# MODELING AVIAN RESPONSES TO CLIMATE CHANGE USING EVOLVING OCCURRENCE MODELS

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## Introduction

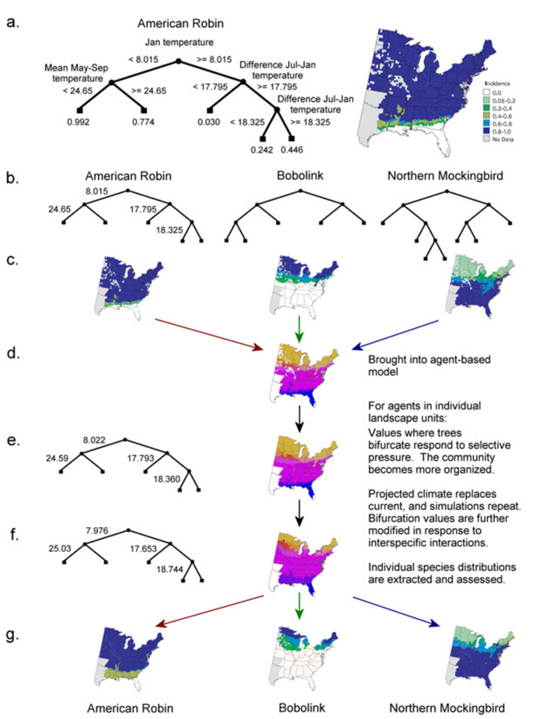
The geographic distributions of species are limited by environmental constraints, some of which are influenced by a changing climate. As climate warms, species are shifting their ranges toward the poles or to higher elevations. We have devised a novel approach to predicting changes in future species distributions that: 1) incorporates intra- and interspecific interactions, 2) allows species involved to subtly alter their niches, and 3) adopts a localized view of the environment that prevents unrealistic dispersal distances. We are representing species and their niche dimensions in an agent-based context, with those niches defined using boosted regression trees with splitting values that will evolve under selective pressure. Spatial surfaces reflecting projected climate change will be substituted for observed climate data. Simulations will continue, with the ranges and incidences of avian species changing in response to the projected change in climate plus the myriad biotic interactions represented in the simulations.

## Methods

We are constructing boosted regression trees for bird species of the coterminous US. Species data are drawn from the USGS Breeding Bird Survey. For more than 40 years thousands of routes have been surveyed annually. We are using a suite of spatial layers (e.g., climate and weather, productivity, land cover, phenology) as explanatory data. Raster layers and bird data have been generalized to EPA EMAP hexagons, which are a statistically rigorous tessellation of the US with hexagons ca. 640 km$^2$. Preliminary analyses indicate between 100 and 150 species will yield trees with usable explanatory power.

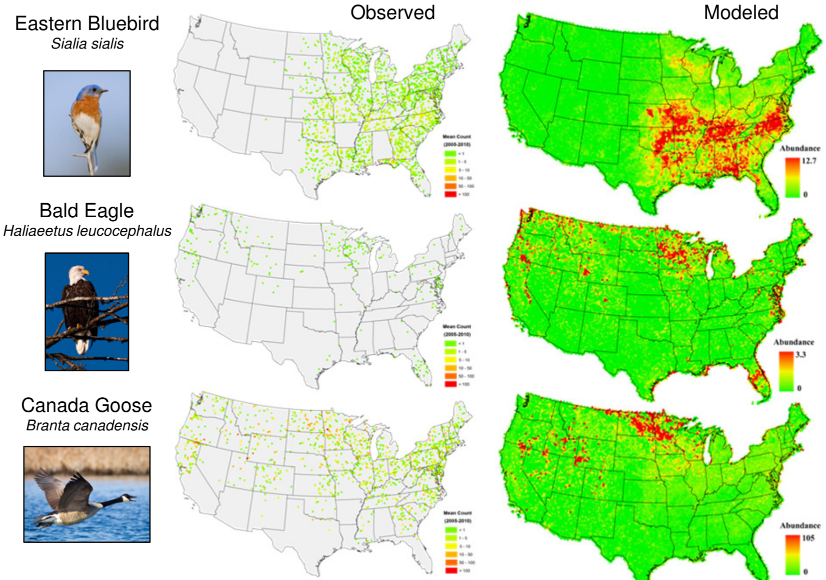
The distribution of each species has been recreated in an agent-based model using the trees and spatial data. The capacity of hexagons to host bird species will be set based on biogeographic theory (e.g., Hansen et al. 2011). Individual species will be allowed to disperse and occupy hexagons to which they are well adapted. An evolutionary programming approach will be used to allow subtle changes in the splitting values in each species' regression tree, enabling niche packing. Surfaces that will change in response to a changing climate (and land use) will be replaced in the model. Species will then be allowed to compete and shift their distributions. When distributions reach stability, those distributions will be compared to those from more traditional methods.

A pictorial representation of our methods, drawing on products from Matthews et al. (2004) for bird information. Regression trees (a) for bird species will describe the incidence of species across the US. These trees (b, c) will be used in an agent-based model (d), where species will compete to occupy landscape units. Points of bifurcation in trees will slowly evolve (e) through simulation cycles, with each agent able to have unique but related values. The simulation will stop when distributions are stable. Current climate data will be replaced with projected climate data in the application (f) and simulations will continue, with agents producing mutated offspring that may occupy nearby landscape units and bifurcations continuing to slowly evolve in response to changing climate and interspecific interactions. Resulting incidences (g) will be the result of both climate change and intra- and interspecific interactions.



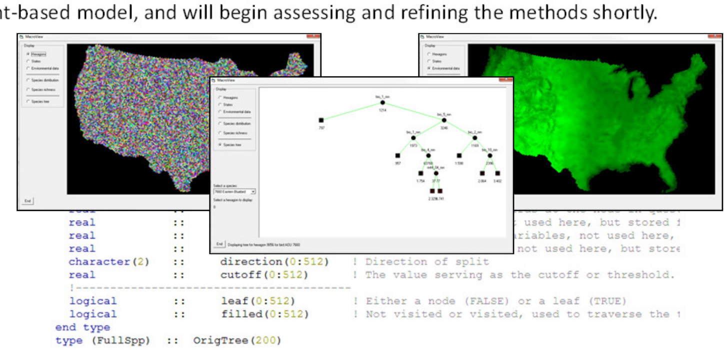

## Creating Boosted Regression Trees

To model avian species distribution, a series of raster layers from various sources (e.g., MODIS Vegetation Continuous Fields, PRISM climate data, and MRLC land-cover) have been amassed to associate with bird species presence locations identified from the Breeding Bird Survey 50-stop data. Boosted Regression Trees (De'ath 2007) are being used to construct statistical models to predict bird species relative abundance in the U.S. This technique recursively partitions the dependent data into two homogeneous groups at an optimal independent variable value. The resulting best fit 'tree' will act to parameterize the agent-based model and evolve changing species distributions over time.




## Agent-based Modeling

The NetLogo application proposed for this work has proven insufficient given the dimensionality involved. We have created the numerically intensive agent-based model in Fortran, and have prepared a graphic viewer of results. Environmental surfaces and species trees may be viewed. In the agent-based model, the model is initialized, including reading of spatial surfaces for EMAP hexagons and bringing in regression trees for the suite of species being considered. We are implementing the evolutionary programming algorithm in the agent-based model, and will begin assessing and refining the methods shortly.




## Merit

Agent-based modeling approaches are rare in macro-biological analyses, and the inclusion of regression trees that can evolve through time is a unique contribution. An agent-based application representing evolving niche dimensions may be used to address questions of island biogeography, evolution and cladistics, fundamental and realized niches, community structure, the neutral niche paradigm, invasion, and climate change.

## Citations and Acknowledgements

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Matthews, S., R. O'Connor, L.R. Iverson, and A.M Prasad. 2004. Atlas of climate change effects in 150 bird species of the Eastern United States. Gen. Tech. Rep. NE-318. Newtown Square, PA: USFS, Northeastern Research Station.

This work is supported by the National Science Foundation, EF 1241583. "Plane filling motif with birds" redrawn from M.C. Escher (1949). Photos: W.H. Majoros (bluebird), E. Frommer (eagle), and D. D'Auria (goose). Contact Randall.Boone@ColoState.edu for information.