# Modeling the Distributions of Rare Plant Species within the National Petroleum Reserve-Alaska

## Final Report

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# Acknowledgements

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## Introduction

To make informed decisions on the management and protection of species of conservation concern, adequate levels of knowledge on the ecology and distribution of these species are necessary. This is particularly relevant when land management goals are potentially in conflict, such as supporting natural resource use and protecting species of conservation concern. Given the lack of information on the ecological requirements and actual ranges of Alaska's rare plant species, current and future oil exploration and development in the National Petroleum Reserve-Alaska (NPR-A), particularly when coupled with the rapidly changing climate of the circumpolar north, could pose a threat to rare species. Previous broader-scale habitat suitability modeling suggested that habitat for a number of North Slope plant species may decline dramatically in the next half century (Carlson and Cortés-Burns 2013). Without a greater understanding of where these species currently occur and what determines their distribution patterns, species that are vulnerable at present could become imperiled in the future.

Ecological niche modeling constitutes a quick and cost-effective way in which to identify those environmental parameters that best explain a species' current distribution. This approach can also estimate the potential range of a species in a given area. Ecological niche modeling offers opportunities to circumvent problems posed by patchy distribution data, paucity of botanical surveys, and lack of ecological knowledge for each target species.

To better locate habitat that is highly suitable for rare plant taxa, the Alaska Natural Heritage Program (AKNHP) proposed to model the potential distributions of rare vascular plant taxa that occur within the Arctic Tundra Unified Ecoregion using the ecological niche modeling program MaxEnt v. 3.3.2b. (Phillips et al. 2004). The habitat suitability maps generated from this analysis rank sites in accordance with their potential to support a rare plant species. This information can be used to conduct detailed inventories in selected areas prior to changes in land use, to gather baseline conservation data, and where necessary, manage habitat to protect rare plant populations.

## Objectives

The main objective of this project was to model potential rare plant species habitats across the Arctic Tundra Unified Ecoregion based on associations of known locations with environmental variables. The analyses and resultant habitat suitability maps can then be used to address questions such as:

1. What are the biophysical parameters that are most useful in explaining rare species distributions?
2. Which areas of the NPR-A should be prioritized for future botanical fieldwork, based on their greater likelihood of containing species of conservation concern?
3. Which species are likely to be affected by expansion of oil/gas exploration and development activities in the NPR-A?
4. Given a set of areas that are: a) identified as providing high quality habitat for one or more rare plant species, and b) currently modified or affected by anthropogenic activities, which should be slated for restoration work?

# Methods

## 1. Study area

Species distributions were modeled for the Arctic Tundra Unified Ecoregion. This Unified Ecoregion includes the Beaufort Coastal Plain, Brooks Foothills and Brooks Range Ecoregions (Nowacki et al. 2001). The BLM-managed NPR-A occupies 22.8 million acres (BLM 2012) of the Beaufort Coastal Plain and Brooks Foothills (Figure 1). The gently rolling hills, broad exposed ridges and braided streams of the foothills give way to the treeless, wind-swept coastal plain, which supports a mosaic of tussock tundra, wet sedge tundra and thaw lakes. The entire region is characterized by a dry, polar climate that is warmer and wetter towards the Brooks Range (Nowacki et al. 2001).

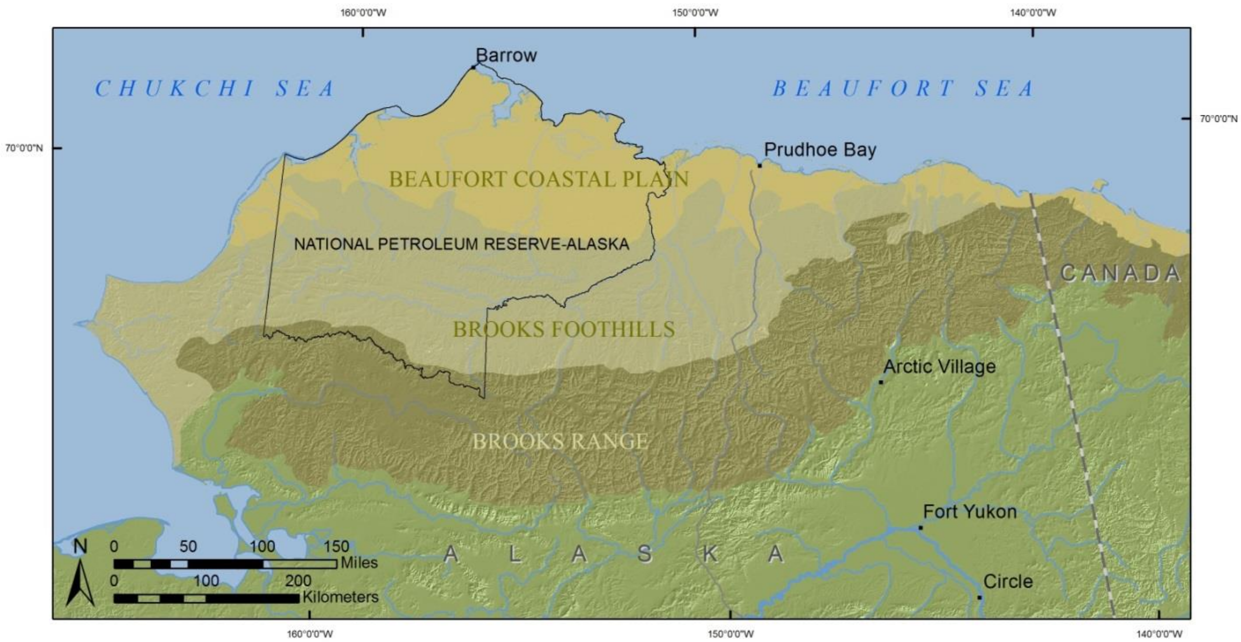



**Figure 1. Location of National Petroleum Reserve-Alaska and associated ecoregions.**

## 2. Selection of target species

Vascular plant taxa were identified as rare within the Arctic Tundra study area by botanists (R. Lipkin, M.L. Carlson, H. Cortés-Burns) at AKNHP, following discussions with arctic flora experts, and after reviewing the AKNHP Rare Plants database and georeferenced herbarium specimens curated by the University of Alaska Fairbanks Herbarium (Cortés-Burns et al. 2009). Of these taxa, we selected eight species for modeling based on the following criteria: globally uncommon or rare (G4 or lower), rare within Alaska (S3 or lower), BLM Sensitive- or Watch-listed, and those which had four or more locations on the North Slope. These requirements are necessary to encompass the species that are of greatest conservation concern in the region, but have enough known populations to facilitate the modeling exercise. Although there is no minimum number of occurrences required to run the MaxEnt algorithms, the recommended number of occurrences is 30 and it is generally accepted that running MaxEnt with less than five records may not yield useful results.

## 3. Generation of environmental layers

Fifteen environmental layers related to topography, temperature and precipitation were selected for the ecological niche modeling (Table 1). Layers were prepared in a GIS environment (ArcGIS 10.0) and converted to ASCII files. All layers have a cell size of 60 meters, following the availability of the digital elevation model (DEM) for Alaska at that resolution. The Curvature, Plan Curvature, Profile Curvature, Slope, and Aspect layers were derived from this DEM.

**Table 1. Environmental layers selected for ecological niche modeling analyses.**

| Layer Name | Description |
|---|---|
| Digital Elevation Model | US Geological Survey (USGS) 60-m DEM for Alaska |
| Slope | A measure of slope steepness (degrees) which can be calculated from elevation in ArcGIS |
| Aspect | Identifies the steepest downslope direction from each cell to its neighbors (i.e. slope direction or the compass direction a hill faces), and can be derived from elevation in ArcGIS |
| Curvature | Derived from the DEM; provides information on the curvature of each pixel/cell. A positive curvature indicates the surface is upwardly convex at that cell. A negative curvature indicates the surface is upwardly concave at that cell. A value of zero indicates the surface is flat. |
| Plan curvature | Derived from the DEM; provides information on whether water/runoff converges or diverges across the pixel/cell. In the plan output, a positive value indicates the surface is upwardly convex at that cell. A negative value indicates the surface is upwardly concave at that cell. A value of zero indicates the surface is flat. |
| Profile curvature | Derived from the DEM; provides information on whether the cell is most likely to be eroded by water or whether water will run off to the sides. In the profile output, a value of zero indicates the surface is flat while positive and negative values indicate concave or convex surfaces. |
| Average summer precipitation | Derived from the PRISM dataset, averaging monthly precipitation for June, July, and August |
| Average winter precipitation | Derived from the PRISM dataset, averaging monthly precipitation for December, January, February |
| Maximum temperature June | Derived from the PRISM dataset |
| Maximum temperature July | Derived from the PRISM dataset |
| Maximum temperature August | Derived from the PRISM dataset |
| Minimum temperature December | Derived from the PRISM dataset |
| Minimum temperature January | Derived from the PRISM dataset |
| Minimum temperature February | Derived from the PRISM dataset |
| Growing season length | Obtained from SNAP dataset (http://www.snap.uaf.edu/gis-maps) |

## 4. Distribution modeling

MaxEnt version 3.3.2b (Phillips et al. 2006) was used to model the potential distributions of the North Slope's rare plant species. A recent comparison of methods for niche-based modeling of species' potential ranges identified MaxEnt as among the best approaches currently available in terms of predictive performance (Elith et al. 2006, 2011). This distribution modeling program uses presence-only species occurrence records (i.e. latitudes and longitudes of known species locations) and environmental data (i.e. GIS layers). In general, the MaxEnt approach seeks to estimate an unknown distribution using incomplete information about distribution and a given set of constraints. For modeling species' potential geographical ranges, the occurrence data are considered to be the incomplete sample of a larger, unknown geographical distribution, and the environmental data are used as constraints (Dudik et al. 2004; Phillips et al. 2006).

At each level of the modeling analysis, 10 random partitions of the point localities were created with 60% of the geographic points used for model training and 40% for model testing. For each model run, 10,000 background pixels were selected at random as 'pseudo-absences.' The maximum number of iterations was 500, the convergence threshold was set to $10^{-5}$, and regularization was set to 'auto,' a setting which allows MaxEnt to automatically adjust the amount of regularization based on the input locality and environmental data (Phillips et al. 2006).

To evaluate overall model performance, we used the area under the receiver operating characteristic curve (AUC) of the training and test data. The receiver operating characteristic curve measures a model's ability to correctly predict presence and absence, and the resulting AUC statistic can be interpreted as the probability that a presence site is ranked above a random background site (Phillips et al. 2006; Phillips & Dudik 2008). Area under the curve (AUC) scores can range from 0 to 1.0, with a random prediction scoring 0.5. We used a one-tailed Wilcoxon rank sum test to determine if model performance was higher than that of random prediction (0.5).

The spatial accuracy of model predictions of individual species was assessed using threshold-dependent tests. The omission/commission analyses provided by MaxEnt were also used to select species for further analysis. Species' whose modeled distributions had omission rates close to the predicted omission rate, and where the training and test data omission rates were also relatively similar, were advanced to the next stage of analysis. Discontinuity between training and test datasets can be due to non-independence of the datasets as a result of spatial autocorrelation in presence sites. The final MaxEnt logistical outputs were reclassified into probability classes of (0-20%, >20%-50%, >50%-70%, >70%-80%, 80%-90%, >90%). The habitat suitability maps provided here only show areas in which the habitat is similar to the predicted optimal habitat derived from the model (in this case, habitat suitability >70%). Note that MaxEnt does not calculate "probability of occurrence" directly. The output maps are presented in colors that are used to illustrate predicted probability that conditions are suitable, with red indicating the highest probability of suitable conditions for the species, yellows indicating conditions typical of those where the species is found, and the background map is visible where conditions are deemed "unsuitable."

# Results

Thirty-two vascular plant taxa were identified as rare within the Arctic Tundra Ecoregion of Alaska (Table 2). Of this total, all taxa are considered critically imperiled to rare on a statewide basis, 15 taxa are considered sensitive by the BLM, 11 are on the BLM watch list, and eight have documented occurrences within the NPR-A. Species descriptions and occurrence maps are taken from the Alaska Rare Plant Field Guide (Nawrocki et al. 2013). Habitat suitability maps were produced for eight taxa that met rarity and occurrence record criteria and for which good threshold and AUC values were obtained. No 60 meter pixel in which more than one rare species had a predicted habitat suitability value greater than 70% were found.

**Table 2. Conservation status and known occurrence of rare vascular plant taxa within Alaska's Arctic Tundra Ecoregion. Taxa in bold were selected for distribution modeling; occurrence counts are current as of 2009.**

| Species name | Global Conservation Status | State Conservation Status | BLM Designation[3] | Number of occurrences: NPR-A[4] | Number of occurrences: Arctic Tundra Ecoregion | Likelihood of occurrence: Arctic Tundra Ecoregion[5] |
|---|---|---|---|---|---|---|
| *Cardamine microphylla* aff. *microphylla* | G3G4 | S2 | WATCH | | 3 | |
| *Carex atherodes* | G5 | S3S4 | | | 1 | |
| *Carex heleonastes* | G4 | S3 | WATCH | | 1 | |
| *Carex holostoma*[1] | G4 | S4 | | | 5 | |
| *Draba micropetala* | NR | S1S2 | SENSITIVE | | 7 | |
| ***Draba pauciflora*** | G4 | S2 | SENSITIVE | 1 | 7 | |
| ***Draba subcapitata*** | G4 | S1S2 | WATCH | | 4 | |
| *Erigeron muirii* | G2G3 | S2S3 | SENSITIVE | | 16 | |
| *Erigeron ochroleucus* | G5 | S1S2 | WATCH | | 2 | |
| *Erigeron porsildii* | G3G4 | S3S4 | WATCH | | 5 | |
| *Festuca edlundiae* | G3G4 | S1 | WATCH | | 2 | |
| ***Koeleria asiatica*** | G4 | S3 | SENSITIVE | 11 | 23 | |
| ***Mertensia drummondii*** | G2G3 | S2 | SENSITIVE | 9 | 16 | |
| *Oxygraphis glacialis* | G4G5 | S3 | WATCH | 2 | 5 | |
| *Oxytropis tananensis* | GNR | S3S4Q | WATCH | | 1 | |
| ***Papaver gorodkovii*** | G3 | S2S3 | SENSITIVE | | 8 | |
| *Pedicularis hirsuta* | G5? | S1 | SENSITIVE | | 1 | |
| ***Pleuropogon sabinei*** | G4G5 | S1S2 | SENSITIVE | 2 | 4 | |
| ***Poa hartzii* ssp. *alaskana*** | G3G4T1T2 | S1S2 | SENSITIVE | 4 | 5 | |
| *Potentilla stipularis* | G5 | S2 | SENSITIVE | | 4 | |
| ***Puccinellia vahliana*** | G4 | S3 | WATCH | | 11 | |
| *Puccinellia wrightii* ssp. *wrightii* | G3G4TNR | S3 | SENSITIVE | 1 | 3 | |
| *Ranunculus camissonis* | GNR | S3 | SENSITIVE | | 3 | |
| *Ranunculus sabinei* | G4 | S1 | WATCH | | 6 | |
| *Rumex aureostigmaticus*[2] | GNR | S1 | | 1 | 7 | |
| *Rumex krausei* | G2 | S2S3 | SENSITIVE | | 6 | |
| *Saxifraga aizoides* | G5 | S1 | | | 1 | X |
| *Saxifraga rivularis* ssp. *arctolitoralis* | G5T2T3 | S2 | | | 4 | X |
| *Smelowskia media* | GNR | S2S3 | WATCH | | 5 | |
| *Stellaria umbellata* | G5 | S3S4 | | | 6 | X |
| *Symphyotrichum pygmaeum* | G2G4 | S2 | SENSITIVE | | 3 | |
| *Trisetum sibiricum* ssp. *litorale* | G5T4Q | S3 | SENSITIVE | | 5 | |

Notes:
[1] Taxon has been removed from the rare plant list as it is under-collected, yet common.
[2] Taxon was previously referred to as *Rumex graminifolius* and included material now considered to be other species.
[3] Sensitive designation - Native species that occur on BLM lands, either have a known or predicted downward decline or depend on threatened habitat, and for which the BLM has significant management capability to affect their conservation status.

Watch designation - Native species that currently lack sufficient data to satisfy the criteria for listing as a BLM Sensitive species but that should be re-evaluated in the future when more data is available.
[4] Although some species occur very close to NPR-A, this designation requires that species are located within the borders of the BLM-administered area.
[5] As suggested by Alaskan botanists, not through distribution modeling.
G1 Critically imperiled; at very high risk of extinction because of extreme rarity, very steep declines, or other factors.
G2 Imperiled; at high risk of extinction because of very restricted range, few occurrences, small populations, steep declines, or other factors.
G3 Vulnerable; at moderate risk of extinction because of restricted range, relatively few occurrences, small populations, recent and widespread declines, or other factors.
G4 Apparently secure but uncommon; some cause for long-term concern because of declines or other factors.
G5 Secure; common, widespread, and abundant.
S1 Critically imperiled within the state; at very high risk of extirpation because of very few occurrences, declining populations, or extremely limited range and/or habitat.
S2 Imperiled within the state; at high risk of extirpation because of few occurrences, declining populations, limited range, and/or habitat.
S3 Rare within the state; at moderate risk of extirpation because of restricted range, narrow habitat specificity, recent population decline, small population sizes, and/or a moderate number of occurrences.
S4 Apparently secure but uncommon within the state; may be a long-term conservation concern.
S5 Secure and widespread within the state; not at risk for extirpation because of widespread abundance.
T Indicates the global rank of a subspecies or variety and is appended to the end of the G rank for the species.
Q Taxon is questionable or uncertain as currently defined but records assigned to that taxon are not questionable.
? Inexact numeric rank reflecting inexact data.
NR Rank not yet assessed.

## *Draba pauciflora* R. Brown

The rare forb *Draba pauciflora* and its habitat. Images used with permission from Bjørn E. Sandbakk 2008.

**Family:** Brassicaceae
**Global Distribution:** Circumpolar high arctic
**Alaska Distribution:** Arctic Tundra
**Ecoregions Occupied:** Beaufort Coastal Plain, Brooks Range
**Conservation Status:** S2 G4; BLM Sensitive
**General Description:** Perennial herb from branched or unbranched caudex sparsely covered by persistent leaf remains; stems unbranched, leafless, 1 to 8 cm tall, pubescent with simple hairs and 2- to 4-rayed hairs
**Habitat:** Near sea level to 1,400 m in Alaska; beach ridges, polygon tundra, polygon troughs, alpine slopes

Figure 2. Known occurrences of *Draba pauciflora* in Alaska

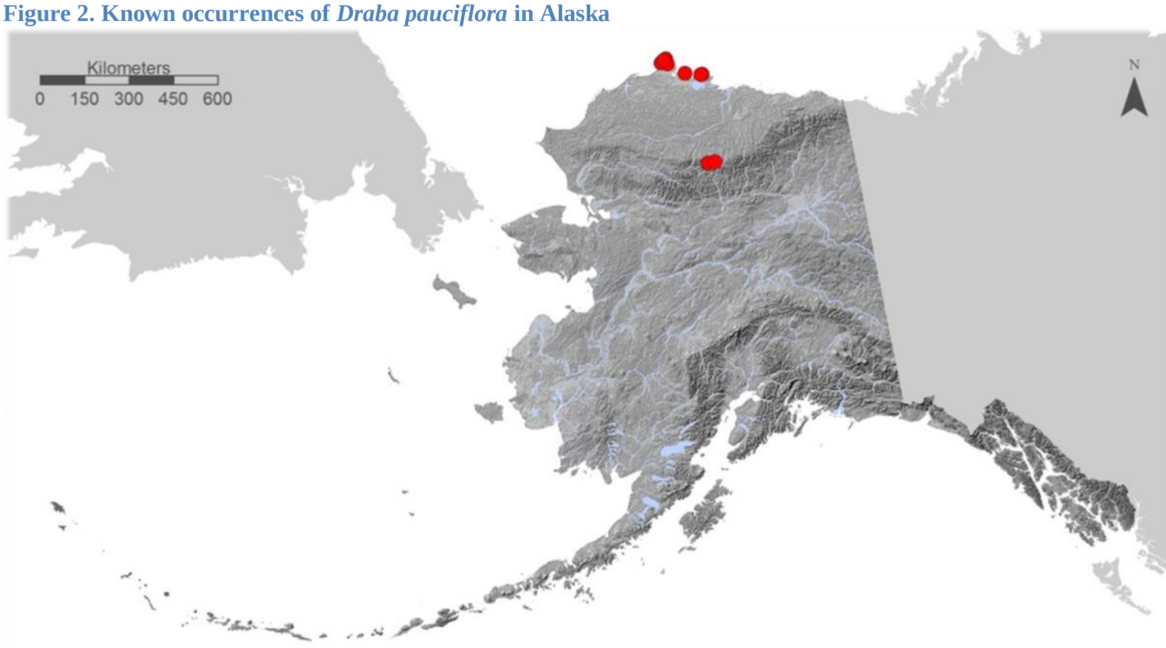
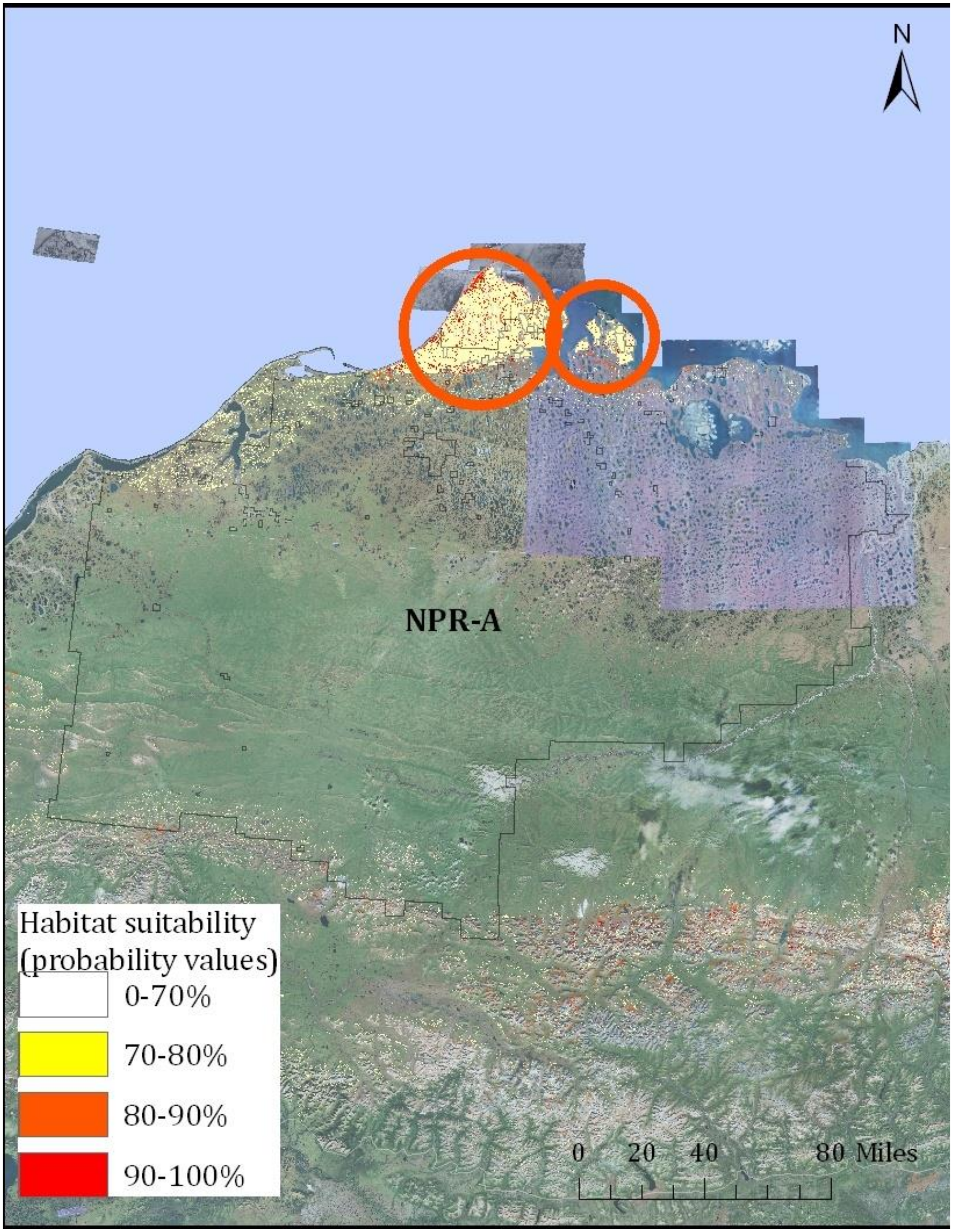


**Figure 3. Distribution of suitable habitat for *Draba pauciflora* in the National Petroleum Reserve-Alaska – areas of highest predicted suitability are highlighted by orange circles.**



## ***Draba subcapitata*** Simmons

The rare forb *Draba subcapitata* and its habitat. Images used with permission from Bjørn E. Sandbakk 2008.

**Family:** Brassicaceae
**Global Distribution:** Circumpolar high arctic
**Alaska Distribution:** Arctic Tundra
**Ecoregions Occupied:** Beaufort Coastal Plain
**Conservation Status:** S1S2 G4; BLM Watch
**General Description:** Perennial herb, caespitose or cushion-forming, from a branched caudex covered in persistent leaf remains, branches sometime terminating in sterile rosettes; stems unbranched, leafless, 0.7 to 5 cm tall, pubescent throughout or rarely glabrous at the top with simple hairs and 2-rayed hairs
**Habitat:** Known from sea level to 20 m in Alaska; coastal bluffs, river bars, pingos, hummocks

Figure 4. Known occurrences of *Draba subcapitata* in Alaska.

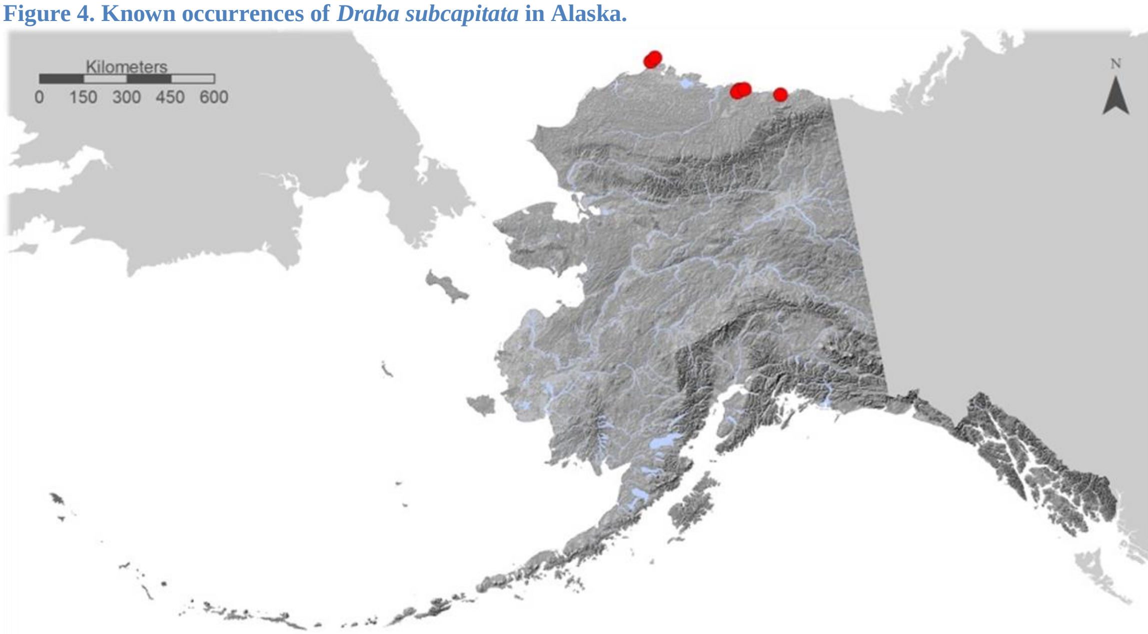
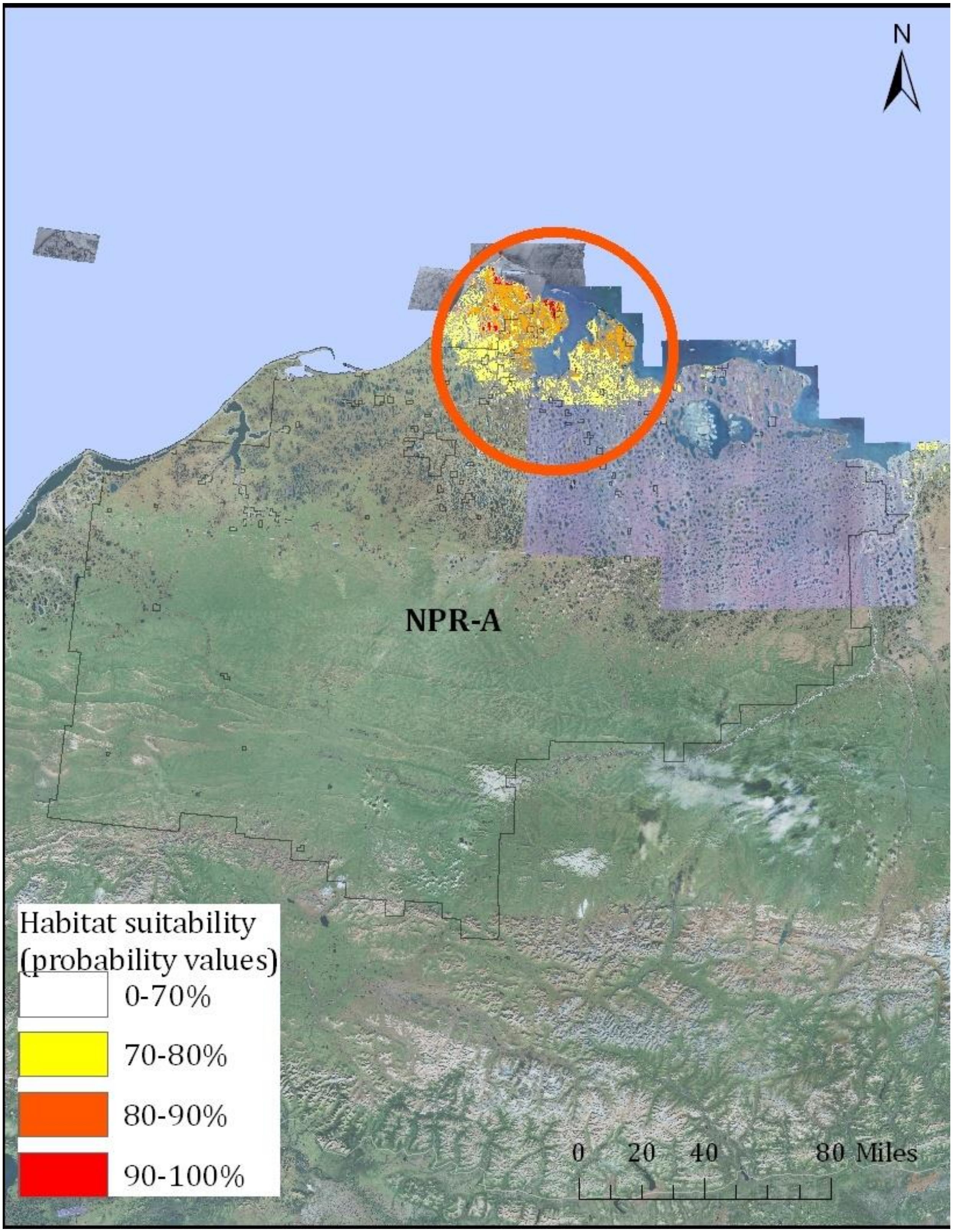


**Figure 5. Distribution of suitable habitat for *Draba subcapitata* in the National Petroleum Reserve-Alaska– areas of highest predicted suitability are highlighted by the orange circle.**



# *Koeleria asiatica* Domin

**The rare grass, *Koeleria asiatica* and its habitat. Images used with permission from Michael Oldman 2006.**

**Family:** Poaceae
**Global Distribution:** North Asia from Ural Mountains through Chukotka Peninsula to Alaska and Yukon
**Alaska Distribution:** Arctic Tundra, Bering Tundra, Bering Taiga
**Ecoregions Occupied:** Beaufort Coastal Plain, Brooks Foothills, Bering Sea Islands, Nulato Hills
**Conservation Status:** S3 G4; BLM Sensitive
**General Description:** Perennial grass, loosely tufted from short rhizomes; culms 5 to 35 cm tall, densely and finely pubescent
**Habitat:** Known from near sea level to 600 m in Alaska; river terraces, river bluffs, river banks, river bars, sand dunes, tundra, alpine slopes, lake shores

**Figure 6. Known occurrences of *Koeleria asiatica* in Alaska.**

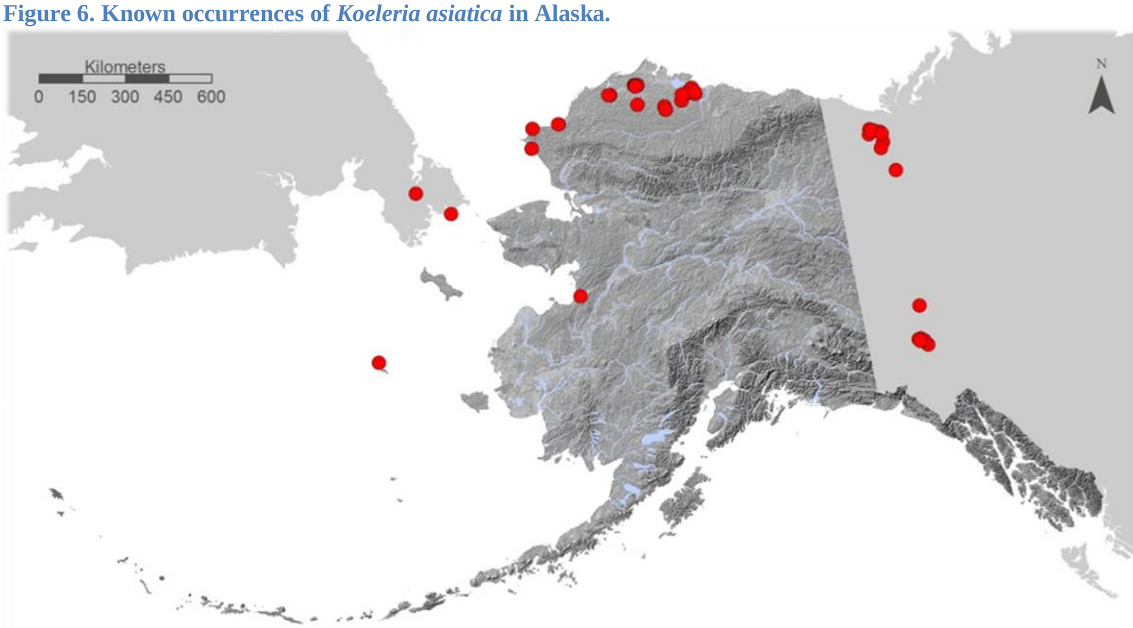
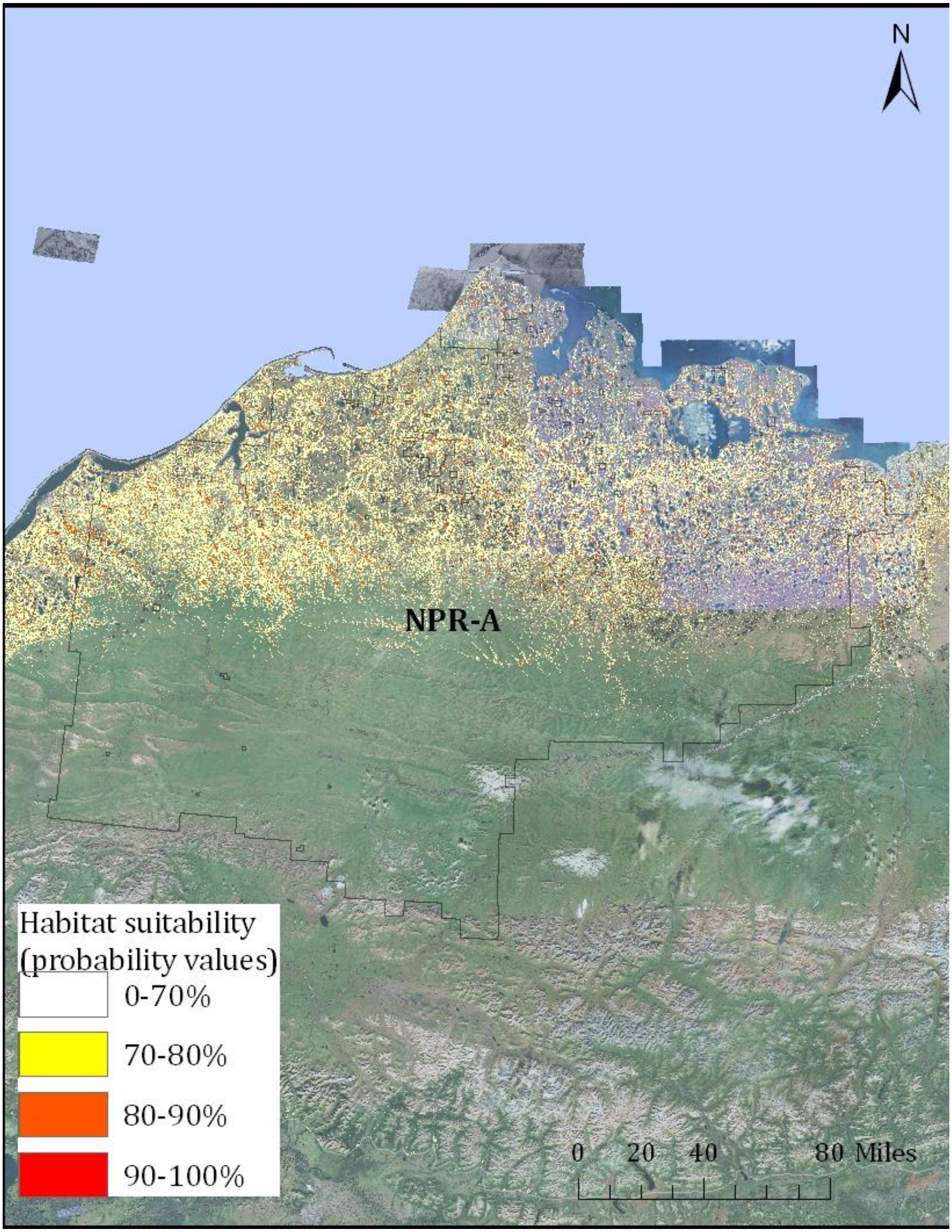


**Figure 7. Distribution of suitable habitat for *Koeleria asiatica* in the National Petroleum Reserve-Alaska.**



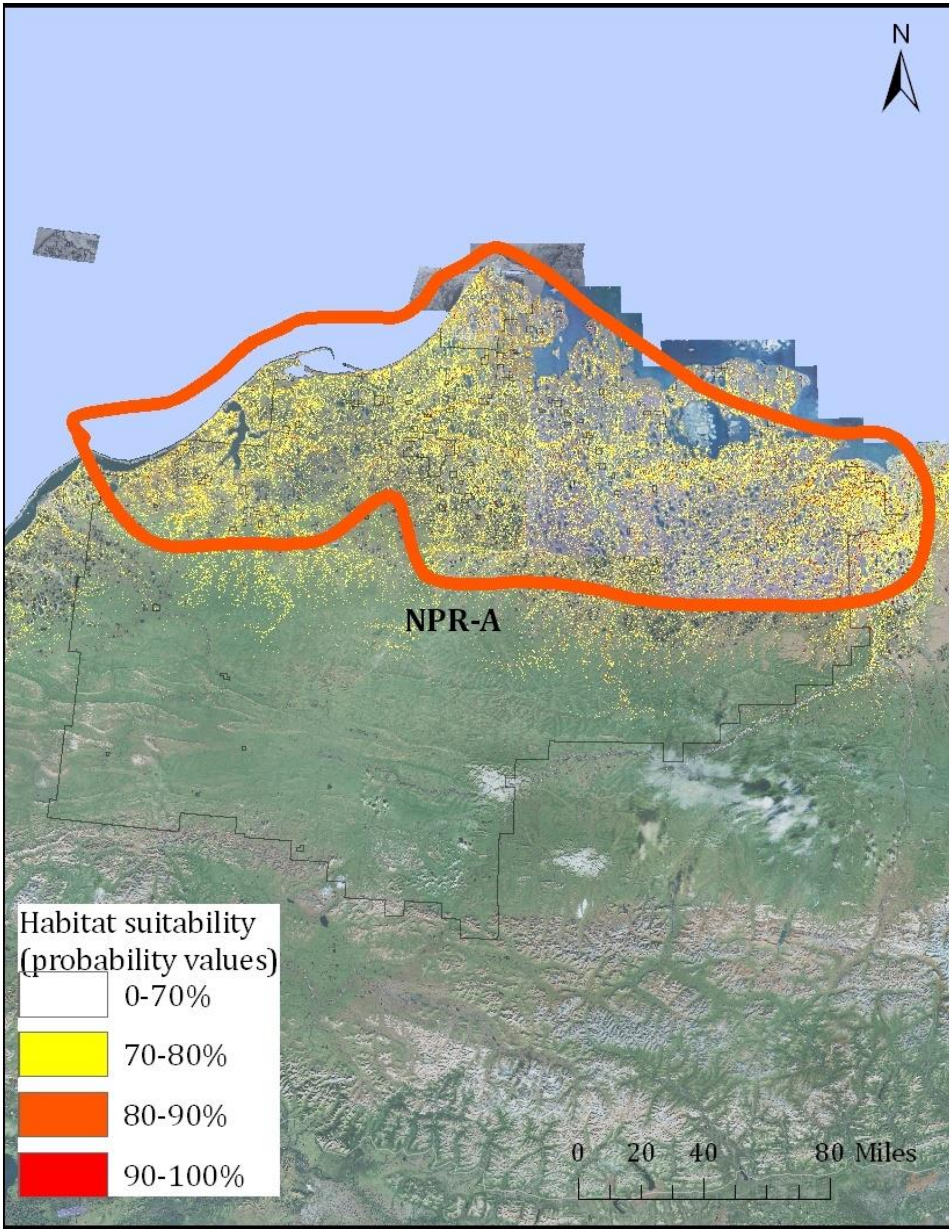
## *Mertensia drummondii* (Lehm.) G. Don

The rare forb *Mertensia drummondii* and its habitat. Images used with permission from Jo Overholt 1997.

**Family:** Boraginaceae
**Global Distribution:** Endemic to arctic Alaska, Northwest Territories, and Nunavut (Victoria Island)
**Alaska Distribution:** Arctic Tundra
**Ecoregions Occupied:** Beaufort Coastal Plain (Meade and Kogosukruk Rivers), barely extending into Brooks Foothills
**Conservation Status:** S2 G2G3; BLM Sensitive
**General Description:** Perennial forb from a slender taproot; caudex dark brown, simple or many-branched; plants 7 to 15 cm tall, sometimes forming clumps up to 50 cm wide; stems erect, ascending or trailing
**Habitat:** 8 m to 95 m in Alaska in active sand areas, including blowouts and dunes, near rivers but not sea shores

Figure 8. Known occurrences of *Mertensia drummondii* in Alaska

**Figure 9. Distribution of suitable habitat for *Mertensia drummondii* in the National Petroleum Reserve-Alaska– areas of highest predicted suitability are highlighted by the orange polygon.**



# *Papaver gorodkovii* Tolmatchew & Petrovsky

The rare forb *Papaver gorodkovii* on Nunivak Island, Alaska. Image used with permission from M.L. Carlson 2013.

**Family:** Papaveraceae
**Global Distribution:** Amphi-Beringian; also reported but not confirmed from Canadian Arctic Archipelago.
**Alaska Distribution:** Arctic Tundra, Bering Tundra.
**Ecoregions Occupied:** Beaufort Coastal Plain, Brooks Foothills, Brooks Range, Bering Sea Islands (reported but not confirmed from Seward Peninsula)
**Conservation Status:** S2S3 G3; BLM Sensitive
**General Description:** Perennial herb, tufted; caudex covered with persistent leaf bases.
**Habitat:** Known from near sea level to 1,060 m in Alaska; river floodplains, gravel bars, rock outcrops, polygon tundra

igure 10. Known occurrences of *Papaver gorodkovii* in Alaska.

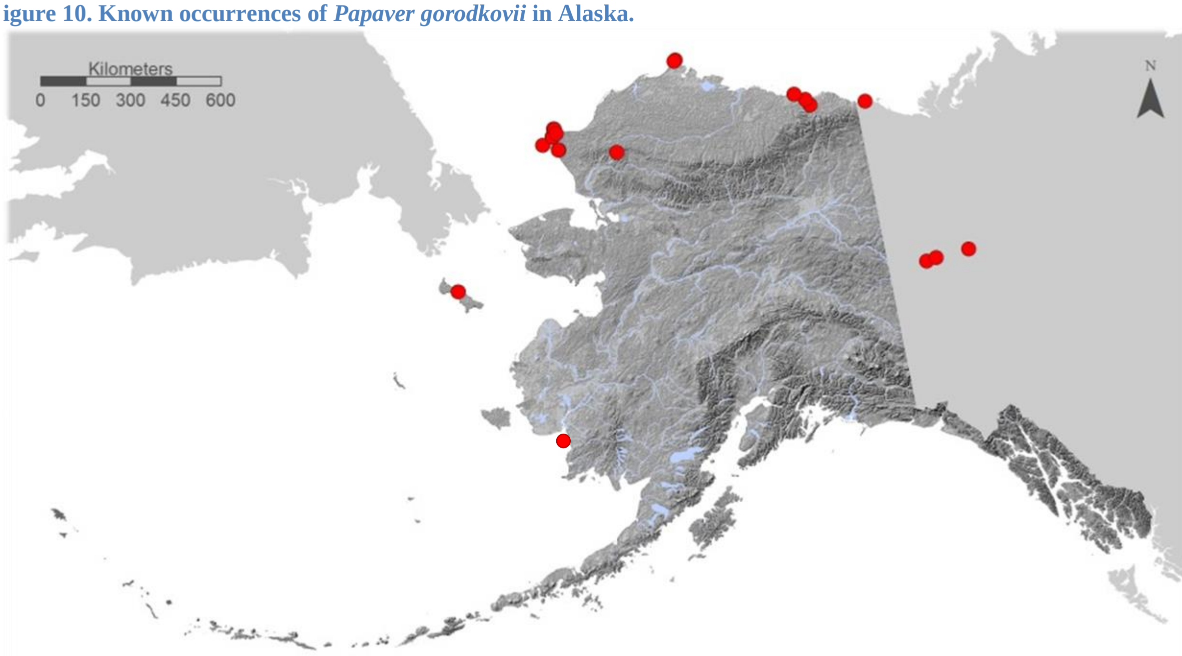
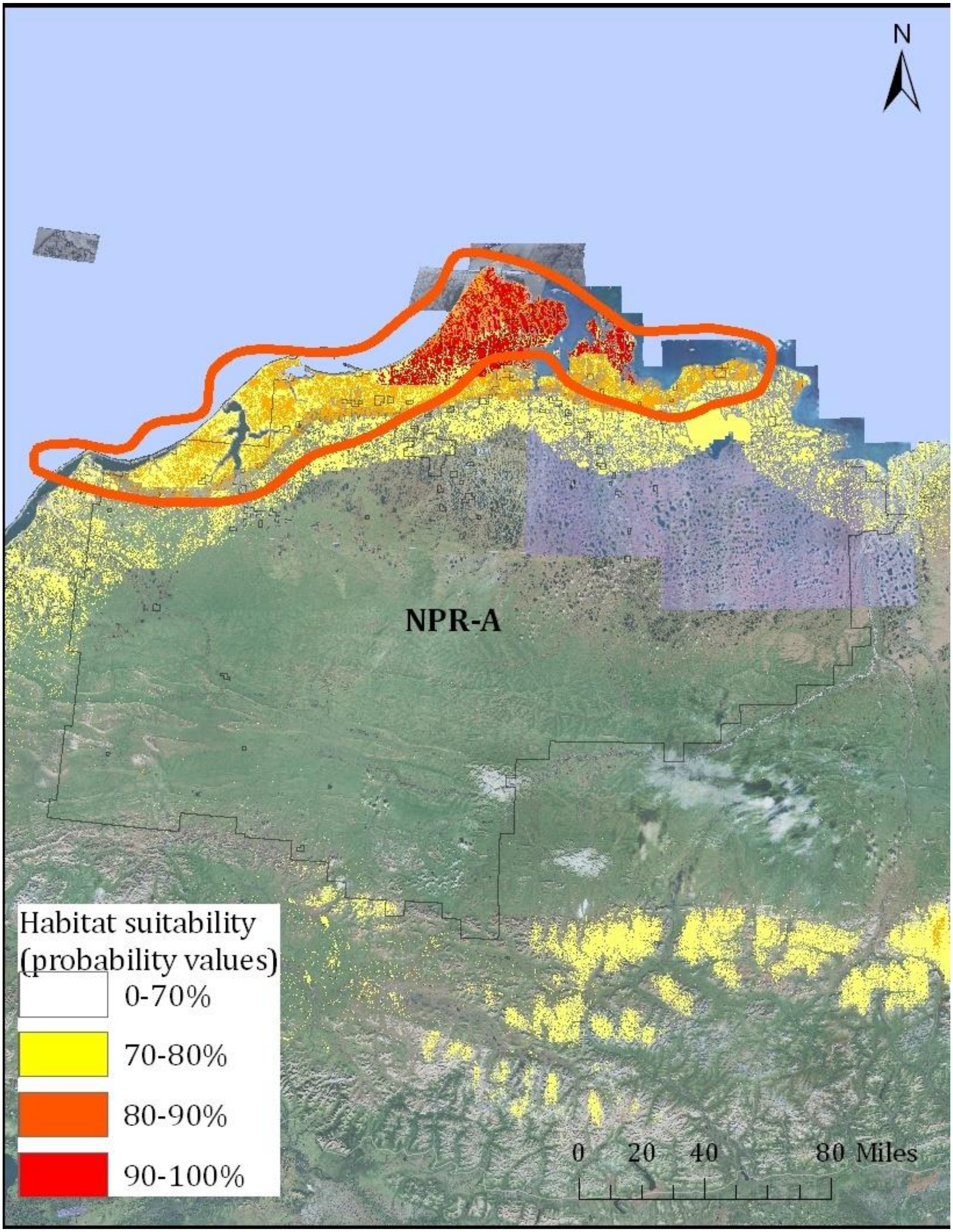


**Figure 11. Distribution of suitable habitat for *Papaver gorodkovii* in the National Petroleum Reserve-Alaska– areas of highest predicted suitability are highlighted by the orange polygon.**



## *Pleuropogon sabinei* R. Br.

**The rare grass *Pleuropogon sabinei* and its habitats. Images used with permission from Robert Soreng and Gier Arnesen 2005.**

**Family:** Poaceae
**Global Distribution:** Circumpolar
**Alaska Distribution:** Arctic Tundra
**Ecoregions Occupied:** Beaufort Coastal Plain; a questionable report from the Seward Peninsula is not included here
**Conservation Status:** S1S2 G4G5; BLM Sensitive
**General Description:** Perennial grass from rhizomes, not tufted; culms 4 to 35 cm tall, 1 to 3 mm wide, erect to decumbent
**Habitat:** Known from near sea level in Alaska; known from up to 700 m on Ellesmere Island in the Canadian Arctic Archipelago; lakeshores, stream banks, river banks, floodplains, marshes, mud flats; always found close to bodies of water

**Figure 12. Known occurrences of *Pleuropogon sabinei* in Alaska.**

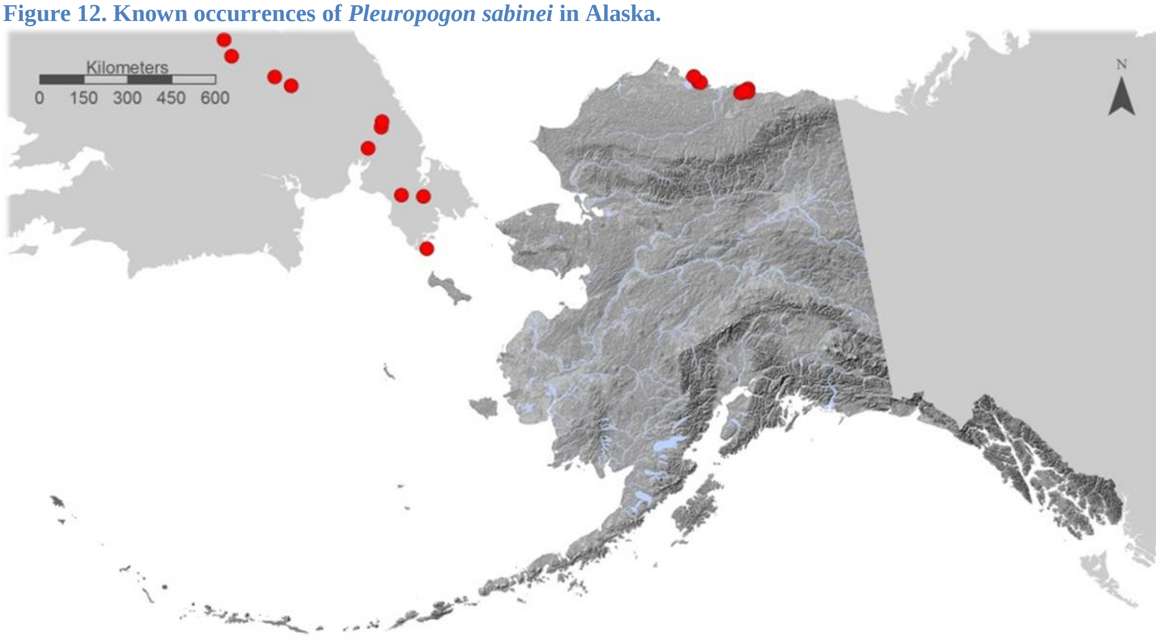
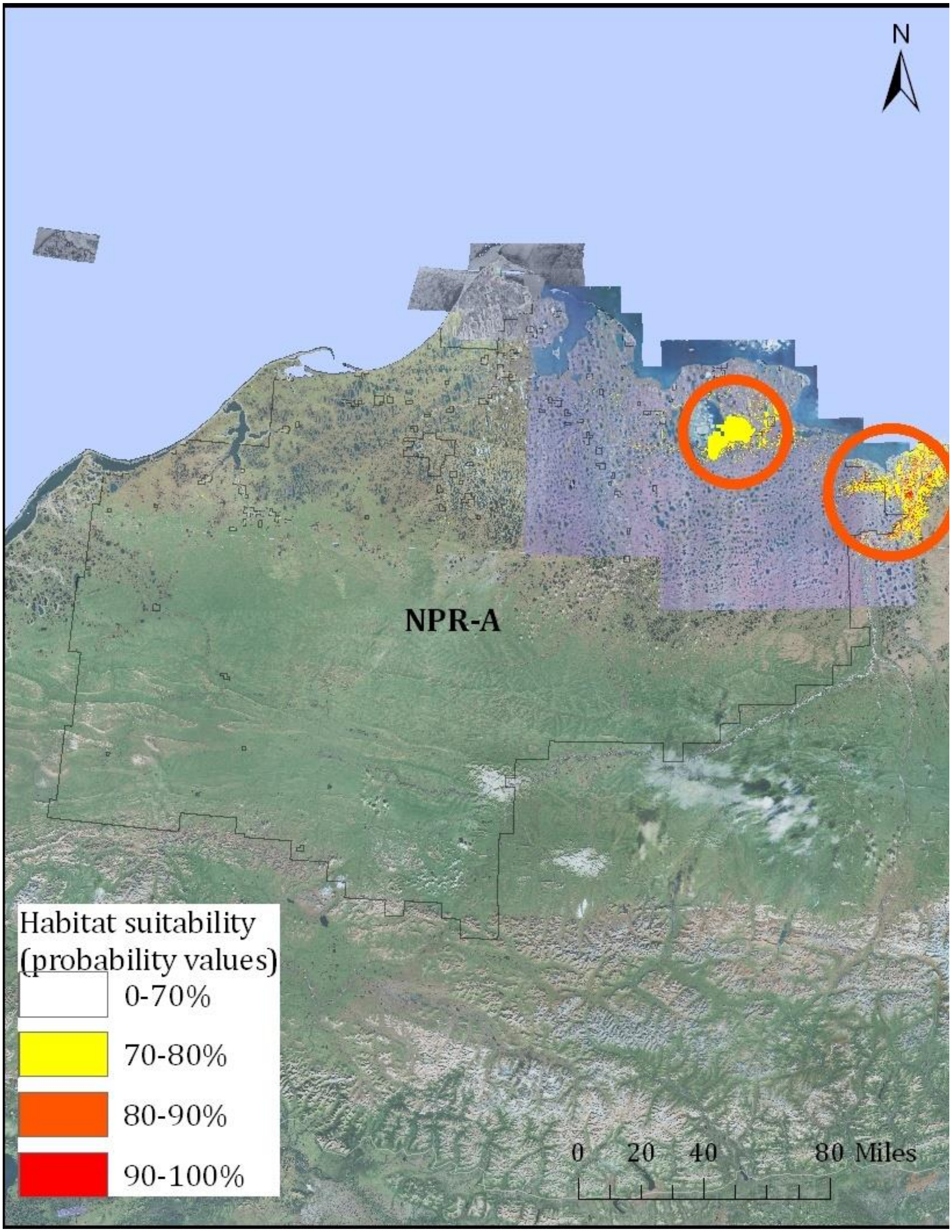


**Figure 13. Distribution of suitable habitat for *Pleuropogon sabinei* in the National Petroleum Reserve-Alaska– areas of highest predicted suitability are highlighted by orange circles.**



## ***Poa hartzii* ssp. *alaskana*** Soreng

**The rare grass *Poa hartzii* ssp. *alaskana* and its habitat. Images used with permission from Rob Lipkin 1997.**

**Family:** Poaceae
**Global Distribution:** Endemic to arctic Alaska
**Alaska Distribution:** Arctic Tundra
**Ecoregions Occupied:** Beaufort Coastal Plain, Brooks Range
**Conservation Status:** S1S2 G3G4T1T2; BLM Sensitive
**General Description:** Perennial grass, loosely tufted; culms 20 to 45 cm tall, usually decumbent; bases of leaves and culms distinctly red or red-purple
**Habitat:** Usually occurs from near sea level to 20 m; known from up to 860 m in the eastern Brooks Range; river bars, floodplains, active sand dunes

**Figure 14. Known occurrences of *Poa hartzii* ssp. *alaskana* in Alaska.**

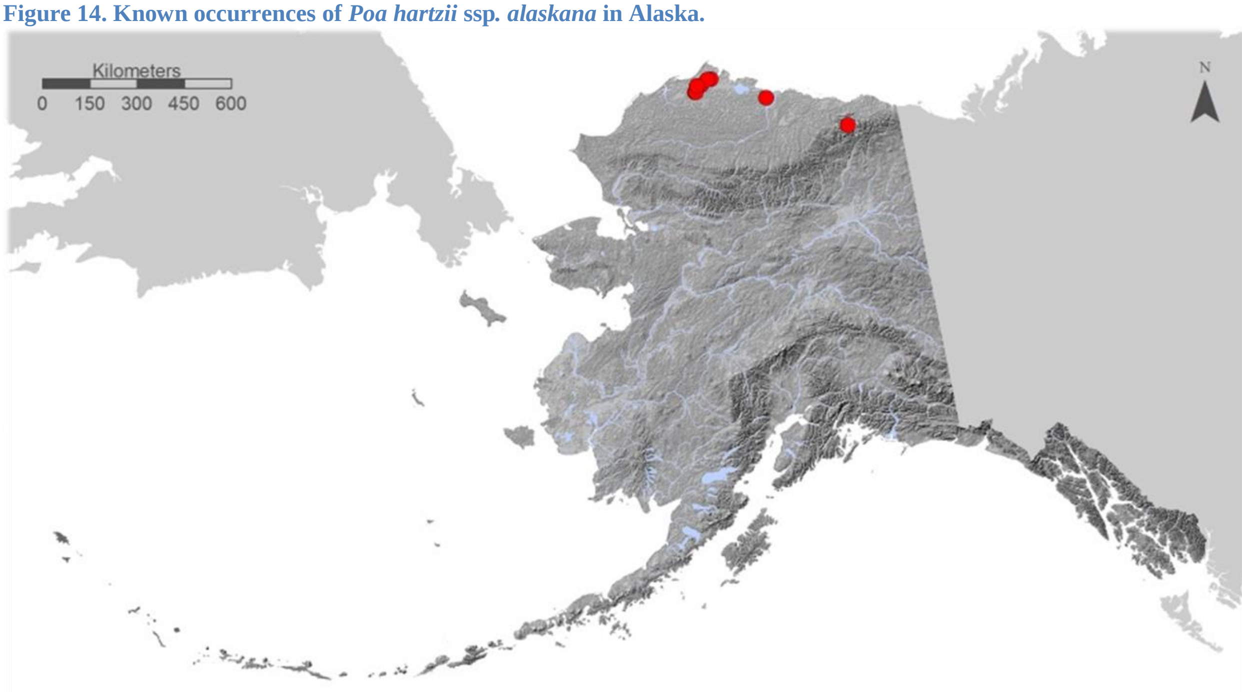
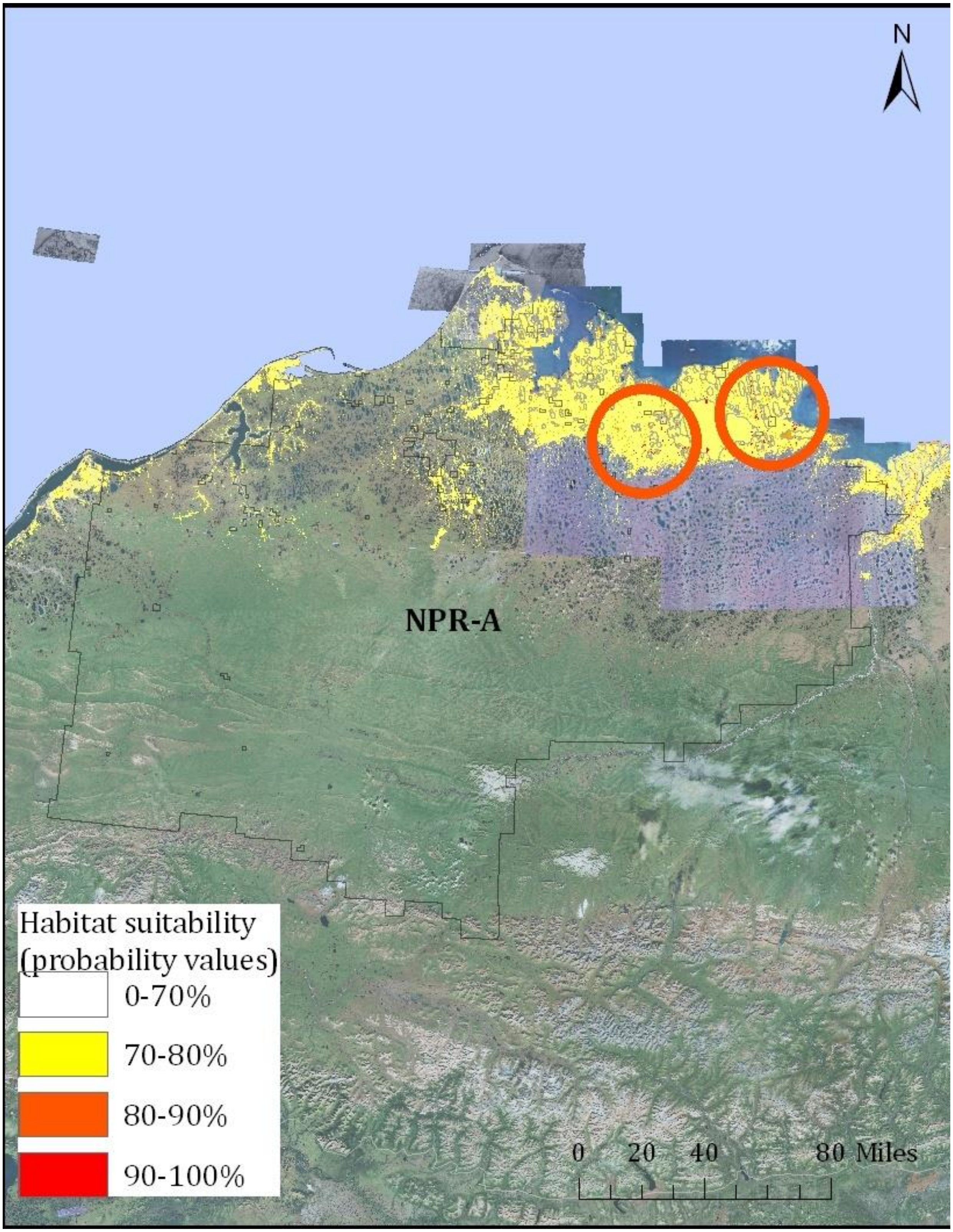


**Figure 15. Distribution of suitable habitat for *Poa hartzii* ssp. *alaskana* in the National Petroleum Reserve-Alaska– areas of highest predicted suitability are highlighted by orange circles.**



## *Puccinellia vahliana* (Liebm.) Scribn. & Merr.


The rare grass *Puccinellia vahliana* and its habitat. Images used with permission from Robert Soreng and Bruce Bennett 2005.

**Family:** Poaceae
**Global Distribution:** Alaska through northern Canada to Greenland, Svalbard, Franz Josef Land, and Novaya Zemlya
**Alaska Distribution:** Arctic Tundra, Bering Tundra, Alaska Range Transition, Coastal Mountains Transition
**Ecoregions Occupied:** Beaufort Coastal Plain, Brooks Range, Kotzebue Sound Lowlands, Alaska Range, Kluane Ranges
**Conservation Status:** S3 G4; BLM Watch
**General Description:** Perennial, tufted grass, not mat-forming, from thick, curled roots; stems erect, 5 to 15 cm tall
**Habitat:** Known from near sea level to 1,920 m in Alaska; alpine slopes, alpine ridges, frost-boils, high-center polygons, pingos, beaches, fens; pond edges and stream banks in dune areas

Figure 16. Known occurrences of *Puccinellia vahliana* in Alaska.

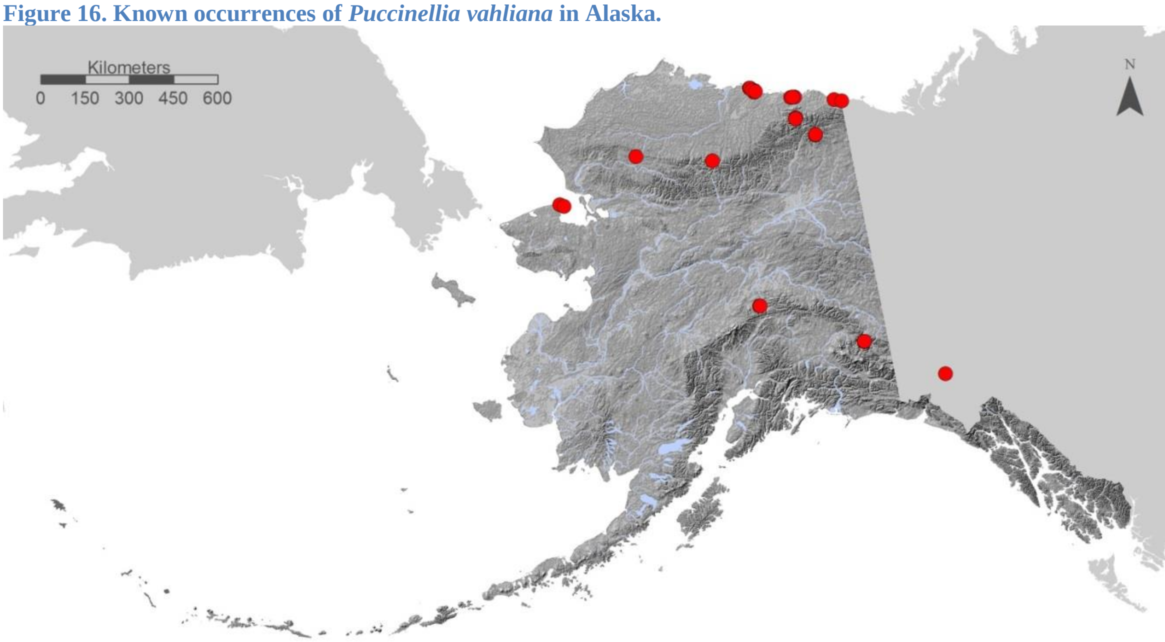
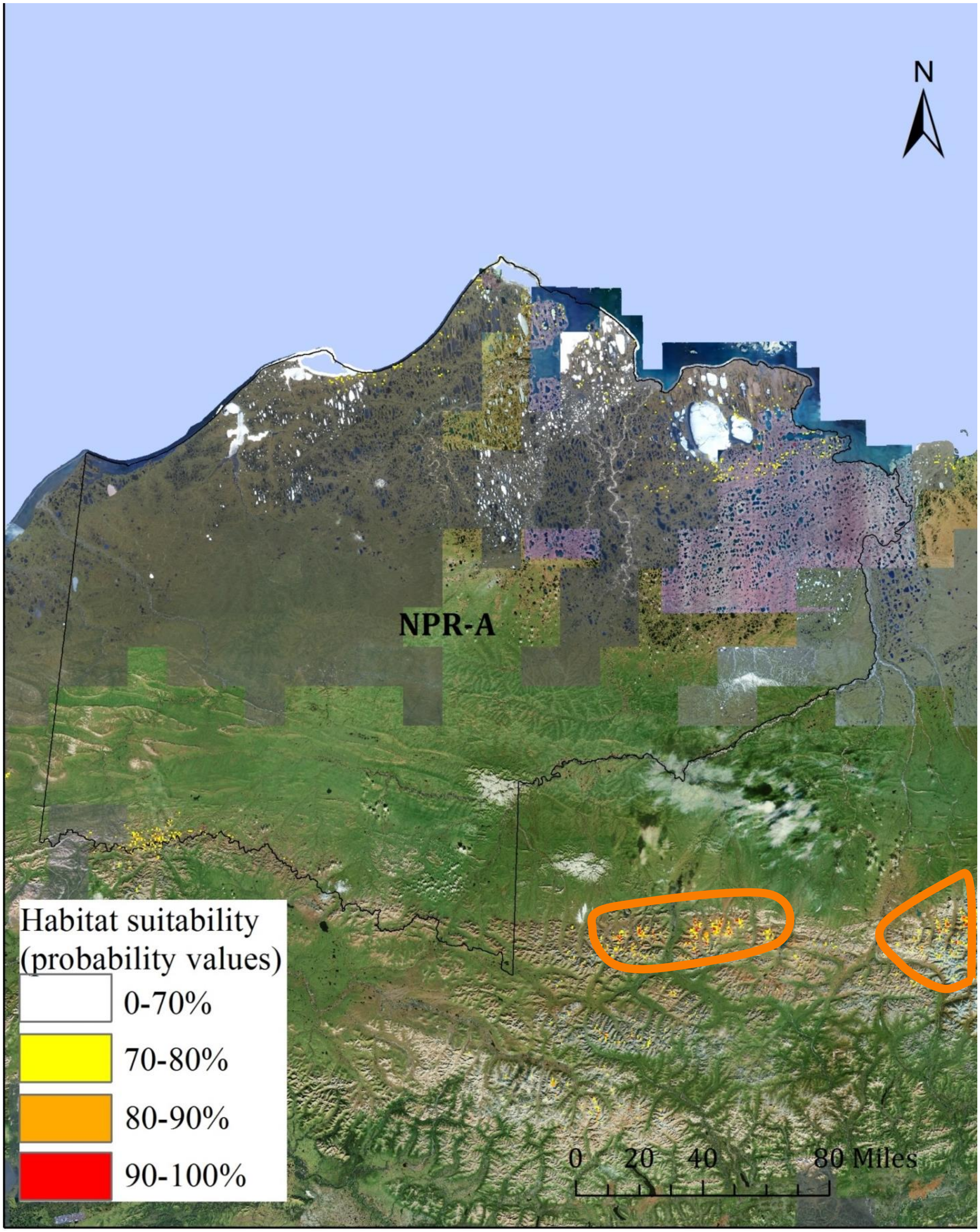


**Figure 17. Distribution of habitat suitability for *Puccinellia vahliana* on the North Slope, Alaska – areas of highest predicted suitability are highlighted by orange polygons.**



## Discussion

The ecological niche models presented here indicate that suitable habitat may exist for rare plant species outside of their known locations within the NPR-A, and more broadly across the Arctic Tundra Ecoregion. The models generated reliable outputs, based on high AUC values, strong continuity between training and test datasets, and the variable distribution of habitat predicted among species. In the case of both *Draba* species, *Pleuropogon sabinei*, and *Puccinellia vahliana*, however, the predicted distributions appear to be over-fit to known occurrence points. This over-fitting likely results from the few and clustered known locations for *D. subcapitata* (four sites), *D. pauciflora* (seven sites) and *P. sabinei* (four sites), which tends to restrict the suite of environmental values associated with these sites and therefore limits the model's ability to draw inference outside of similar habitat. *Puccinellia vahliana* is known from a substantial number of sites (11) across the eastern Arctic Tundra Ecoregion, and therefore model over-fitting is less likely responsible for the highly restricted distribution to the most northerly high elevation mountains in the Brooks Range. The high probability areas identified for this species would be an appropriate initial step for future surveys.

Although the distribution of habitat predicted to be suitable varies among species; models for three species showed some overlap. The most suitable habitat for *Draba pauciflora*, *D. subcapitata*, and *Papaver gorodkovii*, all co-occurred in the most northerly area of the North Slope, between Pt. Belcher and Cape Simpson. The model for *Papaver gorodkovii* suggests a greater region of suitable habitat extending along the coastal fringe, as well as suitable habitat at higher elevations in the Brooks Range and Foothills. These three species have discontinuous circumpolar distributions and are strongly associated with areas with very restricted growing seasons and are presumably more vulnerable to the direct and indirect impacts of increased growing season length. Species such as these, associated with the most northerly and coolest region of Alaska in the Point Barrow area, do not have clear dispersal corridors to track climate envelopes in the context of a rapidly warming Arctic region and may be cause for conservation concern. No data is present in population trends, ecology, nor experimental data on niche parameters, severely limiting our understanding of current and future vulnerabilities. *Draba subcapitata* and *Papaver gorodkovii* tend to be associated with exposed mineral soil (often at very small scales, unlikely to be included in GIS layers) and screening of appropriate habitat at finer geographic scales may only be possible while in the field.

Models for *Pleuropogon sabinei* and *Poa hartzii* ssp. *alaskana* indicated that only areas proximal to known locations had reasonable probabilities of harboring appropriate habitats. Recent floristic and plant ecology work within the NPR-A by AKNHP, which has resulted in floristic surveys of greater than 100 helicopter-accessed sites (approximately an acre in area), has not uncovered populations of these species outside of their known locations. Thus, *Pleuropogon sabinei* and *Poa hartzii* ssp. *alaskana* do indeed appear to have quite restricted distributions in NPR-A. *Poa hartzii* ssp. *alaskana* is a substrate specialist on sand dunes and its rarity is certainly tied to the uncommonness of this habitat. *Pleuropogon sabinei*, on the other hand, is associated with a wide variety of wetland habitats and it is unclear why it has such a restricted distribution on the Arctic Tundra Ecoregion. In contrast, species initially considered to be rare in Alaska, such as *Carex holostoma*, have been found to be much more common following AKNHP surveys and for this reason the species is no longer tracked as rare in Alaska.

Similar to *Poa hartzii* ssp. *alaskana*, *Koeleria asiatica* and *Mertensia drummondii* are also dune specialists; however, the models suggest a much more diffuse and broad range of potentially suitable habitat across the Arctic Coastal Plain and Brooks Range Foothills. This somewhat unexpected distribution reiterates the importance of including substrate information in analysis to better refine the ecological niche space of these species. Populations of these species typically are associated with large substrate features (unlike *Draba subcapitata* and *Papaver gorodkovii*) that are more likely to be included in GIS layers and therefore could be modeled. Regardless, the broad spatial extent of modeled suitable habitat suggests that the distribution of these species is not strongly tied to the degree of climate variation found within the study area currently. It is noteworthy, however, that habitat and climate modeling at the statewide-level for current and future climate scenarios resulted in a distribution with dramatically reduced suitable habitat for both of these species, with effectively no suitable habitat for *Mertensia drummondii* by 2060 (Carlson and Cortés-Burns 2013). Thus, if these species are indeed directly or indirectly tied to current climatic conditions, populations may be vulnerable.

While the habitat suitability maps presented here can be used to direct botanical surveys and habitat management on a broad scale, the paucity of species locations and low accuracy of the data layers used for these analyses limits fine-scale interpretations, such as the identification of rare plant hotspots within the NPR-A. Further analysis incorporating additional species records and environmental layers would likely increase the locational accuracy of highly suitable habitat and enable more efficient and effective land management.

# Recommendations

The strength of future analyses, and consequently management decisions, could be improved by taking the following actions:

1. Search for additional rare plant observations in the area of interest that could strengthen the MaxEnt analyses.
2. Include substrate, bedrock geology, and plant community variables.
3. Identify which environmental variables best determine each species' modeled distribution.
4. Identify the most suitable habitat for each species modeled and compare with expert botanical knowledge.
5. Use experimental approaches to evaluate which ecological factors are most responsible for determining niche space.
6. Monitor population trends of the most at risk taxa.
7. Conduct future scenarios of alterations of land use and climate change on the distributions of rare plants.

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