WASHINGTON NATURAL HERITAGE PROGRAM

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

Prepared for

US Forest Service, Region 6

Prepared by

Jesse E. D. Miller, Irene Weber, Tynan Ramm-Granberg, and Walter Fertig

June 21, 2023

Natural Heritage
Report 2023-03

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES

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

Agreement Number 1240BD22C0010

Washington Natural Heritage Program Report Number: 2023-03

June 21, 2023

Prepared by:
Jesse E. D. Miller, Irene Weber, Tynan Ramm-Granberg, and Walter Fertig

Washington Natural Heritage Program
Washington Department of Natural Resources
Olympia, Washington 98504-7014

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

ON THE COVER: *Eleochoris rostellata* (State Sensitive [G5S2] and Moderately Vulnerable)

Photograph by Tynan Ramm-Granberg

Table of Contents

Page

Tables

Introduction

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

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

In 2019, the Washington Natural Heritage Program (WNHP) received funding from the US Fish and Wildlife Service (USFWS) to apply CCVI protocols to five federally listed plant species (Fertig 2021a; Kleinknecht et al. 2019). WNHP also received funding from the Interagency Special Status and Sensitive Species Program (ISSSSP) of the US Forest Service (USFS) and Bureau of Land Management (BLM) to apply the CCVI protocol to 47 plant species listed as agency Sensitive by USFS and BLM (ISSSP 2019). Fertig (2020) provided a summary of this first set of completed models (hereafter referred to as "Phase I" of this project). In 2020, USFS provided additional funding for CCVI reports on 55 new plant species listed as BLM or USFS Sensitive or WNHP species of concern ("Phase II" of the project; Fertig 2021b; Fertig 2022).

This report represents "Phase III" of the project, containing CCVI reports on 20 additional Washington rare plant species.

Methods

CCVI reports were prepared using the NatureServe Climate Change Vulnerability Calculator Release 3.02 in MS Office Excel (https://www.natureserve.org/conservation-tools/climate-change-vulnerability-index). GIS maps of projected local temperature change, moisture availability (based on the ratio of actual to predicted evapotranspiration), historical thermal niche, and historical hydrological niche were developed for each species by intersecting base map layers from NatureServe (www.natureserve.org/ccvi and www.fs.usda.gov/ccrc/tool/climate-wizard) with element occurrence records from the WNHP Biotics database. Values from these maps were entered directly into the CCVI calculator or scored following criteria in the document *Guidelines for Using the NatureServe Climate Change Vulnerability Index* (Young et al. 2016).

Scores for environmental and life history traits of each species were derived from a review of pertinent literature. Information on current habitat characteristics were based on Biotics records, the *Field Guide to Rare Plants of Washington* (Camp and Gamon 2011; Washington Natural Heritage Program 2021), and *Ecological Systems of Washington State: A Guide to Identification* (Rocchio and Crawford 2015). Additional information on potential impacts from climate change to ecological systems was derived from Rocchio and Ramm-Granberg (2017).

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

Wetland species were emphasized in Phase III due to a near-term need for this information for related projects.

Results and Discussion

Of the 20 vascular plant species examined in Phase III of this project, only two (*Carex gynocrates* and *Triglochin palustris*) scored as Extremely Vulnerable to climate change (Table 3, Table 4, Appendix A). Both of these are high-elevation fen species from the Okanogan Range that occur in areas projected to have increased temperatures, more pronounced temperature variability, and reduced snowpack (Table 3).

Five species in Phase III scored as Highly Vulnerable to climate change (Table 3, Table 4). These species were all associated with high-elevation habitats and / or bog and fen habitats.

The majority of species assessed in Phase III (13 of 20) scored as Moderately Vulnerable to climate change (Table 3, Table 4). Unlike the species rated Extremely or Highly Vulnerable, the Moderately Vulnerable taxa are not strongly correlated with specific geographic areas or habitats. Moderately Vulnerable species are widely distributed across the state.

Broadly, the patterns we identify above correspond to patterns documented in earlier phases of this project (Fertig 2020, Fertig 2022). Because Phase III of this project represents a relatively small addition to the existing data set, we will forgoe further in-depth analysis until additional phases of the project are completed, when it will be more meaningful.

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

Section A: Local Climate		
Ranking Factor	**Condition**	**Score**
1. Temperature Severity (projected local temperature change)	>6.0° F (3.3°C) warmer	% of populations, based on map in Figure 1 of each CCVI (see appendix)
	5.6-6.0° F (3.2-3.3°C) warmer	
	5.0-5.5° F (2.8-3.1°C) warmer	
	4.5-5.0° F (2.5-2.7°C) warmer	
	3.9-4.4° F (2.2-2.4°C) warmer	
	<3.9° F (2.2°C) warmer	
2. Hamon AET:PET moisture (projected decrease in available moisture based on ratio of actual to potential evapotranspiration)	< -0.119	% of populations, based on map in Figure 2 of each CCVI (see appendix)
	-0.097 to -0.119	
	-0.074 to - 0.096	
	-0.051 to - 0.073	
	-0.028 to -0.050	
	>-0.028	
Section B: Indirect Exposure to Climate Change		
Ranking Factor	**Condition**	**Score**
1. Sea level rise (% of area subject to sea level rise)	>90%	Greatly Increase
	50-90%	Increase
	10-49%	Somewhat Increase
	<10%	Neutral
2a. Distribution relative to natural barriers (degree to which natural barriers restrict the ability of a species to migrate)	Barriers completely or almost completely surround current range	Greatly Increase
	Barriers will greatly impede migration	Increase
	Barriers somewhat impede migration	Somewhat Increase
	Barriers are minor or not present	Neutral
2b. Distribution relative to anthropogenic barriers (degree to which human-created barriers restrict the ability of a species to migrate)	Barriers completely or almost completely surround current range	Greatly Increase
	Barriers will greatly impede migration	Increase
	Barriers somewhat impede migration	Somewhat Increase
	Barriers are minor or not present	Neutral
3. Impacts from climate change mitigation (effects of seawalls, tree plantations, renewable energy projects and other infrastructure on life history of a species)	Known to be incompatible and likely to be constructed	Greatly Increase
	Known to be incompatible and may be constructed	Somewhat Increase
	Not likely to be impacted	Neutral
Section C: Sensitivity and Adaptive Capacity		
Ranking Factor	**Condition**	**Score**
1. Dispersal and movements (degree to which a species is physically capable of dispersing)	Severely restricted dispersal (<10 m)	Greatly Increase
	Highly restricted dispersal (10-100 m)	Increase
	Moderately restricted dispersal (100-1,000m)	Somewhat Increase
	Good to excellent dispersal (>1,000 m)	Neutral

Ranking Factor	Condition	Score
2ai Change in historical thermal niche (exposure to large scale temperature variation in past 50 years) Based on Figure 3 in each CCVI report (see appendix)	Very small temperature variation (< 37˚F or 20.8˚C)	Greatly Increase
	Small temperature variation (37-47˚F or 20.8-26.3˚C)	Increase
	Slightly lower than average temperature variation (47.1-57˚F or 26.3-31.8˚C)	Somewhat Increase
	Average temperature variation (57.1-77˚F or 31.8-43.0˚C)	Neutral
2aii. Change in physiological thermal niche (degree to which a species is dependent on cool or cold conditions)	>90% of occurrences restricted to cool or cold sites	Greatly Increase
	50-90% of occurrences restricted to cool or cold sites	Increase
	10-50% of occurrences restricted to cool or cold sites	Somewhat Increase
	Species is not restricted to cool or cold sites	Neutral
2bi. Changes in historical hydrological niche (exposure to precipitation variations in the past 50 years). Based on Figure 4 in each CCVI report (see appendix)	Very small precipitation variation (< 4 inches or 100 mm)	Greatly Increase
	Small precipitation variation (4-10 inches or 100-254 mm)	Increase
	Slightly lower than average precipitation variation (11-20 inches or 255-508 mm)	Somewhat Increase
	Average (20-40 inches or 508-1016 mm) or greater than average (>40 inches or >1016 mm) precipitation variation	Neutral
2bii. Changes in physiological hydrological niche (dependence on a narrowly defined precipitation or hydrologic regime or specific aquatic or wetland habitat (i.e. vernal pool, spring)	>90% of occurrences dependent on a specific aquatic or wetland habitat	Greatly Increase
	50-90% of occurrences dependent on a strongly seasonal water source or specific wetland habitat	Increase
	10-50% of occurrences dependent on a strongly seasonal water source or specific wetland habitat	Somewhat Increase
	Species not dependent on a strongly seasonal water source or specific wetland habitat	Neutral
2c. Dependence on specific disturbance regime (effect of climate change on increasing disturbance or altering existing disturbance patterns)	Strongly affected by change in disturbance regime	Increase
	Moderately affected by change in disturbance regime	Somewhat Increase
	Little or no response to a specific disturbance regime	Neutral
2d. Dependence on ice or snow-covered habitats	>80% of populations dependent	Greatly Increase
	50-80% of populations dependent	Increase
	10-49% of populations dependent	Somewhat Increase
	Little dependence on ice or snow	Neutral
Ranking Factor	**Condition**	**Score**
3. Restricted to uncommon landscape/geological features	Highly dependent (>85% of populations restricted to uncommon features)	Increase
	Moderately dependent (65-85% of populations restricted to uncommon features)	Somewhat Increase
	Not dependent, or found on widely occurring landscape or geologic features	Neutral

Ranking Factor	Condition	Score
4a. Dependence on others species to generate required habitat	Required habitat is generated primarily by one species	Increase
	Required habitat is generated by only a few species	Somewhat Increase
	Required habitat is generated by many species, or not species-dependent	Neutral
4b. Dietary versatility (reliant on other species for nutrition)		Not applicable for plants
4c. Pollinator versatility (dependence on animal species for pollination)	Dependent on one species for pollination	Increase
	Dependent on 2-4 species for pollination	Somewhat Increase
	Dependent on 5 or more species for pollination, or not reliant on animals for pollination (i.e. wind-pollinated plants)	Neutral
4d. Dependence on other species for propagule (fruit or seed) dispersal	Completely or nearly completely dependent on a single animal species	Increase
	Dependent on a small number of species	Somewhat Increase
	Dispersed by many species, or not dependent on animals for dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies (vulnerability to disease or increased herbivory)	Strong negative impact from disease or herbivory due to climate change	Increase
	Moderate negative impact from disease or herbivory due to climate change	Somewhat Increase
	Not affected by disease or herbivory due to climate change, or impacts will be lessened	Neutral
4f. Sensitivity to competition from native or non-native species (competition for resources, such as space, light, and nutrients)	Strongly affected by competition that is likely to increase with climate change	Increase
	Moderately affected by competition that is likely to increase with climate change	Somewhat Increase
	Not affected by competition or competition is likely to decrease with climate change	Neutral
4g. Forms part of an interspecific interaction not covered above (species with mutualistic relationships)	Requires an interaction with a single species for persistence	Increase
	Requires an interaction with a group of similar species for persistence (e.g. mycorrhizal relationships)	Somewhat Increase
	Does not require an interaction with another species, or many species can fulfill this role	Neutral
5a. Measured genetic diversity	Very low	Increase
	Low	Somewhat Increase
	Average	Neutral
5b. Genetic bottlenecks (likelihood of extremely low genetic diversity in the past due to reduced population numbers or number of occurrences)	Evidence that population was reduced to <250 mature individuals in 1 occurrence (or >70% range reduction) in past 500 years	Increase
	Evidence that population was reduced to 251-1000 mature individuals in <10 occurrences (or 30-70% range reduction) in past 500 years	Somewhat Increase
	No evidence that population was reduced to <1000 mature individuals or range was reduced by >30% in part 500 years	Neutral

Ranking Factor	Condition	Score
5c. Reproductive system (breeding system of species and how it likely affects genetic variability; only used if C5a and C5b are "unknown")	Species only reproduces asexually; genetic diversity assumed to be very low	Increase
	Species has mixed or obligate outcrossing, but genetic diversity assumed to be low due to barriers to gene flow, range disjunction, or outbreeding depression	Somewhat Increase
	Species with mixed or obligate outcrossing without major barriers to gene flow and presumed to have average genetic diversity	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Seasonal temperature or precipitation has changed, but phenology has not changed	Increase
	Seasonal temperature or precipitation has changed, and phenology has changed to small degree	Somewhat Increase
	Seasonal temperature or precipitation and phenology have changed in similar way, or seasonal dynamics have not changed	Neutral
Section D: Documented or Modeled Response		
Ranking Factor	**Condition**	**Score**
D1. Documented response to recent climate change (range shifts or changes in abundance have occurred over last 10 years or 3 generations due to climate change)	Distribution or abundance undergoing major reduction (>70%)	Greatly Increase
	Distribution or abundance undergoing moderate reduction (30-70%)	Increase
	Distribution or abundance undergoing small reduction (10-30%)	Somewhat Increase
	Distribution or abundance not decreasing, or species is expanding range and increasing	Neutral
D2. Modeled future (2050) change in population or range size within the assessment area (based on "middle of road" climate projections)	Species is predicted to become extirpated	Greatly Increase
	Predicted range or abundance decreases 50-99%	Increase
	Predicted range or abundance decreases 20-50%	Somewhat Increase
	Predicted range or abundance remains static or increases	Neutral
D3. Overlap of modeled future (2050) range with current range	No overlap between current and predicted future range	Greatly Increase
	Predicted future range overlaps with current range by 30% or less	Increase
	Predicted future range overlaps with current range by 30-60%	Somewhat Increase
	Predicted future range overlaps with current range by >60%	Neutral
D4. Occurrence of protected areas in modeled future (2050) distribution (protected areas include national parks, wildlife refuges, wilderness areas, and natural areas that are protected from outright habitat destruction by human activities)	<5% of modeled future distribution is encompassed by one or more protected areas	Increase
	5-30% of modeled future distribution is encompassed by one or more protected areas	Somewhat Increase
	>30% of modeled future distribution is encompassed by one or more protected areas	Neutral

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

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

Table 3. Summary of Climate Change Vulnerability Index scores for 20 Washington rare plant taxa assessed in Phase III. WA Status: BS = BLM Sensitive; FS = US Forest Service Sensitive; WE = Washington State Endangered, WS = Washington State Sensitive; WT = Washington State Threatened (Fertig 2021b). CCVI Score: EV = Extremely Vulnerable; HV = Highly Vulnerable; LV = Less Vulnerable; MV = Moderately Vulnerable.

Species (Common Name)	Heritage Rank	WA Status	Major Habitat	Geographic Distribution	CCVI Score
Bolandra oregana (Oregon bolandra)	G3/S2	BS, FS, WT	Canyons, cliffs, bedrock & talus	Blue Mountains, E & W Cascades	MV
Botrychium hesperium (western moonwort)	G4/S2	BS, FS, WS	Dry to wet grasslands & meadows	Canadian Rockies, Cascades (N, E, & W), Okanogan	MV
Botrychium lineare (skinny moonwort)	G3/S1	BS, FS, WE	Montane woodlands	Okanogan	HV
Botrychium paradoxum (two-spiked moonwort)	G3G4/S2	BS, FS, WT	Wet meadows, montane grassland & riparian woodland	Canadian Rockies, E Cascades, Okanogan	MV
Botrychium pedunculosum (stalked moonwort)	G3G4/S2	BS, FS, WT	Wet meadows, montane grassland & riparian woodland	Canadian Rockies, N Cascades, Okanogan	MV
Calochortus macrocarpus var. *maculosus* (sagebrush lily)	G5T2/S2?	BS, FS, WT	Dry grassland	Blue Mountains, Columbia Plateau	MV
Carex gynocrates (yellow bog sedge)	G5/S2	BS, FS, WS	Montane fens	Okanogan	EV
Carex stylosa (long-styled sedge)	G5/S2	BS, FS, WS	Fens	North Cascades, PNW Coast	HV
Coptis trifolia (threeleaf Goldenthread)	G5/S1	BS, FS, WS	Bogs & fens	Canadian Rockies, PNW Coast	HV
Eleocharis rostellata (smooth-fruited sedge)	G5/S2	FS, WS	Alkaline marshes, fens & wet meadows	Canadian Rockies, Columbia Plateau, Okanogan	MV
Fritillaria camschatcensis (black lily)	G5/S2	BS, FS, WS	Fens, intertidal wetlands, wet meadows	N & W Cascades, Puget Trough	MV

Species (Common Name)	Heritage Rank	WA Status	Major Habitat	Geographic Distribution	CCVI Score
Lycopodiella inundata (bog clubmoss)	G5/S2	BS, FS, WS	Bogs, fens, & wet meadows	Cascades (N, E, & W), PNW Coast, Puget Trough	MV
Microseris borealis (northern microseris)	G5/S2	BS, FS, WS	Fens, & wet meadows	E & W Cascades, PNW Coast	MV
Navarretia leucocephala ssp. *diffusa* (diffuse navarretia)	G4T1/S1	BS, WE	Vernal pools	Columbia Plateau	HV
Pilularia americana (American pillwort)	G5/S2	BS, FS, WS	Vernal pools	Columbia Plateau	MV
Sisyrinchium sarmentosum (pale blue eyed grass)	G2/S2	BS, FS, WT	Montane wet meadows	E & W Cascades, Puget Trough	HV
Spiranthes porrifolia (western ladies' tresses)	G4/S2	BS, FS, WS	Woodlands, shrublands, vernal pools, pothole ponds, wet prairie	Columbia Plateau, E & W Cascades, Okanogan, Puget Trough	MV
Sullivantia oregana Oregon coolwort)	G2/S1	BS, FS, WE	Bedrock, cliffs & talus	W Cascades	MV
Symphyotrichum boreale (rush aster)	G5/S1	FS, WS	Fens	Canadian Rockies, Puget Trough	MV
Triglochin palustris (marsh arrowgrass)	G5/S1	FS, WS	Alkaline fens	Canadian Rockies, Okanogan	EV

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

See 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. Disp = Dispersal and Movements. Hist Therm N = Historical Thermal Niche. Phys Therm N = Physiological Thermal Niche. Hist Hydr N = Historical Hydrological Niche. Phys Hydr N = Physiological Hydrological Niche. Ice/Snow = Dependence on ice or snow-covered habitats. Geol = Restricted to uncommon landscape/geological features. Genes = combination of 3 criteria: Measured genetic variation, genetic bottlenecks, and reproductive system. **Scoring**: G Inc: = Greatly Increased vulnerability; Inc = Increased vulnerability, S Inc: = Somewhat Increased Vulnerability; Neut = Neutral vulnerability, Unk = Unknown.

Species (Common Name)	CCVI Score	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Bolandra oregana (Oregon bolandra)	MV	Neut	Inc	S Inc	Neut	Inc	Neut	S Inc	Unk
Botrychium hesperium (western moonwort)	MV	S Inc	S Inc-Neut	Neut	Neut	Neut	S Inc-Neut	Neut	S Inc
Botrychium lineare (skinny moonwort)	HV	S Inc	Neut	S Inc	Neut	S Inc	Neut	Neut	S Inc
Botrychium paradoxum (two-spiked moonwort)	MV	S Inc	S Inc-Neut	Neut	Neut	Neut	S Inc-Neut	Neut	S Inc
Botrychium pedunculosum (stalked moonwort)	MV	S Inc	S Inc-Neut	Neut	S Inc-Neut	Neut	Neut	Neut	S Inc
Calochortus macrocarpus var. *maculosus* (sagebrush lily)	MV	Inc	S Inc-Neut	Neut	S Inc-Neut	Neut	Neut	Neut	Unk
Carex gynocrates (yellow bog sedge)	EV	S Inc	Neut	S Inc	S Inc-Neut	Inc	S Inc	Inc	Neut
Carex stylosa (long-styled sedge)	HV	S Inc	G Inc-Inc	S Inc	Neut	Inc	S Inc	Neut	Inc-S Inc-Neut
Coptis trifolia (threeleaf Goldenthread)	HV	S Inc	G Inc	Inc	Neut	G Inc	Neut	Neut	U
Eleocharis rostellata (smooth-fruited sedge)	MV	S Inc	Neut	Neut	Inc-S Inc-Neut	S Inc	S Inc-Neut	Inc	Neut
Fritillaria camschatcensis (black lily)	MV	Inc	S Inc-Neut	Inc-S Inc	Neut	S Inc	Neut	Neut	Neut
Lycopodiella inundata (bog clubmoss)	MV	Neut	G Inc	S Inc	Neut	S Inc	Neut	Neut	U

Species (Common Name)	CCVI Score	Disp	Hist Therm N	Phys Therm N	Hist Hydr N	Phys Hydr N	Ice/ Snow	Geol	Genes
Microseris borealis (northern microseris)	MV	Neut	G Inc	S Inc	Neut	S Inc	Neut	Neut	U
Navarretia leucocephala ssp. *diffusa* (diffuse navarretia)	HV	S Inc	Neut	S Inc	S Inc	G Inc	S Inc-Neut	Inc	Neut
Pilularia americana (American pillwort)	MV	Neut	Neut	S Inc	S Inc	G Inc	S Inc-Neut	Inc	U
Sisyrinchium sarmentosum (pale blue eyed grass)	HV	Neut	Inc	S Inc	Neut	G Inc	S Inc	Neut	S Inc
Spiranthes porrifolia (western ladies' tresses)	MV	Neut	S Inc	S Inc	Neut	G Inc	S Inc-Neut	Neut	U
Sullivantia oregana Oregon coolwort)	MV	Neut	Inc	S Inc	Neut	G Inc	Neut	Inc	U
Symphyotrichum boreale (rush aster)	MV	Neut	S Inc	S Inc	Neut	S Inc	S Inc-Neut	Neut	U
Triglochin palustris (marsh arrowgrass)	EV	S Inc	Neut	S Inc	SI-Neut	Inc	S Inc	Inc	Neut

Acknowledgements

This project was funded by the US Forest Service, Region 6. Bruce Schneider of WNHP developed the climate maps for each CCVI report.

Literature Cited

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

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

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

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

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

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

Fertig, W. 2022. Climate Change Vulnerability Index reports for selected Washington State rare plant species: Phase II. Natural Heritage Report 2022-01. Report prepared for US Forest Service, Region 6. Washington Natural Heritage Program, WA Department of Natural Resources, Olympia, WA. 531 pp.

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

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

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

Kleinknecht, J., D. Wilderman, and W. Fertig. 2019. Climate change and connectivity review of site designs for established natural areas with federally listed plant species. Natural Heritage Report 2019-06. Report prepared for US Fish and Wildlife Service. Washington Natural Heritage Program. Washington Department of Natural Resources, Olympia, WA. 90 pp.

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

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

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

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

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

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

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

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

Appendix A. Climate Change Vulnerability Index reports for 20 Washington Rare Plant Species Assessed in Phase III

Climate Change Vulnerability Index Report

Bolandra oregana (Oregon bolandra)

Date: 24 April 2023 Synonym: NA

Assessor: Irene Weber, 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	33
	3.9-4.4° F (2.2-2.4°C) warmer	17
	<3.9° F (2.2°C) warmer	50
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	17
	-0.074 to - 0.096	78
	-0.051 to - 0.073	6
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Somewhat Increase
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Somewhat Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral
5a. Measured genetic diversity		Unknown

5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	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: Of the 18 current and historic occurrences of *Bolandra oregana*, 6 (33%) occur in areas with a projected temperature increase of 4.5-5.0˚F. Three (17%) are in areas of 3.9-4.4˚ F projected temperature increase. The remaining 9 occurrences (50%) are in areas with a projected temperature increase of less than 3.9˚F (Figure 1).

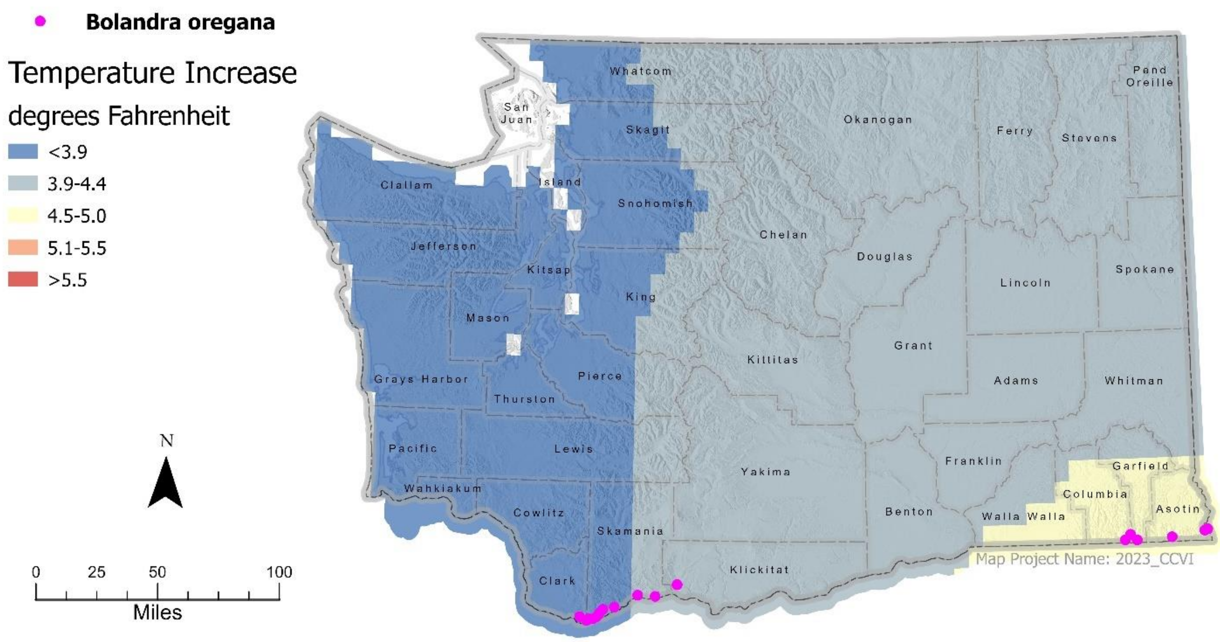


Figure 1. Exposure of Bolandra oregana occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Of the 18 occurrences of *Bolandra oregana* in Washington, 3 (17%) occur in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.097 - -0.119.

Fourteen (78%) occur in areas with a projected decrease in available moisture in the range of -0.074 - -0.096. The remaining occurrence (6%) occurs in in areas with a projected decrease in available moisture in the range of -0.051 - -0.073 (Figure 2).

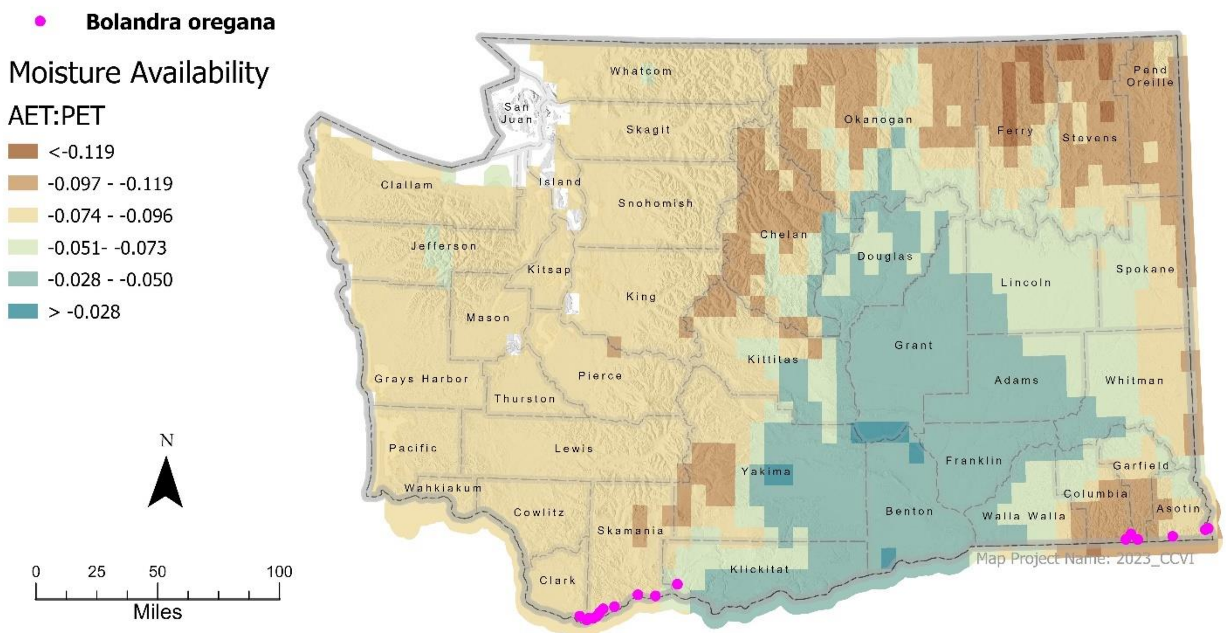


Figure 2. Exposure of *Bolandra oregana* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Bolandra oregana* are found at 60-3900 feet (20-1200 m) and are unlikely to be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Bolandra oregana occurs in low elevation sites along the Columbia River drainage. It is usually found near streams or on cliffs near waterfalls, however it has also been found in open rocky areas and on steep grassy semi-open slopes (Camp and Gamon 2011). This habitat is somewhat limited and surrounding uplands somewhat restricts movement of this species.

B2b. Anthropogenic barriers: Neutral.
The range of *Bolandra oregana* is somewhat fragmented by anthropogenic infrastructure, primarily roads. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.
Climate change mitigation is unlikely to occur in *Bolandra oregana* habitat.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Bolandra oregana produces seeds in 1 cm capsules (Camp and Gamon 2011). Dispersal mechanisms of this plant are unknown but due to seed morphology, seeds are likely dispersed primarily by gravity and water. Seed dispersal does not appear to be a major inhibitor to this species persistence.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Bolandra oregana* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Five occurrences in Washington (28%) are found in 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 due to climate change. Seven occurrences (39%) are in areas that have a slightly lower than average variation in temperature (47.1-57˚F/26.3-31.8˚C) and are at somewhat increased vulnerability due to climate change. The remaining 6 occurrences are in areas that have experiences average temperature variation in the past 50 years (57.1-77˚F/31.8-43.0˚C) and are considered neutral vulnerability due to climate change (Young et al. 2016). Per the guidance in Young et al. (2016) because the highest category that includes at least 10% of the range of this species is within the Increase Vulnerability area, this category has been selected.

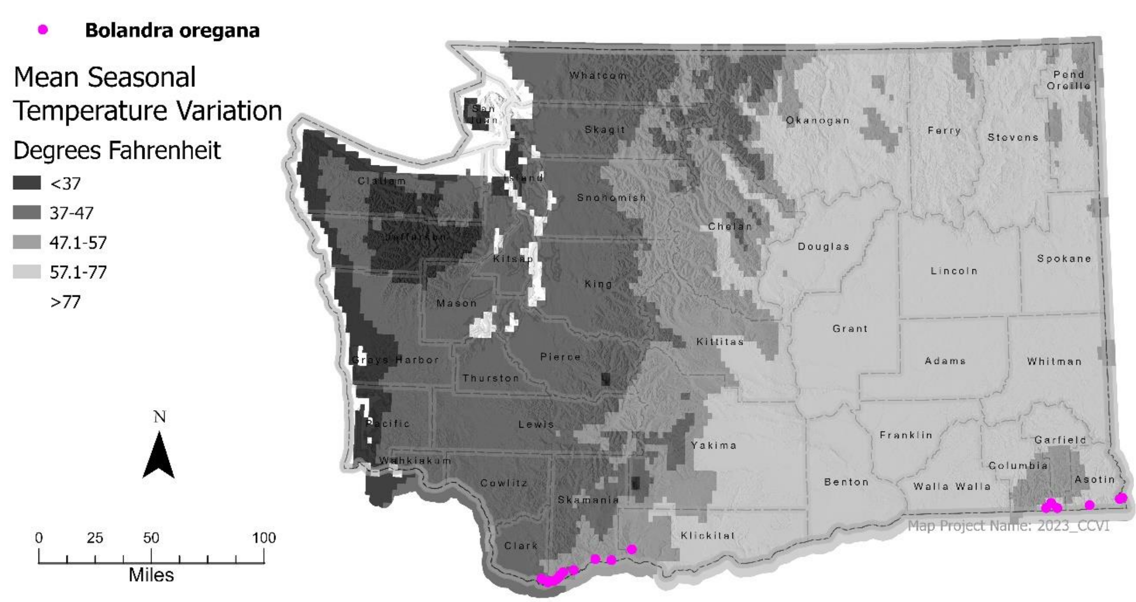


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Bolandra oregana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The moist habitat of *Bolandra oregana* may be associated with cool air. Warming temperatures that alter the cool moist conditions of these sites could adversely affect these species.

C2bi. Historical hydrological niche: Neutral.
Fifteen of the known populations of *Bolandra oregana* (83%) occur in areas of average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm) According to Young et al. (2016), these occurrences are neutral vulnerability due to climate change. The remaining three occurrences are in areas of slightly lower than average precipitation variation (11-20 in/255-508 mm) and are considered at somewhat increased vulnerability due to climate change. (Figure 4).

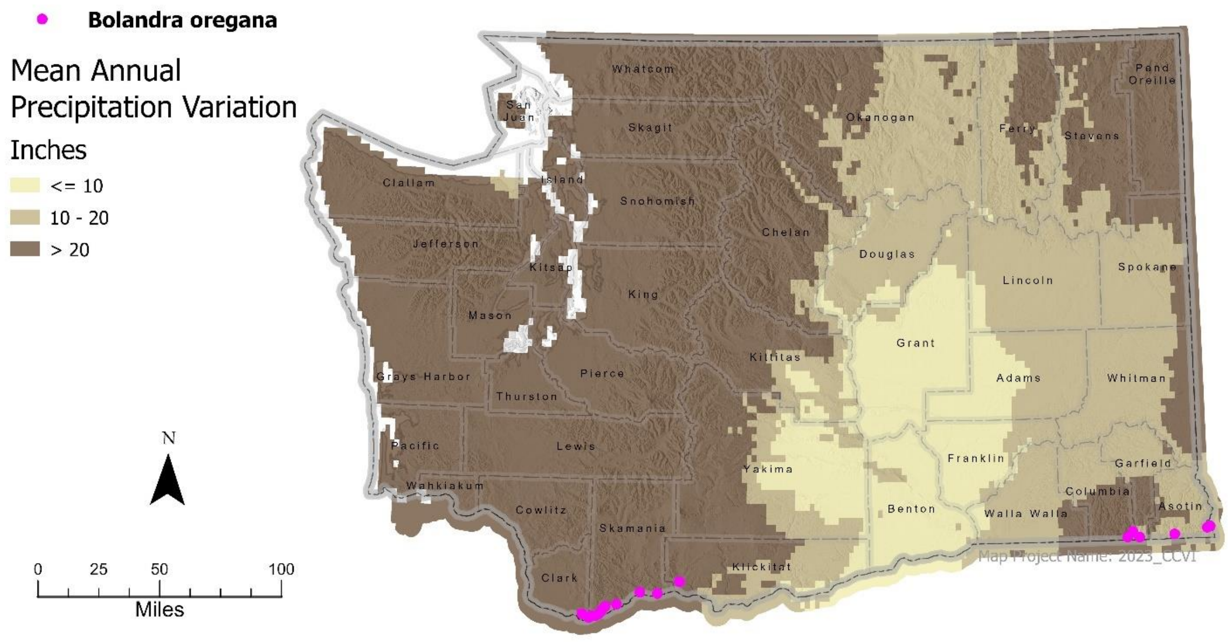


Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of Bolandra oregana occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
This species usually occurs in moist environments that are fed by ground water and/or surface flow. Changes in the amount and timing of precipitation and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017). Reduction and/or change of timing of stream flow volume could reduce the size of the "spray zone" around waterfalls and rocks at the base, thereby reducing the potential habitat of the species.

C2c. Dependence on a specific disturbance regime: Neutral.
Bolandra oregana does not rely on a specific disturbance regime.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Bolandra oregana does not occur in habitat with significant ice or snow-cover. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Somewhat Increase.
Bolandra oregana is primarily dependent on shady, moist, rocky, wooded places associated with cliffs and waterfalls within the North Pacific Montane Massive Bedrock, Cliff, & Talus and Rocky Mountain Cliff, Canyon & Massive Bedrock ecological systems. However, it may sometimes be found in open rocky areas and on steep grassy semi open slopes. (Camp and Gamon 2011, WNHP 2021).

C4a. Dependence on other species to generate required habitat: Neutral.
The habitat occupied by *Bolandra oregana* is maintained largely by natural, abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Little is known about the specific pollinators of *Bolandra oregana*. The perfect, actinomorphic flower shape and presence of a nectary indicates this species is likely pollinated by a variety of insect species (Gornall 1985).

C4d. Dependence on other species for propagule dispersal: Neutral.
Bolandra oregana produces abundant small seeds (Gornall 1985). There is little to suggest that There is little evidence to suggest that this species is limited by propagule dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Somewhat increase.
Non-native species are not a documented threat to the cliff and rock ecosystems where *Bolandra oregana* is commonly found. In the vernally moist and open grassland environments where this species is sometimes found, invasive annual grasses such as cheatgrass (*Bromus tectorum*) may threaten this species.

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

C5a. Measured genetic variation: Unknown.
Genetic variation within *Bolandra oregana* populations is unknown. Due to the isolation of this species it's possible that the genetic variation is low.

C5b. Genetic bottlenecks: Unknown.

The range of *Bolandra oregana* is somewhat restricted but there are no known genetic bottlenecks.

C5c. Reproductive System: Neutral.
Bolandra oregana is diploid (2n=14) and is documented to be self compatible and to outcross. *B. oregana* did not successfully hybridize with other closely related species in one breeding system study (Gornall and Bohm 1984).

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

Section D: Documented or Modeled Response to Climate Change

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

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.

Gornall, R.J. and Bohm, B.A. 1984. Breeding systems and relationships among species of *Boykinia* and related genera (Saxifragaceae). Canadian Journal of Botany. 62:33-37.

Gornall, R.J. 1985. A monograph of *Boykinia*, *Peltoboykinia*, *Bolandra* and *Suksdorfia* (Saxifragaceae). Botanical Journal of the Linnean Society 90:1-71.

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.

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.

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.

Washington Natural Heritage Program. 2021. Bolandra oregana. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa/?species=penstemon%20barrettiae. Accessed 25 April 2023.

Climate Change Vulnerability Index Report

Botrychium hesperium (western moonwort)

Date: 12 May 2023

Assessor: Jesse Miller, 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	96
	<3.9° F (2.2°C) warmer	4
2. Hamon AET:PET moisture	< -0.119	32
	-0.097 to -0.119	56
	-0.074 to - 0.096	12
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat increase
2ai Change in historical thermal niche		Neutral to 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		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		Increase
4g. Forms part of an interspecific interaction not covered above		Increase

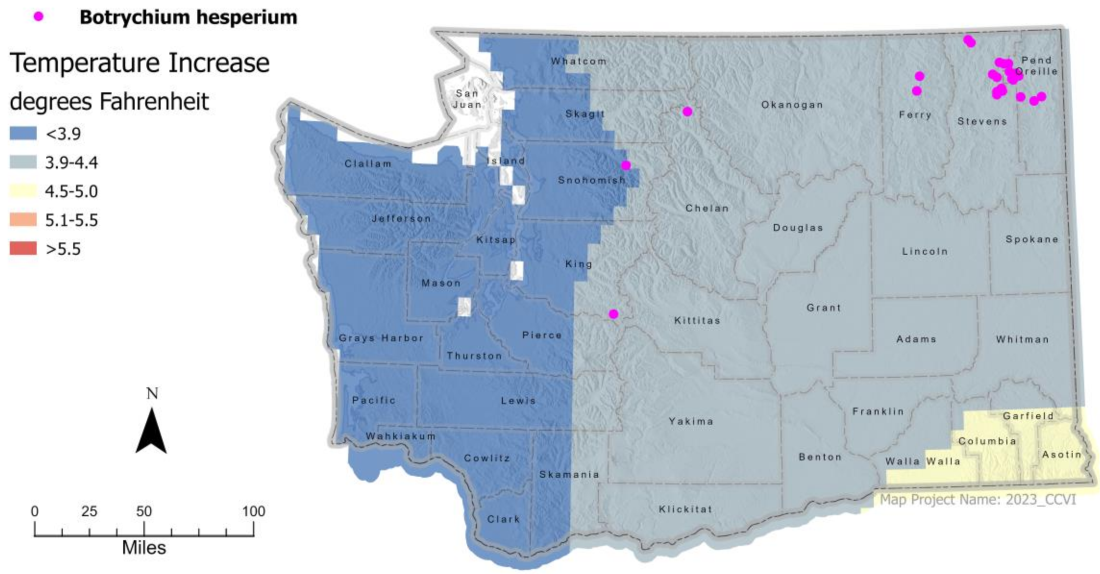


Figure 1. Exposure of *Botrychium hesperium* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Not Applicable
5c. Reproductive system	Not Applicable
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
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: 24 of the 25 known populations of *Botrychium hesperium* in Washington occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1). The other population occurs in an area with a projected temperature increase of < 3.9 ˚ F.

A2. Hamon AET:PET Moisture Metric: Eight of the 25 known occurrences of *Botrychium hesperium* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) of < -0.119 (Figure 2). 14

populations are found in areas with a projected decrease of -0.118 - -0.097, and the other three occurrences are in areas with a projected decrease of -0.096 - -0.074.

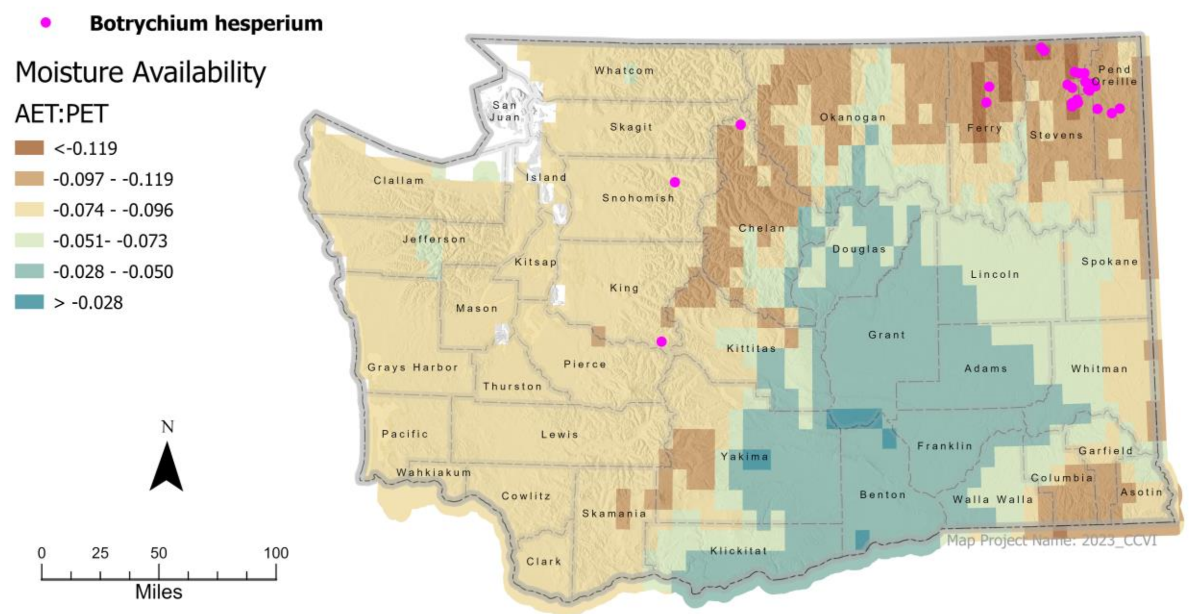


Figure 2. Exposure of *Botrychium hesperium* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Botrychium hesperium* occur from approximately 760-1920 m (2500-6300 ft) and are not at risk from sea level rise (Washington Natural Heritage Program 2023).

B2a. Natural barriers: Neutral.
In Washington this taxon grows in sagebrush steppe, moist and dry meadows, and forest edges (Washington Natural Heritage Program 2023). It occurs in the Rocky Mountain Alpine-Montane Wet Meadow, Northern Pacific Alpine & Subalpine Dry Grassland, and Northern Rocky Mountain Subalpine-Upper Montane Grassland ecological systems in Washington (Rocchio and Crawford 2015). There do not appear to be strong natural barriers to its dispersal. Populations are separated by approximately 1-96 miles (1-155 km).

B2b. Anthropogenic barriers: Neutral.
The Washington populations of *Botrychium hesperium* occurs in areas that are not heavily impacted by anthropgenic alterations to the landscape.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat increase.
Botrychium hesperium, like other ferns, has a complex life cycle involving alternation of two distinct growth forms: the familiar sporophyte phase and a much-reduced gametophyte phase. Sporophyte plants produce large numbers of tiny, seed-like spores that are capable of long-distance dispersal by wind. Spores germinate to form gametophyte plants which reproduce sexually by gametes (sessile eggs retained within the plant and motile sperm that require moist surfaces to travel very short distances for fertilization). Sporophyte plants are produced from fertilized eggs within their parent gametophyte plant, and thus are incapable of further dispersal. Overall, dispersal by spores is not limiting, but the survival of sporophyte plants is strongly tied to gametophytes reaching and persisting in suitable microhabitats. The dependence on proper conditions for gametophyte survival makes ferns more vulnerable to dispersal bottlenecks.

C2ai. Historical thermal niche: Neutral to Increase.
Figure 3 depicts the distribution of *Botrychium hesperium* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). 20 of the 25 populations are in areas that have experienced average or greater than average (>57.1° F/43.0° C) temperature variation in the past 50 years, and are considered to be neutral in regard to vulnerability to climate change (Young et al. 2016). Three occurrences are in areas that experienced slightly lower than average (47.1 - 57° F/26.3 - 31.8° C) temperature variation in the past 50 years, and are considered to be at somewhat increased vulnerability. Two occurrences are in areas that experienced small (37 - 47° F/20.8 - 26.3° C) temperature variation in the past 50 years, and are considered to be at increased vulnerability.

C2aii. Physiological thermal niche: Neutral.
Botrychium hesperium does not appear to be at increased risk from climate change in terms of its physiological thermal niche.

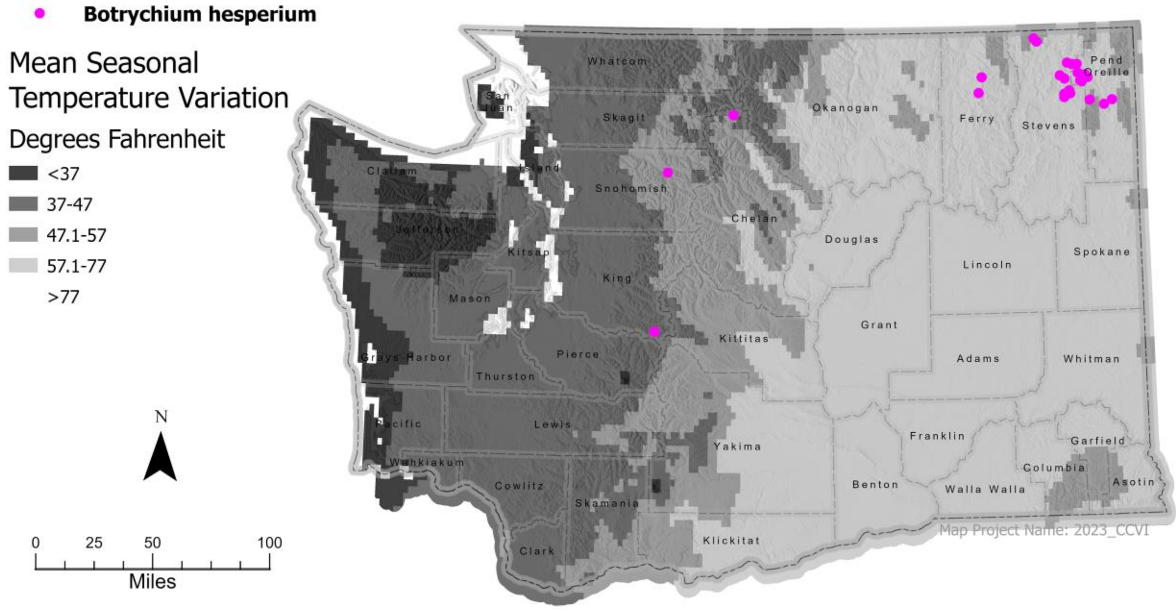


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Botrychium hesperium* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the 25 *Botrychium hesperium* occurrences in Washington are found in areas that have experienced average or above average variation in precipitation (> 20 inches / > 508mm; Figure 4). According to Young et al. (2016), these populations are neutral in terms of vulnerability from climate change.

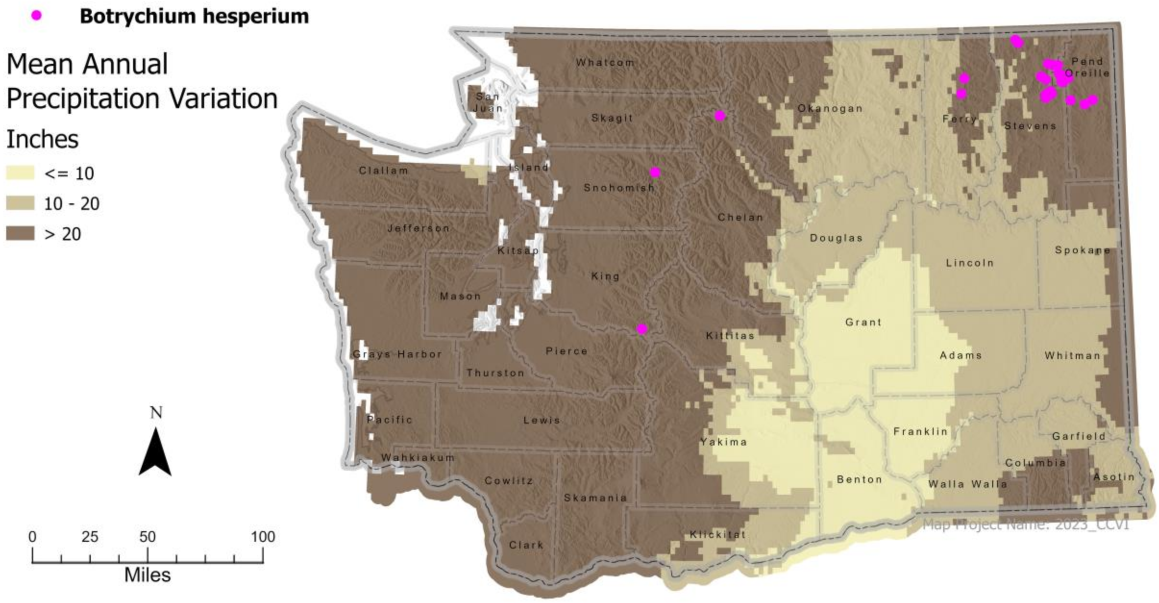


Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Botrychium hesperium* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
Botrychium hesperium is not strongly associated with wet habitats in Washington, and does not appear to be particularly vulnerable to hydrological changes (Washington Natural Heritage Program 2023).

C2c. Dependence on a specific disturbance regime: Neutral.
Botrychium hesperium is not known to be dependent on a specific disturbance regime.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Botrychium hesperium occurs in areas that experience winter snowfall, but does not appear to be strongly reliant on snow or the moisture it produces, though it may remain dormant in drier years (Washington Natural Heritage Program 2023).

C3. Restricted to uncommon landscape/geological features: Neutral.
Botrychium hesperium is not known to be associated with uncommon landscape / geological features.

C4a. Dependence on other species to generate required habitat: Neutral
Botrychium hesperium is not known to be dependent on other species to maintain its habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Botrychium spp. are wind-pollinated and are not dependent on pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Spores of *Botrychium* spp. are dispersed by wind.

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: Increase.
The small stature of *Botrychium hesperium* may make it vulnerable to competition from other plants. Previous research has shown that exotic plant invasions can indirectly harm *Botrychium australe* by facilitating the invasion of exotic worms (Sessions and Kelly 2002). Under future climate change, warmer temperatures could extend the growing season, making the high-elevation areas where *Botrychium hesperium* occurs in Washington more susceptible to invasion by annual introduced species or native perennials adapted to more open and drier sites (Rocchio, F.J. and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Increase.
Botrychium spp. are believed to be dependent on mycorrhizal fungi to complete their lifecycle (Winther and Friedman 2007)

C5a. Measured genetic variation: Somewhat increase.
Genetic variation in *Botrychium* spp. has been reported as low to moderate (Soltis and Soltis 1986, Dauphin et al. 2020).

C5b. Genetic bottlenecks: Not applicable since C5a was included.

C5c. Reproductive System: Not applicable since C5a was included.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Botrychium hesperium* has not been collected enough in Washington to make an assessment of changes in seasonal phenology.

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 *Botrychium hesperium* in Washington since it was first collected in the state in 1998.

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

D3. Overlap of modeled future (2050) range with current range: Unknown

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown

References

Dauphin, B., J. R. Grant, and D. R. Farrar. 2020. Outcrossing Mating System of the Early-Divergent Moonwort Fern (Botrychium lunaria, Ophioglossaceae) Revealed in the European Alps. International Journal of Plant Sciences 181:926–936.

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

Rocchio, F.J., and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment.

Sessions, L., and D. Kelly. 2002. Predator-Mediated Apparent Competition between an Introduced Grass, Agrostis capillaris, and a Native Fern, Botrychium australe (Ophioglossaceae), in New Zealand. Oikos 96:102–109.

Soltis, D. E., and P. S. Soltis. 1986. Electrophoretic Evidence for Inbreeding in the Fern Botrychium Virginianum (ophioglossaceae). American Journal of Botany 73:588–592.

Washington Natural Heritage Program. 2023. Online Field Guide to the Rare Plants of Washington: https://fieldguide.mt.gov/wa.

Winther, J. L., and W. E. Friedman. 2007. Arbuscular mycorrhizal symbionts in Botrychium (Ophioglossaceae). American Journal of Botany 94:1248–1255.

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 3:48.

Climate Change Vulnerability Index Report

Botrychium lineare (skinny moonwort)

Date: 8 May 2023

Assessor: Jesse Miller, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G3/S1

Index Result: Highly Vulnerable Confidence: Very high

Climate Change Vulnerability Index Scores

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

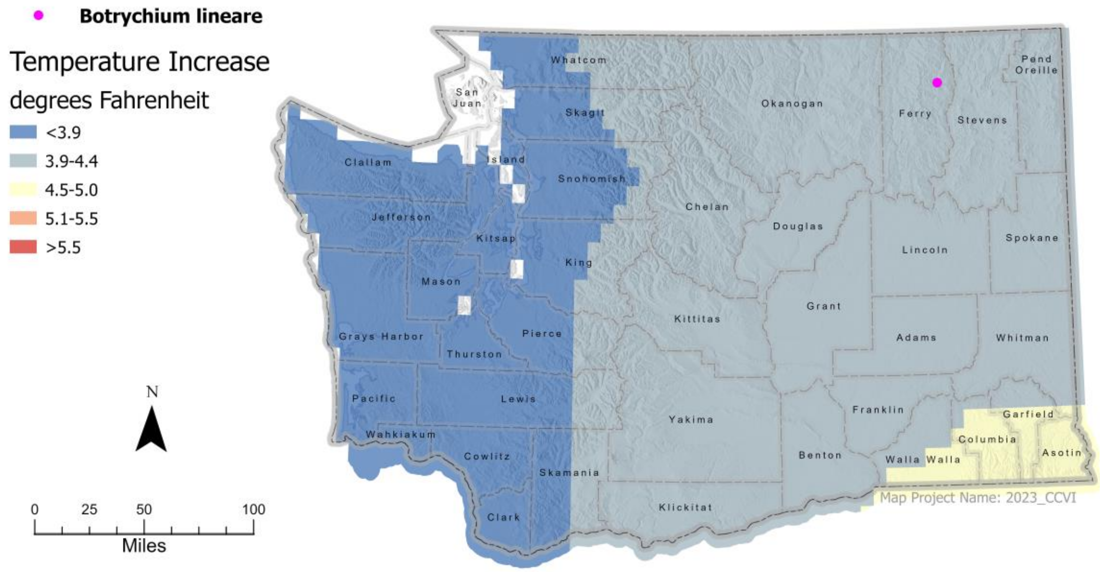


Figure 1. Exposure of *Botrychium lineare* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

5b. Genetic bottlenecks	Not Applicable
5c. Reproductive system	Not Applicable
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
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 one population of *Botrychium lineare* in Washington occurs in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

A2. Hamon AET:PET Moisture Metric: The one occurrence of *Botrychium lineare* 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 < -0.119 (Figure 2).

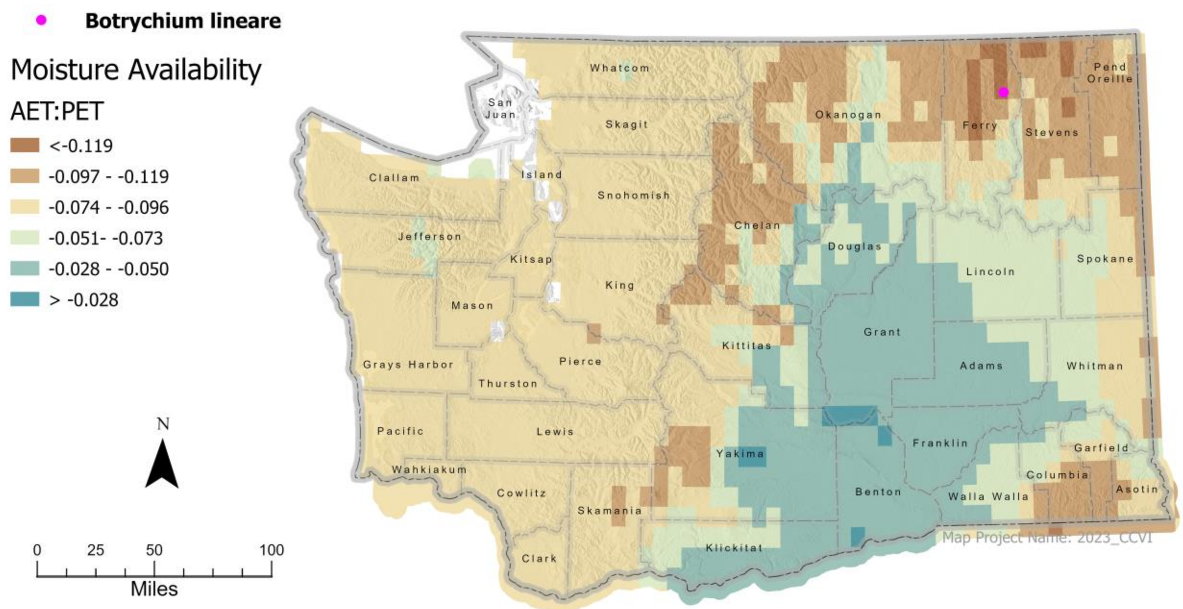


Figure 2. Exposure of *Botrychium lineare* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The one Washington occurrence of *Botrychium lineare* occurs at approximately 33000 ft (1000 m) and is not at risk from sea level rise (Washington Natural Heritage Program 2023).

B2a. Natural barriers: Neutral.
Botrychium lineare occurs on the flood plain of a perennial stream in Washington, in the Rocky Mountain Subalpine-Montane Riparian Woodland ecological system (Rocchio and Crawford 2015). Outside of Washington the species also occurs in grassy meadows, under trees, and on limestone cliffs (Washington Natural Heritage Program 2023). There do not appear to be strong natural barriers to its dispersal.

B2b. Anthropogenic barriers: Neutral.
The Washington population of *Botrychium lineare* occurs in an area that is relatively unimpacted by anthropgenic alterations to the landscape.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat increase.
Botrychium lineare, like other ferns, has a complex life cycle involving alternation of two distinct growth forms: the familiar sporophyte phase and a much-reduced gametophyte phase. Sporophyte plants produce large numbers of tiny, seed-like spores that are capable of long-distance dispersal by wind. Spores germinate to form gametophyte plants which reproduce sexually by gametes (sessile eggs retained within the plant and motile sperm that require moist surfaces to travel very short distances for fertilization). Sporophyte plants are produced from fertilized eggs within their parent gametophyte plant, and thus are incapable of further dispersal. Overall, dispersal by spores is not limiting, but the survival of sporophyte plants is strongly tied to gametophytes reaching and persisting in suitable microhabitats. The dependence on proper conditions for gametophyte survival makes ferns more vulnerable to dispersal bottlenecks.

C2ai. Historical thermal niche: Neutral
Figure 3 depicts the distribution of *Botrychium lineare* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The one population in Washington is an area that has experienced average or greater than average (>57.1° F/43.0° C) temperature variation in the past 50 years, and is considered to be neutral in regard to vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Somewhat increase.
Botrychium lineare occurs at a wet, riparian site in Washington. Thus, the species could be at slightly increased to increased risk from climate in terms of its physiological thermal niche.

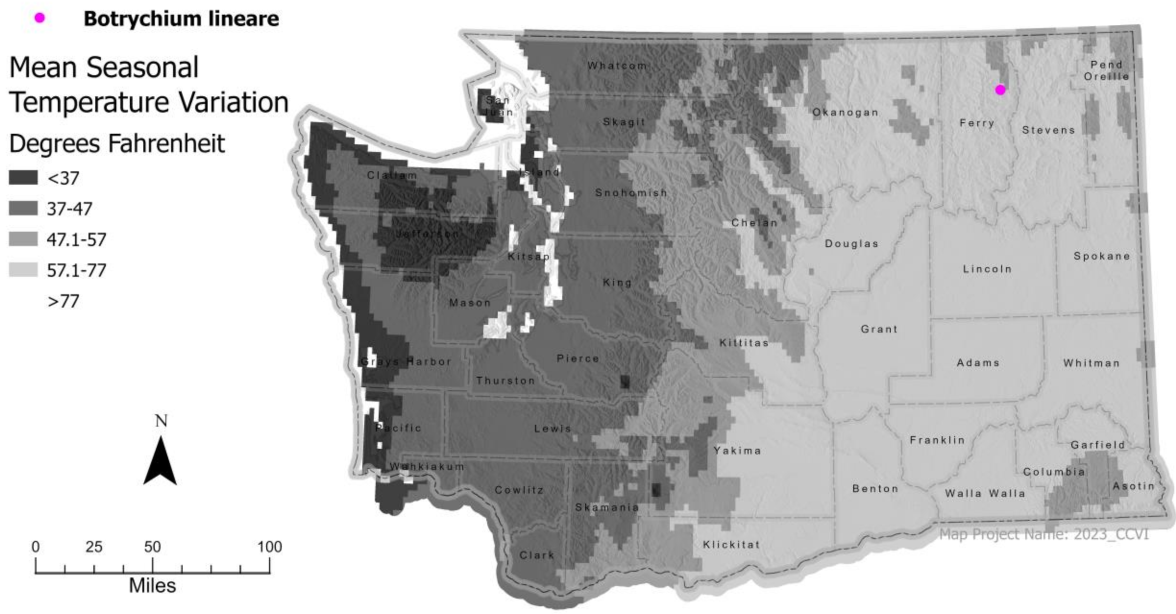


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Botrychium lineare* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
The one known population of *Botrychium lineare* in Washington is found in an area that has experienced average or above average variation in precipitation (> 20 inches / > 508mm; Figure 4). According to Young et al. (2016), this occurrence is at neutral vulnerability from climate change.

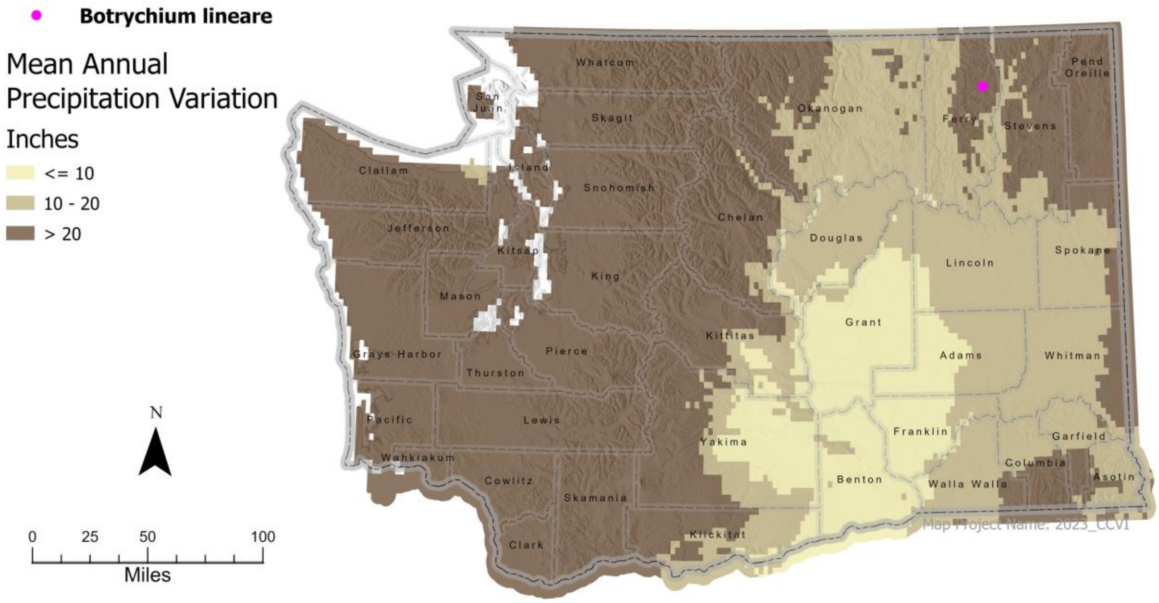


Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Botrychium lineare* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat increase.
The one population of *Botrychium lineare* in Washington occurs in a riparian area, and hydrological changes could be detrimental to the species (Washington Natural Heritage Program 2023).

C2c. Dependence on a specific disturbance regime: Neutral.
Botrychium lineare is not known to be dependent on a specific disturbance regime.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Botrychium lineare is not believed to be strongly associated with ice or snow-covered habitats, although winter snow may occur within its range.

C3. Restricted to uncommon landscape/geological features: Neutral.
Botrychium lineare is not known to be associated with uncommon landscape / geological features.

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

Botrychium lineare is not known to be dependent on other species to maintain its habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Botrychium spp. are wind-pollinated and are not dependent on pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Spores of *Botrychium* spp. are dispersed by wind.

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: Increase.
The small stature of *Botrychium lineare* may make it vulnerable to competition from other plants. Previous research has shown that exotic plant invasions can indirectly harm *Botrychium australe* by facilitating the invasion of exotic worms (Sessions and Kelly 2002). Under future climate change, warmer temperatures could extend the growing season, making the high-elevation areas where *Botrychium lineare* occurs in Washington more susceptible to invasion by annual introduced species or native perennials adapted to more open and drier sites (Rocchio, F.J. and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Increase.
Botrychium spp. are believed to be dependent on mycorrhizal fungi to complete their lifecycle (Winther and Friedman 2007)

C5a. Measured genetic variation: Somewhat increase.
Genetic variation in *Botrychium* spp. has been reported as low to moderate (Soltis and Soltis 1986, Dauphin et al. 2020).

C5b. Genetic bottlenecks: Not applicable since C5a was included.

C5c. Reproductive System: Not applicable since C5a was included.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Botrychium lineare* has not been collected enough in Washington to make an assessment of changes in seasonal phenology.

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 *Botrychium lineare* in Washington since it was first collected in the state in 1996.

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

Dauphin, B., J. R. Grant, and D. R. Farrar. 2020. Outcrossing Mating System of the Early-Divergent Moonwort Fern (Botrychium lunaria, Ophioglossaceae) Revealed in the European Alps. International Journal of Plant Sciences 181:926–936.

Rey-Vizgirdas, E., and B. Behan. 2001. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the plant Botrychium lineare (slender moonwort) as threatened. U.S. Fish and Wildlife, Federal Register 66:30368–30372.

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

Rocchio, F.J., and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment.

Sessions, L., and D. Kelly. 2002. Predator-Mediated Apparent Competition between an Introduced Grass, Agrostis capillaris, and a Native Fern, Botrychium australe (Ophioglossaceae), in New Zealand. Oikos 96:102–109.

Soltis, D. E., and P. S. Soltis. 1986. Electrophoretic Evidence for Inbreeding in the Fern Botrychium Virginianum (ophioglossaceae). American Journal of Botany 73:588–592.

Washington Natural Heritage Program. 2023. Online Field Guide to the Rare Plants of Washington: https://fieldguide.mt.gov/wa.

Winther, J. L., and W. E. Friedman. 2007. Arbuscular mycorrhizal symbionts in Botrychium (Ophioglossaceae). American Journal of Botany 94:1248–1255.

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 3:48.

Climate Change Vulnerability Index Report

Botrychium paradoxum (two-spiked moonwort)

Date: 11 May 2023

Assessor: Jesse Miller, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G3G4/S2

Index Result: Moderately Vulnerable Confidence: Very high

Climate Change Vulnerability Index Scores

Section A	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	30
	-0.097 to -0.119	60
	-0.074 to - 0.096	10
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat increase
2ai Change in historical thermal niche		Neutral to Somewhat increase
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		Neutral to 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		Increase

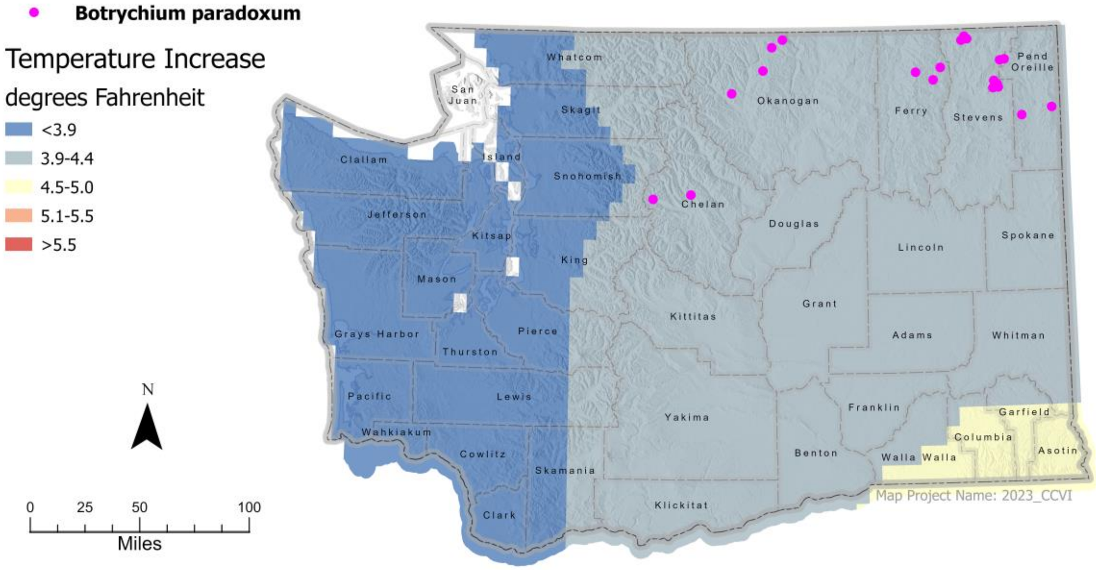


Figure 1. Exposure of *Botrychium paradoxum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

4g. Forms part of an interspecific interaction not covered above	Increase
5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Not Applicable
5c. Reproductive system	Not Applicable
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
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 contemporary and historical populations of *Botrychium paradoxum* in Washington occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

A2. Hamon AET:PET Moisture Metric: Six of the known occurrences of *Botrychium paradoxum* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) of < -0.119 (Figure 2). 12 populations are found in areas with a projected decrease of -0.118 - -0.097, and the other two occurrences are in areas with a projected decrease of -0.096 - -0.074.

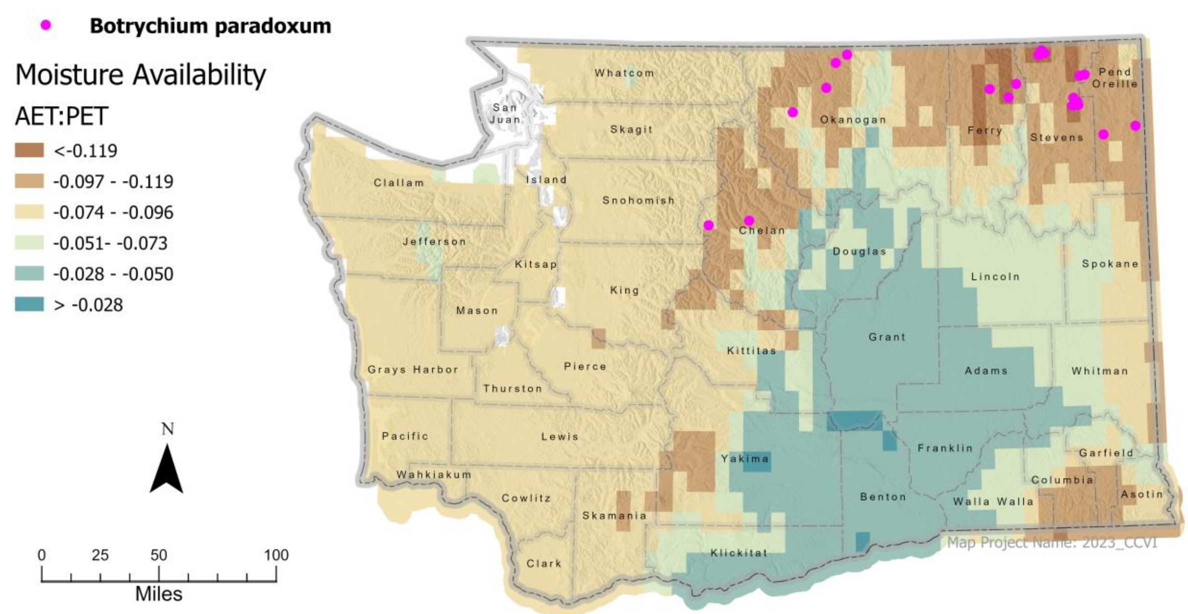


Figure 2. Exposure of *Botrychium paradoxum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Botrychium paradoxum* occur from approximately 1640-6550 ft (750-2000 m) and is not at risk from sea level rise (Washington Natural Heritage Program 2023).

B2a. Natural barriers: Neutral.
In Washington this taxon grows in late-seral western redcedar (*Thuja plicata*) forests on floodplains, perennial or intermittent stream terraces, wet or dry meadows, compacted old roadbeds, rocky subalpine slopes, and early-seral lodgepole pine (*Pinus contorta*) communities

(Washington Natural Heritage Program 2023). It occurs in the Rocky Mountain Subalpine-Montane Riparian Woodland, Rocky Mountain Alpine-Montane Wet Meadow, and Northern Rocky Mountain Subalpine-Upper Montane Grassland ecological systems in Washington (Rocchio and Crawford 2015). There do not appear to be strong natural barriers to its dispersal. Populations are separated by approximately 1-62 miles (1-100 km).

B2b. Anthropogenic barriers: Neutral.
The Washington populations of *Botrychium paradoxum* occurs in areas that are not heavily impacted by anthropgenic alterations to the landscape.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat increase.
Botrychium paradoxum, like other ferns, has a complex life cycle involving alternation of two distinct growth forms: the familiar sporophyte phase and a much-reduced gametophyte phase. Sporophyte plants produce large numbers of tiny, seed-like spores that are capable of long-distance dispersal by wind. Spores germinate to form gametophyte plants which reproduce sexually by gametes (sessile eggs retained within the plant and motile sperm that require moist surfaces to travel very short distances for fertilization). Sporophyte plants are produced from fertilized eggs within their parent gametophyte plant, and thus are incapable of further dispersal. Overall, dispersal by spores is not limiting, but the survival of sporophyte plants is strongly tied to gametophytes reaching and persisting in suitable microhabitats. The dependence on proper conditions for gametophyte survival makes ferns more vulnerable to dispersal bottlenecks.

C2ai. Historical thermal niche: Neutral to Somewhat increase.
Figure 3 depicts the distribution of *Botrychium paradoxum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Ten of the 20 populations are in areas that have experienced average or greater than average (>57.1° F/43.0° C) temperature variation in the past 50 years, and are considered to be neutral in regard to vulnerability to climate change (Young et al. 2016). The other 10 occurences are in areas that experienced slightly lower than average (47.1 - 57° F/26.3 - 31.8° C) temperature variation in the past 50 years, and are considered to be at somewhat increased vulnerability.

C2aii. Physiological thermal niche: Neutral.
Botrychium paradoxum does not appear to be at increased risk from climate change in terms of its physiological thermal niche.

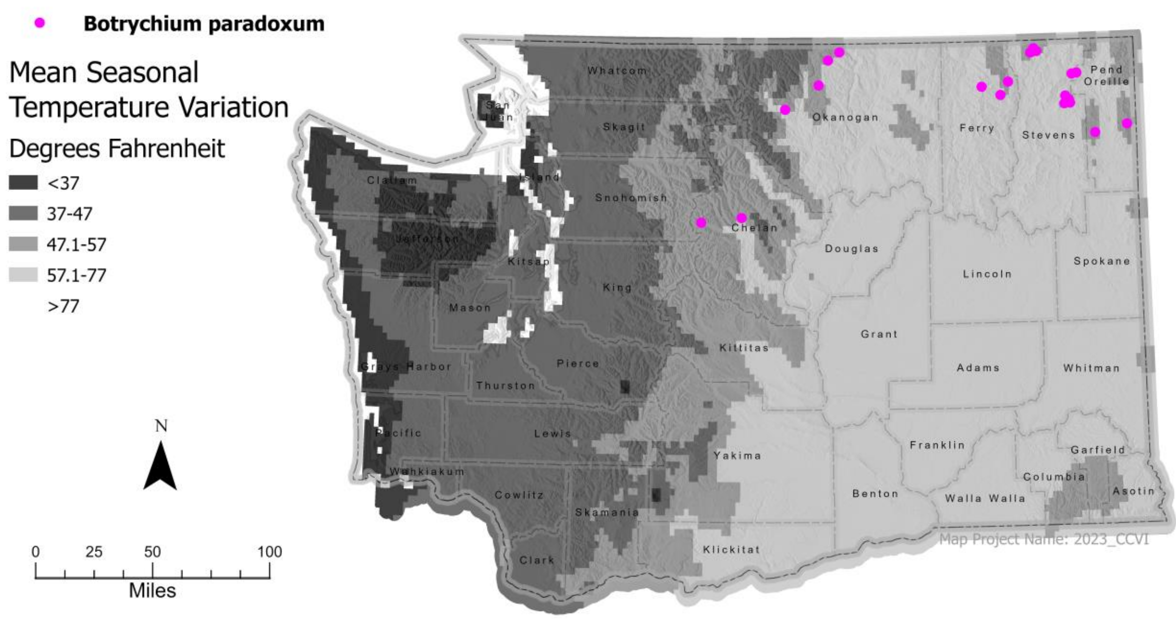


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Botrychium paradoxum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All of the 20 *Botrychium paradoxum* occurrences in Washington are found in areas that have experienced average or above average variation in precipitation (> 20 inches / > 508mm; Figure 4). According to Young et al. (2016), these populations are neutral in terms of vulnerability from climate change.

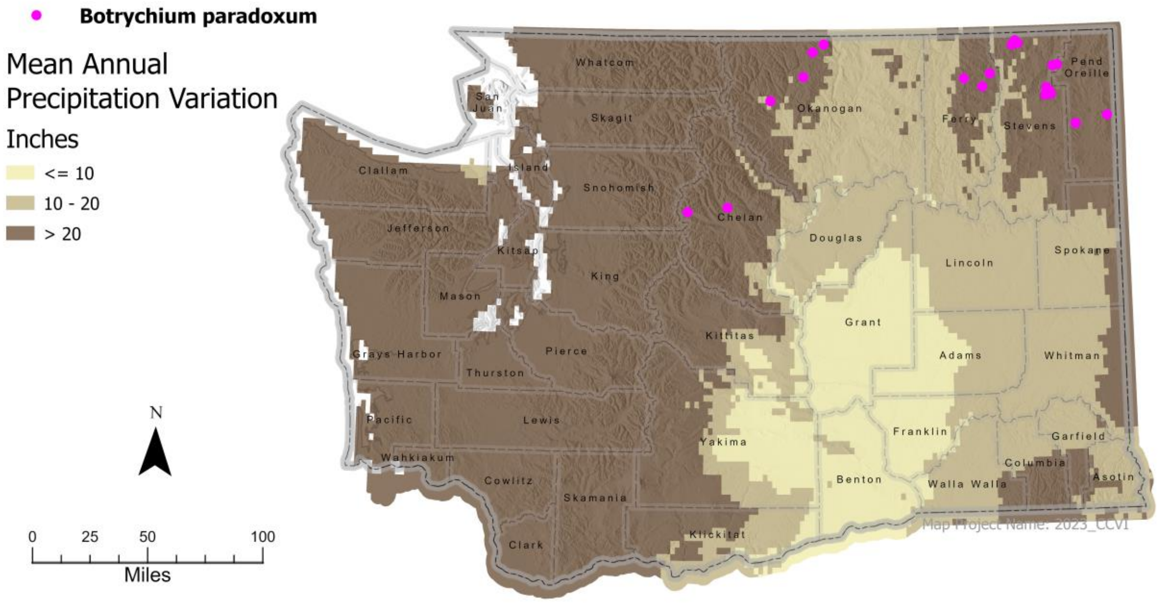


Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Botrychium paradoxum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
Botrychium paradoxum is not strongly associated with wet habitats in Washington, and does not appear to be particularly vulnerable to hydrological changes (Washington Natural Heritage Program 2023).

C2c. Dependence on a specific disturbance regime: Neutral.
Botrychium paradoxum is not known to be dependent on a specific disturbance regime.

C2d. Dependence on ice or snow-cover habitats: Neutral to Somewhat Increase.
Botrychium paradoxum occurs in areas that experience winter snowfall, and snow accumulation is substantial in the subalpine forests at the highest elevations where it occurs. Decreases in winter snowpack could reduce water availability, reducing the suitability of the habitat at higher elevations.

C3. Restricted to uncommon landscape/geological features: Neutral.
Botrychium paradoxum is not known to be associated with uncommon landscape / geological features.

C4a. Dependence on other species to generate required habitat: Neutral
Botrychium paradoxum is not known to be dependent on other species to maintain its habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Botrychium spp. are wind-pollinated and are not dependent on pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Spores of *Botrychium* spp. are dispersed by wind.

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: Increase.
The small stature of *Botrychium paradoxum* may make it vulnerable to competition from other plants. Previous research has shown that exotic plant invasions can indirectly harm *Botrychium australe* by facilitating the invasion of exotic worms (Sessions and Kelly 2002). Under future climate change, warmer temperatures could extend the growing season, making the high-elevation areas where *Botrychium paradoxum* occurs in Washington more susceptible to invasion by annual introduced species or native perennials adapted to more open and drier sites (Rocchio, F.J. and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Increase.
Botrychium spp. are believed to be dependent on mycorrhizal fungi to complete their lifecycle (Winther and Friedman 2007)

C5a. Measured genetic variation: Somewhat increase.
Genetic variation in *Botrychium* spp. has been reported as low to moderate (Soltis and Soltis 1986, Dauphin et al. 2020).

C5b. Genetic bottlenecks: Not applicable since C5a was included.

C5c. Reproductive System: Not applicable since C5a was included.

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Botrychium paradoxum* has not been collected enough in Washington to make an assessment of changes in seasonal phenology.

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 *Botrychium paradoxum* in Washington since it was first collected in the state in 1988.

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

Dauphin, B., J. R. Grant, and D. R. Farrar. 2020. Outcrossing Mating System of the Early-Divergent Moonwort Fern (Botrychium lunaria, Ophioglossaceae) Revealed in the European Alps. International Journal of Plant Sciences 181:926–936.

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

Rocchio, F.J., and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment.

Sessions, L., and D. Kelly. 2002. Predator-Mediated Apparent Competition between an Introduced Grass, Agrostis capillaris, and a Native Fern, Botrychium australe (Ophioglossaceae), in New Zealand. Oikos 96:102–109.

Soltis, D. E., and P. S. Soltis. 1986. Electrophoretic Evidence for Inbreeding in the Fern Botrychium Virginianum (ophioglossaceae). American Journal of Botany 73:588–592.

Washington Natural Heritage Program. 2023. Online Field Guide to the Rare Plants of Washington: https://fieldguide.mt.gov/wa.

Winther, J. L., and W. E. Friedman. 2007. Arbuscular mycorrhizal symbionts in Botrychium (Ophioglossaceae). American Journal of Botany 94:1248–1255.

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 3:48.

Climate Change Vulnerability Index Report

Botrychium pedunculosum (stalked moonwort)

Date: 22 May 2023

Assessor: Jesse Miller, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G3G4/S2

Index Result: Moderately Vulnerable Confidence: Very high

Climate Change Vulnerability Index Scores

Section A	**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	96
	<3.9° F (2.2°C) warmer	4
2. Hamon AET:PET moisture	< -0.119	30
	-0.097 to -0.119	59
	-0.074 to - 0.096	11
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Neutral
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat increase
2ai Change in historical thermal niche		Neutral to Somewhat increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral to 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		Increase

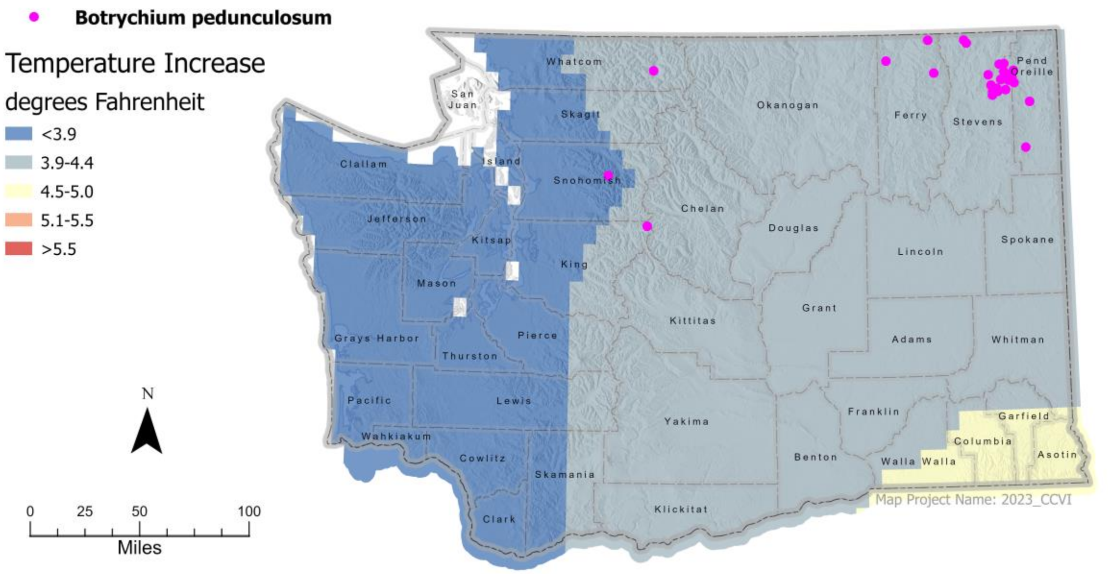


Figure 1. Exposure of *Botrychium hesperium* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

4g. Forms part of an interspecific interaction not covered above	Increase
5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Not Applicable
5c. Reproductive system	Not Applicable
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
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: 24 of the 25 known populations of *Botrychium pedunculosum* in Washington occur in an area with a projected temperature increase of 3.9-4.4˚ F (Figure 1). The other population occurs in an area with a projected temperature increase of < 3.9 ˚ F.

A2. Hamon AET:PET Moisture Metric: Eight of the 25 known occurrences of *Botrychium pedunculosum* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) of < -0.119 (Figure 2). 14 populations are found in areas with a projected decrease of -0.118 - -0.097, and the other three occurrences are in areas with a projected decrease of -0.096 - -0.074.

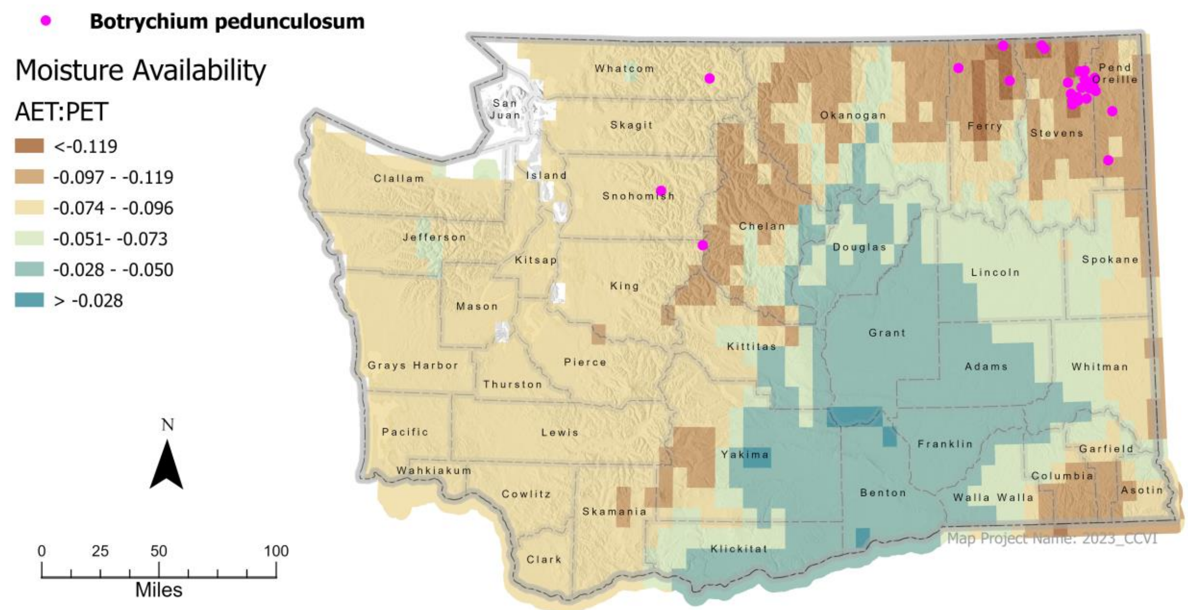


Figure 2. Exposure of *Botrychium hesperium* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Botrychium pedunculosum* occur from approximately 500-1325 m (1640-4340 ft) and are not at risk from sea level rise (Washington Natural Heritage Program 2023).

B2a. Natural barriers: Neutral.
In Washington this taxon grows in moist or dry meadows, springs, stream terraces, coniferous forests, and forest edges (Washington Natural Heritage Program 2023). It occurs in the Rocky Mountain Subalpine-Upper Montane Grassland, Rocky Mountain Alpine-Montane Wet

Meadow, and Rocky Mountain Subalpine-Montane Riparian Woodland ecosystems in Washington (Rocchio and Crawford 2015). There do not appear to be strong natural barriers to its dispersal. Populations are separated by approximately 1-106 miles (1-171 km).

B2b. Anthropogenic barriers: Neutral.
The Washington populations of *Botrychium pedunculosum* occurs in areas that are not heavily impacted by anthropgenic alterations to the landscape.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat increase.
Botrychium pedunculosum, like other ferns, has a complex life cycle involving alternation of two distinct growth forms: the familiar sporophyte phase and a much-reduced gametophyte phase. Sporophyte plants produce large numbers of tiny, seed-like spores that are capable of long-distance dispersal by wind. Spores germinate to form gametophyte plants which reproduce sexually by gametes (sessile eggs retained within the plant and motile sperm that require moist surfaces to travel very short distances for fertilization). Sporophyte plants are produced from fertilized eggs within their parent gametophyte plant, and thus are incapable of further dispersal. Overall, dispersal by spores is not limiting, but the survival of sporophyte plants is strongly tied to gametophytes reaching and persisting in suitable microhabitats. The dependence on proper conditions for gametophyte survival makes ferns more vulnerable to dispersal bottlenecks.

C2ai. Historical thermal niche: Neutral to Somewhat increase.
Figure 3 depicts the distribution of *Botrychium pedunculosum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). 21 of the 27 populations are in areas that have experienced average or greater than average (>57.1° F/43.0° C) temperature variation in the past 50 years, and are considered to be neutral in regard to vulnerability to climate change (Young et al. 2016). Six occurrences are in areas that experienced slightly lower than average (47.1 - 57° F/26.3 - 31.8° C) temperature variation in the past 50 years, and are considered to be at somewhat increased vulnerability.

C2aii. Physiological thermal niche: Neutral.
Botrychium pedunculosum does not appear to be at increased risk from climate change in terms of its physiological thermal niche.

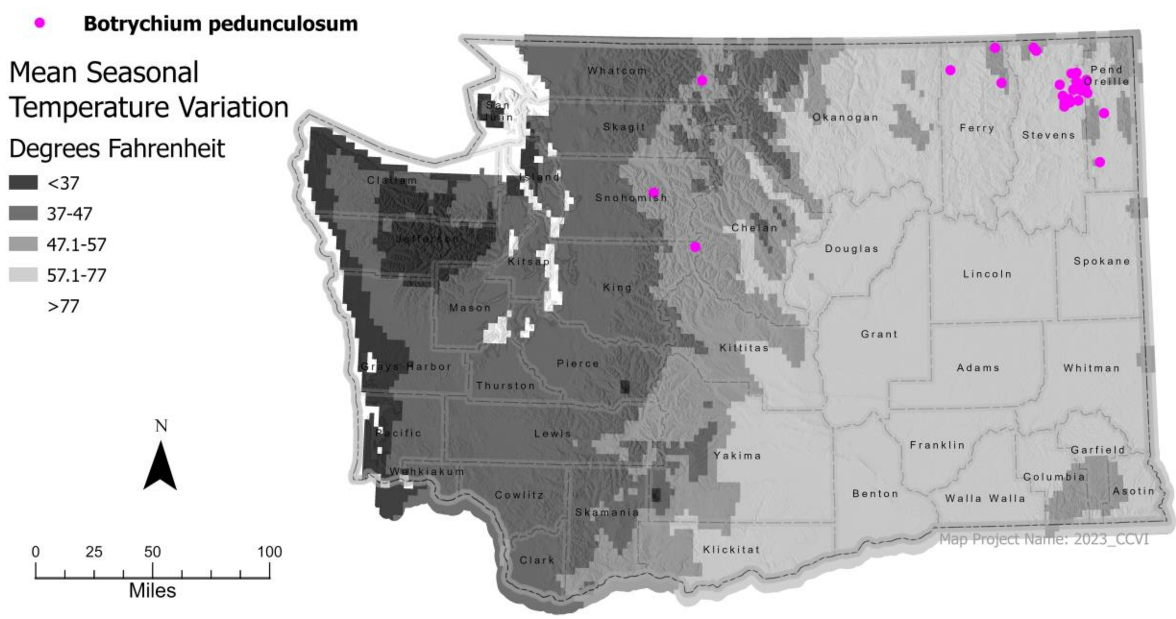


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Botrychium hesperium* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral to Somewhat increase.
26 of the 27 *Botrychium pedunculosum* occurrences in Washington are found in areas that have experienced average or above average variation in precipitation (> 20 inches / > 508mm; Figure 4). According to Young et al. (2016), these populations are neutral in terms of vulnerability from climate change. The other population is in an area that has experienced experienced slightly lower than average (11 - 20 inches/255 - 508 mm) precipitation variation in the past 50 years; it is considered at somewhat increased vulnerability to climate change.

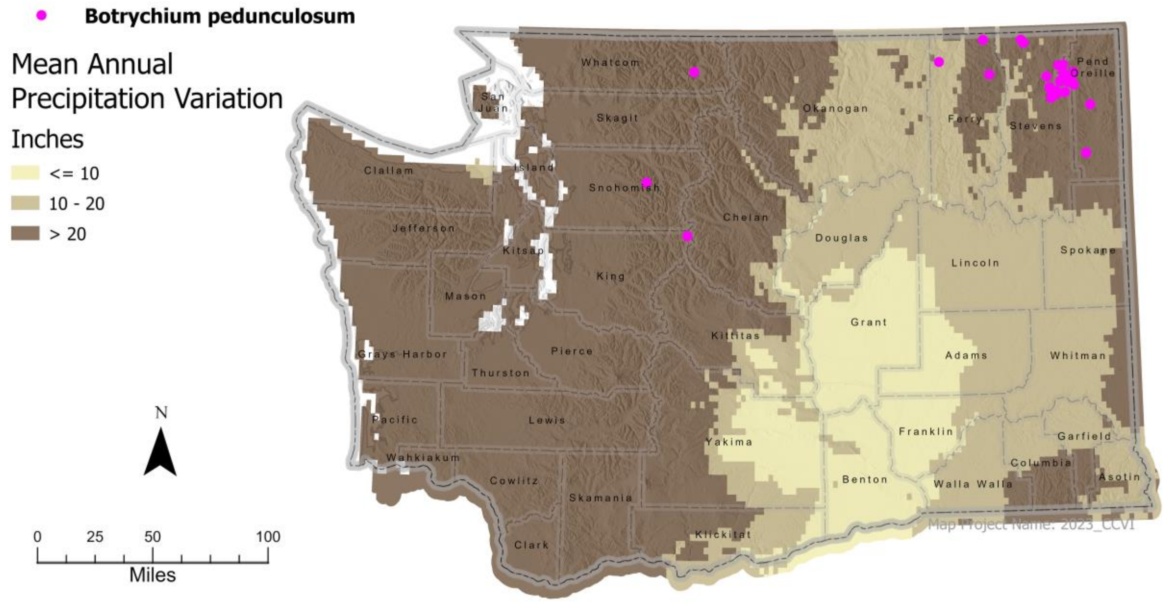


Figure 4. Historical hydrological niche (exposure to past variations in precipitation) of *Botrychium pedunculosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
Botrychium pedunculosum is not strongly associated with wet habitats in Washington, and does not appear to be particularly vulnerable to hydrological changes (Washington Natural Heritage Program 2023).

C2c. Dependence on a specific disturbance regime: Neutral.
Botrychium pedunculosum is not known to be dependent on a specific disturbance regime.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Botrychium pedunculosum occurs in areas that experience winter snowfall, but does not appear to be strongly reliant on snow or the moisture it produces, though it may remain dormant in drier years (Washington Natural Heritage Program 2023).

C3. Restricted to uncommon landscape/geological features: Neutral.
Botrychium pedunculosum is not known to be associated with uncommon landscape / geological features.

C4a. Dependence on other species to generate required habitat: Neutral
Botrychium pedunculosum is not known to be dependent on other species to maintain its habitat.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Botrychium spp. are wind-pollinated and are not dependent on pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Spores of *Botrychium* spp. are dispersed by wind.

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: Increase.
The small stature of *Botrychium pedunculosum* may make it vulnerable to competition from other plants. Previous research has shown that exotic plant invasions can indirectly harm *Botrychium australe* by facilitating the invasion of exotic worms (Sessions and Kelly 2002). Under future climate change, warmer temperatures could extend the growing season, making the high-elevation areas where *Botrychium pedunculosum* occurs in Washington more susceptible to invasion by annual introduced species or native perennials adapted to more open and drier sites (Rocchio, F.J. and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Increase.
Botrychium spp. are believed to be dependent on mycorrhizal fungi to complete their lifecycle (Winther and Friedman 2007)

C5a. Measured genetic variation: Somewhat increase.
Genetic variation in *Botrychium* spp. has been reported as low to moderate (Soltis and Soltis 1986, Dauphin et al. 2020).

C5b. Genetic bottlenecks: Not applicable since C5a was included.

C5c. Reproductive System: Not applicable since C5a was included.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Botrychium pedunculosum* has not undergon major phenological shifts since it was first collected in 1993.

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 *Botrychium pedunculosum* in Washington since it was first collected in the state in 1998.

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

D3. Overlap of modeled future (2050) range with current range: Unknown

D4. Occurrence of protected areas in modeled future (2050) distribution: Unknown

References

Dauphin, B., J. R. Grant, and D. R. Farrar. 2020. Outcrossing Mating System of the Early-Divergent Moonwort Fern (Botrychium lunaria, Ophioglossaceae) Revealed in the European Alps. International Journal of Plant Sciences 181:926–936.

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

Rocchio, F.J., and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment.

Sessions, L., and D. Kelly. 2002. Predator-Mediated Apparent Competition between an Introduced Grass, Agrostis capillaris, and a Native Fern, Botrychium australe (Ophioglossaceae), in New Zealand. Oikos 96:102–109.

Soltis, D. E., and P. S. Soltis. 1986. Electrophoretic Evidence for Inbreeding in the Fern Botrychium Virginianum (ophioglossaceae). American Journal of Botany 73:588–592.

Washington Natural Heritage Program. 2023. Online Field Guide to the Rare Plants of Washington: https://fieldguide.mt.gov/wa.

Winther, J. L., and W. E. Friedman. 2007. Arbuscular mycorrhizal symbionts in Botrychium (Ophioglossaceae). American Journal of Botany 94:1248–1255.

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 3:48.

Climate Change Vulnerability Index Report

Calochortus macrocarpus var. *maculosus* (sagebrush lily)

Date: 18 April 2023

Assessor: Jesse Miller, WA Natural Heritage Program

Geographic Area: Washington | Heritage Rank: G5T2/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	97
	3.9-4.4° F (2.2-2.4°C) warmer	3
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	42
	-0.074 to - 0.096	52
	-0.051 to - 0.073	6
	-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		Increase
2ai Change in historical thermal niche		Neutral to Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Neutral to Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral
4a. Dependence on others species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
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	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: 30 of the 31 occurrences of *Calochortus macrocarpus* var. *maculosus* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F; the other one occurs in an area with a projected temperature increase of 4.5-5.0 ˚ F (Figure 1).

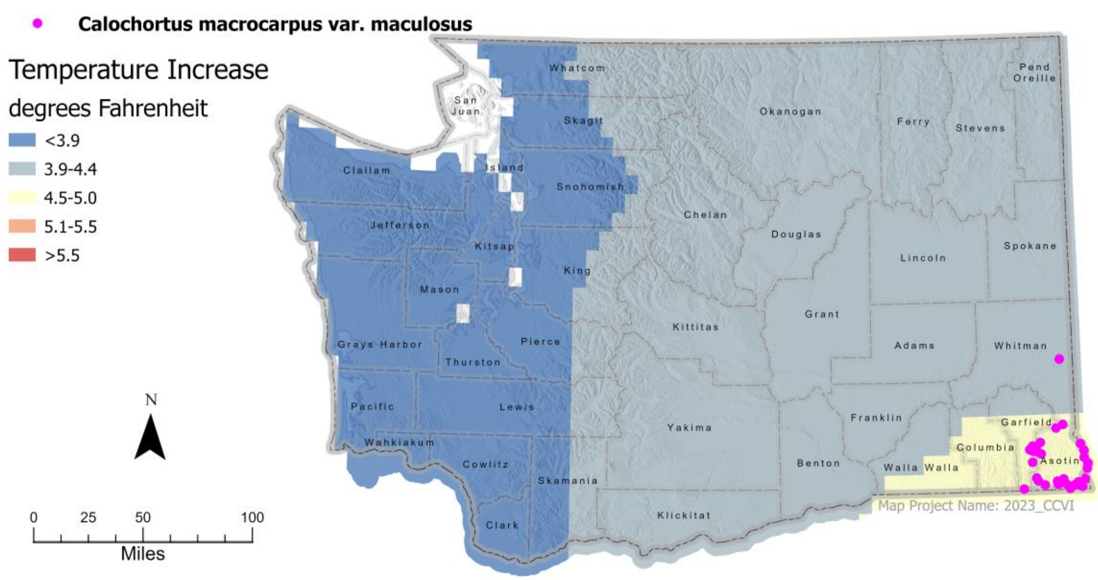


Figure 1. Exposure of *Calochortus macrocarpus* var. *maculosus* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the 31 occurrences (6%) of *Calochortus macrocarpus* var. *maculosus* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 to -

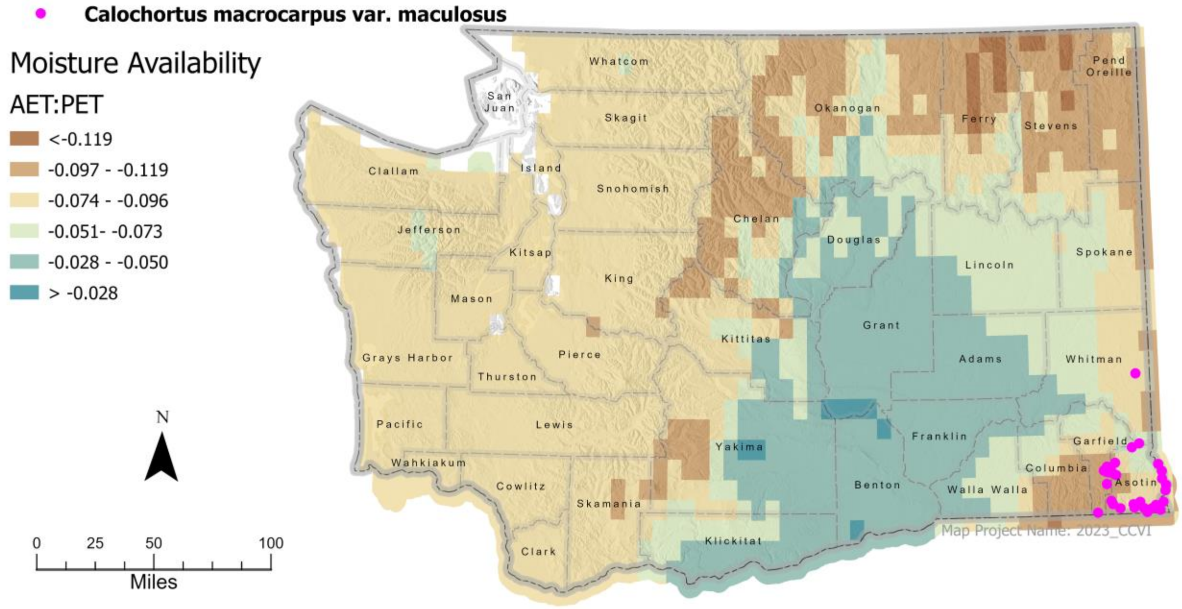


Figure 2. Exposure of *Calochortus macrocarpus* var. *maculosus* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

0.074; 16 occurences (52%) are found in areas with a projected decrease of decrease of -0.074 to -0.096; and 13 occurences (42%) are found in areas with a projected decrease of -0.097 to -0.119 (Figure 2).

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Calochortus macrocarpus* var. *maculosus* are found at 1000-4480 ft (300-1370 m) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
Calochortus macrocarpus var. *maculosus* occurs primarily on undisturbed, dry habitats in rocky hillsides, outcrops, cliffs, and grassland (Camp and Gamon 2011, Washington Natural Heritage Program 2023). This habitat spans three ecological systems: Columbia Basin Foothill and Canyon Dry Grassland, Northern Rocky Mountain Lower Montane, Foothill, and Valley Grassland (Rocchio and Crawford 2015). Populations are separated by approximately 1-30 miles (1-48 km). Unoccupied but apparently suitable habitat likely occurs between populations, so

natural barriers may not be a limiting factor for the distribution of *Calochortus macrocarpus* var. *maculosus*.

B2b. Anthropogenic barriers: Neutral.
There is some fragmentation of habitat in the foothills of the Blue Mountains from roads and conversion of native grassland to dryland agriculture.

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

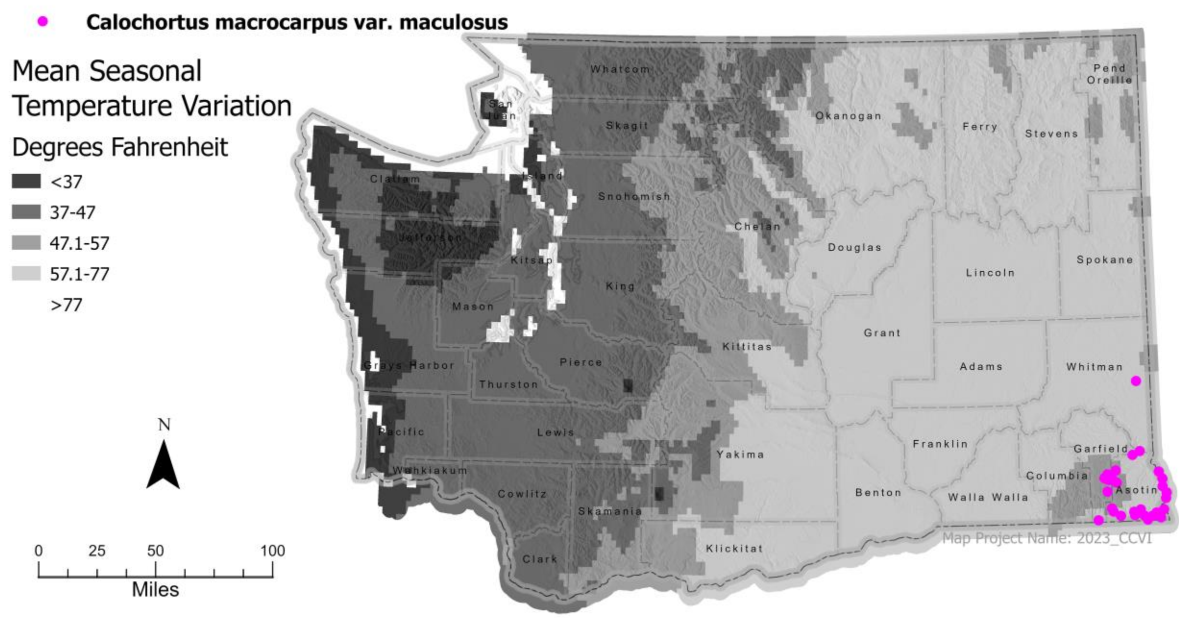
Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase
Calochortus spp. produce large seeds that do not have specialized dispersal adaptations, and generally disperse locally (Patterson and Givnish 2004). Unlike *Calochortus macrocarpus* var. *macrocarpus, Calochortus macrocarpus* var. *maculosus* fruits are not winged

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Calochortus macrocarpus* var. *maculosus* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). 11 of the 31 known occurrences in the state (35%) 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 20 other occurrences (25%) are from areas that have experienced average or above-average variation (> 57.1-77˚F/ 43˚C) in temperature over the same period, which are considered neutral to to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Neutral.
Calochortus macrocarpus var. *maculosus* occurs in dry, rocky habits that are relatively warm during the flowering season, and is therefore not at particular risk of losing a physiological thermal niche associated with cold temperatures.

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

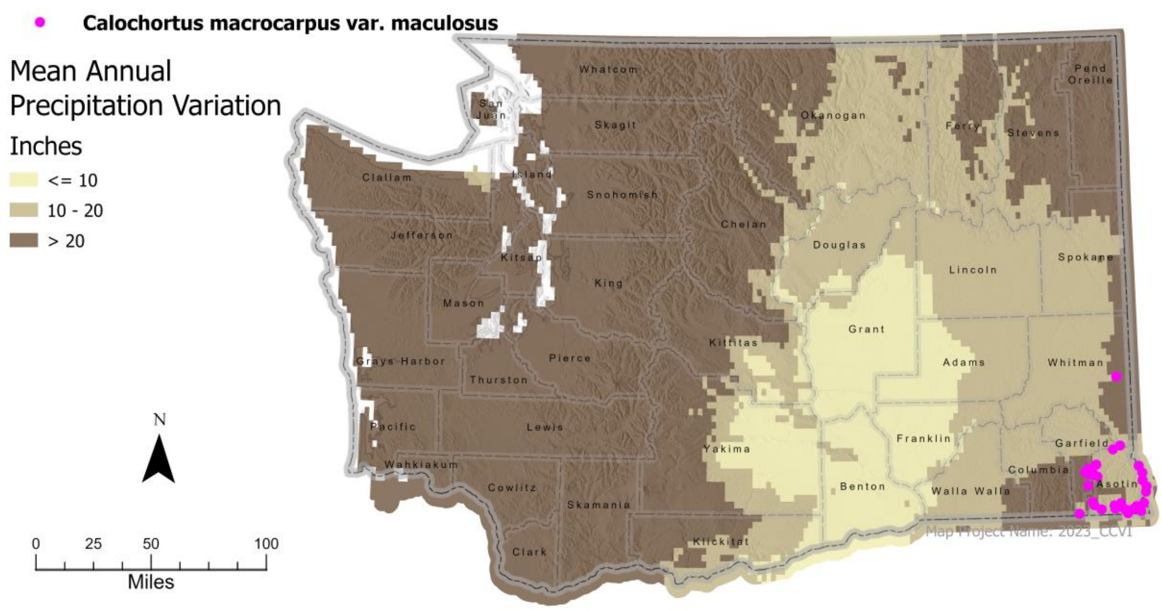


C2bi. Historical hydrological niche: Somewhat increase.

18 of the 31 known populations of *Calochortus macrocarpus* var. *maculosus* in Washington are found in areas that have experienced slightly below average precipitation variation in the past 50 years (11-20 inches/ 255-508 mm), and are considered to be at somewhat increased vulnerability to climate change. The other 13 populations are found in areas that have experienced average or above average variation in precipitation (> 20 inches / > 508mm; Figure 4), which are considered neutral to climate change (Young et al. 2016).

C2bii. Physiological hydrological niche: Neutral.
This species is not dependent on a strongly seasonal hydrologic regime or specific wetland habitats. As a long-lived perennial geophyte, it could be resilient to some degree of seasonal variation in precipitation.

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



C2c. Dependence on a specific disturbance regime: Neutral.
Calochortus macrocarpus var. *maculosus* occurs in open, rocky habitats that do not appear to be reliant on a specific disturbance regime.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Calochortus macrocarpus var. *maculosus* is not believed to be strongly associated with ice or snow-covered habitats, although winter snow may occur within its range.

C3. Restricted to uncommon landscape/geological features: Neutral.
Calochortus macrocarpus var. *maculosus* is associated with basalt, which is a common parent material (Camp and Gamon 2011).

C4a. Dependence on other species to generate required habitat: Neutral
The dry, rocky habitat occupied by *Calochortus macrocarpus* var. *maculosus* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Calochortus spp. are believed to be generalists that attract a diverse assemblage of pollinators (Dilley et al. 2000).

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits of *Calochortus* spp. are believed to be passive dispersers (Patterson and Givnish 2004), and 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.
Invasive species are believed to be a threat to some populations of *Calochortus macrocarpus* var. *maculosus*, and these species could increase as a result of altered fire regimes associated with climate change that have been predicted for Columbia basin foothill and canyon dry grassland communities (Rocchio, F.J. and Ramm-Granberg 2017).

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

C5a. Measured genetic variation: Unknown.
Not known.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Unkown.
Not known.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Calochortus macrocarpus* var. *maculosus* has not changed its typical blooming time since the late 1800s, although there are not enough collections to make a rigorous assessment.

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 *Calochortus macrocarpus* var. *maculosus* in Washington since it was first collected in the state in the late 1800s.

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, editors. 2011. Field Guide to the Rare Plants of Washington. University of Washington Press, Seattle.

Dilley, J. D., P. Wilson, and M. R. Mesler. 2000. The radiation of Calochortus: generalist flowers moving through a mosaic of potential pollinators. Oikos 89:209–222.

Ownbey, M. 1940. A Monograph of the Genus Calochortus. Annals of the Missouri Botanical Garden 27:371–560.

Patterson, T. B., and T. J. Givnish. 2004. Geographic Cohesion, Chromosomal Evolution, Parallel Adaptive Radiations, and Consequent Floral Adaptations in Calochortus (Calochortaceae): Evidence from a cpDNA Phylogeny. The New Phytologist 161:253–264.

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

Rocchio, F.J., and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment.

Washington Natural Heritage Program. 2023. Calochortus macrocarpus var. maculosus. Page Online Field Guide to the Rare Plants of Washington (http://fieldguide.mt.gov/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 3:48.

Climate Change Vulnerability Index Report

Carex gynocrates (yellow bog sedge)

Date: 10 May 2023 Synonym: *Carex alascana, Carex dioica* ssp. *gynocrates, Carex dioica* var. *gynocrates*

Assessor: Tynan Ramm-Granberg, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S2

Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	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		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral to Somewhat Increase
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		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Somewhat Increase
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 7 of the known occurrences of *Carex gynocrates* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

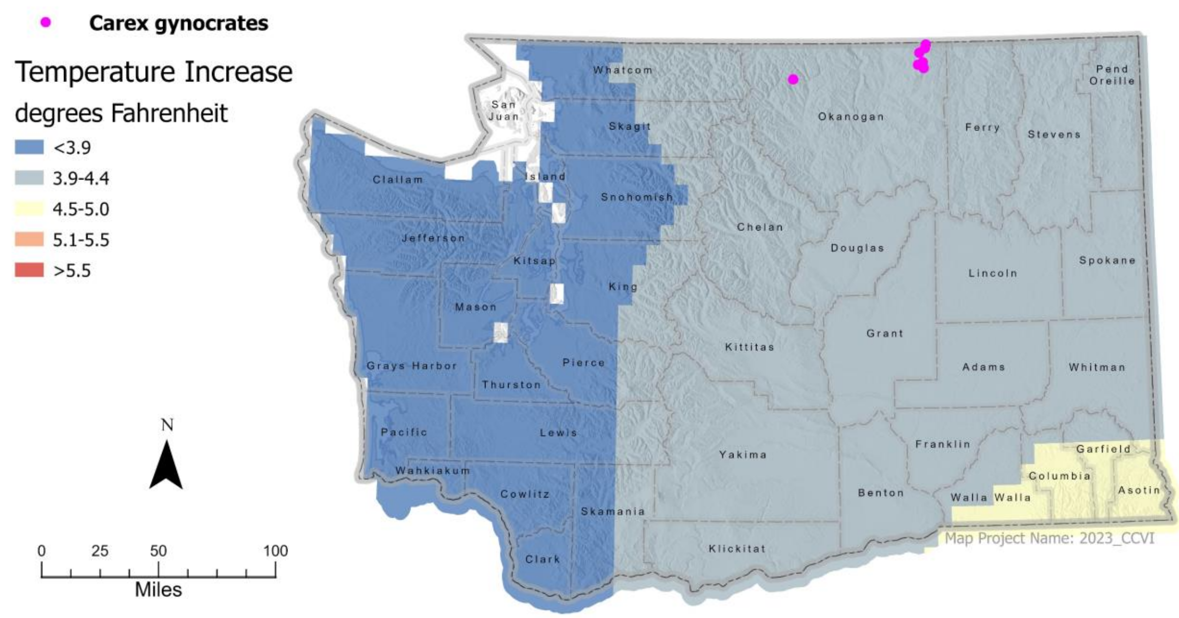


Figure 1. Exposure of *Carex gynocrates* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 7 of the known occurrences of *Carex gynocrates* in Washington are found in areas with a projected change in available moisture (as measured by the ratio of actual to potential evapotranspiration) of -0.097 to -0.119 (the second most 'severe' bin) (Figure 2).

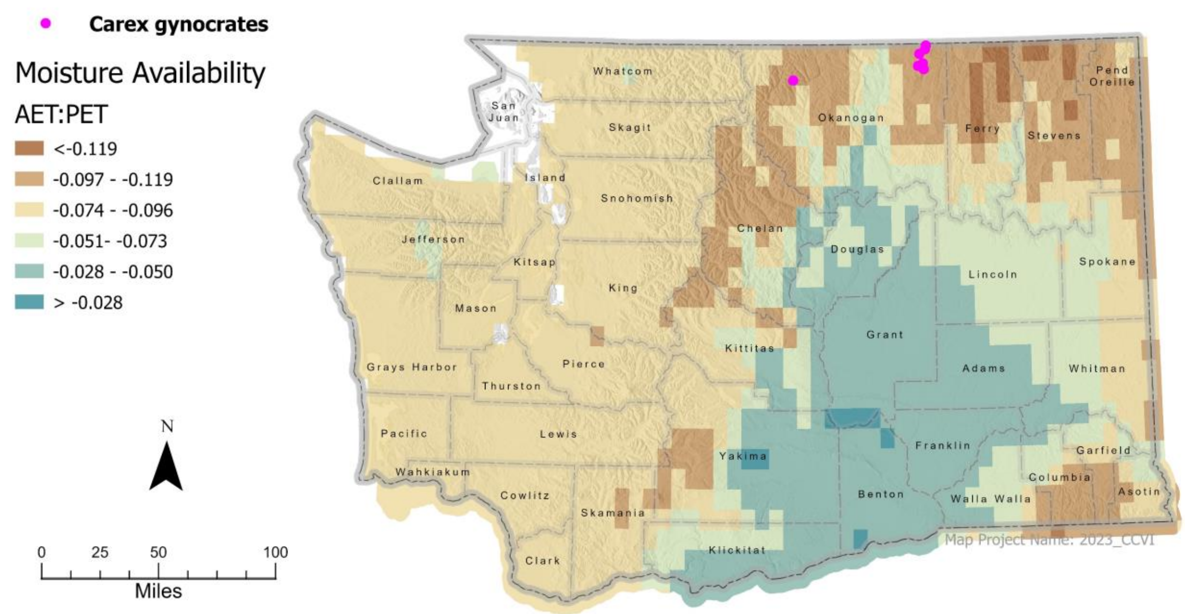


Figure 2. Exposure of *Carex gynocrates* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex gynocrates* are found well above sea level, at elevations of 2650-5800 feet (800-1770 m). Subarctic to Arctic populations to the north occur in coastal bogs, but only the most extreme sea level rise scenarios (>30 feet increase) would impact those sites.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Carex gynocrates* is a wetland obligate of peatlands with a strong preference for calcareous substrates (Camp & Gamon, 2011; Wilson et al., 2014; WNHP, 2021). These habitats are part of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio & Crawford, 2015). Washington populations occur in two distinct clusters. Each occupied peatland complex is isolated by 3-55 miles (5-89 km) of unoccupied and/or unsuitable habitat. Most of the matrix vegetation between occurrences is unsuitable and presents a barrier to dispersal. The Pacific Northwest is at the far southern edge of the range of this species (Wilson et al., 2014).

B2b. Anthropogenic barriers: Neutral.
The range of *Carex gynocrates* in Washington is primarily influenced by its dependence on scattered areas of specialized habitat that are naturally isolated. Most populations are found in mountainous areas with relatively few roads or other intensive anthropogenic land use. Anthropogenic factors are less likely to constrain dispersal than natural ones.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Carex gynocrates spreads by thin rhizomes and produces 1-seeded dry fruits (achenes) enclosed in bladder-like sacs (perigynia) that are light weight, buoyant, and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Dispersal may occasionally be facilitated by achene adhesion to mud on birds or mammals (Leck & Schütz, 2005). Germination rates were reported to be as low as 15%, in one study (Sobze et al., 2019).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Carex gynocrates* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Six of the known occurrences in the state (86%) are found in areas that have experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) during the past 50 years, indicating a neutral impact on climate change vulnerability (Young et al., 2016). One occurrence found at a relatively high elevation (~5800 ft / 1800 m) in the far eastern North Cascades has experienced only small temperature variation (37-47˚F/20.8-26.3˚C). A "Neutral" vulnerability rating characterizes the historical thermal niche of the majority of occurrences.

C2aii. Physiological thermal niche: Somewhat Increase.
The peatland habitats of *Carex gynocrates* are often associated with cold air drainage in montane to subalpine valleys.

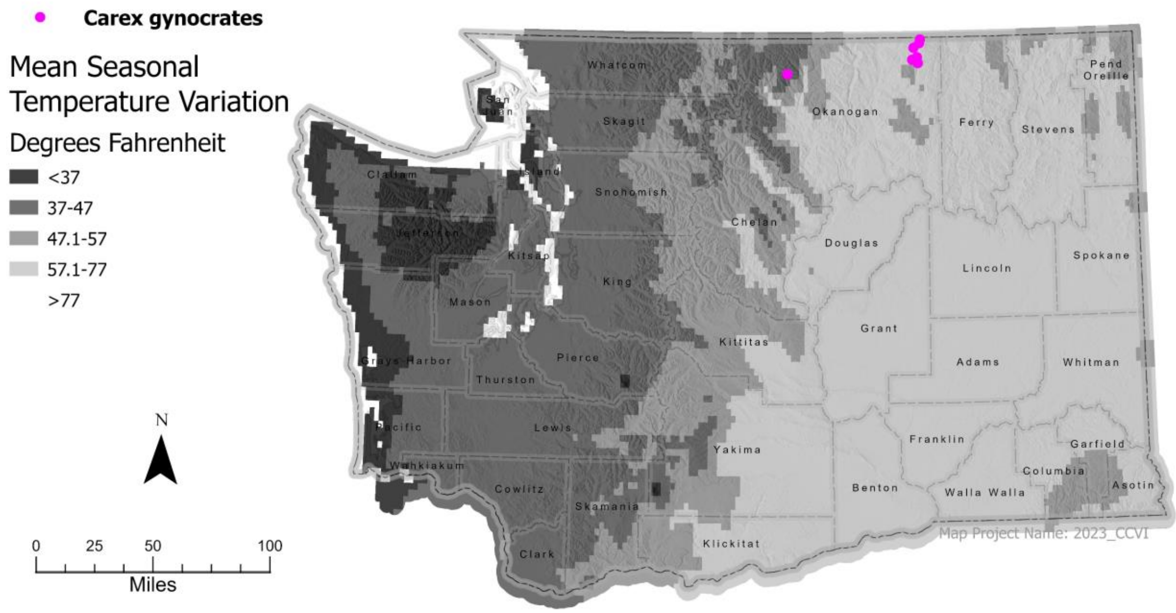


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex gynocrates* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral to Somewhat Increase.
Four of the seven known populations of *Carex gynocrates* in Washington (57%) are found in areas that have experienced slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm), indicating somewhat increased vulnerability to climate change (Figure 4). The remaining three populations (43%) have experienced average or greater than average (>20 inches/508 mm) precipitation variation (neutral impact on climate change vulnerability).

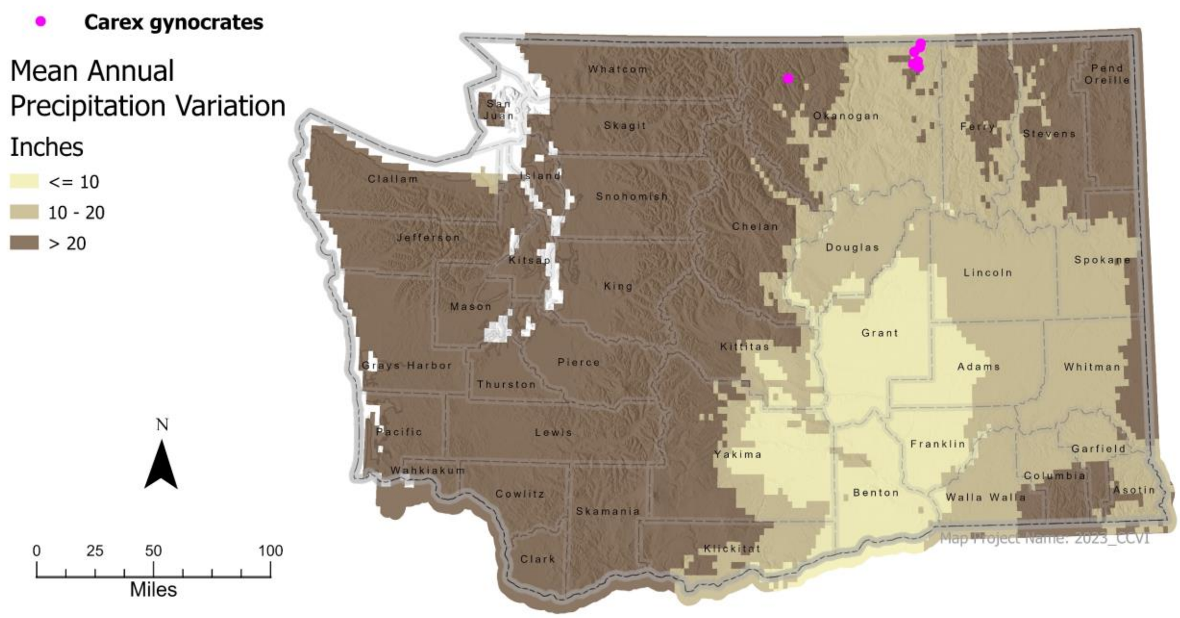


Figure 3. Historical hydrological niche (exposure to past variations in precipitation) of *Carex gynocrates* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Populations of *Carex gynocrates* in Washington are restricted to fens (groundwater-supported peatlands). While groundwater-supported wetlands are somewhat less sensitive to climate change than those that primarily rely on precipitation, they may still be adversely affected by decreased snowpack and lowered water tables under projected climate change scenarios (Winter, 2000; Pitz, 2016; Halabisky et al., 2017). They may also experience changes in water chemistry (Rocchio & Ramm-Granberg, 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Carex gynocrates is not known to be tied to specific disturbance regimes. Peatland habitats that support this species generally remain wet enough to survive moderate fires, but severe burns (potentially more frequent under climate change scenarios) may consume the moss and peat in which it roots (Wilson et al., 2014).

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
In Washington, *Carex gynocrates* is found in areas of moderate snowfall in the foothills of the Okanogan mountains and at higher elevations of the eastern North Cascades. It may be adversely impacted by reduced snowpack or a change in snowmelt timing through cascading impacts on groundwater discharge.

C3. Restricted to uncommon landscape/geological features: Increase.
Carex gynocrates is highly restricted to calcareous peatlands in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
Carex gynocrates habitat is maintained primarily by abiotic conditions.

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.
Although it may be facilitated by animal vectors, dispersal is not dependent on other species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Probably not a limiting factor. Livestock grazing is a potential threat (Camp & Gamon, (eds.), 2011; WNHP, 2021), primarily due to trampling. The palatability of this species and the impacts from native grazers are poorly known.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Reductions in groundwater inputs to the species habitat could allow non-fen species to establish and outcompete this species (Rocchio & 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.
All *Cyperaceae* have cytogenetic features that favor karyotype diversity and differentiation via agmatoploidy, symploidy, and polyploidy (Luceño & Guerra, 1996; Da Silva et al., 2005, 2008; Tena-Flores et al., 2013).

C5b. Genetic bottlenecks: Somewhat Increase.
Because of its rhizomatous habit, the total population of *Carex gynocrates* individuals in Washington is uncertain. The total fruiting stem count of the most recent surveys of known populations is ~ 3000 stems (https://www.dnr.wa.gov/NHPdataexplorer). There are fewer than 10 total occurrences in Washington, indicating somewhat increased vulnerability to climate change. This factor is not included in the overall climate vulnerability score because C5a was assessed.

C5c. Reproductive System: Neutral.
Carex gynocrates is likely either an obligate out-crosser or has a mixed mating system. There are no known major disruptions to gene flow. This factor is not included in the overall climate vulnerability score because C5a was assessed.

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.
All 7 known occurrences in Washington are extant. Trend data are available for only one occurrence, which appears to be stable.

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, WA.

Halabisky M., S. Lee, S.A. Hall, and M. Rule. 2017. Can we conserve wetlands under a changing climate? Mapping wetland hydrology across and ecoregion and developing climate adaptation recommendations. Report prepared for Great Northern Landscape Conservation Cooperative.

Leck M.A. and W. Schütz. 2005. Regeneration of Cyperaceae, with particular reference to seed ecology and seed banks. *Perspectives in Plant Ecology, Evolution and Systematics* 7(2):95–133.

Pitz C.F. 2016. Predicted impacts of Climate Change on groundwater resources of Washington State. Washington State Department of Ecology, Olympia, WA. Publication No. 16-03-006.

Rocchio F.J. and R.C. Crawford. 2015. Ecological Systems of Washington State: a guide to identification. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. NHR-2015-04. Online: https://www.dnr.wa.gov/publications/amp_nh_ecosystems_guide.pdf

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.

Sobze J.M., Ç.K. Yücel, A. Smreciu, and K. Gould. 2019. Effect of cold stratification on germination of 9 boreal sedges. *Native Plants Journal* 20(1):5–13.

Washington Natural Heritage Program (WNHP). 2021. Carex gynocrates. In: Online Field Guide to the Rare Plants of Washington. https://fieldguide.mt.gov/wa/?species=carex gynocrates. Accessed: May 10, 2023.

Wilson B.L., R. 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.

Winter T.C. 2000. The vulnerability of wetlands to climate change: a hydrologic landscape perspective. *Journal of the American Water Resources Association* 36(2):305–311.

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

Climate Change Vulnerability Index Report

Carex stylosa (long-styled sedge)

Date: 11 May 2023 Synonym: *Carex beringiana, Carex nigritella, Carex stylosa var. nigritella*

Assessor: Tynan Ramm-Granberg, 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	9
	<3.9° F (2.2°C) warmer	91
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	9
	-0.074 to - 0.096	82
	-0.051 to - 0.073	9
	-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 to 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 to Greatly Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Somewhat Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase

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

Section A: Exposure to Local Climate Change

A1. Temperature: 10 of the 11 known occurrences of *Carex stylosa* in Washington (91%) occur in areas with a projected temperature increase of < 3.9-4.4˚ F (Figure 1). One occurrence (9%; along the Cascade Crest) has a projected increase of 3.9-4.4˚ F.

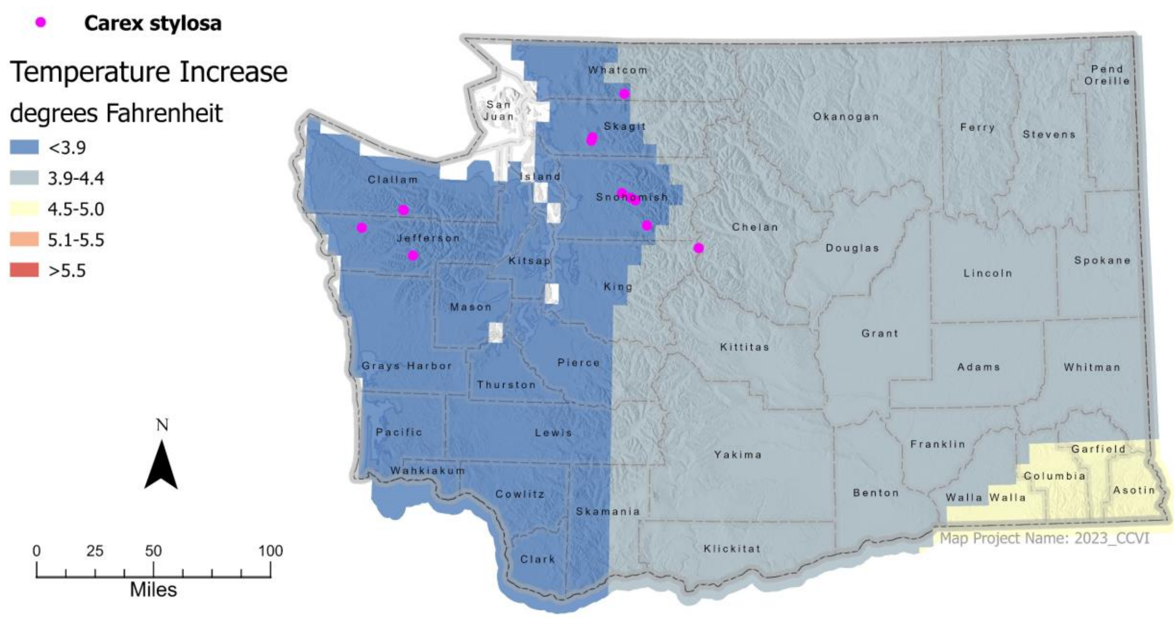


Figure 1. Exposure of *Carex stylosa* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: 9 of the 11 known occurrences of *Carex stylosa* in Washington (82%) are found in areas with a projected change in available moisture (as measured by the ratio of actual to potential evapotranspiration) of -0.074 to -0.096 (Figure 2). One population (9%; along the Cascade Crest) has a projected change of -0.097 to -0.119 (the second most 'severe' bin) and the last one (9%) has a projected change of -0.051 to -0.073.

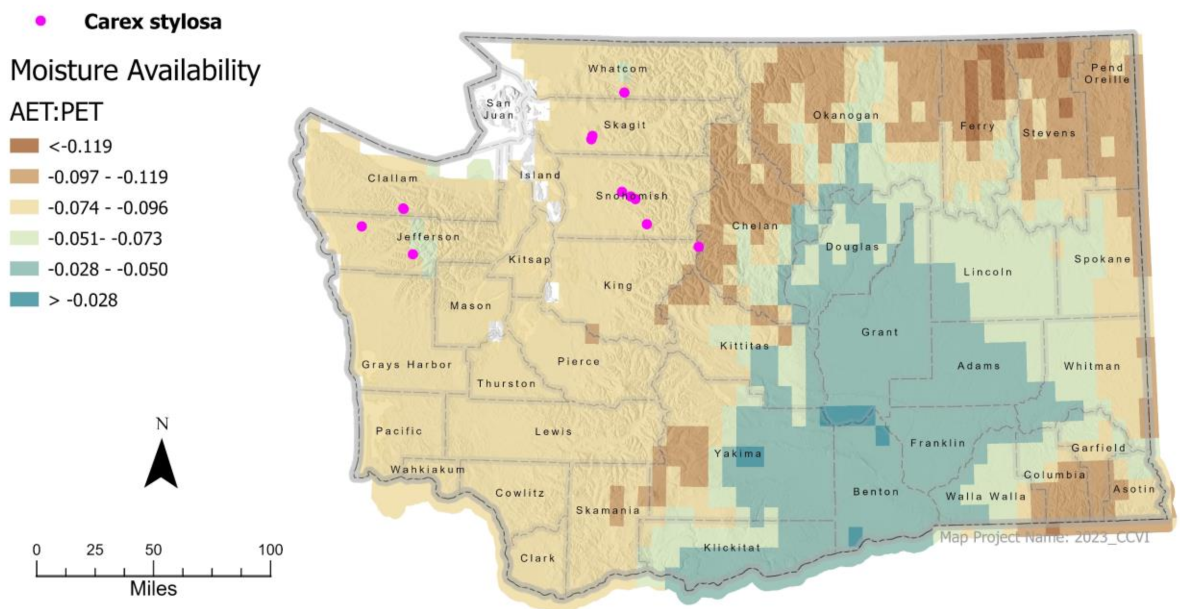


Figure 2. Exposure of *Carex stylosa* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Carex stylosa* are found well above sea level, at elevations of 450-5200 feet (135-1585 m). Some populations in British Columbia and northward occur down to sea level and may be impacted by sea level rise.

B2a. Natural barriers: Somewhat Increase to Increase
In Washington, *Carex stylosa* is a wetland obligate found in montane fens and the lagg (outer margin) of one documented low-elevation coastal bog (Camp & Gamon, 2011; Wilson et al., 2014; Rocchio et al., 2021; WNHP, 2021). These habitats are part of the North Pacific Bog & Fen ecological system (Rocchio & Crawford, 2015). Just to the north, in British Columbia, *Carex stylosa* also occurs in marshes, wet meadows, streambanks, and even on gravelly soils (Wilson et al., 2014). Despite this apparent habitat flexibility, Wilson et al. (2014) note that *Carex*

stylosa appears to be retreating northward with the changing climate, leaving behind isolated, small, genetically distinct populations that may be on paths towards speciation or extirpation. Known populations are isolated by 1.5-35 miles (2.5-56 km) of unoccupied and/or unsuitable habitat. Most of the matrix vegetation between occurrences is unsuitable and presents a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Carex stylosa* in Washington is primarily influenced by its dependence on scattered areas of specialized habitat that are naturally isolated. Most populations are found in mountainous areas with relatively few roads or other intensive anthropogenic land use. Anthropogenic factors are less likely to constrain dispersal than natural ones.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Carex stylosa is a loosely cespitose sedge producing 1-seeded dry fruits (achenes) enclosed in bladder-like sacs (perigynia) that are light weight, buoyant, and passively dispersed by gravity, high winds, or running water, mostly within a short distance of the parent plant (<1000 m). Dispersal may occasionally be facilitated by achene adhesion to mud on birds or mammals (Leck & Schütz, 2005).

C2ai. Historical thermal niche: Increase to Greatly Increase.
Figure 3 depicts the distribution of *Carex stylosa* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Eight of the known occurrences in the state (66.7%) are found in areas that have experienced small temperature variation (37-47˚F/20.8-26.3˚C) during the past 50 years, indicating an increased impact on climate change vulnerability (Young et al., 2016). Two additional occurrences found in the Olympic Mountains have experienced only very small temperature variation (< 37° F/20.8˚C; "greatly increased" vulnerability). The one occurrence along the Cascade Crest has had slightly below average temperature variation (47-57˚F/26.3-31.8˚C) ("somewhat increased" vulnerability).

C2aii. Physiological thermal niche: Somewhat Increase.
The peatland habitats of Washington populations of *Carex stylosa* are usually associated with cold air drainage and/or north-facing slopes in montane to subalpine valleys.

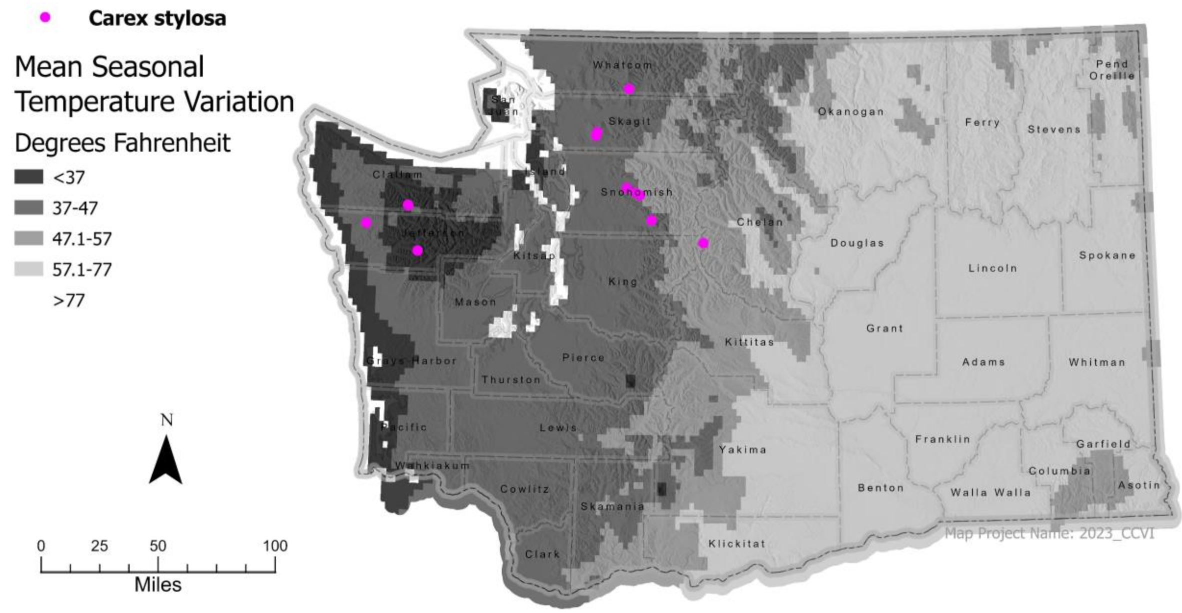


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Carex stylosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All 11 of the known populations of *Carex stylosa* in Washington (including historical records) are found in areas that have experienced average or greater than average (>20 inches/508 mm) precipitation variation (neutral impact on climate change vulnerability) (Figure 4).

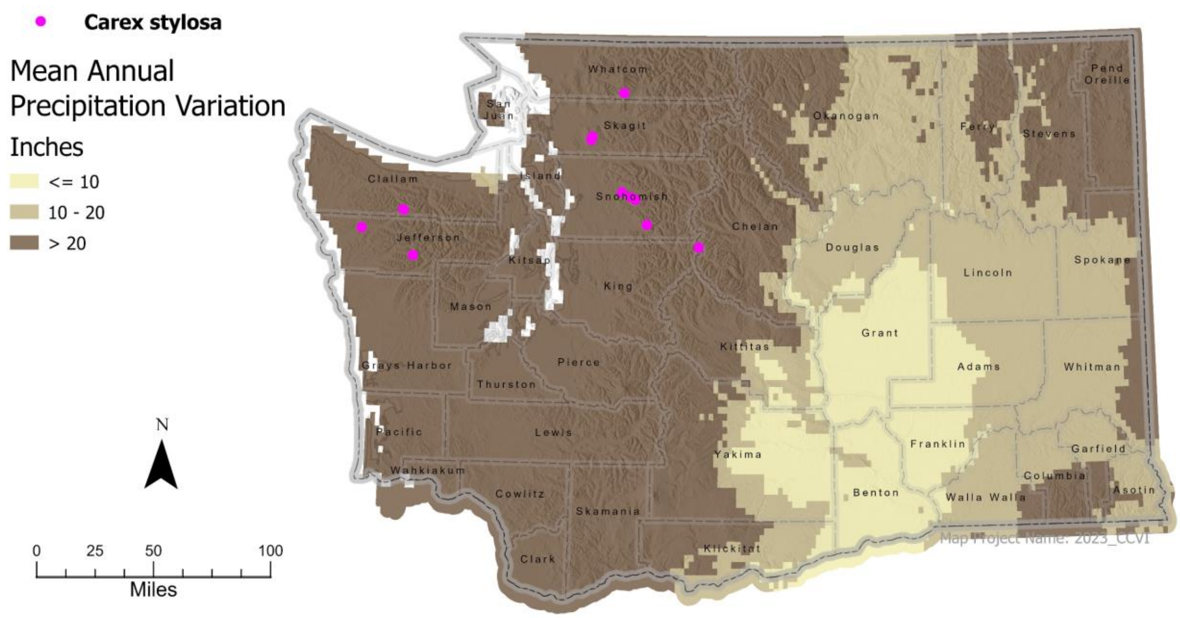


Figure 3. Historical hydrological niche (exposure to past variations in precipitation) of *Carex stylosa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Populations of *Carex stylosa* in Washington are restricted to fens (groundwater-supported peatlands) and a lagg (minerotrophic area surrounding a bog). While groundwater-supported wetlands are somewhat less sensitive to climate change than those that primarily rely on precipitation, they may still be adversely affected by decreased snowpack and lowered water tables under projected climate change scenarios (Winter, 2000; Pitz, 2016; Halabisky et al., 2017). Fens associated with groundwater discharge from large or deep aquifers may be more resilient to climate changes, at least in the short-term, due to the long time frame necessary for decreased recharge to affect discharge (Pitz, 2016). Fens supported by small or shallow aquifers will be more susceptible to changes in precipitation. This is especially true for fens in the montane/subalpine zones (most *Carex stylosa* occurrences) where snowpack is likely to decrease. Snowmelt is more effective at recharge than rainfall, so shallower snowpacks coupled with earlier snowmelt will likely result in decreased recharge for small and shallow aquifers, with a significant impact (i.e., drying effect) on the hydrology of montane fens (Pitz, 2016). If the fen water tables drop beneath 20 cm below the surface for a significant portion of the growing season, a negative shift in the carbon balance could occur, resulting in cessation of peat accumulation and potential loss of the peat body (Silvola et al., 1996; Chimner & Cooper, 2003). A long-term or permanent drop in the water table would eventually convert the fen to a wet meadow.(Rocchio & Ramm-Granberg, 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Carex stylosa is not known to be tied to specific disturbance regimes.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
In Washington, most *Carex stylosa* populations are found in areas of moderate to high snowfall in the Olympic Mountains and on the west slope of the Cascades. It may be adversely impacted by reduced snowpack or a change in snowmelt timing, particularly through cascading impacts on groundwater discharge.

C3. Restricted to uncommon landscape/geological features: Neutral.
In Washington, *Carex stylosa* appears to be restricted to areas impacted by alpine or continental glaciation (widespread in the Cascade and Olympic ranges) (Washington Geological Survey, 2023). However, the primary drivers may be hydrologic or biotic.

C4a. Dependence on other species to generate required habitat: Neutral
Beavers (*Castor canadensis*) may influence the water levels of some peatland systems in which *Carex stylosa* occurs, but habitat is maintained primarily by abiotic conditions.

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.
Although it may be facilitated by animal vectors, dispersal is not dependent on other species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Probably not a limiting factor. The palatability of this species and the impacts from native grazers are poorly known, as are the impacts from potential pathogens.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Populations may be vulnerable to shifts in vegetation from fens and towards marshes, wet meadows, or upland habitats because of potential changes in the amount of available water from precipitation and snowpack (Rocchio & 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 to Increase.
All *Cyperaceae* have cytogenetic features that favor karyotype diversity and differentiation via agmatoploidy, symploidy, and polyploidy (Luceño & Guerra, 1996; Da Silva et al., 2005, 2008; Tena-Flores et al., 2013). As noted above, *Carex stylosa* populations in Washington appear to be increasingly genetically distinct from boreal populations (Wilson et al., 2014). These subpopulations may be able to adapt to local conditions on their way to speciation, but potential new taxa may also be snuffed out as climate change progresses.

C5b. Genetic bottlenecks: Neutral.

There is no evidence that the total population of *Carex stylosa* in Washington was reduced to ≤ 1000 mature individuals and/or that occupied area was reduced by > 30% at any point in the past 500 years. This factor is not included in the overall climate vulnerability score because C5a was assessed.

C5c. Reproductive System: Somewhat Increase.
Carex stylosa is likely either an obligate out-crosser or has a mixed mating system, but populations in Washington are increasingly isolated and disjunct. This factor is not included in the overall climate vulnerability score because C5a was assessed.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Carex stylosa* has not changed its typical flowering time since the 1920s.

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
10 of 11 known occurrences in Washington are extant, although one was not relocated during a 2018 survey (https://www.dnr.wa.gov/NHPdataexplorer). One population is historical. Populations estimates for the remainder have not been collected in a consistent manner necessary to estimate trends.

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, WA.

Chimner R.A. and D.J. Cooper. 2003. Influence of water table levels on CO2 emissions in a Colorado subalpine fen: an in situ microcosm study. *Soil Biology and Biochemistry* 35(3):345–351.

Halabisky M., S. Lee, S.A. Hall, and M. Rule. 2017. Can we conserve wetlands under a changing climate? Mapping wetland hydrology across and ecoregion and developing climate adaptation recommendations. Report prepared for Great Northern Landscape Conservation Cooperative.

Leck M.A. and W. Schütz. 2005. Regeneration of Cyperaceae, with particular reference to seed ecology and seed banks. *Perspectives in Plant Ecology, Evolution and Systematics* 7(2):95–133.

Luceño M. and M. Guerra. 1996. Numerical variations in species exhibiting holocentric chromosomes: a nomenclatural proposal. *Caryologia* 49(3–4):301–309.

Pitz C.F. 2016. Predicted impacts of Climate Change on groundwater resources of Washington State. Washington State Department of Ecology, Olympia, WA. Publication No. 16-03-006.

Rocchio F.J. and R.C. Crawford. 2015. Ecological Systems of Washington State: a guide to identification. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. NHR-2015-04. Online: https://www.dnr.wa.gov/publications/amp_nh_ecosystems_guide.pdf

Rocchio F.J., E. Gage, T. Ramm-Granberg, A.K. Borkenhagen, and D.J. Cooper. 2021. Ecohydrological characteristics of a newly identified coastal raised bog on the western Olympic Peninsula, Washington State, USA. *Ecohydrology* 14(4).

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.

Da Silva C.R.M., M.S. González-Elizondo, L.D.N.A. De Almeida, J.M.D. Torezan, and A.L.L. Vanzela. 2008. Cytogenetical and cytotaxonomical analysis of some Brazilian species of Eleocharis (Cyperaceae). *Australian Journal of Botany* 56(1):82–90.

Da Silva C.R.M., M.S. González-Elizondo, and A.L.L. Vanzela. 2005. Reduction of chromosome number in Eleocharis subarticulata (Cyperaceae) by multiple translocations. *Botanical Journal of the Linnean Society* 149(4):457–464.

Silvola J., J. Alm, U. Ahlholm, H. Nykanen, and P.J. Martikainen. 1996. CO2 fluxes from peat in boreal mires under varying temperature and moisture conditions. *Journal of Ecology* 84(2):219–228.

Tena-Flores J.A., M.S. González-Elizondo, Y. Herrera-Arrieta, N. Almaraz-Abarca, N. Mayek-Pérez, C.R.M. Da Silva, and A.L. Laforga Vanzela. 2013. Karyotype characterization of eight Mexican species of Eleocharis (Cyperaceae). *Botanical Sciences* 91(2):119–128.

Washington Geological Survey. 2023. Geologic Maps—1:100,000-scale. https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/publications-and-maps#geologic-maps.2. Accessed: May 11, 2023.

Washington Natural Heritage Program (WNHP). 2021. Carex stylosa. In: Online Field Guide to the Rare Plants of Washington. https://fieldguide.mt.gov/wa/?species=carex stylosa. Accessed: May 11, 2023.

Wilson B.L., R. 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.

Winter T.C. 2000. The vulnerability of wetlands to climate change: a hydrologic landscape perspective. *Journal of the American Water Resources Association* 36(2):305–311.

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

Climate Change Vulnerability Index Report

Coptis trifolia (threeleaf Goldenthread)

Date: 18 May 2023 Synonym: *NA*

Assessor: Irene Weber, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S1

Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	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		Unknown
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Greatly Increase
2aii. Change in physiological thermal niche		Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		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		Neutral
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		NA
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	Unknown
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: Only one record of *Coptis trifolia* is known to occur in Washington. This population occurs in an area with a projected temperature increase of <= 3.9° F. (Figure 1).

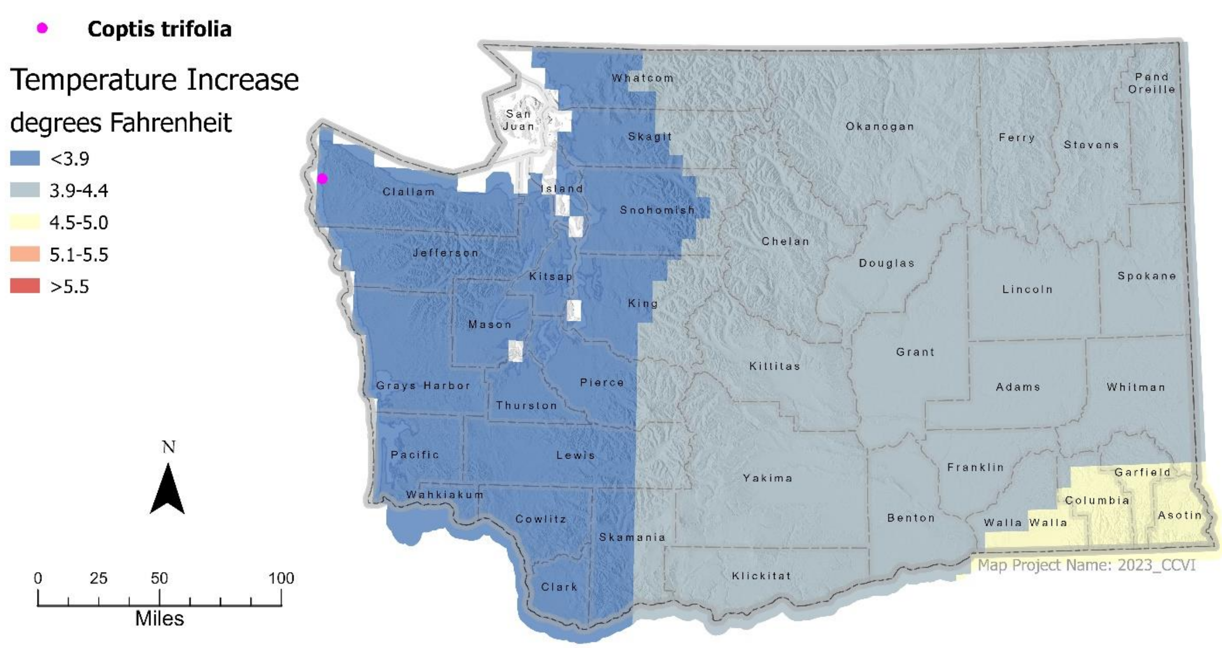


Figure 5. Exposure of Coptis trifolia occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The only known occurrence of *Coptis trifolia* in Washington occurs 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 - -0.096 (Figure 2).

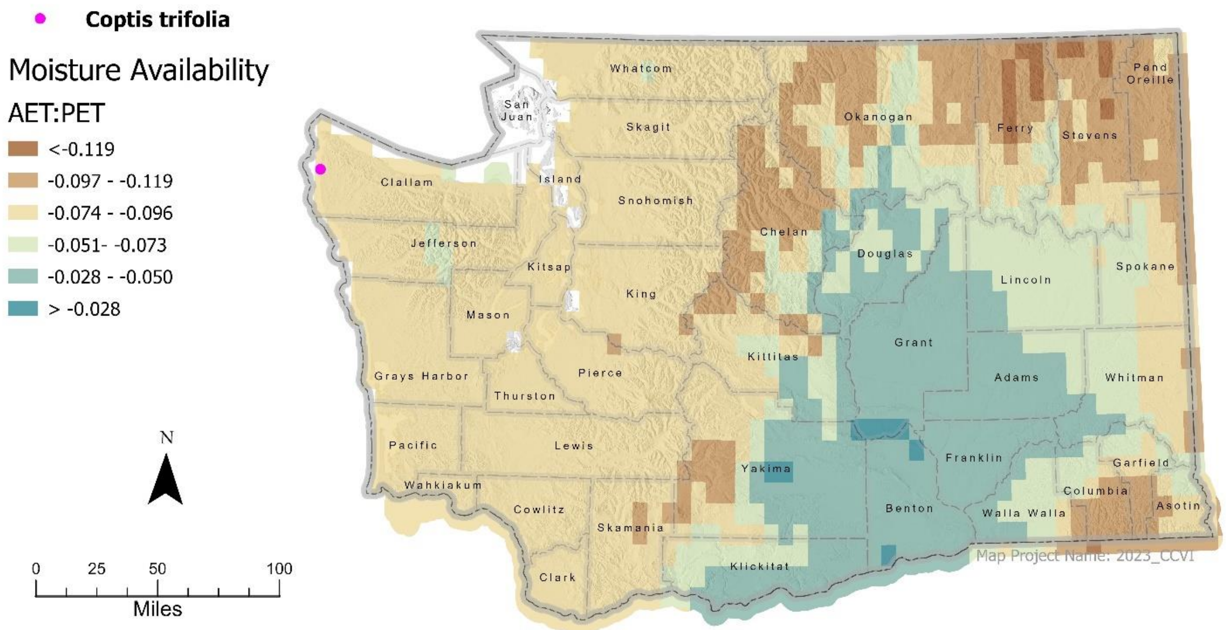


Figure 6. Exposure of Coptis trifolia occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The single population of *Coptis trifolia* in Washington is found at 155 feet (48 m) (Camp and Gamon 2011) and is unlikely to be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
The only known population of *Coptis trifolia* in Washington occurs in a coastal peatland, but in other areas it can be found in wet to mesic forests, muskegs, willow scrub, and tundra (Camp and Gamon 2011). The population in Washington is naturally isolated by intervening uplands that present a barrier to dispersal between watersheds.

B2b. Anthropogenic barriers: Neutral.
The population of *Coptis trifolia* in Washington is within the boundary of Olympic National Park and has few anthropogenic barriers in it's immediate vicinity. More generally, the ecosystems in which *C. trifolia* is known to occur is fragmented by anthropogenic infrastructure including roads and timberlands. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands and waterways.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Coptis trifolia produces 1-1.5 mm seeds (Camp and Gamon 2011). Seeds are likely passively dispersed by gravity, wind, or flowing water. These seeds lack structures such as wings or barbs that assist with dispersal.

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the population of *Coptis trifolia* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). This population occurs in an area that has experienced very small (<37 ° F /20.8 ° C) temperature variation in the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016).

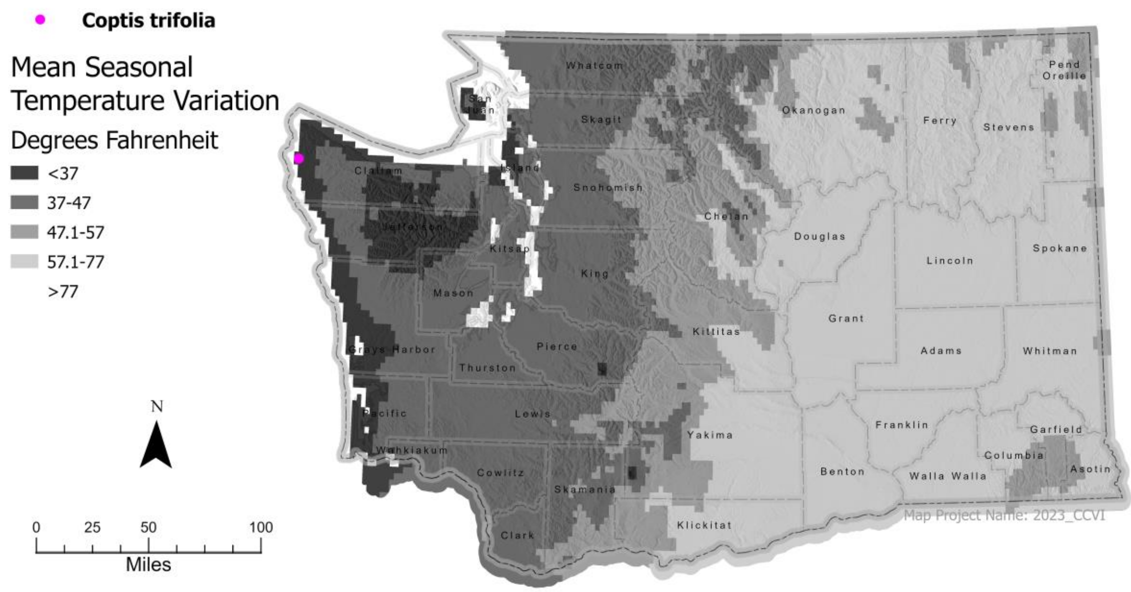


Figure 7. Historical thermal niche (exposure to past temperature variations) of Coptis trifolia occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Increase.
The peatland ecosystem in which *Coptis trifolia* is found in Washington is vulnerable to temperature increase as the development and persistence of peatlands are controlled by the balance of precipitation and evaporation. Temperature increases alter evaporation rates which may result in increased tree encroachment which would result in the conversion of these peatlands into other ecosystem types. Increased temperatures may also alter peat decomposition rates which may result in conversion to non-peat wetland types (Rocchio and Ramm-Granberg 2017).

C2bi. Historical hydrological niche: Neutral.
The known populations of *Coptis trifolia* occurs in an area of average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm), considered neutral for climate change per the guidance in Young (2016) (Figure 4).

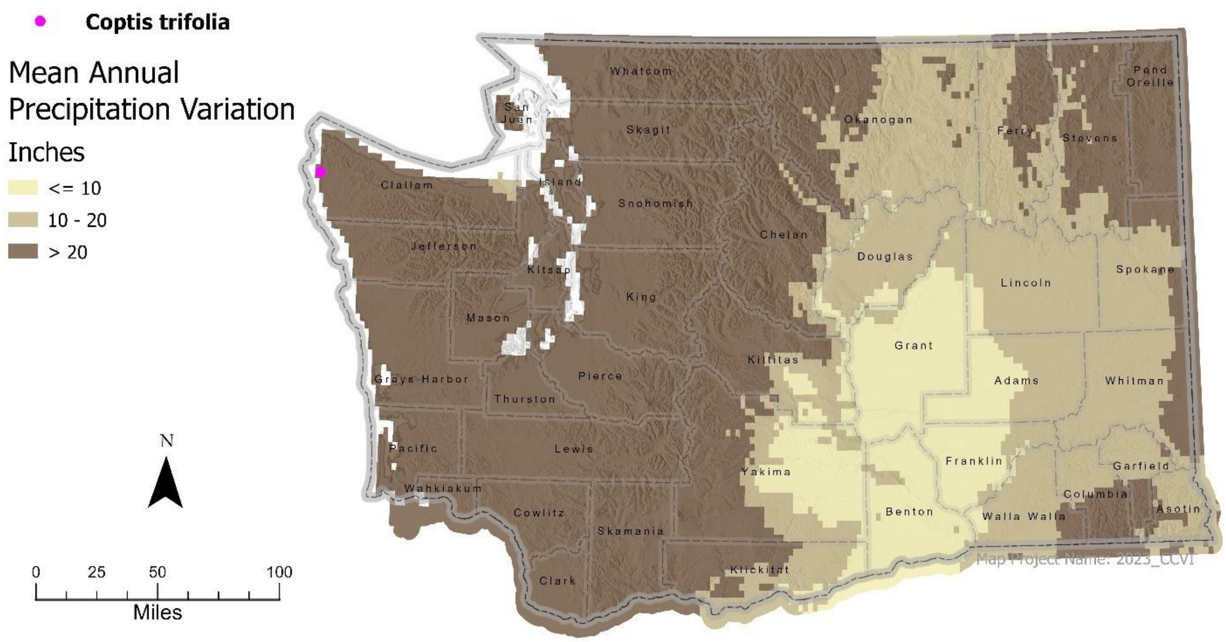


Figure 8. Historical hydrological niche (exposure to past variations in precipitation) of Coptis trifolia occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species occurs in a peatland which may be ombrotrophic (maintained exclusively by precipitation). Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Coptis trifolia is not known to be dependent on episodic disturbance regimes.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The population of *Coptis trifolia* is found as a low elevation site that receive relatively low winter snowfall. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017)

C3. Restricted to uncommon landscape/geological features: Neutral.
The peatland in which *Coptis trifolia* is found in Washington is not tied to any uncommon landscape or geologic features.

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

The wetland habitat occupied by *Coptis trifolia* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Little is known about the specific pollinators of *Coptis trifolia* however the nectaries on the petals may attract solitary bees and hover flies of the family Syrphidae (Stein and Fuentes 2005)

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds are very fine and likely are not dependent on animal species for transport. There is some evidence that this species also reproduces vegetatively (Stein and Fuentes 2005)

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.
Competition from nonnative species may be a threat to *Coptis trifolia* in areas where there has been disturbance allowing nonnative species to invade. Changes in hydrology may also facilitate tree encroachment. (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. *Coptis trifolia* is a diploid species (2n=18) (Ford 1997) but otherwise little is known about measured genetic variation within this species.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Little definitive research exists on the mating system of *Coptis trifolia*, however it is likely to have a mixed mating system and also reproduce vegetatively (Stein and Fuentes 2005)

C6. Phenological response to changing seasonal and precipitation dynamics: Unknown.
There are not enough records of *Coptis trifolia* in Washington to make a determination on changes in its phenological response.

Section D: Documented or Modeled Response to Climate Change

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

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., Kleinknecht J. 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. 177 pp.

Ford, B.A. 1997. Coptis. Pp. 242-245. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 20+ vols. New York and Oxford. Vol. 3: Magnoliophyta: Magnoliidae and Hamamelidae. 590 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.

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.

Stein, M. and Fuentes, T.L. 2005. Conservation Assessment for Coptis trifolia (L.) Salisb. USDA Forest Service Region 6 and USDI Bureau of Land Management, OR and WA. 17 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.

Washington Natural Heritage Program. 2021. *Coptis trifolia*. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Climate Change Vulnerability Index Report

Eleocharis rostellata (smooth-fruited sedge)

Date: 17 April 2023 Synonym: *Scirpus rostellatus*

Assessor: Tynan Ramm-Granberg, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S2

Index Result: Moderately Vulnerable Confidence: Low

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	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	7
	-0.074 to - 0.096	7
	-0.051 to - 0.073	27
	-0.028 to -0.050	27
	>-0.028	33
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		Neutral to Increase
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral to Somewhat Increase
3. Restricted to uncommon landscape/geological features		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		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	Neutral
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 15 of the known occurrences of *Eleocharis rostellata* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

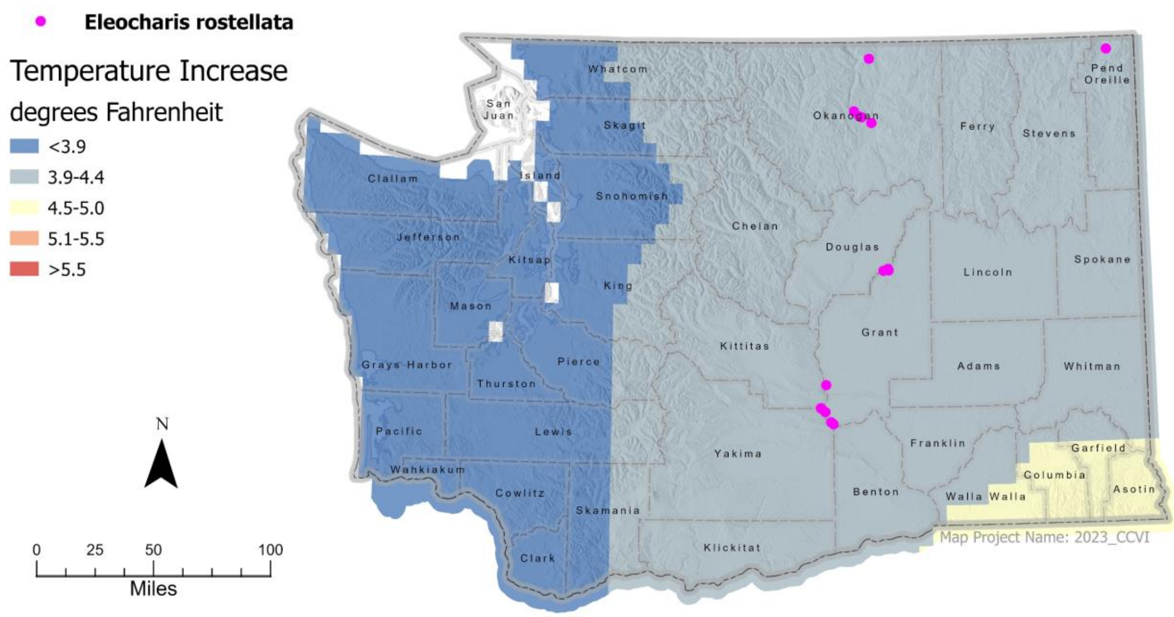


Figure 1. Exposure of *Eleocharis rostellata* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Five of the 15 occurrences (33%) of *Eleocharis rostellata* in Washington are found in areas with a projected change in available moisture (as measured by the ratio of actual to potential evapotranspiration) of > -0.028 (i.e., minimal reduction OR potential increase in moisture) (Figure 2). The remaining populations are projected to experience moisture availabilities nearly across the spectrum: 27% are in areas projected to decrease by -0.028 to -0.050, 27% in -0.051 to -0.073, 7% in -0.074 to -0.096, and 7% in -0.097 to -0.119. Populations in areas with the largest projected change are in Pend Oreille County and the Okanogan Valley. The variability in this ranking factor is unusual compared to other rare species. Microhabitat characteristics may be more important for *Eleocharis rostellata* than broader climatic patterns.

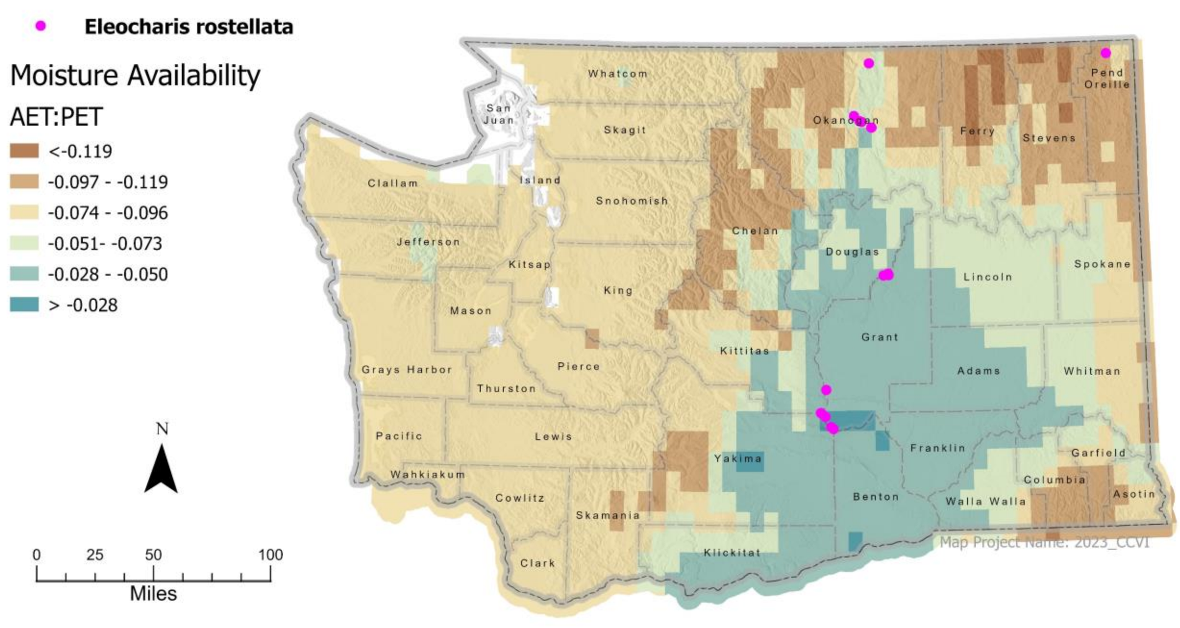


Figure 2. Exposure of *Eleocharis rostellata* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Eleocharis rostellata* are found at 440-1850 feet (135-560 m) and would not be inundated by projected sea level rise. While this species occupies coastal salt marshes elsewhere in its range, no such populations are known from Washington.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Eleocharis rostellata* is known to occur in alkaline wetlands such as around hot springs and in calcareous fens, as well as stream banks, lake margins, springs, and marshes east of the Cascade crest (Camp & Gamon, 2011; WNHP, 2021). These habitats are part of the Inter-Mountain Basins Alkaline Closed Depression; North American Arid West Emergent Marsh;

Rocky Mountain Subalpine-Montane Fen; and Temperate Pacific Freshwater Emergent Marsh ecological systems (Rocchio & Crawford, 2015). Individual populations may be isolated from each other by 0.5-101 miles (0.8-163 km) of unoccupied and/or unsuitable habitat. Most of the matrix vegetation between occurrences is unsuitable and presents a barrier to dispersal. However, populations occurring along stream banks and major rivers are less likely to have dispersal barriers.

B2b. Anthropogenic barriers: Neutral.
The range of *Eleocharis rostellata* in Washington is primarily influenced by its dependence on scattered areas of specialized habitat that are naturally isolated. The human imprint (primarily irrigated agriculture) is significant near some occurrences, but anthropogenic factors are less likely to constrain dispersal than natural ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.
Eleocharis rostellata populations occurring in salt marshes may be impacted by the construction of sea walls or other structures to protect shoreline infrastructure, but no such populations are known from Washington.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Eleocharis rostellata primarily reproduces vegetatively via sprouting and layering. It has very short rhizomes. It also annually 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). The achenes do not float, so longer-range dispersal typically requires flowing water. Dispersal may occasionally be facilitated by achene adhesion to mud on birds or mammals (Leck & Schütz, 2005). Long distance travel in the gizzards of birds has been reported as well (Kedlec & Wentz, 1974).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Eleocharis rostellata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All 15 known occurrences in the state are found in areas that have experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) during the past 50 years, indicating a neutral impact on the climate change vulnerability for this species (Young et al., 2016).

C2aii. Physiological thermal niche: Neutral.
The wetland habitat of *Eleocharis rostellata* is not always associated with cool air drainage or cold microhabitats, although water-logged soils typically stay cool longer into the growing season than adjacent upland substrates. A warming climate may dry out soils more rapidly—and/or earlier in the growing season—in *E. rostellata* habitat.

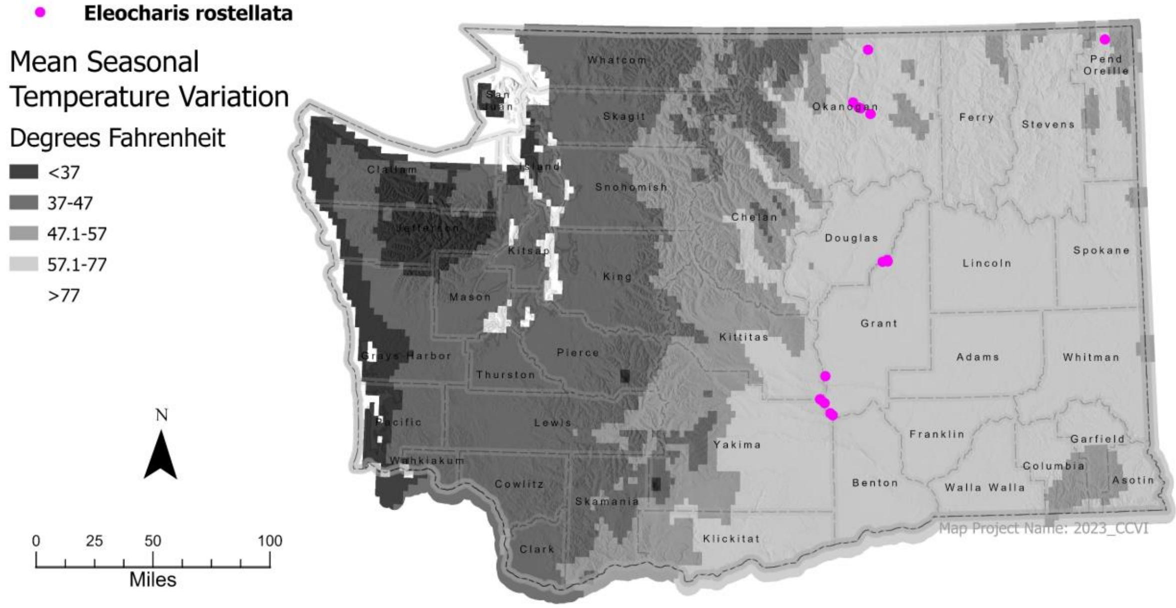


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Eleocharis rostellata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral to Increase.
Nine of the 15 known populations of *Eleocharis rostellata* in Washington (60%) 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), this may indicate increased vulnerability to climate change. These occurrences are found at low elevations in the Columbia Basin, the driest part of the state. Five populations (33%) have experienced slightly lower than average precipitation (11-20 inches/255-508 mm), indicating somewhat increased vulnerability to climate change, while one population (7%) has had average or greater than average (>20 inches/508 mm) precipitation variation (neutral impact on climate change vulnerability).

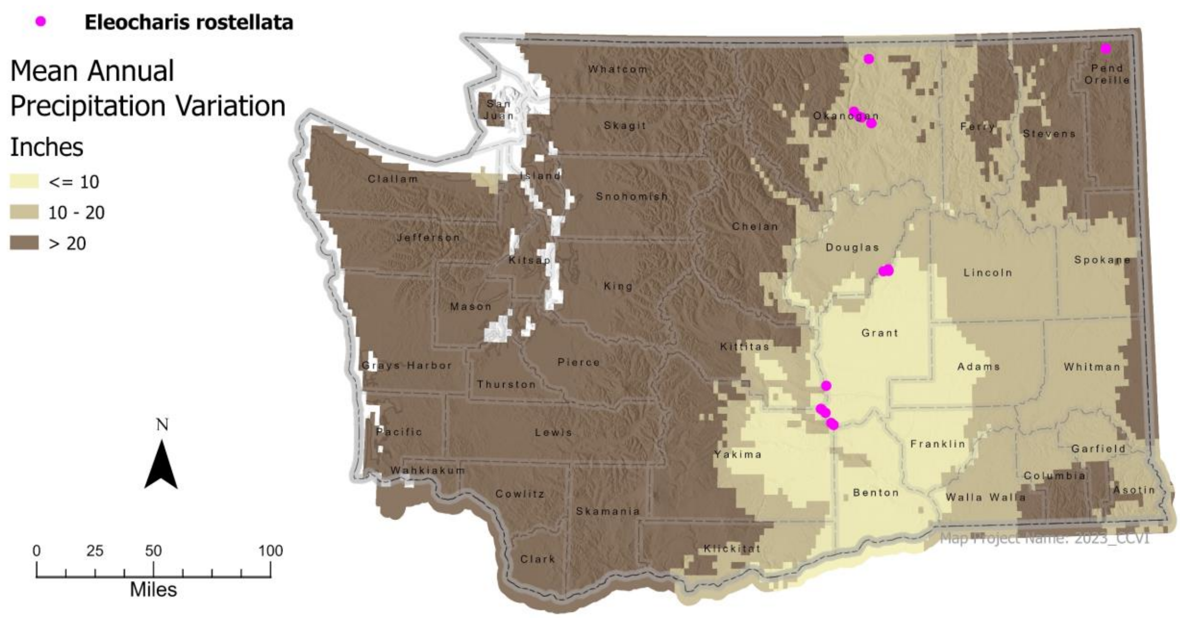


Figure 3. Historical hydrological niche (exposure to past variations in precipitation) of *Eleocharis rostellata* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
Populations of *Eleocharis rostellata* in Washington are associated with alkaline wetlands such as hot springs and calcareous fens, as well as stream banks, lake margins, springs, and marshes. Populations found in the Inter-Mountain Basins Alkaline Closed Depression ecological system are likely dependent on precipitation inputs, making them more vulnerable to climate change than those associated with groundwater discharge (Winter, 2000; Cooper et al., 2006; Pitz, 2016; Halabisky et al., 2017). If precipitation is reduced, or becomes more variable, decreased water table levels could lead to declines in herbaceous wetland species such as *Eleocharis rostellata* and an increase in phreatophyte shrubs. Populations in the North American Arid West Emergent Marsh ecological system are vulnerable to increased temperatures, decreased precipitation, increased drought, and increased flooding that is predicted to occur due to climate change (Rocchio & Ramm-Granberg, 2017). These habitats could be at risk of being converted to wet meadows. Populations associated with peatlands in the Rocky Mountain Subalpine-Montane Fen ecological system are more dependent on groundwater than precipitation. While groundwater-supported wetlands are somewhat less sensitive to climate change, they may still be adversely affected by decreased snowpack and drops in the water table. They may also experience changes in water chemistry (Rocchio & Ramm-Granberg, 2017).

C2c. Dependence on a specific disturbance regime: Neutral.

Eleocharis rostellata is an early colonizer of unvegetated mudflats, but is not known to be tied to specific disturbance regimes. Fen and lake shore occurrences may dry out enough under climate change to be burned more frequently in wildfires. *E. rostellata* has been shown to benefit from fires in salt marshes of the Gulf Coast, so long as burns are not severe enough to consume peat deposits and create areas of open water (Lynch, 1941; Faulkner & de la Cruz, 1982).

C2d. Dependence on ice or snow-cover habitats: Neutral to Somewhat Increase.
Eleocharis rostellata populations at montane elevations may be impacted negatively by reduced snowpack or a change in snowmelt timing: those on lake shores may experience more prolonged summer drawdown periods, while fen and spring populations may be impacted by reduced groundwater recharge. However, *E. rostellata* populations in the Columbia Basin are likely less dependent on winter snowfall.

C3. Restricted to uncommon landscape/geological features: Increase.
Eleocharis rostellata is highly tied to alkaline/calcareous sites in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
Eleocharis rostellata habitat is maintained primarily by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Eleocharis rostellata is wind-pollinated (Dunbar, 1973; Strandhede, 1973).

C4d. Dependence on other species for propagule dispersal: Neutral.
Although it may be facilitated by birds or mammals (Kedlec & Wentz, 1974; Leck & Schütz, 2005), dispersal is not dependent on other species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor. While *Eleocharis* spp. have low palatability to herbivores, they may be damaged by grazing animals accessing streams and lakes for drinking water (Kovalchik, 1987).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Populations may be vulnerable to shifts in vegetation towards alkaline wet meadows or upland habitats because of potential changes in the amount of available water from precipitation and snowpack (Rocchio & 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.
Eleocharis rostellata has been reported to be a polyploid (2n = 60) (Tena-Flores et al., 2013), reflecting its adaptability to a large variety of abiotic stresses (Mayrose et al., 2010; Wang et al., 2011).

C5b. Genetic bottlenecks: Neutral.

There is no evidence that the total population of *Eleocharis rostellata* in Washington was reduced to ≤ 1000 mature individuals and/or that occupied area was reduced by > 30% at any point in the past 500 years. This factor is not included in the overall climate vulnerability score because C5a was assessed.

C5c. Reproductive System: Neutral.
Eleocharis rostellata has a mixed mating system and there are no known major disruptions to gene flow. This factor is not included in the overall climate vulnerability score because C5a was assessed.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Collections are limited, but there has not been a documented change in flowering time since the 1880s (pnwherbaria.org).

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Unknown.
13 of the 15 occurrences in Washington are extant. Trend data are available for 8 occurrences, of which 1 has an increasing population (by area/stem count), 3 appear to be stable, and 4 are decreasing or were not relocated in the past 10 years. Whether these population declines are due to local factors, such as competition with exotic plants, development, hydrologic alterations, 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, WA.

Dunbar A. 1973. Pollen development in the Eleocharis palustris group (Cyperaceae). I. Ultrastructure and ontogeny. *Botaniska Notiser* 126:197–254.

Faulkner S.P. and A.A. de la Cruz. 1982. Nutrient mobilization following winter fires in an irregularly flooded marsh. *Journal of Environmental Quality* 11(1):129–133.

Kedlec J.A. and W.A. Wentz. 1974. State-of-the-art survey and evaluation of marsh plant establishment techniques: induced and natural. Volume I: report of research. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. Contract Report D-74-9.

Kovalchik B.L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. US Department of Agriculture, Forest Service, Pacific Northwest Region, Portland, OR. R6-ECOL-TP-279–87.

Leck M.A. and W. Schütz. 2005. Regeneration of Cyperaceae, with particular reference to seed ecology and seed banks. *Perspectives in Plant Ecology, Evolution and Systematics* 7(2):95–133.
Lynch J.J. 1941. The place of burning in management of the Gulf Coast wildlife refuges. *The Journal of Wildlife Management* 5(4):454–457.

Mayrose I., M.S. Barker, and S.P. Otto. 2010. Probabilistic models of chromosome number evolution and the inference of polyploidy. *Systematic Biology* 59(2):132–144.

Rocchio F.J. and R.C. Crawford. 2015. Ecological Systems of Washington State: a guide to identification. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. NHR-2015-04. Online: https://www.dnr.wa.gov/publications/amp_nh_ecosystems_guide.pdf

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.

Strandhede S.O. 1973. Pollen development in the Eleocharis palustris group (Cyperaceae). II. Cytokinesis and microspore degeneration. *Botaniska Notiser* 126:255–265.

Tena-Flores J.A., M.S. González-Elizondo, Y. Herrera-Arrieta, N. Almaraz-Abarca, N. Mayek-Pérez, C.R.M. Da Silva, and A.L. Laforga Vanzela. 2013. Karyotype characterization of eight Mexican species of Eleocharis (Cyperaceae). *Botanical Sciences* 91(2):119–128.

Wang X., T. Zhang, Z. Wen, H. Xiao, Z. Yang, G. Chen, and X. Zhao. 2011. The chromosome number, karyotype and genome size of the desert plant diploid Reaumuria soongorica (Pall.) Maxim. *Plant Cell Reports* 30:955–964.

Washington Natural Heritage Program (WNHP). 2021. Eleocharis rostellata. In: Online Field Guide to the Rare Plants of Washington. https://fieldguide.mt.gov/wa/?species=eleocharis rostellata. Accessed: April 10, 2023.

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

Climate Change Vulnerability Index Report

Fritillaria camschatcensis (black lily)

Date: 4 May 2023

Assessor: Jesse Miller, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S2

Index Result: Moderately Vulnerable Confidence: Moderate

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	18
	<3.9° F (2.2°C) warmer	82
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 to increase
2a. Distribution relative to natural barriers		Somewhat increase
2b. Distribution relative to anthropogenic barriers		Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Increase
2ai Change in historical thermal niche		Neutral to Somewhat Increase
2aii. Change in physiological thermal niche		Somewhat increase to increase
2bi. Changes in historical hydrological niche		Neutral

2bii. Changes in physiological hydrological niche	Somewhat Increase
2c. Dependence on specific disturbance regime	Somewhat increase
2d. Dependence on ice or snow-covered habitats	Neutral
3. Restricted to uncommon landscape/geological features	Neutral
4a. Dependence on 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	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: Two of the 11 occurrences of *Fritillaria camschatcensis* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F; the other nine occur in areas with a projected temperature increase < 3.9 ˚ F (Figure 1).

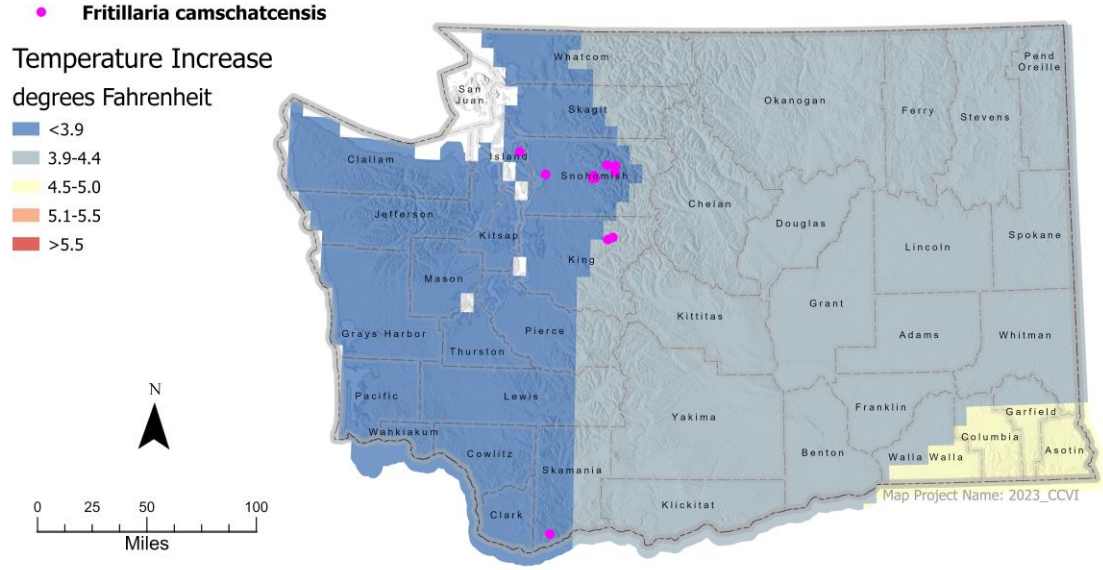


Figure 1. Exposure of *Fritillaria camschatcensis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All of the 11 occurrences of *Fritillaria camschatcensis* in Washington are found in areas with a projected decrease of decrease of -0.074 to -0.096.

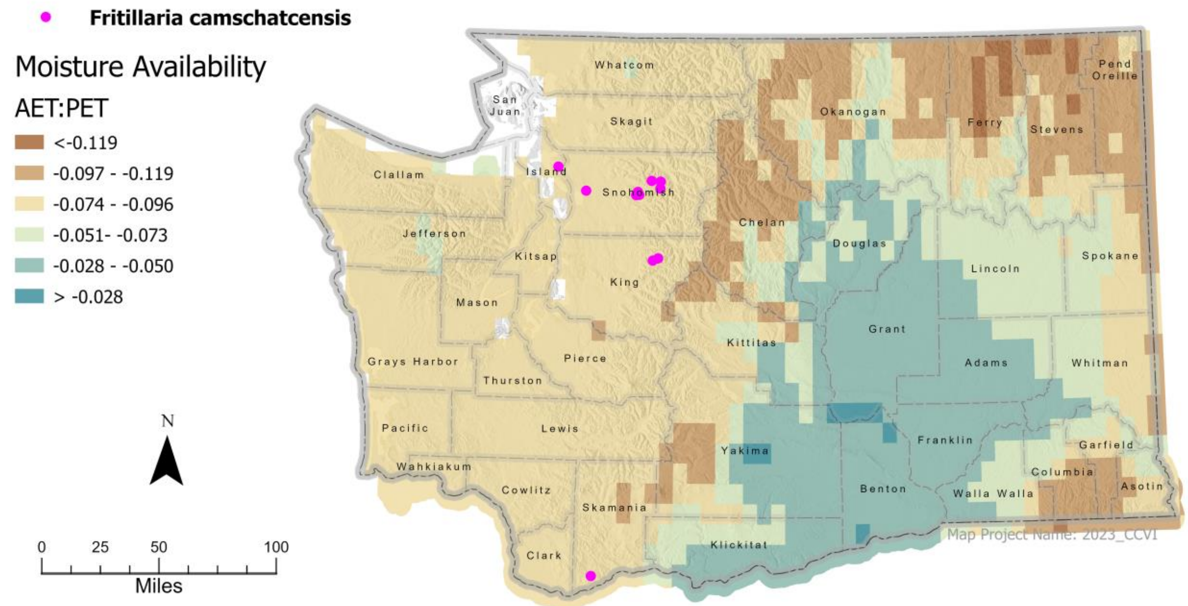


Figure 2. Exposure of *Fritillaria camschatcensis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral to somewhat increase

Washington occurrences of *Fritillaria camschatcensis* occur from sea level to 1000 ft (1370 m); the two coastal occurrences in Washington could be affected by sea level rise (Washington Natural Heritage Program 2023).

B2a. Natural barriers: Somewhat increase.

Fritillaria camschatcensis occurs in wet meadows, salt marshes, montane fens, forested wetlands, and lowland deciduous forests. These habitats are components of three ecosystems: Northern Pacific Bog and Fen, North Pacific Intertidal Freshwater Wetland, and Temperate Pacific Subalpine-Montane Wet Meadows (Rocchio and Crawford 2015). Many of these habitat types are patchy ecosystems that are separated by large areas of unsuitable habitat. Populations are separated by approximately 1-133 miles (1-214 km).

B2b. Anthropogenic barriers: Somewhat increase. The lower elevation populations of *Fritillaria camschatcensis* have experienced substantial habitat loss due to agricultural development and urbanization. Some higher elevation populations in forested ecosystems may have been affected by habitat fragmentation caused by timber harvest.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and *movements*: Increase
Fritillaria spp. are often relatively poor dispersers, and some species reproduce largely through short-distance vegetative reproduction (Badfar-Chaleshtori et al. 2012, Tatarenko et al. 2022), including *Fritillaria camschatcensis* (Zox 2008).

C2ai. Historical thermal niche: Somewhat increase to increase.
Figure 3 depicts the distribution of *Fritillaria camschatcensis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Four of the 11 known occurrences in the state (36%) 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 7 other occurrences (64%) are from areas that have experienced small (37 - 47° F/20.8 - 26.3° C) temperature variation in the past 50 years, and are considered to be at increased vulnerability to climate change (Young et al. 2016).

C2aii. Physiological thermal niche: Slight increase to increase.
Fritillaria camschatcensis occurs at sites with wet to mesic soils. Thus, the species would be at slightly increased to increased risk from climate in terms of its physiological thermal niche.

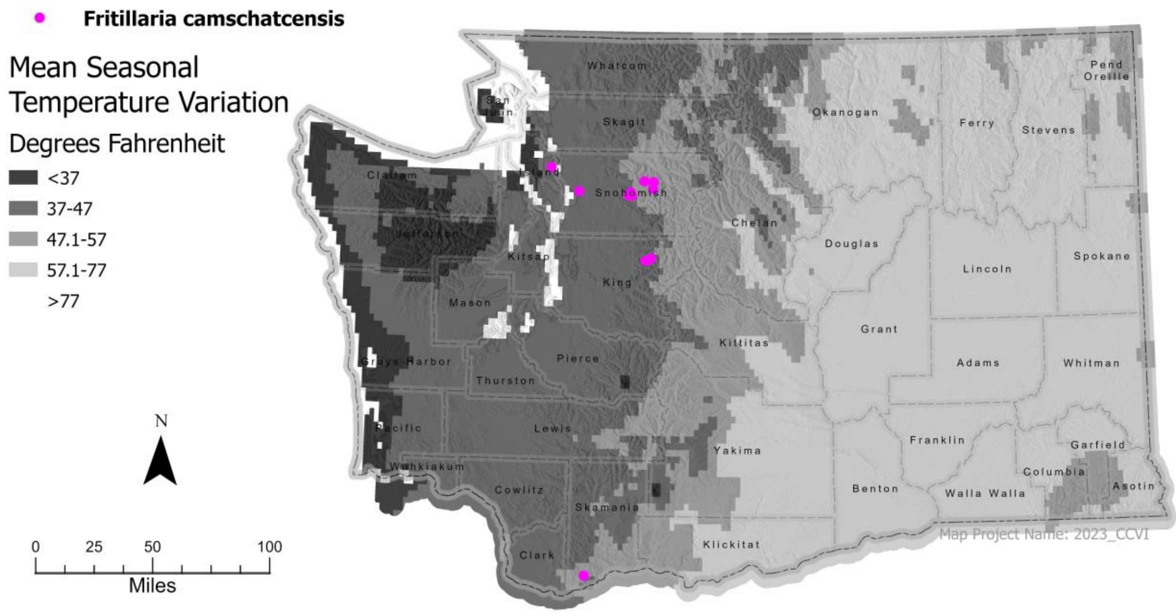


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Fritillaria camschatcensis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral.
All 11 of the known populations of *Fritillaria camschatcensis* in Washington are found in areas that have experienced average or above average variation in precipitation (> 20 inches / > 508mm; Figure 4). According to Young et al. (2016), all of these occurrences are at neutral vulnerability from climate change.

C2bii. Physiological hydrological niche: Somewhat increase.
Habitats where *Fritillaria camschatcensis* occurs range from wet to mesic, and hydrological changes in wetter habitats, in particular, could be detrimental to the species. For example, increased summer drought has been predicted to alter species composition in Temperate Pacific Subalpine-Montane Wet Meadows (Rocchioand Ramm-Granberg 2017). However, as a perennial geophyte, *Fritillaria camschatcensis* could be resilient to some degree of seasonal variation in precipitation.

C2c. Dependence on a specific disturbance regime: Somewhat increase.
Some of the habitats in which *Fritillaria camschatcensis* occurs may be dependent on wildfire to maintain suitable habitat.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Fritillaria camschatcensis is not believed to be strongly associated with ice or snow-covered habitats, although winter snow may occur within its range.

C3. Restricted to uncommon landscape/geological features: Neutral.
Fritillaria camschatcensis is not known to be associated with uncommon landscape / geological features.

C4a. Dependence on other species to generate required habitat: Neutral
Fritillaria camschatcensis is not known to be dependent on other specieis to maintain its habitat.

C4b. Dietary versatility: Not applicable for plants
C4c. Pollinator versatility: Somewhat increase.
Fritillaria spp. are pollinated by flies in the family Calliphoridae (Zox 2008).

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruits of *Fritillaria* spp. are not known to be 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: Neutral.
Invasive species are not noted as a threat to *Fritillaria camschatcensis* in the WNHP Rare Plant Field Guide (Washington Natural Heritage Program 2023).

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

C5a. Measured genetic variation: Neutral.
One study found high genetic variation within a single population of *Fritillaria camschatcensis* in Japan, so genetic variation may not be a limiting factor for this species (Yamagishi et al. 2010).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Somewhat increase.
Although *Fritillaria camschatcensis* can reproduce sexually, seed set may be relatively rare and most reproduction apparently occurs through vegetative spread of bulblets (Zox 2008).

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

since the late 1800s, although there are not enough collections to make a rigorous assessment.

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 *Fritillaria camschatcensis* in Washington since it was first collected in the state in the late 1800s.

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

Badfar-Chaleshtori, S., B. Shiran, M. Kohgard, H. Mommeni, A. Hafizi, M. Khodambashi, N. Mirakhorli, and K. Sorkheh. 2012. Assessment of genetic diversity and structure of Imperial Crown (Fritillaria imperialis L.) populations in the Zagros region of Iran using AFLP, ISSR and RAPD markers and implications for its conservation. Biochemical Systematics and Ecology 42:35–48.

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

Rocchio, F.J., and T. Ramm-Granberg. 2017. Ecological System Climate Change Vulnerability Assessment.

Tatarenko, I., K. Walker, and M. Dyson. 2022. Biological Flora of Britain and Ireland: Fritillaria meleagris. Journal of Ecology 110:1704–1726.

Washington Natural Heritage Program. 2023. Online Field Guide to the Rare Plants of Washington: https://fieldguide.mt.gov/wa.

Yamagishi, M., M. Nishioka, and T. Kondo. 2010. Phenetic diversity in the Fritillaria camschatcensis population grown on the Sapporo campus of Hokkaido University. Landscape and Ecological Engineering 6:75–79.

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 3:48.
Zox, H. 2008. Ecology of Black Lily (Fritillaria camschatcensis): a Washington State sensitive species. Douglassia:17–21.

Climate Change Vulnerability Index Report

Lycopodiella inundata (bog clubmoss)

Date: 19 May 2023 Synonym: *Lycopodium inundatum*

Assessor: Irene Weber, 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	20
	<3.9° F (2.2°C) warmer	80
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		Unknown
Section C		
1. Dispersal and movements		Neutral
2ai Change in historical thermal niche		Greatly Increase
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Somewhat Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral

4a. Dependence on other species to generate required habitat	Neutral
4b. Dietary versatility	NA
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: Sixteen of the 20 current and historical records of *Lycopodiella inundata* (80%) occur in areas with a projected temperature increase of <= 3.9° F. The remaining 4 occurrences (20%) are in areas with a projected temperature increase of 3.91-4.4° F. (Figure 1).

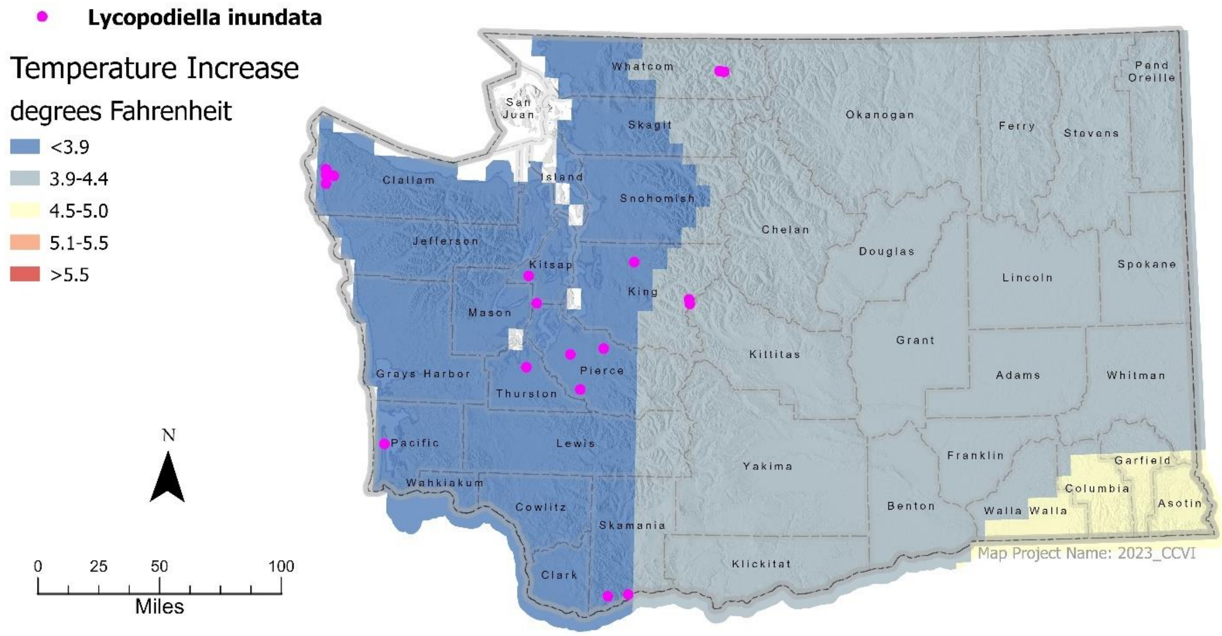


Figure 9. Exposure of Lycopodiella inundata occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All of the known occurrences of *Lycopodiella inundata* in Washington occur in area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 - -0.096 (Figure 2).

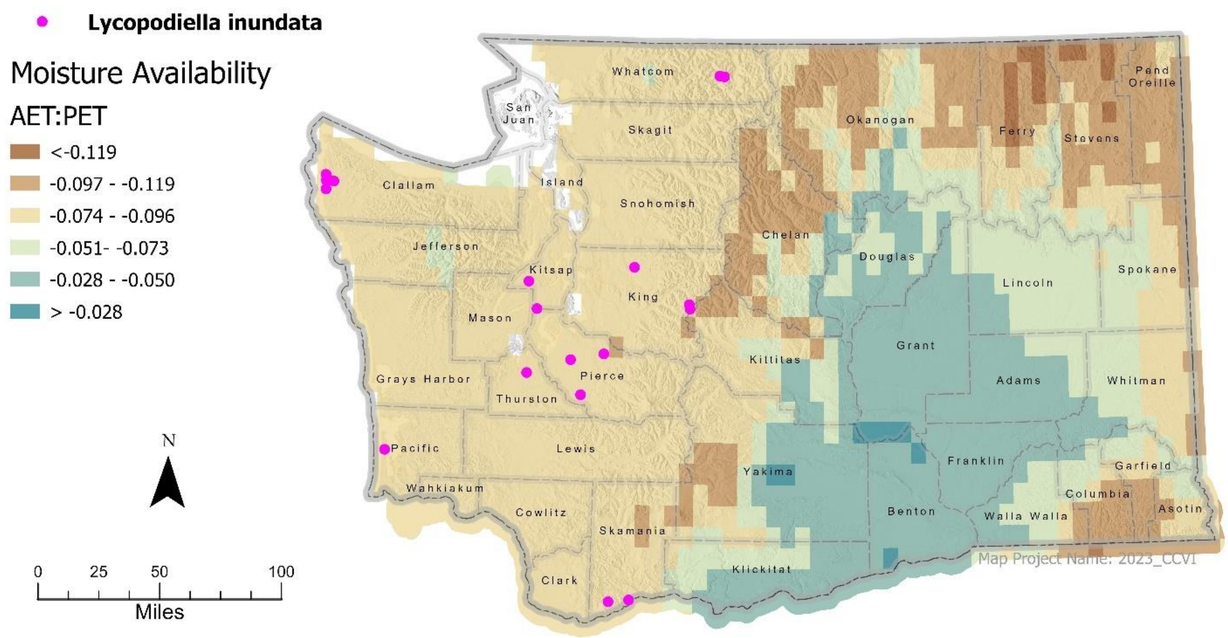


Figure 10. Exposure of Lycopodiella inundata occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The populations of *Lycopodiella inundata* in Washington are found from 10-1880 feet (3-575 m) (Camp and Gamon 2011). Only one occurrence in Pacific County is in an area that may be impacted by sea level rise.

B2a. Natural barriers: Somewhat Increase.
The populations of *Lycopodiella inundata* in Washington occur in bogs, acidic fens, wet sandy places, wetlands adjacent to lakes, marshes, and swampy ground (Camp and Gamon 2011). Populations are separated by 1-155 miles (1-249 km). These ecosystems are naturally isolated by intervening uplands that present a barrier to dispersal between watersheds.

B2b. Anthropogenic barriers: Neutral.
The range of *Lycopodiella inundata* is fragmented by anthropogenic infrastructure including roads, agriculture, dams, and cities. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands and waterways.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Lycopodiella inundata has the same basic lifecycle as all pteridophytes and reproduction via sporophytes and gametophytes. *L. inundata* produces thousands of spores in the summer and fall that are wind-borne and may travel long distances. These spores geminate and develop into gametophytes. Sperm are produced in the antheridia of these gametophytes and swim to eggs produced in archegonia (USFS 2004).

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the populations of *Lycopodiella inundata* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seven of the 20 known occurrences (35%) are in areas that have experienced very small (<37 ° F /20.8 ° C) temperature variation in the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). Nine occurrences (45%) are in areas that have experienced small (37-47° F/20.8-26.3 ° C) temperature variation in the past 50 years and are considered at increased vulnerability to climate change. The remaining 4 occurrences (20%) are in areas that have experienced slightly lower than average (47.1-57° F/26.3-31.8° C) temperature variation in the past 50 years and are considered at somewhat increased vulnerability to climate change. Per the guidance in Young (2016), because greater than 10% of the range falls in the Greatly Increase Vulnerability category, this category has been selected.

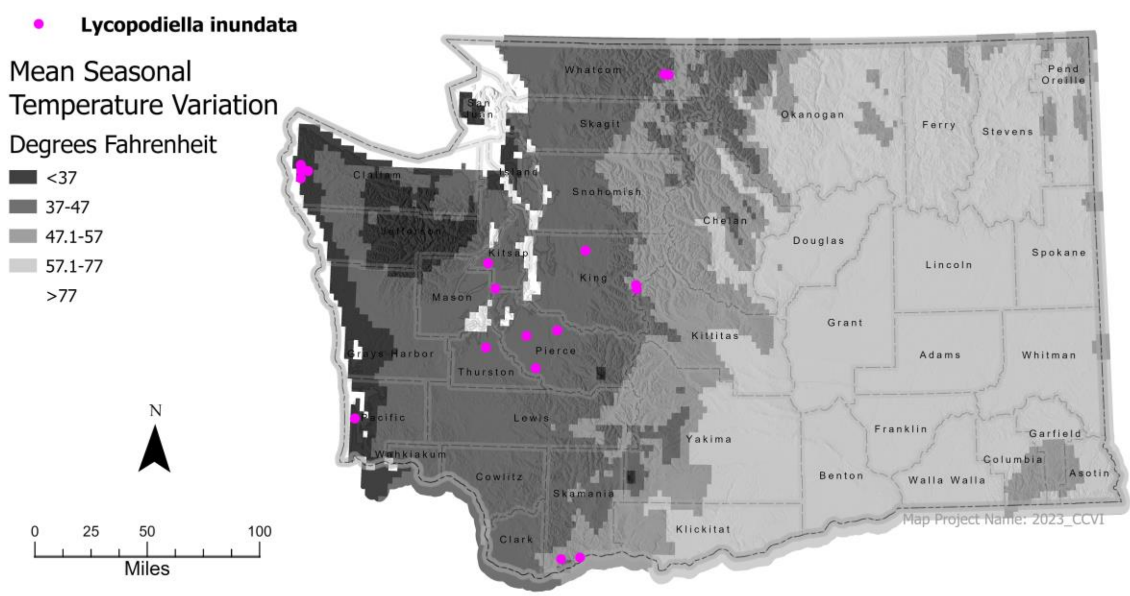


Figure 11. Historical thermal niche (exposure to past temperature variations) of Lycopodiella inundata occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Some populations of *Lycopodiella inundata* are found in peatland ecosystems that are vulnerable to temperature increase as the development and persistence of peatlands are controlled by the balance of precipitation and evaporation. Temperature increases alter evaporation rates which may result in increased tree encroachment which would result in the conversion of these peatlands into other ecosystem types. Increased temperatures may also alter peat decomposition rates which may result in conversion to non-peat wetland types (Rocchio and Ramm-Granberg 2017). *L. inundata* also occurs in other wetland types such as lake margins and marshes which would also be negatively impacted by rising temperatures, but to a somewhat lesser degree than peatlands.

C2bi. Historical hydrological niche: Neutral.
All known populations of *Lycopodiella inundata* occur in areas of average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm), considered neutral for climate change per the guidance in Young (2016) (Figure 4).

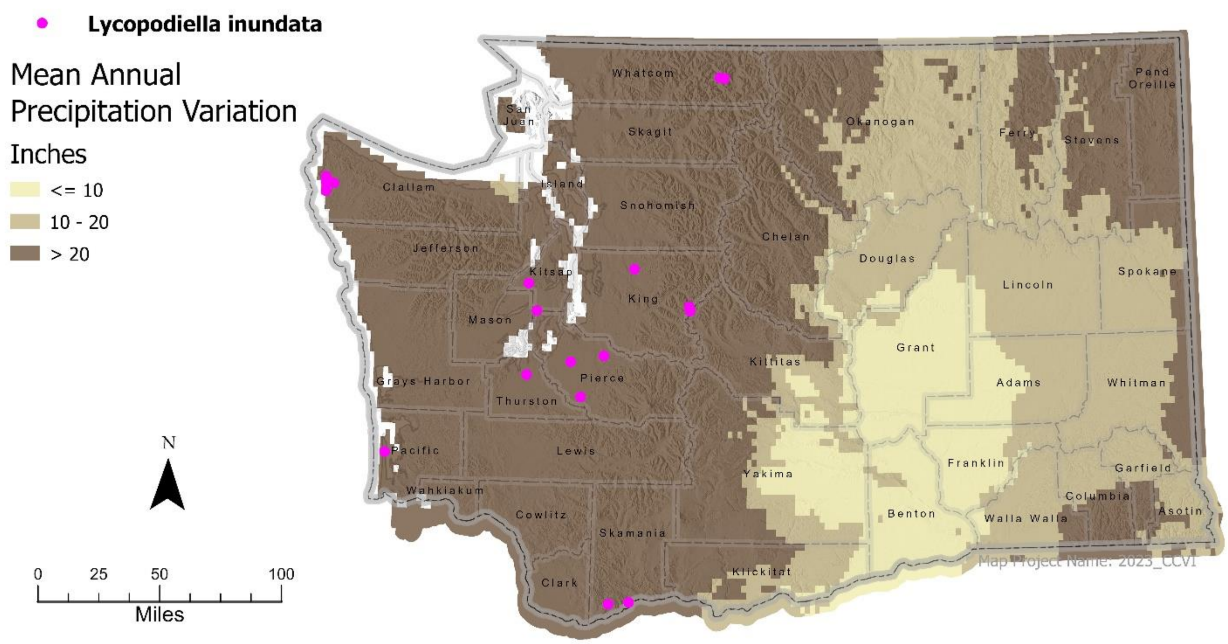


Figure 12. Historical hydrological niche (exposure to past variations in precipitation) of Lycopodiella inundata occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species occurs in a range of wetland environments but are primarily found in acidic peatlands (bogs and acidic fens). Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Lycopodiella inundata is not known to be dependent on episodic disturbance regimes.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The populations of *Lycopodiella inundata* in Washington are found at low elevations that receive relatively low winter snowfall. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Neutral.
The wetlands in which *Lycopodiella inundata* is found in Washington are not tied to any uncommon landscape or geologic features.

C4a. Dependence on other species to generate required habitat: Neutral.
The wetland habitats occupied by *Lycopodiella inundata* are maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants
C4c. Pollinator versatility: Neutral.
Lycopodiella inundata reproduces via sporophytes and gametophytes and is not dependent on pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Propagules in this species are transported via wind and through water.

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.
Competition from nonnative species may be a threat to *Lycopodiella inundata* in areas where there has been disturbance allowing nonnative species to invade. Changes in hydrology may also facilitate tree encroachment. (Rocchio and Ramm-Granberg 2017).

C4g. Forms part of an interspecific interaction not covered above: Neutral.
Lycopodiaceae typically have a symbiotic relationship with endophytic fungi, however species in the *Lycopodiella* genus seem to be less depended on these fungi (USFS 2004)

C5a. Measured genetic variation: Unknown.
Not known. *Lycopodiella inundata* is a diploid species (2n=156) (Wagner 1993) but otherwise little is known about measured genetic variation within this species. Molecular data suggest that Lycopodiaceae species fertilize regularly (USFS 2004).

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.

Lycopodiella does not reproduce asexually and are reliant on outcrossing via gametophytes for sexual reproduction (USFS 2004).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral. Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Lycopodiella inundata* has not changed its emergence period since it was first collected in the state.

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 *Lycopodiella inundata* in Washington since it was first collected in the state.

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 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.

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.

USFS. 2004. Conservation Assessment for Northern Appressed Club-moss (Lycopodiella subappressa J. G. Bruce, W. H. Wagner, & Beitel) and Northern Prostrate Club-moss (Lycopodiella margueritae J. G. Bruce, W. H. Wagner, & Beitel) USDA Forest Service Eastern Region. Hiawatha National Forest. 42 pp.

Wagner, H.W., Jr. and J.M. Beitel. 1993. Lycopodiaceae. pp. 18-37. In: Flora of North America Editorial Committee. 1993-. Flora of North America North of Mexico. Volume 2 Pteridophytes and Gymnosperms. Oxford University Press, New York. 475 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.

Washington Natural Heritage Program. 2021. *Lycopodiella inundata*. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Climate Change Vulnerability Index Report

Microseris borealis (northern microseris)

Date: 19 May 2023 Synonym: *Apargidium boreale*

Assessor: Irene Weber, 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	70
	<3.9° F (2.2°C) warmer	30
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	Unknown
Section C	
1. Dispersal and movements	Neutral
2ai Change in historical thermal niche	Greatly Increase
2aii. Change in physiological thermal niche	Somewhat Increase
2bi. Changes in historical hydrological niche	Neutral
2bii. Changes in physiological hydrological niche	Somewhat Increase
2c. Dependence on specific disturbance regime	Neutral
2d. Dependence on ice or snow-covered habitats	Neutral
3. Restricted to uncommon landscape/geological features	Neutral

4a. Dependence on other species to generate required habitat	Neutral
4b. Dietary versatility	NA
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: Three of the ten current and historical records of *Microseris borealis* (30%) occur in areas with a projected temperature increase of <= 3.9° F. The remaining seven occurrences (70%) are in areas with a projected temperature increase of 3.91-4.4° F. (Figure 1).

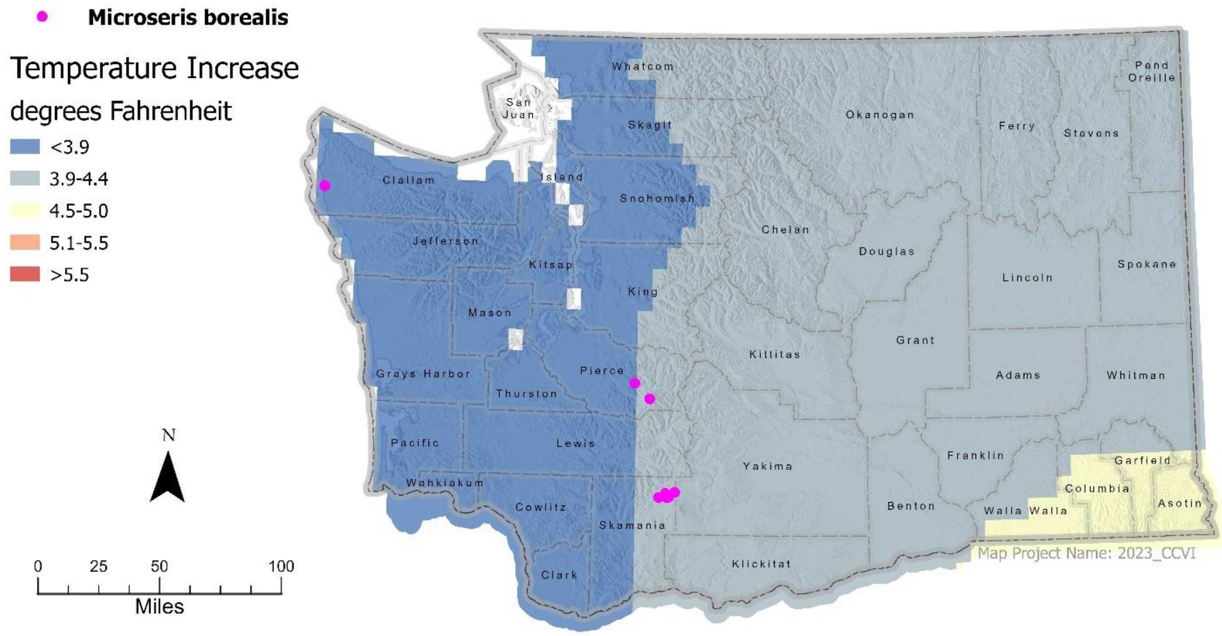


Figure 13. Exposure of *Microseris borealis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All of the known occurrences of *Microseris borealis* in Washington occur in area with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 - -0.096 (Figure 2).

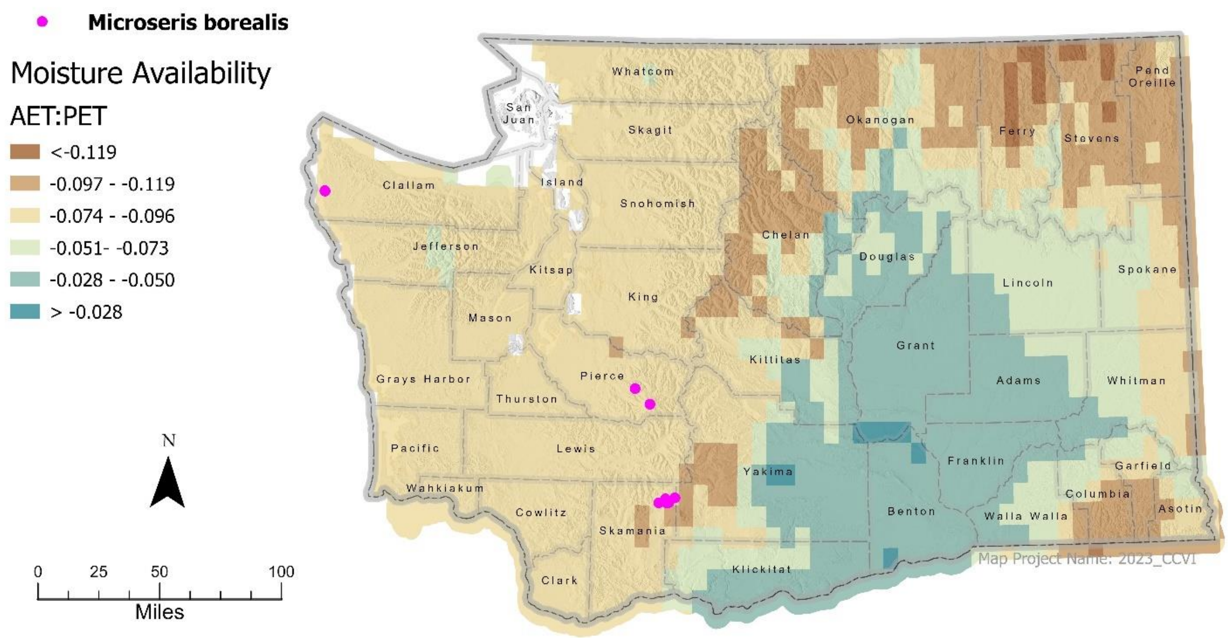


Figure 14. Exposure of *Microseris borealis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change
B1. Exposure to sea level rise: Neutral.
The populations of *Microseris borealis* in Washington are found from 30-4706 feet (10-1450 m) (Camp and Gamon 2011). These populations are unlikely to be affected by sea level rise.

B2a. Natural barriers: Somewhat Increase.
The populations of *Microseris borealis* in Washington occur in coastal to montane wet meadows, coastal acidic fens and similar wet places (Camp and Gamon 2011). Populations are separated by 1-150 miles (1-241 km). These ecosystems are naturally isolated by intervening uplands that present a barrier to dispersal between watersheds.

B2b. Anthropogenic barriers: Neutral.
The range of *Microseris borealis* is fragmented by anthropogenic infrastructure including roads, agriculture, dams, and cities. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands and waterways.

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

Section C: Sensitive and Adaptive Capacity
C1. Dispersal and movements: Neutral.

Microseris borealis produces seeds with a pappus of 24-48 brownish barbed bristles. These seeds can be wind dispersed or become lodged in fur and be dispersed via animals (Camp and Gamon 2011).

C2ai. Historical thermal niche: Greatly Increase.
Figure 3 depicts the populations of *Microseris borealis* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Three of the ten known occurrences (30%) are in areas that have experienced very small (<37 ° F /20.8 ° C) temperature variation in the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). The remaining seven occurrences (70%) are in areas that have experienced small (37-47° F/20.8-26.3 ° C) temperature variation in the past 50 years and are considered at increased vulnerability to climate change. Per the guidance in Young (2016), because greater than 10% of the range falls in the Greatly Increase Vulnerability range, this category has been selected.

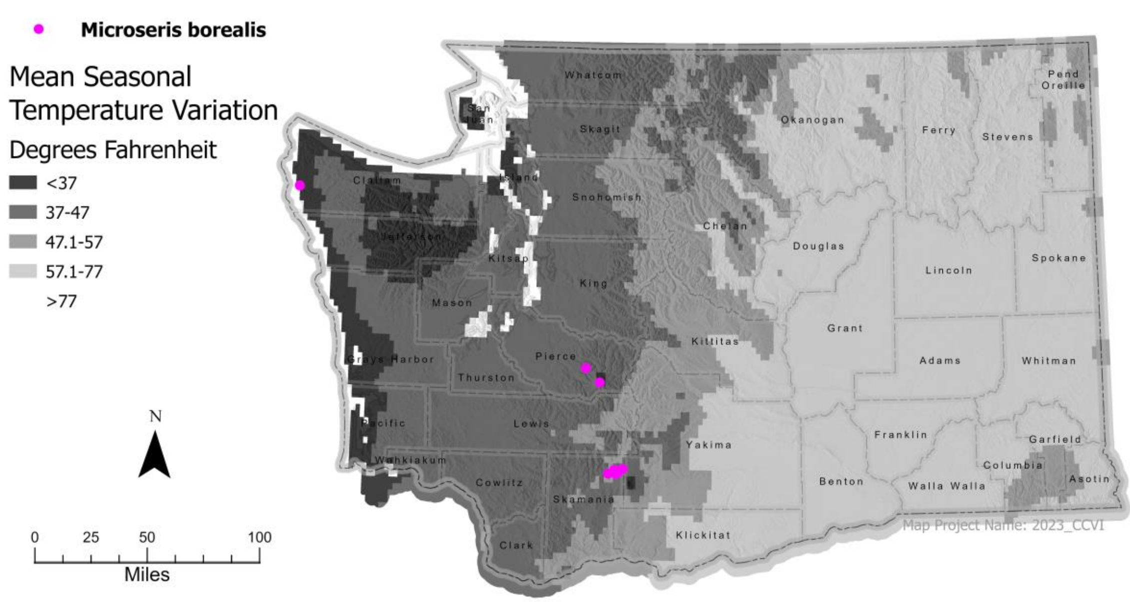


Figure 15. Historical thermal niche (exposure to past temperature variations) of Microseris borealis occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Some populations of *Microseris borealis* are found in peatland ecosystems that are vulnerable to temperature increase as the development and persistence of peatlands are controlled by the balance of precipitation and evaporation. Temperature increases alter

evaporation rates which may result in increased tree encroachment which would result in the conversion of these peatlands into other ecosystem types. Increased temperatures may also alter peat decomposition rates which may result in conversion to non-peat wetland types (Rocchio and Ramm-Granberg 2017). *M. borealis* also occurs in other wetland types such as lake margins and marshes which would also be negatively impacted by rising temperatures, but to a somewhat lesser degree than peatlands.

C2bi. Historical hydrological niche: Neutral.
All known populations of *Microseris borealis* occur in areas of average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm), considered neutral for climate change per the guidance in Young (2016) (Figure 4).

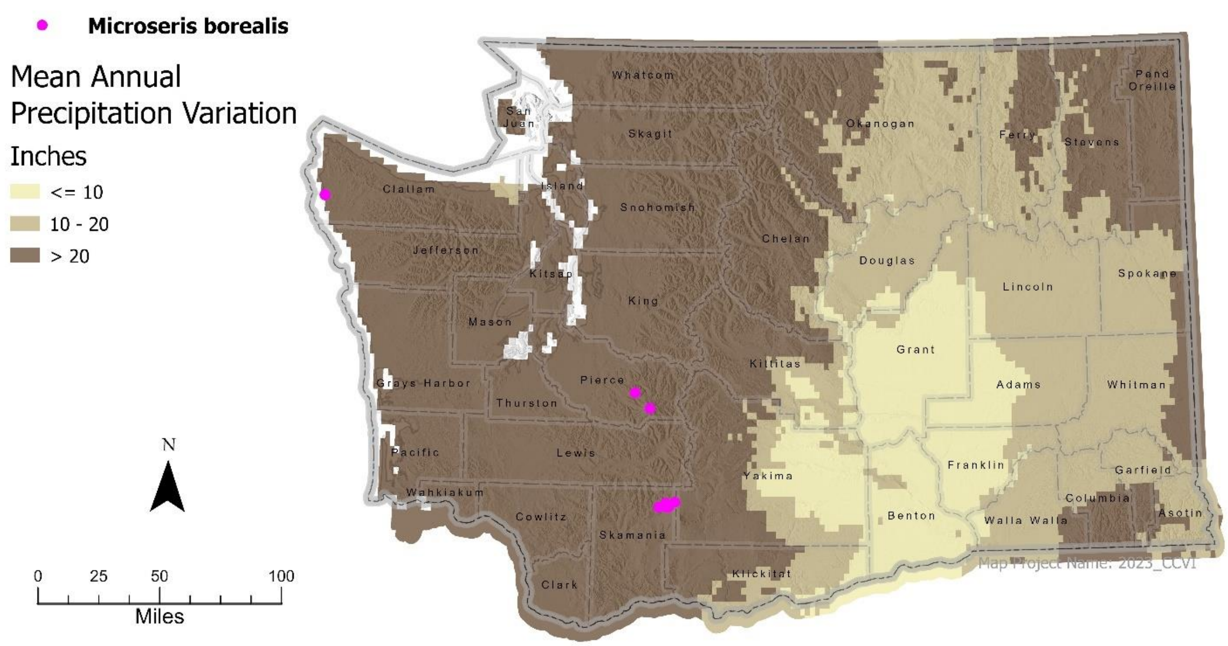


Figure 16. Historical hydrological niche (exposure to past variations in precipitation) of *Microseris borealis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species occurs in a range of wetland environments but are primarily found in peatlands. Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Microseris borealis is not known to be dependent on episodic disturbance regimes.

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

The populations of *Microseris borealis* in Washington are found in areas that receive a high amount of winter precipitation however this precipitation is primarily winter rain. 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.
The wetlands in which *Microseris borealis* is found in Washington are not tied to any uncommon landscape or geologic features.

C4a. Dependence on other species to generate required habitat: Neutral.
The wetland habitats occupied by *Microseris borealis* are maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants
C4c. Pollinator versatility: Neutral.
Little is known about specific pollinators for *Microseris borealis,* however there are no known attributes of this species that would indicate it could not be pollinated by a wide variety of species.

C4d. Dependence on other species for propagule dispersal: Neutral.
Propagules in this species are transported primarily via wind and likely occasionally by adhering to animal fur.

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.
Competition from nonnative species may be a threat to *Microseris borealis* in areas where there has been disturbance allowing nonnative species to invade. Changes in hydrology may also facilitate tree encroachment. (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. *Microseris borealis* is a diploid species (2n=18) (Chambers 1993) but otherwise little is known about measured genetic variation within this species.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Little is known about the reproductive system of *Microseris borealis,* however it it likely to have a mixed mating style which is common in Asteraceae.

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

Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Microseris borealis* has not changed its emergence period since it was first collected in the state.

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 *Microseris borealis* in Washington since it was first collected in the state.

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 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.

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.

Chambers, K. L. 1993. Microseris borealis. pp. 30. In: Flora of North America Editorial Committee. 1993-. Flora of North America North of Mexico. Volume 19 Magnoliophyta, Asteridae (in part): Asteraceae, part 1. Oxford University Press, New York. 475 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.

Washington Natural Heritage Program. 2021. *Microseris borealis*. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Climate Change Vulnerability Index Report

Navarretia leucocephala ssp. *diffusa* (diffuse navarretia)

Date: 11 May 2023 Synonym: *NA*

Assessor: Irene Weber, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G4T1/S1

Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	100
	<3.9° F (2.2°C) warmer	0
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	0
	-0.051 to - 0.073	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		Unknown
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		Greatly Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral to 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	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 of the six occurrences of *Navarretia leucocephala* ssp. *diffusa* in Washington (100%) occur in areas with a projected temperature increase of 3.91-4.4°. (Figure 1).

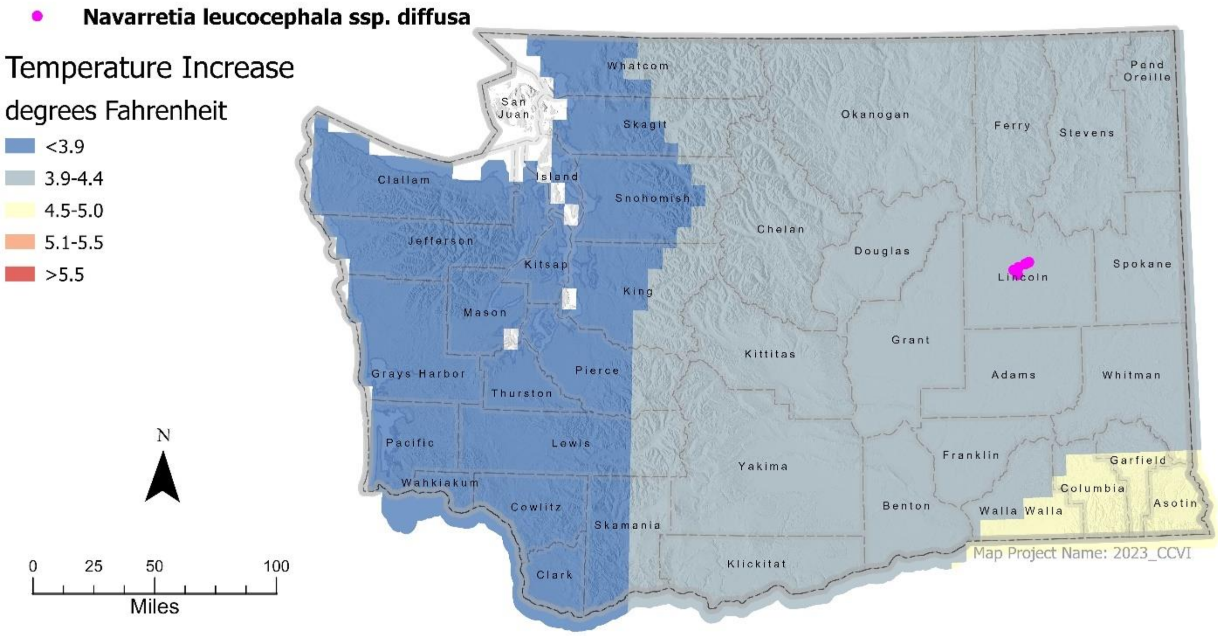


Figure 17. Exposure of *Navarretia leucocephala* ssp. *diffusa* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All of the 6 occurrences (100%) of *Navarretia leucocephala* ssp. *diffusa* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 - -0.073 (Figure 2).

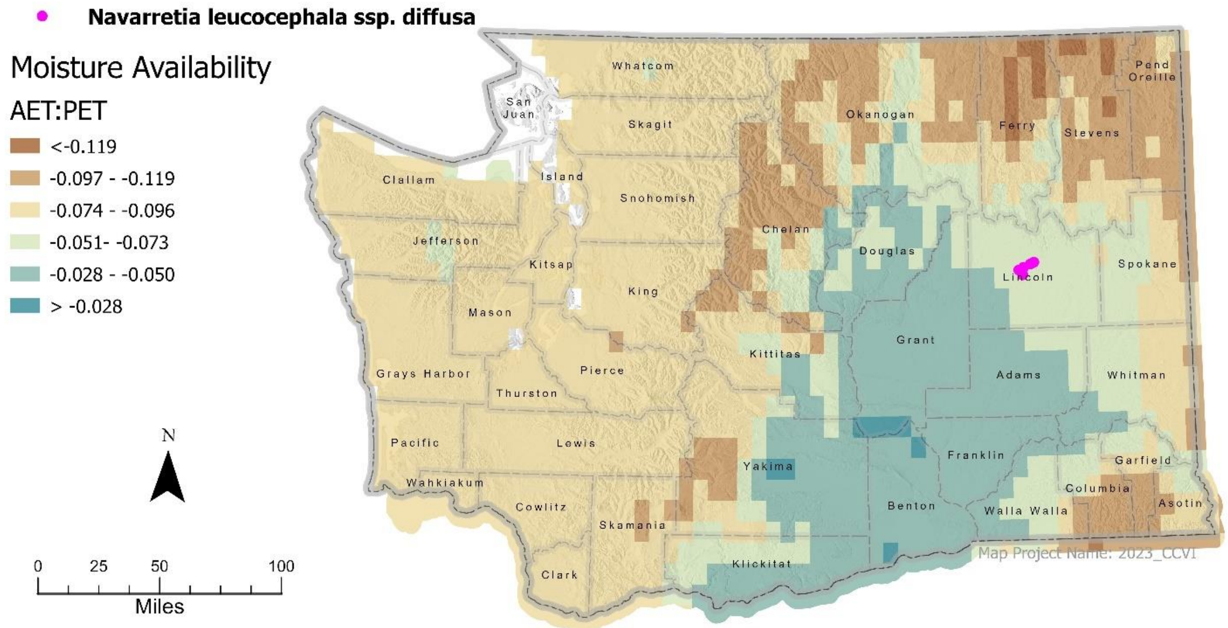


Figure 18. Exposure of *Navarretia leucocephala* ssp. *diffusa* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Navarretia leucocephala* ssp. *diffusa* are found at 2180-2625 feet (665-800 m) and are unlikely to be inundated by projected sea level rise (WNHP 2021).

B2a. Natural barriers: Somewhat Increase.
Navarretia leucocephala ssp. *diffusa* occurs exclusively in vernal pools within the Columbia Plateau Vernal Pool ecological system in Lincoln County (WNHP 2021, Fertig and Kleinknecht 2020). Vernal pools are naturally isolated by surrounding uplands that present a barrier to dispersal. Geographically, this species is restricted to the central channel of the three channels created by the glacial Spokane Flood events and is isolated from subspecies *minima*, which is found in the other channles, by substantial uplands (Bjork 2002).

B2b. Anthropogenic barriers: Neutral.
The range of *Navarretia leucocephala* ssp. *diffusa* is fragmented by anthropogenic infrastructure including tilled agriculture, roads, and rangeland. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with these isolated wetlands.

B3. Predicted impacts of land use changes from climate change mitigation: Unknown.
Section C: Sensitive and Adaptive Capacity
C1. Dispersal and movements: Somewhat Increase.
Navarretia leucocephala ssp. *diffusa* produces 1-2 seeds per small capsule. The capsules are indehiscent and seeds do not disperse until pools refill the following winter or spring (Boose 2005). These populations are endemic to the vernal pools of the central channel of the three channels created by the glacial Spokane Flood events and have not been recorded in vernal pools outside of this channel but seem to be able to disperse along the flood channel (Bjork 2002).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Navarretia leucocephala* ssp. *diffusa* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All of the 6 known occurrences in the state are found in areas that have experienced average (57.1 - 77° F/31.8 -43.0° C) temperature variation in the past 50 years and are considered neutral for climate change per Young (2016).

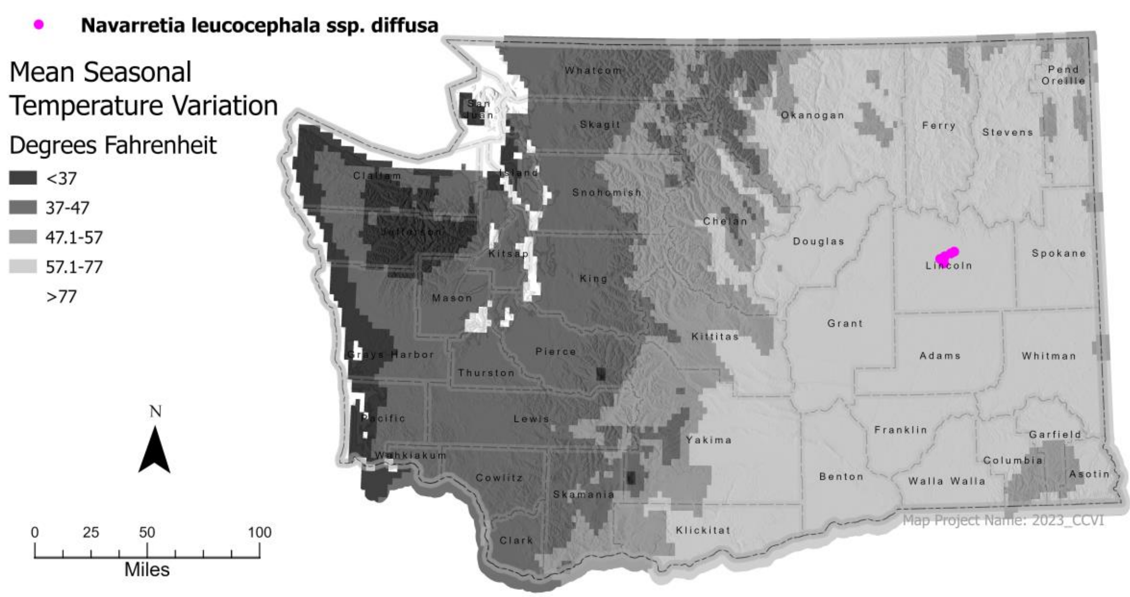


Figure 19. Historical thermal niche (exposure to past temperature variations) of *Navarretia leucocephala* ssp. *diffusa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The vernal pool habitat of *Navarretia leucocephala* ssp. *diffusa* in eastern Washington may be associated with cold soils. These areas could be adversely affected by warmer

temperatures in the future if the evaporation rates of these isolated waterbodies is altered. There is some evidence that *Navarretia leucocephala* ssp. *diffusa* is more drought resistant than other subspecies in the *N. leucocephala* group (Bjork 2002).

C2bi. Historical hydrological niche: Somewhat Increase.
All of the known populations of *Navarretia leucocephala* ssp. *diffusa* are found in areas of slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm) and are a somewhat increased vulnerability due to climate change according to Young et al. (2016).

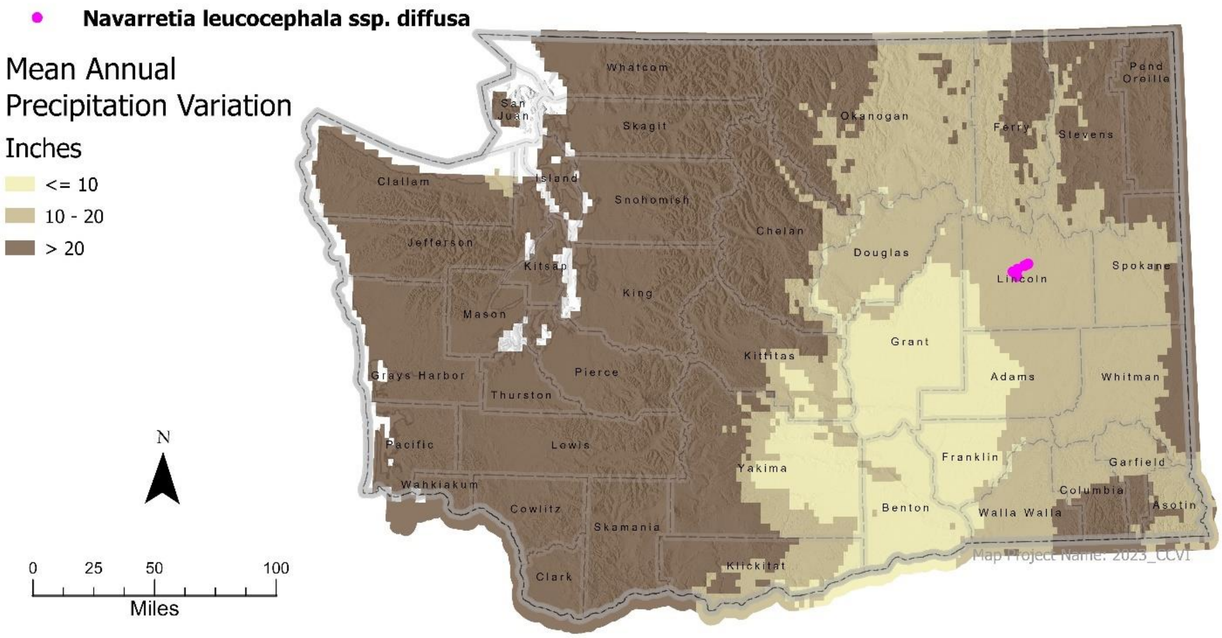


Figure 20. Historical hydrological niche (exposure to past variations in precipitation) of *Navarretia leucocephala ssp. diffusa* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species occurs in vernal pools which are maintained by precipitation. Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Vernal pool species like *Navarretia leucocephala* ssp. *diffusa* are largely adapted to episodic winter/spring flooding from precipitation and snowmelt, followed by seasonal severe drought and desiccation. Future altered precipitation and temperature may alter the hydrology of this site to the detriment of many plant species (Rocchio and Ramm-Granberg 2017, Graham 2016).

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

The populations of *Navarretia leucocephala* ssp. *diffusa* are found at sites from 2180-2625 feet (665-800 m) in elevation and receive low to moderate snowfall. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Navarretia leucocephala ssp. *diffusa* is found exclusively in vernal pools, in very small to rarely large depressions within the exposed, volcanic scablands in one Spokane Flood channel on the Columbia Plateau (Bjork 2002, Rocchio and Crawford 2015).

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal pool habitat occupied by *Navarretia leucocephala* ssp. *diffusa* is maintained largely by abiotic conditions.

C4b. Dietary versatility: Not applicable for plants
C4c. Pollinator versatility: Neutral.
Little is known about the specific pollinators of *Navarretia leucocephala* ssp. *diffusa*. The flower morphology of this species, an inflorescence of 5-30 symmetrical white flowers does not suggest any pollinator limitations.

C4d. Dependence on other species for propagule dispersal: Neutral.
Navarretia leucocephala ssp. *diffusa* produces 1-2 seeds per small indehiscent capsules. Seeds disperse via water when pools refill the following winter or spring (Boose 2005).

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.
Changes in vernal pool hydrology may change plant community structure which may impact this species. Invasive annual grasses are of particular concern in vernal pools. (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.
A study conducted on genetic variation of *N. leucocephala* species in eastern Washington showed that the populations sampled had significant genetic variation both within and between populations. This suggests that although populations of the species are isolated, due to population size and long lasting seed banks, significant genetic diversity is likely maintained (Boose 2005).

C5b. Genetic bottlenecks: Unknown.
Navarretia leucocephala ssp. *diffusa* is a local endemic and has speciated due to isolation from surrounding populations during the catastrophic flooding events 13,000-15,000 years ago but has not experienced significant bottlenecks in the past 500 years.

C5c. Reproductive System: Neutral.
A study of *Navarretia leucocephala* species (Boose 2005) posits that this species likely has a mixed mating system.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP Element Occurrence records, of *Navarretia leucocephala* has not changed its typical emergence period. Records of both *Navarretia leucocephala* ssp. *diffusa* and ssp. *minima* were examined as there are few collections of ssp. *diffusa*.

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 *Navarretia leucocephala* ssp. *diffusa* in Washington since it was described.

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

Björk, C.R. 2002. A new subspecies of Navarretia leucocephala (Polemoniaceae) from vernal pools in eastern Washington. Madroño 49(3):165-168.

Björk, C.R. and P.W. Dunwiddie. 2004. Floristics and distribution of vernal pools on the Columbia Plateau of eastern Washington. Rhodora 106(928):327-347.

Boose, D. L., Harmeling, B. R., & Turcotte, R. T. 2005. Genetic Variation in Eastern Washington Populations of Navarretia Leucocephala (Polemoniaceae) A Vernal Pool Endemic. Madroño, 52(2), 99–106.

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., Kleinknecht J. 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. 177 pp.

Graham, T.B. 2016. Climate change and ephemeral pool ecosystems: Potholes and vernal pools as potential indicator systems. USGS Online publication: https://geochange.er.usgs.gov/sw/impacts/biology/vernal/

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.

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.

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.

Washington Natural Heritage Program. 2021. Navarretia leucocephala ssp. diffusa. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Climate Change Vulnerability Index Report

Pilularia americana (American pillwort)

Date: 1 May 2023 Synonym: *NA*

Assessor: Irene Weber, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S2

Index Result: Moderately Vulnerable Confidence: Low

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	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		Unknown
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		Somewhat Increase
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral to Somewhat increase

3. Restricted to uncommon landscape/geological features	Increase
4a. Dependence on others species to generate required habitat	Neutral
4b. Dietary versatility	Not Applicable
4c. Pollinator versatility	Neutral
4d. Dependence on other species for propagule dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies	Neutral
4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Neutral
Section D	
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 for the seven occurrences of *Pilularia americana* in Washington (100%) occur in areas with a projected temperature increase of 3.91-4.4° F. (Figure 1).

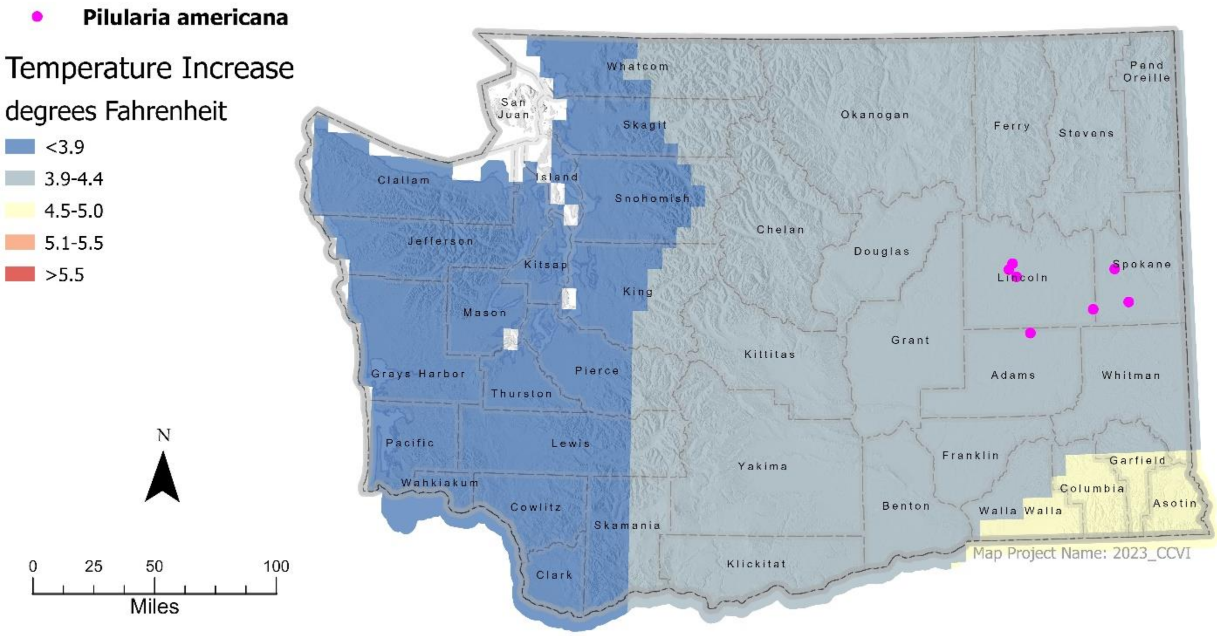


Figure 21. Exposure of *Pilularia americana* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All of the 7 occurrences (100%) of *Pilularia americana* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.051 - -0.073 (Figure 2).

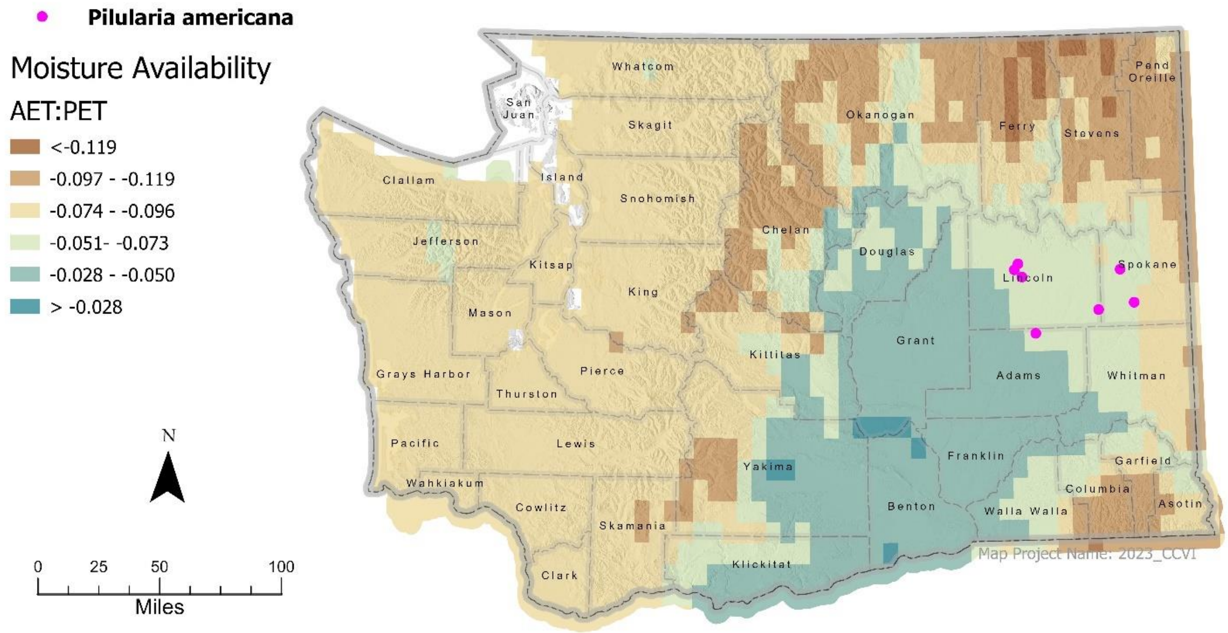


Figure 22. Exposure of *Pilularia americana* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Pilularia americana* are found at 1930-2400 feet (590-730 m) and are unlikely to be inundated by projected sea level rise (Camp and Gamon 2011).

B2a. Natural barriers: Somewhat Increase.
Pilularia americana occurs exclusively in vernal pools within the Columbia Plateau Vernal Pool Ecological System (WNHP 2021, Fertig and Kleinknecht 2020). These vernal pools are naturally isolated by surrounding uplands that present a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.
The range of *Pilularia americana* is fragmented by anthropogenic infrastructure including tilled agriculture, roads, and rangeland. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Pilularia americana reproduce via subterranean sporocarps (Camp and Gamon 2011). Gametes are dispersed through water. The sporocarps may be distributed long distances by waterfowl (Dennis and Webb 1981).

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Pilularia americana* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). All of the 7 known occurrences in the state are found in areas that have experienced average (57.1 - 77° F/31.8 -43.0° C) temperature variation in the past 50 years and are considered neutral for climate change per Young (2016).

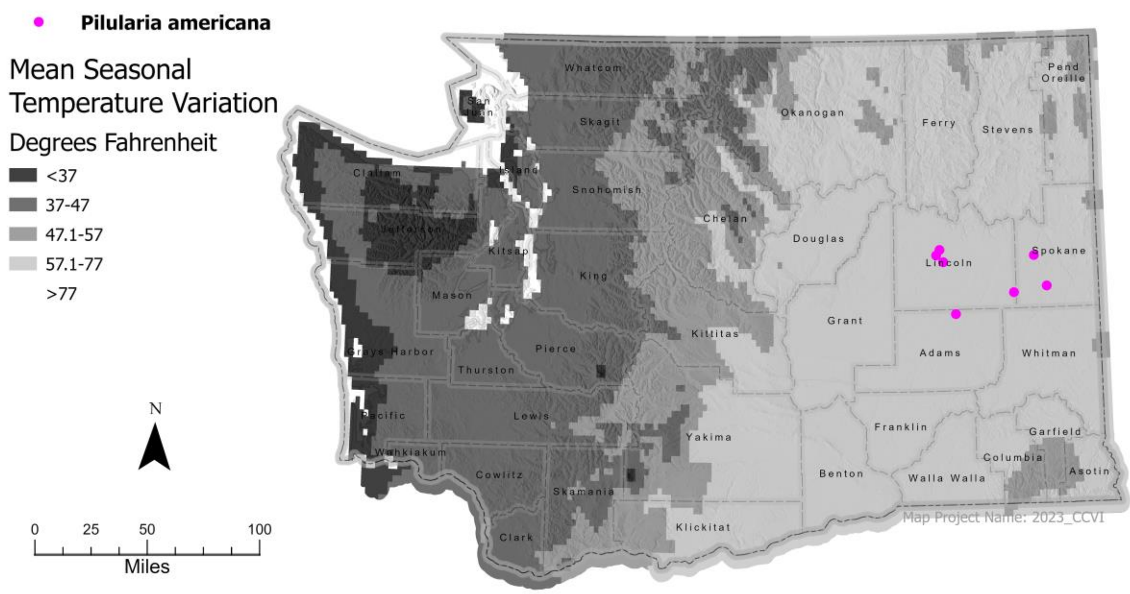


Figure 23. Historical thermal niche (exposure to past temperature variations) of *Pilularia americana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The vernal pool habitat of *Pilularia americana* in eastern Washington may be associated with cold soils. These areas could be adversely affected by warmer temperatures in the future if evaporation rates of these isolated waterbodies are altered.

C2bi. Historical hydrological niche: Somewhat Increased.

All of the known populations of *Pilularia americana* are found in areas of slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm) and are a somewhat increased vulnerability due to climate change according to Young et al. (2016).

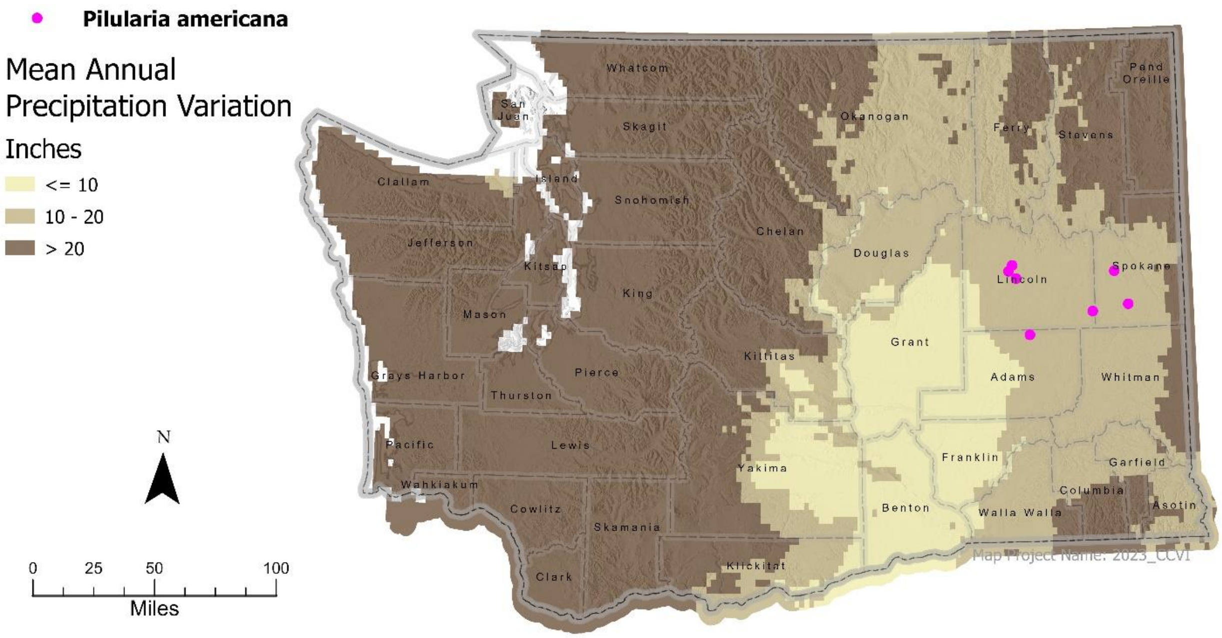


Figure 24. Historical hydrological niche (exposure to past variations in precipitation) of *Pilularia americana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species occurs in vernal pools which are maintained by precipitation and high-water tables. Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Vernal pool species like *Pilularia americana* are largely adapted to episodic winter/spring flooding from precipitation and snowmelt, followed by seasonal severe drought and desiccation. Future altered precipitation and temperature may alter the hydrology of this site to the detriment of many plant species (Rocchio and Ramm-Granberg 2017, Graham 2016).

C2d. Dependence on ice or snow-cover habitats: Neutral to Somewhat increase.
The populations of *Pilularia americana* are found as sites from 1930-2400 feet (590-730 m) in elevation and receive low to moderate winter snowfall. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017).

C3. Restricted to uncommon landscape/geological features: Increase.
Pilularia americana is found exclusively in vernal pools, in very small to rarely large depressions throughout the exposed, volcanic scablands on the Columbia Plateau (Rocchio and Crawford 2015).

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal pool habitat occupied by *Pilularia americana* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Pilularia americana is a fern species that reproduces via spores produced in underground sporocarps and is not reliant on pollinators.

C4d. Dependence on other species for propagule dispersal: Neutral.
Gametes are distributed within individual vernal pools through water. The sporocarps may be distributed long distances by waterfowl (Dennis and Webb 1981).

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.
Changes in vernal pool hydrology may change plant community structure which may impact this species. Invasion by annual grasses is a particular concern for these ecosystems (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. Nagalingum et al (2008) suggests that there are 2 geographically distinct genetic populations of *Pilularia americana* in North America and that there may be some genetic overlap with *P. novae-hollandiae*.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Pilularia americana reproduces both sexually and vegetatively and is not limited by pollinators or dispersal, so is presumed to have average genetic variation.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org) and WNHP element occurrence records, *Pilularia americana* has not changed its typical emergence period however notes from WNHP Element Occurrence

records indicate that in years where vernal pools dried out early or did not fill, *P. americana* populations were not located.

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 *Pilularia americana* in Washington since it was first recorded in the state.

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.

Dennis M. and Webb D.H. 1981. The Distribution of Pilularia americana A. BR. (Marsileaceae) in North America, North of Mexico. SIDA, Contributions to Botany. 9(1):19-24.

Fertig W., Kleinknecht J. 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. 177 pp.

Graham, T.B. 2016. Climate change and ephemeral pool ecosystems: Potholes and vernal pools as potential indicator systems. USGS Online publication: https://geochange.er.usgs.gov/sw/impacts/biology/vernal/

Nagalingum N.S., Nowak M.D., Pryer K.M. 2008. Assessing phylogenetic relationships in extant heterosporous ferns (Salviniales), with a focus on Pilularia and Salvinia. Botanical Journal of the Linnean Society. 157(4):673-685.

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.

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.

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.

Washington Natural Heritage Program. 2021. Pilularia americana. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Climate Change Vulnerability Index Report

Sisyrinchium sarmentosum (pale blue eyed grass)

Date: 18 April 2023 Synonym: formerly included in *S. angustifolium*

Assessor: Irene Weber, 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	94
	<3.9° F (2.2°C) warmer	6
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	13
	-0.074 to - 0.096	81
	-0.051 to - 0.073	6
	-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	Somewhat Increase
Section C	
1. Dispersal and movements	Neutral
2ai Change in historical thermal niche	Increase
2aii. Change in physiological thermal niche	Somewhat Increase
2bi. Changes in historical hydrological niche	Neutral
2bii. Changes in physiological hydrological niche	Greatly Increase
2c. Dependence on specific disturbance regime	Somewhat Increase
2d. Dependence on ice or snow-covered habitats	Somewhat Increase
3. Restricted to uncommon landscape/geological features	Neutral

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	Not Applicable (Unknown)
5c. Reproductive system	Not Applicable (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: One of the 16 extant and historical occurrences of *Sisyrinchium sarmentosum* in Washington (6%) occurs in an area with a projected temperature increase of <= 3.9°F. The remaining 15 occurrences (94%) occur in areas with a projected temperature increase of 3.9-4.4˚F (Figure 1).

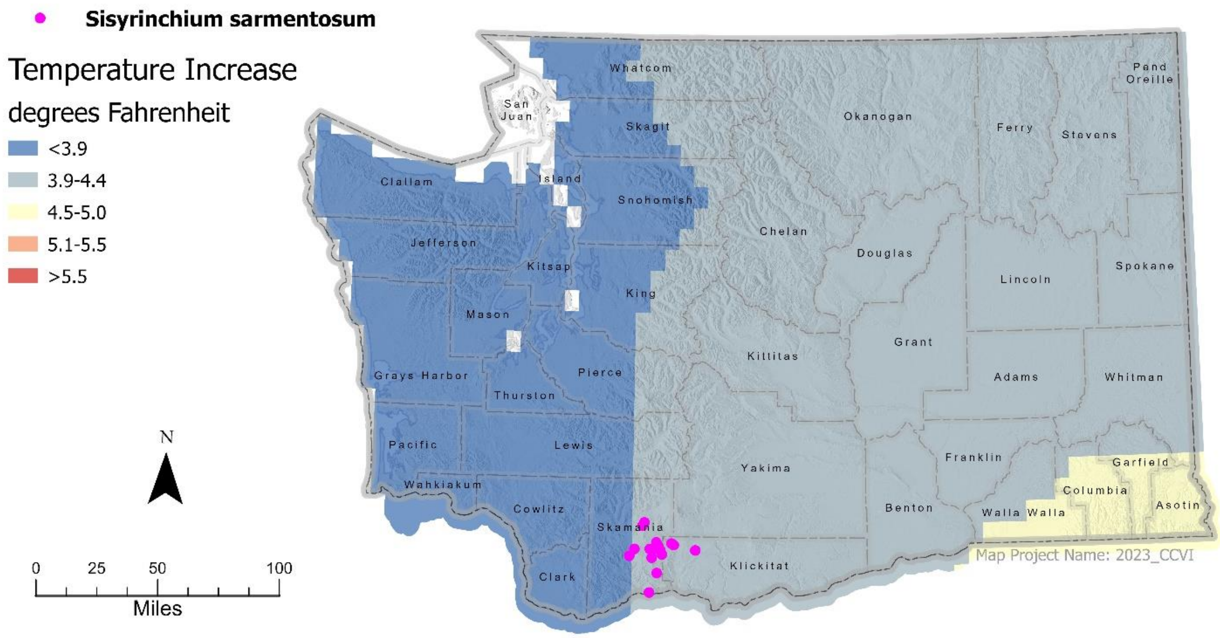


Figure 25. Exposure of *Sisyrinchium sarmentosum* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the 16 occurrences (13%) of *Sisyrinchium sarmentosum* 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). Thirteen occurrences (81%) are in areas with projected decrease of -0.074 - -0.096, 1 occurrence (6%) is in an area with projected decrease of -0.051 - -0.073. (Figure 2)

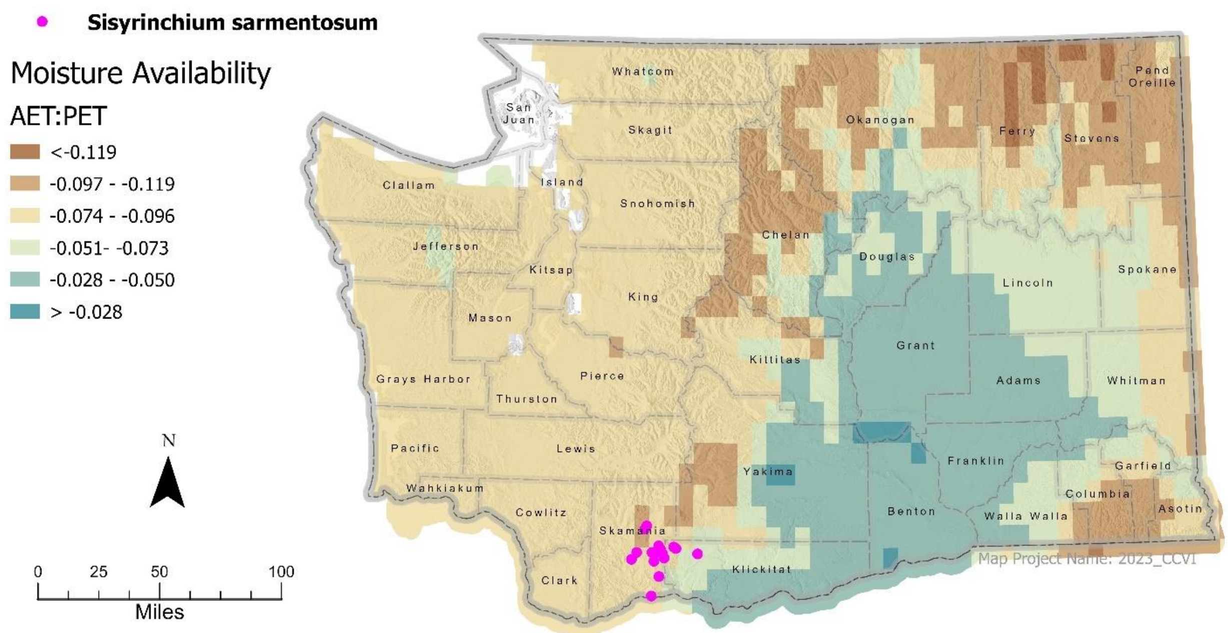


Figure 26. Exposure of *Sisyrinchium sarmentosum* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change
B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Sisyrinchium sarmentosum* are found at 365-5700 feet (100-1700 m) and are unlikely to be inundated by projected sea level rise.

B2a. Natural barriers: Somewhat Increase.
Sisyrinchium sarmentosum occurs primarily in seasonally moist wet meadows and in small forest openings (Camp and Gamon 2011). This species is a regional endemic of southern Washington (Klickitat and Skamania counties) and northern Oregon. Habitat may be limited to shallow catchments and porous geologic substrate where flooding/drying hydrologic events can occur (Fertig 207). Surrounding uplands restrict spread of this species across watersheds. Populations are separated by 1-28 mi (2-45 km).

B2b. Anthropogenic barriers: Neutral.
The range of *Sisyrinchium sarmentosum* is fragmented by anthropogenic infrastructure including tilled agriculture, rangeland, timberland, roads, and towns (to a lesser extent). Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands and waterways.

B3. Predicted impacts of land use changes from climate change mitigation: Somewhat Increase. *Sisyrinchium sarmentosum* occurs in openings within forests. Encroachment from woody species is a known threat to *S. sarmentosum* survival. Reforestation or reduction in certain logging practices within this species' habitat may decrease these openings.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.

Sisyrinchium sarmentosum produces seeds in capsules that split open at maturity (Camp and Gamon 2011). Dispersal mechanisms of this plant are unknown. This species may be distributed via ungulate browse or by water, but there is no evidence to support or refute this theory (Ruchty 2010). Seed dispersal does not appear to be a major inhibitor to this species persistence.

C2ai. Historical thermal niche: Increase.

Figure 3 depicts the distribution of *Sisyrinchium sarmentosum* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). One of the 16 known occurrences in the state (6%) is found in an area that have experienced average (57.1 - 77° F/31.8 -43.0° C) temperature variation in the past 50 years. Nine known occurrences (56%) are found in areas that have experienced slightly lower than average (47.1-57˚F/26.3-31.8˚C) temperature variation during the past 50 years and are considered at somewhat increased vulnerability to climate change (Young et al. 2016). The six other occurrences (38%) 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. Per the guidance in Young (2016), Increased Vulnerability was selected as more than 10% of the occurrences fell within this category.

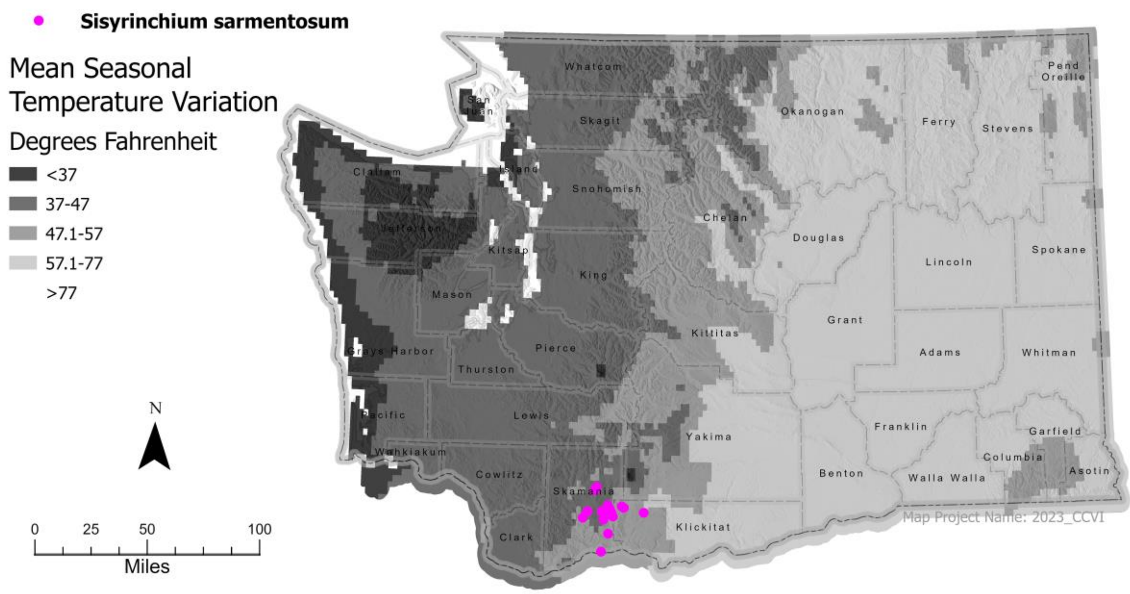


Figure 27. Historical thermal niche (exposure to past temperature variations) of *Sisyrinchium sarmentosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The shallow wetland habitat of *Sisyrinchium sarmentosum* in eastern Washington may be associated with cold soils and cool air drainage. These areas could be adversely affected by warmer temperatures in the future.

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Sisyrinchium sarmentosum* occur in areas of 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.

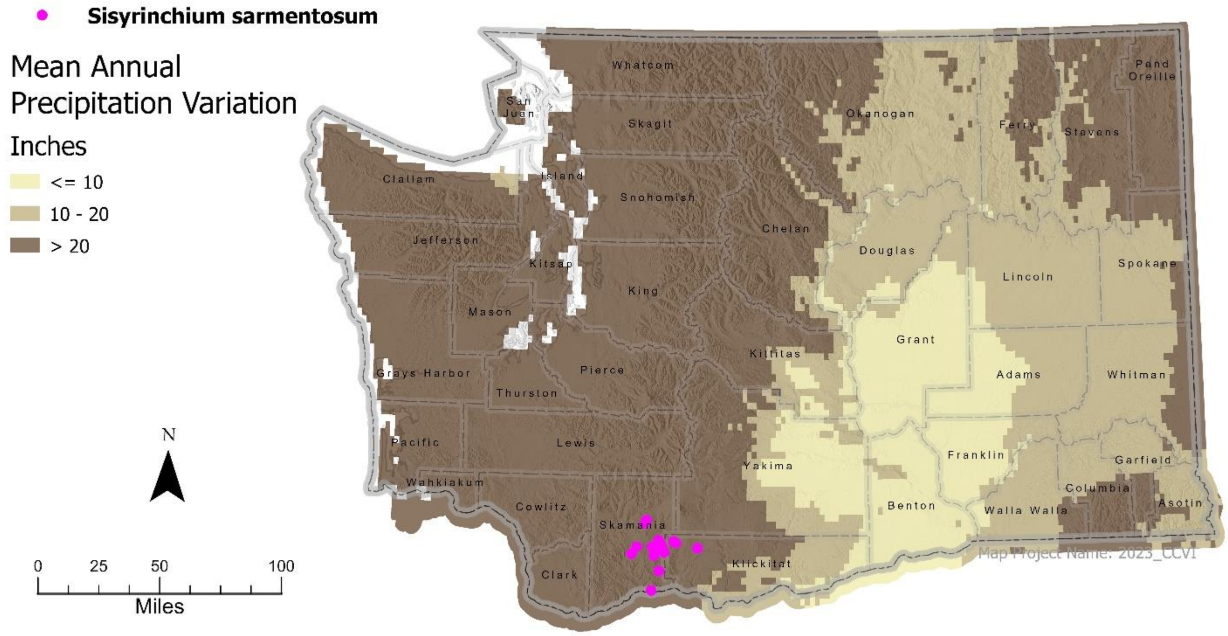


Figure 28. Historical hydrological niche (exposure to past variations in precipitation) of *Sisyrinchium sarmentosum* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species occurs in wet meadow environments that hold moisture during the winter and spring (Camp and Gamon 2011). Changes in the amount and timing of precipitation and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Sisyrinchium sarmentosum may be adapted to small-scale disturbances such as localized fires or windstorms (Fertig 2017). A reduction in fire severity would lead to woody species encroachment, a known stressor for this species. Alternatively, this species may not be adapted to intense or frequent fire.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Sisyrinchium sarmentosum occursin wet meadows that are seasonally flooded in late spring, often from late snow melt (Fertig 2017). 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.
Sisyrinchium sarmentosum may be restricted to porous geologic substrates where a flooding/drying hydrologic environment is possible (Fertig 2017). This species is found

primarily in areas where the underlaying geology is volcanic rocks and deposits, basalt flows, or alpine glacial till (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The wet meadow habitat occupied by *Sisyrinchium sarmentosum* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants
C4c. Pollinator versatility: Neutral.
Sisyrinchium sarmentosum has been observed to have a variety of pollinators including Megachilid and Andrenid bees (Ruchty 2010, Reagan 2018). The morphology of this plant does not suggest pollinator limitation.

C4d. Dependence on other species for propagule dispersal: Neutral.
Sisyrinchium sarmentosum dispersal is not fully understood. This species may be distributed via ungulate browse or by water, but there is no evidence to support or refute this theory (Ruchty 2010). There is little evidence to suggest that this species is limited by propagule dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Non-native species are a documented threat to *Sisyrinchium sarmentosum* in many of the known populations within Washington. Canada thistle (*Cirsium arvense*), tansy ragwort (*Jacobaea vulgaris*) and common houndstongue (*Cynoglossum officinale*) have all been documented as serious stressors to these populations (Reagan 2018). These species are unlikely to decline under climate change as they are highly adaptable. *Sisyrinchium sarmentosum* is also threatened by encroachment by native woody species. Changes in hydrology or fire frequency may increase invasions of nonnative and native species into these ecosystems which may impact this 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: Somewhat Increase.
There is inconsistent information and considerable uncertainty about the genetic variation of *Sisyrinchium sarmentosum*. Overall genetic variability may be low, with the greatest variability between the Oregon and Washington populations. *S. sarmentosum* may be hybridizing with *S. idahoensis* but the extent to which this occurs is also unclear (Reagan 2018). As some studies point to genetic variation in *Sisyrinchium sarmentosum* being low, as well as the potential to hybridize with *S. idahoensis,* this species is likely at somewhat increased vulnerability due to these genetic factors.

C5b. Genetic bottlenecks: NA (Unknown).

Per Young (2016) this metric is not applicable if C5a. Measured genetic variation has been scored. It has been hypothesized that *Sisyrinchium sarmentosum* has recently gone through a genetic bottleneck while it was differentiating as a species (Wilson et al. 2000).

C5c. Reproductive System: NA (Neutral).
Per Young (2016) this metric is not applicable if C5a. Measured genetic variation and/or C5b. Genetic bottlenecks have been scored. *Sisyrinchium sarmentosum* reproduces through both sexual and asexual reproduction (Reagan 2018).

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral. Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Sisyrinchium sarmentosum* 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 *Sisyrinchium sarmentosum* in Washington since it was first discovered in the state.

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., Kleinknecht J. 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. 177 pp.

Fertig, W. 2017. Status review of Sisyrinchium sarmentosum. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. 10 pp.

Reagan, K. 2018. Species status assessment for Sisyrinchium sarmentosum. Version 1.0. Washington Fish and Wildlife Office, US Fish and Wildlife Service, Lacey, WA. 95 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.

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.

Ruchty, A. 2010. Conservation strategy for Sisyrinchium sarmentosum Suks. Ex. Greene. USDA Forest Service Region 6, Oregon and Washington and USDI Bureau of Land Manageent, Oregon and Washington. May 2010.

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

Wilson, B.L., D. L. Doede and V. D. Hipkins. 2000. Isozyme variation in Sisyrinchium sarmentosum (Iridaceae). Northwest Science. 74(4): 342-354.

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

Spiranthes porrifolia (western ladies' tresses)

Date: 13 April 2023

Synonym: *S. romanzoffiana* var. *porrifolia*

Assessor: Irene Weber, 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	83
	<3.9° F (2.2°C) warmer	17
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	17
	-0.074 to - 0.096	39
	-0.051 to - 0.073	9
	-0.028 to -0.050	35
	>-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		Unknown
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		Greatly Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		Neutral to 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 ChangeA1. Temperature: Four of the 23 extant and historical occurrences of *Spiranthes porrifolia* in Washington (17%) occur in areas with a projected temperature increase of <= 3.9°. The remaining 19 occurrences (83%) occur in areas with a projected temperature increase of 3.9-4.4˚ (Figure 1).

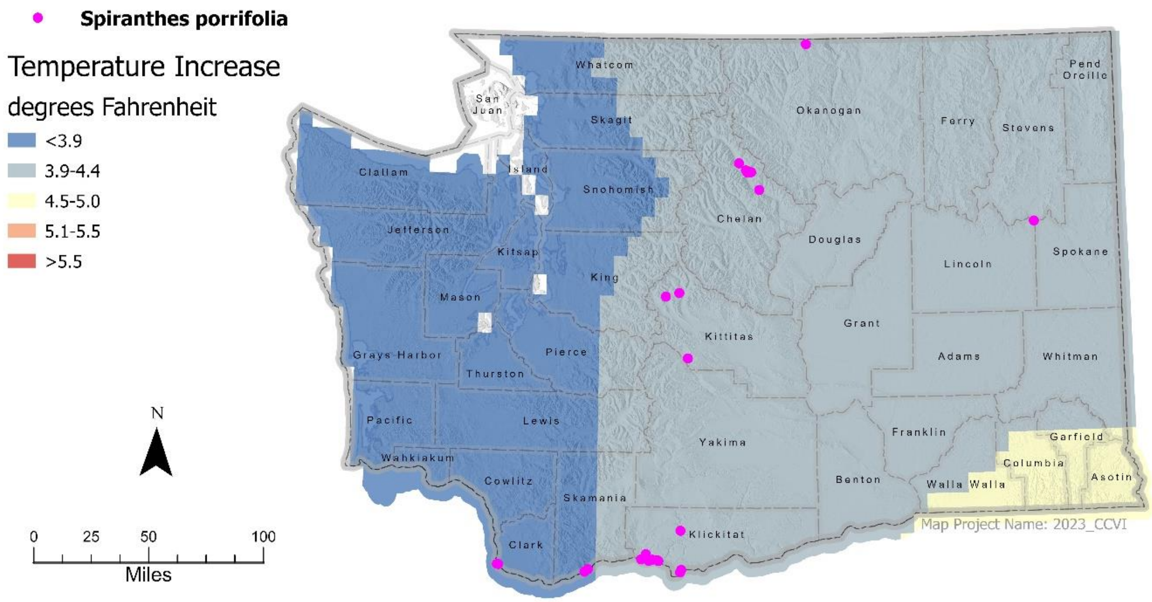


Figure 29. Exposure of *Spiranthes porrifolia* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the 23 occurrences (17%) of *Spiranthes porrifolia* 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). Nine occurrences (39%) are in areas with projected decrease of -0.074 - -0.096, 2 occurrences (9%) are in areas with projected decrease of -0.051 - -0.073. The remaining 8 occurrences (35%) are in areas with projected decrease of -0.028 - .0.05. (Figure 2)

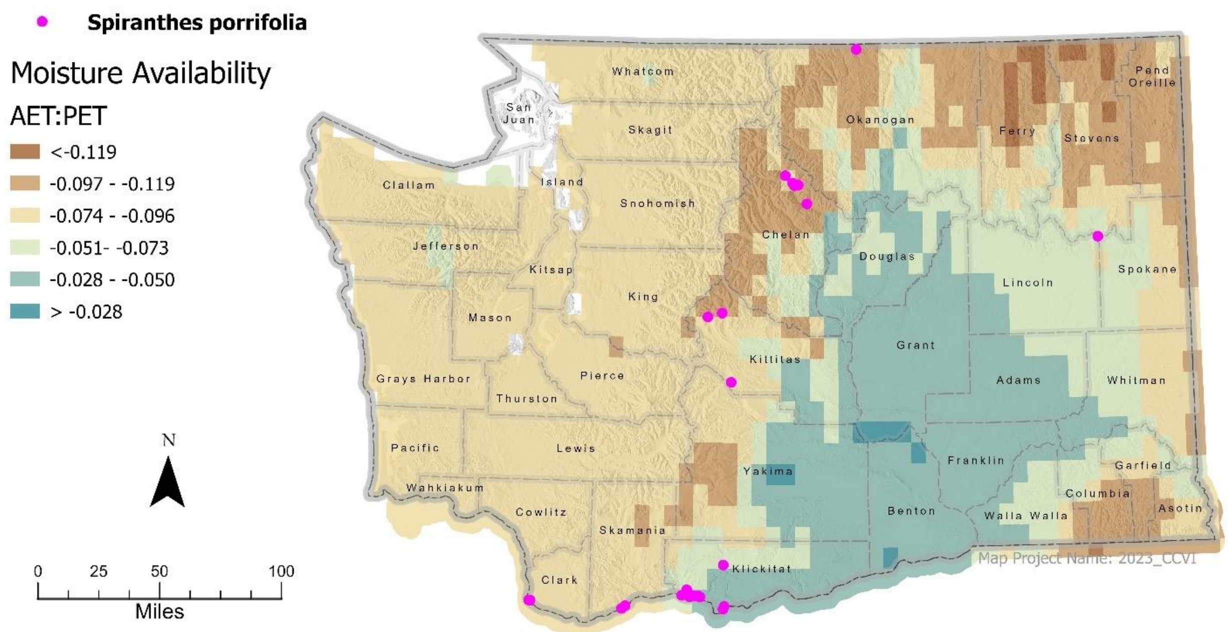


Figure 30. Exposure of *Spiranthes porrifolia* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Spiranthes porrifolia* are found at 10-6800 feet (3-2075 m) and are unlikely to be inundated by projected sea level rise. Thirteen occurrences are located near sea level along the Columbia River, however these are approximately 95 mi (145 km) inland.

B2a. Natural barriers: Somewhat Increase.
Spiranthes porrifolia occurs primarily in wet meadows, fens, streams, and seepage slopes (Camp and Gamon 2011). This habitat is part of the Columbia Basin Foothill Riparian Woodland & Shrubland; Modoc Basalt Flow Vernal Pool; Northern Columbia Plateau Basalt Pothole Ponds; Rocky Mountain Subalpine-Montane Fen, and Willamette Valley Wet Prairie ecological systems (Fertig and Kleinknecht 2020). Populations are separated by 1-120 mi (1-193 km). Most populations in Washington are associated with wetland areas and are naturally isolated by intervening uplands that present a barrier to dispersal between watersheds.

B2b. Anthropogenic barriers: Neutral.
The range of *Spiranthes porrifolia* is fragmented by anthropogenic infrastructure including tilled agriculture, roads, dams, and cities. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands and waterways.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Neutral.
Spiranthes porrifolia produces small seeds in dry capsules that split open at maturity (Camp and Gamon 2011). Seeds are passively dispersed by gravity, wind, or flowing water. These seeds lack structures such as wings or barbs that assist with dispersal but are very light and may be transported by wind moderate distances.

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the distribution of *Spiranthes porrifolia* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Nine of the 23 known occurrences in the state (39%) are found in areas that have experienced average (57.1 - 77° F/31.8 -43.0° C) temperature variation in the past 50 years and are considered neutral for climate change per Young (2016). Eleven known occurrences (48%) 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 (13%) are from areas that have had a small variation (37-

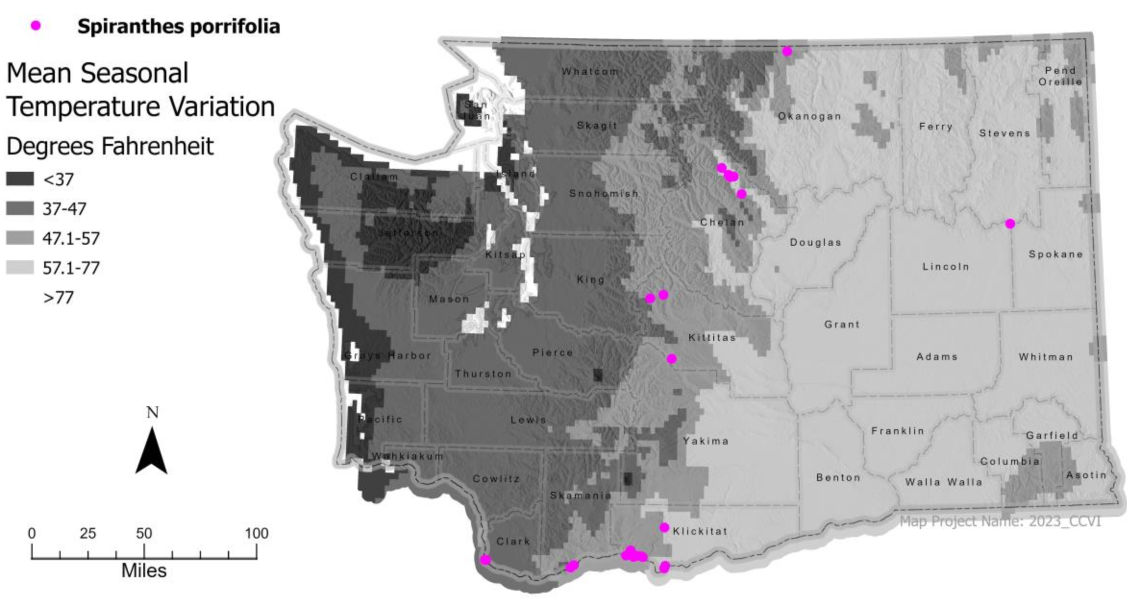


Figure 31. Historical thermal niche (exposure to past temperature variations) of *Spiranthes porrifolia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

47˚F/20.8-26.3˚C) in temperature over the same period and are at increased vulnerability to climate change. Per the guidance in Young (2016), this species would be scored as at somewhat increased vulnerability due to climate change for this metric as most occurrences are within that range.

C2aii. Physiological thermal niche: Somewhat Increase.
The riverbank, pond, and wetland habitat of *Spiranthes porrifolia* in eastern Washington may be associated with cold soils and cool air drainage. These areas could be adversely affected by warmer temperatures in the future.

C2bi. Historical hydrological niche: Neutral.
The majority of the known populations of *Spiranthes porrifolia* (16 of 23; 70%) occur in areas of average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm), neutral for climate change (Figure 4). The remaining 7 occurrences (30%) are found in areas of slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm) and are a slightly increased vulnerability due to climate change. According to Young et al. (2016), this species is neutral for climate change as the majority of occurrences are found in areas of average or greater than average precipitation.

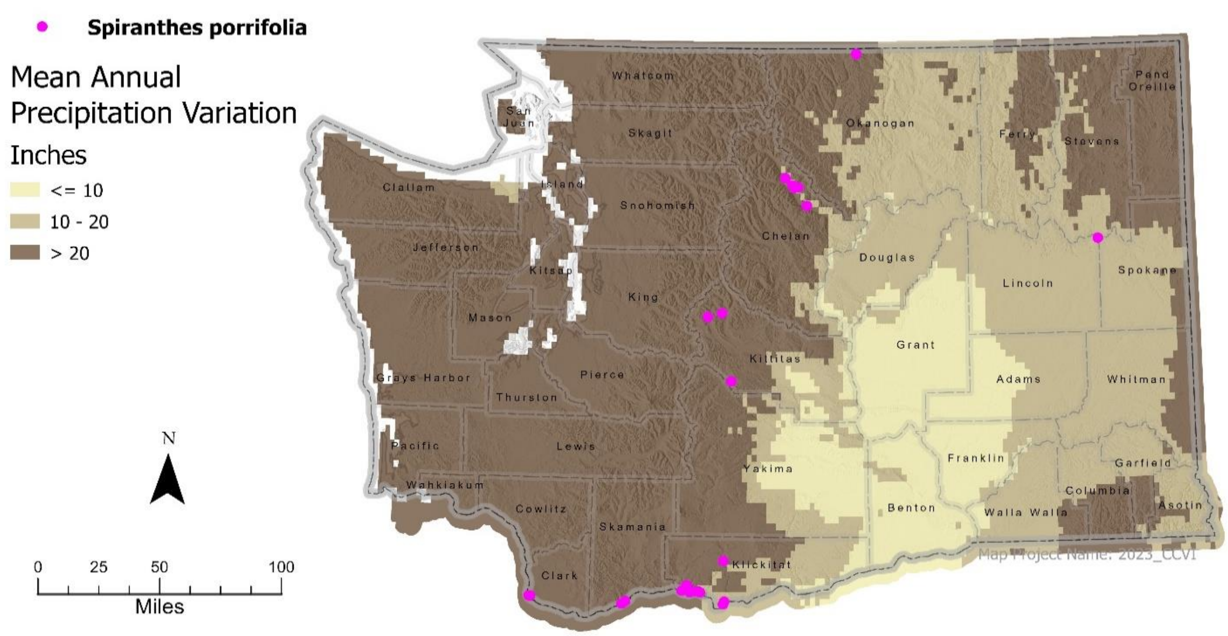


Figure 32. Historical hydrological niche (exposure to past variations in precipitation) of *Spiranthes porrifolia* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species occurs in wide-range wetland environments which are maintained by precipitation and high-water tables. Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought

(Rocchio and Ramm-Granberg 2017). River and pond shore populations way also be vulnerable to changes in the amount or timing of precipitation, including upstream snowmelt and increased temperatures that would exacerbate drought (Rocchio and Ramm-Granberg 2017). *Spiranthes porrifolia* can remain dormant in the soil for several years in drought conditions which may increase short term survival of populations but is unlikely to significantly reduce risk under prolonged climate driven changes to hydrologic conditions.

C2c. Dependence on a specific disturbance regime: Neutral.
Spiranthes porrifolia is not known to be dependent on episodic disturbance regimes however, the related *Spiranthes diluvialis* is an early successional species, and seems to do best in sites where periodic low-intensity disturbance keeps competing vegetation at bay. *S. porrifolia* might be similar in this regard (Fertig, personal communication, April 20 2023).

C2d. Dependence on ice or snow-cover habitats: Neutral to Somewhat increase.
The populations of *Spiranthes porrifolia* are found as sites from 10-6800 feet (3-2075 m) in elevation, suggesting the species is not dependent on winter snowfall. Reduced snowpack due to climate change would decrease the amount of moisture available through runoff (Rocchio and Ramm-Granberg 2017)

C3. Restricted to uncommon landscape/geological features: Neutral.
Spiranthes porrifolia is found on a variety of widespread landscape and geologic features including Columbia River basalt, quaternary alluvium, and tertiary continental sedimentary rocks (Washington Division of Geology and Earth Resources 2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The wetland habitat occupied by *Spiranthes porrifolia* is maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Spiranthes species are pollinated by a variety of native bees (Catling 1983; Pierson et al. 2000). Climate impacts to native bee populations would likely impact *S. porrifolia*.

C4d. Dependence on other species for propagule dispersal: Neutral.
Seeds are very fine and 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.
Competition from invasives species is a known threat to *Spiranthes porrifolia* (Washington Natural Heritage Program 2021). Changes in hydrology or fire frequency may increase invasions of nonnative species into these ecosystems which may impact

this species (Rocchio and Ramm-Granberg 2017). At least one occurrence has a high cover of *Rubus bifrons* (Himalayan blackberry), an invasive species.

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

C5a. Measured genetic variation: Unknown.
Not known. Pace and Cameron (2019) report that *Spiranthes porrifolia* is a diploid or triploid (2n = 44-66) indicating some uncertainty in the genetic variation of this species. If the same population of *S. porrifolia* had both diploid and triploid plants, these would not be inter-fertile, which would reduce overall fecundity.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.
Spiranthes porrifolia appears to either have a mixed mating system or is 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), *Spiranthes porrifolia* 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 *Spiranthes porrifolia* in Washington since it was first discovered in the state.

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.

Catling, Paul M. 2011. Pollination of northeastern North American Spiranthes (Orchidaceae). Canadian Journal of Botany. 61(4): 1080-1093. https://doi.org/10.1139/b83-116

Fertig W., Kleinknecht J. 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. 177 pp.

Pace M.C. and K.M. Cameron. 2019. The evolutionary and systematic significance of hybridization between taxa of Spiranthes (Orchidaceae) in the California Sierra Nevada and Cascade Range. TAXON 68(2):199–217.

Pierson, Kim; Tepedino, Vincent J.; Sipes, Sedonia; Kuta, Kim. 2001. Pollination ecology of the rare orchid, Spiranthes diluvialis: Implications for conservation. In: Maschinski, Joyce; Holter, Louella, tech. eds. Southwestern rare and endangered plants: Proceedings of the Third Conference; 2000 September 25-28; Flagstaff, AZ. Proceedings RMRS-P-23. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 153-164.

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.

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.

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

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

Washington Natural Heritage Program. 2021. *Spiranthes porrifolia*. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Sullivantia oregana S. Watson (Oregon coolwort)

Date: 18 April 2023 Synonym: NA

Assessor: Irene Weber, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G2/S1

Index Result: Moderately Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

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

4a. Dependence on others species to generate required habitat	Neutral
4b. Dietary versatility	Not Applicable
4c. Pollinator versatility	Neutral
4d. Dependence on other species for propagule dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies	Neutral
4f. Sensitivity to competition from native or non-native species	Neutral
4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Somewhat Increase
5c. Reproductive system	Not Applicable (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: Only two occurrences of *Sullivantia oregana* occur in Washington and are within close proximity to each other (~1.3 km). Both (100%) occur in areas with a projected temperature increase of <3.9˚F (Figure 1).

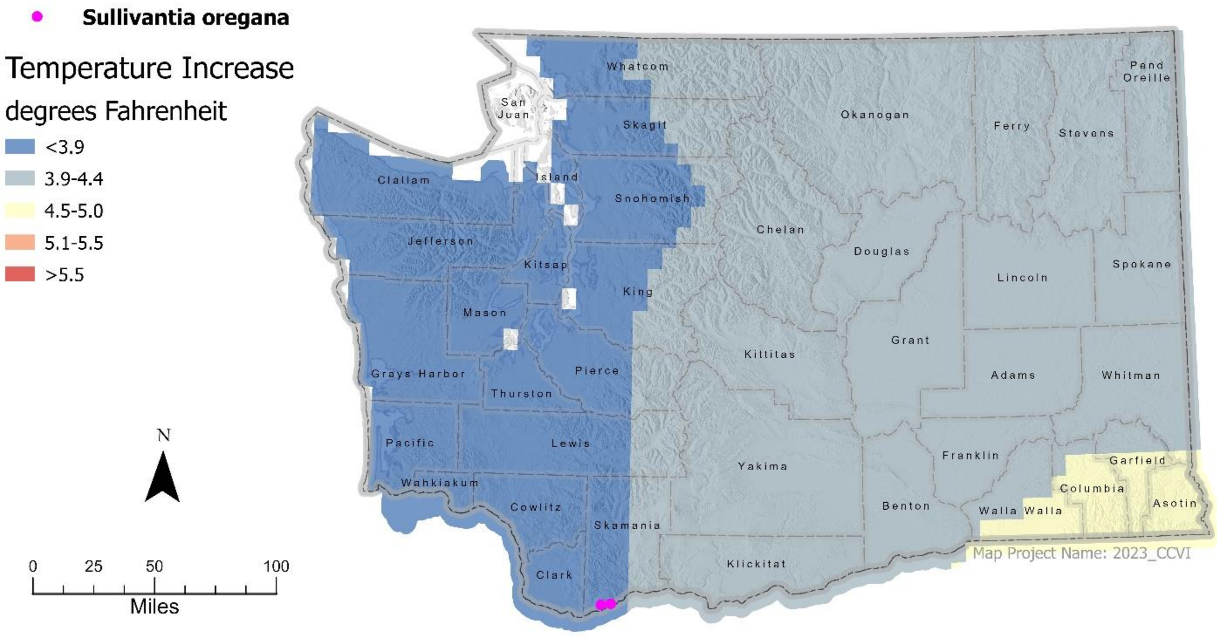


Figure 33. Exposure of *Sullivantia oregana* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Both occurrences of *Sullivantia oregana* occur in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 - -0.096 (Figure 2).

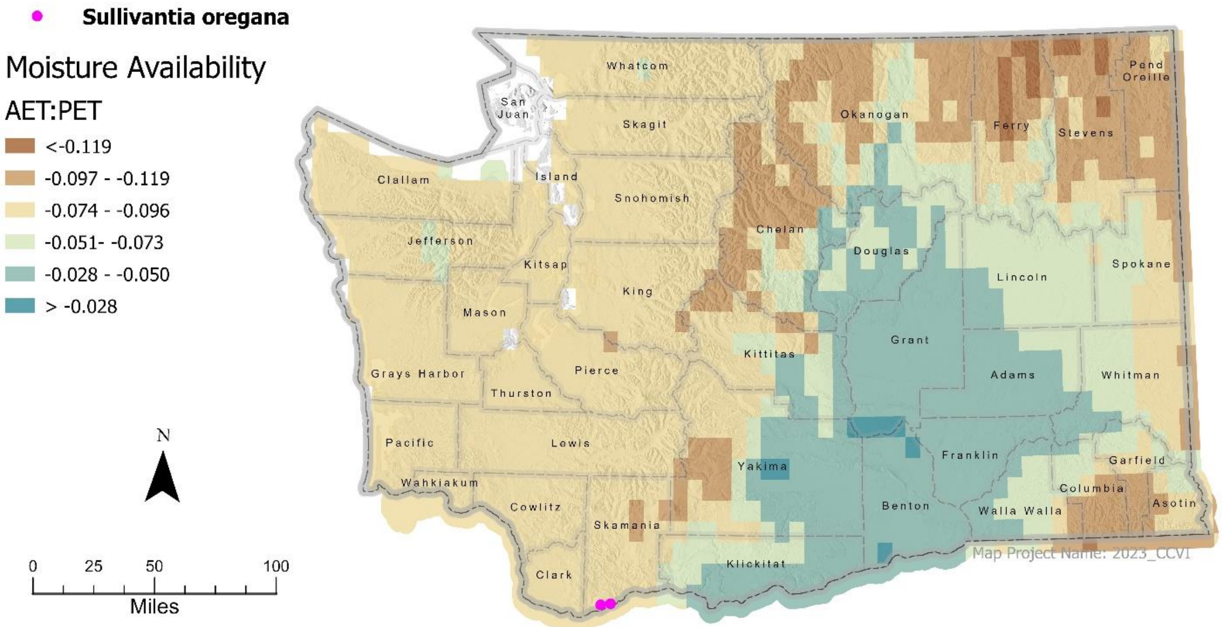


Figure 34. Exposure of *Sullivantia oregana* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change
B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Sullivantia oregana* are found at 70-520 feet (240-1700 m) and are unlikely to be inundated by projected sea level rise.

B2a. Natural barriers: Increase.
Sullivantia oregana is naturally restricted to moist basalt cliffs, seepy rock faces, and spray zones of waterfalls (Camp and Gamon 2011). This habitat is inherently limited. Surrounding uplands and the Columbia River restrict spread of this species. The two populations in Washington are separated by .75 mi (1.2 km).

B2b. Anthropogenic barriers: Neutral.
The range of *Sullivantia oregana* is fragmented by anthropogenic infrastructure, primarily roads. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated cliff habitat.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.
Climate change mitigation is unlikely to occur in *Sullivantia oregana* habitat.

Section C: Sensitive and Adaptive Capacity
C1. Dispersal and movements: Neutral.

Sullivantia oregana produces small seeds in capsules (Camp and Gamon 2011, Soltis 1991). Dispersal mechanisms of this plant are unknown but due to its habitat, seeds are likely dispersed primarily by gravity and water. Seed dispersal does not appear to be a major inhibitor to this species persistence.

C2ai. Historical thermal niche: Increase.
Figure 3 depicts the distribution of *Sullivantia oregana* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). The two occurrences in Washington are found in 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 (Young et al. 2016).

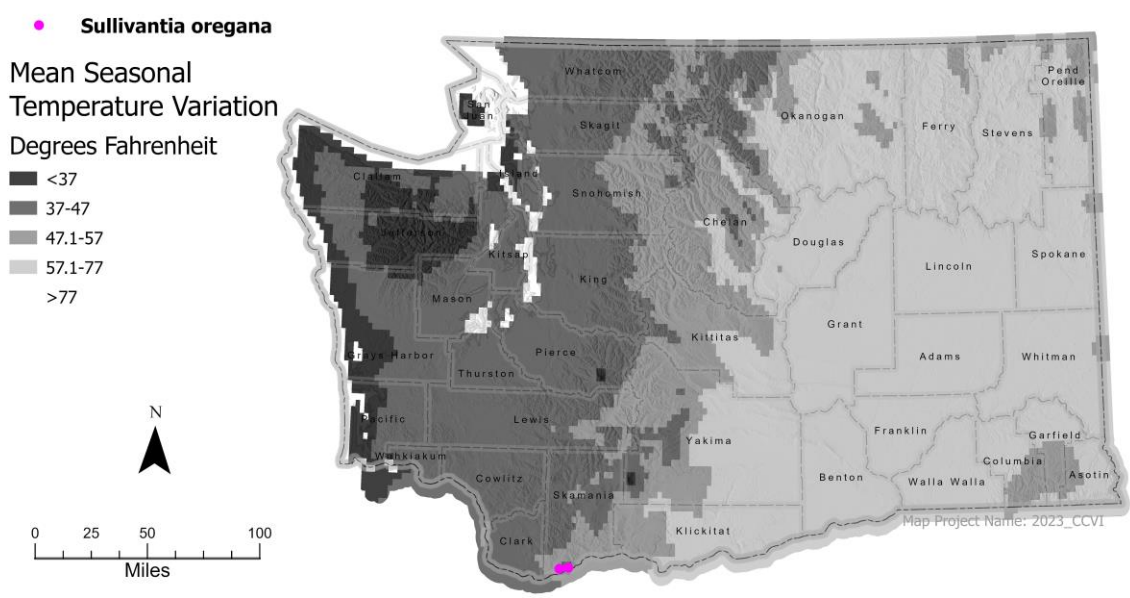


Figure 35. Historical thermal niche (exposure to past temperature variations) of Sullivantia oregana occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
The moist cliff habitat of *Sullivantia oregana* may be associated with cool air. Warming temperatures that alter the cool moist conditions of these sites could adversely affect these species.

C2bi. Historical hydrological niche: Neutral.
All of the known populations of *Sullivantia oregana* occur in areas of 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.

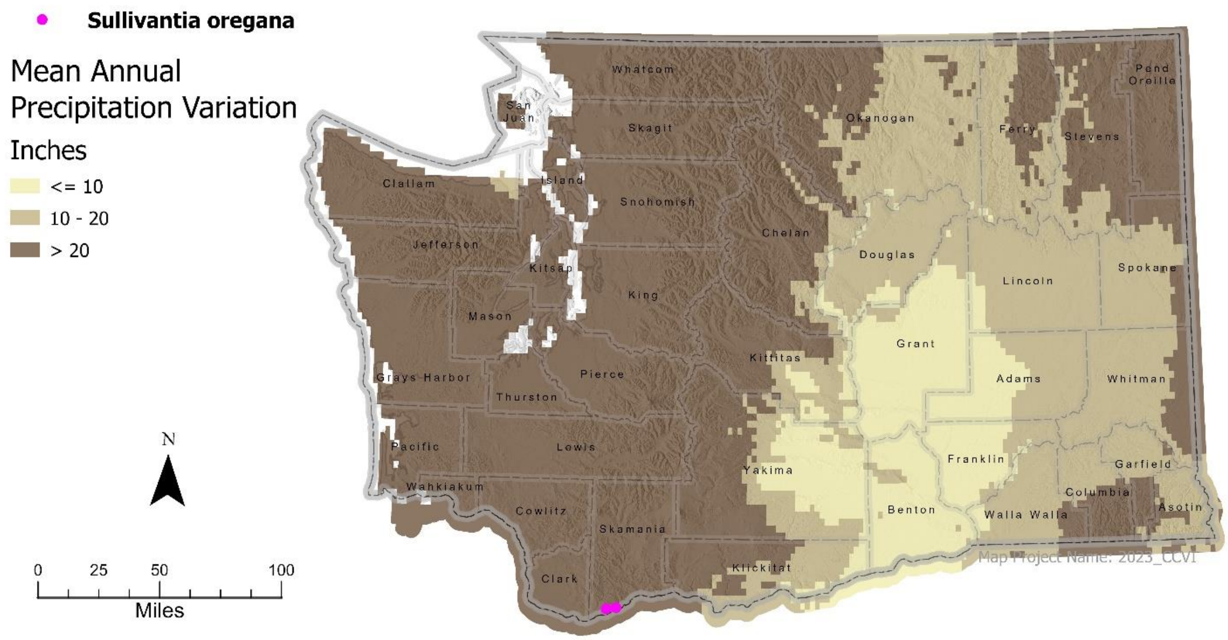


Figure 36. Historical hydrological niche (exposure to past variations in precipitation) of *Sullivantia oregana* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
This species occurs in moist cliff environments that may be fed by ground water or surface flow. Changes in the amount and timing of precipitation and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017). Reduction and/or change of timing of stream flow volume could reduce the size of the "spray zone" around waterfalls and rocks at the base, thereby reducing the potential habitat of the species.

C2c. Dependence on a specific disturbance regime: Neutral.
Sullivantia oregana occurs in habitats that are infrequently disturbed except by occasional rockfall which is not beneficial to the species.

C2d. Dependence on ice or snow-cover habitats: Neutral.
Sullivantia oregana does not occur in habitat with significant ice or snow-cover.

C3. Restricted to uncommon landscape/geological features: Increase.
Sullivantia oregana is highly dependent on moist basalt cliffs, seepy rock faces, and spray zones of waterfalls within the North Pacific Montane Massive Bedrock, Cliff, & Talus ecological system (Camp and Gamon 2011, WNHP 2021).

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

The cliff and rock habitat occupied by *Sullivantia oregana* is maintained largely by natural, abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Sullivantia species are pollinated by a variety of flies (Diptera) and small bees (Hymenoptera). *Sullivantia oregana* is unique in this genus in that it does not self pollinate and reproduces vegetatively via stolons (Soltis 1991).

C4d. Dependence on other species for propagule dispersal: Neutral.
Sullivantia oregana has slightly winged seeds to facilitate aerial and water transport (Soltis 1991). There is little evidence to suggest that this species is limited by propagule dispersal.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Not known, but probably not a limiting factor.

C4f. Sensitivity to competition from native or non-native species: Neutral.
Non-native species are not a documented threat to the cliff and rock ecosystems where *Sullivantia oregana* is found.

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

C5a. Measured genetic variation: Unknown.
Genetic variation within *Sullivantia oregana* populations is unknown. Due to the isolation of this species it's possible that the genetic variation is low.

C5b. Genetic bottlenecks: Somewhat Increase.
The range of *Sullivantia oregana* is very restricted and there are only two occurrences documented in Washington. Per guidance in Young et al. (2016), this species is at somewhat increased vulnerability due to the small population size.

C5c. Reproductive System: NA (Neutral).
Sullivantia oregana is diploid (2n=14) and is documented to reproduce via both sexually and asexually. This species is capable of hybridization in greenhouse settings (Soltis 1981), however there are no other *Sullivantia* species within the range of *S. oregana* for hybridization to occur.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral.
Based on limited herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Sullivantia oregana* 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 *Sullivantia oregana* in Washington since it was first discovered in the state.

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 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.

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.

Soltis, D.E. 1981. Variation in hybrid fertility among the disjunct populations and species of Sullivantia (Saxifragaceae). Canadian Journal of Botany 59:1174-1180.

Soltis, D.E. 1991. A revision of Sullivantia (Saxifragaceae). Brittonia 43 (1):27-53.

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.

Washington Natural Heritage Program. 2021. Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

Climate Change Vulnerability Index Report

Symphyotrichum boreale (rush aster)

Date: 19 May 2023 Synonym: *Aster borealis, Aster junciformis*

Assessor: Irene Weber, 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	60
	<3.9° F (2.2°C) warmer	40
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	60
	-0.074 to - 0.096	40
	-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		Unknown
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		Neutral to Somewhat Increase

3. Restricted to uncommon landscape/geological features	Neutral
4a. Dependence on other species to generate required habitat	Neutral
4b. Dietary versatility	NA
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: Two of the five current and historical records of *Symphyotrichum boreale* (40%) occur in areas with a projected temperature increase of <= 3.9° F. The remaining three occurrences (60%) are in areas with a projected temperature increase of 3.91-4.4° F. (Figure 1).

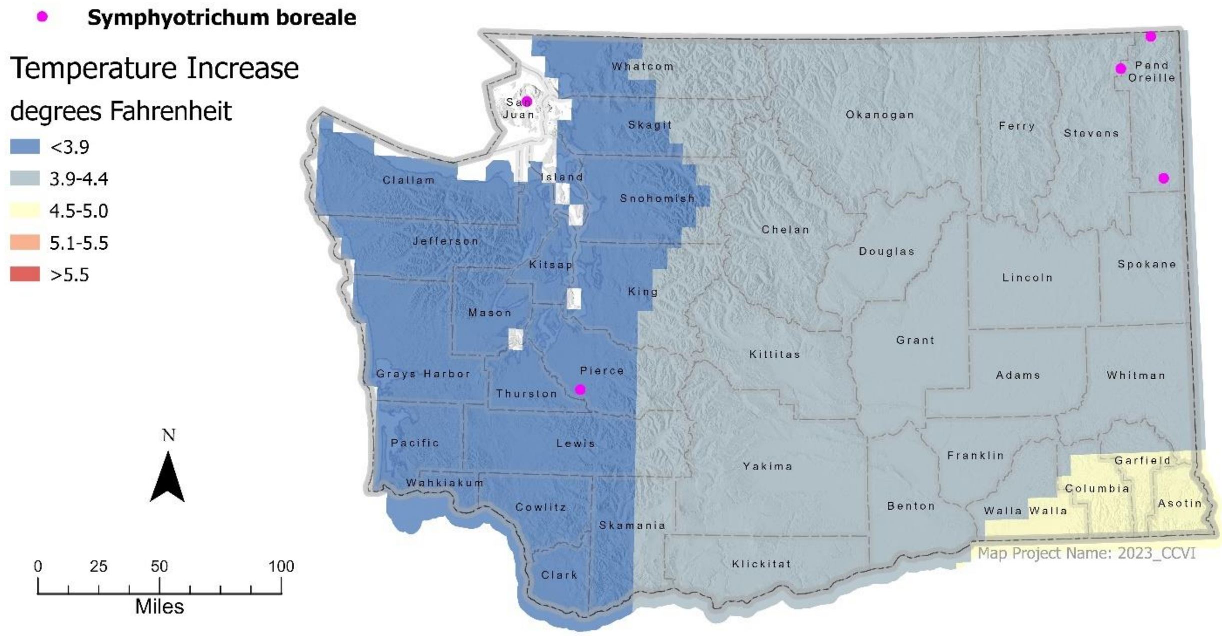


Figure 37. Exposure of *Symphyotrichum boreale* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Two of the five known occurrences of *Symphyotrichum boreale* in Washington occur in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of -0.074 - -0.096. The remaining three occurrences are in areas with a projected decrease in available moisture in the range of -0.097 - -0.119 (Figure 2).

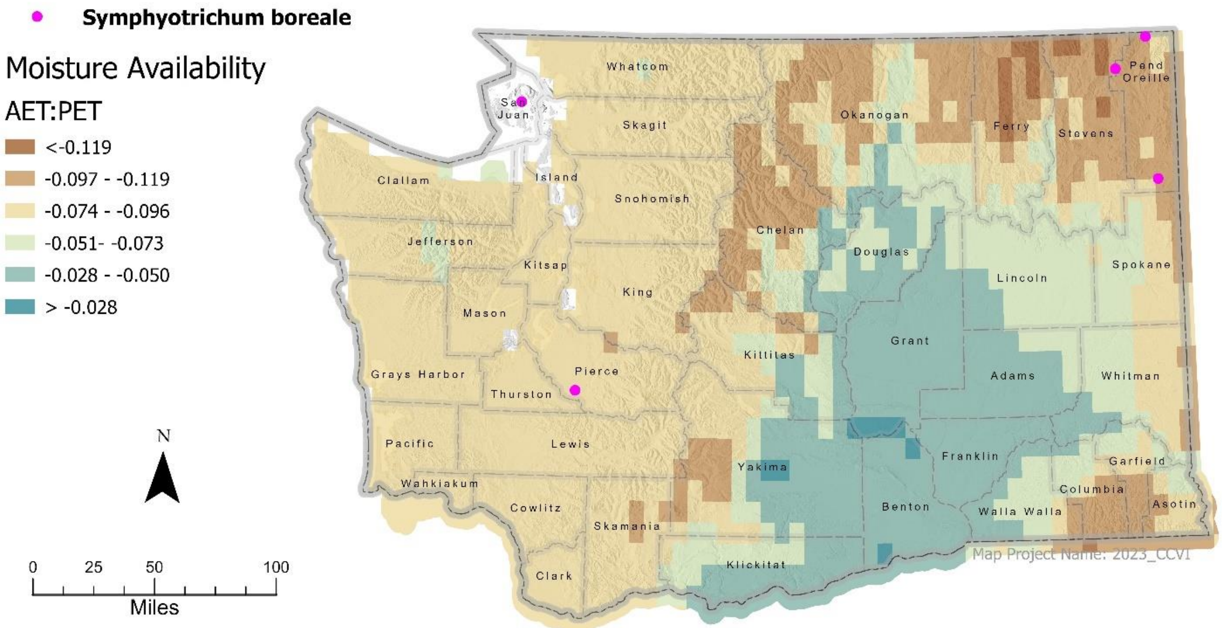


Figure 38. Exposure of *Symphyotrichum boreale* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change
B1. Exposure to sea level rise: Neutral.
The populations of *Symphyotrichum boreale* in Washington are found from 250-2500 feet (75-760 m) (Camp and Gamon 2011). These populations are unlikely to be affected by sea level rise.

B2a. Natural barriers: Somewhat Increase.
The populations of *Symphyotrichum boreale* in Washington occur along lakesides, in marshes, and fens (Camp and Gamon 2011). Populations are separated by 48-255 miles (77-410 km). These ecosystems are naturally isolated by intervening uplands that present a barrier to dispersal between watersheds.

B2b. Anthropogenic barriers: Neutral.
The range of *Symphyotrichum boreale* is fragmented by anthropogenic infrastructure including roads, agriculture, dams, and cities. Dispersal across the human landscape is probably less significant than the natural barriers to dispersal associated with isolated wetlands and waterways.

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

Section C: Sensitive and Adaptive Capacity
C1. Dispersal and movements: Neutral.

Symphyotrichum boreale produces hairy achenes with a pappus of 2.7-6.4 mm bristles. These seeds can be wind dispersed or become lodged in fur and be dispersed via animals (Camp and Gamon 2011).

C2ai. Historical thermal niche: Somewhat Increase.
Figure 3 depicts the populations of *Symphyotrichum boreale* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). One of the five known occurrences (20%) are in areas that have experienced very small (<37 ° F /20.8 ° C) temperature variation in the past 50 years and are considered at greatly increased vulnerability to climate change (Young et al. 2016). One occurrence (20%) is in an area that have experienced small (37-47° F/20.8-26.3 ° C) temperature variation in the past 50 years and are considered at increased vulnerability to climate change. The remaining three occurrences are in areas that have experienced average (57.1-77° F/31.8-43° C) (Young 2016). Because there are so few records, Somewhat Increased Vulnerability has been selected as an intermediate point between the two extreme categories.

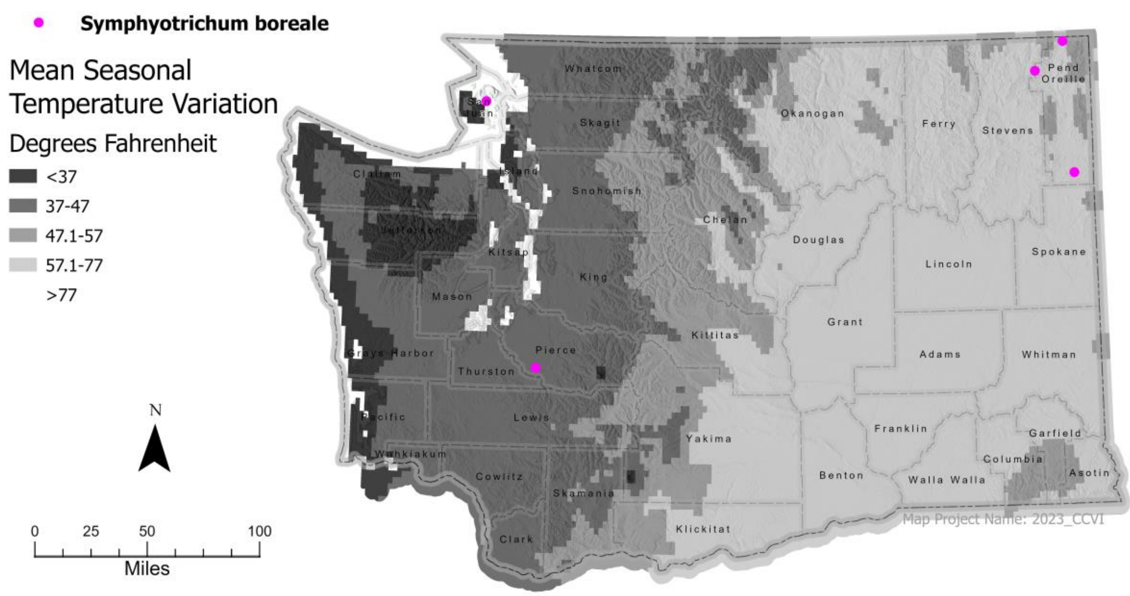


Figure 39. Historical thermal niche (exposure to past temperature variations) of Symphyotrichum boreale occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Somewhat Increase.
Washington populations of *Symphyotrichum boreale* are most often found in fens that are vulnerable to temperature increases. Temperature increases alter evaporation rates which may result in increased tree encroachment which, could result in the conversion

of these peatlands into other ecosystem types. Increased temperatures may also alter peat decomposition rates which may result in conversion to non-peat wetland types (Rocchio and Ramm-Granberg 2017). *S. boreale* also occurs in other wetland types such as lake margins and marshes which are also negatively impacted by rising temperatures, but to a somewhat lesser degree than peatlands.

C2bi. Historical hydrological niche: Neutral.
All known populations of *Symphyotrichum boreale* occur in areas of average or greater than average precipitation variation in the past 50 years (>20 inches/508 mm), considered neutral for climate change per the guidance in Young (2016) (Figure 4).

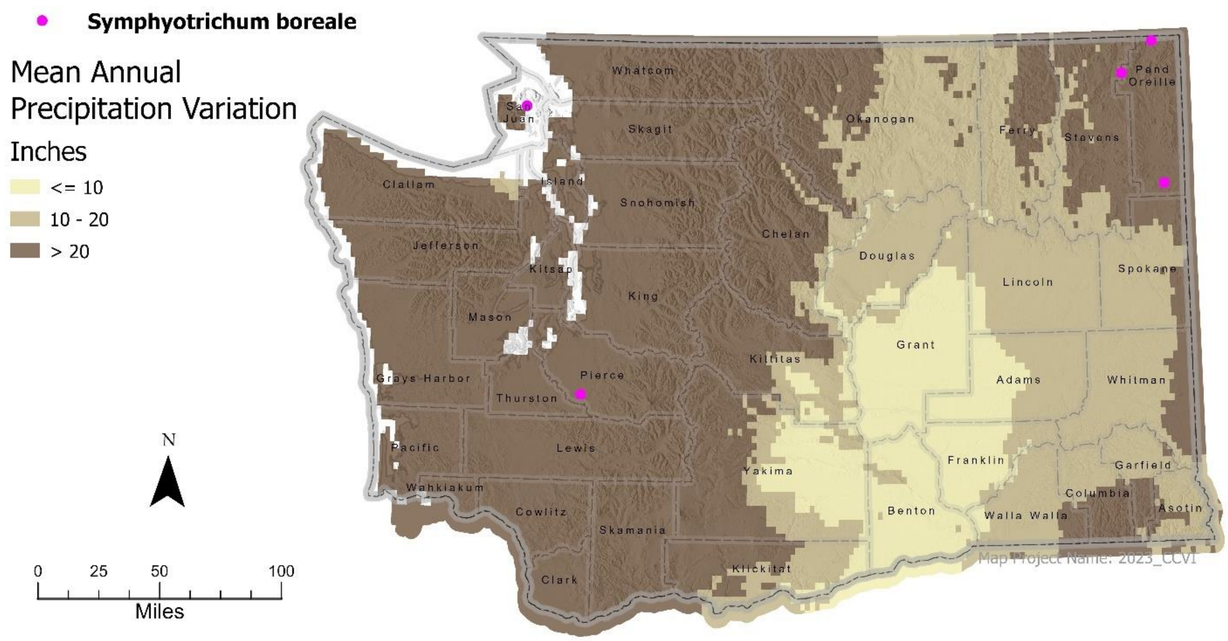


Figure 40. Historical hydrological niche (exposure to past variations in precipitation) of *Symphyotrichum boreale* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Somewhat Increase.
This species occurs in a range of wetland environments but are primarily found in peatlands. Changes in the amount and timing of rainfall and increasing temperatures could make these sites vulnerable to prolonged drought (Rocchio and Ramm-Granberg 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Symphyotrichum boreale is not known to be dependent on episodic disturbance regimes.

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

Populations of *Symphyotrichum boreale* in western Washington are found at low elevation sites that receive relatively low winter snowfall, while populations in northeastern Washington experience substantial winter snowpack. 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.
The wetlands in which *Symphyotrichum boreale* is found in Washington are not tied to any uncommon landscape or geologic features.

C4a. Dependence on other species to generate required habitat: Neutral.
The wetland habitats occupied by *Symphyotrichum boreale* are maintained largely by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
Symphyotrichum boreale is known to be pollinated by various species in the genus *Bombus* (Montana Natural Heritage program 2020). There are no known attributes of this species that would indicate it could not be pollinated by a wide variety of species.

C4d. Dependence on other species for propagule dispersal: Neutral.
Propagules in this species are transported primarily via wind and likely occasionally by adhering to animal fur.

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.
Competition from nonnative species may be a threat to *Symphyotrichum boreale* in areas where there has been disturbance allowing nonnative species to invade. Changes in hydrology may also facilitate tree encroachment. (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 *Symphyotrichum boreale* populations in Washington. Being at the southern edge of its range, Washington populations are likely to have lower overall genetic variation due to inbreeding or founder effects.

C5b. Genetic bottlenecks: Unknown.
Not known.

C5c. Reproductive System: Neutral.

Little is known about the reproductive system of *Symphyotrichum boreale,* however it it likely to have a mixed mating style which is common in Asteraceae.

C6. Phenological response to changing seasonal and precipitation dynamics: Neutral. Based on herbarium records in the Consortium of Pacific Northwest Herbaria website (pnwherbaria.org), *Symphyotrichum boreale* has not changed its flowering period since it was first collected in the state.

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 *Symphyotrichum boreale* in Washington since it was first collected in the state.

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 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.

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.

Montana Natural Heritage Program. 2020. Boreal Aster — Symphyotrichum boreale. Montana Field Guide. Montana Natural Heritage Program. Retrieved on May 19, 2023, from https://FieldGuide.mt.gov/speciesDetail.aspx?elcode=PDASTE8070

Washington Natural Heritage Program. 2021. *Symphyotrichum boreale*. In: Online Field Guide to the Rare Plants of Washington, https://fieldguide.mt.gov/wa. Accessed 13 April 2023.

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

Triglochin palustris (marsh arrowgrass)

Date: 11 May 2023 Synonym: *Triglochin palustre*

Assessor: Tynan Ramm-Granberg, WA Natural Heritage Program

Geographic Area: Washington Heritage Rank: G5/S1

Index Result: Extremely Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**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		Somewhat Increase
2ai Change in historical thermal niche		Neutral
2aii. Change in physiological thermal niche		Somewhat Increase
2bi. Changes in historical hydrological niche		Neutral to Somewhat Increase
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		Increase
4a. Dependence on other species to generate required habitat		Neutral
4b. Dietary versatility		Not Applicable
4c. Pollinator versatility		Neutral
4d. Dependence on other species for propagule dispersal		Neutral
4e. Sensitivity to pathogens or natural enemies		Neutral
4f. Sensitivity to competition from native or non-native species		Somewhat Increase
4g. Forms part of an interspecific interaction not covered above		Neutral

5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Somewhat Increase
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 6 of the known occurrences of *Triglochin palustris* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚ F (Figure 1).

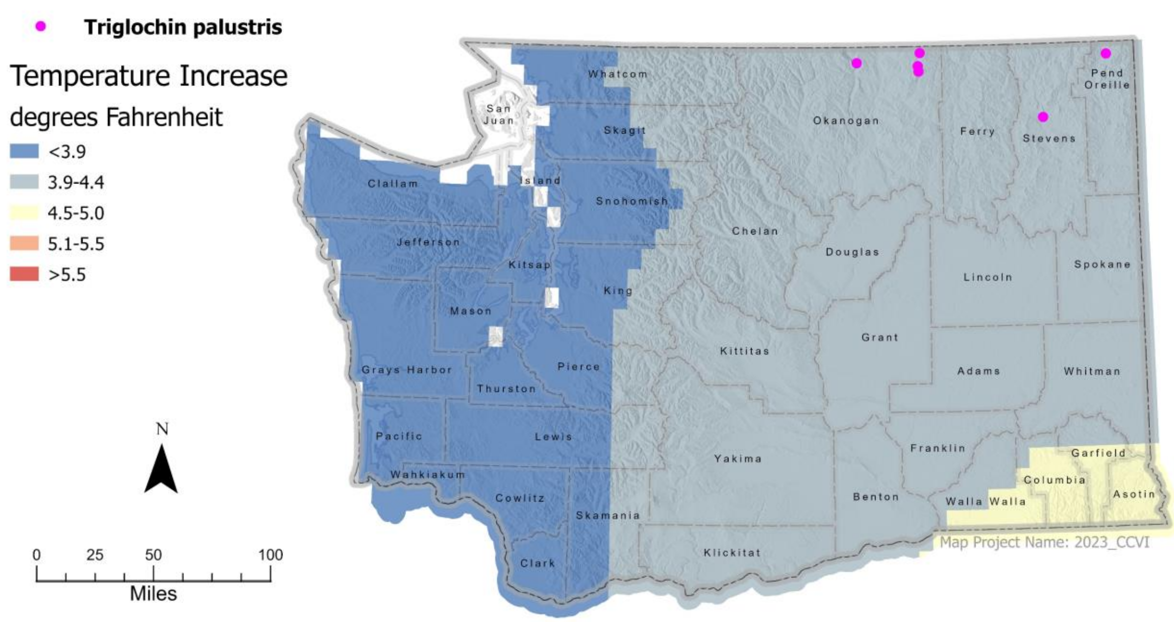


Figure 1. Exposure of *Triglochin palustris* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: Four of the six occurrences (66.7%) of *Triglochin palustris* in Washington are found in areas with a projected change in available moisture (as measured by the ratio of actual to potential evapotranspiration) of -0.097 to -0.119 119 (the second most ‘severe’ bin) (Figure 2). The remaining two populations (33.3%) are projected to experience moisture availability reductions of -0.074 to -0.096.

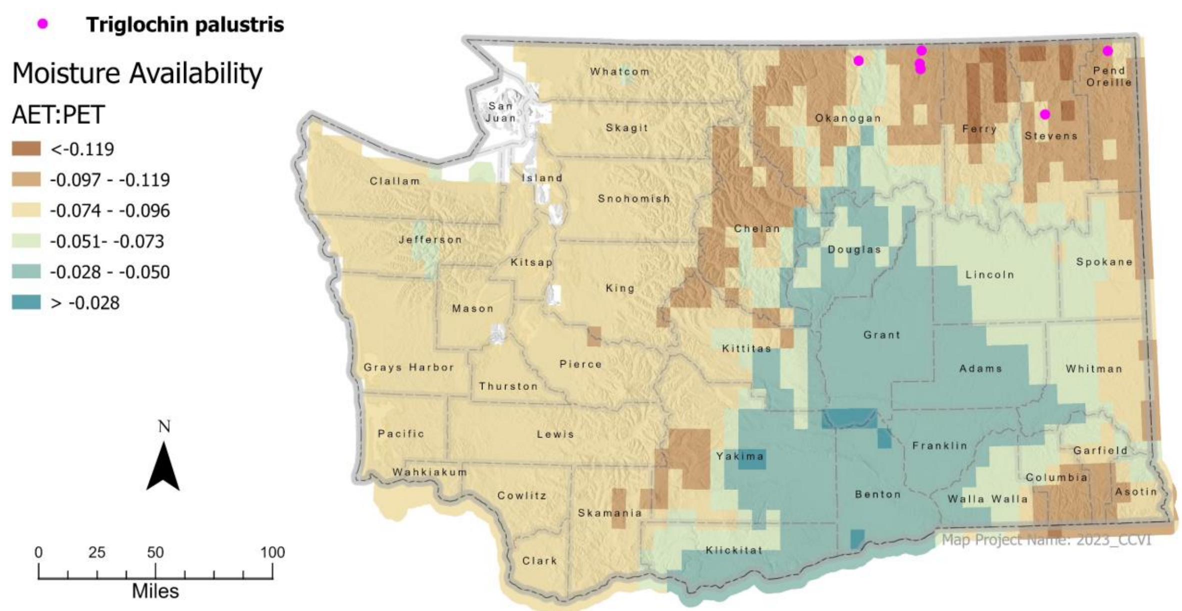


Figure 2. Exposure of *Triglochin palustris* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Washington occurrences of *Triglochin palustris* are found well above sea level, at elevations of 1800-3840 feet (550-1170 m). More northerly populations (outside of the assessment area) may be found in coastal salt marshes that are likely to be impacted by sea level rise.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Triglochin palustris* is known primarily from calcareous fens and less commonly in marshes and wet meadows (likely with alkaline soils) in the Okanogan and Canadian Rockies ecoregions (Camp & Gamon, 2011; WNHP, 2021). These habitats are part of the Rocky Mountain Subalpine-Montane Fen ecological system (Rocchio & Crawford, 2015). Individual populations may be isolated from each other by 2.25-38 miles (3.6-61 km) of unoccupied and/or unsuitable habitat. Most of the matrix vegetation between occurrences is unsuitable and presents a barrier to dispersal.

B2b. Anthropogenic barriers: Neutral.

The range of *Triglochin palustris* in Washington is primarily influenced by its dependence on scattered areas of specialized habitat that are naturally isolated. With the exception of one historical occurrence (not observed since 1902), most populations are found in mountainous areas or foothills with relatively few roads or other intensive anthropogenic land use. Anthropogenic factors are less likely to constrain dispersal than natural ones.

B3. Predicted impacts of land use changes from climate change mitigation: Neutral.
Triglochin palustris populations occurring in salt marshes may be impacted by the construction of sea walls or other structures to protect shoreline infrastructure, but no such populations are known from Washington.

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Research into the dispersal and reproduction of *Triglochin* species has primarily focused on salt marsh habitats, where *Triglochin palustris* reproduces primarily vegetatively via fugacious stolons with terminal bulbs (Buchenau, 1903; von Mering & Kadereit, 2015). Seed viability of other species in this genus is reported to be as low as 5% (Jerling, 1983). The mericarps of the closely related *Triglochin maritima* may float and retain viability for as long as five months in saltwater, with the help of air-filled aerenchyma (Koutstaal et al., 1987), promoting long-distance dispersal (von Mering & Kadereit, 2015). However, flotation may only be maintained for a few days in freshwater (Davy & Bishop, 1991). In isolated calcareous fen habitats, transmission via birds—either through endozoochory or epizoochory—is likely required for dispersal outside of the immediate drainage.

C2ai. Historical thermal niche: Neutral.
Figure 3 depicts the distribution of *Triglochin palustris* in Washington relative to mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”). All 15 known occurrences in the state are found in areas that have experienced average temperature variation (57.1-77˚F/31.8-43.0˚C) during the past 50 years, indicating a neutral impact on the climate change vulnerability for this species (Young et al., 2016).

C2aii. Physiological thermal niche: Somewhat Increase.
The peatland habitats of *Triglochin palustris* are often associated with cold air drainage in montane valleys.

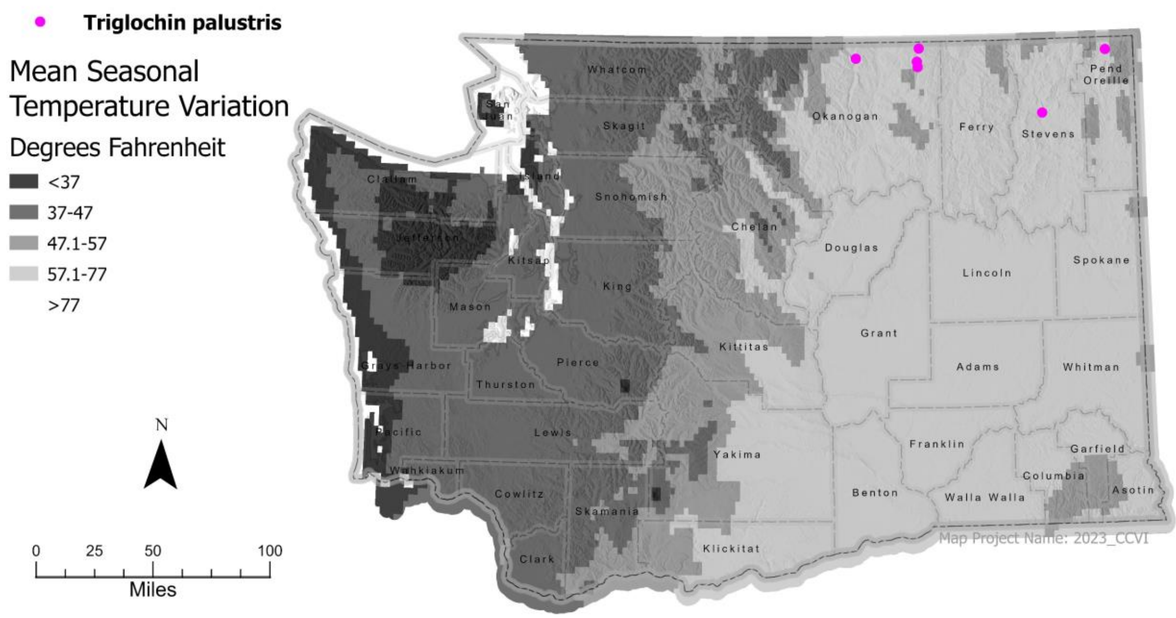


Figure 3. Historical thermal niche (exposure to past temperature variations) of *Triglochin palustris* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bi. Historical hydrological niche: Neutral to Somewhat Increase.
Four of the six known populations (including historical records) of *Triglochin palustris* in Washington (66.7%) are found in areas that have experienced slightly lower than average precipitation variation in the past 50 years (11-20 inches/255-508 mm), indicating somewhat increased vulnerability to climate change (Figure 4). The remaining two populations (33.3%) have experienced average or greater than average (>20 inches/508 mm) precipitation variation (neutral impact on climate change vulnerability).

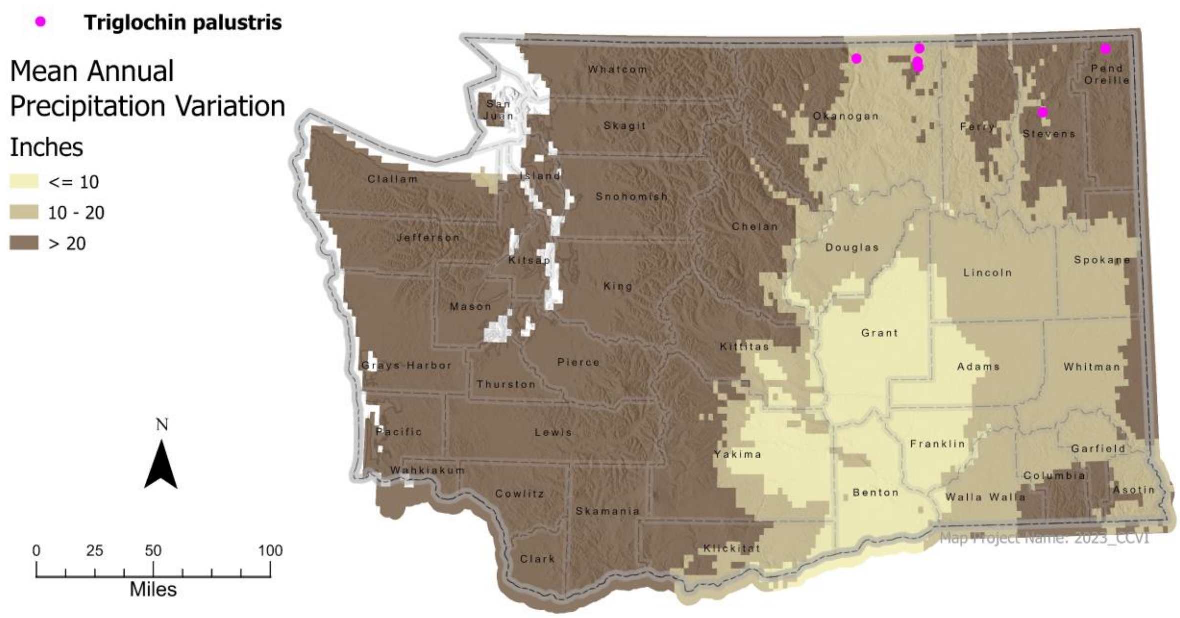


Figure 3. Historical hydrological niche (exposure to past variations in precipitation) of *Triglochin palustris* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Populations of *Triglochin palustris* in Washington are primarily restricted to fens (groundwater-supported peatlands). While groundwater-supported wetlands are somewhat less sensitive to climate change than those that primarily rely on precipitation, they may still be adversely affected by decreased snowpack and lowered water tables under projected climate change scenarios (Winter, 2000; Pitz, 2016; Halabisky et al., 2017). They may also experience changes in water chemistry (Rocchio & Ramm-Granberg, 2017).

C2c. Dependence on a specific disturbance regime: Neutral.
Triglochin palustris is not known to be tied to specific disturbance regimes outside of tidal environments. Peatland habitats that support this species in Washington generally remain wet enough to survive moderate fires, but severe burns (potentially more frequent under climate change scenarios) may consume the organic soils in which it grows.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
In Washington, *Triglochin palustris* is found in areas of moderate snowfall in the foothills of the Okanogan mountains and at slightly higher elevations in the Rocky Mountains. It may be adversely impacted by reduced snowpack or a change in snowmelt timing through cascading impacts on groundwater discharge.

C3. Restricted to uncommon landscape/geological features: Increase.
Triglochin palustris is highly restricted to calcareous peatlands in Washington.

C4a. Dependence on other species to generate required habitat: Neutral
Triglochin palustris habitat is maintained primarily by natural abiotic conditions.

C4b. Dietary versatility: Not applicable for plants

C4c. Pollinator versatility: Neutral.
All species in the *Juncaginaceae* family are entirely wind-pollinated.

C4d. Dependence on other species for propagule dispersal: Neutral.
Although it may be facilitated by animals (von Mering & Kadereit, 2015), dispersal is not dependent on other species.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Triglochin palustris is a preferred forage species for waterfowl (Sedinger & Raveling, 1984; Mulder et al., 1996). The high protein and low fiber contents (Sedinger & Raveling, 1984; Prevett et al., 1985) may also make it palatable to native and/or domesticated ungulates, although the plant becomes toxic when moisture- or frost-stressed (Panter et al., 2011). There is no indication that herbivory is likely to increase as a result of climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase
Populations may be vulnerable to shifts in vegetation from calcareous fens and towards alkaline wet meadows, marshes, or upland habitats because of potential changes in the amount of available water from precipitation and snowpack (Rocchio & Ramm-Granberg, 2017). *Triglochin palustris* may be able to persist—as it is also found in marshes and wet meadows—but the species may not remain competitive if hydrologic changes are accompanied by water chemistry shifts.

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

C5a. Measured genetic variation: Neutral.
Triglochin palustris has been reported to be polyploid (2n = 24) (Löve & Löve, 1944; Funabiki, 1959; Keil, 2012; von Mering & Kadereit, 2015), perhaps reflecting its adaptability to abiotic stresses such as salt marshes (Mayrose et al., 2010; Wang et al., 2011).

C5b. Genetic bottlenecks: Somewhat Increase.
The total population of *Triglochin palustris* individuals in Washington is uncertain and may be as low as 50 individuals (https://www.dnr.wa.gov/NHPdataexplorer). There are only two or three extant occurrences in Washington (three additional historical locations), indicating somewhat increased vulnerability to climate change. However, populations are much larger just outside of Washington in the Rocky Mountains of British Columbia, Alberta, Idaho, and Montana. This factor is not included in the overall climate vulnerability score because C5a was assessed.

C5c. Reproductive System: Neutral.

Triglochin palustris reproduces both vegetatively and through outcrossing. Sequential floral development prevents self-pollination. This factor is not included in the overall climate vulnerability score because C5a was assessed.

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.
Only two or three occurrences in Washington are extant (very little information is available for one). Trend data are not available because these sites have been visited only once.

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

Buchenau F. 1903. Scheuchzeriaceae. *Das Pflanzenreich* (ed. by A. Engler), pp. 1–20. Engelmann, Leipzig, Germany.

Camp P. and J.G. Gamon, (eds.). 2011. *Field Guide to the Rare Plants of Washington*. University of Washington Press, Seattle, WA.

Davy A.J. and G.F. Bishop. 1991. Triglochin maritima L. *Journal of Ecology* 79(2):531–555.

Funabiki K. 1959. Polyploidy in relation to vegetational zonation in the western United States. MS Thesis. Montana State University, Bozeman, MT.

Halabisky M., S. Lee, S.A. Hall, and M. Rule. 2017. Can we conserve wetlands under a changing climate? Mapping wetland hydrology across and ecoregion and developing climate adaptation recommendations. Report prepared for Great Northern Landscape Conservation Cooperative.

Jerling L. 1983. Composition and viability of the seed bank along a successional gradient on a Baltic sea shore meadow. *Holarctic Ecology* 6(2):150–156.

Keil D.J. 2012. Trioglochin palustris. In: Jepson Flora Project (eds.). https://ucjeps.berkeley.edu/eflora/eflora_display.php?tid=47200. Accessed: May 11, 2023.

Koutstaal B.P., M.M. Markusse, and W. De Munck. 1987. Aspects of seed dispersal by tidal movements. *Vegetation between land and sea: structure and processes* (ed. by A.H.L. Huiskes, C.W.P.M. Blom, and J. Rozema), pp. 226–235. Dr. W. Junk Publishers, Dordrecht, Netherlands.

Löve A. and D. Löve. 1944. Cytotaxonomical studies on boreal plants. III. Some new chromosome numbers of Scandinavian plants. *Arkiv för Botanik* 31A(12):1–22.

Mayrose I., M.S. Barker, and S.P. Otto. 2010. Probabilistic models of chromosome number evolution and the inference of polyploidy. *Systematic Biology* 59(2):132–144.

von Mering S. and J.W. Kadereit. 2015. Phylogeny, biogeography and evolution of Triglochin L. (Juncaginaceae) – Morphological diversification is linked to habitat shifts rather than to genetic diversification. *Molecular Phylogenetics and Evolution* 83:200–212.

Mulder C.P.H., R.W. Ruess, and J.S. Sedinger. 1996. Effects of environmental manipulations on Triglochin pPalustris: implications for the role of goose herbivory in controlling its distribution. *The Journal of Ecology* 84(2):267.

Panter K.E., M.H. Ralphs, J.A. Pfister, D.R. Gardner, B.L. Stegelmeier, S.T. Lee, K.D. Welch, B.T. Green, T.Z. Davis, and D. Cook. 2011. Plants poisonous to livestock in the western states. US Department of Agriculture, Agricultural Research Service, Poisonous Plant Research Laboratory, Logan, UT. Agriculture Information Bulletin Number415.

Pitz C.F. 2016. Predicted impacts of Climate Change on groundwater resources of Washington State. Washington State Department of Ecology, Olympia, WA. Publication No. 16-03-006.

Prevett J.P., I.F. Marshall, and V.G. Thomas. 1985. Spring foods of snow and Canada geese at James Bay. *The Journal of Wildlife Management* 49(3):558–563.

Rocchio F.J. and R.C. Crawford. 2015. Ecological Systems of Washington State: a guide to identification. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. NHR-2015-04. Online: https://www.dnr.wa.gov/publications/amp_nh_ecosystems_guide.pdf

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.

Sedinger J.S. and D.G. Raveling. 1984. Dietary selectivity in relation to availability and quality of food for goslings of cackling geese. *The Auk* 101(2):295–306.

Tena-Flores J.A., M.S. González-Elizondo, Y. Herrera-Arrieta, N. Almaraz-Abarca, N. Mayek-Pérez, C.R.M. Da Silva, and A.L. Laforga Vanzela. 2013. Karyotype characterization of eight Mexican species of Eleocharis (Cyperaceae). *Botanical Sciences* 91(2):119–128.

Wang X., T. Zhang, Z. Wen, H. Xiao, Z. Yang, G. Chen, and X. Zhao. 2011. The chromosome number, karyotype and genome size of the desert plant diploid Reaumuria soongorica (Pall.) Maxim. *Plant Cell Reports* 30:955–964.

Washington Natural Heritage Program (WNHP). 2021. Triglochin palustris. In: Online Field Guide to the Rare Plants of Washington. https://fieldguide.mt.gov/wa/?species=triglochin palustris. Accessed: May 11, 2023.

Winter T.C. 2000. The vulnerability of wetlands to climate change: a hydrologic landscape perspective. *Journal of the American Water Resources Association* 36(2):305–311.

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