Impacts of Climate Change on Stream Temperature in the Southern Blue Ridge

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Introduction

Cool temperatures are critical to the health of mountain streams and their ability to support aquatic life, both due to the direct impact of stream temperature on coldwater species such as brook trout (*Salvelinus fontinalis*), and to the higher dissolved oxygen capacity of cooler water. As global temperatures rise over the coming decades, an understanding of the impact of climate change on stream temperature will be critical for resource managers to plan for proper adaptation and mitigation. Projections of water temperature, based on air temperature change as an independent variable, can assist environmental agencies and non-profits in focusing restoration efforts (such as enhancing riparian buffers for shade) on the most susceptible streams.

Given the unique threats that global warming presents to mountain aquatic habitat, the objective of this study was to evaluate impacts of climate change on surface water temperatures in the southernmost portion of the Blue Ridge Mountains. This was achieved by considering historic ambient temperature, projected ambient temperature under two emissions scenarios, and the relationship between air and water temperature.

Figure 1. *Brook trout (*Salvelinus fontinalis*).*

Site Description

The project location is the upper Hiwassee River watershed, consisting of portions of Cherokee and Clay counties in NC, and Towns and Union counties in GA, specifically that area currently monitored by volunteers with the Western Regional Office of MountainTrue (formerly Hiwassee River Watershed Coalition) (Mountain True, Asheville, NC) and which therefore has a good repository of water chemistry data. Elevation ranges from 385 meters at Apalachia Dam in Cherokee County to 1600 meters at Tusquitee Bald in Clay County, making this one of the few areas in the southeast capable of robustly supporting coldwater fisheries. Should that capability be lost in these high-elevation, largely forested headwaters due to climate change, it would likely be lost throughout the greater region.

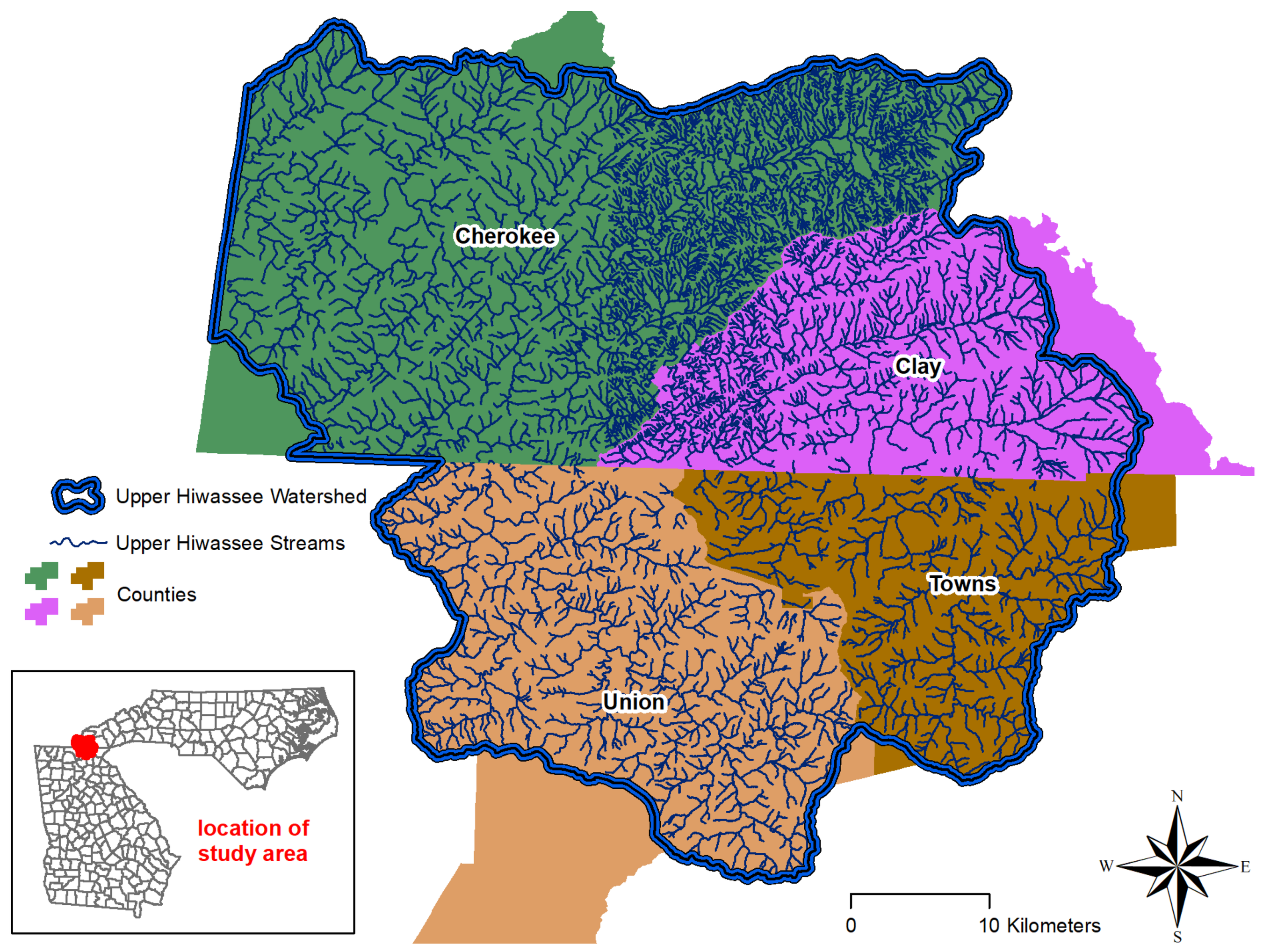

Figure 2. *Upper Hiwassee River basin in the Blue Ridge Mountains of southwestern North Carolina and northeast Georgia.*

Data

Tabular water quality data was downloaded from the Georgia Adopt-A-Stream website (Georgia…c2019) and converted to spreadsheet format. The data, obtained over several years by volunteers, included a row for each monitoring event, with fields including date (sites are monitored monthly), stream name, air temperature, water temperature, decimal degree latitude, and decimal degree longitude, among others.

Thirty-year (1981 to 2010) average air temperature data was obtained from the PRISM Climate Group at Oregon State University (PRISM…c2019). Raster datasets were obtained for the months of March through September.

Air temperature change projections for the year 2099 were downloaded from the United States government's National Climate Assessment website (Downscaled…2016). The download contained 14 rasters: two temperature projections each for the months of March through September 2099, one at a climate change scenario of lower emissions (Representative Concentration Pathway [RCP] 4.5) and the other at higher emissions (RCP 8.5). The chosen global circulation model was Community Earth System Model, Version 1 / Community Atmosphere Model, Version 5, (CESM1-CAM5) which has the highest weight in the Climate Model Intercomparison Project, Phase 5 (CMIP5) (see Table B.2. in Sanderson and Wehner, 2017).

Methods

Using the abundance of Adopt-A-Stream monitoring data, linear regression models of the relationship between ambient temperature and water temperature were developed. Map algebra was used to calculate water temperature normals and RCP 4.5 and RCP 8.5 water temperature projections for the months May through September using formula results of the regression analysis (March and April were included in the data downloads only for providing independent variables for the regression models). Map algebra was then used to project water temperature *changes* under the RCP 4.5 and RCP 8.5 scenarios, using projection-historic difference calculations.

Final results were categorized into qualitative coldwater habitat ratings based upon stream temperature projections for both scenarios and all five months.

Results

Linear regression analysis was performed on the tabular water sampling data using Excel (Microsoft Corporation, Redmond, WA). A multiple regression equation including the current month's and previous month's air temperatures as independent variables produced the strongest statistical significance, as follows, where T_W is predicted water temperature, T_{A-c} is the current month's air temperature, and T_{A-p} is the prior month's air temperature at the site:

$$T_W = 3.8232729 + 0.4876360(T_{A-c}) + 0.1179426(T_{A-p})$$

With the regression relationship established, analysis of the spatial data could be conducted by applying the equation to the air temperature rasters using the Raster Calculator tool in ArcGIS 10.5 (ESRI, Redlands, CA). Predicted current water temperatures, future water temperatures under the RCP 4.5 scenario, and future water temperatures under the RCP 8.5 scenario were mapped over the entire project landscape. Predicted surface water temperature changes were then applied to the individual sites under both scenarios for the months of May through September, with the stream reaches mapped in categories of supporting coldwater aquatic life (green), marginal (yellow), or non-supporting (red). **The resulting maps are discussed in the presentation.**

Discussion and Conclusions

The results of this study support prior research conclusions that water temperature can be effectively predicted from air temperature with relatively simple linear regression models, and that even moderate carbon emissions are a threat to surface water temperatures and coldwater fisheries.

The lower R^2 value of this study (0.72) compared to the studies in the reviewed literature is notable. Improvements could be made with more rigorous statistical analysis, such as performing individual regression analyses for each site, and omitting sites with fewer than 20 months of data (Caldwell et al., 2014, p. 2208). Considering and controlling for solar irradiation (Arismendi et al., 2014) would likely strengthen temperature correlations as well.

Additionally, it should be noted that this study, in the interest of time, considered only one of dozens of global circulation models. Incorporating other models would strengthen the integrity and accuracy of the air temperature projections. Further, since studies of this type tend to inform local adaptation initiatives, they should be replicated at comparable scales of detail in all regions with coldwater habitats. Given the nature of the challenge and the rate of stream temperature increase predicted by many investigations (e.g., Milanovich et al., 2010), it is imperative to conduct this research immediately, so on-the-ground projects can be implemented.

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