PREDICTING JUVENILE SOCKEYE SALMON MOVEMENT IN LAKE WASHINGTON USING A DIET ANALYSIS

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ABSTRACT

Sockeye salmon are a precious commodity in the State of Washington, with sockeye salmon spawning in streams and spending their juvenile stage in Lake Washington. This is a vulnerable time for the juveniles, as they accumulate energy to journey to the ocean and back, and one that greatly determines the yield of mature sockeye salmon that are caught and sold. With this study, we determined the feeding patterns of juvenile sockeye salmon in Lake Washington that use diel vertical migration, in order for fisherman to minimize the bycatch of juvenile sockeye salmon. The data analyzed in this study was obtained by trawling for juvenile sockeye at three different depths, shallow (10 m), intermediate (25 m), and deep (50 m), at two times of day, pre-dusk and post-dusk, and then cutting their stomachs open and recording if they were 0%, 25%, 75%, or 100% full. The average percent gut fullness was then calculated for each of the three depths at each of the two time periods. Through a t-test, F-test, ANOVA tests and Tukey HSD tests, we determined that the average percent gut fullness was significantly higher post-dusk than pre-dusk, and the average percent gut fullness was significantly less at a deep depth than at the shallow and intermediate depths. As juvenile sockeye salmon feed mostly post-dusk at or above 25 m, fishing at shallower depths of Lake Washington in a post-dusk time period is not optimal for getting a better return of mature sockeye salmon.

Keywords: Diel vertical migration; zooplankton; bycatch; trawling; gut fullness; salmon fitness

INTRODUCTION

Fisheries management is a highly studied topic given the economic importance of optimal harvesting, as increased yields result in greater revenue (Krebs 2001). Given the size of the fishing industry, there has been a pattern of dwindling fish populations in some areas due to overfishing since the 1920's (Krebs 2001). In order to effectively obtain the maximum sustainable yield of fish, i.e. the predicted population size of fish that produces the maximum number of individuals per unit of time, data must be collected on the specific behavioral patterns of the population in order to determine when and where to fish and where and when not to fish (Krebs 2001). This hypothesis cannot be studied effectively if the feeding behavior of the species is not known.

Considering species in the state of Washington, Fresh (1994) states that, "Arguably the most important fish in Lake Washington is sockeye salmon" because of it being commercially and recreationally harvested and intensively fished for sport. Sockeye salmon are therefore economically important to the state of Washington. For example, the Bristol Bay Salmon Industry extends from Alaska to Washington and beyond, but its supplies and services are purchased mostly by people in Washington State (Knapp et al. 2013). Sockeye salmon often spawn in streams and then the juveniles live in lakes for about 1 to 2 years before they migrate to the ocean for 1-3 years before returning to spawn (Rich et al. 2009). The period when juvenile sockeye salmon are living in a freshwater ecosystem is important because, at this time, they are not harvestable and the amount that survive their juvenile stage affects the amount of sockeye that are harvested later. By figuring out when and where juvenile sockeye salmon feed, it can be informative to fisherman where and when not to fish, in order to increase the amount of mature sockeye salmon.

In order to discover the feeding patterns of sockeye salmon, it is important to understand diel vertical migration (“DVM”) which Nelson and Perry (1990) define as “the cyclic changes in the position of the aquatic organisms in the water column that occur with 24-h periodicity.” DVM is an important behavior of fish movement and is important in predicting when and where fish feed. Scheuerell and Schindler (2003) describe DVM as a common behavior in freshwater fish such as juvenile sockeye salmon, and describe that juvenile sockeye typically inhabit deeper waters in the day than at night. One explanation for this could be the foraging-opportunity hypothesis, that states that fish perform DVM in order to “track their prey in space and time to maximize foraging” (Scheuerell and Schindler 2003). It can then be theorized that the sockeye salmon in Lake Washington follow their prey by performing DVM.

Juvenile sockeye salmon in Lake Washington primarily feed on zooplankton, specifically *Daphnia* (Hovel et al. 2019). *Daphnia* have been observed to exist most abundantly in the top 10 m of Lake Washington (Edmondson and Litt 1982). This raises the question, if zooplankton are more concentrated in the shallower depths of Lake Washington, then why are the sockeye salmon performing DVM? The explanation could be a combination of the foraging-opportunity hypothesis and the predator-avoidance hypothesis, which states that juvenile sockeye salmon move vertically in the water column to avoid visual detection from predators (Scheuerell and Schindler 2003). This would explain the behavior of juvenile sockeye salmon in Lake Washington, that reside at lower depths during the daytime to avoid visual detection from predators such as cutthroat trout, and at night migrate up to shallower depths in order to feed on the *Daphnia*.

With the knowledge of how juvenile sockeye salmon use DVM, it can be theorized where in the water column of Lake Washington sockeye salmon feed. The overall objective of the study was to determine the feeding behavior of sockeye salmon in Lake Washington by analyzing the gut content of juveniles at different depths, i.e. shallow, intermediate, and deep, at two different time periods, namely, pre-dusk, and post-dusk. The relationship between depth, time and gut contents of sockeye salmon was investigated by testing two hypotheses, namely, that: (1) the guts of sockeye salmon found at shallow depths would have a significantly higher average percent fullness than would the guts of sockeye salmon found in deep or intermediate depths; and (2) guts of sockeye salmon captured post-dusk would have a significantly higher average percent fullness than would guts of sockeye captured pre-dusk. The null hypotheses stated that: (1) there would be no significant difference between the average percent fullness of gut contents of sockeye salmon at shallow depths as compared to intermediate and deep depths; and (2) that there would be no significant difference in the average percent fullness of gut contents of sockeye captured pre-dusk vs. post-dusk.

METHODS

The data analyzed in this study were obtained from reoccurring long-term data collection in Lake Washington that started in 1990. The data collectors operated a mid-water trawl and the towing took place at the same location, east of Sand Point in Seattle, Washington. (Fish 312 course materials). The trawl was operated two different days per year, twice a day, once in the afternoon before dusk and once at dusk going into night, at three different depths, 10 m, 25 m and 50 m, for a total of twelve tows in each year (Fish 312 course materials). The net used had a square opening of 3.2 x 3.2 m and was a modified Kvichak trawl (Fish 312 course materials). All the fish were identified to species and measured unless they were too numerous, in which case the fish were counted and subsampled for length. (Fish 312 course materials). Once the sockeye salmon were identified, they were set aside for a diet analysis, where their stomach content was examined (Fish 312 course materials).

Sockeye salmon set aside for diet analysis were first measured for length and weight, and then dissected using a scalpel to open the abdominal cavity, exposing the stomach (Fish 312 course materials). A cut was made at the esophagus and at the posterior end, allowing the stomach to be carefully removed and placed into a petri dish where a cut was made along the stomach's long axis and pulled back to reveal its contents (Fish 312 course materials). The fullness of each fish was then estimated with a visual inspection and categorized the stomachs as empty, 25%, 50%, 75% or 100% full (Fish 312 course materials). After the fullness was assessed, the material in each stomach was removed with a squirt bottle and subjectively categorized as undigested, partially digested or fully digested (Fish 312 course materials). The contents were then identified and quantified as best as possible using figures and keys from the lab manual (Fish 312 course materials).

From the diet analysis data for all years from 1990 to 2019, the average percent fullness for all the years combined was calculated for sockeye salmon at the three different depths, shallow (10 m), intermediate (25 m) and deep (50 m). The average percent fullness of sockeye salmon between the two different time periods, pre-dusk and post-dusk, was determined by calculating the average start time of dusk, from the station data which ranged in time from 6:08PM to 9:40PM. I found this average dusk start time to be 8:34PM. Sockeye salmon caught before 8:34PM were categorized as pre-dusk, while sockeye salmon caught after 8:34PM were categorized as post-dusk.

RESULTS

The average percent fullness was calculated for the pre- and post-dusk groups of sockeye salmon, with pre-dusk sockeye salmon on average being 52.4%, and post-dusk sockeye salmon being on average 67.5% full. Sockeye salmon caught post-dusk were on average fuller than sockeye salmon caught pre-dusk, by a factor of around 15% (Figure 1). In order to determine if this difference was significant, a two-sample t-test was conducted assuming equal variance (p-value = 8.77E-09), finding a significant difference between pre and post dusk average percent fullness. Equal variance was confirmed from a two sample F-test (p-value = 0.08325).

The average percent fullness of sockeye salmon at different depths was determined by finding the average percent fullness of sockeye salmon captured and dissected at shallow (10 m), intermediate (25 m) and deep (50 m) depths. Sockeye salmon had highest average percent fullness at intermediate depths and lowest average percent fullness at deep depths (Figure 2). The results at the shallow depth were closer in terms of fullness to intermediate depths with an approximate 3% difference in gut fullness between these depth categories. In order to determine if these differences were significant, an ANOVA Single Factor test was run, providing a critical F value of 3.01 and a test F value of 20.73. Since the test F was the larger value it can be concluded that there is a significant difference in at least one of the three depth's average percent fullness. A Tukey HSD test was then run to see specifically which average percent fullness was significantly different from the others. The results provided the following P-values: between deep and intermediate, 6.01E-08; between deep and shallow 1.78E-06; and between intermediate and shallow, 0.72. From this it can be confirmed that the average percent fullness of sockeye salmon found in deep depths is significantly different from those found in shallow and intermediate depths, but average percent fullness is not significantly different between sockeye salmon found in shallow and intermediate depths.

The average percent fullness was then calculated for each of the three depths at each of the two times. All the depths in the post-dusk group had larger average percent fullness than the pre-dusk group with the only exception being shallower depths, where the pre-dusk shallow group had an average percent fullness that was approximately 7% greater than the post-dusk shallow group (Figure 3). A single factor ANOVA test with a Tukey HSD follow up revealed that sockeye salmon caught in shallow depths pre-dusk and sockeye salmon caught in shallow depths post-dusk are not significantly different with a p-value of 0.70.

DISCUSSION

My two hypotheses stated that: (1) the guts of sockeye salmon found at shallow depths would have higher average percent fullness than would the guts of sockeye salmon found in deep or intermediate depths; and (2) guts of sockeye salmon captured post-dusk would have a significantly higher average percent fullness than would guts of sockeye captured pre-dusk. As discussed below, we confirmed that juvenile sockeye salmon are fuller post-dusk, and there is some support that they are also fuller at shallower depths.

Regarding the first hypothesis, we found that the greatest percent fullness of sockeye guts occurred at intermediate depths (Figure 2). We also note that there was a statistically significant difference in at least one of the average percent fullness values at different depths (Figure 2). Through a Tukey HSD test, we confirmed that the average percent fullness at the deepest depth was significantly different than the average percent fullness at the intermediate and shallow depths, and the average percent fullness at the intermediate and shallow depths were not statistically different. From these observations, the first hypothesis is not supported, as the largest average percent fullness occurred at the intermediate depth, rather than at the shallow depth, although the values again, were not statistically different.

For the second hypothesis, there is a statistically significant difference in the average percent fullness between sockeye salmon caught in the post-dusk group and sockeye caught in the pre-dusk group, with the post-dusk group having higher average percent fullness, when looking at the combined data for the different times (Figure 1). This supports the second hypothesis. However, when looking at pre-dusk data versus post-dusk data for the different depths, we see that the average percent fullness at intermediate and deep depths is greater post-dusk as expected, yet average percent fullness at shallow depths is higher pre-dusk (Figure 3). When looking at the combined data for the depths, the second hypothesis is supported, but when we look at the data across depths, the second hypothesis is supported only at deep and intermediate depths, and not at shallow depths. The fact that the average percent fullness for fish caught pre-dusk in the shallow range is not significantly different from the average percent fullness of fish caught post-dusk in the shallow and intermediate depths, may be a function of the fact that much of the data were gathered in a narrow range of time around 8:34pm, the average time of dusk.

Considering related literature, a study done by Clark and Levy (1998) created a model of DVM of sockeye salmon in Great Central Lake, British Columbia and found that sockeye salmon perform DVM and come to shallower depths at dusk, in order to feed on zooplankton The results of the Clark and Levy study are therefore consistent with our findings that sockeye salmon are, on average, more full in post-dusk times than pre-dusk times. However, when it comes to depth, Clark and Levy (1998) found that sockeye come up to a maximum depth of around 15- 35 meters during DVM. This may explain why this study in Lake Washington had more average percent fullness at intermediate depths than shallower depths, given that “intermediate” depth was classified as 25 meters, which falls within the range of where sockeye salmon are found by Clark and Levy to feed. Looking at the data with this new perspective would support the first hypothesis that sockeye salmon are fuller in shallower depths, if “shallow” includes depths down to 35 meters.

Since it has now been confirmed that juvenile sockeye salmon do perform DVM in Lake Washington and are in shallower depths post-dusk in order to track their prey of zooplankton, it is important for fisherman to understand what this means for the population of sockeye salmon. The sockeye salmon in this study have not yet fully matured and are in their juvenile stage, and because of this, must adopt behavior such as DVM to account for their increased vulnerability to visual detection by predators (Eggers 1978). The juvenile salmon spend one year doing this until they have accumulated enough energy to make the journey to the ocean, where they finish maturing and return to freshwater to spawn and die (Eggers 1978).

With these juvenile salmon being in a more vulnerable position, they are susceptible to higher mortality if they are captured as bycatch and released back into the lake. Teffer et al. (2017) conducted a study where they found that adult sockeye salmon captured as bycatch were more susceptible to disease and that catch-and-release had negative impacts on survivability and reproduction, due to anaerobic activity and intracellular immune response. It is important to remember that these are adult sockeye salmon who have been exposed to many hardships such as the journey to the ocean and back, whereas juvenile sockeye salmon may be more delicate and are probably therefore more susceptible to negative long-term bycatch effects. Teffer et al. (2017) also discovered that the act of quickly tossing the salmon back into the water after being caught, although accepted as a good practice by fishermen, still has profound consequences on the fish's survival. It is then important that fisherman should try to avoid fishing techniques that produce bycatch such as trawling during post-dusk times at shallower depths on Lake Washington in order to allow the sockeye that inhabit the area to survive and be able to reach the ocean to mature and come back as fish that can then be caught and sold. In addition, the juvenile sockeye salmon need to be able to feed in order to obtain enough energy to make the journey to the ocean. If this feeding behavior is impaired or changed, it can potentially lead to a higher mortality rate for sockeye salmon making the journey there and back again. This is not only important for maintaining the ecosystem of Lake Washington, by raising salmon fitness, it is also important economically, by making sure that enough salmon are able to mature and become the size fishermen need to sell them effectively.

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Figure Captions

Figure 1: Average percent fullness of sockeye salmon captured and dissected pre-dusk, or before 8:34 PM, and post-dusk, after 8:34 PM.

Figure 2: Average percent fullness of sockeye salmon captured and dissected at three different depths, shallow (10 m), intermediate (25 m) and deep (50 m).

Figure 3: Average percent fullness of sockeye salmon captured and dissected at three different depths, shallow (10 m), intermediate (25 m) and deep (50 m), at two different times, pre-dusk and post-dusk

Fig. 1.

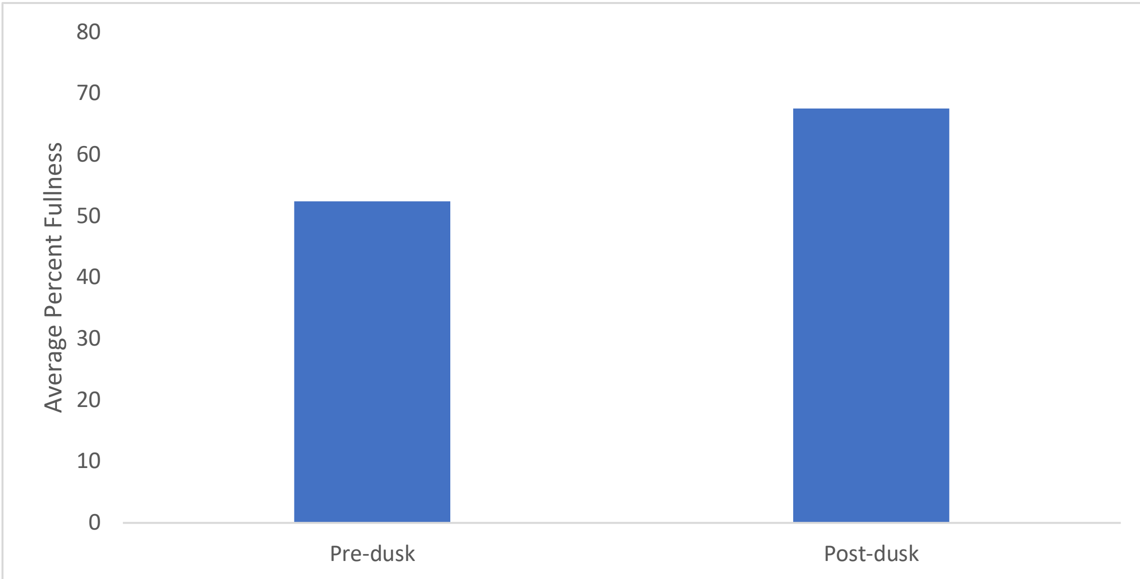
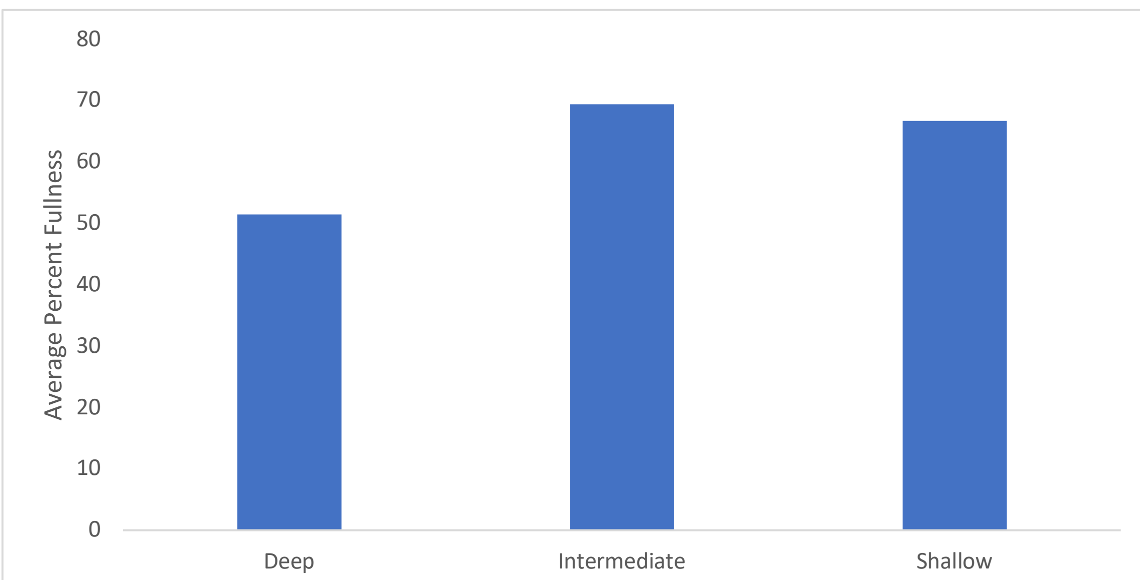
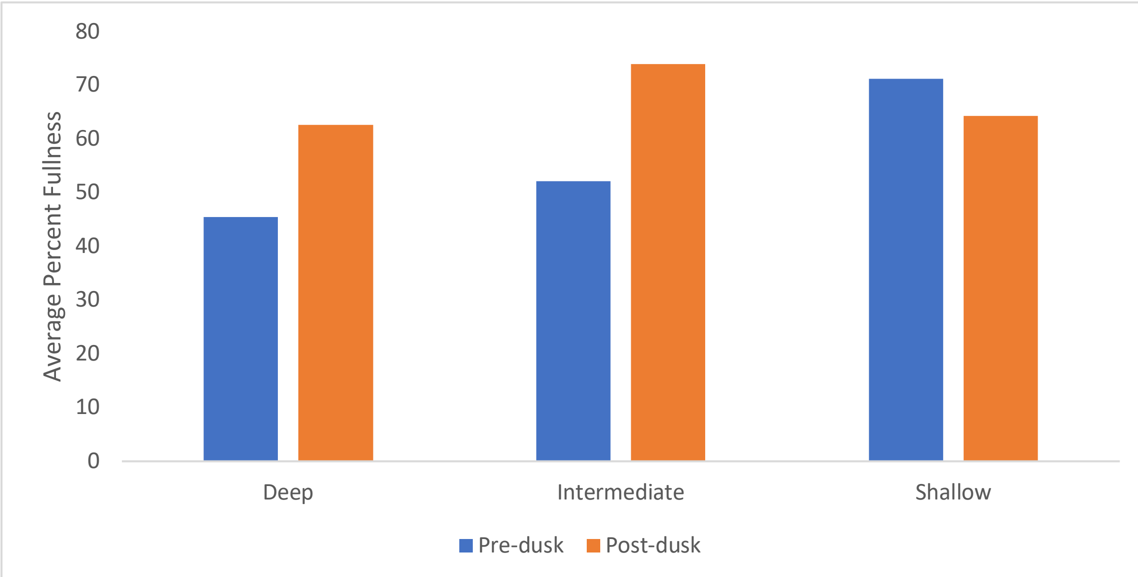

Average Percent Fullness
80
70
60
50
40
30
20
10
0
Pre-dusk
Post-dusk

Fig. 2.


Average Percent Fullness
80
70
60
50
40
30
20
10
0
Deep
Intermediate
Shallow

295 **Fig. 3.**



Average Percent Fullness
80
70
60
50
40
30
20
10
0
Deep
Intermediate
Shallow
Pre-dusk
Post-dusk