**Manuscript 2: Co-occurrence under climate change uncertainty**

**Title**

* Accounting of uncertainty in forecasts of species co-occurrence under climate change across stream networks.

**Journal**

**Abstract**

**Introduction**

* Climate change is expected to alter the occurrence of many species over the next century.
* Forecasting species occurrence under future climates is inherently uncertain, with few attempts to account for uncertainty comprehensively in a probabilistic manner (Wenger et al. 2013).
* Lots of uncertainty influences these predictions:
  + Current occurrence state (current data is limited or imperfect)
  + Predictors are unknown and plastic (model and parameter uncertainty)
  + Future environmental variability is uncertain (climate forecasts and impacts on local habitat conditions)
  + Species-interactions (system uncertainty)
* Accounting for uncertainty is critical for generating risks and insights about conservation planning decisions (what can be done over the next 10-years to reduce impacts given uncertainty).
* Use a forecasting approach to make predictions using multiple models, data sources, and climate conditions (ensemble forecasting – Wenger et al. 2013 (see for more examples of recent studies; Aruajo and New, 2007, Stainforth et al. 2005).
* Objectives:
  + We used a MCMC approach that included uncertainty among completing models (system uncertainty), uncertainty in estimated effects (linear-model parameter uncertainty), uncertainty in environmental conditions (spatial variability), and future climate conditions (climate uncertainty).
  + We forecasted the co-occurrence of two obligate headwater stream species (spring salamander and brook trout) climate-sensitive species of conservation interest. These species are hypothesize to occur in different parts of the stream network, but overlap in the mid-headwater habitats (salamanders in upper and mid-headwaters and trout in mid- and lower headwater)
  + We selected 100? random watersheds (HUC 10) across the northeastern US to evaluate the effect of stream network structure and landscape variation (land use) on co-occurrence and predicted co-occurrence under current, and projected 2020, 2040, and 2080’s climate conditions.
  + Our main objective was to assess the likelihood of large and small declines in species occurrence by generating a set of probability of occurrence estimates for each catchment under alternative climate scenarios. We are also interested in identifying which components of uncertainty (model, parameter, climate) contribute the most to total uncertainty in predictions and explore how results can be used to improve the evaluating of conservation efforts.

**Methods**

*Study species*

* Headwater stream biota
* Brook Trout – vulnerable to temperature and network structure?
* Spring Salamanders – vulnerable to fish presence and low-flows
* Evidence for competition/predation hypothesis
* Evidence for spatial autocorrelation (upstream vs. local effects of habitat)

*Watershed selection*

* Randomly selected X number of HUC 10 (?) watersheds across the NE
  + Start with Deerfield as example for code
* Eliminated non-coastal watersheds (average, max and min area)

*Landscape and environmental metrics*

* Characterized stream network metrics
* Characterized land use patterns (forest cover, impervious cover, agriculture)
* Catchment-level data (limits?) (min size, max size; i.e., only headwaters, not medium to large rivers)
* Upstream-level data (limits?)
* Climate models (multiple or single model?; 4 time periods (current, 2020, 2040, 2060)
* Each climate model affects predictions of air temp, affecting stream temperature (Hocking et al) and flow (precipitation x area; cite)

*Species-level data sources*

* Trout data from state, fed agencies collected from X to X (fully described in Hocking et al). Trout catchment- occupancy predictive model included:
  + Catchment-level:
    - forest cover (percent, acres)
    - wetland habitat (percent, acres)
    - surficial coarseness (geology/geomorphology – rocky habitats)
    - spring salamander presence
* Salamander data from expert elicitation (manuscript 1)
  + Catchment-level
    - forest cover (percent, acres)
    - wetland habitat (percent, acres)
    - surficial coarseness (geology/geomorphology – rocky habitats)
    - brook trout presence

**Results:**

**Discussion:**

*Limitations to our predictive model:*

* choice of climate model(s)
* spatial autocorrelation?
* biased spatial autocorrelation (downstream, upstream bias?)
* spatial arrangement of catchments (in reality – an occupied catchment surrounded by unoccupied catchments may not be sustainable over time, even despite low dispersal and spatial connectivity of these species)

**Literature:**

Wenger, S. J., Som, N. A., Dauwalter, D. C. & Isaak, D. J., et al. 2013 Probabilistic accounting of uncertainty in forecasts of species distributions under climate change. *Glob. Chang. Biol.* 3343–3354. doi:10.1111/gcb.12294

**Tables:**

**Figures:**