# Modeling the Potential Distribution of Three Endemic Plants of the Northern Piceance and Uinta Basins

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U.S. Fish and Wildlife Service

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# INTRODUCTION

## Element distribution modeling

Land managers and owners are under increasing pressure to manage a variety of potentially conflicting resources. Understanding the potential distribution of rare and endemic species can be a key component in regulating and prioritizing different land-use scenarios. Species distribution modeling is one of many tools now available to assist managers in this complex process. Developing a predictive model of the distribution of a particular species can involve several different techniques, and be reported under a variety of names. All such models, however, are based on the ecological principle that the presence of a species on the landscape is controlled by a variety of biotic and abiotic factors, in the context of biogeographic and evolutionary history. Because we rarely, if ever, have complete and accurate knowledge of these factors and history, we can only seek to predict or discover suitable habitat by using characteristics of known occurrences of the taxon in question.

The modeling process is further constrained by our inability to measure habitat characteristics accurately on a continuous spatial scale. As a result, modeling factors are usually an approximation of the environmental factors that control species distribution, using available data that is probably only a surrogate for the actual controlling factors. In the context of our study, Element Distribution Modeling (EDM) is a process that uses a sample of a real distribution (known locations or element occurrences) to build a model (estimate) of suitable environmental conditions (and, by implication, unsuitable conditions), and map that model across a study area.

In this study we used two modeling approaches to investigate the potential distribution of three rare species: *Penstemon grahamii*, *Lesquerella congesta,* and *Physaria obcordata.* Both types of model used spatially referenced datasets of environmental variables (i.e., elevation, soil, geology, temperature, precipitation, and other factors). The envelope model (range-intersection or range model of Fertig 2002) was constructed by using the range of values for each environmental variable at known locations of the target elements. The DOMAIN model was developed through a computerized procedure that uses a point-to-point similarity metric to classify sites within the study area according to their proximity in environmental space to the most similar known location (Carpenter et al. 1993). Modeling techniques are further discussed under “Methods” below.

It is important to regard these models as hypotheses intended to be field tested, and not as definitive maps of suitable habitat. A variety of life-history and biogeographic factors may preclude the presence of the target element in areas of predicted suitable habitat. Likewise, errors or lack of precision in modeling assumptions, input data, or procedures may incorrectly predict suitable habitat where none exists. In addition, users should be aware that the true resolution of these distribution models is only as fine as the coarsest layer of input data (in this case 1 km-square cells). It is not appropriate to base land management decisions of 1-1000 m scale entirely on this analysis without additional field verification.

## Study elements

*Penstemon grahamii*

*Penstemon grahamii* Keck, the Uinta Basin beardtongue, is a diminutive member of the Scrophulariaceae or figwort family. The species was described by D.D. Keck in Graham (1937), from specimens collected in 1933 by Graham. The small plants have one to several stems up to 20 cm tall that rise from a basal rosette. The large showy flowers are tubular, light to deep lavender, with a golden-yellow densely bearded sterile stamen protruding from the opening. Flowering is from late May to early June.

Habitat is described as knolls, bluffs, ledges, benches, talus slopes, or dry washes in loose shale soils derived from the Evacuation Creek and Parachute Creek Members of the Green River Formation (CNE et al. 2002, Colorado Natural Heritage Program 2006, Utah Conservation Data Center 2006). The Evacuation Creek Member is described by Cashion (1973) as gray marlstone and yellow-brown siltstone and sandstone. In the Uinta Basin it is the uppermost member of the Green River Formation, lying below the Uinta Formation and above the Parachute Creek Member. The Parachute Creek Member consists of gray marlstone and dark-gray oil shale; some yellow brown sandstone, siltstone, and tuff (Cashion 1973). In digital geologic maps of the area, these two substrates are not separated from the larger Green River Formation.

*Penstemon grahamii* is currently known from 20 element occurrences (consisting of 95 distinct mapped polygons) along the southern margin of the Uinta basin in northeastern Utah and northwestern Colorado. Occurrences are known from Uintah, Duchesne, and Carbon counties in Utah, and from the western edge of Rio Blanco County in Colorado. The species is ranked G2 by NatureServe (2006), S2 by the Utah Conservation Data Center (2006), and S1 by the Colorado Natural Heritage Program (2006), indicating that it is imperiled both globally and in the two states, at high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.

*Lesquerella congesta*

*Lesquerella congesta* Rollins, the Dudley Bluffs bladderpod, is an herbaceous perennial member of the Brassicaceae (mustard family) that is endemic to northwestern Colorado. The species was described by Reed Rollins (1984) from specimens collected at North Dudley Gulch, Rio Blanco County, Colorado. The entire range as currently known lies within 10 miles of this type locality. Plants are small, cushion-shaped, up to 3 cm in diameter, with a congested mass of bright yellow flowers and silvery leaves rising from a long, thin taproot. Flowering is typically during April and May, and fruit set from late May into June.

*Lesquerella congesta* is believed to be more-or-less confined to outcrops of the Thirteenmile Creek Tongue of the Green River Formation. This formation is described by Hail and Smith (1994):

> [The] Thirteenmile Creek Tongue, which is one of the most widespread tongues of Green River Formation in northern part of Piceance Creek basin, consists of mostly light-gray to white, variably silty marlstone, smaller amounts of locally oolitic, ostracodal, and algal limestone, and some sandstone, siltstone, and

> claystone; it includes three or four thin oil-shale beds in the southern part of the outcrop area. Thickness of Thirteenmile Creek Tongue is about 20-200 ft (6.1-61m).

Hail and Smith (1994) included the Thirteenmile Creek Tongue as the lowermost part of their group C of tongues of the Uinta and Green River Formations. Reported habitat is described as barren white shale outcrops exposed along downcutting drainages. Known occurrences are concentrated in the Piceance Creek drainage near its intersection with Ryan Gulch, and in the Yellow Creek drainage to northwest, including the Duck Creek drainage. Group C and Group B of the Green River tongues are shown in Figure 1.

The Dudley Bluffs bladderpod was first listed on February 06, 1990, and is currently designated as Threatened under the Endangered Species Act. *Lesquerella congesta* is currently known from seven occurrences (consisting of 61 distinct mapped polygons) in the northern Piceance Basin in Rio Blanco County. The species is ranked G1S1, critically imperiled both globally and within the state, by the Colorado Natural Heritage Program (2006) and NatureServe (2006).

*Physaria obcordata*

*Physaria obcordata* Rollins, the Piceance Basin twinpod, is also a perennial member of the Brassicaceae. *Physaria obcordata* was described by Rollins (1983) from specimens collected by Baker and Naumann during a 1982 survey of the Piceance Basin. The specific epithet *obcordata* refers to the heart-shaped silique or fruit. Plants have flowering stems 12-18 cm tall that arise from a basal tuft of silvery leaves. Flowers are yellow, and typically present in May and June.

The range as currently known is slightly broader than that of *Lesquerella congesta*, with some occurrences being separated by as much as 23 miles. It is sympatric with *L. congesta* in the Piceance Creek/Ryan Gulch area, and also occurs in the Yellow Creek drainage. Additional occurrences are known further to the northwest in the East Fork of Spring Creek and Yanks Gulch drainages. O'Kane (1988) reported that *Physaria obcordata* occurs primarily on the Thirteenmile Creek Tongue and on the Parachute Creek Member of the Green River Formation. The main body of the Parachute Creek Member in the Northern Piceance Basin is described by Hail and Smith (1994) as:

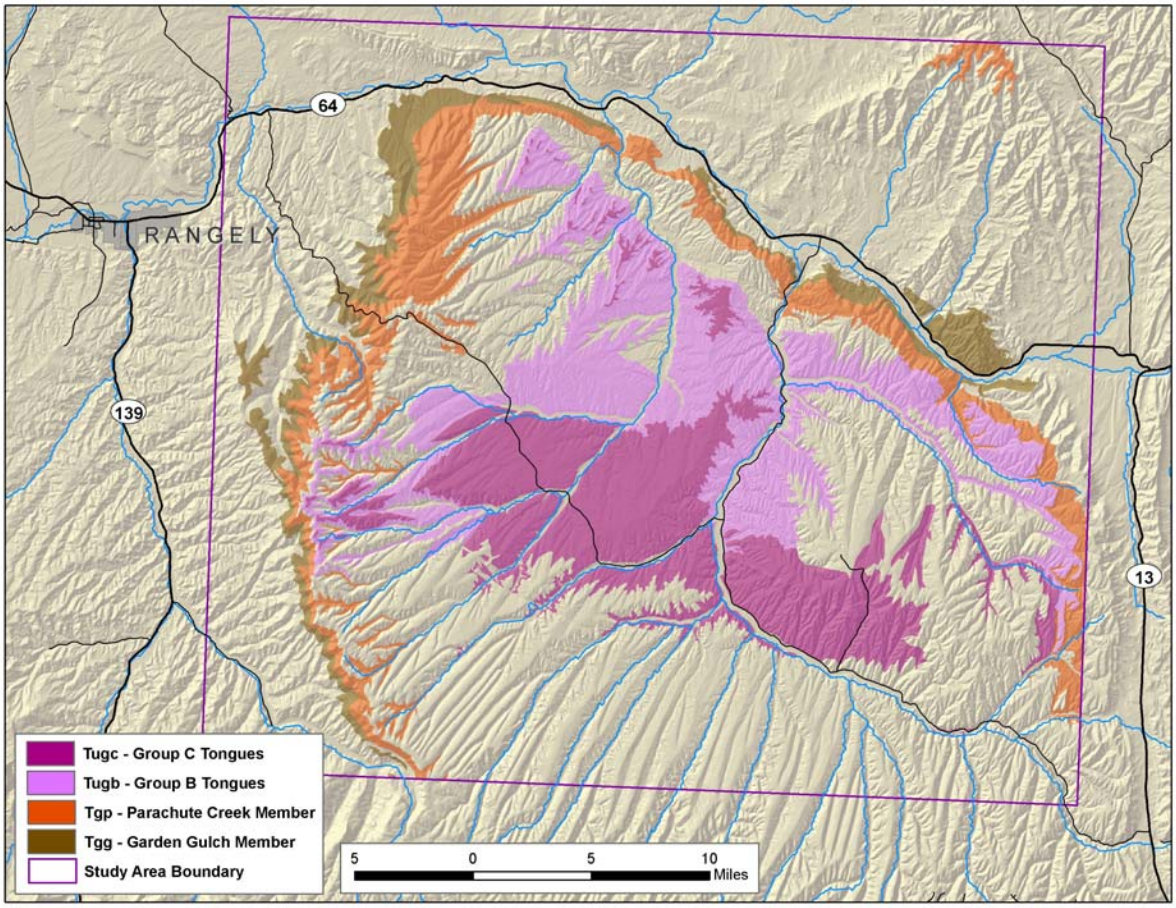
> Dolomitic marlstone, oil shale, and some marly siltstone and sandstone, numerous thin beds of analcimized tuff, and sparse algal limestone beds. Marlstone is massive to platy, gray to light grayish brown, weathers light gray. Oil shale is thin, even bedded, locally papery, medium to dark brown, weathers light gray; richest oil shale weathers light bluish gray. Clay shale is thin bedded to papery, brown to brownish gray. Parachute Creek Member contains several zones of rich, potentially valuable oil shale, constituting by far most of the oil-shale resources in the Green River Formation. … Thickness of entire member on outcrop south of White River ranges from about 400 ft (120m) in eastern part of basin to about 1600 ft (488 m) in western part of basin. Thickness in subsurface may exceed 2000 ft (610m).

The Parachute Creek Member includes the Mahogany ledge, one of the richest oil-shale zones in the basin, as well as potentially valuable deposits of nahcolite and dawsonite. This member lies below the intertongued Uinta and Green River Formations and above the Wasatch Formation. The adjacent Garden Gulch Member beneath the Parachute Creek Member (Figure 1) may also support some occurrences.

*Physaria obcordata* was listed as Threatened under the Endangered Species Act at the same time as *Lesquerella congesta*, and is known from nine occurrences (comprised of 38 distinct mapped polygons) in the northern Piceance Basin in Rio Blanco County. The species is ranked G2S2

(Imperiled both globally and in the state, at high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors) by the Colorado Natural Heritage Program (2006) and NatureServe (2006).

**Figure 1: Units of the Green River and Uinta Formations supporting *Lesquerella congesta* and *Physaria obcordata* in the Northern Piceance Basin (based on Hail and Smith 1994).**

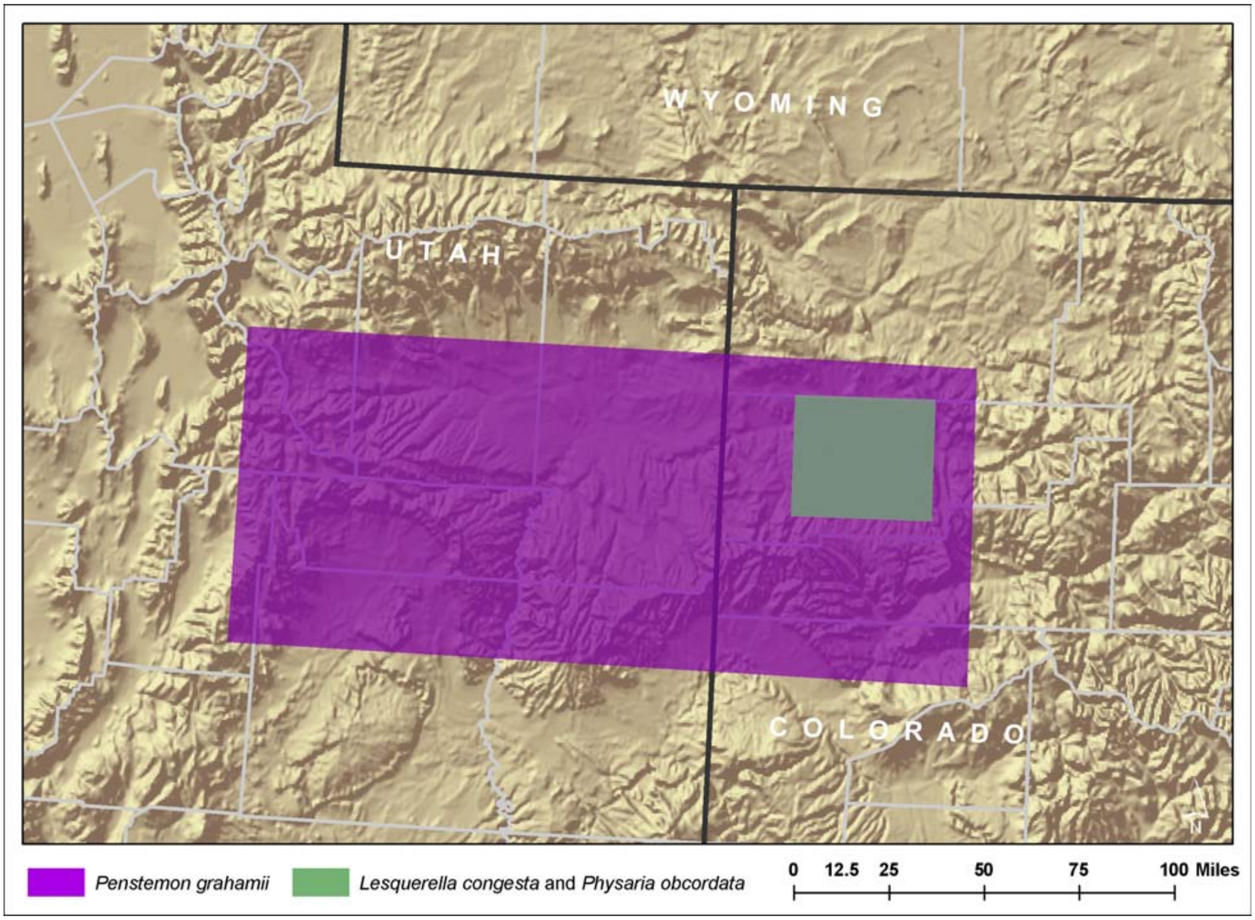



# METHODS

## Input data

Our study area for *Penstemon grahamii* included portions of northeastern Utah and northwestern Colorado (Figure 2). The study area for *Lesquerella congesta* and *Physaria obcordata* was the northern portion of the Piceance basin (Figure 2). Study areas were chosen to encompass the geologic substrates known to support the target species, according to the precision with which these substrates are mapped. Models were constructed with data from known locations of the target species using element occurrence records from the Utah Conservation Data Center and the Colorado Natural Heritage Program databases. Element occurrence records were updated and reviewed for completeness prior to modeling, to ensure that the most accurate information was used.  Element occurrence polygons were converted to point locations, and processed in order to eliminate points that were within the minimum occurrence separation distance (2000 m).  From these positive model points, approximately 25% were withheld from the modeling dataset for later use in model validation.  This resulted in modeling datasets of 32 points for *Penstemon grahamii*, 7 points for *Lesquerella congesta*, and 7 points for *Physaria obcordata*, and validation datasets of 11, 2 and 3 positive points, respectively.

**Figure 2: Study areas**




Environmental attributes for model points were derived from digital raster data in ArcGIS 9.0 (ESRI 2004).  Datasets were processed to a common projection, clipped to the appropriate study area, and resampled as necessary to a uniform cell size.  Environmental data used and sources are listed in Table 1.

**Table 1: Environmental variables used in modeling.**

| **Continuous Variables** | **Units** | **Source** |
|---|---|---|
| Elevation | m | USGS 30m Digital Elevation Model (DEM) for Colorado |
| Local Relief | m | Derived from DEM |
| Annual mean precipitation | cm | Daymet - Climatological summaries for the conterminous United States 1980- |

| | | |
|---|---|---|
| | | 1997 http://www.daymet.org/ (1km) |
| "Summer" precipitation (Jun/Jul/Aug, driest 3 consecutive months) | cm | Daymet |
| Precipitation frequency* (proportion of wet days) | proportion | Daymet |
| Coefficient of variation of monthly relative humidity | | Daymet |
| Annual temperature range (max-min) | °C | Daymet |
| April minimum air temperature | °C | Daymet |
| Growing degree days – annual (average air temp above 0 °C) | degree-days | Daymet |
| Number of frost days* | days | Daymet |
| | | |
| **Categorical Variables** | **Values** | **Source** |
| Surface Geology - *Penstemon grahamii*<br><br>Surface Geology – *Lesquerella congesta* and *Physaria obcordata* | | USGS National Gap Analysis Program. 2004. 1:500,000 Scale Geology for the Southwestern U.S. Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.<br><br>Digitized onscreen from: Hail Jr., W.J., and M.C. Smith. 1994. Geologic map of the northern part of the Piceance Creek Basin, northwestern Colorado. |
| Soil type** | | USDA Soil Conservation Service. 1994. General Soil Associations (STATSGO) for Colorado. |
| Vegetation type | | USGS National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University. |

***Penstemon grahamii* envelope model only   **not used for *Penstemon grahamii*

## Envelope model

Values for each input variable were determined for all positive model points. In the case of continuous environmental variables such as climate and elevation, the range of values covered by the known locations was broadened by 10% above the maximum observed and 10% below the minimum observed to improve the predictive ability of the model. New raster datasets containing only the categories or range observed for model points were created, then intersected to identify all areas within the study area possessing the combination of environmental conditions found at known locations.

## DOMAIN model

The DOMAIN modeling procedure was developed by Carpenter et al. (1993), and the DOMAIN implementation used in this project was developed by the Center for International Forestry

Research (CIFOR no date). Each cell in the study area is assigned a coordinate in the *n*-dimensional space formed by the input layers of environmental variables. The DOMAIN procedure uses the Gower metric as a measure of similarity to map cells that are most similar to cells where the target taxon is known to occur (model points). The model output is a new data layer where cell values reflect the multivariate "distance" to the nearest known point where the species occurs. The resulting grid is more-or-less equivalent to a continuous "similarity" surface, where the highest values (close to 100) represent areas most similar to known occurrence points, and lowest values are most unlike known occurrence points. The values do not represent probability estimates, but can be interpreted as a measure of classification confidence (Carpenter et al. 1993). Because the model does not give a discrete boundary for mapping potential habitat, user-defined thresholds are used to indicate confidence levels, and to map the results.

Due to the low number of points available for modeling in this study, four levels of similarity are reported:

1 – includes 95% of modeling points
2 – includes all model points
3 – includes all points, both model and validation
4 – includes 95% of area of all mapped Element Occurrences

**Model Validation**

Both the envelope and DOMAIN models were tested with an independent validation dataset of points randomly withheld from the original datasets. Validation points were overlaid on the distribution maps to determine the number of correct identifications. Here we report the validation success of each model as the percent of independent records that were correctly classified. For each similarity level of the DOMAIN model, the percent of correctly classified points and occurrence acreage is also reported.

## RESULTS

*Penstemon grahamii*

The potential distribution derived from intersecting values of environmental factors found at known locations (orange dots) of *Penstemon grahamii* is shown in Figure 3. There were a total of 11 validation points available. Seven points or 64% were correctly classified by the envelope model (Table 2). Results from the DOMAIN model are also shown in Table 2.

**Table 2: Model validation, *Penstemon grahamii***

| | | Model points n = 32 | Validation pts n = 11 | EO acres (1268 ac) |
|---|---|---|---|---|
| Envelope | | 32 | 7 | 1003 (79%) |
| DOMAIN level | Similarity score | | | |
| 1 | >90 | 30 | 6 | 578 (46%) |
| 2 | >81 | 32 | 10 | 1030 (81%) |
| 3 | >79 | 32 | 11 | 1076 (85%) |
| 4 | >75 | 32 | 11 | 1224 (97%) |

**Figure 3: Map of potential distribution of *Penstemon grahamii* - envelope model.**

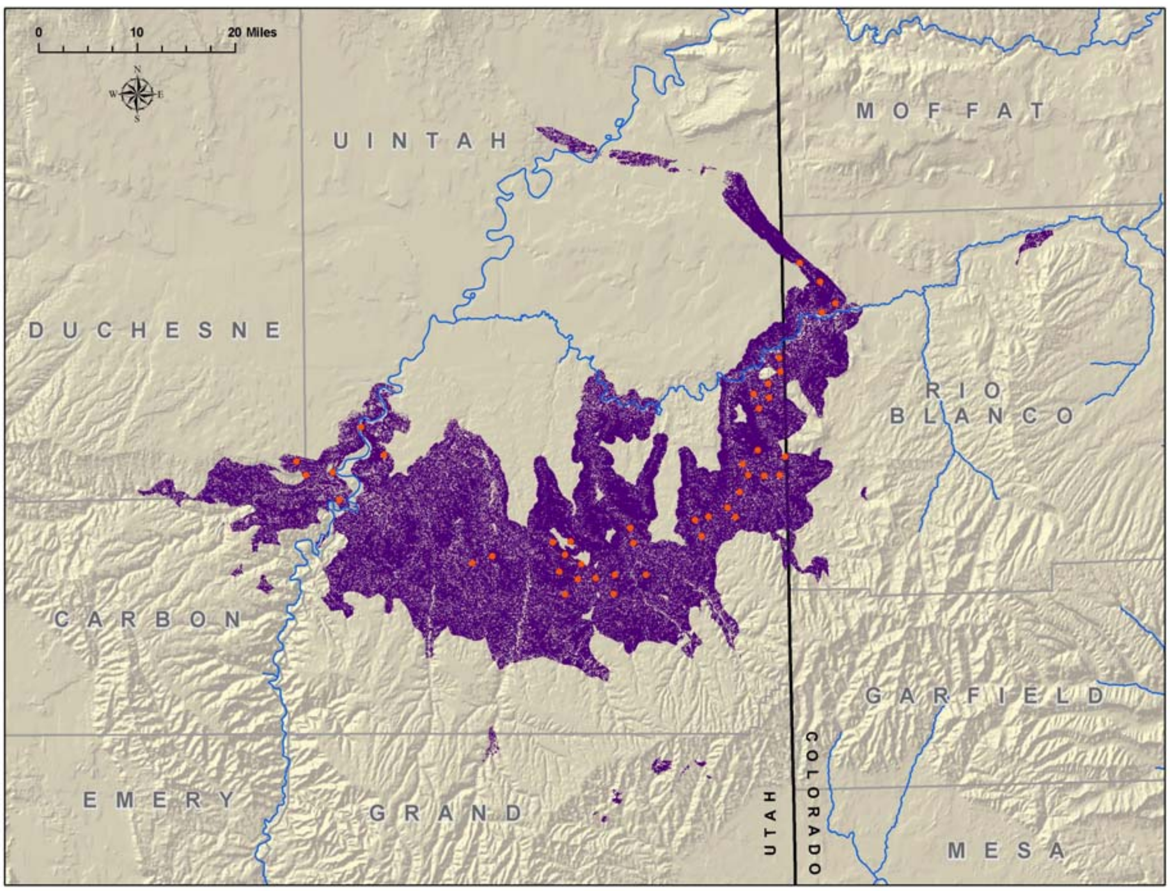
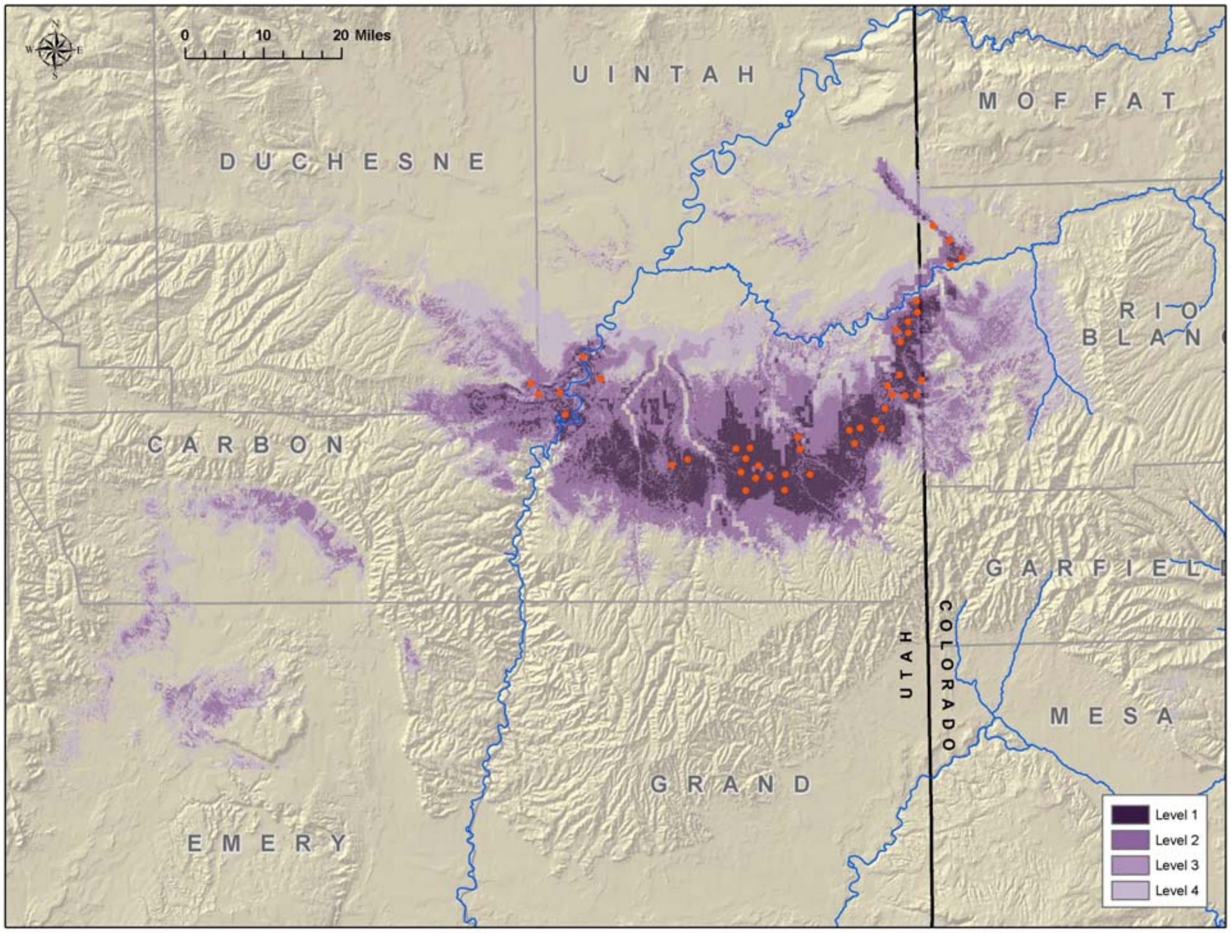


**Figure 4: Map of potential distribution of *Penstemon grahamii* - DOMAIN model.**



*Lesquerella congesta*

The potential distribution derived from intersecting values of environmental factors found at known locations of *Lesquerella congesta* (orange dots) is shown in Figure 5, and the results of the DOMAIN model in Figure 6. There were a total of 2 validation points available. One point (50%) was correctly classified by the envelope model. Results from the DOMAIN model are shown in Table 3.

**Table 3: Model validation, *Lesquerella congesta.***

| | | Model points (n = 7) | Validation pts (n = 2) | EO acres (739 ac) |
|---|---|---|---|---|
| Envelope | | 7 | 1 | 639 (86%) |
| DOMAIN level | Similarity score | | | |
| 1 | >87 | 6 | 0 | 119 (16%) |
| 2 | >76 | 7 | 0 | 388 (52%) |
| 3 & 4 | >53 | 7 | 2 | 707 (96%) |

**Figure 5: Map of potential distribution of *Lesquerella congesta* - envelope model.**

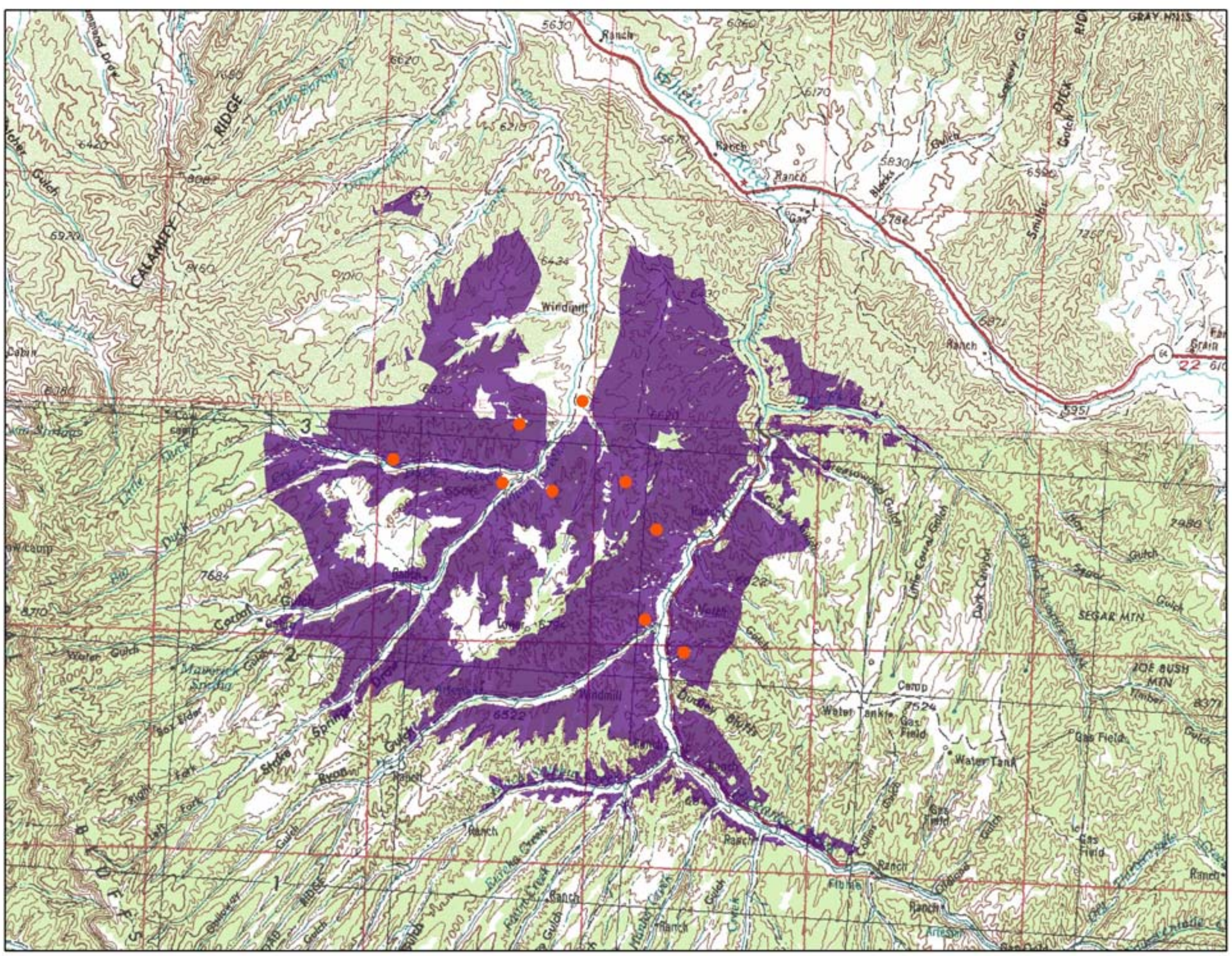
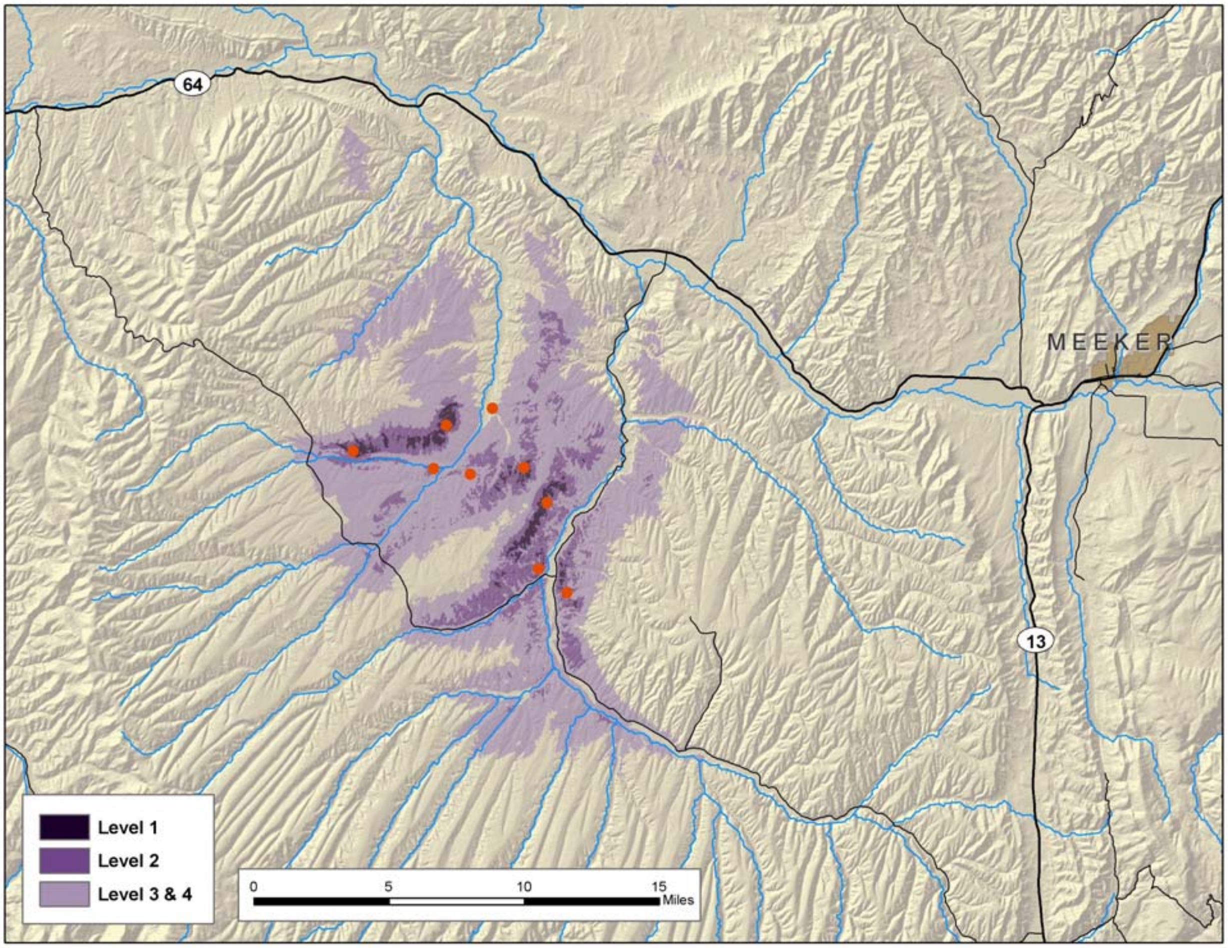


**Figure 6: Map of potential distribution of *Lesquerella congesta* - DOMAIN model.**



*Physaria obcordata*

The potential distribution derived from intersecting values of environmental factors found at known locations of *Physaria obcordata* (orange dots) is shown in Figure 7, and the results of the DOMAIN model in Figure 8. There were a total of 3 validation points available, and all were correctly classified by the envelope model. Results from the DOMAIN model are shown in Table 4.

**Table 4: Model validation, *Physaria obcordata.***

| | | Model points n = 7 | Validation pts n = 3 | EO acres (473 ac) |
|---|---|---|---|---|
| Envelope | | 7 | 3 | 376 (79%) |
| DOMAIN level | Similarity score | | | |
| 1 | >88 | 6 | 0 | 193 (41%) |
| 2 | >87 | 7 | 1 | 225 (48%) |
| 3 | >84 | 7 | 3 | 361 (76%) |
| 4 | >73 | 7 | 3 | 449 (95%) |

**Figure 7: Map of potential distribution of *Physaria obcordata* - envelope model.**

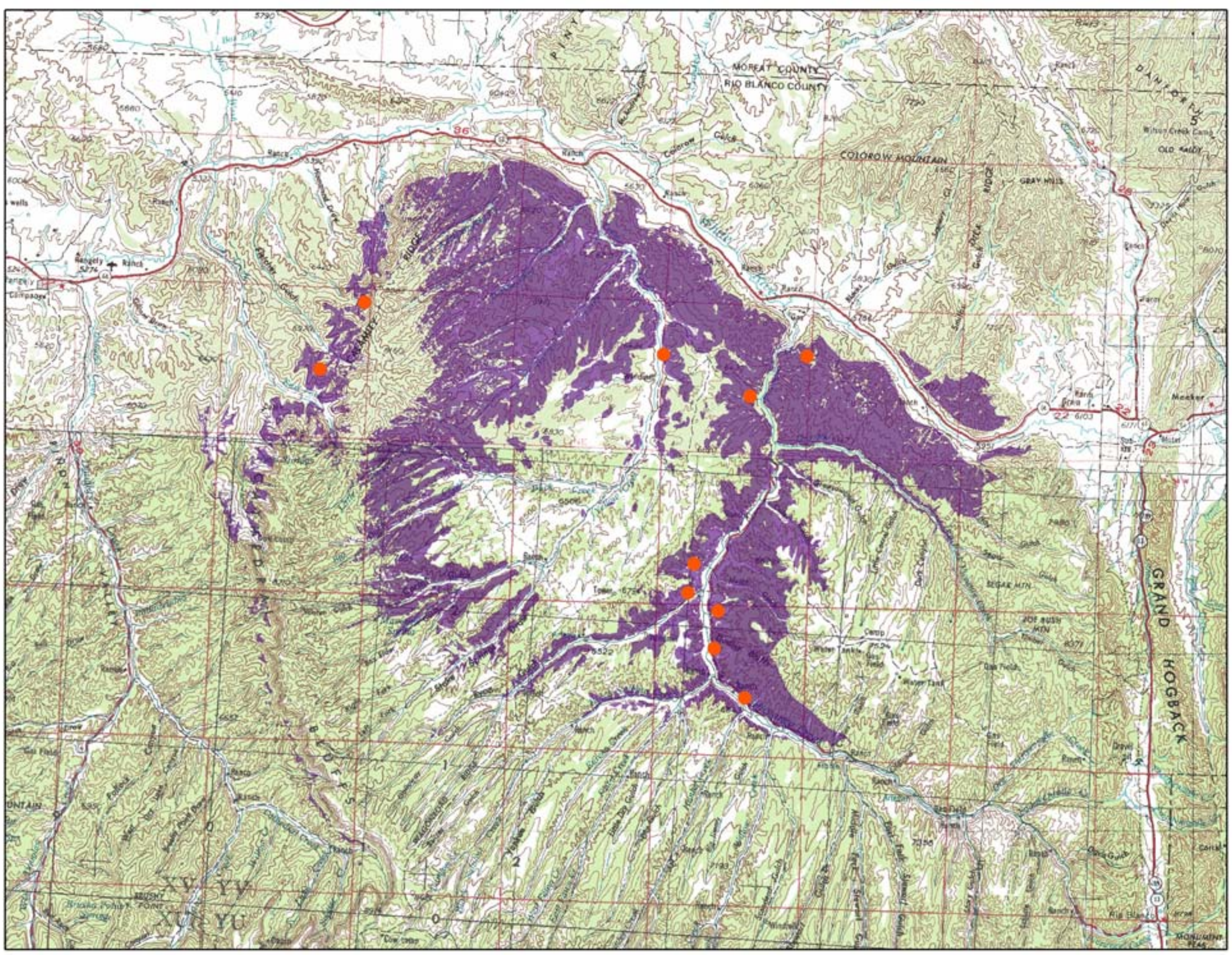
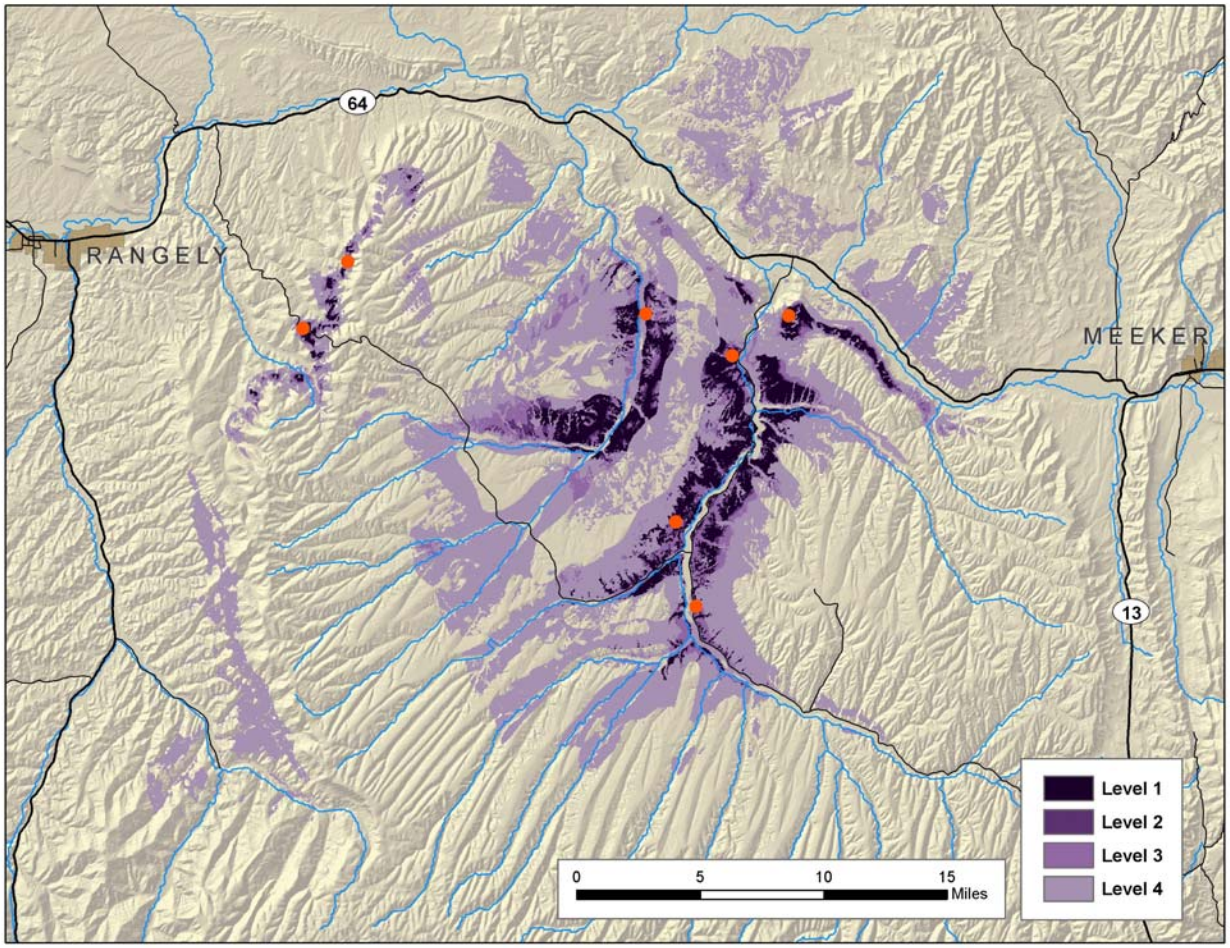


**Figure 8: Map of potential distribution of *Physaria obcordata* - DOMAIN model.**



## DISCUSSION

*Penstemon grahamii*

Results from both models of *Penstemon grahamii* potential habitat indicate that suitable habitat is patchily distributed within the known range, and there is good correspondence between the models with regard to the range extent. The models did not narrow potential habitat much beyond the area already known to support the species. It is likely that more refined models could be produced with more detailed geology data in digital format. The envelope and DOMAIN models appear to include all areas recently proposed for critical habitat designation (US Fish and Wildlife Service 2006), but this should be confirmed by overlaying the GIS layers.

*Lesquerella congesta*

Because mapped *Lesquerella congesta* occurrences are large and apparently internally heterogeneous, the single modeling point selected from each does not adequately capture variation in all model variables. As a result, potential habitat may be underestimated in the envelope model and in the higher similarity levels of the DOMAIN model. Model results indicate that suitable habitat for this species is essentially confined to the north-central Piceance Basin, with the known occurrences forming the core of the area. Some habitat of lower similarity extends to the north of the White River in the vicinity of Colorow Mountain. Most, but not all known locations of *Lesquerella congesta* fall near the boundary between Group C and Group B Tongues of the Green River Formation (Hail and Smith 1994), corresponding to the position of the Thirteenmile Creek Tongue as the lowermost member of Group C, adjacent to Group B. An alternative modeling technique would be to identify and map this boundary either on existing geologic maps or possibly on aerial imagery, and buffer it to compensate for mapping error and for actual surface conditions resulting from local erosion, etc. With current information it is not possible to determine if plants are truly restricted to the Thirteenmile Creek Tongue in all cases (i.e. if mapping is not precise enough), or if plants really can grow on adjacent, similar substrates.

*Physaria obcordata*

*Physaria obcordata* does not appear to be as restricted in substrate as *Lesquerella congesta*, and the habitat models consequently include a larger portion of the study area. Refining these models would require more information about what conditions are controlling the species distribution on a micro scale (e.g. germination site requirements, micro-relief, etc.). These factors, however, are probably not amenable to mapping due to the fine level of resolution needed to depict variation at a local scale.

*Conclusions*

Unfortunately, habitat models are not a guarantee of species presence or absence, and interpreting the results presented by different models can be a challenge for land managers.

Keeping in mind the potential for new occurrences to be discovered in sites not included in the model, we provide the following general guidelines for interpretation.

The envelope models present a single class of habitat – everything that covers the range of environmental characteristics across all locations used to construct the model. Because a subset of point locations is used, these models do not always include all areas where the species is known to be present. The area represented by the envelope model can be considered as an overall indicator of the central area of interest for the species, within which land management activities have the greatest potential to affect known or yet-to-be-discovered occurrences.

The DOMAIN model presents a continuous gradient of habitat classification, and gives managers a relative scale of how similar an area of interest is to most of the areas where the plant is known to occur. The graded nature of habitat scores can facilitate the use of the DOMAIN model as a prioritization tool, although the characteristics of the target species should also be taken into account. For instance, Level 1 & 2 similarity indicate areas with the highest similarity to the points used to generate and validate the model. For species such as *Penstemon grahamii* and *Physaria obcordata* whose mapped occurrences are small and well represented by a point sample, Level 1 & 2 areas would receive the highest priority for inventory or clearance work, in the absence of other compelling evidence. In the case of *Lesquerella congesta*, which has fewer, larger occurrences that are not well represented by point samples, it is more appropriate to consider similarity Level 3 or 4, to account for all habitat that is similar to mapped occurrences.

For all three species, the lack of finely mapped geology is a limiting factor in modeling suitable habitat. If models are to be further refined, it may be most cost effective to fund digitization of printed geologic maps (or to obtain this information from sources in the private sector, if available).

All of the model results indicate that there may be additional tracts of potential suitable habitat beyond the known occupied habitat for these species. However, these hypotheses should be further evaluated by field survey and by expert opinion of botanists and ecologists familiar with the species. With additional resources, the predictions presented here could be refined and alternative models explored. These models can not by themselves confirm the presence or absence of a species at a particular location, and it is not appropriate to base land management or conservation planning decisions entirely on this analysis without additional field verification.

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