The effect of turbidity on the diet of Longfin Smelt (*Spirinchus thaleichthys*) in Lake Washington

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Abstract

Longfin smelt (*Spirinchus thaleichthys)* are a species of small fish that inhabit lakes, estuaries, and marine waters of the Pacific coast of North America. Longfin smelt are visual predators, meaning they use sight to find their prey, and they are known to consume zooplankton, including cladocerans and copepods. Turbidity, a measure of water clarity, likely has an effect on their ability to find zooplankton as it impairs their sight. This paper investigates the question of how turbidity affects longfin smelt's prey choice between two common prey, cladocerans and copepods. This was accomplished by using data on the stomach contents of longfin smelt and secchi depth (a measure of turbidity) over fifteen years. The stomach contents were collected through dissection and stomach content analysis which involved quantifying and identifying the prey consumed by each individual smelt. The results show that an increase in secchi depth has an opposite effect on the type of prey consumed by longfin smelt. In clearer, less turbid, waters, the dominant prey is cladocerans, while in cloudier, more turbid, waters the dominant prey is copepods. These results appear to due to the size of prey, as cladocerans are larger, they are more positively selected for than copepods, which are generally smaller.

Key words: Secchi depth, visual predation, abundance, cladocera, copepod.

Introduction

Changing environmental conditions can influence organisms within the environment in different ways depending on the nature of the condition and the type of environment. In marine environments, the amount of dissolved oxygen plays a huge role in how active organisms in an area are, affecting feeding, breeding, and other behavior (Kramer, 1987). Dissolved oxygen can be affected by many different environmental variables, such as surface water agitation or the amount of respiration in the water column (Downing and Truesdale, 1955). In the rocky intertidal zone, organisms face constant changes in environmental parameters as the tides change and they go from submerged to immersed. This affects the humidity, temperature, salinity, amount of wave action, and risk of predation for many of the organisms in the intertidal, resulting in changes in behavior of those organisms (Tomanek and Helmuth, 2002). For example, the owl limpet (*Lottia gigantea*) is commonly found within the rocky intertidal zone of the west coast of the United States and eats algae off rocks when submerged, but has to change its behavior and stop eating algae so it can avoid desiccation and predation when emerged (Harley et al, 2009).

An environmental parameter that is highly variable and can have a large impact on many species of fish is turbidity. Turbidity is a measure of water clarity and is commonly taken as a measure of secchi depth. Depending on the species of fish and environment, changes in turbidity can have a range of consequences. Lake ecosystems can see increased turbidity when the amount of phytoplankton increases rapidly due to eutrophic conditions (Sinha et al, 2017). This can decrease the penetration of light in the lake, consequently decreasing the ability of organisms that rely on visual predation to find food (Gregory et al., 1998). Visual predation by planktivorous fish has been shown to be directly impacted by the level of turbidity by Confer et al (1978), when they showed that as turbidity increases, the distance by which fish react to prey in front of them also decreases. Turbidity has also been seen to affect the behavior of fish. In cichlid fish species of Lake Victoria, mating is based on the coloration and color morphs of potential mates. Turbidity decreases the ability of the cichlids to perceive color, resulting in less sexual selection among populations in more turbid waters (Seehausen, 1997).

Lake Washington is a freshwater lake located in Seattle, Washington that feeds into the Puget Sound estuary. The lake experiences a recurring algal bloom in the spring which increases the turbidity of the lake and likely affects the juvenile fish residing in the lake that rely on sight for predation (Arhonditsis, 2003). The lake is habitat for anadromous and non-anadromous juvenile fish, including sockeye salmon (*Oncorhynchus nerka*), threespine stickleback (*Gasterosteus aculeatus*), and longfin smelt (*Spirinchus thaleichthys*), that feed on zooplankton. Zooplankton commonly found in Lake Washington include species of copepods and cladocerans, and due to their abundance, they make up a large percentage of the diet of the juvenile fish in the lake (Hampton, 2006).

Lake Washington is also home to a long-term observational study conducted by the University of Washington. The University's study has compiled data on fish community of the lake collected via midwater trawl, as well as data on abiotic conditions like temperature and turbidity, the diet of collected fish, and zooplankton abundance in the spring from 1990 until 2019. Using data from the University of Washington, I investigated how the turbidity of Lake Washington affects the type of zooplankton consumed by longfin smelt. Longfin smelt were chosen as the subject of this study as they are by far the most common of the fish species caught and thus have the most data collected on them. The hypothesis for this study is that with increased turbidity, the ratio of the copepods to cladocerans should not change, as they are similar in size and color (Ebert and Dieter, 2005).

Methods

From 1990 to 2019, fish were collected in late April from east of Sand Point in Lake Washington via midwater trawls at depths of 10, 25, and 50 meters below the surface. These trawls were repeated two times in the afternoon and two times at night at each depth, corresponding to a total of twelve trawls per year. The net used was a modified Kvichak trawl with a square opening of 3.2 meters. Juvenile longfin smelt were collected and measured from the trawls and their stomach contents were analyzed later in the lab. Secchi depth was recorded each year by lowering a secchi disk into the water until the disk was no longer visible. The depth at which the secchi disk is no longer visible was recorded as secchi depth (Fish 312, 2020).

To collect data on the stomach contents, longfin smelt were dissected by making incisions in the esophagus and the posterior end of the stomach to remove the stomach. The stomach was then placed on a petri dish and opened using a scalpel and a magnifying glass. The contents of the stomach were washed out using squirt bottles and the types and abundance of prey consumed were quantified. Prey were identified as specifically as possible, usually down to the genus. Once stomach contents were recorded, the percent of each type of organism present in an individual’s stomach was calculated.

Data on the abundance of zooplankton in Lake Washington was collected by lowering a plankton net into the lake and collecting plankton. The abundance was determined for each species of plankton collected in terms of individuals per liter.

The diet data was analyzed by plotting the average percent of the two most abundant prey groups (cladocerans and copepods) against secchi depth. To achieve this, the data was filtered so that only secchi depths that contained data on cladocerans and copepods were used and only data from spring trawls were included. This was done to limit the amount of unknown variables. The abundance of zooplankton data was plotted against secchi depth to show the change in the amount of the cladocerans or copepods as a function of turbidity.

Results

I found that with an increase in secchi depth, the stomachs of longfin smelt contained higher percentages of cladocerans (Figure 1). The lowest percentage of cladocerans found in longfin smelt was 4.99% seen at a secchi depth of 3.5 meters, high turbidity, and the highest percentage was 72.3% seen at 10.7 meters, low turbidity. The difference between the minimum and the maximum percentages was 67.31 percent.

I also found that as the secchi depth increases, the percent of copepods in the stomachs of longfin smelt decrease (Figure 2). The lowest percentage of copepods found in longfin smelt was 1.94% seen at a secchi depth of 9.5 meters, low turbidity, and the highest percentage was 64.8% seen at 3.0 meters, high turbidity. The difference between the minimum and the maximum percentages is 62.31 percent.

The results show that change in turbidity (secchi depth) has an opposite effect on the type of prey consumed by longfin smelt. In clearer and less turbid waters, the dominant prey is cladocerans, while in cloudier and more turbid waters the dominant prey is copepods.

It was also found that as secchi depth increases, the abundance of cladocerans increases slightly (Figure 3) and the abundance of copepods stays roughly the same (Figure 4).

Discussion

The general trends seen show that as turbidity decreases, the percent of stomach contents that are cladocerans increase (Figure 1), and the opposite trend is seen for the percent of stomach contents that are copepods (Figure 2). These figures support the alternative hypothesis that the diet composition of longfin smelt changes with turbidity as more cladocerans are consumed in less turbid waters and more copepods are consumed in more turbid waters. However, this could be deceptive due to the limited sample size of diet data for the longfin smelt.

One potential explanation of this trend could come from a change in behavior of the prey in the presence of increased turbidity. E. Buskey (1984) found that if the increase in turbidity is caused by an increase in phytoplankton, then the amount of “pause behavior,” or stationary behavior, seen in copepods increases. This change in behavior could make it harder for the smelt to see copepods. If the copepods are not moving as frequently, it could force the smelt to rely more heavily on eating cladocerans. This might not be the case, however, because the movement of cladocerans also decreases as turbidity increases, and the two groups of zooplankton are close in size, meaning that the results seen likely come from factors other than a change in movement (Chen et al, 2012).

Another explanation for the increase in copepods and decrease in cladocerans in the diet of longfin smelt as turbidity increases could be that cladoceran abundance increases in less turbid waters, making them more available to the smelt in clearer waters. Figure 3 does show that this appears to be the case, despite missing some of the greater secchi depths seen in Figure 1. However, the other necessary component of this explanation is that copepod abundance should decline at greater secchi depths or decreased turbidities, and Figure 4 shows that this is not the case; the trend between copepods and secchi depth is almost flat. This leads to another potential explanation of the trends seen in Figure 1 and Figure 2; cladocerans could be the prey of choice for longfin smelt. Sibley and Chigbu (1994) found that longfin smelt showed “strong positive selection for *Daphnia* spp. and negative selection for copepod species.” This information does support the results seen, as with greater water clarity, the smelt consume more cladocerans. The reasoning for why smelt prefer cladocerans appears to be related to the size of zooplankton prey. Sibley and Chigbu (1994) saw that the size of *Daphnia* (a genus under the order cladocera) consumed by smelt were on average larger than those collected using plankton nets. That said, we do not have information on the size of the zooplankton that were consumed by smelt, so this is still just speculation.

In conclusion I found that secchi depth and cladoceran consumption are positively correlated and secchi depth and copepod consumption are negatively correlated. These results do not support my original hypothesis that there would be no change in diet with secchi depth. The results seem to be explained by the size of the prey leading to a preference in cladocerans as they are generally larger and have more caloric value than copepods. This could have an impact on the lake ecosystem when the spring algal bloom occurs increasing the lakes turbidity.

Because the smelt likely consume more copepods during this event, they could potentially compete with other planktivorous fish, and decrease the abundance of their competitors. This could include Sockeye salmon, a fish that many people consume regularly.

Some issues with the Lake Washington dataset limited the amount of data that could be used for this study. The dataset tracks secchi depth from 1990 to 2019, but only has consistent data on the diet of longfin smelt starting in 2004. This initially limited the sample size to sixteen years, but because of other holes in the diet analysis data, the final sample size was thirteen points. An example of a hole in the data would be if a year had data on cladocerans, but not copepods, it was excluded from the analysis. Another factor that limited the data was that some of the years had the same secchi depths, and in that scenario, the diet data was averaged so a single data point could be displayed for each secchi depth. This resulted in further reduction of data points to just nine. The issue of similar data could partially be mitigated by using a more precise instrument to measure turbidity, such as a turbidimeter, that would provide more precise data so there would be less bias in the turbidity data.

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Figure Captions:

Figure 1: Average percent of Cladocera found in stomachs of longfin smelt at different secchi depths (m). The regression line is in blue and the error for the regression line is in grey. Each point has an error bar that represents the variability of the data point.

Figure 2: Average percent of Copepods found in stomachs of longfin smelt at different secchi depths (m). The regression line is in blue and the error for the regression line is in grey. Each point has an error bar that represents the variability of the data point.

Figure 3. Cladocerans per Liter at different secchi depths (in meters). This data is only for spring. The regression line is in blue and the error for the regression line is in grey.

Figure 4. Copepods per Liter at different secchi depths (in meters). This data is only for spring. The regression line is in blue and the error for the regression line is in grey.

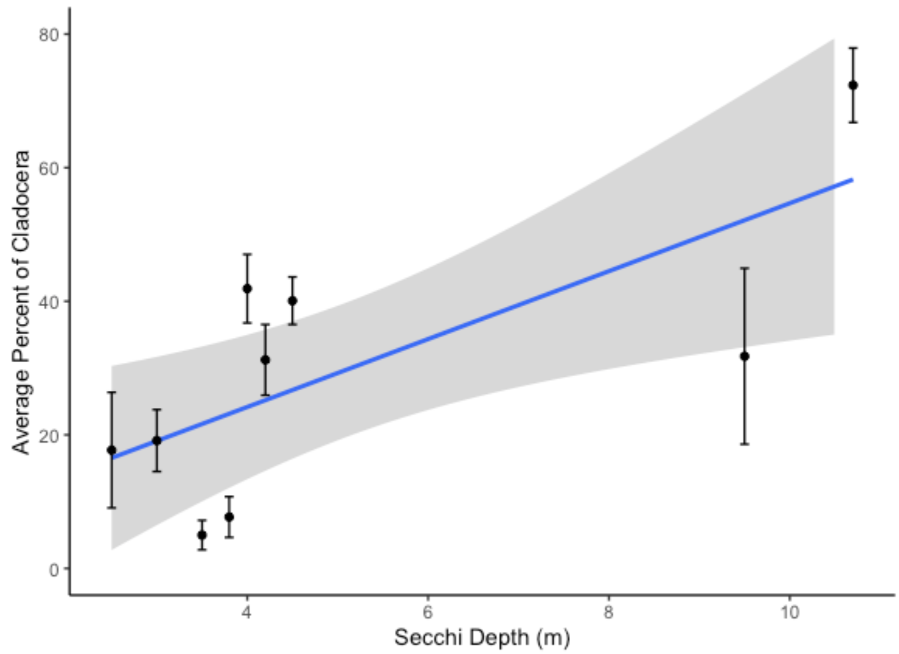

Figure 1

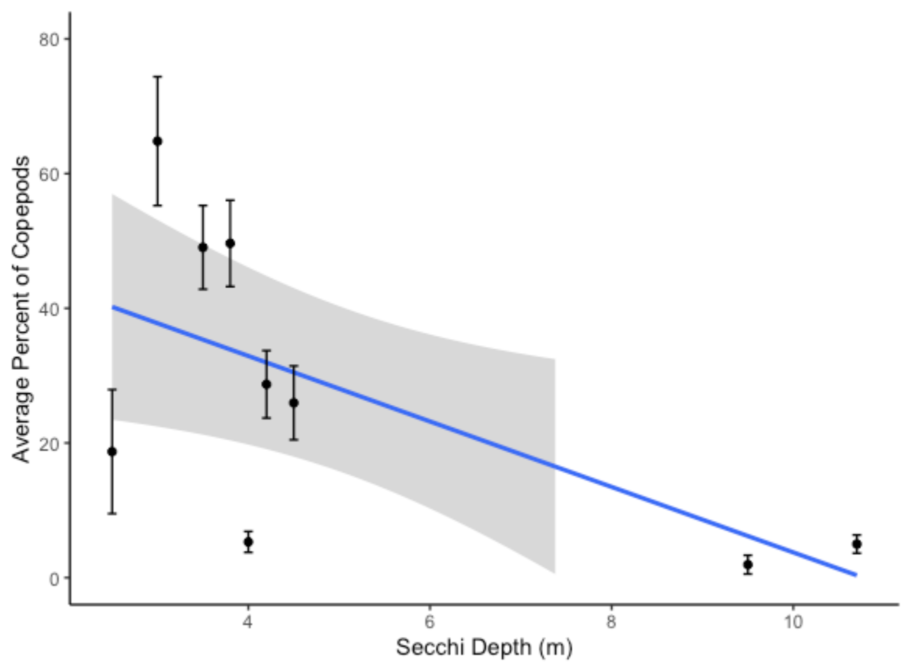

Figure 2

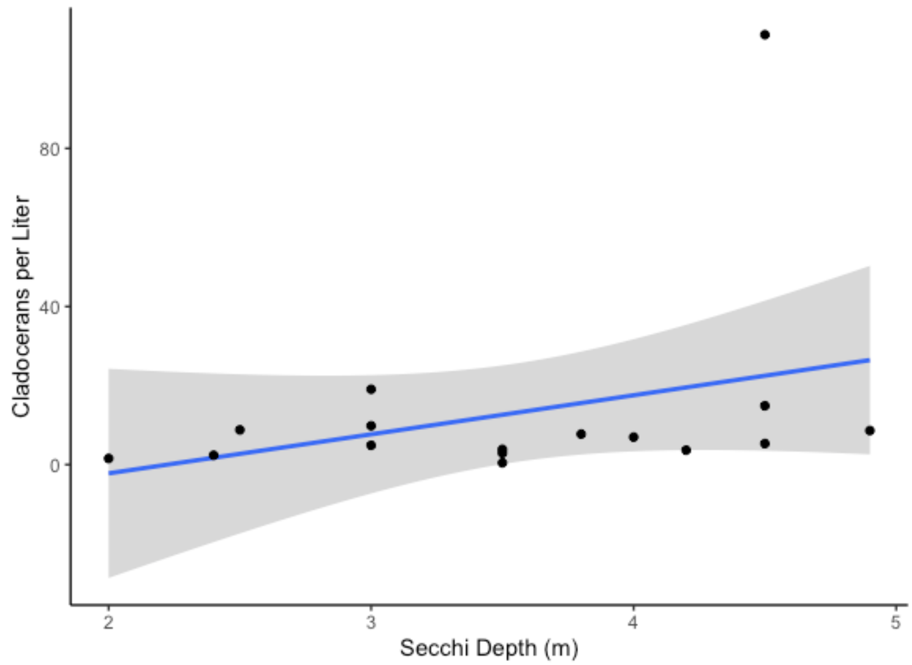

Figure 3

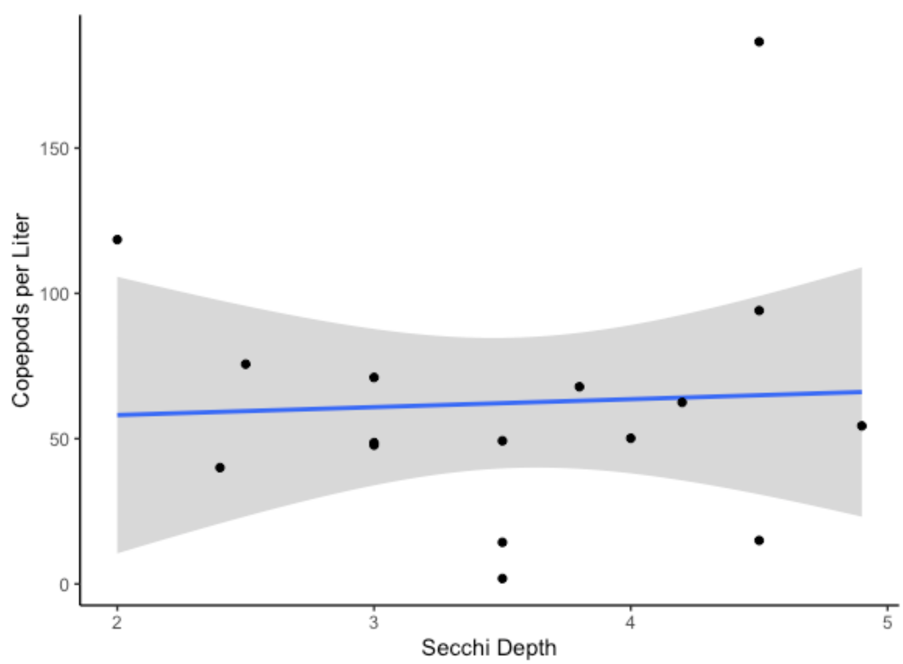

Figure 4