Climate change and *Perca flavescens*: How milder winters may impact growth and survival of Yellow Perch in northern Michigan lakes

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ABSTRACT

Yellow Perch (*Perca flavescens*) are an ecologically and economically important species in a large number of lakes and rivers across North America. With recent climate change producing milder winters, perch year-class strength and first year growth are negatively impacted with potential harms to total length in future years. Yellow Perch were sampled from two lakes in the upper peninsula of Michigan (Morris Lake and Tenderfoot Lake) using fyke nets. Key metrics for each specimen (total length, standard weight, relative weight, age, and first year growth) were examined compared to winter intensity (harsh, mild, or intermediate) to test for impacts by climate change. Yellow Perch first year growth was back calculated and age estimated by scale annuli to develop a model for ideal growth. It was found that first year growth increases when the winter preceding spawning is harsh (-10°C or lower) but growth in later years is impacted by the interaction by both climate and the lake environment.

KEY WORDS yellow perch, climate change, spawning, first year growth, winter intensity

INTRODUCTION

One of the greatest challenges of the modern era is climate change. In the wake of such circumstances, research into factors that both demonstrate and predict climate change across a wide variety of biomes becomes all the more imperative. One unused but potential model organism for climate change across North American bodies of water is *Perca flavescens,* or Yellow Perch. Yellow Perch are a popular sport fish, frequently sought after for commercial and recreational interests. Additionally, perch inhabit a large number of streams and lakes where they play a critical ecological role as a mid-level consumer in most food webs (Brown et al 2009). Yellow Perch act as a major piscivore on juvenile fishes, including their own young, but can also serve as an important food source for larger fish species, such as Northern Pike (*Esox lucius*), Walleye (*Sander vitreus*), and Largemouth Bass (*Micropterus salmoides*), among many others (Moyle 2002). Given their prevalence across the North American continent, adaptability, and presence as both predator and prey, Yellow Perch make an ideal model organism for mapping climate change by reflecting changes to trophic levels both above and below it.

Generally hardy and adept, Yellow Perch spawn in the spring after ice-out, typically April, when water temperatures are anywhere from 2°C to 18.6°C (Clady 1976). Bradshaw and Holzapfel 2006 show that as poikilotherms, Yellow Perch reproductive success is negatively impacted by shorter winters. Farmer et al. 2014 demonstrated that warmer winters over Lake Erie have directly impacted perch year-class strength; longer, colder winters yield higher numbers of young than shorter, milder winters. Preliminary research from this ongoing study also reveals that one potential reason for low recruitment may be due to the smaller and weaker eggs that are spawned following milder winters. Conversely, after long, harsh winters, perch eggs tend to be larger and more hardy, suggesting already that climate change is reshaping the morphological traits of perch in the north. Johnson and Evans 2011 found that in simulated winter trials, Yellow Perch had lower mortality rates during harsher winters (2.5°C) than during milder winters (4°C).

The following study will investigate the morphological traits of Yellow Perch and the environmental parameters, such as lake size, perch population size, and predation pressure, of the two lakes these perch inhabit in the upper peninsula of Michigan. By estimating the age and first year growth of Yellow Perch and relying on winter weather data for the past five years at the University of Notre Dame Ecological Research Center (UNDERC), this investigation will attempt to determine if there is any relationship between winter intensity, first year growth rates, and the morphological features of perch at this site as seen exhibited in Lake Erie. It is hypothesized that mild winters produce fish that grow more slowly in their first year whereas harsh winters produce fish that grow significantly faster in the first year. Additionally, it is hypothesized that harsh winters yield higher numbers of Yellow Perch, and thus, will account for more members of the total perch population.

MATERIALS & METHODS

Study site

This study was carried out on private research property located in the upper peninsula of Michigan bordering Wisconsin. The property consists of predominantly second growth hardwood forest with a few patches of open field and a number of lakes scattered throughout the property. All fish samples were obtained from Morris Lake and Tenderfoot Lake. Morris Lake is a small (12 acres of surface area), eutrophic lake on the northern side of the property. Tenderfoot Lake is a large (453 acres), eutrophic lake located on the southern edge of the UNDERC property. It receives freshwater inputs from Tenderfoot Creek.

Collection of weather data

Climate data collected by the National Climatic Data Center (NCDC) as a subdivision of the United State's National Oceanic and Atmospheric Administration (NOAA) was utilized in this study. Seeing as the oldest fish obtained in this study were 5 years old, weather data from December of 2012 to March 2017 were used in direct comparison. Data dating back fifteen years (January 2002) were used to assess for recent climate trends but not used directly in fish data comparison.

Collection of Yellow Perch

Perch were sampled using fyke nets (20-mm stretch mesh, 12.5-m main lead and 7.5-m side leads, 1.3-m x 1.3-m frame, 0.95-m diameter hoops) and rod and reel fishing for 8 weeks. Both total and standard body lengths (mm) and weight (g) were recorded per specimen (Anderson and Neumann 1996). Gender, age, first year growth, length at age, and relative weight were determined and recorded.

a. *Determining gender*

To determine the gender of a perch, the specimen's urogenital papilla, or UGP, and anus must be examined. In regards to the UGP, there are three factors to consider, particularly in the case of sexing immature perch: the size, shape, and coloration. Females have UGP's that are narrower, anteriorly rounded and posteriorly pointed, and generally lacked red coloration. Conversely, males have UGP's that are wider, uniformly round, and with reddish coloration. In regards to the anus, females often exhibit swelling around the rectal opening when pressure is applied to the abdomen whereas males do not (Malison et. al 2011, Shepherd et. al 2013).

b. Determining relative weight

Because of the natural variation amongst fish specimens in length and mass, comparing such parameters may prove difficult, especially between different bodies of water. Relative weights allow for standardization by determining the standard weight of the fish as measured and comparing it to the measured weight (Blackwell et al 2000). Relative weight (W_r) is determined with the following equation:

$$Wr = (W/W_s) \times 100 \quad [1]$$

where W = specimen weight, and W_s = a standard weight for fish of the same length.

c. Age estimation

To estimate the age of a perch specimen, scale annuli, or yearly growth rings, were counted using methods outlined by Schneider 2001. Scales were removed from each specimen's left ventral side behind the head and above the lateral line using a knife. Scales were then dried, mounted, and imaged under 12.5 magnification with a Leica EZ 4D dissecting microscope with Leica Application Suite software. Each specimen's annuli were counted by two separate agers to minimize bias.

d. Determining first year growth

Two measurements using ImageJ were taken per scale: scale radius and distance to the first annulus. The Fraser-Lee equation relied on the ratio of first annulus length over total scale radius in order to back-calculate each specimen's length for its first year (Schneider et al 2000).

Statistical Analyses

All statistical analyses were run in the open source program RStudio. 1- and 2- way analysis of variance (ANOVA) tests were conducted to look for relations between perch total length, age, first year growth, and winter intensity across both lakes and each lake individually. Alpha was set a priori at 0.05.

RESULTS

The original hypothesis of this investigation was that Yellow Perch grow more in their first year if the winter preceding their spawning was cold and harsh. The second hypothesis was Yellow Perch that spawned following a harsh winter will account for most of the population sampled. Both of these hypotheses were supported but the results suggest there are greater nuances than climate alone in influencing total fish length and first year growth.

Descriptive statistics for both lakes and each individual lake were generated in RStudio so as to allow for a broad understanding of each lake's perch population. Morris Lake yielded greater numbers of longer (*X= 207 mm, SE= 5.96 mm*) and older (*X= 3.72 yr, SE= 0.15 yr*) fish distributed non-normally (FIGURES 1, 2, 4). Tenderfoot Lake yielded a more normal distribution of shorter (*X= 178 mm, SE= 3.77 mm*) and younger (*X= 3.14 yr, SE= 0.14 yr*) fish. (FIG. 1, 3, 5) Weights were measured and used to calculate relative weights, which were lower in Morris (*X= 76.93 g, SE= 2.23 g*), despite the fish's longer total lengths, and higher in Tenderfoot (*X= 92.51 g, SE= 1.86 g*).

Before conducting any further analyses on the perch data, it was necessary to examine the weather data that would serve to frame the study. A 1-way ANOVA was conducted to determine what temperature range constituted a 'harsh', 'mild', or 'intermediate' winter (December to February). Harsh winters are defined as -10°C or lower, mild winters are -7°C or higher, and intermediate winters are between these extremities (*d.o.f.= 14, F-value= 26.55, p-value < 0.001*).

The entire data set for both lakes was analyzed to show first year growth does increase with increasing winter intensity (*d.o.f. = 87, F-value= 3.386, p-value= 0.0385*). All additional ANOVA tests examining first year growth to winter intensity and lake effect alone suggested that there is no statistically significant difference. However, all ANOVAs examining total length in response to the intensity of the winter preceding their spawning and lake effect alone suggested that there is a difference between lakes correlated with winter intensity (*both lakes: d.o.f.= 87, F-value= 16.6, p-value < 0.001; Morris Lake only: d.o.f.= 43, F-value= 5.06, p-value= 0.0109; Tenderfoot Lake only: d.o.f.= 43, F-value= 4.63, p-value= 0.0154*). This indicates that neither total length nor first year growth can be explained by winter intensity preceding spawning nor the lake conditions alone.

The first 2-way ANOVA examined total length in relation to winter intensity and lake effect. This model had a significant interaction between winter intensity and the lakes and as such, makes it difficult to conclude which of the individual factors is truly impacting total length (*d.o.f.= 2, 82; F-value= 8.0119; p-values* < 0.001). Of the individual factors, winter intensity was only trending towards significant (d.o.f.= 2, 82, F-value= 2.7579, p-value= 0.0693) but the effect of the lakes alone was significant (d.o.f.= 1, 82; F-values= 17.8628, p-values < 0.001). In the second 2-way, first year growth was examined in relation to winter intensity and lake effect. The overall model was not significant but winter intensity did significantly affect first year growth, suggesting that harsher winters are correlated with increased first year growth (*d.o.f.= 2, 82; F-value= 3.3571, p-value= 0.0397*).

Other additional factors to consider aside from effects of lake are the morphological features of the perch themselves. Yellow Perch as a species have been known to exhibit sexual dimorphism in Northern waters where females can be larger than males (Moyle 2002). Chi-square analysis found that the distribution of gender was normal ($x^2= 1.08$, *d.o.f= 1, p-value= 0.4*). From there, more 1-way ANOVA tests were conducted but suggested that neither total length nor first year growth varied between genders.

DISCUSSION

As expected, climate change impacts nearly every realm of ecology, and Yellow Perch in northern Michigan lake systems are no exception. The findings of this investigation suggest that warmer winters negatively impact first year growth in Yellow Perch. As climate change continues to increase overall temperatures and produce more mild winters, this proves problematic for the future health of Yellow Perch populations. In the present time, however, as specimens age, other environmental factors become increasingly important in influencing overall growth patterns. These other factors include lake size, predation pressures, available food, and habitat supply.

Initial descriptive statistics indicated that there is a difference in the size of the perch collected from each lake - a trend corroborated by field observations. Perch collected from Morris Lake were longer than the specimens collected from Tenderfoot Lake. However, relative weight calculations revealed that the perch in Morris Lake were in worse condition than the perch in Tenderfoot Lake, an indication of a stunted perch population.

In order to better understand what factors or conditions contributed to this stunted population in Morris Lake and to the normal population in Tenderfoot Lakes, it is necessary to examine how the two environments differ from each other. Although Morris Lake and Tenderfoot Lake are both eutrophic, they vary in nearly every other regard. Morris is small and shallow private lake (12 acres), with lots of aquatic vegetation like water lilies and water weeds all along the edges and well into the water. Tenderfoot is a large, public lake (453 acres) with lots of variation in terms of aquatic growth- both in terms of species and abundance. In Tenderfoot, predation pressure from pike, Walleye, bass and other piscivores along with human fishing and recreation may be potential sources of perch removal that Morris Lake does not have. Although the Wisconsin Department of Natural Resources has no size limits on perch in Tenderfoot Lake, there is a bag limit of 25 which may incentivize fishers to select and remove only larger perch. Conversely, predation potential in Morris consists of a population of stunted Northern Pike that has been reported in Morris Lake in the past. However, anecdotal data suggests a much smaller population than previously reported, possibly allowing for a rise in Yellow Perch numbers and eventually, stunting of growth.

To understand the degree to which Morris's perch population is stunted, especially in comparison to Tenderfoot's population, a von Bertalanffy growth model was generated (FIG. 6). The model, taken in conjunction with the relative weight of each lake (Morris= 76.93 +/- 2.23 g and Tenderfoot= 92.51 +/- 1.86 g) and the length frequency distribution of each lake (FIG. 2 and 3), indicates that although growth rate is consistently higher in Morris, the perch there are not gaining sufficient mass to remain proportional.

It is interesting to note the general trends of growth within a lake, as well. Morris perch grow extremely fast within the first year of life but that growth rate then stagnates and even decreases slightly before finally climbing again at age 3. Tenderfoot perch, on the other hand, exhibit slower but much steadier growth. This indicates that in Morris, very young fish do exceptionally well - most likely due to the abundance of vegetation for habitat and food. As they grow older though, there is so much competition that it becomes very difficult to gain body mass so their weights and relative weights are significantly lower than expected for a fish of their length class.

Furthermore, one of the parameters used to generate the von Bertalanffy growth model is a measure of the theoretical maximum length that the average specimen of a population could potentially reach or, the L-infinity. The L-infinity value generated for Morris Lake was 225.47 mm whereas for Tenderfoot Lake, the L-infinity value was 265.08 mm, indicating that perch in Tenderfoot have greater potential in terms of projected total length.

In Tenderfoot, however, the most abundant group of perch length is between 170 and 180 mm, suggesting that there is a size selection, probably attributable to fishing selection - anglers are most likely harvesting fish larger than 180 mm, and thus, eliminating some of the pressure from having larger perch competing for resources and preventing population stunting, as well.
These factors lend to the original conclusion then, that although climate plays a critical role in influencing first year growth, other factors take precedence on a perch's overall growth in its life. One major impact of climate change however, is its impact on class strength. Of the 88 fish sampled across Morris and Tenderfoot, 75% were of the 3 year or 4 year old classes, meaning these fish spawned in either 2013 or 2014, following two harsh winters in a row. The remaining 25% of specimens were attributed to both mild and intermediate intensity winters. This indicates that harsh winter climates are very well-correlated with stronger year classes (FIG. 7).

In conclusion, while Yellow Perch growth is dependent upon a broad class of environmental factors, climate change most certainly has long-lasting impacts on the number of Yellow Perch even present. Protecting Yellow Perch in response to changing climate is critical for a wide variety of reasons. First and foremost, Yellow Perch are ecologically important, not just for biodiversity's sake, but also because they serve as mid-level consumers, critical for regulating the juvenile fish population while also feeding larger piscivores. Beyond that, Yellow Perch are also economically and recreationally important to anglers and the fishing industry here along the

Michigan-Wisconsin borders. Future projects could seek to replicate this study with larger sample sizes so as to decrease uncertainty on aging and increase robustness of the growth model. Alternatively, researchers could look at other lakes on the UNDERC to see if perch total length and first year growth are equally as impacted by milder winters, or other fish species from the same or different lakes could also be studied to see if these environmental and climate change impacts hold. Finally, other environmental factors such as continentality, salinity in lakes that receive external inputs from other bodies of water, etc., that may influence Perch growth (or fish growth in general) may be examined in light of parsing out factors that both predict and indicate climate change.

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FIGURES

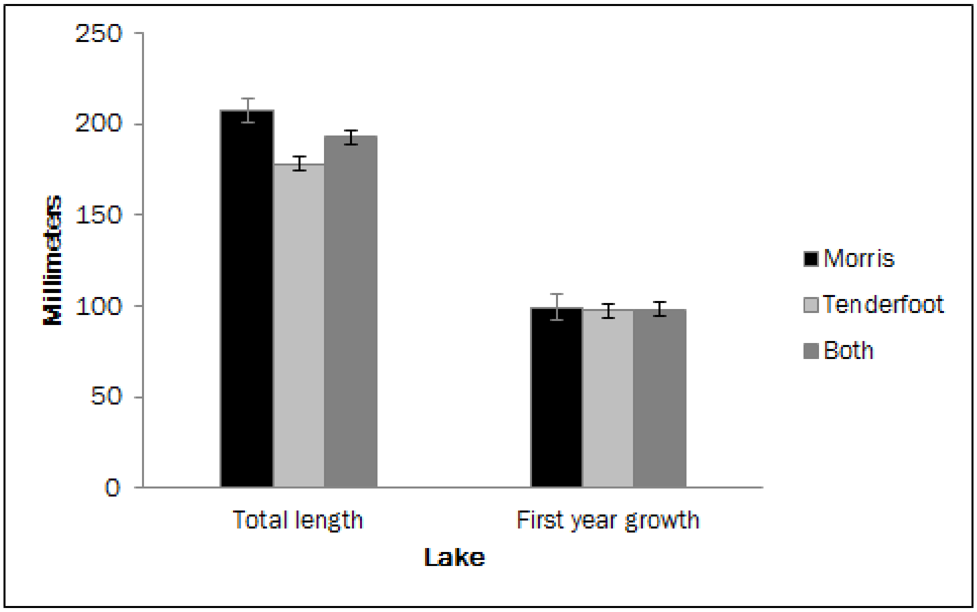

FIGURE 1 - *Average total lengths and first year lengths across Morris Lake, Tenderfoot Lake, and both lakes* - Morris Lake had an average total length of 207 mm (+/- *6.1 mm*) and first year growth of 99.30 mm (+/- *3.09 mm*). Tenderfoot Lake had an average total length of 178 mm (+/- *3.77 mm*) and first year growth of 97.49334 mm (+/- *2.90 mm*). The sample size was 44 fish per lake, 88 fish in total.

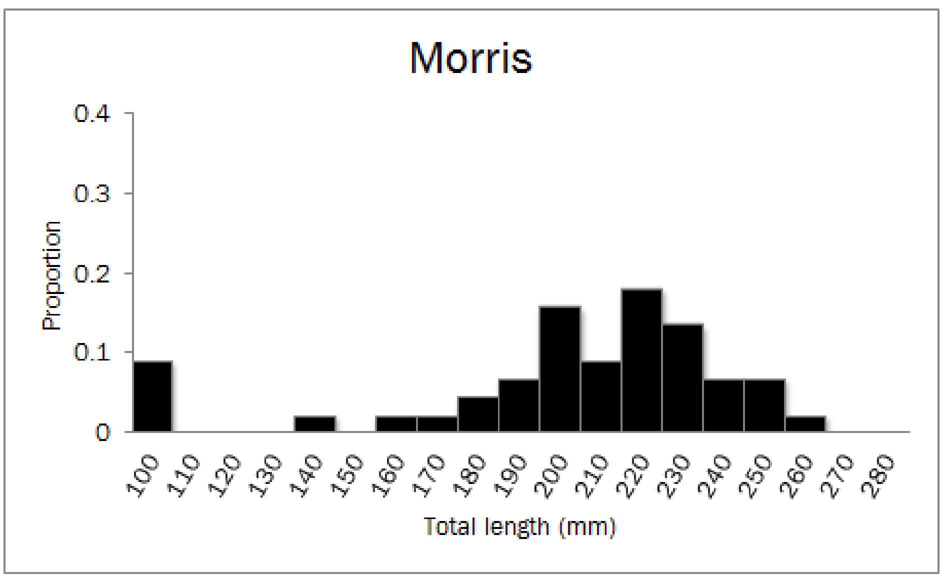

FIGURE 2 - *Frequency distribution of Yellow Perch total lengths from Morris Lake* - The above figure shows the frequency distribution for the total lengths of the 44 perch sampled. Perch total lengths appear left-skewed by a disproportionate number of very small individuals and an almost bimodal distribution amongst longer individuals. This non-normal distribution was confirmed by a Shapiro-Wilk test (*W= 0.91283*, *p-value= 0.002765*).

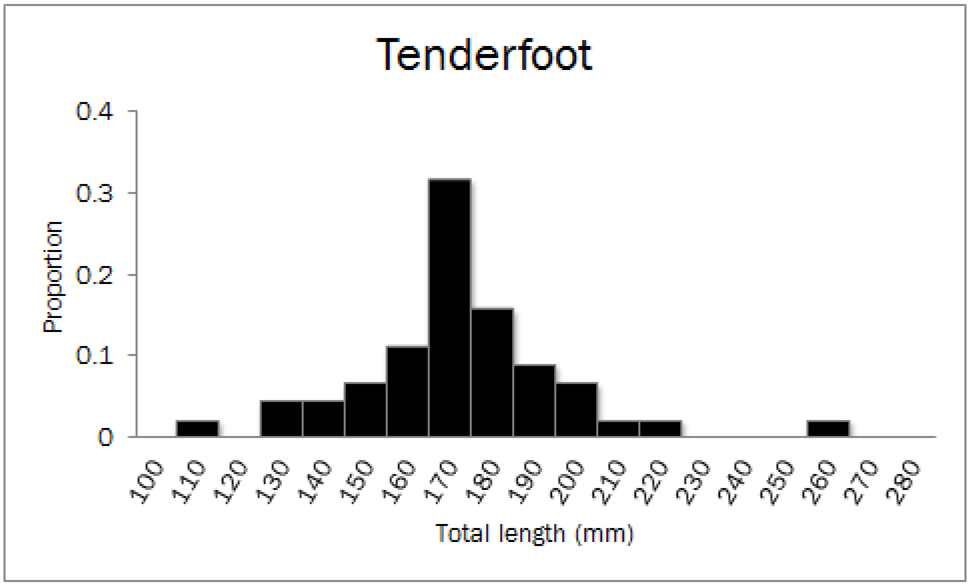

FIGURE 3 - *Frequency distribution of Yellow Perch total lengths from Tenderfoot Lake* - The above figure shows the frequency distribution for the total lengths of the 44 perch sampled. Tenderfoot Lake perch total lengths appear to be normally distributed, confirmed by a Shapiro-Wilk test (*W= 0.95221*, *p-value= 0.06653*).

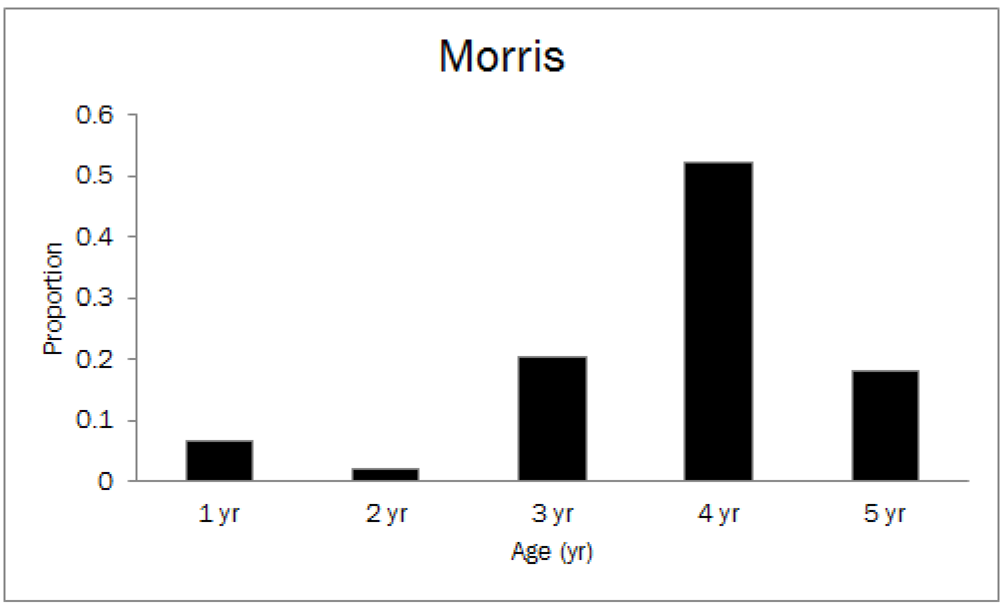

FIGURE 4 - *Frequency distribution of Yellow Perch ages in Morris Lake* - The above figure shows the frequency distribution of the ages of the 44 perch sampled from Morris Lake. The perch population in Morris Lake tended to be older (*X= 3.72 yr*, *SE= 0.15 yr*).

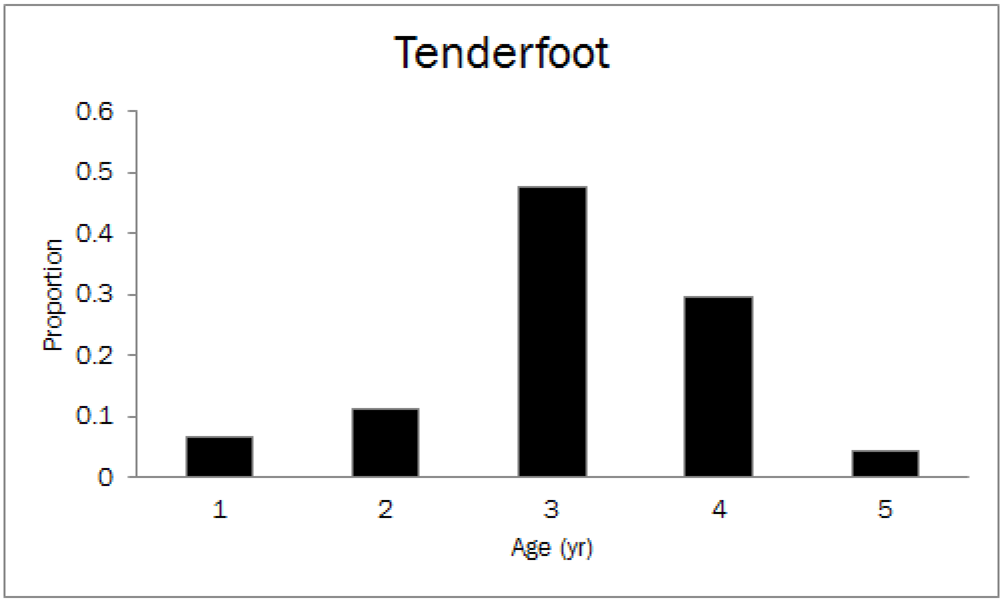

FIGURE 5 - *Frequency distribution of Yellow Perch ages in Tenderfoot Lake* - The above figure shows the frequency distribution of the ages of the 44 perch sampled from Tenderfoot Lake. The perch population in Tenderfoot Lake was slightly younger (*X= 3.14 yr, SE= 0.14 yr).*

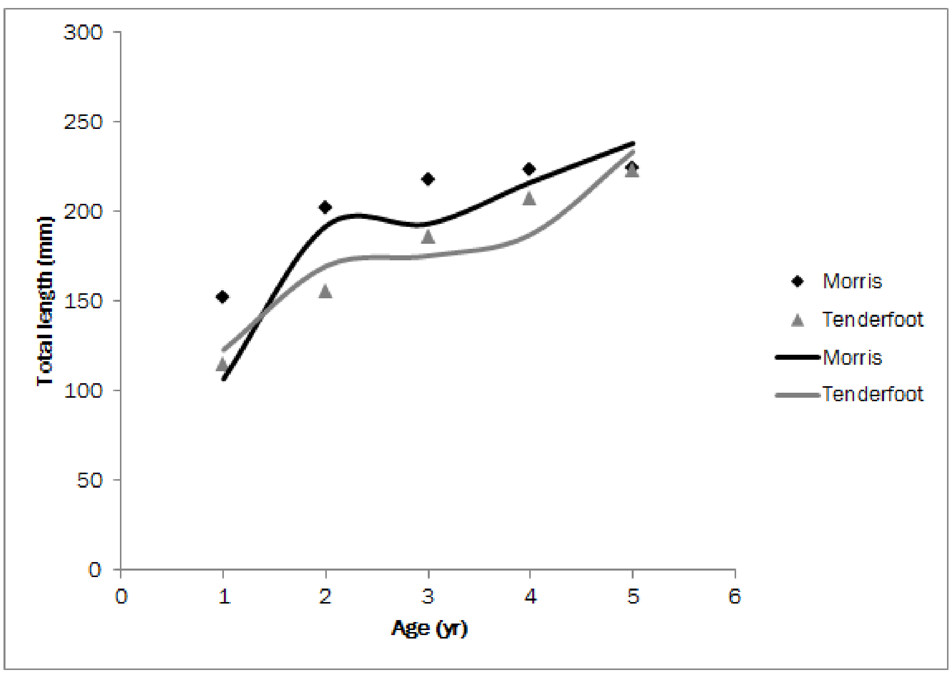

FIGURE 6 - *von Bertalnffy growth model for average perch total length over time* - Note the variable growth rates between the two lakes. Morris perch consistently grow more but at extremely variable rates. Tenderfoot perch, on the other hand, exhibit slower but much steadier growth. This indicates that as Morris fish grow older, competition makes it difficult to gain body mass, leading to fish in worse condition than as observed in Tenderfoot.

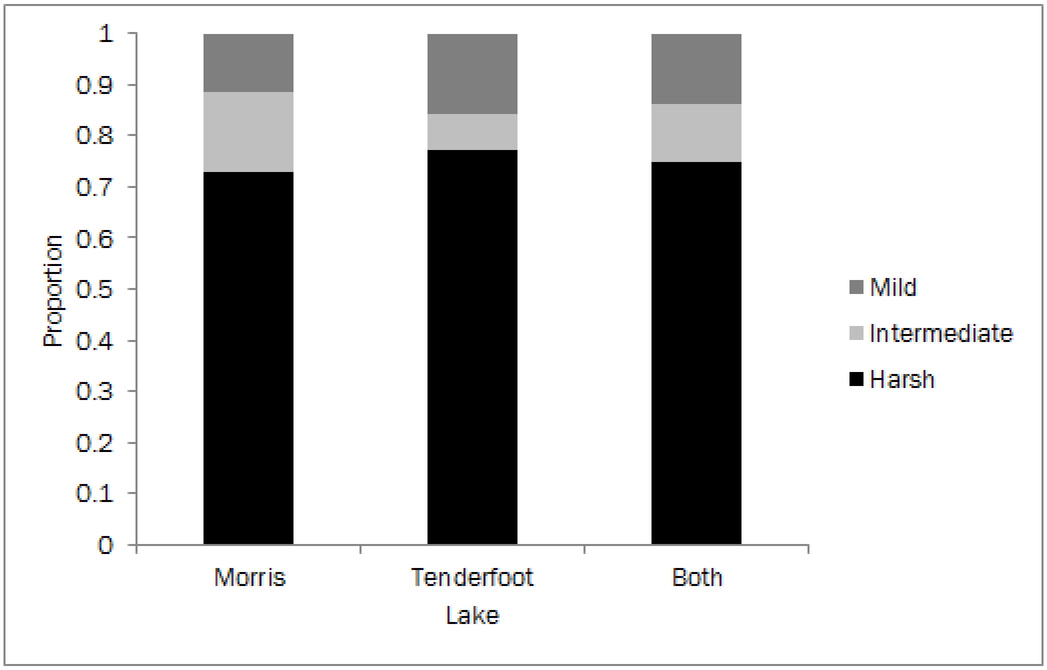

FIGURE 7 - *Frequency distribution of winter intensities preceding each specimen's spawning* - The above figure shows the intensity of the winter preceding each perch's spawning as an analysis on whether or not harsh, mild, or intermediate winters correspond with weaker or stronger year-classes. It can be seen that 75% of all fish sampled belonged to the harsh winter intensity class.