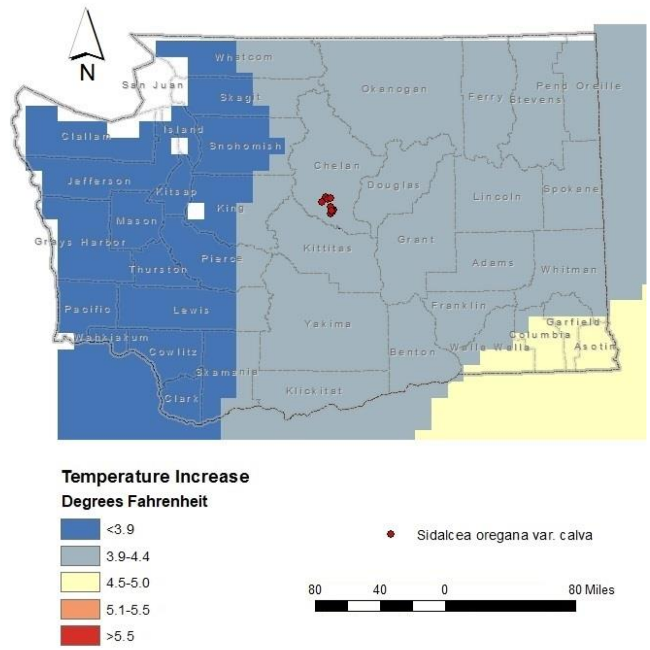
WASHINGTON NATURAL HERITAGE PROGRAM



Climate Change and Connectivity Review of Site Designs for Established Natural Areas with Federally Listed Plant Species

Prepared for
US Fish and Wildlife Service Region 1

Prepared by
Jake Kleinknecht, David Wilderman, and Walter Fertig
December 26, 2019

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

Natural Heritage
Report 2019-06

Climate Change and Connectivity Review Of Site Designs for Established Natural Areas with Federally Listed Plant Species

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

ON THE COVER: Map of projected temperature increase in Washington State relative to the distribution of the federally Endangered Wenatchee Mountains checkermallow (*Sidalcea oregana* var. *calva*). Inset photo of Wenatchee Mountains checkermallow by Walter Fertig.

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Introduction

The Washington State Natural Areas program was established by the state legislature in 1972 to protect outstanding examples of undisturbed native ecosystems and habitat for rare plant and animal species (WDNR 2007). There are currently 95 Natural Area Preserves (NAP) and Natural Resource Conservation Areas (NRCA) managed by the Washington Department of Natural Resources (DNR), covering over 164,500 acres (WNAP 2019). Both NAPs and NRCAs preserve priority species and ecosystems, but NAPs also focus on research and education, while NRCAs more explicitly allow low-impact recreation (WNHP 2018). Collectively, NAPs and NRCAs protect the habitat of at least 80 vascular plant species of special concern in Washington (WNHP 2019) and 126 ecosystem types of high conservation significance (WNHP 2018 appendix). Seven current or proposed NAPs and NRCAs conserve populations of five federally Threatened or Endangered plant species (Table 1).

Table 1. Federally Listed Plant Species found in Washington Natural Area Preserves.

Species	Natural Heritage Rank	Federal Status	State Status	Natural Area Preserve or Natural Resource Conservation Area
Castilleja levisecta (Golden paintbrush)	G2/S2	Threatened	Threatened	Admiralty Inlet NAP Mima Mounds NAP (introduced) Rocky Prairie NAP
Howellia aquatilis (Water howellia)	G3/S2	Threatened*	Threatened	Dishman Hills NRCA
Lomatium bradshawii (Bradshaw’s desert-parsley)	G2/S1	Endangered*	Endangered	Lacamas Prairie NAP
Sidalcea oregana var. *calva* (Wenatchee Mountains checkermallow)	G5T1/S1?	Endangered	Endangered	Camas Meadows NAP
Silene spaldingii (Spalding;s catchfly	G2/S2	Threatened	Threatened	Proposed Steptoe Butte NAP

*Proposed for de-listing by US Fish and Wildlife Service in 2019

NAP and NRCA boundaries are selected to capture the distribution and ecological needs of target ecosystem types and species to the fullest extent possible. In some cases, the approved boundaries of these conservation areas may exceed the area presently under DNR ownership, or include tracts in need of significant restoration. The long-term goal is to complete acquisition of these NAPs or NRCAs as properties become available for purchase.

In the future, the boundaries of some NAPs and NRCAs may need to be adjusted to take into account impacts from projected climate change. Over the next century the Pacific Northwest is projected to experience increased fire frequency, higher temperatures, reduced snowpack, decreased precipitation during the growing season, lower stream flows in summer, and a shift from snow to rain dominance in mountain watersheds (Abatzoglou et al. 2014; Halofsky et al.

2018; Mote 2006; Peterson and Halofsky 2019). All of these changes could have significant impacts on the natural values and rare species presence in the state's natural area network.

In 2017, the US Fish and Wildlife Service contracted with the Washington Natural Heritage Program (WNHP) under a Section 6 agreement to conduct a study of the potential impacts of projected climate change on four federally listed Threatened or Endangered plant species found in four state NAPs or NRCAs (Figure 1). These targets include:

1. *Castilleja levis*ecta (Golden paintbrush) on Rocky Prairie NAP
2. *Howellia aquatilis* (Water howellia) on Dishman Hills NRCA
3. *Lomatium bradshawii* (Bradshaw's desert-parsley) on Lacamas Prairie NAP
4. *Sidalcea oregana* var. *calva* (Wenatchee Mountains checkermallow) on Camas Meadows NAP

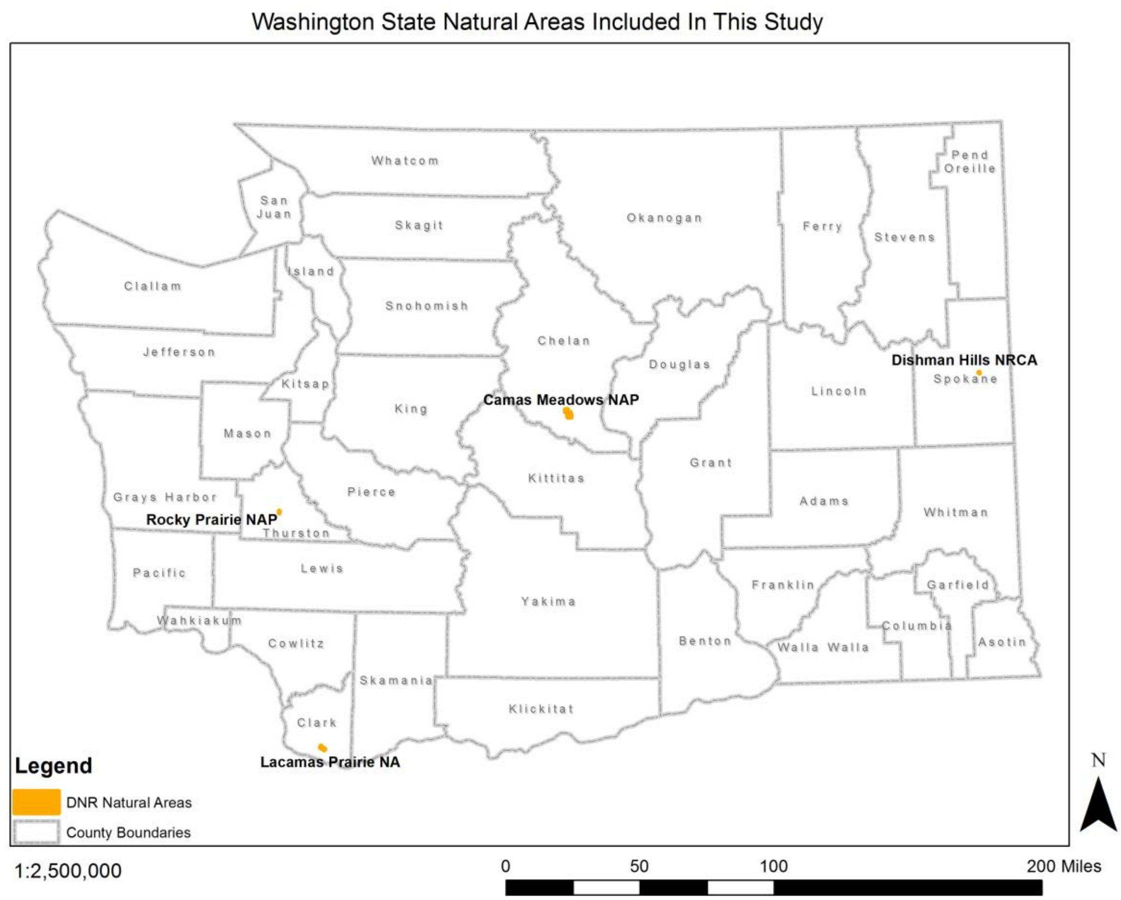

Figure 1. Washington State natural areas included in this study.

Our assessment includes measuring and monitoring the hydrologic characteristics of the NAPs and NRCAs and how these might impact the distribution of the four rare plant taxa (three of which are primarily wetland species). We also address potential management or boundary changes ("Potential Conservation Opportunities") that might be needed in the course of adaptation planning for each of the natural areas. Finally, we discuss the climate vulnerability of the four listed plant species using NatureServe's Climate Change Vulnerability Index (Young et al. 2016).

Study Areas

Camas Meadows Natural Area Preserve

Camas Meadows NAP is located in the Wenatchee Mountains of Chelan County, about 10 miles north of Blewett Pass and 10 miles west of Wenatchee. The preserve includes most of Camas Land, a flat, shallow, sandstone basin surrounded by a rim of intrusive volcanic diabase. The NAP contains 1,987 acres of seasonally wet meadows, riparian areas, aspen woodlands, and East Cascades dry conifer forests (WNAP 2000). Three rare plant species have been documented from the NAP: Tall agoseris (*Agoseris elata*), a Washington State Sensitive species; Wenatchee larkspur (*Delphinium viridescens*), a Wenatchee Mountains endemic and Washington State Threatened species; and Wenatchee Mountains checkermallow (*Sidalcea oregana* var. *calva*), a Wenatchee Mountains endemic listed as Endangered under the US Endangered Species Act and by the state of Washington (WNAP 2000, WNHP 2019). The larkspur and checkermallow are found primarily in wet meadows and moist aspen woodlands bordering wet areas. Camas Meadows NAP contains the largest and best protected occurrences of both of these species, and so is critical for their long-term conservation (Fertig 2019; WNAP 2000).

The climate of Camas Meadows NAP is characterized by warm and dry summers and cold, relatively wet winters (Figure 2). Mean annual temperature, extrapolated from the nearest weather station in Leavenworth, WA, is 49˚F (9.4˚C), with mean January temperature of 16 ˚F (-8.8 ˚C) and mean July temperature of 88 ˚F (31 ˚C) (WNAP 2000). Average annual precipitation for the area is 32.8 inches (Hegewisch and Abatzoglou 2019). The wetlands within Camas Lands are primarily seasonal and derived from melting snowpack from fall and winter precipitation, and local springs, becoming dry by late May or June (WNAP 2000).

Soils in the Camas Meadows NAP are a nearly even mixture of sand, silt, and clay with 11% organic matter (Loomis 1985). Most of the area is mapped as the Stemilt-Scotties-Nard soil association which is characterized by deep, well-drained residuum and colluvium derived from sandstone and volcanic ash (Aho and Beieler 2007). Other soils in the area include McCree-Ardenmont and Jumpe-Berson associations derived from weathered glacial till and basalt (Aho and Beieler 2007).

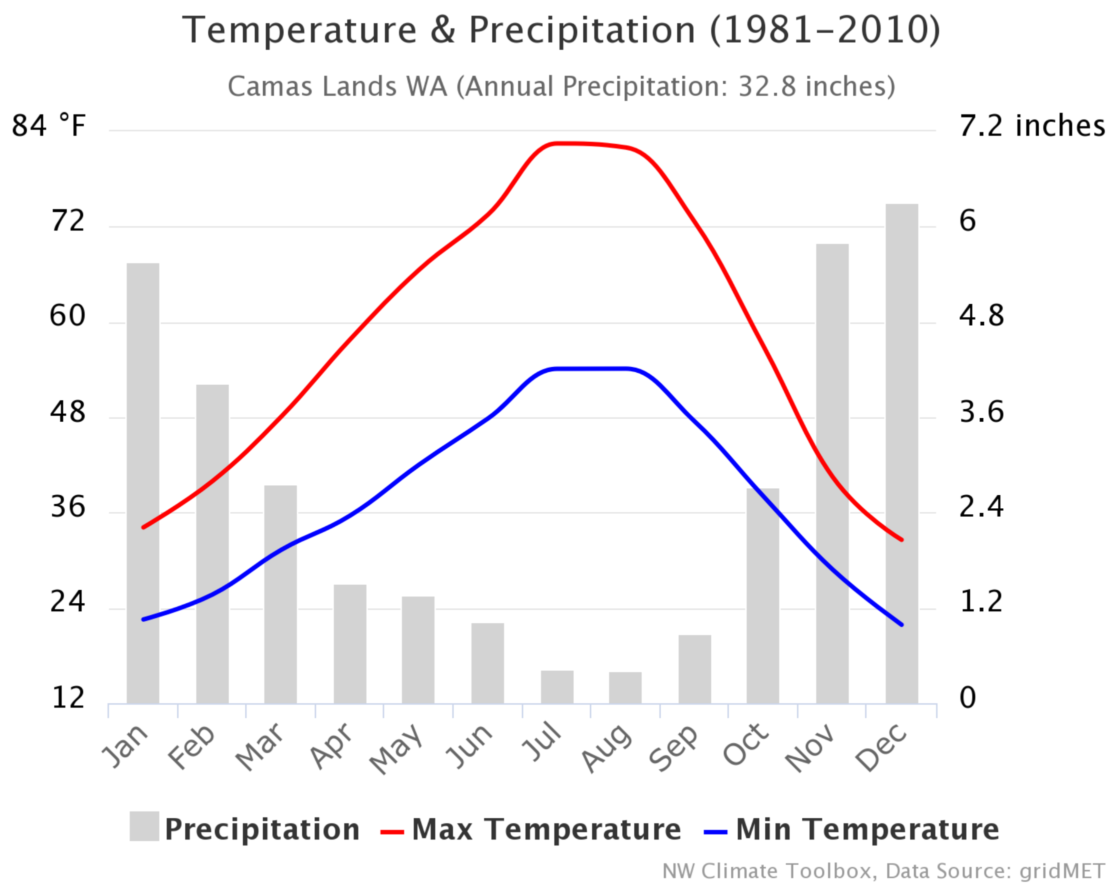

Figure 2. Average annual temperature and precipitation (1981-2010) at Camas Meadows NAP. Derived from NW Climate Toolbox (Hegewisch and Abatzoglou 2019).

Dishman Hills Natural Resource Conservation Area

Dishman Hills NRCA is located east of Spokane in Spokane County. The area contains dramatically sculpted ledges, gullies, and pothole lakes scoured by the flooding from Glacial Lake Missoula approximately 10,000 years ago (Andelman et al. 1992). Covering 512 acres, the Dishman Hills is one of the last remnants of relatively undisturbed vegetation in the Spokane Valley and protects one occurrence of the federally Threatened Water howellia (*Howellia aquatilis*) (Fertig 2019).

The climate of the Spokane area is characterized by warm and dry summers and cold and damp winters (Figure 3). Mean annual temperature is 47.1˚F (8.38˚C) (Spokane climate data cited in Andelman et al. 1992). Mean annual precipitation at Dishman Hills is 17.7 inches (Hegewisch and Abatzoglou 2019). The majority of precipitation occurs from December through February as snow (Andelman et al. 1992).

The dominant soil type in the Dishman Hills NRCA is the Uhlig-Hesseltine-Cheney soil association which is a moderately deep to shallowly gravelly or rocky soil characteristic of the channel basalt scablands of the Spokane area (Donaldson and Giese 1968).

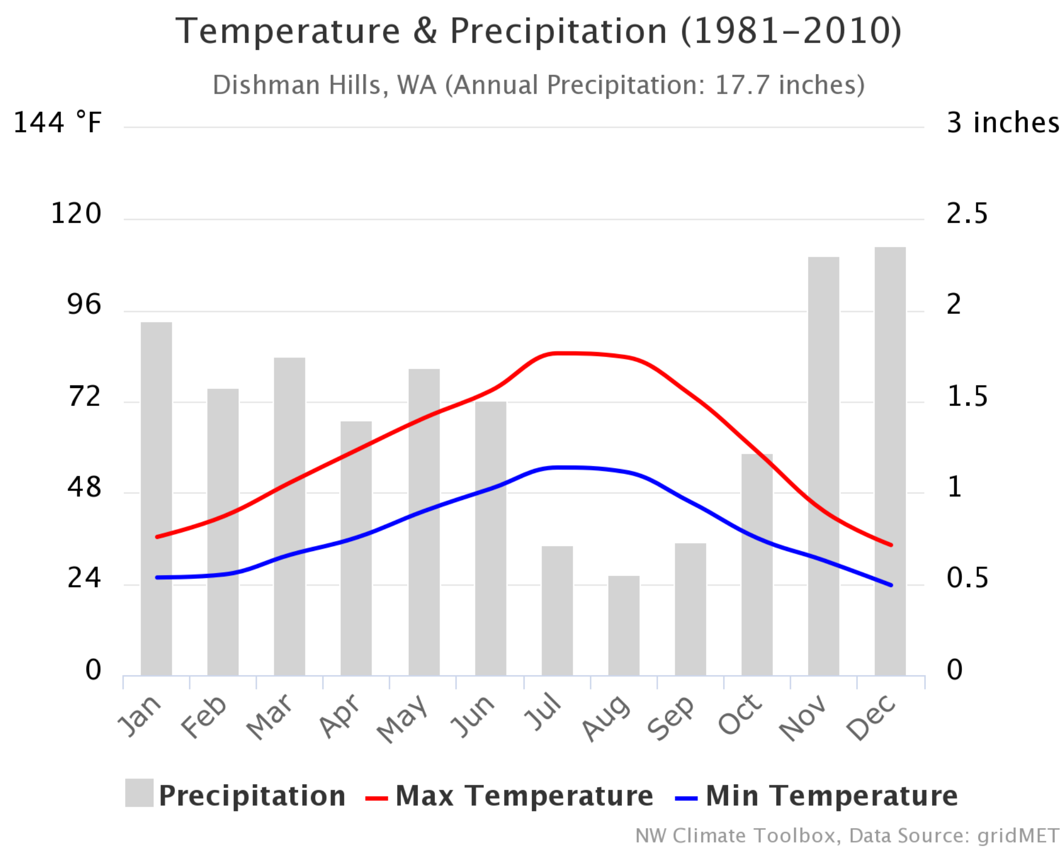

Figure 3. Average annual temperature and precipitation (1981-2010) at Dishman Hills NRCA. Derived from NW Climate Toolbox (Hegewisch and Abatzoglou 2019).

Lacamas Prairie Natural Area Preserve

Lacamas Prairie NAP is located east of Vancouver (Clark County) and contains the highest quality remaining wet prairie in the state (Ramm-Granberg and Rocchio 2018). Part of the area is managed by the Washington Department of Natural Resource as a NAP, and a buffer area is managed as a NRCA, though much of the proposed preserve remains in private ownership pending potential purchase by the state. Lacamas Prairie contains habitat for 8 rare plant species tracked by WNHP, including the state's only known occurrences of Tall beardtongue (*Penstemon hesperius*) and the federally Endangered Bradshaw's desert-parsley (*Lomatium* *bradshawii*). Three rare plant associations also occur in the NAP/NRCA: Dense sedge-Tufted hairgrass (*Carex densa-Deschampsia cespitosa*) wet prairie, Woolly sedge (*Carex pellita*) wet prairie, and Oregon white oak (Oregon ash)/Common snowberry (*Quercus garryana-Fraxinus latifolia*/*Symphoricarpos albus*) riparian forest (Ramm-Granberg and Rocchio 2019).

The climate of the Vancouver, WA area is characterized by warm, dry summers and mild, wet winters (Figure 4). Average daily maximum temperature in August (the warmest month of the year) is 79.1˚F (26.2 ˚C), while the average daily minimum temperature in January (the coldest month) is 32.4 ˚F (0.22 ˚C) (WNAP 2007). Average annual precipitation is 50.3 inches (Hegewisch and Abatzoglou 2019).

Soils in the Lacamas Prairie area are classified as the Hillsboro-Dollar series (McGee 1972) or Cove series (the name used for comparable soils in Oregon) (Arnett 2010). These soils are deep and well drained to poorly drained with medium to fine texture and are associated with river terraces and wet meadows or riparian woodlands.

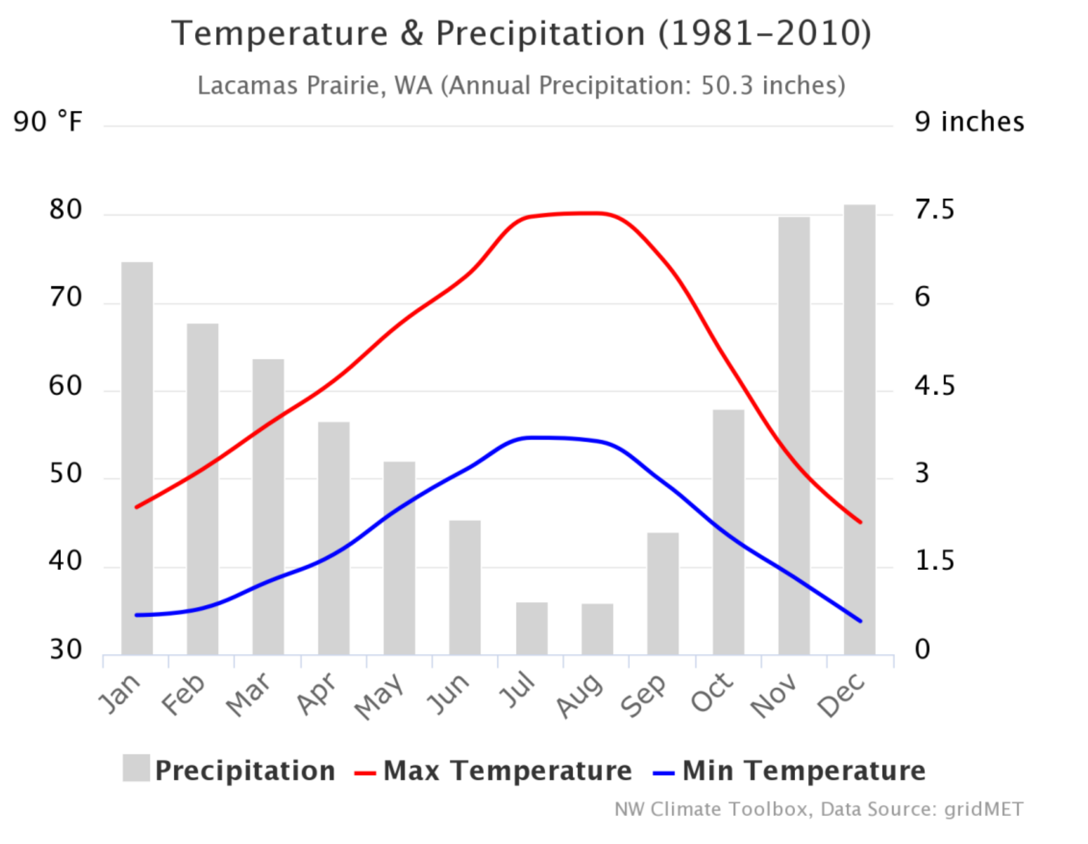

Figure 4. Average annual temperature and precipitation (1981-2010) at Lacamas Prairie NAP/NRCA. Derived from NW Climate Toolbox (Hegewisch and Abatzoglou 2019).

Rocky Prairie Natural Area Preserve

Rocky Prairie NAP is a 35-acre remnant patch of native prairie located in Thurston County, about five miles southeast of the Olympia airport. The preserve was established to protect the largest remaining native population of the federally Threatened Golden paintbrush (*Castilleja levisecta*) (Evans et al. 1984; Fertig 2019). The NAP also provides habitat for White-top aster (*Sericocarpus rigidus* or *Aster curtus*), a Washington State Sensitive species, and three uncommon Roemer fescue (*Festuca roemeri*)-dominated ecosystem types (Schuller 1990).

The climate of the Rocky Prairie NAP is marked by dry summers but is wet the rest of the year (Figure 5). Mean annual temperature is 50.7˚F (10.4˚C), with average January temperature of 38.1˚F (3.4 ˚C) and average July maximum temperature of 77.5 ˚F (25.3 ˚C) (Olympia airport climate data cited in Schuller 1990). Average annual precipitation is 50.0 inches (Hegewisch and Abatzoglou 2019).

Soils in the Rocky Prairie vicinity are primarily moderately to well-drained gravelly sandy-loams derived from glacial outwash (Pringle 1990). Representative soil associations include Everett-Alderwood and Spanaway-Nisqually.

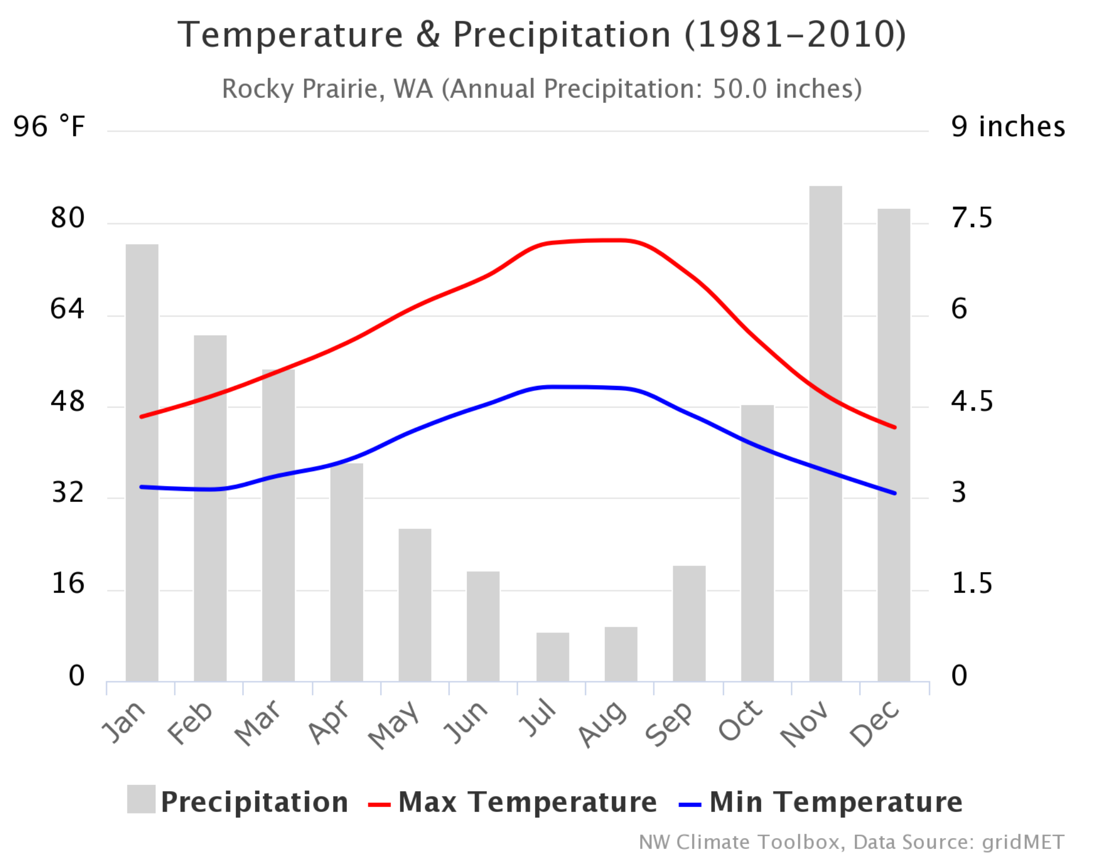

Figure 5. Average annual temperature and precipitation (1981-2010) at Rocky Prairie NAP. Derived from NW Climate Toolbox (Hegewisch and Abatzoglou 2019).

Target Species

Castilleja levisecta (Golden paintbrush)

Castilleja levisecta is a perennial herb with bright yellow sepals and flower bracts and is native to prairie habitats of the Puget Trough and Willamette Valley, extending from southern British Columbia and western Washington to northwestern Oregon. It is currently known from 10 extant and 10 introduced populations in western Washington, 3 native populations in British Columbia, and 32 introduced occurrences in Oregon (Fertig 2019; Kaye 2019). An additional 25 historical populations are considered extirpated (Fertig 2019).

The number of flowering plants observed in introduced populations increased from just over 29,000 in 2012 to over 555,000 in 2018, though this number dropped to approximately 334,000 plants in 2019 (Fertig unpublished data). In the same time period, native populations have declined from an estimated 30,000 plants in 2012 to 2800 in 2019, a decrease of 91% (Fertig 2019, unpublished data). The cause of the steep decline in native populations is poorly understood, but may be related to recent atypically hot and dry spring weather (especially during the flowering period in May), a decline in native pollinators and reduction in seed production, or increased herbivory on fruits and seeds by deer, rabbits, or voles (Dunwiddie and Pelant 2019).

Rocky Prairie NAP contains the largest surviving natural population of *Castilleja levisecta*. This population was first discovered in 1934 and has been monitored since 1983. In 1983, the population at Rocky Prairie was estimated at 15,634 plants (Evans et al. 1984). Numbers have fluctuated since then (Figure 6), but have been declining steadily in the last decade. From 2008 to 2019, the number of flowering stems has decreased from 9,392 to 890, a decline of over 90%. The trend at Rocky Prairie mirrors the range-wide decline of native occurrences (Fertig 2019).

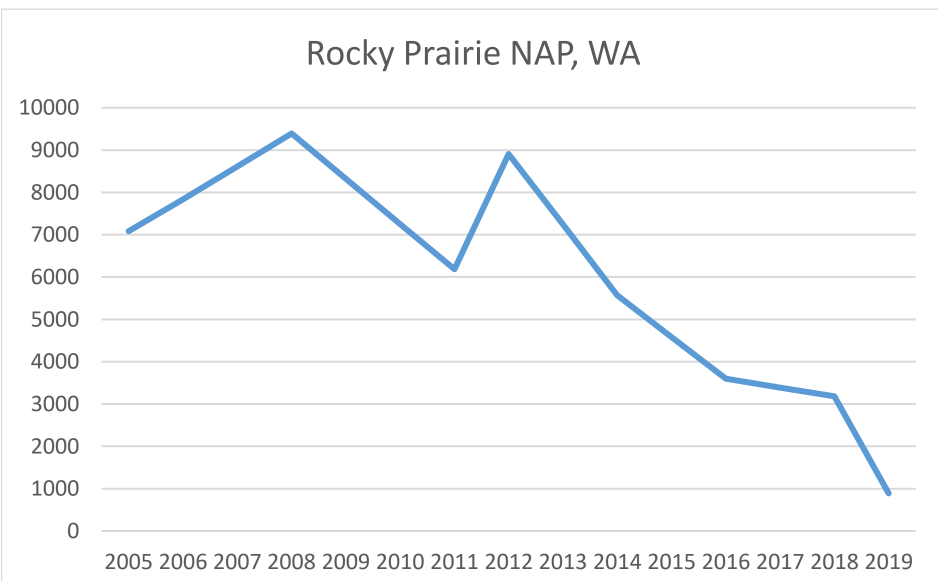

Figure 6. Population trend of *Castilleja levisecta* at Rocky Prairie NAP from 2005-2019. Counts based on individual flowering plants. Adapted from Fertig (2019).

Howellia aquatilis (Water howellia)

Howellia aquatilis is an aquatic annual herb found in seasonally flooded ponds and riverbanks. The species requires exposed moist mudflats for seed germination in the fall and winter, but shallow to deep water to grow, flower, and produce fruits the following spring and summer (Lesica 1992). In Washington, Water howellia is found in small vernal ponds and wetlands associated with channeled scablands or glacially-scoured terrain, often associated with woodlands of aspen or *Fraxinus latifolia* (Gamon 1992). It is presently known from 73 extant occurrences and two historical records, although at least 10 of the extant populations have not been relocated since 1987 (Fertig 2019). Individual occurrences may contain from 20 to several thousand individuals. The statewide population was estimated at 6,724-37,694 plant in 2005 (Mincemoyer 2005). Populations are threatened by competition from invasive plants (especially *Phalaris arundinacea*) and loss of wetland habitat to development or changes in hydrology (Fertig 2019).

The population of *Howellia aquatilis* at Dishman Hills was first discovered in 1978 and has been monitored periodically since. Plants occur along the shore of two ponds (East and West pond). The largest population is found at East Pond and is bordered by *Populus tremuloides* and *Pinus ponderosa* forest. The occurrence at West Pond is more open or has small patches of *P. tremuloides*, *P. ponderosa*, and *Pseudotsuga menziesii*. In 2002, the two ponds contained 217 plants, while in 2011 only 50 plants were reported from both ponds. RareCare volunteer Mary Water found 185 vegetative Water howellia plants in East Pond in June 2019, but only two flowering individuals in West Pond. In recent years, *Phalaris arundinacea* and *Typha latifolia* have been increasing along the edges of West Pond, potentially threatening the long-term suitability of the site.

Lomatium bradshawii (Bradshaw's desert-parsley)

Lomatium bradshawii is a yellow-flowered perennial herb restricted to remnant wet or seasonally flooded meadows along creeks and small rivers in the southern Puget Trough and northern Willamette Valley of southwestern Washington and northwestern Oregon. It is known from a single occurrence in Washington, centered on the Lacamas Prairie NAP and adjacent private lands in Clark County, east of Vancouver (Fertig 2019). The Lacamas Prairie population was first discovered in 1994 and estimated to contain several thousand plants. This number was revised to over 70,000 individuals in 1995 (Wentworth 1996) and later to more than 816,000 plants (St. Hilare 1999). Arnett (2010) established random plots and transects within homogenous stands of *L. bradshawii* (excluding unoccupied habitat) to derive an estimate of 9,150,000 plants. Since 1998, Wilderman (2019) has monitored the Lacamas NAP population (which is a subset of the entire occurrence) and documented a long-term decline. Historically, the species has probably lost a significant amount of its occupied habitat due to conversion or draining of wet prairies for agriculture and human settlements. Current threats include competition from introduced plants, invasion of meadow sites by shrubs and trees, fire suppression, and changes in hydrology (Arnett 2010, Ramm-Granberg and Rocchio 2018).

Sidalcea oregana **var.** *calva (Wenatchee Mountains checkermallow)*

Sidalcea oregana var. *calva* is a pink-flowered perennial herb distinguished by the presence of stiff, ciliate hairs along the margins of the calyx. It is endemic to the Wenatchee Mountains of north-central Washington in Chelan County. Two additional observation records from Kittitas

County have not been relocated since the early 1980s and may be misidentified (Fertig 2019). There are ten native populations in Chelan County, of which four are historical and probably extirpated (including populations in the towns of Peshastin and Leavenworth). Two of the six presumed extant occurrences could not be relocated in 2019 and are suspected to be recently extirpated due to conversion of former open meadow habitat to dense forest (Fertig unpublished data).

The largest occurrence of *Sidalcea oregana* var. *calva* is found at Camas Land, mostly within the boundaries of the Camas Meadows NAP (some subpopulations extend onto adjacent private or US Forest Service lands). This occurrence has been known since 1935, but was not thoroughly mapped and inventoried until 1999-2000. At that time, the population was estimated at 11,125 plants in 123 discrete patches. Since 2012, a subset of polygons have been re-counted and remapped each year, with the ultimate goal of re-surveying the entire occurrence. As of 2019, 21,030 plants have been observed in 223 polygons (Fertig 2019, Bugner unpublished data). The remaining 80 polygons are planned to be surveyed in 2020.

Methods

Maps of Potential Conservation Opportunities

Camas Meadows Natural Area Preserve

While best known for protecting the largest known populations of *Sidalcea oregana* var. *calva* and *Delphinium viridescens*, another defining characteristic of Camas Meadows is the relative large, flat area it occupies in an otherwise steep and mountainous landscape. To identify potential conservation opportunities near Camas Meadows, we used two data products produced from DNR's LiDAR data products: the Bare Earth Elevation layer and Bare Earth Hillshade layer.

With the LiDAR data, we tried to identify other relatively flat areas within the vicinity of Camas Meadows that were also slightly higher in elevation, under the assumption that the existing climate envelope may move uphill in the future. We also identified areas where we have historical *Sidalcea oregana* var. *calva* observations or where field staff have identified potentially suitable sites.

Dishman Hills Natural Resource Conservation Area

Dishman Hills NRCA protects *Howellia aquatilis*, which, in this part of the state, tends to grow in small kettle-lakes that function as ephemeral wetlands. To identify more areas like this that could provide suitable habitat, we used the Bare Earth Elevation layer and Bare Earth Hillshade layer produced from DNR's LiDAR data.

Lacamas Prairie Natural Area Preserve

The defining characteristic of Lacamas Prairie is the Willamette Valley wet prairie ecosystem, so the first task was to see if we could spatially identify areas with similar wet, open landscapes. To do this, we used the National Land Cover Dataset 2016, or NLCD2016 (Yang et. al 2018). The "woody wetland" and "emergent herbaceous wetlands" land cover types were the two identified at Lacamas Prairie that fit best with our goal of recognizing other wet-prairies. After isolating these two land cover types from the rest of the dataset, and consolidating them into one "Woody Wetlands/Emergent Herbaceous Wetlands" land cover type, we identified several open spaces with suitable land cover in the vicinity of Lacamas Prairie.

<u>Rocky Prairie Natural Area Preserve</u>

This natural area protects *Castilleja levisecta* and is a small example of native Puget prairie grassland. Much of the remaining native Puget prairie habitat has been developed or encroached by forest. To identify remaining remnants to conserve, we used orthoimagery of Thurston and Lewis counties with a one-foot spatial resolution. This imagery was used to verify the current status of prairies listed in a report on southern Puget Trough prairies (Fertig 2018).

Hydrology Monitoring

Because three of the four species (*Sidalcea oregana* var. *calva, Lomatium bradshawii*, and *Howellia aquatilis*) occur in seasonal wetland or pond habitats, understanding the hydrology and establishing a baseline for monitoring hydrology is important to their long-term conservation and for assessing future climate change impacts. To help accomplish this, water depths were monitored at 1-4 locations within the natural area sites that support these species: Lacamas Prairie NAP, Camas Meadows NAP, and Dishman Hills NRCA. Measurements were not taken at Rocky Prairie NAP since *Castilleja levisecta* does not occur in habitats characterized by surface water or high water tables.

At the three sites, hydrology was monitored by installing automatic dataloggers (Rugged TROLL 100, manufactured by In-Situ, Inc.) into shallow wells constructed of slotted PVC pipe. The wells were installed by augering a hole into the ground approximately two-three feet deep, and placing the slotted PVC pipe (with a bottom cap) into the hole. The datalogger was suspended by wire attached to a locking cap placed on top of the well, so that the datalogger reached close to, but did not touch, the bottom of the well. Dataloggers recorded water depth (via pressure measurements) and temperature every two hours, for the duration of the monitoring periods in 2017-18 and 2018-19. Measurement periods differed between sites but generally began in fall and ended in late spring or early summer, with the intent to capture the time period when seasonal flooding and soil saturation would occur, as well as a significant portion of the plants' growing seasons. Datalogger pressure measurements were corrected for barometric pressure by installing a single barometric datalogger at each site (Rugged BaroTROLL, manufactured by In-Situ, Inc.).

While this study covers only two monitoring periods (2017- 2018 and 2018- 2019), the Natural Areas Program plans to continue collecting water level data for at least the life of the equipment (5 years). Additional years of data will help to account for annual variability, providing a more representative set of reference points for assessing future trends.

Camas Meadows Natural Area Preserve

Water levels were monitored at three locations, as follows:

Location	**Elevation (LiDAR) (ft)**	**Habitat Description**	***Sidalcea oregana* var. *calva***
Camas-1	2883.0	Shallow swale in narrow forest opening. Typically seepy in spring, but no running water or significant inundation.	Moderate-high density occurrence
Camas-2	2831.0	Main meadow near stream channel, edge of *Populus tremuloides* stand, and foot of slope. Just downstream from water structure installed in 2014 to restore hydrology. Receives significant water flow and inundation in spring.	Moderate density occurrence.
Camas-3	2853.5	Main meadow in low depression near main stream channel. Stream overflow inundates in spring.	Not present. Closest plants are ca. 60m away.

Water levels were recorded November 1, 2017 – June 11, 2018 and November 8, 2018-July 1, 2019. In both periods, the barometric datalogger failed to record accurately either due to an equipment fault or perhaps due to water accumulation and subsequent freezing within the datalogger housing. As a result, the water levels from all three wells at this site are uncorrected and therefore do not provide absolute depth measurements. However, they were used to compare relative water levels between wells on the same date/time since barometric pressure is presumed to be the same at each well on a given date/time. The barometric datalogger at this site has been replaced with a new unit, which will hopefully provide for corrected, absolute water level measurements in the future.

Dishman Hills Natural Resource Conservation Area

Because *Howellia aquatilis* is only present consistently in one pond at this site (East Pond), water levels were monitored at that single location:

Location	**Elevation (LiDAR) (ft)**	**Habitat Description**	***Howellia aquatilis***
East Pond	2,159.3	Well is located near the lowest elevation of this seasonal pond. Pond is ca.70m long x 45m wide, with *Carex* spp., *Scirpus acutus*, *Bidens frondosa*. Rimmed by *Populus tremuloides, Cornus stolonifera, Pinus ponderosa*.	This pond supports the sole occurrence at Dishman Hills NRCA. Estimated 185 plants in 2019.

Water levels were recorded November 1, 2017 – June 15, 2018 and November 10, 2018-October 8, 2019. The more extended measurement period in 2018-19 was based on the unexpectedly long duration of surface water in late summer 2018.

Lacamas Prairie Natural Area

Water levels were monitored at four locations, as follows:

Location	**Elevation (LiDAR) (ft)**	**Description**	***Lomatium bradshawii***
Lac-1	193.5	At southern end of wet prairie on NAP, in mixed grass-forb community. In Macroplot 2 used for monitoring *Lomatium bradshawii*.	High-density occurrence.
Lac-2	195.25	Northern end of wet prairie on NAP, in high-density *Deschampsia cespitosa* community.	None present. Closest plants ca. 50m away.
Lac-3	192.0	On adjacent private land, in mixed grass-forb wet prairie community.	Extremely high-density occurrence.
Lac-4	196.75	In dense *Phalaris arundinacea* community on northern end of NAP.	None present. Closest plants ca. 150m away.

Water levels were recorded November 1, 2017 – May 30, 2018 and November 3, 2018-June 1, 2019.

Climate Maps and Climate Change Vulnerability Index

The climate maps were produced using data from AdaptWest (AdaptWest 2015; Wang et. al 2016), which provides historical and modelled-future conditions within a 1km raster grid. Two variables from this dataset were used, mean annual temperature (MAT) and mean annual precipitation (MAP). For each of the four natural areas, the average MAT and MAP values were derived from the 1981-2010 historical datasets. Using these historical averages, output rasters were generated from 2080-predicted datasets of two potential climate outcomes, as represented by their Representative Concentration Pathways (RCPs), RCP4.5 and RCP8.5, for both variables of interest. RCP8.5 represents a 'worst case' scenario, with climate change resulting in rising radiative forcing leading to 8.5 W/m2 in 2100, while RCP4.5 represents an optimal 'stabilization without overshoot scenario' leading to 4.5 W/m2 at stabilization after 2100 (IPCC 2019).

The raster outputs were created by first creating one raster per variable per RCP, within which a pixel value of one is assigned where the MAT or MAP value falls between 90% and 110% of the mean historical value, and a value of zero is assigned where the MAT or MAP value falls outside that range. Then, for each RCP, the two binary rasters were then multiplied by each other to produce one raster per RCP of areas where similar average temperatures and precipitation are expected to occur.

Data from STATSGO2 (Soil Survey Staff, 2019) were used to assess how well these future climate conditions align with known soil compatibilities for the elements being protected at each natural area. This data set was used because of its broad coverage and generalized soil association units, to prevent being "boxed in" by narrow definitions of soil classes. For each natural area, two-to-four soil association units were isolated based on either existing within the natural area or existing on a cluster of element occurrences nearby. These soil association units were then extracted from the larger dataset to show where in Washington soils may occur that are conducive to these plant taxa.

NatureServe, the umbrella network of state and provincial natural heritage programs, has developed a ranking tool in MS Excel 2010 for assessing the potential impact of projected climate change on plant and animal species and ecosystem types (Young et al. 2014, 2016). The Climate Change Vulnerability Index (CCVI) employs 29 variables based on modeled changes in temperature and moisture availability and biological traits of the target organism to derive a final vulnerability score, ranging from extremely vulnerable to less vulnerable (or "insufficient evidence" if adequate data are unavailable). Biological traits used in the CCVI include dispersability, genetic variability, breeding system, pollinator availability, and physiological thermal and hydrological niche (Young et al. 2016). Each of the attributes in the CCVI table is scored based on available data from the full range of each species in Washington. A confidence ranking is determined for each index based on the completeness of the available data. CCVIs were calculated for the four target rare plant species and are included in Appendices A-D.

Results

Potential Conservation Opportunities

<u>Camas Meadows Natural Area Preserve</u>

The current boundaries of the Camas Meadows NAP encompass most of the approximately 300 documented subpopulations of *Sidalcea oregana* var. *calva* from Camas Lands and vicinity (Figures 7, 8). Two large subpopulations are located on Okanogan-Wenatchee National Forest lands immediately to the east and south of the NAP in the Poison Creek and Brushy Fork drainages. Several additional subpopulations occur on private inholdings within the NAP boundaries (Arnett 2011). Five other *S. oregana* var. *calva* occurrences are found within a radius of 2 miles of Camas Meadows NAP on Forest Service and private lands. At least three of these occurrences ("Tip Top", FS Road 120 south of rock quarry, and SW of Camas Lands on FS Road 7200) are historical or extirpated due to loss of habitat from encroachment of aspen or conifer forests (Figure 7).

Acquisition of inholdings within Camas Meadows NAP would increase the amount of protected habitat for *Sidalcea oregana* var. *calva*, as well as other rare species known from the area (including *Delphinium viridescens*, and *Agoseris elata*). The NAP could also be expanded along its western and southern border to include adjacent private lands (if these were available for sale) with known or potential habitat identified in our modeling.

Okanogan-Wenatchee National Forest has taken an active interest in monitoring *S. oregana* var. *calva* populations on its lands bordering Camas Meadows NAP (Arnett 2011), and conducted some controlled burns to enhance *Sidalcea* and wet meadow habitat in these areas (with additional burns planned for 2020). The Poison Canyon and Brushy Creek populations on USFS lands might be considered for potential Special Botanical Area designation by the Forest Service to recognize their conservation significance. The Deer Park Spring area (located about 1 mile northwest of Tip Top, and the probable collection site of J.W. Thompson in 1934) on Okanogan-Wenatchee NF has an extensive wet meadow that provides habitat for *Delphinium viridescens* (a species that occurs in similar habitat at Camas Land) and could be a viable reintroduction site for *S. oregana* var. *calva*. Other small occurrences on USFS lands may require periodic burning or thinning to prevent the encroachment of woody species into patches of wet meadows around springs or streams.

Our simple climate modeling of *Sidalcea oregana* var. *calva* suggests that the climate and soil envelope currently occupied by this species at Camas Meadows NAP is likely to shift to the south (and higher elevations) under both optimal and worst case climate change scenarios in the next 60 years (Figures 9, 10). To persist, the population at Camas Meadows NAP will likely require active management by DNR staff to further restore hydrologic conditions in the wetland (some of the meadows have been ditched and drained in the past). In the future, optimal habitat for this species may be in the Thomsen Ridge-Naneum Ridge-Mission Peak area along the Chelan-Kittitas County line in the southeast Wenatchee Range (Figure 8). Much of this area is managed by Okanogan-Wenatchee National Forest, Washington Department of Fish and Wildlife (Colockum State Wildlife Area), and Washington Department of Natural Resources. This area has a reported occurrence of *S. oregana* var. *calva* (EO # 011, south of Grouse Spring), though it has not been relocated in five site visits since 1980 and may be a misidentification or extirpated (Arnett 2011; Fertig 2019). If var. *calva* is no longer present, managers might need to consider direct out-planting or seeding to establish a new population. The Thomsen Ridge-Naneum Ridge-Mission Peak area also does not have the extensive flat valley bottom terrain of Camas Lands, and may not be able to support as large a population of *S. oregana* var. *calva* and other rare species as Camas Meadows NAP currently does. Furthermore, these areas may need to be managed intensively to create open, wet meadow conditions favored by this species.

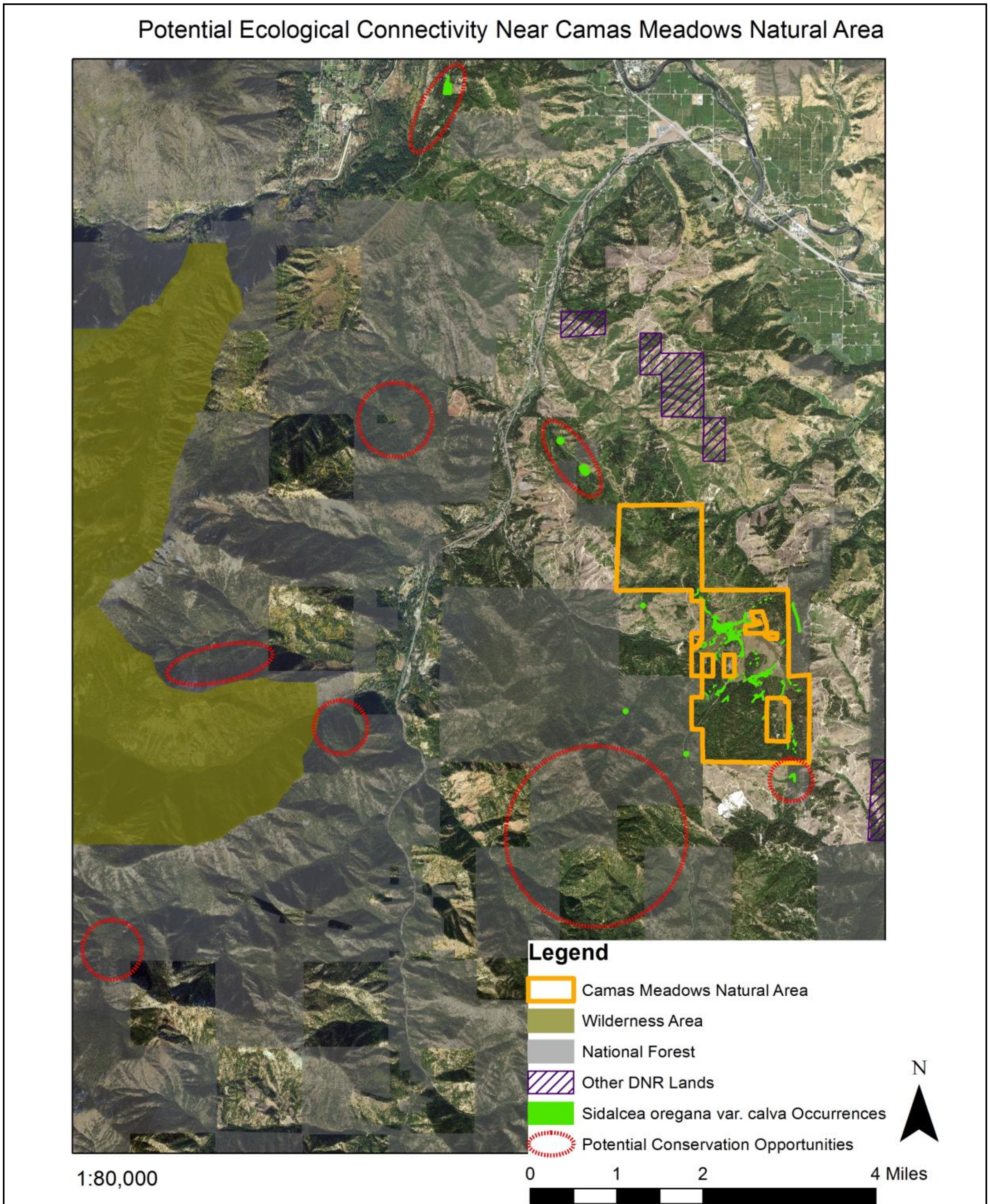

Figure 7. Potential ecological connectivity west of Camas Meadows Natural Area Preserve.

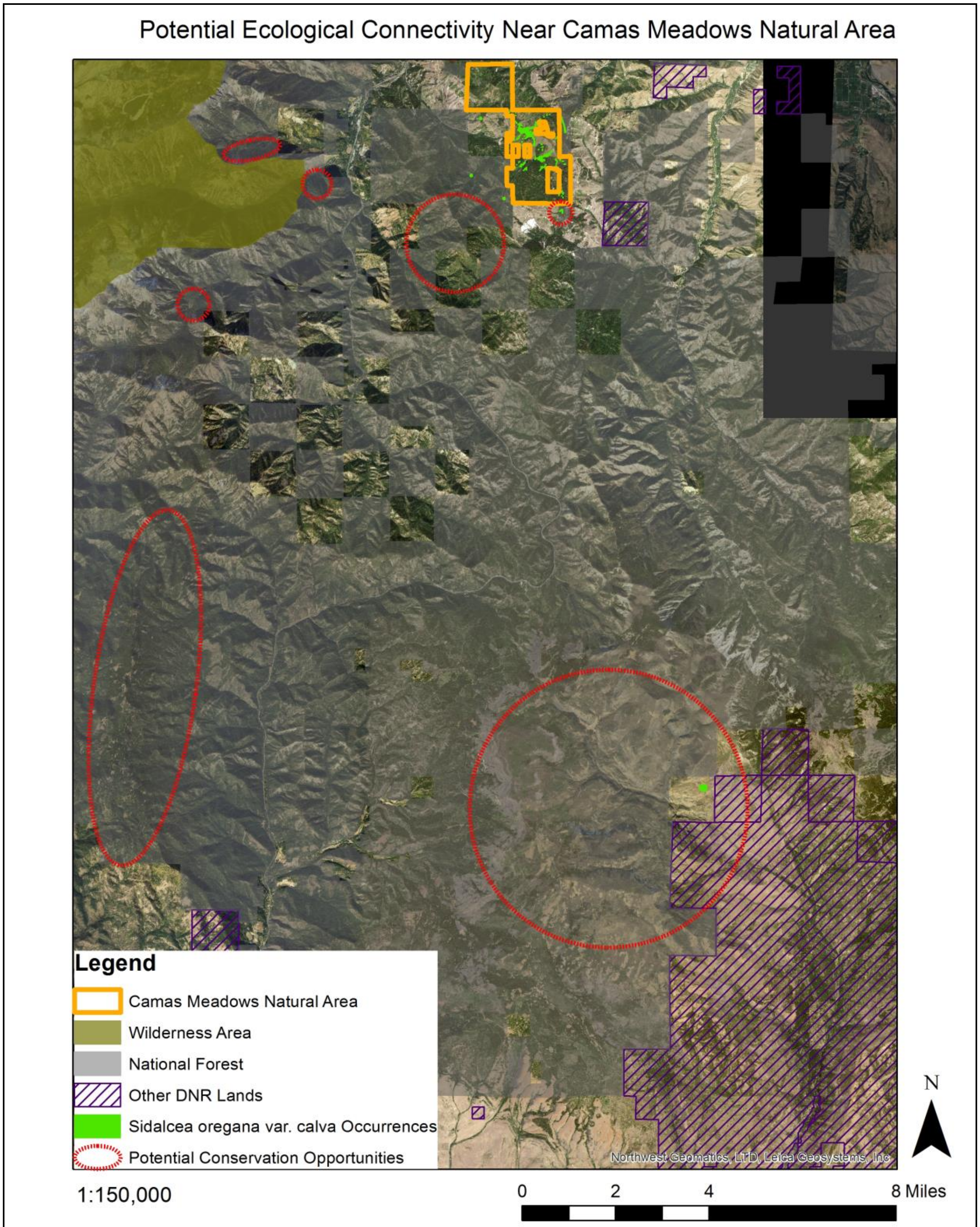

Figure 8. Potential ecological connectivity south of Camas Meadows Natural Area

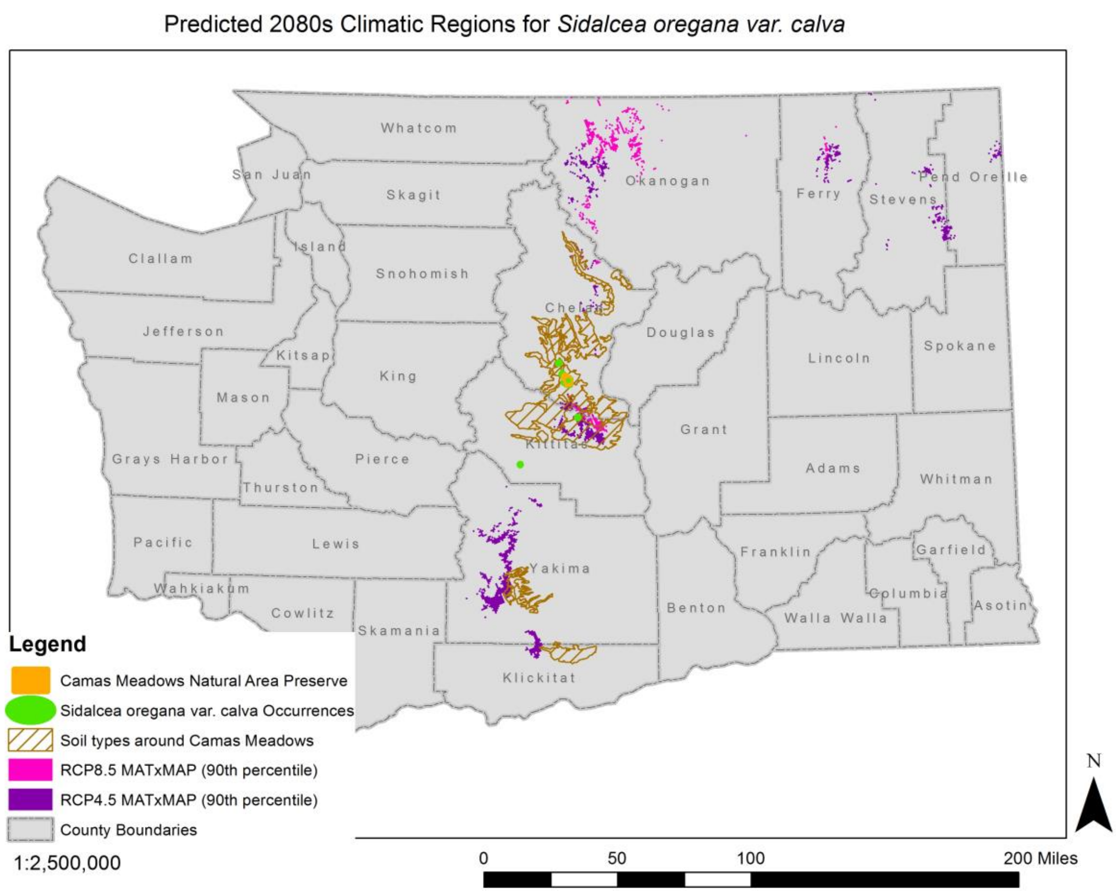

Figure 9. Predicted future soil and climate envelope for *Sidalcea oregana* var. *calva* in Washington, based on modeled conditions at Camas Meadows Natural Area Preserve.

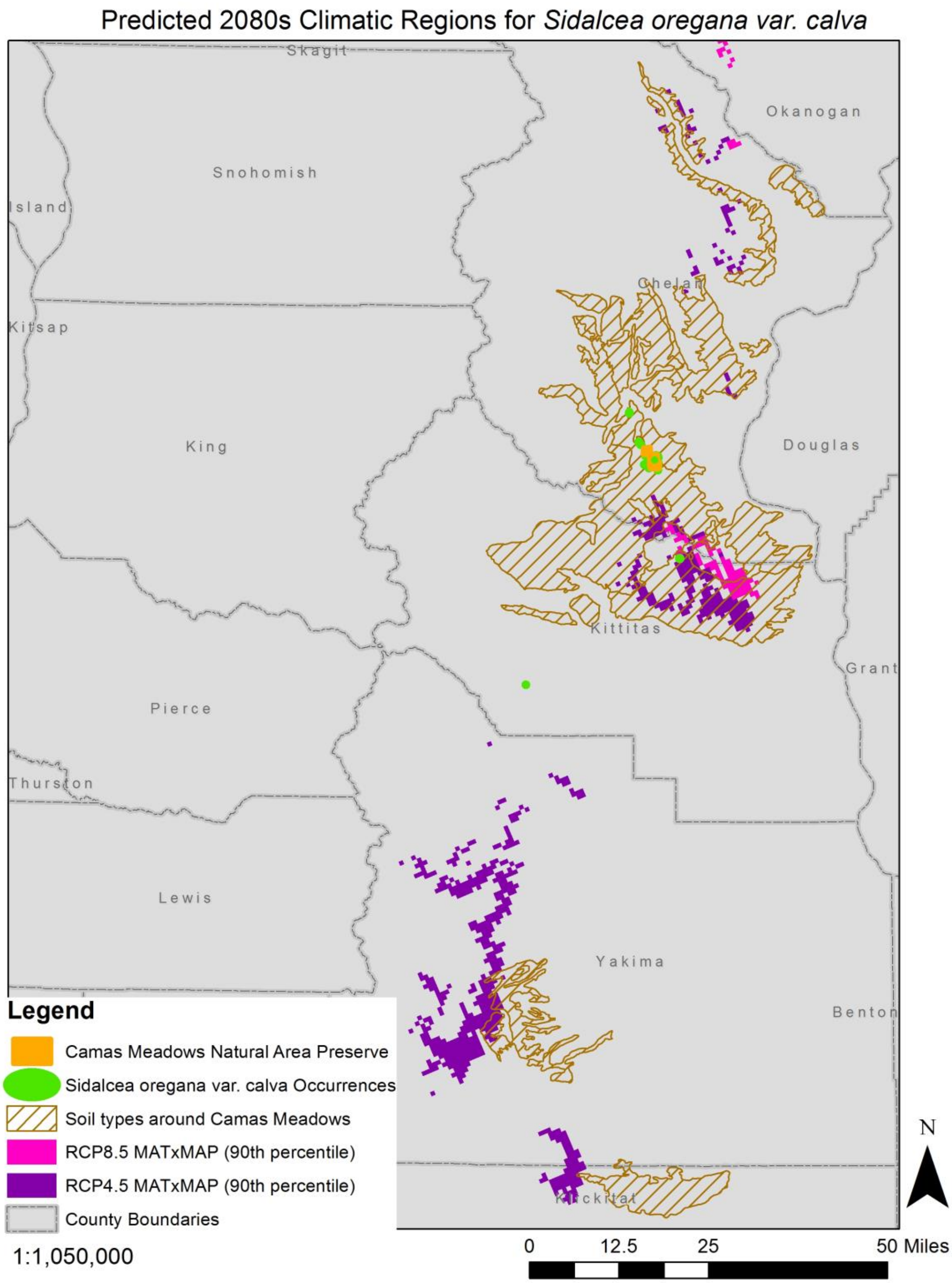

Figure 10. Predicted future soil and climate envelope for *Sidalcea oregana* var. *calva* in the Camas Meadows NAP area.

Dishman Hills Natural Resource Conservation Area

The Dishman Hills Natural Area includes 70 acres managed by DNR and 448 acres owned by Spokane County and the private Dishman Hills Conservancy (Figure 11). The approved boundary of the NRCA extends south to encompass a forested ridge system in the Iller Creek Conservation Area. Several small kettle ponds in the DNR-managed NRCA provide habitat for *Howellia aquatilis*. Most of the rest of the approved NRCA does not include kettle pond terrain, though there are additional ponds in the patchwork of private and state lands extending to the southwest towards Turnbull National Wildlife Refuge (NWR). Two of these areas are highlighted in Figure 11, including a dozen known *H. aquatilis* occurrences on DNR or private lands. Additional ponds in this general area have either not been surveyed or may no longer have suitable habitat for this species. Expansion of the Dishman Hills NRCA towards Turnbull NWR may not be possible due to the patchwork of diverse land ownership, but individual, isolated tracts could be identified for potential conservation attention through the DNR registry program, conservation easements with local land trusts, or purchase from willing sellers.

Our simple model of the current soil/climate envelope of *Howellia aquatilis* at Dishman Hills NRCA (Figures 12, 13) identifies an extensive area of potential habitat in eastern Washington under the optimal climate scenario in 2080 (RCP4.5). The size of the predicted area is driven by the broad distribution of the Uhlig-Hesseltine-Cheney soil association in the channeled scablands region, but does not reflect the exacting microhabitat requirements (seasonally flooded shallow to deep ponds) of *H. aquatilis*, and thus significantly over-predicts its potential range. No potential habitat is projected for this species in the Dishman Hills region under the worst case climate projection (RCP8.5) (Figure 13).

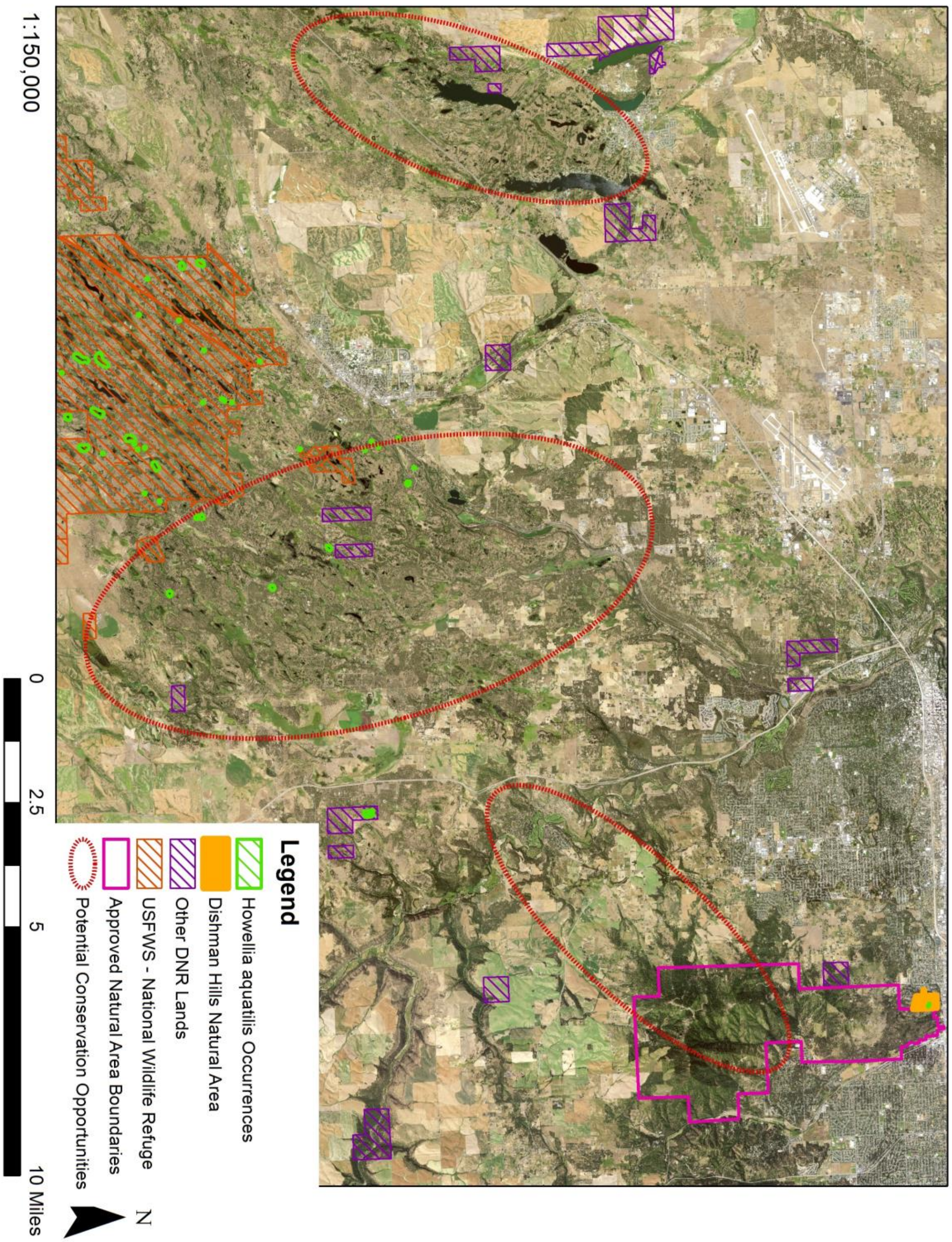

Figure 11. Potential ecological connectivity near the Dishman Hills NRCA.

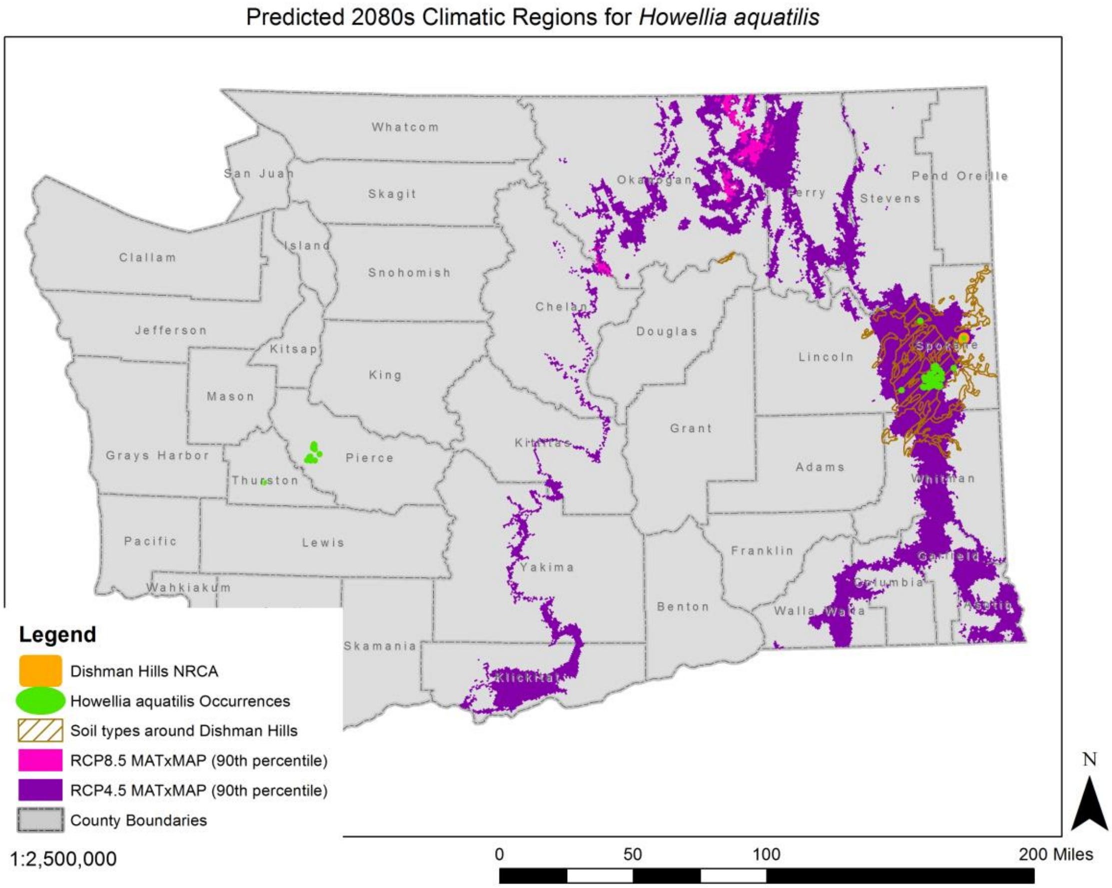

Figure 12. Predicted future soil and climate envelope for *Howellia aquatilis* in eastern Washington. Model based on conditions at Dishman Hills NRCA.

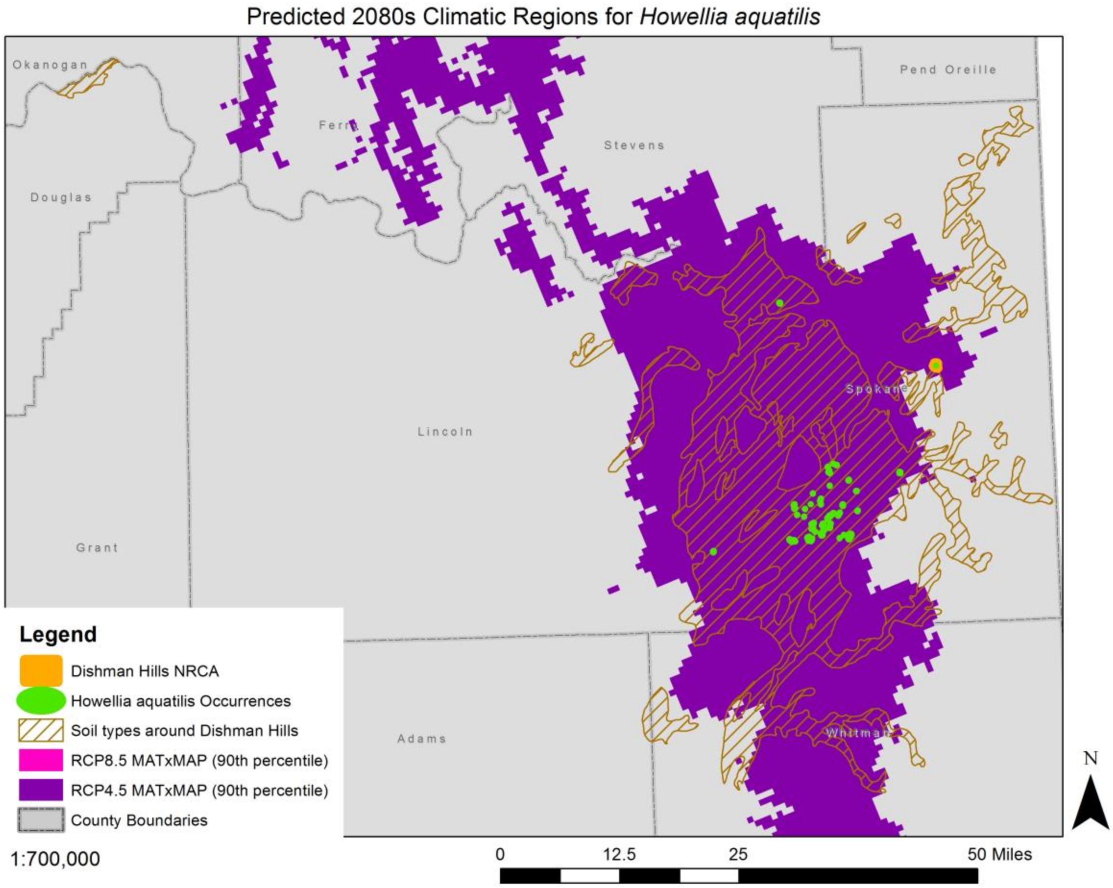

Figure 13. Predicted future soil and climate envelope for *Howellia aquatilis* in the Dishman Hills NRCA area.

Lacamas Prairie Natural Area Preserve/Natural Resource Conservation Area

The Lacamas Prairie NAP and NRCA was approved in 2007 and presently contains 189 acres of DNR-owned lands (Figure 14). The approved boundary of the natural area (i.e. the boundary within which DNR can pursue conservation purchase or easements) includes 1,622 acres and extends for about 3 ½ miles from above the confluence of Spring Branch and Lacamas Creek southeast to the Camas Meadows Golf Club and Lacamas Lake (Arnett 2010). Lacamas Prairie NAP is a subset of the total area and is located along Lacamas Creek in the former Green Mountain Resort.

Based on an analysis of soils and surviving wet prairie vegetation, Arnett (2010) identified extensive areas of potential *Lomatium bradshawii* habitat in southern Clark County. Many of these areas on public lands or visible from roads were surveyed by WNHP staff in the mid-1990s and early 2000s, but no new occurrences were documented (Arnett 2010; Wentworth 1996). Our modeling suggests there are areas of potential habitat within the proposed boundaries of the Lacamas Prairie NAP/NRCA as well as along Lacamas Creek southeast of Lacamas Lake towards the north shore of the Columbia River (northwest of Steigerwald National Wildlife Refuge) and in wetlands due south of the NAP in the Grass Valley area (Figure 14). These latter sites are not within the approved boundary of the NAP/NRCA. These areas would be worth surveying for *L. bradshawii* and other rare wet prairie species of the southern Puget Trough (Fertig 2018). Conservation actions could include adding private properties to the state's voluntary site registry program, purchase of conservation easements by local land trusts, or purchase by DNR (if landowners are willing).

Our modeling of the soil/climate envelope for *Lomatium bradshawii* at Lacamas Prairie NAP suggests that under future mean annual temperature and precipitation the Lacamas Prairie area may become too hot or dry for this species (Figures 15, 16). One area that might become better suited for *L. bradshawii* under "worst case" climate scenarios is southwestern Klickitat County and the vicinity of the Conboy National Wildlife Refuge. Arnett (2010) also suggested that Conboy NWR might offer potential habitat for *L. bradshawii* based on the presence of other rare wet prairie species (such as *Eryngium petiolatum*) at the refuge.

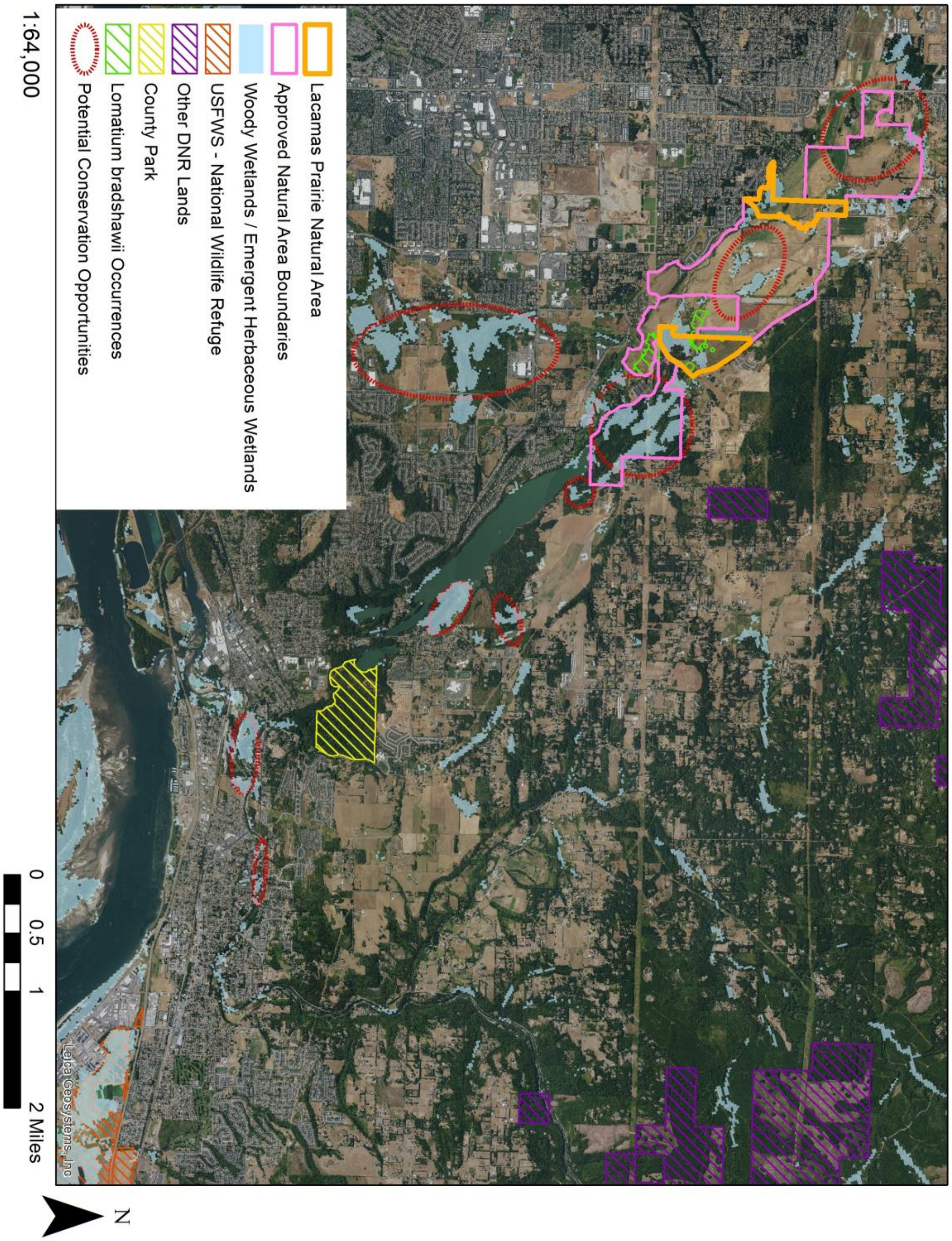

Figure 14. Potential ecological connectivity near Lacamas Prairie NAP.

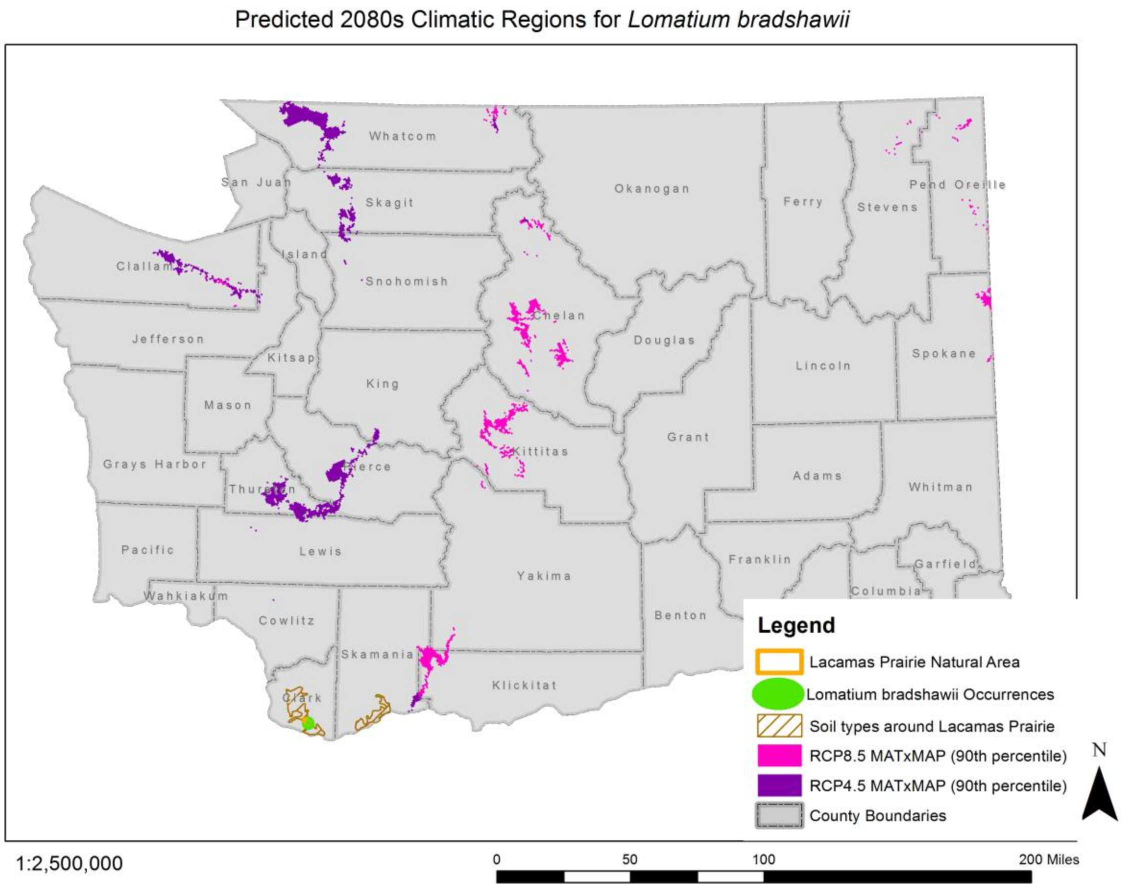

Figure 15. Predicted future soil and climate envelope for *Lomatium bradshawii* in Washington. Model based on conditions at Lacamas Prairie NAP/NRCA.

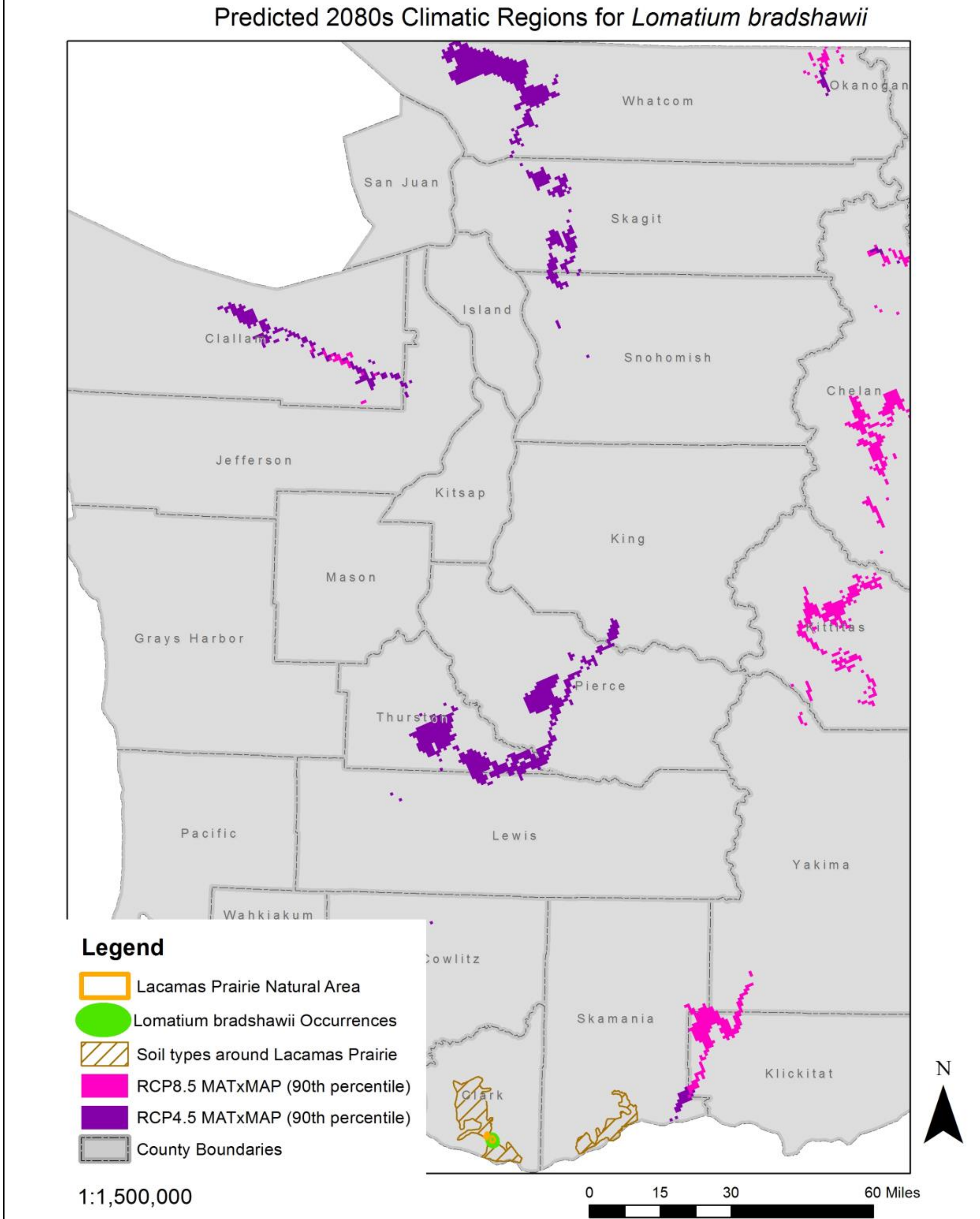

Figure 16. Predicted future soil and climate envelope for *Lomatium bradshawii* in the Lacamas Prairie NAP/NRCA area.

Rocky Prairie Natural Area Preserve

Rocky Prairie NAP is a 35 acre wedge-shaped parcel of native Puget Sound prairie dotted with large glacial cobbles. The NAP is bound on the east and west by a railroad line and state highway, and much of the surrounding area has been converted to agricultural fields, home sites, or second-growth forest (Figure 17). Two other protected areas with remnant prairie patches and introduced populations of *Castilleja levisecta* occur within 1.5 miles of the NAP to the southeast (Wolf Haven) and southwest (West Rocky Prairie) and at least five others occur within 8 miles (including Mima Mounds NAP, Glacial Heritage Preserve, Cavness easement, and Scatter Creek State Wildlife Area; Figure 17). Like Rocky Prairie NAP, these other sites occur within a highly fragmented landscape. Although Rocky Prairie NAP could potentially be expanded to the southeast to connect with Wolf Haven (Figure 17) the other remnant prairie sites in the area are too isolated to be realistically combined with the NAP.

Based on our modeling of current soil/climate relationships at Rocky Prairie and projected future MAT and MAP in 2080, the prairie habitats of western Washington may become too hot and dry to support *Castilleja levisecta* (Figures 18, 19). The soil characteristics in our model may be too generalized or coarse to identify microsites actually favored by *C. levisecta* (Dunwiddie and Martin 2016). Intensive management of Puget Trough remnant prairies, such as controlled burning (Dunwiddie et al. 2001), supplemental watering, or control of herbivores may be necessary to ensure or prolong the persistence of this species at Rocky Prairie.

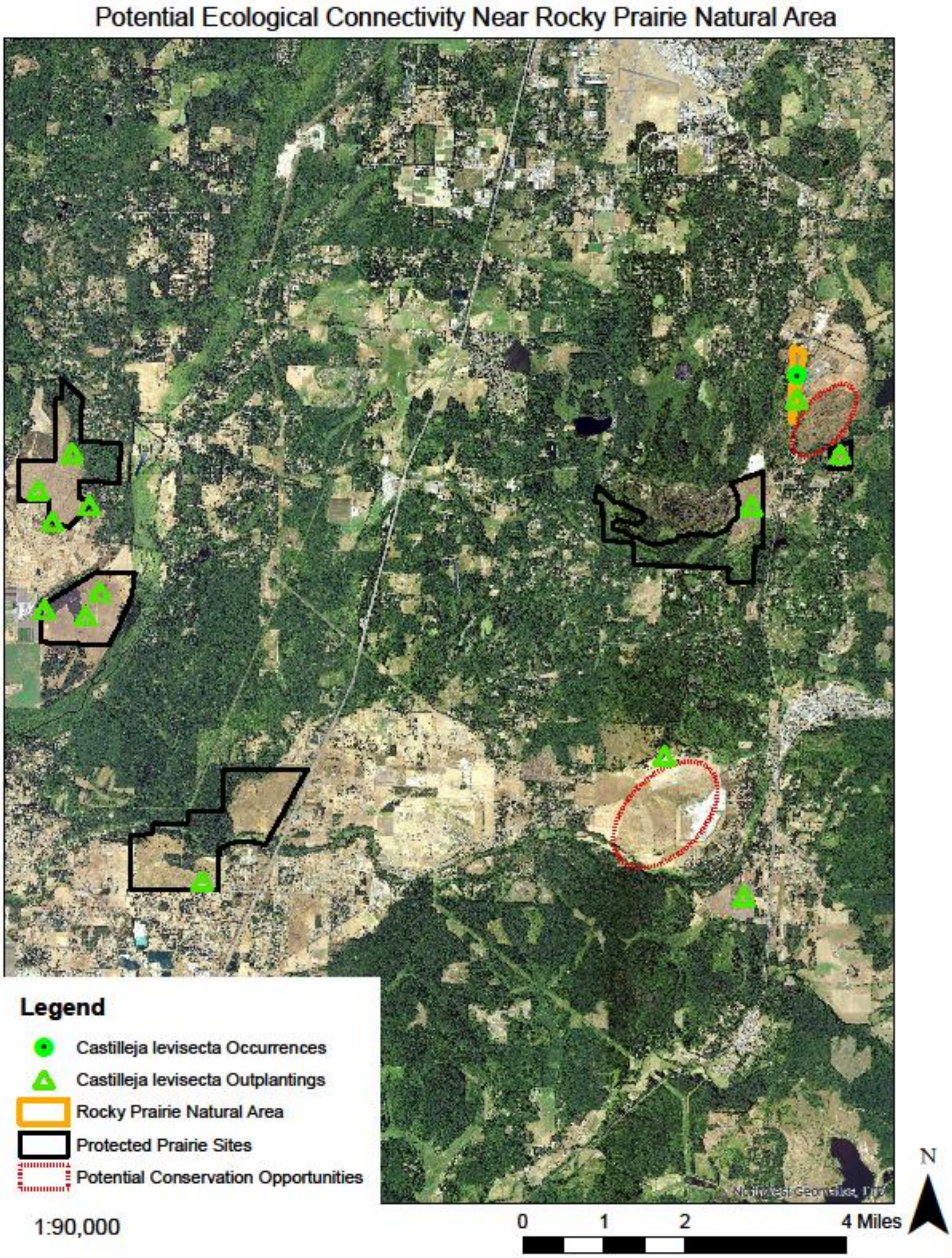

Figure 17. Potential ecological connectivity near Rocky Prairie Natural Area Preserve.

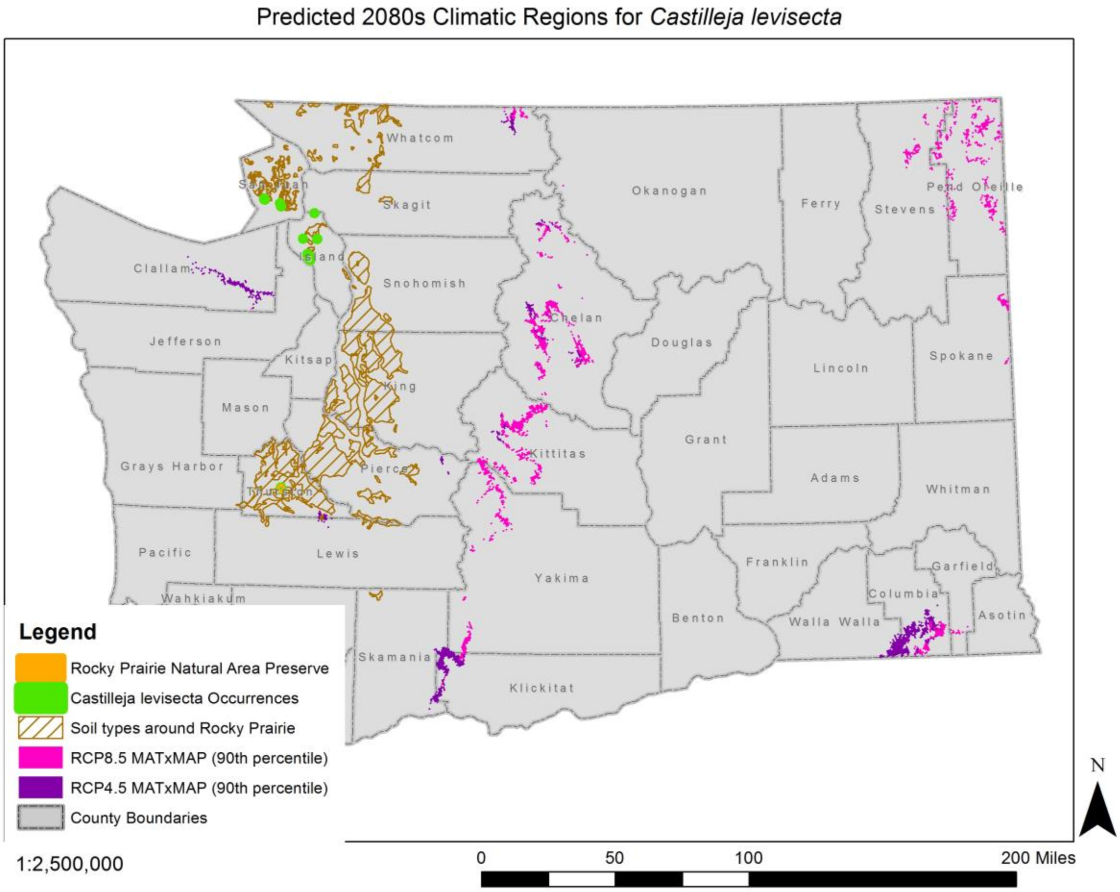

Figure 18. Predicted future soil and climate envelope for *Castilleja levisecta* in Washington. Model based on conditions at Rocky Prairie Natural Area Preserve.

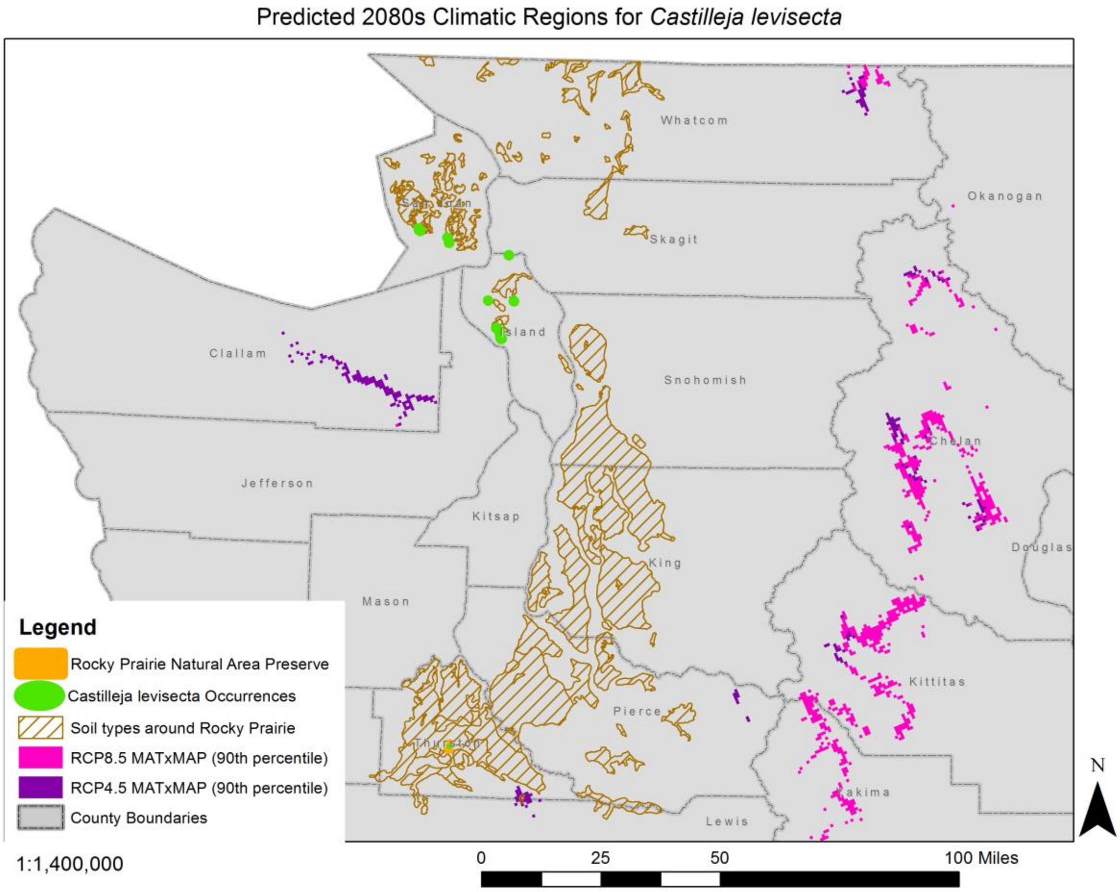

Figure 19. Close-up of Predicted future soil and climate envelope for *Castilleja levisecta* in the Rocky Prairie NAP area.

Hydrology Monitoring

<u>Camas Meadows Natural Area Preserve</u>

Due to failure of the barometric dataloggers at this site, it was not possible to determine absolute water levels; however, the uncorrected water levels did allow for a relative comparison of the three well locations (Table 2). In both 2017-18 and 2018-19, Camas-2 generally had the highest water levels during the growing season (estimated as April 1 through the end of data recording each year) and Camas-1 the lowest, although levels were similar in the early portion of the seasons (see Figures 20, 21). Camas-1 and Camas-2 (both with *Sidalcea oregana* var. *calva*) converged in the later part of the growing season in 2019 and both were at lower levels than Camas-3 from this point on (data recording ended in mid-June 2018, so it is not known if this pattern occurred in both years). For context, based on years of anecdotal observations, Camas-1 is estimated to be near the dry end of suitable habitat conditions for this plant at Camas Meadows, while Camas-2 is at or near the wet end.

In both monitoring periods, the variance in water levels was by far the highest in Camas-1, while Camas-2 and Camas-3 were similar (Table 2). This indicates that water levels rose and fell more frequently and/or more dramatically in this location, which is also apparent in the graphs (Figures 20, 21). Camas-1 water levels generally remained within about a 6”-8” range during most of the growing season, while Camas-2 levels fluctuated within about a 15”-20” range during this period.

Site	Average (uncorrected) Water Level (in) (Apr 1 - June 15)		Water Level Variance (in) (Apr 1 - June 15)	
	2017-18	2018-19	2017-18	2018-19
Camas-1 (shallow swale w/ *S. oregana* var. *calva*)	359.4	360.1	134.4	79.1
Camas-2 (main meadow w/ *S. oregana* var. *calva*)	366.5	368.2	58.1	17.3
Camas-3 (main meadow, no *S. oregana* var. *calva*)	361.6	361.9	40.4	21.6

Table 2. Water level data summary for measurements recorded during the growing season of *Sidalcea oregana* var. *calva* (April 1 – June 15).

While the lack of absolute water levels limits the conclusions that can be drawn, a few patterns are apparent. One is that the two *S. oregana* var. *calva* sites were both characterized by high water tables (and shallow inundation per other observations) in the early spring, confirming that this is an important condition for the species. Secondly, however, water levels in Camas-1 and Camas-2 were substantially different (1 -2 feet) for most of the remaining growing season. This suggests that, within the confines of seasonally-wet habitats, the species can tolerate a fairly wide range of water level conditions after mid-spring. The high variability in water levels in Camas-1, (i.e. “flashier” hydrology), and the more consistent levels in Camas-2, also suggest this.

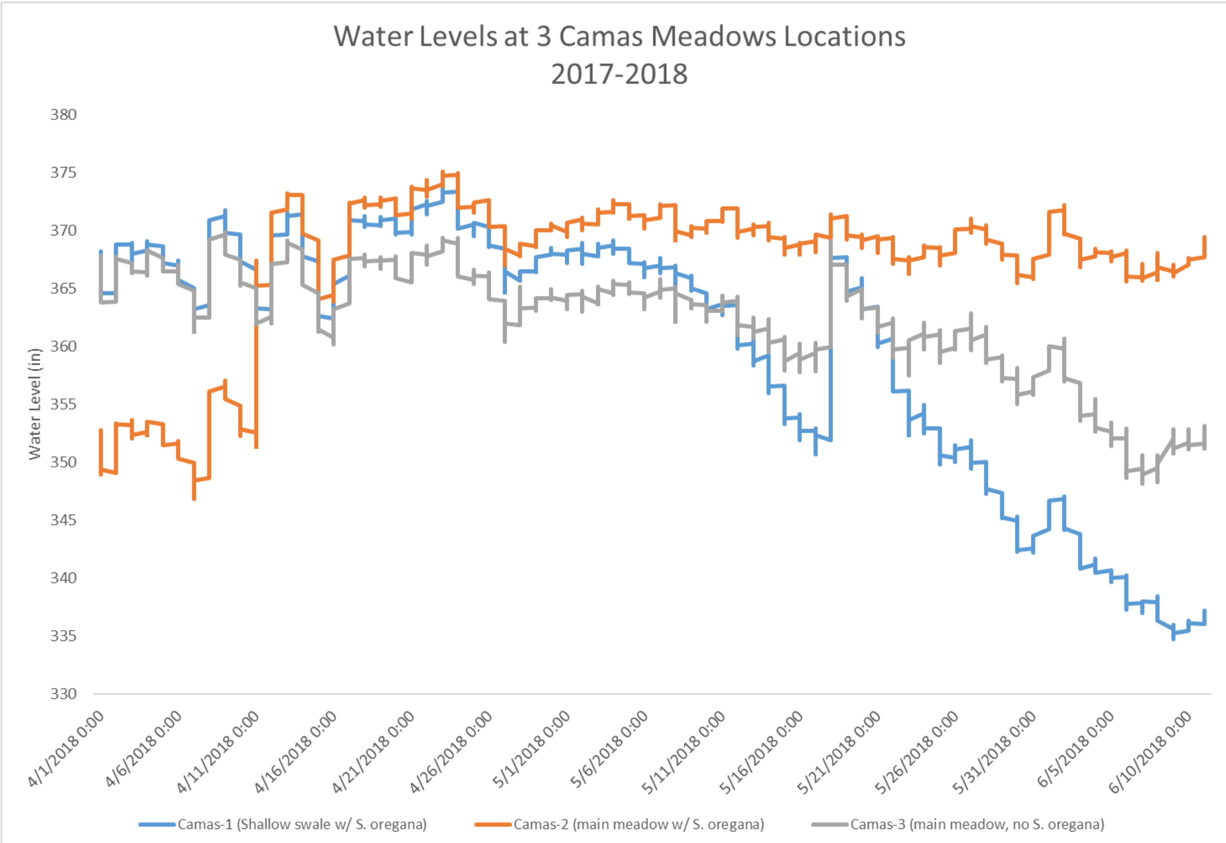

Figure 20. Water levels at four different locations in Camas Meadows during the 2018 *Sidalcea oregana* var. *calva* growing season (April 1 – June 15). Zero on the vertical axis corresponds to ground level and negative numbers refer to depth below ground level.

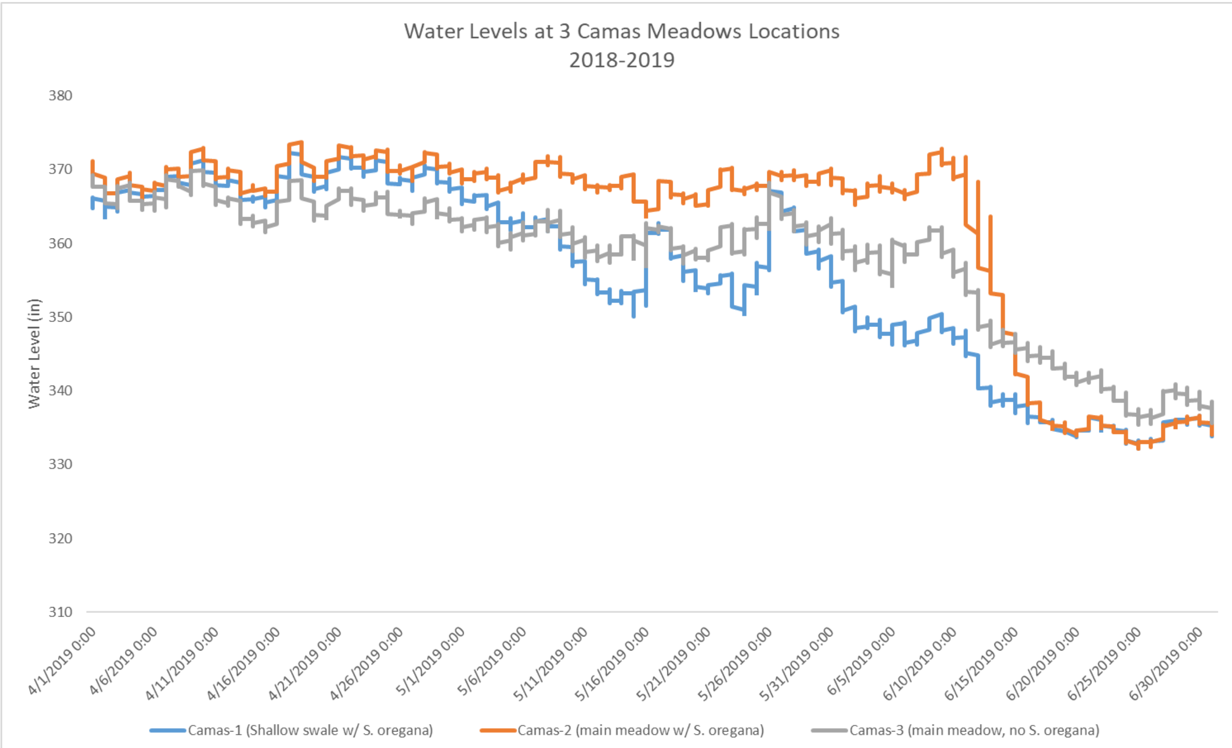

Figure 21. Water levels at four different locations in Camas Meadows during the 2019 *Sidalcea oregana* var. *calva* growing season (April 1 – June 30). Zero on the vertical axis corresponds to ground level and negative numbers refer to depth below ground level.

Dishman Hills Natural Resource Conservation Area

While the Dishman Hill data are from only a single, occupied pond, they do provide a fine-scale quantification of water levels in this one site that can help inform our understanding of suitable habitat for *Howellia aquatilis*, and begin to establish a baseline for assessing future changes and trends.

Water level data from East Pond showed that in both years, the pond was inundated starting in the third week of December (12/19/17 and 12/24/18) and continuing through late summer (Figure 22). In 2019, the pond remained inundated through August 21. In 2018, the datalogger had been programmed to stop recording in mid-June (which was anticipated to be approximately when the water would recede), however there was still nearly 23" of water present (via manual measurement) when the datalogger was retrieved in late July. Water levels were considerably higher for most of the Dec - March period in 2017-18 compared to 2018-19, likely due to somewhat higher precipitation during fall and early winter 2017-18 (12.99" vs. 11.37"). However, they were very similar from March through June of both years, with 2018 levels just 1-2 inches higher through mid-May and 2019 levels 1-2 inches higher after mid-May. In addition, the 23" measurement in late July 2018 is very close to the 25" level recorded by the datalogger on the same date in 2019, suggesting that water levels were very similar throughout the growing season of *Howellia aquatilis* (early May – July) in both years. Maximum water depth occurred on nearly the same date in both years: 58.6" on 4/16/18 and 59.2" on 4/14/19. These depths were substantially higher than the three feet that has previously been estimated as the maximum depth of *Howellia* ponds in Washington (Shelly and Gamon 1996).

In addition to characterizing hydrology in this species' habitat and helping establish baseline conditions, these data could be used to help predict the amount of suitable habitat that could be present under changed future conditions related to climate change. For instance, if climate change led to an average 1-foot change (increase or decrease) in water levels during the growing season, the resulting area of suitable water levels (as determined by this study and refined with future data) could be determined using fine-scale elevation data. Note that under a decreased water level, the area of habitat would almost certainly be reduced, as the "band' of suitable water depth/habitat would occur around a smaller polygon. An increase in water level could result in increased suitable habitat, although at East Pond this may be limited due to steep rock outcrops that partially confine the pond.

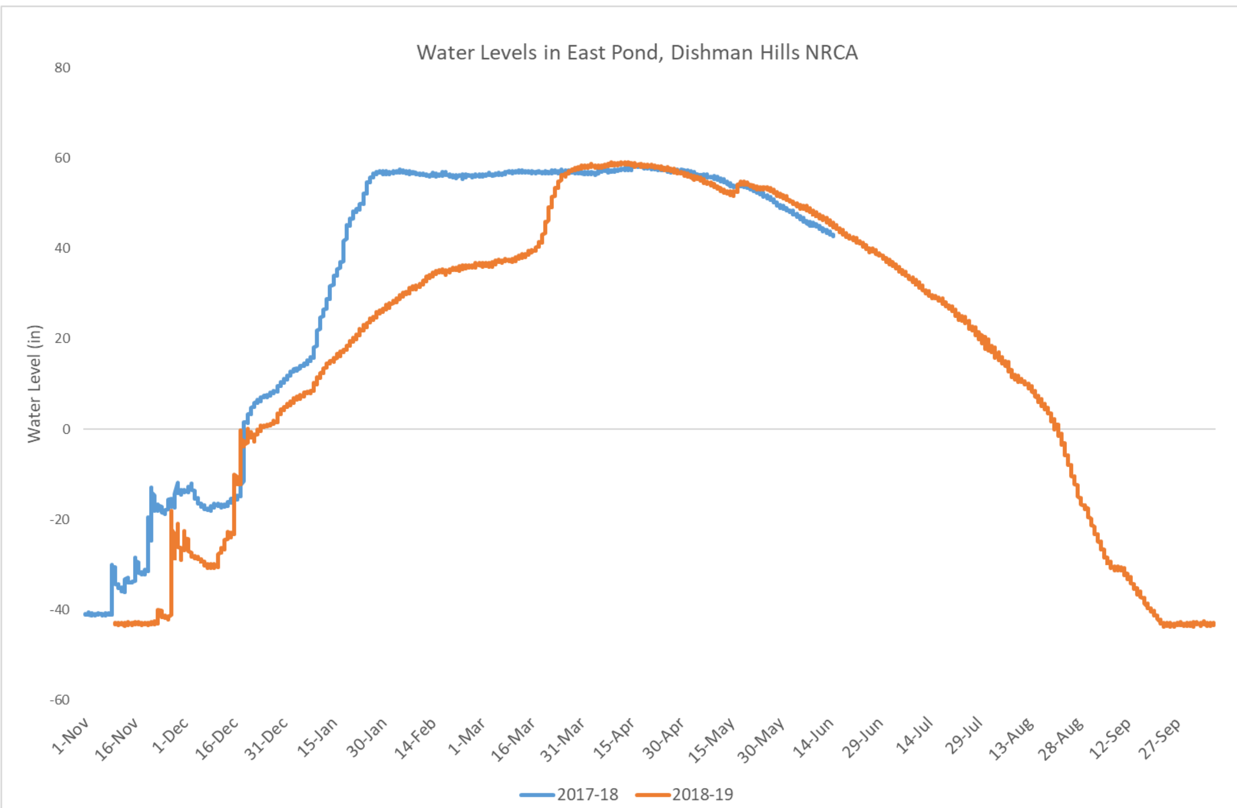

Figure 22. Water levels in East Pond at Dishman Hills NRCA during the 2017-18 and 2018-19 monitoring periods. Zero on the vertical axis corresponds to ground level and negative numbers refer to depth below ground level.

Lacamas Prairie Natural Area Preserve

Water level data from Lacamas Prairie showed distinctly different hydrologic patterns in sites with *Lomatium bradshawii* vs. those with without (see Figures 23, 24). In both monitoring periods (2017-18 and 2018-19), water level patterns in *L. bradshawii* habitat (Lac-1 and Lac-3) were similar to each other, and were generally drier than Lac-2 (*Deschampsia*-dominated) and wetter than Lac-4 (*Phalaris*-dominated). However they dried down earlier and more rapidly, and were therefore drier in the later portion of the growing season (starting in early May) than the locations without *L. bradshawii*.

During both growing seasons, the *L. bradshawii* locations had a distinctive pattern of occasional inundation to depths of generally 1 inch or less, interspersed with periods where water levels were below the surface. In 2017-18 (a period of relatively average precipitation), this pattern was characterized by periodic inundation to very shallow depths (<1") for 1-11 days, interspersed with periods of below-surface water levels for 1-8 days. In 2018-19 (drier than average, especially in March), both locations had a single period of inundation in mid-April lasting 9 days. In contrast, the *Deshamspsia*-dominated location (Lac-2) had a single long period of indundation (generally 1"-3" depth) in each monitoring period, lasting 44 days in 2017-18 and 19 days in 2018-19. This confirmed and helped quantify anecdotal observations that the *Deschampsia*-dominated portion of the NAP tended to be shallowly inundated for longer periods of time than the nearby *L. bradshawii* habitat, even though it is at a slightly higher elevation. The *Phalaris*-dominated location (Lac-4) had only a 2-day period of inundation in 2017-18 and none in 2018-19.

Table 3 includes several measures that further illustrate the differences between the four locations and between the locations with and without *L. bradshawii*. In *L. bradshawii* habitat, the percent of total measurements during the primary growing season of *L. bradshawii* (defined as March 1 – May 15) at or above ground level (i.e. ≥ 0" depth) was 47% and 27% in 2017-18 and 12% and 13% in 2018-19 in Lac-1 & Lac-3, respectively. This was substantially lower than in the *Deschampsia* location (70% in 2017-18, 41% in 2018-19), but higher than in *Phalaris* location (3% in 2017-18, 0% in 2018-19). Average inundation depth (i.e. average depth when water was above ground) over the growing season showed the same relative pattern, with depths in *L. bradshawii* habitat generally between the other two. The variance in water levels over the growing season (a measure of the amount of water level fluctuations) was substantially greater in the *L. bradshawii* locations than in either of the other locations, indicating that water levels rose and fell more frequently and/or more dramatically in *L. bradshawii* habitat.

The percentage of measurements during the growing season at or above -12" (i.e. 12" below ground or higher, the estimated rooting depth of *L. bradshawii*) ranged from 52-74% in *L. bradshawii* locations, substantially lower than the 85-100% in the other two locations. Interestingly, the percentage was highest in the *Phalaris* location, indicating that, while water levels do not reach ground level or inundation levels very often here, the belowground water table remains relatively high into the summer compared to the others.

While variability in annual climate and hydrology, and the short dataset (two years), limit the conclusions that can be drawn, the observed patterns and conditions do help to refine and quantify our understanding of *L. bradshawii* habitat. The data suggest that *L. bradshawii* habitat has a relatively narrow range of hydrologic conditions during the growing season, at least in this area, characterized by relatively short periods of very shallow inundation interspersed with similar periods of drying. Neither of the other locations exhibited this type of pattern, suggesting that even a relatively small shift in hydrology toward either consistently wetter or drier conditions could negatively impact *L. bradshawii*. Note that while water levels during the growing season were generally lower in 2018-19 than in 2017-18 (and the *L. bradshawii* population was stable or increased in this period based on NAP data), this is only a single year and cannot be used to infer that *L. bradshawii* can tolerate such conditions on a frequent basis. This period was also drier than average per precipitation records.

The data also provide some insight into hydrologic characteristics that may favor dominance by other species on this site. The *Deschampsia* location was characterized by prolonged inundation of 1-3" depth during the growing season and while the *Phalaris* location had very little if any inundation, but maintained a relatively high water table into the early summer. Finally, and perhaps most importantly, the data will help to establish a baseline for assessing future changes and trends.

Site	% Measures ≥ 0" (Mar 1 - May 15)		% Measures ≥ 12" (Mar 1 - May 15)		Average Inundation Depth (in) (Mar 1 - May 15)		Water Level Variance (in) (Mar 1 - May 15)	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Lac 1 (High-density *L. bradshawii*)	47%	12%	74%	52%	0.8	0.4	74.1	66.2
Lac 2 (*Deschampsia* dominated, no *L. bradshawii*)	70%	41%	99%	89%	2.2	1.0	14.9	25.7
Lac 3 (Extremely high-density *L. bradshawii*)	27%	13%	72%	62%	0.9	1.0	68.4	58.6
Lac 4 (*Phalaris* dominated, no *L. bradshawii*)	3%	0%	100%	85%	0.2	0	9.6	18.5

Table 3. Water level data summary for measurements recorded during the estimated growing season of *Lomatium bradshawii* (March 1 – May 15).

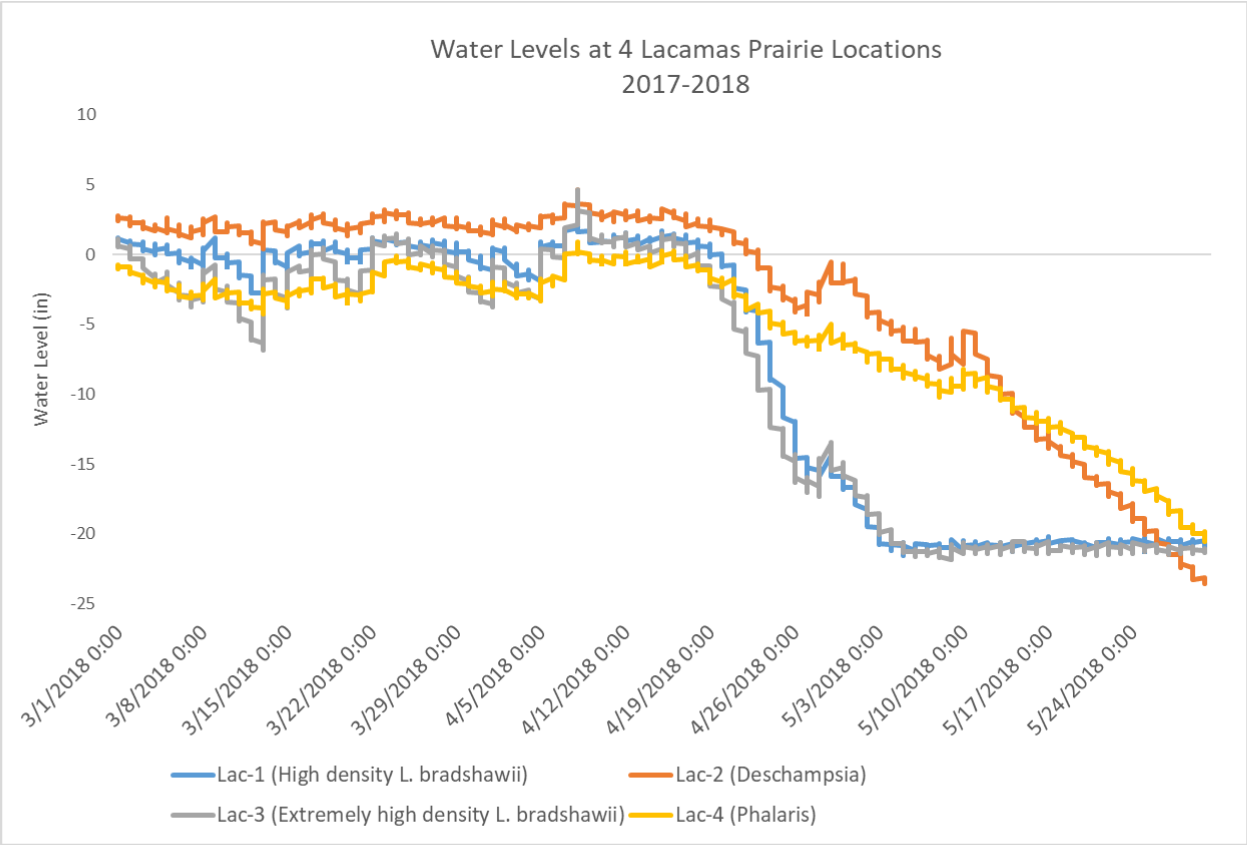

Figure 23. Water levels at four different locations in Lacamas Prairie during the 2018 *Lomatium bradshawii* growing season (March 1 – May 15). Zero on the vertical axis corresponds to ground level and negative numbers refer to depth below ground level.

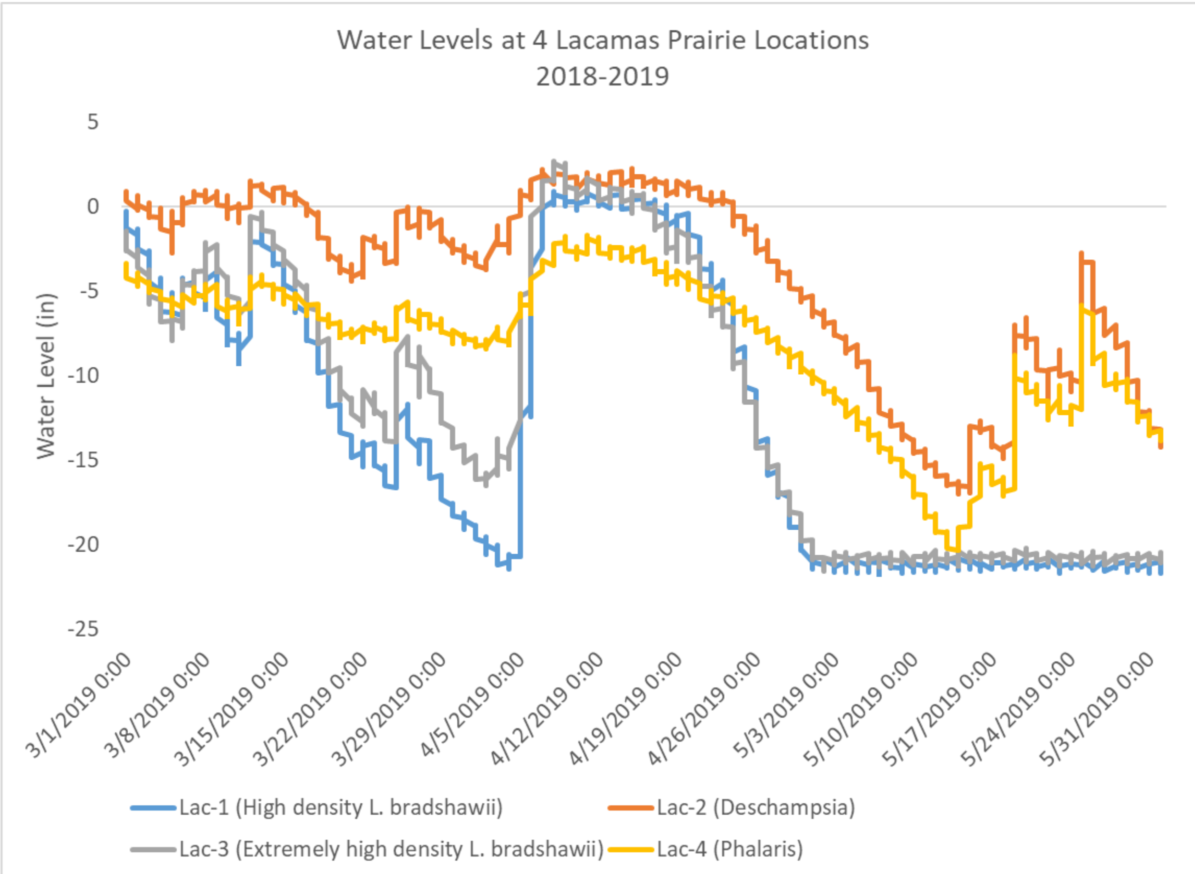

Figure 24. Water levels at four different locations in Lacamas Prairie during the 2019 *Lomatium bradshawii* growing season (March 1 – May 15). Zero on the vertical axis corresponds to ground level and negative numbers refer to depth below ground level.

Climate Change Vulnerability

Castilleja levisecta (Golden paintbrush)

Based on the NatureServe CCVI (Young et al. 2016), *Castilleja levisecta* is “Highly Vulnerable” to climate change (Appendix A). Golden paintbrush is particularly vulnerable to increased moisture stress in its habitat (as determined by the Hamon ratio of actual to potential evapotranspiration) and changes to its historical thermal niche. Additional contributors to its vulnerability rank include impediments to dispersal across natural and anthropogenic barriers, reduced pollinator versatility, increased competition from exotic weeds, and encroachment of shrubby and woody vegetation in prairie habitats. Recent declines in the abundance of native occurrences of *C. levisecta* in Washington may already be attributable to recent drought and high temperatures in the May flowering period (Dunwiddie and Pelant 2019; Fertig 2019). See Appendix A for a more detailed discussion of the CCVI results.

Our model of the soil/climate envelope for *Castilleja levisecta* at Rocky Prairie NAP (Figure 19) suggests that under projected climate scenarios for 2080 there will be minimal overlap between the distribution of suitable prairie soils and amenable climate for this species in western Washington (Figure 18). Only a small area of South Sound prairie along the Thurston/Lewis county line will retain hospitable soil and climate conditions for this species in 60 years (Figure 19). Dunwiddie and Martin (2016), however, found that site micro-characteristics, such as local topography, soil depth, and associated species, were better predictors of the distribution and survival of outplanted *C. levisecta* plants than coarse-scale environmental attributes, such as soil or vegetation type. Out-plantings may also be more sensitive indicators of environmental conditions suitable for *C. levisecta* than native occurrences, which tend to be restricted to drier, rockier, and shallower soils that were unsuited for farming (Dunwiddie and Pellant 2019). Thus our present model may be too coarse to adequately predict future conditions for this species. Long-term survival of *C. levisecta* in the South Sound area may be more dependent on intensive management to maintain early-seral habitat conditions, reduce competition with invasive plants, ease impacts from wildfires that burn too hot, or lessen herbivory from deer, elk, rabbits, and voles (Dunwiddie and Pelant 2019).

Howellia aquatilis (Water howellia)

The NatureServe CCVI score for *Howellia aquatilis* is "Extremely Vulnerable" (Appendix B). This species is especially vulnerable to changes in hydrology from decreased or more variable precipitation and higher temperatures that affect water availability in its vernal wetland habitat (Shelly and Gamon 1996). The unusual life history of this annual, in which it requires both exposed mudflats for germination and deep water for growth and reproduction, and its short-lived seedbank, makes *H. aquatilis* highly susceptible to long-term drought or periods of prolonged inundation (Lesica 1992). Other biological factors contributing to its extreme vulnerability include decreased ability to disperse across human and natural barriers, reduced gene flow between populations as its range becomes more fragmented, and increased competition with invasive weed species (such as *Phalaris arundinacea*) or encroaching *Pinus ponderosa*, *Pseudotsuga menziesii*, *Populus tremuloides*, or *Fraxinus latifolia* woodlands. Long-term persistence of *H. aquatilis* may depend on the presence of both shallow and deep ponds within the same general area, allowing plants to survive in shallow ponds during wetter years and deeper ponds during extended drought (Lesica 1992). See Appendix B for more detail on the CCVI rating for this species.

Our model of the future soil/climate envelope for *Howellia aquatilis* (Figures 12, 13) emphasized environmental attributes of the Dishman Hills area, so may not be applicable to occurrences from the western half of Washington. Although a large area of potential habitat was recognized based on soil characters, the range of the species may be constrained in the future under different climate scenarios. In the optimal projection, much of the current habitat of *H. aquatilis* in the Spokane area would still be viable in 2080, but none would remain suitable under the worst case scenario (Figure 13).

***Lomatium bradshawii* (Bradshaw's desert-parsley)**

Bradshaw's lomatium is scored as "moderately vulnerable" to climate change according to the NatureServe CCVI ranking system (Appendix C). This score is driven by the risk of *Lomatium bradshawii* to changes in moisture availability, poor dispersability across an increasingly fragmented human-dominated landscape, impacts from competing weed and riparian woodland vegetation, and dependence on disturbance events (such as periodic fire) to maintain habitat conditions. See Appendix C for a more complete discussion of the CCVI ranking.

Based on our modeling of the soil/climate envelope at Lacamas Prairie, the current mean annual temperature and mean annual precipitation patterns will shift to the north or east and migrate upslope into the foothills of the Cascade and Olympic ranges under both best and worst case climate change projections (Figures 15, 16). Unfortunately, none of these new areas contains the same soil characteristics as the Lacamas Prairie area.

***Sidalcea oregana* var. *calva* (Wenatchee Mountains checkermallow)**

Sidalcea oregana var. *calva* is ranked "Highly Vulnerable" to the effects of climate change based on NatureServe's CCVI system (Appendix D). This species is especially sensitive to changes in its physiological hydrological niche due to its dependence on seasonal flooding during the growing season which is likely to be reduced due to changes in precipitation patterns, reduction in snow and ice cover, and higher predicted temperatures. Other factors contributing to the vulnerability of *S. oregana* var. *calva* include human-influenced barriers to dispersal, dependence on specialized pollinators, increased predation of fruits and seeds by weevils, and increased competition with invasive wetland plants (Arnett and Birkhauser 2008; Caplow 2003; Goldsmith 2003). Other factors that could negatively impact this species, such as reduced genetic diversity, are poorly known. See Appendix D for the full CCVI report and a more detailed description of the various factors used in the ranking.

Our simple modeling of the distribution of *S. oregana* var. *calva* based on soil properties of the Camas Meadows NAP occurrence and projected MAT and MAP in 2080 (Figures 9, 10) suggests that the optimal soil/climate envelope for this species may shift to the southeastern Wenatchee Range in the future. The model also suggests that climate conditions under worst case (RCP8.5) and optimal (RCP4.5) scenarios might no longer intersect with soil characteristics utilized by this species at Camas Meadows NAP. The model does not take into account other environmental or biological attributes (such as elevation, extreme climate events, geologic substrate, vegetation types, landforms, or pollinator distribution) in identifying potential shifts in the soil/climate envelope. Long-term persistence of the species may be dependent on active management of existing populations (such as mitigating changes in hydrology, reducing competing weeds or shrubby species, population augmentation) or facilitated dispersal to new sites with suitable conditions.

Management Considerations

Due to the uncertainties in predicting climate change at a particular location and the complexities involved in predicting how these changes will influence a particular species and habitat, making management recommendations to address specific conditions in the future is very speculative. One of the most widely recommended strategies relating to conservation land management (such as natural area preserves), at least in the near term, is to focus on reducing non-climate stressors and to maintain or restore ecological resilience (e.g. Stein et al. 2014, Olson et al. 2009, USFWS 2010). This includes addressing issues such as invasive species, modifications of natural processes, and unauthorized land uses, and restoring native species composition and structure. By addressing these non-climate stressors, target species and their habitats will have an increased chance of persisting through whatever climate change effects do occur.

For the four natural areas that were the focus of this project, potential management actions that should be considered, or continue to be implemented, are outlined below. Many of these management actions are a part of the traditional management of natural areas (and other conservation lands), which generally has a focus on reducing existing stressors and managing for ecosystem resilience through maintenance of intact plant communities, processes, and habitats. While the information below does not necessarily identify "new" management recommendations for these sites, it does help to emphasize actions that are likely to have the greatest benefits in light of climate change. In some cases, it also identifies climate change considerations that should be taken into account when designing and implementing management activities. Similar considerations would apply to most other sites with the four target species as well.

Camas Meadows Natural Area Preserve

The primary non-climate stressors at this site are very similar to those at Lacamas Prairie: invasive species (both native and non-native), past modifications to the hydrology, and altered fire regime. Key invasives include native trees and shrubs (e.g., *Pinus ponderosa*, *Pseudotsuga menziesii*, *Symphoricarpos albus*), pasture grasses, *Phalaris arundinacea*, and several non-native forbs. Continuing to control these species to minimize their impacts on *Sidalcea oregana* var. *calva* is critical to improving and maintaining resilience of this population and habitat. Prescribed fire, both for invasive control and for more general ecosystem process maintenance, should be continued and expanded. As noted above, adjustments in scheduling are likely to be needed under future climate conditions. In addition to prescribed fire, mechanical treatments of surrounding forest habitat should also be considered. While not directly affecting the majority of the population on the site, the altered forest conditions and fuel loadings on the site are important to consider. These conditions, combined with projections for increased wildfires under climate change, greatly enhance the risk of severe, high-intensity wildfire on the site, rather than the more frequent, low-intensity fires that occurred historically. This would likely result in increased spread of introduced species and sedimentation into riparian and wet meadow habitats, including areas occupied by *S. oregana* var. *calva*.

With regard to hydrology, *S. oregana* var. *calva* does appear to have some latitude in conditions after early spring, but saturated or flooded conditions in the early spring are clearly important. Because most of this early spring moisture is from snowmelt, the reduced snowpack predicted by climate models could significantly affect both the timing and duration of seasonal moisture in this species' habitat. Management should include an assessment of human-induced impacts to hydrology and attempt to address these through restoration, prioritizing actions that will restore appropriate levels of water retention and seasonal flooding. Future needs may require additional manipulations of hydrology to maintain suitable habitat, e.g. artificial impoundments or excavation to create appropriate topography.

Dishman Hills Natural Resources Conservation Area

Key non-climate stressors for *Howellia aquatilis* at Dishman Hills include invasive species, fire suppression, and trampling/soil disturbance associated with recreational hiking. The primary invasive species of concern at this site is *Phalaris arundinacea*, although it is currently present in very small amounts and may actually be a native genotype. Monitoring should be continued to determine if it expands and if control measures are necessary. Fire suppression has altered the forest composition and structure of surrounding uplands, and perhaps modified the immediate shoreline of East Pond as well. Addressing these conditions through mechanical treatments and/or prescribed fire should be considered in light of climate change predictions, particularly if wildfires are likely to cause significant sedimentation into the pond due to surrounding heavy fuel loads.

Recreational use in and around East Pond could result in the introduction of new invasive species, or increase the spread of existing ones. It also disturbs the soil within the pond, which could disrupt germination and establishment of *H. aquatilis* plants. Use levels should be monitored and steps taken to limit access directly into the pond. The hydrology of this site has not been noticeably modified from its natural condition, therefore no hydrologic restorations or enhancements are currently needed. In the future, extreme reductions in water levels could result in a need to manipulate topography to provide the appropriate hydrology for this species, e.g. augment existing ponds or carefully excavate artificial ponds of appropriate depth and shape.

Lacamas Prairie Natural Area Preserve

The main non-climate stressors at this site include invasive species (both native and non-native), past modifications to the hydrology, and an altered fire regime. Key invasives include several trees and shrubs (*Fraxinus latifolia, Rosa* spp.), invasive grasses (predominantly *Alopecurus pratensis*), and various forbs. Continuing to control these species to minimize their impacts on *Lomatium bradshawii* and on the native wet prairie plant community is critical to improving and maintaining resilience of this population and habitat. Prescribed fire, both for invasive control and for more general ecosystem process maintenance, should be continued. Adjustments in scheduling are likely to be needed in the future, due to shifting and/or narrowing weather and fuel windows under which burns can be done.

Maintaining suitable hydrologic conditions into the future will be critical for *L. bradshawii* at Lacamas Prairie. Past hydrologic modifications to this site are not well understood, but include agricultural ditching, roads, and various light industrial and residential drainage infrastructure on adjacent lands. Additional modifications continue to occur in the surrounding landscape. Because *L. bradshawii* appears to have a somewhat narrow range of suitable hydrologic conditions, any restoration or rehabilitation efforts related to hydrology should be implemented cautiously and on a small scale. Any significant changes should incorporate additional research to help determine appropriate target conditions. The hydrology monitoring conducted as part of this project suggests that any efforts to manipulate hydrology should be particularly careful to avoid creating conditions of prolonged inundation or saturated soils during the species' growing season. In addition, it suggests that more flashy hydrology under climate change (as predicted by some climate models) may not be a major cause of concern, although this will depend heavily on the degree of change and on other components of the hydrologic regime. Perhaps the best approach for managing this and other *L. bradshawii* sites would be to emphasize maintenance or improvement of other habitat characteristics, e.g. native plant composition, low shading, across areas with a variety of current hydrologic regimes. This could help ensure that at least some portion of the areas that develop suitable hydrology in the future will also be suitable with regard to other habitat characteristics, allowing *L. bradshawii* to colonize these areas.

Rocky Prairie Natural Area Preserve

Key non-climate stressors at Rocky Prairie NAP, and at other south Puget Sound prairie sites, include invasive species, fire suppression, and population isolation resulting from fragmentation and small site size. Primary invasives are several trees and shrubs (*Cytisus scoparius*, *Pseudotsuga menziesii*, *Symphoricarpos albus*), and non-native grasses (*Arrhenatherum elatius*, *Anthoxanthum odoratum*), and a number of forbs. Continued control of these species to minimize their impacts on *Castilleja levisecta* and on the native prairie plant community is critical to improving and maintaining resilience of this population and habitat. Prescribed fire, both for invasive control and for more general ecosystem process maintenance, should be continued and expanded if possible. Adjustments in scheduling are likely to be needed in the future, due to shifting and/or narrowing weather and fuel windows under which burns can be done.

The small size of this site and its separation from other *C. levisecta* sites could lead to reduced fitness of the population due to genetic isolation. In addition, pollinator abundance and diversity may be lower within such a small site compared to larger prairies, and could become further reduced under climate change. Because *C. levisecta* is dependent on insect pollinators for consistent seed set, this could have a substantial impact on the population. Opportunities to expand this site into adjacent areas that could support native prairie vegetation and *C. levisecta* should be considered.

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Appendix A. Climate Change Vulnerability Index Report

Castilleja levisecta (Golden paintbrush)

Date: October 2019

Assessor: Walter Fertig, WA Natural Heritage Program (update from Gamon 2014)

Geographic Area: Washington Heritage Rank: G2/S2

Index Result: Highly Vulnerable Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	0
	<3.9° F (2.2°C) warmer	100
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	100
	-0.051 to - 0.073	0
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		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		Greatly 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	Somewhat Increase
4d. Dependence on other species for propagule dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies	Neutral
4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Neutral
5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Increase
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All 22 native occurrences of *Castilleja levisecta* in Washington (11 of which are extant and 11 extirpated or historical) occur in areas with a projected temperature increase less than 3.9˚F (Figure A-1).

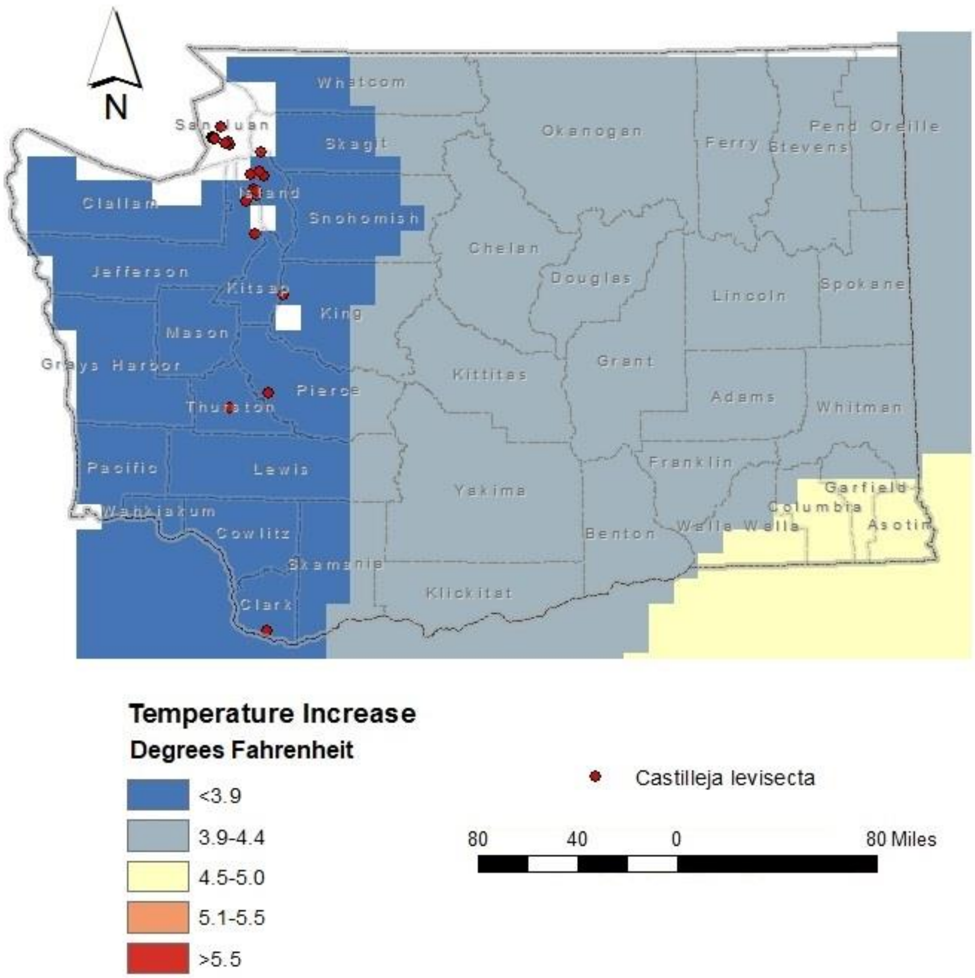

Figure A-1. Exposure of *Castilleja levisecta* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: All 22 native occurrences of *Castilleja levisecta* in Washington are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of – 0.074 to – 0.096 (Figure A-2).

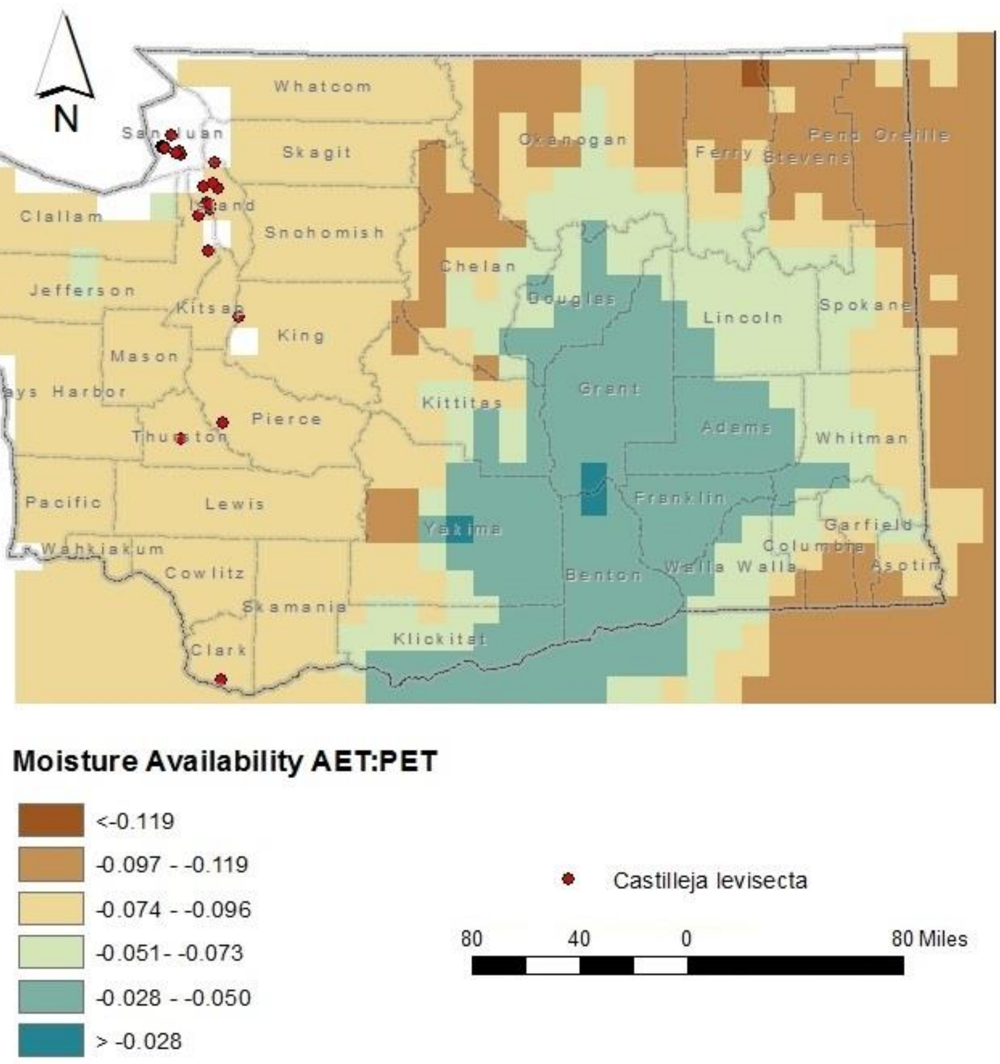

Figure A-2. Exposure of *Castilleja levisecta* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
Of the 11 extant native occurrences of *Castilleja levisecta* only a portion of one occurs below 1 m of sea level (and would be inundated under average climate change scenarios), while the

remaining populations are at elevations from 2-76 m above sea level. Historical native occurrences and recently reintroduced populations are also found above 1 m of elevation and are unlikely to be flooded due to sea water increase.

B2a. Natural barriers: Somewhat Increase.
Mainland occurrences of *Castilleja levisecta* in Washington are found in remnant prairies dominated by *Festuca roemeri* and *F. rubra* on gravelly or clayey glacial outwash. Island occurrences are often found on the upper slopes of steep west or southwest-facing sandy bluffs and patches of coastal prairie that may be exposed to salt spray (Chappell and Caplow 2004; Gamon 1995; Fertig 2019). Traditionally, these habitats were maintained by periodic wildfire, abetted by summer drought or anthropogenic actions. Today, more than 97% of the state's historic prairie sites have become replaced by forests, agriculture, or human development (Chappell et al. 2001) and are more fragmented and isolated.

B2b. Anthropogenic barriers: Increase.
Conversion of western Washington prairies to agriculture, roads, and human settlements and suppression of wildfires that historically kept grassland sites open from tree encroachment have greatly increased the fragmentation of prairie habitats and acts as a barrier to dispersal of *Castilleja levisecta* seed and pollinators (USFWS 2000).

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Castilleja levisecta produces abundant seed. These seeds are dispersed passively through rupture of the dry fruit capsule wall and have no specialized structures for further dispersal. The seeds are quite small, however, (1 mm long) and could be dispersed by strong winds. The majority of seeds, however, probably fall within a few meters of their parent plant (Caplow 2004).

C2ai. Historical thermal niche: Greatly Increase.
Figure A-3 depicts the distribution of extant and historical native *Castilleja levisecta* occurrences in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Seventeen of the 22 native *C. levisecta* occurrences in Washington (77%) are found on islands in the northern Puget Sound and Salish Sea in an area that has experienced very small temperature variation (< 37˚F) during the past 50 years. These populations are considered to have greatly increased vulnerability under projected climate change (Young et al. 2016). The remaining native occurrences (23%) are found in areas with a small (37-47˚F) temperature variation over the past 50 years and are considered to have an increased vulnerability.

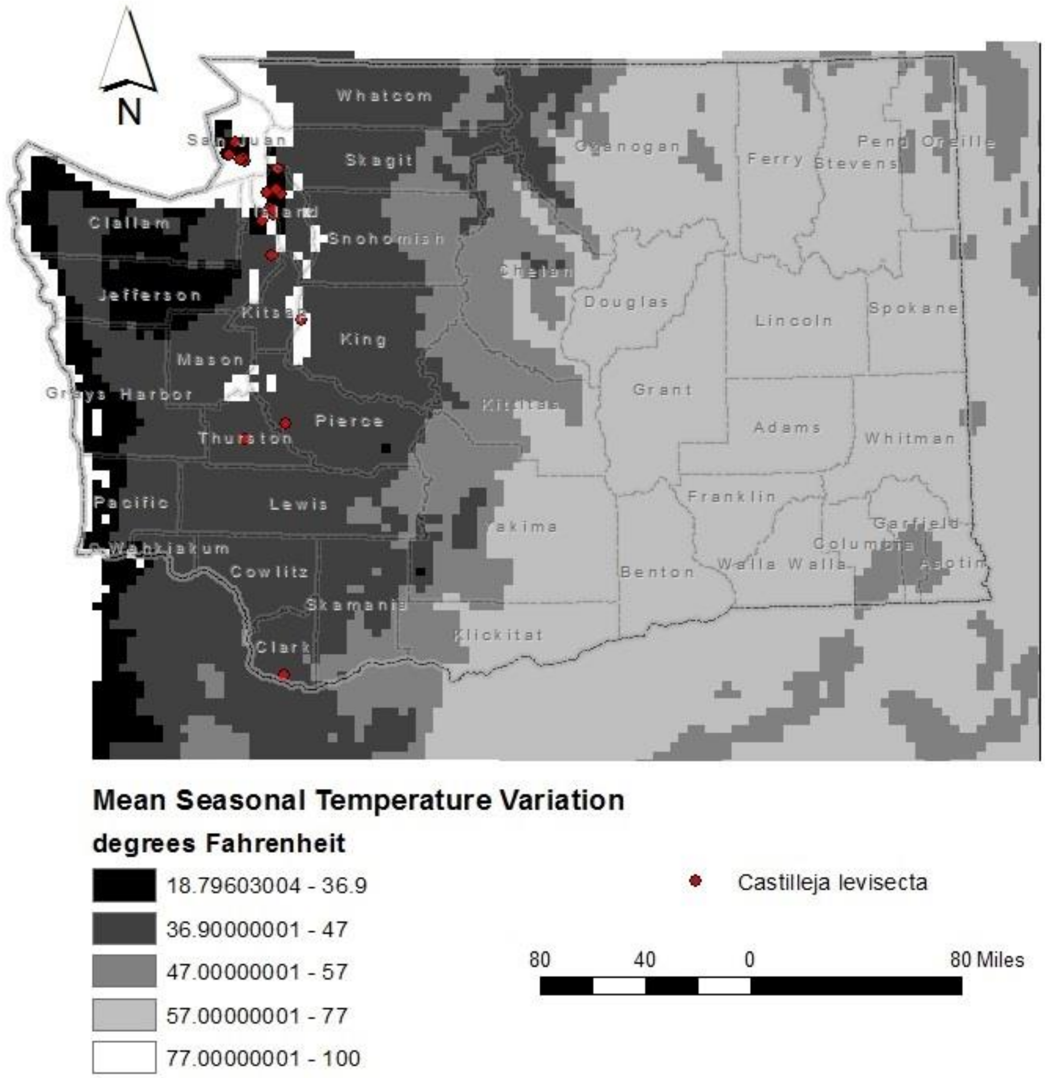

Figure A-3. Historical thermal niche (exposure to past temperature variations) of *Castilleja levisecta* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
Castilleja levisecta occurrences in Washington are found in remnant prairie habitats that are not associated with cold air pockets or other microsites that are more vulnerable to climate change.

C2bi. Historical hydrological niche: Neutral.
All 22 extant and historical native occurrences of *Castilleja levisecta* in Washington (Figure A-4) are found in areas that have experienced average or greater than average precipitation variation (> 20 inches) over the past 50 years and are considered Neutral in terms of risk from climate change (Young et al. 2016).

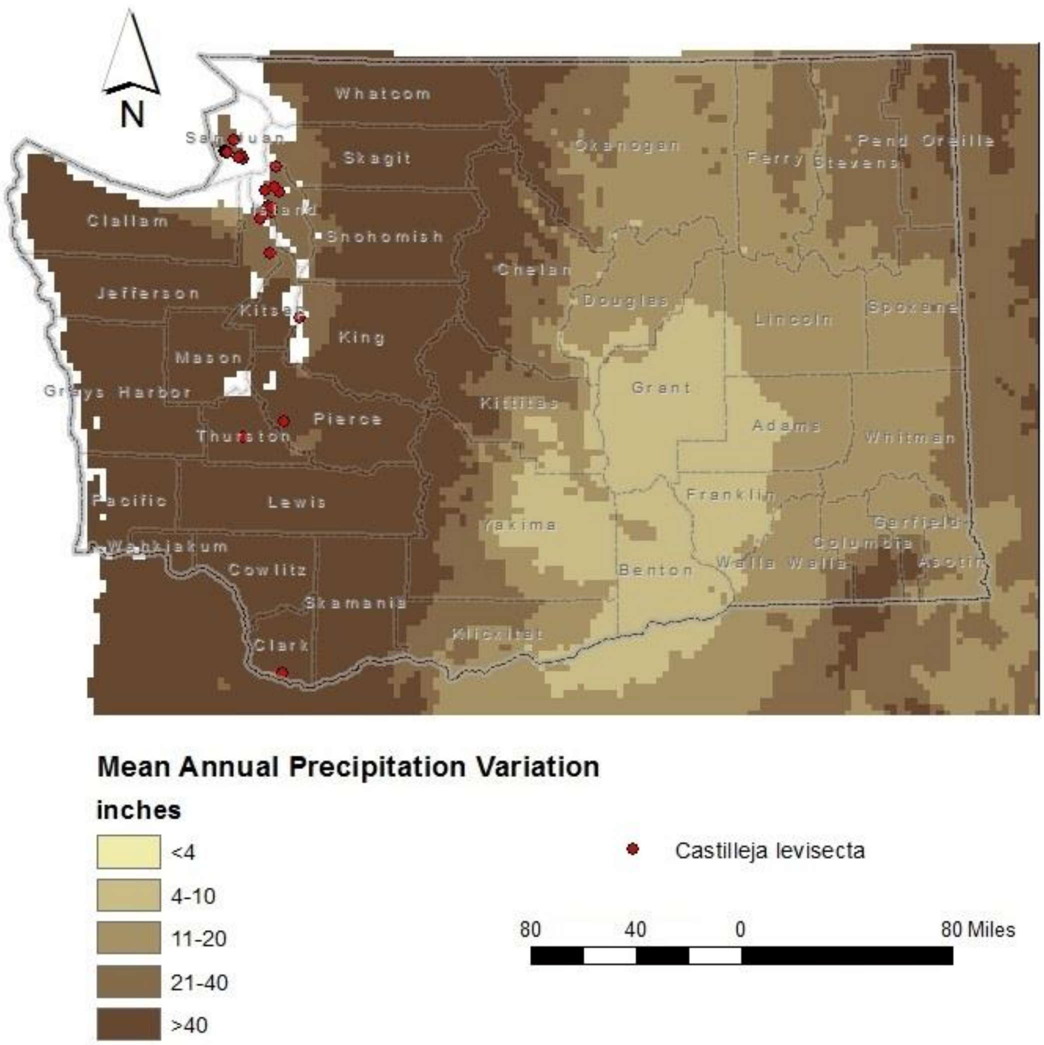

Figure A-4. Historical hydrological niche (exposure to past variations in precipitation) of *Castilleja levisecta* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Neutral.
Castilleja levisecta is an upland species that is not strongly dependent on aquatic/wetland habitats or a seasonal hydrologic regime.

C2c. Dependence on a specific disturbance regime: Neutral.
The prairie grassland habitat occupied by *Castilleja levisecta* is largely dependent on periodic drought or wildfire to curb the expansion of conifer forest or oak woodland habitat (Dunwiddie et al. 2001; USFWS 2000). Climate change is likely to increase the frequency of drought within the range of this species. The potential incidence of wildfire might also increase, though the fragmentation of the region by roads, farms, and urban infrastructure may reduce this risk. These effects of climate change could have a net positive impact on the habitat of *Castilleja levisecta*.

C2d. Dependence on ice or snow-cover habitats: Neutral.
The Washington occurrences of *Castilleja levisecta* are at low enough elevation where snow and ice are minor contributors to overall precipitation.

C3. Restricted to uncommon landscape/geological features: Neutral.
Most *Castilleja levisecta* occurrences are found on gently sloping areas. One native and at least one introduced occurrence are found in areas with prominent mima mounds, though these features are not the main reason for the presence of this species. A few island populations are on steep sandy slopes along the coast that are a product of extreme wind erosion. Overall, the native and introduced occurrences of *C. levisecta* are not associated with areas of unusual geology or water chemistry.

C4a. Dependence on other species to generate required habitat: Neutral.
Castilleja levisecta is largely dependent on natural phenomena (drought, fire) or anthropogenic assistance (controlled fire), rather than other animal species to create and maintain its grassland habitat.

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Somewhat Increase.
Castilleja levisecta is insect pollinated. The primary pollinators are probably bumblebees (genus *Bombus*, including *B. californicus*) (USFWS 2000, Waters 2018). Self-pollination is possible in *C. levisecta* (Kaye and Lawrence 2003), but resulting seed production is exceptionally low compared to crosses between sibling or neighboring plants. Wentworth (1994) found that fruit set was 5 times greater in unbagged (outcrossed) vs. bagged (selfed) inflorescences. Long term persistence of *C. levisecta* populations may be dependent on the survival of its pollinators and maintenance of pollinator habitat, including other food plants and appropriate nesting sites (USFWS 2000).

C4d. Dependence on other species for propagule dispersal: Neutral.
Castilleja levisecta seed is dispersed passively and not by animals (with the possible exception of short distance transport of seed-bearing fruits by small rodents).

C4e. Sensitivity to pathogens or natural enemies: Neutral.
Castilleja levisecta is edible and leaves, stems, and inflorescences may be browsed by voles, rabbits, or deer. Herbivory can be an important factor in periodically reducing reproductive success in some populations (Gamon 1995; USFWS 2000). Caterpillars of several butterfly and

moth species also feed on *C. levisecta*. No pathogens are known. Overall, the impacts of herbivores are relatively low at present, or not expected to increase due to climate change.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
Two major threats to *Castilleja levisecta* in Washington (and range-wide) are competition from invasive introduced species and vegetation succession in the absence of fire or other disturbance (Camp and Gamon 2011; Fertig 2019, USFWS 2000). Increased drought conditions could result in more wildfire, however, which could reduce competing tree cover. The abundance and density of competing invasive plant species may increase due to climate change.

C4g. Forms part of an interspecific interaction not covered above: Neutral.
Castilleja levisecta is a facultative hemiparasite that is capable of photosynthesis but also may derive additional nutrition from host plants via underground root-like structures (haustoria). The species is not host-specific, although recent monitoring studies of outplantings have found it is especially successful when using *Eriophyllum lanatum* as a host (Pearson and Dunwiddie 2006). The Endangered Taylor's checkerspot butterfly (*Euphydras editha taylori*) utilizes *C. levisecta* as a host plant for its eggs and larvae (Waters 2018).

C5a. Measured genetic variation: Neutral.
Godt et al. (2005) found unusually high genetic diversity in sampled populations of *Castilleja levisecta* in Washington compared to other narrowly endemic plant species.

C5b. Genetic bottlenecks: Unknown.
Individual occurrence of *Castilleja levisecta* (such as Ebey's Landing) have lower genetic diversity and fewer alleles per polymorphic loci than the entire population of the species as a whole, suggesting there has been a past genetic bottleneck or the population had a limited number of founders (Godt et al. 2005). Whether there has been a significant genetic bottleneck for all populations of *C. levisecta* is not known.

C5c. Reproductive System: Neutral.
Castilleja levisecta is essentially an obligate outcrosser (it is self-compatible, but with very low viability of seed) with relatively high genetic diversity, and thus not highly vulnerable to impacts from climate change.

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

Section D: Documented or Modeled Response to Climate Change

D1. Documented response to recent climate change: Increase .
The five largest native occurrences of *Castilleja levisecta* in Washington have declined by 52-85% from 2012 through 2018 (Fertig 2019) and continued to decline in 2019 (Fertig unpublished data). Total abundance in Washington has increased significantly over this same time period due to the successful establishment of 9 new occurrences created by outplanting plugs or direct seeding (Caplow 2004). In 2018 the total population in the state reached 195,324 reproductive plants, of which 97.4% were from introduced occurrences (Fertig 2019). These numbers declined by 28.6% in 2019 to 139,293 reproductive plants (Fertig unpublished

data). The greatest decreases came in outplanted populations which may be self-thinning to reach a lower, but more sustainable population threshold. Native occurrences continue to decline as well, and this may be related to recent unseasonable warm and dry weather in the spring growing season.

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

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

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

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Appendix B. Climate Change Vulnerability Index Report

Howellia aquatilis (Water howellia)

Date: October 2019

Assessor: Walter Fertig, WA Natural Heritage Program (update from Gamon 2014)

Geographic Area: Washington | Heritage Rank: G3/S2S3

Index Result: Extremely Vulnerable | Confidence: Very High

Climate Change Vulnerability Index Scores

Section A	**Severity**	**Scope (% of range)**
1. Temperature Severity	>6.0° F (3.3°C) warmer	0
	5.6-6.0° F (3.2-3.3°C) warmer	0
	5.0-5.5° F (2.8-3.1°C) warmer	0
	4.5-5.0° F (2.5-2.7°C) warmer	0
	3.9-4.4° F (2.2-2.4°C) warmer	68.5
	<3.9° F (2.2°C) warmer	31.5
2. Hamon AET:PET moisture	< -0.119	0
	-0.097 to -0.119	0
	-0.074 to - 0.096	67
	-0.051 to - 0.073	33
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Somewhat 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		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Somewhat Increase
2bii. Changes in physiological hydrological niche		Greatly Increase
2c. Dependence on specific disturbance regime		Somewhat Increase
2d. Dependence on ice or snow-covered habitats		Neutral
3. Restricted to uncommon landscape/geological features		Neutral

4a. Dependence on others species to generate required habitat	Neutral
4b. Dietary versatility	Not Applicable
4c. Pollinator versatility	Neutral
4d. Dependence on other species for propagule dispersal	Somewhat Increase
4e. Sensitivity to pathogens or natural enemies	Neutral
4f. Sensitivity to competition from native or non-native species	Increase
4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Somewhat Increase
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Increase
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: 23 of the 73 known occurrences of *Howellia aquatilis* in Washington (31.5%) occur in areas with a projected temperature increase of less than 3.9˚F (Figure B-1). The remaining 50 known occurrences (68.5%), all from the Spokane area, have a projected temperature increase of 3.9-4.4˚F.

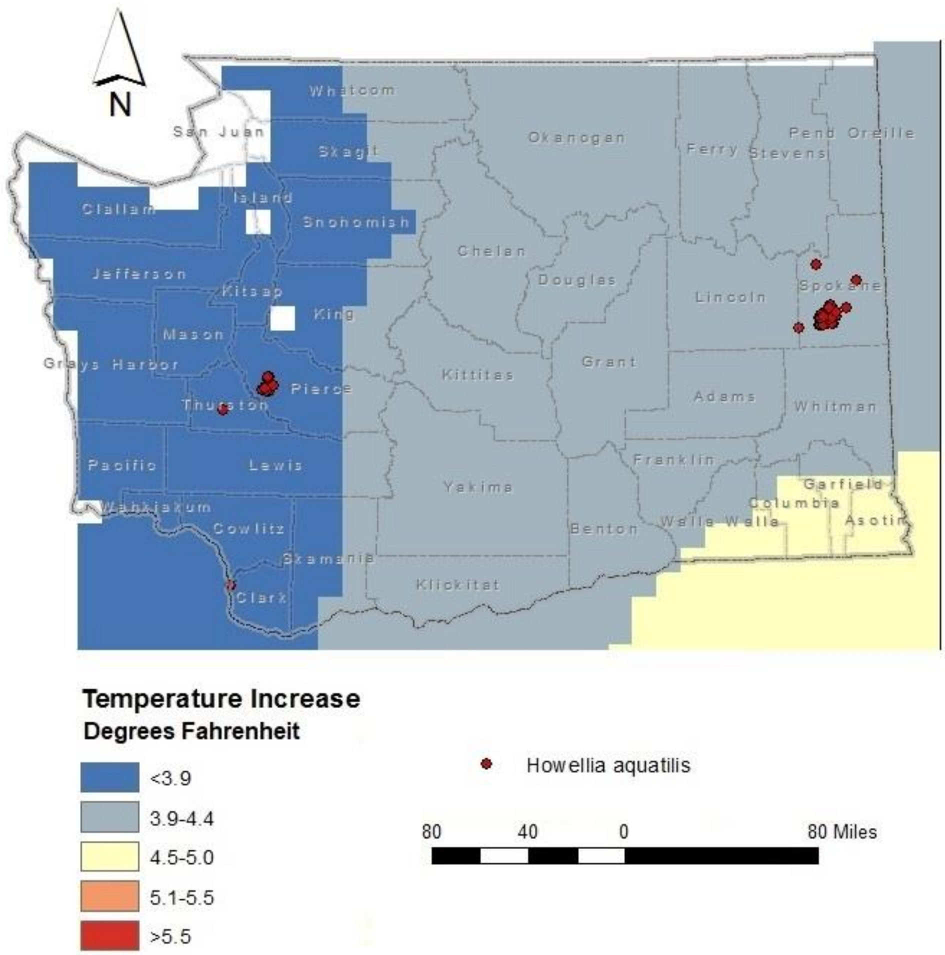

Figure B-1. Exposure of *Howellia aquatilis* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: 49 of 73 occurrences of *Howellia aquatilis* in Washington (67%) are found in areas of eastern Washington with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of – 0.097 to – 0.074 inches (Figure B-2). The remaining 24 occurrences are from the west side of the state in areas with a predicted decrease in available moisture between -0.074 and – 0.051 inches.

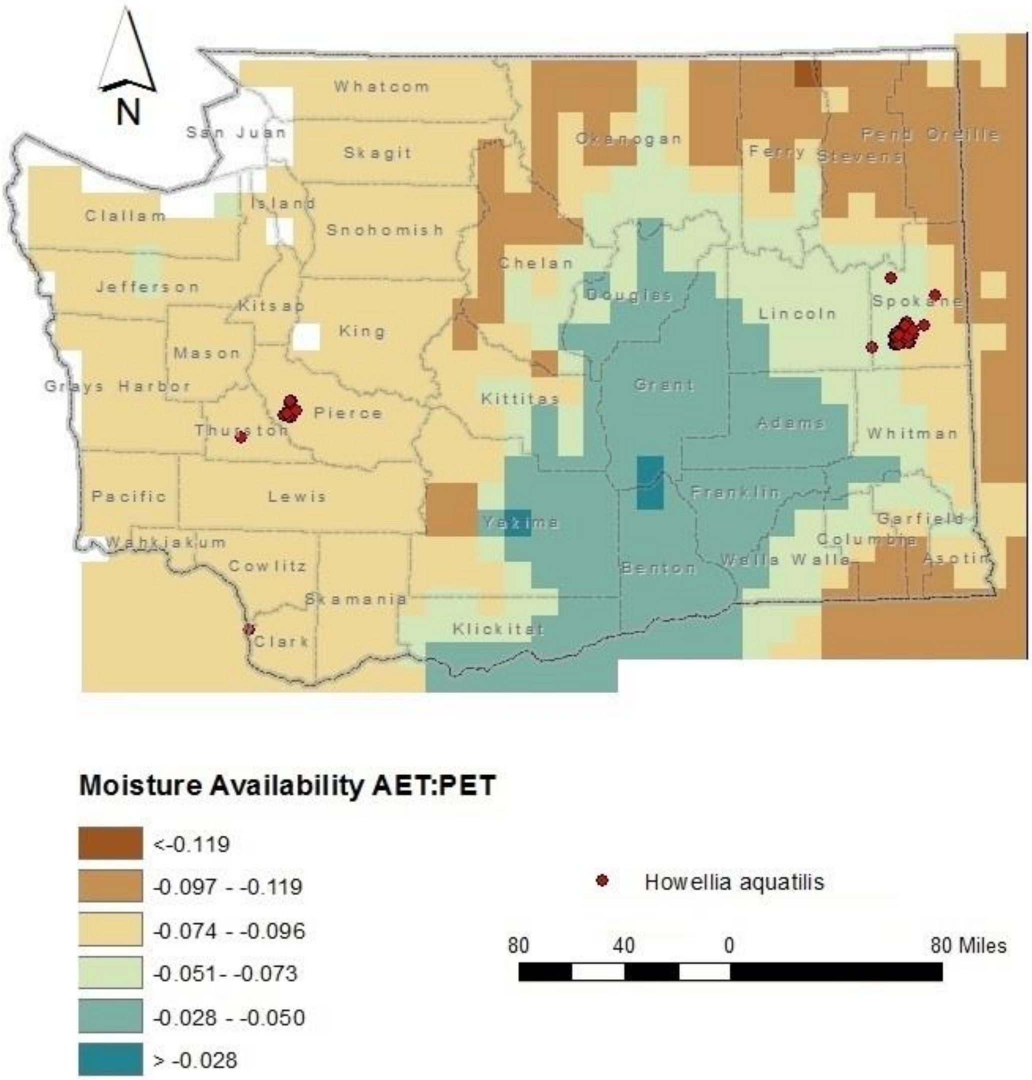

Figure B-2. Exposure of *Howellia aquatilis* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Somewhat Increase.
One *Howellia aquatilis* occurrence in Clark County occurs at an elevation of 3m (10 ft) above sea level and would likely be impacted by sea level rise. The remaining occurrences (98.6%) are found at elevations between 67-730m (220-2400 ft) and would not be inundated by rising seas.

B2a. Natural barriers: Somewhat Increase.
In Washington, *Howellia aquatilis* is largely restricted to small vernal ponds that dry out in the fall but are flooded in the spring and summer (Gamon 1992). Each occupied pond has traditionally been treated as a separate element occurrence, though many are located within 1.5 km of each other and might be better considered subpopulations (Fertig 2019). Increasingly, these ponds are embedded in a matrix of dense forest vegetation, which could impede dispersal by waterfowl. If a large number of the more shallow ponds occupied by *H. aquatilis* dry out in the future, occurrences would become more isolated from each other, restricting potential dispersal between ponds (Lesica 1992, Mincemoyer 2005).

B2b. Anthropogenic barriers: Increase.
Habitat fragmentation will make it increasingly difficult for *Howellia aquatilis* to disperse over long distances.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Increase.
Howellia aquatilis fruits and seeds lack any specialized structures, such as wings or hooks, to facilitate their dispersal by wind or animals. Dispersal appears to be largely passive, though facilitated by water currents within ponds. Schierenbeck and Phipps (2010) hypothesized that *Howellia aquatilis* seed might be dispersed in mud picked up by waterfowl. However, the likelihood of waterfowl accessing other small ponds with similar environmental attributes (drawing down in fall, flooded in spring/summer) may be low. Rod Gilbert (personal communication), biologist at Joint Base Lewis McChord, has suggested that black bears or other mammals might disperse seed or fragments of plants to adjacent ponds. Seed or plant fragments are capable of dispersal by water within ponds, but overland flow by flooding is unlikely given the kettle-like terrain of most populations in Washington (but flooding might be a factor in dispersal in riverine habitat in Idaho or other states). Average dispersal distance is probably very short in Washington (less than 100m) and the high habitat specificity of the species (vernal ponds that are dry in the fall but flooded in spring and summer) make rapid dispersal in response to climate change unlikely.

C2ai. Historical thermal niche: Somewhat Increase.
Figure B-3 depicts the distribution of known *Howellia aquatilis* occurrences in Washington relative to mean seasonal temperature variation for the period from 1951-2006 (“historical thermal niche”). Twenty-three of the 73 known *H. aquatilis* occurrences in Washington (31.5%) are found on the west side of the Cascades in an area with increased vulnerability for temperature variation. The remaining 50 occurrences from Spokane County (68.5%) are

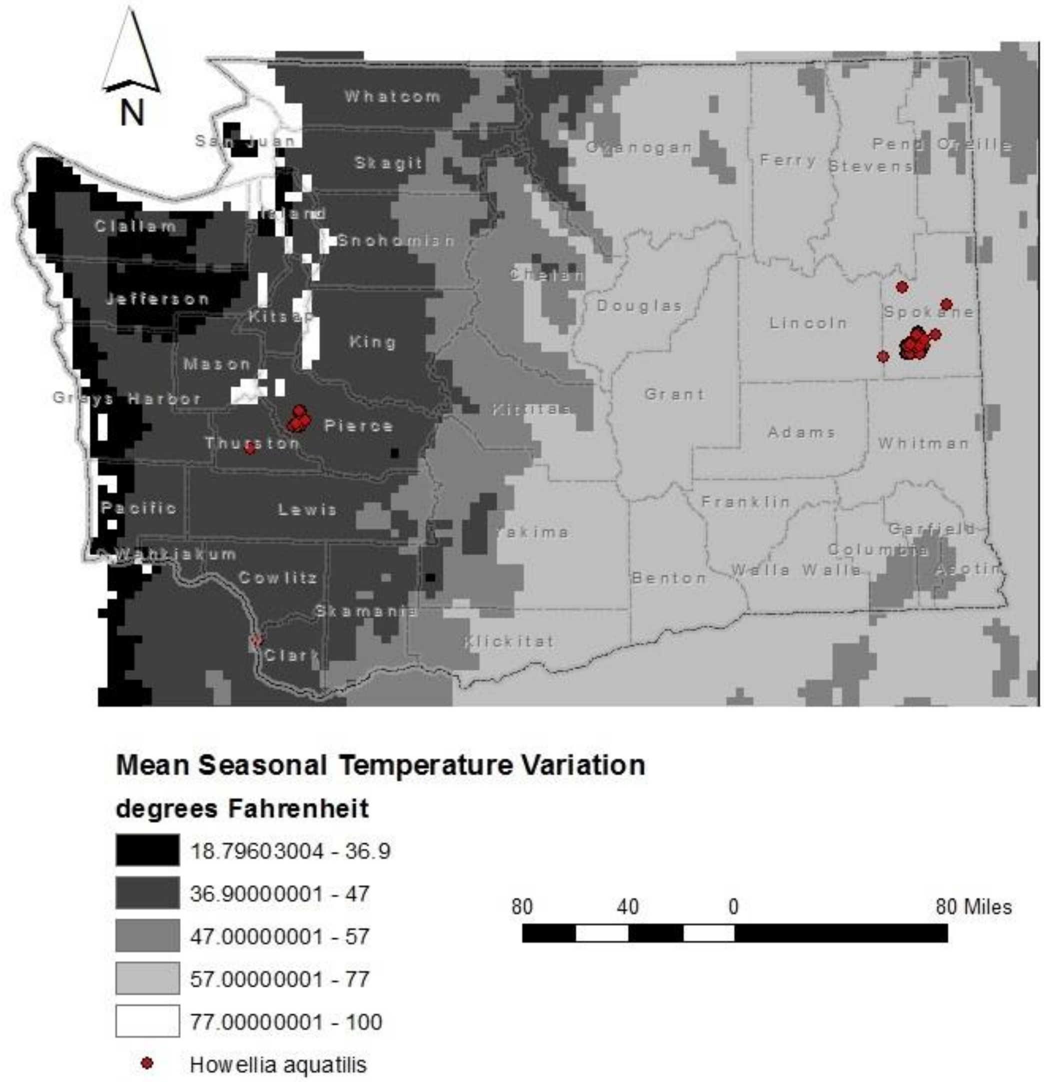

Figure B-3. Historical thermal niche (exposure to past temperature variations) of *Howellia aquatilis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

predicted to have a neutral impact. Averaging among all the populations leads to a score of "somewhat increased" vulnerability.

C2aii. Physiological thermal niche: Neutral.
Howellia aquatilis occurrences in Washington are associated with small vernal ponds within forested areas that are sometimes within a matrix of more open, upland terrain. These sites may be slightly cooler microsites, though not sufficiently cold as to increase the vulnerability of this species to climate change.

C2bi. Historical hydrological niche: Somewhat Increase.
Fifty of 73 occurrences of *Howellia aquatilis* (68.5%) in the Spokane area have received a small change (4-10 inches) in precipitation variability over the past 50 years (Figure B-4) and are considered to be at increased vulnerability to climate change (Young et al. 2016). The remaining 23 occurrences on the west side of the Cascades have experienced more than 40 inches of greater precipitation variability in the same time period and are considered Neutral by Young et al. (2016). Averaged across the range of the species in Washington, the score for this factor would be "somewhat increased' vulnerability.

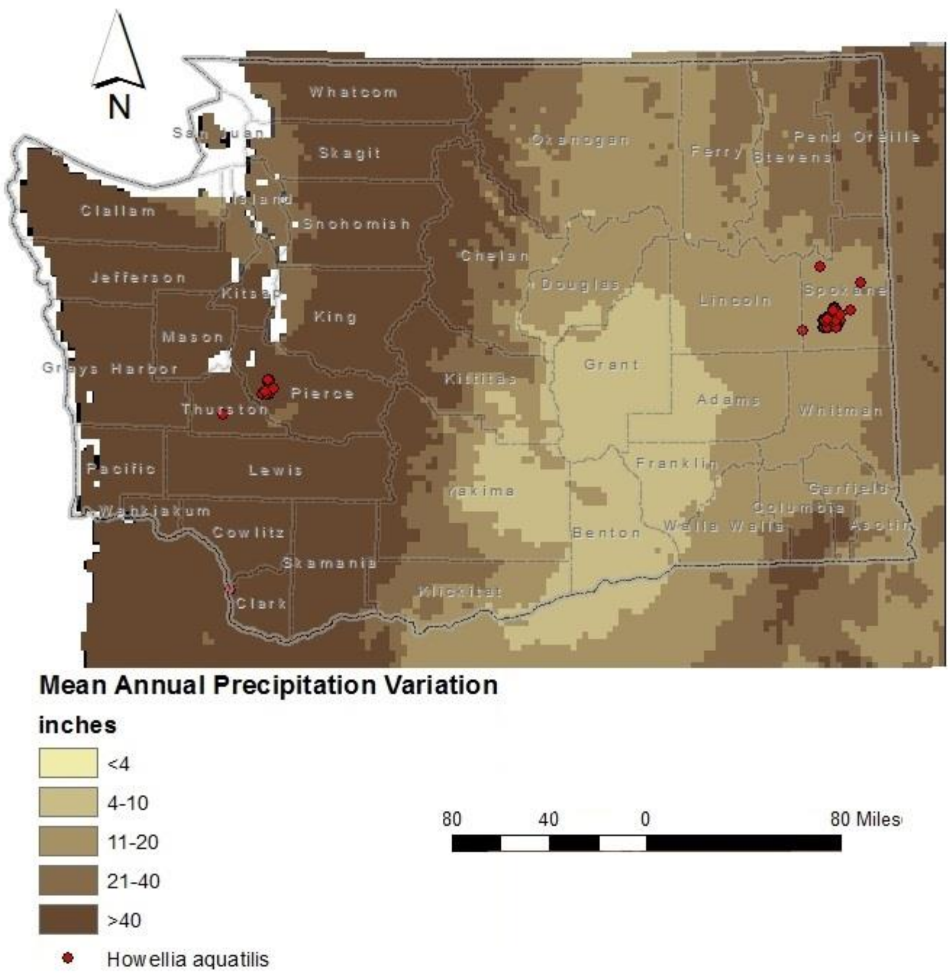

Figure B-4 Historical hydrological niche (exposure to past variations in precipitation) of *Howellia aquatilis* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Greatly Increase.
Howellia aquatilis has an extremely specialized hydrological niche that depends on summer/ early fall drought to expose mudflats for seed germination alternating with winter/spring rainfall to create flooded conditions for plant growth and reproduction. Compounding this specialization is the plant's annual growth form and relatively short-lived seedbank (Lesica 1992). Changes in hydrology could have significant impacts on this species that will depend in part on the physical contours of its habitat. Lesica (1992) suggests that long term persistence of *Howellia* metapopulations will depend on a mix of shallow and deep ponds being available, with shallow ponds being especially important during wet years and deep ponds important during prolonged drought. Large scale changes in moisture availability are likely to upend this delicate balance.

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Howellia aquatilis is dependent on annual patterns of summer drought and fall/winter precipitation to maintain its specialized vernal pond habitat and accommodate seed germination on bare soil. Any long-term deviation from this cycle, such as a prolonged drought, or multiple years of excessive precipitation or flooding will disrupt this cycle (Shelly and Gamon 1996). How long the species can persist at a site under these conditions (and without input of new seed from other subpopulations within a metapopulation, as suggested by Lesica, 1992) is not adequately documented. Potential impacts from wildfire on forested habitats in which *Howellia* habitat is embedded is poorly known (Gamon 1992).

C2d. Dependence on ice or snow-cover habitats: Neutral.
Most *Howellia aquatilis* occurrences in Washington are dependent on winter and spring rainfall to refill vernal pond areas that are dry at the end of summer or early fall. The Washington occurrences are at low enough elevation where snow and ice are minor contributors to overall precipitation.

C3. Restricted to uncommon landscape/geological features: Neutral.
While *Howellia aquatilis* is dependent on shallow to deep kettle depressions, this dependency is adequately addressed under historical and physiological hydrologic criteria cited above. According to the guidance provided by Young et al. (2016) for CCVI assessments, physical habitat restrictions address water chemistry or unusual geologic substrates or soil types, which are not an issue for this species (Gamon 1992).

C4a. Dependence on other species to generate required habitat: Neutral.
The vernal pools inhabited by *Howellia aquatilis* in Washington were produced as a result of glacial activity (specifically massive, region-wide, short-term flooding events) and not a consequence of ecosystem engineering by other organisms.

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Neutral.
Howellia aquatilis produces both chasmogamous flowers that open for out-crossing and cleistogamous flowers that remain closed and are self-pollinated. The actual pollinators of *Howellia* are poorly known. Lesica et al. (1988) found that the majority of seeds were produced

by cleistogamous flowers. The ability of this species to produce seed by self-pollination makes it largely impervious to loss of pollinators from climate change.

C4d. Dependence on other species for propagule dispersal: Somewhat Increase.
Although waterfowl have been suggested as dispersers of seed or plant fragments (which can sometimes still flower and set fruit) from one wetland to another, there is little evidence to actually document this (Gamon 2014). *Howellia* lacks physical structures to promote long distance dispersal, so probably is dependent on animals for this to occur.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
There is no evidence that *Howellia aquatilis* populations are being adversely impacted by disease or herbivory.

C4f. Sensitivity to competition from native or non-native species: Increase.
One of the major threats to *Howellia aquatilis* in Washington (and range-wide) is competition from invasive introduced wetland plants, such as reed canarygrass (*Phalaris arundinacea*) (Camp and Gamon 2011, Fertig 2019, Lesica 1997, USFWS 1994). In addition, many Washington populations are being impacted by natural vegetation succession in the absence of disturbances, such as fire, beaver activity, or tree blowdown. Climate change could have a net positive impact on the spread and vigor of reed canarygrass. Increased drought conditions could result in more wildfire, however, which could reduce competing tree cover.

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

C5a. Measured genetic variation: Somewhat Increase.
Using isozyme data, Lesica et al. (1988) documented very low genetic diversity within and among populations of *Howellia aquatilis* in Montana. Brunsfeld and Baldwin (1998), however, studied chloroplast DNA and found high genetic divergence between disjunct populations of *Howellia* in Montana and California. Climate change could impact genetic structure of the species through localized extirpation of smaller populations, resulting in greater isolation of populations and potentially reduced opportunities for gene flow between them.

C5b. Genetic bottlenecks: Unknown.
Brunsfeld and Baldwin (1998) suggest that fluctuating population sizes in *Howellia aquatilis* populations might lead to reduced genetic diversity in isolated occurrences, but this remains an area for future research.

C5c. Reproductive System: Increase.
Howellia aquatilis has low genetic diversity and reproduces primarily by self-fertilized cleistogamous flowers (Mincemoyer 2005).

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.
Trend data are lacking for nearly 40% of all Washington occurrences of *Howellia aquatilis* (Fertig 2019). Occurrences that have been monitored are either stable to decreasing in the short term, possibly due to competition with reed canarygrass or habitat succession. Data on trend relating to climate change specifically are lacking.

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

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

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

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Appendix C. Climate Change Vulnerability Index Report
Lomatium bradshawii (Bradshaw's desert-parsley)

Date: October 2019

Assessor: Walter Fertig, WA Natural Heritage Program (update from Gamon 2014)

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		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		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	Neutral
4d. Dependence on other species for propagule dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies	Neutral
4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Neutral
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: The single occurrence of *Lomatium bradshawii* in Washington (Figure C-1) is found in an area with a projected temperature increase less than 3.9˚F.

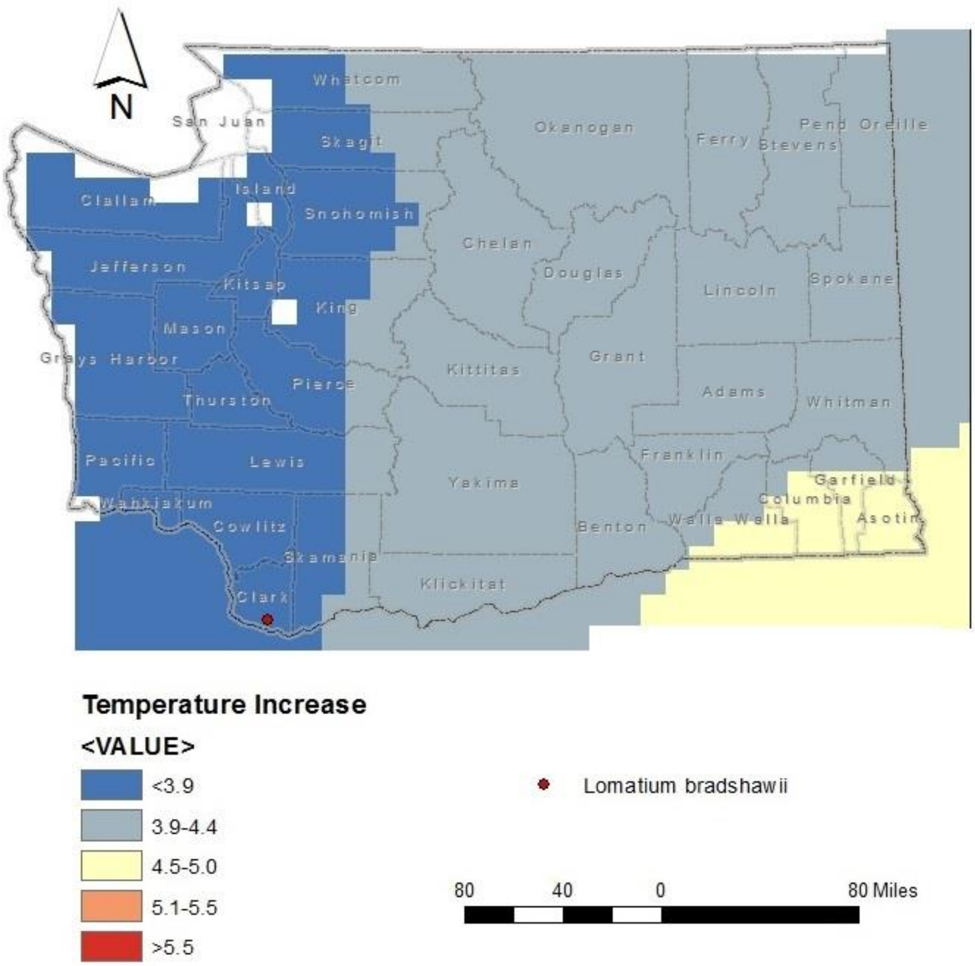

Figure C-1. Exposure of *Lomatium bradshawii* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: The single occurrence of *Lomatium bradshawii* in Washington is found in an area with a predicted decrease in available moisture between -0.074 and – 0.096 (Figure C-2).

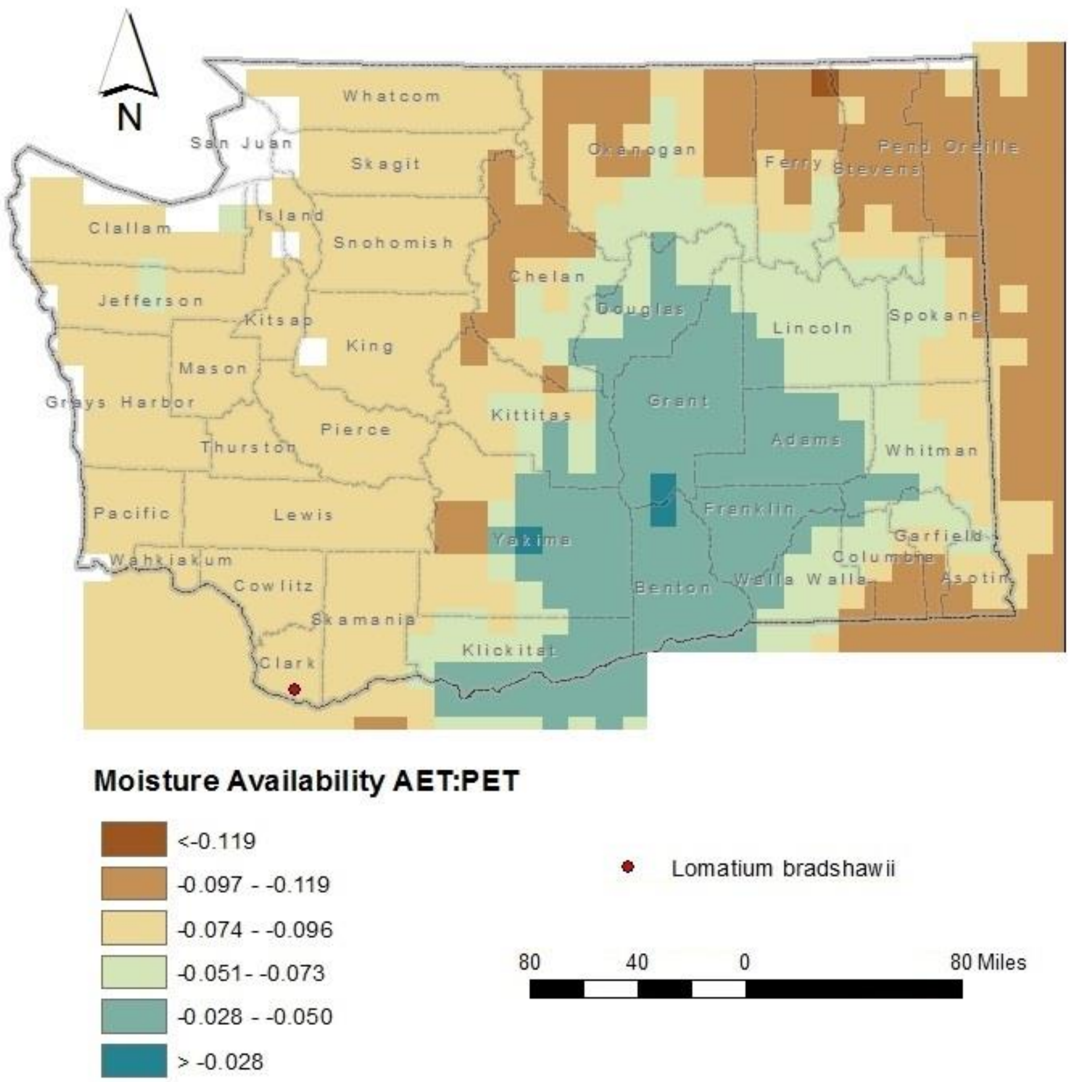

Figure C-2. Exposure of *Lomatium bradshawii* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
The entire range of *Lomatium bradshawii* in Washington is at an elevation of 56m (185 ft) and would not be inundated by projected sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Lomatium bradshawii* is found in seasonally flooded prairies and grasslands dominated by *Deschampsia cespitosa* in a narrow hydrologic ecotone between dry uplands and wet creek banks (Camp and Gamon 2011; Fertig 2019; Rush and Gamon 1999). This habitat occurs within a matrix of drier grasslands, oak woodlands, agricultural fields, and urban and suburban development. Historically, there was a moderate amount of connectivity between potential habitat sites following riparian corridors.

B2b. Anthropogenic barriers: Somewhat Increase.
Most of the likely historical habitat for *Lomatium bradshawii* in the southern Puget Trough in Washington has been converted to agriculture or urban/suburban development. As a result, areas of potential habitat for this species are highly fragmented and the matrix vegetation and less conducive for migration.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Lomatium bradshawii fruits are dry, 1-seeded and have a prominent raised wing-like margin, which would suggest that dispersal could be facilitated by wind. Kagan (1980) observed that dispersal was very limited, with many fruits traveling no more than 1 meter from their parent. Studies of other *Lomatium* species have also documented surprisingly short dispersal distances, which may account for the unusually high degree of local endemism in the genus (Marsico and Hellman 2009).

C2ai. Historical thermal niche: Increase.
The single occurrence of *L. bradshawii* in Washington is found on the west side of the Cascades in an area with increased vulnerability for temperature variation (Figure C-3).

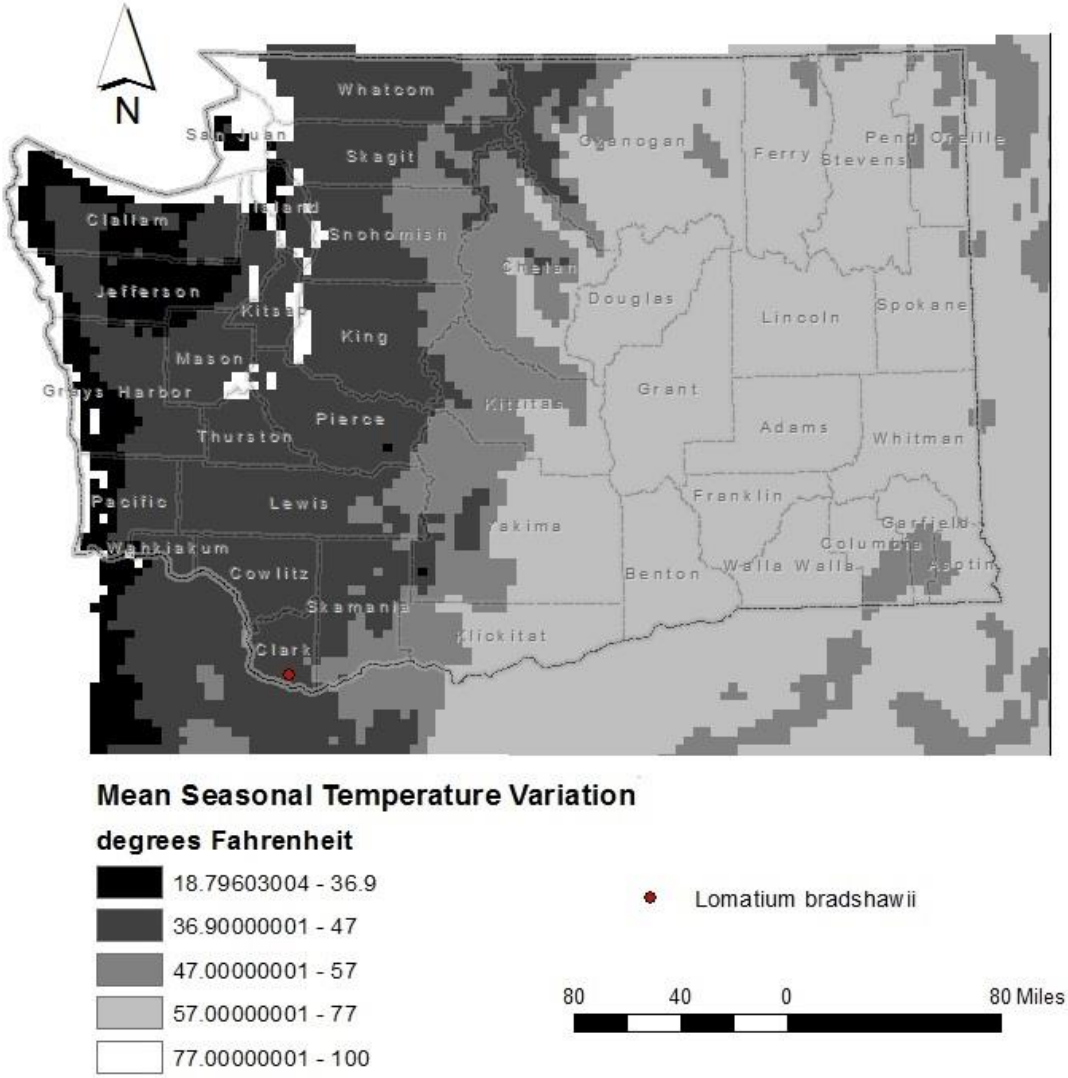

Figure C-3. Historical thermal niche (exposure to past temperature variations) of *Lomatium bradshawii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
The *Lomatium bradshawii* occurrence in Washington is found in a broad wetland valley that may be slightly cooler than the surrounding uplands, though not sufficiently different to make the site more vulnerable to projected climate change.

C2bi. Historical hydrological niche: Neutral.
The Washington occurrence of *Lomatium bradshawii* (Figure C-4) is found in an area with more than 40 inches of mean annual precipitation variation. This is considered "Neutral" under the CCVI guidelines Young et al. 2016).

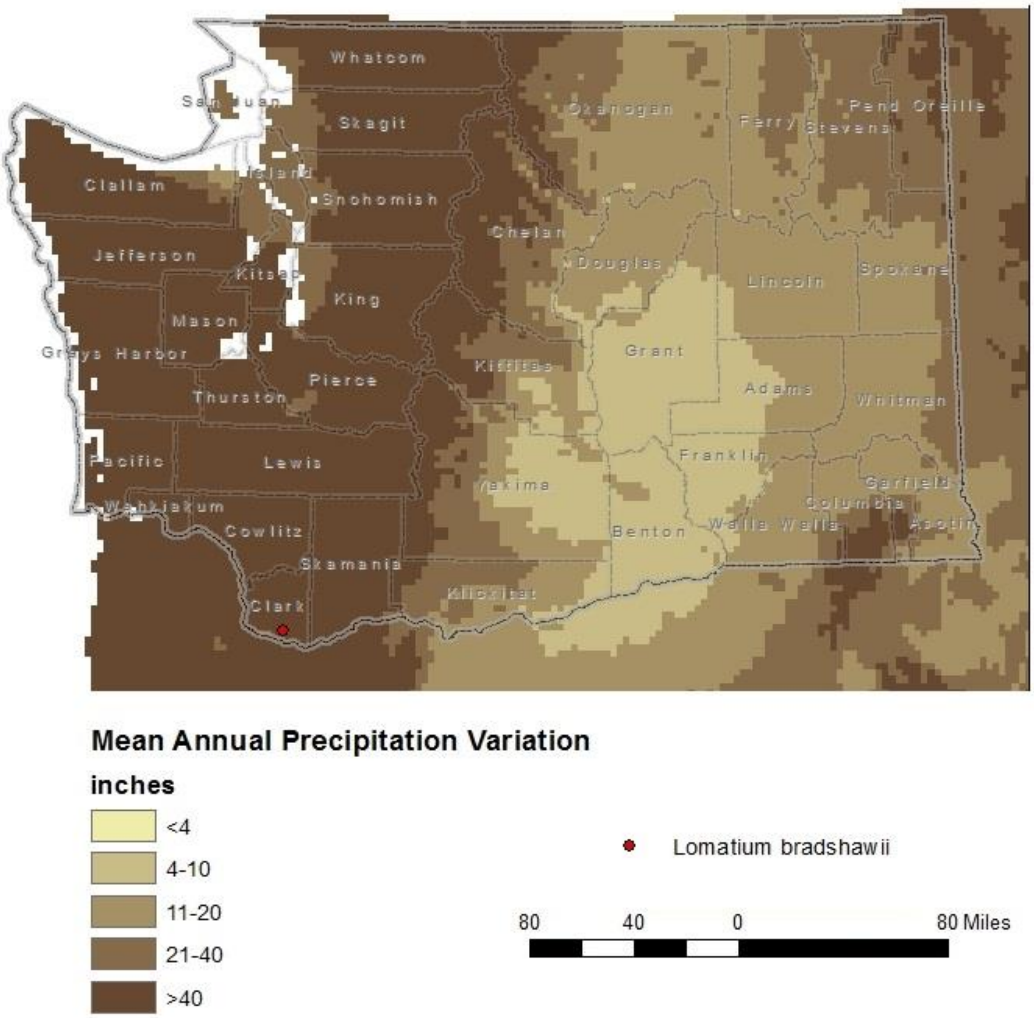

Figure C-4. Historical hydrological niche (exposure to past variations in precipitation) of *Loamtium bradshawii* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Lomatium bradshawii is dependent on wet prairie habitats with poorly drained clay soils that are seasonally flooded (though not in the growing season) (Wentworth 1996). This relatively narrow ecological niche is vulnerable to significant changes in hydrological patterns.

C2c. Dependence on a specific disturbance regime: Somewhat Increase.
Lomatium bradshawii responds positively to low intensity fire through increased growth and density, at least in the first 1-3 years after disturbance (Pendergass et al. 1999). Periodic disturbance may be necessary to maintain habitat conditions suitable for this species (USFWS 2010). The absence of disturbance and resulting competition from other vegetation is one of the important threats to *L. bradshawii* (Fertig 2019; USFWS 2010).

C2d. Dependence on ice or snow-cover habitats: Neutral.
The single *Lomatium bradshawii* occurrence in Washington is at a low enough elevation where snow and ice are minor contributors to overall precipitation.

C3. Restricted to uncommon landscape/geological features: Neutral.
Although the Washington occurrence of *Lomatium bradshawii* is restricted to an alluvial clay loam soil type (Wentworth 1996), this does not qualify as an uncommon geologic substrate according to CCVI guidance from Young et al. (2016).

C4a. Dependence on other species to generate required habitat: Neutral.
The wet meadow habitats occupied by *Lomatium bradshawii* in Washington were produced by natural geologic phenomena, and not a consequence of ecosystem engineering by other organisms.

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Neutral.
A pollinator exclusion study in Oregon by Kaye and Kirkland (1994) found that *Lomatium bradshawii* requires insects for pollination. At least 38 different insect species have been documented visiting *L. bradshawii* flowers in the Willamette Valley. The majority of these potential pollinators are solitary bees (*Andrena* sp., Halictidae), syrphid flies, or other flies (Diptera) (Kaye and Kirkland 1994). The diversity of potential pollinators suggests that reproduction in *L. bradshawii* is not pollinator limited.

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruit dispersal appears to be limited to passive means (Kagan 1980), rather than by animals.

C4e. Sensitivity to pathogens or natural enemies: Neutral.
The Washington occurrence has been impacted by vole herbivory (Wentworth 1996). Browsing by cattle and deer have also been reported. Kagan (1980) reported evidence of damage by spittle bugs and aphids and parasitism by a fungus. The overall impact of herbivory and pathogens is probably low.

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
One of the major threats to *Lomatium bradshawii* in Washington is invasion of its wet prairie habitat by introduced weeds and upland trees and shrubs. Controlled burns and herbicide treatment have been effective in reducing these threats for short periods of time, but need to be repeated every 3 years or so (Pendergrass et al. 1999; Ramm-Granberg and Rocchio 2018).

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

C5a. Measured genetic variation: Neutral.
Based on AFLP markers, Gitzendanner (1998) documented high levels of genetic diversity in most populations of *Lomatium bradshawii*.

C5b. Genetic bottlenecks: Unknown.
Although the range of *Lomatium bradshawii* has contracted due to habitat loss in the past century, it is unknown whether there has been a significant bottleneck in the past 500 years reducing the total size of the population to less than 1000 individuals required to score this factor (Young et al. 2016).

C5c. Reproductive System: Neutral.
Lomatium bradshawii has relatively high genetic diversity and has been documented to require insect pollinators for fruit set (Kaye and Kirkland 1994), seemingly refuting the report of potential self-compatibility by Kagan (1980) based on a small sample size. The reproductive system of *L. bradshawii* promotes outcrossing through andromonoeicy (the formation of separate staminate and bisexual hermaphroditic flowers) and protogyny (the earlier maturation of stigmas and styles than stamens in hermaphroditic flowers) (Kagan 1980; Kaye and Kirkland 1994; USFWS 2010).

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.
Trend data in Washington have been ambiguous, in part due to the difficulty in accurately estimating population numbers due to the extremely high density of plants in some areas and the difficulty in differentiating between individuals. Population size has ranged from 70,411 based on ocular estimates (Wentworth 1996) to 22 million based on extrapolation from plot data in especially dense patches. Arnett and Goldner (2017) estimated the total number to be 8.7-12.8 million based on more random sampling. Wilderman (2019) has been monitoring populations on Lacamas Natural Area preserve from 1998-2019 and documented a longterm decline (Fertig 2019). Data specifically linking population trends to climate change are lacking.

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

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

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

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Appendix D. Climate Change Vulnerability Index Report

Sidalcea oregana var. *calva* (Wenatchee Mountains checkermallow)

Date: October 2019

Assessor: Walter Fertig, WA Natural Heritage Program (update from Gamon 2014)

Geographic Area: Washington   Heritage Rank: G5T1/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	60
	-0.051 to - 0.073	40
	-0.028 to -0.050	0
	>-0.028	0
Section B		**Effect on Vulnerability**
1. Sea level rise		Neutral
2a. Distribution relative to natural barriers		Neutral
2b. Distribution relative to anthropogenic barriers		Somewhat Increase
3. Impacts from climate change mitigation		Neutral
Section C		
1. Dispersal and movements		Somewhat Increase
2ai Change in historical thermal niche		Somewhat Increase
2aii. Change in physiological thermal niche		Neutral
2bi. Changes in historical hydrological niche		Neutral
2bii. Changes in physiological hydrological niche		Increase
2c. Dependence on specific disturbance regime		Neutral
2d. Dependence on ice or snow-covered habitats		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	Somewhat Increase
4d. Dependence on other species for propagule dispersal	Neutral
4e. Sensitivity to pathogens or natural enemies	Somewhat Increase
4f. Sensitivity to competition from native or non-native species	Somewhat Increase
4g. Forms part of an interspecific interaction not covered above	Unknown
5a. Measured genetic diversity	Unknown
5b. Genetic bottlenecks	Unknown
5c. Reproductive system	Neutral
6. Phenological response to changing seasonal and precipitation dynamics	Unknown
Section D	
D1. Documented response to recent climate change	Unknown
D2. Modeled future (2050) change in population or range size	Unknown
D3. Overlap of modeled future (2050) range with current range	Unknown
D4. Occurrence of protected areas in modeled future (2050) distribution	Unknown

Section A: Exposure to Local Climate Change

A1. Temperature: All ten confirmed occurrences of *Sidalcea oregana* var. *calva* in Washington occur in areas with a projected temperature increase of 3.9-4.4˚F (Figure D-1). Two reported occurrences from Kittitas County may be misidentifications and have been excluded from this analysis.

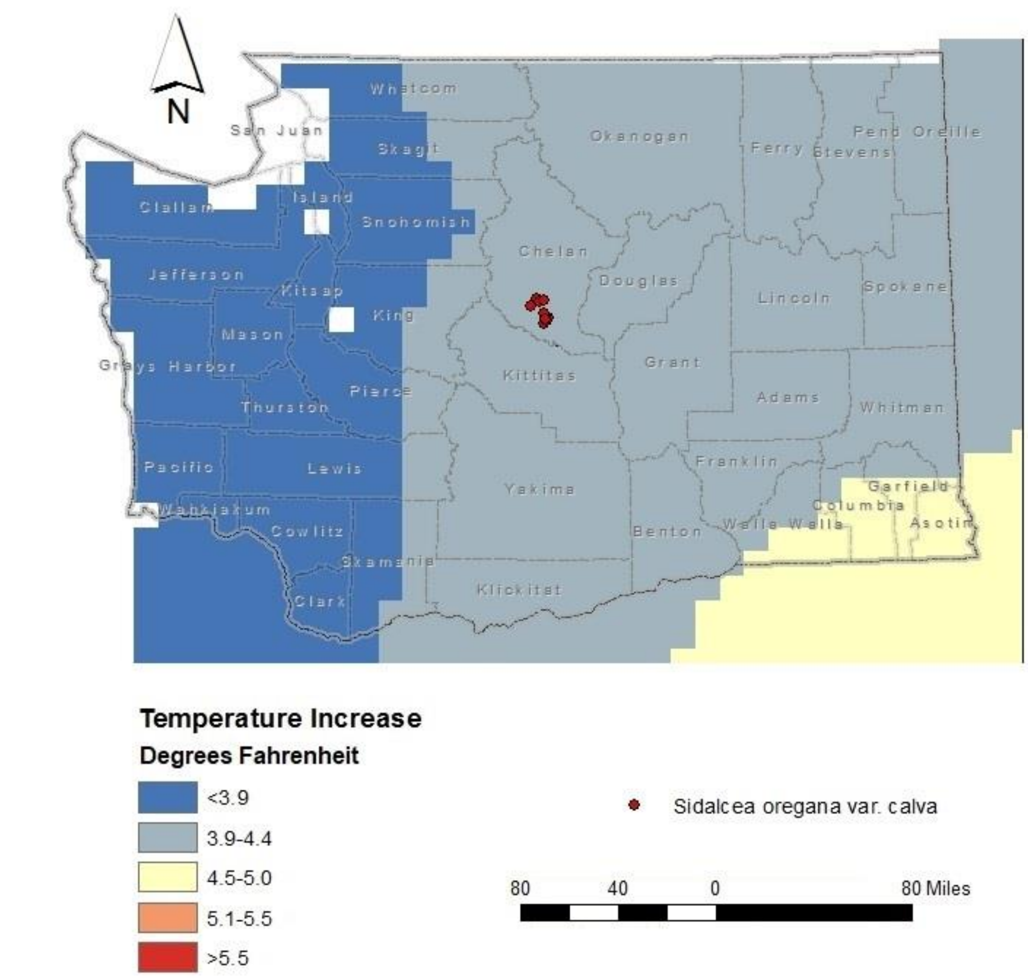

Figure D-1. Exposure of *Sidalcea oregana* var. *calva* occurrences in Washington to projected local temperature change. Base map layers from www.natureserve.org/ccvi

A2. Hamon AET:PET Moisture Metric: 6 of the 10 confirmed occurrences of *Sidalcea oregana* var. *calva* in Washington (60%) are found in areas with a projected decrease in available moisture (as measured by the ratio of actual to potential evapotranspiration) in the range of - 0.074 and - 0.096 (Figure D-2). The remaining 4 occurrences (40%) are from areas with a predicted decrease in available moisture between -0.051 and – 0.073.

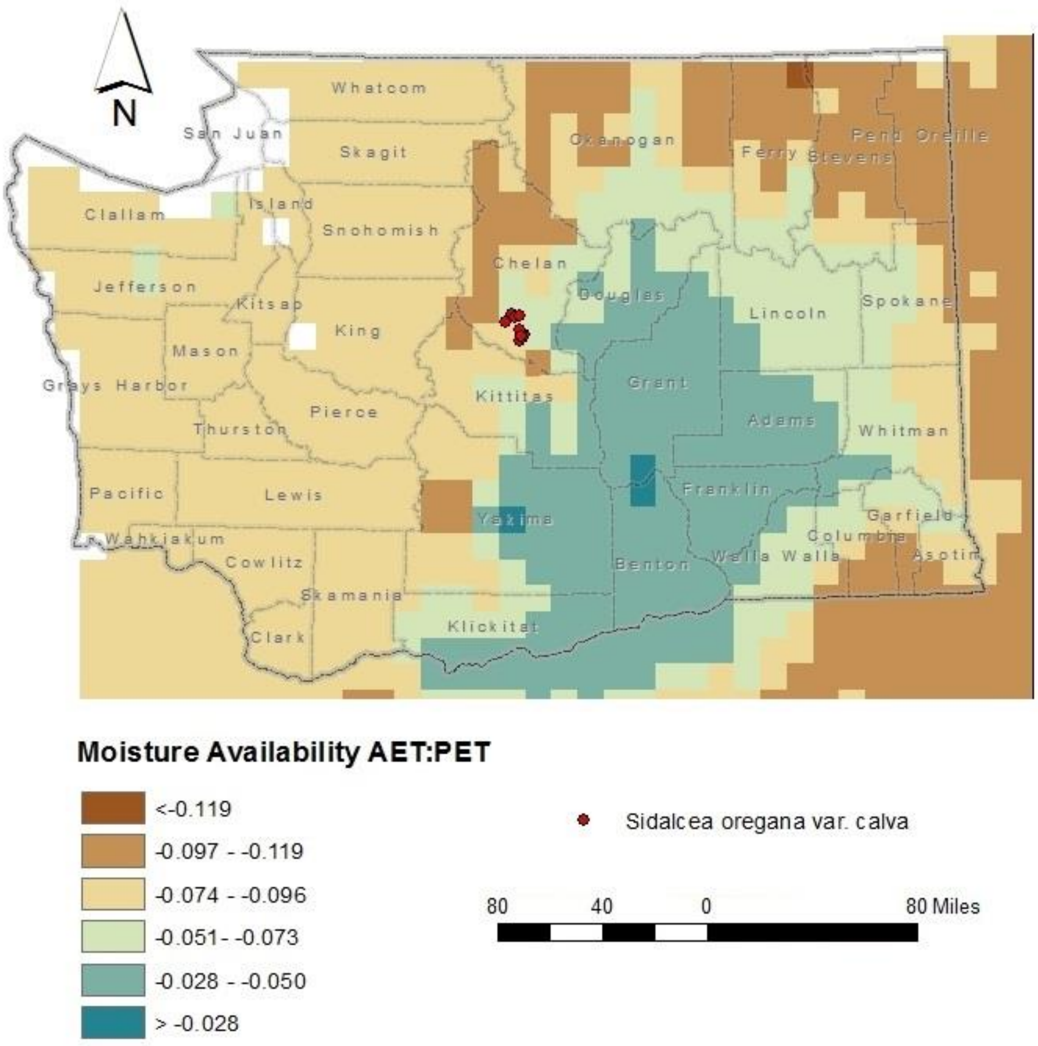

Figure D-2. Exposure of *Sidalcea oregana* var. *calva* occurrences in Washington to projected moisture availability (based on ratio of actual to predicted evapotranspiration). Base map layers from www.natureserve.org/ccvi

Section B. Indirect Exposure to Climate Change

B1. Exposure to sea level rise: Neutral.
All occurrences of *Sidalcea oregana* var. *calva* are found at elevations from 335-1375m (1100-4500 ft) and would not be inundated by sea level rise.

B2a. Natural barriers: Neutral.
In Washington, *Sidalcea oregana* var. *calva* is restricted to open meadows and forest edges with poorly drained soils. These sites have a high water table or are seasonally flooded in the winter and early spring before drying out in mid summer (Arnettt 2011; Caplow 2003; USFWS 2004). These openings may have been maintained historically by fire (including anthropogenic fire by Native Americans to promote *Camassia quamash*) (USFWS 2004). The areas of suitable habitat for *S. oregana* var. *calva* are widely scattered and embedded within a matrix of unsuitable upland Douglas-fir or Ponderosa pine forest habitat, which currently limit natural dispersal. Climate change that results in increased regional drought and wildfire could reduce fragmentation or create new openings for this species to occupy.

B2b. Anthropogenic barriers: Somewhat Increase.
At least three historical occurrences of *Sidalcea oregana* var. *calva* in the Leavenworth and Peshastin areas are probably extirpated due to development of wet meadow habitat for homes or agriculture (Caplow 2003). Anthropogenic disturbances, such as roads, timber harvest, channelization of wetlands, and home construction have fragmented the range of this taxon. These impacts may be exacerbated by projected climate change.

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

Section C: Sensitive and Adaptive Capacity

C1. Dispersal and movements: Somewhat Increase.
Sidalcea oregana var. *calva* reproduces by one-seeded dry fruit wedges called mericarps (a type of schizocarp) and have no specialized structures such as wings or hooks to facilitate long distance dispersal by wind or animals. The clumped distribution pattern observed in the Camas Meadows Natural Area occurrence suggest that fruits do not disperse far from their parent plant. Limited dispersal could be possible by fruit-caching rodents or by water (Goldsmith 2003).

C2ai. Historical thermal niche: Somewhat Increase.
Figure D-3 depicts the distribution of verified *Sidalcea oregana* var. *calva* occurrences in Washington relative to mean seasonal temperature variation for the period from 1951-2006 ("historical thermal niche"). Six of the 10 confirmed *S. oregana* var. *calva* occurrences (60%) have a 47-57˚ F (26.3-31.8˚C) average temperature variation and are considered to have a "somewhat increased vulnerability" to climate change (Young et al. 2016). The other four occurrences are from areas with seasonal temperature variation of >57˚ F (31.8˚C) and are considered neutral in terms of climate change. This factor is scored as "Somewhat Increase" because the majority of occurrences fall in this category.

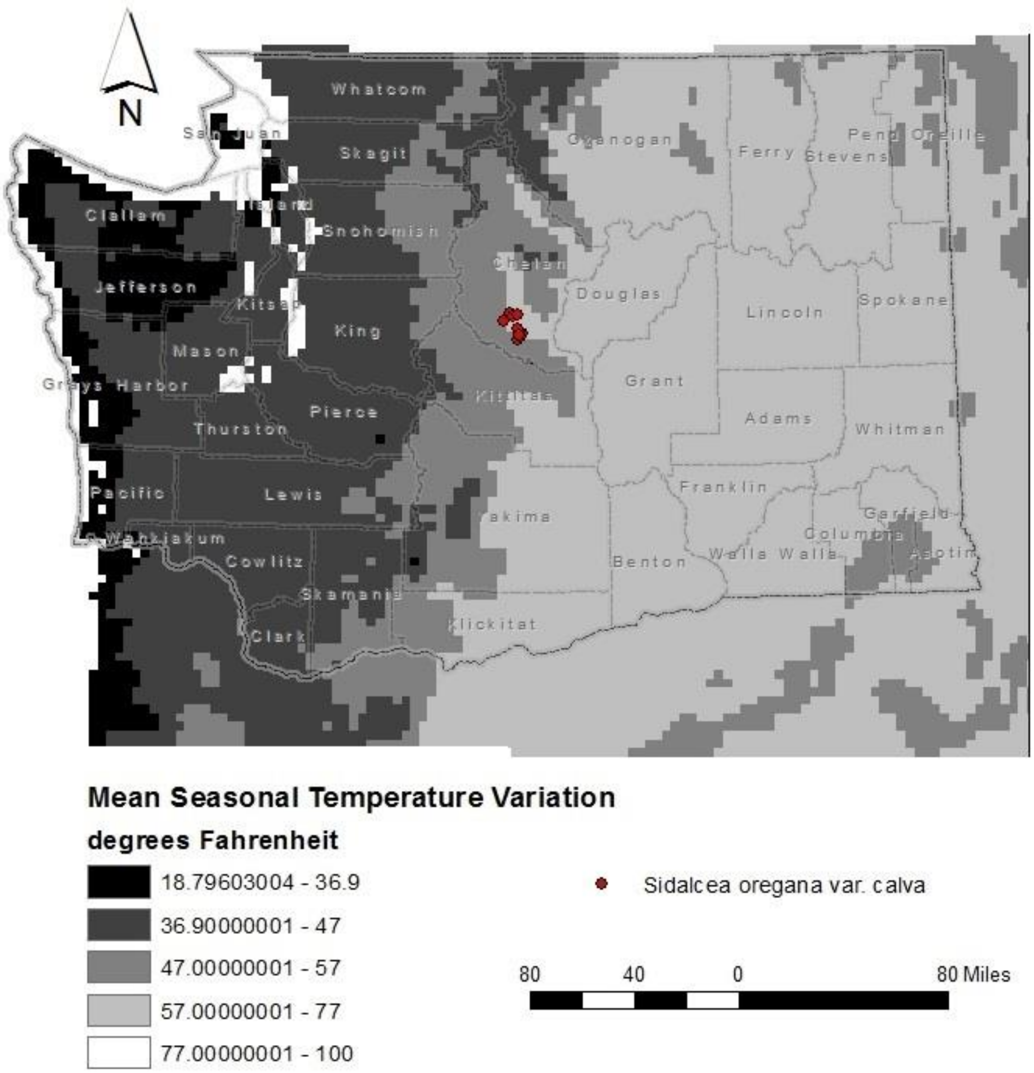

Figure D-3. Historical thermal niche (exposure to past temperature variations) of *Sidalcea oregana* var. *calva* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2aii. Physiological thermal niche: Neutral.
Sidalcea oregana var. *calva* occurrences in Washington are associated with wet meadows that occur along perennial streams or ditches, often in valley bottoms that may be cold air drainages. Small populations occur in moist openings in forests, but these occurrences may be short-lived due to succession. Such areas may be slightly cooler microsites, though not sufficiently cold to increase the vulnerability of this species to climate change.

C2bi. Historical hydrological niche: Neutral.
All 10 of the confirmed occurrences of *Sidalcea oregana* var. *calva* occur in areas where the mean annual precipitation variation is over 21 inches (Figure D-4). These sites are scored as Neutral for climate change impacts by Young et al. (2016).

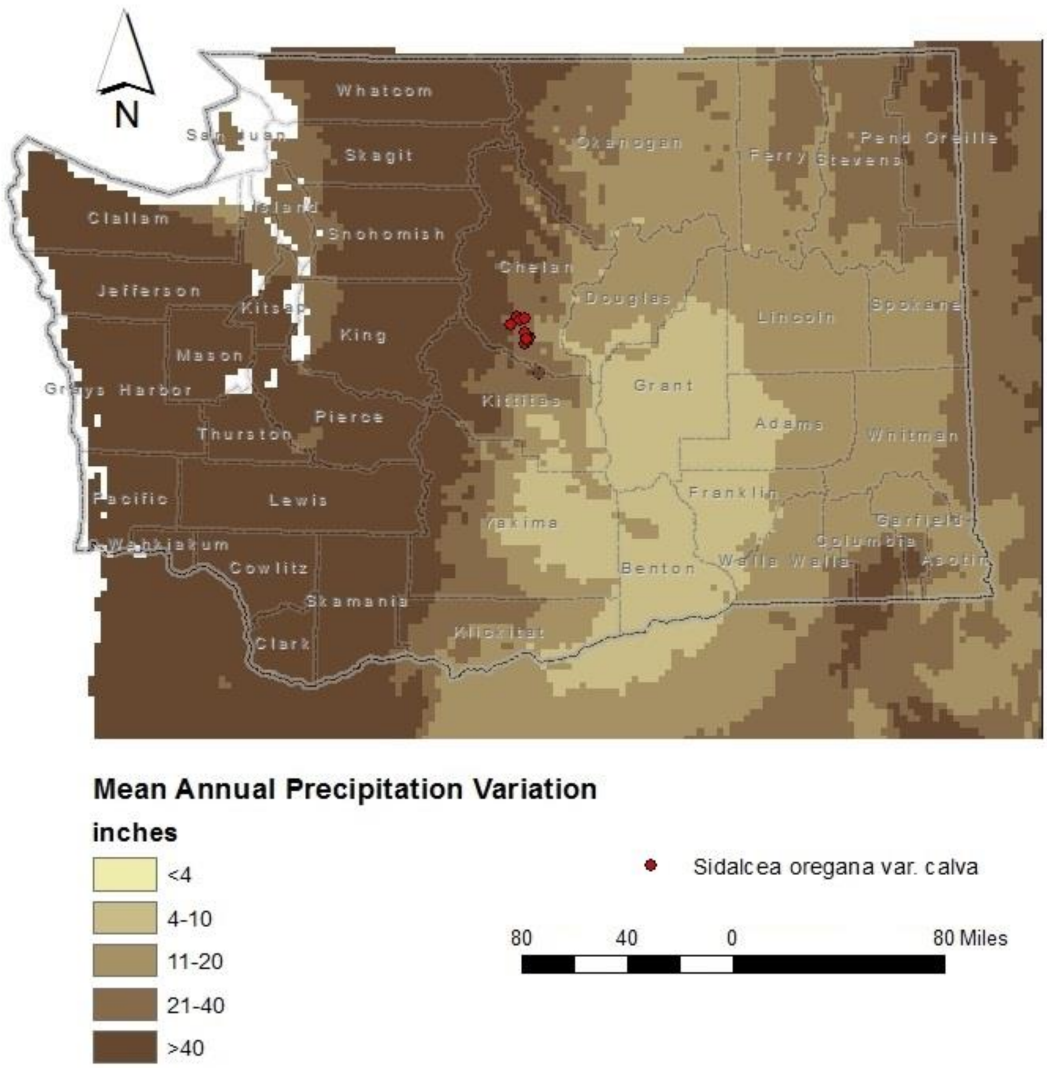

Figure D-4. Historical hydrological niche (exposure to past variations in precipitation) of *Sidalcea oregana* var. *calva* occurrences in Washington. Base map layers from www.natureserve.org/ccvi

C2bii. Physiological hydrological niche: Increase.
Sidalcea oregana var. *calva* has a specialized hydrological niche dependent on seasonal flooding early in the growing season followed by summer drought (Caplow 2003). Change in hydrology

is considered one of the primary threats to this taxon (USFWS 2004) and one of the main reasons it was listed under the Endangered Species Act. Reduction in the amount or seasonality of available moisture due to climate change will continue to be a significant threat in the future.

C2c. Dependence on a specific disturbance regime: Neutral.
Historically, fire helped maintain the open meadow conditions favored by *Sidalcea oregana* var. *calva* by controlling the spread of trees and shrubs. In addition, the species may be adapted to low intensity fire. In 2018, a new subpopulation of *S. oregana* var. *calva* appeared in the Poison Canyon area following burning of slash piles in a formerly forested area that had been thinned (W. Fertig, personal observation). The population at Camas Meadows has also responded with more vigorous growth following wildfire, and fire management has been used to improve habitat conditions in the preserve (Caplow 2003, Wilderman 2015). Climate change will likely increase the frequency of fire in most of the range of this taxon, which may have a net positive effect.

C2d. Dependence on ice or snow-cover habitats: Somewhat Increase.
Sidalcea oregana var. *calva* occurrences in Washington are found at a sufficient elevation where winter snow contributes at least one-quarter of the annual precipitation total. Warmer temperatures associated with climate change are likely to reduce the amount of snowfall, though it may increase the amount of rain.

C3. Restricted to uncommon landscape/geological features: Neutral.
The largest *Sidalcea oregana* var. *calva* occurrence is found in a broad, flat montane valley (Arnett 2011). Other occurrences tend to be associated with small openings associated with perennial streams or springs. None of these sites are in areas with atypical soil, geologic, or water chemistry characteristics that would be impacted by climate change.

C4a. Dependence on other species to generate required habitat: Neutral.
The wet meadow habitats occupied by *Sidalcea oregana* var. *calva* in Washington are primarily a consequence of local geomorphology and hydrologic patterns. Beaver may have played a role historically in reducing tree and shrub cover in wet meadow habitats (Caplow 2003).

C4b. Dietary versatility: Not applicable for plants.

C4c. Pollinator versatility: Somewhat Increase.
Goldsmith (2003) observed the native ground bee *Diadasia nigrifrons* to be the primary pollinator of *Sidalcea oregana* var. *calva*. This species is a specialist on other species in the genus *Sidalcea*. As a ground-nesting species, *Diadasia* may be vulnerable to surface-disturbing activities and fire (Caplow 2003). Goldsmith noted at least seven other bee species (including *Bombus, Hoplitis*, and *Osmia*) visiting *Sidalcea* flowers to collect nectar, but not pollen. Weevils may pollinate some flowers incidentally while they are consuming fruits (Caplow 2003). Goldsmith (2003) found fruit production to be relatively low (32-36%) and observed little difference between bee pollination and hand pollination in reproductive success. If *S. oregana* var. *calva* is dependent on a single species for pollination, it would be at increased (rather than somewhat increased) vulnerability to climate change.

C4d. Dependence on other species for propagule dispersal: Neutral.
Fruit dispersal in *Sidalcea oregana* var. *calva* appears to be primarily passive and does not depend on animal species (Gamon 1987).

C4e. Sensitivity to pathogens or natural enemies: Somewhat Increase.
Some herbivory of *Sidalcea oregana* var. *calva* has been observed at Camas Meadows NAP, but is not considered detrimental (Caplow 2003). Seed predation can be significant, accounting for 26-70% loss of seeds (Caplow 2003). The most important seed predators are two species of weevils (*Macrorhoptus niger* and *Anthonomus sphaeralcea*) and aphids (Arnett and Birkhauser 2008; Goldsmith 2003, Goldsmith-Zimmerman & Reichard 2005).

C4f. Sensitivity to competition from native or non-native species: Somewhat Increase.
One of the factors contributing to listing *Sidalcea oregana* var. *calva* as Endangered is competition from other plant species (USFWS 2004). This includes encroachment of trees and shrubs into wetland habitats and impacts from invasive non-native species, such as reed canarygrass (*Phalaris arundinacea*). Climate change could have a net positive impact on the spread and vigor of reed canarygrass. Increased drought conditions could result in more wildfire, however, which could reduce competing tree cover.

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

C5a. Measured genetic variation: Unknown.
Data appear to be lacking on genetic diversity in *Sidalcea oregana* var. *calva*.

C5b. Genetic bottlenecks: Unknown.

C5c. Reproductive System: Neutral.
Sidalcea oregana var. *calva* is a facultative outcrosser and is pollinated by ground-nesting bees. Fruit production is lower than might be expected and seed predation is high (Goldsmith-Zimmermann and Reichard 2005). Based on current data, reproduction by seed does not appear to be a limiting factor in the life history of this species.

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.
Trend data are mixed for *Sidalcea oregana* var. *calva*. The two largest occurrences (Camas Meadows and Mountain Home) appear to be increasing, though this could be due to more thorough monitoring efforts (Fertig 2019 and unpublished data). Several small occurrences, however, appear to be extirpated due to loss of habitat from succession (Fertig unpublished data). The impact of climate change on these population dynamics is not known.

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

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

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

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