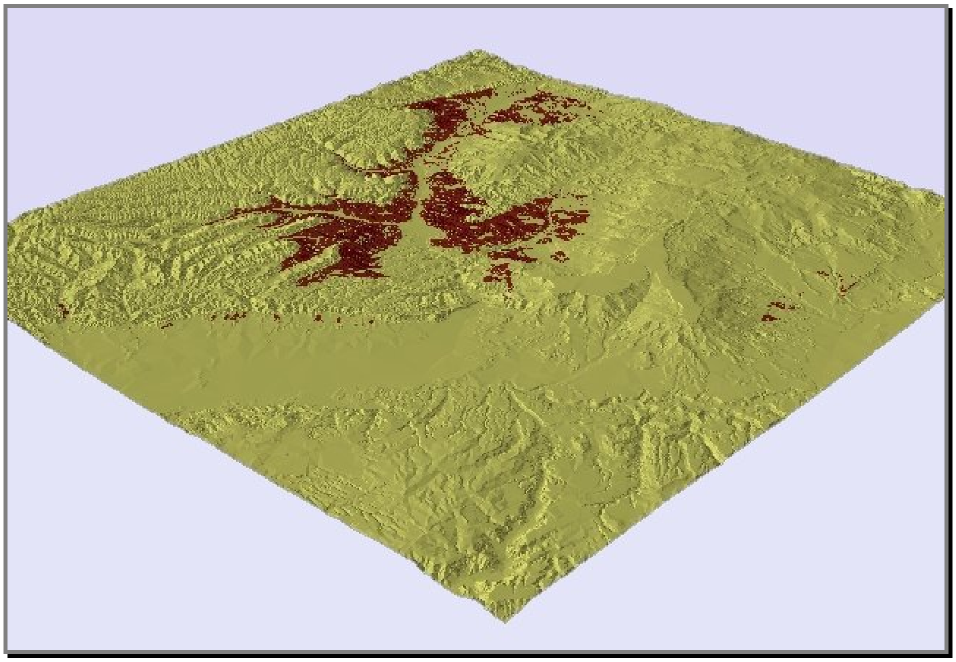
Modeling the Potential Distribution of *Phacelia scopulina* var. *submutica* (Debeque phacelia) and *Astragalus debequaeus* (Debeque milkvetch) in Western Colorado



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INTRODUCTION

Element distribution modeling

The process of developing a predictive model of the distribution of a particular species or ecosystem goes by a variety of different names and may involve several different techniques. All such modeling is based on the ecological principle that the presence of species and ecosystems (i.e., elements of biodiversity, or "elements") 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 element 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, loosely following the methods of Fertig (2002) and Fertig and Thurston (2003), to investigate the potential distribution of two Colorado endemic species: *Phacelia scopulina* var. *submutica (=Phacelia submutica)* and *Astragalus debequaeus.* Both types of model used spatially referenced datasets of environmental variables (i.e., elevation, slope, aspect, soil/geology, 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 in western Colorado. The classification and regression tree (CART) model was developed through a computerized procedure of binary recursive partitioning (Lewis 2000), wherein each group of element presence or absence points is successively split into two new groups, based on the values of independent (environmental) variables for those points. 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 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

Phacelia scopulina var. *submutica*

Phacelia scopulina (A. Nels.) J.T. Howell var. *submutica* (J.T. Howell) Halse, also called *Phacelia submutica*, is an annual member of the Hydrophyllaceae or Waterleaf family. First collected by G.E. Osterhout in 1911 near DeBeque in Mesa County, Colorado, it was described as *P. submutica* by Howell (1944); he considered it distinct from although related to *P. scopulina*, which has a distribution to the north and west of Colorado. Halse (1981) reduced *P. submutica* to a variety of *P. scopulina*. In his revision, Halse also included a specimen collected near Winzlow, Arizona by J.S. Newberry, the naturalist on the Colorado River Expedition of 1957-58 lead by Lieutenant J.C. Ives. Because the collection location of the Arizona specimen has never been relocated, and the species has never been collected from that state again, this historical disjunct locality is not generally regarded as forming a realistic part of the current range of *P. scopulina* var. *submutica*.

Over time, more by usage than by research, botanists have gradually refined the habitat description of *Phacelia scopulina* var. *submutica*, so that it is now generally believed to be more-or-less confined to soils derived from what Donnell (1969) identified as the Atwell Gulch and Shire members of the Wasatch Formation in western Colorado. These are typically described as brown or gray clay or adobe badlands lying immediately above (Shire) or below (Atwell Gulch) the blueish-gray Molina member of the Wasatch Formation. Because geology and soils are not yet mapped at the fine scale necessary to determine the exact substrate of any particular point location, substrate information at this level of precision could not be included in the model. Moreover, because the geologic substrate at known occurrences has not always been field-verified by trained geologists, surveyors should remain open to the possibility that the species can occur on other, similar substrates.

The fact that *Phacelia scopulina* var. *submutica* is an annual plant that does not necessarily appear every year makes it difficult to confirm presence or absence in a single observation. A survey in an unfavorable year or at the incorrect time of year can not rule out the possibility that *Phacelia scopulina* var. *submutica* is actually present at the site in the seed bank.

Phacelia scopulina var. *submutica* is currently known from 35 element occurrences (consisting of 85 distinct mapped polygons) in Mesa and Garfield Counties, within a 20 mile radius of DeBeque, Colorado. The species is ranked S2 (Imperiled 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 (CNHP 2005). The global rank is G4T2, indicating that it is an imperiled variety of an otherwise apparently secure species (NatureServe 2005).

Astragalus debequaeus

Astragalus debequaeus is a perennial member of the Fabaceae or Pea family that was described by Welsh (1985) from specimens he collected in the vicinity of DeBeque, Colorado. It has been taxonomically stable since that time. The known range of *A. debequaeus* is similar to that of *Phacelia scopulina* var. *submutica*, and the species is believed to occupy similar substrates on the Wasatch Formation. Although the perennial nature of *Astragalus debequaeus* means it is more likely to be detected at a site in unfavorable years, it should be noted that an absence of the species during survey does not necessarily rule out the possibility that the habitat is favorable but currently unoccupied.

Astragalus debequaeus is currently known from 17 occurrences (comprised of 67 distinct mapped polygons) in Mesa and Garfield Counties, within a 32 mile radius of Debeque. 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 (2005) and NatureServe (2005).

Figure 1: Target species

Phacelia scopulina var. *submutica*

Astragalus debequaeus

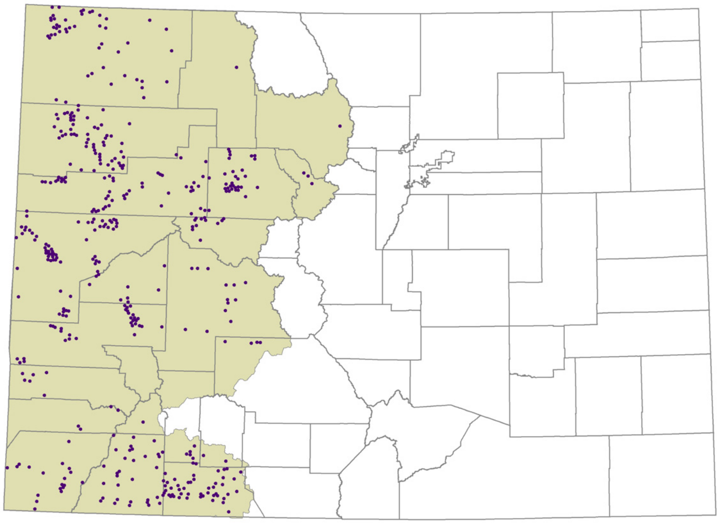
METHODS

Input data

Our study area was the portion of Colorado lying on the western slope of the Continental Divide (Figure 2). Both types of models were constructed with data from known locations of the target species using element occurrence records from the Colorado Natural Heritage Program database. 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 28 points for *Phacelia scopulina* var. *submutica* and 16 points for *Astragalus debequaeus,* and validation datasets of 9 and 6 positive points, respectively.

Figure 2: Study area and absence points



Absence data were generated for the CART modeling process by compiling point locations of vegetation plots collected by CNHP staff or others for which a complete species list was available. Our assumption was that these "pseudo-absence" points represent locations where there is a reasonable assumption that the target species were in fact absent. Points from habitat where an occurrence of either of the target species was extremely unlikely (e.g., alpine, subalpine forest, wetland and riparian areas, etc.) were not included. From the compiled dataset of 1252 plot locations, a random sample of 447 points was selected such that no point was within 2000 m of another, or within 2000 m of a known location of the target species (Figure 2). A smaller number of absence points derived from actual negative survey results for the target species was also available. In the case of *Phacelia scopulina* var. *submutica*, these data points were not included in the model, because of the annual and potentially ephemeral nature of the species. Twenty-five negative survey points were included in the absence points dataset for *Astragalus debequaeus*. As with the presence datasets, 25% of the absence points were withheld from the modeling datasets for validation.

Environmental attributes for both presence and absence points were derived from digital raster data in ArcGIS 9.0 (ESRI 2004). Datasets were processed to a common projection, clipped to the portion of Colorado lying to the west of the Continental Divide, and resampled as necessary to a 30 m cell size. Environmental data used and sources are listed in Table 1. Temperature variables were chosen as the four months with the highest absolute values on the first axis of a principal components analysis (PCA). Precipitation variables were identified as factors contributing the most variation to the first two axes of a PCA. In order to reduce the number of categories, geologic formations were reclassified by age and major rock type into 29 categories, following the classification used in the Geologic Map of Colorado (Tweto 1979), and soils were combined at the "great group" taxonomic level into 26 categories. Geology and soils categories are given in the Appendix.

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
Slope	degrees	Derived from DEM
August precipitation	cm	Daymet - Climatological summaries for the coterminous United States 1980-1997 http://www.daymet.org/ (1km)
"Winter" precipitation (November+Feb +Mar)	cm	Daymet (aggregated)
January average air temperature	°C	Daymet
February average air temperature	°C	Daymet
July average air temperature	°C	Daymet
August average air temperature	°C	Daymet
March minimum air temperature	°C	Daymet
April minimum air temperature	°C	Daymet
July minimum air temperature	°C	Daymet
August minimum air temperature	°C	Daymet
January maximum air temperature	°C	Daymet
February maximum air temperature	°C	Daymet
June maximum air temperature	°C	Daymet
July maximum air temperature	°C	Daymet
Number of frost days	days	Daymet
Precipitation frequency (proportion of wet days)	proportion	Daymet
Growing degree days – annual (average air temp above 0 °C)	degree-days	Daymet
Heating degree days - annual	degree-days	Daymet
Cooling degree days - annual	degree-days	Daymet
Categorical Variables	**Values**	**Source**
Aspect	N, NE, E, SE, S, SW, W, NW, Flat	Derived from DEM
Surface Geology	see Appendix	Colorado State Geologic Survey. 1995. The Digital Geologic Map of Colorado in ARC/INFO Format. From Tweto, O. 1979. Geologic Map of Colorado.
Soil type	see Appendix	USDA Soil Conservation Service. 1994. General Soil Associations (STATSGO) for Colorado.
Vegetation type	see Appendix	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.

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.

Classification and Regression Tree (CART) model

CART analyses use a variety of algorithms for predicting continuous or categorical variables from a set of continuous or categorical effect variables. Regression-type analyses generally attempt to predict the values of a continuous variable and classification-type analyses attempt to predict values of a categorical dependent variable (class, group membership, etc.). In this study, we used a simple binary classification-type analysis predicting the presence or absence of a species according to the values of various environmental factors. At each iteration, the recursive CART process determines which environmental variable and value best divides the set of all points into a "mostly present" and "mostly absent" set. The final result is a dichotomous tree showing the conditions of each split that describe suitable (present) and unsuitable (absent) environments.

An important issue in the use of CART analyses is deciding when to stop splitting. The CART process can continue to split datasets until all environmental variables have been accounted for and each terminal node is composed of strictly one class or the other (i.e. overfitting). Real-world data typically contains random error or noise that may result in splits which are not ecologically meaningful. Overfit models, while perfectly predicting the distribution of locations used in the model, may be less accurate in predicting independent validation points. The general approach to "pruning" the classification tree is to stop generating new split nodes at a point when subsequent splits give only a small overall improvement of the level of prediction.

CART was implemented in the statistical software program SPSS 13.0, with the Classification Trees model option. Environmental attributes for present and absent locations were used as independent variables in a Classification and Regression Trees (CRT) tree-growing procedure with the Gini node impurity measure (SPSS for Windows 2004). The CRT method attempts to maximize within-node homogeneity and the Gini measure finds splits that maximize the homogeneity of new nodes with respect to the value of the dependent variable. The Gini coefficient is based on squared probabilities of membership for each category of the dependent variable, and reaches its minimum of zero when all data points in a node fall into a single category (SPSS for Windows 2004). In order to avoid overfitting in the CART model, we did not obtain a complete tree by splitting until all nodes were pure present or absent terminal nodes. Pruning was accomplished by setting the minimum number of points for a new node at 10% of the number of present points (3 for PHSU and 2 for ASDE), and the minimum number of points required in the node being split at twice the number of the new node minimum. Following the example of Fertig and Thurston (2003), we assigned each positive path a likelihood class: High

= percent of points in that class greater than or equal to twice the average percentage for all classes, Medium = percent of points less than twice the average and greater than or equal to one half the average, Low = percent of points less than one half the average.

Model Validation

Both the envelope and CART models were tested with an independent validation dataset of points randomly withheld from the original datasets. Validation points (both presence and absence) were overlaid on the distribution maps to determine the number of correct identifications, the number of false positives, and the number of false negatives. Precision and accuracy of the resulting classification were calculated as shown below:

CP Correct Positive FP False Positive CN Correct Negative FN False Negative	Precision: The proportion of predicted positive cases that were correct. $= CP / (CP + FP)$ Accuracy: The proportion of the total number of predictions that were correct. $= (CP + CN) / (CP + CN + FP + FN)$

Note that precision and accuracy as calculated above are sensitive to the relative proportion of presence and absence points. A low proportion of presence points makes this a less useful measure of model success.

RESULTS

Envelope model

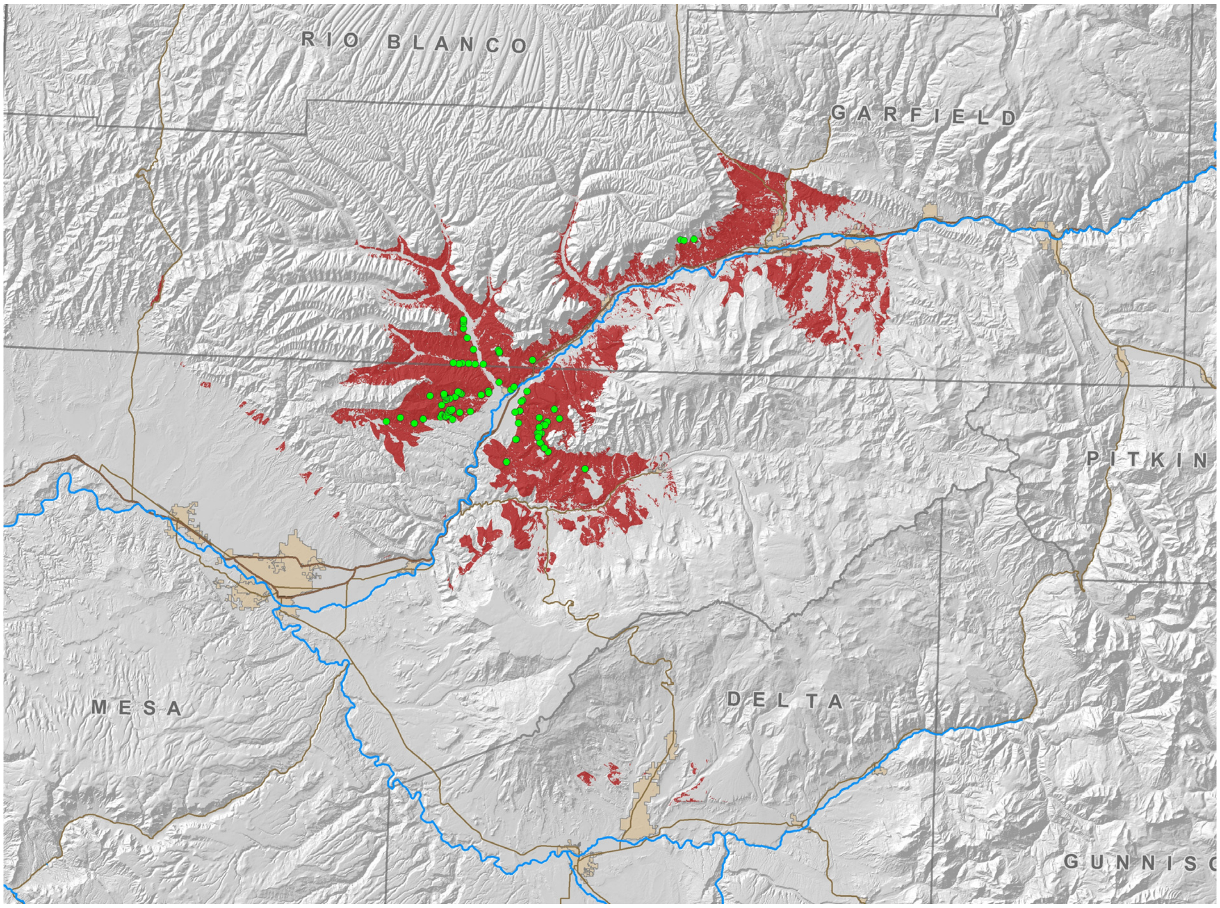
Phacelia scopulina var. *submutica*

The potential distribution derived from intersecting values of environmental factors found at known locations of *Phacelia scopulina* var. *submutica* is shown in Figure 3. There were a total of 121 validation points (9 present and 112 absent) available. Overall, 115 points or 95% were correctly classified by the envelope model (Table 2), but the model precision was only 61.5%.

Table 2: Envelope model validation, *Phacelia scopulina* var. *submutica*.

	Model present	**Model absent**
Known present	8 (CP)	1 (FN)
Known absent	5 (FP)	107 (CN)
% correct positives: 90% % correct negatives: 95.5%	**Precision = .615** **Accuracy = .950**	

Figure 3: Map of potential distribution of *Phacelia scopulina* var. *submutica* derived from envelope model.



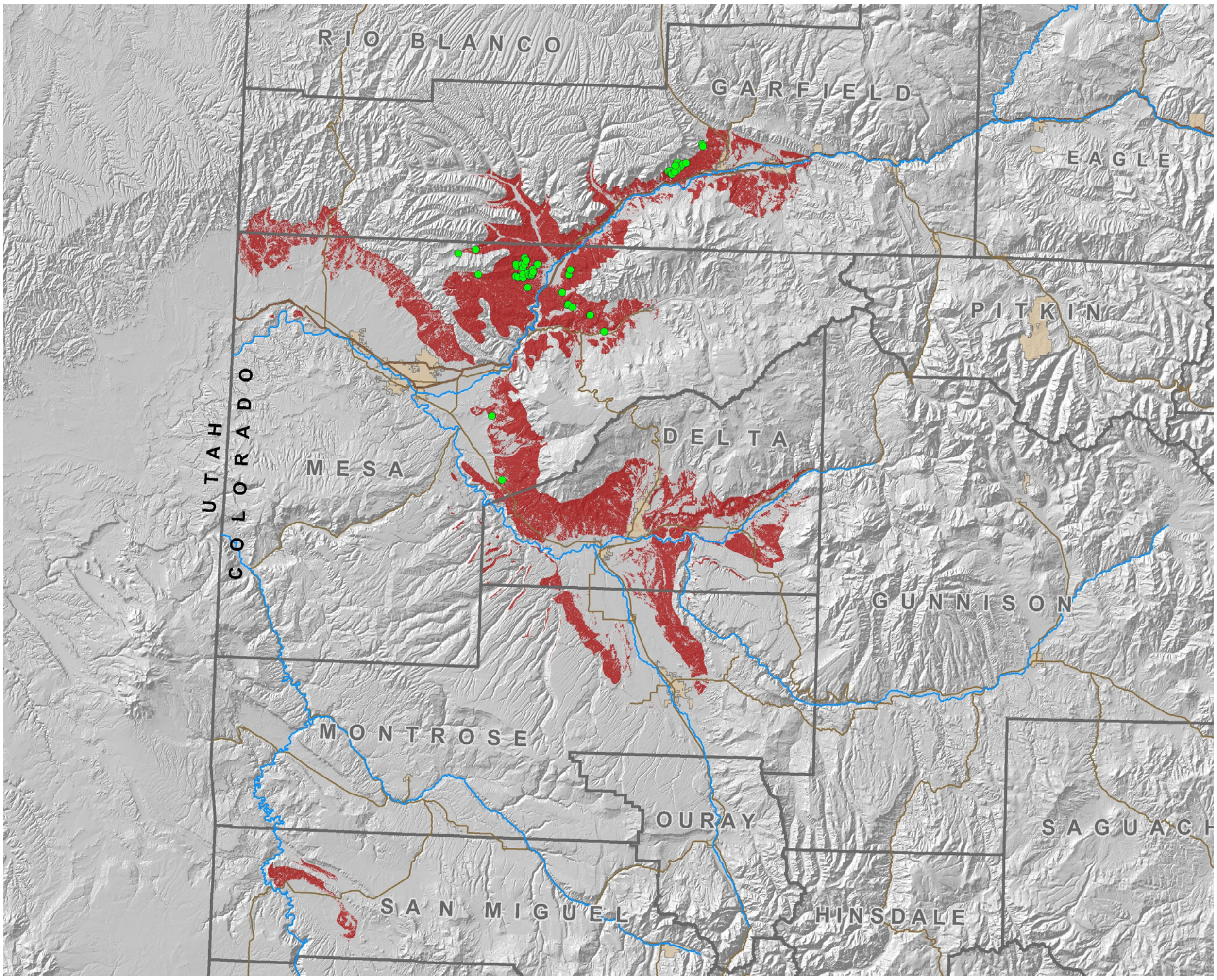
Astragalus debequaeus

The potential distribution derived from intersecting values of environmental factors found at known locations of *Astragalus debequaeus* is shown in Figure 4. There were a total of 125 validation points (6 present and 119 absent) available. Overall, 112 points or 90% were correctly classified by the envelope model (Table 3), but the precision was only 27%.

Table 3: Envelope model validation, *Astragalus debequaeus.*

	Model present	**Model absent**
Known present	4 (CP)	2 (FN)
Known absent	11 (FP)	108 (CN)
% correct positives: 66.7% % correct negatives: 90.8%	**Precision = .267** **Accuracy = .896**	

Figure 4: Map of potential distribution of *Astragalus debequaeus* derived from envelope model.



CART model

Phacelia scopulina var. *submutica*

The modeling dataset of 363 points (335 absent and 28 present) resulted in three positive terminal nodes, and one negative node with a present point (Figure 5). The characteristics of each pathway are summarized in Table 4.

Table 4: Pathway summary for presence nodes of *Phacelia scopulina* var. *submutica*.

Pathway	**# present points**	**% present points**	**Likelihood class**
Soils 8,13 Feb avg temp > -0.67 °C (30.8 °F) Elevation >1574 m (5164 ft)	22	78.6%	High
Soils 8,13 Feb avg temp > -0.67 °C (30.8 °F) Elevation <=1574 m (5164 ft) Annual wet days >19%	3	10.7%	Low
Soils 12, 21 Aspect W Mar min temp > -6.13 °C (21 °F)	2	7.1%	Low
Soils 8,13 Feb avg temp <= -0.67 °C (30.8 °F)	1	3.6%	Classified as absent

Overall, 116 points or 95.9% were correctly classified by the CART model (Table 5), and the precision of the model was 70%.

Table 5: CART model validation, *Phacelia scopulina* var. *submutica.*

	Model present	**Model absent**
Known present	7 (CP)	2 (FN)
Known absent	3 (FP)	109 (CN)
% correct positives: 77.8% % correct negatives: 97.3%	**Precision = .70** **Accuracy = .959**	

Figure 5: Classification Tree for *Phacelia scopulina* var. *submutica*.

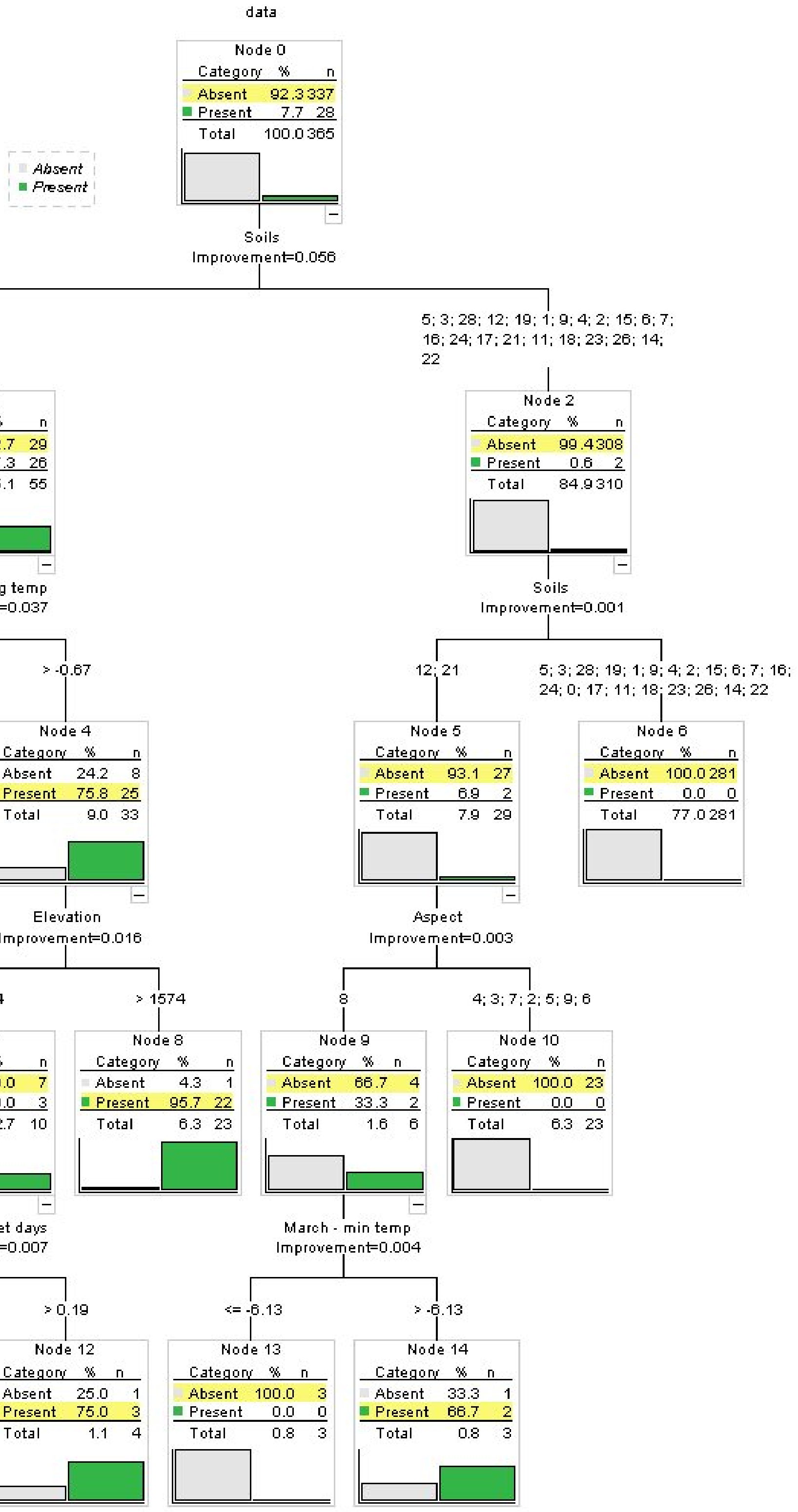
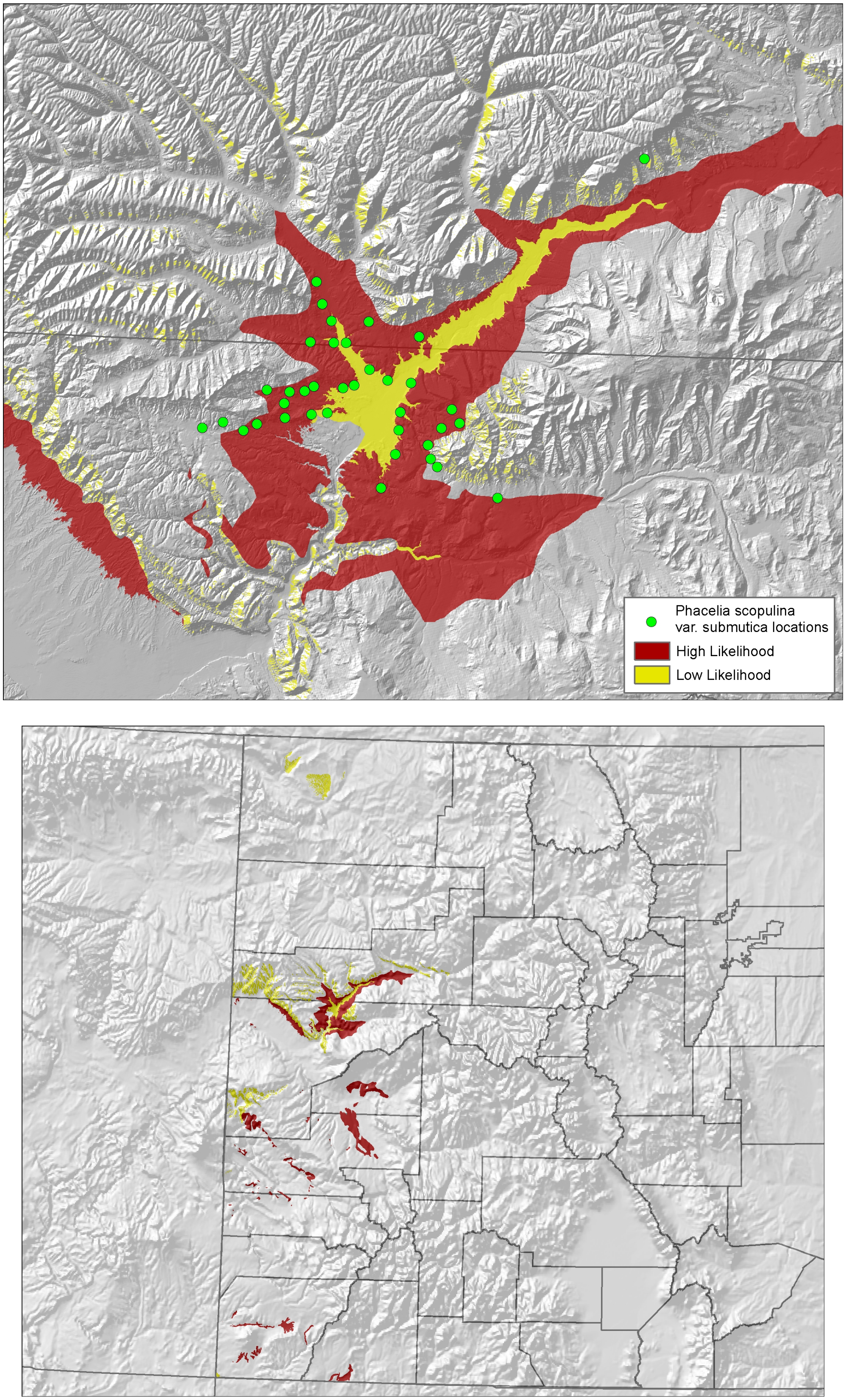


Figure 6: Map of potential distribution of *Phacelia scopulina* var. *submutica* derived from CART model.



Astragalus debequaeus

The modeling dataset of 369 points (353 absent and 16 present) resulted in seven positive terminal nodes (Figure 6). The characteristics of each pathway are summarized in Table 5.

Table 6: Pathway summary for presence nodes of *Astragalus debequaeus*.

Pathway	# present points	% present points	Likelihood class
Soils 8,13 Vegetation type 46, 58, 9, 50 April min temp > -0.71°C (30.7 °F) Aspect E, SE, S	6	37.5%	High
Soils 8,13 Vegetation type 46, 58, 9, 50 April min temp > -0.71°C (30.7 °F) Aspect SW, W, NW Annual wet days <=19%	2	12.5%	Medium
Soils 8,13 Vegetation 41, 36, 104, 48, 10, 40, 42, 82, 121, 5, 79 Jan max temp > 3.55 °C (38.4 °F)	2	12.5%	Medium
Soils 8,13 Vegetation 41, 36, 104, 48, 10, 40, 42, 82, 121, 5, 79 Jan max temp <=3.55 °C (38.4 °F) Slope >25.27º	2	12.5%	Medium
Soils 8,13 Vegetation 41, 36, 104, 48, 10, 40, 42, 82, 121, 5, 79 Jan max temp >3.38 °C and <=3.55 °C Slope <=25.27º	1	6.25%	Low
Soils other than 8, 10, 13, 18, 20, 25, 27 Mar min temp > -1.18 °C (29.9 °F) Vegetation type 10, 40	2	12.5%	Medium
Soils other than 8, 10, 13, 18, 20, 25, 27 Mar min temp <= -1.18 °C (29.9 °F) Slope >38.5º	1	6.25%	Low

Overall, 114 points or 91.2% were correctly classified by the CART model (Table 7), but the precision was only 22.2%.

Table 7: CART model validation, *Astragalus debequaeus.*

	Model present	**Model absent**
Known present	2 (CP)	4 (FN)
Known absent	7 (FP)	112 (CN)
% correct positives: 33.3% % correct negatives: 94.1%	**Precision = .222** **Accuracy = .912**	

Figure 7: Classification Tree for *Astragalus debequaeus*

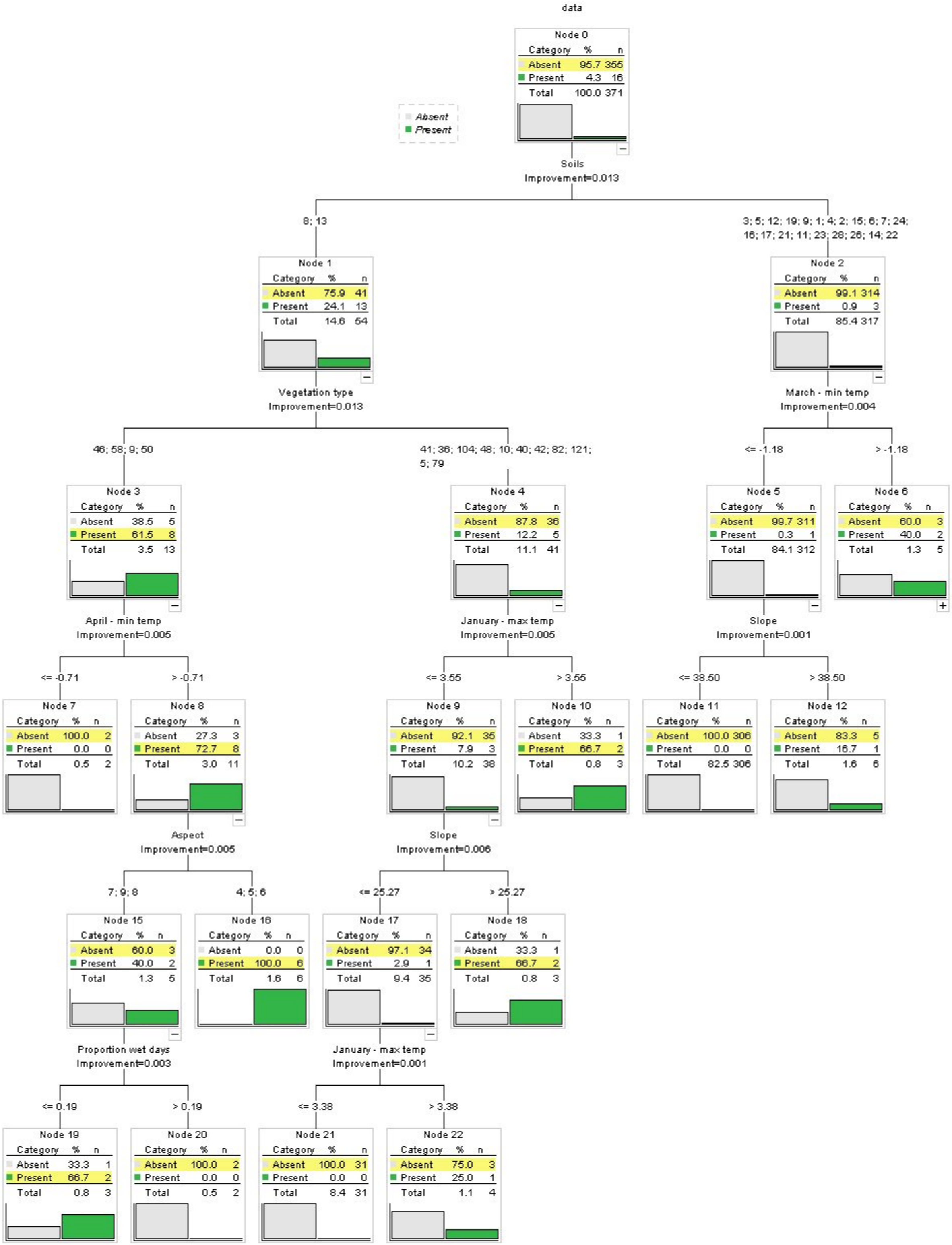
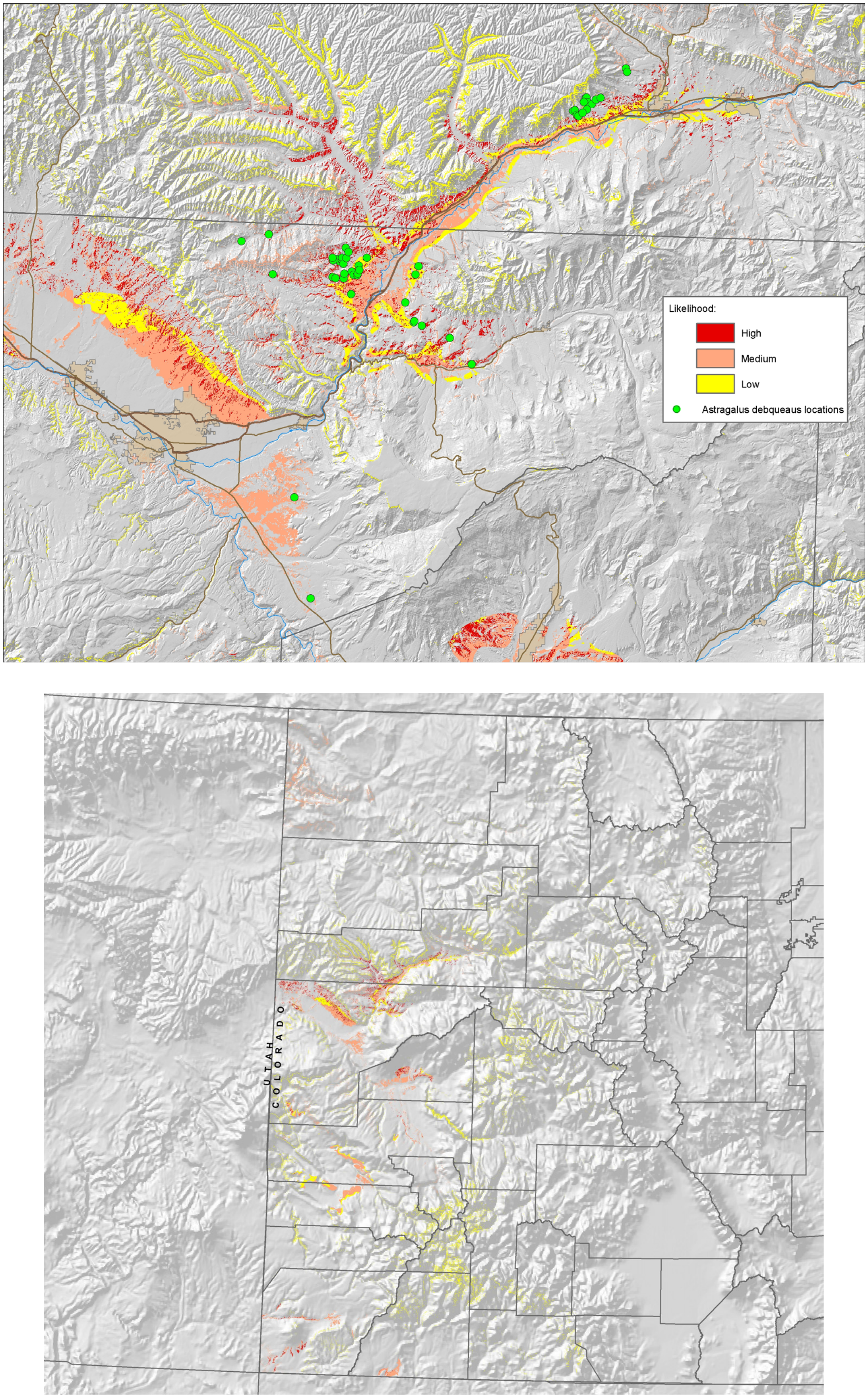


Figure 8: Map of potential distribution of *Astragalus debequaeus* derived from CART model.



DISCUSSION

Although *Phacelia scopulina* var. *submutica* and *Astragalus debequeaus* are generally believed to have very similar habitat requirements, the modeling results show some striking differences between the two. In addition, there are notable differences between the results of the two modeling techniques for each species.

Phacelia scopulina var. *submutica*

The distribution predicted by the envelope model is primarily concentrated in the uplands within 15-20 miles of the Colorado River valley between Silt and Palisade. Potential habitat is bounded by the Grand Hogback to the east and extends onto the flanks of the Roan Plateau to the north and lower Grand Mesa/Battlement Mesa to the south. Small patches also occur on the lower slopes of the Book Cliffs north of Grand Junction and Fruita, and on the southern edge of the Grand Mesa in the vicinity of Cedaredge and Orchard City.

The central portion of potential habitat resulting from the CART model is broadly similar to the envelope model results, but greatly extended within the study area. The precision and accuracy of both models are comparable for this species. In the CART model, areas of high likelihood are more extensive below the Book Cliffs, on the southern edge of the Grand Mesa, and in the valley of the North Fork of the Gunnison River from Cedaredge to south of Montrose. Additional high likelihood areas are found on the southwestern edges of the Uncomphahgre Plateau, at Yellow Jacket canyon, the McElmo Creek drainage, the Mancos River valley below the town of Mancos, the southeastern foot of Sleeping Ute Mountain, and in McDermott Arroyo southwest of Durango. These areas are selected largely because their combination of soils, late winter temperature and elevation are similar to those of the known habitat around DeBeque. Low likelihood areas also appear at the margins of higher likelihood areas as well as in the Sand Wash and Vermillion Creek drainages of Moffat County.

Astragalus debequeaus

For *Astragalus debequeaus*, the distribution predicted by the envelope model is similar but noticeably larger than that of *Phacelia*. It encompasses the uplands in the Colorado River valley downstream of the Grand Hogback, but also includes more extensive areas along the Book Cliffs as far as the Utah border (presumably it would extend beyond), much of the lower margins of Grand Mesa/Battlement Mesa around to the valley of the North Fork of the Gunnison as far as Paonia, and the margins of the Gunnison River valley from Montrose north to the confluence with the Colorado River. There are also a few disjunct areas further south in the salt anticline valleys east of the Dolores River in San Miguel County (Big Gypsum and Disappointment Valleys).

The CART modeling procedure for *Astragalus debequeaus* produced numerous pathways for potential habitat combination, although only one of these accounted for more than 2 points. The use of real absence points resulted in a noticeable restriction of high-likelihood potential habitat in comparison with the envelope model. The majority of these high likelihood patches have the same general distribution as in the envelope model. Medium- and low-likelihood habitat is less well defined. In general, medium- and low-likelihood areas are at lower elevations than those predicted by the envelope model, although there is overlap in many areas. In addition, there are numerous narrow bands and small patches of potential habitat throughout the study area, from the Green River in the north to the washes of the Four Corners area in the south. All of these areas represent areas whose soil, vegetation, slope, aspect, and temperature regime are similar to those of known locations.

The *Astragalus debequeaus* CART model performed poorly in validation. The only two validation points that were correctly classified as present fell on areas designated as "low likelihood". Most of the paths for potential habitat were based on only one or two points. The inclusion of real absence points appears to have artificially constrained the model to be narrower than necessary in some areas, while also including many areas that are probably not truly suitable habitat for *A. debequeaus*. Because the modeling process does not address most aspects of the autecology and reproductive biology of a species, it is impossible to determine if the discrepancy between known distribution and predicted habitat is a result of physiological constraints or an artifact of biogeographic history. It is possible that *A. debequeaus* could survive in areas predicted as potential habitat by the CART model, but simply has not yet been able to disperse to these areas. The broad distribution of small patches of potential habitat in the CART model may indicate that some important factor controlling the distribution of this species was not included in the model. In this instance the model results are probably more informative about the inadequacy of available environmental data than about potential habitat for *A. debequeaus*.

Conclusions

The results obtained through different modeling techniques underscore the potential variation arising from errors or lack of precision in input data, and differences in modeling assumptions and procedures. In particular the results obtained for *Astragalus debequeaus* indicate that in some instances it may be better to avoid the inclusion of one-time negative survey data for otherwise suitable habitats. Although this exercise proved to be a useful heuristic tool, we recommend that the CART model for *A. debequeaus* not be used as a map of potential habitat.

All of the model results indicate that there may be substantial tracts of potential suitable habitat for *Phacelia scopulina* var. *submutica* and *Astragalus debequeaus.* 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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APPENDIX

Geologic categories used in the modeling process:

Code	**Description**	**Colorado Units**
XG	Precambrian granitic and mafic - 1700MY	Xg, Xm
XM	Precambrian metamorphic (igneous) - 1700MY	Wr, Xb, Xfh, Xq
YXg	Precambrian granitic - 1400 and 1700MY	Yxg
YG	Precambrian granitic - 1000, 1400MY	Yam, Yg
YM	Precambrian metamorphic (sedimentary) - 1000, 1400MY	Yu, Yxu
MDOC	Pre-Pennsylvanian Paleozoic (Mississippian, Devonian, Ordovician, Cambrian) sedimentary	_am, _l, _s, M_, M_ml, MD, MD_, MDO, Mm, Mz, MzPz, O_
TRPP	Triassic, Permian, and Pennsylvanian sedimentary	@Pcp, @Pcs, @Pdc, @Pjs, @Pmc, @Pr, @Ps
PP	Permian – Pennsylvanian sedimentary	P&m, P&w, P&wm, Pc, Pp
Penn	Pennsylvanian sedimentary	&b, &e, &ee, &h, &m, &mb, &mr, &rh
TR	Triassic sedimentary	@c, @cc, @ch, @d, @kc, @m, @wc
JT	Jurassic and Triassic sedimentary	J@g, J@gc, J@mc, J@mg
J	Jurassic sedimentary	Jm, Jmc, Jmce, Jme, Jmj, Jms, Jmse, Jmw, Jmwe
KJ	Cretaceous and Jurrasic sedimentary	KJde, KJdj, KJdm, KJds, KJdw
KL	Lower Cretaceous sedimentary	Kd, Kdb, Kfd, Kh, Ki
KU1	Upper Cretaceous (lower) sedimentary	Kkf, Kl, Kls
KU2	Upper Cretaceous (upper) sedimentary	Kc, Kch, Km, Kmfm, Kmgs, Kmj, Kmp, Kmv, Kmvl, Kmvu, Kmw, Kp, Kpcl, Ksc, Kw
LAR	Laramide intrusives (early Tertiary and late Cretaceous)	Tki
TK	Early Tertiary and late Cretaceous sedimentary	TKa, Tkec
TL	Lower Tertiary sedimentary	Tb, Tc, Td, Te, Tf, Tg, Tgl, Tglm, Tglu, Tglw, Tgp, Tgt, Tn, Tsj, Tu, Tw, Twc, Twn, Two
TU	Upper Tertiary sedimentary	Tbp, Tgv, Tos, Tt
TMI	Middle Tertiary Intrusives	Tmi
TOV	Oligocene volcanics	Taf, Tial, Tiql, Tpl
TUI	Upper Tertiary Intrusives	Tui
TUV	Pliocene-Miocene volcanics	Tbb, Tbbi, Tbr, Tbrt, Tv
QT	Quaternary-Tertiary unconsolidated surficial deposits and rocks	Qa, Qd, Qdo, Qg, Qgo, Qta
QV	Quaternary - basalt flows	Qb
Qaeol	Quaternary - Eolian deposits	Qe
Qls	Quaternary - Landslide deposits	Ql
H20	Water	Water

Vegetation categories used in the modeling process:

Code	**Description**
1	North American Alpine Ice Field
2	Rocky Mountain Alpine Bedrock and Scree
4	Rocky Mountain Alpine Fell-Field
5	Rocky Mountain Cliff and Canyon
8	Inter-Mountain Basins Cliff and Canyon
9	Colorado Plateau Mixed Bedrock Canyon and Tableland
10	Inter-Mountain Basins Shale Badland
11	Inter-Mountain Basins Active and Stabilized Dune
13	Inter-Mountain Basins Wash
14	Inter-Mountain Basins Playa
22	Rocky Mountain Aspen Forest and Woodland
24	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland
26	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
28	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
29	Rocky Mountain Lodgepole Pine Forest
30	Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland
32	Rocky Mountain Montane Mesic Mixed Conifer Forest and Woodland
34	Rocky Mountain Ponderosa Pine Woodland
35	Southern Rocky Mountain Pinyon-Juniper Woodland
36	Colorado Plateau Pinyon-Juniper Woodland
38	Inter-Mountain West Aspen-Mixed Conifer Forest and Woodland Complex
40	Inter-Mountain Basins Mat Saltbush Shrubland
41	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
42	Rocky Mountain Lower Montane-Foothill Shrubland
44	Inter-Mountain Basins Mountain Mahogany Woodland and Shrubland
46	Colorado Plateau Pinyon-Juniper Shrubland
48	Inter-Mountain Basins Big Sagebrush Shrubland
50	Colorado Plateau Mixed Low Sagebrush Shrubland
53	Colorado Plateau Blackbrush-Mormon-tea Shrubland
58	Inter-Mountain Basins Mixed Salt Desert Scrub
62	Inter-Mountain Basins Montane Sagebrush Steppe
64	Inter-Mountain Basins Juniper Savanna
67	Inter-Mountain Basins Semi-Desert Shrub Steppe
69	Rocky Mountain Dry Tundra
70	Rocky Mountain Subalpine Mesic Meadow
71	Southern Rocky Mountain Montane-Subalpine Grassland
76	Inter-Mountain Basins Semi-Desert Grassland
77	Rocky Mountain Subalpine-Montane Riparian Shrubland
78	Rocky Mountain Subalpine-Montane Riparian Woodland
79	Rocky Mountain Lower Montane Riparian Woodland and Shrubland
82	Inter-Mountain Basins Greasewood Flat
85	North American Arid West Emergent Marsh
86	Rocky Mountain Alpine-Montane Wet Meadow
104	Wyoming Basins Low Sagebrush Shrubland
108	Southern Colorado Plateau Sand Shrubland
110	Open Water

Soils categroies used in the modeling process:

ID	CODE	GREAT GROUP	MUIDs
1	MBOCR	Cryoborolls	CO001, CO015, CO017, CO019, CO024, CO029, CO038, CO039, CO040, CO059, CO067, CO068, CO070, CO103, CO105, CO112, CO115, CO126, CO132, CO133, CO141, CO312, CO410, CO413, CO466, CO478, CO480, CO481, CO482, CO516, CO519
2	WATER	Water	COW
3	IOCCR	Cryochrepts	CO016, CO021, CO022, CO041, CO064, CO072, CO102, CO104, CO127, CO472, CO473, CO515, CO517, CO518
4	MBOAR	Argiborolls	CO004, CO031, CO066, CO111, CO119, CO124, CO475, CO506, CO514, CO663, CO667
5	EORTO	Torriorthents	CO006, CO008, CO034, CO035, CO051, CO060, CO063, CO121, CO122, CO129, CO137, CO139, CO140, CO454, CO457, CO459, CO502, CO505, CO509, CO664
6	DARHA	Haplargids	CO011, CO012, CO028, CO053, CO062, CO069, CO504, CO510, CO512, CO645, CO668, CO670
7	EORCR	Cryorthents	CO005, CO027, CO134, CO468, CO471
8	DORCL	Calciorthids	CO003, CO033, CO052, CO055, CO131, CO669
9	ABOCR	Cryoboralfs	CO018, CO026, CO058, CO107, CO113, CO303, CO412, CO461, CO467, CO474, CO477
10	IUMCR	Cryumbrepts	CO023, CO023, CO101, CO411
11	VUSCH	Chromusterts	CO013, CO014, CO452, CO455
12	ROCK OUTCROP	Rock outcrop	CO007, CO044, CO057, CO114, CO464, CO469, CO646, CO666
13	EFLTO	Torrifluvents	CO002, CO054, CO123, CO456, CO501, CO503, CO665
14	MALAR	Argialbolls	CO479
15	ABOEU	Eutroboralfs	CO460, CO462, CO511, CO520
16	DORCM	Camborthids	CO037, CO661, CO662
17	MBOHA	Haploborolls	CO030, CO036, CO143
18	EFLUS	Ustifluvents	CO458
19	EPSTO	Torriorthents	CO009, CO010
20	MBOPA	Paleborolls	CO032
21	MBOCA	Calciborolls	CO056
22	DARNT	Natrargids	CO508
23	MUSAR	Argiustolls	CO061, CO451, CO453
24	DORGY	Gypsiorthids	CO647
25	MAQCR	Cryaquolls	CO128, CO128, CO328
26	ABOPA	Paleboralfs	CO465
27	HHECR	Cryohemists	CO470
28	AUSPA	Paleboralfs	CO476