Models of species’ climatic niche

Jessica J. Hellmann | Director, Institute on the Environment
For purposes of basic knowledge and conservation planning, ecologists seek to characterize the climatic conditions that limit where species live on Earth. To do this, they build statistical models that describe the climatic niche of individual species based on its geographic occupancy. These models, e.g., MaxEnt, are classification algorithms that aim to distinguish occupied from non-occupied points from a set of climatic descriptors. With a description of a species' ecological niche, it is possible to project these conditions forward in time according to global circulation model output and identify locations that might be suitable for the focal species in the future. We will discuss some examples of how these models are used, criticisms that ecologists have leveled at these models, and one particular dilemma having to do with local adaptation of populations within a species' range.
The world is changing...

2030

2100

°C increase

IPCC 2007 | National Climate Assessment 2013
The world is changing...
Preserving biodiversity under climate change

Species | Genetic Diversity | Ecosystem Function | Ecosystem Services
Questions

1. What factors most limit the distribution of a species?
2. Where might a species live under future climate?
3. How far might an invasive species spread?

Management implications
Ecological Niche Modeling

- Also called species distribution modeling, environmental niche modeling, and bioclimatic envelope modeling
- Predict the distribution of species
- Can use to make future projections

1. occurrence points
2. environmental layers
3. algorithm
4. environmental space
5. model projection

http://openmodeller.sourceforge.net/img/enm_diagram_small.png
Multinomial logistic regression

They all have in common a **dependent variable to be predicted** that comes from one of a limited set of items which cannot be meaningfully ordered, as well as a set of independent variables (also known as features, explanators, etc.), which are used to predict the dependent variable. Multinomial logit regression is a particular solution to the **classification problem that assumes that a linear combination of the observed features** and some problem-specific parameters can be used to determine the probability of each particular outcome of the dependent variable.

finds a model that can best differentiate presences from background locations
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Management implications
Maxent modeling

**Figure 1.** Map of Red Shiner presence locations used in the Maxent model. The native distribution of Red Shiner (NatureServe 2010) is shown in dark gray.
Table 1. Environmental predictor variables evaluated for inclusion in the red shiner species distribution models, their native spatial resolution, and data sources. Variables marked with asterisks were those that were included in the final Maxent model.

<table>
<thead>
<tr>
<th>Predictor variables</th>
<th>Description</th>
<th>Native spatial resolution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ppt*</td>
<td>mean precipitation 1980-1997</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Tmax</td>
<td>mean maximum air temperature 1980-1997</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Tmin*</td>
<td>mean minimum air temperature 1980-1997</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Jantmin</td>
<td>mean minimum air temperature of the coldest month</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Augtmax*</td>
<td>mean maximum air temperature of the hottest month</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Sumprecip</td>
<td>average summer precipitation</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Summheat*</td>
<td>summer heat: (mean warmest month temperature)/(mean summer precipitation/1000)</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>RH</td>
<td>relative humidity</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Frostdays</td>
<td>number of frost days</td>
<td>1 km</td>
<td>Daymet¹</td>
</tr>
<tr>
<td>Upstream flow*</td>
<td>flow length toolbox in ArcGIS</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Downstream flow*</td>
<td>flow length toolbox in ArcGIS</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Flow accumulation*</td>
<td>flow accumulation from ArcHydro extension of ArcGIS</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Watershed slope*</td>
<td>slope of the watershed in degrees</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Downslope elevation change*</td>
<td>calculated as the difference between a cell’s elevation in meters and the lowest elevation</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Stream power index</td>
<td>erosive power of overland flow measured as the area of the catchment area multiplied by the tangent of the slope calculated using Whitebox Geospatial Analysis Tools (Lindsay 2009)</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Upslope neigh</td>
<td>number of upslope neighbors</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Sed trans</td>
<td>sediment transport capacity index (Burrough and McDonnell 1998)</td>
<td>30 m</td>
<td>National Hydrography Dataset²</td>
</tr>
<tr>
<td>Impervious</td>
<td>% impervious surfaces</td>
<td>30 m</td>
<td>USGS³</td>
</tr>
<tr>
<td>Baseflow*</td>
<td>baseflow index grid from USGS stream gauges, expressed as percentage of baseflow relative to total flow</td>
<td>30 m</td>
<td>USGS³</td>
</tr>
<tr>
<td>Saturation overland flow*</td>
<td>estimated by TOPMODEL (Beven and Kirkby 1979)</td>
<td>Vector dataset</td>
<td>USGS³</td>
</tr>
</tbody>
</table>

¹ Daymet
² National Hydrography Dataset
³ USGS
Figure 2. Maxent results for red shiner including A) the habitat prediction map, and B) the standard deviation among the 25 model iterations using different subsets of point data to test for model sensitivity to presence locations, and C) the presence-absence habitat prediction map for each hydrologic unit (USGS 6-digit HUC) in the United States. The threshold for conversion to binary predictions was derived using the maximum sensitivity plus specificity criterion. The native distribution of *C. lutrensis* is shown in gray.
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Fig. 1. Consistent predictions of climate-induced (A–C) species range losses, (D–F) expansions, and (G–I) species turnover for lower B1 (A, D, G), mid A1B (B, E, H), and mid-high A2 (C, F, I) greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change (as a percentage) based on 10 different climate-change projections. Species-loss values assume no dispersal of individuals to newly created suitable climatic environments whereas both expansion and turnover values assume that species will be able to move into expanding ranges. Eighty percent of the climate projections (eight of the 10) resulted in losses, gains, and turnover values greater than the values represented in the maps.
Critiques

1. assumes climate limits geographic distribution
2. does not include ecology, e.g., species interactions
3. junk in, junk out & rigorous assumptions about sampling
4. does not account for local adaptation
Karner Blue Butterfly
(Lycaeides melissa san)

Hällfors et al. In press. Ecological Applications. Photo Flickr Justin Meissen
Questions

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Management implications
Managed relocation

Intervention technique aimed at reducing negative effects of climate change on biological units, involving the intentional movement of these units from areas of current occupancy to locations where the probability of future persistence is predicted to be higher.

A Hunt for Seeds to Save Species, Perhaps by Helping Them Move

By ANNE RAVEN

CHICAGO—Pusher's thistle, whose fuzzy leaves and creamy pink puffs once thrilled in the wind, now doing so in several of the Great Lakes, was driven from the shores of Lake Michigan in a different wave of environmental disaster. A species that was once native to Michigan near popular beaches is now extinct.

The good news is that it helps species that generally grow near one another to migrate to a new range.

**Pros**

- Prevent extinction
- Enhance ecosystem goods
- Enhance ecosystem functions

**Cons**

- Create pests
- Endanger source populations
- Incur opportunity costs

**FLOWERING:** Native plants like black-eyed Susans are growing in what had been a vacant Chicago lot.

The Dann seed bank at the Chicago Botanic Garden houses not only species from the tallgrass prairie, but also those of the tundra, desert and other systems of the prairie region. It also studies the working collections of species staged out for restoration.

Dr. Havens said that once the dracaena specie is dispersed, the horticultural center that can be used is the most important strategy for the recovery of the species.

Climate models are showing that their habitats may be moving north, but they do not specify where the climate of the future may be.

Dr. Havens added that an increase in the number of plants grown in the botanic garden, which does not appeal to plants, will need another center, which should be provided by governors and state agencies.

**Is it wise or foolish to assist with the migration of plants?**

The most important conservation work gets harder with these changes. It's time to use our resources.
Future research

1. process-based models
2. algorithm improvements
3. better sampling
4. experimental transplants
THANK YOU
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