Random Forest Species Model Documentation

Developed for the NCDOT ATLAS Project

Heller's blazing star *(Liatris helleri)*

- **Lead modeler**: Ashton Drew, KDV Decision Analysis (ashton.drew@kdv-decisions.com) 919-886-2811
- **Model version**: Version 1 (2019-09-29)
- **Delivered Products**:
  - *Potential Habitat, Version 1*: A 3-level reclassification of the model prediction for use by ATLAS (shapefile)
  - *Model summary documentation*: This document.
  - *Probability of Potential Habitat, Version 1*: Appendix 1. The 30-m resolution probability raster map produced by the model (tif).
  - *Model R code and associated documentation*: Appendix 2. This collection of files includes model code (R), the lookup tables used to define environmental data layers and post-processing masks (Excel), figures and R data products used to assess model performance (various), and a README document explaining the contents.
  - *Desktop Review Results, Draft model*: Appendix 3. Reviewer comments (shapefile) and a summary of review interpretation and recommendations for model improvement (pdf).
  - *Field Assessment Results, Version 1 model*: Appendix 4. Reviewer comments (shapefile) and a summary of field observations and recommendations for model improvement and application (pdf).

The Heller's blazing star model is a Random Forest (machine-learning) model. As such, it returns the **probability of potential habitat**, based on the core assumption that current presence locations are representative of potential habitat within the state of North Carolina. For the purposes of ATLAS applications, this model is reclassified to a 3-level map product distinguishing 30-m raster grid cells with predicted low, moderate, and high probability of potential habitat.

Species Description

Heller's blazing star, endemic to the Blue Ridge Mountains of North Carolina, occurs in the High Elevation Rocky Summit natural community on high elevation ledges, rock outcrops, cliffs, and balds at elevations of 3,500–5,999 feet above mean sea level. This early pioneer, perennial herb grows in acidic and generally shallow humus or clay loams on igneous and metasedimentary rock. Known occurrences are intermittently saturated and excessively to moderately poorly drained. The plant generally occurs in full sunlight with grasses, sedges, and other composites. Blue Ridge goldenrod, Roan Mountain bluet, and spreading avens are a few of its common associate species.

Data Resources

Species Data

We gathered presence data from multiple sources, listed below, and rasterized these to a 30-m scale to match our environmental data. Any grid cell intersecting known occurrence points or polygons was attributed as "presence". No true absence data were available, so the remaining grid cells (areas without known occurrence) were attributed as "pseudoabsence".

1. **US Fish and Wildlife Service (USFWS) Range Data**: The model extent was defined based on USFWS current range data, applied through agreements between NCDOT and USFWS.
2. **NC Natural Heritage Program (NCNHP) Element Occurrence (EO) Data**: Observations evaluated for use in the model included all plant species records where STATUS=Current and ACCURACY=1-Very High, 2-High, and 3-Medium as of the most recent Tier 2 data release. Some, but not all, models included the medium accuracy data.
3. **NC Department of Transportation (NCDOT) Field Pre-Validation Survey Data**: Field surveys conducted to verify current EO status and improve the accuracy of EO records for several species added new data for some species.
4. **NCDOT Past NRTR Project Data**: Data gathered from past project files provided 6 years of presence/absence polygons and up to 2 years of habitat/non-habitat polygons within NRTR study areas.
5. **Expert Reviewer AGOL Desktop Review Data**: Species experts completed a structured, spatially explicit review of a draft version of this model (see below). Experts' potential habitat/non-habitat judgments served as additional input for some models.

Within the USFWS range there are 6,465,438 30-m raster grid cells. From the intersection of these grid cells with the available occurrence data, we obtained:

- **Presence**: 189 cells attributed as high precision, current observations of Heller's blazing star. All presence locations were used to train the model, because the random forest model process includes randomized out-of-bag testing as part of development.
- **Mediums**: 802 cells attributed as moderate precision, but current observations. The use of these presence cells to train the model depended on how much noise versus signal they added. Medium cells were included from this version of the model.
- **Historic**: 0 cells attributed as historic (extirpated) observations. These observations were not used to train the model but were referenced during model review.
- **Associates**: 0 cells attributed as current, high precision observations of associated species, but without record of the Heller's blazing star. If present, these observations were not used to train the model but were referenced during model review.

- **Target Taxa Group**: 12,973 cells attributed as current, high precision observations of other plant species where the Heller's blazing star was not documented as present. Target taxa group cells were handled as a special class of pseudoabsence data.
- **Pseudoabsence**: No true absence data were available for this project, so random draws from the remaining grid cells served as pseudoabsence data. The number of points drawn for each model run was equal to the total number of presence points.

Environmental Data

We had access to 70 environmental data layers across 6 thematic areas: Geology and Soils, Land Cover and Vegetation, Disturbance, Landform, Climate, Spectral. All data are in NAD 1983 State Plane North Carolina FIPS 3200 (US feet), 30-m spatial resolution, with state-wide extent. Appendix 2 includes further documentation of environmental data layers.

We initiated this model with a subset of 26 variables based on variable importance in earlier drafts (the reviewed draft initiated with all 52 layers available at that time), previously untested layers (new or updated data layers), reviewer feedback, and interpretation of patterns in earlier versions. The initial subset of variables presented to the model was further refined by testing for multicollinearity and performing model selection.

Table 1. Environmental variable set provided to the random forest model.

Group	Variable
Climate	Mean Annual Precipitation
Disturbance	Burn Area Density
Disturbance	Distance to Linear Disturbance
Geology and Soils	Available Water Storage
Geology and Soils	Hydrologic Group D
Geology and Soils	Predominant Lithology
Geology and Soils	Soil Percent Clay
Geology and Soils	Soil Percent Organics
Geology and Soils	Soil pH
Land Cover and Vegetation	Biophysical Setting Classification (merged)
Land Cover and Vegetation	Canopy Percent Cover
Land Cover and Vegetation	Distance to Streams
Land Cover and Vegetation	NLCD Land Cover
Landform	Elevation
Landform	Slope
Landform	Geomorphon Classification
Landform	Geomorphon: Depression
Landform	Geomorphon: Flat

Landform	Geomorphon: Footslope
Landform	Geomorphon: Hollow
Landform	Geomorphon: Ridge
Landform	Geomorphon: Shoulder
Landform	Geomorphon: Slope
Landform	Geomorphon: Spur
Landform	Geomorphon: Summit
Landform	Geomorphon: Valley

Model Approach and Output

Random forest models generate predictions through repeated construction of decision-tree style models. At multiple points during model construction and assessment, the random forest draws a random subset of presence and pseudoabsence data, as well as random subset of available environmental data. The model procedure tracks (1) how frequently sites are predicted to be presence vs absence, (2) which variables contribute most to accurate classification of presence vs absence sites, and (3) overall statistics about model performance. We ran the model in R using the randomForest (Liaw and Weiner 2002) and rfUtilities (Evans and Murphy 2018) packages. This document summarizes key aspects of the model specification and outputs, as well as results of a desktop review and field assessment. The model code and further details are available in Appendix 2.

The model predicts the probability of potential habitat for the species, given the assumption that the available presence data are representative of suitable habitat within the state.

The predicted probability of potential habitat (0 to 1) reflects the frequency with which a raster grid cell was classified as potential habitat versus non-habitat through all the permutations of random forests (see Appendix 1).

We created the 3-level (low, moderate, and high probability of potential habitat) representation of the model prediction by setting probability thresholds at 0.36 (low/moderate) and 0.76 (moderate/high). These thresholds were set through discussion with the expert biologists in reference to their observations of model strengths and weaknesses during the field assessments. The selection of a threshold is a judgement based on acceptable risk and desired level of precaution for a given application of the model. As a threshold is dropped, more area with decreasing similarity to known presence locations will be categorized as the higher level class (e.g., lowering the moderate/high threshold labels more habitat as high probability). Model documentation (Appendix 3) provides a table of all possible thresholds, in 0.01 percent increments, with associated percent correctly classified, sensitivity, and specificity accuracy statistics.

Figure 1. The model uses data from, and makes predictions for, the species' county range area (red) as designated by USFWS IPaC as of 2019-09-29.

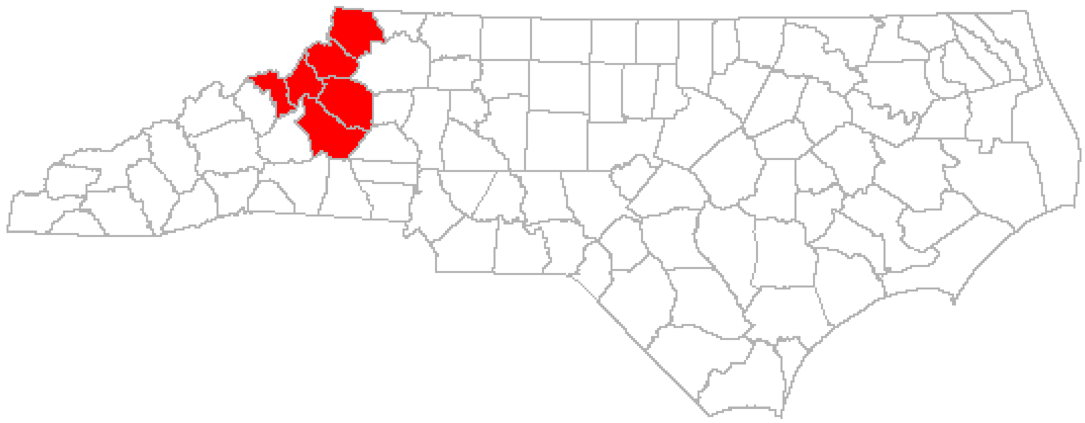


Figure 2. The probability of potential habitat as predicted by the random forest model (raster map data available in Appendix 1).

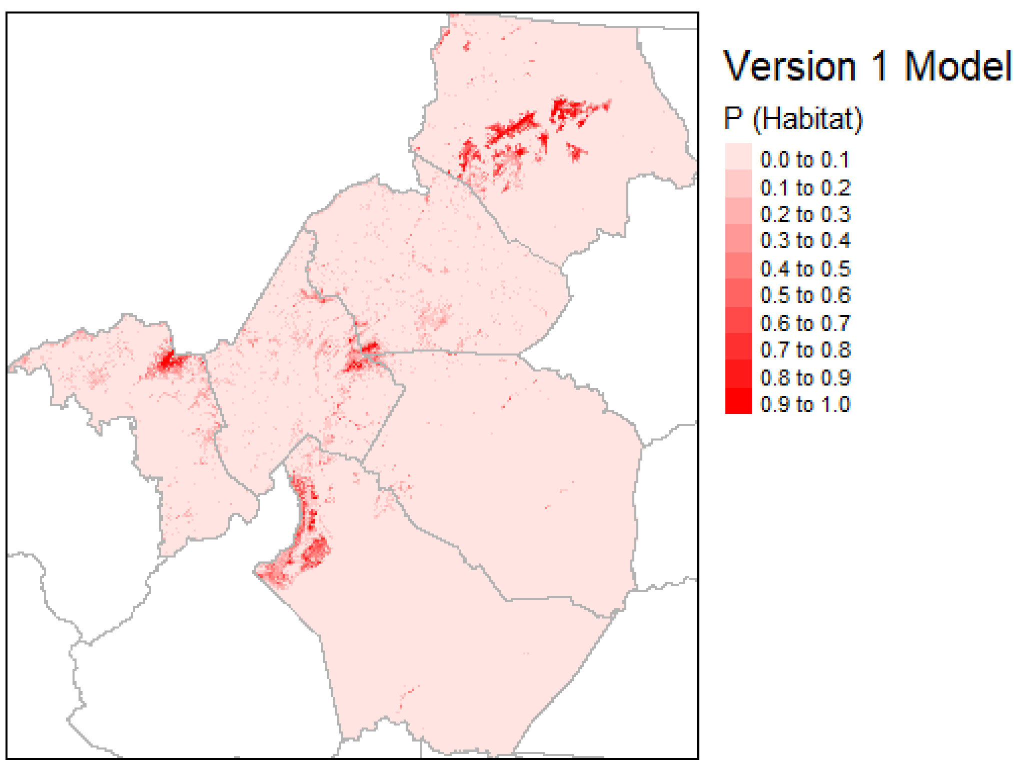
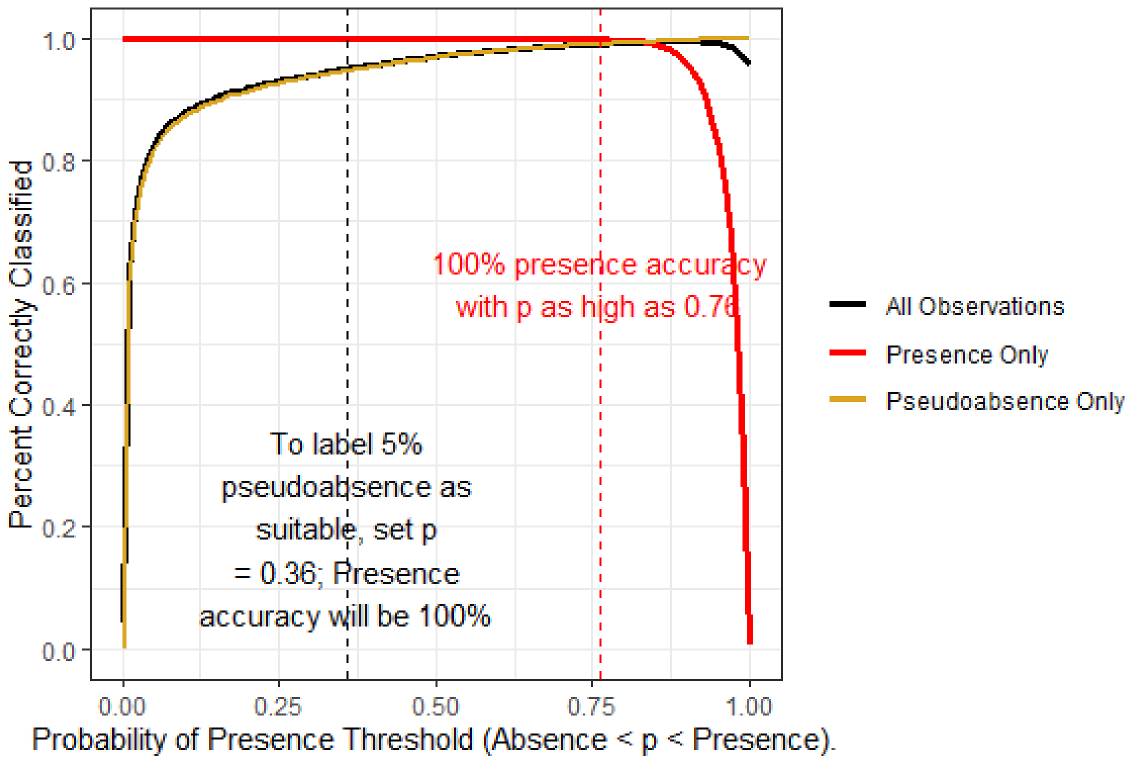


Table 2. Variable importance scores for the final set of environmental variables used in the random forest model (after testing for multicollinearity and parsimony). Mean decrease in accuracy refers to how much more poorly the model performs if the variable is excluded. Mean decrease in Gini refers to how the Gini coefficient, a measure of homogeneity within groups after a random forest split, is affected by the removal of the variable.

Variable	Mean Decrease in Accuracy	Mean Decrease in Gini
Distance to Linear Disturbance	77	415
Mean Annual Precipitation	71	319
Distance to Streams	58	236
Elevation	58	560
Predominant Lithology	54	340
Soil Percent Organics	47	489
Soil Percent Clay	46	425
Canopy Percent Cover	44	191
Slope	43	356
Biophysical Setting Classification (merged)	35	162
Burn Area Density	34	104
Available Water Storage	30	194
Soil pH	30	206
Geomorphon: Shoulder	27	37
Geomorphon: Summit	27	41
NLCD Land Cover	27	50
Hydrologic Group D	24	58
Geomorphon: Footslope	22	79
Geomorphon: Valley	11	28

Figure 3. Threshold plot showing the percent correctly classified at all possible probability thresholds. At lower thresholds, more of the landscape is classified as potential habitat; all known presence (red line) are correctly classified, but many pseudoabsence (gold line) are also called presence. At very high threshold values, most pseudoabsence are classified as absence, but some known presence sites are misclassified as absence.



Draft Model Review and Improvements

We conducted draft model reviews and analysis of reviewer feedback between September 2018 and July 2019 (Appendix 3). The experts providing feedback on a draft model, via an ArcGIS Online (AGOL) portal, were:

- Lesley Starke, the Plant Conservation Program Manager with NC Department of Agriculture and Consumer Services. She has worked with North Carolina's imperiled plant species through her work at the Plant Conservation Program since 2010 and has a strong background in remote sensing and species distribution modeling.
- Rebekah Reid, a Listing and Recovery Biologist with the US Fish and Wildlife Service.<U+202F> She is the species lead for 15 plant species in present in North Carolina.
- Suzanne Mason, a data manager for the North Carolina Natural Heritage Program. She has been with the NCNHP since 2005 and specializes in maintaining conservation data for federally-protected species. Suzanne previously studied the genetic diversity of Schweinitz's sunflower for her Master of Science thesis.

The AGOL review requested each reviewer to individually examine the model at approximately 20 flagged locations chosen by the modeler plus a minimum of 20 additional locations of the reviewer's choice. For this review, we presented a binary representation of the continuous probability prediction, where "potential habitat" represented a proposed threshold for "moderate to high probability of potential habitat" and "non-habitat" represented grid cells with lower probability. We requested comments address both modeled non-habitat and potential habitat, with at least 5 sites where they disagreed and 5 where they agreed with the classification within each category. At each location, the reviewer (1) indicated if the modeled classification (potential habitat or non-habitat) matched their own best professional judgment given their experience, the aerial imagery, and any additional information they chose to consult, and (2) commented on how they reached their conclusion. Multiple responses at flagged locations gave insight into reviewer consensus while their dispersed comments ensured breadth of spatial coverage. Reviewer comments (Appendix 3) informed model improvements and supplemented available occurrence data.

The experts provided an unbalanced review, commenting more on predicted habitat areas than predicted non-habitat areas. Though, as with other high elevation species, we required fewer reviewer comments to inform model improvements. Based on their feedback and our own review of model performance, we made the following changes:

- Create and add geomorphons for additional information to distinguish suitable ridgelines, summits, and slopes from unsuitable hollows and valleys.
- Update and then reevaluate NLCD land cover and all associated derived layers with the 2016 data.
- Force reevaluation of soil pH within the updated dataset given these have strong univariate signature (dropped from draft model due to multicollinearity).

Based on reviewer feedback, we also applied a mask to the final model. Under any of the following conditions, model predictions were overruled and converted to 0 probability of potential habitat: Open water, High density urban development, Impervious surface, Interior fields and ditches.

Figure 4. Binary classification of the draft model as presented to reviewers

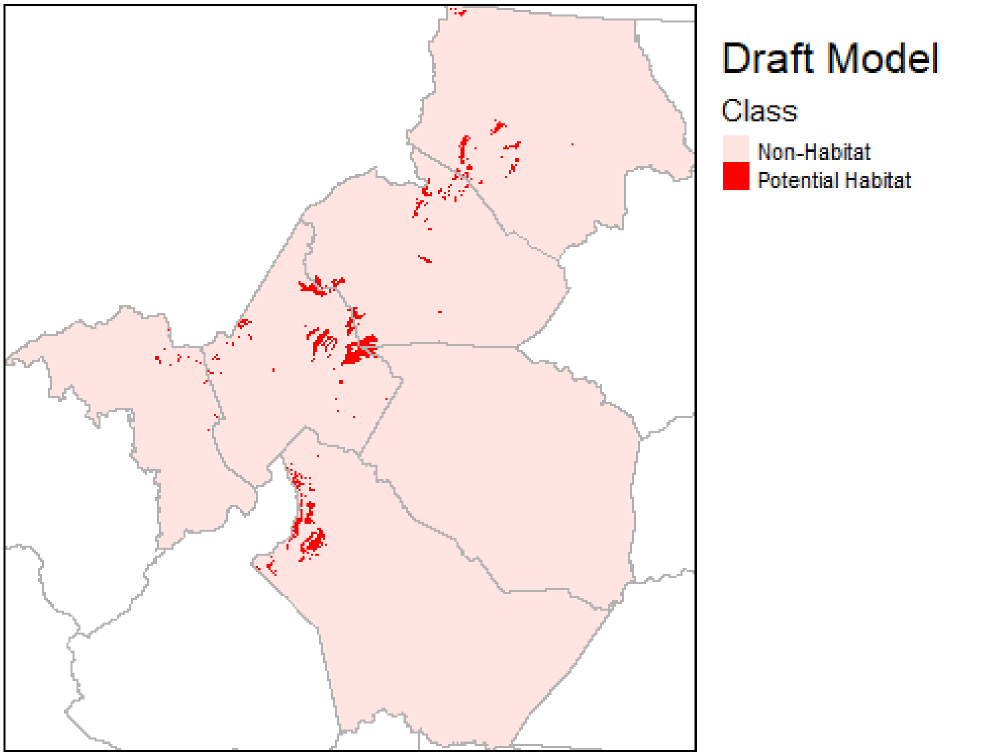


Figure 5. Locations and class of AGOL desktop reviewer comments.

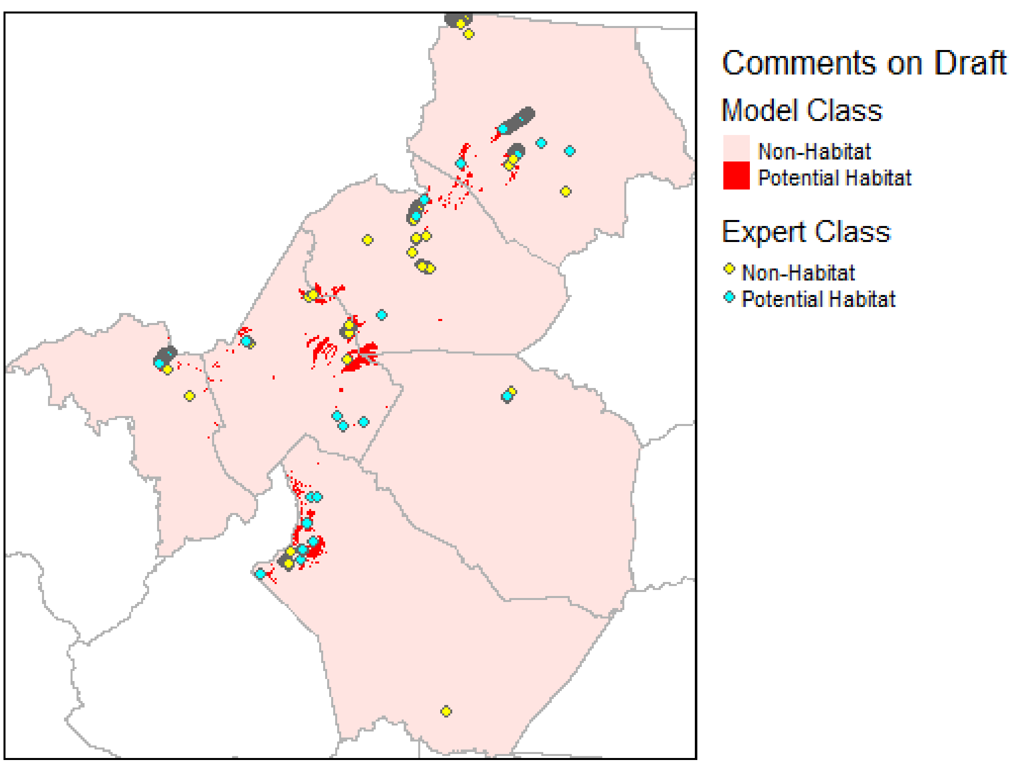
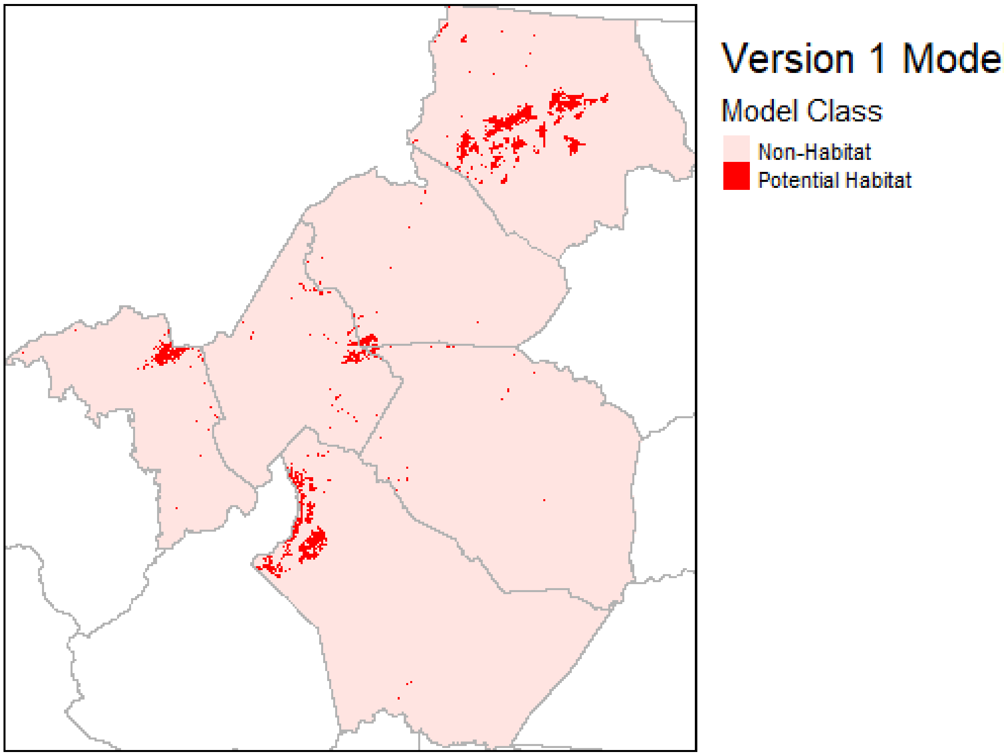


Figure 6. Binary classification of Version 1 of model. We assessed changes in model performance by comparing the accuracy statistics (based AGOL Review comments) of the Draft versus Version 1 model. We then used the binary classification to design a stratified sample for field assessment of the Version 1 model.



Accuracy Improvements: Draft to Version 1

We assessed model improvement from the draft to Version 1 by calculating the accuracy statistics of each based on the desktop review point and polygon location judgments. This was an assessment of the binary classification, not the probability prediction of the model; accuracy scores are dependent upon both the underlying model and the selected threshold(s).

Figure 7. Accuracy summary of Draft (left) and Version 1 binary (right) models.

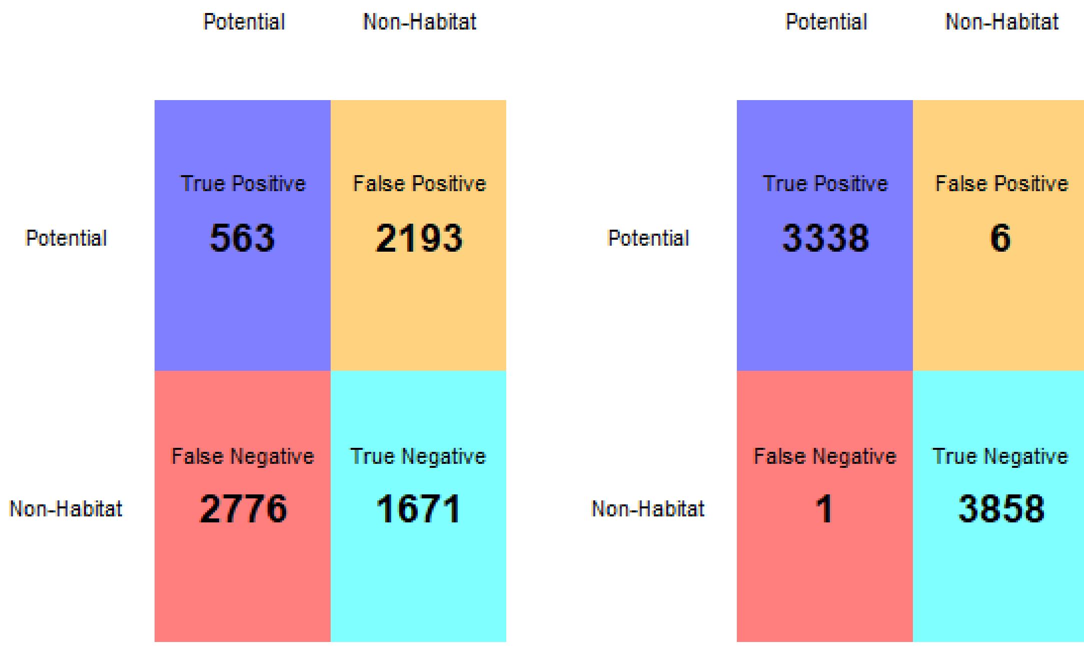


Table 3. Desktop review accuracy statistics based on the counts in the summary table.

Statistic	Draft	Version 1
Percent Correctly Classified	31.0	99.9
Sensitivity	0.2	1.0
Specificity	0.4	1.0

- *Percent Correctly Classified*: Sum of all True Positives and True Negatives divided by total number of review points.
- *Sensitivity*: Sum of all True Positives divided by sum of all points modeled as potential habitat. Lower numbers indicate bias towards calling everything habitat to avoid missing a single habitat location, but it means that any given site predicted to be potential habitat has a high likelihood of being a false prediction. A high sensitivity model is usually most useful where predicting non-habitat.
- *Specificity*: Sum of all True Negatives divided by sum of all points modeled as non-habitat. Lower numbers indicate bias towards calling everything non-habitat, even at the risk of missing one or two potential habitat sites. A high specificity model is usually most useful where predicting potential habitat.

Version 1 Model Field Assessment

No field assessment has yet been conducted on this model. As a high elevation species, expected interscetion of potential habitat with NCDOT projects is low.

Final Three-Level Classification of Version 1 Model for ATLAS

With the gathered data and in direct consultation with the field biologists, we assessed model performance and adjusted the thresholds to create a three-level version of the model for delivery to ATLAS. The three levels are: Low, Moderate, and High Probability of Potential Habitat (based on similarity of environmental conditions to those found at known occurrence locations). These levels represent the fact that given limited knowledge of species biology, continuously changing environments, and potential for gaps and error in both species and environment data, a model prediction dependent on remotely-sensed data can never predict species occurrence or habitat with absolute accuracy and precision. Thus, "Low" probability habitat represents regions and sites where biologists would be very surprised to find this species and its habitat (occurrence here should be extremely rare). In "High" probability habitat, biologists expect to frequently encounter areas that look like potential habitat based on visible environmental and vegetation community characteristics. The thresholds for this species are: Low-Moderate (0.36) and Moderate-High (0.76).

Table 4. Distribution of desktop review points across the Low, Moderate, and High classification of the predicted probability of Potential Habitat. The minimum, median, and maximum associated probability values are also shown. Note: The models never predict 0 probability of Potential Habitat; a 0 only occurs where model predictions are overwritten by an expert mask (e.g., open water, >85% impervious surface, etc.).

Predicted Class	Desktop Review	N	Min	Median	Max
Low	Non-Habitat	3857	0.000	0.008	0.349
Low	Potential Habitat	0	NA	NA	NA
Moderate	Non-Habitat	7	0.393	0.514	0.714
Moderate	Potential Habitat	22	0.616	0.717	0.758
High	Non-Habitat	0	NA	NA	NA
High	Potential Habitat	3317	0.764	0.995	1.000

Figure 8. Probability density of sites identified as "Potential Habitat" and "Non-Habitat" during desktop review of draft model. The desktop review data have been resampled by prediction class (n=200 each class, with replacement), to ensure balanced sample within each probability class. NHP data are shown below the x-axis. The correspondence of the experts' desktop judgments with the Version 1 model probability predictions reflects the fact that these same judgments informed model development.

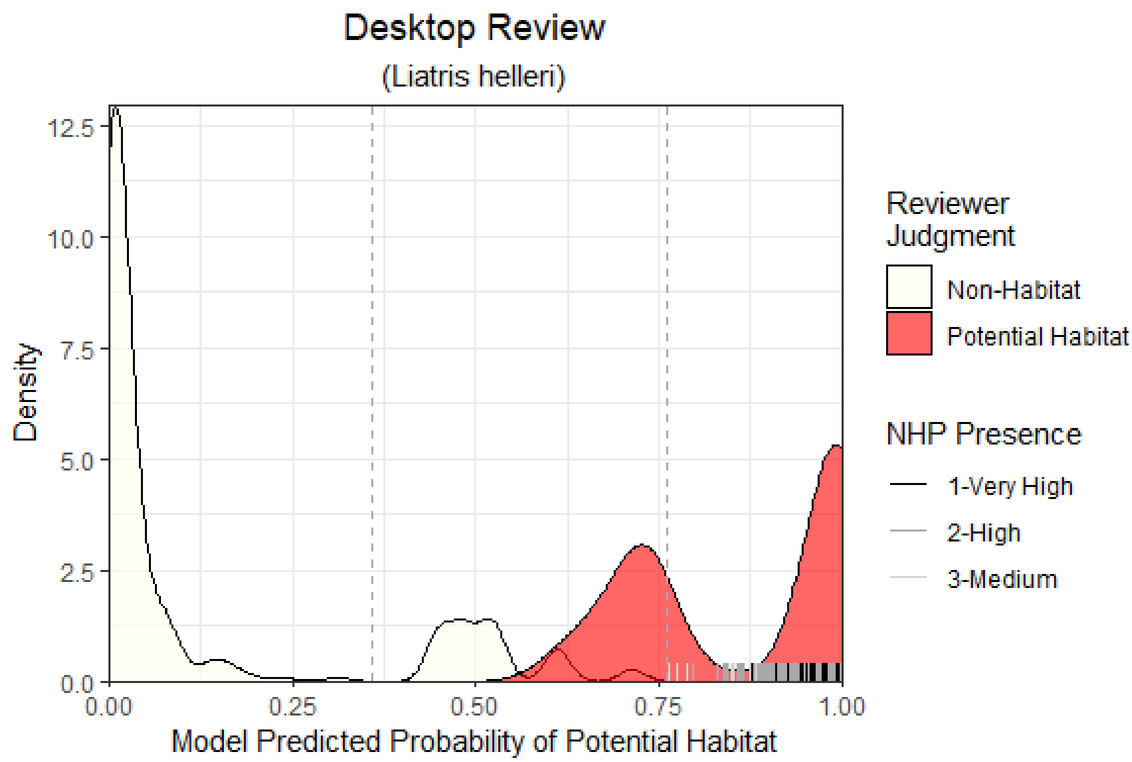
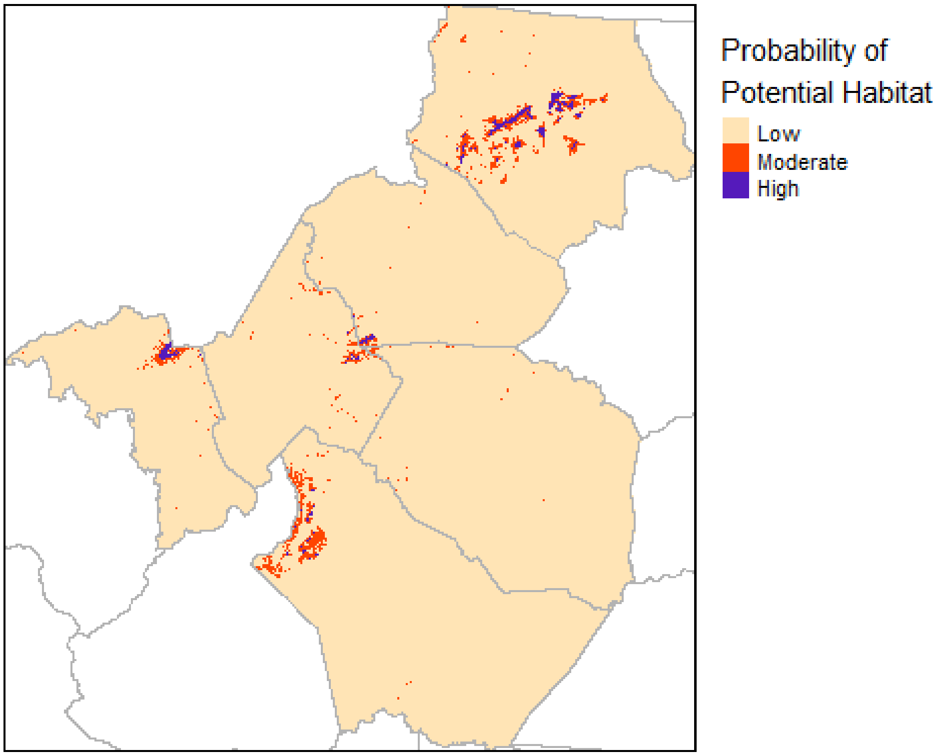


Figure 9. Final three-level map product approved based on all available observational data and discussions with field biologists.



Model Recommendations

No specific recommendations regarding environmental data layers. The performance difference between draft and this version is strongly influenced by the unbalanced review. Additional review comments and/or additional field data could be gathered to better evaluate model performance.

References

- Liaw A, Wiener M (2002) Classification and Regression by randomForest. R News 2(3) 18-22.
- Evans JS, Murphy MA (2018) rfUtilities. R package version 2.1-4, https://cran.r-project.org/package=rfUtilities.

Model R Code

Appendix 2 provides (1) the R files used for final data prep, models, model assessment, and report generation of this model, (2) associated reference data (environment layers lookup, species information lookup, and post-model mask lookup), and (3) a guide to these resources. General details of this model:

- R version 3.6.1 and R Studio version 1.2.1578
- Consultant internal model reference code: Liatris_helleri_Alt_WithMedNoAssocWithRev
- Core modeling packages: randomForest 4.6-14 and rfUtilities 2.1-4
- Training data:
  - Use "mediums" as presence to train model: TRUE
  - Use "associates" as presence to train model: FALSE
  - Use "target taxa" as pseudoabsence to train model: TRUE
  - Use reviewer judgments as habitat and non-habitat to train model: TRUE
  - Number of grid cells provided as presence: 4330
- Environmental data:
  - Number of environmental variables provided: 26
  - Test for multicollinearity and remove indicated variables?: YES
  - Use model selection procedures to improve model parsimony?: YES
  - Number of environmental variables in final model: 19
- Model parameters:
  - Number of trees: 501
  - Number of variables tested per split: 4
  - Model averaging: YES, 10 iterations, each with unique balanced sample of pseudoabsence
- Model evaluation:
  - Cross-validation performed: YES (out-of-bag method)
  - Significance testing performed: YES
    - Random OOB error: 0.501
    - Model OOB error: 0.021
- Final out-of-bag accuracy statistics (draft values in parentheses):
  - Percent Correctly Classified: 92.6 (90.5)
  - Area Under the Curve: 0.75 (0.9)
  - Kappa: 0.63 (0.6)
  - Sensitivity: 1 (0.9)
  - Specificity: 0.5 (1)