# Using Northern Pike and Yellow Perch to Attempt a Trophic Cascade

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In the midwestern USA, water clarity has decreased in shallow lakes as a result of large populations of Fathead Minnow *Pimephales promelas* and agriculture that impact the life that depend on shallow habitats, such as waterfowl, fish, and aquatic plants. Northern Pike *Esox lucius* and Yellow Perch *Perca flavescens* were stocked in a few lakes in attempt to create a tropic cascade and reduce populations of nuisance Fathead Minnows. Northern Pike were stocked as fry and Yellow Perch were stocked as adults either pre-spawn or post-spawn. Lake managers hypothesized adult Yellow Perch would spawn and the age-0 Perch would feed age-0 Northern Pike. After age-0, Northern Pike diets would switch to predominately Fathead Minnow and produce a trophic cascade. We used bioenergetics modeling to estimate relative consumption rates in three study lakes in Southern Minnesota to determine if Fathead Minnow was a primary diet item of the stocked fishes. Northern Pike diets based on mass consisted mainly of Yellow Perch (60-78%), some Fathead Minnow (8-39%), and some invertebrates (2-25%). The age-1 Northern Pike were feeding on both Yellow Perch and Fathead Minnow, but the older Northern Pike were feeding almost exclusively on Yellow Perch, which did not support the hypothesis. Yellow Perch diets based on mass highly varied, ranging from 100% invertebrates in age-0 and juveniles to nearly 100% fish in adults. Although creating a tropic cascade failed, highly desirable Northern Pike and Yellow Perch fisheries were created for the public to enjoy.

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## Introduction

Shallow lakes are vital to many different organisms such as waterfowl, fish, and aquatic plants. In some systems in the Midwest water clarity has been reduced as a result of large populations of Fathead Minnow *Pimephales promelas* and agriculture (Zimmer et al. 2002). To reverse those changes, piscivorous fish such as Northern Pike *Esox lucius* and Yellow Perch *Perca flavescens* have been stocked in attempt to create tropic cascades (Zimmer et al. 2002; Herwig et al. 2016). A trophic cascade acts through selective predation, where variability at the top of the food web cascades through lower trophic levels such as zooplankton and phytoplankton to influence ecosystem processes (Carpenter and Kitchell 1996). Therefore, it may be possible to stock piscivores in shallow lakes and return the turbid-water state lakes back into their original clear-water state and improve habitat conditions for the organisms (Zimmer et al. 2000; Potthoff et al. 2008). It is hypothesized that the piscivorous fish will consume a large amount of the Fathead Minnow population which will cascade through the trophic levels and improve the habitat.

Large populations of Fathead Minnows can have large influences on water quality, nutrient cycling, and abundances of aquatic invertebrates, and phytoplankton (Zimmer et al. 2003 a,b; Zimmer et al. 2006; Potthoff et al. 2008). Benthic feeding organisms such as Fathead Minnows can have a pivotal role in creating shallow turbid-state lakes. When Fathead Minnows feed, nutrients that have settled in the soil are released into the water column. Potthoff et al. (2008) found when Fathead Minnow populations reach high enough densities, they can reduce zooplankton and macroinvertebrate abundances by turning the lake into a turbid-water state. A turbid lake can result in low invertebrate densities which is less desirable for waterfowl species that prey on invertebrates.

Previous studies have tried to stock piscivorous fish to manipulate ecosystem characteristics (Moss et al. 1996; Scheffer 2004). Many previous studies have failed to create a trophic cascade (Friederichs et al. 2011). Potthoff et al. (2008) conducted a 3-year study in shallow lakes throughout eastern parts of the Prairie Pothole Region of North America. They stocked walleye fry into lakes with high densities of Fathead Minnows and found there was potential to induce trophic cascades by using biomanipulation. The results only lasted for a short duration, which suggests repeated stockings may be required to achieve a long-term trophic cascade. In Denmark, a 7-year study in which Northern Pike and Yellow Perch were stocked annually reported increased Secchi depth measurements and a decrease in suspended substrates during the study period which indicates that piscivorous fish could induce a trophic cascade (Skov et al. 2002).

The objectives of the study were to estimate the consumption rates of stocked fishes in three shallow lakes in Minnesota, USA. We aimed to compare the percentage of Fathead Minnows consumed over the study period in the three study lakes by Northern Pike and Yellow Perch and their age classes.

## Methods

*Study Area*

The three study lakes were in Southern Minnesota in Owatonna and Albert Lee counties, which are nested in the agriculture belt. The three study lakes that were stocked with Northern Pike fry and adult Yellow Perch either pre-spawn (P) or post-spawn (p) include lakes Geneva, Pickerel, and Rice (Table 1). The adult Yellow Perch were stocked to spawn and provide forage for the age-0 Northern Pike. Prior to the study, Geneva had a minor winter drawdown in 2013 and 2014. Northern Pike fry were stocked in Geneva in 2007, 2008, 2009, and 2014. Adult Yellow Perch were stocked in Geneva in 2008. Pickerel had a complete winter kill in 2013-2014. Northern Pike fry were stocked in 2014 and 2016 and Adult Yellow Perch were stocked in 2014 (p) and 2015 (P). Rice Lake had repeated drawdown events, but no winterkill ever resulted (2006, 2007, 2010-2014). Northern Pike fry were stocked in 2011, 2014, 2015, 2017, and 2018 and Adult Yellow Perch were stocked in 2015 (P) and 2018 (P).

*Field Collection*

Northern Pike and Yellow Perch were sampled in May, July, and August of 2017 and 2018. Fish were sampled by one 150-ft offshore gill net, two 300-ft seine hauls, three minnow trap nets along the shoreline, and two hours of boat electrofishing. These methods were used to capture a range of fish sizes and to find relative abundance (CPUE). Gill nets and trap nets were soaked for approximately 14-24 hours. All fish were measured to create a length-frequency histogram and a weight-length relationship. Every month at each lake fifteen fish from each species had the stomachs removed and preserved in 95% ethanol for diet analysis later at the laboratory. Length-weight regressions and length-frequency histograms were created for each species. Fish that were not weighed were assigned a weight from a length-weight relationship. The length-frequency histograms were used to define the cohorts (fish within the same species in the same lake and same age class). Temperature loggers were placed in each lake in 2017 and 2018 from May to July in each lake. In 2017 Rice and Pickerel Lakes had lost temperature loggers. Because all three lakes temperature trends were similar in 2018, Geneva's water temperature was used as the input for the bioenergetics models in 2017.

TABLE 1. Stocking densities of Northern Pike and Yellow Perch in the study lakes. Northern Pike were stocked as fry and Yellow Perch as adults either pre-spawn (P) or post-spawn (p). One pound of Northern Pike is approximately 45,000 fry.

| | Pounds of Stocked Fish (Total Number) | | | | |
|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 |
| **Northern Pike** | | | | | |
| Geneva | 4.2 | | | | |
| Pickerel | 2.9 | | 1.3 | | |
| Rice | 1.3 | 1.5 | | 0.4 | 2.4 |
| **Yellow Perch** | | | | | |
| Geneva | | | | | |
| Pickerel | 310 p (3198) | 14 P (392) | | | |
| Rice | | 150 P (750) | | | 70 P (3500) |

*Diet Analysis*

In the laboratory, technicians examined the stomach contents under a microscope. Zooplankton, macroinvertebrates, and fish were recorded as a count. Fish were identified down to species and invertebrates were identified to the most practical taxonomic unit (family or genus). This was done to measure proportions of each species in each lake for later bioenergetics modeling.

*Bioenergetics Modeling*

Bioenergetics modeling is a theoretical tool for quantifying energy allocation in fishes by partitioning consumed energy into three basic components: (1) metabolism, (2) wastes, and (3) growth (Winberg 1956; Ney 1993, Deslauriers et al. 2017; Figure 1). Fish Bioenergetics 4.0 was used to estimate consumption rates of Northern Pike and Yellow Perch. The number of fish in each cohort that was modeled is shown in Table 2 and Table 3. Each Bioenergetics 4.0 model required five inputs including diet proportions, prey energy density, predator energy density, indigestible prey, and water temperature (Deslauriers et al. 2017). Diet proportion data came from the laboratory analysis. Prey energy density came from literature sources (Table 4). The Bioenergetics 4.0 default was used for predator energy density (Bevelheimer et al. 1985). Indigestible prey was assumed to be very low, so the input value in the model was always zero. Once the data was prepped for the model it was ran using RStudio with the 'shiny' package (Deslauriers et al. 2017). The model was ran for 93 days and outputted individual rates of net production (g), specific growth ($g^{-1}g^{-1}d^{-1}$), consumption all items ($g\ d^{-1}$), consumption of Fathead Minnow ($g\ d^{-1}$), consumption of Yellow Perch ($g\ d^{-1}$), consumption of invertebrates ($g\ d^{-1}$), specific egestion rate, specific excretion rate, specific consumption rate, and proportion maximum consumption ("p-max").

TABLE 2. Number of Northern Pike in each cohort used in the bioenergetics model.

| Northern Pike | Age-1 | Age 2-4 |
|---|---|---|
| Geneva | 9 | 8 |
| Pickerel | 14 | 7 |
| Rice | 5 | 6 |

*Assessment of Stocking Effectiveness at reducing the Fathead Minnow*

To compare the percentage of Fathead Minnows consumed by stocked fishes during the study period in the three lakes, we used stacked bar charts showing consumption of Fathead Minnow, Yellow Perch, and invertebrates for each cohort. To assess the effectiveness of stocking Northern Pike and Yellow Perch a pie chart was created for each fish showing individual consumption rates by combining all three study lakes.

TABLE 3. Number of Yellow Perch in each cohort used in the bioenergetics model.

| Lake | 2017 Age-0 | 2017 Adult | 2017 Juvenile | 2018 Juvenile |
|---|---|---|---|---|
| Geneva | | | 13 | 15 |
| Pickerel | | | 15 | 5 |
| Rice | 8 | 18 | | |

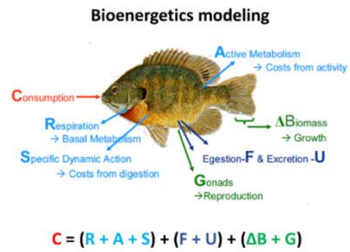


FIGURE 1. The mass balance equation used in bioenergetics modeling (Kraft 1992). Figure curtesy of K. Zimmer.

TABLE 4. Prey energy densities used in bioenergetic modeling.

| Prey Item | Energy density (J/g) | Reference |
|---|---|---|
| Ceratopogonidae lavae | 1762 | Cummins and Wuychuck 1971 |
| *Ceriodaphnia* spp. | 2514 | Vijerberg and Frank 1976 |
| Chironomidae | 1762 | Cummins and Wuychuck 1971 |
| Chironomidae pupae | 1762 | Cummins and Wuychuck 1971 |
| *Chydorus* spp. | 2514 | Vijerberg and Frank 1976 |
| *Daphnia* spp. | 2514 | Vijerberg and Frank 1976 |
| Physidae | 5273 | Driver et al. 1974 |
| Planoribidae | 5273 | Driver et al. 1974 |
| Trichoptera | 4225 | McCarthy et al. 2009 |
| Hirudinea | 4745 | Driver et al. 1974 |
| Black Bullhead | 4103 | Duffy 1998 |
| Ostracods | 2514 | Vijerberg and Frank 1976 |
| Fathead Minnow | 4103 | Duffy 1998 |
| Yellow Perch | 2512 | Post 1990 |

**Results**

*Consumption Rates – Northern Pike*

Age-1 fish in Geneva Lake consumed 17.22 g $d^{-1}$ consisting of 10.63 Fathead Minnow, 2.79 Yellow Perch, and 3.8 invertebrates. Age-1 fish in Pickerel Lake consumed 33.55 g $d^{-1}$ consisting of 15.5 Fathead Minnow, 16.82 Yellow Perch, and 1.23 invertebrates. In Rice Lake, Northern Pike consumed 38.24 g $d^{-1}$ consisting of 38.24 Fathead Minnow. Age-2-4 fish in Geneva consumed 46.22 g $d^{-1}$ consisting of 3.82 Fathead Minnow, 31.07 Yellow Perch, and 11.33 invertebrates. Age 2-4 fish in Pickerel consumed 75.4 g $d^{-1}$ consisting of 11.87 Fathead Minnow, 58.97 Yellow Perch, and 4.56 invertebrates. Age 2-3 fish in Rice Lake consumed 52.35 g $d^{-1}$ consisting of 20.63 Fathead Minnow, 31.74 Yellow Perch, and 0.01 invertebrates.

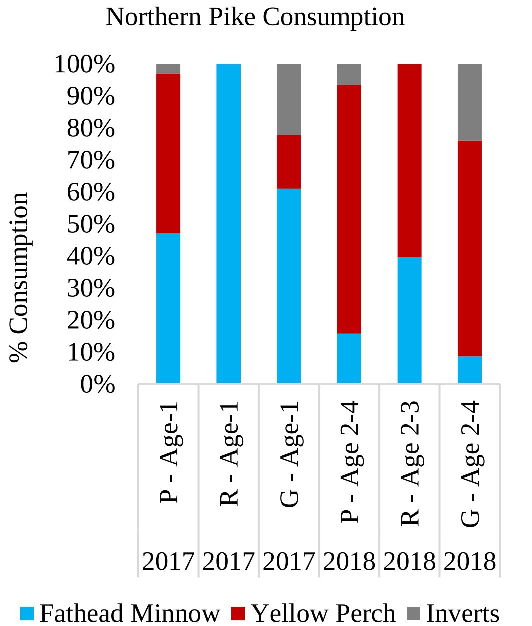


FIGURE 2. Northern Pike daily consumption based on mass as a percentage in the three study lakes for age-1 (2017) and age-2-4 (2018). Age-1 Northern Pike consumed mostly Fathead Minnows in all lakes. Consumption in age 2-4 fish shifted to mainly Yellow Perch in all study lakes.

*Consumption Rates – Yellow Perch*

In 2017, age-0 Yellow Perch in Rice consumed 0.17 g $d^{-1}$ consisting of 0.17 invertebrates. Adult Yellow Perch in Rice consumed 9.74 g $d^{-1}$ consisting of 7.64 Fathead Minnow, 1.35 Yellow Perch, and 0.75 invertebrates. Juvenile Yellow Perch in Pickerel consumed 0.53 g $d^{-1}$ consisting of 0.02 Fathead Minnow and 0.51 invertebrates. Juvenile Yellow Perch in Geneva consumed 0.16 g $d^{-1}$ of invertebrates. In 2018, Juvenile Yellow Perch in Geneva consumed 0.25 g $d^{-1}$ of invertebrates. Juvenile Yellow Perch in Pickerel consumed 0.9 g $d^{-1}$ of invertebrates.

*Comparing Percentages of Fathead Minnows Consumed by weight*

Age-1 Northern Pike in all three study lakes consumed mainly Fathead Minnows (Figure 2). Fathead Minnows made up 100% of the diets in Rice Lake, 78.6% of the diets in Geneva, and 47% of the diets in Pickerel. Percentages of Fathead Minnows of Age 2-4 Northern Pike decreased from Age-1 fish in all three lakes. In Geneva, Pickerel, and Rice, 9, 16, and 40% of the diets were Fathead Minnows, respectively.

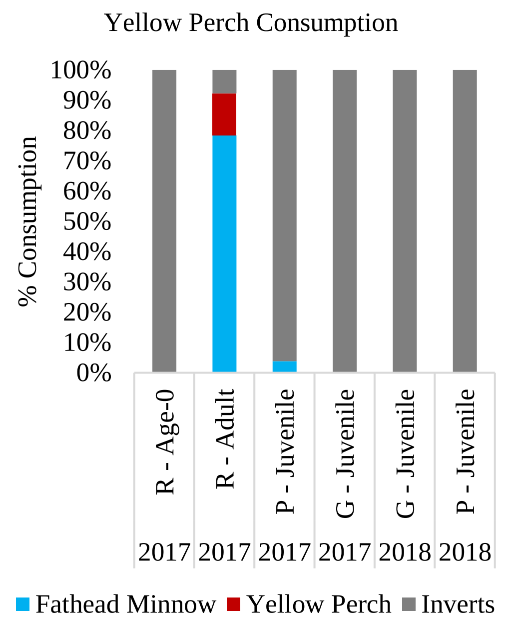


FIGURE 3. Yellow Perch daily consumption based on mass as a percentage in the three study lakes for age-0, juvenile, and adults. Age-0 and juvenile Yellow Perch consumed almost exclusively invertebrates. Adult Yellow Perch were highly piscivorous and consumed mainly Fathead Minnows.

Fathead Minnows were only consumed by adult and juvenile Yellow Perch (Figure 3). Adult Yellow Perch diets in Rice consisted of 78% Fathead Minnows and juvenile diets in Pickerel consisted of 4% Fathead Minnows.

*Assessment of Stocking Effectiveness at reducing the Fathead Minnow Populations*

Northern Pike consumption rates in all three study lakes were combined and consumed 141.61 g $d^{-1}$ (54%) Yellow Perch, 101.37 g $d^{-1}$ (38%) Fathead

Minnows, and 21.03 g $d^{-1}$ (8%) invertebrates (Figure 4).

Yellow Perch consumption rates in all three study lakes were combined and consisted of 432.65 g $d^{-1}$ (52%) invertebrates, 339.6 g $d^{-1}$ (41%) Fathead Minnows, and 59.4 g $d^{-1}$ (7%) Yellow Perch (Figure 5).

Fathead Minnows were not the main diet item of Northern Pike or Yellow Perch and it is unlikely that either species reduced the Fathead minnow population.

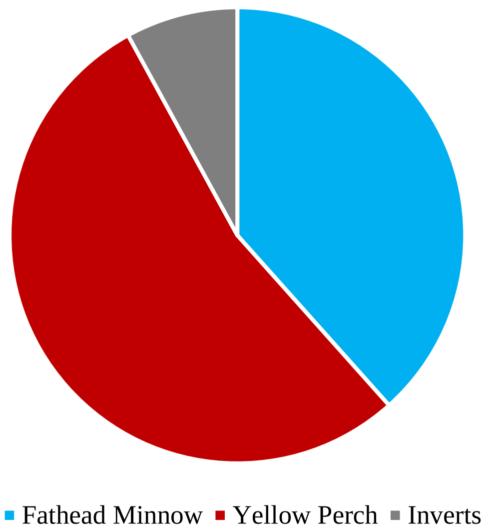


FIGURE 4. Percent of daily consumption based on mass of Northern Pike. Consumption rates for each diet item in the three study lakes were combined. Over half of the diet of Northern Pike were Yellow Perch, and approximately 30% were Fathead Minnow.

**Discussion**

Lakes have many different limnological characteristics and other factors that affect what state the lake is in (turbid or clear). These circumstances make creating a tropic cascade very difficult. This study indicates that stocking Northern Pike and Yellow Perch may not be the best way to induce a tropic cascade in shallow lakes because the stocked fishes did not consume a high proportion of the Fathead Minnow, which is known to create turbid conditions (Zimmer et al. 2002).

Northern Pike were highly piscivorous and consumed some invertebrates. This finding was consistent with Pierce (2012), who found Northern Pike diets can consist of 90% fish. Fathead Minnows only made up a large portion of age-1 Northern Pike diets in Geneva and Rice Lakes (62% and 100%). Age 2-4 Northern Pike experienced a shift in prey items, consisting of mainly Yellow Perch (62-79%). Many other studies showed Yellow Perch are a key component of Northern Pike diets in North America Lakes (Lawler 1965; Diana 1979). In Spirit Lake, Iowa, Larsheid et al. (2002) found Northern Pike diets were dominated by Yellow Perch. When we combined consumption in all three study lakes, over half (54%) of the diets were made up of Yellow Perch. These results were not expected as it was thought that Fathead Minnows would be the main prey item of older Northern Pike.

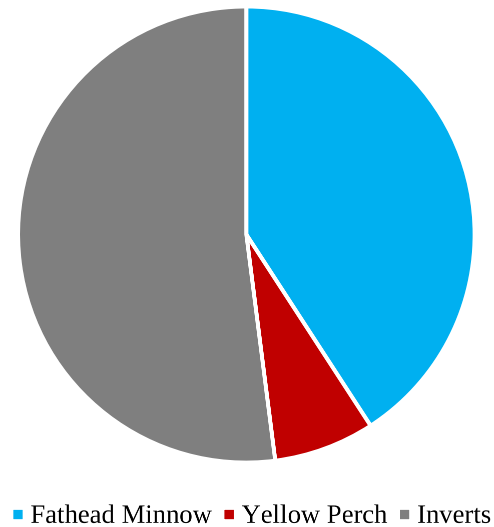


FIGURE 5. Percent of daily consumption based on mass of Yellow Perch. Consumption rates for each diet item in the three study lakes were combined. Half of the diet of Yellow Perch were invertebrates and approximately 40% were Fathead Minnow.

Almost all diets of age-0 and juvenile Yellow Perch consisted of invertebrates. There was a switch in diets for adult Yellow Perch which were highly piscivorous with diets consisting of mainly Fathead Minnows. When all three study lakes consumption rates were combined, over half (51%) of the diets were made up of invertebrates. The Yellow Perch were intended to feed the Northern Pike for the first year and then the Yellow Perch would not play a big role in the systems. Instead, the age-0 and juvenile Yellow Perch diets consisted of nearly 100% invertebrates that were intended for the waterfowl. However, Fathead Minnows made up 78% of adult Yellow Perch diets. Although this is a positive, in our study systems there was more age-0 and juvenile than adult Yellow Perch. On a lake-wide scale, age-0 and juvenile Yellow Perch were consuming more invertebrates and the adult Yellow Perch were not consuming a lot of Fathead Minnows. This means more invertebrates are being consumed which is a negative.

Our results show that the percentage of Fathead Minnows in Northern Pike diets is unlikely to cause the tropic cascade. Herwig et al. (2019) findings in the same study lakes concluded that a tropic cascade was not created because turbid states persisted in the stocked lakes. At the same time, the Northern Pike and Yellow Perch became very abundant in all lakes. Although creating a tropic cascade failed, highly desirable Northern Pike and Yellow Perch fisheries were created for the public to enjoy.

**Acknowledgements**

This research was funded by the MNDNR Fisheries and Wildlife and the University of St. Thomas. We especially thank Kyle Zimmer, Brian Herwig, Mark Hanson, and Nicole Hansel-Welch for help with and study design and project execution, Stein Innvaer and Jake Carleen for help with fish sampling, Ben Miller and Mike Collins for diet analysis, and Abigail LeVoir for bioenergetics modeling.

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