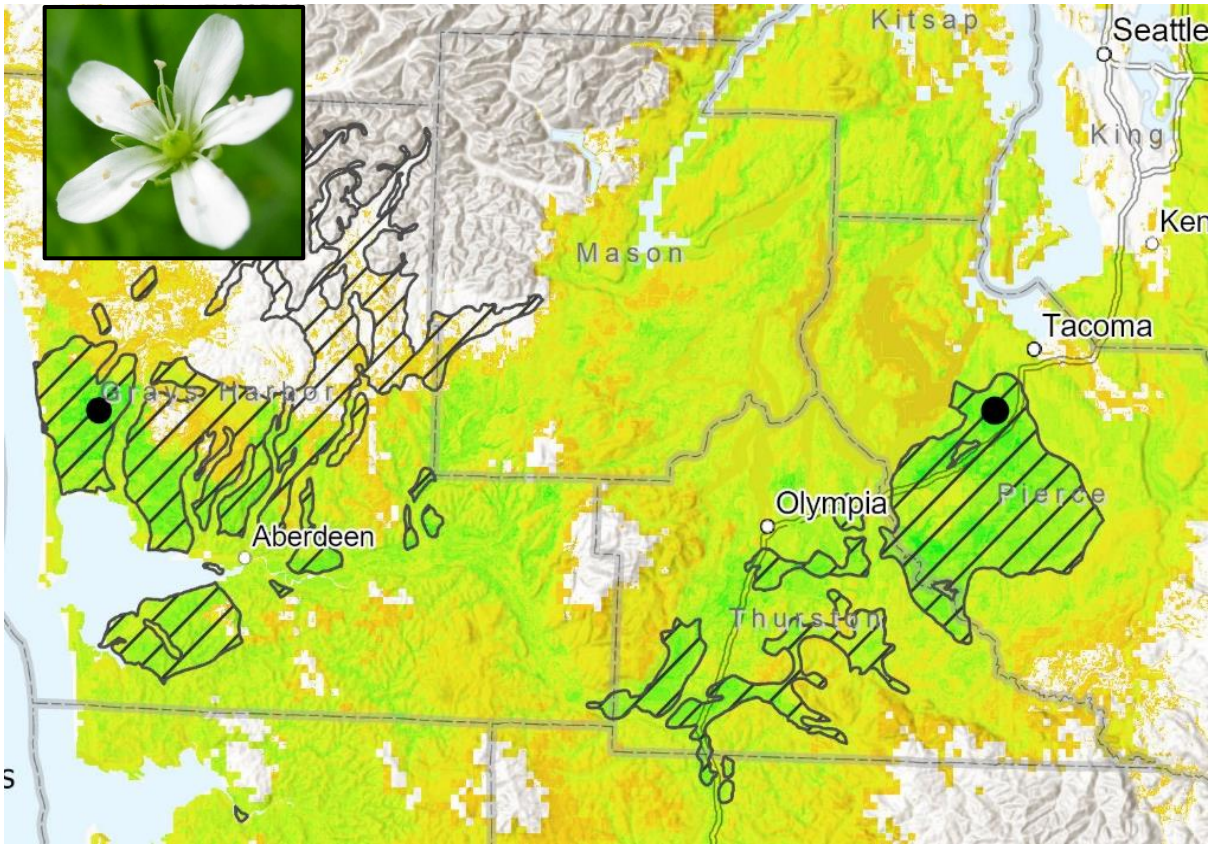
WASHINGTON NATURAL HERITAGE PROGRAM



Modeling Potential Suitable Habitat for Reintroduction of *Arenaria paludicola* in Washington

Prepared for
U.S. Fish and Wildlife Service

Prepared by
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ON THE COVER: *Arenaria paludicola* (marsh sandwort) flower. Photo by John Chestnut, California Native Plant Society San Luis Obispo Chapter sourced from CalPhotos.; Model of potentially suitable habitat for *Arenaria paludicola* (marsh sandwort) in Washington.

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My apologies (and thanks!) to anyone I may have omitted.

1 Introduction

Arenaria paludicola (marsh sandwort) is a diminutive wetland obligate plant species in the family Caryophyllaceae that associates with coastal freshwater habitats where soils remain perennially moist including marshes, swamps, and bogs. The distribution of this herbaceous perennial is restricted by a moderately narrow range of soil moisture and salinity levels (U.S. Fish & Wildlife Service, 2020). The historical range of this species spans from Central Mexico to Guatemala, with disjunct populations along the coast of central California and western Washington (Hartman et al. 2005). In the United States, it is presently known only from one wild population at Oso Flaco Lake in the Oceanio Dunes State Vehicular Recreation Area.

Arenaria paludicola was formally listed as Endangered under the Endangered Species Act in 1993 and it continues to face several threats to its few remaining populations. These include extensive urban development, increased competition as a result of changes to hydrological regimes, tree encroachment, and nutrient deposition (U.S. Fish & Wildlife Service, 2020; Washington Natural Heritage Program, 2023). Additionally, the small size of extant populations increases the risk of extinction due to stochastic events. *Arenaria paludicola* is now the only federally listed species to be completely extirpated in Washington (Fertig, 2021), with only two confirmed historical occurrences that have been re-surveyed but have not been re-observed since 1896.

The status of this species as extirpated in one of only two U.S. states where it historically occurred has underscored the need for recovery actions such as reintroduction through outplanting. Without restoration efforts, it is likely to go extinct, as shown by downward population trends in California (Ventura Fish and Wildlife Office, 2018). Additionally, the Recovery Plan for *Arenaria paludicola* outlines requirements for delisting which include the establishment and persistence of at least 5 populations (>500 individuals each) with at least some of the populations occurring in the historical range within the U.S. outside of California (U.S. Fish & and Wildlife Service, 1998). These requirements have not yet been met as of March 2024.

Prior to 2020, *Arenaria paludicola* had not been formally surveyed in Washington State since the early 1990s when it was last confirmed to be extirpated in the state (Gamon 1991). Habitat at historical locations in Washington has likely been severely degraded or destroyed by continuing development and invasion of aggressive exotic species such as *Phalaris arundinacea* (reed canary grass) (Fertig, 2021; Washington Natural Heritage Program, 2023). The need for new information about remaining suitable habitat where *Arenaria paludicola* may be re-discovered or successfully reestablished through planned planting efforts by the U.S. Fish and Wildlife Service was the impetus for new field surveys and the development of a spatial model of potentially suitable habitat in Washington. The results of these efforts are outlined in this report.

2 Methods

2.1 Pre-Modeling Fieldwork

The Washington Natural Heritage Program was contracted by the U.S. Fish and Wildlife service in 2020 to conduct surveys for *Arenaria paludicola* to inform the development of a model of potentially suitable habitat. The main goal of fieldwork in Washington was to collect updated information on *Arenaria paludicola* presence and habitat integrity at known historical occurrences or new potential occurrences to parameterize the habitat suitability model with the best available data.

Surveys were conducted at two historical occurrences: Flett Creek near Lakewood, WA (EO #7252) and Carlisle Bog Natural Area Preserve (EO #6277). Most other historical occurrences have been deemed erroneous due to misidentifications (later verified to be either *Stellaria borealis*, Boreal starwort, or *Gentiana sceptrum,* King's scepter gentian) and were not revisited (Fertig, 2021). The Mud Mountain dam occurrence (EO #3636) was planned for a field visit but didn't happen due to COVID limitations on field work. The validity of the Mud Mountain dam occurrence is still under question as there is no photo or specimen to substantiate it, and therefore it was not included in the model. Exploratory field surveys were also conducted at new locations which were thought to be ecologically appropriate for *Arenaria paludicola*, including Kennedy Creek wetland (Thurston County), Preacher's Slough (Grays Harbor County), and Lake Terrell (Whatcom County; Fertig, 2021). These locations were indicated to have high suitability in a pilot version of this model which was developed to direct early survey efforts.

Additional fieldwork was originally planned to collect data on the range of environmental conditions at occurrences in California, the only other U.S. state within the range of *Arenaria paludicola* and the only state with extant occurrences. However, due to COVID, this field work could not be completed. We instead overlaid occurrence data from the California Natural Diversity Database (CNDD; California Department of Fish and Wildlife 2023) with the same variables selected for the habitat suitability model (Table 1) to compare the environmental contexts of California and Washington occurrences and determine if the inclusion of California occurrences would be useful for future refinement of the model parameters.

2.2 Habitat Suitability Modeling Methods

A GIS model (Figure 2) was developed to identify areas of suitable habitat for surveys or outplantings based on correlations between selected environmental variables and the historical distribution of *Arenaria paludicola* in Washington. Several model iterations were tested, and variable weights were explored and assessed for accuracy before a final model was selected. The final model was produced by overlaying values for mean monthly precipitation and temperature

from 1980-2010 (January, April, July, October), soils, surface geology, elevation, landscape position (local relief), land cover, and vegetation type (Table 1) with known historical occurrences from Flett's Creek near Lakewood, WA (EO #7252) and Carlisle Bog Natural Area Preserve (EO #6277) in Pierce and Grays Harbor Counties. Landscape position was calculated as the average difference between minimum and maximum elevation using a 10 meter digital elevation model (DEM) of Washington. Solar radiation was originally included in the model but was later excluded to improve model accuracy and reduce overprediction. Both occurrences were used to define the suitable range (min and max) for each variable, though the validity of the Carlisle Bog occurrence is unconfirmed. These two occurrences represent the best available records and correspond with plausible habitat. All other historical occurrences were excluded from the model due to misidentification or other evidence of erroneous reports (Fertig, 2021).

To create a suitability heat map, we assigned additive suitability values to raster pixels in a blank raster layer of the state of Washington. Categorical variables that intersected with the known distribution of *Arenaria paludicola* (Table 1) were identified and scored as 1 for "predicted present", while all others were scored as 0 for "predicted absent". For the continuous climate variables, we first identified the range of temperature and precipitation values present at known *Arenaria paludicola* occurrences and added a 5% buffer (95% of the minimum and 105% of the maximum). Temperature and precipitation values falling within the selected range were then assigned a score of 1 for present, while other values were assigned 0 for absent. We created a topographic predictor raster by calculating the elevation and slope of known *Arenaria paludicola*, buffering these values by 5% (95% of the minimum and 105% of the maximum), and then using a digital elevation model (DEM; USGS 2020) to identify topographically similar areas in Washington. Pixels matching the buffered values were scored 1 and those not matching scored 0. Ecosystem types that matched the known *Arenaria paludicola* occurrences were selected and scored 1 while those not matching scored 0.

Table 1. Environmental parameters derived from an overlay with Washington occurrences of *Arenaria paludicola.* *"*Suitable Habitat Values" were the parameters used to constrain model predictions of habitat suitability. Areas with corresponding values of each variable that matched or were within the range of the defined suitable habitat values were identified and scored as 1 for "predicted present" in the model.

Environmental Variable	Source	Suitable Habitat Values
Surface Geology	DNR Geology Program (Washington Division of Geology and Earth Resources, 2016)	● 'Pleistocene continental glacial drift' ● 'Pleistocene alpine glacial drift'
Soil Series	Natural Resource Conservation Service (NRCS) Gridded Soil Survey Geographic (gSSURGO) (Soil Survey Staff, 2020)	● 'Spanaway-Nisqually (s8557)' ● 'Le Bar-Hoquiam (s8543)'
Land Cover (Ecosystems_NVC Divisions)	National Landcover Dataset (NLCD) (Dewitz, 2019) NatureServe Ecological Systems data (Comer et al 2003; LANDFIRE 2020)	● 'Emergent Herbaceous Wetlands' ● 'Shrub/Scrub' ● 'Woody Wetlands' ● 'North Pacific Lowland Riparian Forest and Shrubland' ● 'North Pacific Shrub Swamp' ● 'Temperate Pacific Freshwater Emergent Marsh'
Elevation 10 m (DEM)	US Geological Survey (2020)	88-272 ft
Local Relief (10 m DEM)	US Geological Survey (2020)	13-40 ft
January mean monthly precipitation (PPT01)	AdaptWest (2015) for time period 1980-2010	146-351 mm
April mean monthly precipitation (PPT04)	AdaptWest (2015) for time period 1980-2010	79-175 mm
July mean monthly precipitation (PPT07)	AdaptWest (2015) for time period 1980-2010	23-45 mm
October mean monthly precipitation (PPT10)	AdaptWest (2015) for time period 1980-2010	92-220 mm
January mean monthly temperature (Tave01)	AdaptWest (2015) for time period 1980-2010	5-5.3 °C
April mean monthly temperature (Tave04)	AdaptWest (2015) for time period 1980-2010	8.8-9.6 °C
July mean monthly temperature (Tave07)	AdaptWest (2015) for time period 1980-2010	15.2-18.1 °C
October mean monthly temperature (Tave10)	AdaptWest (2015) for time period 1980-2010	10.5-10.8 °C

The final suitability heat map was then color-coded to reflect the degree of habitat suitability based on the cumulative pixel values or "scores" from each model variable (Table 1). Habitat suitability scores range from low suitability (value=6) colored in yellow to high suitability (value=14) colored in green (Figure 2). Scores lower than 6 were considered completely unsuitable and were omitted from the map. We further restricted the suitability map by adding an overlay grid at the intersection of suitable surface geology (Table 1) and modeled highly suitable habitat to further delineate the most plausible habitat and avoid overpredicted areas (Figure 3; striped polygons). Due to COVID limitations, follow-up field surveys were not completed but should be conducted at critical sites identified by the model prior to outplanting.

3 Results

3.1 Environmental Parameters

3.1.1 Washington

Field visits in 2020 did not yield any new observations of *Arenaria paludicola*. Based solely on the two historical occurrences in Washington, which were not relocated during 2020 surveys, we were able to identify the range of key environmental factors which correspond with suitable habitat for *Arenaria paludicola* (Table 1). Washington occurrences are found near sea level (88-272 ft) on flat to gently sloping terrain in North Pacific Bog and Fen, North Pacific Lowland Riparian Forest and Shrubland, North Pacific Shrub Swamp, and Temperate Pacific Freshwater Emergent Marsh ecological systems (Rocchio & Crawford, 2015).

The freshwater wetlands that *Arenaria paludicola* historically occupied in Washington occur along the outer coast of the Olympic peninsula and the Puget Sound. Carlisle Bog Natural Area Preserve contains a mix of small ponds within a matrix of acidic peatlands and forested swamps. Flett Creek in Tacoma is an 80-acre wetland connected to a stream surrounded by a *Quercus garryana (*Garry oak) woodland (North Pacific Oak Woodland Ecological System). It is a natural drainage that is now connected to a large stormwater runoff system also managed for urban wildlife. These wetlands are mostly *Carex* spp. (sedge) dominated marshes or hardwood-conifer swamps that are seasonally flooded and can contain a significant amount of organic soil. They are generally found within a larger evergreen forest or oak woodland matrix. Dominant species of the shores include *Carex* spp*., Tsuga heterophylla* (western hemlock), *Pinus contorta var. contorta* (shore pine), and *Quercus garryana*. Other suitable wetland types identified by the model included swamps and marshes around ponds and lakes and depressional wetlands such as kettle ponds.

Carlisle Bog is generally cooler (January avg: 5.3 °C, April avg: 8.8 °C, July avg: 15.2 °C, October avg: 10.5 °C), receives more precipitation (January: 351 mm, April: 175 mm, July: 45 mm, October: 220 mm), and is closer to sea level (88-91 ft) than Flett Creek (Table 1). It falls under the Köppen-Geiger climate classification Cfb- Oceanic Climate. Flett Creek falls under

Csb- Warm-Summer Mediterranean Climate (Kottek et al. 2006) with generally warmer year-round temperatures (January avg: 5 °C, April avg: 9.6 °C, July avg: 18.1 °C, October avg: 10.8 °C) and much less overall precipitation (January: 146 mm, April: 79 mm, July: 23 mm, October: 92 mm). Flett Creek is somewhat higher than sea level (232-273 ft). Both locations are strongly influenced by ocean air currents which produce fog. They also follow similar seasonal patterns of cool to warm and dry summers and mildly cool, wet winters with most precipitation in the form of rain.

The most common soil types associated with modeled highly suitable habitat include Vashon Stade and Steilacoom gravel glacial outwashes produced by the recession of the Cordilleran Ice Sheet. Both are locally widespread in the Puget Sound and are often associated with Puget prairies (Washburn, 1988). The soils associated with *Arenaria paludicola* in Washington are predominately sandy-loam or gravelly outwash glacial soils with high sand and peat content. Soils are deep and rapidly draining with minimal runoff and very low surface flows, occurring in areas without a history of significant overbank flooding. They are also acidic to strongly acidic with high electrical conductivity and occur in a matrix with depressional pockets of nutrient-rich organic soils where perennial wetlands are supported (e.g., Dupont muck, Orcas peat).

3.1.2 California

Arenaria paludicola is currently known from only one remaining wild occurrence at Oso Flaco Lake just south of San Luis Obispo. It has been introduced at four sites in California (Acierto et al., 2012): Sweet Springs Marsh at Morro Bay, the Guadalupe-Nipomo Dunes National Wildlife refuge in southern San Luis Obispo County, Wilder Ranch/Baldwin Creek in Santa Cruz County, and Golden Gate Recreation Area in Marin County (not included in CNDDB data). Only the Sweet Springs and Golden Gate outplantings are known to be persisting.

In comparison to Washington occurrences, California occurrences of *Arenaria paludicola* are or were historically found across a much larger elevation range (0-1000ft) on flat to steep terrain. Occurrences are found on seasonally saturated, quick-draining sandy soils along rivers, springs, and ephemeral wetlands and in dune areas exposed to ocean salt spray (NatureServe 2024). Dominant cover of the habitat can be herbaceous, shrubby, or broad-leaved trees and palms. The wetland types where *Arenaria paludicola* can be found in include marsh, wet meadow, wet shrublands, and flooded forest.

The only remaining wild occurrence at Oso Flaco Lake is a “floating peat bog” that drains into a lagoon and has both areas which are permanently inundated and area with only seasonally moist soils (U.S. Fish & Wildlife Service, 2020). Historical occurrences are commonly associated with marshes in matrices of partially stabilized sand dunes. In these wetlands, *Arenaria paludicola* commonly grows among moderate to dense cover of native and exotic wetland species that are also common to Washington wetlands, including *Carex* spp.

Juncus spp. (rushes)*, Typha latifolia* (cattail)*, Scirpus* spp. (bulrushes)*, Sparganium* spp. (bur-reed)*, and Schoenoplectus* spp. (bulrushes).

The Köppen-Geiger climate classification for California occurrence is the same as the Flett Creek occurrence in Washington, (Csb) Warm-summer Mediterranean (Peel et al., 2007). However, temperatures in California are higher in every month, especially in the summer (January: 10-14 °C, April: 13-17 °C, July: 15-25 °C, October: 15-20 °C), and precipitation is much lower in every month (January: 59-237 mm, April: 19-73 mm, July: 0-2 mm, October: 10-54 mm) in comparison to the climate in Washington (Table 1). This climate type is still characterized by warm, very dry summers and cool, wet winters with precipitation falling in the form of rain.

Soils are largely mineral but can contain shallow organic layers and are comprised of Quaternary sand deposits, alluvium, and marine deposits which are generally sandier than Washington's glaciated soils in all layers. California soil types include Oceano sand, Baywood fine sand, and Elkhorn sandy loam. These are excessively draining soils with a neutral to strongly acidic pH that form in association with active or stabilized eolian dune systems.

Figure 1. Map of extant and extirpated occurrences of *Arenaria paludicola* in California sourced from the California Natural Diversity Database (CNDDB 2020).

3.1.3 Rangewide Summary (North America)

The environmental conditions of historical and extant occurrences of *Arenaria paludicola* in both Washington and California share several commonalities. *Arenaria paludicola* prefers intermediate levels of inundation, soil moisture, light availability, and density of neighbors. It occurs in freshwater wetlands located in warm-summer climates where maritime influence and

marine fog keep summer temperatures lower than surrounding areas due to proximity to the Pacific Ocean and Puget Sound. Summers in these climates are temperate and dry while winters are mildly cool and wet. *Arenaria paludicola* associates with a variety of wetland types which occur in a patchy distribution within larger wetland matrices, including marshes, wet meadows, depressional wetlands, and shrubby swamps that frequently drain into larger bodies of water.

Typical soils are partially-saturated acidic soils with high sand and peat content and rapid permeability which are not especially widespread in North America or along coastlines (Bontrager et al., 2014; U.S. Fish & Wildlife Service, 2020; Washington Natural Heritage Program, 2023). Hydrological regime is possibly the most critical environmental prerequisite for *Arenaria paludicola* occurrences, as it requires shallow inundation during the wet season (fall and winter) and partial drying in summer months with at least some moisture retained within the soil (U.S. Fish & Wildlife Service, 2020).

3.2 Habitat Suitability Model Results

Areas of potentially suitable habitat with appropriate soil types (Nisqually-Spanaway and Le Bar-Hoquiam series; Table 1) to support *Arenaria paludicola* were identified by the model as occurring in Grays Harbor, Thurston, and Pierce counties of Washington (Figure 2). Moderate probability areas identified by the model in other counties are dubious and expected to be a result of model overprediction as they do not clearly correlate with known environmental parameters of *Arenaria paludicola* which were used as model inputs (Table 1). Modeled areas of highest suitability were largely associated with soil series and surface geology, which we further highlighted by overlaying a soils grid to show the spatial extent of appropriate edaphic conditions and visually exclude overpredicted areas (Figure 3). Future model iterations should consider restricting outputs to the range of known suitable soils and geology. This grid also bounds the spatial extent of the highest pixel values in the model (>12), or the top 20% of suitable areas.

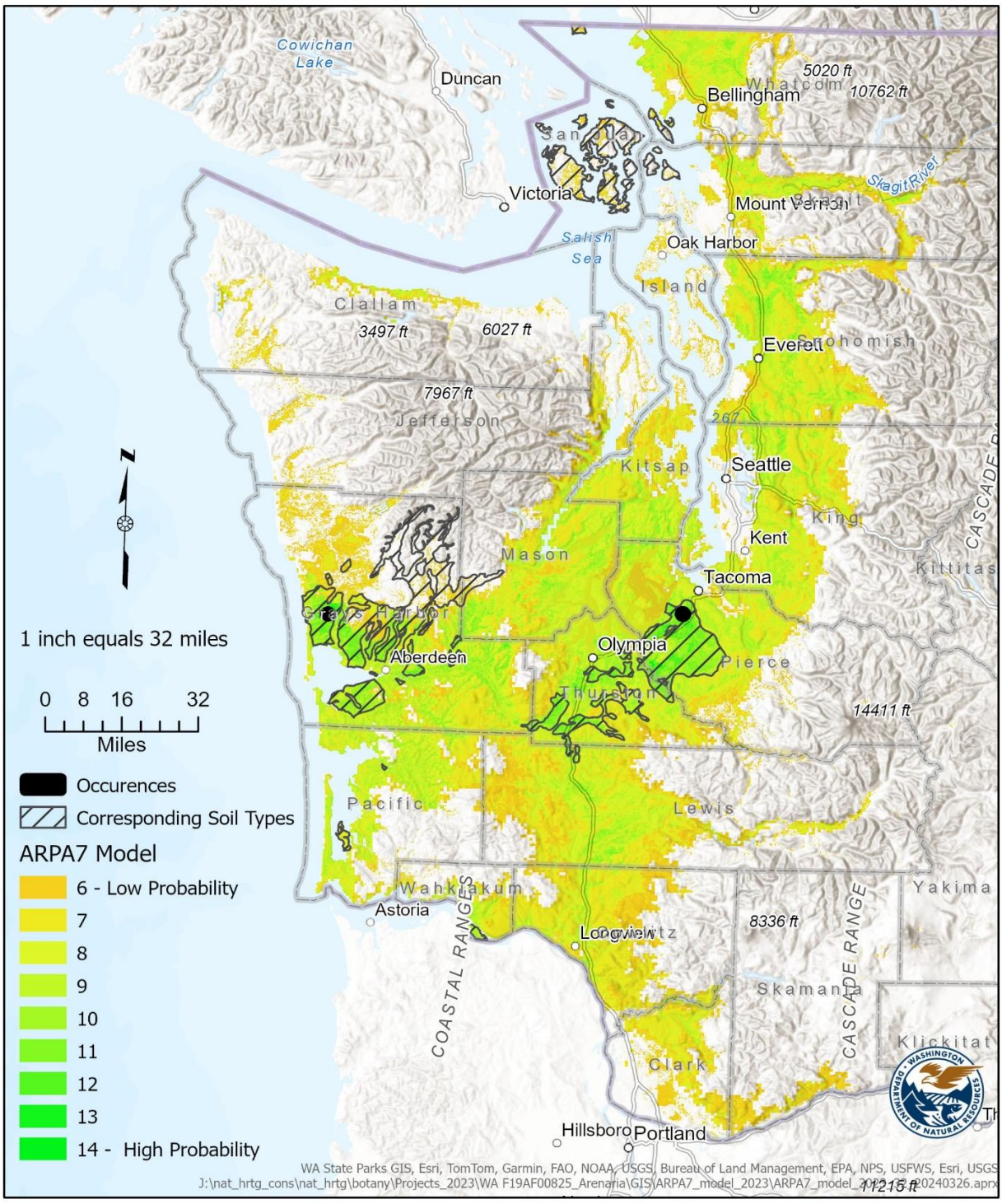

Figure 2. Full modeled extent of potential habitat of *Arenaria paludicola* in Washington. Striped polygons contain the most likely habitat based on the intersection of modeled high probabilities and the extent of suitable surface geology, within which ideal soil series also occur (Table 1). Black points indicated reported historical occurrences in western Washington.

Two major epicenters of suitable habitat identified by the model were immediately adjacent to the historical occurrences in areas surrounding Lakewood, WA, and Carlisle Bog (Figure 3). The largest remaining habitat occurs to the northeast of Carlisle Bog and in patches to the west and south surrounding Copalis Crossing, both in Grays Harbor County. These areas outside of the Carlisle Bog Natural Area Preserve are marshes and swamps in an upland forest matrix with many roads and clearcuts on county lands, DNR trust lands, and private lands. Most of Joint Base Lewis McChord and surrounding areas owned and managed by the Nisqually Tribe and Nisqually River Basin Land Trust were identified as suitable by the model and contain several complexes of moderately-sized kettle ponds, marshes, and seasonal floodplains.

Several smaller focal areas with pixel values greater than or equal to 12 were identified by the model, indicating suitability in the top 20% percent of possible values (pixel range = 0-14). Most of the highest suitability areas identified by the model in Thurston County and Pierce County have been converted into golf courses, airports, or baseball fields, potentially because the flat terrain and lack of forest cover were conducive to these purposes. For example, nearly all patches of potentially suitable habitat identified in the area south of Olympia and along SR 12 between Aberdeen and Olympia (Thurston County) have been fully developed. Other areas identified in Thurston County and Pierce County were small wetlands in dense urban areas or thin bands of floodplain between rivers, housing developments, and forests which are too small and fragmented to be suitable habitat. Areas identified by the model around American Lake, Steilacoom Lake, and Spanaway Lake in Pierce County are nearly surrounded by development and are probably not ideal for reintroduction.

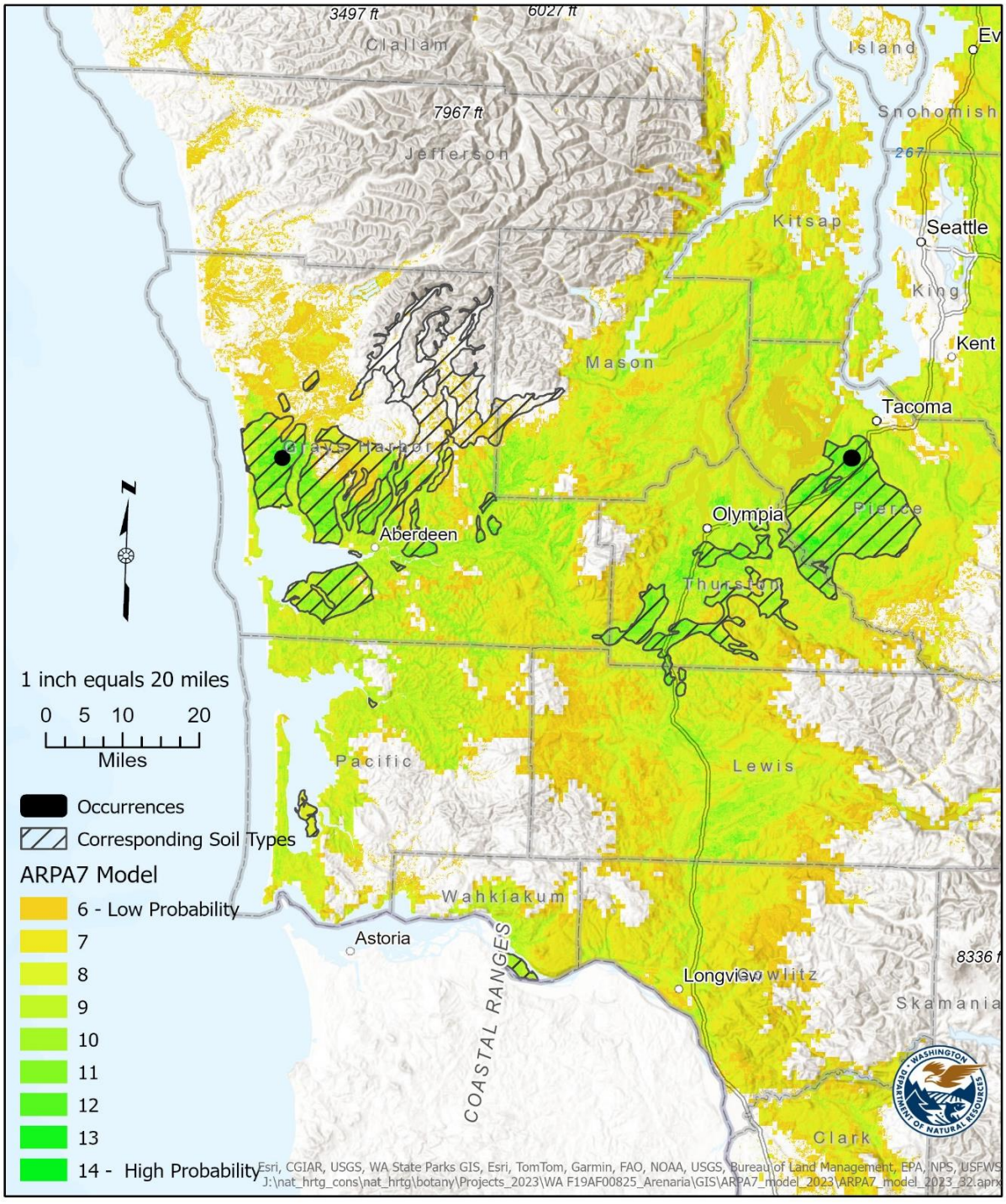

Figure 3. Focal areas of most likely suitable habitat for *Arenaria paludicola* in Washington. Striped polygons contain the most likely habitat based on the intersection of modeled highest probabilities and the extent of suitable surface geology, within which ideal soil series also occur (Table 1). Black points indicated reported historical occurrences in western Washington.

3.3 Field Assessment

Site visits in 2020 to areas of potential suitable habitat indicated by the model (Figure 3) in the Spanaway Creek wetland complex and 10 ephemeral wetlands at Joint Base Lewis-McChord (JBLM) did not lead to the discovery of any extant populations of *Arenaria paludicola*. Several of the JBLM wetlands, particularly those along Spanaway Creek in the northeastern corner of the base, now contain dense and extensive stands of the exotic grass *Phalaris arundinacea*. This exotic wetland grass is expected to outcompete *Arenaria paludicola* for space and resources as it has with other rare aquatic species that share similar habitat requirements such as *Howellia aquatilis* (water Howellia) (Washington Natural Heritage Program, 2023).

New areas of potentially suitable habitat that were searched for new occurrences prior to model development based on a pilot version of the model (Kennedy Creek, Preacher's Slough, and Lake Terrell) and the Mud Mountain Dam historical occurrence (EO#3636) did not lead to new populations. Additionally, these locations were not identified as highly suitable by the final model. Limitations on fieldwork imposed by COVID-19 did not allow for the completion of planned field visits to select wetlands in Tacoma and the Flett Creek Drainage but the general region is known to be significantly invaded by *Phalaris arundinacea* (Fertig, 2021). Extensive development in western Washington, particularly in the Puget Trough ecoregion, has further reduced available habitat for *Arenaria paludicola* and many smaller patches of otherwise suitable land are now too fragmented to consider further. Field assessment is still needed on other managed lands identified by the model as potential outplanting areas (see Section IV) to determine whether the habitat is truly suitable and to assess logistical feasibility. High invasive species cover, alterations to hydrological regimes, and potential impacts from bordering developed areas would cause sites to be ruled out as unsuitable habitat.

3.4 Suitable Reintroduction Sites

It is critical to strategically select candidate areas for reintroduction that are well-positioned to allow the adoption of long-term management and monitoring plans for recovery success. An important tool for identifying this conservation capacity is the nationwide Protected Areas Database which assigns one of four "GAP" statuses codes to which we refer in this report. Status codes indicate the following (USGS-GAP, 2022): 1) primarily managed for biodiversity with permanent protection from land conversion, 2) primarily managed for biodiversity, 3) managed for multiple uses including conservation and extraction, and 4) no known mandate for biodiversity protection. Much of the remaining undisturbed and undeveloped suitable habitat identified as highest suitability by the model is located on private lands and county lands which are not sufficiently protected for *Arenaria paludicola* to be reintroduced (i.e., these lands were identified as GAP Status 4).

<u>Best Available Sites</u>

The most extensive areas of potential habitat which are actively managed as conservation areas or are at least somewhat protected from development are located at Carlisle Bog Natural Area (310 acres) and Joint Base Lewis McChord (JBLM, >90k acres). Carlisle Bog is protected and managed for biodiversity conservation by the Washington Department of Natural Resources, Natural Areas Program (GAP Status 1) and JBLM is managed by the JBLM Fish and Wildlife Program which already manages for other rare wetland plant species at some of the lakes identified as suitable by the model (e.g., *Howellia aquatilis*). Despite being an active military base, which does not have mandates to prevent habitat conversion beyond Endangered Species Act compliance, there is an established track record of successful conservation work at JBLM. Suitable habitats at these sites which are not documented as heavily invaded or degraded include:

A. peatlands and lake floodplains at Carlisle Bog located primarily in the northwestern section of the preserve around the Carlisle Lakes region;

B. a marsh complex including Edmond Marsh, Hanner Marsh, and MacKay Marsh northeast of Dupont in JBLM;

C. a linear stretch of patchy small to large kettle lakes and marshes on JBLM land to the northeast of Roy including Johnson Marsh, Shaver Lake, Dailman Lake, Hamilton Lake, Chambers Lake, Halverson Marsh, and Brandenburg Lake (many of which actively harbor the rare aquatic plant *Howellia aquatilis*);

and

D. Nisqually River delta, marsh, and floodplain areas at JBLM to the east of the Nisqually Reservation around Nisqually Lake and Farnsworth Lake.

These sites are likely to be the most optimal for reintroduction of *Arenaria paludicola* due to the size of the managed areas, the number of suitable marsh and swamp microsites available, availability of onsite management and monitoring resources, and the botanical expertise possessed by the current land managers. Dailman Lake needs a follow-up site visit to confirm suitability based on reports of human activity and trails running through wetlands.

Secondary Sites

In Grays Harbor County, additional smaller parcels of marsh habitat remain on lands owned and managed by the Grays Harbor Audubon Society (GAP Status 2) in the Humptulips River watershed surrounding Carlisle Bog. These may be viable outplanting sites as they are currently protected and managed for wildlife but it is unknown if there is existing capacity and expertise for reintroduction and monitoring. The most promising protected Thurston County sites include:

A. a small wetland section of Billy Frank Jr. Nisqually Wildlife Refuge delta (>4.5k acres) along the Black River managed by U.S. Fish and Wildlife (GAP Status 2) and located just outside of the model soil boundaries but still within suitable soil types;

B. marshy areas and floodplains north of Deep Lake in Millersylvania State Park (south of Olympia, 903 acres) that are managed by Washington State Parks and Recreation Commission (GAP Status 3) and are just outside of the model soil boundaries but are still likely to be suitable;

and

C. seasonal depressional wetlands in a larger prairie-oak woodland matrix located in the Scatter Creek Unit (915 acres) managed by the Washington Department of Fish and Wildlife (GAP Status 2).

These areas are actively managed for biodiversity with varying levels of recreation access. In areas with mounded prairie (i.e. mima mounds), such as Scatter Creek, a shallow impermeable layer results in seasonally waterlogged soils (Washburn, 1988). In California, mima mounds are often associated with vernal pools, and in Washington they are frequently associated with depressional wetlands, both of which frequently support rare aquatic species which depend on a similar hydrology as *Arenaria paludicola*.

Less Satisfactory Sites

The Flett Creek drainage in Pierce County (south of Tacoma) is highly developed but contains small areas managed primarily for recreation which still support suitable marshes and swamps which were selected by the model. These include:

A. Wards Lake Park/Natural Area (22 acres) and Seeley Lake County Park (47 acres) managed by the City of Lakewood (GAP Status 4)

and

B. Woodside Pond Nature Park (3.5 acres) and Leach Creek Wetland Open Space (13 acres) managed by the City of University Place Parks Department (GAP Status 4).

Some of these potentially suitable areas in the Tacoma region and Flett Creek drainage are known to have ongoing resource concerns surrounding public use and the recent development of tiny home villages that may preclude reintroduction and management activities. Additional field surveys should be conducted to collect more information on these logistical site specifics prior to planning outplanting projects.

4 Future Modeling Recommendations

The results of our model provide valuable insight into the ecological requirements of *Arenaria paludicola* and identify several promising sites for reintroduction in Washington. However, we found that the model significantly overpredicted, selecting large areas that were clearly unsuitable (e.g., uplands, developed areas) and were well outside the known historical range of *Arenaria paludicola* in Washington (Figure 2). Due to time and budget constraints, we were unable to produce another version of the model. Instead, we visually bounded the intersection of suitable surface geology and soils and the highest suitability areas identified by the model to narrow in on best available areas for outplanting (Figure 3). Soils and geology were spatially correlated with high modeled suitability and future model iterations should consider excluding areas that are not known to be edaphically appropriate or weighing soils and geology higher in the model. Additionally, the vegetation maps used may be too coarse to capture microsite differences relevant to wetlands. Future iterations may reduce model overprediction by including wetland-specific maps such as those available through the National Wetlands Inventory.

Additional modeling efforts could also incorporate other variables and data from California occurrences to fine-tune the model and potentially locate additional areas of suitable habitat. California ecological associations, soil types, and absolute value ranges of precipitation and temperature are too different from those in Washington to be used directly in a model for Washington. However, California element occurrences could be used to derive finer-scale quantitative information for additional variables relevant to Washington.

Critical variables to consider that are intrinsically included in but not directly assessed by our model include soil pH, soil organic matter content (%), soil sand content (%), canopy cover, wetland size, and other wetland characteristics that could be assessed by remote sensing such as hydroperiod and water depth. *Arenaria paludicola* occurrences appear to be highly associated with fog zones and variables or topographic features which capture fog frequency may be useful model parameters. The frequency and abundance of known “indicator” associate species such as *Oenanthe sarmentosa* (water parsley) and *Carex* spp. may also be useful predictors of suitable habitat (Bontrager et al., 2014). A future model could potentially be further fine-tuned using wetland-specific vegetation mapping units or by removing coarse vegetation data altogether.

Lastly, follow-up visits and record searches should be conducted to verify the legitimacy of the Mud Mountain Dam (EO #3636) occurrence for potential inclusion in the model as it is potentially erroneous. The validity of the Carlisle Bog occurrences (EO #6277) is still under some scrutiny because there is no associated photo or specimen and it has not been relocated in nearly 50 years. It would be pertinent to attempt a model based around the single fully verified occurrence at Flett Creek (EO #7252) and compare results.

5 Outplanting Recommendations

There have been four attempts to introduce this species into suitable habitat within its historical range in California, only two of which have persisted for more than a few years (Figure 1; Acierto et al., 2012; Ventura Fish and Wildlife Office, 2018). This is probably, at least in part, because *Arenaria paludicola* has a narrow tolerance range of soil moisture and saline conditions. It will not tolerate deep standing water or overly saturated soil but simultaneously will not remain in seasonally wet areas if they remain dry for too long. It also historically occurs only in freshwater with maritime influence and frequent fog to keep temperatures in the ideal range.

Recent greenhouse studies have shown that *Arenaria paludicola* is tolerant to a broader range of conditions than previously assumed and that it can persist in environmental conditions outside of the parameters found in its remaining wild habitat, including brackish water (Bontrager et al., 2014). With the onset of climate change and the continuing development of historically suitable habitats, it may become necessary to consider "novel" habitats for reintroduction which meet the ecological needs and basic habitat constraints of the species but do not necessarily fall within historical categories and values. *Arenaria paludicola* is a cryptic species that can be hard to locate and has probably been historically under collected. Floras and field notes clearly indicate that this species has been steadily declining since at least 1944 and that it was once much more widespread (U.S. Fish & and Wildlife Service, 1998). Some of the former Washington range may have extended into estuarine habitats.

Based on model results and current literature on *Arenaria paludicola* propagation, we provide the following considerations for future reintroduction efforts in Washington:

1. Genetic source material from extant California occurrences should be selected with consideration of the different environmental conditions in Washington. Plant materials may need to be sourced from the coolest, wettest areas of the California range to ensure survival and persistence. On the other hand, planting of materials from the more arid California occurrences may ultimately increase the capacity of reintroduced Washington populations to adapt to climate change via assisted genetic migration. Historical concerns regarding interbreeding with Washington populations are now moot due to the complete extirpation of the species in the state.

2. Experimental studies and previous reintroduction efforts have shown that *Arenaria paludicola* propagates well vegetatively and will root from stem nodes (Bontrager et al., 2014). Little is known about propagation from seed and therefore reproduction from cuttings is the preferred method.

3. Outplantings of *Arenaria paludicola* should ideally be accompanied by other commonly co-occurring native "indicator" species (Bontrager et al. 2014; U.S. Fish & Wildlife Service, 2020) that create hummocks (e.g., *Carex* spp.) to lift plants out of

deeper standing water and help maintain suitable habitat conditions (e.g., *Oenanthe sarmentosa*).

4. Perennial standing water should be avoided when outplanting, since *Arenaria paludicola* persists better in slightly dry soils with seasonal moisture than in saturated soil (Acierto et al., 2012; Bontrager et al., 2014). It cannot survive in areas with much overland movement of water (sheet flow). Simultaneously, seasonal wetlands that are predicted to dry out for extended periods under climate change should be avoided if possible. *Arenaria paludicola* cannot recover after 20 days of desiccation (Bontrager et al., 2014). The edges of large marshes and shorelines of lakes may provide optimally balanced seasonal inundation.

5. *Arenaria paludicola* prefers an open canopy with moderate light availability. As such, woody plant encroachment is a threat to *Arenaria paludicol*a. The species can benefit from gentle canopy thinning and shrub trimming, but only when treatments are conducted after plants are well-established and care is taken to avoid damage to any plants using neighbors as structural supports (Acierto et al., 2012). Additionally, invasive species management may be a challenge in areas with *Arenaria paludicola* outplantings as the species is likely to be threatened by herbicides frequently used to treat aquatic vegetation such as *Phalaris arundinacea.* Furthermore, prescribed low doses of glyphosate-based herbicides labeled for wetland use have rarely been successful for abating *Phalaris arundinacea* (Lichthardt, 2007). Mechanical removal will be necessary to prevent damage to outplantings and may be necessary to restore potential suitable habitat to conditions conducive to outplanting (e.g., at JBLM and near Flett Creek). Because aggressive native or exotic wetland species are likely to rapidly crowd out *Arenaria paludicola,* treatments must be widespread and assertive.

7. *Arenaria paludicola* strongly prefers areas with maritime influence near the Pacific Ocean and Puget Sound. Some of these areas predicted by the model are projected to be at risk of inundation from sea level rise (e.g. Nisqually Wildlife Refuge) and these risks should be considered when selecting outplanting sites (Office for Coastal Management, 2023). King tides in California have washed out entire populations in the past (U.S. Fish & Wildlife Service, 2020). High precipitation events that cause flooding could cause similar mass mortality events in freshwater systems.

6 References

Acierto, K. R., Hendericks, R. S., Bontrager, M., & Parker, I. M. (2012). Transplant success for the endangered herb Arenaria paludicola at Golden Gate National Recreation Area: Effect of site, propagation type, and competition (Prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Game). University of California Department of Ecology and Evolutionary Biology.

https://www.nps.gov/goga/learn/management/upload/-2038-Acierto-et-al-2012-transplant-success-Arnaria-paludicola-at-GGNRA.pdf

AdaptWest Project. (2015). Gridded current and projected climate data for North America at 1km resolution, interpolated using the ClimateNA v5.10 software (T. Wang et al., 2015) [dataset]. https://adaptwest.databasin.org/

Bontrager, M., Webster, K., Elvin, M., & Parker, I. M. (2014). The effects of habitat and competitive/facilitative interactions on reintroduction success of the endangered wetland herb, Arenaria paludicola. Plant Ecology, 215(4), 467–478. https://doi.org/10.1007/s11258-014-0317-z

California Department of Fish and Wildlife, Biogeographic Data Branch. (2023). California Natural Diversity Database [dataset]. http://www.dfg.ca.gov/biogeodata/cnddb/

Comer, P., Faber-Langendoen, D., Evans, R., Gawler, S., Josse, C., Kittel, G., Menard, S., Pyne, M., Reid, M., Schulz, K., & Teague, J. (2003). Ecological systems of the United States: A working classification of U.S. terrestrial systems. NatureServe, Arlington, VA.

Dewitz, J. (2019). National Land Cover Database (NLCD) 2019 Products (ver. 3.0, February 2024) [dataset]. U.S. Geological Survey. https://doi.org/10.5066/P9KZCM54

Fertig, W. (2021). Status of Federally Listed Plant Taxa in Washington State (Prepared for U.S. Fish and Wildlife Service, Region 1 Natural Heritage Report 2021-0 1). https://www.dnr.wa.gov/publications/amp_nh_status_fed_listed_2021.pdf

Gamon, J. (1991). Report on the status of *Arenaria paludicola* Robinson. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA. 20 pp.

Hartman, R.L., R.K. Rabeler, and F.H. Utech. 2005. *Arenaria*. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 20+ vols. New York and Oxford. Vol. 5: Magnoliophyta: Caryophyllidae, part 2. pp 51-56.

The National Map LANDFIRE. (2020). LANDFIRE National Existing Vegetation Type layer [dataset]. U.S. Department of Interior, Geological Survey. http://gisdata.usgs.net/website/landfire/

Lichthardt, J. (2007). Monitoring of *Howellia aquatilis* (water Howellia) and its Habitat at the harvard-Palouse River Flood Plain Site, Idaho: Third-Year Results (Report Prepared for Idaho Department of Parks and Recreation through Section 6 Funding from U.S. Fish and Wildlife Service, Region 1). Idaho Department of Fish and Game. 18 pp. https://idahodocs.contentdm.oclc.org/digital/collection/p16293coll7/id/106531

Office for Coastal Management. (2023). NOAA Office for Coastal Management Sea Level Rise Data: 1-10 ft Sea Level Rise Inundation [dataset]. https://www.fisheries.noaa.gov/inport/item/48106

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11(5), 1633–1644. https://doi.org/10.5194/hess-11-1633-2007

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

Soil Survey Staff. (2020). Gridded Soil Survey Geographic (gSSURGO) Database for Washington [dataset]. United States Department of Agriculture, Natural Resources Conservation Service. https://gdg.sc.egov.usda.gov/

U.S. Fish & Wildlife Service. (2020). Marsh Sandwort (Arenaria paludicola) 5-Year Review. Ventura Fish and Wildlife Office. https://www.fws.gov/node/261530

U.S. Fish & and Wildlife Service. (1998). Recovery Plan for Marsh Sandwort (Arenaria paludicola) and Gambel's Watercress (Rorippa gambelii). U.S. Fish and Wildlife Service. https://www.nps.gov/goga/learn/management/upload/-2032-marsh-sandwort-recovery-plan.pdf 50 pp + appendices.

U.S. Geological Survey (USGS) Gap Analysis Project (GAP). (2022). Protected Areas Database of the United States (PAD-US) 3.0: U.S. Geological Survey data release [dataset]. https://www.usgs.gov/programs/gap-analysis-project/science/pad-us-data-download

U.S. Geological Survey (USGS). (2020). 1 meter Digital Elevation Models (DEMs)—USGS National Map 3DEP Downloadable Data Collection [dataset]. https://data.usgs.gov/datacatalog/data/USGS:77ae0551-c61e-4979-aedd-d797abdcde0e

Ventura Fish and Wildlife Office. (2018). Recovery Plan for Marsh Sandwort (Arenaria paludicolu) and Gambel's Watercress (Rorippa gambelii), Draft Amendment. U.S. Fish and Wildlife Service, Pacific Southwest Region. 7 pp. https://www.fws.gov/sites/default/files/documents/news-attached-files/Draft%20Recovery%20Plan%20Amendment%20NAGA%20ROGA.pdf

Washburn, A. L. (1988). Mima Mounds: An Evaluation of Proposed Origins with Special Reference to the Puget Lowlands. Washington State Department of Natural Resources, Division of Geology and Earth Resources. 64 pp.

Washington Division of Geology and Earth Resources. (2016). Surface geology, 1:100,000—GIS data (3.1, previously released June 2010) [dataset]. Washington Division of Geology

and Earth Resources Digital Data Series DS-18. http://www.dnr.wa.gov/publications/ger_portal_surface_geology_100k.zip

Washington Natural Heritage Program. (2023). Arenaria paludicola. In Online Field Guide to the Rare Plants of Washington (http://fieldguide.mt.gov/wa). https://fieldguide.mt.gov/wa/?species=arenaria%20paludicola