University of North Carolina Asheville
Journal of Undergraduate Research
Asheville, North Carolina
Spring 2024

Assessing Climate Change Effects on Fish Distribution in the Swannanoa River Watershed

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ABSTRACT

Climate change is one of the top threats to freshwater ecosystem health and biodiversity. The relationship between fish distribution and water temperature can accurately predict the future impacts of climate change on fish. This study focuses on the water temperature and fish distribution of seven tributaries in the Swannanoa River watershed in Western North Carolina ranging from urban to forested streams. A significant relationship between fish distribution and water temperature averages, and daily variation is hypothesized. Data loggers were placed in these sites from mid-May 2022 until mid-June 2022 documenting water temperature every two hours. In August - September 2022, fish samples were collected using a backpack electrofisher and identified in the field. At each of the sites water quality was measured by conductivity which is an indicator of pollution in streams. I calculated the average maximum temperature, daily temperature variation, and species abundance. Then, I calculated the correlation coefficient between the average maximum temperature of the sites compared to the abundance of each fish species. The relative abundance of seven fish species was significantly correlated with average daily maximum water temperature or daily variation. Of these seven species, four had a significant relationship to warmer temperatures. A significant relationship between fish

abundance and conductivity was also found. The data from 2022 was compared to water temperature data in 2023 resulting in a decrease in water temperature over one year. Data from this study could be beneficial in predicting the impacts of warming temperatures on fishes in Western North Carolina streams.

INTRODUCTION

Over the course of this century, it is predicted that the earth will experience rapid temperature changes primarily due to human causes through an increase in greenhouse gas emissions (IPCC, 2013). Climate change poses a large threat to stream health and biodiversity (Woznicki, 2016), as freshwater ecosystems are more sensitive to changes in temperature than terrestrial systems (Comte et al., 2013). Declines in biodiversity are thought to be far greater in freshwater than the most affected terrestrial ecosystems (Dudgeon et al., 2006). Climate-induced changes are already causing shifts in species distributions and are predicted to continue over the next decade (VanCompernolle et al. 2019). Species distribution can be highly dependent on water temperature, and native species, such as trout can be particularly sensitive (Isaak, 2010). Due to climate change impacts on streams, a loss of biodiversity is predicted in coming years, with water quality and species distributions changing as a result (VanCompernolle et al. 2019).

To understand the effects of climate change on freshwater ecosystems, studying the fish habitat shifts within smaller geographic ranges can provide a better understanding of how climate change could impact fish distribution (VanCompernolle et al., 2019). Focusing on tributaries at higher and lower altitude of the Swannanoa River can The Swannanoa River watershed is located in Buncombe County, North Carolina, and is a major tributary to the French Broad River. The Swannanoa River has four sections that are on the Environmental Protection Agency's 303d list of impaired water bodies (EPA, 2024). Understanding the water temperature and water quality of tributaries that run into the Swannanoa River can help us understand more about the relationship between these tributaries and the impaired sections of the Swannanoa River. This can help us understand if poor water quality is coming from a stream higher or lower elevation on the Swannanoa River. This study explores the extent to which fish distribution in seven tributaries of the Swannanoa including Sweeten Creek, Beetree Creek, Haw Creek, Grassy Branch, Burgins Cove, Camp Branch and Flat Creek are affected by water temperature and water quality. It is hypothesized that water temperature and conductivity will have a significant relationship with fish distribution.

METHODS

Study Sites

The seven tributaries of the Swannanoa River that my study focuses on include a variety of surrounding habitats such as urban, suburban and forested streams. This provides a range of environmental conditions to understand how temperature and water quality impact fish distribution. Sites Flat Creek, Burgins Cove, and Camp Branch are the highest elevation of the seven sites and significantly more forested than Sweeten Creek, Haw Creek, Beetree Creek, and Grassy Branch (Figure 1). Sweeten Creek is the most urban stream running through Biltmore Village in Asheville, NC. Sweeten Creek, Haw Creek, and Grassy Branch are lower elevation and more urbanized than the other sites. Beetree is in between urban and forested stream sites and in between lower and higher elevations.

Figure 1: The seven study sites: Sweeten Creek, Haw Creek, Grassy Branch, Beetree Creek, Flat Creek, Camp Branch and Burgins Cove. (USGS, 2024)

Water Temperature Measurements

I placed HOBO Pendant Temperature Data Loggers in each of the seven tributaries beginning on May 16th 2022 until June 16th 2022 and recorded water temperature every two hours. I secured the data loggers to ensure that they would withstand variation in water flow and depth. Data loggers were placed in PVC pipes attached to rebar using thin metal rope, the rebar was sledgehammered into the stream to secure it.

Fish Sampling

I sampled fish distribution in August and September, using a single backpack electrofisher (Halltech, 2022). To calculate the size of the sample areas, I measured stream width and multiplied the width by 20 to determine the length of the stream. Each of the sampling sites included two pools and two riffles to ensure representation of available in-stream habitats. The electrofisher was used downstream to upstream in a zig-zagging pattern to include all microhabitats. Fish specimens were identified in the field. In addition to fish sampling, I measured conductivity using a Hach Portable Multimeter. Conductivity measures the presence of ions and indicates the level of pollution in the stream. This measurement provides insight into the habitat quality in addition to the temperature within the sampled streams. Each stream was sampled once for fish and conductivity.

Data Analysis

Data analysis involved multiple steps. I calculated species relative abundance, average daily maximum temperature and average daily temperature variation. To calculate relative species abundance, I first found the abundance of fish at each site by calculating the sum of the total number of fish sampled. Then to determine relative species abundance, the total number of each species found was divided by the total fish found at the site. Maximum temperature was determined by finding the highest temperature for each day water temperature was measured. Daily temperature variation was calculated by finding the difference between the daily maximum and minimum temperature of every day sampled. The daily variation of each day and daily maximum temperature were both averaged to compare to fish species relative abundance. To determine which species were affected by water temperature and conductivity, significance was calculated and the thermal niche was determined. Pearson's correlation coefficient was utilized to test the statistical significance of the relationship between fish species relative abundance and temperature and water quality, this correlation was based on species abundance. Significance testing at an Alpha level of 0.05 resulted in a critical value of 0.621 for Pearson's Correlation Coefficient. To determine the thermal niche of each species, the weighted average of species with a critical value of ≤ 0.621 or ≥ -0.621 was calculated by multiplying the average maximum temperature of each site and the average daily variation by the relative abundance of each fish species at the sites. Weighted average of conductivity was calculated by multiplying the species abundance by conductivity of each site then finding the product, finally divided by the total number of individuals.

Temperature Change
I compared the 2022 temperature measurements to two similar studies of the same stream sites including a previous study in 2020 and another study in 2023 temperature data. was determined by finding the P value using a t-test.

RESULTS
The lowest mean daily maximum temperature and the smallest mean daily temperature variation, were both found at Flat Creek with a max temperature of 16.81℃ and a mean variation of 1.40 ℃ suggesting this stream was in the best condition of the seven streams. This forested stream had a visually larger riparian zone than urban streams Sweeten Creek and Grassy Branch. Camp Branch followed a similar trend with the second lowest mean daily temperature variation, mean daily maximum temperature, and conductivity. The stream with the largest mean daily temperature variation was Grassy Branch with a variation of 2.95℃, this is 1.55℃ greater than the mean daily temperature variation of Flat Creek. Sweeten Creek experienced the highest average temperature with a calculated mean daily maximum temperature of 20.52 ℃ (Table 1).

Table 1: Mean daily maximum temperature, mean daily temperature variation, and conductivity of the seven stream sites, organized from lowest to highest mean daily maximum temperature.

Stream Site	Mean Daily Max Temperature (℃)	Mean Daily Temperature Variation (℃)	Conductivity (us/cm)
Flat Creek	16.81	1.40	23.1
Camp Branch	17.01	2.34	33.7
Burgins Cove	18.47	2.40	70.7
Haw Creek	18.58	1.71	143.9
Beetree Creek	19.48	2.20	33.9
Grassy Branch	19.93	2.95	85.1
Sweeten Creek	20.52	2.61	143.2

Average	18.68	2.23	76.23

A total of 24 fish species were collected across the seven streams (Table 2). Of the 24 species, seven species exhibited a significant correlation with average daily maximum temperature and/or average daily temperature variation determining the thermal niche for these species (Figure 2).

The identified species with a significant thermal niche are: *Clinostomus funduloides* (Roseyside Dace), *Campostoma anomalum* (Central Stoneroller), *Oncorhynchus mykiss* (Rainbow Trout), *Hypentelium nigricans* (Northern Hogsucker), *Etheostoma flabellare* (Fantail Darter), *Lepomis cyanellus* (Green sunfish), and *Luxilus coccogenis* (Warpaint shiner) (Figure 2). *Luxilus coccogenis* has a significant relationship to average daily variation but no correlation to average maximum temperature.

Among these seven species, two species were graphed closely together, *C. funduloides* and *O. mykiss* were exclusively found in Burgins Cove, Flat Creek, and Camp Branch, the coolest temperature and highest elevation streams, shown in the lower left corner of the graph. This drastic preference indicates a specific thermal niche where these species can thrive, and a preference for higher elevation. Species *L. coccogenis* had a significant relationship with a lower mean daily temperature variation but did not have a correlation to mean daily maximum temperature. Four species experienced a positive correlation with water temperature while three demonstrated a negative correlation to average daily maximum temperature and average daily temperature variation. These four species are grouped closely together in the graph in the upper right corner.

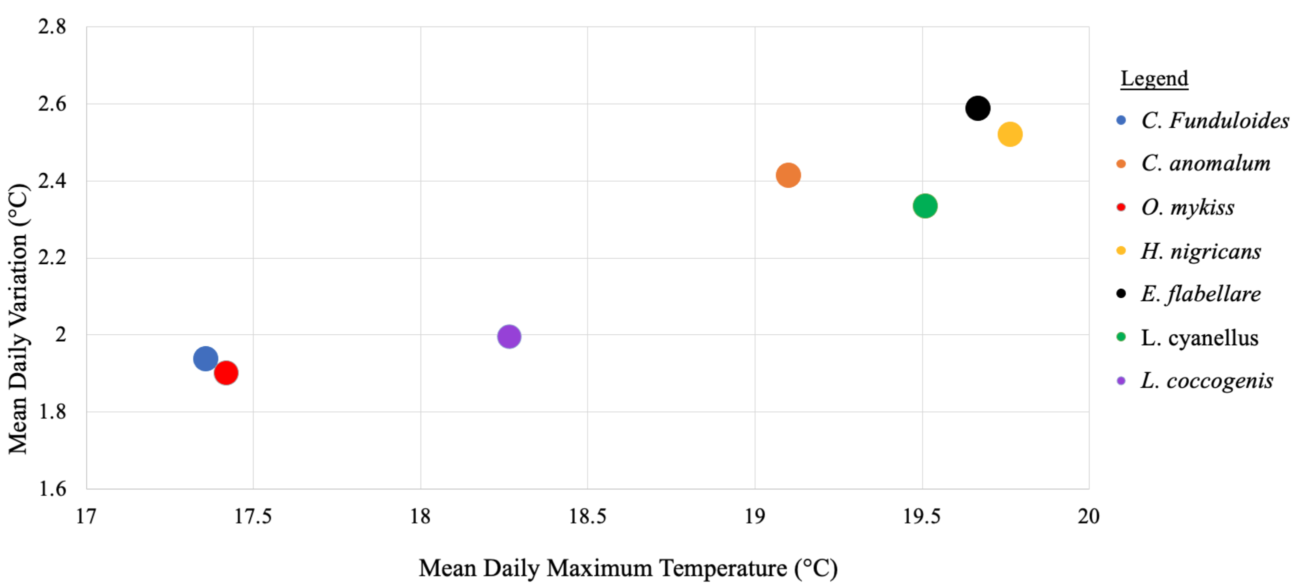

Figure 2: Graph of species thermal niche.

Six species had a significant relationship to conductivity (Table 2). Species

R. cataractae, C.funduloides, Scorpaeniformes, L. cyanellus, Moxostoma, N. leuciodus in order of lowest to highest weighted conductivity.

Table 2: Species with significant correlation to conductivity.

Species	*R. cataractae*	*C. funduloides*	*Scorpaeniformes*	*L. cyanellus*	*Moxostoma*	*N. leuciodus*
Weighted Conductivity	29.2	40.0	41.1	107.7	131.1	143.5

Grassy Branch and Flat Creek experienced a statistically significant change between 2022 and 2023 temperature data (Table 3). In Flat Creek, the mean daily maximum temperature decreased by 1.26℃ 2022 to 2023. In Grassy Branch the average maximum temperature decreased by 1.88 ℃. Both of these sites, Flat Creek as the coolest of our sites and Grassy Branch with the largest mean daily temperature variation in 2022, experience a decrease in temperature in the year 2023. From 2020 to 2023 during July 10 to September 16th, Sweeten Creek

Table 3: Years 2020, 2022 and 2023 temperature change.

Stream	Years Compared	Timeline	Difference (Recent- Past)	P(T=0)
Grassy Branch	**2022** - 2023	6/1 - 6/16	-1.88	<0.001
Sweeten Creek	**2020** - 2023	7/10 - 9/16	-0.25	<0.001
Flat Creek	2020 - **2023**	7/8 - 9/17	1.16	<0.001
Flat Creek	**2022** - 2023	6/1 - 6/16	-1.26	<0.001

DISCUSSION

There is a growing concern about climate change impacting ecosystems across the globe. Understanding mountain freshwater species thermal niche provides crucial information on how Western North Carolina mountain streams will adapt to warming temperatures. The results of this study provide an idea of which fish species in southern Appalachian streams will be most impacted by climate change effects on temperature and stream health. *C. funduloides* and *O. mykiss* were only sampled from our coolest streams Burgins Cove, Flat Creek, and Camp Branch suggesting these species will struggle with a rise in water temperatures. Species *C. funduloides* is less environmentally tolerant with a much lower thermal niche and lower conductivity tolerance than all the other species sampled. On the opposite side of the thermal niche, species *Campostoma anomalum, Hypentelium nigricans, Etheostoma flabellare, Lepomis cyanellus,* and *Luxilus coccogenis* thrived in warmer temperatures suggesting they would be able to adapt better to a warming climate.

With changes in habitat, fish distribution shifts from lower to higher elevation streams expected and already occurring (McDonnell et al.,2015). Studies show that cold-water species such as the family Salmonidae are more likely to be negatively affected by climate changes while warm-water species (Centrarchidae and Cyprinidae) are more likely to have positive changes in their distribution and populations (Comte et al., 2013). A study in Idaho estimated a smaller amount of suitable habitat for rainbow trout due to climate changes (Issak, 2010). My study suggests a similar trend could occur due to the intolerance of warmer, more polluted streams.

Water temperature and conductivity are correlated, in future studies it would be beneficial to incorporate additional and diverse stream sites. Collecting data from sites that are urban and higher elevation or lower elevation and forested streams will isolate what aspects of ecosystem health are contributing to the fish distribution. Additionally, considering other impacts on water temperature such as flow and precipitation would provide a better understanding of the negative change in water temperature from 2022 to 2023 in Grassy Branch and Flat Creek (Woznicki, 2016). Although 2023 was reported as a record breaking increase in air temperature worldwide, the results from this study mostly report a decrease in water temperature in Grassy Branch and Flat Creek. In addition to climate change impacting air and water temperature, there can also be a shift in flow, precipitation, vegetation cover, sediment and pollution run off from climate change (VanCompernolle et al. 2019). Including water flow and precipitation measurements in future studies would narrow down the cause of this change in water temperature.

Continuing to study these changes in our freshwater ecosystems can help to predict and mitigate the impacts of climate change. This study provides valuable information that can be used in future studies and encourages protection of our delicate mountain stream ecosystems.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. David Gillette, my research advisor for all of his advising throughout the planning, field work and data analysis of this research project and for the access to the equipment used in this study. I would also like to thank UNC Asheville Undergraduate Research for the summer research grant that made this research project possible.

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