Forecasting changes in stream flow, temperature, and salmonid populations in Eastern U.S. as a result of climate change - *What's going to happen, how certain are we, and how can we help managers help fish?*

Project update, June 2012.

Former personnel:
Dr. Michael Morrissey, 2011, currently in a faculty position at the University of St Andrews, Scotland. *Hierarchical modeling*

Dr. Doug Sigourney, 2011, currently a post-doc at the University of Maine, *Hierarchical modeling*

Current personnel:
Kryzsztof Sakrejda, PhD student at UMass. *Hierarchical modeling*.

Dr. Yoichiro Kanno, post-doc, *temperature modeling, occupancy modeling.*

Dr. Ron Bassar, post-doc, *integral projection models, incorporating fish models into web site*.

Dr. Austin Polebitski, research faculty in Department of Civil and Environmental Engineering, UMass, *flow and temperature modeling.*

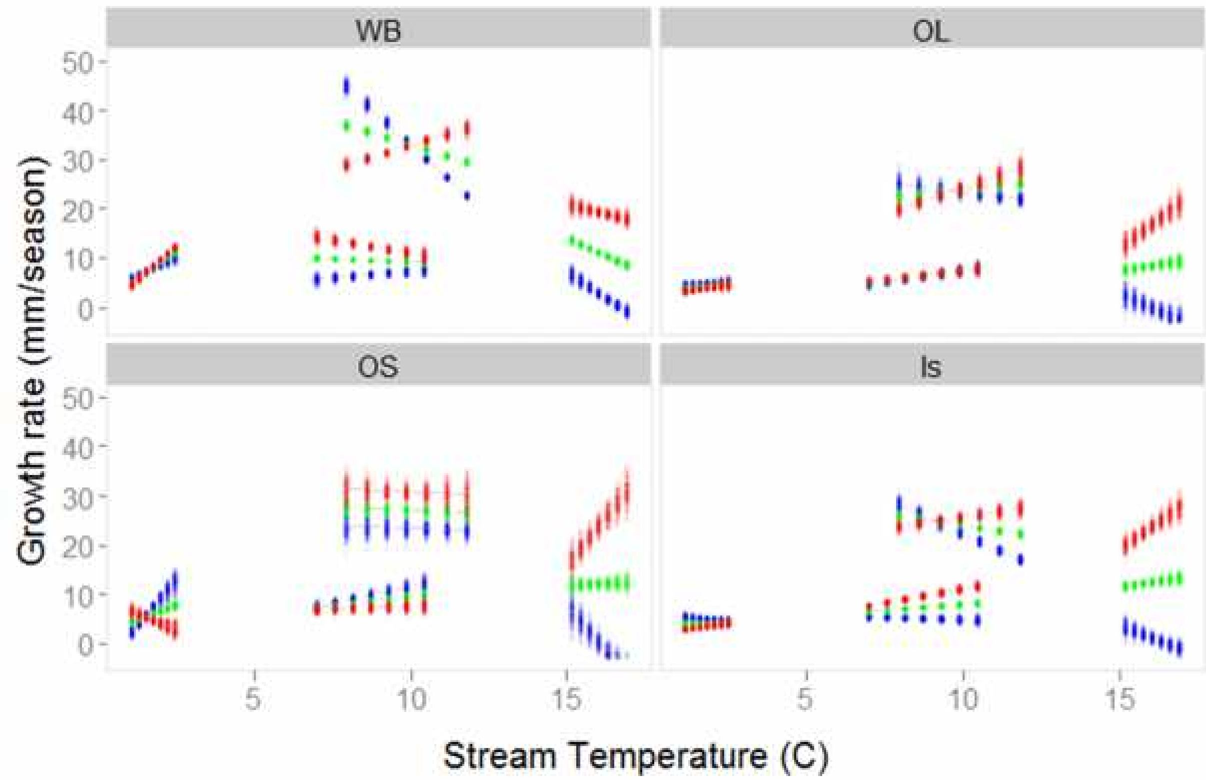
Dr. Tim Richards, faculty in Computer Science Department at UMass, *web-site development and database creation*.

Description of Work:

A. The University of Massachusetts - Amherst shall:

Task 1: *Hierarchical modeling framework to account for multiple scales and sources of uncertainty in climate change predictions*. UMass will develop the theory and application of a hierarchical Bayesian model to forecast local (catchment scale) population persistence of brook trout. Estimated cost 2011 – 2013 $170,000.

Done. Manuscript in preparation.
Example figure.



Predicted growth as a function of stream temperature and discharge for each river (panel). Stream discharge is represented by the different colors (red=high flow [+1.5 s.d. units], green=average flow [0 s.d. units], blue=low flow [-1.5 s.d. units]). Each collection of points/lines represents one season and each point on the graph is the predicted value for one MCMC iteration.

The hierarchical (parameter estimation) model describes how survival, body growth, and movement vary as a function of season, stream flow, and stream temperature. An example of one of these relationships is in the figure above, where we show growth rate as a function of stream temperature and flow for each of the four seasons. There are clear and strong effects of flow and temperature and their interactions across seasons.

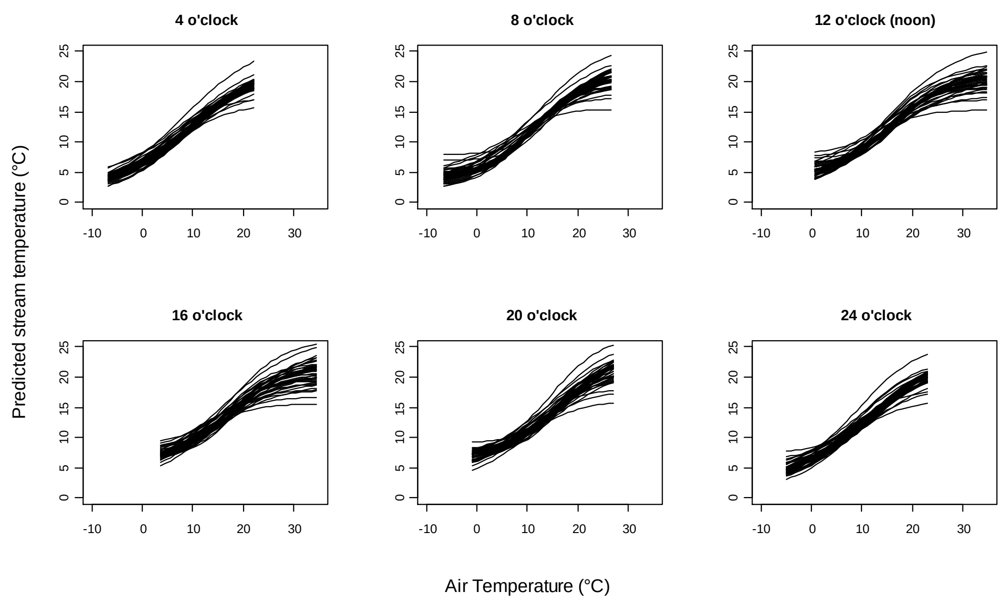
All the relationships in the parameter estimation model are now summarized in a population projection model ('integral projection model') that we can use to forecast how population dynamics respond to changes in steam temperature and flow. A version of this projection model is what will be adapted to provide users the ability to scenario-test and evaluate climate change impacts using the web-site created in Task 4

Task 2: *Statistical models to predict stream flow and temperature based on air temperature and precipitation.* UMass will develop an empirical model for the relationship between air temperature and water temperature as a function of local environmental conditions. Estimated cost 2011 – 2013 $50,000.

<u>Flow</u>: We have developed 3 flow models. Models 1-3 increase in complexity.

1. Watershed area ratio scaling. The closest gage to the target watershed is used to interpolate flow and then flows are scaled based simply on watershed area ratios between the target watershed and the gaged watershed. [Done]
2. Interpolation and Watershed area ratio scaling. Nearby gages are used to interpolate flow and then flows are scaled based simply on watershed area ratios between the target watershed and the gaged watersheds. This is very similar to the SYE (sustainable yield estimator) developed by the MA/RI USGS WRD office. [Done]
3. ABCDE model. A simple compartmental model that estimates how water moves through a few 'boxes'. The boxes represent surface water, subsurface water, snow, and stream water. The model estimates exchange rates between the boxes as a function of local conditions, and can be linked directly to climate change forecasts of precipitation and air temperature as well as to landchange forecasts (from the NALCC). [90% done. Adding spatial covariance structure among sites.]

Temperature: We have tested simple statistical models of the relationship between air temperature and stream temperature. Based on an extensive dataset collected by new NALCC post-doc Yoichiro Kanno during his dissertation at UConn, we have modeled how the relationship between air and water temperature varies over space (40 sites) and time (within-day and across months).



We will apply this simple modeling technique to data that range across the NALCC. Ralph Abele (EPA) and I convened a meeting at USFWS R5 offices in May 2012 to determine what kinds of datasets exist and whether there is coordination among states. The data are unfortunately slim.

There is a key need to develop an open source temperature database across the NALCC and beyond. There is also a key need to collect more temperature data with a common protocol across the NALCC. Austin Polebitski and I have just recently received funding from the NE Climate Science Center to get a start on compiling existing data into a database and to develop a pilot temperature sensor network. The project funds a MS student at UMass and about 500 temperature sensors.

Task 3: *Incorporate climate change forecasts into population persistence models*. UMass will obtain an 'envelope' of downscaled global circulation data on precipitation and air temperature and incorporate these into the models in Task 1 using relationships from Task 2 in order to forecast local population persistence across climate change scenarios. Estimated cost 2011 – 2013 $50,000.

Done. Datasets of downscaled precipitation and air temperature have been set up. They are ready to feed into the fish models. We will incorporate this dataset into the fish models once the website (see below) is functional. The website will grab the appropriate subset of data depending on the user-selected watershed. These data will drive the fish model.

Task 4: *Develop a decision support system for evaluating effects of alternate management strategies in the face of climate change*. UMass will develop a web-based application for examining effects of management scenarios on local population persistence. Estimated cost 2011 – 2013 $130,000.

This component of the project is recently underway. I have hired a faculty member of the Computer Science Department to develop the web site. Dr Richardson's interests lie in database development and in creating functional websites linked to databases. He has suggested using a 'documents-based' database rather than the more typical SQL-based database. These new databases (e.g. mongoDB) are more flexible that SQL-based databases and can easily deal with different data types and data collected at different space and time scales (a persistent problem with temperature data).
Dr Richardson has also created a beta version of the web interface for the environmental models (flow and temperature) and the fish models (http://livestreams.herokuapp.com/). Users select a stream segment, the site goes to USGS stream stats to get the watershed boundary upstream of the selected location, and then Austin's flow models are run (Task 2). Results from the flow models are presented on the web page and include predicted flow for the selected location for the last 5 years and forecasts based on the downscaled climate change data from Task 3.
Once the *temperature* model is functional, we will add predictions and forecasts for temperature to the site.
We are working currently on incorporating the *fish* model to the site.

1. This involves presenting a user-selectable stream network within the selected watershed,
2. allowing users to 1) select network segments where fish may be present and 2) assign a stream type to each segment of the network (mainstem, ephemeral tributary, perm, tributary, isolated tributary),

3. automatic creation of the fish population dynamics model for the selected watershed (based on the model in Task 1),
4. running model scenarios, e.g. specific scenarios (e.g. flow reduction or culvert removal) or fish population response to future climate and/or landuse change,
5. presentation of user-selected output (details TBD in focused workshops with users)

The major remaining efforts for this task include incorporating the terrestrial NALCC project landuse model into the site and fish model, fully testing the website, and getting user feedback from the beta version.

Task 5. *Develop curriculum and run training workshops for users of the decision support system*. Hold workshops at USFWS Region 5 office to train potential users. Estimated cost 2011-2013 $20,000.

We will conduct workshops once the web site is completed. We anticipate and beta version of the site will be ready for testing late 2012 or early 2013.

'Holdback' funds

Products

- Pattern identification
  - Identification of patterns of flow variation across a wide variety of stream/river types
  - Decomposition of sources of flow variance.
- Flow alteration
  - Tools for identifying extent of flow alteration from predicted base conditions (based on pattern identification results).
  - Results could be used for before/after (e.g. dam construction) analysis of flow variation, and for setting minimum safe withdrawal guidelines.
- Flow prediction
  - Tools for prediction of flow under climate change scenarios. Conversion of predicted precipitation patterns into flow variation across a variety of stream/river types.
- A peer-reviewed scientific papers detailing the application of DLMs to hydrologic analysis and flow predictions under climate change scenarios, illustrated using regional and national case studies.
- A scientific workshop providing a general overview of the methodology and computer-based labs illustrating the application of DLMs.

Since writing the proposal for the 'holdback' funds, we have determined that DLMs are not the best way to model flow across the landscape. DLMs are very good at identifying patterns in time series data, but not so good at incorporating the processes that govern local flow. Using a model that includes the minimal necessary process (ABCDE, Task 2) will make it feasible to apply the model broadly across space and time. With the ABCDE model, we can fulfill all the objectives in the DLM proposal, but with a model that is not a purely statistical model (like DLM) and one that, in theory, could be applied easily across a wide range of LCCs.

Associated activities:

Powell Center working group: Working group to identify and develop best way to extend models like those developed in Task 1 across the landscape. Two-year project involving 17 statisticians/modelers.

NE CSC grant: Stream temperature monitoring and modeling. Funds a MS student and loggers.

TNC connectivity project: Project to develop tools to prioritize barrier removal/repair based on population persistence of stream salmonids. Will dovetail with the NALCC web site.

NIWR proposal: Proposal to The National Institutes for Water Resources to do stream temperature monitoring and modeling