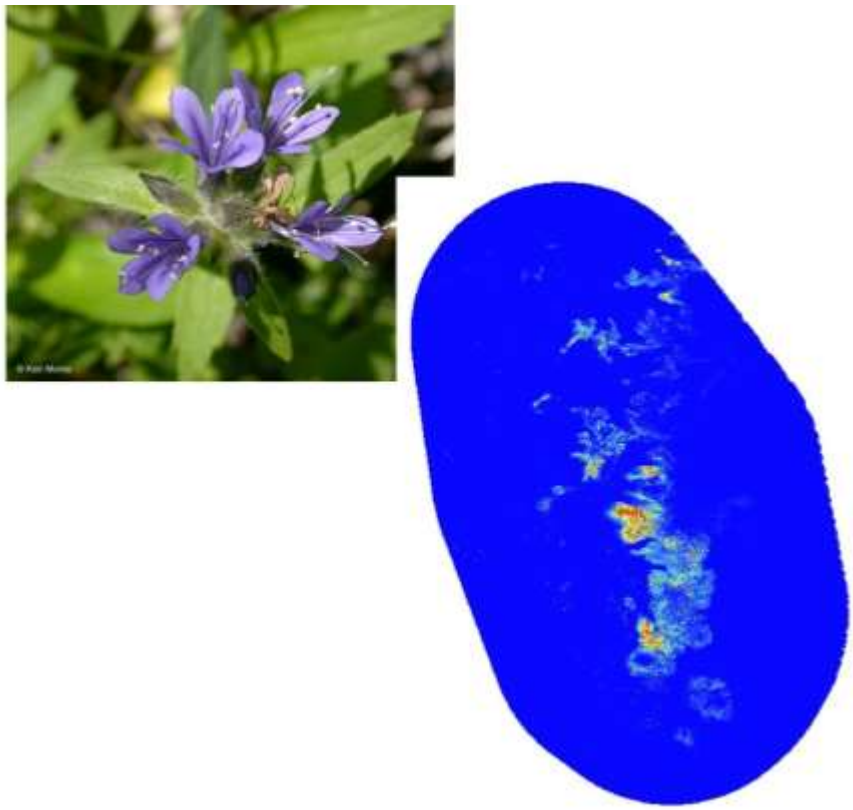
Habitat Modeling of Fire Associated Vascular Plant Species of Conservation Concern



2019

Report to the Bureau of Land Management, Medford District and US Forest Service, Rogue River-Siskiyou National Forest

Report prepared by Matt A. Bahm and Dana Ikeda

Institute for Applied Ecology

PREFACE

This report is the result of an agreement between the Institute for Applied Ecology (IAE) and federal agencies. IAE is a non-profit organization whose mission is conservation of native ecosystems through restoration, research and education. Our aim is to provide a service to public and private agencies and individuals by developing and communicating information on ecosystems, species, and effective management strategies and by conducting research, monitoring, and experiments. IAE offers educational opportunities through 3-4 month internships. Our current activities are concentrated on rare and endangered plants and invasive species.

Institute for Applied Ecology

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Cover photograph: *Collomia mazama* (Mt. Mazama collomia; ©2010 Keir Morse) and the current predicted distribution calculated in Maxent.

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EXECUTIVE SUMMARY

This report summarizes the results of species distribution models (SDMs) developed for 17 fire-dependent species of concern found in the Rogue River Valley. We used publicly available data for climatic and non-climatic variables to develop SDMs using Maxent. Models were evaluated using accepted procedures, field visits to a subset of locations for a subset of species, and subjective judgement regarding the utility of the map products for land management agency personnel.

Eight species models (*Adiantum jordanii, Arctostaphylos hispidula, Cupressus bakeri, Ericameria arborescens, Iliamna latibracteata, Rhamnus ilicifolia, Sidalcea malviflora* ssp. *patula, Trillium kurabayashii*) were determined to be of limited utility for management purposes. The remaining nine species models (*Calochortus howellii, Collomia mazama, Frasera umpquaensis, Horkelia tridentata* ssp. *tridentata, Lupinus tracyi, Rafinesquia californica, Silene serpentinicola, Solanum parishii, Sophora leachiana*) had high AUC values, strong model characteristics, and should provide valuable information to land managers in the region.

The maps included in the report are for supporting the text summaries, and should not be used to interpret in great detail. The original map files should be used for interpretation of model results and application for other land management agency uses.

Habitat Modeling of Fire Associated Vascular Plant Species of Conservation Concern

REPORT TO THE BUREAU OF LAND MANAGEMENT, MEDFORD DISTRICT AND US FOREST SERVICE, ROGUE RIVER-SISKIYOU NATIONAL FOREST

INTRODUCTION

Rare plant species, while often seemingly minor components of ecosystems, often possess functional traits that contribute to ecological functions like productivity, organic matter degradation, and extirpation can potentially alter biogeochemical and dynamic ecosystem processes (Mouillot et al. 2013). Rare species are vulnerable to extinction, with recent trends showing a decline in biodiversity and loss of rare species (Mouillot et al. 2013). Rare herbaceous plants are useful indicators of biodiversity due to the specificity of habitat and resources (Gilliam 2007).

In fire-dependent ecosystems of southern Oregon, rare plants are part of the herbaceous layer of many systems, and contribute to ecosystem biodiversity. Many of the rare herbaceous plants often are fire-adapted. With increases in severity of wildfires, it is becoming increasingly important to monitor the effects of these fires on rare plant species. Although fire-adapted, increasing severity and return-intervals could have negative impacts on rare plant species. A first step in protecting these species is to model current and potential habitats for these species.

Species distribution models (SDMs) that relate field habitat observations where species are found to environmental predictor variables to quantify species-environment relationships are a potential method to identify rare plant habitat (Guisan & Thuiller 2005). SDMs predict potential suitable habitat where species are likely to occur based on known locations, making the models useful for conservation projects. Maps of potential habitat suitability aid in management of rare, threatened, and endangered species by identifying sites for potential restoration, protection for species introduction, and can lead to discovery of new populations (Hernandez et al. 2006). Because absence data are often lacking, and when available can be of questionable value, presence-only data may be more reliable than presence-absence (Phillips et al. 2006).

The purpose of this project was to develop SDMs for 17 fire-dependent species of concern that are found in the Rogue River Basin. The models provide managers with information to help protect habitat for fire-dependent species found in this region, and can be used with other recent and future efforts to improve conservation efforts.

METHODS

Species Data

Species data for 17 fire associated vascular plant species (Table 1) were obtained from a variety of sources to obtain occurrences for the study region. BLM and USFS plant locations were provided Bryan Wender and Clint Emerson, respectively. Oregon Biodiversity Information Center (ORBIC, http://inr.oregonstate.edu/orbic), CalFlora (http://www.calflora.org/), NatureServe (http://www.natureserve.org/), and the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) provided additional plant locations. All plant descriptions included throughout the report are taken from Flora of the Pacific Northwest (Hitchcock and Cronquist 2018) and Flora of North America (1993+).

Environmental Variables

In an effort to characterize the current ecological niche and future climate niche of the 17 species analyzed here, we used a combination of soils, geology, vegetation, elevation (DEM) and climate data (Table 2). We used both current and future 23 bioclimate variables and downloaded from the AdaptWest website (https://adaptwest.databasin.org/pages/adaptwest-climatena) (AdaptWest Project 2015) based on methods described in Wang et al. (2016). Current variables were averaged between the time periods 1981 and 2010 and were at a 30 arc-second (~1 km) spatial resolution. All current environmental layers were spatially downscaled from 1km to 30m in order to match the high-resolution vegetation data. We used the bilinear interpolation method due to the balance of ease of use and accuracy (Lorenz et al. 2016; Araújo et al. 2011; Hijmans & Graham 2006).

Since correlated variables can lead to model overfitting and spurious results (Warren et al. 2014), we used the variable reduction method described in Warren et al. (2014). Specifically, all variables were included for initial model runs and variables with contribution scores less than 5% were removed from subsequent analyses. We used a Pearson's correlation analysis to test for variable correlations. If two variables were highly correlated (<70%), the variable with the higher contribution score was retained (Warren et al. 2014).

Model Calibration and Evaluation

We used MaxEnt version 3.4.1 (http://biodiversityinformatics.amnh.org/open_source/maxent/) to develop models of current distribution of suitable habitat of 17 plant species. MaxEnt is a machine learning algorithm which estimates a species ecological niche by finding the distribution with the maximum entropy subject to constraints by environmental variables chosen *a priori* (Philips et al. 2006, Philips & Dudik 2008). Furthermore, Maxent has been shown to be particularly robust with species with relatively few occurrence points (Wisz et al. 2008) and performs well compared with other presence-background algorithms (Elith et al. 2006, Evangelista et al. 2009, Kumar et al. 2009). Since the spatial extent in which background points are selected in Maxent can influence model performance (Phillips et al. 2009, VanDerWal et al. 2009), we restricted the selection of background points to the sampling extent using a Minimum Convex Polygon (Flory et al. 2012). We used a tenfold cross-validation method, which uses 90% of the data for model training and 10% for model testing for 10 iterations (Elith et al. 2010). Model performance was evaluated using the Area Under the receiver operating Curve (AUC) (Phillips et al. 2006, 2009). Linear, quadratic, product, hinge and threshold functions of predictor variables were

employed and variable importance was assessed using a jackknife analysis (Phillips et al. 2006). A binomial probability test was used to assess the accuracy of each predicted distribution compared to that expected by chance (Phillips et al. 2006). We evaluated variable importance by examining the permutation importance each bioclimatic variable had on the model building process. The output format was specified to a logistic form for easy interpretation, in which all model results are a probability of presence between 0 and 1 (Phillips et al. 2006).

In the fall of 2018 and 2019, we visited 14 field locations predicted by the models. We visited two locations each for *Calochortus howellii*, *Cupressus bakeri*, and *Iliamna latibracteata*, and four locations each for *Frasera umpquaensis* and *Solanum parishii*. Field visits were to document potential habitat for each species at the location(s), and were not intended to be surveys for the individual species.

TABLE 1. FIRE ASSOCIATED PLANT SPECIES INCLUDING FOR MODELING DITRIBUTIONS USING MAXENT. PLANT NAMES FOLLOW USDA PLANTS DATABASE (HTTPS://PLANTS.USDA.GOV).

SCIENTIFIC NAME	COMMON NAME	CODE	GROUP	FAMILY	DURATION	GROWTH HABIT
Adiantum jordanii	California maidenhair	ADJO	Fern	Pteridaceae	Perennial	Forb/herb
Arctostaphylos hispidula	Gasquet manzanita	ARHI5	Dicot	Ericaceae	Perennial	Shrub
Calochortus howellii	Howell's mariposa lily	CAHO11	Monocot	Liliaceae	Perennial	Forb/herb
Collomia mazama	Mt. Mazama collomia	COMA	Dicot	Polemoniaceae	Annual/Perennial	Forb/herb
Cupressus bakeri	Modoc cypress	CUBA	Gymnosperm	Cupressaceae	Perennial	Tree
Ericameria arborescens	goldenfleece	ERAR27	Dicot	Asteraceae	Perennial	Shrub
Frasera umpquaensis	Umpqua green-gentian	FRUM2	Dicot	Gentianaceae	Perennial	Forb/herb
Horkelia tridentate ssp. tridentata	threetooth horkelia	HOTR	Dicot	Rosaceae	Perennial	Forb/herb
Iliamna latibracteata	California wild hollyhock	ILLA2	Dicot	Malvaceae	Perennial	Forb/herb
Lupinus tracyi	Tracy's lupine	LUTR	Dicot	Fabaceae	Perennial	Forb/herb
Rafinesquia californica	California plumeseed	RACA	Dicot	Asteraceae	Annual	Forb/herb
Rhamnus ilicifolia	hollyleaf redberry	RHIL	Dicot	Rhamnaceae	Perennial	Shrub, Tree
Sidalcea malviflora ssp. *patula*	Siskiyou checkerbloom	SIMAP	Dicot	Malvaceae	Perennial	Forb/herb, Subshrub
Silene serpentinicola	serpentine Indian pink	SISE10	Dicot	Caryophyllaceae	Perennial	Forb/herb
Solanum parishii	Parish's nightshade	SOPA	Dicot	Solanaceae	Perennial	Forb/herb, Subshrub
Sophora leachiana	western necklacepod	SOLE3	Dicot	Fabaceae	Perennial	Tree
Trillium kurabayashii	giant purple wakerobin	TRKU	Monocot	Liliaceae	Perennial	Forb/herb

TABLE 2. DESCRIPTION, TYPE AND SOURCE OF VARIABLES USED TO MODEL PREDICTED DISTRIBUTION OF 17 FIRE DEPENDENT RARE PLANTS.

Variable	Description	Original spatial resolution	Variable type	Source
Climate[1]				
MAT	mean annual temperature (°C)	1km	continuous	Climate wNA
MWMT	mean temperature of the warmest month (°C)	1km	continuous	Climate wNA
MCMT	mean temperature of the coldest month (°C)	1km	continuous	Climate wNA
TD	difference between MCMT and MWMT, as a measure of continentality (°C)	1km	continuous	Climate wNA
MAP	mean annual precipitation (mm)	1km	continuous	Climate wNA
MAR	mean monthly temperature ranges (°C)	1km	continuous	Climate wNA
MSP	mean summer (May to Sep) precipitation (mm)	1km	continuous	Climate wNA
AHM	annual heat moisture index, calculated as (MAT+10)/(MAP/1000)	1km	continuous	Climate wNA
SHM	summer heat moisture index, calculated as MWMT/(MSP/1000)	1km	continuous	Climate wNA
DD_0	degree-days below 0°C (chilling degree days)	1km	continuous	Climate wNA
DD5	degree-days above 5°C (growing degree days)	1km	continuous	Climate wNA
DD_18	degree-days below 18°C	1km	continuous	Climate wNA
DD18	degree-days above 18°C	1km	continuous	Climate wNA
NFFD	the number of frost-free days	1km	continuous	Climate wNA
bFFP	the julian date on which the frost-free period begins	1km	continuous	Climate wNA
eFFP	the julian date on which the frost-free period ends	1km	continuous	Climate wNA
FFP	frost-free period	1km	continuous	Climate wNA
PAS	precipitation as snow (mm)	1km	continuous	Climate wNA
EMT	extreme minimum temperature over 30 years	1km	continuous	Climate wNA
EXT	extreme maximum temperature over 30 years	1km	continuous	Climate wNA
Eref	Hargreave's reference evaporation	1km	continuous	Climate wNA
CMD	Hargreave's climatic moisture index	1km	continuous	Climate wNA
RH	mean annual relative humidity (%)	1km	continuous	Climate wNA
Tave_wt	winter (Dec to Feb) mean temperature (°C)	1km	continuous	Climate wNA
Tave_sm	summer (Jun to Aug) mean temperature (°C)	1km	continuous	Climate wNA
PPT_wt	winter (Dec to Feb) precipitation (mm)	1km	continuous	Climate wNA

PPT_sm	summer (Jun to Aug) precipitation (mm)	1km	continuous	Climate wNA
Non-Climate				
DEM[2]	Digital Elevation Model	30m	continuous	Open Topo
GNN[3]	Vegetation	30m	categorical	GNN & GAP
Soil[4]	Soils	0.02 Decimal Degree	continuous	STATSGO
Geology[5]	Geology	0.02 Decimal Degree	categorical	USGS

[1]Data downloaded from: https://adaptwest.databasin.org/pages/adaptwest-climatena
[2]Data downloaded from: http://opentopo.sdsc.edu/raster?opentopoID=OTSRTM.082015.4326.1
[3]Data downloaded from: https://lemma.forestry.oregonstate.edu/data
[4]Data downloaded from: https://sdmdataaccess.sc.egov.usda.gov
[5]Data downloaded from: https://mrdata.usgs.gov/catalog/

RESULTS

Adiantum jordanii

Species Description

Adiantum jordanii (California maidenhair), a pteridophyte, is a fern that is native to Oregon, California, and Baja California (Mexico). *A. jordanii* sporulates early spring-midsummer; its habitat includes seasonally moist, shaded, rocky banks, canyons, and ravines [elevation: 0-1000 m].

Model Results

The AUC converged to 0.9174 [AUC Standard Deviation (SD) = 0.0141] and 0.9088 (SD = 0.0162) for the final *A. jordanii* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, eFFP (36.992%), winter precipitation (13.747%), GNN vegetation (11.461%), and geology (9.669%) had the highest percent contribution. When considering only climate variables in the model, eFFP (31.755%) and winter precipitation (24.229%) had the highest percent contribution.

The model(s) show high probability of occurrence accurately centered around the presence locations for the southern portion of the *A. jordanii* range, but declines in the northern portions of the range (Figure 1).

Implications for Management and Conservation Efforts

Although the model had a relatively high AUC value, the utility of the model for managing the species in the Rogue River Valley is likely limited. The strength of the model is restricted to the more southerly portions of the range, with little area for high probability of occurrence predicted in the more northern populations (Figure 1). This could be the result of the more northerly populations occupying less suitable habitats near the edge of the species range, lower numbers of populations in the northern portion of the range limited the influence on the overall model, and/or lack of detailed more detailed habitat parameters that could be used in the model(s).

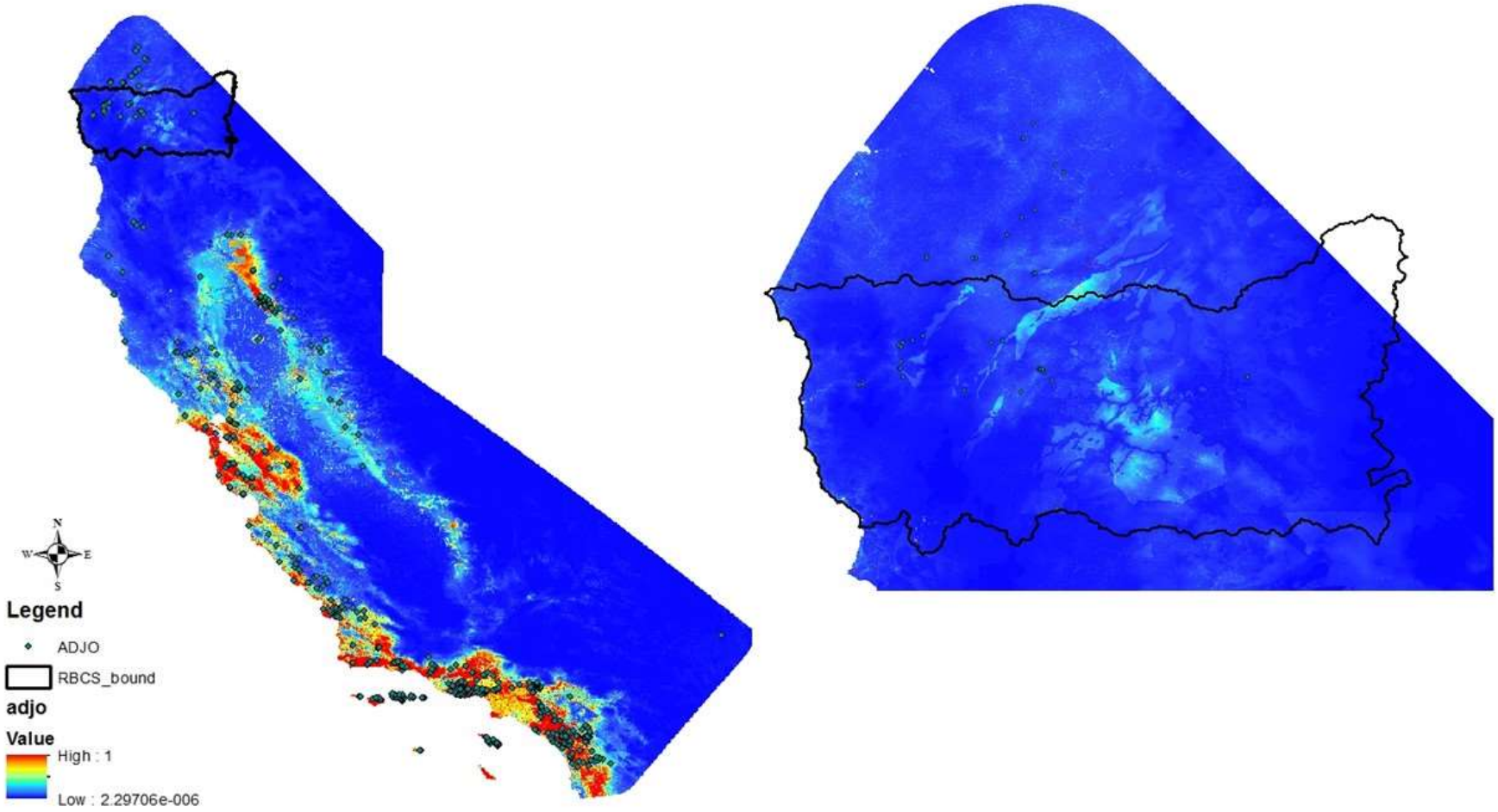

FIGURE 1. PREDICTED DISTRIBUTION OF *ADIANTUM JORDANII* THROUGHOUT ITS RANGE AND IN THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Arctostaphylos hispidula

Species Description

Arctostaphylos hispidula (Gasquet manzanita) is a member of the Ericaceae family. The species worldwide ranges from Curry County, Oregon south through Humboldt County, California with disjunct populations in northern Sonoma County, California. The plant mostly grows in open rocky conditions where ultramafic serpentine soils have dictated vegetative assemblages. It also is found in non-serpentine situations on coastal mountain balds dominated by postfire brushfields. *A. hispidula* blooms from March to April.

Model Results

The AUC converged to 0.8738 (SD = 0.0501) and 0.9003 (SD = 0.0404) for the final *A. hispidula* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, GNN vegetation (42.547%), winter precipitation (23.263%), AHM (7.744%), geology (7.513%), and frost-free period (5.199%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, winter precipitation (55.473%) and TD (10.713%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show high probability of occurrence centered around the presence locations for portions of the *A. hispidula* range, with much of the predicted high probability of occurrence areas near the west-central portion of the Rogue River Basin (Figure 1Figure 2). While the model shows other potential areas of high probability of occurrence, they are often very small, and show minimal suitable habitat outside of the known species occurrences (Figure 2).

Implications for Management and Conservation Efforts

Although the model had a relatively high AUC value, the utility of the model for managing the species in the Rogue River Valley is likely limited. The model predicted little area for high probability of occurrence, with several documented occurrences not included within the predicted area (Figure 2). This could be the result of *A. hispidula* being found in open habitats on both serpentine and non-serpentine areas. GNN had the highest percent contribution and the model seems to show predicted highly suitable habitat in areas that follow closely with open habitats in the GNN model.

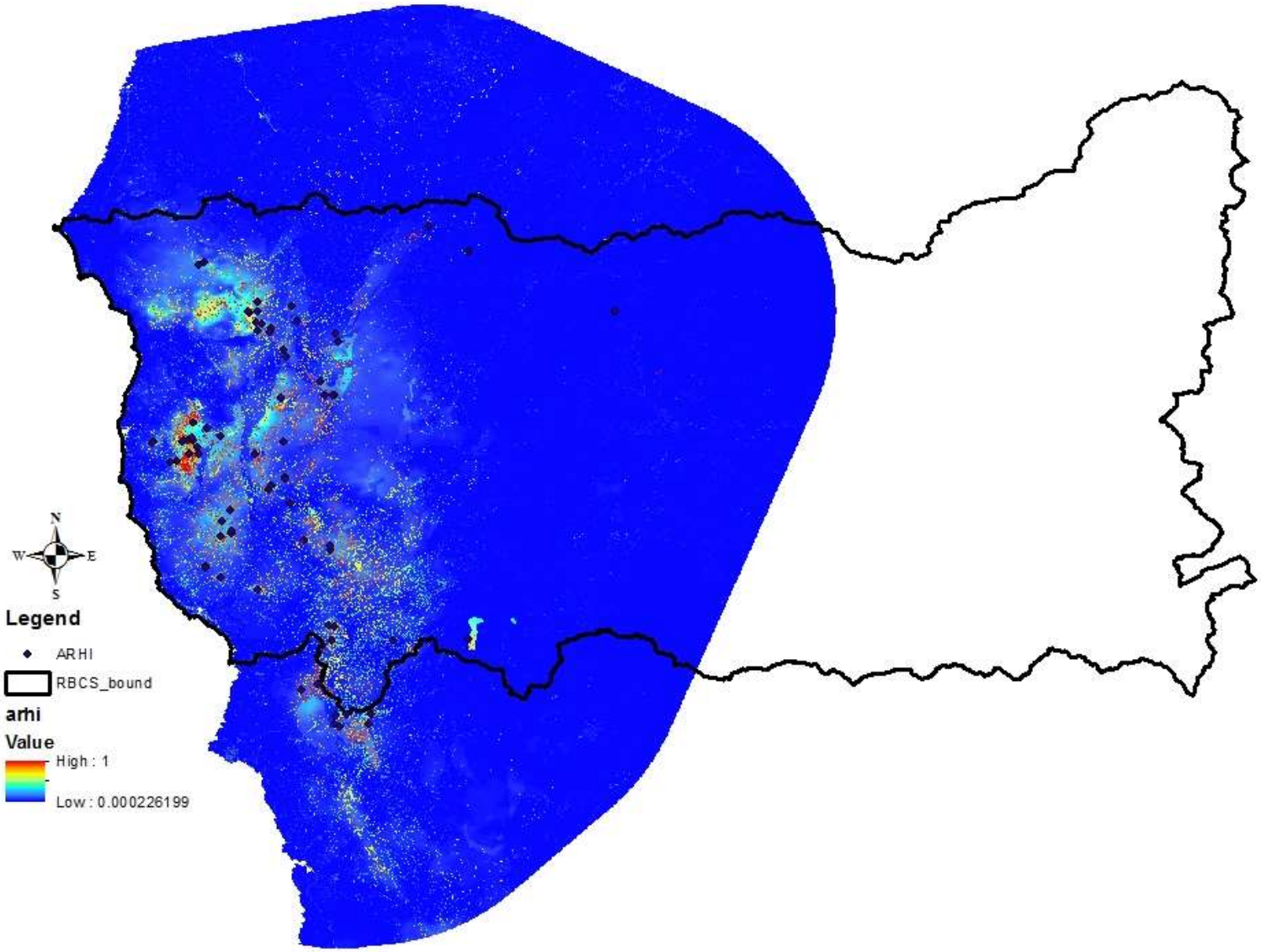

FIGURE 2. PREDICTED DISTRIBUTION OF *ARCTOSTAPHYLOS HISPIDULA* IN THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Calochortus howellii

Species Description

Calochortus howellii (Howell's mariposa lily) is a member of the Liliaceae family. Populations of *C. howellii* are concentrated along the Illinois River drainage in southwest Oregon. The northernmost occurrence is located a few miles west of Selma, with populations extending south along the Illinois to within a few miles of the California border. *C. howellii* is typically found on dry, rocky slopes with serpentine derived soils in the Illinois River valley. These soils are wet in early spring as plants emerge, but dry quickly as the season progresses. *C. howellii* blooms in June and July.

Model Results

The AUC converged to 0.9721 (SD = 0.0097) and 0.9634 (SD = 0.0128) for the final *C. howellii* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, soils (50.201%), eFFP (23.140%), winter precipitation (7.428%), and GNN vegetation (5.986%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, eFFP (41.371%) and winter precipitation (13.471%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence accurately centered around the presence locations for *C. howellii*, with minimal potential habitat outside of known locations (Figure 3).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations, with the exception of a single disjunct population to the northeast. Field visits to two areas modeled as high probability of occurrence were found to be on dry, rocky slopes that are indicative of *C. howellii* habitat. The main area of the predicted habitat provides a good indication of the habitat available for the species in that region (Figure 3). The outlying population should be re-surveyed to confirm the species, and if so, habitat parameters should be recorded to allow comparison to the main concentration of populations. If the population is confirmed, suitable habitats between the populations could be surveyed to identify any previously unidentified populations. If new populations are located in the area, models should be recalculated incorporating the new data.

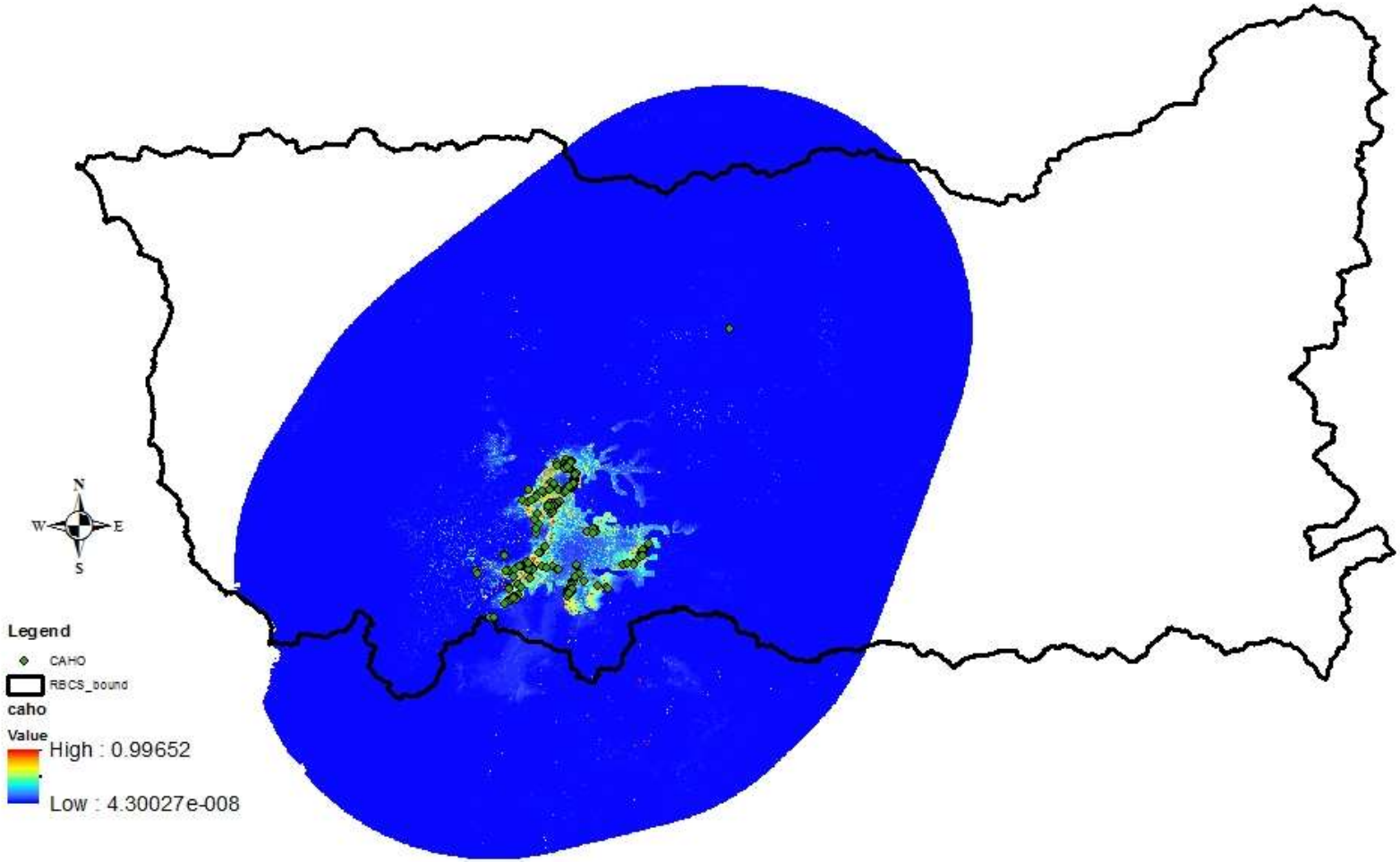

FIGURE 3. PREDICTED DISTRIBUTION OF *CALOCHORTUS HOWELLII* IN THE ROGUE RIVER BASIN (ENCOMPASSES ENTIRE KNOWN RANGE OF SPECIES) FOR MODELS CONTAINING ALL VARIABLES.

Collomia mazama

Species Description

Collomia mazama (Mt. Mazama collomia) is a member of the Polemoniaceae family. C. *mazama* is endemic to Crater Lake NP and adjacent lands on the Rogue River and Winema National Forests (USFS). It is a perennial species primarily restricted to the open woods and meadows of the lodgepole pine and true fir forest communities of southern Oregon's Cascade Range. C. *mazama* blooms from June through September.

Model Results

The AUC converged to 0.9681 (SD = 0.0105) and 0.9703 (SD = 0.0107) for the final C. *mazama* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, precipitation as snow (24.266%), geology (17.959%), soils (15.020%), GNN vegetation (12.608%), eFFP (7.407%), and winter precipitation (6.579%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, precipitation as snow (45.302%), eFFP (22.792%) and mean summer precipitation (10.425%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence accurately centered around the presence locations for C. *mazama*, with minimal potential habitat outside of known locations (Figure 4).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations. The area of the predicted habitat provides a good indication of the habitat available for the species in that region (Figure 4). There are some areas of suitable habitat predicted away from documented populations that could be surveyed, but the majority is only predicted as moderately suitable.

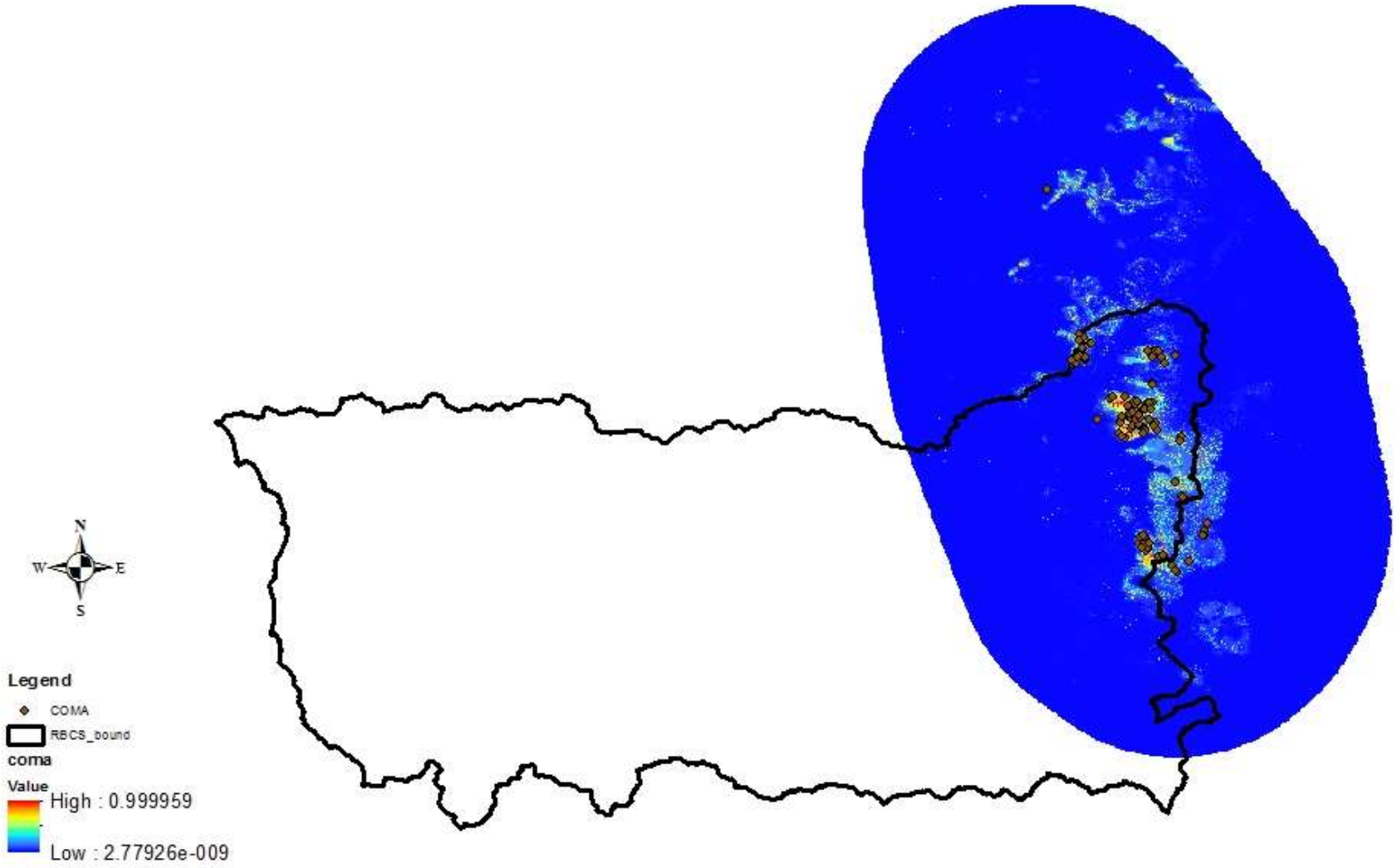

FIGURE 4. PREDICTED DISTRIBUTION OF *COLLOMIA MAZAMA* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Cupressus bakeri

Species Description

Cupressus bakeri (Modoc cypress) is a member of the Cupressaceae family. C. *bakeri* occurs in Oregon and California in mixed evergreen forests [elevation: 1100-2000 m]. In the Siskiyou Mountains, C. *bakeri* occurs on serpentine soils; in the Sierra Nevada and Cascade Range, it occurs on basic volcanic rock. C. *bakeri* is a fire-adapted, fire-dependent species; reproduction is usually restricted to burned sites.

Model Results

The AUC converged to 0.7708 (SD = -0.3082) for the final C. *bakeri* models containing all variables. Models containing climate only variables were unable to converge on a suitable model, and thus are no included for C. *bakeri*. Of the parameters used in the model containing all variables, GNN vegetation (62.412%), soils (25.860%), and geology (10.604%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables..

The model shows high probability of occurrence centered around the presence locations for the southern portion of the C. *bakeri* range, while declining in the northern portions of the range (Figure 5). Overall, the model suggest little potential habitat outside of the currently know locations (Figure 5).

Implications for Management and Conservation Efforts

The model had a relatively low AUC value, did not encompass all documented populations, and the utility for managing the species in the Rogue River Valley is likely limited. Field visits to two areas modeled as high probability of occurrence were found to be in unsuitable habitats dominated by Douglas fir (*Pseudotsuga menziesii*). The low utility of the model could be due to the difference in habitats between the OR and CA populations.

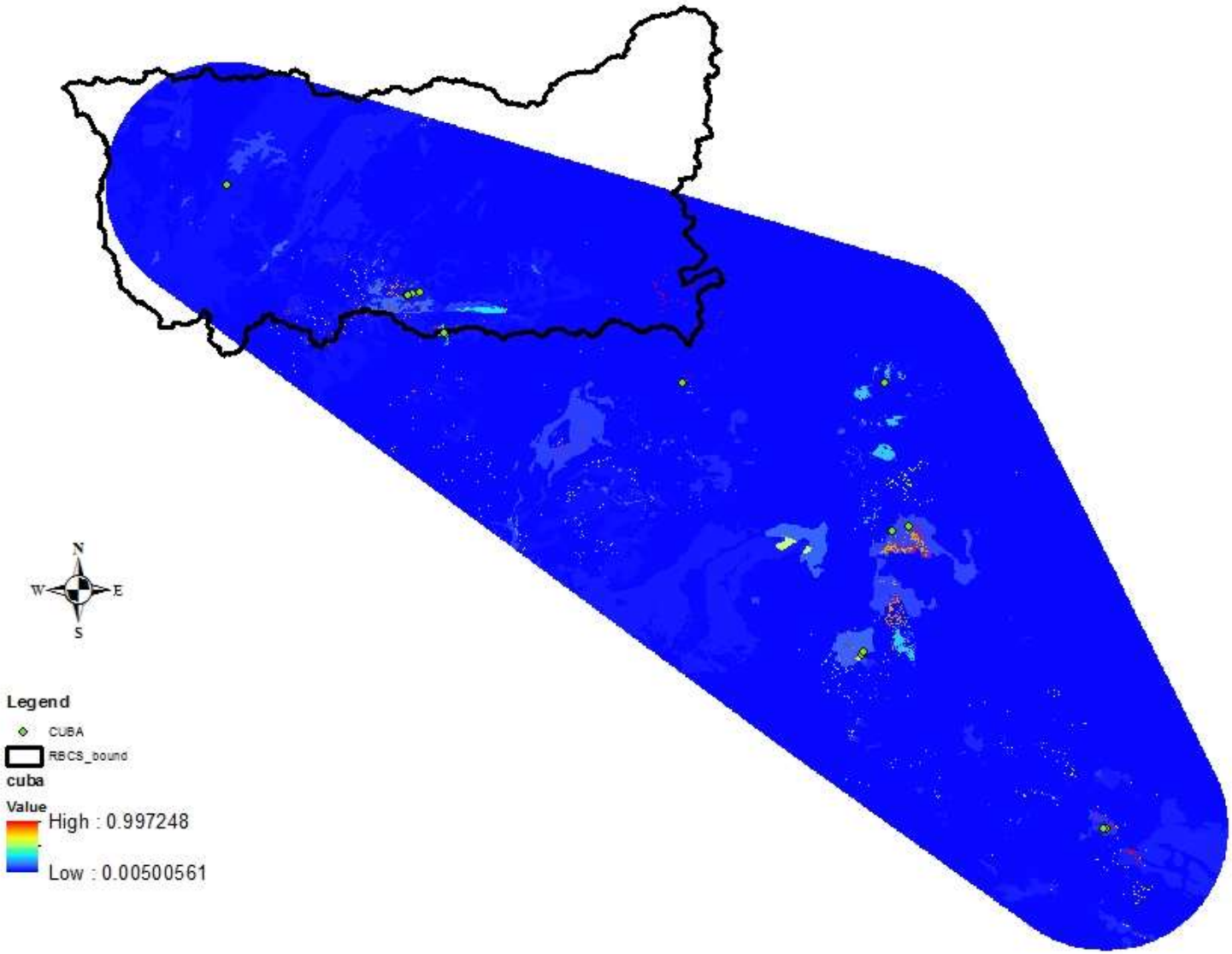

FIGURE 5. PREDICTED DISTRIBUTION OF *CUPRESSUS BAKERI* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Ericameria arborescens

Species Description

Ericameria arborescens (goldenfleece) is a member of the Asteraceae family. *E. arborescens* occurs in California and southwestern Oregon, where it grows in woodland, open forest, and chaparral, often in burned areas [elevation: generally < 1700 m]. *E. arborescens* flowers from August to September.

Model Results

The AUC converged to 0.9134 (SD = 0.0295) and 0.8507 (SD = 0.0698) for the final *E. arborescens* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, GNN vegetation (64.753%), soils (13.335%), geology (11.668%), and bFFP (6.897%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, bFFP (48.425%), winter precipitation (8.387%), and degree days over 18C (8.212%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show the predicted probability of occurrence accurately centered around the presence locations for *E. arborescens*, with minimal potential habitat outside of known locations (Figure 6).

Implications for Management and Conservation Efforts

Although the model had a relatively high AUC value, the utility of the model for managing the species in the Rogue River Valley is likely limited. Most of the documented populations are included in the areas predicted as highly suitable, with the exception of two populations, but the highly suitable areas are small and scattered throughout the area (Figure 6). This makes interpretation difficult from a management perspective when trying to determine areas to protect.

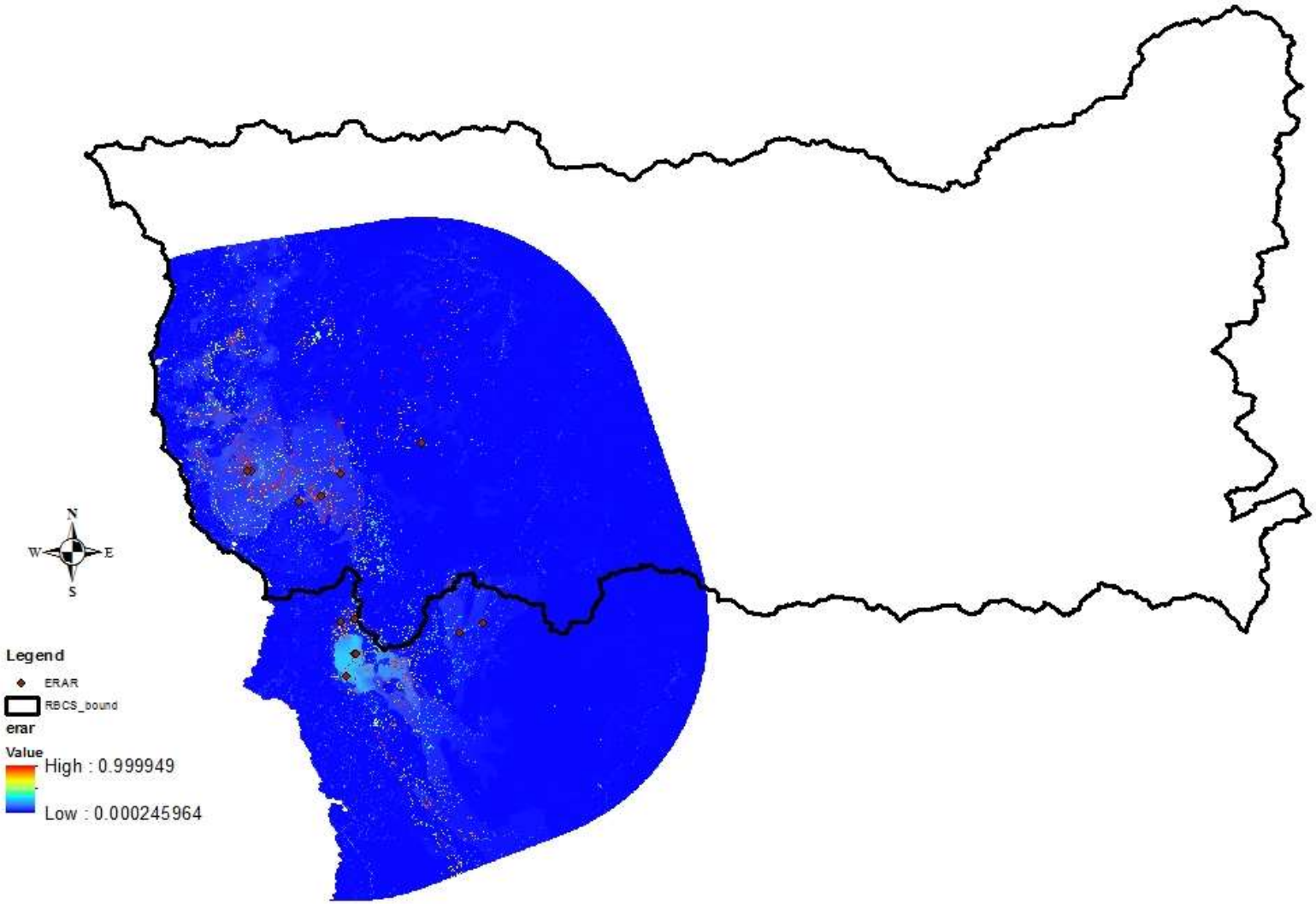

FIGURE 6. PREDICTED DISTRIBUTION OF *ERICAMERIA ARBORESCENS* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Frasera umpquaensis

Species Description

Frasera umpquaensis (Umpqua green-gentian) is a member of the Gentianaceae family. *F. umpquaensis* occurs in northwestern California and southwestern Oregon. It grows in chaparral, lower montane coniferous forest, meadows and seeps, and North Coast coniferous forest mountain meadows [elevation: 1700--1900 m]. *F. umpquaensis* flowers from July to August.

Model Results

The AUC converged to 0.9732 (SD = 0.0128) and 0.9700 (SD = 0.0149) for the final *F. umpquaensis* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, soils (25.904%), precipitation as snow (24.447%), geology (20.289%), and GNN vegetation (13.359%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, precipitation as snow (34.478%), mean summer precipitation (19.607%), and mean annual relative humidity (14.116%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence accurately centered around the presence locations for *F. umpquaensis* (Figure 7). While there is additional predicted moderate probability of occurrence outside of known locations for the west-central portion of the population, suitable habitat appears to be limited in the more northern populations (Figure 7).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations. Four areas predicted as moderately suitable in the northwest portion were surveyed and found to contain some features of suitable habitats. Although some features were documented, the large area of potential moderately suitable habitat (and likely the other smaller areas) without any documented populations in the Rogue River Valley should be of lower priority than the areas encompassing the documented populations (Figure 7). The areas modeled as moderately suitable could be surveyed to determine if undocumented *F. umpquaensis* exist, and the model(s) recalculated as new data is added. The populations in the northeast of the Rogue River Valley are included in areas that the model predicted as highly suitable (Figure 7).

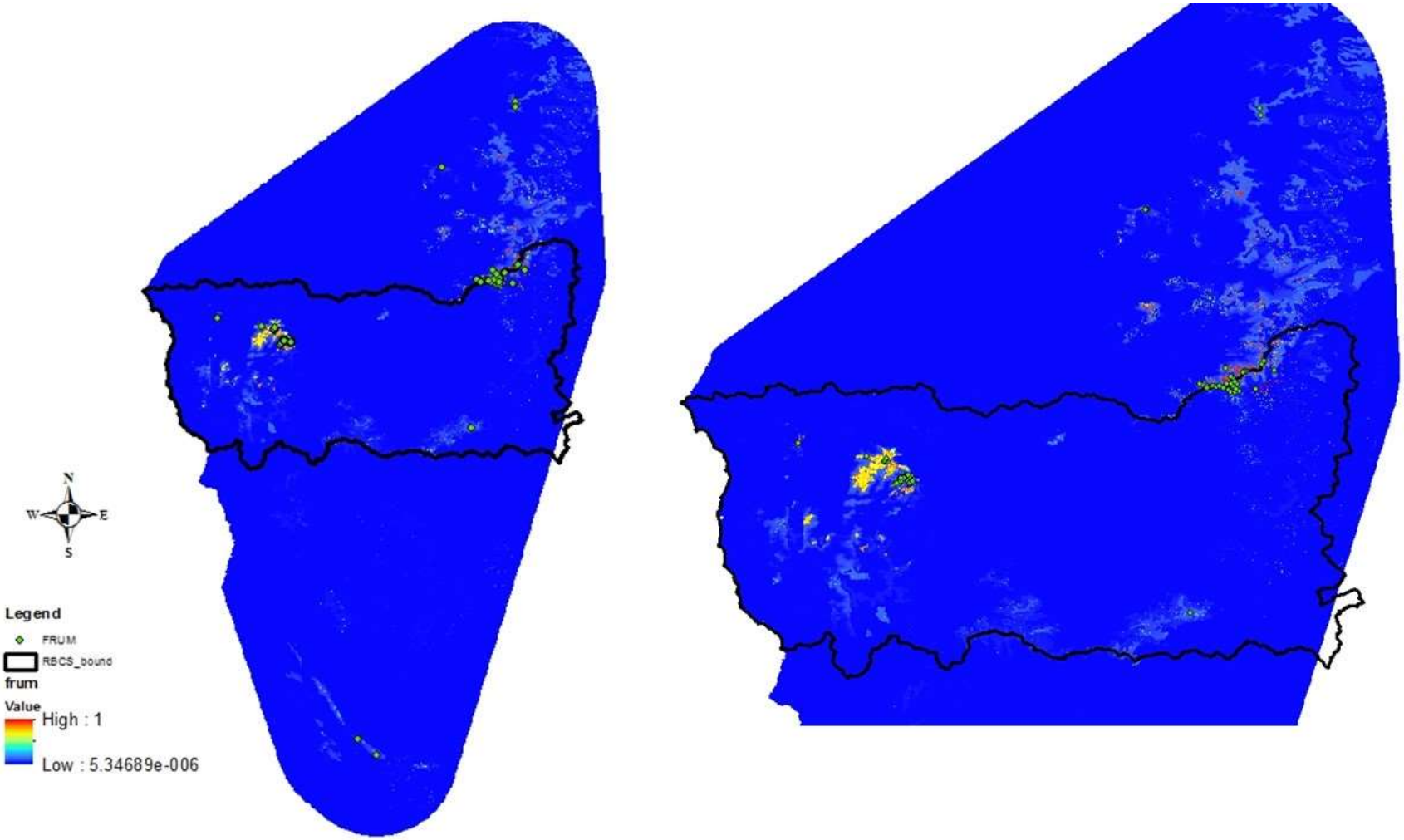

FIGURE 7. PREDICTED DISTRIBUTION OF *FRASERA UMPQUAENSIS* THROUGHOUT ITS RANGE AND IN THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Horkelia tridentata ssp. *tridentata*

Species Description

Horkelia tridentata (threetooth horkelia) is a member of the Rosaceae family. *H. tridentata* occurs throughout the Cascade Mountains and Sierra Nevada of California, and barely extends into southern Oregon near Ashland, Josephine County. *H. tridentata* grows in open areas, primarily in sagebrush communities and conifer woodlands, mainly on granitic or volcanic soils [elevation: 300--2500 m]. *H. tridentata* flowers from April to August.

Model Results

The AUC converged to 0.9912 (SD = 0.0031) and 0.9682 (SD = 0.0108) for the final *H. tridentata* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, geology (37.641%), soils (28.298%), GNN vegetation (24.821%), and degree days below 0C (7.408%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, mean summer precipitation (18.301%), mean annual relative humidity (17.199%), degree days below 0C (12.645%), and mean monthly temperature range (11.702%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence accurately centered around the presence locations for *H. tridentata*, with small disjunct potential low to moderate probability of occurrence areas predicted (Figure 8).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations. The area of the predicted habitat provides a good indication of the habitat available for the species in that region (Figure 8). There are some areas of suitable habitat predicted away from documented populations that could be surveyed, but the majority is only predicted as moderately to minimally suitable.

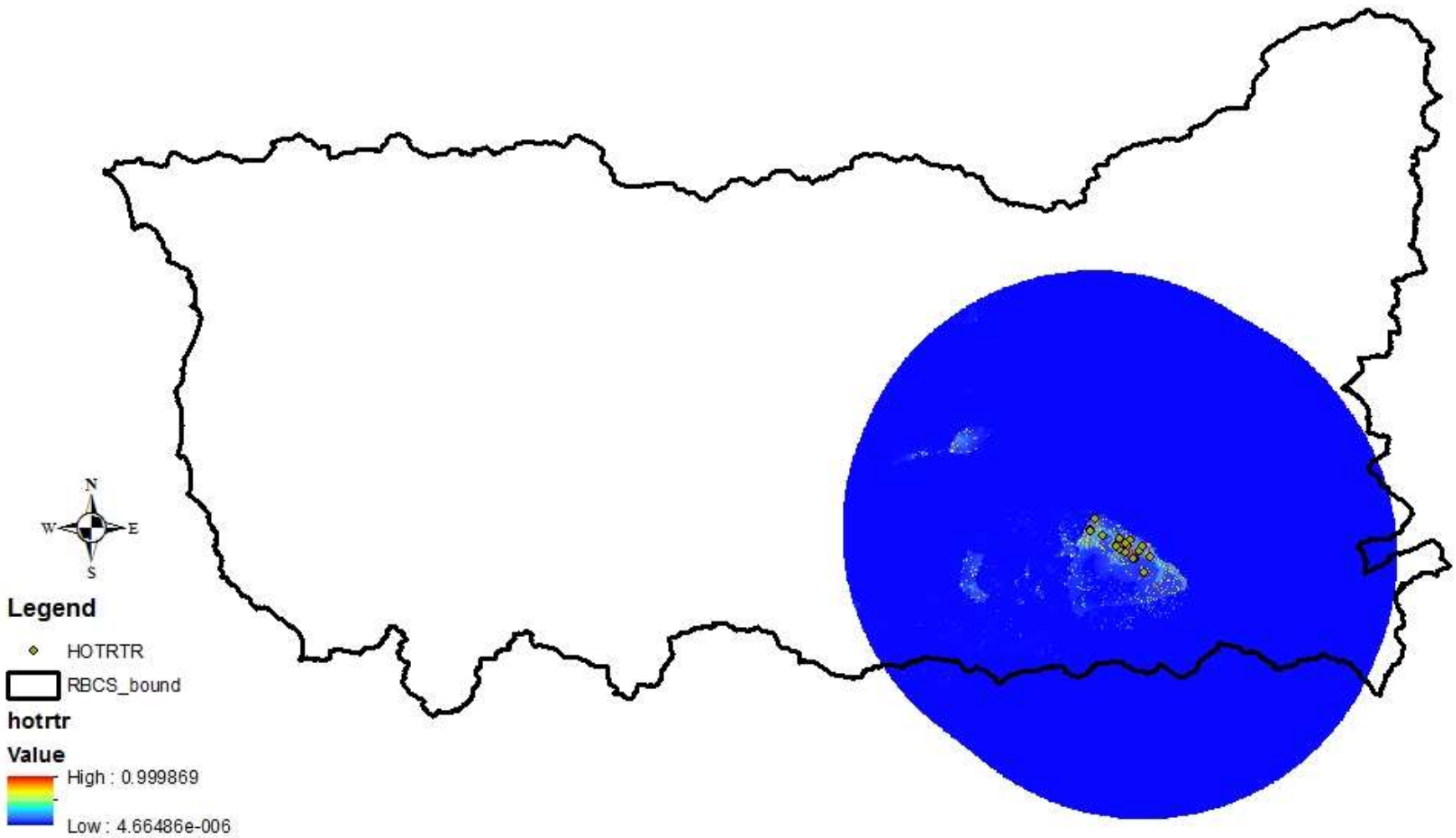

FIGURE 8. PREDICTED DISTRIBUTION OF *HORKELIA TRIDENTATA* VAR. *TRIDENTATA* IN THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Iliamna latibracteata

Species Description

Iliamna latibracteata (California wild hollyhock) is a member of the Malvaceae family. *I. latibracteata* occurs in northwestern California and southwestern Oregon (i.e. Curry and Josephine Counties). Habitat for *I. latibracteata* includes chaparral (montane), lower montane coniferous forest, North Coast coniferous forest (mesic), and riparian scrub (streambanks) [elevation: 500-2000 m]; it often occurs in burned areas. *I. latibracteata* blooms from June to August.

Model Results

The AUC converged to 0.9021 (SD = 0.0328) and 0.8905 (SD = 0.0390) for the final *I. latibracteata* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, soils (34.369%), GNN vegetation (29.747%), geology (9.302%), and TD (5.212%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, TD (16.706%), precipitation as snow (15.940%), mean annual relative humidity (11.551%), summer precipitation (11.373%), and eFFP (7.665%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence accurately centered around the presence locations for the central portion of the *I. latibracteata* range, but only low to moderate probability of occurrence throughout the remainder of the range, including areas with many documented occurrences (Figure 9). There are several areas of potential high probability of occurrence predicted in areas with no documented occurrences (Figure 9).

Implications for Management and Conservation Efforts

Although the model had a moderately high AUC value, the utility of the model for managing the species in the Rogue River Valley is likely limited. Two areas predicted as highly suitable in the northwest portion were surveyed and found to fit the general habitat description(s) for *I. latibracteata*. Although general habitats were documented, the large area of potential highly suitable habitat without any documented populations in the Rogue River Valley should be used with caution. Although there are a cluster of documented populations at the southwest portion of the area predicted as highly suitable (Figure 9), there are also documented populations in areas with little to no suitable habitat predicted and areas of predicted high suitability that are disjucnt from documented populations.

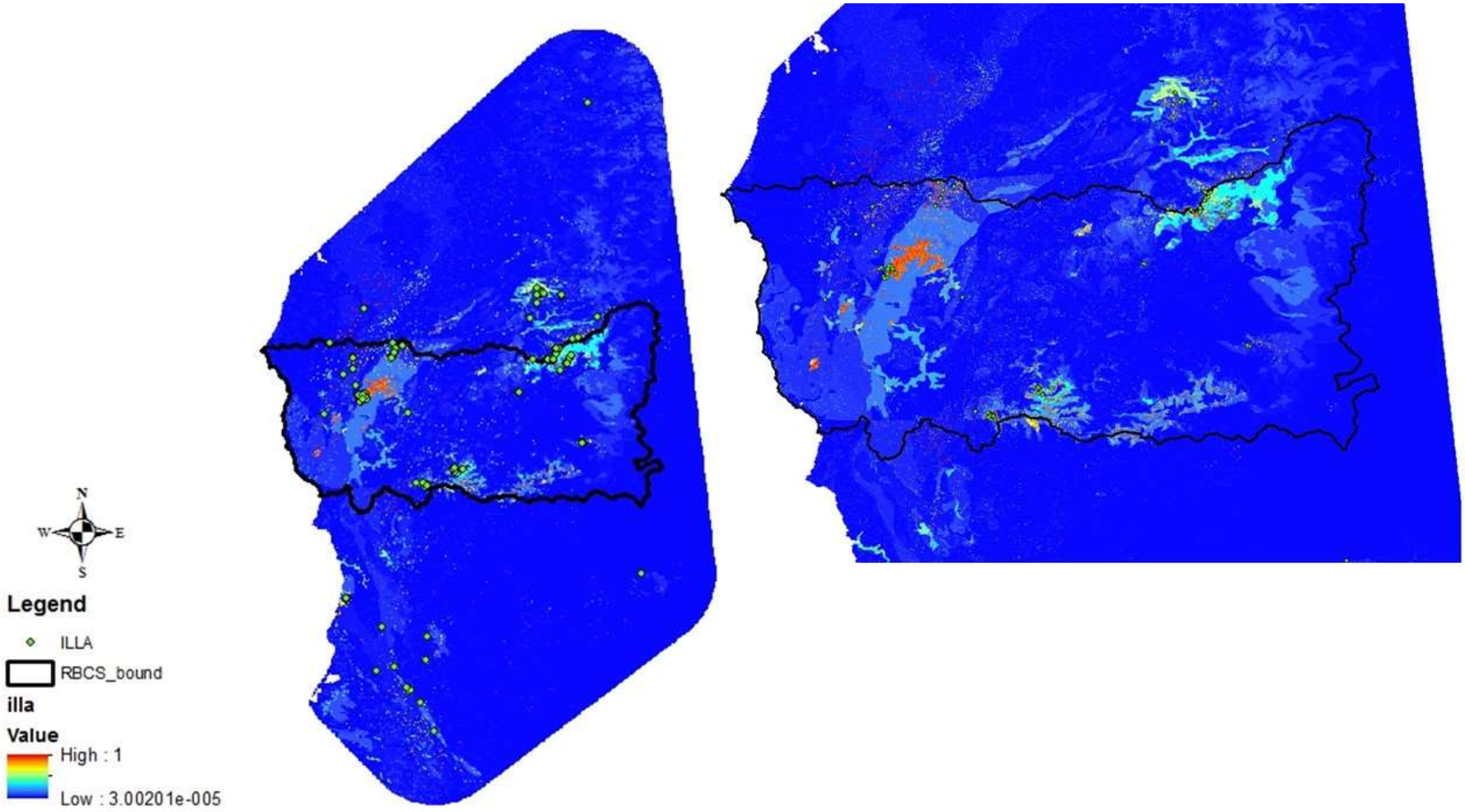

FIGURE 9. PREDICTED DISTRIBUTION OF *ILIAMNA LATIBRACTEATA* THROUGHOUT ITS RANGE AND IN THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Lupinus tracyi

Species Description

Lupinus tracyi (Tracy's lupine) is a member of the Fabaceae family. *L. tracyi* is endemic to the Klamath Mountains in southwestern Oregon and northwestern California. *L. tracyi* occurs in dry, open montane forests [elevation: 1500--2000 m]. *L. tracyi* blooms in July.

Model Results

The AUC converged to 0.9721 (SD = 0.0157) and 0.9699 (SD = 0.0130) for the final *L. tracyi* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, GNN vegetation (27.281%), precipitation as snow (25.866%), AHM (13.605%), geology (12.891%), and soils (10.503%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, winter precipitation (71.673%) and bFFP (14.832%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show mid to high probability of occurrence centered around the presence locations for *L. tracyi*, with small areas of high probability of occurrence outside of documented locations (Figure 10).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations. The area of the predicted habitat provides a good indication of the habitat available for the species in that region (Figure 10). There are some areas of suitable habitat predicted away from documented populations that could be surveyed, but in the absence of surveys priority should be to areas surrounding documented populations.

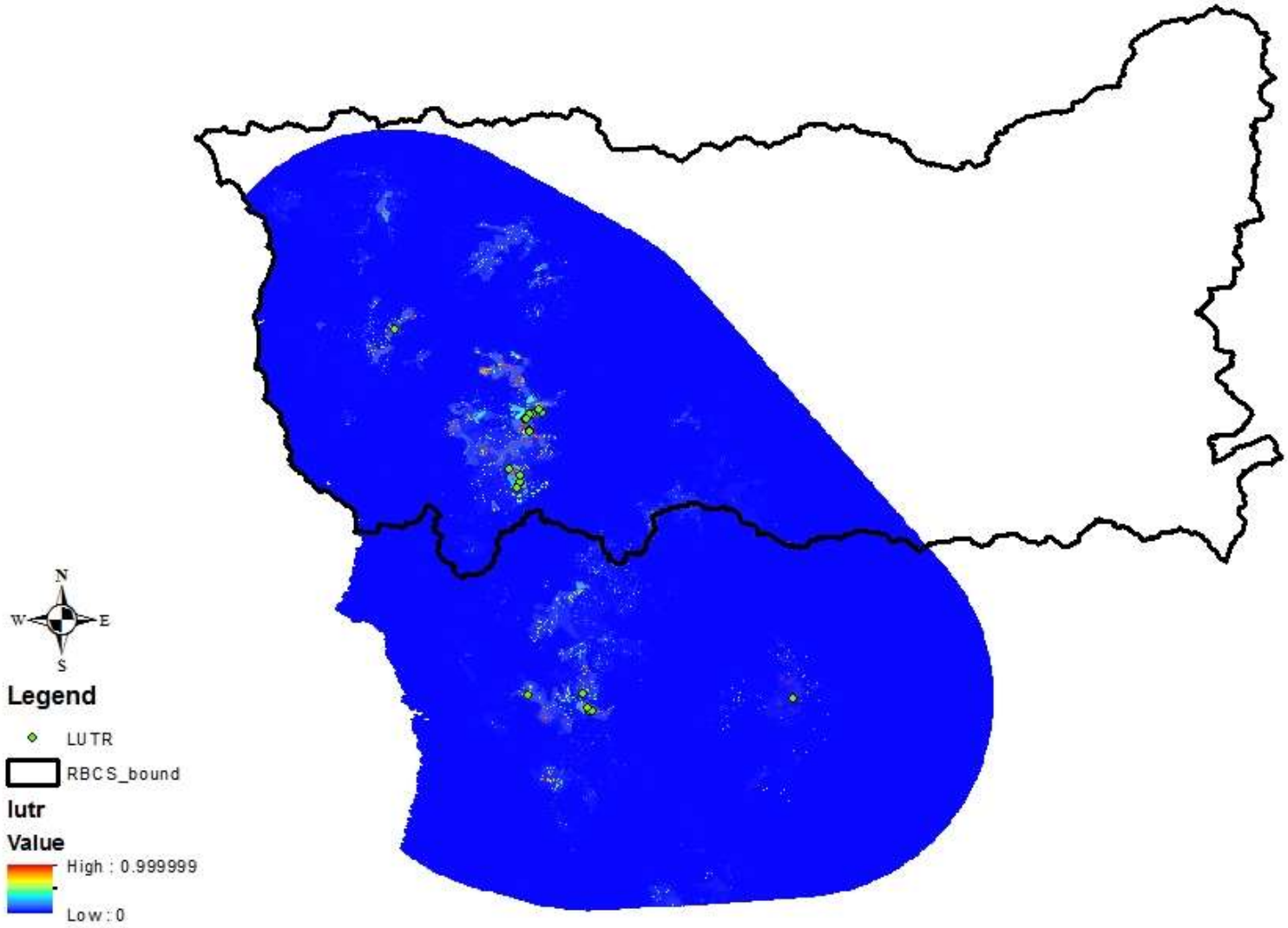

FIGURE 10. PREDICTED DISTRIBUTION OF *LUPINUS TRACYI* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Rafinesquia californica

Species Description

Rafinesquia californica Nutt. (California plumeseed) is a member of the Asteraceae family. *R. californica* is native to much of the southwestern US, reaching into Baja California (Mexico), and as far north as southwestern Oregon. *R. californica* occurs in open places in coastal sage scrub, chaparral, oak woodlands and is often found after fires. *R. californica* blooms from April to June.

Model Results

The AUC converged to 0.9601 (SD = 0.0159) and 0.9375 (SD = 0.0203) for the final *R. californica* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, geology (27.951%), soils (26.199%), GNN vegetation (20.808%), and AHM (7.297%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, AHM (17.021%), precipitation as snow (16.823%), and summer precipitation (12.808%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show the probability of occurrence accurately centered around the presence locations for *R. californica*, with only small areas of high probability of occurrence predicted outside of documented locations (Figure 11).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations. The area of the predicted habitat provides a good indication of the habitat available for the species in that region (Figure 11). There are some areas of suitable habitat predicted away from documented populations that could be surveyed, but in the absence of surveys priority should be to areas surrounding documented populations.

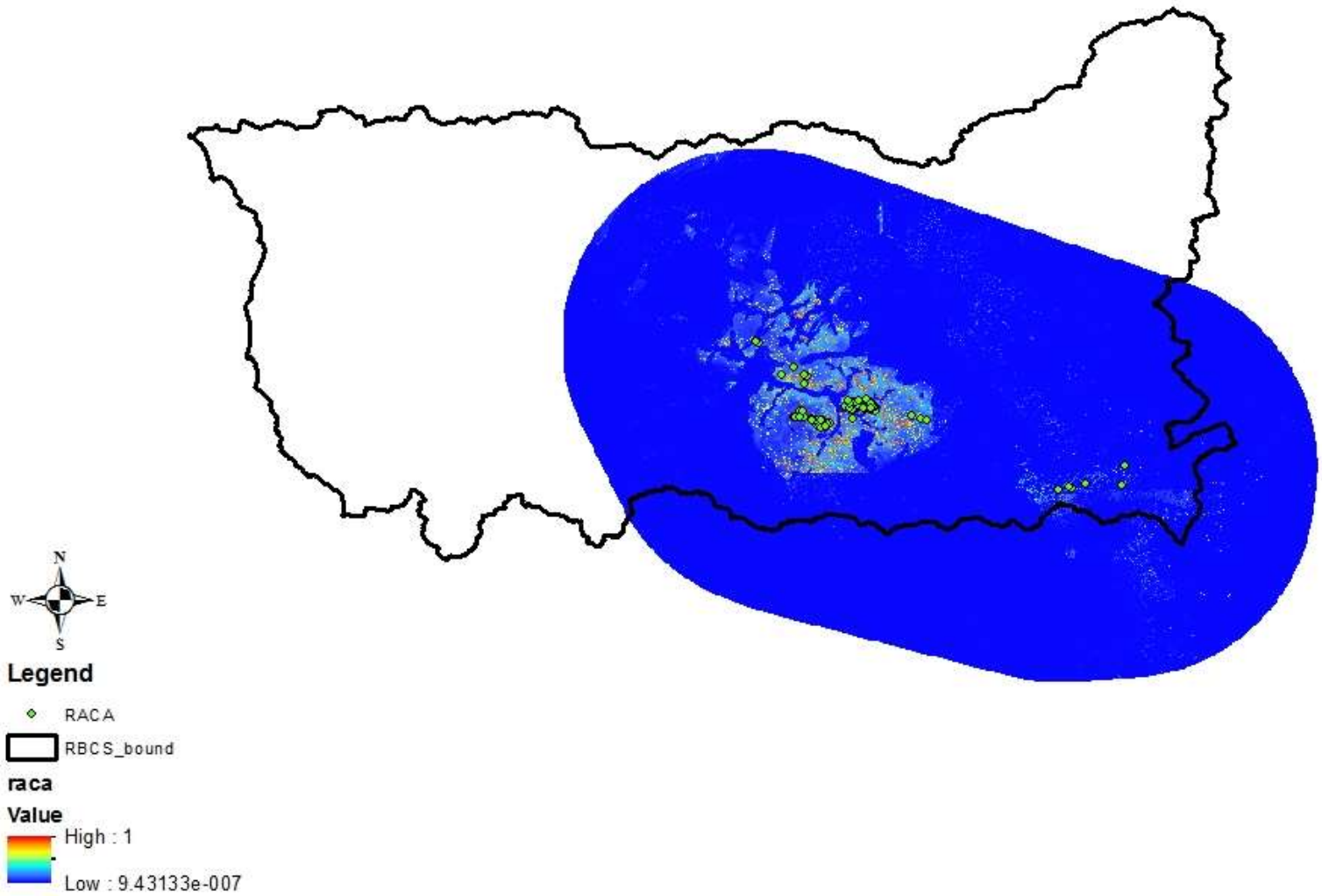

FIGURE 11. PREDICTED DISTRIBUTION OF *RAFINESQUIA CALIFORNICA* IN THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Rhamnus ilicifolia

Species Description

Rhamnus ilicifolia (hollyleaf redberry) is a member of the Rhamnaceae (Buckthorn) family. *R. ilicifolia* is found in the southwest and western United States in Arizona, California, Nevada, and Oregon. *R. ilicifolia* grows in chaparral, desert scrub, and montane forest [elevation: < 1150 m]. *R. ilicifolia* flowers from April to June.

Model Results

The AUC converged to 0.8363 (SD = 0.0162) and 0.8363 (SD = 0.0162) for the final *R. ilicifolia* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, precipitation as snow (19.479%), mean annual precipitation (16.713%), eFFP (15.709%), and geology (8.230%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, mean annual precipitation (18.617%), eFFP (17.116%), precipitation as snow (11.593%), degree days above 18C (8.893%), and TD (6.453%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show high probability of occurrence accurately centered around the presence locations for the southern portion of the *R. ilicifolia* range, but declines in the northern portions of the range (Figure 12). The majority of the Rogue River Basin is predicted as moderate probability of occurrence, with only small areas of high probability of occurrence (Figure 12).

Implications for Management and Conservation Efforts

The model had a relatively low AUC value, and the utility of the model for managing the species in the Rogue River Valley is likely limited. The model predicted little area for high probability of occurrence, with none of the documented occurrences included within the predicted area (Figure 12). The area of predicted high suitability is north of any documented populations and likely of minimal value. Throughout the range of the species, the model predicted mostly only moderately suitable habitat (Figure 12). This could be due to the large distribution of *R. ilicifolia* that includes a range of habitats and variability in climatic factors.

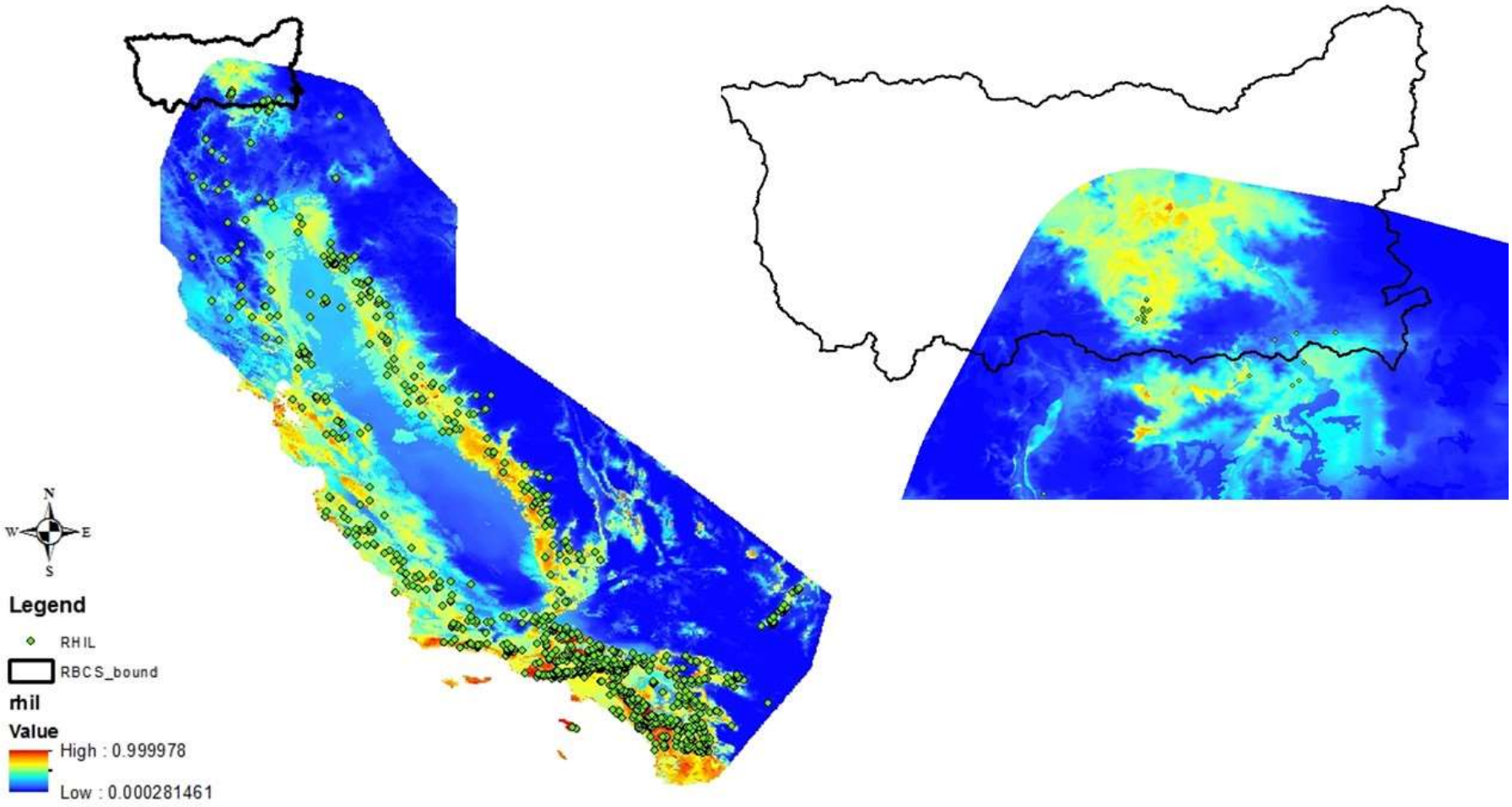

FIGURE 12. PREDICTED DISTRIBUTION OF *RHAMNUS ILICIFOLIA* THROUGHOUT CALIFORNIA AND OREGON, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Sidalcea malviflora ssp. *patula*

Species Description

Sidalcea malviflora ssp. *patula* (Siskiyou checkerbloom) is a member of the Malvaceae (Mallow) family. *S. malviflora* ssp. *patula* occurs in northwestern California and southwestern Oregon. It grows in open coastal forests and bluffs, and often roadcuts [elevation: generally <700 m]. *S. malviflora* ssp. *patula* blooms from May to August.

Model Results

The AUC converged to 0.8892 (SD = 0.0541) and 0.8492 (SD = 0.0779) for the final *S. malviflora* ssp. *patula* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, GNN vegetation (41.203%), soils (29.073%), and summer precipitation (25.022%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, summer precipitation (70.817%) and CMD (6.279%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show high probability of occurrence centered around the presence locations for the southern portion of the *S. malviflora* ssp. *patula* range, with higher concentrations of predicted high probability of occurrence near known coastal occurrences and minimal outside of those areas (Figure 13).

Implications for Management and Conservation Efforts

The model had a moderate AUC value, but the utility of the model for managing the species in the Rogue River Valley is likely limited. Most of the documented populations are included in the areas predicted as highly suitable, with the exception of central populations, but the highly suitable areas are small and scattered throughout the area (Figure 13). This makes interpretation difficult from a management perspective when trying to determine areas to protect.

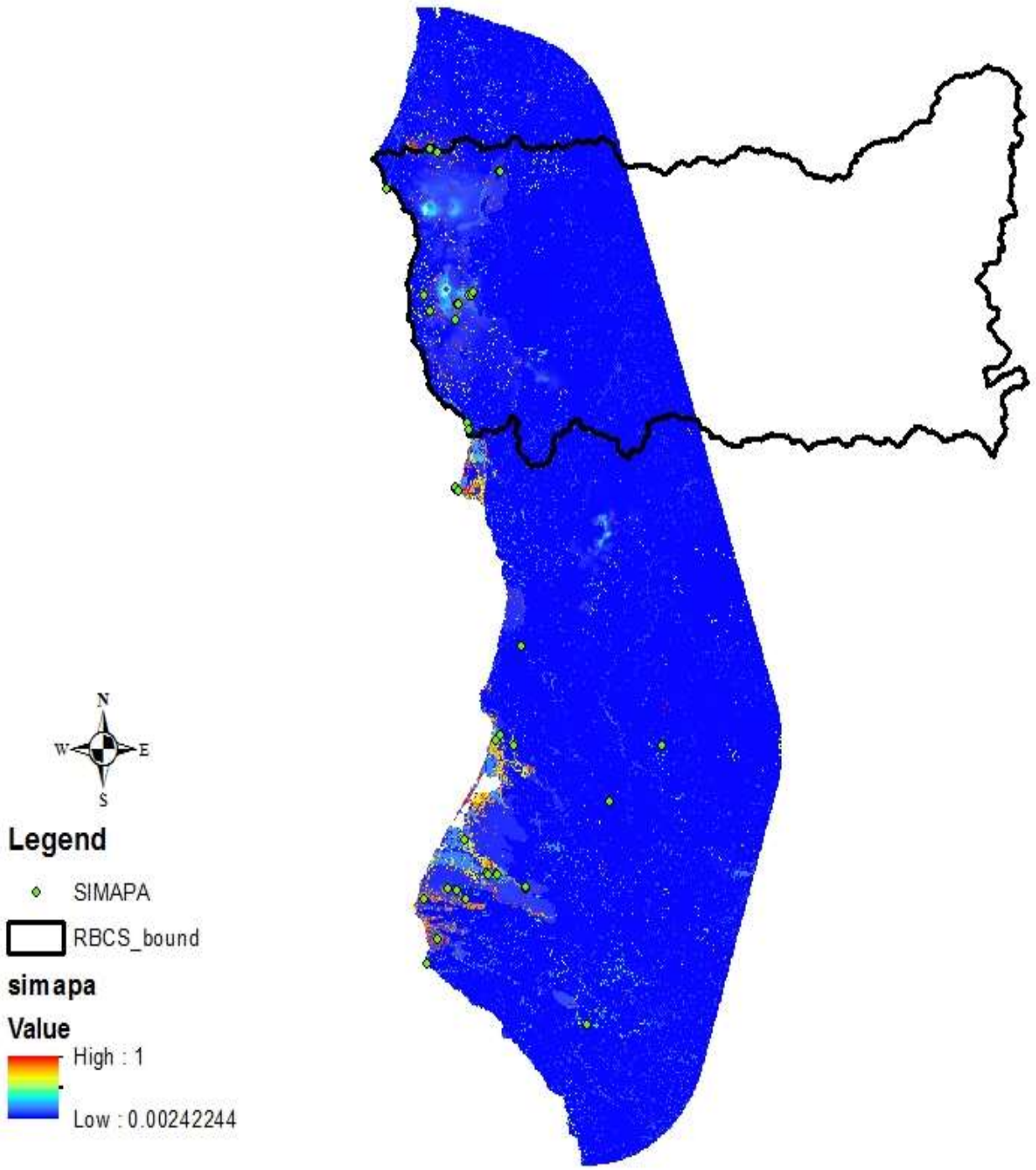

FIGURE 13. PREDICTED DISTRIBUTION OF *SIDALCEA MALVIFLORA* SSP. *PATULA* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Silene serpentinicola

Species Description

Silene serpentinicola (serpentine Indian pink) is a member of the Caryophyllaceae (Pink) family. *S. serpentinicola* is a narrow endemic that is mostly confined to the north fork Smith River basin, with a few populations found in the middle fork and south fork Smith River drainages (northwestern CA; southwestern OR (Curry County)). *S. serpentinicola* occurs in grassy, gravelly, or rocky openings in chaparral, woodlands, and coniferous forest on serpentine soils [elevation: 100-800 m]. *S. serpentinicola* flowers in early summer (May-July).

Model Results

The AUC converged to 0.9571 (SD = 0.0259) and 0.9268 (SD = 0.0351) for the final *S. serpentinicola* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, geology (44.638%), GNN vegetation (24.262%), bFFP (14.793%), soils (7.190%), and extreme maximum temperature (6.360%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, bFFP (19.567%), extreme maximum temperature (17.619%) and winter precipitation (16.696%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence centered around the presence locations for *S. serpentinicola,* except for one outlying documented occurrence (Figure 14).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations, with the exception of a single disjunct population to the southeast. The main area of the predicted habitat around the documented populations provides a good indication of the habitat available for the species in that region (Figure 14).

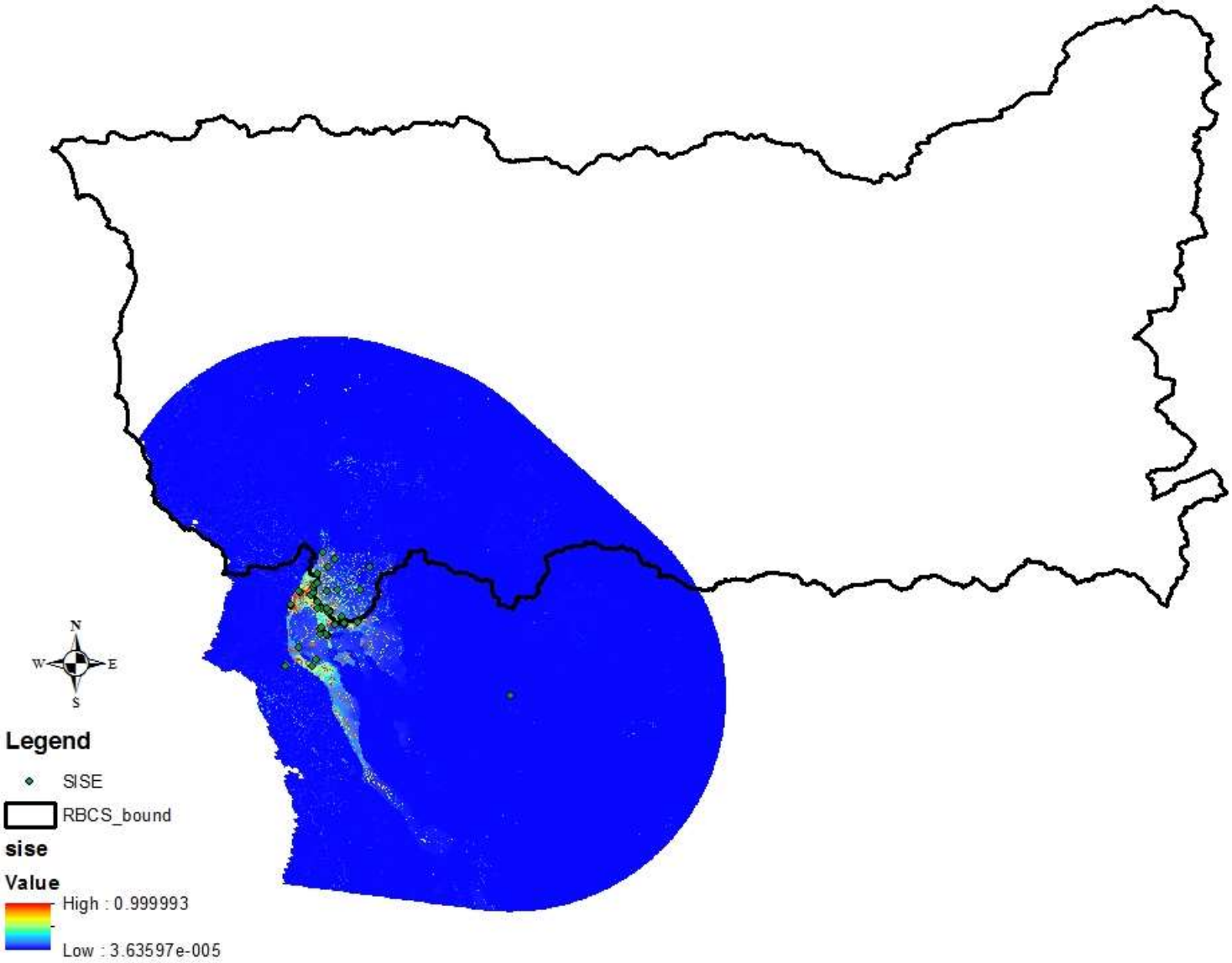

FIGURE 14. PREDICTED DISTRIBUTION OF *SILENE SERPENTINICOLA* THROUGOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAINING ALL VARIABLES.

Solanum parishii

Species Description

Solanum parishii (Parish's nightshade) is a member of the Solanaceae (Nightshade) family. *S. parishii* is found from southern Oregon to Baja California (Mexico). It grows in dry chaparral (maritime and inland), oak/pine woodland, and pine forests [elevation: <2000 m]. *S. parishii* flowers from April to July.

Model Results

The AUC converged to 0.9016 (SD = 0.0211) and 0.9114 (SD = 0.0197) for the final *S. parishii* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, soils (17.214%), summer precipitation (13.000%), extreme minimum temperature (12.575%), geology (10.802%), and winter precipitation (8.029%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.. When considering only climate variables in the model, summer precipitation (32.620%), extreme minimum temperature (16.491%), winter precipitation (12.431%), TD (9.414%), and annual heat moisture index (8.643%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables..

The model(s) show high probability of occurrence accurately centered around concentrations of presence locations throughout the range of *S. parishii*, but also include many areas with predicted high probability of occurrence in areas where there have been no previous observations (Figure 15).

Implications for Management and Conservation Efforts

Although the model had a moderately high AUC value, the utility of the model for managing the species in the Rogue River Valley requires detailed interpretation. The model put the majority of documented populations in areas of predicted high suitability. Four areas predicted as highly suitable in the northwest portion were surveyed and found to fit the general habitat description(s) for *S. parishii*. The areas predicted as highly suitable (red or orange in Figure 15) could be used to protect documented populations, as well as provide areas of potential habitat for additional survey and/or conservation efforts. The areas of moderate to low suitability would not appear to be of value for conservation efforts.

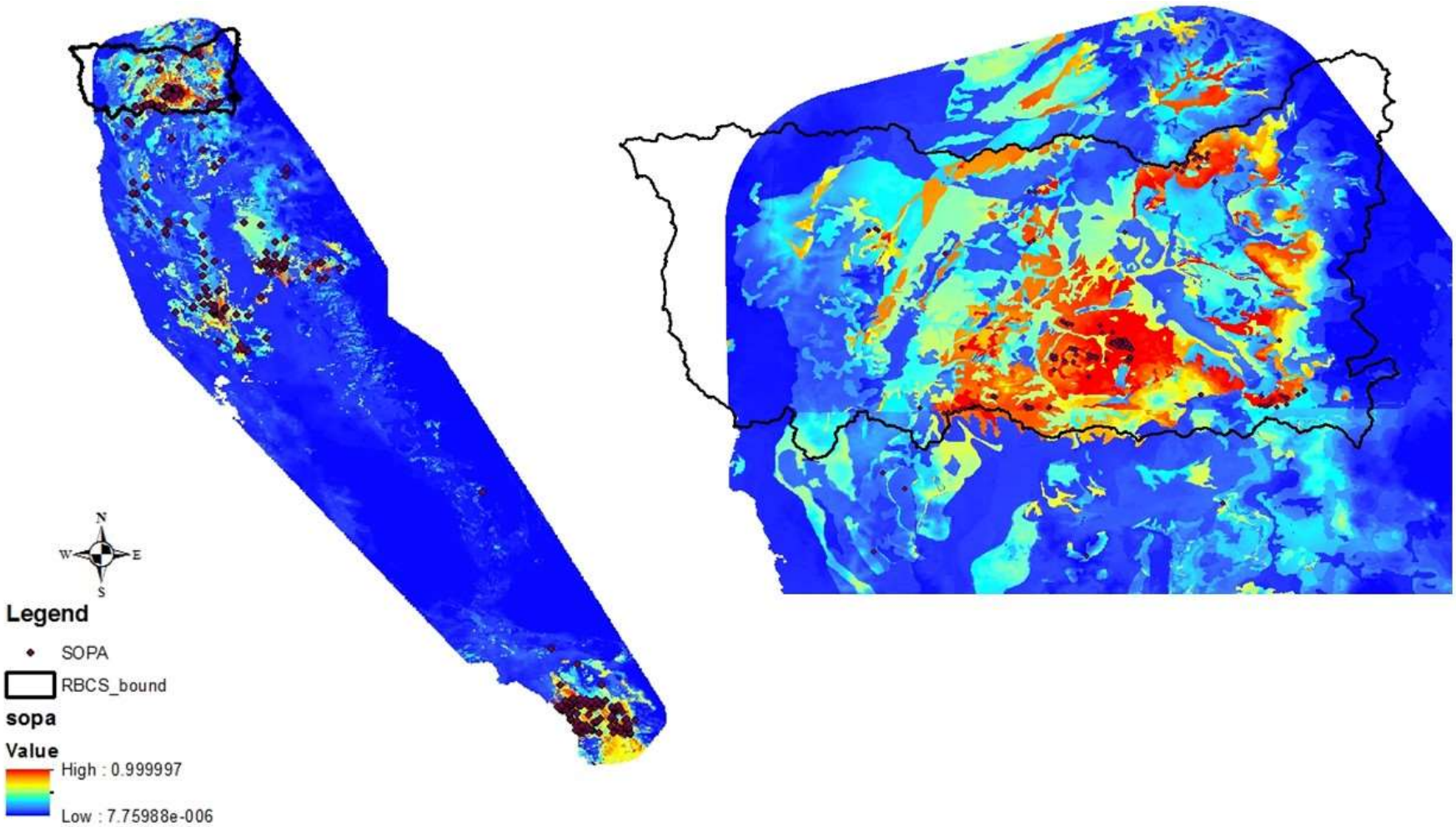

FIGURE 15. PREDICTED DISTRIBUTION OF *SOLANUM PARISHII* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR MODELS CONTAING ALL VARIABLES.

Sophora leachiana

Species Description

Sophora leachiana (western necklacepod) is a perennial herb in the Fabaceae (Pea) family. *S. leachiana* is endemic to Josephine County, Oregon. It is restricted to open, disturbed sites (often found in clear cuts) within mixed evergreen-oak woodlands. It is usually found at lower elevations, on south or west facing slopes near creeks or other perennial drainages, often on serpentine substrates. *S. leachiana* blooms from April to June.

Model Results

The AUC converged to 0.9689 (SD = 0.006) and 0.8988 (SD = 0.0146) for the final S. *leachiana* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, geology (22.674%), soils (17.275%), winter precipitation (14.418%), CMD (13.306%), FFP (8.178%), GNN vegetation (6.032%), and SHM (5.277%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, CMD (30.295%) and FFP (12.973%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

With the exception of two documented occurrences, the model(s) show moderate to high probability of occurrence accurately centered around the known presence locations for S. *leachiana* (Figure 16).

Implications for Management and Conservation Efforts

The model had a high AUC value, and successfully encompassed all documented populations, with the exception of a single disjunct population to the north. The main area of the predicted habitat around the documented populations provides a good indication of the habitat available for the species in the region (Figure 16). Areas predicted as highly suitable, but without documented populations, could be high priority to receive additional surveys to determine presence.

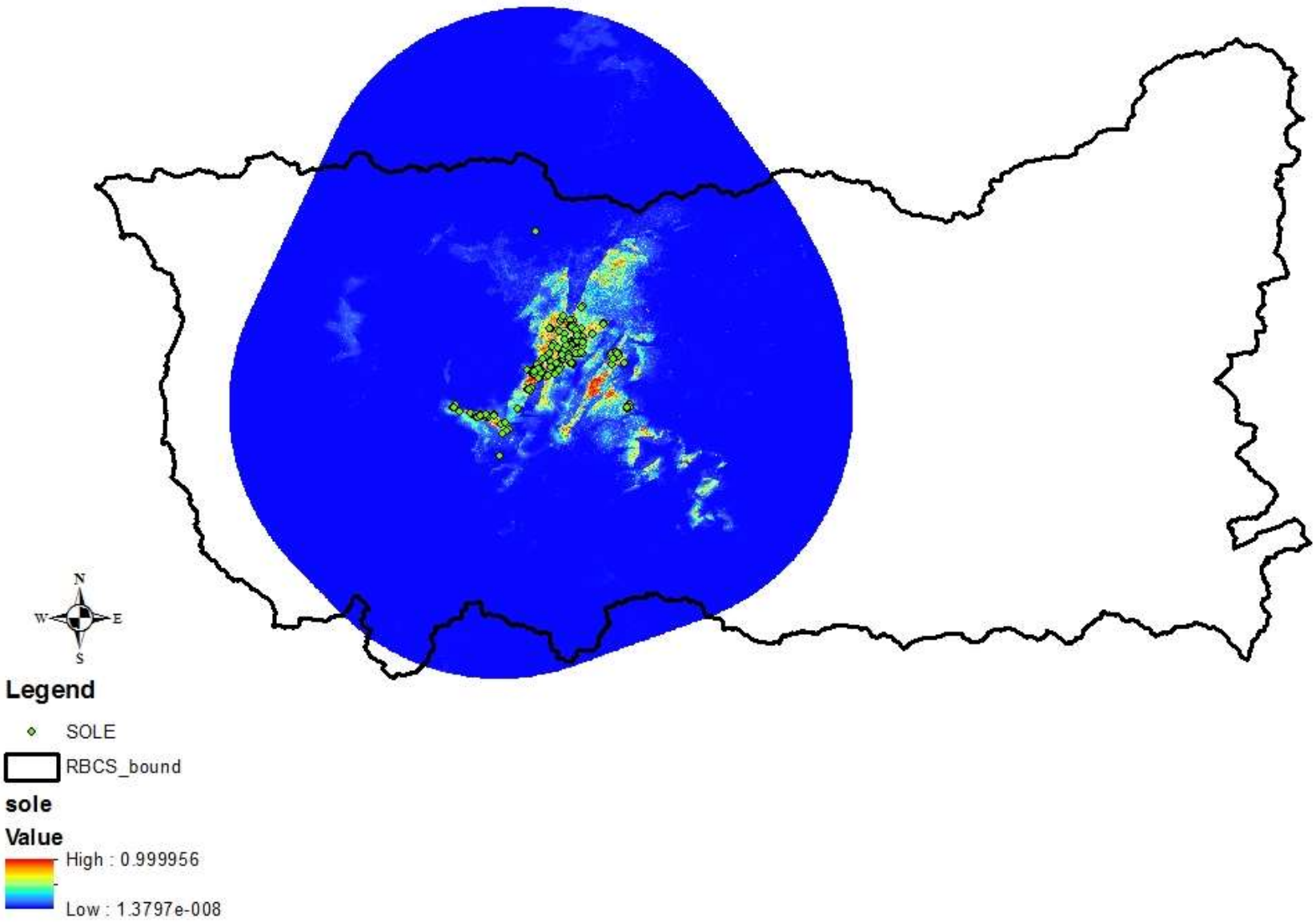

FIGURE 16. PREDICTED DISTRIBUTION OF *SOPHORA LEACHIANA* IN THE ROGUE RIVER BASIN FOR THE MODEL CONTAINING ALL VARIABLES.

Trillium kurabayashii

Species Description

Trillium kurabayashii (giant purple wakerobin) is a member of the Liliaceae (Lily) family. Populations of *T. kurabayashii* are found in southwest Oregon and northwest California. *T. kurabayashii* grows in rich, moist conifer-hardwood forests, slopes, especially lower slopes, predominantly deciduous flat woods along streams, edges of Sequoia groves, and alder, vine maple, and fern thickets along streams, especially older, higher flood terraces, not the lowest and wettest; at higher elevations, it can be found both in forests and in open grassy meadows with scattered oak trees [elevation: 20--500+ m]. *T. kurabayashii* blooms in early spring (late March to early May).

Model Results

The AUC converged to 0.9058 (SD = 0.0692) and 0.9185 (SD = 0.0511) for the final *T. kurabayashii* models containing all variables and models containing climate only variables, respectively. Of the parameters used in the model containing all variables, GNN vegetation (35.040%), degree days below 18C (19.609%), soils (17.923%), and winter precipitation (9.149%) had the highest percent contribution (Appendix A. Relative contribution of variables used in the final model(s) for each species when including all variables.). When considering only climate variables in the model, degree days below 0C (41.915%) and winter precipitation (32.309%) had the highest percent contribution (Appendix B. Relative contribution of variables used in the final models for each species when considering only climate variables.).

The model(s) show moderate to high probability of occurrence around the concentration of known presence locations in the Rogue River Basin, but also included potential high probability of occurrence in areas with no previously documented occurrences (Figure 17).

Implications for Management and Conservation Efforts

The model had a moderate AUC value, but the utility of the model for managing the species in the Rogue River Valley is likely limited. Most of the documented populations were included in areas predicted as only moderately or lowly suitable, with several documented locations that the model did not consider being suitable habitat (Figure 13). This makes interpretation difficult from a management perspective when trying to determine areas to protect.

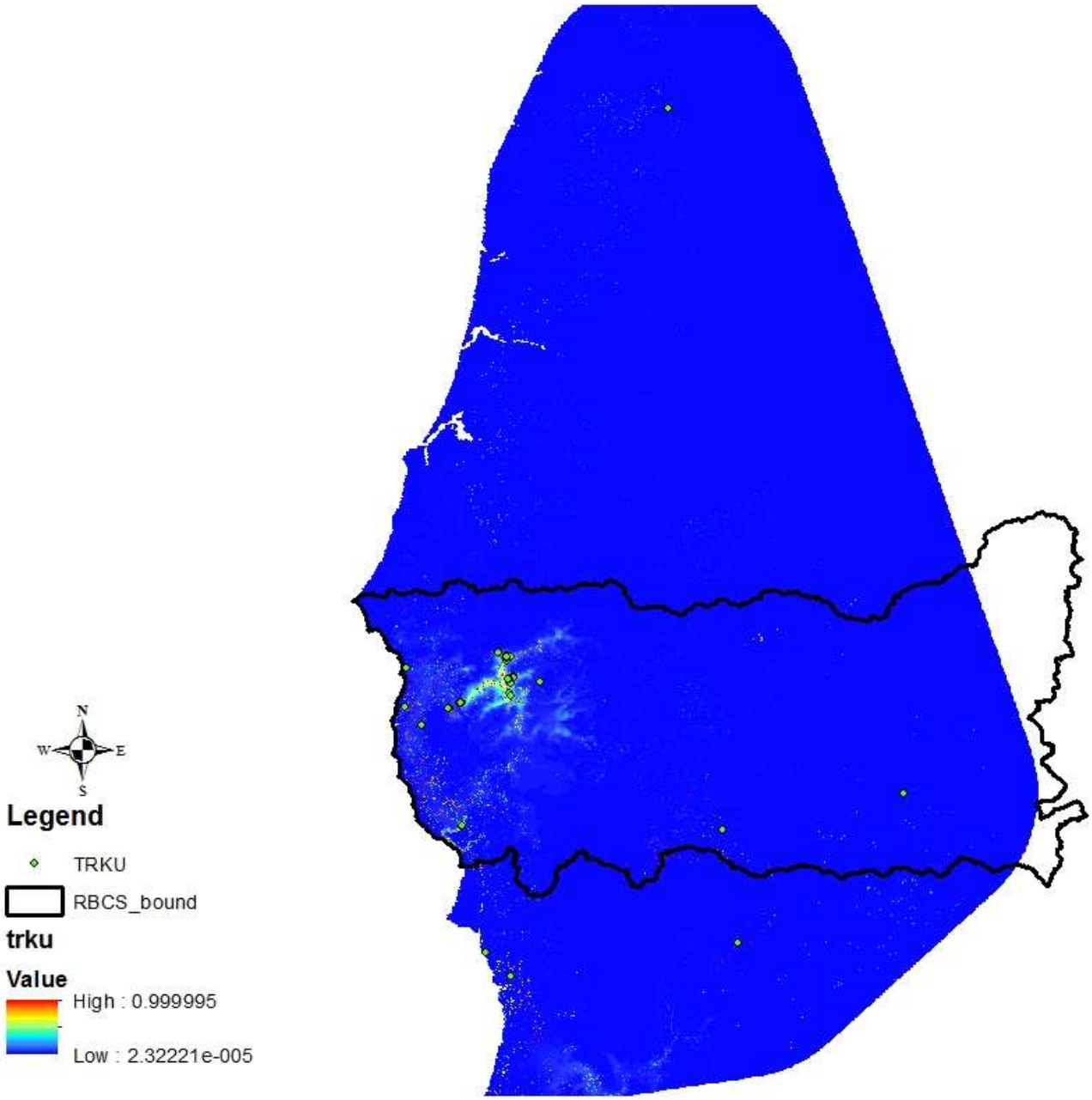

FIGURE 17. PREDICTED DISTRIBUTION OF *TRILLIUM KURABAYASHII* THROUGHOUT ITS RANGE, INCLUDING THE ROGUE RIVER BASIN FOR THE MODEL CONTAINING ALL VARIABLES.

SUMMARY

These models represent an initial effort to develop SDMs for 17 fire-dependent species of concern in the Rogue River Valley. We used a combination of climatic and non-climatic variables from publicly available sources to develop models using the MaxEnt program. All species models had moderate to high AUC values, with the exception of C. *bakeri* which had a low AUC value, although the utility of each model varied. Eight species models were of limited utility for management purposes. The remaining nine species models (*Calochortus howellii, Collomia mazama, Frasera umpquaensis, Horkelia tridentata* ssp. *tridentata, Lupinus tracyi, Rafinesquia californica, Silene serpentinicola, Solanum parishii, Sophora leachiana*) had high AUC values, strong model characteristics, and should provide valuable information to land managers in the region.

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APPENDIX A. RELATIVE CONTRIBUTION OF VARIABLES USED IN THE FINAL MODEL(S) FOR EACH SPECIES WHEN INCLUDING ALL VARIABLES.

Variables in bold have contribution scores >5%, but were not included in final model(s) due to correlation with other variables. Variables in red were not correlated, had the highest contribution scores, and were included in the final model(s).

Variable	Species																
	ADJO	ARHI15	CAHO11	COMA	CUBA	ERAR27	FRUM2	HOTRTR	ILLA2	LUTR	RACA	RHIL	SIMAP	SISE10	SOLE3	SOPA	TRKU
AHM	0.08	7.74	0.34	0.22	0.00	0.09	0.13	0.03	0.17	13.60	7.30	2.26	0.24	0.12	0.13	**7.89**	0.01
bFFP	4.59	0.02	0.53	0.03	0.02	6.90	0.43	0.00	0.48	0.12	0.98	0.19	0.45	14.79	0.91	1.19	0.00
CMD	0.20	0.05	0.49	0.03	0.00	0.00	0.03	0.00	0.19	0.17	0.00	0.72	0.10	0.28	13.31	0.21	0.00
DD18	0.16	0.00	0.48	**6.54**	0.66	0.02	0.30	0.00	1.18	0.00	2.15	0.61	0.09	0.10	0.87	1.20	0.00
DD5	1.97	0.00	0.03	0.10	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.16	0.35	0.00	0.25	0.82	0.00
DD_0	0.46	0.20	0.00	0.08	0.14	0.99	0.00	7.41	0.00	0.00	0.05	0.18	0.00	0.00	0.94	2.13	**11.36**
DD_18	0.60	0.32	0.55	0.16	0.00	0.00	0.12	0.00	0.01	0.00	0.07	0.25	0.00	0.00	0.01	0.13	19.61
DEM	1.01	0.59	0.08	0.52	0.25	1.37	0.49	0.09	2.88	0.28	0.34	**11.19**	0.03	0.28	0.09	3.54	1.35
eFFP	36.99	1.87	23.14	7.41	0.00	0.45	1.16	0.00	0.24	0.00	0.00	15.71	0.00	0.00	0.54	0.92	0.00
EMT	0.54	0.01	0.19	0.10	0.00	0.17	0.07	0.11	2.62	0.00	0.12	1.63	0.00	0.02	3.26	12.58	0.01
Eref	0.16	0.00	0.24	0.04	0.00	0.00	0.05	0.00	0.42	0.00	0.04	0.55	0.00	0.26	0.55	0.04	0.91
EXT	0.83	0.15	0.42	0.15	0.00	0.00	0.01	0.00	0.25	0.00	0.01	0.07	0.04	6.36	0.28	0.01	0.00
FFP	3.31	5.20	0.84	0.01	0.00	0.00	0.01	0.00	0.00	0.24	0.00	0.53	0.00	0.00	8.18	0.26	0.01
Geology	9.67	7.51	3.78	17.96	10.60	11.67	20.29	37.64	9.30	12.89	27.95	8.23	2.78	44.64	22.67	10.80	4.00
GNN	11.46	42.55	5.99	12.61	62.41	64.75	13.36	24.82	29.75	27.28	20.81	1.14	41.20	24.26	6.03	1.85	35.04
MAP	0.03	0.20	0.18	0.03	0.00	0.00	0.10	0.20	0.06	0.00	0.08	16.71	0.32	0.00	0.96	0.21	0.02
MAT	0.44	0.51	0.01	0.11	0.00	0.00	0.01	0.00	0.13	0.00	0.14	0.03	0.00	0.00	0.43	0.08	0.06
MCMT	3.43	0.01	0.00	0.46	0.00	0.00	0.00	0.04	0.00	0.00	0.07	2.14	0.00	0.02	0.00	**6.29**	0.12
MSP	0.17	0.71	0.05	5.66	0.00	0.00	3.47	0.48	3.11	2.07	0.02	**5.66**	0.08	0.00	0.56	0.43	0.00
MWMT	0.78	0.13	0.34	0.07	0.00	0.00	0.05	0.00	0.01	0.00	0.06	0.19	0.01	0.07	0.00	0.00	0.00
NFFD	1.78	0.20	0.01	0.04	0.00	0.00	0.57	0.00	0.40	0.25	4.01	1.10	0.00	0.00	0.65	0.05	0.00
PAS	0.98	0.43	0.08	24.27	0.00	0.04	24.45	0.00	2.43	25.87	0.11	19.48	0.00	0.12	0.26	2.23	0.30
PPT_sm	0.26	0.60	0.87	0.08	0.00	0.00	4.37	0.13	3.54	4.53	4.53	1.22	25.02	0.02	0.53	13.00	0.12
PPT_wt	13.75	23.26	7.43	6.58	0.00	0.00	0.17	0.18	0.35	0.00	0.05	3.58	0.00	0.49	14.42	8.03	9.15
RH	1.05	0.01	1.96	0.87	0.00	0.00	3.80	0.00	1.48	0.00	0.10	0.16	0.00	0.72	0.08	0.89	0.00
SHM	2.04	0.11	0.00	0.12	0.00	0.04	0.52	0.26	0.45	2.18	0.01	1.21	0.21	0.00	5.28	3.92	0.02
Soil	0.40	6.73	50.20	15.02	25.86	13.34	25.90	28.30	34.64	10.50	26.20	0.95	29.07	7.19	17.27	17.21	17.92
Tave_sm	0.71	0.00	0.09	0.06	0.00	0.00	0.05	0.00	0.06	0.00	0.00	0.29	0.00	0.14	0.09	0.01	0.00
Tave_wt	1.43	0.00	0.00	0.33	0.05	0.12	0.00	0.00	0.61	0.00	0.00	0.41	0.00	0.12	1.39	0.15	0.00
TD	0.72	0.88	1.68	0.34	0.00	0.00	0.09	0.32	5.21	0.00	4.80	3.23	0.00	0.00	0.06	3.91	0.00

APPENDIX B. RELATIVE CONTRIBUTION OF VARIABLES USED IN THE FINAL MODELS FOR EACH SPECIES WHEN CONSIDERING ONLY CLIMATE VARIABLES.

Variables in bold have contribution scores >5%, but were not included in final model(s) due to correlation with other variables. Variables in red were not correlated, had the highest contribution scores, and were included in the final model(s).

Variable	Species															
	ADJO	ARHI15	CAHO11	COMA	ERAR27	FRUM2	HOTRTR	ILLA2	LUTR	RACA	RHIL	SIMAP	SISE10	SOLE3	SOPA	TRKU
AHM	0.5416	1.3942	0.3002	0.02	2.7489	1.9728	4.0977	0.1337	**8.6292**	17.0208	**5.4985**	1.4632	0.3155	0.3759	8.6427	0.4816
bFFP	3.2862	0.5624	0.2602	0.0814	48.4249	2.3374	0	**6.9595**	14.8324	4.635	2.3031	0.39	19.5666	3.5866	0.0723	0.0289
CMD	2.44	0.2085	0.7441	0.6443	1.0936	0.0516	0.0044	1.4136	0	0.1049	0.5353	6.2789	**10.7486**	30.295	0.6612	0
DD18	1.5812	0.0838	**5.5215**	4.92	8.212	3.543	0.5233	2.857	0	1.5876	8.8928	2.9563	**5.5396**	2.8918	2.5144	0.5588
DD5	1.7024	0.144	0.0213	0.2104	1.2461	0.0676	0	0.1334	0	0.077	0.6575	3.4404	0	0.3635	0.3035	0.0089
DD_0	1.4478	0.5818	0.1061	0.3433	**11.1639**	4.8938	12.6447	0.2247	0	1.5864	0.8873	0.1677	2.4223	2.0744	1.5463	41.9154
DD_18	0.959	4.3498	0.5144	0.45	0.0699	0.3153	0	0.0869	0	0.0397	0.1419	0	0.0027	0.2109	0.1129	**13.0646**
eFFP	31.7554	4.4319	41.3707	22.7921	2.9968	0.6523	0.0449	7.6653	0	1.7318	17.1157	1.1663	0.0024	1.1654	1.5214	4.7149
EMT	1.3519	0.035	2.3532	0.481	1.994	1.1147	0.0365	0.821	0	0.2237	0.498	0	0.0661	**6.3165**	16.4913	0.1385
Eref	0.6514	0	1.4054	0.0981	0	0.3964	0.3476	0.5437	0	0.2727	0.5501	0.1142	0.1384	2.0755	0.0358	1.4102
EXT	0.3578	0.1533	0.2801	0.7423	1.43	0.9959	0.7544	0.7275	0.0997	**8.0419**	0.445	0.5217	17.6191	0.2041	0.0048	0.4606
FFP	2.6659	2.7132	0.523	0.156	0.0155	0.2243	4.523	0.872	1.6513	0.0383	0.5958	0	**10.1005**	12.9731	0.5148	0.0386
MAP	4.8944	**5.269**	4.3433	0.3619	0	0.3089	2.9204	2.9034	1.3645	0.9364	18.6167	2.2193	**7.2238**	0.1578	0.3334	0.1298
MAR	0.8998	0.0062	0.0585	0.0486	0	0.3444	11.7023	1.7956	0	4.0923	0	0	0	0.1421	4.6523	0.4078
MAT	0.1578	0.0015	0.1099	0.018	0.0191	0.0998	0.0308	0.0038	0	1.8788	0.0502	0	0.0134	0.3192	0.0027	0.0008
MCMT	1.6039	0.3577	0.0178	2.3823	0.1812	0.1448	0.2282	0.0932	0.4706	1.4891	4.0698	0.0314	0.0123	0.0005	2.3257	0
MSP	0.664	0.4473	0.0189	10.4254	2.2506	19.6073	18.3007	4.4631	0	2.7787	**9.4812**	4.4827	0.0189	0.6644	0.9955	0.0027
MWMT	0.7007	0.3718	1.4512	0.0448	0	0.1772	0	0.206	0.3139	0.345	0.3475	0.1211	0.0081	0.5051	0.0076	0.3533
NFFD	1.0684	0.4272	0.1713	0.2968	4.9292	1.6591	1.0963	**5.4404**	0	2.8827	2.6454	0	0.0741	3.4978	0.6923	0.2259
PAS	**10.254**	1.5604	1.63	45.3017	0.6808	34.4783	0.0193	15.9401	0.1868	16.8231	11.5931	1.3432	1.7003	0.6374	1.1335	1.4972
PPT_sm	0.2591	**9.5964**	1.2305	1.7564	0	**7.1658**	**8.344**	11.373	0	12.8077	3.4261	70.8172	0.9463	0.0804	32.6203	0.7021
PPT_wt	24.2286	55.4725	13.4708	3.5957	8.3868	0.4142	**13.5677**	2.7083	71.6733	**7.1058**	2.2403	1.7876	16.6959	**24.7846**	12.4309	32.3085
RH	2.3603	0.0906	**13.6764**	2.7912	0.5599	14.1156	17.1988	11.5514	0	0.5261	0.7141	0.8627	0.357	0.9119	0.0528	0
SHM	0.7297	0	1.1756	0.266	0.4643	0.5376	2.8204	1.9282	0	0.5544	0.823	1.6639	4.581	0.0974	1.0244	1.4146
Tave_sm	0.7697	0.0869	0.0492	0.0849	0.139	0.1321	0.3324	0.7881	0	0.0695	0.2907	0.1723	0.0284	0.7914	0.0226	0
Tave_wt	1.7965	0.9419	0.0398	0.8467	2.9935	0.0336	0	1.6607	0	0.1307	1.1276	0	0.1176	3.1738	0.7739	0
TD	0.8726	10.713	**9.1566**	0.8403	0	4.2161	0.4622	16.7064	0.7785	**12.2196**	6.4532	0	1.7011	1.7035	9.414	0.1364