Climbing the Mountain: Niche Modeling of *Hymenopappus filifolius* and *Hymenopappus mexicanus* using ArcGIS and Maxent

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Introduction

It is well known that organisms live in specific areas determined by many things, but especially by the local environment. Plant distributions are known to be sensitive to factos such as soil (geochemistry) and climate and that the prescence or absence of particular environmental factors may drive their distributions. Different factors affect different species.

One method for examining the importance of different factors in plant distributions is niche modeling[1]. This method combines climate data and maps for different geochemistry variables, with observations of where particular species have been found growing and generates models that predict the areas where environmental conditions are suitable for each species (identifies where the conditions are similar and so predicts the total distribution). Niche models allow us to identify which environmental variables most strongly explain where each species is able to grow. Once these specific factors are identified, and by comparing differing niches to those of related species, we can ask questions about how adaptation to particular variables may have driven their evolutionary histories and whether adaptation to different niches was involved in driving speciation and diversification.

This project examines the distributions and environmental characters of two closely related plant species in the dais family (Compositae: Bahieae), Hymenopappus filifolius and Hymenopappus mexicanus, that have overlapping but not identical distributions. It asks the questions: 1) Does niche modeling predict different distribution patterns for the two species? 2) Do they differ in their ecological niches? And if so 3) Are these differences potential drivers of a speciation event?

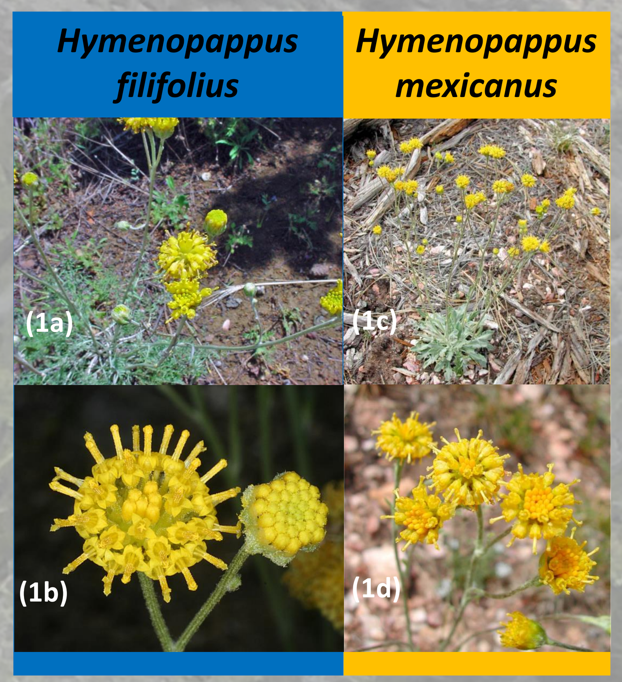

Fig. 1: Hymenopappus filifolius vs. Hymenopappus mexicanus

Members of the genus *Hymenopappus* are nested within the Bahieae tribe (family Compositae).

Figures 1a and 1b: *Hymenopappus filifolius* a) habitat, b) inflorescence.
Figures 1c and 1d: *Hymenopappus mexicanus* a) habitat, b) inflorescence.

Note the similarities between the two species.

Background

The Compositae are the biggest family of plants with over 23,600 species in over 1,620 genera[2]. The genus *Hymenopappus* is a member of the Bahieae tribe and is only relatively recently radiated. The center of diversity for the genus is the western United States and north western Mexico, a highly environmentally variable and challenging environment. Putative sister species *H. filifolius* and *H. mexicanus* are of particular interest as they have broadly sympatric (overlapping) distributions, yet appear to have localized separation between populations across an altitudinal gradient. Recent radiation in a heterogeneous environment makes this a good candidate for examining the potential role of climate and soils in speciation.

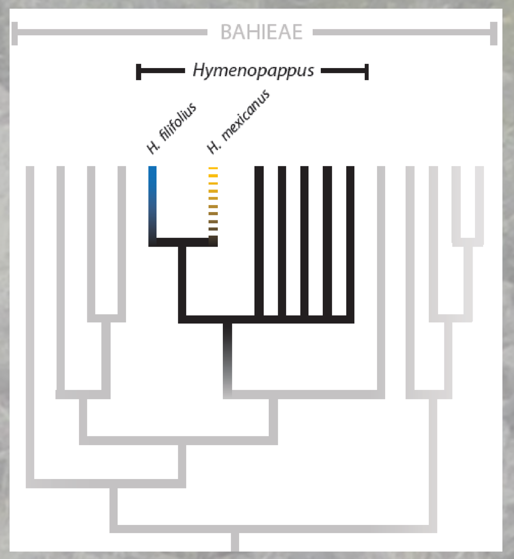

Figure 2: Bahieae tribe

Methods

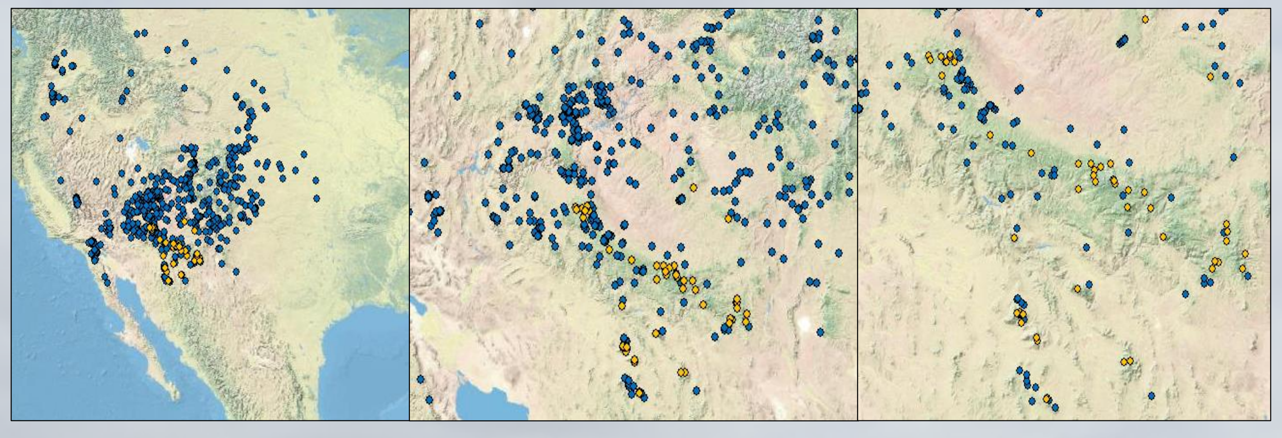

Figure 3: Distribution of *H. filifolius* (blue) and *H. mexicanus* (orange)

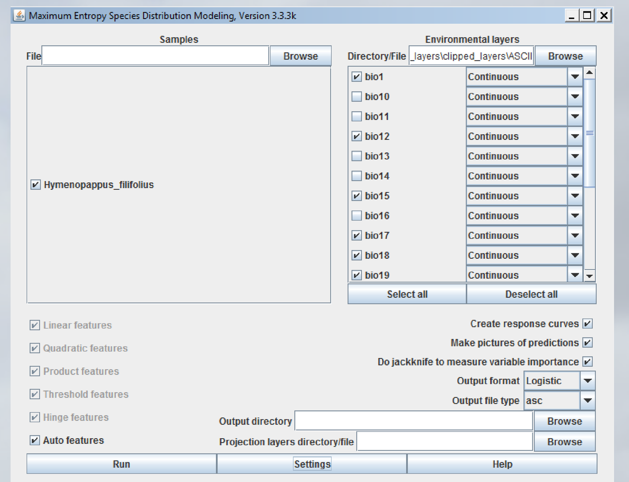

Figure 4: Maxent program

Distribution data for *H. filifolius* & *H. mexicanus* were gathered from online databases (GBIF, iDigBio, BISON) and specimens in the US National Herbarium. For *H. filifolius*, an original 3,209 downloaded records was cleaned down to 845 records. For *H. mexicanus* an original 139 downloaded records was cleaned down to 54 records. The cleaned data were then uploaded to ArcMap 10.2[3] and mapped as seen in Figure 2.

Bioclimatic Data were downloaded from the WorldClim database[4]. Using methods described in a previous study citing a coefficient of correlation of R>0.95 between variables, the variables Bio1, Bio2, Bio4, Bio5, Bio6, Bio9, Bio12, Bio15, Bio17, Bio18, and Bio19 were tested in making a niche model[1]. To accomplish niche modeling, the presence-only modeling software, Maxent ,Version 3.3.3k[5]. Outputs from these analyses were then uploaded as layers into ArcMap.

Results

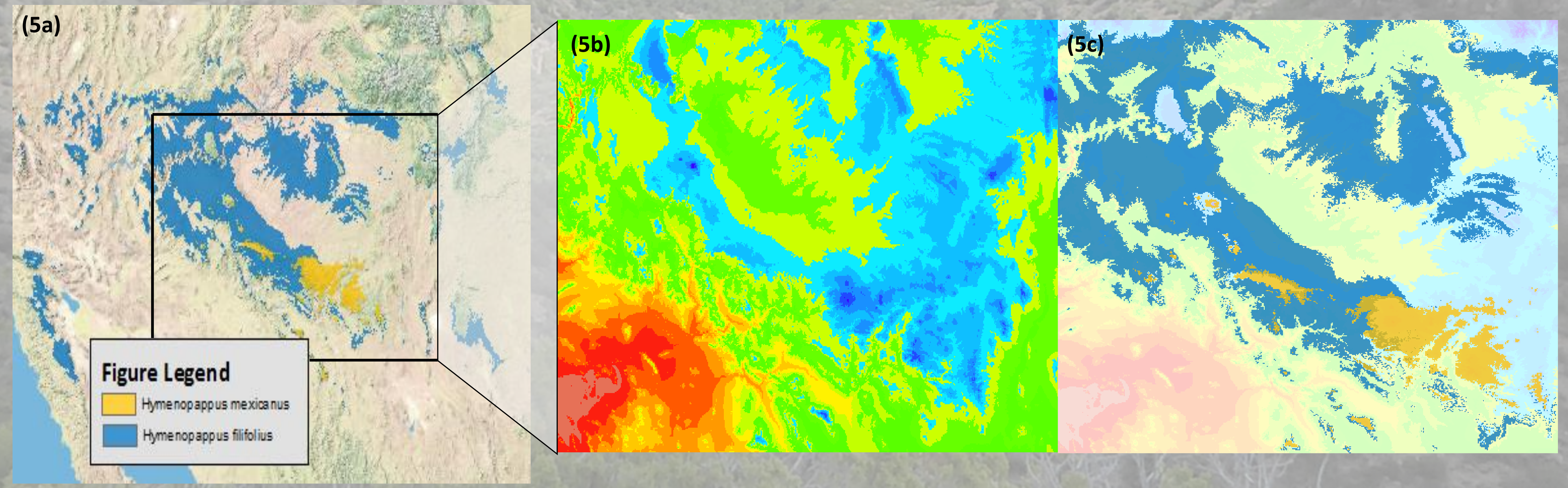

Figure 5: Maxent Projection of Data using Bioclimatic Data
(5a) Niche model representing >0.60 niche potential for *H. mexicanus* and H. filifolius overlaid on GIS US Terrain map. (5b) Magnification of map area with a heat map representing elevation (cool colors = higher elevation). (5c) Integration of Maxent projection and elevation layer.

Bioclimatic Data Response	
Hymenopappus filifolius	*Hymenopappus mexicanus*
Mean Diurnal Temp. Range (25.6%)	Temp. Seasonality (29.3%)
Precip. Warmest Quarter (23.2%)	Annual Mean Temp. (16.1%)
Annual Mean Temp. (15.7%)	Precip. Seasonality (15.1%)
Temp. Seasonality (11.5%)	Mean Diurnal Temp. Range (11.6%)
Annual Precip. (8.7%)	Precip. Warmest Quarter (10.9%)

Table 1: Percent Contribution of Different Bioclimatic Variables

Variables are associated with bioclimatic variables found on WorldClim's database. The top 5 variables that contribute to the modeling of the niche of the according species are exhibited here, with those that contribute more to the model appearing closer to the top of the list.

Discussion

While the environmental data used in this study are only climatic (temperature and precipitation) it is surprising that two neighboring niches, apparently distributed along an altitudinal gradient, are predicted to be characterised by very different sets of these (figure 5). Typically it would be expected that, across altitude, an increases or decreases in a variable would characterize both niches. There are three main plausible hypotheses for these results:

1. - the results we see here are accurate and that seasonality of growing conditions is of greater influence to *H. mexicanus* living at higher elevations than it's sister species
2. - that the environmental variable(s) responsible for niche separation between these two species were not included in our model (e.g. soil)
3. - that modeling one widespread species against a narrowly restricted species confounds the model. Figure 6 shows *H. filifolius*: *H.filifolius var. nanus* and *H. filifolius var. cinereus*. These represent just two of the 12 **subspecies** of *H. filifolius* that occupy ranges across the western US. This figure shows that model predictions change considerably when looking at subspecies on their own. This means that when using a model for the entire distribution area of *H. filifolius* (figure 3) it is likely that predictions are being made using environmental values irrelevant to the local dynamics actually responsible for differentiation between the local populations of the two species under consideration here.

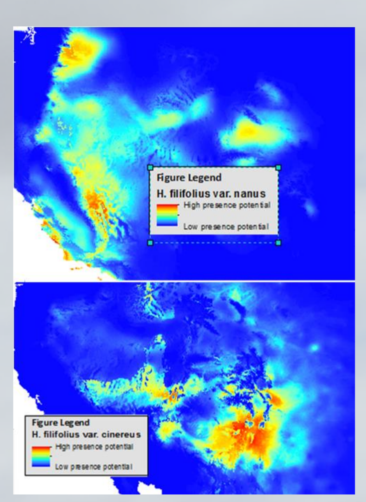

Figure 5: Comparison of Maxent projections between *H. filifolius var. nanus* (top) and *H. filifolius var. cinereus* (bottom).

Conclusions

The modeling showed that the niche occupied by *H. filifolius* is mostly determined by **Mean diurnal range** and **Precipitation during the warmest quarter**. In contrast the niche of *H. mexicanus* is most influenced by the **Temperature seasonality** (a coefficient of variability) as well as **Precipitation seasonality** (another coefficient of variability). So there is not only a marked difference between the two sets of variables but also in the amount of contribution from each variable and as a result we can infer that each species occupies its own niche. Even more striking is that when the projections are overlain over a map of elevation, it appears that elevation is correlated to niches of both species.

More investigation is needed to further distinguish between the niches, but this study exemplifies not only the driving forces separating the niches of this clade, but also the importance of climate in influencing species distribution and divergence. Insights provided by this study and similar studies become of increasing importance when considering themes of global warming and climate change. As the diversity of climate regions is lost and suitable habitats for plants disappear, the potential for a chain effect of species elimination grows exponentially. By understanding the variables that contribute to the niches of organisms, though, more information can be supplied to help combat the growing problem of climate change.

Future Directions

- To test the predicted ranges by conducting fieldwork in areas that are predicted to have specimens but have no collections.
- To Incorporate soil geology and geochemistry data (once available) into modeling to produce a better understanding of the niche parameters of the two species.
- To expand methods and information garnered from this study to learn more about if and how the endemic western North American plants in the Compositae family adapt to extreme environments.
- To investigate the subspecies of *H. filifolius* further to see if there are finer niche distinctions.

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[1]McCormack JE, Zellmer AJ, and Knowles LL 2009. Does Niche Divergence Accompany Allopatric Divergence in Aphelocoma Jays as Predicted Under Ecological Speciation?: Insights from Tests with Niche Models. Evolution 64(5): 1231-44. Web. 18 Jul. 2016.
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Picture References:
(1a) Kleinman, Russ. *Hymenopappus filifolius*. May 19, 2007. Western New Mexico University Department of Natural Sciences. *Vascular Plants of the Gila Wilderness*. Web. 25 Jul. 2016
(1b) Kleinman, Russ. *Hymenopappus filifolius, closeup of inflorescence*. May 16, 2009. Western New Mexico University Department of Natural Sciences. Vascular Plants of the Gila Wilderness. Web. 25 Jul. 2016
(1c) Lichner, Max. *Hymenopappus mexicanus*. Arizona State University Vascular Plant Herbarium. Web. 25 Jul. 2016
(1d) Lichner, Max. Hymenopappus mexicanus. Arizona State University Vascular Plant Herbarium. Web. 25 Jul. 2016
(background) Edwards, Robert. *Arizona Landscape*. 2016. Photograph.

Institution References:
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