ENERGY DENSITY OF FISH WITHIN AN AQUACULTURE EXPERIMENT

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ABSTRACT

Understanding how small-bodied fish are affected by aquaculture is important to help complete the picture on how aquaculture affects all levels of the ecosystem. I analysed the energy density for small-bodied fish in the presence of aquaculture. The experiment was done in a whole lake ecosystem within the boreal shield. This study focused specifically on finescale dace within two similar lakes; Lake 375 had aquaculture operating for 5 years and Lake 373 was monitored as a reference lake. Aquaculture likely had a positive impact on the energy density of finescale dace as they had access to an increased food source. While the energy density of minnows was higher in Lake 375 than Lake 373, there was a higher overwinter mortality rate in Lake 375. Based on findings presented here and from information reported elsewhere, I conclude that previously reported minnow overwinter mortality was largely due to an increase of predation of minnows from lake trout, rather than due to energetic deficits. While aquaculture appears to benefit the minnows where they displayed increased energy density and population densities, overwinter mortality may cause the minnow population densities to become unpredictable and volatile with an aquaculture operation.

Table of Contents

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INTRODUCTION

Aquaculture is a rapidly growing industry in Canada for food production as the demand for seafood has been rapidly increasing worldwide (Rennie et al. 2019). To meet global demands for seafood products, sustainable production and harvest methods of seafood are required to keep up (Anderson et al. 2017). As this demand for seafood increases, it will become harder to sustainably harvest native fish species. Currently, there are about 25-30% of fish species being over-exploited or have already been significantly depleted world-wide (Khan & Neis. 2010). To counteract this crisis of the depletion of native fish stocks, a sustainable solution is required to protect our fisheries. Aquaculture has been proposed as a potential solution for the increased demand of seafood as it can be implemented in a sustainable way and does not require the harvesting of native fish species. Continued expansion of aquaculture in Canada will be crucial for future development. In 2021, aquaculture in Canada is primarily driven by the farming of finfish as finfish produce $1.2 billion in revenue of a $1.4 billion aquaculture industry (Government of Canada 2021). While coastal provinces are leading the way with aquaculture revenues, development of aquaculture in Ontario is important to keep up with future demands. Within Ontario, the primary source for aquaculture locations are enclosed freshwater ecosystems which present unique environmental issues in the large-scale development of aquaculture (Rennie et al. 2019).

From 2003 to 2007, the International Institute for Sustainable Development (IISD) conducted an experiment within the Experimental Lakes

Area (ELA) to determine how aquaculture would affect the native species that inhabit an aquatic ecosystem (Kennedy et al. 2019). This aquaculture experiment was done on a small inland lake in northern Ontario. For normal aquaculture usage, this lake would have been deemed inappropriate to use as it was too small and not suitable for aquaculture. However, the experiment was done here to amplify the effects that aquaculture could have on the surrounding ecosystem in order to determine clear pathways of effect and determine the different species and parts of the ecosystem that were most affected by aquaculture. One major issue facing the expansion of freshwater aquaculture in Ontarios' natural environment is the uncertainty of how it affects native aquatic species.

Nutrient loading is a main concern when it comes to environmental issues related to aquaculture development in freshwater ecosystems. Freshwater aquaculture has been known to cause significant influxes of nutrients such as phosphorus and nitrogen into ecosystems which can lead to the eutrophication of lakes (Bristow et al. 2008). This influx of nutrients may cause behavioral changes throughout all living organisms in an aquatic ecosystem (Kennedy et al. 2019, Grant & Tonn. 2002, Paterson et al. 2011). In the aquaculture experiment conducted at the IISD ELA, one of the main nutrients added was phosphorus, although 88% was deposited in the sediment underneath the aquaculture cage (Bristow et al. 2008). Most of the nutrients deposited was from the excretion of the farmed rainbow trout although some did come from the feed that was fed to the rainbow trout. This influx of nutrients may cause behavioral changes throughout all living organisms in an aquatic ecosystem (Kennedy et al. 2019, Grant & Tonn. 2002, Paterson et al. 2011). This change in organisms was particularly noted in regards to the biomass of phytoplankton as it increased 4 times its original size each year aquaculture was conducted. There were also increased algal blooms that were observed as their seasonal biomass increased 12 times with the introduction of aquaculture (Findlay et al. 2009). Decomposition of algae could lead to lower hypolimnetic dissolved oxygen levels which can have negative effects on cold water organisms such as freshwater shrimp (*Mysis diluviana)* populations (Paterson et al. 2011). In this same experiment, a decline in dissolved oxygen led to a decline of *Mysis* habitat, which put added pressure on lake trout, the apex predator (Kennedy et al. 2019). This loss of a main food source for lake trout could have them adapt and switch their feeding patterns to more small-bodied fish (Kennedy et al. 2019).

Small-bodied fish are a main species of concern when it comes to aquaculture as they connect the lower (e.g. primary consumers, mainly zooplankton or benthic invertebrates) and upper (e.g. secondary and higher consumers, mainly fish) components of the food chain in aquatic ecosystems. Minnows' diets consist mainly of detritus, algae, zooplankton and benthic invertebrates (Price et al. 1991). The increase in biomass of phytoplankton was similar to the observed increase of minnow catch per unit effort (CPUE) during the ELA aquaculture experiment, as the mean annual CPUE of minnows increased 5 times from the mean annual CPUE of minnows before aquaculture in Lake 375 (Kennedy et al. 2019) compared to the 4 times increase in phytoplankton. While the mean annual CPUE of minnows rose during the aquaculture experiment, there was large variability of minnow CPUE across seasons, whereby the high CPUE of littoral minnows during the fall was not observed during the spring, which other authors suggest was due to high overwinter mortality of minnows (Rennie et al. 2019).

Understanding the energetics of fish can be helpful in predicting how a species will react to change, as energy density represents the energy available within an organism to hunt, reproduce or grow (Johnson et al., 2017, Paterson et al. 2009). Energy density can also provide context for an organism's ability to survive winter (Post and Evans 1989). The energy density within an individual is typically size-dependant and will vary based on both fish size and maturity (Geissinger et al., 2023). Immature fish have lower energetic requirements than mature fish, as the mature fish have an added energetic requirement in reproduction (Rowan & Rasmussen, 1996).

MATERIALS AND METHODS

Location

The freshwater aquaculture experiment was conducted at the Experimental Lakes Area (IISD ELA). This experiment focused on two main lakes in the IISD ELA area, the aquaculture lake, Lake 375 (49°44'43.61" N, 93°47'15.56" W) and a reference lake, which was Lake 373 (49°44'41.46" N, 93°47'55.35" W). Lake 375 is located downstream of Lake 373 so that there was no contamination of the reference lake and both lakes have similar fish communities (Rennie et al. 2019). Lake 375 is 23.2 hectares of surface area and has a maximum depth of 26 m. Lake 373 has a surface area of 27.3 hectares and a max water depth of 21 m, (Rennie et al., 2019). In 2003, an aquaculture cage measuring 10 m x 10 m x 10 m was anchored in Lake 375 in water 16m deep (Bristow et al., 2008). From 2003-2007, approximately 10 000 Rainbow Trout fingerlings were added to the cage each year until 2007 (Bristow et al. 2008). To simulate commercial aquaculture operations, the fish were fed twice daily with Martin Mills Profishent feed (Rennie et al. 2019). Additional data and specific details pertaining to the execution of the experiment can be found in Bristow et al. (2008) and Rennie et al. (2019).

Fish Collection

The native minnow community of Lake 375 consists of the minnows finescale dace (*Chrosomus neogaeus*), northern redbelly dace (*Chrosomus eos*), pearl dace (*Margariscus margarita*), and fathead minnow (*Pimephales promelas*). The native fish community of Lake 373 is similar, but fathead minnows are absent. Fish were collected using Beamish-style trap nets (Beamish 1973). Between two and three trap nets were set simultaneously at fixed locations in both lakes during the spring and fall of each year. Nets were fished for 2 to 5 days and were reset immediately after collections. Between three and seven sets were used in each time period (Kennedy et al. 2019). Additional information on sampling of trap nets and minnow processing upon capture can be found elsewhere (Guzzo et al. 2014; Mills et al. 2000; Kennedy et al. 2019).

Species Analysis

This study utilized minnow carcasses originally sampled for other purposes for the estimation of energy density. Finescale dace were chosen for energy density analysis because they were the most prevalent species available in historic samples. The minnows analyzed represent the period during aquaculture (2003-2007) and immediately after the cessation of aquaculture (2008-2009).

Energy Density Analysis

A 6725 Parr semi-micro bomb calorimeter was used to measure the energy density within the ground homogenate samples. To facilitate energy density estimates, a pellet was made from the dried ground fish homogenate using a pellet press. Each pellet weighed between 0.2 and 0.3 grams and its weight recorded to 4 decimal places. Once a sample was run, EE (energy equivalent) values, temperature rise, and the gross heat were recorded, and associated with fish length, mass and other biological attributes using the unique sample code of each fish. For quality control purposes, a standardized reference material (benzoic acid tablet) was run every eight samples. For samples that had enough homogenate, duplicates were run to determine analytical error. To determine the energy density of each fish, the following equation was used:

$$\text{Temp rise/g wet mass} = \text{Energy Density}$$

RESULTS

Changes in Energy Density Due to Aquaculture

Generally, the energy density of finescale dace from Lake 375 was greater than those from Lake 373, with the possible exception of 2004. In Lake 375, the average annual energy density of a finescale dace was 2.0 KJ and the average annual energy density of Lake 373 was 1.3 KJ. The average energy for the year 2003 in Lake 375 was 3.1 KJ which was higher than any other yearly average for Lake 375. During the aquaculture experiment, from 2003-2007, the average energy density of the finescale dace was 2.1 KJ. After the aquaculture experiment was over, there was a slight decline in average energy density to 1.6 KJ over both 2008 and 2009 in Lake 375.

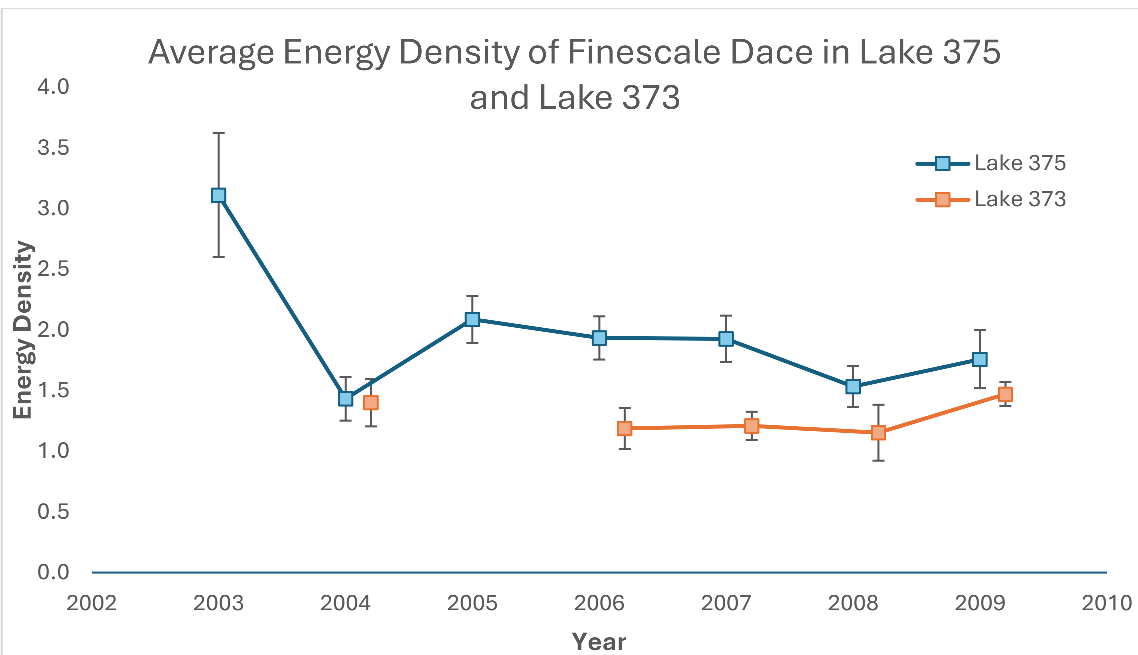

***Figure 1**:Comparison of energy density of finescale dace in Lake 375 and Lake 373*

When looking at energy density in relation to fork length, there was a noticeable difference in the relationship between Lake 375 and Lake 373. Within Lake 373, the relationship between the energy density of finescale dace and fork length declined gradually, and the R squared value for a logarithmic fit of energy density with fork length was 0.26. In Lake 375, the energy density of finescale dace decreased more rapidly with fork length compared to Lake 373, and the R squared value of the logarithmic fit for Lake 375 was 0.59. The energy density of the finescale dace at 45-50mm was much greater in Lake 375 than the energy density of finescale dace in Lake 373. Although finescale dace above 60mm had an energy density was much more similar.

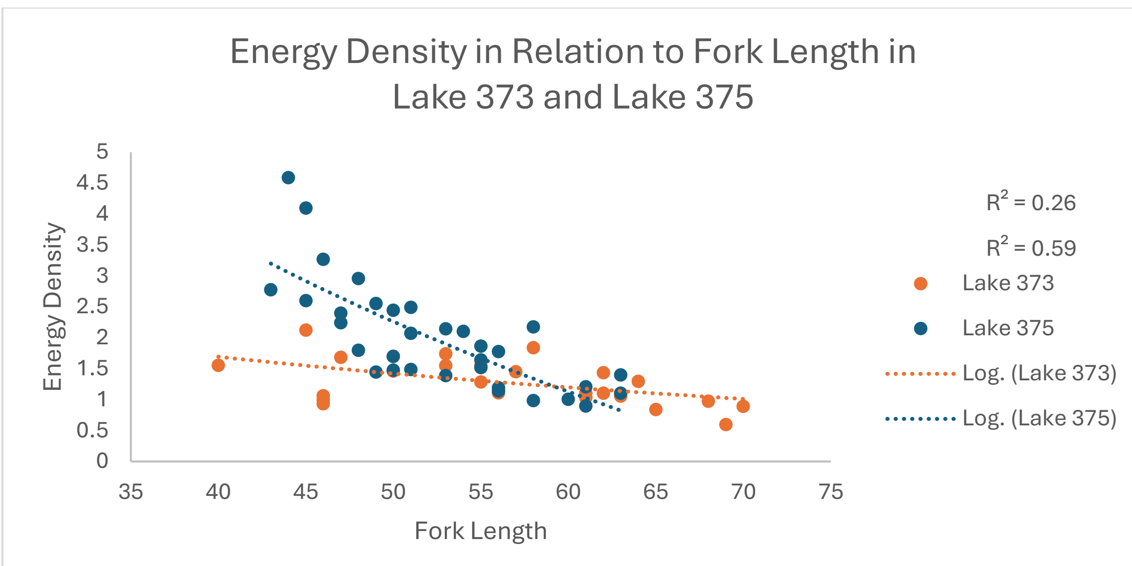

Figure 2: Comparison of energy density to fork length in Lake 375 and Lake 373

DISCUSSION

Based on my results, aquaculture appears to have had an impact on the energy density of small-bodied fish. The impact on energy density can likely be attributed to the overall increase of lake productivity which is a result of an increase of phosphorus and nitrogen. The increase of phosphorus led to an increase of algae blooms biomass by 12 times and phytoplankton biomass by 4 times which are the main food sources of small-bodied fish (Kennedy et al. 2019). In this time there was also an increase in minnow populations in Lake 375 of a similar magnitude to the food source which could suggest an association between the two,

In both populations investigated here, the energy density of finescale dace declined as they increased in size. The energy density within an individual is size-dependent and will vary based on fish size and maturity (Geissinger et al., 2023), but is typically expected to increase as fish grow larger. Immature fish have a lower energetic requirement than a mature fish as the mature fish have an added energetic requirement in reproduction that immature fish do not have (Rowan & Rasmussen, 1996). This decline of energy density in Lake 375 with fish size may be a consequence of allocations to reproduction as the fish had already spawned and gonadal investments in reproduction are not captured in the sampled biomass of the fish evaluated in this study.

When looking at the minnow population densities in Lake 375 throughout the year reported elsewhere (Rennie et al. 2019), there was a noticeable change in population densities between autumn and spring. Small-bodied fish (minnows, including finescale dace) increased in relative abundance in the autumn during aquaculture, but spring abundance seemed to show no response to aquaculture and was similar to pre-manipulation densities (Rennie et al. 2019). With our results and the sum of evidence available, it suggests that the energy density of minnows increased with the aquaculture due to an increased food supply. The large difference in minnow abundance between autumn and spring may be attributable to predation by lake trout. Kennedy et al. (2019) demonstrated that the energy assimilation of lake trout shifted towards littoral energy sources as the aquaculture experiment progressed, and away from pelagic sources. With lake trout shifting their feeding to littoral zones and minnow populations fluctuating, it is likely that these are attributed to each other and the lake trout are feeding on the minnows. The increase of algae in an ecosystem leads to decomposition of algae which leads to a lower hypolimnetic dissolved oxygen levels (Paterson et al. 2011). The freshwater shrimp *Mysis diluviana* are affected by a decrease in hypolimnetic dissolved oxygen as their habitat range is hypolimnetic cold water. A decline of dissolved oxygen led to a decline of *Mysis* habitat (Kennedy et al. 2019). Mysis are also a preferred food source for lake trout which are the apex predator in Lake 375. As *Mysis* habitat became limited, their habitat shrunk into a thin layer of water that matched both oxygen and temperature requirements, making them easier to eat for lake trout until they were consumed nearly to extirpation (Paterson et al. 2011). This dramatic reduction in *Mysis* densities was associated with the timing of lake trout switching to littoral resources (Kennedy et al. 2019). Within Lake 375 the main source of littoral energy available to lake trout is likely minnows. While minnows are not readily available during summer while the lake is stratified, they are when the lake mixes between fall (post-spawning) and spring and could provide a significant energetic subsidy for lake trout during this time (Guzzo et al. 2017). Although minnows were consumed by lake trout throughout the experiment, they became an increasingly important food source for the lake trout one Mysis were nearly extirpated.

CONCLUSION

The results of this experiment indicate a possible positive impact of aquaculture on the energy density of the small-bodied fish. While the data suggests a positive impact of aquaculture on energy density, having pre-aquaculture energy density data would help to be sure. Based on a sum of available evidence, the increased food source for the minnows likely led to a higher energy density in minnows which likely allowed them to reproduce at elevated rates. While the energy density of minnows increased, their overwinter survivability did not. One possible explanation for this pattern is due to predation by lake trout during the cold-water season. With lake trout being the apex predator within Lake 375, if their feeding patterns shifted to minnows during the cold-water months, then the pattern of minnow density can be at least partially explained (Kennedy et al. 2019), given that ED of minnows was actually greater in the presence of aquaculture relative to the reference lake investigated in this study. Future investigations may benefit from sampling minnows before the aquaculture experiment (if available) in order to more clearly attribute differences in ED between lakes to aquaculture.

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