PREDICTED RISK OF BROOK TROUT TO CLIMATE CHANGE IN LAKE SUPERIOR'S NORTH SHORE STREAMS

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Abstract

Brook trout in the North Shore region of Lake Superior are very sensitive to temperature and hydrology changes. Climate change is expected to cause increases in water temperature and possible decline of summer low flow. To estimate the effects of climate change to brook trout in this region, we developed several empirical models to predict stream temperature, and brook trout presence/absence using current (1996-2009) hydrology, air temperature and land cover. Together with projected air temperature and stream flow, these models forecasted the future (2020-2089) stream temperature and the risk of brook trout in more than 400 survey sites located in 329 streams in this region. Results indicated that averagely summer stream temperature in this region will increase by 1.2°C in 50 years. Consequently, 20% of current trout streams may lose trout, particularly in the lower shore area, where trout were predicted to disappear from almost all streams. In middle shore area, brook trout may be extirpated from half of current trout presence streams. Streams in the upper shore were less affected by climate change. Overall, suitable brook trout habitat in North Shore streams was predicted to shift northward in response to climate change.

Introduction

Climate change in the near future is expected to have warmer and dryer summer, and more precipitation as rain instead of snow in Lake Superior north shore region (Graham and Harrod 2009). These changes cause direct effects like air temperature rise and evaporation increase. Indirectly, water temperatures and stream flow amount are shifted to temperature rise and flow reduction. These changes are particularly pronounced over land than over ocean, meaning effects to freshwater biological ecosystem could be more profound than marine (Jonsson and Jonsson 2009). Climate change and its likely consequences have become threats to fish population and size (Brander 2007).

Water temperature and flow regimes are two of the most important climate-related drivers affecting trout population (Johnson 2003; Jonsson and Jonsson 2009; Issak et al. 2010). The increasing temperature in streams has been evident to reduce reproductive capacity or growth, and make fish ecosystem vulnerable to be sustainable, such as salmon (Brander 2007). The temperature rise expected from climate change may extirpate trout population. Water flow has impacts to water accessibility and connectivity of habitat for spawning, migration and returning adult trout (Bunn and Arthington 2002). Therefore, the combination of these two parameters are of major importance for the trout population (Wenger et al. 2011). Except the effects of climate change, land development adds additional stress to trout population by modifying water temperature and flow amount. Water temperature is affected by catchment area, latitude, forest cover, agriculture, wetland and geology (Wehrly et al. 2006). Stream low flow is identified as a function of land use, geomorphy, forest cover and channel density. To evaluate the effects of water temperature and low flow to brook trout, these land features must be considered as well.

Study Area

Lake Superior North Shore region (Figure 1)
- 427 stream temperature survey sites from 1996 to 2009
- 371 brook trout presence/absence survey sites for two time periods of 1997 to 1999 and 2008 to 2011
- 79 collocated stream temperature and brook trout survey sites
  - 49 sites: brook trout presence, ratio=49/79=62%
  - 30 sites: brook trout absence, ratio=30/79=38%

Landscape characteristics
- Land cover of drainage catchment and stream buffers of 50 m, 100 m and 150 m
- Forest type
- Quaternary geology
- Soil Properties
- Lithology
- Slope
- Percent impervious

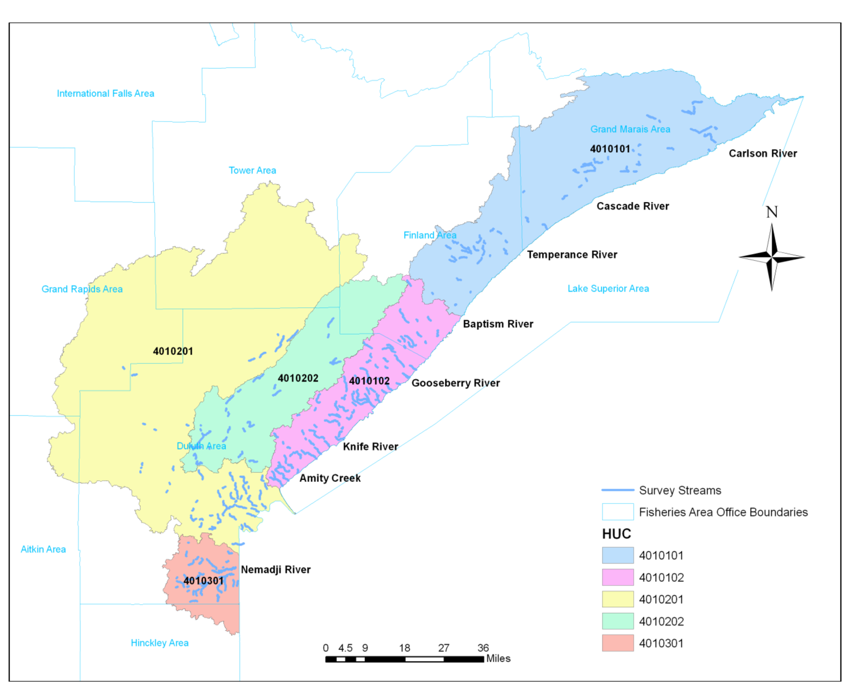

Figure 1. Map of survey streams.

Methods

1. Develop multiple linear model to predict stream water temperature
   Potential predictors: air temperature, watershed area, land cover, forest type, quaternary geology class, lithology type, soil properties, wetland cover, percentage of impervious cover area, slope, latitude and distance to shoreline
   Methods: Stepwise regression to select model predictors

2. Develop empirical models to predict brook trout presence/absence
   Predictors: July monthly average temperature, August low flow and other potential landscape variables
   Methods: logistic regression model

3. Using developed models and projected future air temperature and precipitation to forecast brook trout risk level in Lake Superior North Shore regions. The risk level of brook trout were classified into three categories: absence when presence probability below 0.5; at risk when presence probability between 0.5 and 0.62; and presence when probability above 0.62.

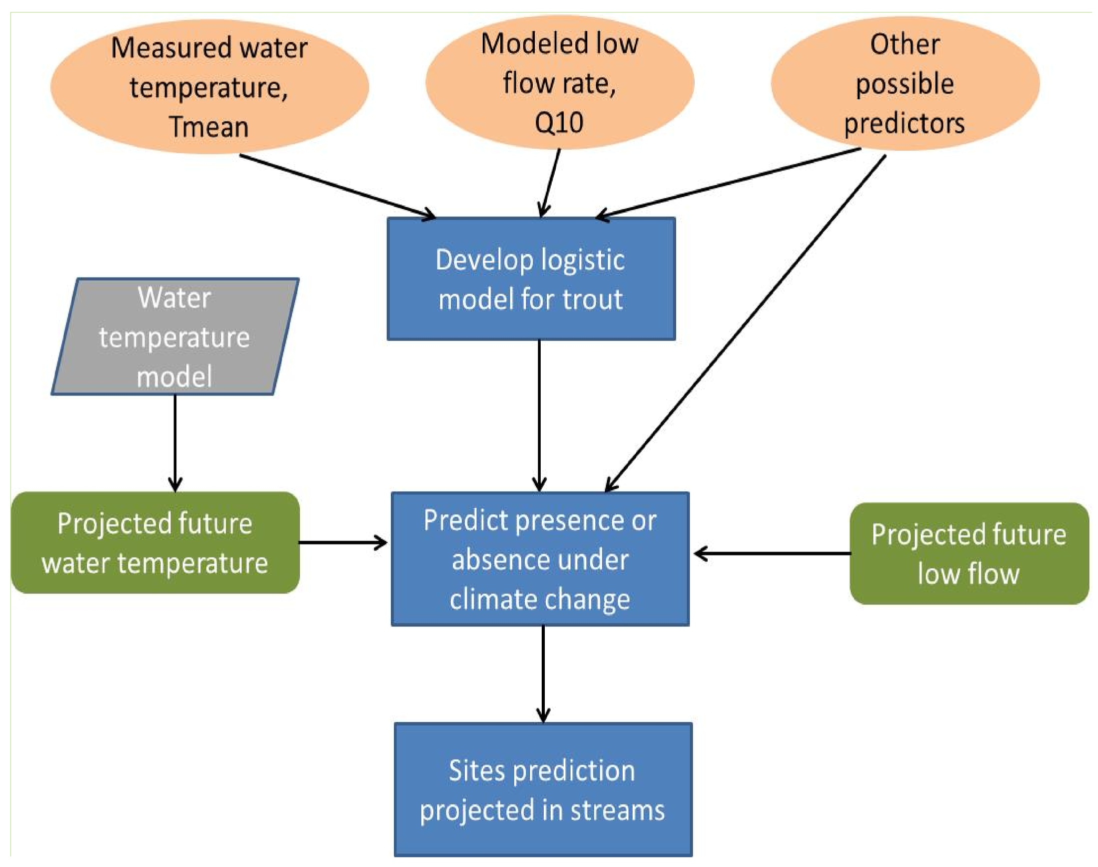

Figure 2. Work flow scheme.

Results: Predicted Stream Temperature

Overall stream temperatures were strongly related to air temperature (40% variance of model), drainage watershed size (40% variance of model), but relatively weakly related to woody wetland coverage, soil permeability and latitude.

1. Stream temperature model
- July monthly mean water temperature

$$T_{mean} = -33.35 + 0.67T_{ave_{air}} + 1.51\log(Wshed_{Area}) + 2.05sqrt[\arcsin(\%WoodyWetlands_{150m})] - 1.33\log(Permeability) + 6.52\times10^{-6}Latitude \quad (1)$$

N = 369, R^2=0.40, R^2_{adj}=0.39, p<0.01

Where, $T_{ave_{air}}$ is July average air temperature, $Wshed_{Area}$ is basin area, $\%WoodyWetlands_{150m}$ is used for woody wetlands area in the riparian zone of stream 150 m buffer, $Permeability$ is soil permeability of the drainage basin, and $Latitude$ represents site latitude.

2. Temperature regimes for brook trout presence probability

$$log\frac{p}{1-p} = 7.48 - 0.37T_{mean} \quad (2)$$

Where, *p* is brook trout presence probability, T_{mean} is July mean water temperature. Based on this model, the relationship between July mean temperature and trout presence probability was present in Table 1.

Table 1. Water temperature and trout presence probability.

Probability of trout presence	July mean temperature, °C
0.68	18
0.62	18.68*
0.59	19
0.50	20*
0.41	21
0.32	22
0.25	23
0.18	24
0.13	25
0.023	30

* The temperature thresholds for trout presence or absence

Results: Predicted Trout Risk

Brook trout presence/absence model:

$$log\frac{p}{1-p} = 15.19 - 0.63T_{mean} + 0.37Q_{10} - 5.28\,\%Deciduous\_Forest\_150m \quad (3)$$

Where, *p* is the brook trout presence probability, T_{mean} is the July mean water temperature, Q_{10} is the 10th percentile August flow, and *%Deciduous_Forest_150m* represents the proportion of deciduous forest cover in a150m stream buffer area.

Assuming future forest cover remained unchanged, the brook trout risk levels were projected in Figure 4.

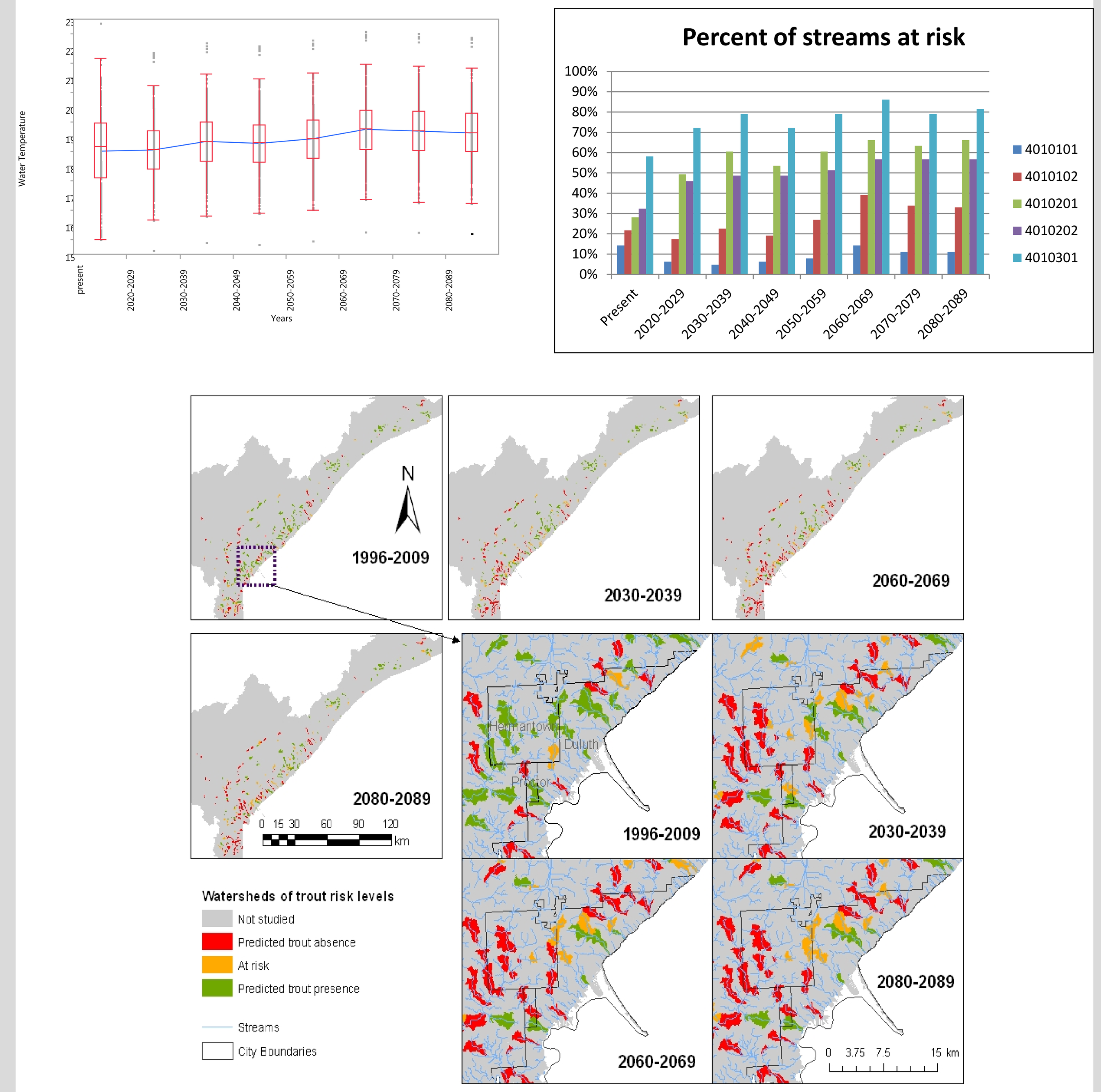

Figure 3. Projected water temperature and brook trout risk levels in 329 streams and in Duluth area from present to 2089.

Future Work

Current work assumed the landscape characteristic kept unchanged in next 60 years. This assumption should be checked by using updated maps, such as digital soils data for Cook and Lake Counties, National Wetland Inventory data, more detailed digital elevation maps and more detailed riparian vegetation cover maps. Besides the improvement of land data maps, additional fish data, including other fish species and potential competitors should be include to add more model predictors. In additional, model development should consider the geographic difference to create different models for different area, such as upper shore or lower shore.

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