Effects of Temperature and The Round Goby on Benthic Species in Lake Ontario

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Abstract

The compounded impacts of both changing temperatures and invasive species *Neogobius melanostomus* is thought to have an overall negative impact upon the native species of Lake Ontario; however, these impacts on species occupying the same ecological niche is relatively unclear. This study investigates the impacts on native species fitness, measured by body weight and species abundance, by both the impacts of temperature and interactions with the round goby. Exploring historical data prior to the introduction of the invasive species and the populations of the present day, native species' body weights and abundances were predicted to be negatively impacted. However, across all species, our results indicate that the effects of temperature is significant on some native species' fitness, while minimal impacts were observed from the increased abundance of *Neogobius melanostomus*, indicating further studies should be performed to determine a more conclusive result.

Introduction

Neogobius melanostomus, or the round goby, is a bottom-dwelling, small, saltwater species native to the Caspian Sea in Eastern Europe. *Neogobius melanostomus* is thought to have been introduced to the Great Lakes in the late 20th century from the ballast water of ships(Karsiotis et al. 2012).

The round goby has been noted to have negative impacts upon native flora and fauna of the Great Lakes. *Neogobius melanostomus* were observed consuming the eggs and fry of native species, potentially leading to the decline of native species that occupy a similar niche(Corkum et al. 2004). *Neogobius melanostomus's* high fecundity, opportunistic feeding strategy and potential vector for parasites has potential to further alter the biomass of the Great Lakes. A previous study also suggested that native trophic predators(e.g Lake Trout) were observed to avoid predation of the round goby(Burkett & Jude, 2015) in Michigan. Lack of predation has possibly contributed to the large relative abundance of round gobies in the great lakes, although studies on specific species interactions is limited.

Furthermore, the average water temperature of Lake Ontario is predicted to increase by 4.8℃ within this century(Ricciardi & Reid, 2021) due to the effects of climate change. As the temperatures of the Great Lakes begin to match the temperatures in the native range of *Neogobius melanostomus*, our study wants to predict whether or not there will be any changes to species abundance within the Great Lakes.

This research is based upon an extended study conducted in Lake Ontario since 1978. Each annual April species were collected from the lake bed by bottom trawling, measured, and tallied(Holden et al. 2022). We aim to compare several variables. To study the abundances of native species and the round goby, variables of importance include the abundance of the round goby, water temperature, and the abundances of native fish species (slimy sculpin, three-spine stickleback, etc) that occupy a similar benthic niche. We want to find out if there is any correlation between changing temperature and the abundance of native benthic species(slimy sculpin, three-spine stickleback, etc). Furthermore, we hope to determine if the increase in relative abundance of the round goby is influencing the relative abundances of native species. Besides relative abundance, we want to see if the introduction of the Round Goby has exhibited any morphological changes in native species; to accomplish this, we will use average mass as an indicator of the health of the fishes. We hope this will help understand the threats faced by native species and whether they are more threatened by the round goby or by the temperature, or both.

Hypothesis 1

We hypothesise that temperature has a different effect on the relative abundance of native species compared to the round goby because the round goby and native species are not equally affected by temperature changes. Since the round goby's native range is warmer than the average temperature of the great lakes region(Ricciardi & Reid, 2021), we predict that as the average water temperature increases, the abundance and average weight of the round goby would increase, as its fitness would benefit in its preferred temperature range. As the round goby breeds continuously throughout the year, increased temperatures may extend their spawning season and the number of spawning per year, which would rapidly increase their population. On the other hand, we predict native species to be negatively impacted both in terms of abundance and weight, as native species are more acclimated to a colder temperature. Should the null hypothesis stand true(i.e temperature does not have a different impact on the relative abundance and weight of species), all species would observe the same impact on abundance and weight as a result of the increase in temperature.

Hypothesis 2

We also hypothesize that the increase in round goby's abundance negatively influences the abundance of native species. We predict that when round goby populations increase, this would increase competition for limited resources, resulting in decreased abundances of native species. As previously mentioned, the round goby were observed to also consumes the young of native species(Corkum et al. 2004), which could cause a decrease in their populations.

Methods

I. Data Description and Manipulations

The raw dataset of our interest "TrawlCatch_SpringPreyFishBottomTrawl.csv" is a part of a larger study on the Great Lakes Region for conservation and fisheries. This dataset contains specimens collected from the Great Lakes research vessels of the US Geological Survey and the Ontario Department of Natural Resources and Fisheries. The specimens were collected annually during April from the year of 1978 to 2022 in various locations across Lake Ontario using trawl fishing (bottom fishing). While the study mainly focuses on the capture of the alewife--which schools up in the benthic regions of the lake during April--the round goby is also a benthic fish and was also collected in high abundance. Columns of importance in the dataset include "fishing temperature” (water temperature), “commonName” (species name), “latitude” (the latitude of location of catch), “longitude” (the longitude of location of catch), “life stage”, “n” (number of this species collected), mass (mass of individual), and “average mass”. Using this dataset, relative population densities of various species can be determined based upon the total yearly catch from all sites.To prepare the data for general analysis (for studying both abundances and weight), we first removed columns from the dataset that were irrelevant to our analysis, such as towing time, speed of the research vessel, etc. Furthermore, the dataset was mutated to label the species as either native or non-native("exotic"), within a new column called “inv.status”. This allows for easier grouping of species. We then tallied up the total number of individuals by species, keeping the species with more than 200 observations. Species with less than 200 individuals observed likely indicate that said species does not occupy a niche within the benthic layer of water, and were caught by mistake, thus they would have less little interaction with the round goby. After filtering out our desired species that met this requirement, we obtained our fish species of interest. They are slimy sculpin, deepwater sculpin, yellow perch, trout perch, johnny darter, lake trout, round goby and threespine stickleback.

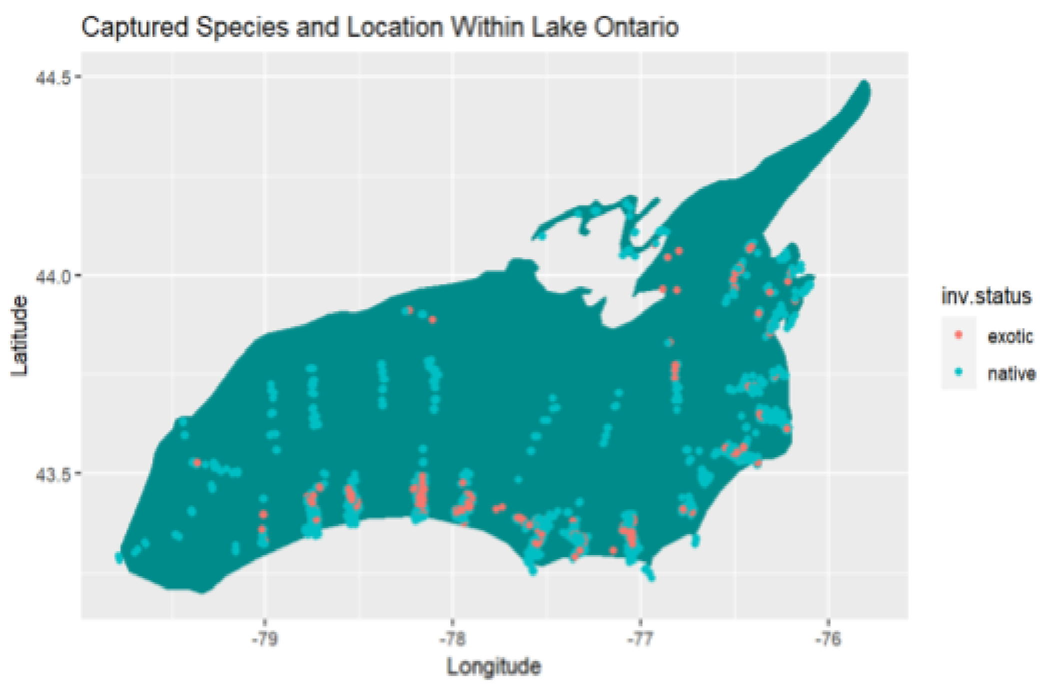

Figure 1: Observations plotted on a generated map of Lake Ontario; Colours Indicate invasive status. Spatial Sites are not Defined

Since the dataset contains spatial data, it is necessary for our study to consider the random effects caused by different sites. The dataset itself did not define any sites; as shown in Fig 1, there appears to be clusters of observations that can constitute a “site.” Our final dataset manipulation added sites by utilizing k-means clustering. We estimated there to be 25 sites in the study, and utilized this machine-learning algorithm to obtain the most optimized grouping for sites.

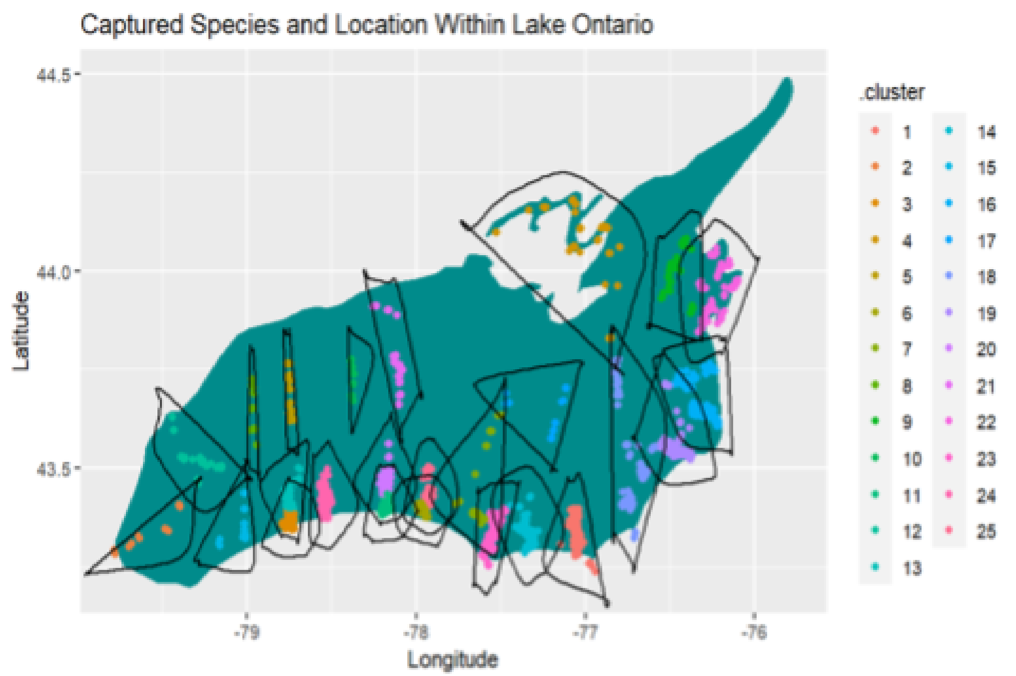

Figure 2: Captured Specimens and their locations within Lake Ontario, with generated clusters. Each cluster is indicated with geom_encircle and colour-coded; in all, 25 sites were generated

II. <u>Data Analysis</u>

To test our hypothesis on temperature and its influence on the fitness of native fish species (shown as abundance and weight), simple linear models were first created for each of the seven fish species as well as the invading round goby (Neogobius melanostomus), whereby the abundance and weight of each species were plotted against temperatures. In these linear models, the dependent variable would be the relative species abundance or weight of the fish species (either native species or round goby), while the independent variable would be the water temperature. To test the significance of all applied linear models, the assumptions of linear model were validated by generating residual plots and normal quantile-quantile plots which tested homogeneity of variance and normality respectively (see Supplementary). Logarithm transformations were also performed on those models that indicate right-skewness to show normality.

To test our hypothesis on the interactions between the round goby and its effect on the abundance of 7 native fish species, simple linear models were again created for both abundance and weight of each native species. Before starting our data analysis, we grouped our data by site and by year so that each point would be the summed abundance at one site for one year. In each model, the abundances and weight of each native species were plotted against round goby abundance. The dependent variables would be relative species abundance or average weight of native species, while the independent variable would be the abundance of round goby. Once again,assumptions of applied models were validated through normality and homogeneity tests using normal quantile-quantile plots and residual plots respectively (see Supplementary). Logarithm transformations were also performed on those models that indicate right-skewness to show normality. Our model assumptions can be found in the supplementary appendix.

While we attempted to utilize mixed-effect models, our analysis indicated that the random effects were overall not very significant. The Residual variance explained by random effects(sites) was found to be ~3%. With the fixed effects being responsible for the majority of the variance, we chose to ignore sites and proceed with only linear models in determining both the impacts of temperature and round goby interactions with native species.

Results

		Species Name	Slope Estimate	P-Value	Significance (alpha=0.05)
Hypothesis 1	Effect of temperature on species abundance	Yellow Perch	18.70	6.05E-14	*
		Deepwater Sculpin	-0.34	0.00568	*
		Trout Perch	0.26	2.32E-09	*
		Johnny Darter	-0.17	7.82E-05	*
		Lake Trout	0.08	0.00104	*
		Slimy Sculpin	-0.13	0.00584	*
		Threespine Stickleback	0.26	1.20E-05	*
		Round Goby	-0.28	3.36E-06	*
	Effect of temperature on average mass	Yellow Perch	0.11	1.11E-05	*
		Deepwater Sculpin	-5.03	1.48E-11	*
		Trout Perch	0.29	0.00452	*
		Johnny Darter	0.03	1.58E-01	
		Lake Trout	0.15	1.87E-06	*
		Slimy Sculpin	-0.22	2.00E-16	*
		Threespine Stickleback	0.02	6.18E-01	

		Round Goby	-2.90	2.00E-16	*
Hypothesis 2	Effect of round goby abundance on species abundance	Yellow Perch	0.00	0.9715	
		Deepwater Sculpin	0.00	6.65E-03	*
		Trout Perch	-0.01	0.2153	
		Johnny Darter	0.00	0.26944	
		Lake Trout	0.00	0.00121	*
		Slimy Sculpin	0.00	0.262	
		Threespine Stickleback	0.00	0.3752	

Figure 3: Model Summaries

To determine significance, all models were inputted into the summary() function. The p-value helps determine whether the relationship between the relationship response/dependent variable(abundance, weight) and the predictor (coefficient of interest, e.g temperature) occurs due to chance. A small p-value of <= 0.05 indicates a significant result; just from observing the p-value within our models, we observe that all species abundance appears to be impacted by temperature. As indicated by figure 4, interestingly, there appears to be an increase in round goby abundance in cooler temperatures. In all, the p values and directionality of the models indicate that all species are impacted by temperature. Each species responded slightly differently to temperature, thus rejecting the null hypothesis.

The relationship between temperature and average weight of most species also appears to be significant(except for the Johnny Darter and Threespine Stickleback). Figure 4 and figure 5 seem to indicate abundances and weight appear to show the same directionality in response to temperature.

Surprisingly, increase in round goby abundance does not appear to have a significant correlation with the abundances of native species. For most species, the p values suggest that the null hypothesis cannot be rejected. Our models indicate that only the abundances of Deepwater Sculpin and Lake Trout appear to be impacted. When plotting the abundances of native species against the round goby, as seen in figure 6 all slope estimates were found to be extremely small and pretty much insignificant; even within the species that were suggested to have a relationship with round goby abundance.

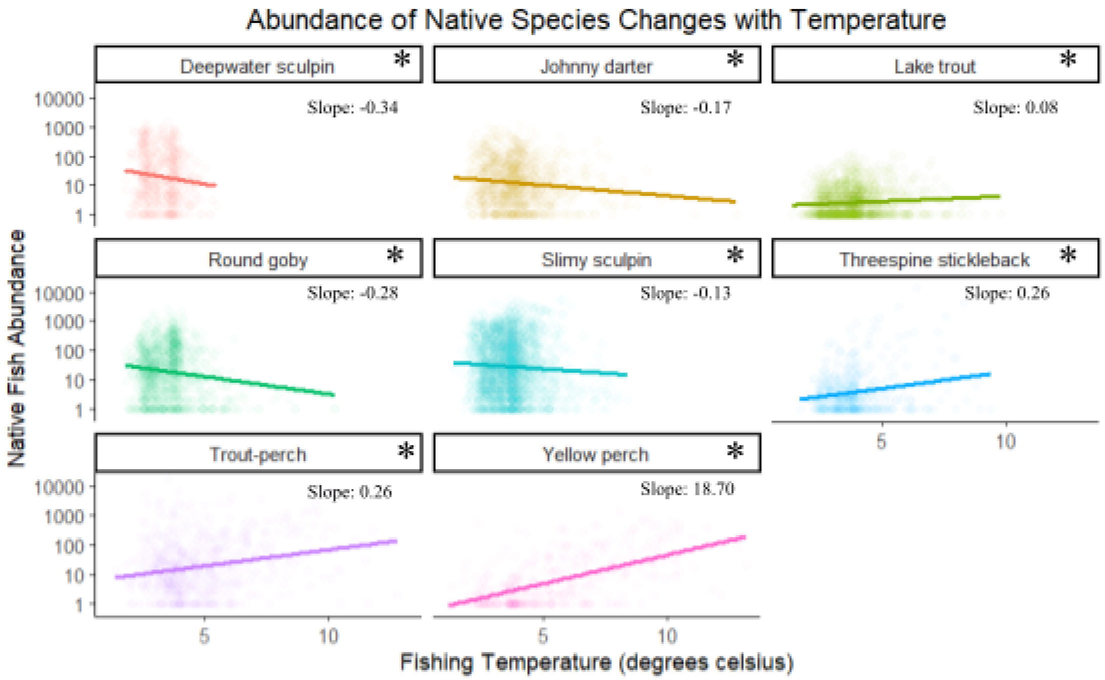

Figure 4: Abundance of fish species compared with temperature using a general linear model. Significance (alpha = 0.05) indicated with *. Fish abundance has been log scaled for easier viewing. Estimated slopes are indicated on each graph.

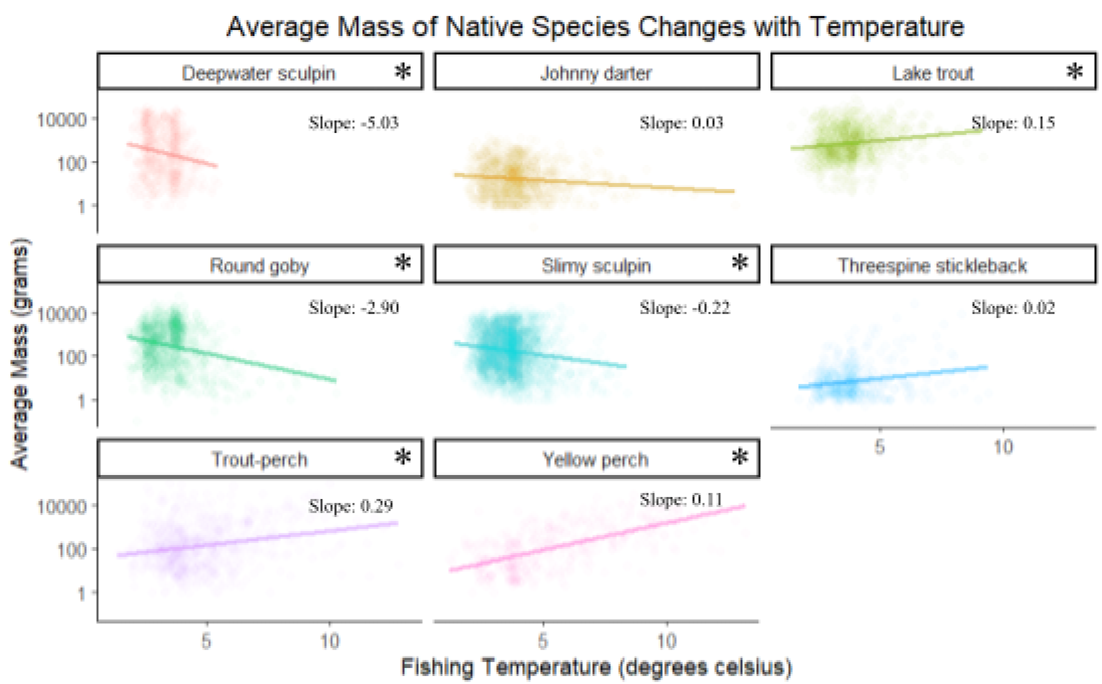

Figure 5: Average mass of fish compared with temperature using a general linear model. Significance (alpha = 0.05) indicated with *. Fish abundance has been log scaled for easier viewing. Estimated slopes are indicated on each graph.

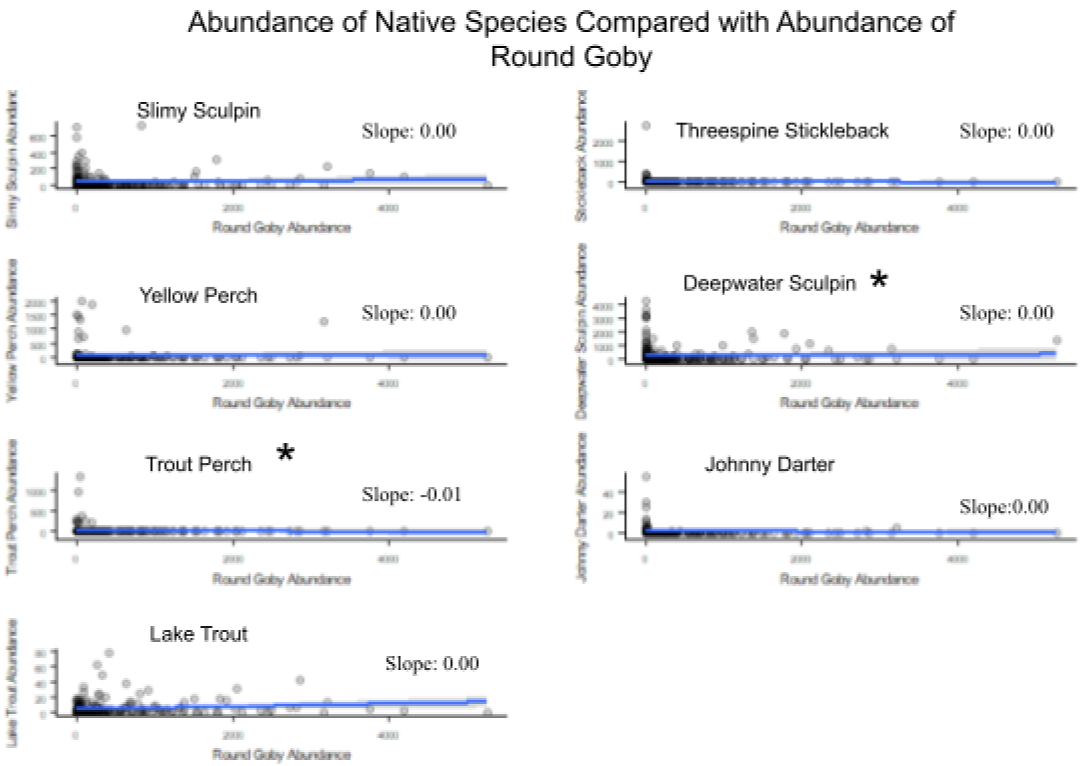

Figure 6: Abundance of native fish species compared with abundance of round goby using a general linear model. Each point is the total fish collected at one site in one year. Significance (alpha = 0.05) indicated with *. Fish abundance has been log scaled for easier viewing. Estimated slopes are indicated on each graph.

Discussion

Our first analysis concerning the effects of temperature yielded a lot of significant results, however, most of the effects were not particularly strong - showing relationships that did not have major effects on the abundance or mass of native species. Where we did see effects, some species were negatively affected by warming temperatures and some were positively affected by warmer temperatures. The largest effect was in the yellow perch which preferred warmer temperatures. The round goby was negatively affected by warming temperatures and tended to be healthier and more abundant in the cooler areas even though the effect was small. We expected that the round goby would be healthier at warmer sites and that native species would not be as successful in warmer areas. We found that native species can be either positively or negatively affected by increased temperature, but most species are not affected that much. In this case we can reject our null hypothesis because there is a difference in tolerance to temperature change among species, but we still did not get the result we expected.

The second analysis examined the abundance of each species in comparison with the abundance of the round goby. This helps to determine if the round goby is having a negative effect on the abundance of local native species. We found that while there were some significant results, they all showed slopes of nearly 0, meaning that there is almost no effect of the round goby on the abundances of those species. In this case we fail to reject the null hypothesis because the round goby does not have an effect on the abundance of these native species.

We filtered our dataset to find native species with at least 300 observations which means that we had to ignore a lot of rarer species. While this made our analysis possible, it also means we may be missing the effects that the round goby could be having on rare species especially since rare species may already be affected by climate change. Our data was also taken exclusively during April. If there are seasonal changes in the movements of any of these focal fishes we may be missing that data and not accounting for those changes. The data for temperature was also only from the fishing temperature. It was taken at the time and location of fishing. We cannot, therefore, account for the overall temperature over a period of time. This data cannot display changes in mean temperature over time or even the average temperature at a site. It can only capture a single snapshot in time which makes it hard to compare across sites because a difference in temperature may just be because it was a particularly cold or warm day.
The original data comes from an long term observational study that primarily focused on the alewife. We also suspect that some sites may simply be preferable to all species. The places where we see an increase in the round goby but also an increase in other species may be places where the habitat is favorable for all species which is not something we accounted for in this research. We also noticed that our dataset has some seemingly impossible numbers. For example, there are samples of almost 20,000 individuals listed, and others as high as 4,000 or 5,000 in one catch (Supplementary 2). While we imagine there may be a large number of individuals at a site, it seems unlikely that one research vessel would pull up that many on one sampling instance. We would remove these as outliers, except that they are fairly common in the dataset. Before using this data for conservation purposes it would be prudent to reach out to the original researchers and ensure that this data is accurate.

The goal of our research was to inform conservation efforts. In this case, because we do not find a definitive negative effect of the round goby on other species abundances, and we do not have evidence to show that the round goby population will dramatically increase with climate change we cannot conclude that immediate conservation action is necessary. We cannot conclude from the current data that the increased abundance of the round goby is harming these native species. We do, however, suggest that further research be conducted. There is very little current literature regarding the realized effects of the round goby. There are some lab experiments showing that the round goby consumes fish eggs and fry alongside its main diet items, and there is evidence that it causes a decline in 2 species, however, no further observation experiments have been completed in lake ontario and the direct effects on native species have not been studied. It is difficult, therefore, to conclude based solely on this information whether or not the round goby should be of primary conservation concern. Further research should focus on understanding the round goby and its direct effects on the interactions between species that result from the introduction of the round goby. While there are hypothesized effects, there needs to be further research on the actual effects in nature.

Understanding how climate change will affect different species, particularly declining native species is extremely important for future conservation planning. With the recent and projected rise in the round goby it's important to understand not only how they will affect other species but also how they may be affected by climate change. We suggest future studies continue to explore these relationships.

References

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Supplementary

1. Residual plots and normal quantile-quantile plots that were used to test the homogeneity and normality validated the assumptions of linear models. Logarithm transformations were also performed for those models that indicated right-skewness.

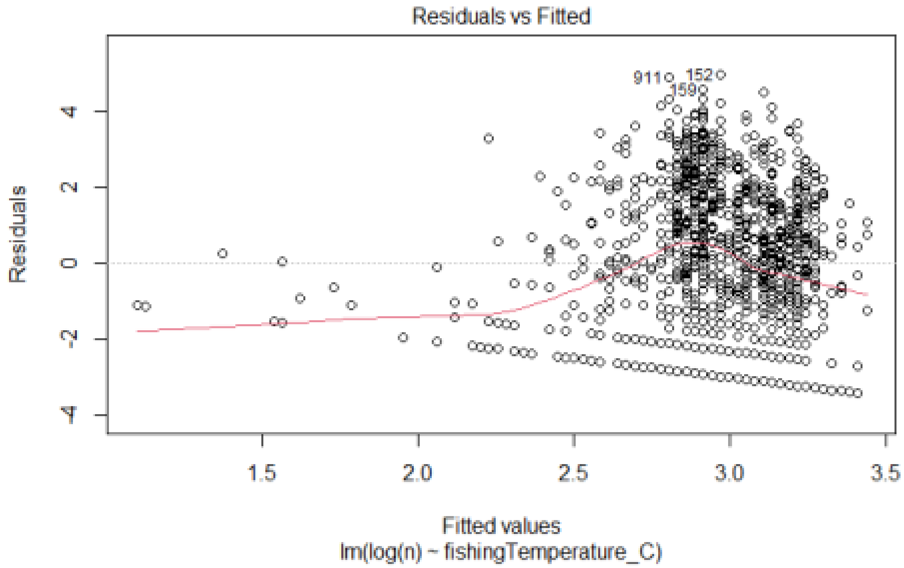

Figure S1.1: Residual plot of linear model between log(number of round goby) and temperature

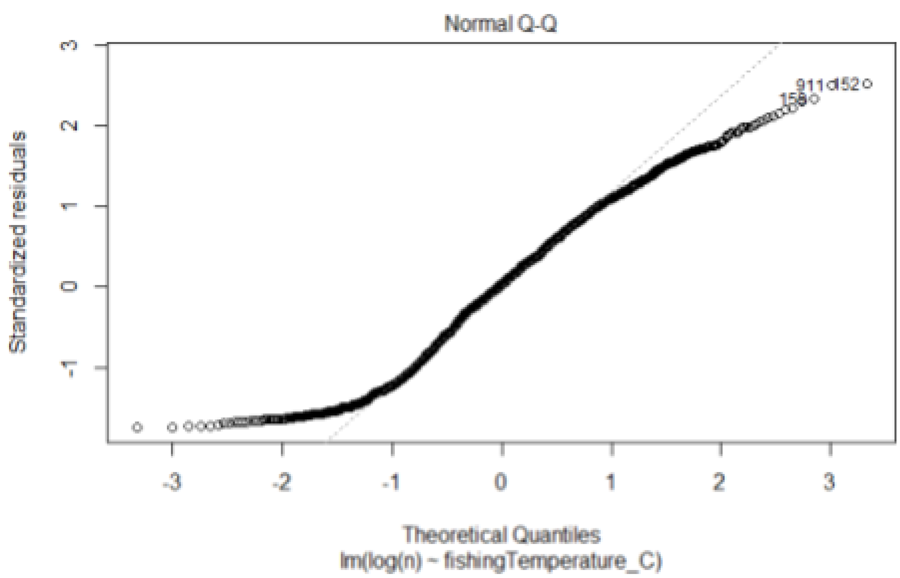

Figure S1.2: Normal Q-Q plot of linear model between log(number of round goby) and temperature

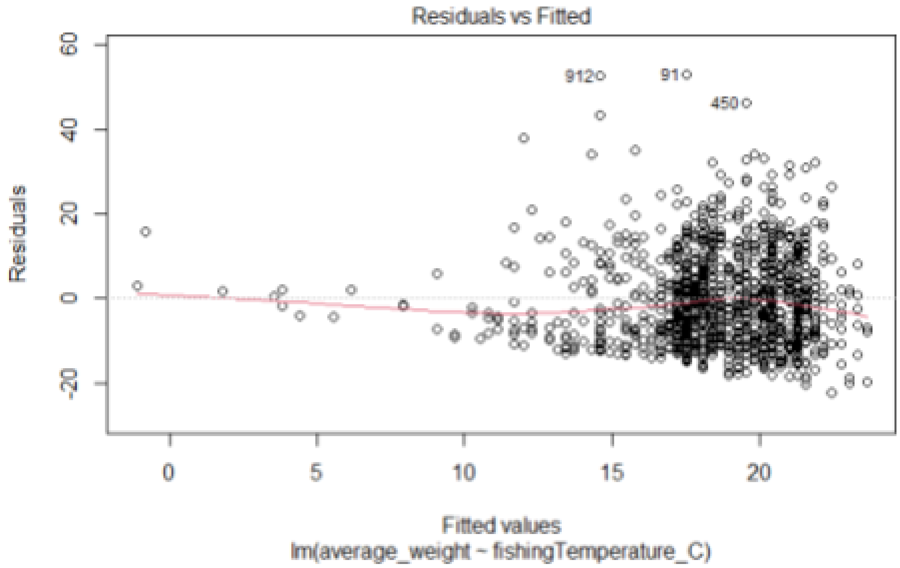

Figure S1.3: Residual plot of linear model between log(weight of round goby) and temperature

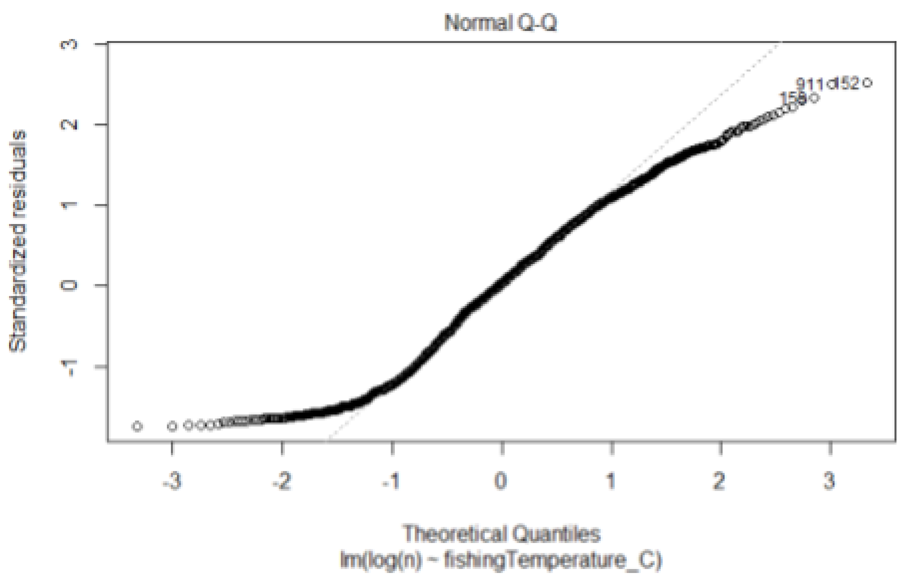

Figure S1.4: Normal Q-Q plot of linear model between log(weight of round goby) and temperature

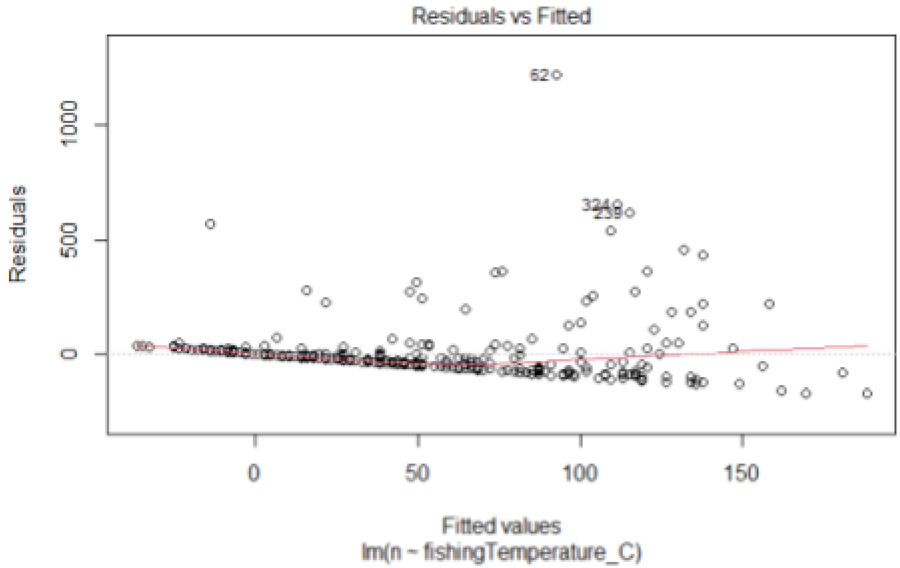

Figure S1.5: Residual plot of linear model between log(number of yellow perch) and temperature

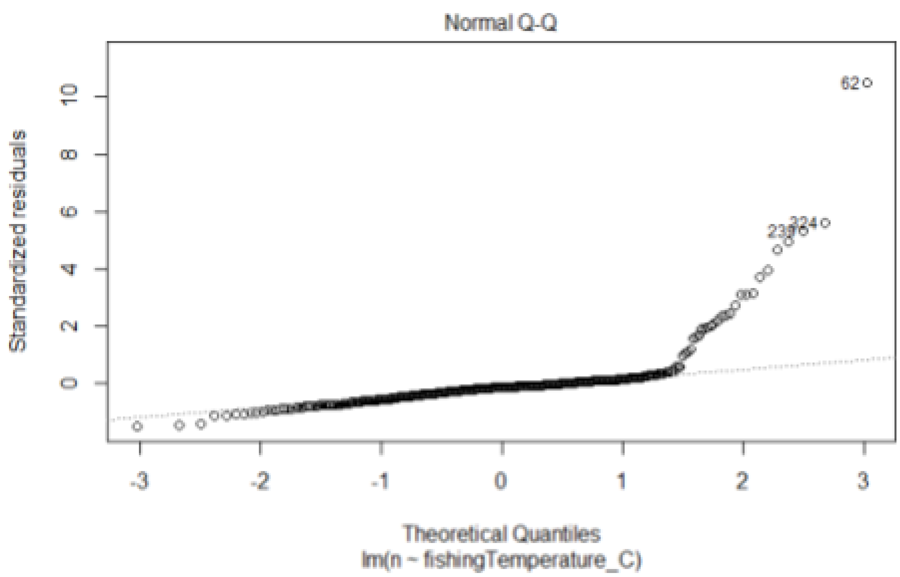

Figure S1.6: Normal Q-Q plot of linear model between the number of yellow perch and temperature

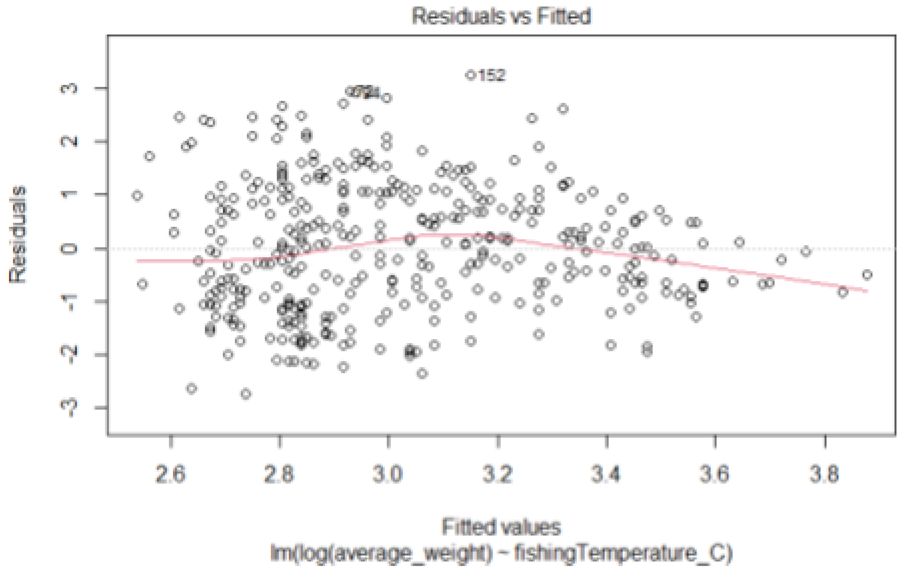

Figure S1.7: Residual plot of linear model between log(weight of yellow perch) and temperature

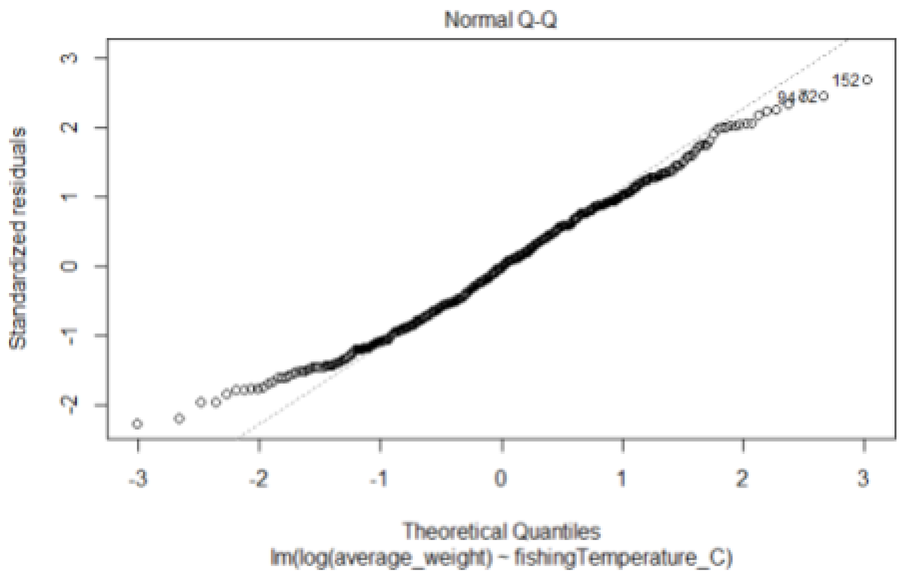

Figure S1.8: Normal Q-Q plot of linear model between log(weight of yellow perch) and temperature

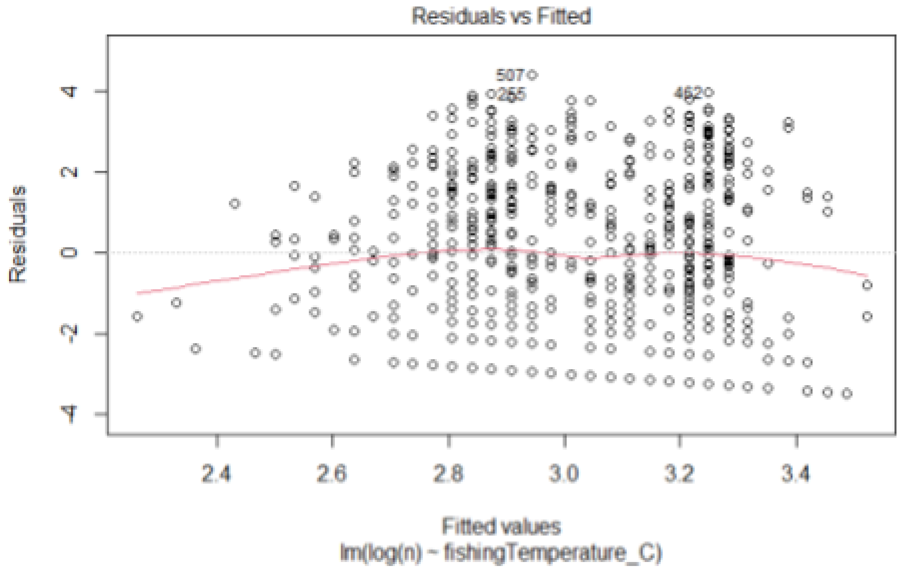

Figure S1.9: Residual plot of linear model between log(number of deepwater sculpin) and temperature

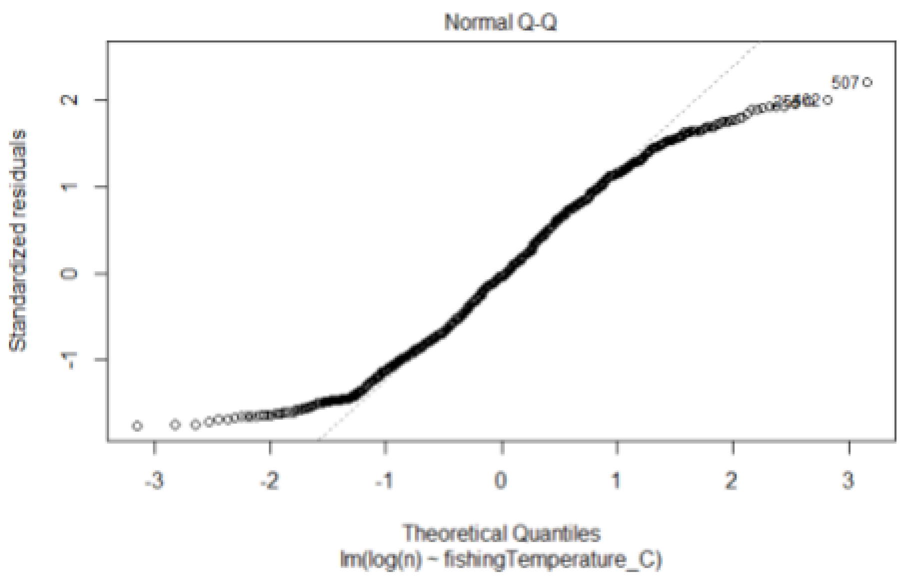

Figure S1.10: Normal Q-Q plot of linear model between the number of deepwater sculpin and temperature

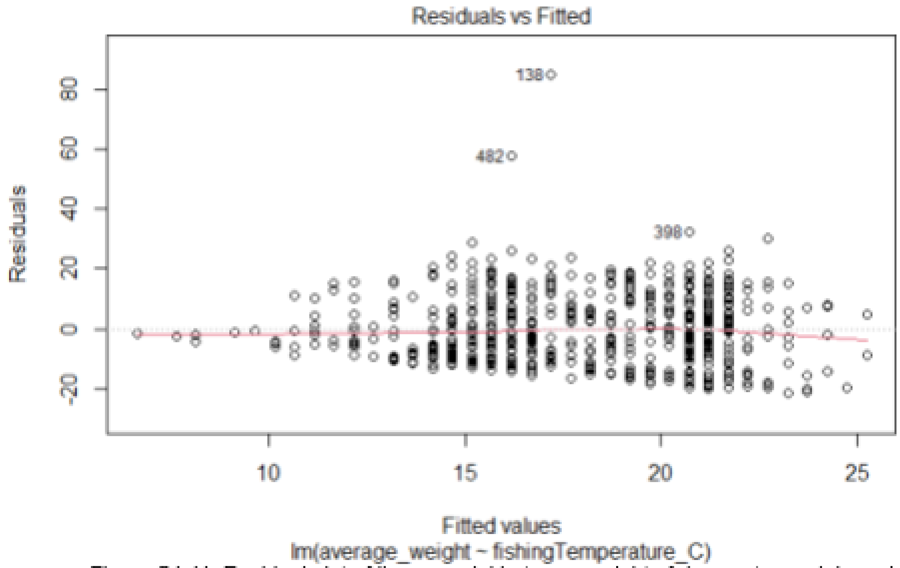

Figure S1.11: Residual plot of linear model between weight of deepwater sculpin and temperature

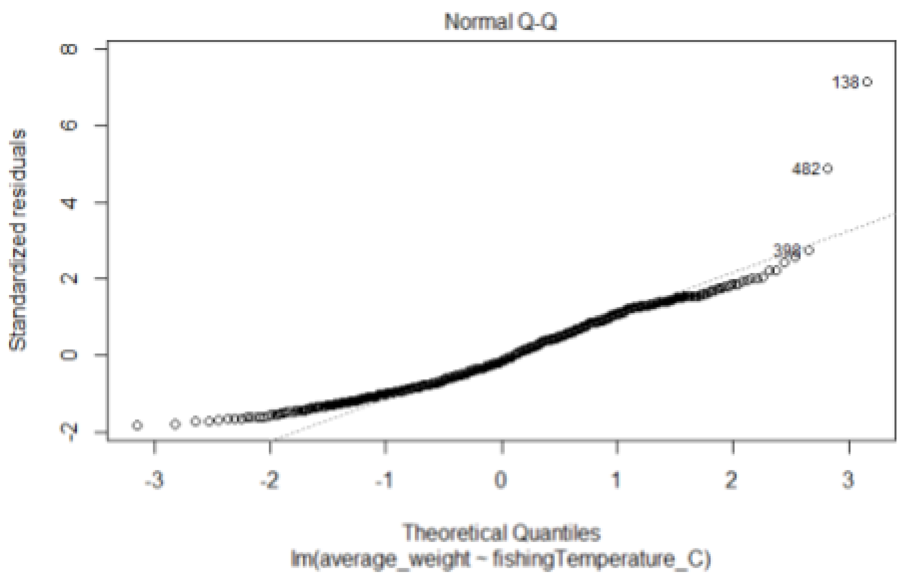

Figure S1.12: Normal Q-Q plot of linear model between weight of deepwater sculpin and temperature

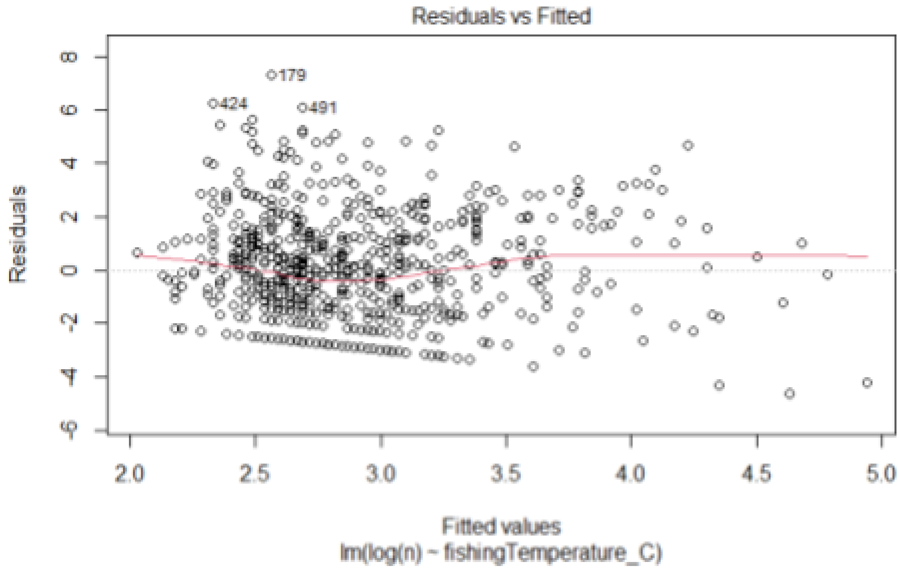

Figure S1.13: Residual plot of linear model between log(number of troutperch) and temperature

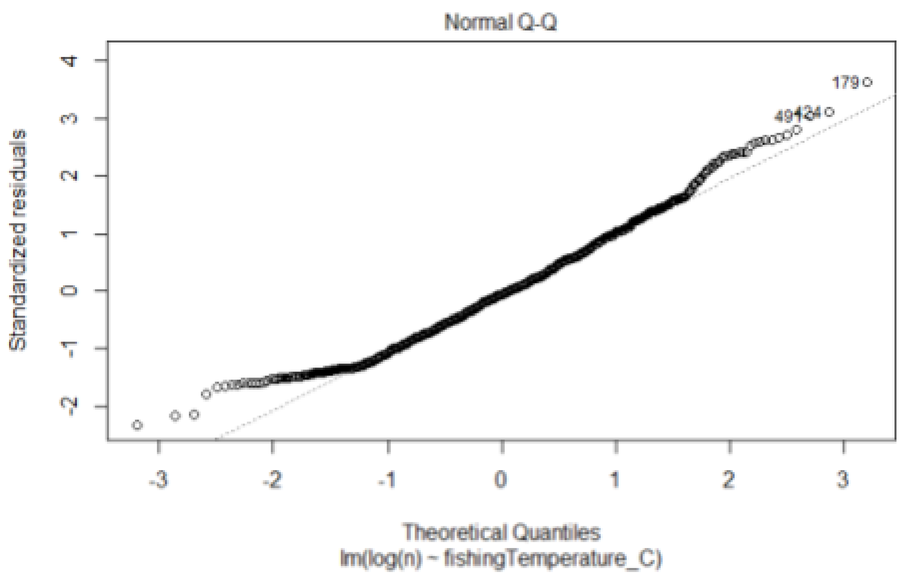

Figure S1.14: Normal Q-Q plot of linear model between log(number of trout perch) and temperature

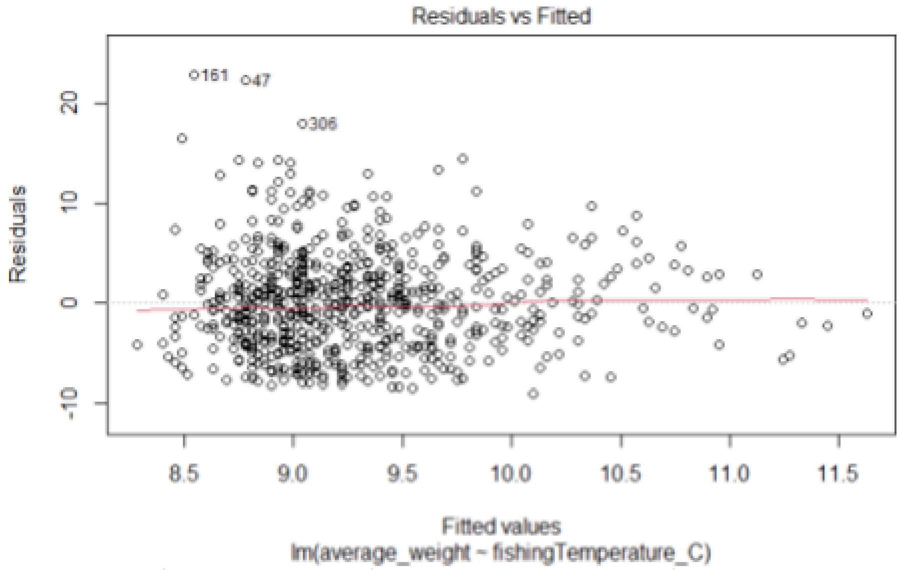

Figure S1.15: Residual plot of linear model between weight of trout perch and temperature

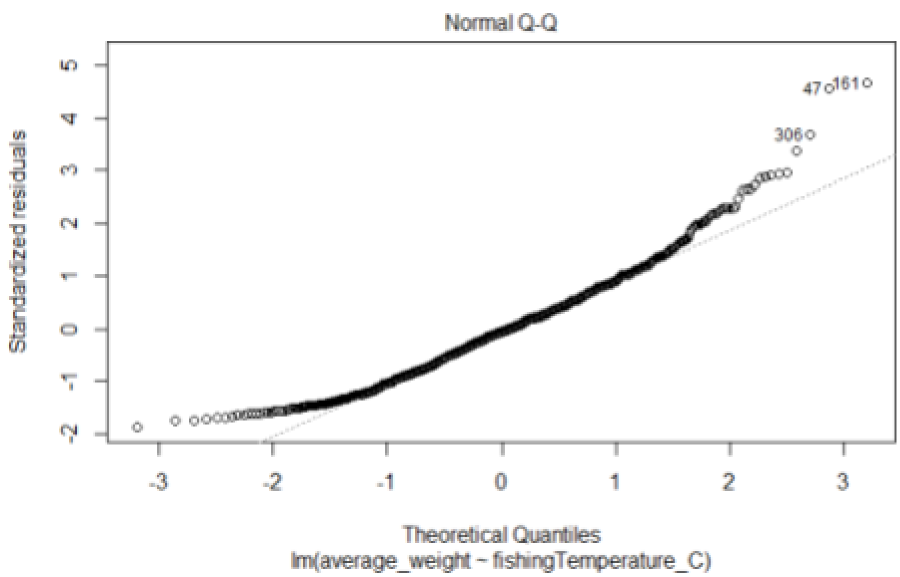

Figure S1.16: Normal Q-Q plot of linear model between weight of trout perch and temperature

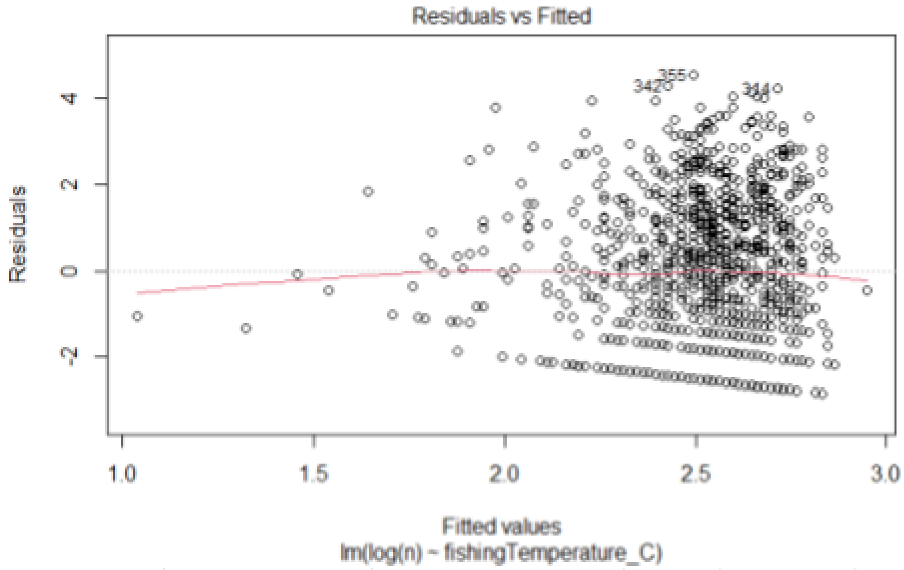

Figure S1.17: Residual plot of linear model between log(number of johnny darter) and temperature

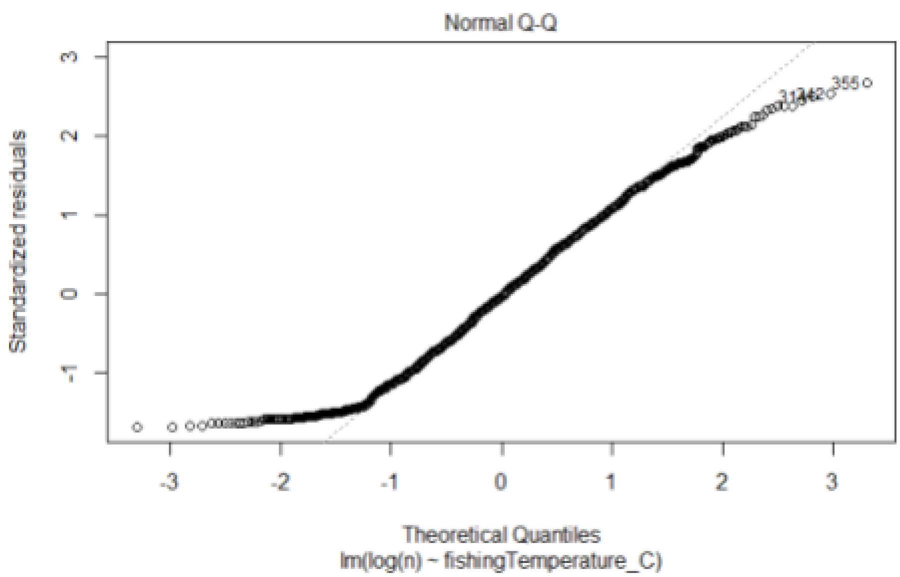

Figure S1.18: Normal Q-Q plot of linear model between log(number of johnny darter) and temperature

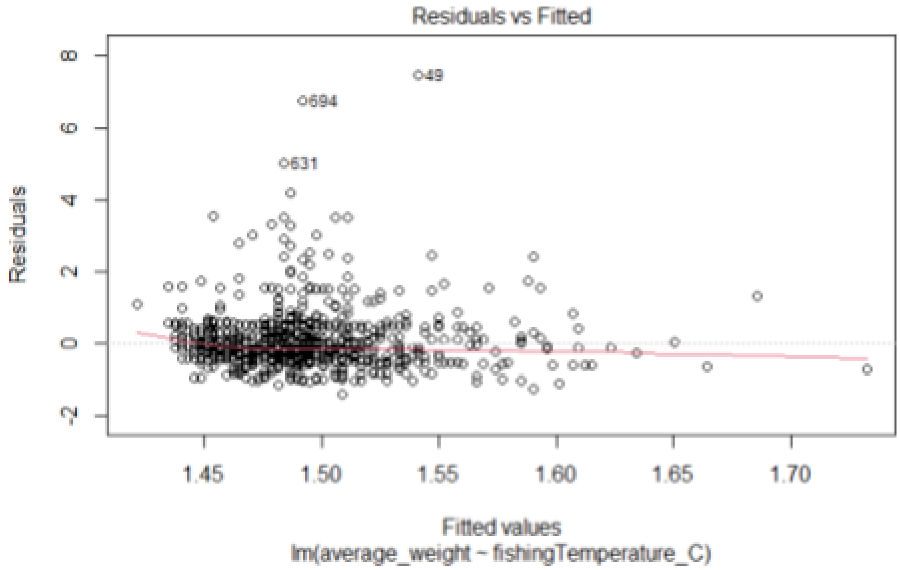

Figure S1.19: Residual plot of linear model between johnny darter and temperature

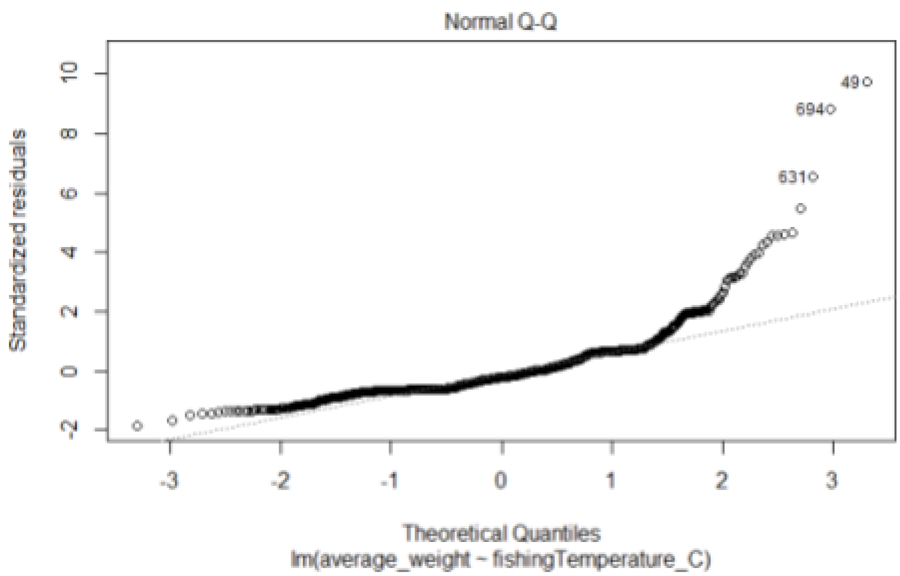

Figure S1.20: Normal Q-Q plot of linear model between weight of johnny darter and temperature

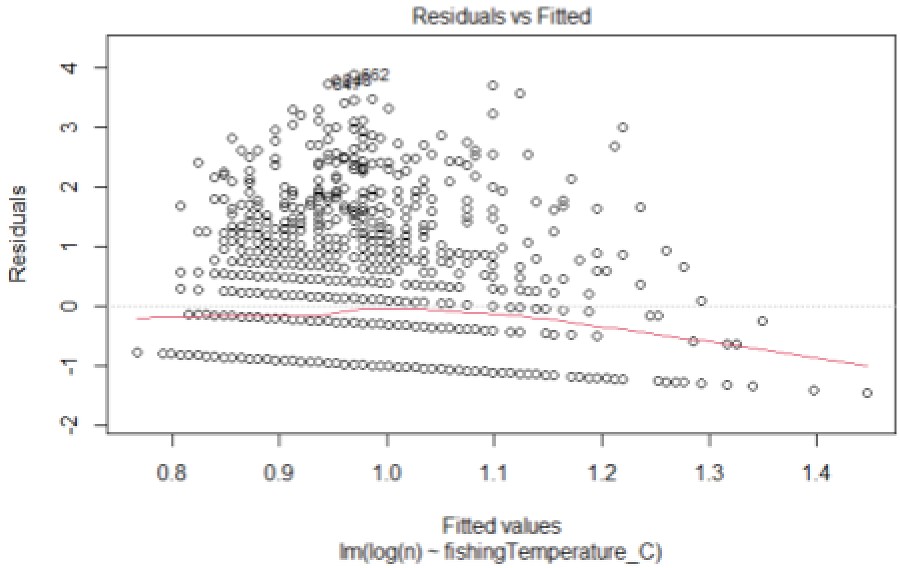

Figure S1.21: Residual plot of linear model between log(number of lake trout) and temperature

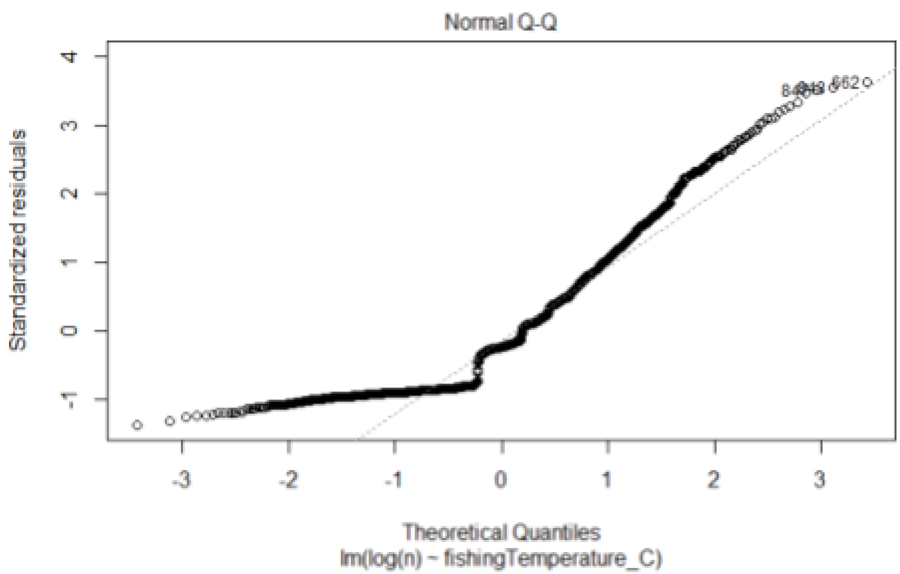

Figure S1.22: Normal Q-Q plot of linear model between log(number of lake trout) and temperature

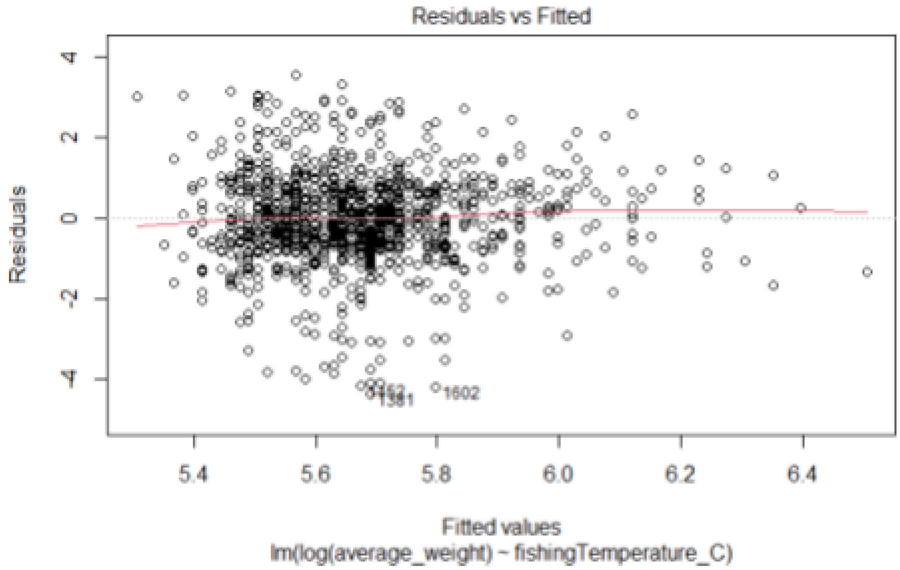

Figure S1.23: Residual plot of linear model between log(weight of lake trout) and temperature

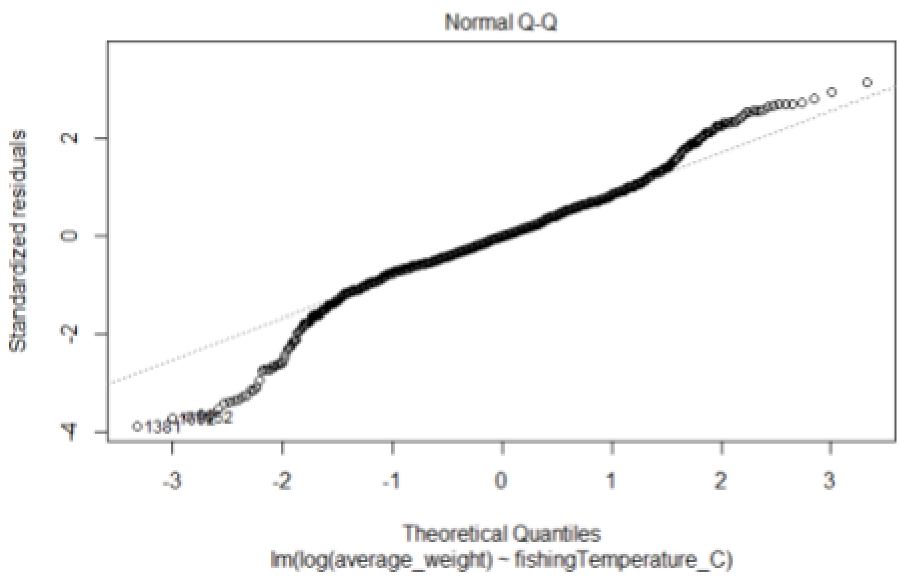

Figure S1.24: Normal Q-Q plot of linear model between log(weight of lake trout) and temperature

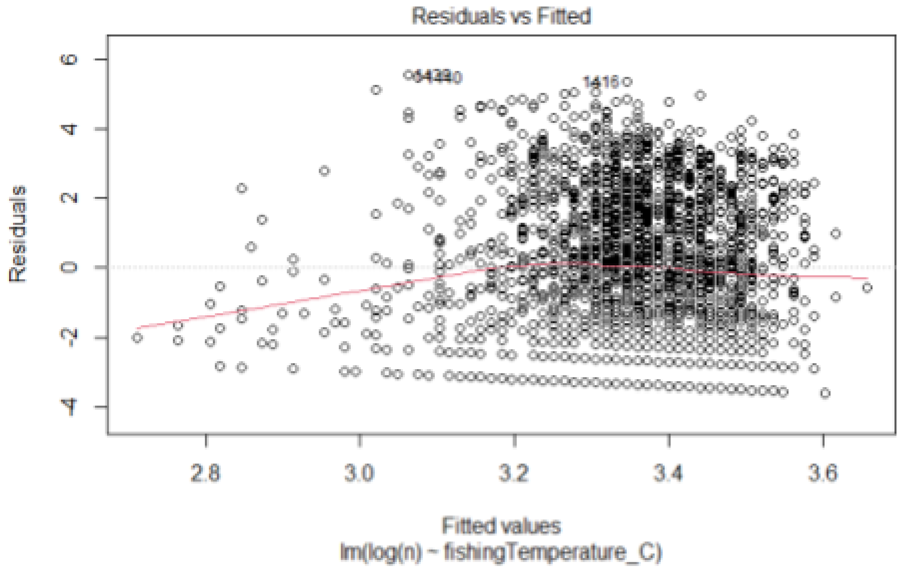

Figure S1.25: Residual plot of linear model between log(number of slimy sculpin) and temperature

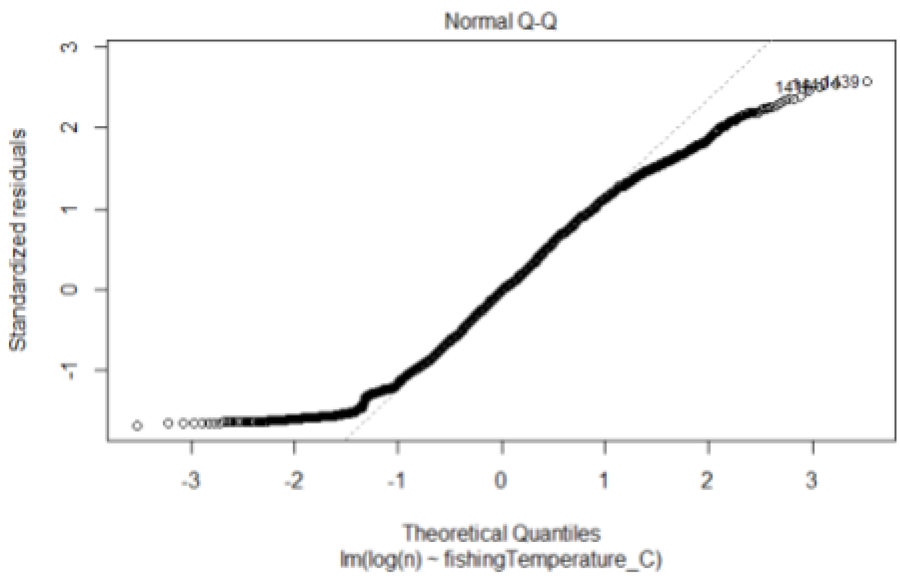

Figure S1.26: Normal Q-Q plot of linear model between log(number of slimy sculpin) and temperature

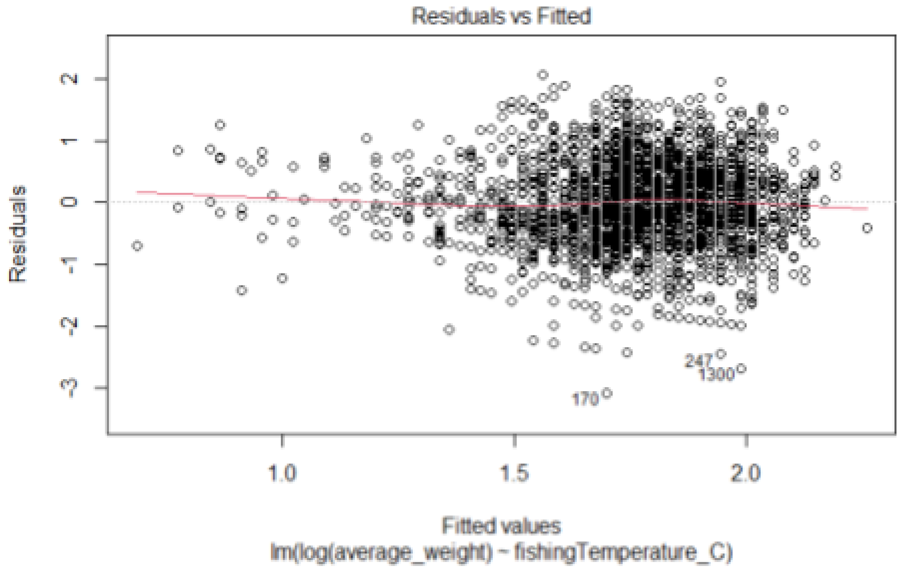

Figure S1.27: Residual plot of linear model between log(weight of slimy sculpin) and temperature

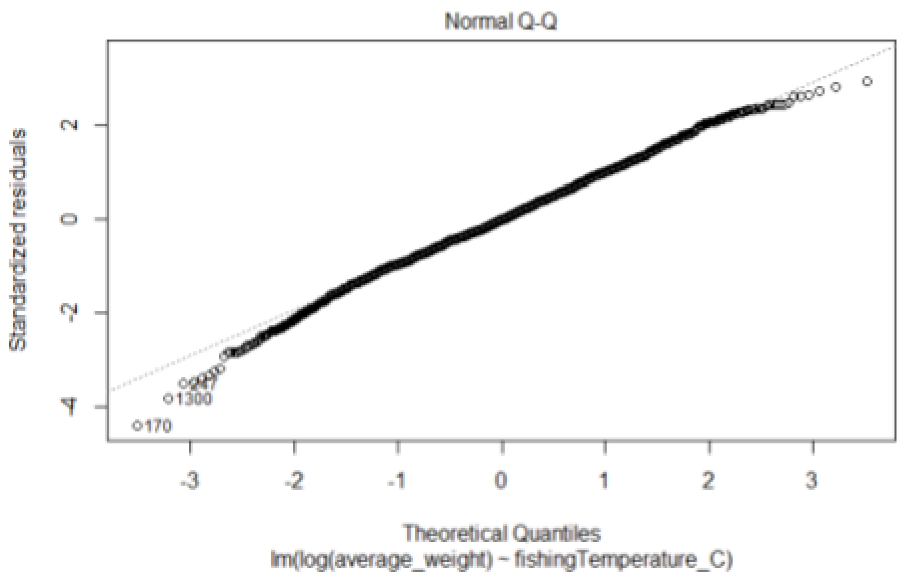

Figure S1.28: Normal Q-Q plot of linear model between log(weight of slimy sculpin) and temperature

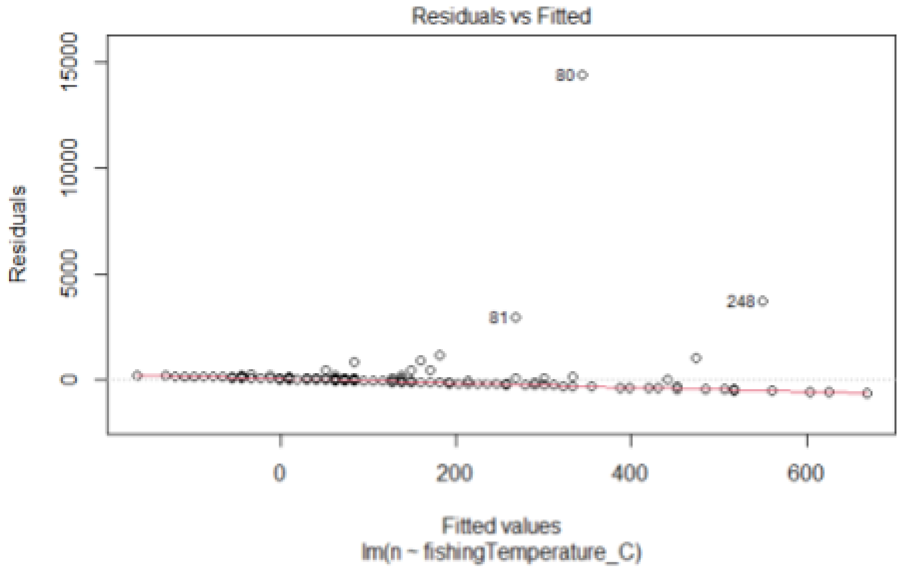

Figure S1.29: Residual plot of linear model between number of threespine stickleback and temperature

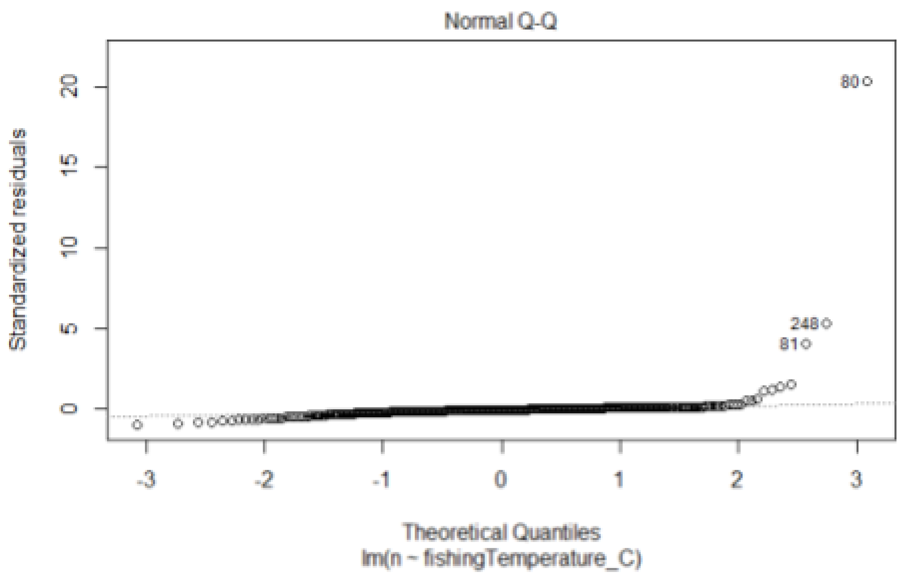

Figure S1.30: Normal Q-Q plot of linear model between log(number of threespine stickleback) and temperature

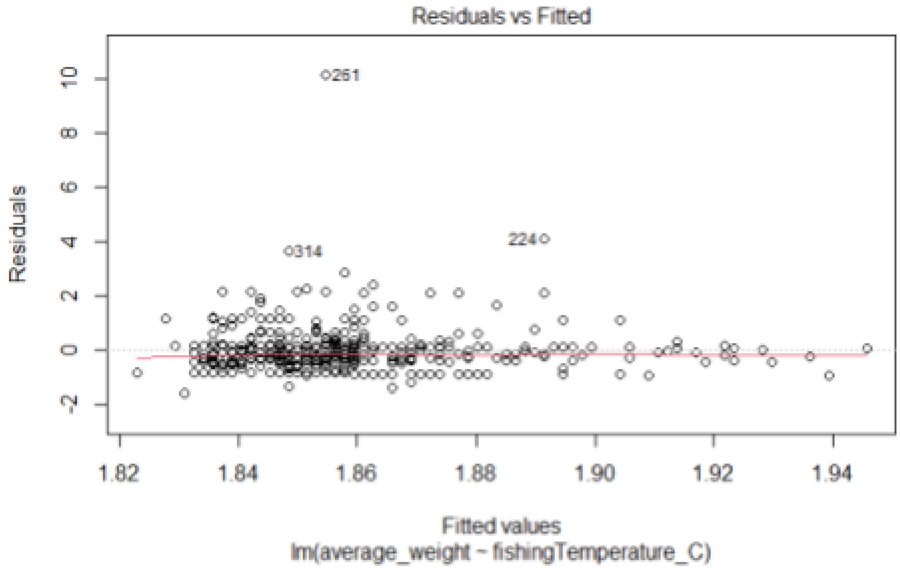

Figure S1.31: Residual plot of linear model between weight of threespine stickleback and temperature

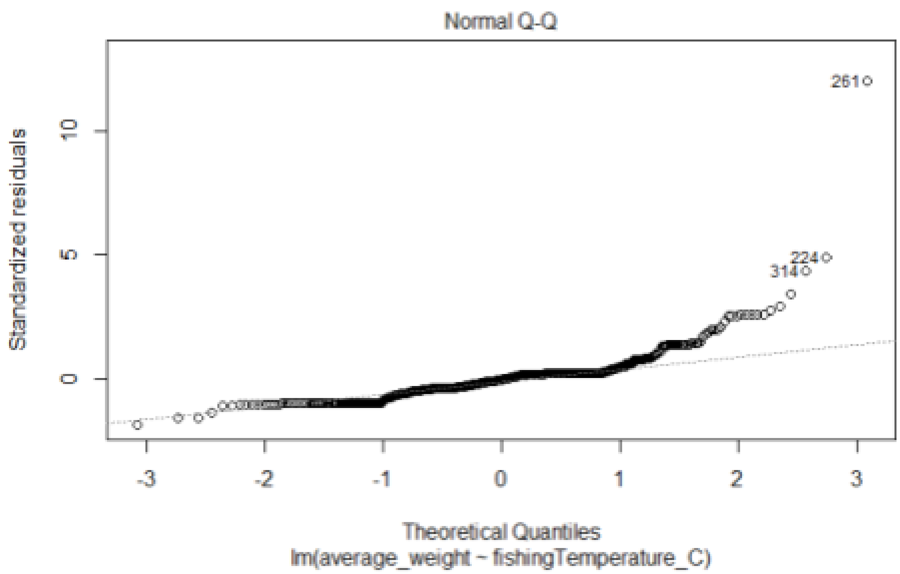

Figure S1.32: Normal Q-Q plot of linear model between weight of threespine stickleback and temperature

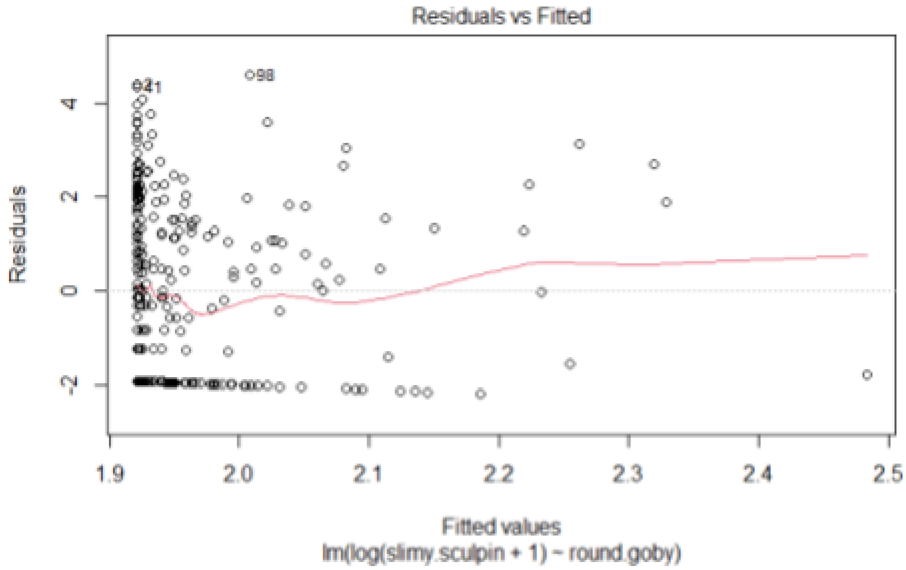

Figure S1.33: Residual plot of linear model between log(number of slimy sculpin)+1 and round goby

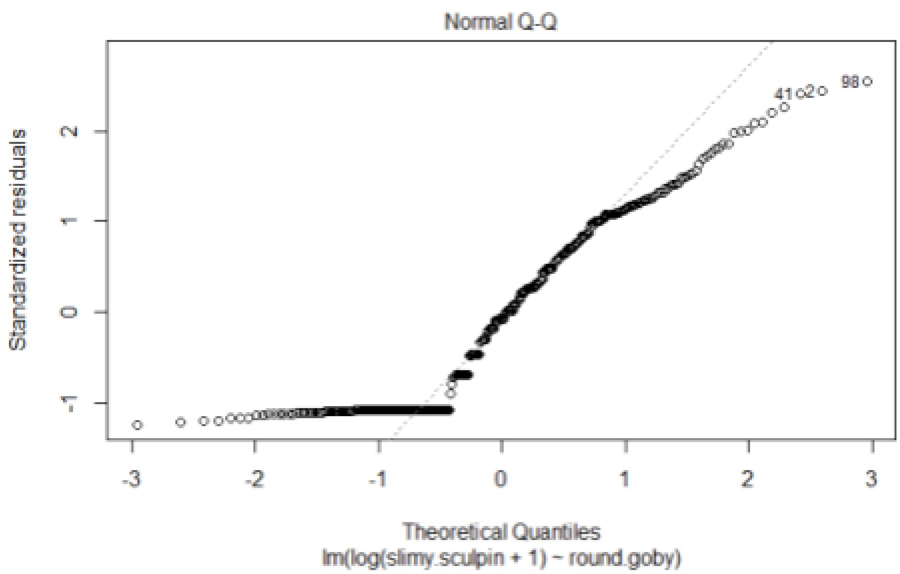

Figure S1.34: Normal Q-Q plot of linear model between log(number of slimy sculpin)+1 and temperature

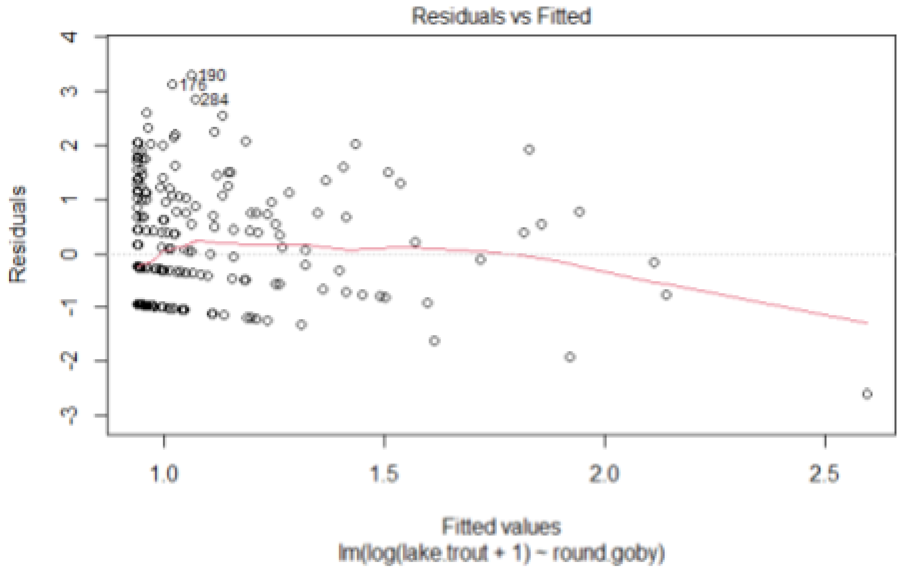

Figure S1.35: Residual plot of linear model between log(number of lake trout)+1 and round goby

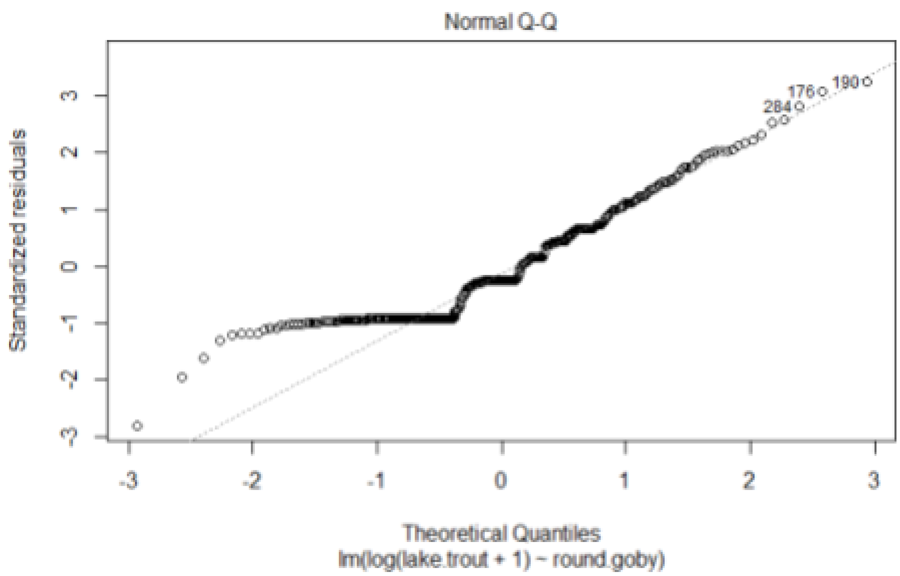

Figure S1.36: Normal Q-Q plot of linear model between log(number of lake trout)+1 and temperature

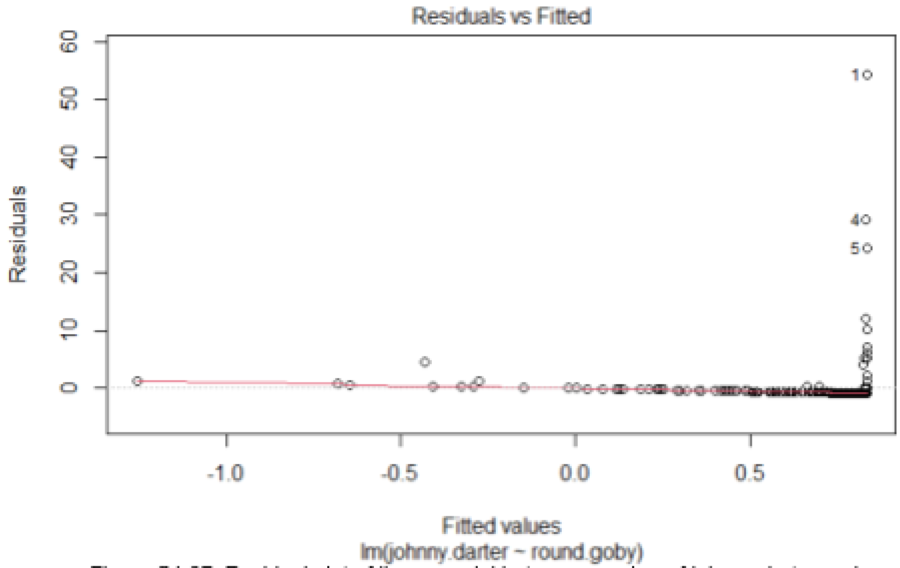

Figure S1.37: Residual plot of linear model between number of johnny darter and round goby

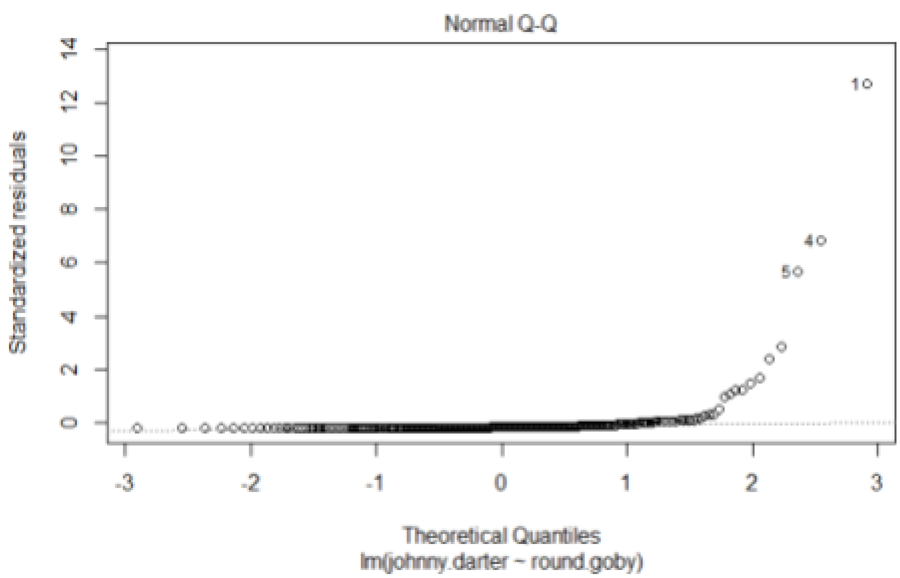

Figure S1.38: Normal Q-Q plot of linear model between number of johnny darter and temperature

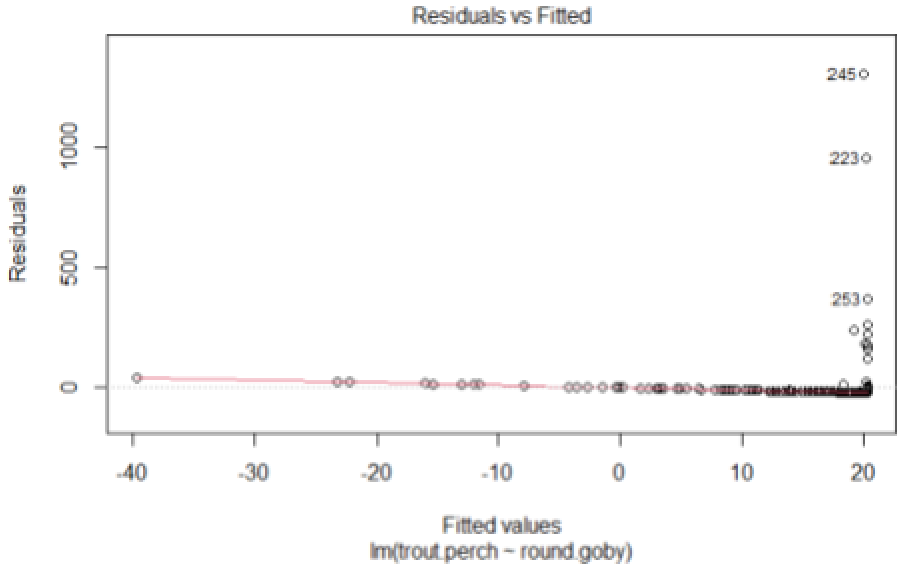

Figure S1.39: Residual plot of linear model between number of trout perch and round goby

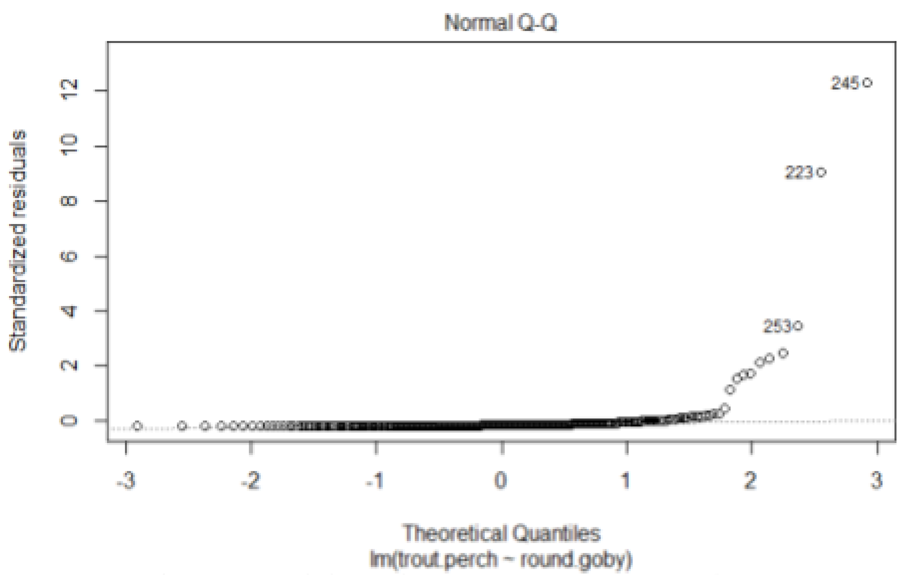

Figure S1.40: Normal Q-Q plot of linear model between number of trout perch and temperature

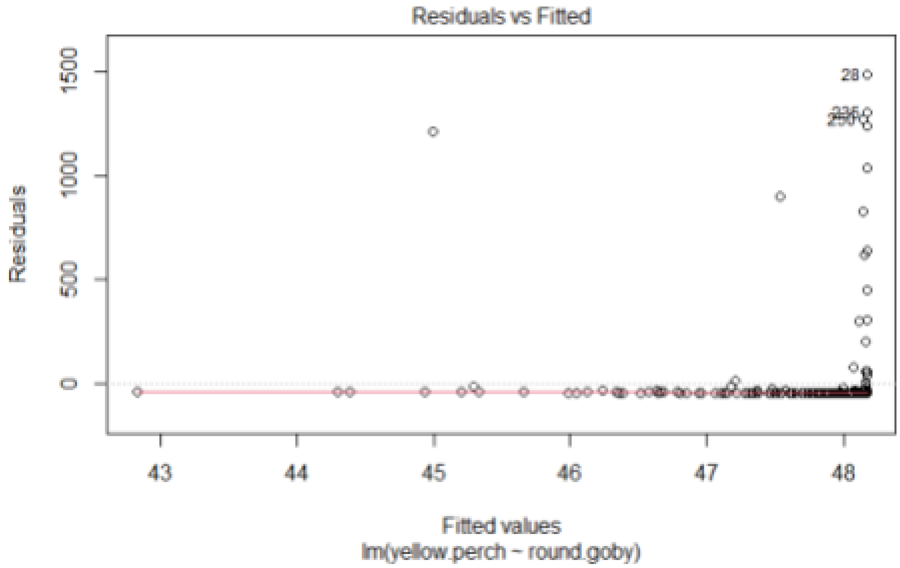

Figure S1.41: Residual plot of linear model between number of yellow perch and round goby

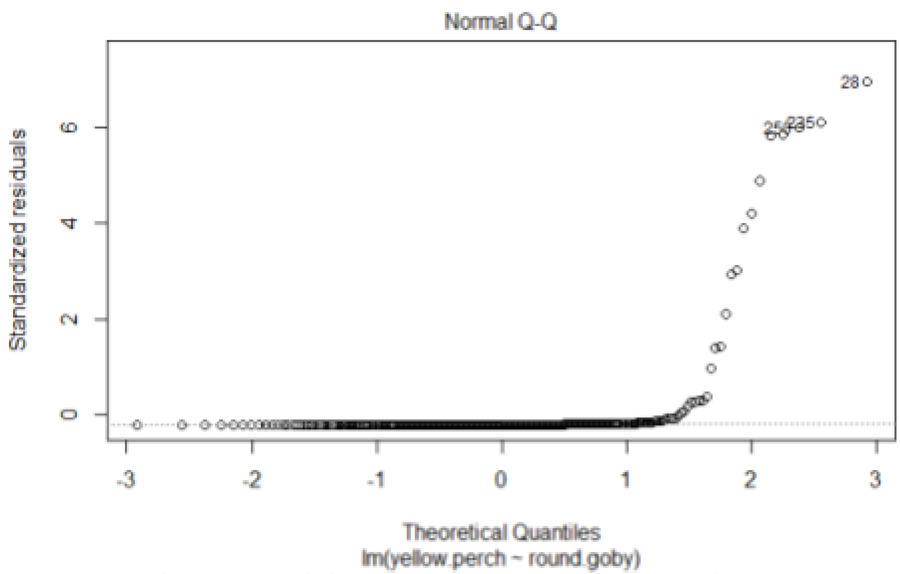

Figure S1.42: Normal Q-Q plot of linear model between number of yellow perch and temperature

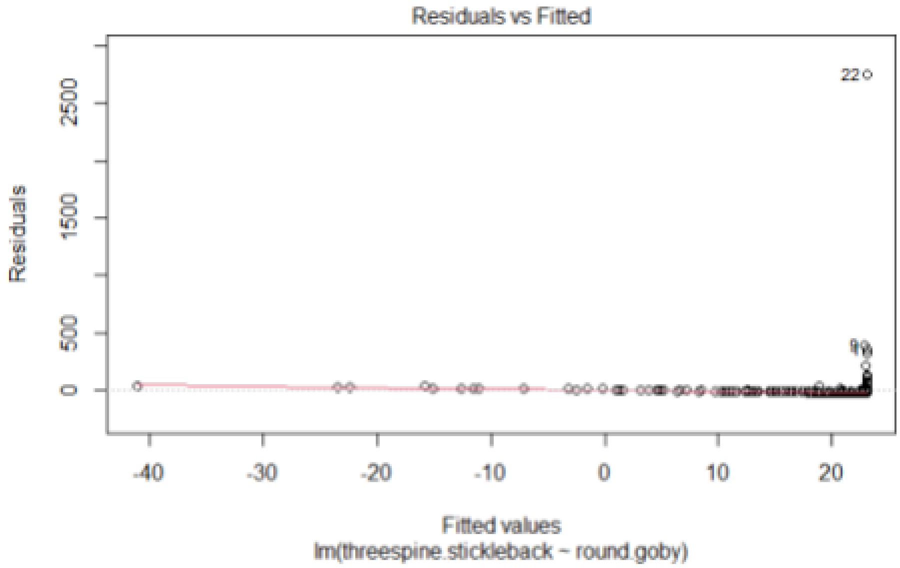

Figure S1.43: Residual plot of linear model between number of threespine stickleback and round goby

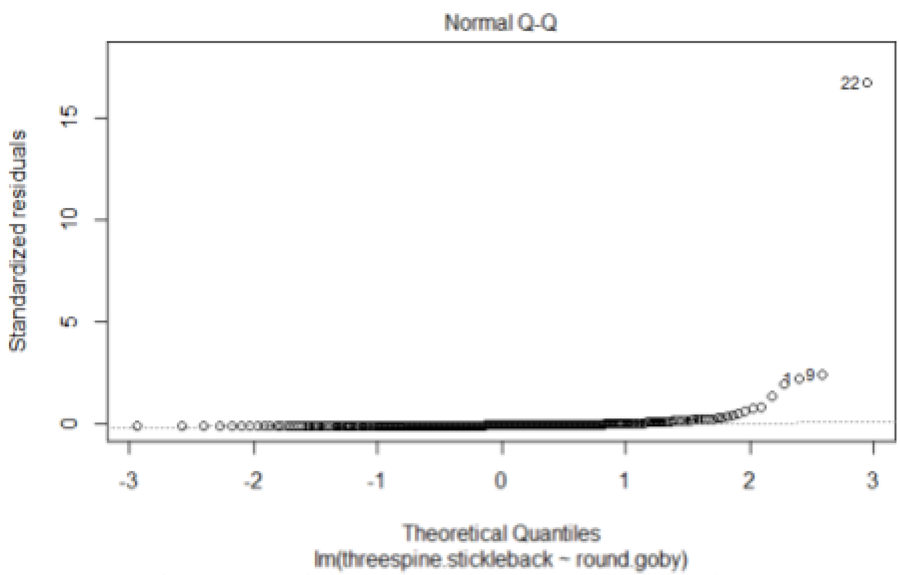

Figure S1.44: Normal Q-Q plot of linear model between number of threespine stickleback and temperature

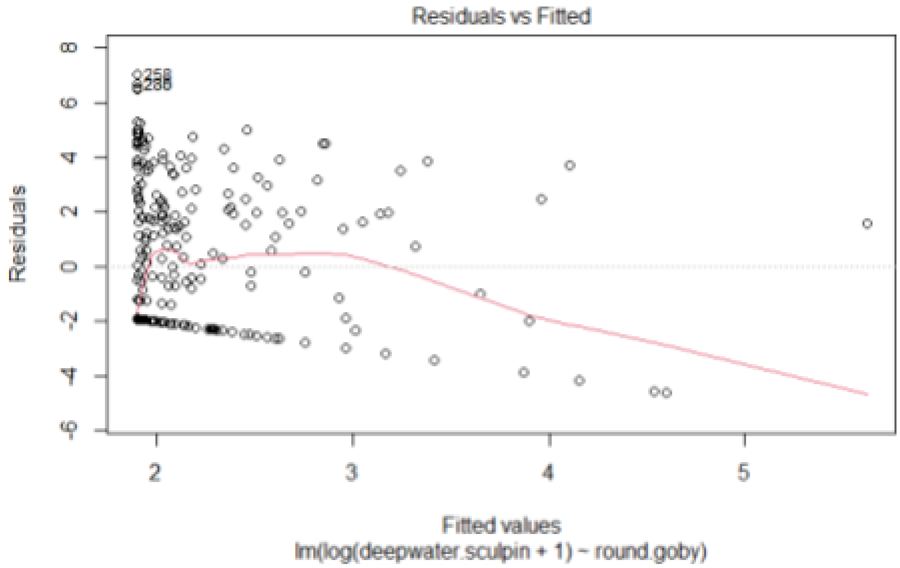

Figure S1.45: Residual plot of linear model between log(number of deepwater sculpin)+1 and round goby

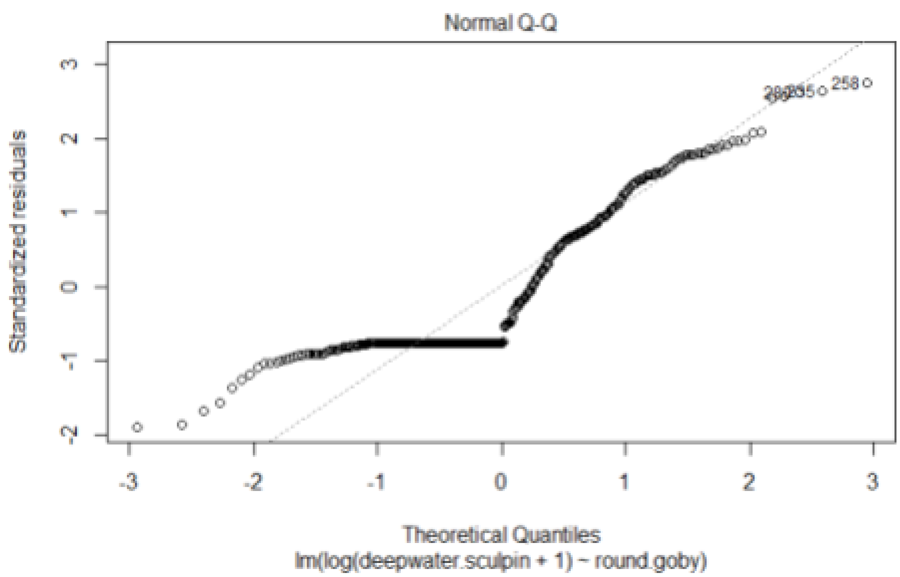

Figure S1.46: Normal Q-Q plot of linear model between log(number of deepwater sculpin)+1 and temperature

2. Scatterplots on abundance of species over temperature show extreme values of fish individuals were recorded in one catch, according to the original dataset from Lake Ontario April Prey Fish Bottom Trawl Survey.

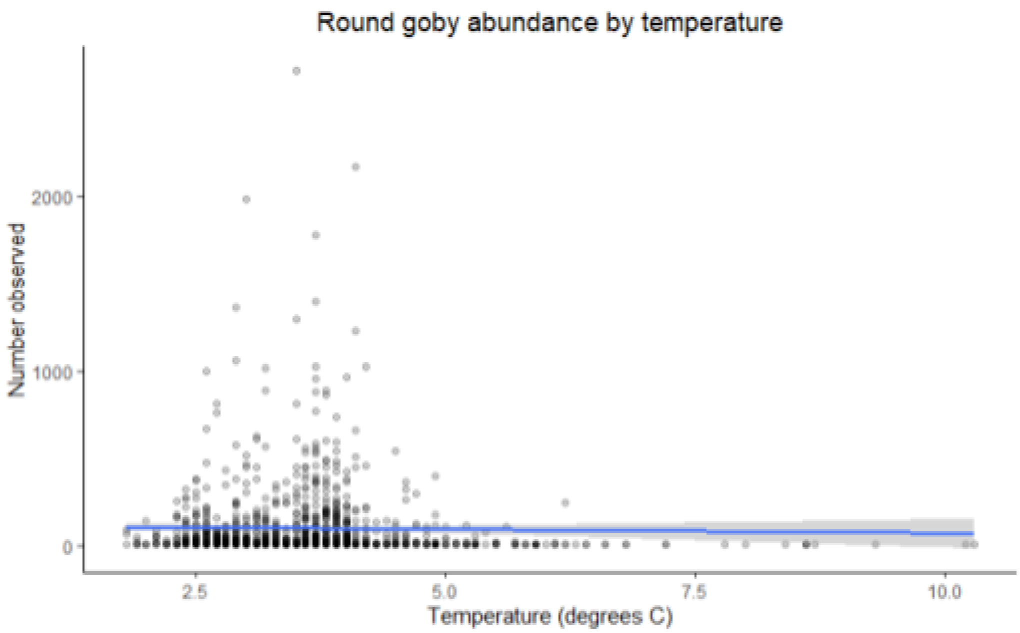

Figure S2.1: Scatterplot on round goby abundance over temperature shows several extreme values of the quantity of round goby in one observation

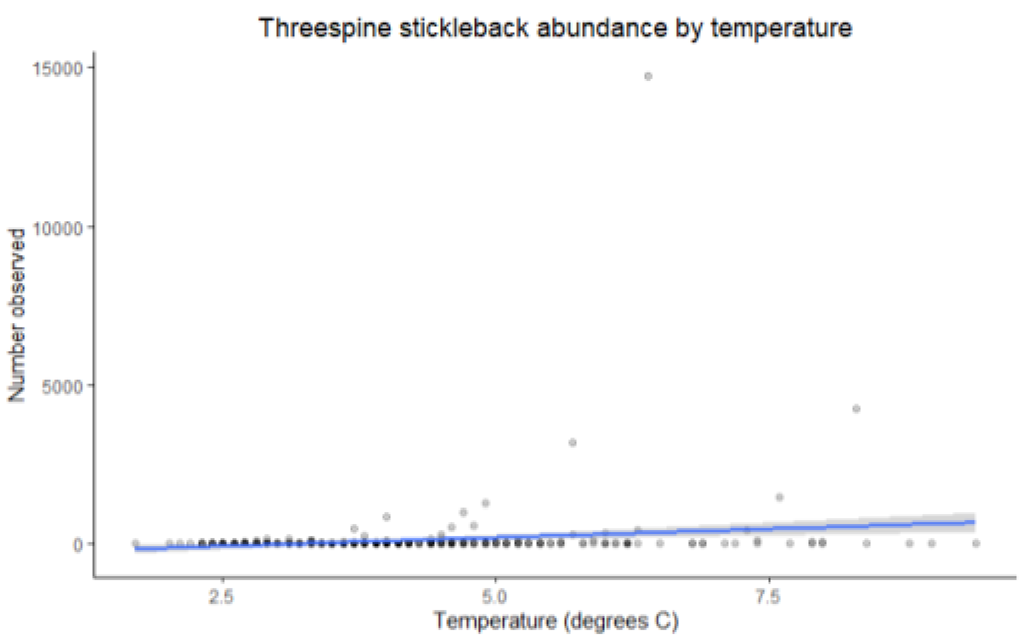

Figure S2.2: Scatterplot on threespine stickleback abundance over temperature shows several extreme values of the quantity of individuals in one observation

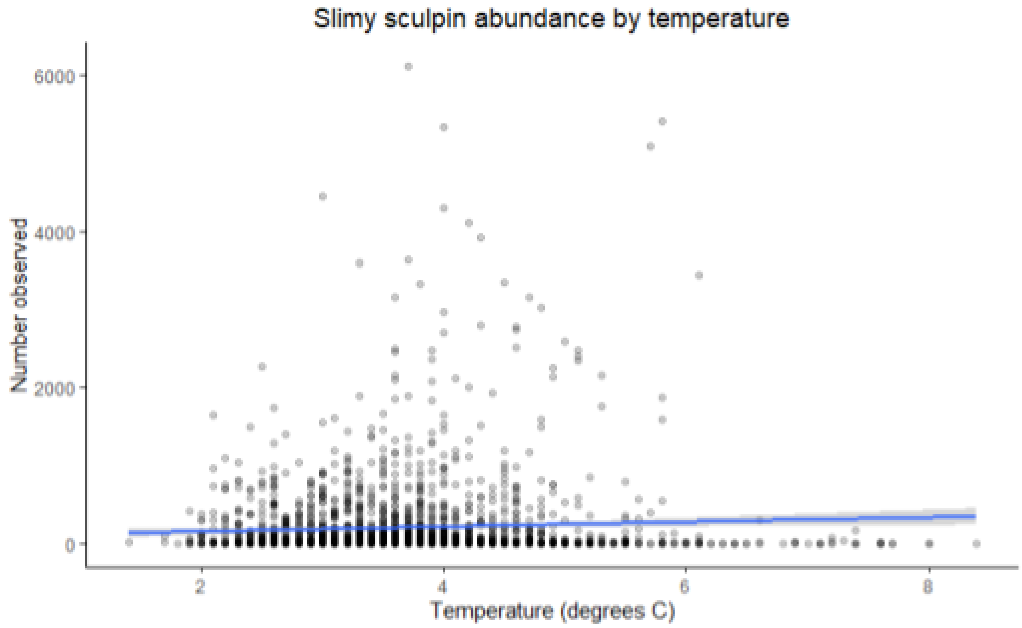

Figure S2.3: Scatterplot on slimy sculpin abundance over temperature shows several extreme values of the quantity of individuals in one observation

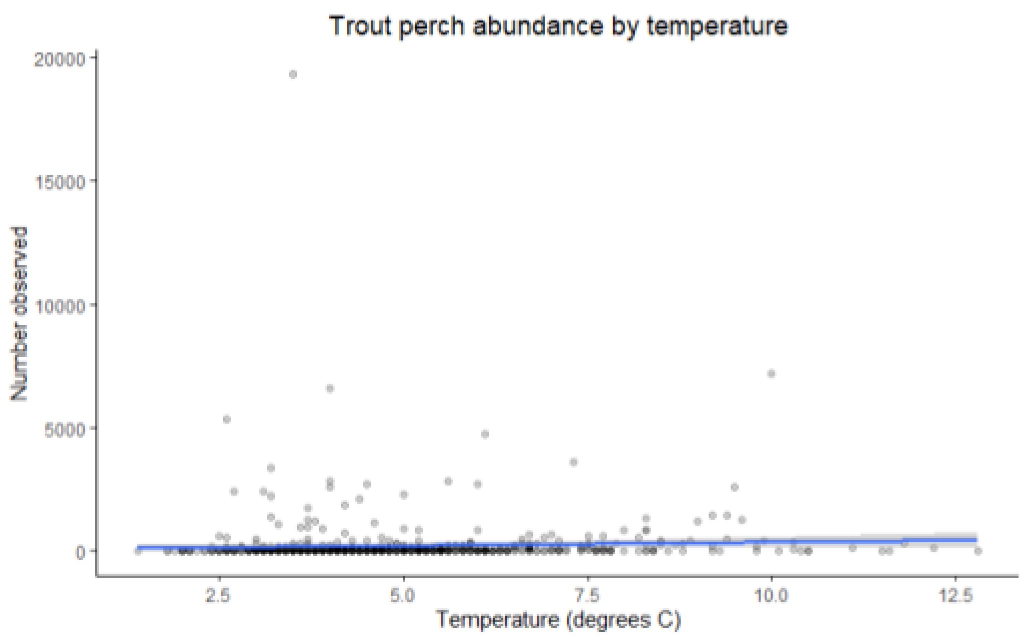

Figure S2.4: Scatterplot on trout perch abundance over temperature shows several extreme values of the quantity of individuals in one observation