The impact of dissolved organic carbon on the feeding effectiveness of bluegills

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Erin Hanratty

Mentor: Nicola Craig

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ABSTRACT

Dissolved organic carbon (DOC) plays an important role in aquatic ecosystems, and anthropogenic activities may be driving the recent increase in DOC concentrations in freshwater lakes. High concentrations of DOC lead to the darkening of water, which may potentially inhibit the feeding effectiveness of visual predators, such as bluegills. The focus of this study is to investigate the relationship between the amount of chironomids consumed by bluegills along a controlled increasing DOC gradient (4-28 mg/L). Feeding trials were performed using bluegills collected from a lake with low DOC concentration, as well as a lake with high DOC concentration, in order to determine whether DOC plays a role in feeding adaptations. No significant relationship between DOC concentration and the number of chironomids consumed by the bluegills from either lake. However, there was a significant difference between the average number of chironomids consumed per trial between bluegills collected from the low DOC concentration lake and high DOC concentration lake (0.04908). The bluegills from a high DOC lake consumed less chironomids, suggesting that DOC plays an important role in the trophic interactions of aquatic ecosystems.

INTRODUCTION

Dissolved organic carbon (DOC), a form of dissolved organic matter found within aquatic ecosystems, is an important factor contributing to the ecological processes and interactions within lake environments. Caused predominantly by the leeching of organic material from adjacent soil, DOC concentration is known to vary both among lakes, as well as temporally within a single lake (Sucker and Krause 2010). Studies have shown that DOC levels have increased in freshwater lakes over recent decades (Sucker and Krause 2010). Evidence suggests that human activity is a driving factor for these increasing DOC levels (Sucker and Krause 2010). An increase in anthropogenic CO_2 emissions is associated with an increase in primary production, is which subsequently supplies more organic material within soil available to be leeched into aquatic systems (Freeman et al 2004). Furthermore, human-induced runoff leads to higher DOC concentrations by increasing the amount of nutrients in lakes (Agren et al 2008).

In light of human-driven DOC inputs, it is important to understand the ecological implications of increasing DOC concentrations. One of the consequences is the phenomena called browning, in which the refractory particles of DOC darken the color of the water by absorbing solar radiation (Christensen et al 1997; Stanley et al 2011). The darkening of lake water associated with higher DOC levels may inhibit the success of visual predators, such as fish that feed on benthic invertebrates (Stasko et al 2012). Feeding limitations for fish could lead to slower growth rates, and subsequently, higher mortality rates for the species' young during the winter months (Port et al 1998). Increasing mortality rates within a single population of an ecosystem will likely have cascading impacts on the interactions and survival of organisms throughout the entire ecosystem and could potentially cause the collapse of these ecosystems (Frank et al 2005). Consideration of such cascading implications is crucial to sustaining aquatic ecosystems, especially when human activity could be the catalyst driving mortality of a predator within a system.

The purpose of this study is to investigate the potential impact of increasing DOC concentrations on the feeding effectiveness of bluegills at the University of Notre Dame Enviromental Research Center (UNDERC). Prior to this study, a brief series of related trials was conducted at UNDERC and displayed a significant decrease in the amount of zooplankton consumed by bluegills at higher DOC levels (Zwart, J. & Baglini, K. 2012). Benthic invertebrates also serve as an important source of food for fish, especially young and/or insectivorous fish such as bluegills (Weidel et al 2008). Therefore, this study focuses on the relationship between differing concentrations of DOC and the feeding effectiveness of bluegills on benthic invertebrates, in particular chironomids. The experiment tested the hypothesis that increased DOC levels will lead to lower feeding rates of fish on their prey, exhibited by less consumption of chironomids by bluegills along a controlled DOC gradient. The experiment also tested for the possible role of adaptation involved with feeding effectiveness, specifically, whether or not fish that permanently inhabit darker environments tend to acquire adaptations for overcoming the feeding limitations associated with dark water. This phase of the experiment tested the hypothesis that bluegills collected from a dark lake will have overall higher feeding rates along the DOC gradient than the feeding rates of bluegill collected from a clear lake.

METHODS

Organism Collection

In order to prepare for the experiment, minnow traps were used to collect bluegills (60-80 mm in length) from both Bay Lake and Hummingbird Lake. Bay Lake served as a sample lake with low DOC concentration (DOC~ 5.26 mg/L), while Hummingbird Lake served as a lake with high DOC concentration (DOC~ 19.53 mg/L). The bluegills collected served as the predator whose consumption of prey was measured at along a controlled DOC gradient. Upon collection, bluegills were held (without food in oxygenated water from Tenderfoot Lake) in 40-L tanks in the UNDERC wet lab for 2-4 days before testing was performed, in order to become acclimated to tank conditions and to digest all previously consumed food. Bay bluegills were acclimated in tanks with a DOC level of approximately 9 mg/L, and the Hummingbird fish were acclimated in tanks with DOC level of approximately 20 mg/L, representing DOC concentrations close to that of their original lake environments. All chironomids used during feeding trials were collected using an Eckman dredge from the west portion of Long Lake at UNDERC.

Experimental Set-up

A 9-level DOC gradient was created using 40-L fish tanks, identical to the holding tanks. Filtered lake water from Tenderfoot Lake (DOC~9.005 mg/L), was used to fill testing tanks. Each specific DOC level was created by adding appropriate measurements of Superhume (and additional tap water for DOCs less than 9 mg/L). The gradient consisted of concentrations from 4-28 mg/L DOC, and was tested in estimated increments of 3 mg/L (ie, tank #1 = 4 mg/L, tank #2 = 7 mg/L, tank #3 = 10 mg/L). Actual DOC concentrations were measured for experimental consistency using a spectrometer to report the wavelength of a water sample from each testing tank, followed by a conversion involving the reported wavelength (wavelength /.01*2.303 = approx. [DOC]). All tanks included a thin layer of sand and gravel in order to simulate a lake's benthic environment.

Feeding Trial Procedure

After bluegill acclimation and gradient setup were complete, feeding trials were performed. One trial consisted of one bluegill from either Bay or Hummingbird Lake being placed in one of the testing tanks with 15 red chironomids (~10 mm). One feeding trial lasted 15 minutes, after which the bluegill was removed from the testing tank. The feeding rate of the bluegill along the DOC gradient was measured by observing how many chironomids were eaten by each bluegill during the 15 minute trial period. An induced gastric lavage method was performed in order to retrieve and count the chironomids consumed by each bluegill. After each feeding trial, the number of chironomids consumed (ranging from 0-15), bluegill length (mm), bluegill mass (g), and testing tank DOC concentration were recorded.

Statistical Analysis

A simple linear regression test was used to analyze whether or not there was a significant decrease in bluegill feeding effectiveness along the increasing DOC gradient. A single trial served as a replicate, and all trials were statistically considered in relationship to their respective DOC level. The number of chironomids consumed served as the response variable, with each DOC concentration as the independent variable. A separate regression was run for trials with fish from Bay Lake (n=39) and for trials with fish from Hummingbird Lake (n=48).

A two-sample independent t-test was also used to analyze the potential difference in average number of chironomids consumed during a single feeding trial between bluegills from Bay and Hummingbird. The purpose of this test was to illustrate intrinsic differences in feeding habits between bluegills that originally inhabited lakes with low DOC vs high DOC. A linear regression was used to analyze any possible relationship between the exact length of a bluegill and the number of chironomids consumed, as well as a two-sample independent t-test to compare the average length of fish sampled between lakes.

RESULTS

The linear regression analysis did not illustrate a significant relationship between the number of chironomids eaten and DOC concentration levels for bluegills from either of the two lakes sampled. The feeding effectiveness of bluegills from Bay Lake declined a slight amount along the increasing DOC gradient, but the relationship was insignificant (Fig 1) (R-squared=0.018926, p-value = 0.4036). The feeding effectiveness of bluegills from Hummingbird

Lake declined to a slightly greater extent than the Bay bluegills, only tending towards a significant relationship (Fig 2) (R-squared=0.0667, p-value = 0.0763).

The two-sample independent t-test of average number of chironomids consumed per feeding trial between fish from each lake collectively displayed a significant difference (t = 1.998271, df = 80.065396, p=0.049082). Bluegills from Bay Lake ate collectively more chironomids than bluegills from Hummingbird Lake (Fig 3). The t-test comparing the average length of bluegills sampled from each lake produced significant results (t = 3.800890, df = 76.693328, p = .000287), showing that the bluegills used in trials from Hummingbird were collectively larger than those from Bay (avg Hummingbird = 70 mm, avg Bay = 65 mm). The regression analyzing a relationship between bluegill length and number of chironomids eaten, however, did not prove to be significant (R-squared =0.0487, p-value = .364197).

DISCUSSION

Based on the results of this study, my hypothesis that there would be a significant decline in bluegill feeding effectiveness along an increasing DOC gradient was not confirmed. Bluegills from both Hummingbird and Bay Lake did not consume significantly less chironomids in water with higher DOC concentrations. Furthermore, the bluegills from Hummingbird Lake, a high DOC environment, exhibited a slightly greater decline in chironomid consumption along the increasing DOC gradient than the fish from Bay Lake, a low DOC environment. This contradicts the hypothesis that fish which inhabit lakes with an intrinsically higher DOC concentration may evolve adaptations to compensate for foraging challenges. Despite the results not being scientifically significant, they displayed a slight decline in feeding rates along the increasing DOC gradient for bluegills from both of the two lakes.

The insignificant decline in chironomid consumption along the DOC gradient observed in this study may be attributed to experimental design, rather than a true lack of relationship. An improved version of this study could be performed in order to more accurately assess the relationship between bluegill feeding effectiveness and increasing DOC concentrations. Instead of relatively small 40-L tanks, larger pool-like tanks could be used to create a more authentic lake-like setting in which feeding trials would take place. The use of a wider range of benthic invertebrates and habitat sediments, as well as a longer experimental time-frame would allow for a more natural opportunity for prey to hide from fish predators. Such experimental modifications would likely provide a more accurate illustration of the impacts of DOC on bluegill feeding effectiveness.

Despite limitations of this study's experimental design, these drawbacks may not have been to blame for its unexpected results. For instance, bluegills may not be purely visual predators. This would theoretically mitigate the obstacle involved with prey-seeing in darker water at higher DOC concentrations. Previous studies have demonstrated the prevalence of non-visual predator-prey interactions in freshwater benthos environments in the form of chemical cues (Dodson et al 1994). Furthermore, evidence has suggested that some fish rely on chemical cues as an antipredator tactic when conditions are not conducive to utilizing visual cues (Elvidge et al 2013). While studies have yet to focus purely on potential chemical cues involved in the predation of bluegills on chironomids, these studies suggest the possibility of such relationship. Additionally, bluegills are known to possess four specific nerve fibers located in the pectoral fins used for proprioceptive sensory tasks, which contribute to environmental interactions including predation (Williams et al 2013). The sensory capabilities of bluegills likely encompass more than information received visually, serving as a possible explanation for the minimal impact that increasing DOC concentrations had on the feeding activity of bluegills in this study.

While the data collected in this study did not support a significant relationship between the number of chironomids consumed and the concentration of DOC, it suggests that the differing DOC levels of lakes may influence the overall feeding behavior of the fish that inhabit them. This is demonstrated by the results of the t-test comparing the average number of chironomids consumed during each feeding trial between bluegills from Bay and bluegills from Hummingbird. These results suggest that fish in lakes with a higher concentration of DOC have adapted to eating less than those in lower DOC lakes. The possibility that variability in length of fish could have led to skewed averages of chironomids consumed between lakes was statistically accounted for and confirmed to not be a confounding variable. While there was a significant difference in average length of bluegills used from Hummingbird and those used from Bay, there was not a significant relationship (yet slight increasing trend) in number of chironomids consumed and length (within the range of lengths of bluegills used in this study).

The findings of this study that suggest an overall lower feeding rate is inherent in bluegills that inhabit lakes with a higher DOC concentration supports previous studies that have exhibited lower production rates in fish that inhabit lakes with higher DOC (Karlsson et al 2009). Lower productivity, as well as the lower feeding rates observed within this study, propose that there are ecological costs involved with foraging that must be overcome when living in a high DOC environment. While this study does not statistically support the expected relationship between a DOC gradient and fish feeding, it does not by any means confirm the notion that changes in DOC are an irrelevant to the feeding behavior of bluegills. The effects of DOC on the effectiveness of fish foraging are still not fully understood, providing many relevant avenues for future research endeavors. Ultimately, the potential impacts of recent trends of increasing DOC within aquatic systems should not be ignored, especially in the context of trophic interactions within freshwater systems.

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REFERENCES

Agren, A., Jansson M., Hans, I., Bishop K., Seibert, J. 2008. Seasonal and runoff related changes in total organic carbon concentrations in the River Ore, Northern Sweeden. *Aquatic Sciences, 70,* 21-29.

Christensen D. L., S. R. Carpenter, K. L. Cottingham, S. E. Knight, J. P. LeBouton, D. E. Schindler, N. Voichick, J. J. Cole, M. L.Pace. 1997. Pelagic Responses to Changes in Dissolved Organic Carbon Following Division of a Seepage Lake. *Limnology and Oceanography* 41: 553-559.

Dodson, S. I., Crowl, T. A.. Peckarsky, B. L., Kats L. B., Covich, A. P., Culp, J. M. 1994. Non visual communication in freshwater benthos: an overview. *The North American Benthological Society*. 13(2):268-282.

Elvidge, C. K., Macnaughton, C. J., Brown, G. E. May 2013. Sensory complementation an antipredator behavioral compensation in acid-impacted juvenile Atlantic salmon. *OECOLOGIA*. 172(1):69-78. 10.1007/s00442-012-2478-6.

Frank, K. T., Petrie B., Choi, J. S., Leggett, W.C. 2005. Trophic Cascades in a Formerly Cod Dominated Ecosystem. *Science, 308,* 1621-1623.

Freeman, C., Fenner, N., Ostle, N. J., Kang, H., Dorwich, D. J., Reynolds, B., Lock, M. A., Sleep, D., Hughes, D., Hudson, J. 8 July 2004. Export of dissolved organic carbon from peatlands under elevated carbon dioxide levels. *Nature, Vol 430.*

Karlsson, J., Bystrom, P., Ask, J., Ask, P., Persson, Jansson, M. 2009. Light limitation of nutrient-poor lake ecosystems. *Nature*. Vol 460.

Post, D. M., Kitchell, J. F., & Hodgson, J. R. (1998). Interactions among demography, spawning date, growth rate, predation, overwinter mortality, and the recruitment of largemouth bass in a northern lake. *Canadian Journal of Fisheries and Aquatic Sciences, 55*,2588-2600.

Stanley, E. H., S. M. Powers, N. R. Lottig, I Buffam and J. T. Crawford. 2011. Contemporary changes in dissolved organic carbon (DOC) in human-dominated rivers: is there a role for DOC management? *Freshwater Biology.* 10.1111/j.1365-2427.2011.02613.x.

Stasko, A. Gunn, J. & Johnston, T. (2012). Role of ambient light in structuring north temperate fish communities: potential effects of increasing dissolved organic carbon concentration with a changing climate. *Environmental Reviews, 20,* 173-190.

Sucker, C. and K. Krause. 2010. Increasing dissolved organic carbon concentrations in freshwaters: what is the actual driver? *iForest* 3: 106-108 [online: 2010-07-15]

Weidel, B., Carpenter, S., Cole, J., Hodgson, J., Kichell, J., Pace, M., Solomon, C. Dec 2008. Carbon sources supporting fish growth in a north temperate lake. *Aquatic Sciences*. 70(4) 446-458. 10.1007/s00027-008-8113-2.

Williams, R. IV, Neubarth, N., Hale, M. E. 16 April 2013. The function of fin rays as proprioceptive sensors in fish. *Nature Communications*. 10.1038/ncomms2751.

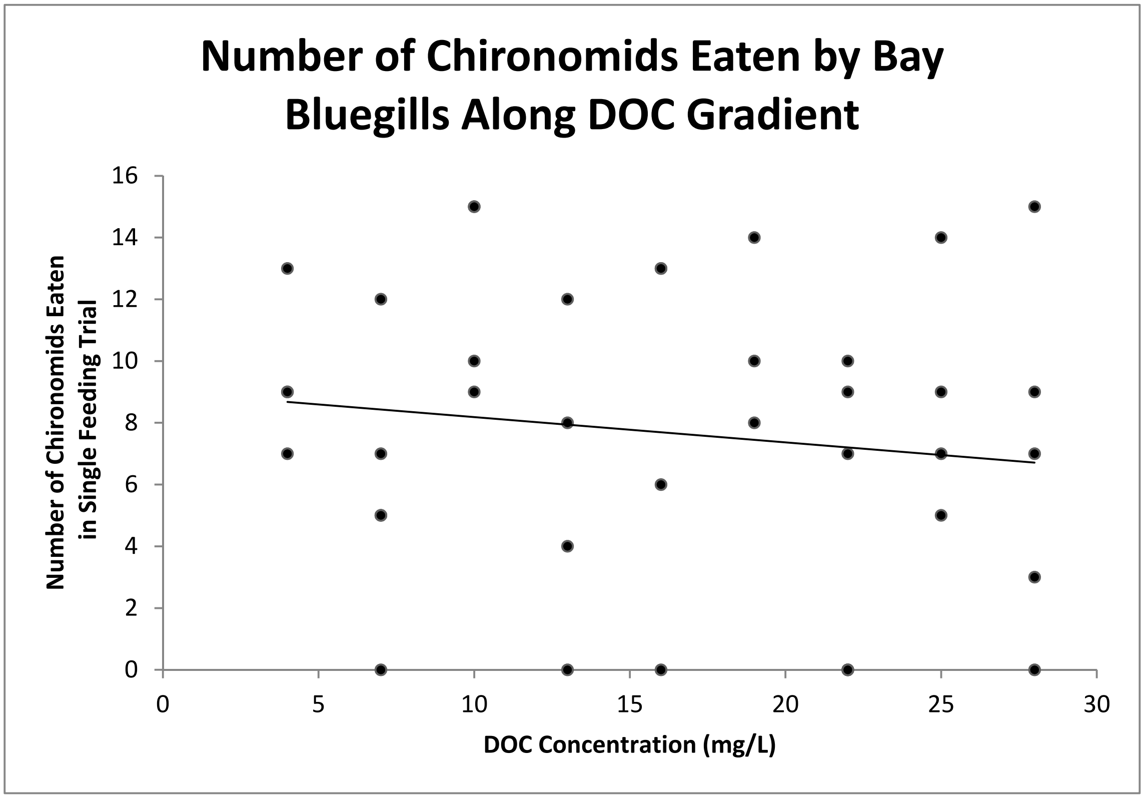

Fig 1: Relationship between number of chironomids eaten by each bluegill from Bay Lake and level of DOC concentration (mg/L). There was not a significant linear relationship (R-squared = 0.018926, p-value = 0.4036); however, the data suggested an extremely slight decline in feeding along the increasing DOC gradient.

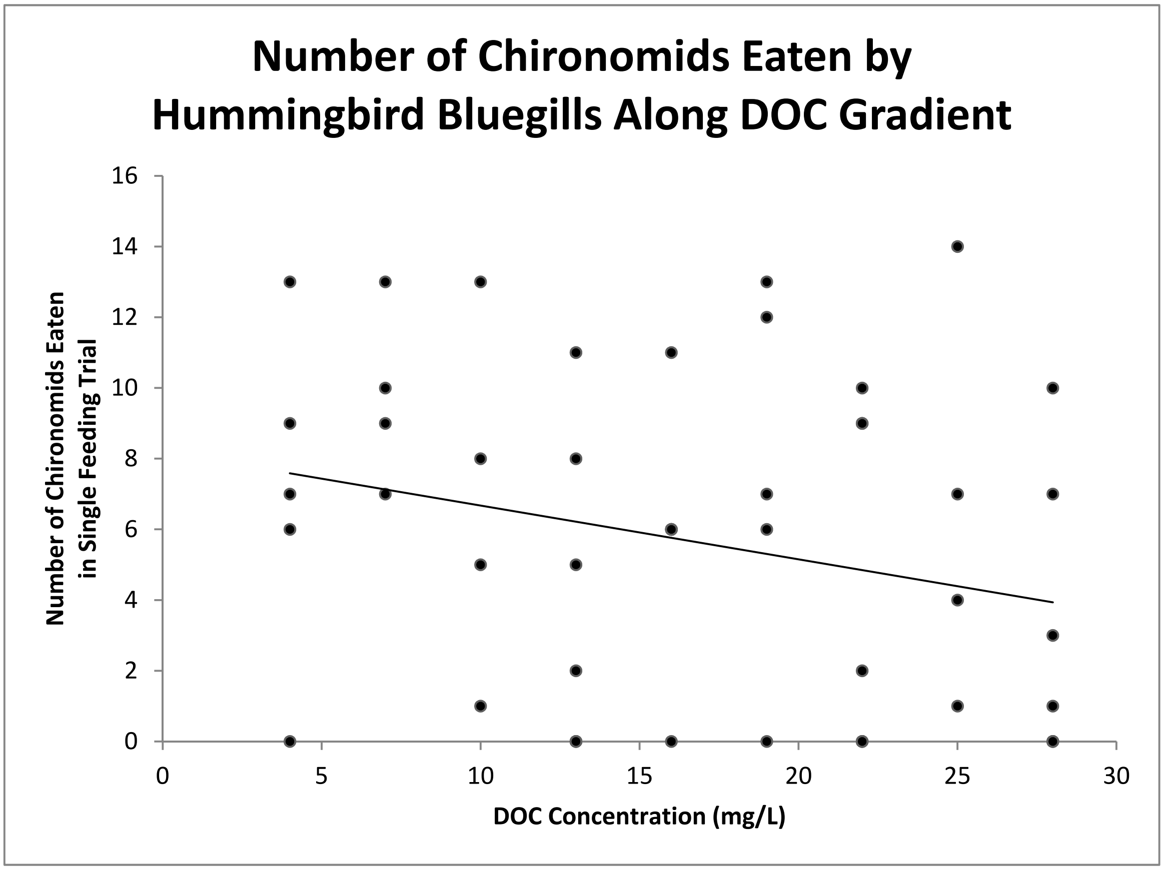

Fig 2: Relationship between number of chironomids eaten by each bluegill from Hummingbird Lake and level of DOC concentration (mg/L). There was not a significant linear relationship (R-squared =0.0667, p-value = 0.0763); however, the data suggested a slight decline in feeding along the increasing DOC gradient.

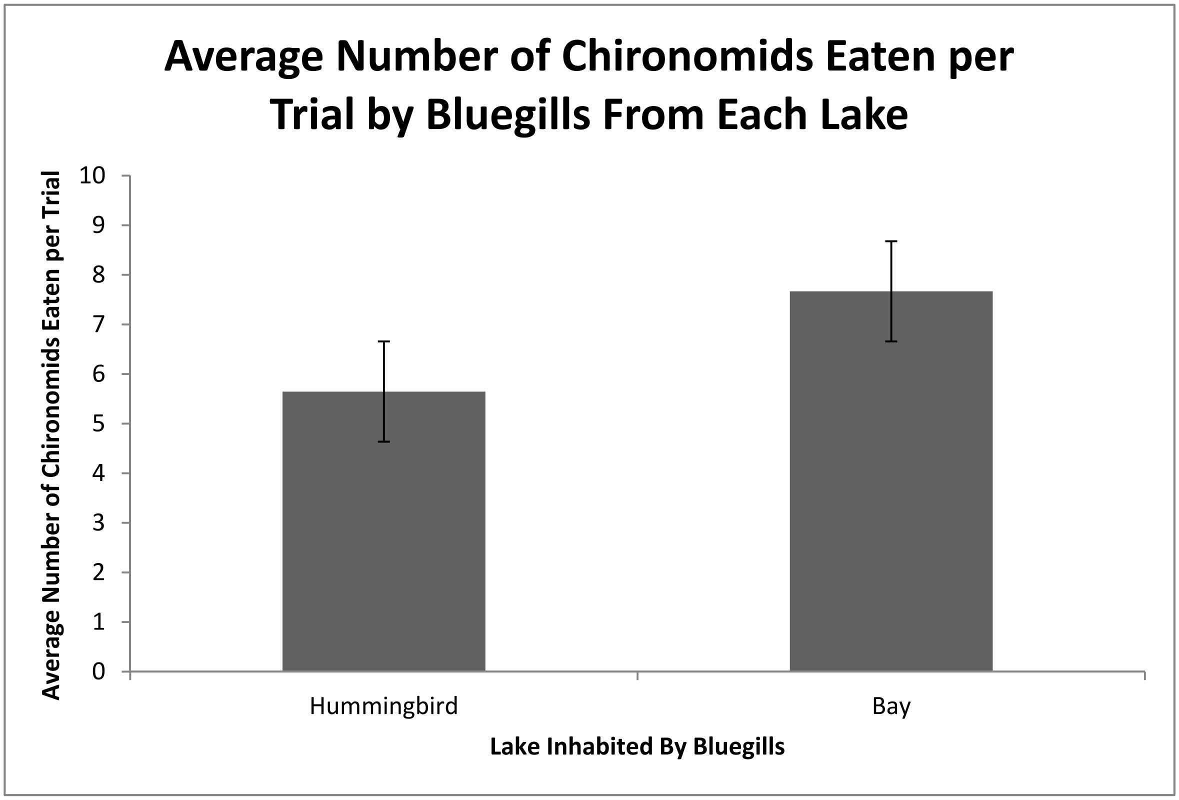

Fig 3: Average number of chironomids eaten per feeding trial by fish from each of two lakes used in study. On average, bluegills from Bay Lake ate significantly more chironomids per trial than those from Hummingbird Lake (p=0.04908).