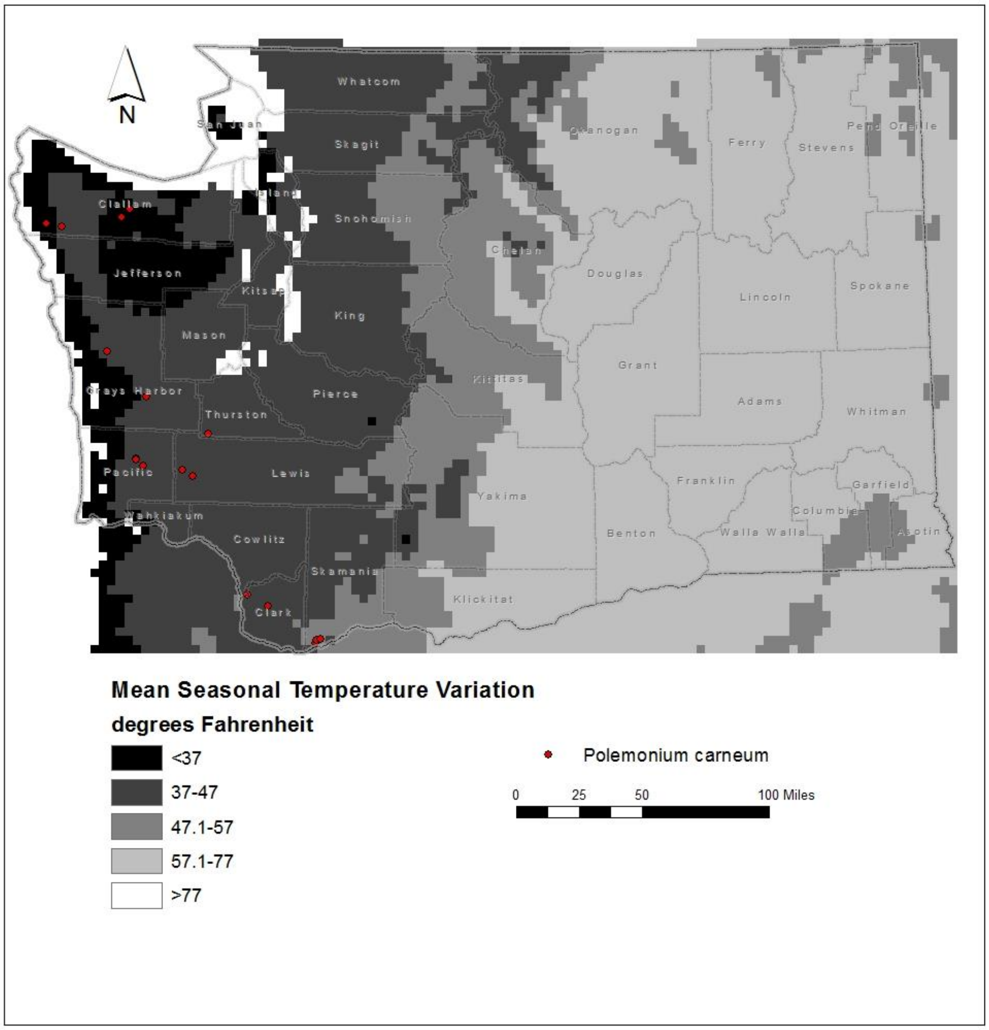

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Polemonium carneum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The open forest and meadow ecotone habitat of *Polemonium carneum* is not associated with cold air drainage during the growing season and would have neutral vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
All 17 of the populations of *Polemonium carneum* in Washington (100%) are found in areas that have experienced greater than average (>20 inches/508 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.

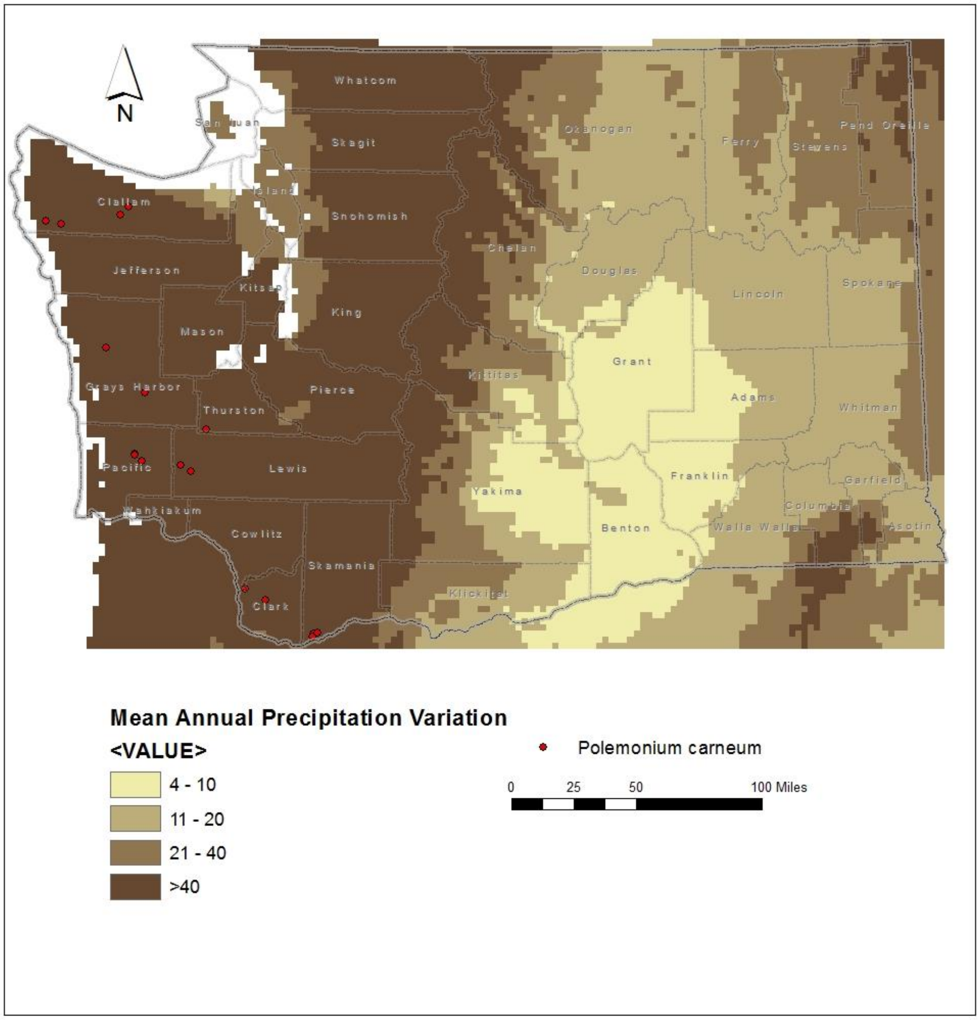

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Polemonium carneum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species is found in sites where moisture from precipitation is typically not limiting. Reduced precipitation and increased temperatures could make its habitats more at risk from wildfire under projected climate change scenarios (Rocchio and Ramm-Granberg 2017).

Increased fire could actually benefit *Polemonium carneum* in creating or maintaining meadow or forest ecotone conditions.

C2c. Dependence on a specific disturbance regime: Somewhat Increase/Neutral.
Polemonium carneum is dependent on periodic disturbances, such as high winds or low intensity wildfire to maintain its open meadow or early seral habitat. Increased temperatures and decreased precipitation projected from climate change are likely to increase the frequency and intensity of wildfires and wind-throw (Rocchio and Ramm-Granberg 2017), which could benefit this species by favoring grasslands over forests. Reduced soil moisture, however, could impact herbaceous plants, like *P. carneum*, and increased disturbance could result in greater competition from invasive non-native plants.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The populations of *Polemonium carneum* in Washington occur primarily in areas of moderate winter snowfall. Populations associated with North Pacific herbaceous balds in the Olympic Peninsula could be impacted by reduced snow accumulation or changes in snowmelt patterns (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Polemonium carneum is found on a variety of geological substrates in western Washington, including Eocene marine sediments, Quaternary alluvium and glacial till, and various post-glacial flood deposits. These formations are all widespread in this part of the state.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Polemonium carneum* is maintained primarily by natural abiotic processes, especially wind and fire.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Polemonium carneum is an outcrosser and is insect pollinated (Worley et al. 2009). The exact pollinators are not known. Related species of *Polemonium* with large flowers are pollinated by bumblebees in the genus *Bombus* (Zimmerman 1980).

C4d. Dependence on other species for propagule dispersal: Neutral.
Polemonium carneum seeds are released passively when the dry capsule fruits are mature and split open. The seeds become mucilaginous and sticky when wettened, and can potentially be transported long distance in muddy soil stuck to birds.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species may be vulnerable to livestock grazing (Camp and Gamon 2011), but effects of grazing by native species is not known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The habitat of *Polemonium carneum* is in meadows and prairie areas bordered by Douglas-fir forests and is vulnerable to invasion by trees in the absence of periodic disturbance, such as fire or wind-throw. Climate change is likely to increase fire frequency and intensity, which could

reduce tree cover but make sites prone to invasion and competition by invasive non-native species (Rocchio and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Genetic data are not available from Washington. A study comparing genetic diversity among 18 taxa in the genus *Polemonium* (Worley et al. 2009) found that *P. carneum* had a higher degree of genetic variability than all but three species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Polemonium carneum produces showy, insect-pollinated flowers and is an obligate outcrosser (Worley et al. 2009). It is likely to have average genetic variability based on these life history traits.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on records from the Consortium of Pacific Northwest Herbaria, the phenology of this species has not changed significantly since it was first documented in Washington in the 1890s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Somewhat Increase.
Eight of the 17 occurrences of *Polemonium carneum* in Washington have not been relocated since 1980 and are considered historical. These populations may be locally extirpated due to changes in habitat condition from vegetation succession or 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.

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.

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Climate Change Vulnerability Index Report

Polyctenium fremontii (Fremont's combleaf)

Date: 25 February 2020

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	**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		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		Unknown
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	
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 *Polyctenium fremontii* in Washington (100%) occurs in an area with a projected temperature increase of 3.9-4.4° F (Figure 1).

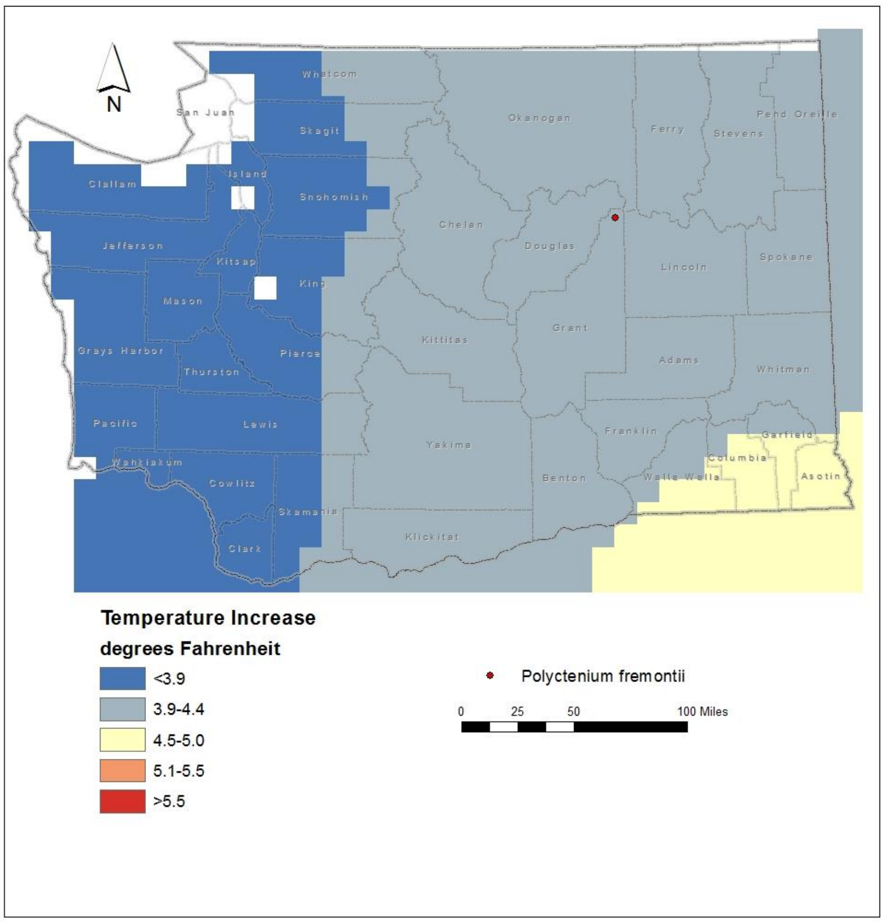

Figure 1. Exposure of *Polyctenium fremontii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single Washington occurrence of *Polyctenium fremontii* (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).

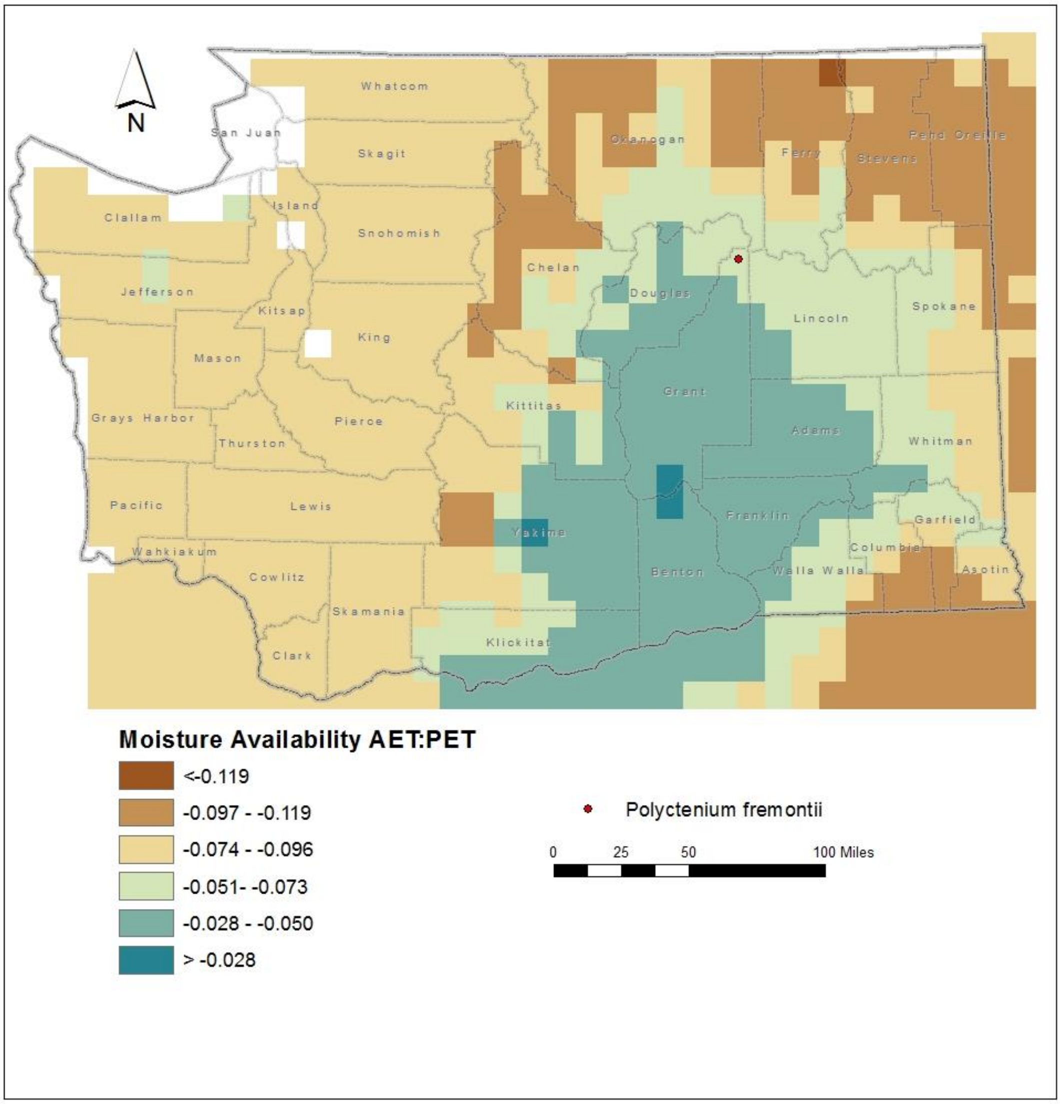

Figure 2. Exposure of *Polyctenium fremontii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Polyctenium fremontii* are found at 2300 feet (700 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Polyctenium fremontii* is found in shallow vernal depressions in basalt bedrock with 4-10 inches of cobbley to gravelly lithosol loam within sagebrush grassland (Camp and Gamon 2011, Fertig and Kleinknecht 2020). This habitat corresponds with the Columbia Plateau Vernal Pool ecological system (Rocchio and Crawford 2015). Elsewhere in its range, *P. fremontii* occurs in sagebrush desert and pinyon and Ponderosa pine woodlands (Hitchcock and Cronquist 2018). The single Washington occurrence occupies a small area embedded within a matrix of sagebrush, scabland, and agricultural vegetation and isolated from other areas of potential habitat.

B2b. Anthropogenic barriers: Neutral.
The range of *Polyctenium fremontii* in Washington is embedded within a matrix of native and human-influenced lands. The species is probably more isolated by natural barriers 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.
Polyctenium fremontii produces many-seeded dry fruits that split along two sutures to release seeds passively by gravity or strong winds. Average dispersal distances are probably relatively short (100-1000 meters). The related species, *P. williamsiae* (a vernal wetland endemic of Nevada and California) is reported to have mucilaginous seeds, which would aid in its long-distance dispersal (Holland and Morefield 2003). Holmgren (2005) contends that the seeds of *Polyctenium* are not mucilaginous, which would suggest dispersal is limited to passive means.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Polyctenium fremontii* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The single known 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.

C2aii. Physiological thermal niche: Neutral.
The vernal pool/sagebrush/lithosol habitat of *Polyctenium fremontii* is not associated with cool environments in the growing season and would have neutral vulnerability to climate change.

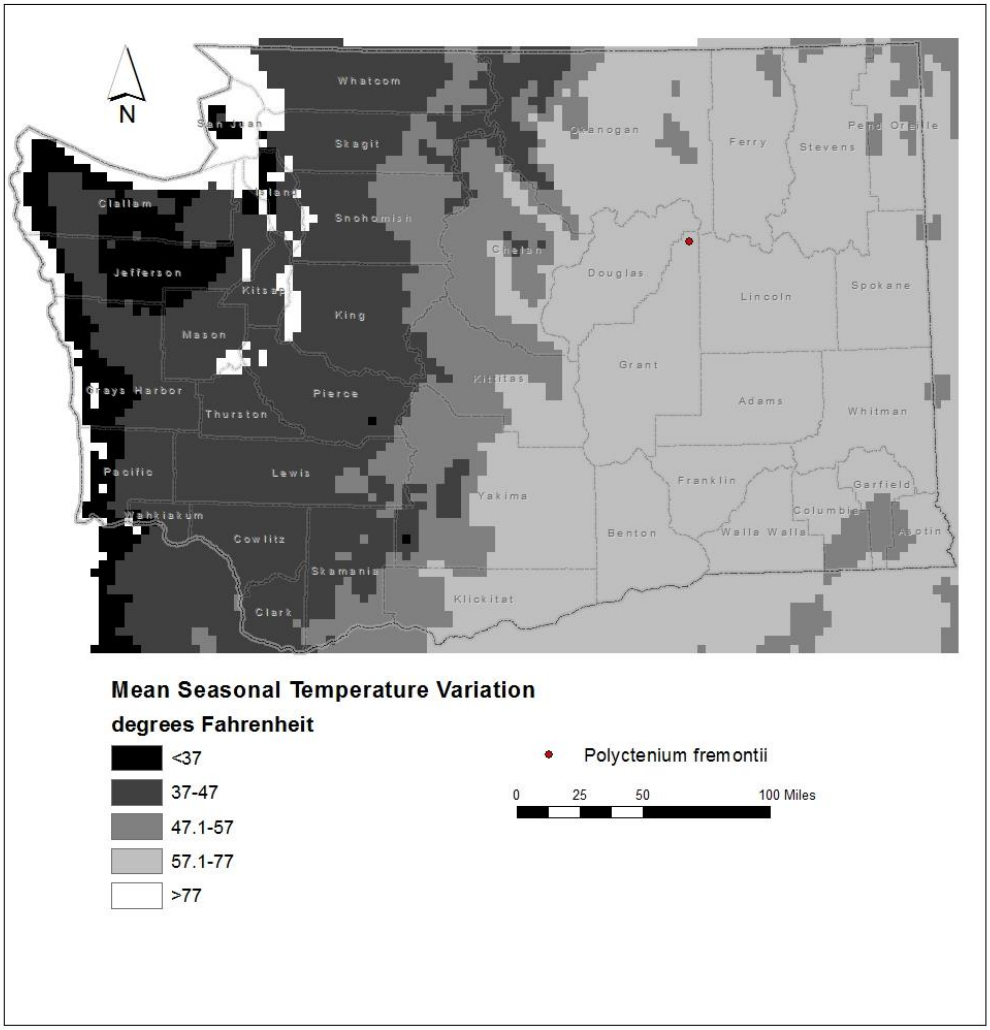

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Polyctenium fremontii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
The single population of *Polyctenium fremontii* 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 areas are at somewhat increased vulnerability from climate change.

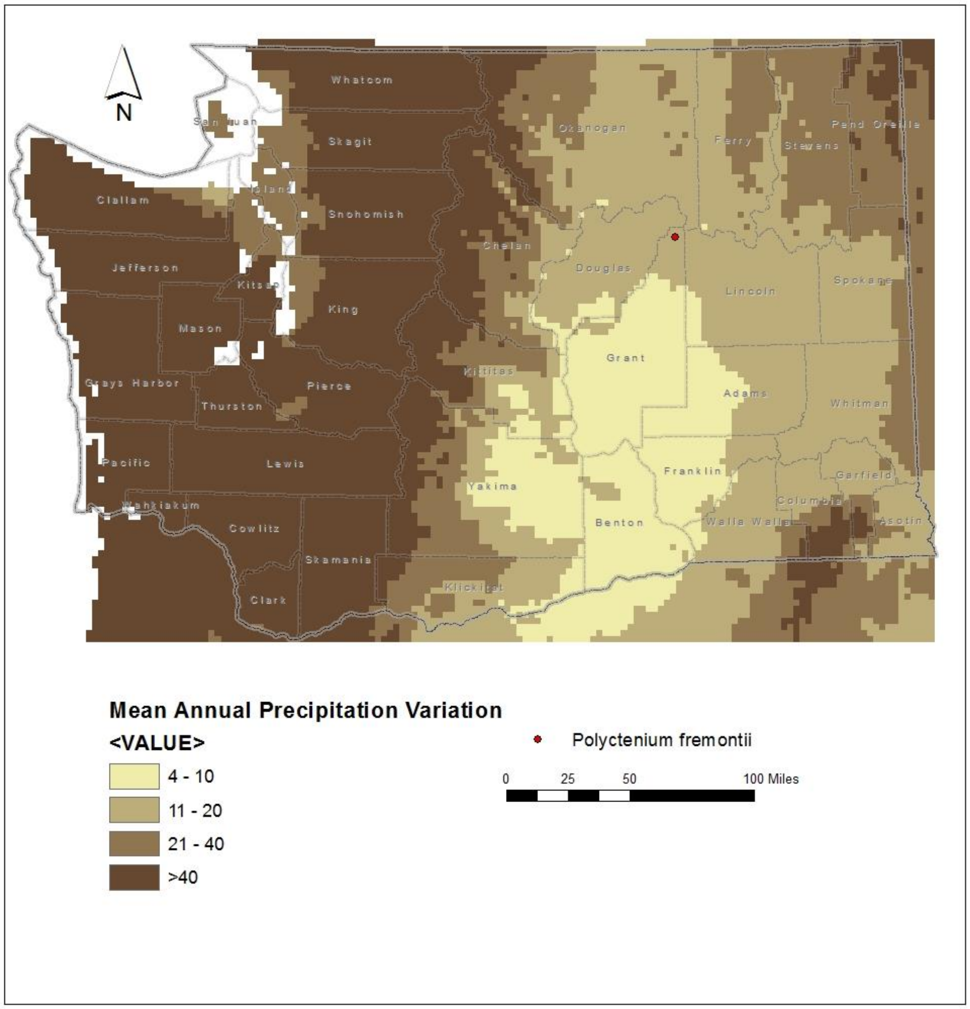

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Polyctenium fremontii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
In Washington, *Polyctenium fremontii* is a vernal pool obligate associated with basalt bedrock and thus dependent on winter or spring snow or rain (and not groundwater), followed 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 the ecological system to the sparsely vegetated Intermountain Basins Cliff and Canyon type.

C2c. Dependence on a specific disturbance regime: Neutral.
Polyctenium fremontii is not dependent on periodic and unpredictable disturbances to maintain its vernal pool/basalt outcrop habitat (although it does require predictable summer drought to prevent the sites from converting to another wetland ecological system) (Rocchio and Ramm-Granberg 2017). Increased disturbances related to prolonged drought (such as increase in fire frequency) would affect the sagebrush-grassland matrix in which the vernal pool systems are embedded.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The range of *Polyctenium fremontii* in Washington in the northern Columbia Plateau is an area of relatively low snowfall (though vernal pool depressions would likely accumulate blowing snow). Also, the basalt bedrock underlying vernal pools in this area is not recharged by snow-melt.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
In Washington, *Polyctenium fremontii* is strongly associated with shallow depressions in basalt scabland outcrops with thin lithosols and standing water in spring. While basalt outcrops are common in the Columbia Plateau, eroded depressions of appropriate depth to support vernal pool vegetation is less common, and probably an important limiting factor in the distribution and abundance of this species.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Polyctenium fremontii* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Unknown.
Pollinators are not known, but related species are visited by a variety of small insects (Holland and Morefield 2003).

C4d. Dependence on other species for propagule dispersal: Unknown.
Seed dispersal in *Polyctenium fremontii* is probably passive, with small seeds spreading by gravity or high winds once the dry fruit capsule is ripe and splits open. There is disagreement in the literature whether the seeds are mucilaginous when wet, and thus could be transported long distances by waterfowl (Holland and Morefield 2003, Holmgren 2005).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
The related *Polyctenium williamsiae* is occasionally infected by rust fungi (Holland and Morefield 2003). *Polyctenium fremontii* is probably grazed by rabbits and insects. Impacts from livestock are poorly known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Polyctenium fremontii could be vulnerable to competition from other native or introduced plant species if its specialized vernal pool habitat became completely dried out due to climate change (Rocchio and Ramm-Granberg 2015).

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

C5a. Measured genetic variation: Unknown.
No studies of genetic variability for this species are known.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral /Somewhat Increase
Polyctenium fremontii is pollinated by a variety of insects and is likely an outcrosser. The Washington occurrence is disjunct from others and probably has less genetic diversity due to founder effects or genetic drift.

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.
No changes in the distribution of this species in Washington has been observed 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.

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Climate Change Vulnerability Index Report

Pyrrocoma hirta var. *sonchifolia* (Sticky goldenweed)

Date: 26 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G4G5T3/S2

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	28.5
	-0.074 to - 0.096	43
	-0.051 to - 0.073	28.5
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		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	
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 known occurrences of *Pyrrocoma hirta* var. *sonchifolia* in Washington (100%) occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

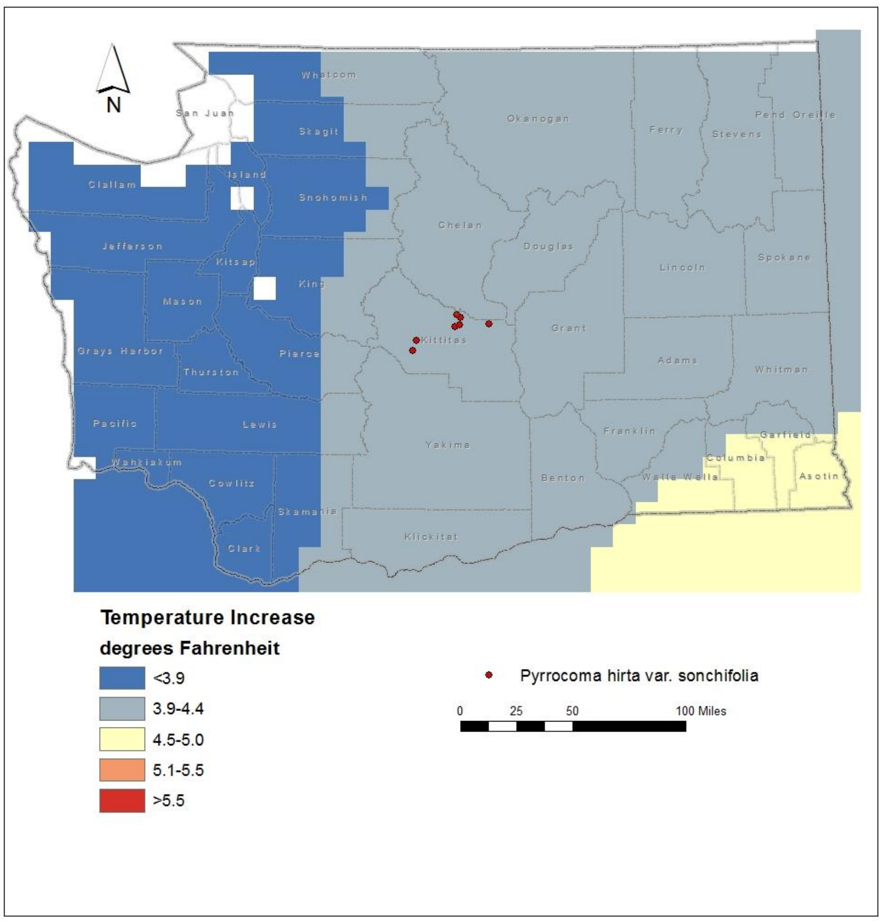

Figure 1. Exposure of *Pyrrocoma hirta* var. *sonchifolia* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the seven Washington occurrence of *Pyrrocoma hirta* var. *sonchifolia* (28.5%) 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 -0.051 to -0.073 (Figure 2). Three other populations (43%) are found in areas with a projected decrease in moisture of – 0.074 to – 0.096 and two (28.5%) are found in areas with a projected decrease of -0.097 to – 0.119.

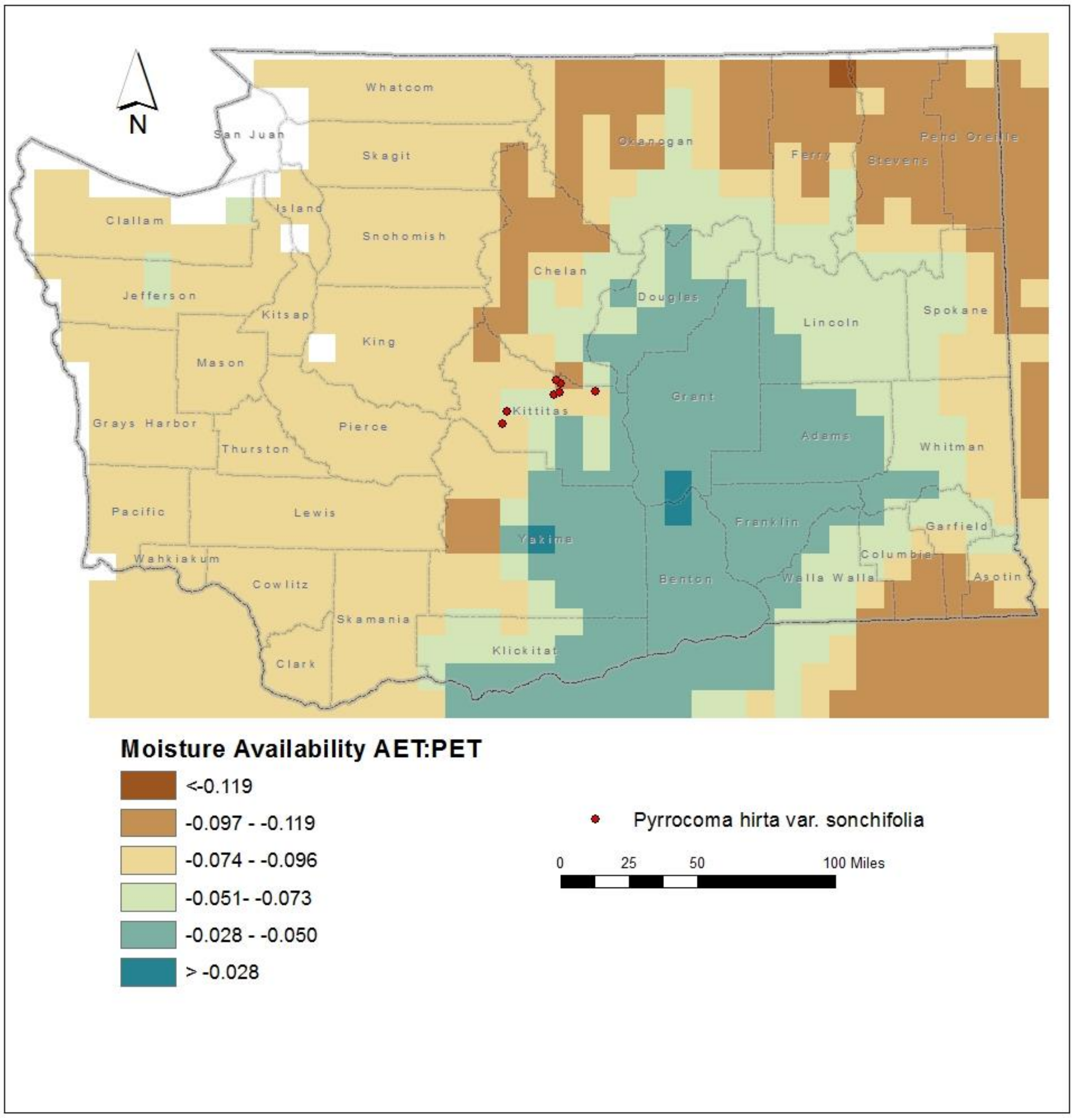

Figure 2. Exposure of *Pyrrocoma hirta* var. *sonchifolia* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Pyrrocoma hirta* var. *sonchifolia* are found at 4040-5600 feet (1230-1710 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Pyrrocoma hirta* var. *sonchifolia* is found in seasonally moist meadows (wet in the spring, but dry in summer and fall) on flats or shallow depressions of clay-rich soil over basalt bedrock within a matrix of conifer forests dominated by *Pinus ponderosa, P.monticola, P. contorta, Abies grandis* and *Pseuodotsuga menziesii* (Camp and Gamon 2011, Fertig and Kleinknecht 2020). This habitat is a component of the Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland ecological system (Rocchio and Crawford 2015). Washington populations are separated by 3-28 km (2-17 miles) an often occupy small areas of suitable habitat, embedded within less-suitable forest systems that could create a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Pyrrocoma hirta* var. *sonchifolia* in Washington is embedded within a matrix of native and human-influenced lands. The species is probably more isolated by natural barriers 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: Neutral.
Pyrrocoma hirta var. *sonchifolia* produces numerous 1-seeded achenes topped by a pappus of bristles to facilitate dispersal by wind. These propagules can probably travel at least 1 km.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Pyrrocoma hirta* var. *sonchifolia* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All seven of the known occurrences (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 risk from climate change.

C2aii. Physiological thermal niche: Somewhat Increase.
The seasonally moist montane grassland habitat of *Pyrrocoma hirta* var. *sonchifolia* is associated with cold air drainage in the growing season and could be somewhat vulnerable to increased temperatures associated with climate change.

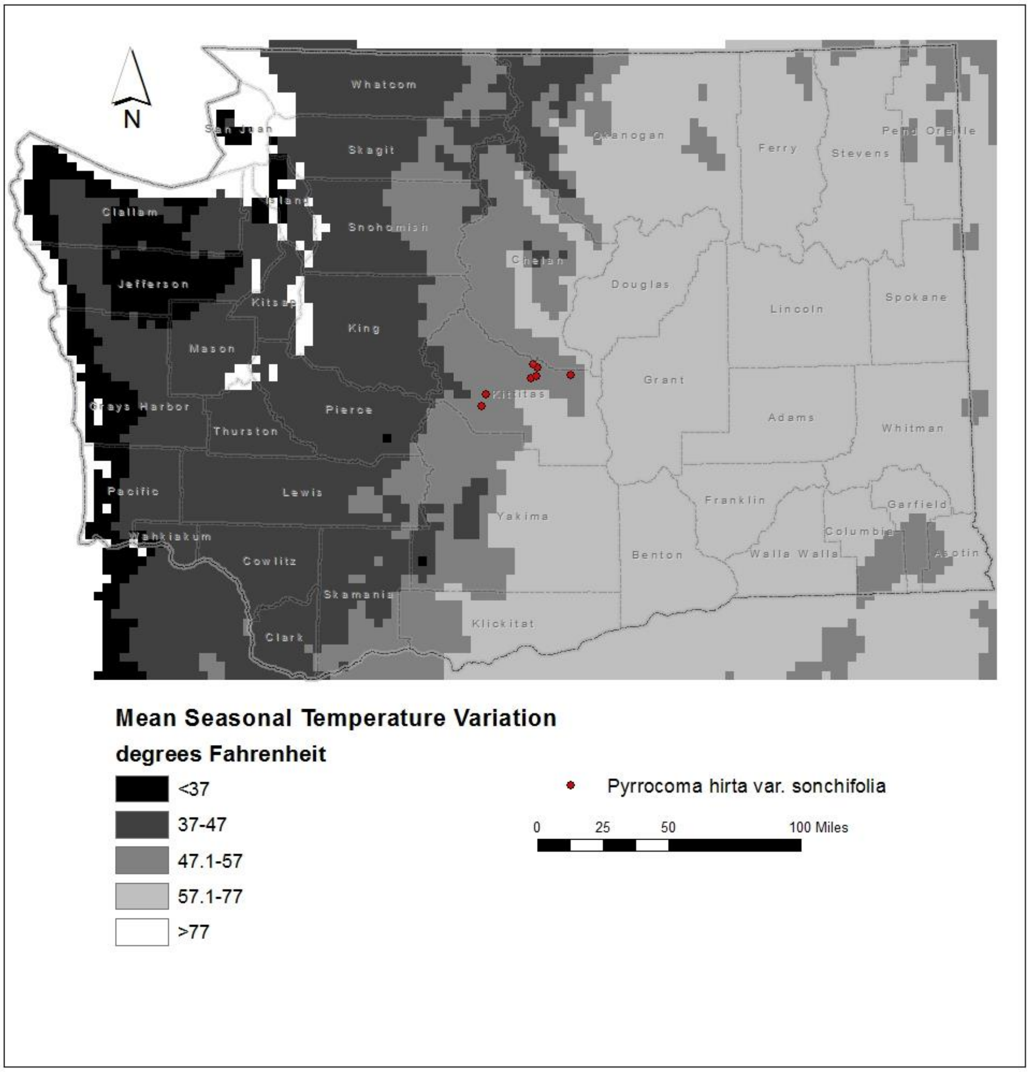

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Pyrrocoma hirta* var. *sonchifolia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

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

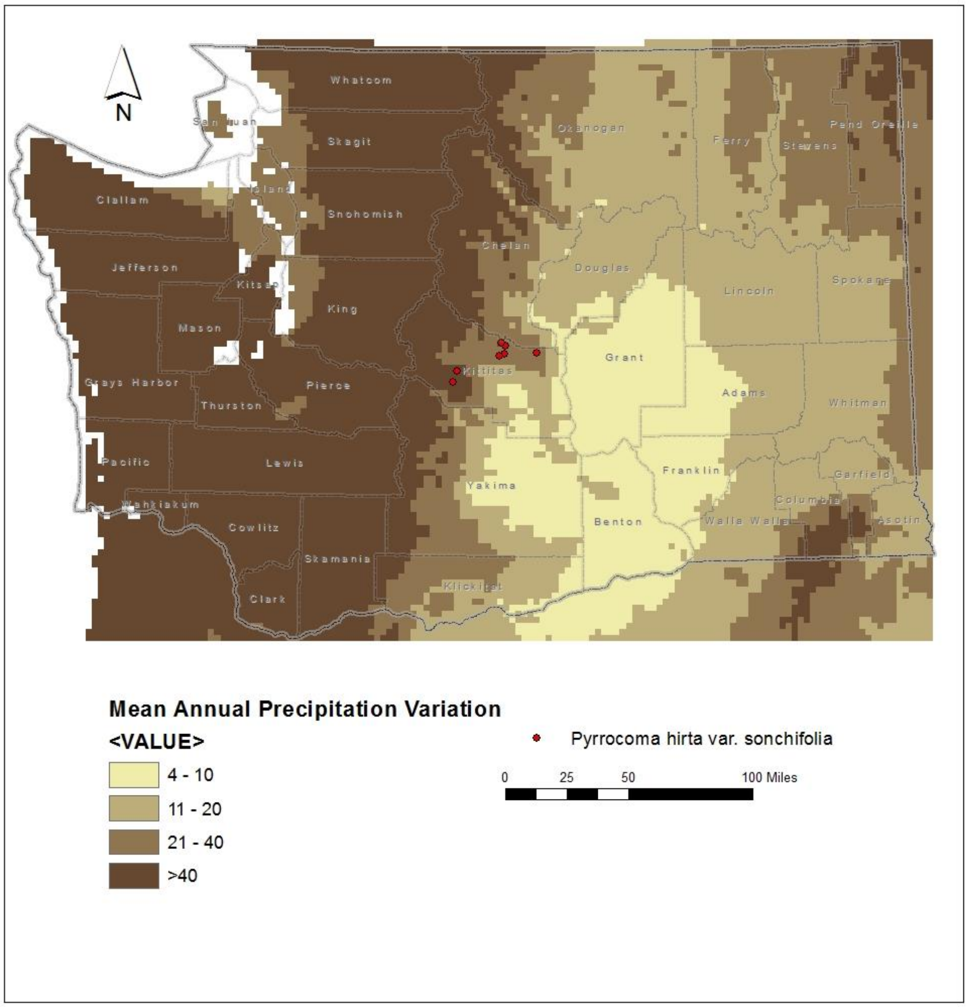

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Pyrrocoma hirta* var. *sonchifolia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
In Washington, *Pyrrocoma hirta* var. *sonchifolia* is found in slight depressions or other areas of high clay soil that are seasonally wet in spring, but become dry in summer. These vernal pool-like microsites within the Northern Rocky Mountains Lower Montane, Foothills and valley Grassland ecological system are dependent on winter and spring moisture and thus vulnerable

to changes in the amount and timing of precipitation from climate change (Rocchio and Ramm-Granberg 2017). Increased drought and temperatures in the growing season could lead to an increased risk of wildfire.

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Pyrrocoma hirta var. *sonchifolia* occurs on clay rich soils that support meadow communities within a matrix of mixed conifer forest. These openings could be created or maintained by periodic wildfire. These disturbances could become more frequent under projected climate change.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The range of *Pyrrocoma hirta* var. *sonchifolia* on the east slope of the Cascades in Washington has low to moderate snowfall. Drifting or late-melting snow may be an important source of additional moisture for creating vernal pool-like conditions in the spring.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Washington, *Pyrrocoma hirta* var. *sonchifolia* is strongly associated with shallow depressions in basalt with thin clay soil and standing water in spring. Basalt is widespread across central and eastern Washington, and not limiting.

C4a. Dependence on other species to generate required habitat: Neutral
The meadow habitat and depressions occupied by *Pyrrocoma hirta* var. *sonchifolia* could be enhanced by wallowing animals, such as elk, but is probably maintained mostly by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Like other members of the Asteraceae, *Pyrrocoma hirta* var. *sonchifolia* is adapted for pollination by numerous, unspecialized (generalist) species of insects and is unlikely to be pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seed dispersal in *Pyrrocoma hirta* var. *sonchifolia* is enitely passive, with the small one-seeded fruits spreading by wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species does not appear to be a preferred forage species by livestock or native grazers.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Pyrrocoma hirta var. *sonchifolia* could be vulnerable to competition from other native or introduced plant species if its specialized vernal pool-like habitat became completely dried out due to climate change, or more susceptible to frequent wildfire (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 for this species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Pyrrocoma hirta var. *sonchifolia* is pollinated by a variety of insects and is likely an outcrosser. Genetic diversity is probably average.

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.
No changes in the distribution of this species in Washington has been observed 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.

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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Ranunculus populago (Mountain buttercup)

Date: 28 February 2020

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	**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	80
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<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		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		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	
D1. Documented response to recent climate change	Neutral
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: Four of the five occurrences of *Ranunculus populago* in Washington (80%) occur in areas with a projected temperature increase of 4.5-5˚ F (Figure 1). One additional population (20%) is from an area with a predicted temperature increase pf < 3.9˚ F.

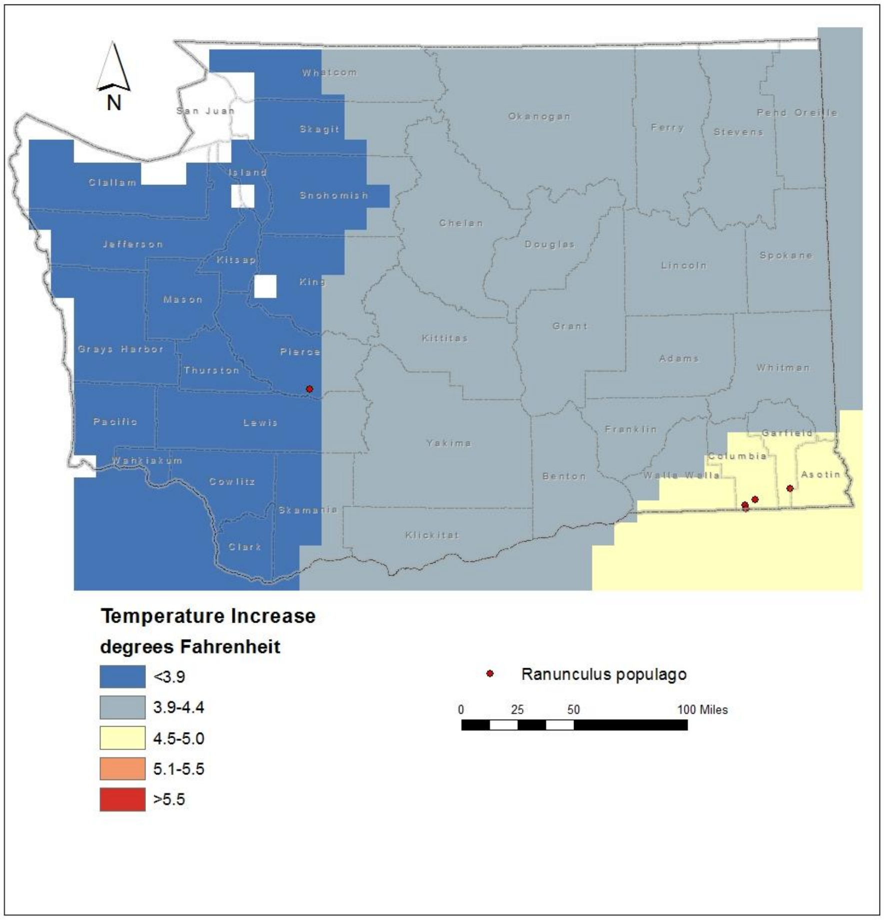

Figure 1. Exposure of *Ranunculus populago* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the five Washington occurrences of *Ranunculus populago* (80%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2). One occurrence (20%) is found in an area with a projected decrease in moisture of -0.074 to -0.096.

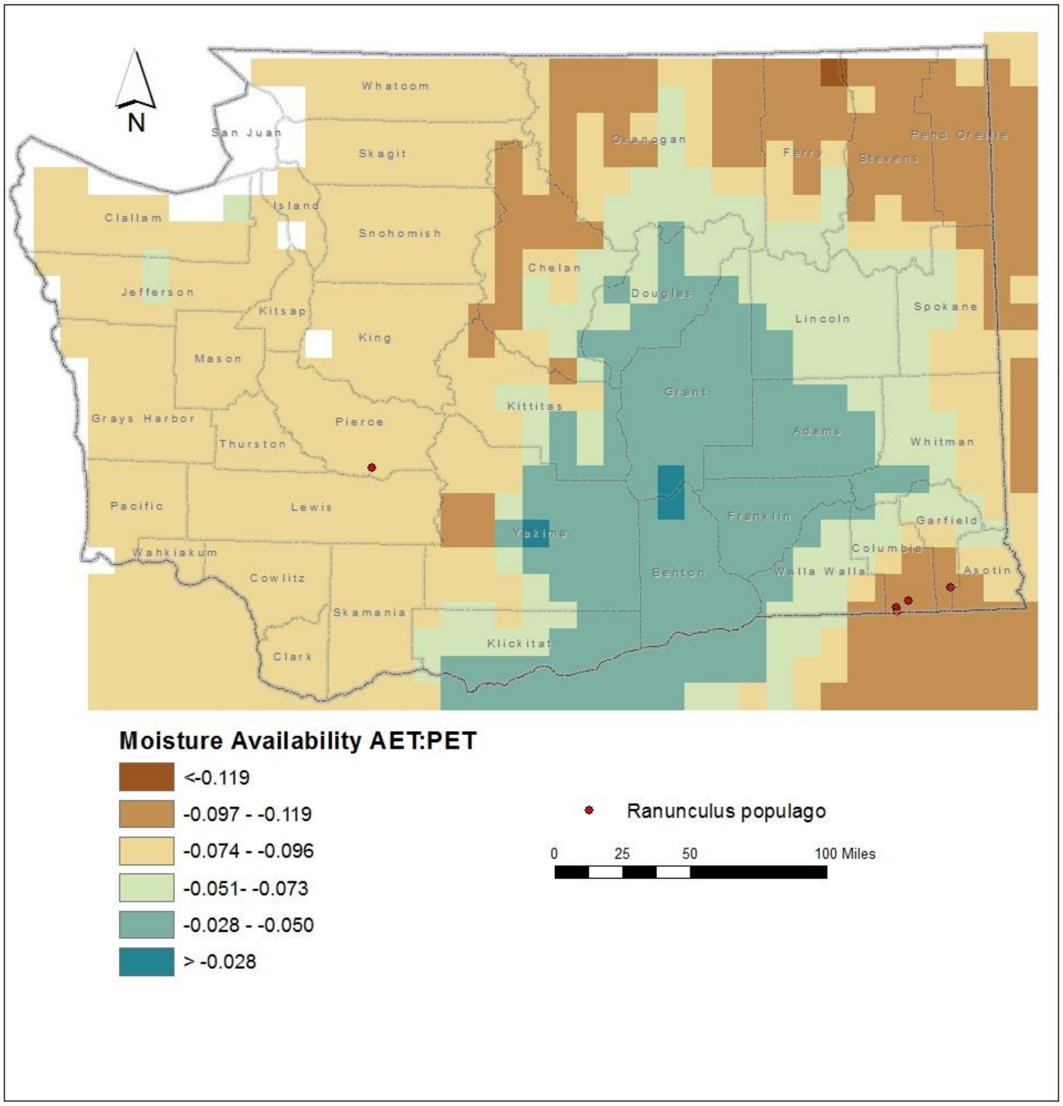

Figure 2. Exposure of *Ranunculus populago* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Ranunculus populago* are found at 4400-6000 feet (1300-1800 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Ranunculus populago* is found primarily in moist meadows, stream terraces, and riparian corridors within montane forests (Camp and Gamon 2011). Several populations are associated with springs (WNHP records). The habitat of *R. populago* is a component of the Rocky Mountain Alpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). Individual populations in the Blue Mountains are separated by 1.6-11 km (2-16 miles), while the Mount Rainier National Park record is 321 km (200 miles) away. Intervening areas are probably not suitable habitat and could be a barrier to dispersal and gene flow.

B2b. Anthropogenic barriers: Neutral.
The range of *Ranunculus populago* in Washington is probably more constrained by natural conditions than human 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.
Ranunculus populago produces 7-25 1-seeded achenes per flower head. The achenes are small, flat, and have a small pointed beak to aid dispersal in the fur or feathers of animals or on muddy feet of waterfowl. Dispersal distances are mostly in the range 100 to 1000 m, but infrequent longer dispersal is possible.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Ranunculus populago* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the five of the known occurrences (80%), all from the Blue Mountains, 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. The fifth population from Mount Rainier (20% of the state occurrences) is from an area with small (37-47˚F/20.8-26.3˚C) temperature variation in the same period and is considered at increased vulnerability to climate change.

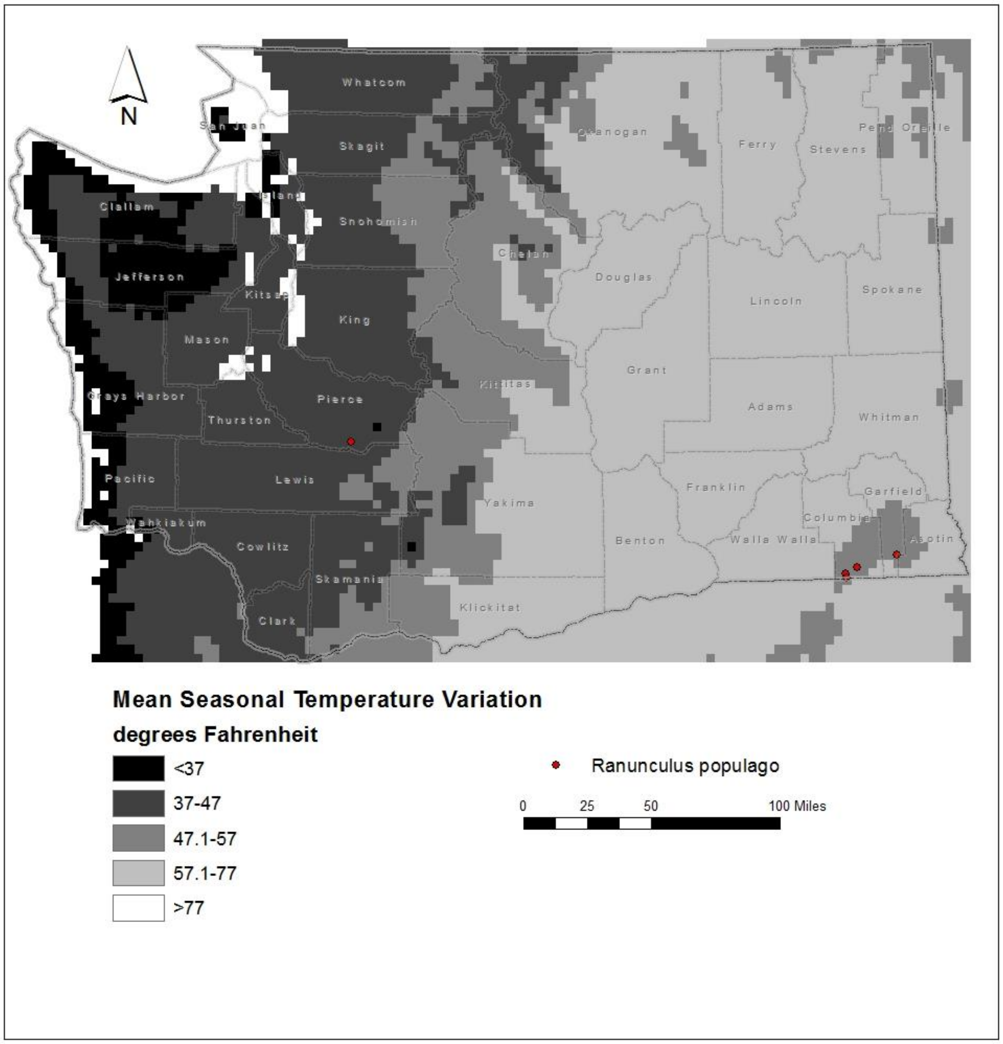

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Ranunculus populago* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The moist mountain meadows occupied by *Ranunculus populago* are associated with cold air drainage or partial shade during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
All five of the populations of *Ranunculus populago* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 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.

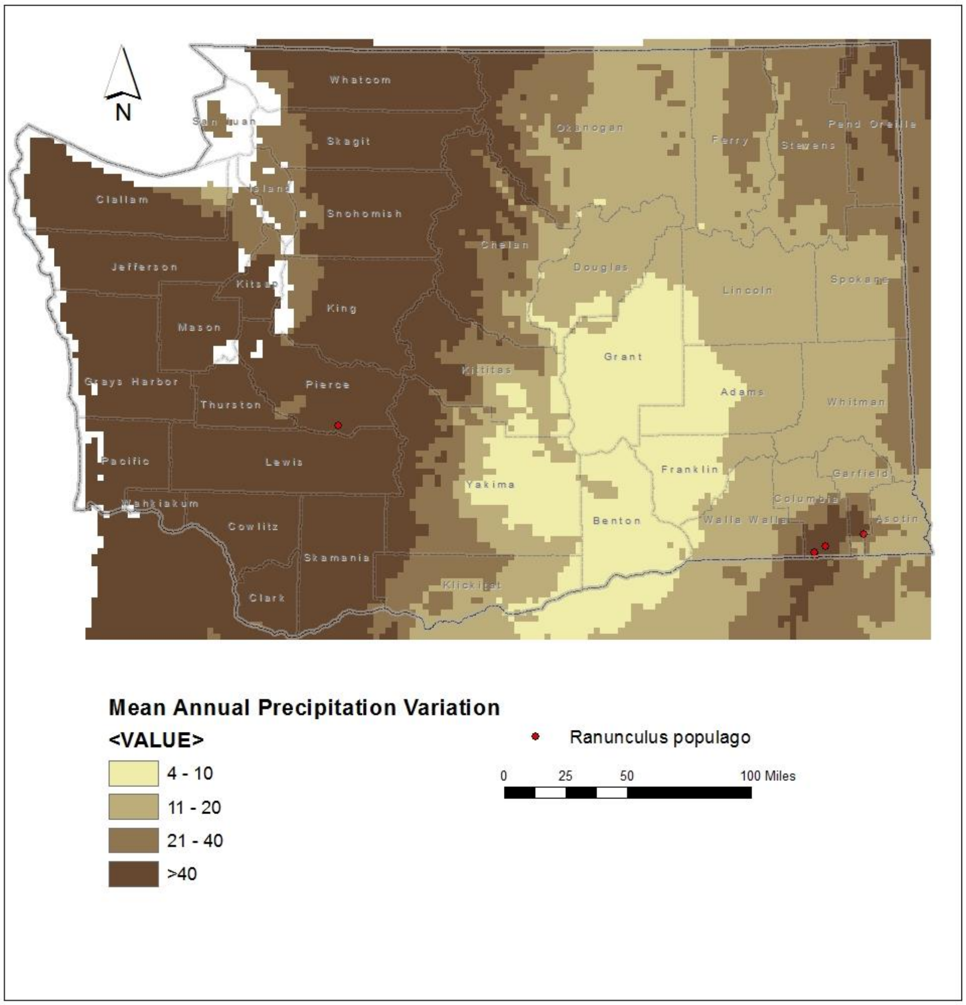

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Ranunculus populago* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The montane meadow habitat of this species is dependent on spring-fed moisture or precipitation. The Rocky Mountain Alpine-Montane Wet Meadow ecological system is vulnerable to changes in the timing or amount of precipitation and drought from increased temperature (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Ranunculus populago is probably not dependent on periodic disturbances to maintain its montane wet meadow habitat, which may be too wet to support trees. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased precipitation that might favor conversion of this habitat to drier meadow conditions or forest encroachment (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The five populations of *Ranunculus populago* in Washington occur in areas of moderate to high accumulations of snow. Recharge of groundwater from melting snow may be important for maintaining adequate moisture in spring-fed wet meadows. *R. populago* populations could be vulnerable to reductions in the depth or changes in rate of melting of snowpack (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
The populations of *Ranunculus populago* from the Blue Mountains are associated with the Grande Ronde basalt, which is a widespread geological formation in southeastern Washington. At Mount Rainier, the population is found on glacial drift material. This species is not strongly associated with unusual geology types or landforms in the state, and so ranked neutral.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Ranunculus populago* 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.
Ranunculus flowers are unspecialized and visited by a wide variety of generalist insect pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seed dispersal in *Ranunculus populago* is facilitated by animals, with the small, flattened 1-seeded fruits able to stick to fur or feathers by a pointed beak. Fruits might also be distributed in mud on the feet of waterfowl, or by passive means (gravity, water, wind). Dispersal is probably not a limiting factor.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. Impacts from herbivory are poorly known, but probably low.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
The moist mountain meadow habitat of *Ranunculus populago* could be vulnerable to competition from other native or introduced plant species if these sites become drier and cover of dry meadow or forest species increases (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 *Ranunculus populago* in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Ranunculus populago produces open, perfect flowers that are pollinated by a variety of insects. Due to the small size of the flowers, the species might be capable of some self-pollination. There is little in the life history of this species to suggest it has low genetic diversity overall, though the populations in Washington are at the edge of its continuous range (or widely disjunct, in the case of the Mount Rainier occurrence) and so could have lower genetic diversity due to founder effects or inbreeding depression.

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 *Ranunculus populago* 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.

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.

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

Rubus arcticus ssp. *acaulis* (Nagoonberry)

Date: 28 February 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5T5/S1

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		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		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Somewhat Increase

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 three of the occurrences of *Rubus arcticus* ssp. *acaulis* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

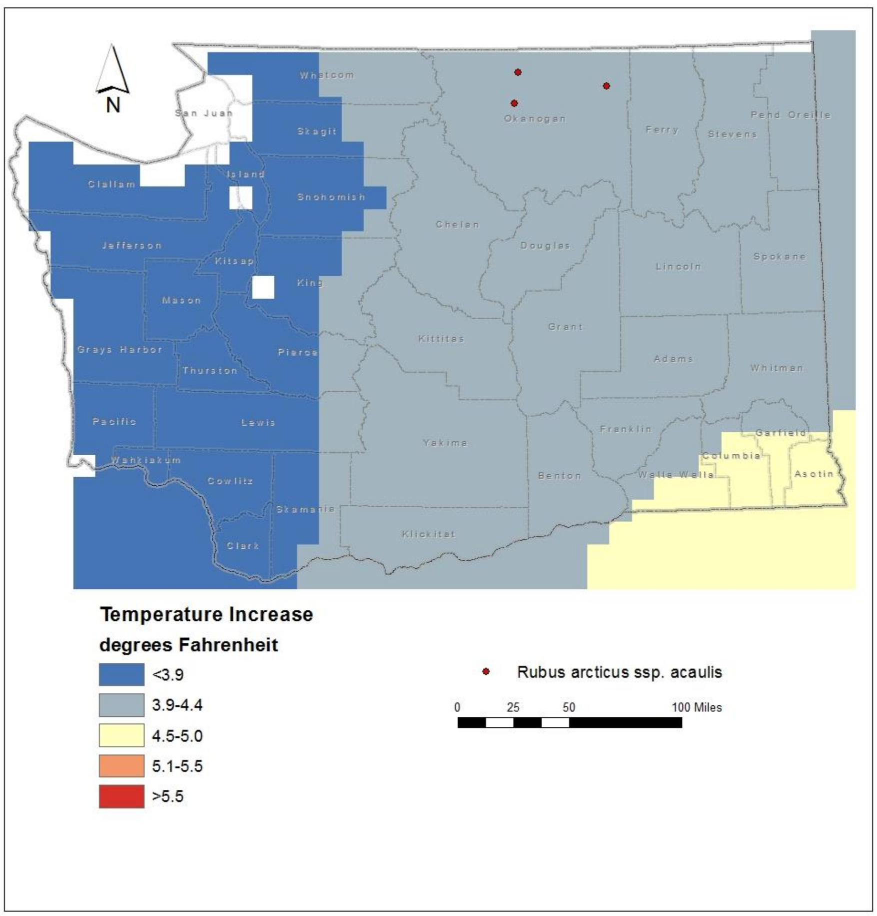

Figure 1. Exposure of *Rubus arcticus* ssp. *acaulis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All three of the Washington occurrences of *Rubus arcticus* ssp. *acaulis* (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).

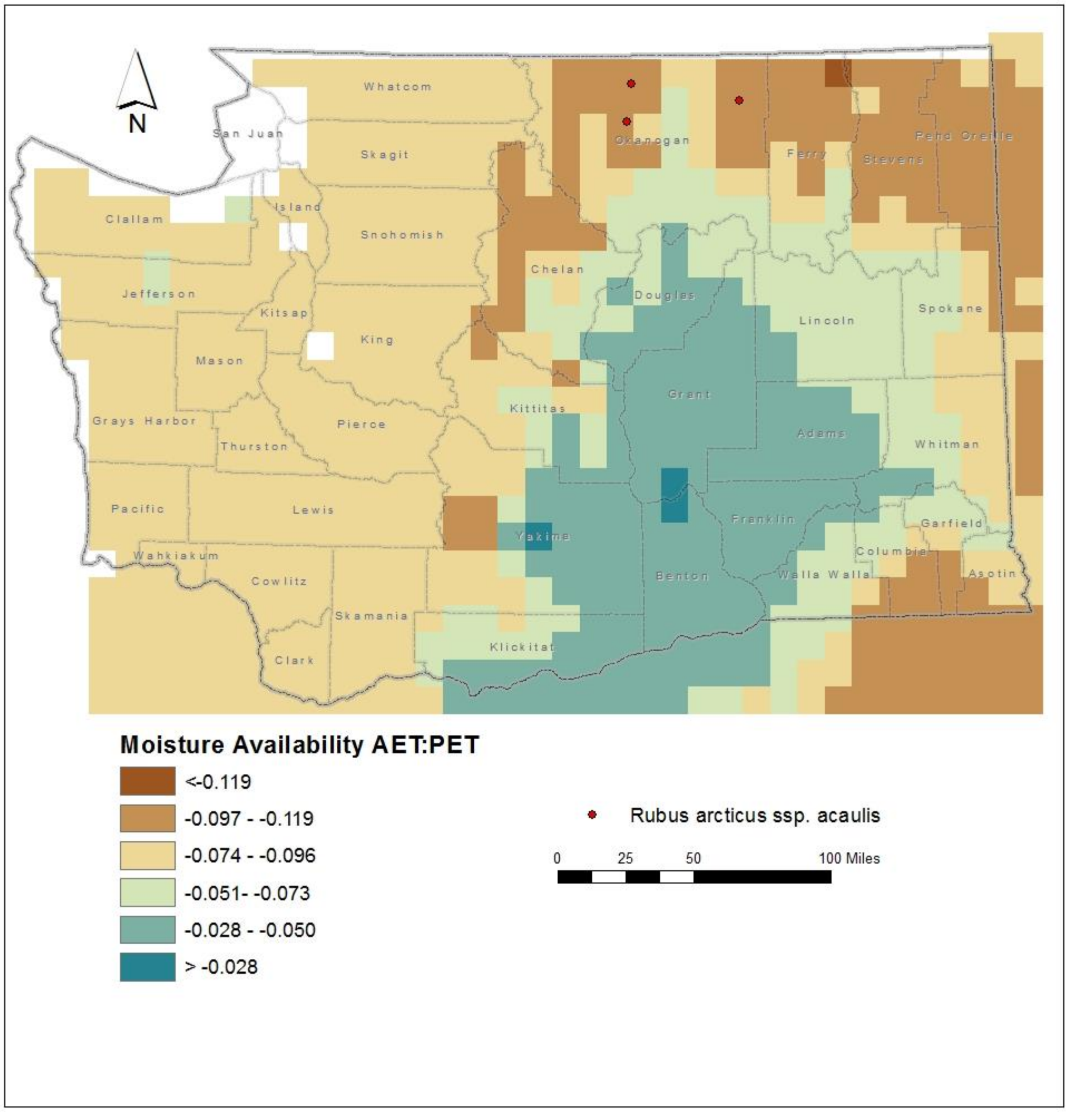

Figure 2. Exposure of *Rubus arcticus* ssp. *acaulis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Rubus arcticus* ssp. *acaulis* are found at 3550-5950 feet (1080-1815 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Rubus arcticus* ssp. *acaulis* is found in forested Engelmann spruce wetlands and fens (Camp and Gamon 2011). These habitats are components of the Rocky Mountain Subalpine-Montane Riparian Woodland and Rocky Mountain Subalpine-Montane Fen ecological systems (Rocchio and Crawford 2015). Individual populations are small and separated by 23-64 km (14-40 miles) of mostly unsuitable habitat that would act as a barrier to gene flow.

B2b. Anthropogenic barriers: Neutral.
The range of *Rubus arcticus* ssp. *acaulis* in Washington is probably more constrained by natural conditions than human ones.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Rubus arcticus ssp. *acaulis* produces edible, aggregate fruits comprised of 20-30 fleshy, 1-seeded drupelets that are readily consumed by humans, rodents, birds, and other wildlife. Seeds can be dispersed short to long distances and the small seeds excreted in feces.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Rubus arcticus* ssp. *acaulis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Two of the three known occurrences (66.7%) 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. The third population (33.3% of the state occurrences) is historical and from an area with average (57.1-77˚F/31.8-43.0˚C) temperature variation in the same period and is considered at neutral vulnerability to climate change.

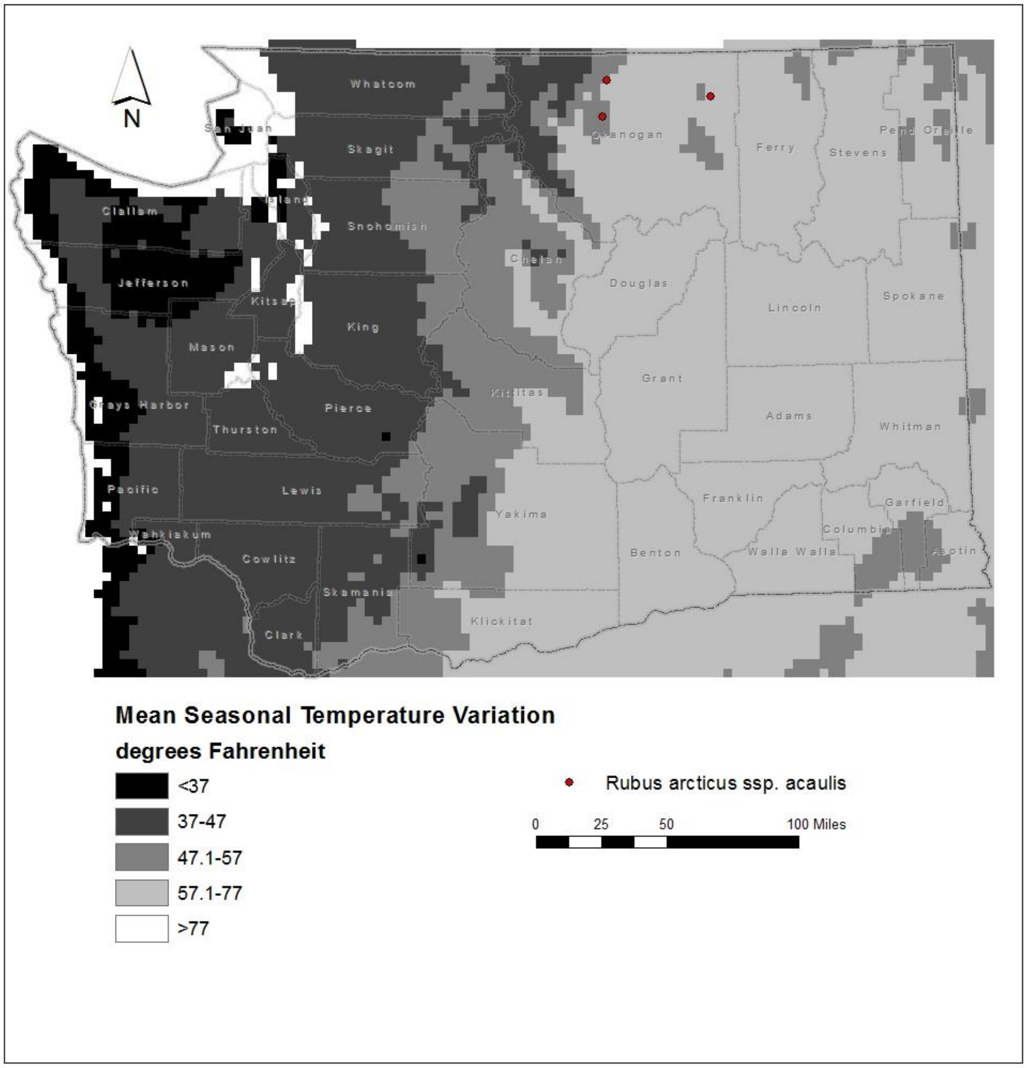

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Rubus arcticus* ssp. *acaulis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The swamp forest and Sphagnum fen sites occupied by *Rubus arcticus* ssp. *acaulis* are associated with cold air drainage or partial shade during the growing season and would have somewhat increased vulnerability to climate change.

C2bi. Historical hydrological niche: Neutral.
All three of the populations of *Rubus arcticus* ssp. *acaulis* in Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 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.

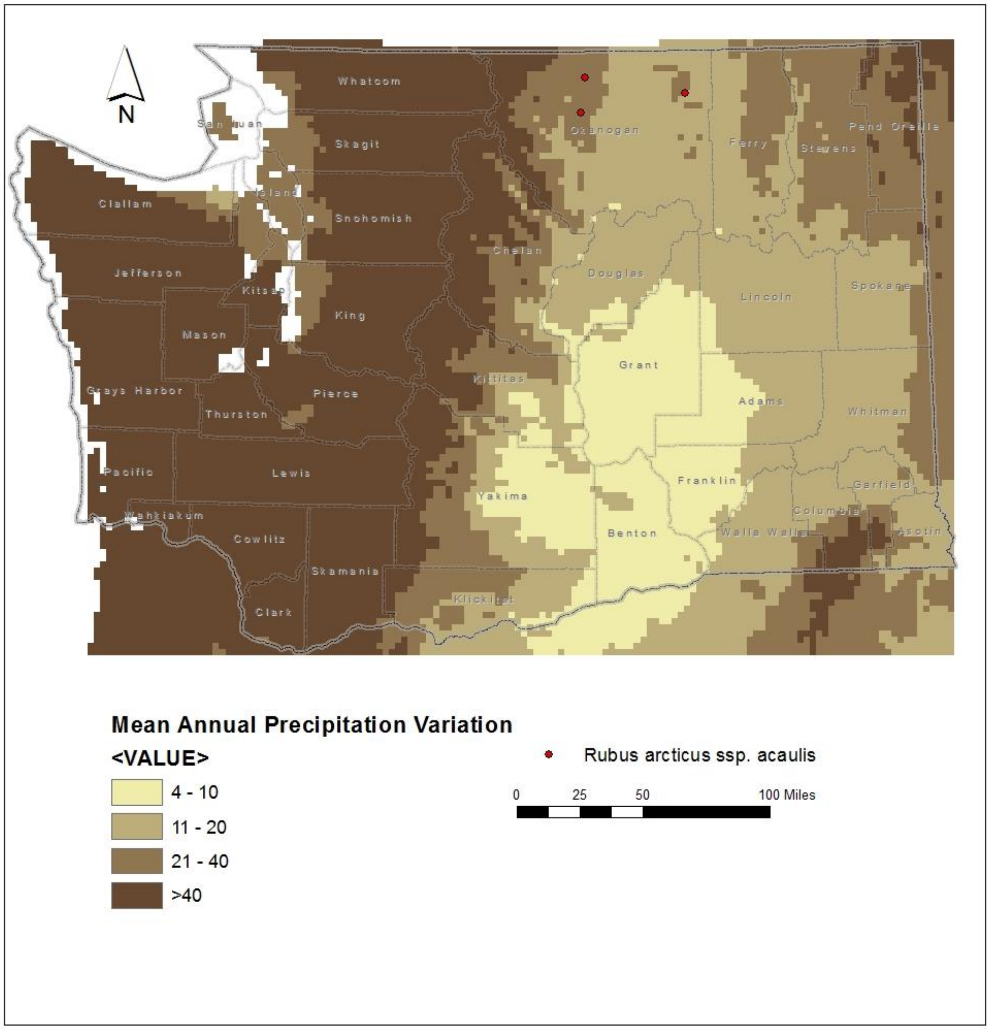

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Rubus arcticus* ssp. *acaulis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
In Washington, *Rubus arcticus* ssp. *acaulis* is restricted to forested wetland and Sphagnum fen habitats. Forested wetlands are especially sensitive to changes in moisture levels related to precipitation, snowmelt, and drought (Rocchio and Ramm-Granberg 2017). Fen habitats are

more dependent on groundwater discharge and less susceptible to climate change, at least in the short term (Rocchio and Ramm-Granberg 2017). Long-term, fen sites are vulnerable to displacement by moist to dry meadow species as water tables become lowered due to reduced snowmelt, increased drought, and changes in the amount or timing of precipitation.

C2c. Dependence on a specific disturbance regime: Neutral.
Rubus arcticus ssp. *acaulis* is probably not dependent on periodic disturbances to maintain its forest wetland or Sphagnum fen habitat.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Rubus arcticus ssp. acaulis* in Washington occur in areas of moderate to high accumulations of snow. Recharge of groundwater from melting snow is especially important for maintaining adequate moisture in fen wetlands. Populations could be vulnerable to reductions in the depth or changes in rate of melting of snowpack (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
The populations of *Rubus arcticus* ssp. *acaulis* in Washington occur on a variety of intrusive batholith, mixed metamorphic and igneous, and glacial till substrates that are relatively common in the mountains of the north-central portion of the state.

C4a. Dependence on other species to generate required habitat: Neutral
The habitat occupied by *Rubus arcticus* ssp. *acaulis* 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.
Rubus arcticus ssp. *acaulis* produces relatively large flowers that are pollinated by bumblebees and other bees (Ladyman 2006). Studies in Europe have shown that different genetic strains (genotypes) can occur within the same population. Fertilization and fruit production may depend on crosses between different genotypes due to gametophytic self-incompatability (Tammisola 1988). Reduced fruit production in some populations, such as those in the Rocky Mountains of Colorado and Wyoming (Ladyman 2006; Fertig 2000) may be related to populations that are genetically incompatible (although still capable of spreading vegetatively) or triploid. Washington populations appear to be vigorous and capable of producing large amounts of flowers and fruits, so may not have the reproductive barriers found in the Rocky Mountains.

C4d. Dependence on other species for propagule dispersal: Neutral.
Rubus arcticus ssp. acaulis fruits are edible and can be potentially transported long distances by a variety of animal species. Dispersal, per se, is probably not a limiting factor, although finding new places with suitable habitat for germination is more problematic.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Ladyman (2006) reports that *Rubus arcticus* ssp. *acaulis* is potentially vulnerable to several virus diseases and from floral herbivory by thrips. Herbivory of stems and leaves is probably minor.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Shading by shrubs and taller vegetation is considered a threat to some European populations (Ladyman 2006). The wet forest and Sphagnum fen habitat could be vulnerable to competition from invasive species or displacement by native species adapted to drier conditions or adapted to fire under increased drought or reduced precipitation in the future (Rocchio and Ramm-Granberg).

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 *Rubus arcticus* ssp. *acaulis* in Washington. Studies in Finland found high levels of genetic diversity between population of *R. acaulis*, suggesting the importance of sexual reproduction within populations and limitations to gene flow between populations (Lindqvist-Kreuze et al. 2003). The disjunct populations at the south edge of the species' range in western North America (such as Washington, Colorado, and Wyoming) suggest that genetic diversity may be low due to founder effects or inbreeding depression.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Somewhat Increase
Rubus arcticus ssp. acaulis produces large, unspecialized flowers that are pollinated by a variety of insects. Studies suggest that it can form self-incompatible clones and fruit production may be dependent on 2-3 different genetic clones being present in the same population for out-crossing. Genetic diversity is probably high for the species overall, but isolated populations in Washington would likely have lower diversity due to founder effects or inbreeding depression.

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 *Rubus arcticus* ssp. *acaulis* has probably not changed notably in the last 50 years. One population in Okanogan County is considered historical, but is from private lands and it appears no attempt has been made to relocate it.

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.

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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.

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Climate Change Vulnerability Index Report

Salix candida (Hoary willow)

Date: 3 March 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
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		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: All four of the known occurrences of *Salix candida* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

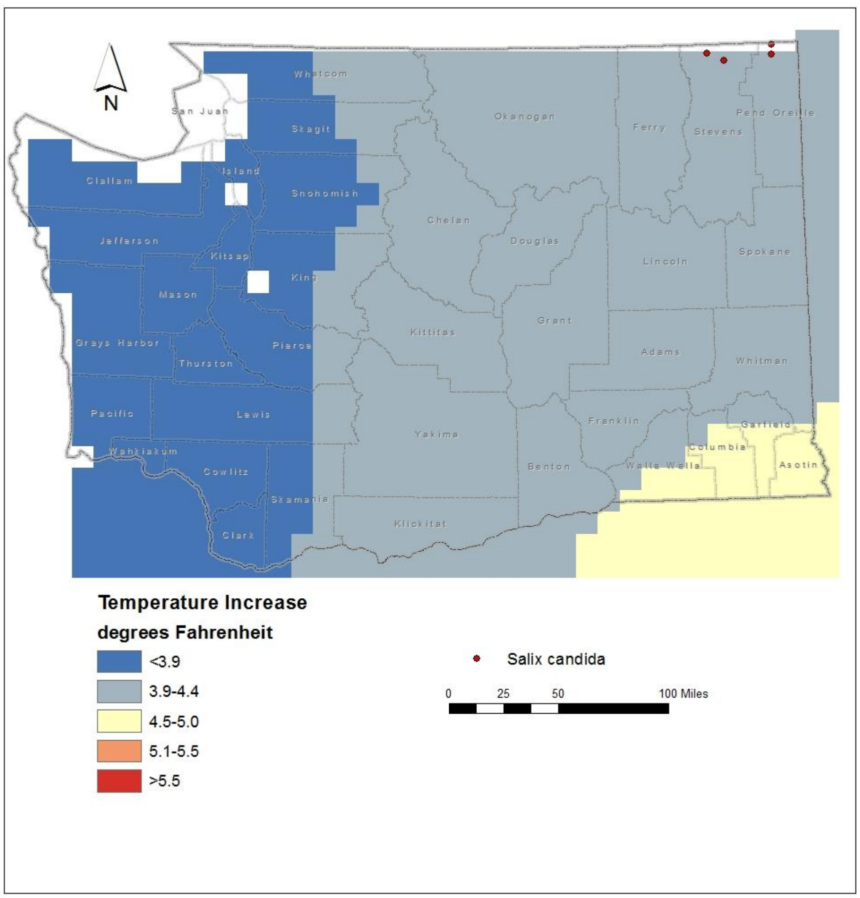

Figure 1. Exposure of *Salix candida* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All four of the occurrences of *Salix candida* (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 -0.097 to -0.119 (Figure 2).

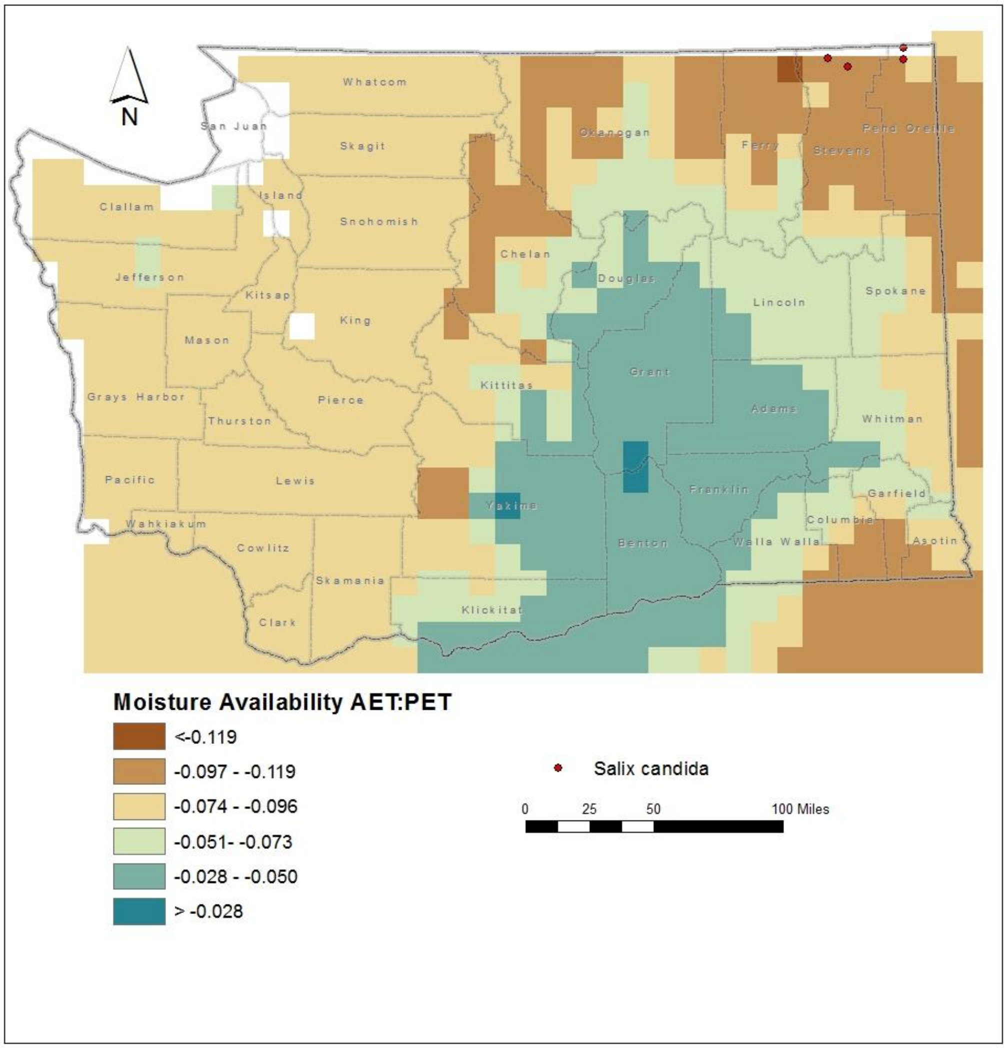

Figure 2. Exposure of *Salix candida* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Salix candida* are found at 2000-2950 feet (600-900 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Salix candida* is found in fens and willow carrs associated with peat and limestone soils on undulating or hummocky terrain, sometimes surrounding small ponds (Camp and Gamon 2011; WNHP records). Rangewide, it is usually found in nutrient-rich fens with high mineral content and alkaline pH (Decker 2006). In Washington, *S. candida* habitat is a component of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio and Crawford 2015). Individual populations occupy sites as small as 0.5-3 acres and are separated by 6.5-35 km (4-22 miles). These specialized habitats are naturally isolated from each other with mostly unsuitable habitat in-between.

B2b. Anthropogenic barriers: Neutral.
The range of *Salix candida* is naturally fragmented. Human impacts on the landscape of northeastern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Salix candida produces numerous, many-seeded dry capsules. Seeds are small and have a tuft of wavy hairs to assist in dispersal by wind. Although average dispersal distance may be short, some seeds are capable of moving over 1 km, and so the species is not dispersal limited.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Salix candida* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All four 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 to climate change.

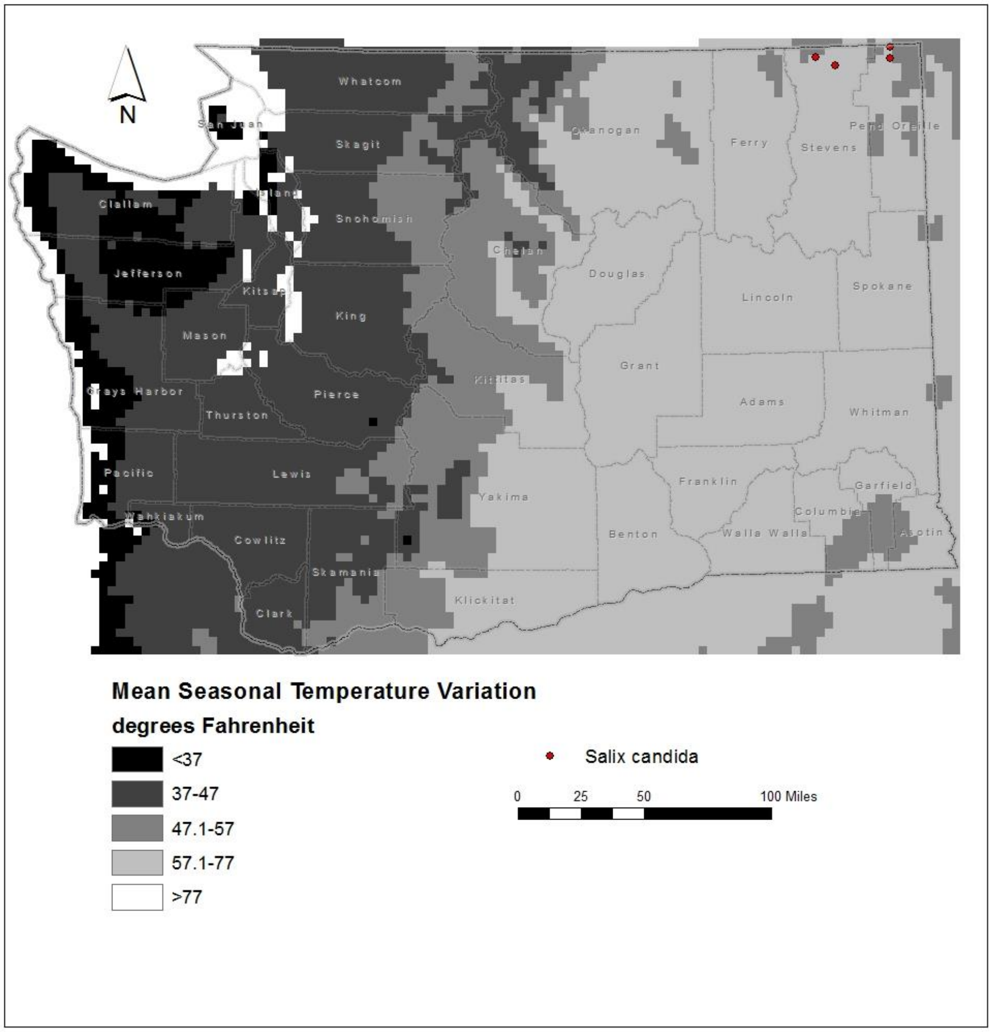

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Salix candida* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Greatly Increase.
The fen habitat of *Salix candida* is associated with cold air drainage during the growing season and would have greatly increased vulnerability to temperature changes associated with global warming.

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

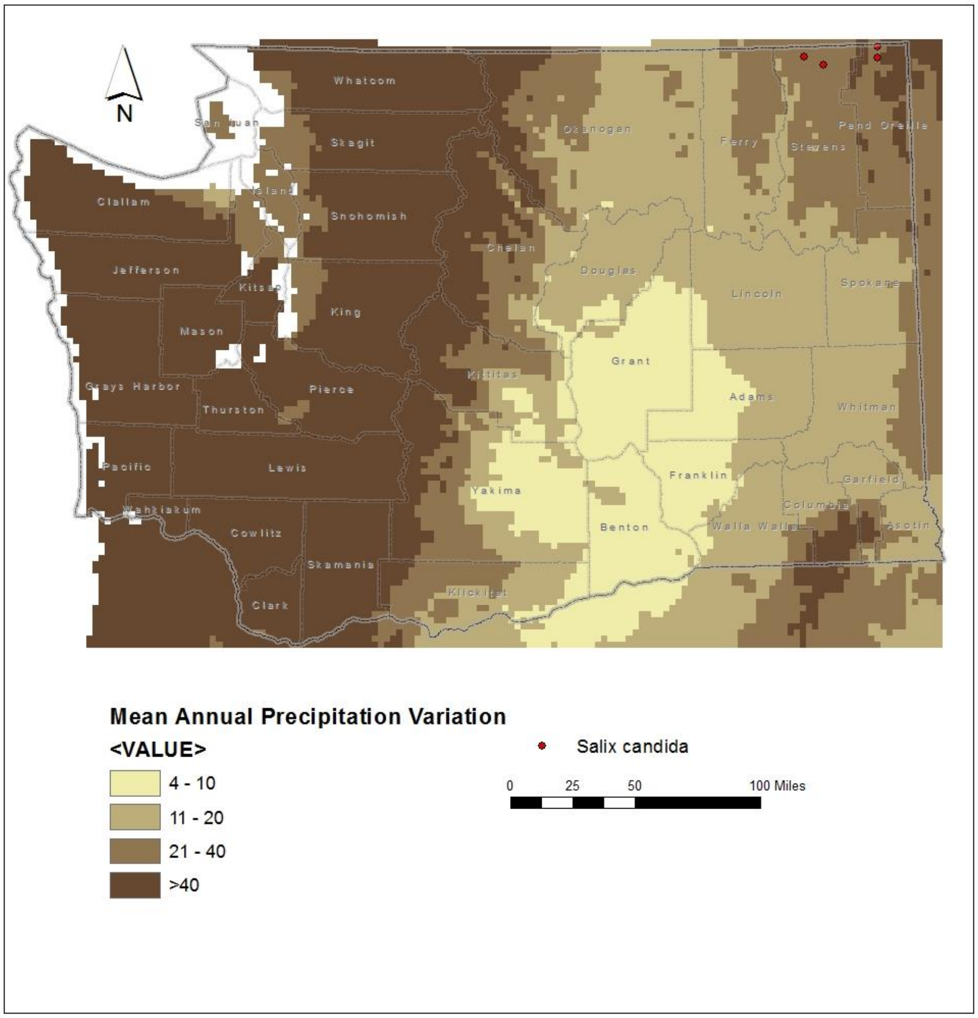

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Salix candida* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The calcareous fen habitat of *Salix candida* in Washington is largely dependent on groundwater, although fens associated with ponds may also have some connection with surface water (Rocchio and Ramm-Granberg 2017). Groundwater-fed wetlands are more reliant on adequate snowpack (see C2d below), but reduction in the timing and amount of precipitation and

increased drought would make these sites more vulnerable to climate change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Salix candida is not dependent on periodic disturbances to maintain its fen or wet meadow habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased snowpack that might favor conversion of this habitat to forest or meadows, or increase fire frequency (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Salix candida* in Washington are found in the mountains of northeast Washington in areas with high snowfall. The fen wetlands occupied by this species are dependent on late-lying snowbanks for recharging groundwater (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow or when the snow melts could lead to shifts in the dominance of herbaceous species or invasion of trees or shrubs.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Salix candida is found mostly on glacial drift deposits or spoils derived from the Metaline Formation, a limestone and dolomite formation found sporadically in northeastern Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The wetland habitat occupied by *Salix candida* is maintained primarily by natural abiotic processes.

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 small insect pollinators, especially flies, bees, and butterflies (Decker 2006).

C4d. Dependence on other species for propagule dispersal: Neutral.
Willow seeds have a tuft of wavy, silky hairs and are dispersed passively by wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Although willows are susceptible to rust fungi, no impacts to *Salix candida* are known (Decker 2006). Hoary willow is reported as being heavily browsed in some wetlands (Decker 2006), and often is browsed before fruiting catkins can mature at sites in Wyoming (Fertig 1998). Once established, however, plants are long-lived and capable of re-sprouting following herbivory (Decker 2006).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Salix candida could be sensitive to competition from other plant species if its specialized wetland habitat became drier due to drought or reduced snowpacks and water recharge under future 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 in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Salix candida is dioecious (with separate staminate and pistillate individuals) and is thus an obligate outcrosser. Pollination can occur by insects or long-distance dispersal by wind. Seed dispersal occurs by wind. The life history of this species suggests that it should have average genetic diversity across populations. The occurrences in Washington are near the edge of the species range and could have slightly lower genetic diversity due to founder effects or inbreeding depression.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No recent changes in the distribution of this species in Washington have been detected.

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.

Decker, K. 2006. *Salix candida* Fluegge ex Willd. (sageleaf willow): A technical conservation assessment. Colorado Natural Heritage Program, Fort Collins, CO. 45 pp.

Fertig, W. 1998. Plant species of special concern and vascular plant flora of the National Elk Refuge. Wyoming Natural Diversity Database, Laramie, WY. 59 pp. + app.

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.

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 glauca var. *villosa* (Glaucous willow)

Date: 3 March 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5T5?/S1S2

Index Result: Moderately Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

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

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

Section A: Exposure to Local Climate Change

A1. Temperature: All five of the known occurrences of *Salix glauca* var. *villosa* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

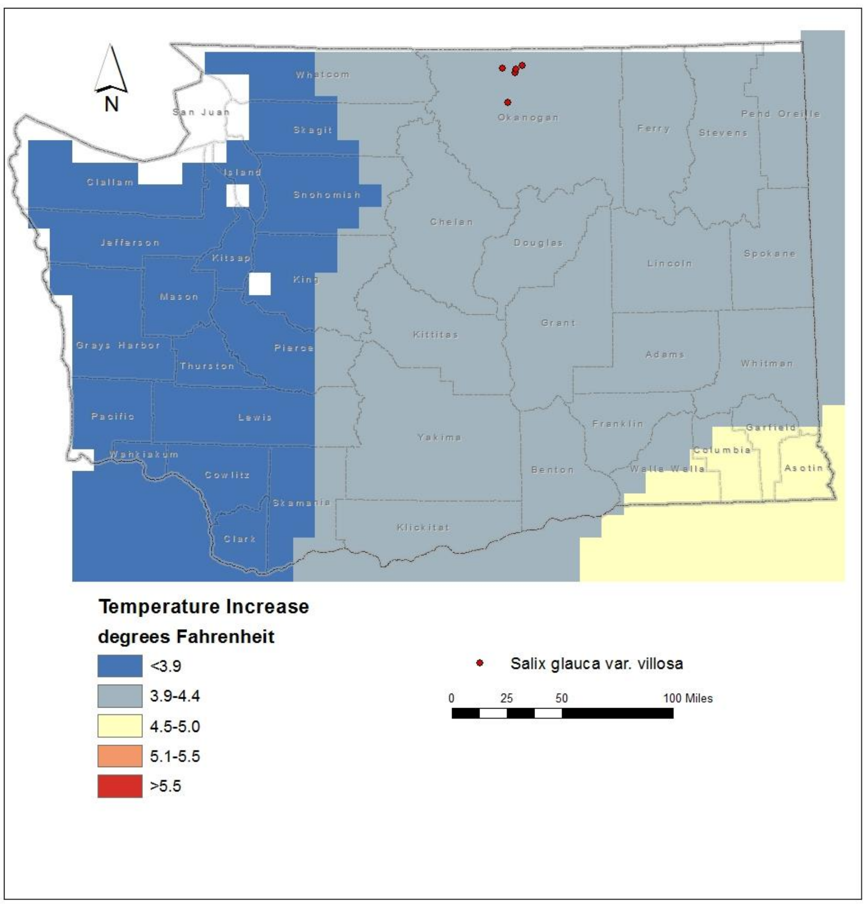

Figure 1. Exposure of *Salix glauca* var. *villosa* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All five of the occurrences of *Salix glauca* var. *villosa* (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 -0.097 to -0.119 (Figure 2).

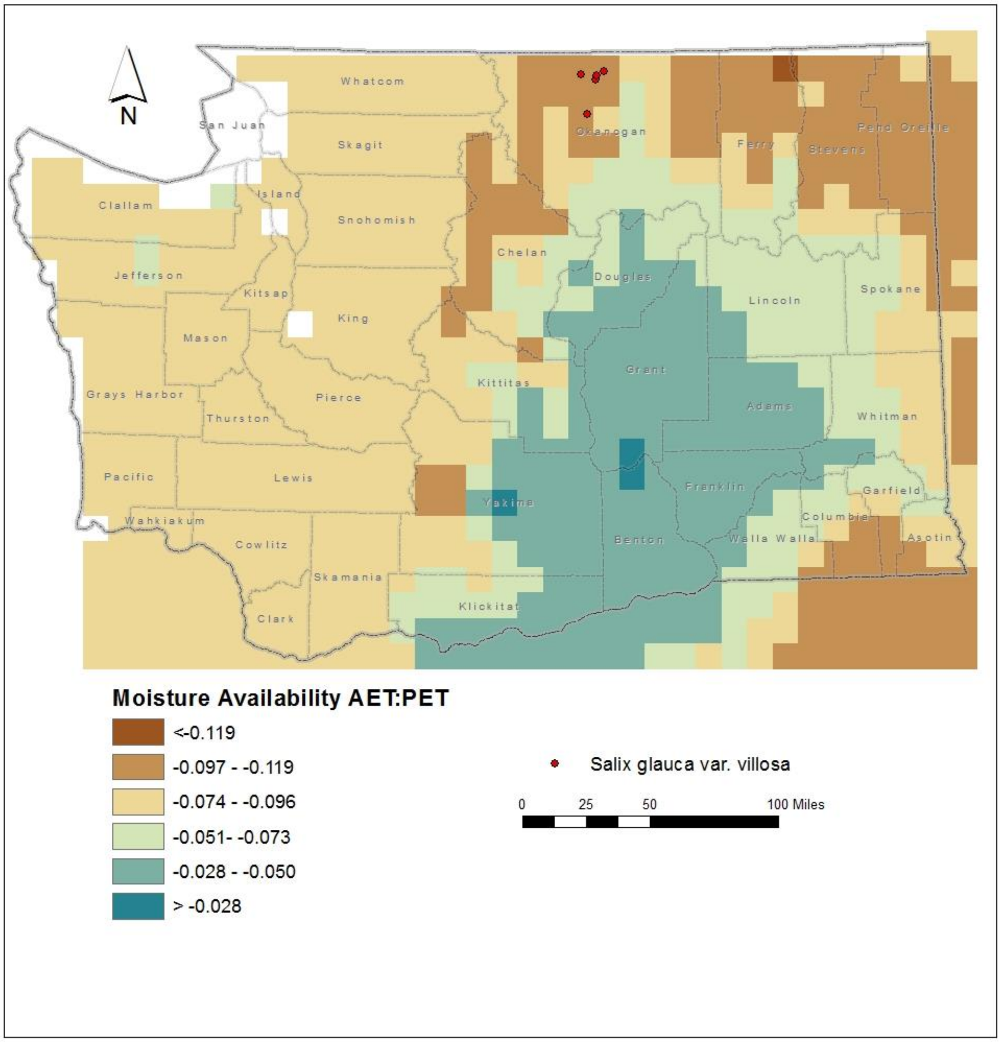

Figure 2. Exposure of *Salix glauca* var. *villosa* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Salix glauca* var. *villosa* are found at 4400-5900 feet (1340-1800 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Salix glauca* var. *villosa* occurs in a variety of habitats, including montane streamsides, shrubby wetlands, and granitic cirques near timberline (Camp and Gamon 2011, WNHP records). Lower elevation riparian sites occupied by this species correspond with the Rocky Mountain Subalpine-Montane Riparian Shrubland ecological system, while populations from rocky sites at timberline fit the Rocky Mountain Alpine Dwarf-Shrubland, Fell-Field, and Turf ecological system (Rocchio and Crawford 2015). Individual populations can occur along streams for over 5 km or be separated from other occurrences by up to 14 miles (22.3 km). Populations are found mostly in valleys and isolated from each other by low mountain ridges. These barriers may not be sufficient to completely restrict dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Salix glauca* var. *villosa* is naturally somewhat fragmented. Human impacts on the landscape of northeastern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Salix glauca var. *villosa* produces numerous, many-seeded dry capsules. Seeds are small and have a tuft of wavy hairs to assist in dispersal by wind. Although average dispersal distance may be short, some seeds are capable of moving over 1 km, and so the species is not dispersal limited.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Salix glauca* var. *villosa* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the five known occurrences (80%) 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. One other occurrence (20%) is from an area with average (57.1-77˚F/31.8-43.0˚C) temperature variation during the same period and is considered at neutral risk to climate change.

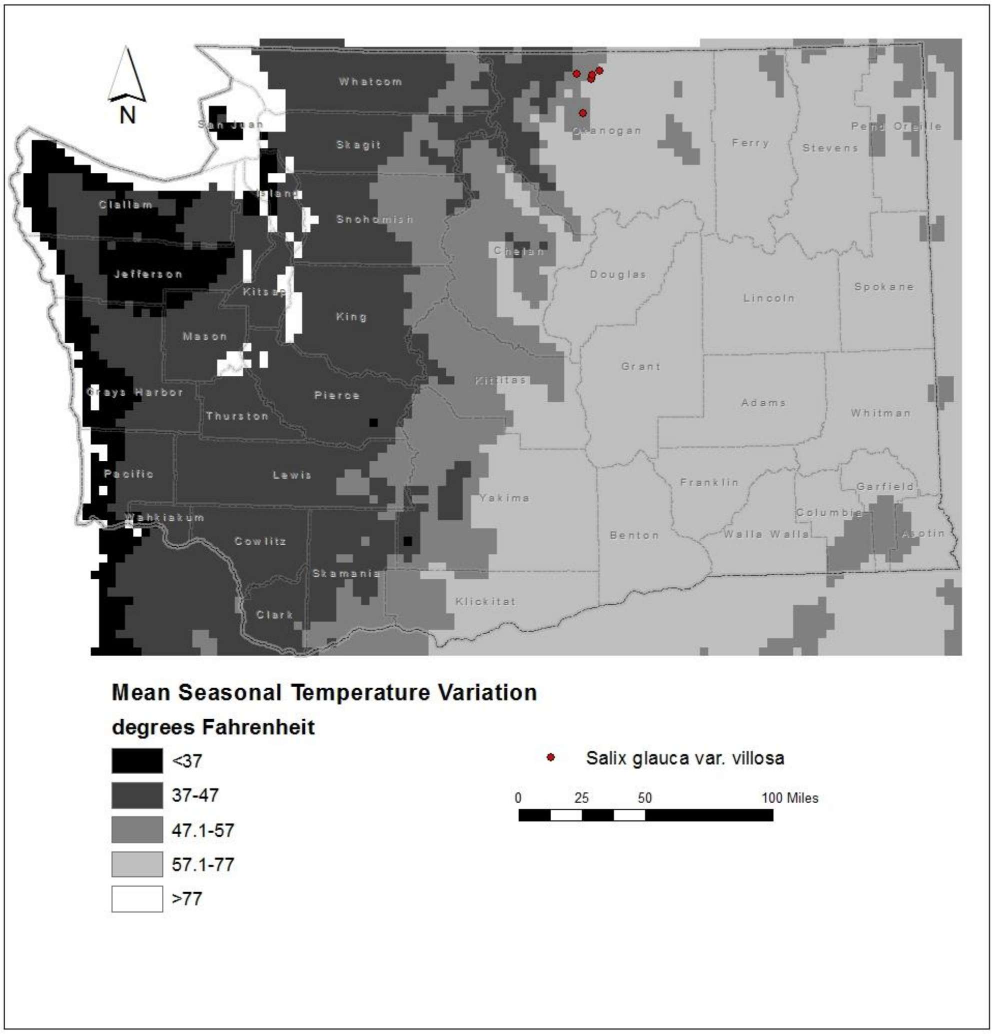

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Salix glauca* var. *villosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The montane riparian shrub and timberline cirque habitat of *Salix glauca* var. *villosa* in Washington is associated with cold air drainage during the growing season and would have increased vulnerability to temperature changes associated with global warming.

C2bi. Historical hydrological niche: Neutral.
All five of the populations of *Salix glauca* var. *villosa* in Washington (100%) are found in areas that have experienced average (>20 inches/508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), these occurrences are at neutral vulnerability to climate change.

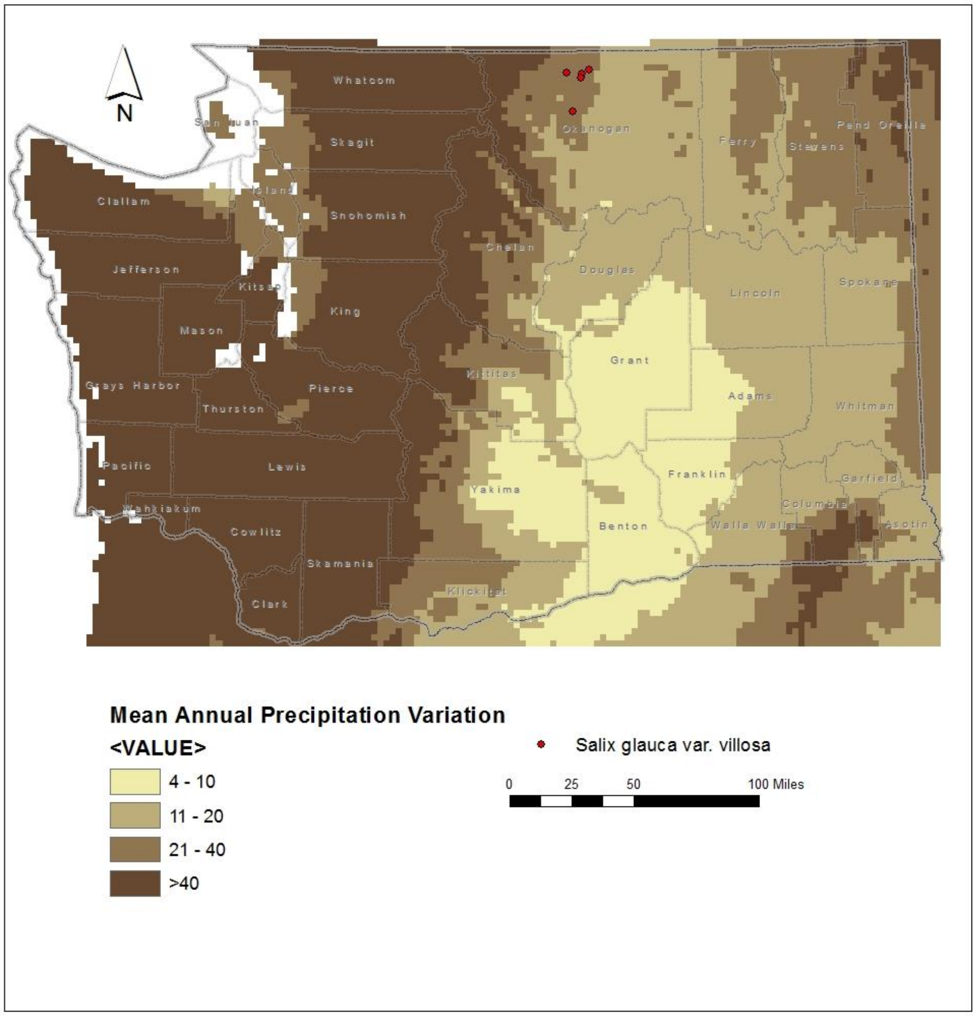

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Salix glauca* var. *villosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The montane streamside habitat of *Salix glauca* var. *villosa* in Washington is largely dependent on springtime flooding due to snowmelt to maintain moisture conditions (Rocchio and Ramm-Granberg 2017). Timberline cirque habitats would be more influenced by the amount and duration of snowpack, rather than rainfall. Increased temperatures, greater likelihood of

drought, and changes in amount and timing of precipitation could alter vegetation patterns in both ecological systems and favor conversion to habitats better adapted to water stress (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Salix glauca var. *villosa* is not dependent on periodic disturbances to maintain its montane riparian and timberline granitic cirque habitat. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased snowpack that might favor conversion of this habitat to forest or wet meadows, or increase fire frequency (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Salix glauca* var. *villosa* in Washington are found in the Okanogan Mountains of northern Washington in areas with high snowfall. The wetlands and cirque habitats occupied by this species are dependent on late-lying snowbanks for recharging groundwater or spring flooding (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow or when the snow melts could lead to shifts in the dominance of herbaceous species or invasion of trees or shrubs.

C3. Restricted to uncommon landscape/geological features: Neutral
Salix glauca var. *villosa* is found mostly on gneiss-derived soils and outcrops of the Cathedral Batholith, Tiffany Mountain gneiss, and Tillman Mountain gneiss, all of which are widespread in the Okanogan region of north-central Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The wetland and cirque habitat occupied by *Salix glauca* var. *villosa* is maintained primarily by natural abiotic processes.

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 small insect pollinators, especially flies, bees, and butterflies.

C4d. Dependence on other species for propagule dispersal: Neutral.
Willow seeds have a tuft of wavy, silky hairs and are dispersed passively by wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Although willows are susceptible to rust fungi, no impacts to *Salix glauca* var. *villosa* are known. This species may be vulnerable to herbivory by beavers and livestock (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Salix glauca var. *villosa* could be sensitive to competition from other plant species if its wetland habitat becomes drier due to drought or reduced snowpack and water recharge under future 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 in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Salix glauca var. *villosa* is dioecious (with separate staminate and pistillate individuals) and is thus an obligate outcrosser. Pollination can occur by insects or long-distance dispersal by wind. Seed dispersal occurs by wind. The life history of this species suggests that it should have average genetic diversity across populations. The occurrences in Washington are near the edge of the species range and could have slightly lower genetic diversity due to founder effects or inbreeding depression.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No recent changes in the distribution of this species in Washington have been detected.

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.

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 pseudomonticola (False mountain willow)

Date: 3 March 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		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		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	
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 of the known and reported occurrences of *Salix pseudomonticola* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

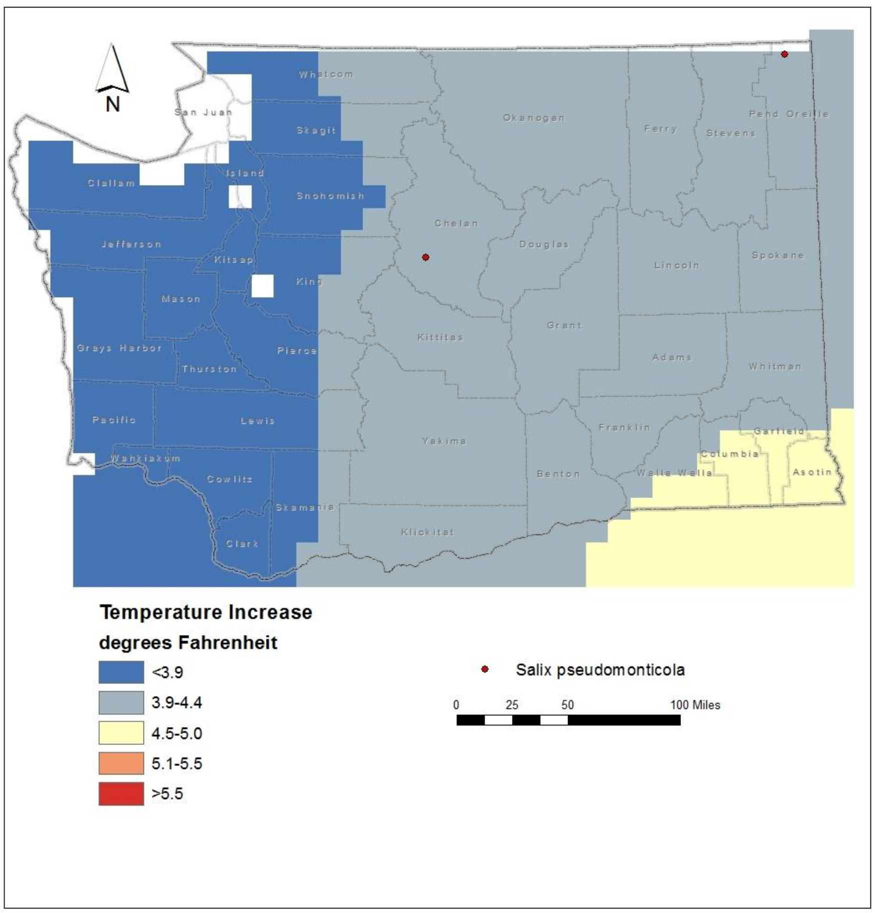

Figure 1. Exposure of *Salix pseudomonticola* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both of the confirmed and reported occurrences of *Salix pseudomonticola* (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 -0.097 to -0.119 (Figure 2).

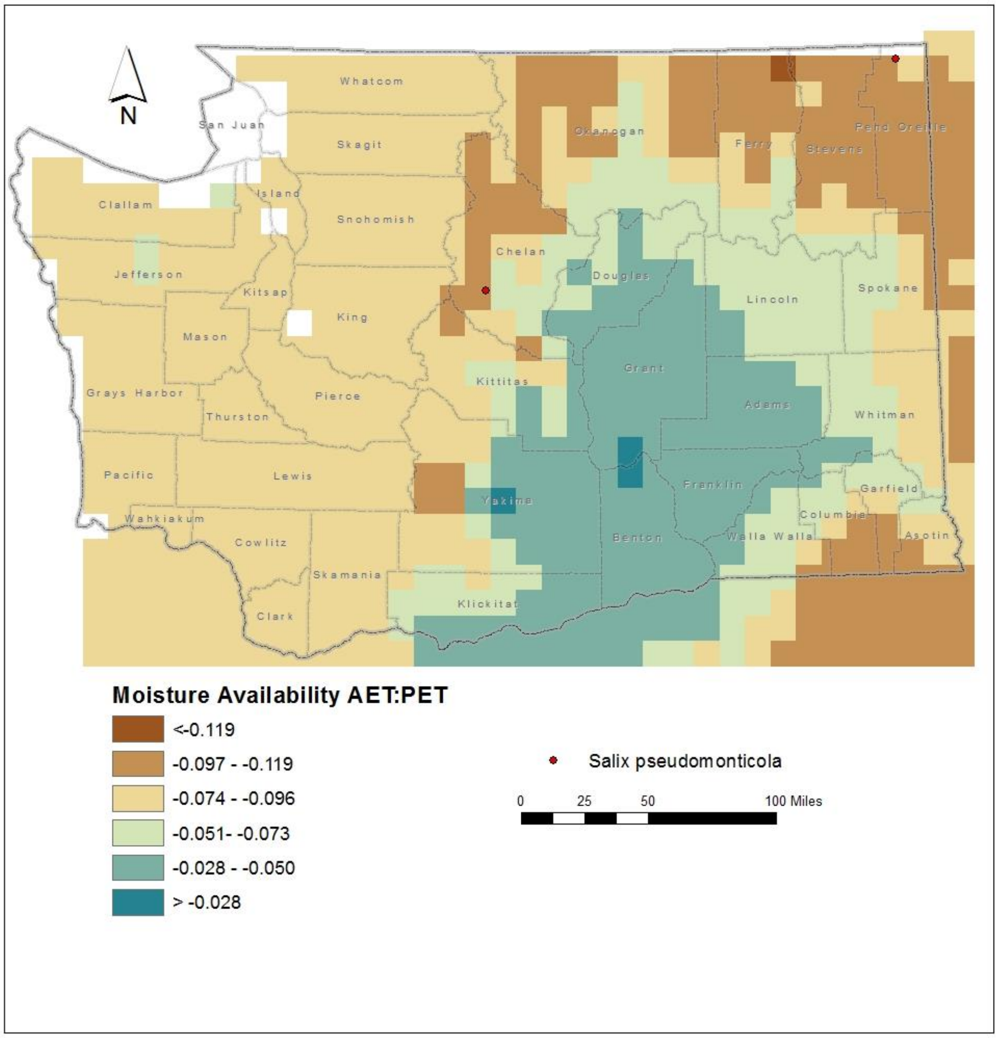

Figure 2. Exposure of *Salix pseudomonticola* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Salix pseudomonticola* are found at 2950-5500 feet (900-1680 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, one occurrence of *Salix pseudomonticola* has been confirmed and is from a hummocky calcareous fen with marl-like soil in Pend Oreille County (Camp and Gamon 2011, WNHP records). This site is a component of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio and Crawford 2015). A second report from Chelan County is found in a wet meadow along a mountain trail and needs to be confirmed (Fertig and Kleinknecht 2020). The habitat description is too vague to classify further. The Pend Oreille County occurrence is disjunct from other populations and embedded within unsuitable habitat, which creates a barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Salix pseudomonticola* is naturally somewhat fragmented. Human impacts on the landscape of northeastern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Salix pseudomonticola produces numerous, many-seeded dry capsules. Seeds are small and have a tuft of wavy hairs to assist in dispersal by wind. Although average dispersal distance may be short, some seeds are capable of moving over 1 km, and so the species is not dispersal limited.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Salix pseudomonticola* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The one confirmed occurrence from Pend Oreille County is from an area with 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. The unconfirmed population from Chelan County is from an area with slightly lower than average (47.1-57˚F/26.3-31.8˚ C) temperature variation during the same period and would be at somewhat increased risk from climate change (Young et al. 2006).

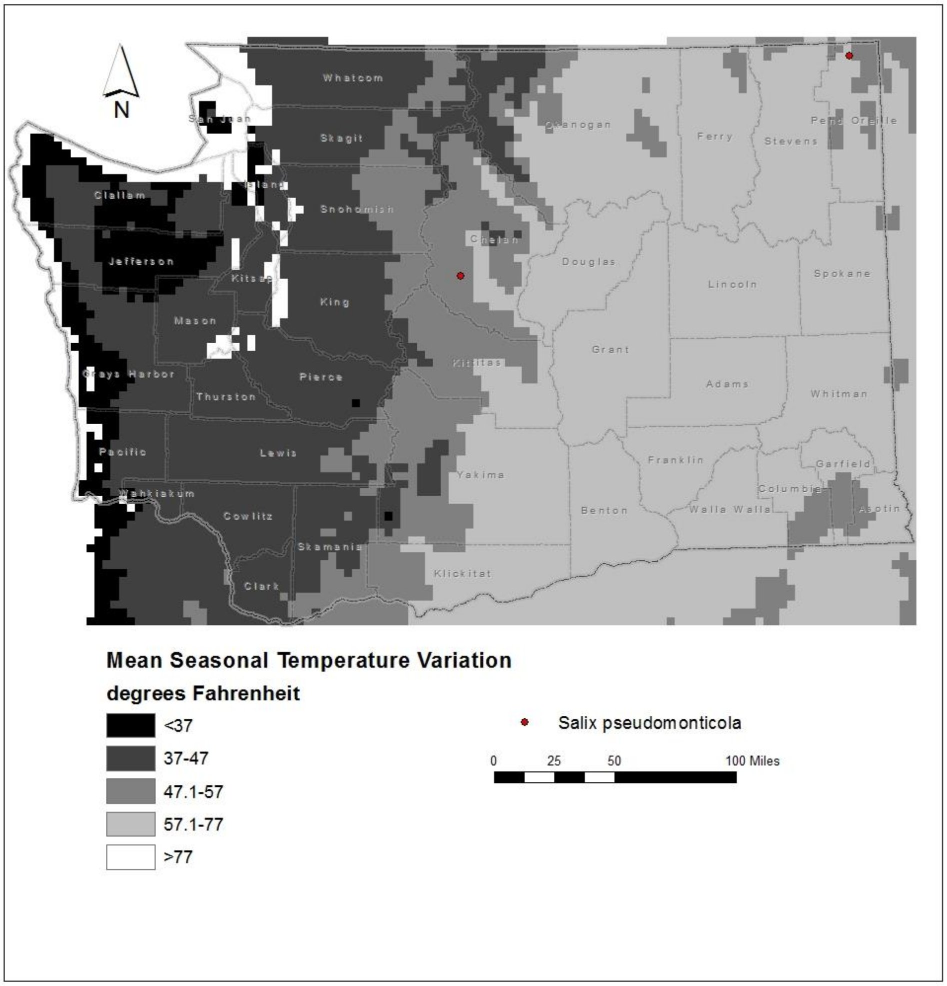

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Salix pseudomonticola* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The montane fen habitat of *Salix pseudomonticola* in Pend Oreille County, Washington is associated with cold air drainage during the growing season and would have increased vulnerability to temperature changes associated with global warming.

C2bi. Historical hydrological niche: Neutral.
Both populations of *Salix pseudomonticola* confirmed and reported from Washington (100%) are found in areas that have experienced average or greater than average (>20 inches/508 mm) precipitation variation in the past 50 years (Figure 4). According to Young et al. (2016), this occurrence is at neutral vulnerability to climate change.

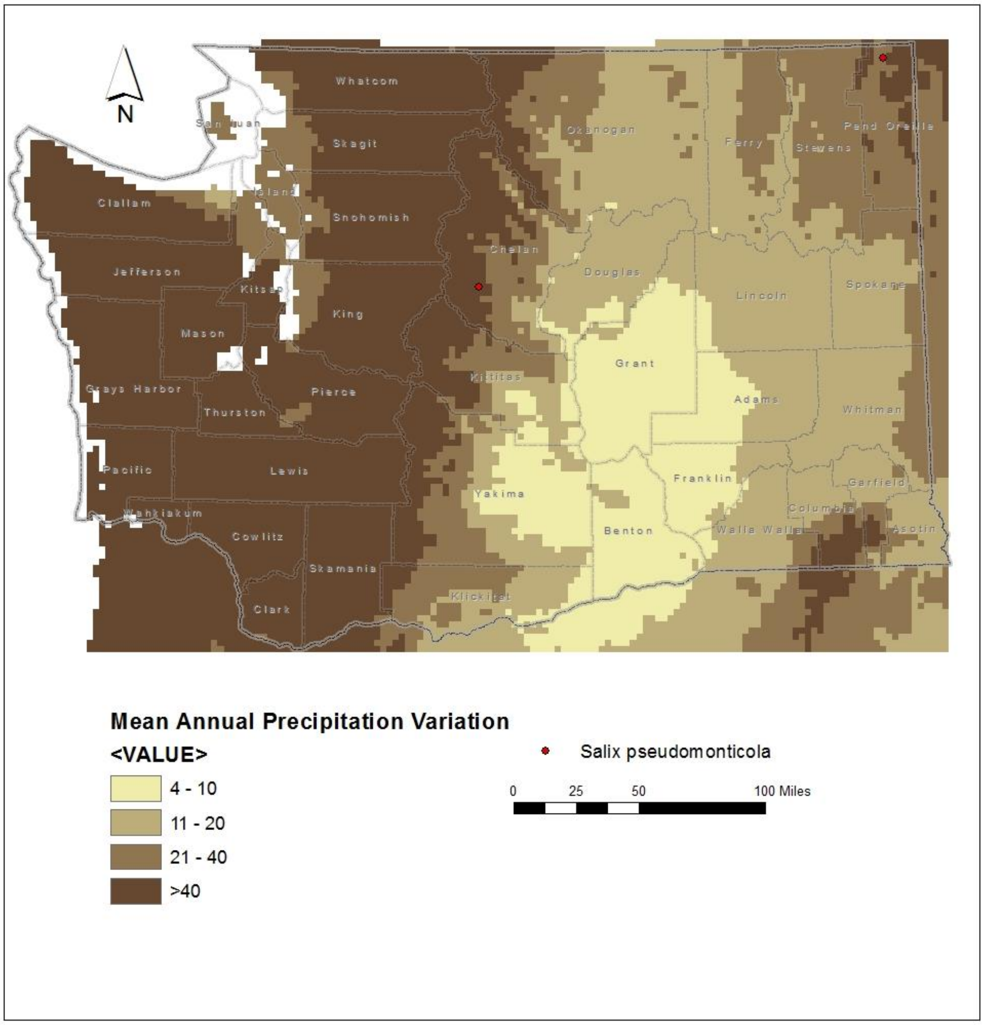

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Salix pseudomonticola* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
The fen habitat of *Salix pseudomonticola* in Pend Oreille County, Washington is largely dependent on groundwater, and thus more reliant on snowpack for regeneration than rainfall (Rocchio and Ramm-Granberg 2017). Reduction in the timing and amount of precipitation and

increased drought would make these fens and wet meadow habitat in Chelan County more vulnerable to climate change (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Salix pseudomonticola is not dependent on periodic disturbances to maintain its fen or wet meadow habitat in the state. The species could, however, be detrimentally affected by increased summer temperatures, drought, or decreased snowpack that might favor conversion of this habitat to forest or drier meadows, or increase fire frequency (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Increase.
The populations of *Salix pseudomonticola* in Washington are found in the mountainous areas with high snowfall. Its fen and wet meadow habitat is dependent on late-lying snowbanks for recharging groundwater (Rocchio and Ramm-Granberg 2017). Changes in the amount of snow or when the snow melts could lead to shifts in the dominance of herbaceous species or invasion of trees or shrubs.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
In Pend Oreille County, *Salix pseudomonticola* is found on glacial drift material associated with the Metaline limestone and dolomite, a formation found sporadically in northeastern Washington. The reported occurrence from Chelan County is found on the Chiwaukum Schist, a formation of limited extent in the Wenatchee Range.

C4a. Dependence on other species to generate required habitat: Neutral.
The fen and wet meadow habitat occupied by *Salix pseudomonticola* is maintained primarily by natural abiotic processes.

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 small insect pollinators, especially flies, bees, and butterflies.

C4d. Dependence on other species for propagule dispersal: Neutral.
Willow seeds have a tuft of wavy, silky hairs and are dispersed passively by wind.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Although willows are susceptible to rust fungi, no impacts to *Salix pseudomonticola* are known. This species may be vulnerable to browsing.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Salix pseudomonticola could be sensitive to competition from other plant species if its wetland habitat becomes drier due to drought or reduced snowpack and water recharge under future 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 in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Salix pseudomonticola is dioecious (with separate staminate and pistillate individuals) and is thus an obligate outcrosser. Pollination can occur by insects or long-distance dispersal by wind. Seed dispersal occurs by wind. The life history of this species suggests that it should have average genetic diversity across populations. The occurrences in Washington are near the edge of the species range and are likely to have slightly lower genetic diversity due to founder effects or inbreeding depression.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No recent changes in the distribution of this species in Washington have been detected.

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

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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.

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Saxifraga cernua (Nodding saxifrage)

Date: 5 March 2020

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	**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	33.3
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Greatly Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on 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		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
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: All six of the occurrences of *Saxifraga cernua* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

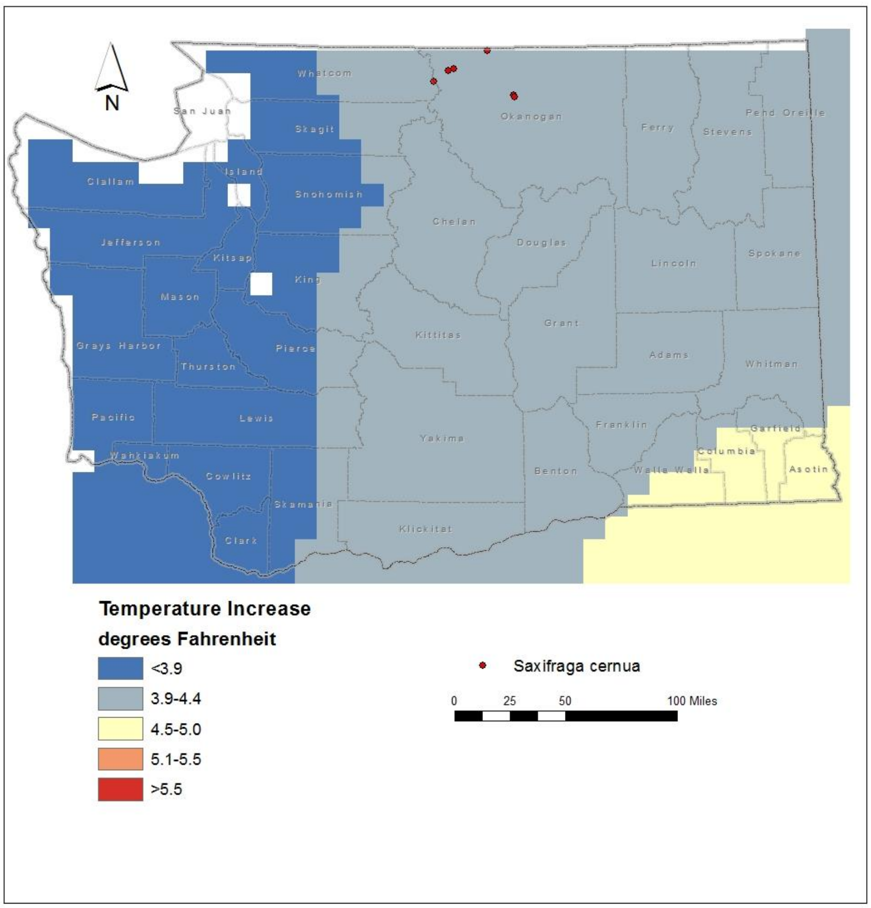

Figure 1. Exposure of *Saxifraga cernua* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the six extant and historical occurrences of *Saxifraga cernua* (66.7%) 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 occurrences (33.3%) are from sites with a projected decrease of -0.074 to - 0.096.

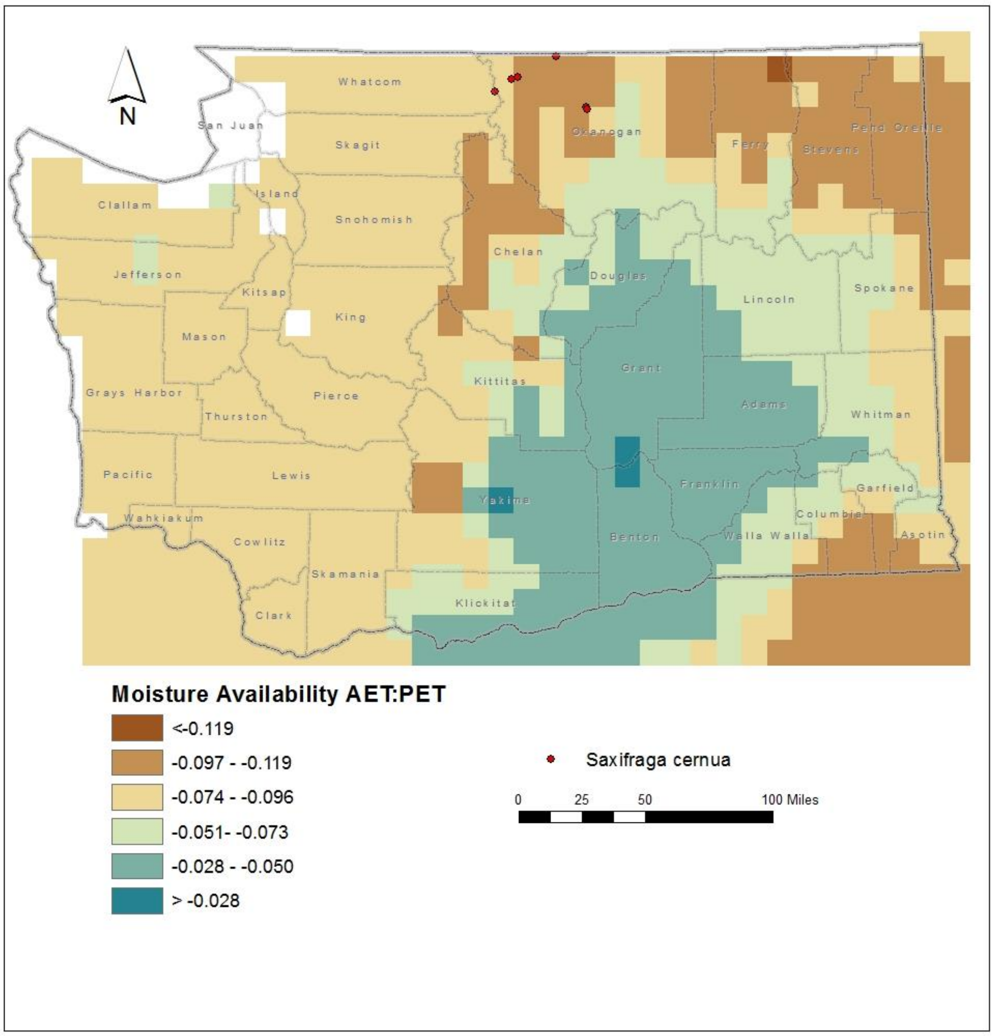

Figure 2. Exposure of *Saxifraga cernua* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Saxifraga cernua* are found at 5700-8120 feet (1740-2500 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Saxifraga cernua* occurs in shady, moist alpine cliffs and talus slopes (Camp and Gamon 2011; WNHP records). This habitat is a component of the Rocky Mountain Alpine Dwarf Shrubland, Fell-Field, and Turf ecological system (Rocchio and Crawford 2015). Washington occurrences are restricted to small patches of suitable habitat separated by distances of 1-23 miles (1.5-38 km). The natural patchiness of the populations and large extents of unsuitable habitat between mountain peaks create a barrier for dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Saxifraga cernua* is naturally somewhat fragmented. Human impacts on the landscape of northern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Saxifraga cernua reproduces primarily by asexual bulbils produced in the axils of inflorescence bracts in place of ordinary flowers. These propagules are genetically identical to their parent and capable of short-distance dispersal by strong winds, water, or passive means. Plants may also produce terminal flowers, but fruit and seed production is rare. Fruits are many-seeded capsules and individual seeds are small and can be dispersed passively or by wind. Overall dispersal distances for bulbils or seeds is probably small (less than 100 m), although genetic data suggest that long-distance dispersal occurs often enough to maintain relatively high levels of genetic diversity, at least in the core areas of its circumboreal range (Gabrielsen and Brochmann 2002, Bauert et al. 2007).

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Saxifraga cernua* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the six occurrences in the state (66.7%) 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. The two other populations (33.3%) are from areas with slightly lower than average (47.1-57˚F/26.3-31.8˚ C) temperature variation during the same period and would be at somewhat increased risk from climate change (Young et al. 2006).

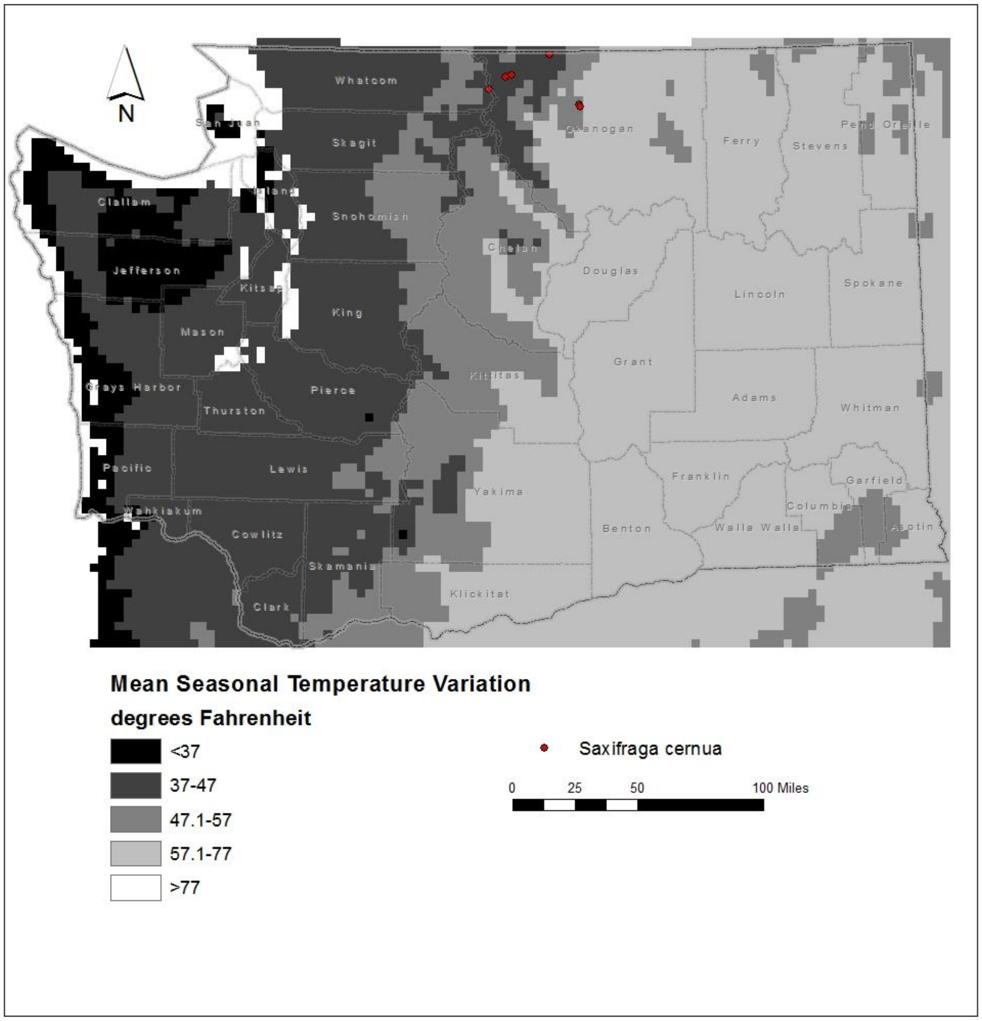

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Saxifraga cernua* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Greatly Increase.
The alpine talus and cliff habitat of *Saxifraga cernua* is strongly correlated with cold air drainage during the growing season and would have greatly increased vulnerability to temperature changes associated with global warming.

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

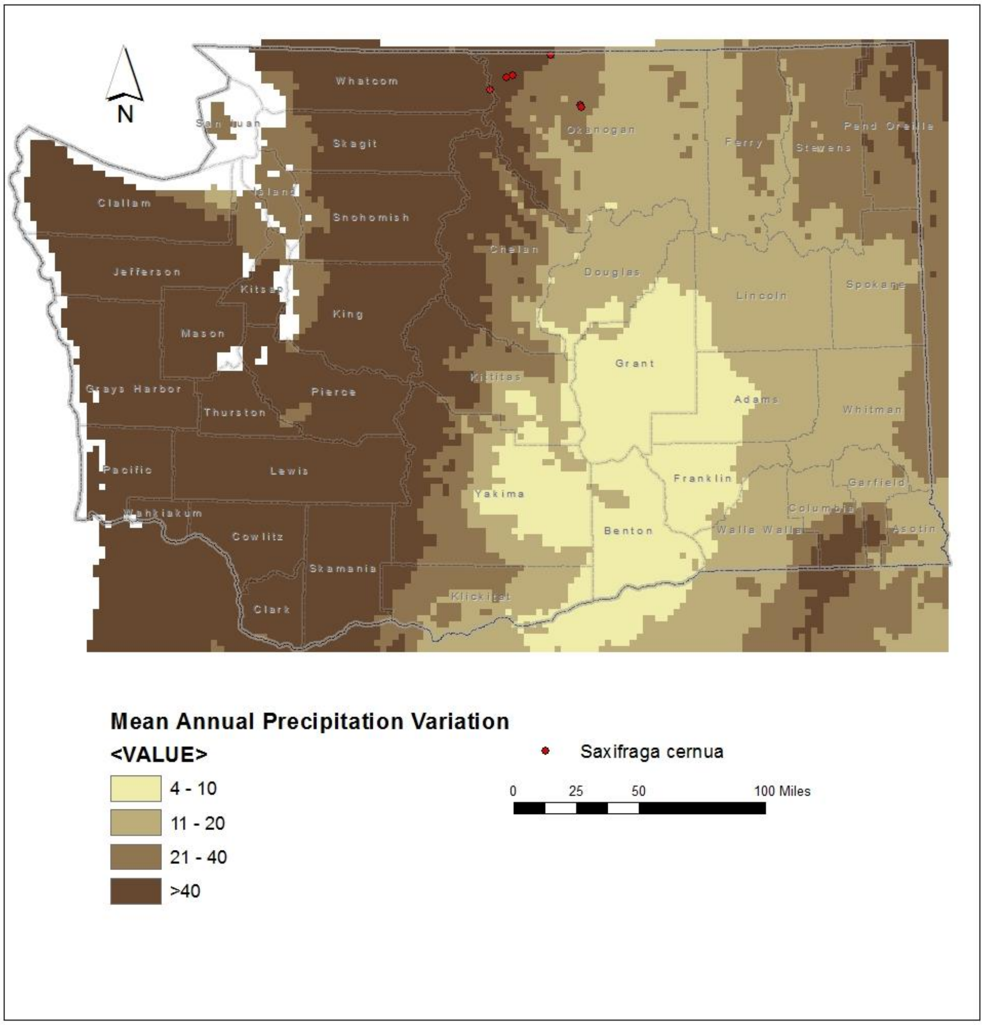

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Saxifraga cernua* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is often associated with small seeps that keep the habitat moist year round. The ultimate source of this moisture is precipitation and slow-melting snow. Changes in the amount and timing of precipitation could be detrimental to the habitat of *Saxifraga cernua*, allowing

shrubs or dry meadow species to displace alpine talus and rock field taxa (Rocchio and Ramm-Granberg 2017). See "Dependence on ice or snow-cover habitats" below.

C2c. Dependence on a specific disturbance regime: Neutral.
Saxifraga cernua occurs in alpine rock ledge and scree habitats. Other than occasional rock fall, these are largely undisturbed sites at present. Under future climate change scenarios, these areas 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: Somewhat Increase.
The populations of *Saxifraga cernua* in Washington are found in moist and shady alpine talus and cliff sites. The primary source of growing-season moisture is meltwater from late-lying and slow-melting snow or spring and summer precipitation. Reduced snowpack due to climate change would lessen the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
Populations of *Saxifraga cernua* in Washington occur on a variety of substrates, including quartz monzonite, metamorphic/igneous gneiss of the Tiffany Formation, and Winthrop Sandstone (WNHP records). These outcrops are relatively widespread in the Okanogan and North Cascades ranges.

C4a. Dependence on other species to generate required habitat: Neutral.
The alpine talus and cliff habitat occupied by *Saxifraga cernua* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Saxifraga cernua flowers are insect pollinated, but the species rarely produces fruit or seed (Bauert et al. 2007), reproducing instead by asexual bulbils formed in place of flowers in the inflorescence.

C4d. Dependence on other species for propagule dispersal: Neutral.
The bulbils and seeds of *Saxifraga cernua* are primarily dispersed short distances by passive means, such as wind or gravity (rather than by animals).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. This species is not vulnerable to browsing because of protection provided by its rocky habitat.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Under present conditions, competition from non-native species is minimal, as few introduced plants are adapted to the harsh environmental conditions of subalpine talus slopes and cliffs. 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.
Data are not available on the genetic diversity of this species in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Saxifraga cernua reproduces primarily by asexual bulbils, and so might be expected to have low genetic diversity among populations and higher diversity between isolated occurrences. Kjølner et al. (2006) found high levels of genetic variation, suggesting some sexual reproduction is occurring as well as long distance transport of seed or bulbils. Isolated populations in the Alps, however, had little genetic diversity, suggesting impacts from inbreeding depression or founder effects (Bauert et al. 2007). Washington occurrences are at the southern edge of the species range in the Pacific Northwest and isolated from other occurrences in the Rocky Mountains, and might be expected to have lower diversity.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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: Somewhat Increase?
Three occurrences of *Saxifraga cernua* have not been relocated from 1916 to 1980 and are considered historical or possibly extripated. Whether these occurrences have been overlooked and are still present or lost due to climate change or other factors 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

Bauert, M.R., M. Kälin, P.J. Edwards, and M. Baltisberger. 2007. Genetic structure and phylogeography of alpine relict populations of *Ranunculus pygmaeus* and *Saxifraga cernua*. Botanica Helvetica 117:181-196.

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Gabrielsen, T.M. and C. Brochmann. 2002. Sex after all: High levels of diversity detected in the arctic clonal plant *Saxifraga cernua* using RAPD markers. Molecular Ecology 7(12): 1701-1708.

Kjølner, S., S.M. Såstad, and C. Brochmann. 2006. Clonality and recombination in the arctic plant *Saxifraga cernua*. Botanical Journal of the Linnaean Society 152(2): 209-217.

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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.

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

Scribneria bolanderi (Scribner's grass)

Date: 6 March 2020

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	**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	33.4
	-0.051 to - 0.073	33.3
	-0.028 to -0.050	33.3
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral/Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Unknown
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	
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 accepted occurrences of *Scribneria bolanderi* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

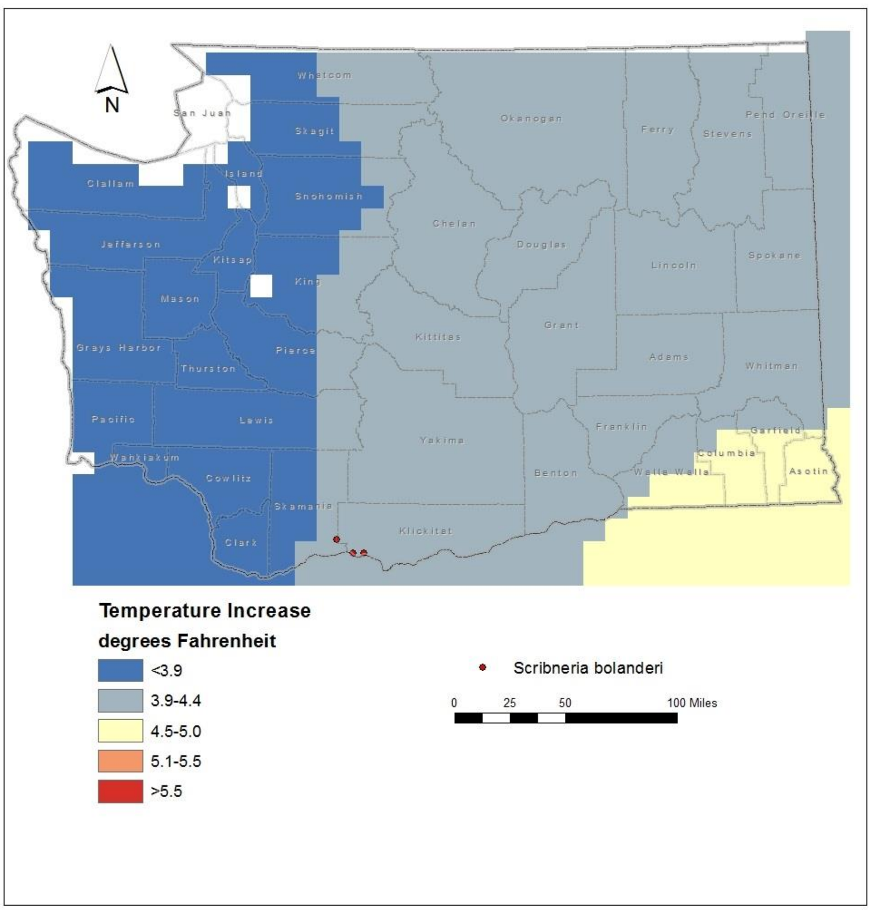

Figure 1. Exposure of *Scribneria bolanderi* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: One of the three accepted occurrences of *Scribneria bolanderi* (33.4%) 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 population (33.3%) is found in an area of projected decrease in available moisture of -0.051 to -0.073 and one other (33.3%) is found in an area of projected decrease in moisture of -0.028 to -0.050 (Figure 2).

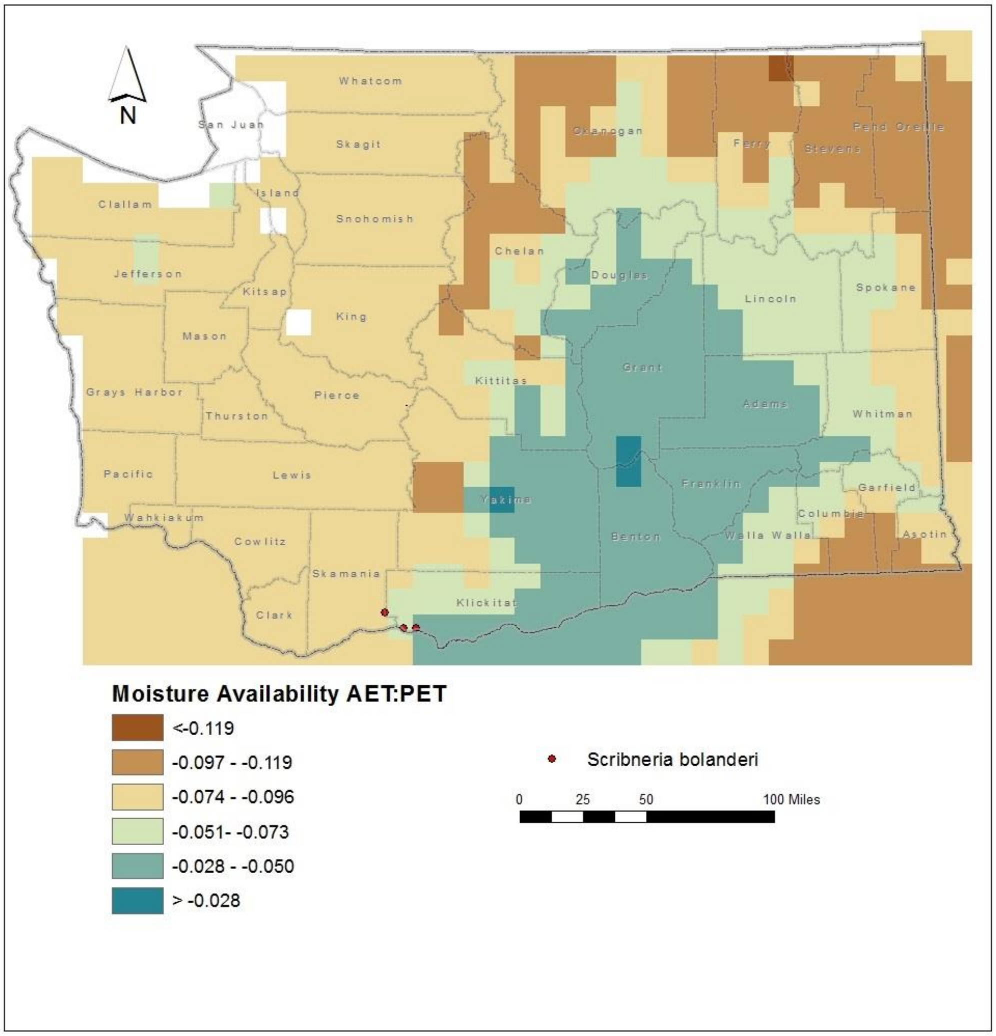

Figure 2. Exposure of *Scribneria bolanderi* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Scribneria bolanderi* are found at 90-2900 feet (28-890 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Scribneria bolanderi* is found in dry sandy or lithic soils along roadsides, river banks, and vernally moist areas (Camp and Gamon 2011; Hitchcock and Cronquist 2018). This habitat may correspond with the Columbia Plateau Vernal Pool ecological system (Rocchio and Crawford 2015). One population reported from Douglas-fir forests in the West Cascades is probably based on a misidentification and has been excluded. The confirmed populations are often restricted to small patches of suitable habitat separated by 10-575 meters within a matrix of grasslands. Other populations may be 5-9.5 miles (8 -16 km) apart. These sites are embedded within a matrix of unsuitable natural habitat and areas of human development. Of the two, natural barriers may be more significant than anthropogenic barriers in restricting dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Scribneria bolanderi* is naturally fragmented. Human impacts in southern Washington have little effect on this condition.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Scribneria bolanderi reproduces by one-seeded dry fruits (caryopsis) that are equipped with a long awn and a tuft of basal hairs to assist with dispersal by wind or by catching onto the fur or feathers of animals. These fruits are capable of long-distance dispersal (over 1 km), though most fruits may spread by gravity and land close to their parent.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Scribneria bolanderi* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All three of the known occurrences (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.

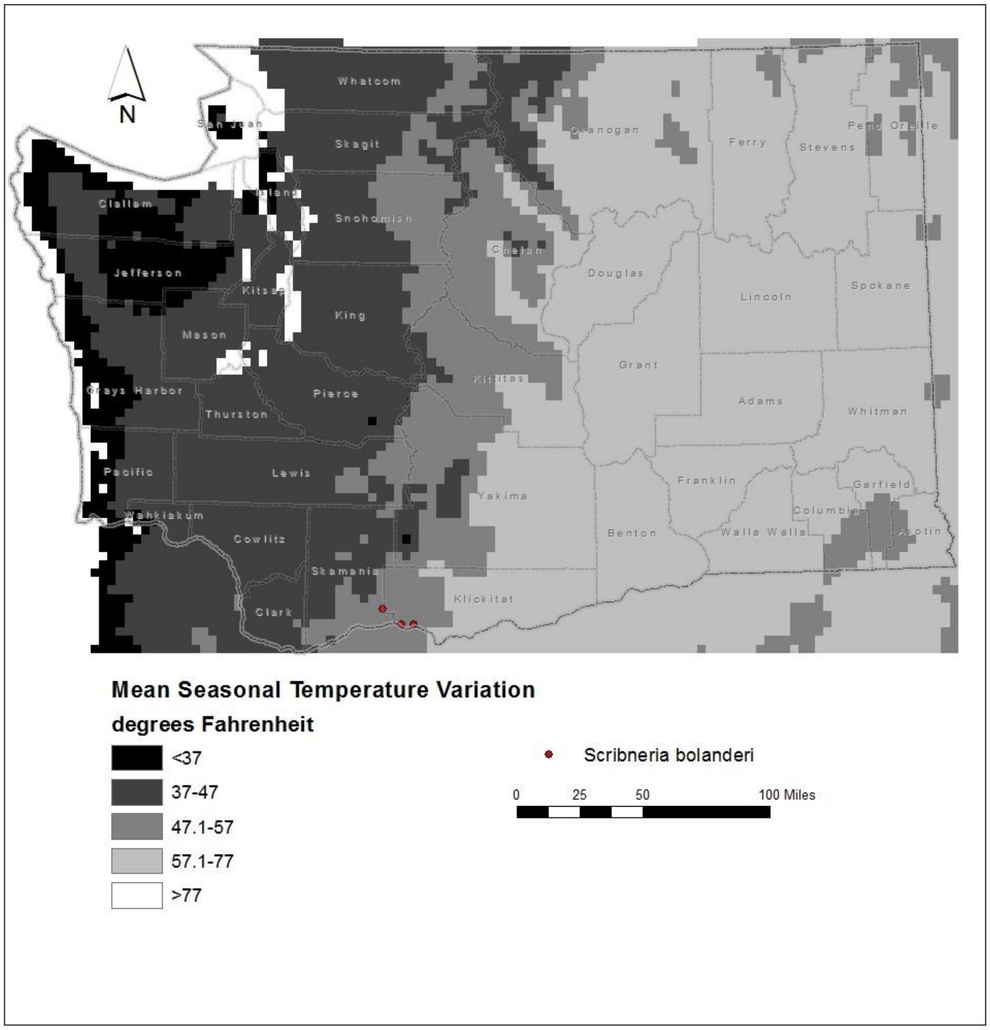

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Scribneria bolanderi* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral/Somewhat Increase.
The vernal area and roadside habitat of *Scribneria bolanderi* is not associated with cold air drainage during the growing season. Increased temperatures and longterm drought could convert vernal habitats to dry rock outcrop or meadow communities under climate change scenarios (Rocchio and Ramm-Granberg 2017).

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

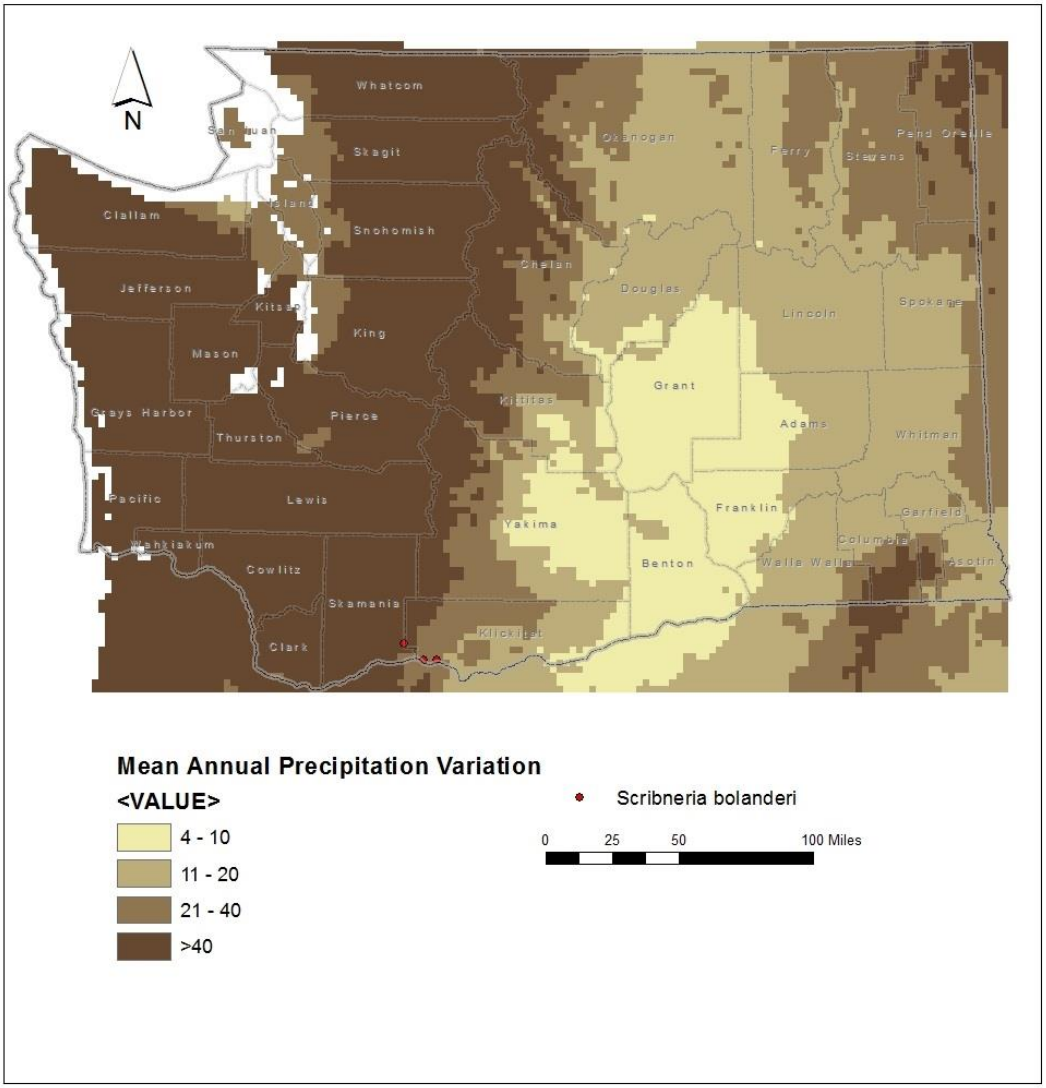

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Scribneria bolanderi* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species is dependent on episodic winter and early spring precipitation and snow melt followed by severe drought to maintain its specialized vernal wetland habitat. It is especially vulnerable to changes in the amount and timing of precipitation (Rocchio and Ramm-Granberg 2017). Potentially higher amounts of precipitation in winter could be offset by higher temperatures and greater evapotranspiration. Unpredictable climatic events could also be significant on this annual species which must rely on a seed bank to persist through unfavorable years.

C2c. Dependence on a specific disturbance regime: Neutral.
Some populations of *Scribneria bolanderi* in Washington are associated with periodic disturbances, such as road blading or river scour, to maintain their relatively open habitat characteristics. These kinds of disturbances are not likely to be affected by climate change (or might even increase in the case of roadside disturbance under drier conditions). Increased summer temperatures and drought could lead to the conversion of vernal habitats to sparsely vegetated scablands, or make the sites more vulnerable to invasion and competition by non-native annuals (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Reduced snowpack or changes in snow melt are a threat to many scabland vernal pool communities in the Columbia Plateau Columbia River Gorge (Rocchio and Ramm-Granberg 2017). Increased drought would favor transition to sparsely vegetated scabland communities.

C3. Restricted to uncommon landscape/geological features: Unknown.
Although *Scribneria bolanderi* is associated with vernally moist areas (these may in turn be tied to shallow depressions in basalt bedrock), the species is also found along disturbed roadsides and riverbanks in geologic substrates that are not necessarily limiting. Better information is needed on the specific microsite conditions needed for this species to become established and persist.

C4a. Dependence on other species to generate required habitat: Neutral
The vernal wetland habitat occupied by *Scribneria bolanderi* is probably maintained by natural abiotic processes and geologic conditions, rather than by interactions with other species. Disturbed roadside habitats are maintained by human activity (arguably, humans might be considered the ecosystem engineer in this instance).

C4b. Dietary versatility: Not applicable for plants

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

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Scribneria bolanderi* are probably dispersed by sticking to the feet or feathers of waterfowl. It is probably not dependent on just a few seed vector species.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Impacts from pathogens are not known. *Scribneria bolanderi* could be vulnerable to herbivory by livestock or native grazers.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Scribneria bolanderi could be sensitive to competition from other plant species (especially non-native invasive annuals) if its vernal wetland habitat became 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.
No genetic data are available for Washington populations.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Scribneria bolanderi probably has average genetic diversity across populations due to its ability to outcross, accept pollen from distance sources, and disperse widely by wind. Washington populations are located at the northern edge of the species range and probably have less genetic diversity than occurrences from Oregon or California due to founder effects or genetic drift.

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.
Significant changes in the distribution of *Scribneria bolanderi* have not been documented.

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

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Climate Change Vulnerability Index Report

Sericocarpus oregonensis ssp. *oregonensis* (Oregon white-topped aster)

Date: 9 March 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G5TNR/S1

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Neutral
2c. Dependence on specific disturbance regime		Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on 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		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		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: Both occurrences of *Sericocarpus oregonensis* ssp. *oregonensis* in Washington (100%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

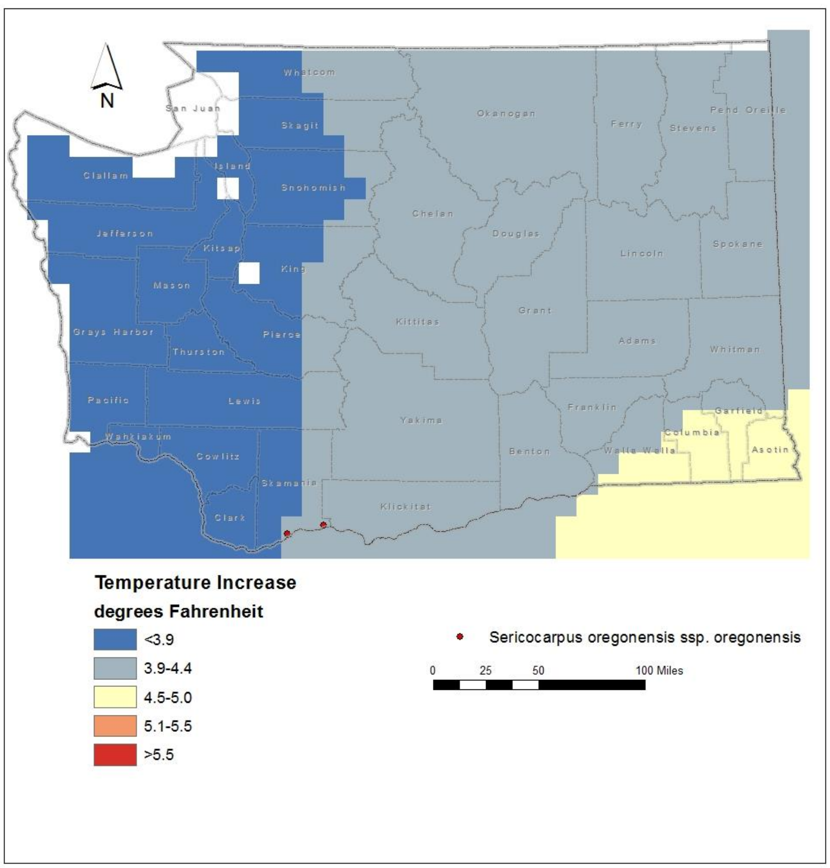

Figure 1. Exposure of *Sericocarpus oregonensis* ssp. *oregonensis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both occurrences of *Sericocarpus oregonensis* ssp. *oregonensis* (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).

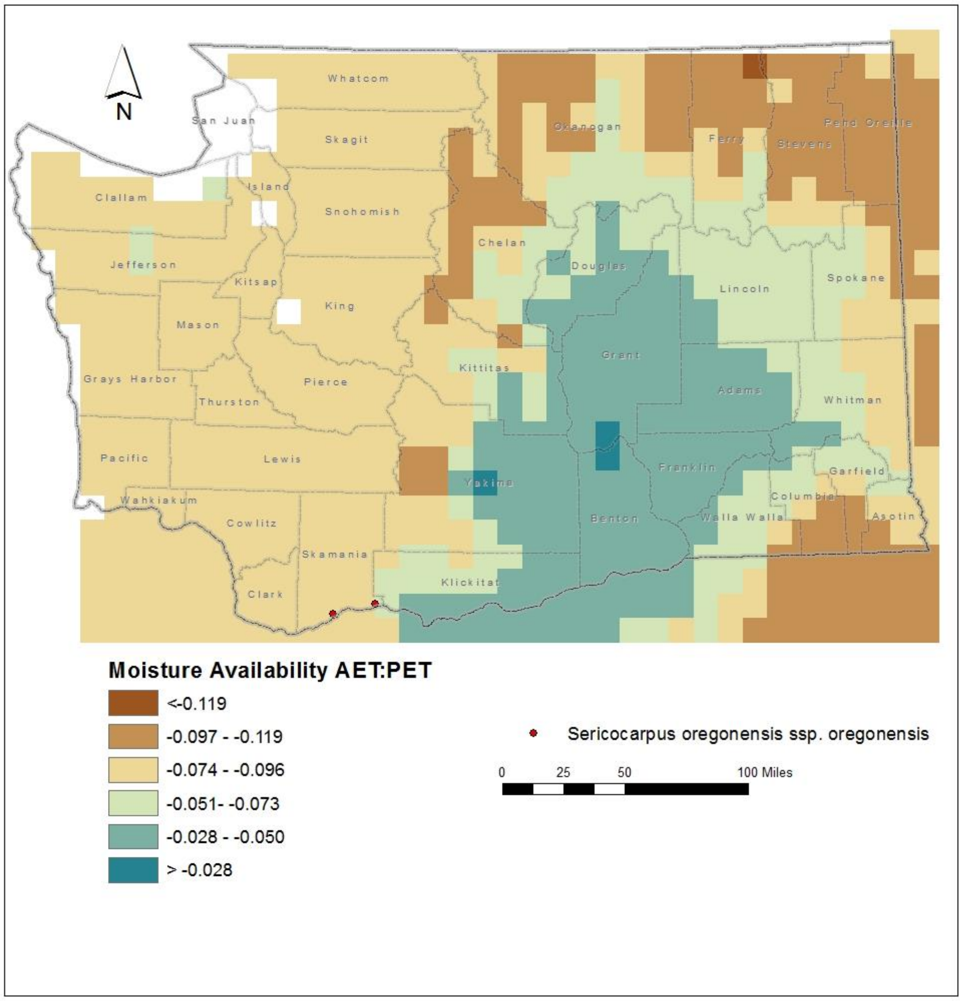

Figure 2. Exposure of *Sericocarpus oregonensis* ssp. *oregonensis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Sericocarpus oregonensis* ssp. *oregonensis* are found at 320-1150 feet (100-350 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Sericocarpus oregonensis* ssp. *oregonensis* is found in mesic to well-drained open woodlands and dry, rocky conjfer forests (Camp and Gamon 2011, Fertig & Kleinknecht 2020). In Oregon, this species is often associated with Douglas-fir or Ponderosa pine in wooded grasslands on thin soils over basalt (Consortium of Pacific Northwest Herbaria records). This habitat probably corresponds with the Northern Rocky Mountain Ponderosa Pine Woodland and Savanna ecological system (Rocchio and Crawford 2015), but might also fit the substrate-restricted Northern Rocky Mountain Foothill Conifer Wooded Steppe system. The single extant occurrence occupies a few areas of suitable habitat and is isolated from another historical population by 17.5 miles (28 km). These sites are embedded within a matrix of unsuitable natural habitat and areas of human development. Of the two, anthropogenic barriers may be more significant in restricting dispersal today, while natural barriers may have been significant historically (see below).

B2b. Anthropogenic barriers: Somewhat Increase.
The range of *Sericocarpus oregonensis* ssp. *oregonensis* may be naturally fragmented in Washington, but this has been greatly exacerbated by human impacts within its range.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Sericocarpus oregonensis ssp. *oregonensis* reproduces by one-seeded dry achenes that have a tuft of hairs (pappus of capillary bristles) for dissemination by wind. Most fruits land close to their parent, but some have the potential to travel over 1 km.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Sericocarpus oregonensis* ssp. *oregonensis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Both of the known occurrences (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.

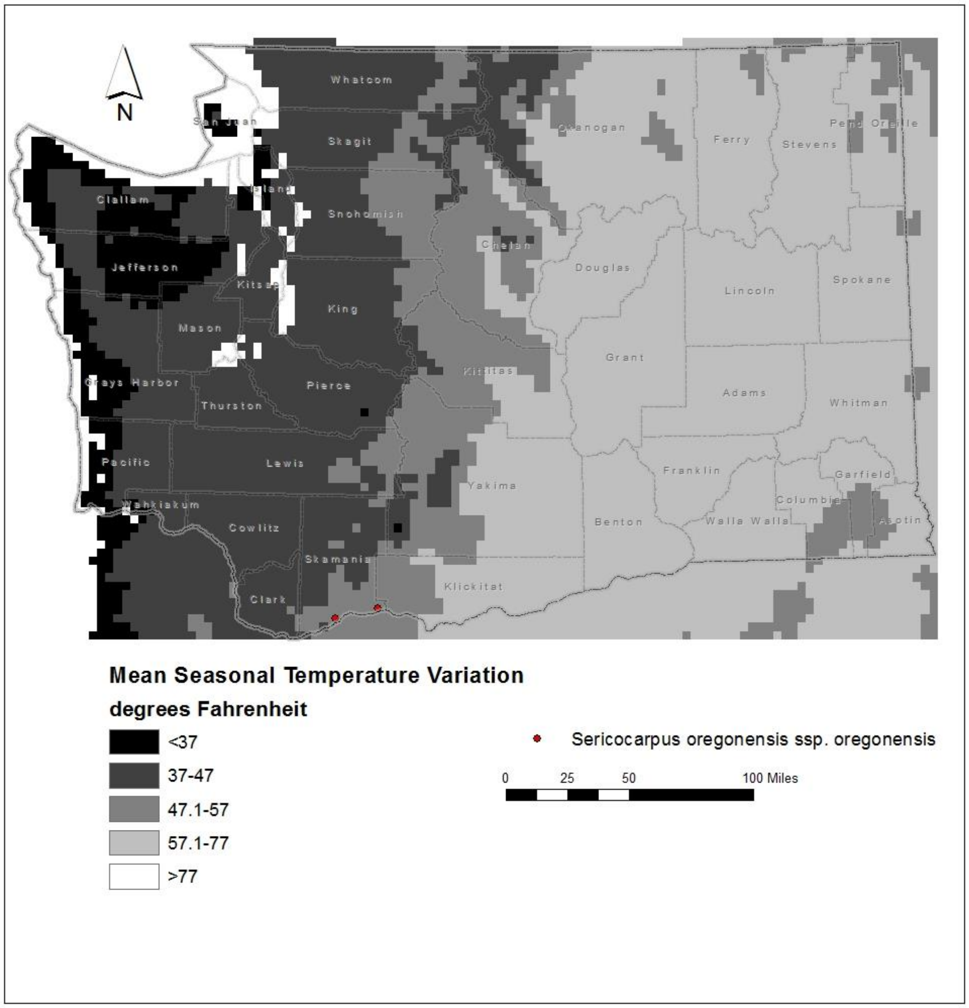

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Sericocarpus oregonensis* ssp. *oregonensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The dry Ponderosa pine-Douglas-fir forest habitat of *Sericocarpus oregonensis* ssp. *oregonensis* is not associated with cold air drainage during the growing season and would have neutral vulnerability to temperature changes due to global warming.

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

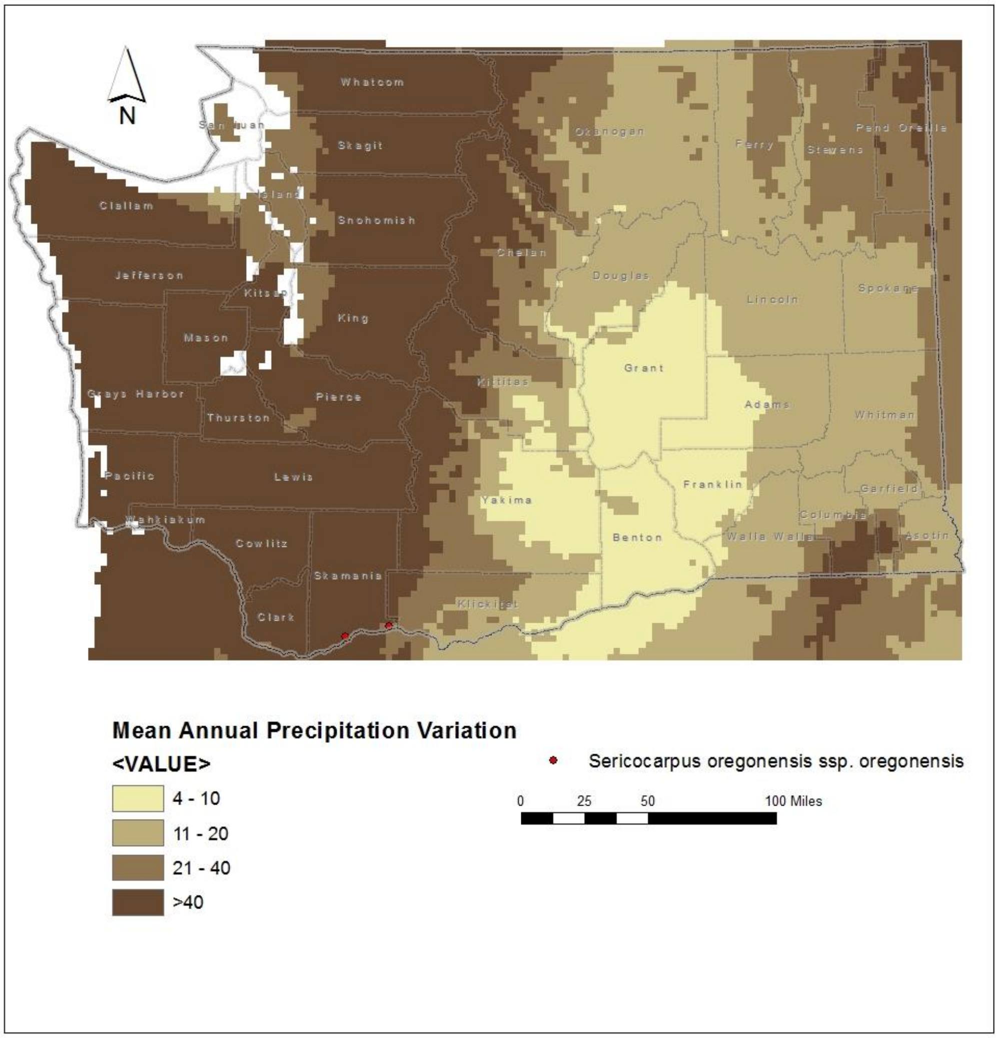

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Sericocarpus oregonensis* ssp. *oregonensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
This species usually occurs in upland dry forest habitat (though the one extant occurrence in Washington is on the slopes above a small lake). These sites are not strongly tied to wetland features dependent on high amounts of spring/summer precipitation or winter snowfall, but may be vulnerable to drought and increased wildfire however (see below). Increased drought or fire could shift this community to shrub steppe or grassland habitats (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Increase.
The dry Ponderosa pine and Douglas-fir forest habitat of *Sericocarpus oregonensis* ssp. *oregonensis* in Washington is associated with frequent, low severity wildfire to maintain its open physiognomy and species composition (Rocchio and Crawford 2015). Under increased drought and reduced summer precipitation (and due to past fire suppression building up fuels) these sites may become more vulnerable to stand-replacing crown fires and become replaced by shrub or grassland-dominated ecological systems (Rocchio and Ramm-Granberg 2017).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Snowpack in the range of *Sericocarpus oregonensis* ssp. *oregonensis* in Washington is moderate, but groundwater-recharge from slow-melting snow is not limiting in the dry forest habitats occupied by this species.

C3. Restricted to uncommon landscape/geological features: Neutral.
Washington occurrences of *Sericocarpus oregonensis* ssp. *oregonensis* are associated with Quaternary landslide deposits and the Quaternary Underwood Mountain basalt, which is fairly widespread in the Columbia River Gorge and southern Cascades.

C4a. Dependence on other species to generate required habitat: Neutral
The dry conifer forest habitat occupied by *Sericocarpus oregonensis* ssp. *oregonensis* is maintained by natural abiotic processes (such as fire and seasonal drought) rather than by interactions with other species.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Sericocarpus oregonensis ssp. *oregonensis* is pollinated by a variety of butterflies and other insects (Shepherd et al. 2006).

C4d. Dependence on other species for propagule dispersal: Neutral.
The dry, one-seeded fruits of *Sericocarpus oregonensis* ssp. *oregonensis* have a pappus of capillary bristles and are readily dispersed by the wind.

C4e. Sensitivity to pathogens or natural enemies: Unknown.
Impacts from pathogens and grazing animals are not known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Sericocarpus oregonensis ssp. *oregonensis* could be sensitive to competition from other plant species (especially non-native invasive annuals) if its dry forest habitat becomes converted to

shrub or grassland dominated systems due to increased drought or catastrophic wildfire (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.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Sericocarpus oregonensis ssp. *oregonensis* probably has average genetic diversity across its range due to its ability to outcross and disperse widely by wind. Washington populations are located at the northern edge of the species range and probably have less genetic diversity than occurrences from Oregon or California due to founder effects or genetic drift.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral
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.
Significant changes in the distribution of *Sericocarpus oregonensis* ssp. *oregonensis* have not been documented.

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

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Climate Change Vulnerability Index Report

Swertia perennis (Swertia)

Date: 10 March 2020

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	**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	66.7
	<3.9° F (2.2°C) warmer	33.3
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		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		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Unknown
4f. Sensitivity to competition from native or non-native species		Neutral
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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: Two of the three occurrences of *Swertia perennis* in Washington (66.7%) occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1). One other populations (33.3%) is form an area with a projected temperature increase of < 3.9˚ F.

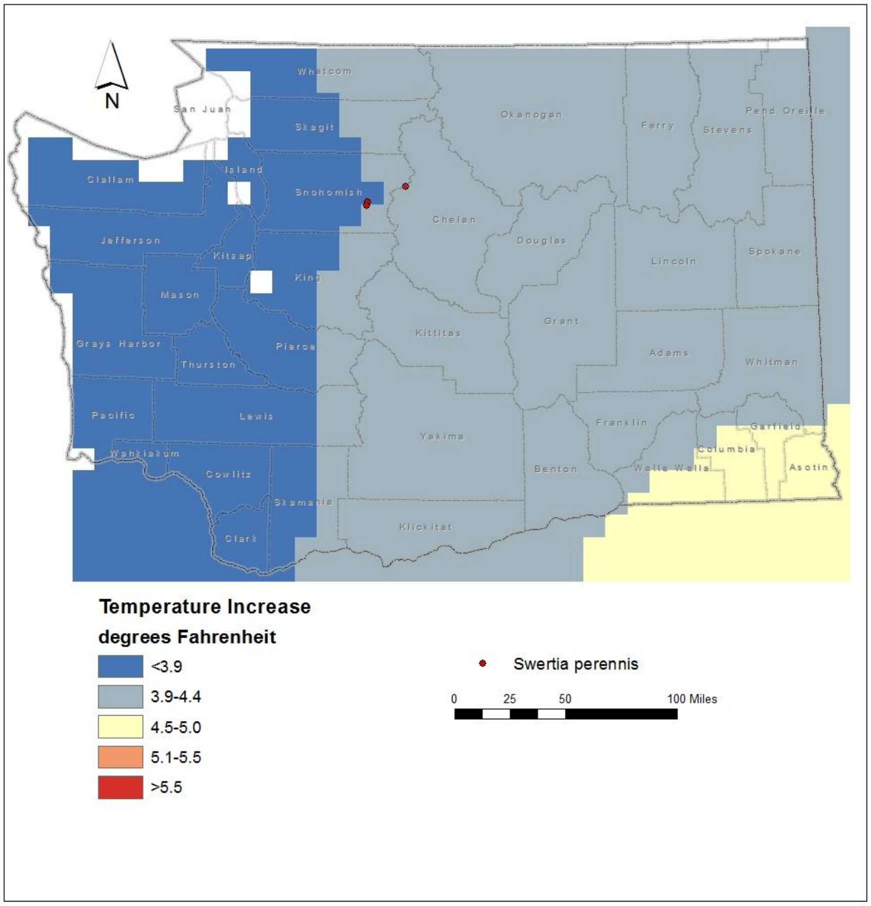

Figure 1. Exposure of *Swertia perennis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All three of the occurrences of *Swertia perennis* (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).

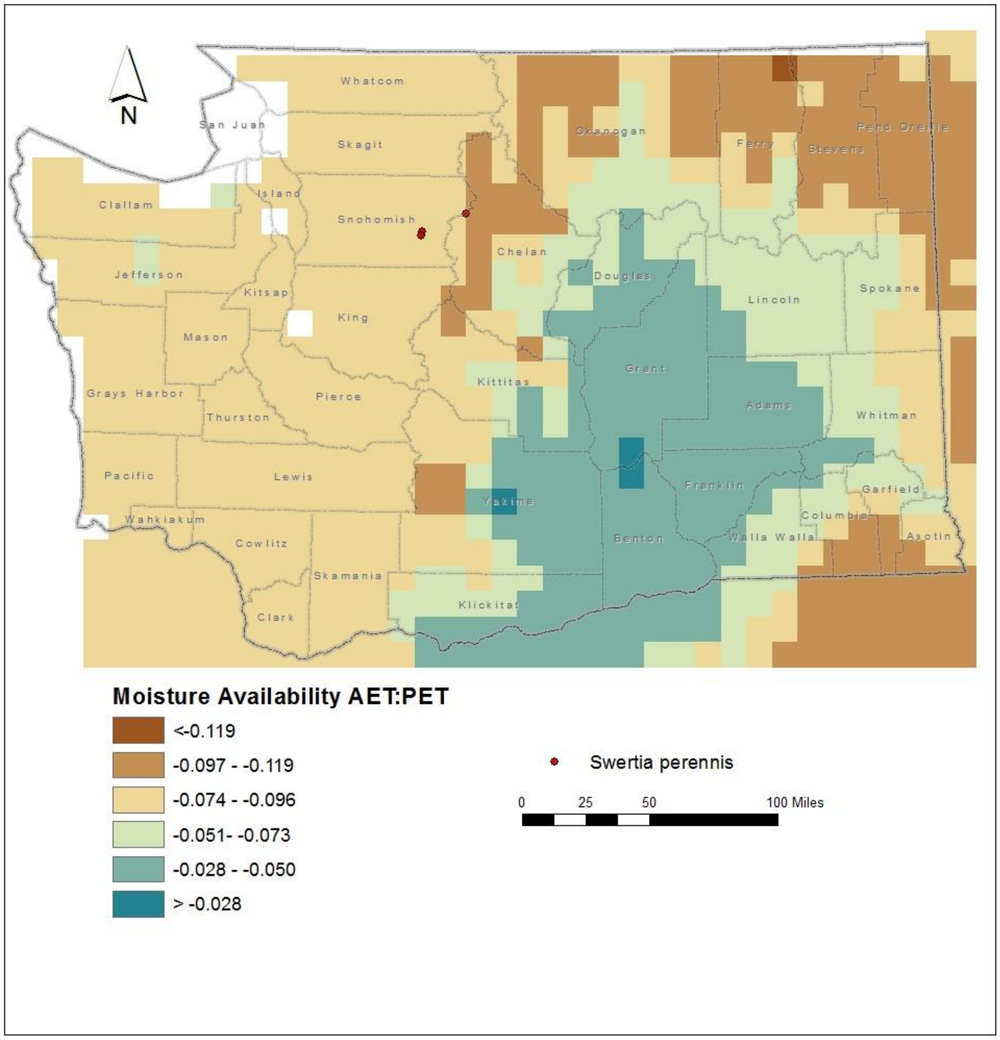

Figure 2. Exposure of *Swertia perennis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Swertia perennis* are found at 4000-5680 feet (1220-1730 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Swertia perennis* occurs in montane to subalpine moist meadows and streambanks (WNHP 2005). Populations are found in gravelly swales where extra water may accumulate (WNHP records). This habitat is probably a component of the Temperate Pacific Subalpine-Montane Wet Meadow ecological system (Rocchio and Crawford 2015). Elsewhere in its range (Rocky Mountain states and across boreal Canada and Eurasia), *S. perennis* is often found in bogs, wet meadows, and streambanks in mountains (Cronquist et al. 1984) and populations tend to be discontinuous and patchy (Urbaniak et al. 2018). Washington occurrences are restricted to small patches of suitable habitat separated by distances of 2-19 miles (3-30 km). The natural patchiness of the populations and large extents of unsuitable habitat between forests and dry meadows and valleys probably create a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Swertia perennis* is naturally somewhat fragmented. Human impacts on the landscape of the Cascade crest where this species occurs have been moderate. In Europe, however, centuries of conversion and development of fen wetlands has greatly increased the fragmentation of populations (Leinert et al. 2002).

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Swertia perennis produces dry capsules containing as many as 50 flat, wing-margined seeds (Lienert et al. 2002). The seeds are dispersed passively by dehiscence of the mature capsule, but may be able to spread further by wind or water. Lienert et al. (2002) found that dispersal distances between patches of *S. perennis* in Switzerland were less than 1000 m.

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

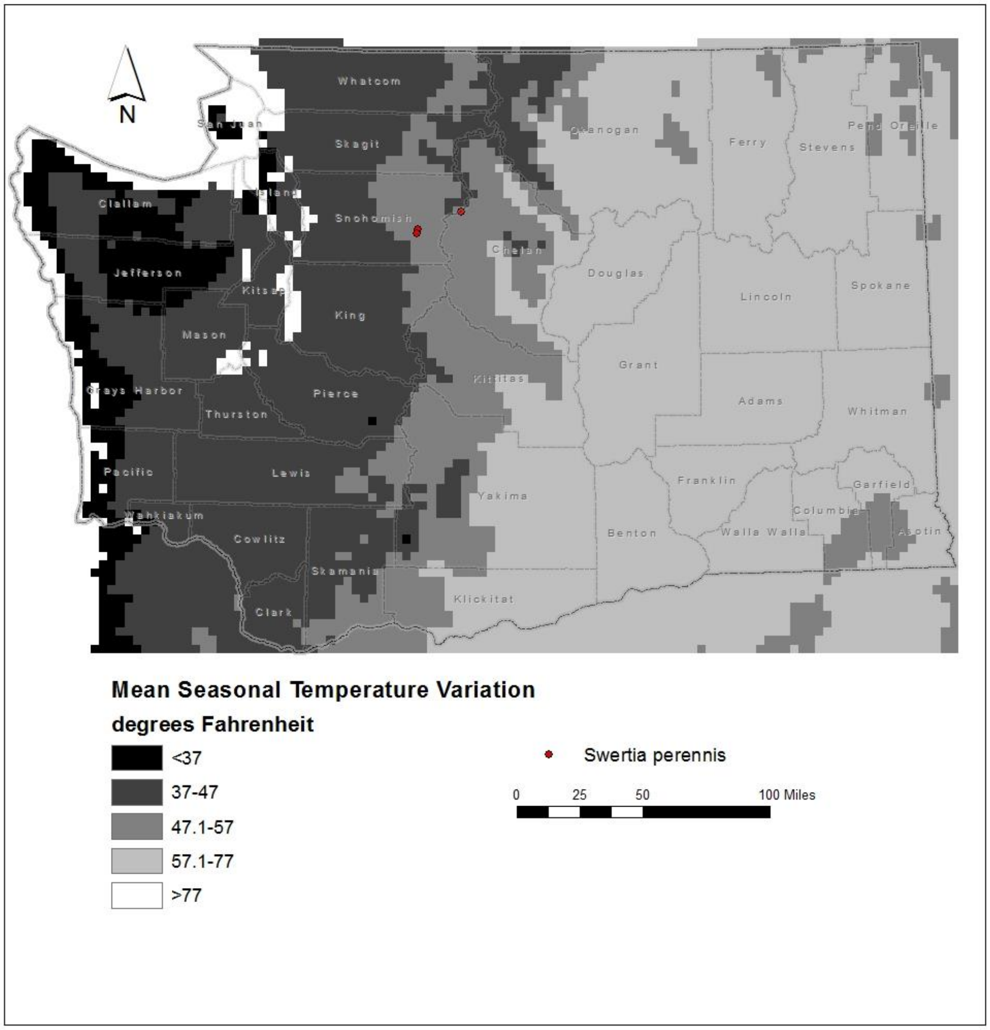

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Swertia perennis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The montane to subalpine wet meadow habitat of *Swertia perennis* may be associated with cold air drainages during the growing season and would have increased vulnerability to temperature changes associated with global warming.

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

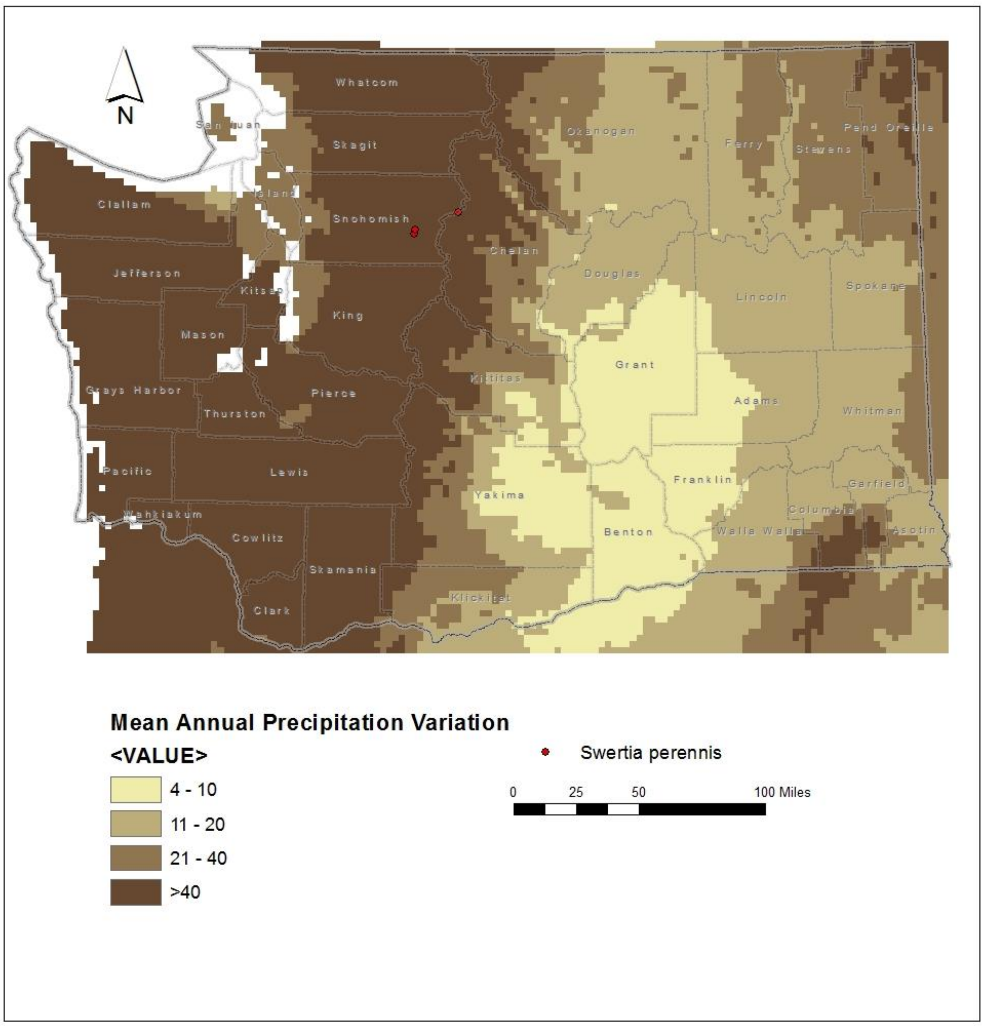

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Swertia perennis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species is associated with wet meadows that may be fed by groundwater or augmented by spring and summer precipitation. In Washington, *Swertia perennis* populations tend to be associated with shallow, gravelly swales that may accumulate more runoff than surrounding areas (WNHP records). Groundwater-derived wet meadows would be more affected by changes

in the amount and timing of melt of snowpack (see C2d below). Montane wet meadows in Washington may be augmented by surface flow and rainfall, and thus vulnerable to changes in the timing and amount of precipitation during the growing season (Rocchio and Ramm-Granberg 2017). Such changes could hasten the conversion of wet meadows to less mesic plant communities or increase the likelihood for invasion by forests or increased wildfire.

C2c. Dependence on a specific disturbance regime: Neutral.
Swertia perennis occurs in montane to subalpine wet meadow habitats that are maintained by high water tables that restrict the invasion of forest trees and exclude herbaceous plants adapted to drier conditions. Under future climate change scenarios, these areas 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: Somewhat Increase.
The populations of *Swertia perennis* in Washington are found in wet meadows in the montane and subalpine zones that are associated with relatively deep and slow-melting snow. Groundwater recharge from snow is an important source of moisture during the growing season and reductions in the amount of snow or timing of melt could result in long term shifts in vegetation composition of these sites, favoring forests or drier meadows (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Populations of *Swertia perennis* in Washington occur on a variety of substrates, including mica-quartz of the Napeequa unit of the Chelan Mountains terrane, granodioirite of the Grotto batholith, and Quaternary volcanic talus. These populations may also be restricted to swale-like depressions and avalanche tracks that accumulate extra moisture. These geology types and landforms are somewhat uncommon in the Cascade Range, and so this factor is scored as Somewhat Increase rather than neutral.

C4a. Dependence on other species to generate required habitat: Neutral.
The montane and subalpine wet meadow habitat of *Swertia perennis* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Swertia perennis flowers are pollinated by a wide variety of insects, including beetles, butterflies, syrphid flies, bees, and wasps Leinert et al. 2002).

C4d. Dependence on other species for propagule dispersal: Neutral.
The seeds of *Swertia perennis* are winged and dispersed by wind or water, rather than by animals.

C4e. Sensitivity to pathogens or natural enemies: Unknown.
Impacts from pathogens are not known. This species is probably not impacted by grazing, but little information is available.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Competition with other species is probably low at present. In the future, as the montane wet meadow habitat of *Swertia perennis* becomes drier due to increased temperatures or changes in the seasonality of precipitation, this species could be more vulnerable to competition with trees or other herbs adapted to forest or dry meadow 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.
Data are not available on the genetic diversity of this species in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Swertia perennis is an outcrosser and reproduces sexually by seed. Lienert et al. (2002) and Urbaniak et al. (2018) found high levels of genetic diversity across populations in Europe, suggesting that gene flow has been occurring, at least in the recent past. Small and isolated occurrences in Europe did have reduced genetic variability (Lienert et al. 2002). Populations in Washington are at the southern edge of the species range in northwestern North America and probably have lower genetic diversity than populations in the Rocky Mountains due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No changes in the distribution of this species have been noted due to 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

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Climate Change Vulnerability Index Report

Thelypodium sagittatum ssp. *sagittatum* (Arrow thelypody)

Date: 2 March 2020

Assessor: Walter Fertig, WA Natural Heritage Program

Geographic Area: Washington

Heritage Rank: G4T4/S1

Index Result: Moderately Vulnerable

Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	80
	-0.028 to -0.050	20
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		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		Somewhat Increase
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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 five of the known occurrences of *Thelypodium sagittatum* ssp. *sagittatum* in Washington (100%) occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

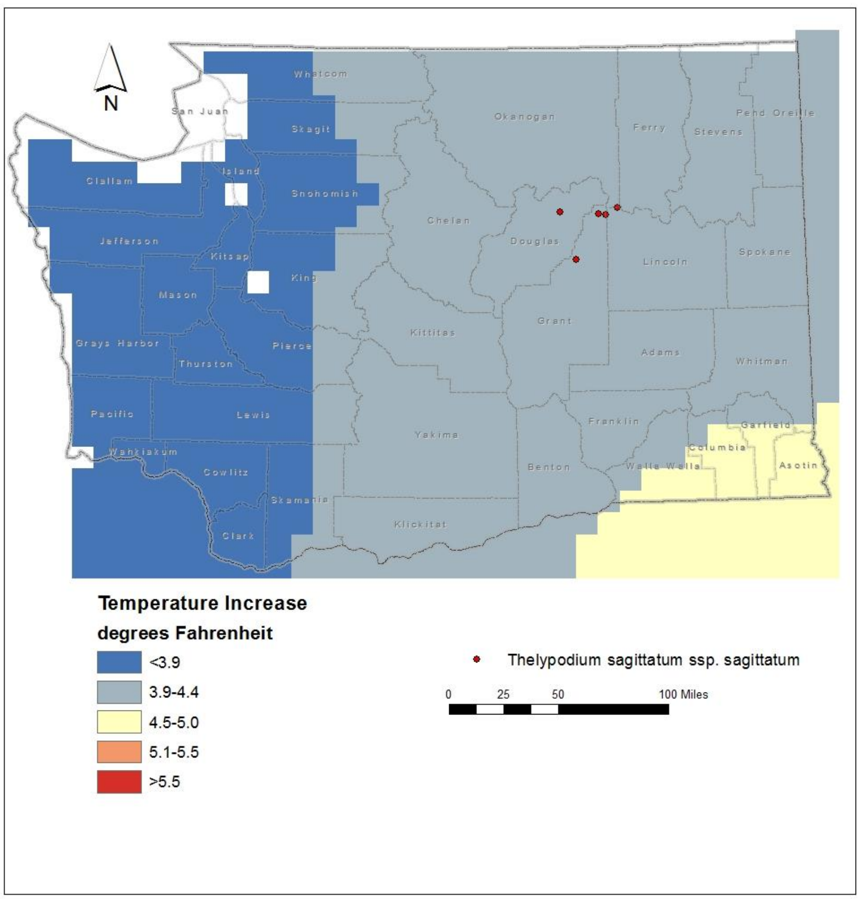

Figure 1. Exposure of *Thelypodium sagittatum* ssp. *sagittatum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the five Washington occurrence of *Thelypodium sagittatum* ssp. *sagittatum* (80%) 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 -0.051 to -0.073 (Figure 2). One other population (20%) is found in an area with a projected decrease in moisture of – 0.028 to – 0.050.

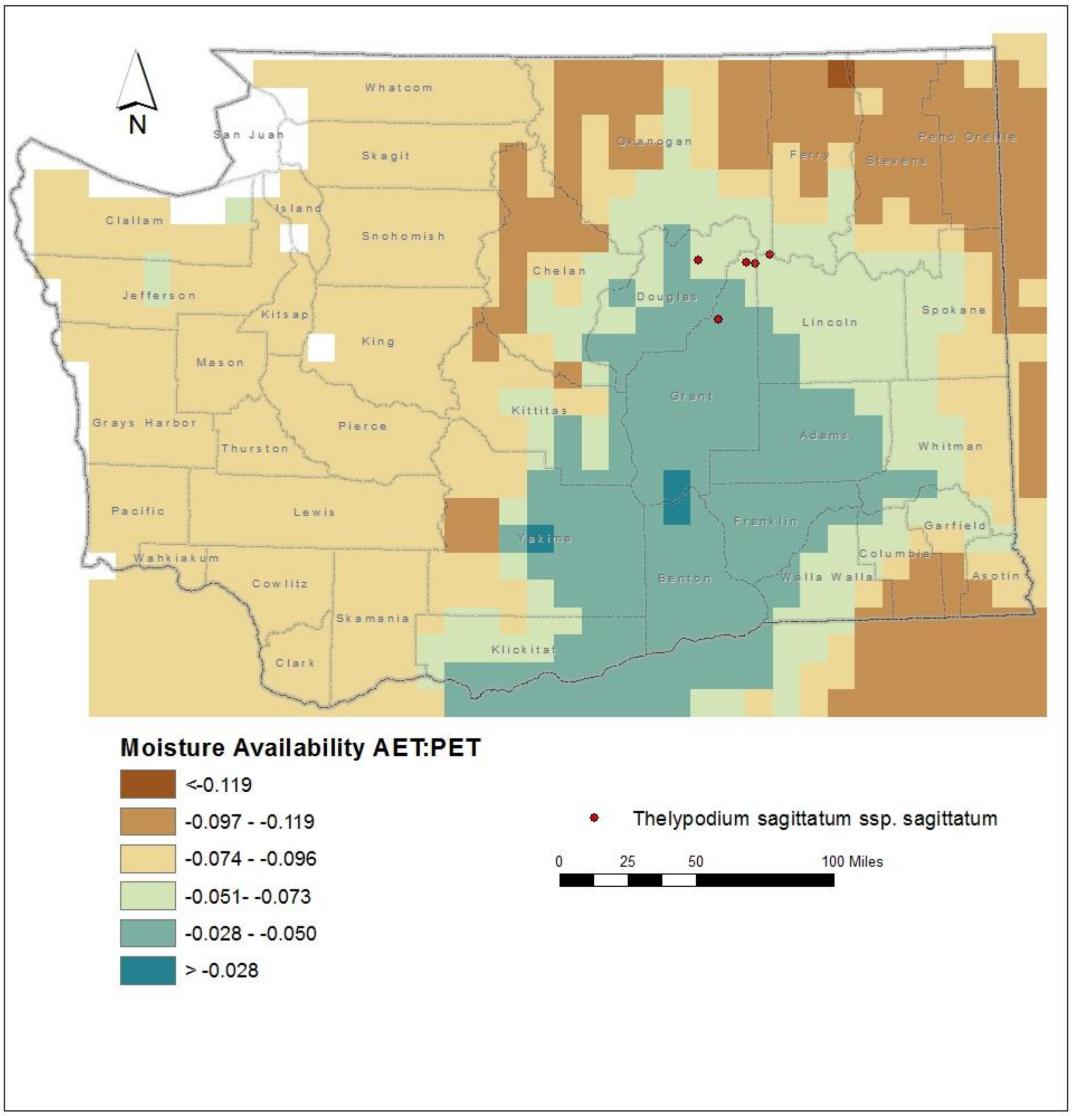

Figure 2. Exposure of *Thelypodium sagittatum* ssp. *sagittatum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Thelypodium sagittatum* ssp. *sagittatum* are found at 1600-2300 feet (500-700 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Thelypodium sagittatum* ssp. *sagittatum* is found in shallow, alkali marshes, moist swales, and salt flats over basalt within a matrix of upland sagebrush and bunchgrass vegetation (Camp and Gamon 2011, Fertig and Kleinknecht 2020). This habitat is a component of the North American Arid West Emergent Marsh ecological system (though grading towards the Northern Columbia Plateau Basalt Pothole Ponds system) (Rocchio and Crawford 2015). Washington populations are separated by 5-37 km (3-23 miles) and occupy small areas of habitat within a matrix of unsuitable sagebrush steppe and scablands that create a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Thelypodium sagittatum* ssp. *sagittatum* in Washington is embedded within a matrix of natural and agricultural lands. The species is probably more isolated by natural barriers 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.
Thelypodium sagittatum ssp. *sagittatum* produces numerous, many-seeded silique fruits per inflorescence. The fruits open along two sutures at maturity to passively release the small, un-ornamented seeds for dispersal by gravity, water, or wind. Seeds are mostly shed close to their parent, but may be able to travel 100-1000 m.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Thelypodium sagittatum ssp. sagittatum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All five of the 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.

C2aii. Physiological thermal niche: Neutral.
The shallow, alkali wetlands inhabited by *Thelypodium sagittatum* ssp. *sagittatum* in the Columbia Plateau of eastern Washington are not associated with cold air drainage in the growing season and not vulnerable to projected temperature increases due to climate change.

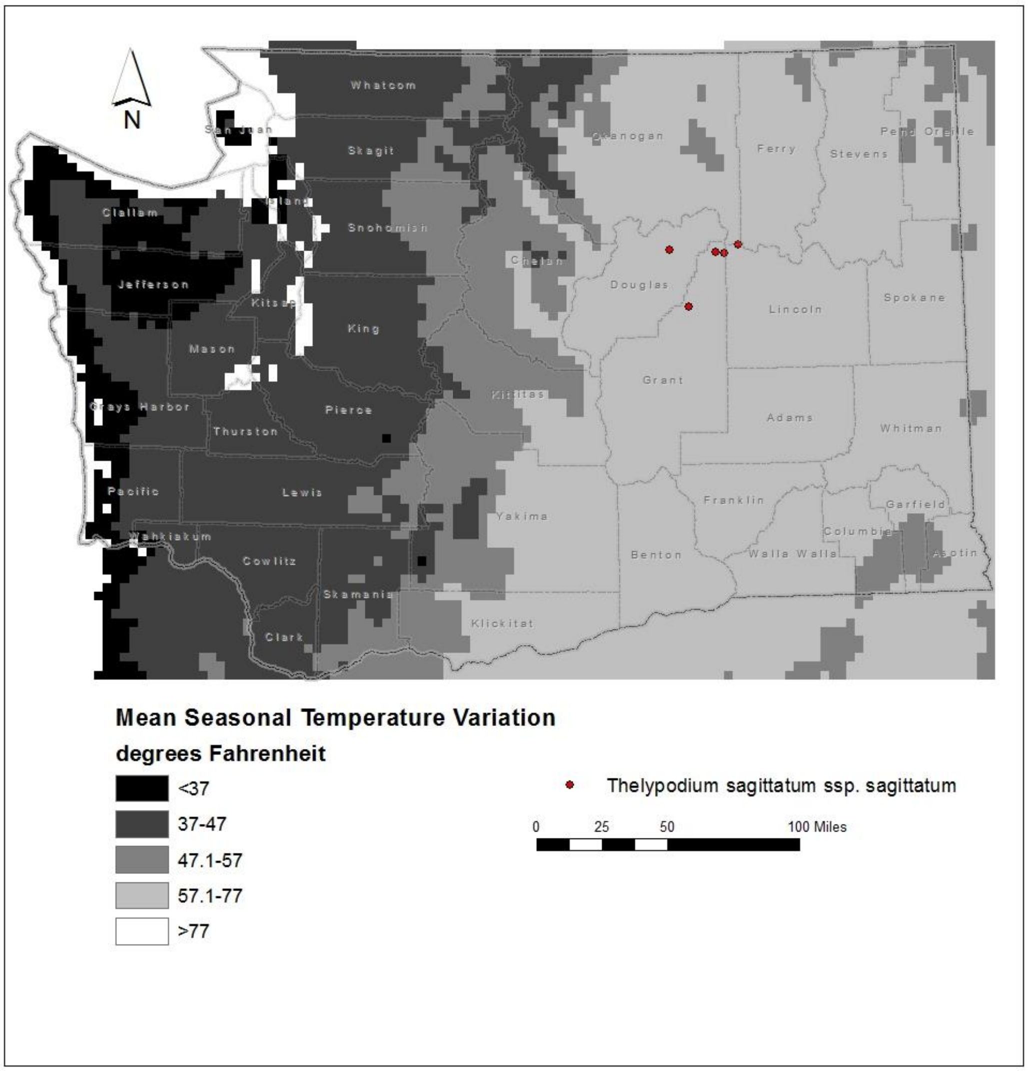

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Thelypodium sagittatum* ssp. *sagittatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Somewhat Increase.
Four of the five populations of *Thelypodium sagittatum* ssp. *sagittatum* in Washington (80%) 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 from climate change. One other occurrence is found in an area with small (4-10 inches/100-254 mm) precipitation variation in the same period and is considered at increased risk from climate change.

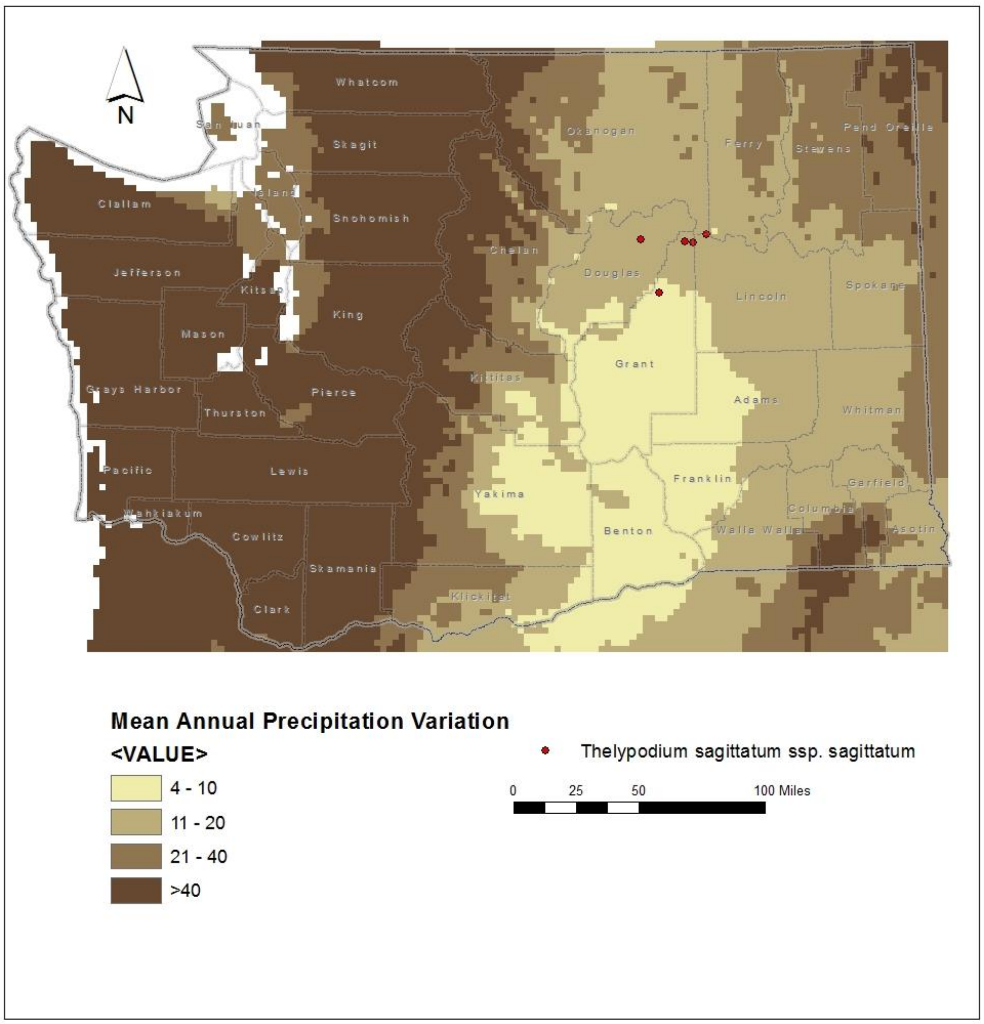

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Thelypodium sagittatum* ssp. *sagittatum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
In Washington, *Thelypodium sagittatum* ssp. *sagittatum* is found in shallow alkali depressions and other marshy meadows over basalt. These wetland areas are probably supported by rainfall, rather than groundwater. Such sites are vulnerable to changes in timing and amount of precipitation, increasing temperatures, and summer drought (Rocchio and Ramm-Granberg 2017). Marsh and pothole wetland systems are likely to convert to wet meadow communities under prolonged climate change.

C2c. Dependence on a specific disturbance regime: Neutral.
Thelypodium sagittatum ssp. *sagittatum* occurs in shallow depressions in basalt bedrock with vernal alkali wetlands surrounded by sagebrush or bunchgrass vegetation on deeper soils. The wetland communities are maintained by precipitation, seasonal drought, and soil depth and chemistry, more so than disturbances, such as fire.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The range of *Thelypodium sagittatum* ssp. *sagittatum* in the Columbia Plateau in Washington has low snowfall. Drifting or late-melting snow is a supplemental source of moisture along with spring and winter rainfall.

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
In Washington, *Thelypodium sagittatum* ssp. *sagittatum* is strongly associated with shallow depressions in basalt with thin clay soil. While basalt is widespread across central and eastern Washington (and not limiting), the depressions and thin, alkali soil layers required by this species may be relatively uncommon.

C4a. Dependence on other species to generate required habitat: Neutral
The alkali marshy meadow habitat of *Thelypodium sagittatum* ssp. *sagittatum* is probably maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Like other members of the Brassicaceae, *Thelypodium sagittatum* ssp. *sagittatum* is adapted for pollination by numerous, unspecialized (generalist) species of insects such as moths, butterflies, bees, and flies. It is unlikely to be pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seed dispersal in *Thelypodium sagittatum* ssp. *sagittatum* is entirely passive, with the small seeds spreading by wind, water, or gravity.

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Impacts from pathogens are not known. This species may be threatened by livestock grazing (Camp and Gamon 2011).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Thelypodium sagittatum ssp. *sagittatum* could be vulnerable to competition from other native or introduced plant species if its specialized vernal alkali marsh habitat became converted to wet

meadow vegetation due to changes in the timing or amount of precipitation (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 for this species.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Thelypodium sagittatum ssp. *sagittatum* is pollinated by a variety of insects and is likely to be an outcrosser. Genetic diversity is probably average.

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.
No changes in the distribution of this species in Washington has been observed 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

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Young, B.E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2016. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 3.02. NatureServe, Arlington, VA. 48 pp. + app.

Climate Change Vulnerability Index Report

Vaccinium myrtilloides (Velvetleaf blueberry)

Date: 16 March 2020

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	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	100
	-0.074 to - 0.096	0
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		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		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		Unknown
5b. Genetic bottlenecks		Unknown
5c. Reproductive system		Neutral

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

Section A: Exposure to Local Climate Change

A1. Temperature: The single occurrence of *Vaccinium myrtilloides* in Washington (100%) occurs in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

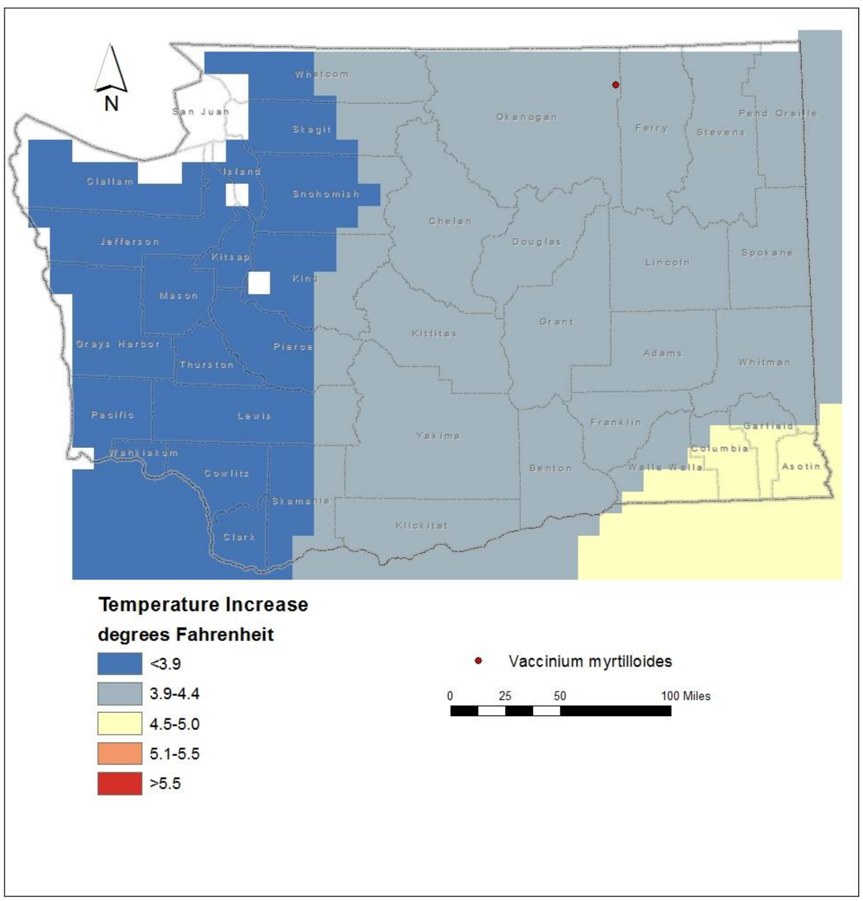

Figure 1. Exposure of *Vaccinium myrtilloides* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Vaccinium myrtilloides* (100%) in Washington is found in an area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 to -0.119 (Figure 2).

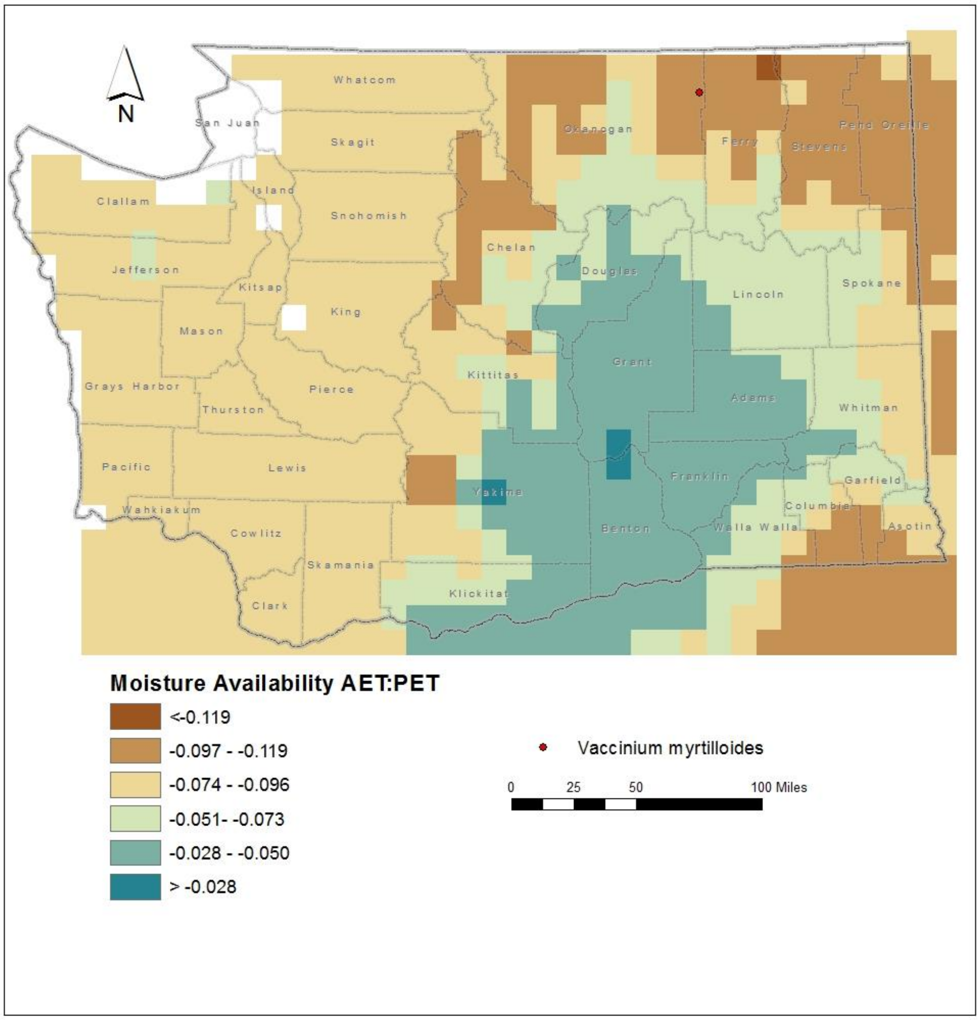

Figure 2. Exposure of *Vaccinium myrtilloides* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Vaccinium myrtilloides* are found at 3400-3500 feet (1035-1065 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Vaccinium myrtilloides* occurs in small, moss-rich openings within semo-mature *Picea engelmannii* forests with an understory of *Symphoricarpos albus, Cornus canadensis*, and *Linnaea borealis* (Camp and Gamon 2011). This habitat is probably a component of the Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland ecological system (Rocchio and Crawford 2015). The single Washington occurrence covers an area of less than 20 acres. The full extent of its range, and its dependence on micro-habitat characteristics, are probably incompletely known. Its distribution may be constrained by natural barriers.

B2b. Anthropogenic barriers: Neutral.
The range of *Vaccinium myrtilloides* in the Okanogan Range has some human imprint from roads and pockets of forestry and agriculture, but the dispersal of this species is probably more influenced by natural barriers 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: Neutral.
Vaccinium myrtilloides produces edible, many-seeded berries that are dispersed by birds and mammals. Research on the related species, *V. membranaceum*, shows that animal-dispersed blueberry seeds can be transported 1.5-10 km from their parent plant (Yang et al. 2008). Assuming comparable dispersal ability for *V. myrtilloides*, the range of this species is more likely to be constrained by the paucity of suitable habitat for germination.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Vaccinium myrtilloides* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The single occurrences in the state (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 vulnerability to climate change (Young et al. 2006).

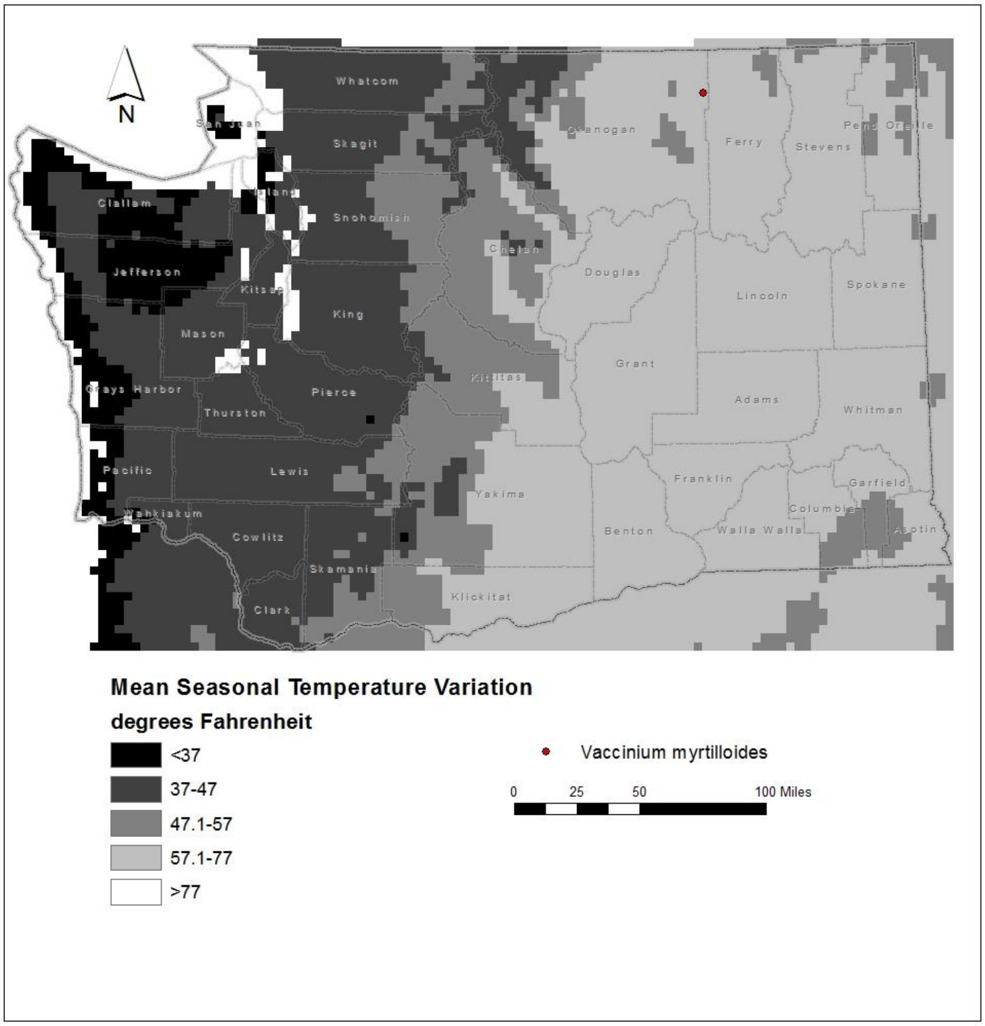

Figure 3. Historical thermal niche (exposure to past temperature variations) of *Vaccinium myrtilloides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The Rocky Mountain Subalpine Mesic Spruce-Fir habitat of *Vaccinium myrtilloides* is moderately restricted to cold air drainages during the growing season and would have increased vulnerability to temperature changes associated with global warming.

C2bi. Historical hydrological niche: Somewhat Increase.
The single population of *Vaccinium myrtilloides* 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 occurrences are at somewhat increased vulnerability to climate change.

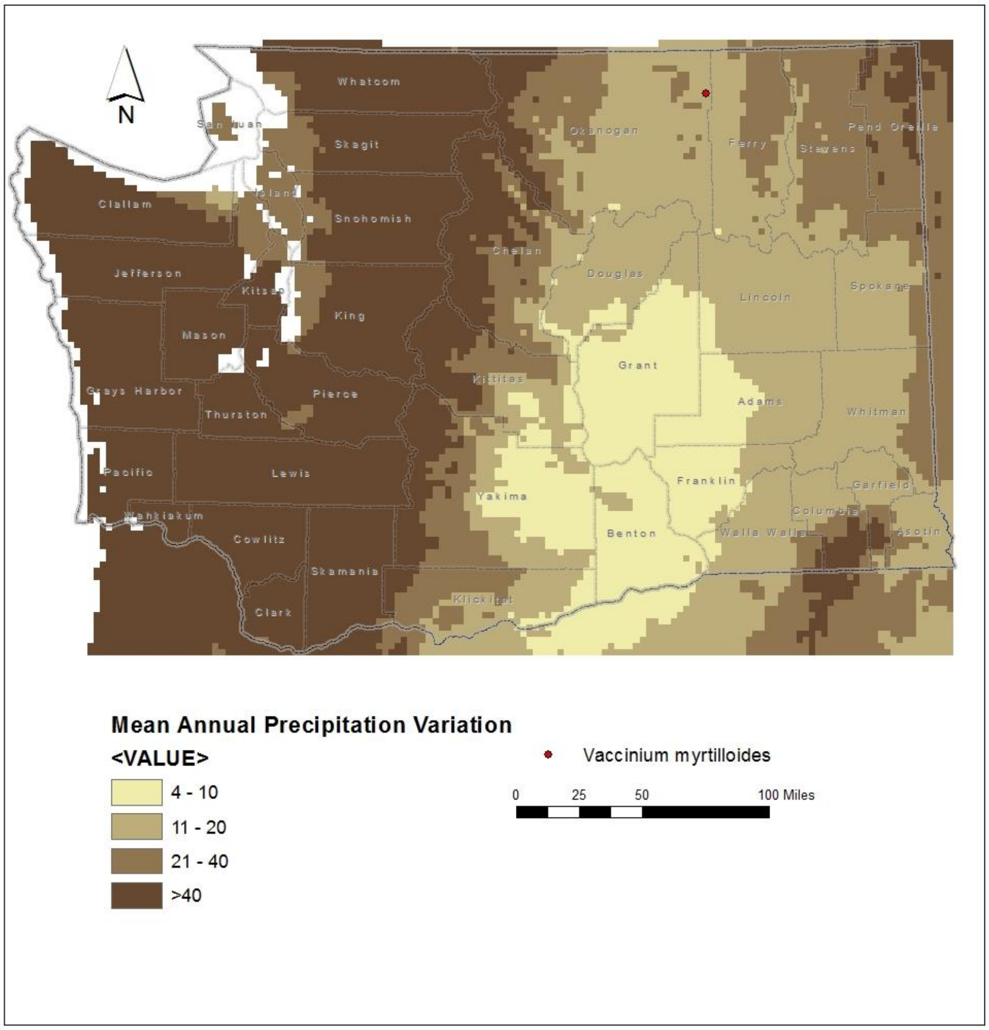

Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Vaccinium myrtilloides* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
In Washington, *Vaccinium myrtilloides* is associated with moss-rich openings in *Picea engelmannii* forests and might be dependent on rainfall or subsurface moisture to maintain this habitat. Increased drought and fire frequency could facilitate conversion of the Rocky Mountain Subalpine Mesic Spruce-Fir ecological system to shrub or *Pinus contorta*-dominated systems more adapted to periodic wildfire (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Vaccinium myrtilloides occurs in open, subalpine Engelmann spruce forests that are vulnerable to wildfire or insect outbreaks (Rocchio and Ramm-Granberg 2017). These sites develop in environments where large scale disturbance regimes are infrequent.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
The populations of *Vaccinium myrtilloides* in Washington are found in areas of moderate snowpack and in sites where subsurface moisture recharged by snowmelt is an important ecosystem driver. Groundwater recharge would be reduced if the amount of snow and timing of its melting were to change significantly due to rising temperatures. The Rocky Mountain Subalpine Mesic Spruce-Fir ecological system could convert to shrublands or Lodgepole pine forest under drier conditions in the future, or as a result of increased fire (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
The single population of *Vaccinium myrtilloides* in Washington is found on rhyolite of the Klondike Mountain Formation, which is of limited distribution in the Okanogan Range. The species does not appear to be associated with specific geologic formations outside of Washington.

C4a. Dependence on other species to generate required habitat: Neutral.
The montane and subalpine wet meadow habitat of *Vaccinium myrtilloides* is maintained primarily by natural abiotic processes.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Vaccinium myrtilloides flowers release pollen in tetrads through apical pores in the anthers. This is done through buzz pollination, in which vibrations caused by flight muscles of large-bodied insects (mostly bees, but occasionally syrphid flies) shakes pollen loose from the anther onto the body of the insect, to then be deposited on stigmas of other flowers. Stephens (2012) observed pollination primarily by bumblebees (*Bombus*), although *Andrena* bees were also potential pollinators. *V. myrtilloides* is also capable of self-pollination.

C4d. Dependence on other species for propagule dispersal: Neutral.
The many-seeded berries of *Vaccinium myrtilloides* are edible and widely dispersed by numerous species of birds and mammals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Impacts from pathogens are not known. *Vaccinium myrtilloides* is not a preferred forage species for browsers and may increase under grazing pressure from livestock (Hall 1955).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Competition with other species is probably moderate at present. In the future, as the subalpine mesic spruce-fir forest habitat of *Vaccinium myrtilloides* becomes drier due to increased temperatures or changes in the seasonality of precipitation, this habitat could become more

prone to catastrophic wildfire and replacement of existing vegetation with more fire-adapted shrublands or Lodgepole pine forest (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 in Washington.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral
Vaccinium myrtilloides is a diploid outcrosser and reproduces sexually by seed. Hokanson and Hancock (1998) found that populations of diploid *V. myrtilloides* in Michigan had levels of heterozygosity and numbers of alleles per gene locus comparable to other woody plants, but lower than those for tetraploid species of *Vaccinium*. Populations in Washington are at the southern edge of the species range in northwestern North America and probably have lower genetic diversity than populations in the Rocky Mountains due to inbreeding or founder effects.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
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.
No changes in the distribution of this species have been noted due to 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

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