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EFFECT OF BODY SIZE AND TEMPERATURE ON OXYGEN CONSUMPTION OF *SALVELINUS FONTINALIS*

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ABSTRACT

Climate change continues to have negative effects on all organisms. This is specifically true for ectotherms, which rely on the external environment to maintain homeostasis. It has been reported that fish metabolic rate is negatively correlated with body size and positively correlated with water temperature. This study was conducted by analyzing data on *Salvelinus fontinalis* from Fishbase. *S. fontinalis* are the only trout native to the eastern United States and are a useful indicator for water quality and overall ecosystem health. The data consisted of 150 samples from different studies and reported oxygen consumption (mg/kg/h) at temperatures varying from 5 to 20 *°C*. Correlation analysis of our data is consistent with previous studies. Our data suggested a moderate positive correlation between temperature and oxygen consumption with a Pearson correlation coefficient of 0.746. Our data also suggested a negative correlation between body size and oxygen consumption with a Pearson correlation coefficient of -0.322. Although our findings are consistent with previous studies, it would be beneficial to have a larger sample size for future experiments as well as examining the effects of different activity levels on oxygen consumption.

Keywords: Salvelinus fontinalis, temperature, metabolic scaling, physiological ecology, brook trout,

INTRODUCTION

Climate change continues to have profound effects on all organisms. Scientists have been conducting research on the effects of climate change on different organisms for several decades. The warming of atmospheric and aquatic temperatures has caused an increased extinction rate to several species that have not adapted to a quickly changing climate. This is especially true for ectotherms. Ectotherms do not have the ability to regulate their body temperature. Instead, these organisms rely solely on the external environment to maintain homeostasis (Messmer et al., 2017). The effects of increasing aquatic temperatures on ectotherms, such as fish, has been a major concern in recent decades.

It has been found that body size in fish has decreased due to the stress of increased temperatures. Increased water temperature decreases the amount of readily available dissolved oxygen in the water. Higher temperatures lead to a greater oxygen requirement in fish. In other words, standard aerobic rate (SMR) is positively correlated with temperature (Gillooly et al., 2001). This is the case, particularly in tropical and arctic habitats, because these fish evolved in stable environments (Tewksbury et al., 2008). With less dissolved oxygen in warmer water, fish no longer have the oxygen requirements needed to reach a large size (Czarnoleski et al., 2015). Smaller body size also influences metabolic rate. There is usually a negative correlation between body size and metabolic rate. Smaller fish tend to have larger energy requirements and faster metabolic rates (Clarke & Johnston, 1999). When fish are deprived of adequate oxygen supply, they are forced to depress aerobic metabolism and larger fish decrease aerobic metabolism more rapidly than small fish. However, studies have found larger

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fish are better equipped to enact anaerobic metabolism which may explain why there is a negative correlation between body size and metabolic rate (Urbina & Glover, 2013).

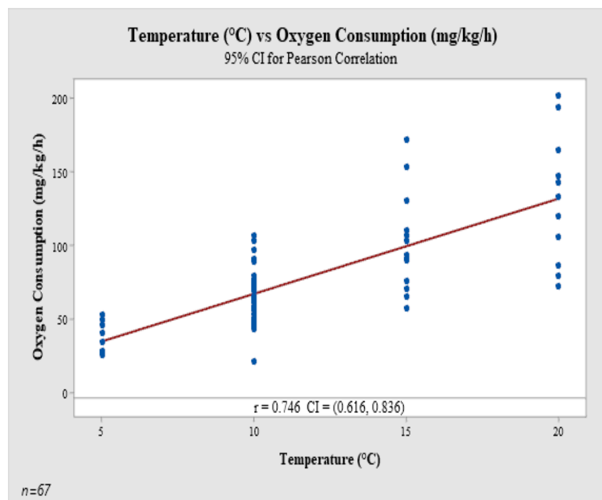
The results of these studies and a growing concern for climate change has led us to investigate the relationships of temperature and body size on the metabolic rates of *Salvelinus fontinalis*. *S. fontinalis* are the only trout native to the eastern United States and have thrived in coldwater streams and lakes for the last several million years. *S. fontinalis* thrive in water temperatures ranging from 13-18*°C.* Due to the habitat *S. fontinalis* lives in, it is a great indicator species for water quality and the overall health of ecosystems (U.S. Fish & Wildlife Service). Because of this, *S. fontinalis* has been at the forefront of conservation efforts (Hartman & Cox, 2008). With increasing temperatures due to climate change, fish that live in coldwater streams are experiencing increased stress, reducing their fitness. This is of particular importance to fisheries conservation because body size has been shown to positively correlate with fecundity (Blueweiss et al., 1978). Information gained from this study on how temperature and body size affect the metabolic rates of *S. fontinalis* will aid in preserving and managing healthy populations of *S. fontinalis* in coldwater fisheries. We hypothesize that oxygen consumption in *S. fontinalis* will be greater at higher temperatures and smaller body sizes. This study seeks to analyze data on *S. fontinalis* to understand the effects of temperature and body size on oxygen consumption.

METHODS AND MATERIALS

We constructed our study with the intention of using an online database (Fishbase) for our data. For this study we looked at the data of oxygen consumption studies for *Salvelinus fontinalis.* The data consisted of 150 samples from different studies and reported oxygen consumption (mg/kg/h) at temperatures varying from 5 to 20 *°C.* The technique used to collect data for each sample was an intermittent-flow respirometry system (Thruston and Gehrke 1993). Each sample had an oxygen consumption reading at 20*°C.* The weight of the individual sampled was also given for each datapoint. Activity level and applied stress were also listed. To remove variation such as stressors and activity level, we eliminated samples that contained stressors and any activity levels that were not defined as "standard." Standard activity level means that the Standard Metabolic Rate (SMR) would be benchmarked in each fish. Standard Metabolic Rate is the metabolic rate of a resting fish at a specified temperature in the middle of its normal range (Gilooly et al., 2001). After compiling all the data into a spreadsheet, we used the data analysis program Minitab to conduct correlation analyzes of our data.

RESULTS

After examining the data, we obtained from Fishbase (www.fishbase.de), we were left with a sample size of 150. To remove variation such as stressors and activity level, we eliminated samples that contained stressors and any activity levels that were not defined as "standard." This left us with 67 total usable data points. Below, we performed a correlation test between temperature and oxygen consumption (mg/kg/h), in order to determine the relationship between the two variables in our study.



Pairwise Pearson Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Oxygen Consumption (mg/kg/h)	Temperature (°C)	67	0.746	(0.616, 0.836)	0.000

Figure 1. This graph illustrates the results of our Pearson correlation test between temperature (°C) and oxygen consumption (mg/kg/h). We plotted temperature (°C) against oxygen consumption (mg/kg/h) for our 67 samples. Depicted on the graph is a trend line resulting from linear regression (y = 6.4697x + 2.4016). The Pearson correlation test resulted in a moderate positive correlation coefficient of 0.746. The 95% confidence interval of the Pearson correlation coefficient is shown in parentheses. We

reported the P-value for this test below the graph with a value of less than 0.000 which indicates significant correlation.

The graph above suggests that there is a moderate positive correlation between temperature and oxygen consumption in *Salvelinus fontinalis* with a Pearson correlation coefficient of 0.746. The line of regression displayed on the graph illustrates an upward trend in which our samples exhibited increased metabolic rates at higher temperatures. Ranges of temperatures in which measurements were performed were between 5 and 20*°C.* Oxygen consumption ranged between 21 and 202 (mg/kg/h). Our analysis indicates that oxygen consumption in *S. fontinalis* increases in response to increased water temperature. The 95% confidence interval derived from Pearson correlation coefficient gives us the probability of containing *r* with repeated sampling. Our included P-value determined the significance of the relationship

Pairwise Pearson Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Oxygen Consumption at 20°C	Body Mass (g)	67	-0.322	(-0.522, -0.089)	0.008

between oxygen consumption and temperature which found a significant correlation ($P < 0.05$). The significant Pearson correlation coefficient suggests that the data supports our hypothesis that oxygen consumption would increase with an increase in water temperature.

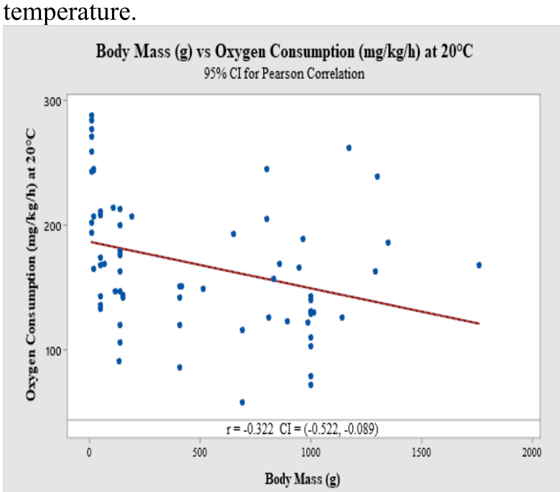


Figure 2. This graph illustrates the results of our Pearson correlation test between body mass (g) and oxygen consumption (mg/kg/h) at a temperature of 20°C. We plotted body mass (g) against oxygen consumption (mg/kg/h) for our 67 samples. Depicted on the graph is a trend line resulting from linear regression (y = -0.0373x + 186.77). The Pearson correlation test resulted in a weak negative correlation coefficient of -0.322. The 95% confidence interval of the Pearson correlation coefficient is shown in parentheses. We reported the P-value for this test below the graph with a value of 0.008 which indicates that our correlation is significant.

Our data above indicates that there is a weak negative correlation between body mass and oxygen consumption at a standard temperature of 20*°C* in our 67 samples of *S. fontinalis*. The range of body mass in which measurements were taken were between 5 and 1760 (g). Oxygen consumption in the 67 samples ranged from 58 to 289 (mg/kg/h). Our analysis resulted in a Pearson correlation coefficient of -0.322 which suggests that there is an inverse relationship between oxygen consumption and body size. A line of regression on the graph illustrates this relationship between decreasing oxygen consumption in relation to increasing body mass. The derived 95% confidence interval gives a range of Pearson correlation coefficient values that we could expect with repeated sampling. This data analysis resulted in a P-value of 0.008 which is less than 0.05, indicating that this relationship is significant. The findings from this analysis support our hypothesis that oxygen consumption would negatively correlate with body size.

Temperature	Median	N <= Overall Median	N > Overall Median	Q3 – Q1	95% Median CI
5	40.00	9	0	20.50	(26.4558, 48.3163)
10	62.00	33	0	28.00	(53.9949, 73.0051)
15	98.00	11	3	40.75	(75.6912, 111.081)
20	154.35	14	64	75.95	(142.950, 169.125)
Overall	119.90				

Test

Null hypothesis	H_0: The population medians are all equal
Alternative hypothesis	H_1: The population medians are not all equal

DF	Chi-Square	P-Value
3	78.62	0.000

Table 1. Mood's Median Test: Oxygen Consumption (mg/kg/h) versus Temperature (°C)

The table above is our results from Mood's Median test between oxygen consumption (mg/kg/h) and temperature *(°C)*. We used Mood's Median test to determine whether the medians of our temperature groups differed. For this test we combined all 67 samples with different temperatures and the 67 samples with a standard temperature of 20*°C.* The median oxygen consumption for each temperature is listed. The overall median from our combined samples was 119.90 (mg/kg/h). The 95% confidence intervals for each median are listed in the most right column.

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Our analysis resulted in a P-value less than 0.000 which means that population medians are not all equal. This test illustrates the distribution of oxygen consumption values across temperatures. 20*°C* has the most samples with oxygen consumption being greater than the overall median with 64 samples.

DISCUSSION

Climate change is a pressing issue for the survival of native coldwater fishes, due to this, it is important to understand the impacts temperature and body size have on the metabolic rates of *S. fontinalis*. Climate change is resulting in increasing atmospheric and aquatic temperatures across the globe. The effects of increasing aquatic temperatures on fish has been a growing concern for decades. Increasing aquatic temperatures decrease the amount of readily available dissolved oxygen in the water. Higher temperatures lead to a greater oxygen requirement in fish. A previous study has found that the standard aerobic rate (SMR) is positively correlated with temperature, meaning that as temperature increases so does the metabolic rate of the fish. This increase in metabolic rate obviously puts more stress on the fish, leading to decreased fitness. Fish that are under stress are less likely to grow, thrive, and reproduce. One aspect of our study was to further this research to determine how increasing temperatures affect a temperature sensitive coldwater fish species *S. fontinalis.* We were able to determine in our study that the metabolic rate of *S. fontinalis* positively correlated with increasing temperature. Our results from our correlation test supported our hypothesis that oxygen consumption would increase with increasing temperatures. Our analysis provided us with a Pearson correlation coefficient of 0.746, which indicates a moderate positive correlation between oxygen consumption and temperature. The P-value from the correlation test was less than 0.000 indicating that our data was statistically significant. This is consistent with previous findings that the metabolic rates of fish positively correlate with increasing temperature (Killen et al., 2016; Gillooly et al., 2001). Although our findings are consistent with previous studies, it would be beneficial to have a larger sample size for future experiments as well as examining the effects of different activity levels on oxygen consumption.

Another aspect of our study was to examine how body size impacts the oxygen consumption of *S. fontinalis* at a standard temperature (20*°C*). Previous studies suggest there is usually a negative correlation between body size and metabolic rate in fish (Clarke & Johnston, 1999; Urbina & Glover, 2013). This is due in part to the metabolic mechanisms of fish and their ability to depress aerobic metabolism in favor of anaerobic metabolism in low oxygen environments. Our data supports our hypothesis that there is a negative correlation between body size and oxygen consumption in *S. fontinalis*. Our correlation test provided us with a Pearson correlation coefficient of -0.322, indicating a moderately weak negative correlation between oxygen consumption and body size. We also obtained a P-value of 0.008 which means our data is statistically significant. This is also consistent with the previously mentioned studies and may be due to the fact that larger fish are more efficient at depressing aerobic metabolism and enabling anaerobic metabolism (Urbina & Glover, 2013). This would explain why larger fish in high temperature water (20*°C*) would consume less oxygen then smaller fish. Although our data was statistically significant, it would be worthwhile conducting another experiment with a greater sample of individuals with larger body mass (>1000 g). Of our 67 samples only 6 samples had a body mass of greater than 1000 grams. It would add to the validity of our results to incorporate more individuals with a body mass of greater than 1000 grams. If this study incorporated larger body mass individuals, there may have been a more significant negative correlation between body size and oxygen consumption and as a result better represent the relationship between metabolic rate and body size in *S. fontinalis.*

ACKNOWLEDGMENTS

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LITERATURE CITED

Blueweiss, L., Fox, H., Kudzma, V., Nakashima, D., Peters, R., Sams, S., 1978. Relationships between body size and some life-history parameters. Oecologia **37**: 257–272.

Bowers, M.A., and J.H. Brown., 1992. Body size and co-existence in desert rodents: chance or community structure. Ecology **63**: 391-400.

Clarke, A., Johnston, N., 1999. Scaling of metabolic rate with body mass and temperature in teleost fish. Journal of Animal Ecology **68**: 893–905.

Czarnoleski, M., Ejsmont-Karabin, J., Angilletta, M., Kozlowski, J., 2015. Colder rotifers grow larger but only in oxygenated waters. Ecosphere **6**: 164

Gillooly, J., Brown, J., West, G., Savage, V., Charnov, E., 2001. Effects of size and temperature on metabolic rate. Science **293**: 2248–2251.

Hartman, K., & Cox, M., 2008. Refinement and testing of a brook trout bioenergetics model. Transactions of the American Fisheries Society **137**: 357-363.

Killen, S., Glazier, D., Rezende, E., Clark, T., Atkinson, D., Willener, A., Halsey, L., 2016. Ecological Influences and Morphological Correlates of Resting and Maximal Metabolic Rates across Teleost Fish Species. The American Naturalist. **187**. 000-000

Messmer, V., Pratchett, M., Hoey, A., Tobin, A., Coker, D., Cooke, S., and Clark, T., 2017. Global warming may disproportionately affect larger adults in a predatory coral reef fish. Global Change Biology **23**: 2230-2240.

Tewksbury, J., Huey, R., Deutsch, C., 2008 Ecology – putting the heat on tropical animals. Science **320**: 1296–1297.

Thurston, R., and Gehrke P., 1993. Respiratory oxygen requirements of fishes: description of OXYREF, a data file based on test results reported in the published literature. p. 95-108. In R.C. Russo & R.V. Thurston (eds.) Fish Physiology, Toxicology, and Water Quality Management. Proceedings of an International Symposium, Sacramento, California, USA, September 18-19, 1990. US Environmental Protection Agency EPA/600/R-93/157.

Urbina, M., and Glover, C,. 2013. Relationship between Fish Size and Metabolic Rate in the Oxyconforming Inanga *Galaxias maculatus* Reveals Size-Dependent Strategies to Withstand Hypoxia. Physiological and Biochemical Zoology. **86**: 740-9