Investigating the implications of changes in fishing mortality of yellow perch (*Perca flavescens*) in the Upper Peninsula of Michigan

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Abstract

Recreational fisheries have a significant role in the economy of the Great Lakes region. This study attempted to find the optimal balance between yellow perch abundance and length so that both are optimized for the most effective and publicly attractive fishing management style. This was accomplished using theoretical K values and comparing low and high mortality rates for various age cohorts. Data points were gathered in the field using fyke nets and subsequently fitted to a Von Bertalanffy curve and modeled using RStudio. Results showed that the optimal balance between length and abundance was approximately 40% to 50% annual mortality of each age cohort. In addition, fishing mortality was shown to have a significant impact on population characteristics, even more so than fish growth rate (K). This is important because it shows that the varying methods of fishery management are extremely important in ensuring that the population is not overfished nor underfished. Likely, the most effective management practices are instituting bag limits or length limits to allow for a limited mortality rate. Catch and release fishing is less effective because the population experiences virtually no mortality and maintains a population with both high density and high competition. This leads to shorter fish lengths, which are less appealing to anglers.

Introduction

The commercial and recreational fishing industry is a large component of the economy of the Great Lakes region of the United States. One of the largest problems faced by this industry is striking the balance between overfishing and underfishing of the populations of the various species of preferred fish. This can be a complicated endeavor because many of these fish rely on each other as sources of prey or as a balance of the ecosystem. However, most fisheries have some sort of proper fishing practices to prevent this from happening. One method is catch and release fishing, which usually allows for the catching of an unlimited amount of fish provided they are released after being caught. This leads to a theoretical zero in fishing mortality so that the fish populations are always plentiful. Systems with strict regulations promote catch and release fishing, which over time creates dense fish populations providing anglers with high catch rates and a generally smaller average fish size. Another method is to set regulations to promote trophy and harvest fishing, where fish mortality due to harvest is an influencing factor on the population. Due to the higher mortalities, there are fewer fish, but the average size is larger than in catch and release angling. These fish are generally harvested for food or trophies. This method can be managed through size or bag limits, where only fish of a certain size or a set quantity of fish may be harvested. This typically allows the juvenile and younger fish to reach mature reproductive age to continue to supplement the population. This method generally has the highest fishing mortality due to the larger populations of fish and limited regulations. No matter what policy is used, however, the effects of human fishing, as well as development and farming alter the natural composition of the fishery.

Fisheries in general have an inherent coupled relationship between human and natural systems. Arlinghaus et al. (2017) describes how these coupled natural-human systems are often difficult to manage because both the natural fish population biology and the human components must be understood. Due to this difficulty, many fisheries around the world and in the Great Lakes region are in danger of being negatively impacted by over-harvesting or under-harvesting, despite fishing regulations set to prevent these problems. In recreational fisheries, these challenges are well-documented, as Post et al. (2002) cites problems with mismanagement of regulations on angling and under-utilized preventative measures that are leading to a largely unnoticed collapse of Canada's fisheries. Many studies have been conducted on recreational fisheries with reference to how catch rates affect the population statistics. Allen et al. (2008) examined the implications of largemouth bass fishing and how the policies on fishing rates affected average lengths and mortality rates of different lake populations. Faust and Hansen (2016) reported on muskellunge (muskie) fishing implications and the preferable length of fish that should be removed from fisheries to maintain a viable and self-replenishing population. Finally, Kuparinen et al. (2010) investigated pike fisheries and optimal angling mortality rates to balance harvest rates and average fish lengths so that preferred longer trophy lengths could be harvested while the maximum amount of catch events was optimized.

Inland recreational fisheries have also been affected by a gradual switch to catch and release fishing over the past century. As more individuals within the population survive to longer average life spans, the competition within the fishery grows as overcrowding begins to occur (Oplinger et al. 2011). This can ultimately lead to a shorter average length of fish within an age group. These effects can impact anglers directly by displacing effort from one system to another, or indirectly by altering food web interactions between the focal species (yellow perch) and the species it is predator and prey for, which can alter the dynamics of fisheries for other species in these systems. In order to understand how fish populations respond to both full catch and release fishing and overharvest, I collected field data from Morris lake on fish length and age. The objectives for this study include (1) fitting a Von Bertalanffy growth curve to these data in order to estimate maximum fish size and growth rate for perch in Morris lake in the un-harvested catch and release fishing condition, (2) using these baseline estimates to inform an age-structured population model where fishing mortality will be manipulated to examine the response in maximum fish size, growth rate, etc, and (3) examine the effects of fishing mortality on length and abundance of perch at varying growth rates. The hypothesis that this experiment is testing is that higher rates of harvesting (mortality) of yellow perch will result in higher average length when compared to lower rates of harvest. This is because higher rates of harvest lead to less dense populations, creating the opportunity for increased fish size through decreased competition for resources. I also hypothesize that higher rates of harvest will lead to lower abundance of perch.

Methods

Data Collection:

The study was conducted on the University of Notre Dame's Environmental Research Center (UNDERC), which covers land on both sides of the border between the Upper Peninsula (UP) of Michigan and Wisconsin. Morris Lake served as the focal lake from which I collected data to inform the model experiment. In order to gather field data to inform the model, fyke nets were used to trap yellow perch. Traditional hook and line methods were not used due to time constraints and the high success rate in capturing perch with the fyke nets. Each captured fish was measured in total length (in mm) and scales were removed for aging in the lab. After a fish was caught and measured, the anal fin was clipped on each fish to prevent sampling the same fish multiple times.

The scale aging method involves removing scales from the lateral side below the dorsal fin. Each scale is then taken to the lab, dried, and analyzed under a microscope by counting the rings to determine the age of the fish. The ages were counted by multiple researchers to ensure correct measurements. The age and length data was then compiled together and sorted into age bins for analysis. Each age bin contained at least 10 replicates.

Data Analysis:

The data was fit with a Von Bertalanffy growth model to age and length data to describe the changes in fish length with age. This yielded coefficients, which were used to inform an age-structured fish population model for the yellow perch. This model allowed us to modify the values of fishing mortality to examine the effect of various levels of harvest on yellow perch population characteristics such as abundance, density, and mean length. These outputs (maximum size, density, and growth rate) from the models were run for each age cohort with high and low fishing mortality with reference to varying levels of K, or growth rate of fish. This allowed us to gather values for hypothetical length and abundance of perch at differing potential growth rates. The outputs for ages 1, 2, 4, and 5 were then compared using two-way ANOVAs to determine whether or not the lengths and densities of the yellow perch significantly differ across different rates of fishing and different values of K.

The values of K were used as ranges, where K of 0.25 implies a range from K = 1 to 25% of K. Smaller ranges such as K to 75% of K (0.75) are expected to show less variation between different mortality rates. 100% of K is a constant growth rate no matter how the population characteristics change.

Results

Generally, both fish abundance and lengths were significantly different between model runs in high and low fishing mortality scenarios. Noteable, though, were the differences between high and low fishing mortality model runs, where all lengths for age 2 were non-significant, as well as abundance for age 1 with K values ranging from K to 25% of K and the lengths for ages 1 and 5 at 0.5 K. All other t-tests showed significant difference to a $p < 0.05$ (Table 1).

In addition, the data on fish abundance and length at different ages over different mortalities showed that perch abundance decreased with higher fishing mortalities when compared to lower mortalities and length increased with high mortalities when compared to lower mortalities. For Age 2 perch, the optimal mortality level for perch length was 30% of the population (Figure 1), while the optimal mortality level for abundance was 15% with a growth rate ranging from K to K*0.5 and 45% with a growth rate of K to K*0.25 or K*0.75 (Figure 2). For Age 4 perch, optimal mortality level for fish length was 35% for a K range to 0.5 and 45% for K ranges to 0.25 and 0.75 (Figure 3). Optimal mortality for abundance of Age 4 fish was approximately 10% for K ranges of 0.25 and 0.75 and 35% for a K range to 0.5 (Figure 4). The optimal balance for mortality levels between these values is somewhere between 40% and 50% mortality rate.

Discussion

The results from the ANOVAs generally demonstrated the expected outcomes that fishing has an effect on abundance and length when not size selective. For abundance, fishing caused a significant decrease in population sizes for most ages and growth rates as higher mortalities decreased the amount of fish in the lake. Meanwhile, higher mortalities demonstrated a significantly positive relationship with fish length as the fewer fish in the lake decreased competition and increased the mean size for the perch. The results also showed that the changes in fish growth (K) were not as important to cohort (age grouping) length and abundance as mortality experienced by the cohort. This means that the rate of mortality was much more impactful upon population dynamics than fish growth rates. This is important because it shows that no matter the actual growth rate of the perch population, the quantity of harvest events within the cohort will be more predictive of the characteristics of that cohort.

While most of the ANOVAs demonstrated statistical significance, there were several that showed no significance. For the lengths of Age 1 and Age 5 with K-values ranging from K to 50% of K, these p-values (0.2294 and 0.1100, respectively) are likely due to the stochasticity within the model, which accounts for random variation within a normal environment. Prior to the ANOVA, the model was run 100 times with programmed chance variation in the maximum fish size, K, and natural mortality to gather a mean value on length and age, while accounting for chance outside factors. This likely led to some outliers affecting the set as a whole and providing non-significance.

One important aspect of this study is that the model was informed by field data collected for the exact purpose of the model: it used estimates from fish growth parameters that were gathered from an actual lake. This serves the purpose of grounding the model in reality. The model method is also much more efficient than doing several field studies for multiple reasons. First, it can be run multiple times and allows for replication. Second, there are limited costs and/or logistical constraints involved with modeling when compared to multiple field studies. Third, models help to better conceptualize what we do and do not know about an ecological system. Once unknown aspects of the system are identified with the model, we can then run experiments to gather that information. Finally, the experimental question in general would have been difficult to answer as a long term study given the time constraints. I could not follow the fish populations for extended periods of time, much less follow the populations, make a small change in the environment, and follow the population for another period of time. These processes are not instantly observable and thus, it is much more efficient to build a model based on the gathered field data. In addition, this study cares more about the large scale, general trends and processes of perch populations rather than the minute differences and small changes in population dynamics. These smaller differences are better isolated in a different style of experimentation that does not assess the long time horizons for these populations, such as fish size and abundance over time.

The results charting mortality versus length showed that a fishing mortality of approximately 40% to 50% of the population was most effective at providing a reasonable balance between fish abundance and length. This allows for the fish to grow to relatively preferable size for anglers while still maintaining about half of the population within the lake for easier harvest. The modeling method is effective in this data analysis as well because it allows us to compare a multitude of varying scenarios on fish density and length to find optimal management strategies. This type of modeling can be used on most recreational fish populations and it is effective at lending insight into the most effective management type. For fish populations with slow growth, low abundance, or slow regeneration, it is more beneficial for the fishery to utilize catch and release methods to ensure that the population is sustained. For high fish densities and quick regeneration, it is recommended that bag limits or length limits are put in place, allowing for a percentage of angling mortality within the lake.

While this model was useful for creating outputs with non-size selective fish mortalities, it is recommended that a more complex model be created for further study to take into account the different mortality rates for each age cohort. This is an important component and factor in fish populations that was not analyzed due to the complexity of the coding for the model and the time constraints that prevented the development of such a model. However, if a later study was to analyze the varying mortality levels per cohort, it is important to note the differences. Yellow perch are recognized for their cannibalism and will actively eat smaller perch when given the chance. This was observed in my own study when we would gather the fyke nets. Often, smaller, Age 1 fish could be pulled out of the mouths of the larger, Age 5 and 6 fish. This has been reported in other previous studies, which found that Age 1 fish are most often preyed upon due to their smaller size (Tarby 1974). This data implies that Age 1 fish face a much higher mortality rate than other medium-sized fish. Perch in higher age cohorts are also susceptible to death due to old age or difficulty maintaining peak physical condition with high competition for larger food. In addition, larger fish are preferred by anglers, which means there is a lower chance they will be released after being caught. The medium-sized fish ranging from approximate Ages 2-4 will likely have lower mortality rates overall because their size allows them to eat at a wider range of depths as well as be more likely to be released after a catch event. Importantly, the percent mortality of each age group year to year should follow something similar to a bimodal curve as the early and late stages of life have a much higher amount of fish deaths.

In addition to further study on size-selectivity, it would also be beneficial to conduct several studies on the impacts of commercial fishing on populations of fish in the Great Lakes region, specifically among trophy fish, which are a draw for recreational anglers. The interaction between both commercial and recreational fishing could prove beneficial in regulating and managing the larger populations of fish in the Great Lakes, which are constantly shifting in dynamics due to introduced species and overexploitation of fisheries (Brenden 2013).

In conclusion, the over- or under-harvest of any population is likely to produce unsatisfactory recreational opportunities for anglers. Over-harvest can result in decreased or extirpated fish populations in a lake, while under-harvest can lead to high amounts of fish within a population, but limit the size differences between age cohorts due to the high degree of competition between individuals. The results also showed that the best management practice for yellow perch is likely a policy that permits about an annual 50% mortality rate for the population, which is the optimal balance between length and abundance to provide satisfactory recreational fishing. In addition, I found that fish length and abundance is sensitive to density in general, in addition to being highly sensitive to mortality rates. Finally, it is important to note that there are very few scenarios where the catch and release management option is the most effective. This is generally only useful if offering a "buffet" option on multiple lakes, where certain lakes offer an easier catch, given that the fish is released, while other lakes offer larger, trophy-sized fish for more avid anglers. While the implications of this study extend to recreational perch fisheries, the modeling of fish populations is a useful tool for highlighting the potential negative effects of both over- and under-harvesting of populations, which can extend to all fished populations.

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References

Allen, M. S., Walters, C. J., & Myers, R. (2008). Temporal Trends in Largemouth Bass Mortality, with Fishery Implications. *North American Journal of Fisheries Management,28*, 418-427.

Arlinghaus, R., & Cooke, S. J. (2017). Recreational Fisheries: Socioeconomic Importance, Conservation Issues and Management Challenges. *Recreational Hunting, Conservation and Rural Livelihoods,*39-58. doi:10.1002/9781444303179.ch3

Faust, M. D., & Hansen, M. J. (2016). Effects of Consumption-Oriented versus Trophy-Oriented Fisheries on Muskellunge Population Size Structure in Northern Wisconsin. *North American Journal of Fisheries Management,36*(6), 1336-1346. doi:10.1080/02755947.2016.1214646

John R. Post , Michael Sullivan , Sean Cox , Nigel P. Lester , Carl J. Walters , Eric A. Parkinson , Andrew J. Paul , Leyland Jackson & Brian J. Shuter (2002

Kuparinen, A., Klefoth, T., & Arlinghaus, R. (2010). Abiotic and fishing-related correlates of angling catch rates in pike (Esox lucius). *Fisheries Research,105*(2), 111-117. doi:10.1016/j.fishres.2010.03.011

Oplinger, R. W., Wahl, D. H., & Nannini, M. A. (2011). Effect of Predators on Growth and Reproductive Investment in Bluegills: Comparison of Populations with Differing Size and Age of Maturation. *Transactions of the American Fisheries Society,140*(6), 1532-1539. doi:10.1080/00028487.2011.638590

Tarby, M. J. (1974). Characteristics of Yellow Perch Cannibalism in Oneida Lake and the Relation to First Year Survival. *Transactions of the American Fisheries Society,103*(3), 462-471. doi:10.1577/1548-8659(1974)1032.0.co;2

Taylor, W. W., Lynch, A. J., & Leonard, N. J. (2013). *Great Lakes fisheries policy & management: A binational perspective*. East Lansing: Michigan State University Press.

Table 1

ANOVA Output for Abundance and Length

Abundance

Age		df	Sum Sq	Mean Sq	F-value	p-value
1	mort	1	1928	1928	27.02	2.78E-07
	model	2	792	396.1	5.55	0.00409
	mort:mode	2	794	396.8	5.56	0.00405
	Residuals	594	42393	71.4		
2	mort	1	1686	1685.9	43.158	1.10E-10
	model	2	91	45.6	1.166	0.312
	mort:mode	2	91	45.5	1.164	0.313
	Residuals	594	23203	39.1		
4	mort	1	1928	1928	27.02	2.78E-07
	model	2	792	396.1	5.55	0.00409
	mort:mode	2	794	396.8	5.56	0.00405
	Residuals	594	42393	71.4		
5	mort	1	1686	1685.9	43.158	1.1E-10
	model	2	91	45.6	1.166	0.312
	mort:mode	2	91	45.5	1.164	0.313
	Residuals	594	23203	39.1		

Length

Age		df	Sum Sq	Mean Sq	F-value	p-value
1	mort	1	958	958.4	17.674	3.03E-05
	model	2	3051	1525.6	28.131	2.12E-12
	mort:mode	2	266	133	2.453	0.0869
	Residuals	594	32212	54.2		
2	mort	1	164	163.7	2.741	0.098344
	model	2	918	459	7.687	0.000506
	mort:mode	2	79	39.5	0.662	0.516056
	Residuals	594	35470	59.7		
4	mort	1	958	958.4	17.674	3.03E-05
	model	2	3051	1525.6	28.131	2.12E-12
	mort:mode	2	266	133	2.453	0.0869
	Residuals	594	32212	54.2		
5	mort	1	164	163.7	2.741	0.098344
	model	2	918	459	7.687	0.000506
	mort:mode	2	79	39.5	0.662	0.516056
	Residuals	594	35470	59.7		

Table 1. A chart of all ANOVA output for age cohorts of 1, 2, 4, and 5. Almost all p-values for mortality (mort) and model were significant, save model effects on abundance and mortality effects on length for Ages 2 and 5.

Figure 1

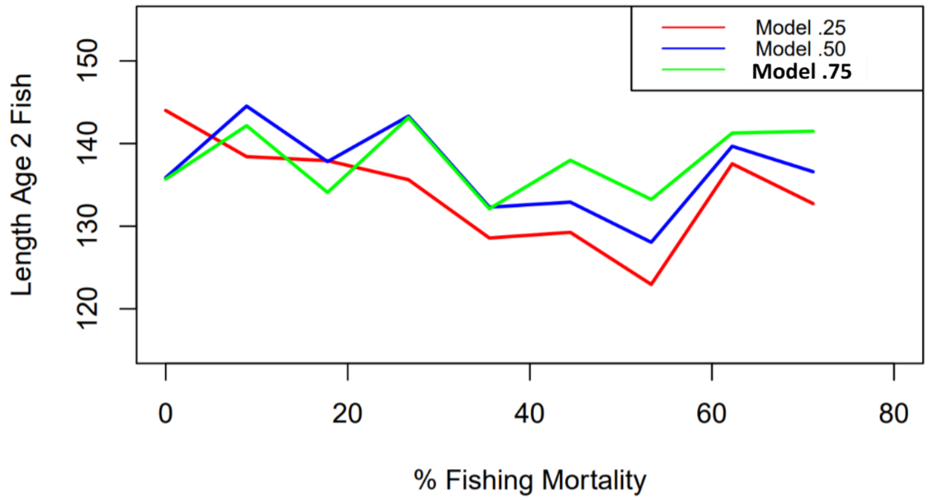

Figure 1. Graphing the model outputs for length of perch over increasing fishing mortality of the population given specific K values. Optimal mortality levels to maximize length are approximately 30%.

Figure 2

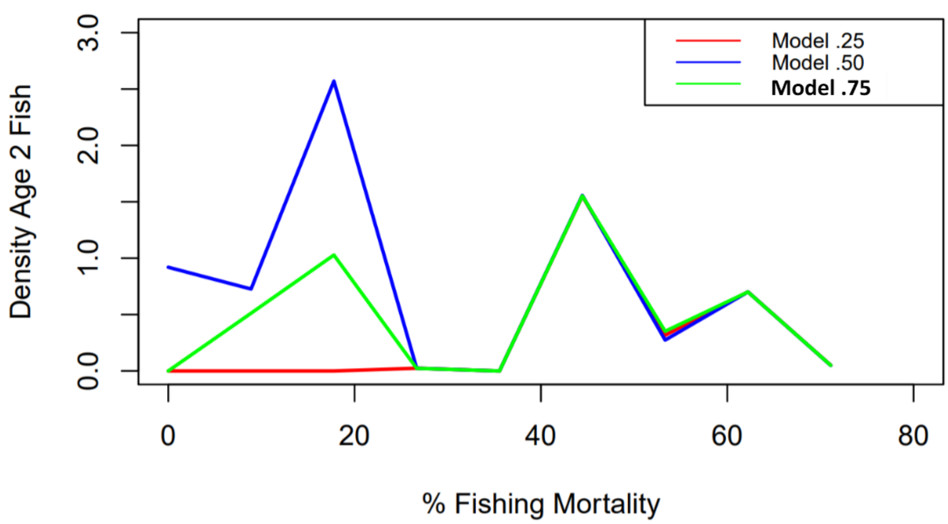

Figure 2. Graphing the model outputs for population density of perch over increasing fishing mortality of the population given specific K values. Optimal mortality levels to maximize density are approximately 15% for K of 0.5 and 45% for K of 0.25 and 0.75.

Figure 3

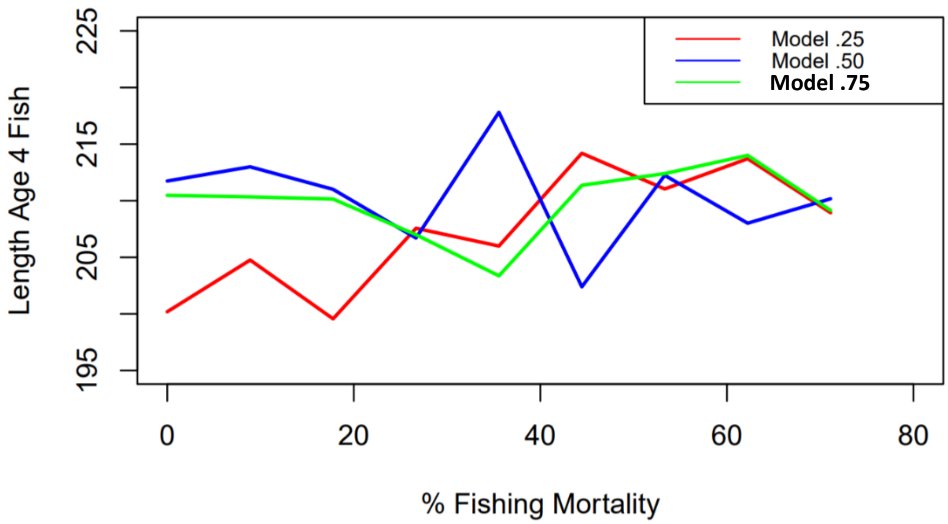

Figure 3. Graphing the model outputs for length of perch over increasing fishing mortality of the population given specific K values. Optimal mortality levels to maximize length are approximately 35% for a K of 0.5 and 45% for K values of 0.25 and 0.75.

Figure 4

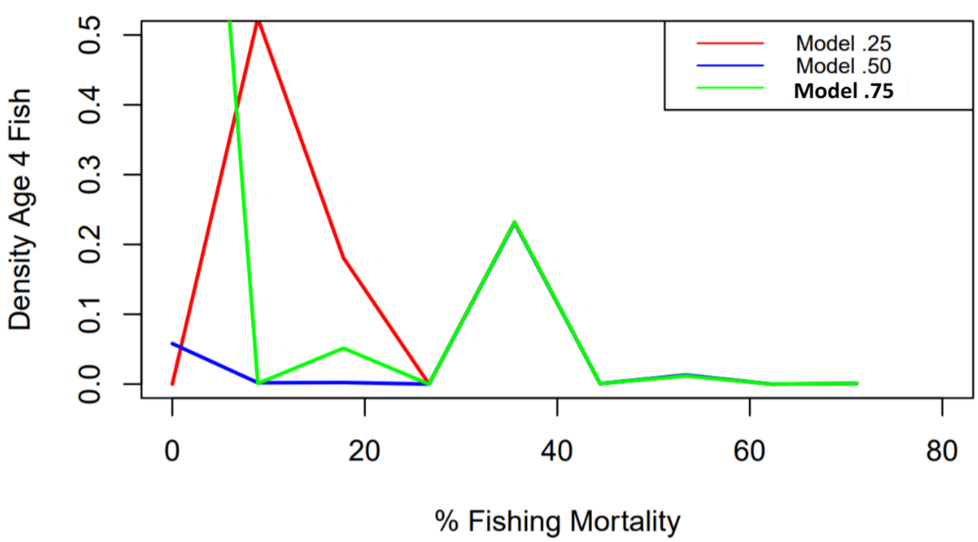

Figure 4. Graphing the model outputs for population density of perch over increasing fishing mortality of the population given specific K values. Optimal mortality levels to maximize density are approximately 10% for K values of 0.25 and 0.75 and 35% for a K value of 0.5.

Appendix A

Species	Total Length (mm)	Age
YP	151	3
YP	171	3
YP	167	3
YP	160	2.5
YP	159	3
YP	205	4
YP	189	3.5
YP	169	3
YP	193	3
YP	302	6.5
YP	166	4
YP	150	2
YP	229	4.5
YP	203	3
YP	265	4
YP	207	3
YP	245	3.5
YP	259	4
YP	210	3.5
YP	282	4
YP	235	3
YP	120	2
YP	228	3
YP	136	2
YP	256	3.5
YP	147	1
YP	262	3
YP	167	2
YP	238	3.5
YP	267	4.5
YP	236	3.5
YP	270	4
YP	271	4
YP	272	4
YP	274	4
YP	293	6
YP	252	4
YP	138	1
YP	175	2
YP	138	2.5

YP	252	4
YP	189	2.5
YP	257	3
YP	144	2
YP	251	4
YP	122	1
YP	307	6
YP	306	5
YP	74	1
YP	207	4
YP	301	6
YP	87	1
YP	90	1
YP	80	1
YP	86	1
YP	95	1

YP	86	1
YP	70	1
YP	215	4
YP	115	1
YP	85	1
YP	84	1
YP	83	1
YP	91	1
YP	78	1
YP	77	1
YP	83	1
YP	81	1
YP	79	1
YP	84	1
YP	87	1
YP	84	1

Appendix A. Raw field data showing the species sampled (YP, or yellow perch), the length in millimeters (mm), and the age recorded after using the scale-aging method. Each sample is listed in the order that it was sampled. Ages with a half increment were inconclusive between two ages after being examined by two different sources.