

Effects of turbidity and light availability on consumption rate
and feeding behavior in
Rhinichthys atratulus (Eastern blacknose dace)



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Abstract

Anthropogenic activities alter turbidity level and light availability in freshwater ecosystems through anthropogenic climate change and deforestation. Changes in turbidity and light availability often influence fish foraging, predator response, and mate selection, which can shift community composition and alter ecosystem dynamics. In this study, we investigated the influence of a range of turbidity levels (0, 3.5, 6, 10, 20, 22, 25, and 35 NTU) and light levels (400 lx and 1000 lx) on prey consumption in *Rhinichthys atratulus* (Eastern blacknose dace), and we ran a preliminary study on reactive distance, comparing the reactive distance between the 0 NTU low light and 6 NTU low light conditions. We found differences in prey consumption as a function of turbidity under both high light and low light conditions. Within each turbidity level, prey consumption only varied based on light level at 25 NTU, with increased consumption under the lower light level (400 lx). Prey consumption increased at moderate turbidity levels (6 NTU, 10 NTU) under both light levels, likely due to decreased anti-predator behavior as the turbid water can be perceived as a refuge from predators. Prey consumption also increased at higher turbidity levels (25 NTU, 35 NTU) perhaps due to a reliance on senses other than vision. Reactive distance decreased in 6 NTU treatments compared to 0 NTU treatments, likely as a consequence of reduced visual range. These results indicate that relatively low magnitude changes in turbidity level and light availability can significantly influence prey consumption and foraging behavior in blacknose dace, which has major implications for aquatic communities. Since anthropogenic changes in light availability and especially turbidity level affect foraging behavior in blacknose dace, these factors could influence blacknose dace population size and community dynamics.

Introduction

High turbidity of freshwater systems can result from various anthropogenic factors. As a consequence of anthropogenic climate change, an increased frequency of heavy precipitation events is expected (IPCC 2013). Heavy rainfall carries organic matter, soil, and sand particles into bodies of water, which increases water turbidity. Similarly, inputs of organic matter result in eutrophication and algal blooms, which further increase water turbidity (Utne-Palm 2001). Agriculture and deforestation are also often responsible for increased sediment input to

freshwater systems, as these land-use practices result in increased soil erosion (Wolanski et al. 2004).

Turbidity has been shown to alter community structure through benthic smothering, reduced penetration of light for photosynthesis, and reduced visual range of sighted organisms (Vogel and Beauchamp 1999). Diminished visual range can have various behavioral effects on individuals, including altered foraging, predator response, and mate selection (Gregory 1993; Vogel and Beauchamp 1999; Seehausen et al. 1997).

Along with turbidity, light availability also influences an organism's visual range. Light intensity fluctuates constantly, depending on time of day, shading by plants, and amount of cloud cover. Anthropogenic climate change influences light availability through changes in cloud cover (Groisman et al. 2004) as well as changes in the distribution of shade-producing trees, such as the Eastern Hemlock and Carolina Hemlock (Paradis et al. 2007).

Underwater irradiance is absorbed and scattered by particles, such as plankton or sand. Up to a specific saturation level, increased light intensity positively affects the visual range of fish; however, past this saturation level, light intensity can negatively affect the visual range of fish due to backscattering, which decreases the contrast between an object and its background (Vinyard and O'Brien 1976; Lythgo 1979; Utne-Palme 2002). Above the saturation level, the negative effects of backscattering become stronger with higher turbidities (Utne-Palme 2002). Fluctuation in light availability can have significant impacts on fish feeding behaviors. For example, reaction distance of yellow perch was found to decrease as light intensity decreased (Richmond et al. 2004). Similarly, reaction distance of lake trout decreased with diminished light intensity as well as with increased turbidity (Vogel and Beauchamp 1999).

In this study, we investigated how light intensity and turbidity influence consumption rate and reactive distance in *Rhinichthys atratulus* (Cypriniformes, Cyprinidae; common name: Eastern blacknose dace) in a laboratory setting. To our knowledge, no study has investigated the effects of these factors on foraging in blacknose dace. We expected increased consumption at moderate turbidity levels compared to lower turbidity levels due to decreased anti-predator behaviors. Additionally, we expected increased consumption at high light levels compared to lower light levels due to increased visual range, which is optimal for visual foraging. Finally, we expected reaction distance to decrease as turbidity increased, as a consequence of decreased visual range.

Methods

Rhinichthys atratulus (Cypriniformes, Cyprinidae; common name: Eastern blacknose dace) inhabit Atlantic slope drainage basins from Nova Scotia to South Carolina and Lake Ontario (Jenkins and Burkhead 1994). They prefer rocky or cobble bottom headwaters or small rivers, often resting on the bottom under or beside rocks in pools or slower runs (NatureServe 2013). Their diet is composed of algae and benthic macroinvertebrates, and they often feed in the morning (Tarter 1970). Average length of adult blacknose dace is 5.7 cm, although they can reach up to 12.4 cm in length (Paige and Burr 2011). Length of individuals used in this study ranged from 2.4 - 5.6 cm. Blacknose dace are also an essential bait species, and serve as prey for higher trophic level species, such as trout (Scott and Crossman 1973).

We collected blacknose dace from a reach of the Battenkill River located in Greenwich, New York on January 29th, 2017 using a seine net (1.5 x 3 m, 0.32-cm mesh), and we transported 60 individuals to a laboratory at Skidmore College (Saratoga Springs, NY) in two coolers. Once in the laboratory, the lids to the coolers were propped open, and the blacknose dace remained in the coolers for four days while they acclimated. Subsequently, we moved the blacknose dace into two 20-gallon holding tanks (30 individuals / tank) when the temperature of the water in the coolers was similar to the temperature of the water in the holding tanks. Holding tanks were filled with stream water collected from a small tributary in Saratoga Springs, NY. The bottom of each holding tank was covered in rounded cobbles, and two aerators were present in each holding tank. We fed the blacknose dace 200 bloodworms twice per day.

We ran two experimental trials daily from February 8th, 2017 through February 24th, 2017. There were six 10-gallon experimental tanks, which had glass sides covered in laminated black paper to prevent light from entering the tanks from the sides and mimic natural stream conditions. Experimental tanks also contained a pile of two to three cobble-sized rocks. Two hours prior to each experiment, we moved two individuals into each experimental tank using aquarium nets, and measured the length of each fish using calipers or rulers. After the blacknose dace acclimated to the experimental conditions for two hours, we placed an opaque plastic divider in each tank with both individuals on the same side, and we added 15 bloodworms to the tank on the other side of the divider. The plastic divider was removed after 30 seconds, and the blacknose dace were allowed to forage for 10 minutes, after which, we returned the blacknose dace to a holding tank using aquarium nets. Any remaining bloodworms were removed from the

experimental tanks using aquarium nets and counted. We calculated prey consumed for each experimental tank by subtracting the number of remaining bloodworms from the 15 original bloodworms.

Treatments for experimental tanks consisted of 8 turbidity levels: 0, 3.5, 6, 10, 20, 22, 25, and 35 NTU (nephelometric turbidity units). This range of turbidity levels is similar to conditions found in the Battenkill River. We established turbidity levels using bentonite, and turbidity levels were verified using a turbidity meter (Hach 2100P). These experimental tanks were aerated at all times besides the 10 minutes of foraging associated with each trial. Turbidity was verified and readjusted before the blacknose dace were moved into experimental tanks and before bloodworms were added to each tank. After each trial, we again verified turbidity level and found a negligible settling rate of bentonite during each trial. For each turbidity level, two light conditions were tested: high light (1000 lx) and low light (400 lx). After each experimental trial, the two blacknose dace were returned to a new holding tank that only contained individuals who had already been exposed to that specific treatment. Each individual was never exposed to the same treatment twice.

The experimental tanks were divided into two groups of three tanks that were at different turbidity levels. First, we tested 0 and 20 NTU, then 3.5 and 22 NTU, followed by 6 and 25 NTU, and finally 10 and 35 NTU. The blacknose dace were maintained in their two original groups of 30 individuals for the entire study, with one group exposed to a turbidity level at only high light conditions, while the other group was exposed the same turbidity level at only low light conditions in order to eliminate exposure of the same fish to the same turbidity level multiple times. Group 1 of blacknose dace was exposed to the 0 NTU treatment at high light, while Group 2 was exposed to the 20 NTU treatment at high light. Following these trials, Group 1 was exposed to the 20 NTU treatment at low light, while Group 2 was exposed to the 0 NTU treatment at low light. Next, Group 1 was exposed to the 3.5 NTU treatment at high light, while Group 2 was exposed to the 22 NTU treatment at high light, and so on for all pairs of turbidity levels and light levels. We followed this pattern in turbidity and light level treatments in order to minimize pseudoreplication.

Two experimental tanks were equipped with GoPro cameras, and we recorded 16 trials of 0, 3.5, 6, and 10 NTU treatments, eight under high light conditions and eight under low light conditions. Using PremierePro, we exported stills from the videos that displayed reactive

distance. Reactive distance was measured as the distance between the blacknose dace and its prey (a bloodworm) when the individual first oriented itself toward a bloodworm before continuing forward to consume it in one continuous motion. Then, using ImageJ, we measured the reactive distance in centimeters. We focused on measuring reactive distances in the 0 NTU and 6 NTU treatments under low light conditions as a preliminary study on blacknose dace reactive distance.

Since our consumption data was not normally distributed (Shapiro-Wilks: $p > 0.05$), we analyzed this data using nonparametric statistics. Using Kruskal-Wallis tests, we analyzed bloodworms consumed as a function of turbidity level under both high light and low light conditions. Additionally, we ran Mann-Whitney paired tests at each turbidity level to test for differences in consumption between the high light condition and the low light condition. A Kendall's Tau-b was used to analyze whether there was a correlation between the average length of the two fish in the trial and the number of bloodworms consumed. For this test, we used the average length of the two fish present in the trial. Finally, we ran a T-test to analyze whether reactive distance varied significantly between the 0 NTU low light conditions and the 6 NTU low light conditions. The T-test and Kruskal-Wallis tests were conducted on JMP Pro 11.0.0, while the Mann-Whitney paired tests and Kendall's Tau-b test were conducted on SPSS.

Results

Consumption of bloodworms varied significantly under low light conditions ($X^2_{7, 95} = 39.198$, $p < 0.001$) as well as under high light conditions ($X^2_{7, 90} = 33.302$, $p < 0.001$; Fig. 1). There was no significant difference between consumption in high light compared to low light conditions for all turbidity levels ($p > 0.05$) except at the 25 NTU turbidity level ($U = 29$, $n = 23$, $p = 0.023$). At 25 NTU, 12.3 ± 0.67 (mean $\pm$ 1 SEM, here and following) bloodworms were consumed under low light conditions, which is around 25% greater than the 9.1 ± 0.76 bloodworms consumed under high light conditions. Average length of the two fish in each tank was also correlated with number of bloodworms consumed ($T_b = 0.257$; $N = 185$; $p < 0.001$).

Reactive distance was greater in the 0 NTU low light treatment compared to the 6 NTU low light treatment ($T_{18, 35} = -2.05$, $p = 0.027$). In the 6 NTU low light treatment, reactive distance was 1.9 ± 0.05 cm, which is over 33% shorter than the reactive distance of 3.0 ± 0.5 cm in the 0 NTU low light treatment (Fig. 2).

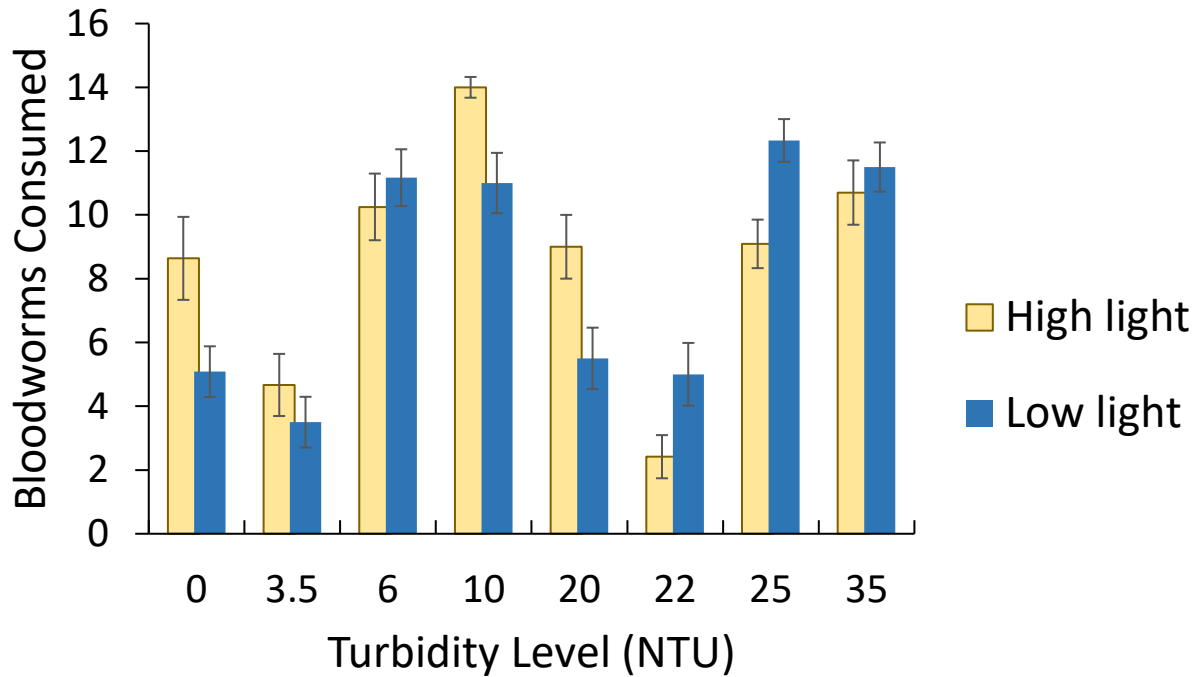


Figure 1. The number of prey consumed by blacknose dace varied based on turbidity level under both high light ($X^2_{7, 90} = 33.302, p < 0.001$) and low light ($X^2_{7, 95} = 39.198, p < 0.001$) conditions. At every turbidity level, the number of prey consumed was statistically similar between the low light and high light treatments ($p > 0.05$), except at 25 NTU, with more prey consumed in the low light treatment than in the high light treatment ($T_b = 0.257$; $N = 185$; $p < 0.001$). Error bars represent one standard error.

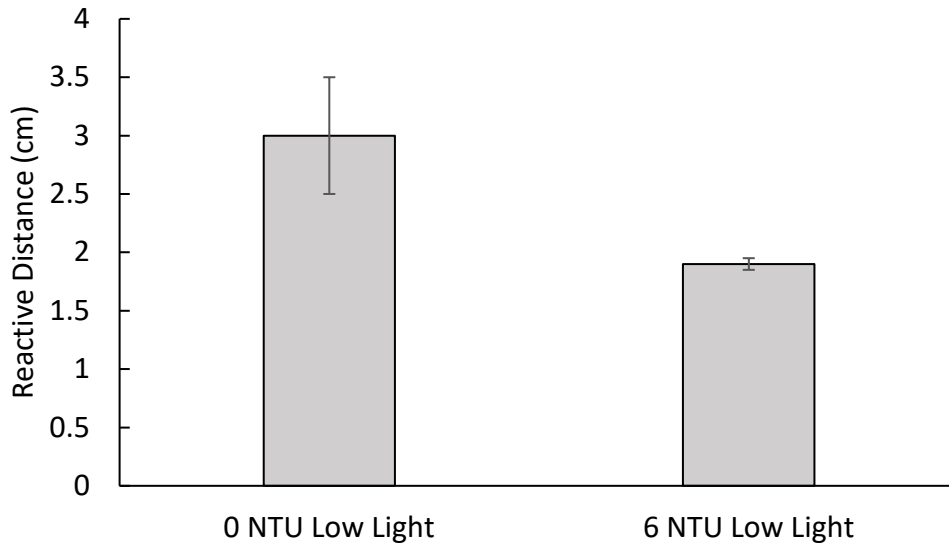


Figure 2. Reactive distance of blacknose dace was greater under the 0 NTU low light treatment compared to 6 NTU low light treatment ($T_{18.6, 35} = -2.05$, $p = 0.027$). Error bars represent one standard error.

Discussion:

As shown in this study, light level had no significant impact on foraging in almost all circumstances; however, consumption varied significantly based on turbidity and length of blacknose dace. Our results showed the highest consumption for blacknose dace being at moderate (6 NTU, 10 NTU) and extreme (25 NTU, 35 NTU) turbidity levels. These findings somewhat vary from results found on the impact of turbidity on foraging in other species. In fact, the rosieside dace, a very similar relative of the blacknose dace, displayed a significant negative curvilinear relationship between turbidity and capture success (Zamor and Grossman 2007). Many other laboratory studies have found similar results as the rosieside dace, with an overall negative trend between turbidity and consumption in species such as the fountain darter and the gulf killifish (Becker et al. 2016; Benfield and Minello 1996; Vinyard and Yuan 1996).

While the increase in consumption at moderate and extreme turbidity levels in the blacknose dace is unusual compared to these studies, there are many likely explanations for these results, the first of which being alterations in anti-predator behavior. Increased turbidity levels have been shown to influence an individual's awareness of predation risk in a variety of species across the United States (Gregory 1993; Gregory and Northcote 1993; Lehtiniemi 2005). The

increase in consumption at 6 NTU and 10 NTU found in our study can potentially be explained by this heightened perception of predator protection; these levels of turbidity may still be clear enough to allow for effective foraging, however the fish may also perceive this level of cloudiness to be a refuge from predators. In some cases, increased turbidity can also increase the contrast between prey and its background, also known as the “physical effect hypothesis” (Hinshaw 1985). If this is acting in our system with the blacknose dace, it is plausible that we see an uptick in foraging at 6 and 10 NTU as a result of increased contrast, and therefore a heightened ability for the fish to see the prey.

The increase in consumption at 25 NTU and 35 NTU is also notable for being unlike the results found among other species. Many studies on juvenile and adult aquatic species show the lowest consumption being at the highest turbidity levels (Vinyard and Yuan 1996; Wellington et al. 2010; Zamor and Grossman 2007). We hypothesize that the increase in foraging in blacknose dace at these extreme turbidity levels may be the result of switching from visual foraging techniques to other sensory systems, such as a lateral line system or olfactory cues. Non-visual cues, particularly the lateral line system, have proven to be critical to foraging success in species such as torrentfish, mottled sculpin, and common bullies in habitats with either extremely low light availability or high turbidity (Montgomery and Milton 1993; Hoekstra and Janssen 1985; Rowe and Dean 1998). Our results support this trend where after the water passes a threshold of turbidity somewhere between 22 NTU and 25 NTU, the blacknose dace begin to rely heavily on non-visual cues for foraging due to a severe reduction in their visual range at these high turbidities. This is arguably a very successful strategy for this species because by potentially switching to non-visual mechanisms, the fish were able to increase their foraging again at these extreme conditions.

The final inconsistency we found in our results compared to our hypotheses was the trend for an increase in foraging under low light conditions compared to high light at 22 NTU and above. There was only a significant difference between light conditions at the 25 NTU level, however the trend is still worth discussing. We expected that because of the effect that ambient light level has on visibility by fish underwater, consumption would always be greater under the high light conditions (Utne-Palm 2002). However it is possible that the combination of high light with high turbidity actually inhibited foraging for the blacknose dace. Once the light intensity passes the light saturation threshold for a fish species, a high light setting can become

problematic. In order for a fish to see its prey, the fish must be able to distinguish the prey from its background. Therefore, there must be high contrast between the prey and its surroundings (Utne-Palm 2002). This contrast is drastically reduced when backscattering increases (Ranaker et al. 2012); it is likely that at 22 NTU and above, a higher light setting is disadvantageous for the blacknose dace due to increased backscattering off bentonite particles, making the low light setting more successful for individuals at the higher turbidity.

In our preliminary study of reactive distance at 0 and 6 NTU we found that at higher turbidities, the reactive distance of the fish decreased. These results were exactly as expected because visual range in aquatic species is often predicted to decrease following a non-linear trend as turbidity increases (Aksnes 1993). Many other studies have found similar results in which the reactive distance of a species decreased at an exponential rate as turbidity increased (Sweka and Hartman 2003; Vogel et al. 1999). While our study did not determine whether reactive distance decreased exponentially with turbidity for the blacknose dace, it did confirm that reactive distance was still negatively impacted by low levels of turbidity within this species.

Overall, it is clear that foraging for this species may be altered with climate change. Consumption for the blacknose dace is highest at moderate (6 NTU, 10 NTU) and extreme (25 NTU, 35 NTU) levels of turbidity, however light alone typically did not have a significant effect. These changes in foraging with turbidity have the potential to yield extreme shifts in ecosystem dynamics within a natural system through population changes and trophic cascades (Van de Meutter 2005). However in order to truly understand the mechanisms behind these changes in foraging behavior, future studies must be completed to better comprehend the system. It has been found that turbidity has no impact on foraging for species that rely on chemosensory techniques rather than visual cues (Lunt and Smee 2015). In order to determine if the blacknose dace utilize another sensory system for foraging at higher turbidities, alternate studies should be completed involving the removal of visual systems from the fish during foraging. The effect of humic water conditions on the foraging of blacknose dace is also of interest; due to the different properties between humic brown water and turbid water, foraging of aquatic species has been shown to be impacted differently between these two conditions (Jönsson et al. 2013). Since climate change will also cause changes in water color from the influx of organic substances into aquatic systems, similar studies should be completed on blacknose dace in order to determine the effect of light and water brownification on foraging.

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