# The effects of dissolved organic carbon on the size distributions of bluegill sunfish (*Lepomis macrochirus*)

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## Abstract

Dissolved organic carbon (DOC) is an important ecosystem driver known to affect several chemical and biological aspects of aquatic systems.  DOC causes lakes to develop a brown color, which lowers primary productivity through shading.  This study, conducted at the University of Notre Dame Environmental Research Center (UNDERC), investigated the effect of DOC on the size distributions of bluegill sunfish (*Lepomis macrochirus*).  Gee minnow traps were used to catch 400 juvenile bluegills across four lakes on property: two with low concentrations of DOC and two with high concentrations of DOC.  The average length and weight of bluegills was significantly higher in lakes with low concentrations of DOC compared to lakes with high concentrations of DOC.  There was also a significant difference in both weight and length among individual lakes.  These results suggest that factors associated with lake shading, such as decreased primary productivity or decreased bluegill predation due to lower predator visibility, have a significant effect on bluegill populations.  Future studies are necessary to determine which factors associated with shading cause these differences in size distributions.

*Key words: aquatic ecology; bluegill; dissolved organic carbon (DOC); lake shading; primary productivity*

## Introduction

Aquatic ecosystems play a vital role in the carbon cycle. Various forms of carbon are present in aquatic ecosystems, including dissolved organic carbon. Dissolved organic carbon (DOC) is known to affect several ecosystem drivers; for example, high DOC levels cause shallower thermoclines, resulting in less volume for phytoplankton production (Beisner *et al.* 2003). Decreased phytoplankton production can influence other trophic levels because phytoplankton are at the base of the food chain. Colored dissolved organic matter (CDOM), measured as DOC, is a mixture of organic compounds such as humic acid, which in high concentrations cause lakes to develop a brown color (Klug and Cottingham 2001). DOC can have both positive and negative effects on aquatic organisms. For example, DOC may bind metals, decreasing metal toxicity to fish, invertebrates, and phytoplankton (Klug and Cottingham 2001). However, DOC can also alter the availability of inorganic and organic compounds, such as phosphorous, iron, and carbon, affecting the nutrient uptake of phytoplankton and bacteria (Klug and Cottingham 2001). These various effects on ecosystems are determined by different sources of DOC.

There are two primary sources of DOC: allochthonous DOC, which enters water through terrestrial sources such as soil and leaf litter, and autochthonous DOC, which accumulates through autotrophic activities within the body of water (Jansson *et al*. 2000). Concentrations of allochthonous DOC are much higher than autochthonous DOC (Jansson *et al*. 2000). Humic materials, such as those found in allochthonous DOC, can be important substrates for bacterial growth. Autochthonous DOC plays a very minor role in bacterial growth compared to allochthonous DOC in most systems. In addition to soil and leaf litter, variations in climate and atmospheric carbon levels contribute to changing levels of allochthonous DOC (Jansson *et al*. 2000).

Climate change, specifically increasing atmospheric carbon dioxide, can cause an increase in net photosynthetic carbon uptake by phytoplankton, increasing autochthonous DOC concentrations in aquatic systems (Song *et al.* 2014). Climate change can also affect allochthonous DOC by increasing the supply of organic matter through rising atmospheric carbon dioxide levels, thus lowering primary productivity due to shading (Jansson *et al*. 2000).

Aquatic organisms such as bluegill sunfish (*Lepomis macrochirus*) play an important role in carbon cycling by consuming and releasing nutrients rich in DOC. DOC can have direct and indirect effects on aquatic organisms. For example, high concentrations of DOC cause lake shading, which may decrease juvenile bluegill predation on small invertebrates due to limited visibility. In addition, decreased primary productivity due to shading reduces the amount of available energy in the food web, indirectly affecting bluegills. Therefore, organic matter accumulation can have negative effects on bluegills and other freshwater fish.

Bluegills have an r-selected life history strategy, meaning survival is low while reproduction is high. Therefore, juvenile bluegills far outnumber adult bluegills. Because lakes have a high abundance of juveniles, bluegills must compete for resources intraspecifically and interspecifically. Juveniles are restricted by predators to the protection of shallow water vegetation and feed on small benthic invertebrates (Olson *et al.* 1995). Adult bluegills are able to feed in the open water on more energetically profitable zooplankton due to lower risk of predation (Olson *et al.* 1995).

Despite serving as a primary food source for many predatory fish, bluegills dominate the fish community in small lakes in the eastern and Midwestern United States and therefore have important ecological roles in ecosystems (Mittelbach and Osenberg 1993). Bluegills control populations of benthic invertebrates and play a vital role in the food chain. Bluegills also serve an important role in human consumption as well as in sport fishing. Given their ecological and commercial significance, it is important to understand the effects of dissolved organic carbon on the size distributions of bluegills.

For this study, I predicted that high concentrations of DOC would decrease the size distributions of bluegill sunfish (*Lepomis macrochirus*) due to decreased light that in turn results in decreased primary productivity. This study provides further insight into the physiological responses of freshwater fish to highly concentrated DOC environments, as well as the overall role of DOC in ecosystem health and functioning. To my knowledge, no other studies have focused on the effects of DOC on the size distributions of bluegills. This study therefore provides new information on bluegill response to dissolved carbon.

## Methodology

This study was conducted at the University of Notre Dame Environmental Research Center (UNDERC) in the Upper Peninsula of Michigan and northern Wisconsin. Gee minnow traps were used to catch a total of 400 juvenile bluegill sunfish (100 in each site) at Hummingbird Lake, Morris Lake, Bay Lake, and Crampton Lake. Hummingbird and Morris lakes have high concentrations of DOC, while Bay and Crampton lakes have low concentrations of DOC (Table 1; Craig *et al.* 2015). In order to maintain consistency in bluegill size, the traps were set only during the weeks of June 12 and June 26, 2016, which is during the peak of bluegill spawning season (Olson *et al.* 2006).

Traps were placed in areas consistent with bluegill habitat, primarily shallow water with high amounts of vegetation and coarse woody debris. The traps were checked in the morning and the afternoon to minimize the predation of bluegills by larger predatory fish (such as largemouth bass) that enter the minnow traps. The length and weight of the bluegills was measured to determine the size distributions of populations in each of the four lakes. After measurements were taken, the fish were released to the same area the traps were located.

Data were analyzed using R Studio statistical software (R Studio 2016). Because neither length nor weight were normally distributed (Shapiro-Wilk, W = 0.891; p = 2.97e-16; W = 0.706; p = 2.2e-16, respectively), two Kruskal-Wallis tests were conducted to determine if the length and weight of the bluegills differed between lakes with high and low concentrations of DOC.

A ranked repeated measures analysis of covariance (ANCOVA) was conducted to determine if the relationship between length and weight for each of the four lakes differ from each other. Because the interaction between length and weight was significant (ranked repeated measures ANCOVA, df = 3, p = 0.00541), a different test had to be used to separate the variables. Therefore, two Kruskal-Wallis tests were conducted to determine if length and weight differed between lakes. A post-hoc Kruskal Nemenyi test was used for individual pair-wise comparisons.

## Results

Bluegills in lakes with low concentrations of DOC had a higher average length and weight (mean ± SE; 5.82 ± 0.104 cm and 3.035 ± 0.178 g) than those in lakes with high concentrations of DOC (5.065 ± 0.0416 cm and 1.9 ± 0.0737 g). The Kruskal-Wallis test revealed a significant difference in both the length and weight between high and low concentrated DOC lakes (Length, df = 3; p = 0.00094; Weight, df = 3; p = 7.855e-05; Figures 1 and 2).

The second Kruskal-Wallis test indicated that there is a significant difference in length and weight among all four lakes (Length, Figure 3, df = 4; $p < 2.2e\text{-}16$; Weight, Figure 4, df = 4; $p < 2.2e\text{-}16$). Hummingbird Lake had the lowest average bluegill length and weight (mean ± SE; 4.78 ± 0.037 cm, 1.21 ± 0.017 g), while Crampton Lake had the highest average length and weight (6.49 ± 0.118 cm, 3.89 ± 0.263 g). The post-hoc Kruskal Nemenyi test revealed that the length of bluegills in Bay and Crampton, Hummingbird and Crampton, Bay and Morris, Crampton and Morris, and Hummingbird and Morris were significantly different from each other (Table 2). The weight of bluegills was significantly different between each individual lake (Table 3).

## Discussion

High DOC concentrations can potentially be an important factor limiting bluegill growth. Smaller bluegill size distributions in lakes with high concentrations of DOC may be due to lower primary productivity due to shading or increased predation due to shading. Decreases in net primary productivity can affect bluegills by limiting the amount of available energy in the food web, thus requiring an increase in consumption to maintain the minimum energy needed for growth and survival.

In addition, lake shading resulting from DOC may inhibit the capacity of bluegills to escape predation due to limited visibility, further increasing bluegill mortality rates. Bluegills undergo a major niche shift during ontogeny, moving from the protection of the littoral zone as juveniles to open water as adults (Mittelbach and Osenberg 1993). In lakes with low DOC concentrations, juveniles may seek the protection of the littoral zone for a longer period of time because predators are more likely to prey on bluegills in lakes with high visibility than in shaded lakes. This would explain the higher occurrence of larger juveniles in transparent lakes. Higher primary production may also explain this pattern. Transparent lakes typically have high levels of primary productivity due to increased sunlight penetration. Therefore, lakes with low concentrations of DOC likely have more available energy in the food web, resulting in an overall healthier fish condition.

Fish health or condition is an important variable to consider when comparing populations of bluegills across lakes with varying DOC concentrations. Fish condition is related to the age and size at which fish reach adulthood (Morgan 2004). Poor fish condition can result in increased mortality and lower potential fecundity, severely impacting population sizes. Poor condition is typically associated with low energy reserves resulting from reduced feeding or unfavorable environmental conditions. Several environmental stressors can affect bluegill health and growth rates, especially water temperature. Bluegill growth rates significantly decrease with lower water temperatures (Olson 1996). Cooler temperatures can therefore delay bluegill spawning and increase susceptibility to predation due to delayed growth. Hummingbird Lake exhibited the lowest average bluegill length and weight and also has the lowest average lake temperature (9.6 °C) compared to Bay Lake (17.3 °C), Crampton Lake (16.8 °C), and Morris Lake (15.3 °C) (Craig *et al.* 2015). Therefore, temperature may help explain both the bluegill size trends and the overall fish condition in each lake.

Another likely explanation for the large discrepancy in bluegill size between lakes is the presence of large predators. The largest bluegill caught in Hummingbird was 5.6 cm and 2 g, while the largest bluegill caught in Crampton Lake was 11.6 cm and 20 g. Hummingbird Lake has a large population of largemouth bass, which are one of the primary predators of bluegills. Juvenile largemouth bass share the same habitat as juvenile bluegills before the bass move from the littoral zone vegetation to the open-water limnetic zone as adults (Olson 1996). Therefore, there are likely few large juvenile bluegills in Hummingbird Lake because few survive to adulthood.

High intraspecific competition may also have a large impact on the size distributions of bluegills. Lakes with large populations of juvenile bluegills have higher levels of intraspecific competition due to limited resources, thereby also contributing to bluegill mortality rates. Lake replication was vital in this study because each lake is different in terms of water chemistry as well as fish community structure. A large sample size was also important because I was not able to tag each individual fish; therefore, it is possible that some fish were recaptured. In the future, this could be corrected by using tags to keep track of fish that were already caught.

The findings of this study support the hypothesis that bluegills exhibit smaller size distributions in lakes with high DOC concentrations compared to low DOC concentrations. However, without further study, it is impossible to determine whether this pattern is due to lower primary productivity, higher predation on bluegills, higher intraspecific competition, or if these factors work synergistically. Although the cause of these differences in size distributions could not be determined, this study provides new information about the impact of DOC on the size distributions and condition of bluegill sunfish as well as possibly many other freshwater fish that inhabit these lakes.

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## Tables and Figures

Table 1. DOC concentrations in each lake.

| Site | DOC Concentration (mg/L) |
|---|---|
| Bay lake | 6.1 |
| Crampton lake | 5.3 |
| Hummingbird lake | 19.9 |
| Morris lake | 15.7 |

Table 2. P-values from Kruskal Nemenyi test comparing length of bluegills across all four lakes. Values below 0.05 indicate significance.

| | Bay | Crampton | Hummingbird |
|---|---|---|---|
| Crampton | 3.3e-14 | - | - |
| Hummingbird | 0.82 | 3.4e-14 | - |
| Morris | 1.6e-05 | 8.0e-06 | 1.7e-07 |

Table 3. P-values from Kruskal Nemenyi test comparing weight of bluegills across all four lakes. Values below 0.05 indicate significance.

| | Bay | Crampton | Hummingbird |
|---|---|---|---|
| Crampton | 1.1e-13 | - | - |
| Hummingbird | 0.0039 | 1.8e-14 | - |
| Morris | 5.5e-06 | 0.0275 | 4.4e-14 |

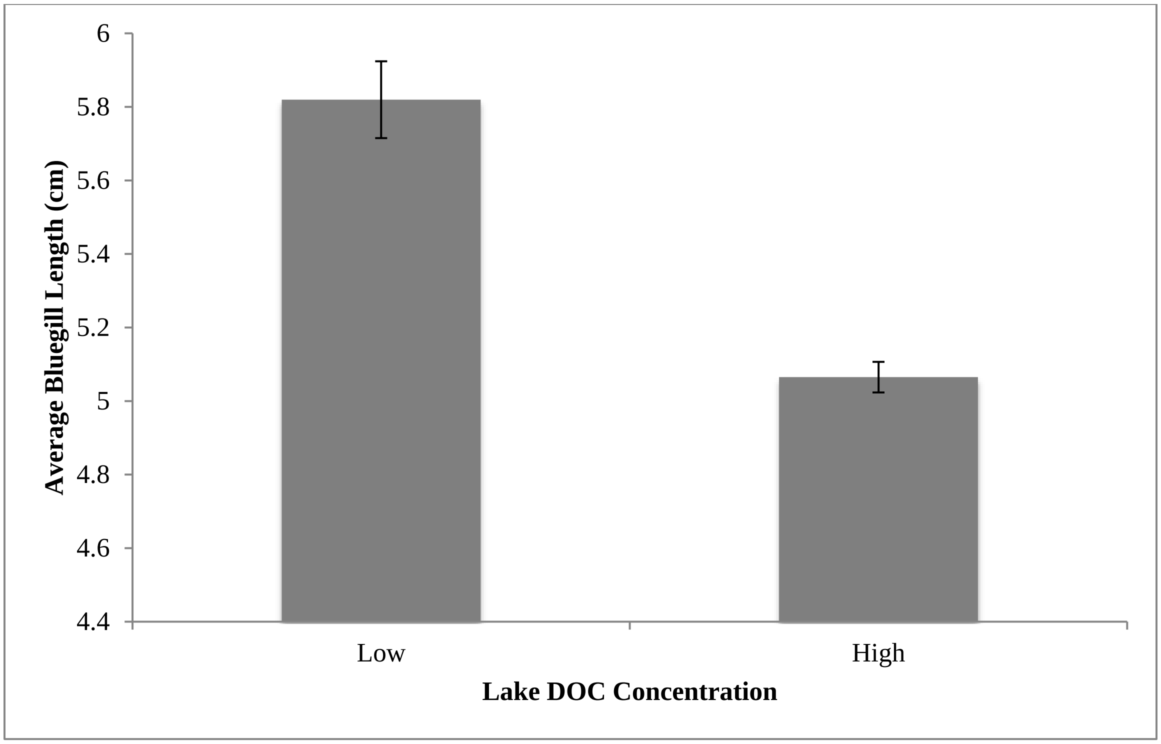

Figure 1. Average bluegill length in lakes with low DOC concentrations (mean ± SE; 5.82 ± 0.104 cm) and high DOC concentrations (5.065 ± 0.0416 cm). There is a significant difference in bluegill length between DOC concentrations (df = 3; p = 0.00094), suggesting that DOC negatively affects the growth rates of bluegills.

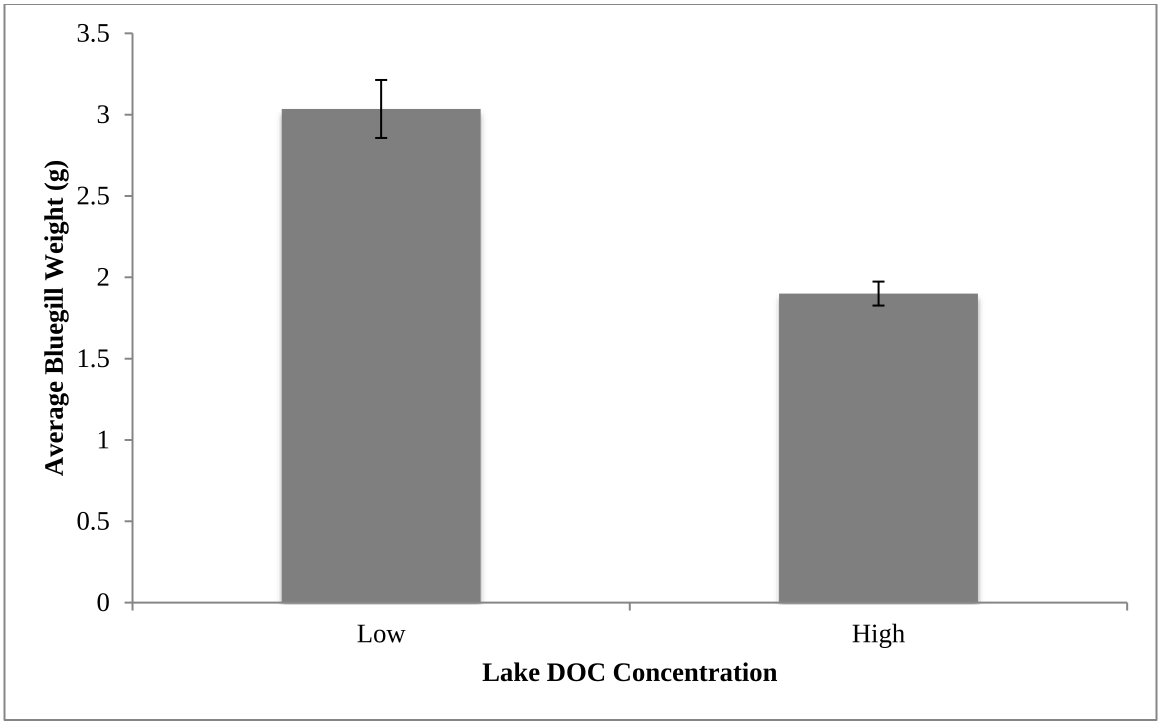

Figure 2. Average bluegill weight in lakes with low DOC concentrations (mean ± SE; 3.035 ± 0.178 g) and high DOC concentrations (1.9 ± 0.0737 g). There is a significant difference in bluegill weight between DOC concentrations (df = 3; p = 7.855e-05).

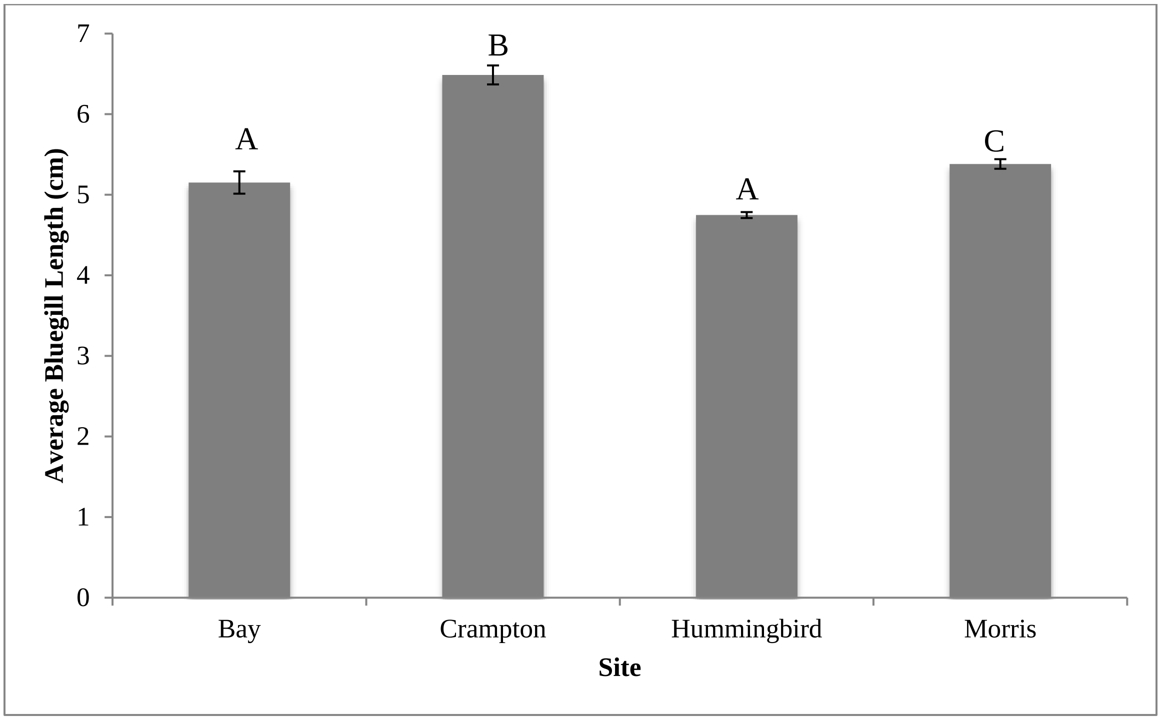

Figure 3. Average bluegill length in Bay Lake (mean ± SE; 5.512 ± 0.139), Crampton Lake (6.487 ± 0.118), Hummingbird Lake (4.748 ± 0.0371), and Morris Lake (5.382 ± 0.0596). All lakes are significantly different from each other with the exception of Hummingbird Lake and Bay Lake (Table 2, p = 0.82).

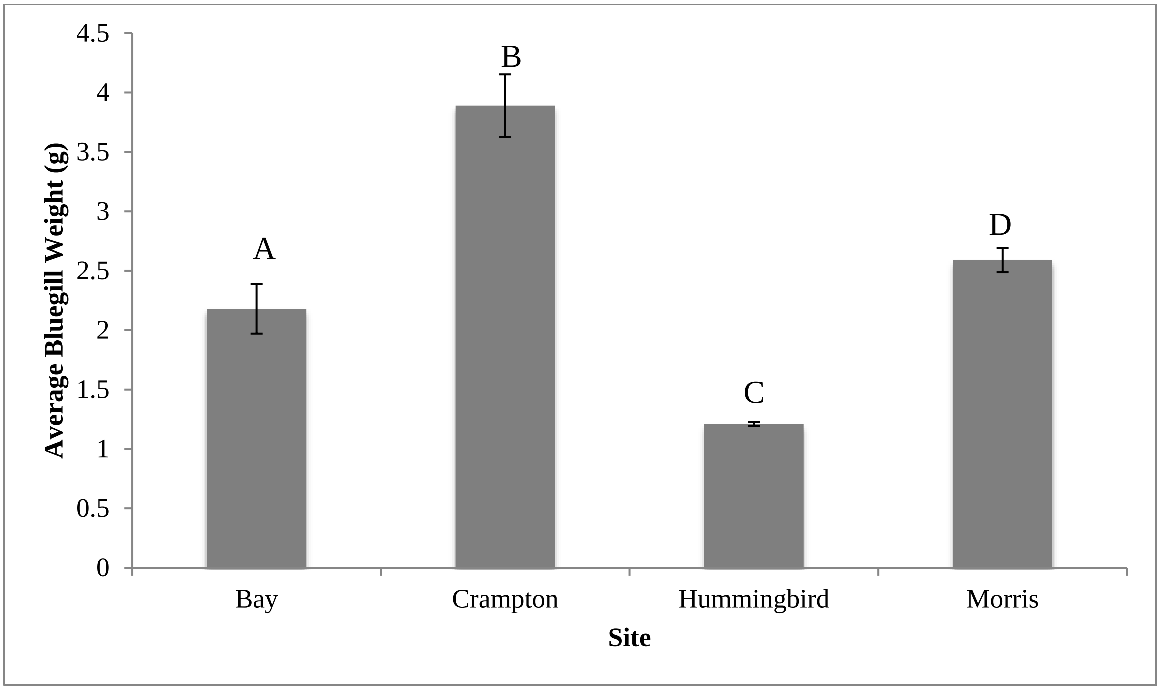

Figure 4. Average bluegill weight in Bay Lake (mean ± SE; 2.18 ± 0.209), Crampton Lake (3.89 ± 0.263), Hummingbird Lake (1.21 ± 0.0166), and Morris Lake (2.59 ± 0.103). All lakes are significantly different from each other (Table 3).