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Comparison of the Diets of Hatchery and Wild Subyearling Chinook Salmon in the Columbia River Estuary

by

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This paper was prepared
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for eight credits.

I dedicate this thesis to my family and friends, whom provide endless encouragement and love.

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ABSTRACT

Currently, Chinook salmon populations are declining (NRC, 1996). In the attempt to restore these populations, people have built hatcheries, which release fish into natural habitats (NRC, 1996; Olla *et al.*, 1998). Ideally, this influx of fish should take pressures off of wild populations, enabling them to recover. However, this solution may actually be responsible for worsening their decline (NRC, 1996; Daly *et al.*, 2011). The purpose of this study was to examine stomach fullness and contents of wild and hatchery subyearling Chinook salmon of two stocks. If the wild and hatchery salmon diets were similar, there would be potential for competition, which may result in further decline of wild populations.

In general, the results showed that the diets of hatchery and wild salmon were very similar, with only a couple of significant differences in prey items consumed. However, the diets of fish significantly differed between years and between months, which may have resulted from varying environmental factors. The overall similarities between diets of hatchery and wild salmon may point to competition for food. This is important to consider when managing the number of hatchery fish released, so that both wild and hatchery fish have enough to eat in the estuary.

INTRODUCTION

Currently, many salmon populations are listed as either endangered or threatened under the Endangered Species Act (ESA) (NOAA, 2015). This presents a real problem, since these fish are important to the health of their ecosystems, as well as to the lives of many people around the world (NRC, 1996). For instance, salmon are important economically and culturally, and are consumed by millions of people. In the attempt to restore their populations, people have built hatcheries to raise and release fish into natural habitats (NRC, 1996; Olla *et al.*, 1998). Ideally, this influx of fish should help take pressures off of wild populations, enabling them to recover. However, many studies have found or suggested that this solution may in fact be responsible for worsening the decline in salmon populations (NRC, 1996; Daly *et al.*, 2011). In my thesis, I compared the diets of hatchery and wild subyearling Chinook salmon. Similarities between the diets may possibly point to competition, which may be linked to this further decline in population.

Chinook salmon, which is one salmon species that has seen a decline, are ecologically, economically, and culturally important, especially in the Pacific Northwest (NRC, 1996; Daly *et al.*, 2011). Chinook salmon critically impact their ecosystems in various ways. They are an important food source for many animals, including other fish, spiny dogfish, birds, and mammals, such as harbor seals and bears (Gende *et al.*, 2002; Nickelson, 2003). Also, when these salmon die and decompose in freshwater systems, their bodies serve to increase the nutrient contents in aquatic and surrounding terrestrial environments, which may impact the habitats of many other species (Gende *et al.*, 2002). For example, bears catch salmon near streams and rivers, but often eat the fish in the nearby forests (Gende *et al.*, 2002). The remaining parts of the fish are left to degrade, thus providing nutrients, such as nitrogen and phosphorus to the area, which can be absorbed by plants and fungi (Gende *et al.*, 2002). Further, the nutrients provided by the salmon carcasses can affect the food chains in estuaries (Fujiwara and Highsmith, 1997). For example, *Ulva* sp., which is an algae found in many estuaries, take up these nutrients from the water (Fujiwara and Highsmith, 1997). Copepods, which are crustaceans that dwell in estuaries, prey on the *Ulva* sp. (Fujiwara and Highsmith, 1997). In turn, salmon eat these copepods, which can affect salmon population size (Fujiwara and Highsmith, 1997).

Another reason that Chinook salmon are ecologically important is that they are a part of predator-prey interactions that are essential to the preservation of populations of multiple species (Williams *et al.*, 2011). For instance, southern resident killer whales, which can often be found off the coast of Washington, only eat fish, and specifically target Chinook salmon, even in cases when other salmon species outnumber Chinook salmon populations (Williams *et al.*, 2011). This selectivity has led these killer whales to be highly dependent on Chinook salmon (Williams *et al.*, 2011). Therefore, when Chinook salmon populations are diminished, negative effects are seen in the southern resident killer whale populations (Williams *et al.*, 2011). Some of these effects include greater mortality and lower reproductive success of these killer whales (Williams *et al.*, 2011).

Furthermore, Chinook salmon are economically important, especially in the fishing industries in the Pacific Northwest. Commercial fishing not only creates jobs, but also contributes millions of dollars every year to Pacific Northwest economies. For instance, in 2010, the value of Chinook salmon caught in Oregon was $6,852,714, and was $12,692,610 in Washington (NOAA, 2011). Additionally, Chinook salmon sport fishing benefits local economies by increasing tourism in those areas (Heard *et al.*, 2007). Many sport fishers seek Chinook salmon fishing opportunities because these salmon are often larger and more rare than many other types of salmon (Heard *et al.*, 2007).

Chinook salmon, which were named after the Chinook tribe, are also culturally important to many Native American tribes in the Pacific Northwest, especially to those in the Columbia River basin (Ruby *et al*., 2010). For many of these people, salmon are their livelihood, primary food source, and are important for the maintenance of their overall health (CRITFC, 2015a). For instance, salmon was traditionally one of the main food sources for the Karuk tribe, located along the Klamath River, but declining salmon populations have caused a decrease in the amount of fish available to eat (Lynn *et al*., 2013). This has been associated with a large increase in diabetes and heart disease in the tribal population, due to relying on a less nutritious diet to compensate for lower salmon availability (Lynn *et al*., 2013). Moreover, salmon have large roles in tribal stories regarding the creation of people, and so, are traditionally important to tribal religion (CRITFC, 2015b). They are often used in tribal ceremonies and religious services (CRITFC, 2015b). For example, many Pacific Northwest tribes have "The First Salmon Feast," where they honor and consume these fish (CRITFC, 2015b).

Despite their importance to various aspects of ecology and society, Chinook salmon populations have declined (NRC, 1996). One reason for the decline in salmon populations is the building of dams (NRC, 1996). Many dams inhibit salmon migrations to and from the ocean, which disrupts their life cycle. Chinook salmon (*Oncorhynchus tshawytscha*), similarly to many other salmonid species, are anadromous (Thorpe, 1994). They are born in freshwater, move into the ocean where they spend most of their adult lives, and then return to freshwater to reproduce (Thorpe, 1994). These salmon must pass through an estuary, where the freshwater and saltwater mix, when traveling both to and from the ocean (Thorpe, 1994). Estuaries play an important role in the Chinook salmon life cycle, since they provide the appropriate habitat for smoltification, or the ability to adapt from living in freshwater to saltwater (Thorpe, 1994). Studies have found that estuaries provide protection from predators and good access to food for these juvenile fish (Thorpe, 1994). Dams can make it harder, if not impossible, for these fish to make it to estuaries, thus disrupting salmon life cycles and their ability to reproduce, possibly leading to a decline in overall population.

Natural causes, such as predation, are also responsible for the declines seen in Chinook salmon populations (NRC, 1996). For example, Williams *et al.* (2011) found that Chinook salmon made up about 83% of the total diet of southern resident killer whales during the summer. Relatively small amounts of killer whales can consume large amounts of fish (Williams *et al.*, 2011). For instance, 87 killer whales can eat about 12 to 23% of the Chinook salmon belonging to the Fraser River stock (Williams *et al.*, 2011). This high demand for salmon is detrimental to overall salmon populations, especially when these populations are already in decline.

Disease is another natural cause of declining salmon populations (NRC, 1996; Kocan *et al.*, 2004; Miller *et al.*, 2014). For example, ichthyophoniasis is a disease that is caused by a parasite (*Ichthyophonus* sp.) and results in white lesions forming on the heart and skeletal muscle of the salmon (Kocan *et al*., 2004). Prior to the mid-1980s, this disease was not found in Pacific salmon populations (Kocan *et al*., 2004). It has since been recorded in populations of Pacific salmon, such as the Yukon River Chinook salmon (Kocan *et al*., 2004). Studies have suggested that this disease causes increased levels of mortality before the fish are able to spawn, resulting in lower reproduction and a decline in population size (Kocan *et al*., 2004).

Hoping to counteract this decline and help rebuild salmon populations, people have built salmon hatcheries (NRC, 1996; Olla *et al.*, 1998). These hatcheries raise salmon, until they are smolts. Then, the fish are released into various streams and rivers. It is at this point that these hatchery-raised fish intermingle with wild populations and start migrating towards the ocean. The number of fish released varies greatly from hatchery to hatchery.

People also use these hatcheries in an attempt to decrease the negative impacts that humans have on wild salmon populations (NRC, 1996). For instance, hatchery salmon may help take fishing pressures off of wild populations. Since the late 1990s, when fish are released from hatcheries, their adipose fin is removed (clipped). This indicates to fishermen that these fish are hatchery fish and can be fished. Fish with intact adipose fins are to be thrown back. This helps reduce the number of wild fish killed by fishermen. Furthermore, some hatchery fish are not clipped, so that they are also returned to the water, and are more likely to survive and reproduce, helping to replenish salmon populations.

As these hatcheries have released fish over the years, the numbers of these fish have become more abundant than wild salmon populations in many places (NRC, 1996). Despite intentions, this large amount of hatchery fish may negatively affect wild populations (NRC, 1996; Daly *et al.*, 2011). This abundance of hatchery fish may lead to possible genetic problems, spreading of disease, as well as possible negative interactions with wild fish, such as competition for prey items (NRC, 1996; Daly *et al.*, 2011).

Genetic issues in hatchery fish can arise from a decrease in genetic variation and inbreeding (Naish *et al.*, 2008). Also, hatchery fish may adapt to the hatchery environment, which often differs from the wild environment, by domestication selection (Naish *et al.*, 2008). When these genetically different fish are released into the wild and mix with wild populations, they can negatively affect the genetics of the wild populations (Naish *et al.*, 2008).

This decrease in genetic diversity can make the fish more susceptible to disease, especially if hatchery fish have alleles that may lower their resistance to diseases found in the wild (Naish *et al*., 2008). Currently, the idea that hatchery fish may directly help diseases spread through wild populations is not well studied, but one way this may occur is when fish within hatcheries become infected (Naish *et al.*, 2008). Hatchery fish are often vulnerable to many different diseases because of their high number, close proximity to each other, and other factors (Naish *et al*., 2008). Pathogens can build up in the hatcheries and be released into the environment through the hatchery waste (Naish *et al*., 2008). This concentrated amount of pathogens near the hatcheries may negatively affect the health of wild populations in the area (Naish *et al*., 2008). Additionally, it is possible for salmon released from hatcheries to directly transmit diseases to wild salmon, especially if they are together in stressful situations (Naish *et al*., 2008).

The large amount of hatchery fish may also cause wild fish to become more susceptible to predation by other fish, spiny dogfish, birds, and mammals (Nickelson, 2003; Kostow, 2009). When many hatchery fish are released at once, predators often become attracted to these large quantities of fish, and can often be found near release areas (Nickelson, 2003; Kostow, 2009). This becomes a problem for wild fish when they mix with these large numbers of hatchery fish

(Nickelson, 2003). This results in an increase in vulnerability to predation for the wild fish (Nickelson, 2003).

Additionally, previous research has shown that wild and hatchery Chinook salmon in coastal marine water have similar diets (Daly *et al.*, 2011). As Daly *et al.* (2011) pointed out, these similar diets may suggest potential competition between the wild and hatchery fish, which may negatively affect wild populations. However, due to the lack of research on wild and hatchery salmon diets in estuaries, not much is known about the differences and similarities between the diets and whether this may also suggest potential competition. This leads to the purpose of this study, which is to examine stomach fullness and contents of wild and hatchery subyearling Chinook salmon of the stocks Upper Columbia River summer/falls (UCR) and West Cascade falls (WCF), caught in the Columbia River estuary. I chose to concentrate on these two stocks because I had access to sufficient fish from each stock to make comparisons, and both hatchery and wild fish live in both areas. Furthermore, these stocks originate from different parts of the Columbia River Basin, which may lead to differences between the diets of the stocks. For instance, the WCF stock originates in the lower portion of the Columbia River, which is closer to the sampling locations in the lower estuary, while the UCR stock originates in the upper section of the river. It is important to note that "summer" and "falls" indicate the seasons that the adult salmon return to freshwater. If the wild and hatchery Chinook salmon diets are similar, there may be potential for competition for food, which may be detrimental to salmon populations.

Stomach Fullness:

Table 1: Hypotheses for stomach fullness.

Stomach Fullness:	Wild salmon will have fuller stomachs than hatchery fish.
	The different stocks, UCR and WCF, will have different levels of stomach fullness. I predict that the UCR fish will have fuller stomachs than the WCF fish.
	Stomach fullness will differ between years.
	Fish will have fuller stomachs in later months than earlier months.

While studying stomach fullness, I hypothesized that, overall, wild salmon would have fuller stomachs than hatchery fish because they would have more experience finding and eating food in the wild; a skill hatchery fish must learn once released (Olla *et al.*, 1998). Various studies have shown that wild fish eat more than hatchery fish due to differences in behavior (Olla *et al.*, 1998; Weber and Fausch, 2003). Also, I hypothesized that the different stocks, UCR and WCF, would have different levels of stomach fullness due to their distinctive origin points, which may have resulted in variation in food availability between these stocks. I predicted that the UCR fish would have fuller stomachs than the WCF fish because the UCR fish would have had to travel further to reach the estuary, and so, would have had more time to learn how to catch food.

I also hypothesized that the stomach fullness of the Chinook salmon would differ between years, since various conditions, such as prey availability, can vary from year to year. Furthermore, I hypothesized that the fish may have fuller stomachs in later months than earlier months because they would have had more time to learn where to find food.

Stomach Contents:

Table 2: Hypotheses for stomach contents.

Stomach Contents:	The stomach contents will differ between the various stocks and production type combinations.
	Hatchery fish will have consumed more nonfood items than wild fish.
	The stomach contents will differ between wild and hatchery fish.
	The stomach contents will differ between UCR and WCF fish.
	The stomach contents will change from year to year.
	The stomach contents will change between months.

While studying stomach contents, I hypothesized that the stomach contents would differ between the various stock and production type combinations (Upper Columbia River summer/falls (UCR) wild, UCR hatchery, West Cascade falls (WCF) wild, and WCF hatchery) because the UCR fish would have had to travel further than the WCF fish to reach the estuary, so they would have had more experience identifying food. Also, these different stocks would have different origin points, and so may have been exposed to different types of prey.

I further hypothesized that hatchery fish would have consumed more nonfood items than wild fish consumed because they would have less experience identifying edible substances and would be more likely to mistake objects, such as plastic, as food.

Additionally, I hypothesized that the stomach contents would differ between wild and hatchery subyearling Chinook salmon, in general, because the wild fish would have more experience and be better at finding and identifying food than hatchery fish, possibly due to differences in behavior and prior experiences with more types of living prey (Sosiak *et al.*, 1979; Olla *et al.*, 1998).

I hypothesized that the stomach contents would differ between UCR and WCF fish because the UCR fish would have traveled further to reach the estuary allowing them more time to determine how to more efficiently catch and consume food.

I also hypothesized that the stomach contents would change from year to year due to changing conditions and prey availability between years. Finally, I hypothesized that the stomach contents would change between months due to changing conditions and prey availability.

MATERIALS AND METHODS

Subyearling Chinook salmon were collected from two stations in the Columbia River estuary, which is located at the border between Oregon and Washington. The two stations were North Channel (46°14.2'N, 123°54.2'W) and Trestle Bay (46°12.9'N, 123°57.7'W) (Figure 1). The fish were collected using a fine-mesh purse seine (10.6 m deep and 155 m long) set up as either round hauls or tows. The fish used in this study were collected monthly from May to October during the years of 2007 to 2012.

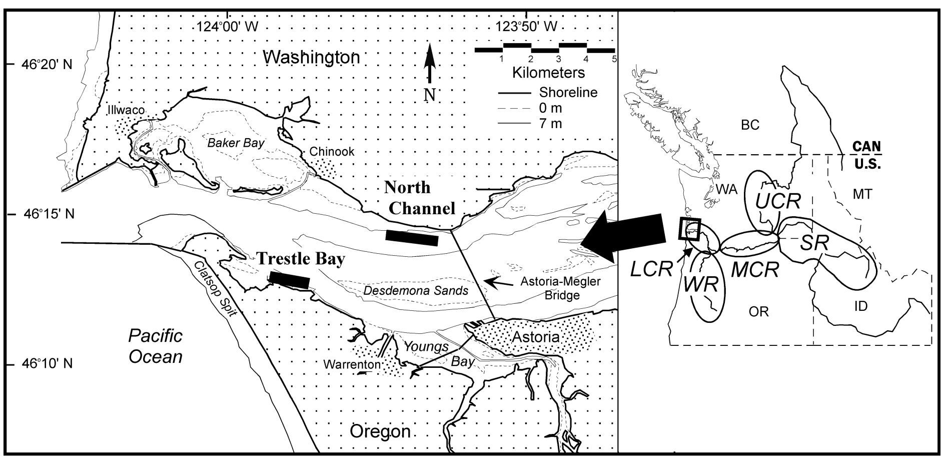

Figure 1. Map of Columbia River estuary. North Channel and Trestle Bay are the two stations where Chinook salmon were collected. UCR (labeled on the map on the right) stands for Upper Columbia River (Weitkamp *et al.*, 2012).

After the fish were caught, their fork lengths were measured. The fork length refers to the fish's length from the tip of the snout to the center of the fork in the tail. They were also checked for adipose fin clips (removal of entire adipose fin), coded-wire tags (CWTs), and passive integrated transponder (PIT) tags. A subset of randomly selected fish were kept and frozen, while the other fish were released back into the estuary. Collected fish were stored in a -80° freezer, until further analysis.

In the lab, the lengths of the fish were remeasured and the fish were weighed. Tags were removed from the fish. Later, the fish were thawed and their stomachs, as well as other parts, were removed for future study. This took place during a "cutting party," which refers to many people congregating at the same time to measure, weigh, and remove certain parts of the fish. The stomachs were fixed in formaldehyde and stored in 70% ethanol.

For this study, stomachs belonging to two stocks of subyearling Chinook salmon, including Upper Columbia River summer/falls (UCR) and West Cascade falls (WCF), were dissected. The fish were identified as belonging to these stocks based on information from the CWTs and PIT tags, as well as genetics. The information from the tags, as well as from the presence or absence of the adipose fin enabled us to estimate whether or not the fish were wild or hatchery. Overall, 241 wild fish and 232 hatchery fish were used. Of the wild fish, 189 were UCR and 52 were WCF. Of the hatchery fish, 138 were UCR and 94 were WCF. Stomach fullness was recorded on a scale of 0 to 5, with 0 indicating that the stomach was empty and 5 indicating that the stomach was full and distended. The stomach contents were then emptied and identified using a microscope. For ease of study, the stomach contents were grouped into ten groups, including amphipods, cladocera, corophium, crab larvae, fish, insects, shrimp, other crustaceans, other noncrustaceans, and nonfood. The material for each prey type in each stomach were then weighed.

For the analysis of fullness, the percent fullness was calculated by:

$$\%\ \text{fullness} = \frac{\text{sum of prey weight (g)}}{\text{Fish weight (g)} - \text{sum of prey weight (g)}} \text{ x } 100.$$

Then, the natural log was taken of the percent fullness to meet the assumption of a normal distribution. A general linear model was used to analyze the fullness data, with ln (fullness) acting as the dependent variable, and wild, hatchery, stocks, years, and months as independent variables. Logistic regression was used to analyze the stomach contents data, where the dependent variables were the individual prey items, and the independent variables included wild, hatchery, stocks, years, and months. A nonmetric multidimensional scaling (MDS) plot was also used to analyze how similar the diets of the stock and production type combinations (UCR wild, UCR hatchery, WCF wild, WCF hatchery) were to each other.

RESULTS

Stomach Fullness:

Overall, there was no statistically significant difference in stomach fullness between hatchery and wild subyearling Chinook salmon, or between stocks (UCR and WCF) (Figures 2-5; Appendix Table 1).

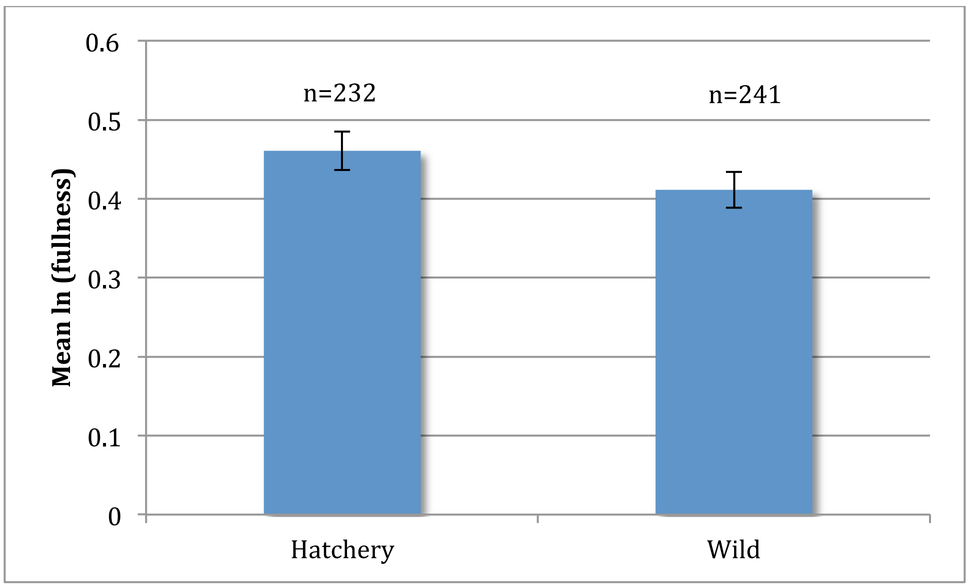

Figure 2. Hatchery and Wild Stomach Fullness. Mean stomach ln (fullness) for hatchery and wild fish. The error bars equaled ± 1SE. ($p=0.059$).

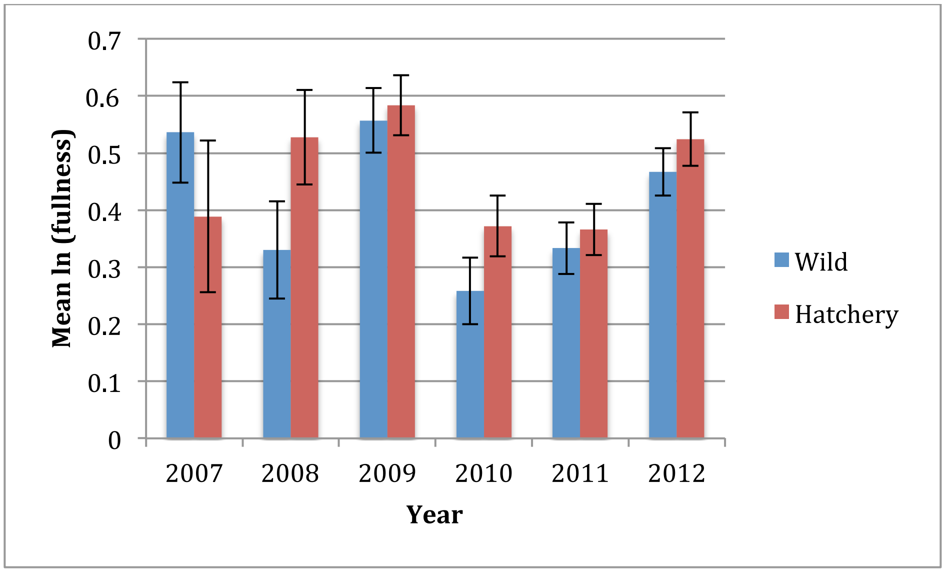

Figure 3. Stomach Fullness of Production Types by Year. Mean stomach ln (fullness) for wild and hatchery fish across year. The error bars equaled ± 1SE. (n(2007,wild)=16, n(2007,hatchery)=7, n(2008,wild)=17, n(2008,hatchery)=18, n(2009,wild)=39, n(2009,hatchery)=45, n(2010,wild)=36, n(2010,hatchery)=44, n(2011,wild)=61, n(2011,hatchery)=62, n(2012,wild)=72, n(2012,hatchery)=56).

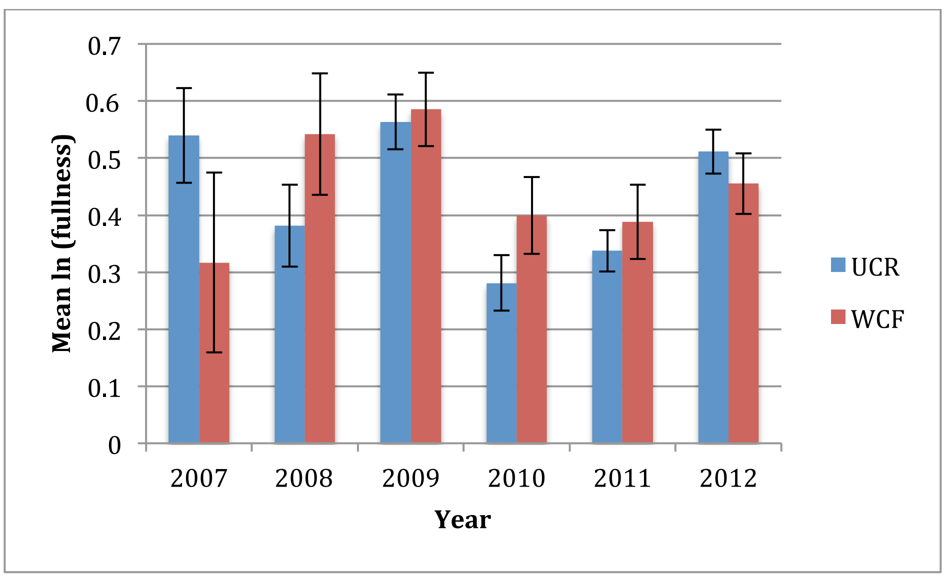

Figure 4. Stomach Fullness of Stocks by Year. Mean stomach ln (fullness) for Upper Columbia River summer/falls (UCR) and West Cascade falls (WCF) fish across year. The error bars equaled ± 1SE. (n(2007,UCR)=18, n(2007,WCF)=5, n(2008,UCR)=24, n(2008,WCF)=11, n(2009,UCR)=54, n(2009,WCF)=30, n(2010,UCR)=53, n(2010,WCF)=27, n(2011,UCR)=94, n(2011,WCF)=29, n(2012,UCR)=84, n(2012,WCF)=44).

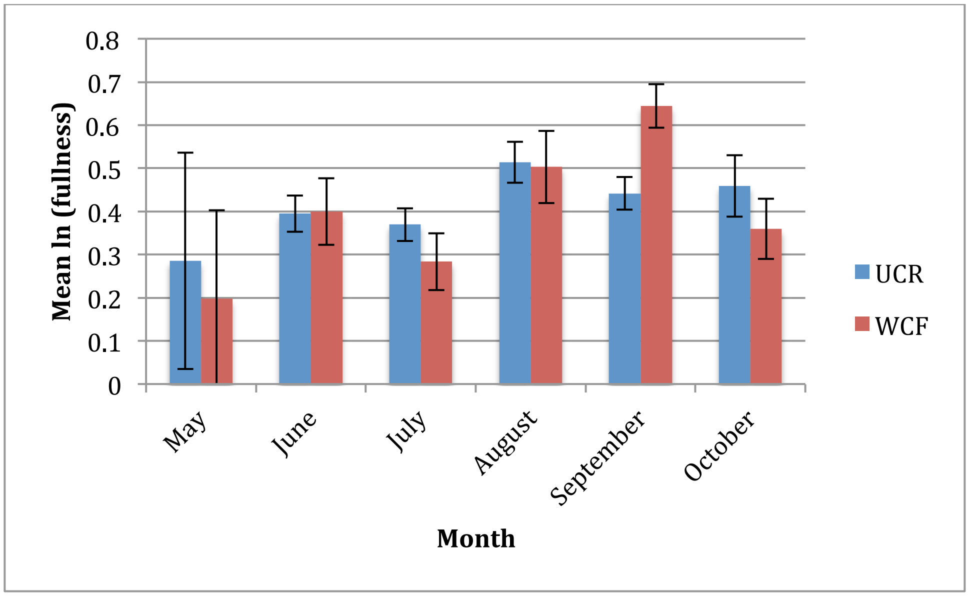

Figure 5. Stomach Fullness of Stocks by Month. Mean stomach ln (fullness) of stocks, Upper Columbia River summer/falls (UCR) and West Cascade falls (WCF), across month. The error bars equaled ± 1SE. (n(May,UCR)=2, n(May,WCF)=3, n(June,UCR)=72, n(June,WCF)=21, n(July,UCR)=87, n(July,WCF)=29, n(August,UCR)=55, n(August,WCF)=18, n(September,UCR)=86, n(September,WCF)=49, n(October,UCR)=25, n(October,WCF)=26).

However, when considering overall stomach fullness for all fish, there was a statistically significant difference between some of the years, as well as between some of the months (Figures 6 and 7; Appendix Table 1).

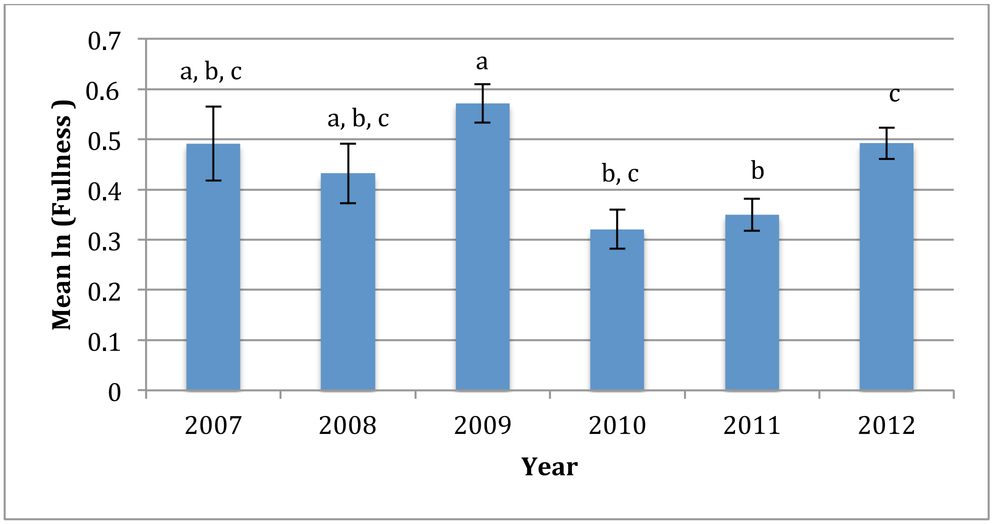

Figure 6. Stomach Fullness and Year. Mean stomach ln (fullness) for all fish from the year 2007 to 2012. The error bars equaled ± 1SE. (n(2007)=23, n(2008)=35, n(2009)=84, n(2010)=80, n(2011)=123, n(2012)=128).

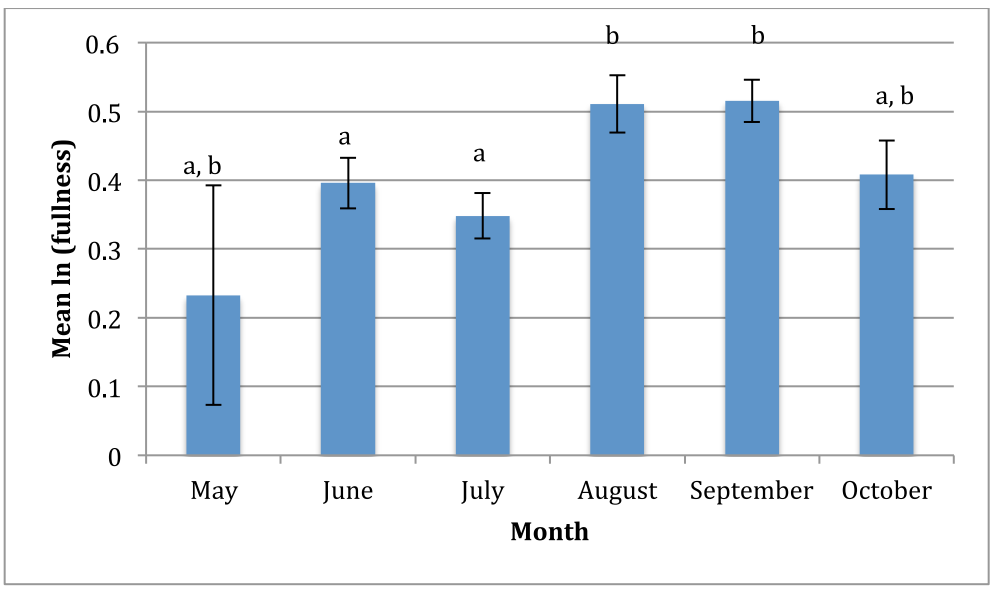

Figure 7. Stomach Fullness and Month. Mean stomach ln (fullness) for all fish across month. The error bars equaled ± 1SE. (n(May)=5, n(June)=93, n(July)=116, n(August)=73, n(September)=135, n(October)=51).

Stomach Contents:

The stomach contents of all of the stock and production type combinations contained the same groups of prey items, just in different amounts (Figure 8 and 9). These groups included amphipods, cladocera, corophium, crab larvae, fish, insects, shrimp, other crustaceans, other noncrustaceans, and nonfood. The nonfood group contained objects, such as plastic, rocks, and plant material.

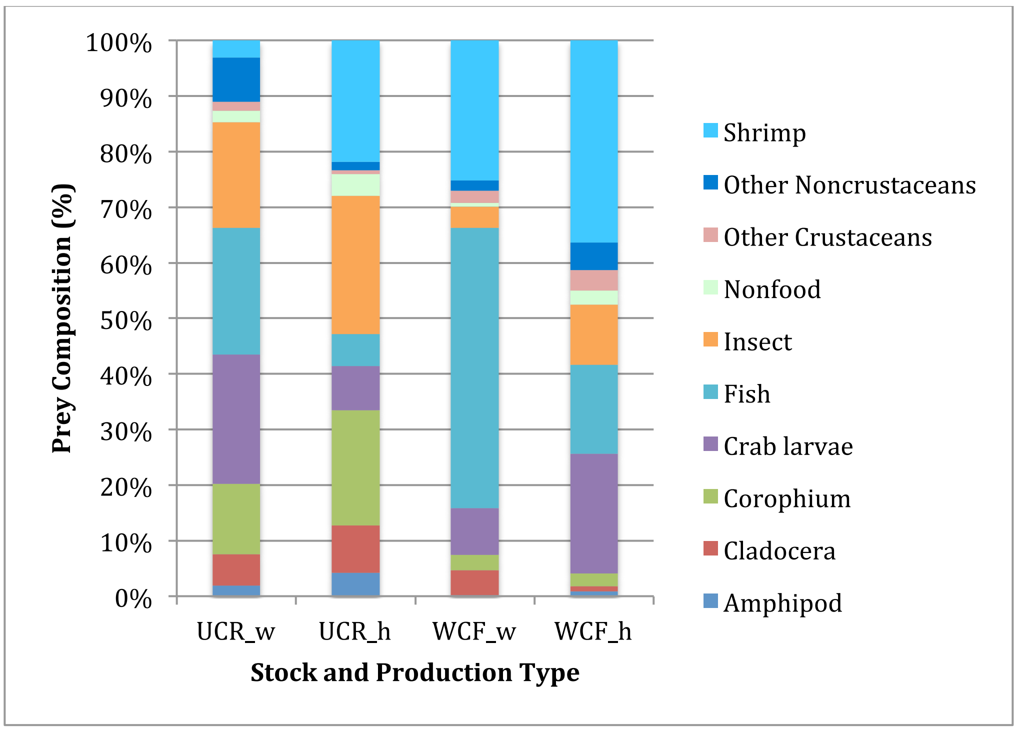

Figure 8. Prey Composition by Stocks and Production Types. Prey composition found in the stomachs of fish belonging to the stocks, Upper Columbia River summer/falls (UCR) and West Cascade falls (WCF), and production types, wild (w) and hatchery (h). (n(UCR_w)=161, n(UCR_h)=117, n(WCF_w)=46, n(WCF_h)=73).

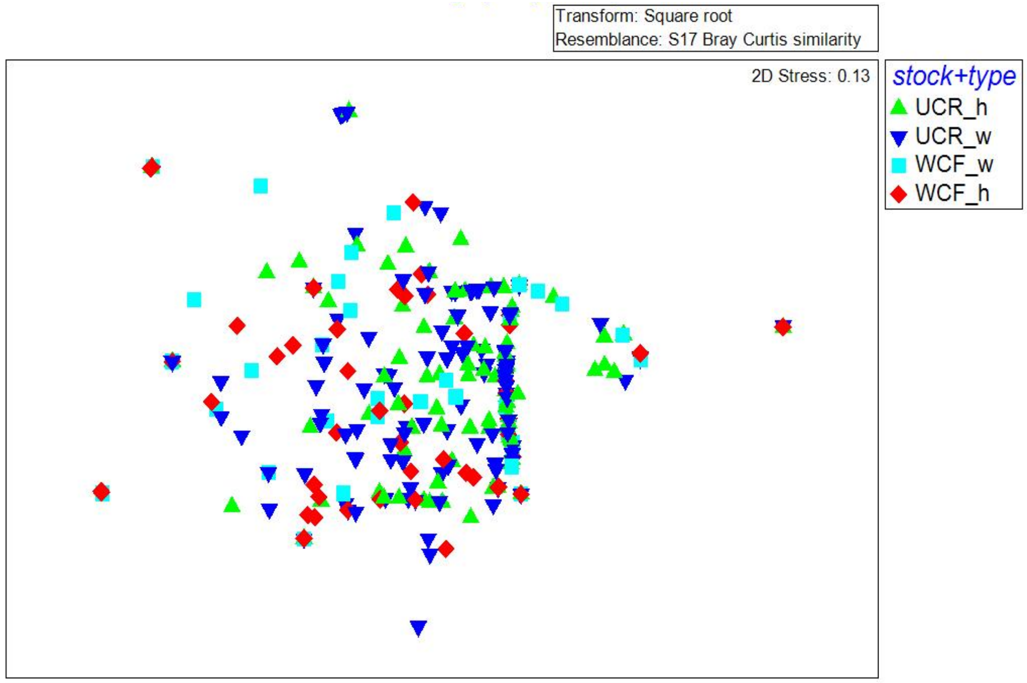

Figure 9. Nonmetric multidimensional scaling (MDS) plot showing similarity of prey composition between stocks, Upper Columbia River summer/falls (UCR) and West Cascade falls (WCF), and production types, wild (w) and hatchery (h). The closer together the symbols for each group, the more similar the groups are to each other. (n(UCR_w)=161, n(UCR_h)=117, n(WCF_w)=46, n(WCF_h)=73).

Overall, the mean percent of identifiable prey items that was considered nonfood in hatchery fish was over double what it was in wild fish (Figure 10). The wild fish were 0.542 times less likely to eat nonfood items than hatchery fish, when controlling for stock, year, and month (Appendix Table 2).

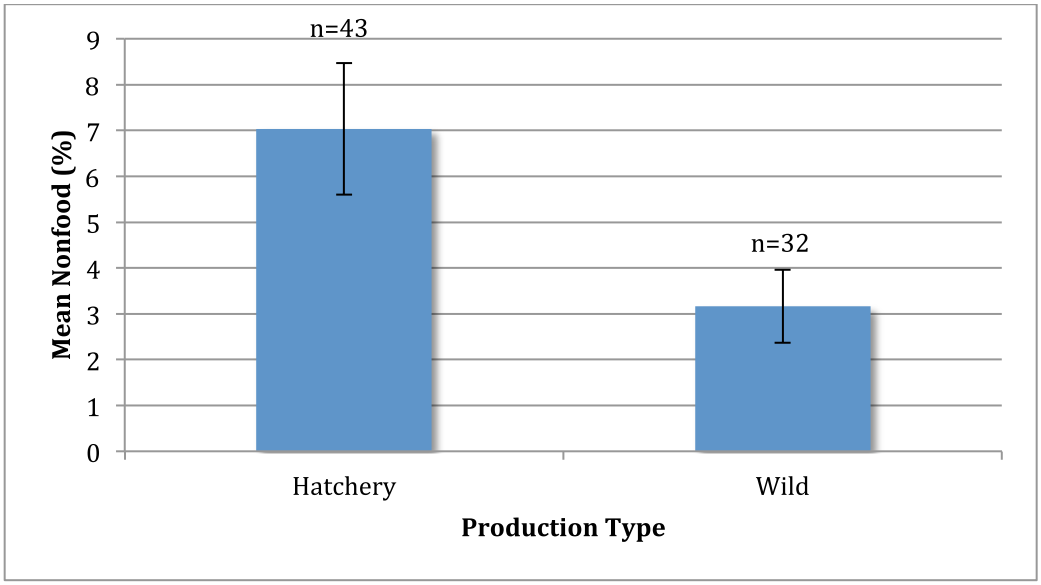

Figure 10. Percent of Nonfood by Production Types. The mean percent of identifiable prey items that was considered nonfood in the stomachs of hatchery and wild Chinook salmon. The error bars equaled ± 1SE. (p=0.031).

When considering the stocks and production type combinations, there was a statistically significant difference in mean percent of identifiable prey items that were considered nonfood between the WCF hatchery fish and the WCF wild fish (ANOVA; $p<0.05$) (Figure 11).

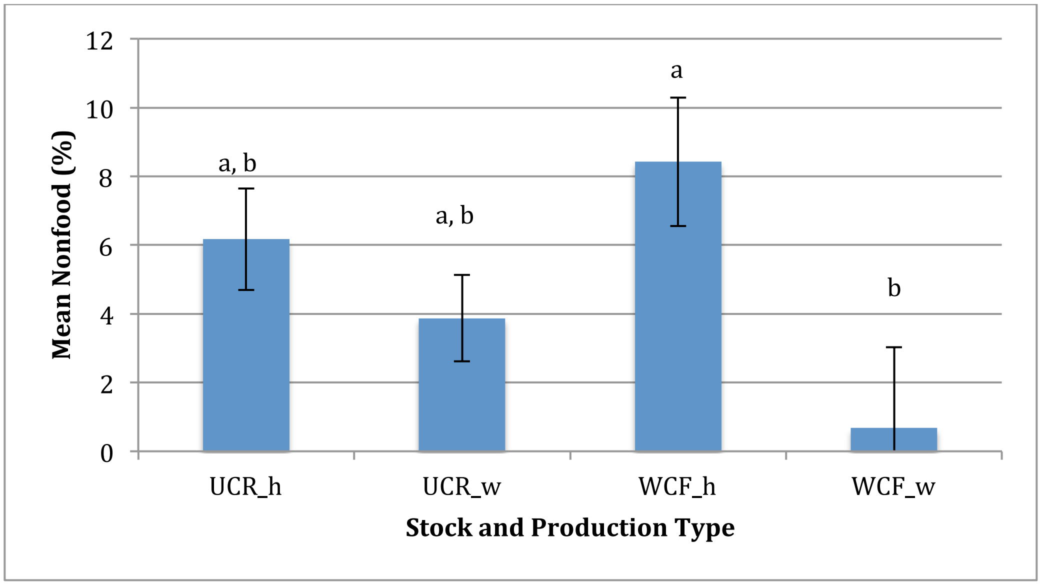

Figure 11. Percent of Nonfood by Stocks and Production Types. The mean percent of identifiable prey items that was considered nonfood in the stomachs of Chinook salmon across the stocks, Upper Columbia River summer/falls (UCR) and West Cascade Falls (WCF), and production types, hatchery (h) and wild (w). The error bars equaled ± 1SE. (n(UCR_h)=26, n(UCR_w)=30, n(WCF_h)=17, n(WCF_w)=2)).

Also, wild fish were 2.43 times more likely to eat fish compared to hatchery fish, when controlling for stock, year, and month (Appendix Table 2).

Only two prey items significantly differed between the UCR and WCF fish: amphipods and insects (Appendix Table 2). UCR fish were 3.572 times more likely to eat amphipods and were 2.468 times more likely to eat insects than WCF fish, when controlling for production type, year, and month (Appendix Table 2).

Many of the prey items significantly fluctuated from year to year (Appendix Table 2 and 3). For instance, fish in 2008 were significantly less likely to have eaten corophium compared to those in all of the other years (2007, 2009-

2012) (Appendix Table 2 and 3). Also, fish in 2012 were less likely to eat nonfood items compared to those in 2008, 2009, and 2011 (Appendix Table 2 and 3).

There was also fluctuation in prey items between months (Appendix Table 2 and 4). Some of the prey items seemed to vary seasonally. For example, fish in May and October ate significantly more amphipods compared to the fish in the months June to September (Appendix Table 2 and 4).

DISCUSSION

This study was conducted to determine whether or not hatchery and wild subyearling Chinook salmon have similar diets in the Columbia River estuary, which may lead to competition between these fish and a decline in wild salmon populations.

Stomach Fullness:

In regards to stomach fullness, the results did not support the first hypothesis, which stated that stomach fullness would be higher in wild subyearling Chinook salmon than in hatchery salmon (Figures 2 and 3). This may have occurred because by the time the fish reached the estuary, many of the hatchery fish would have travelled a relatively large distance from the hatcheries (>300 km), and so, would have had enough time to learn how to catch live prey (Olla *et al.*, 1998; pers. com. Laurie Weitkamp). The time it takes for the salmon to travel these large distances depends on when they start to migrate to the estuary, which is influenced by environmental signals, such as temperature and flow (Sykes *et al.*, 2009). Brown *et al.* (2003) found that hatchery raised salmon can learn how to find and capture prey by watching other experienced fish. The hatchery fish in my study may have learned how to effectively forage by observing wild and other successful hatchery fish. Any hatchery fish unable to adjust to capturing live prey would have most likely died before reaching the estuary.

The results also did not support the next hypothesis, which stated that Upper Columbia River summer/falls and West Cascade falls fish would have different levels of stomach fullness (Figures 4 and 5). This may have happened because these two stocks may have had access to similar amounts of prey, despite their different origin points. Moreover, there may not have been enough, if any, difference in behavior between these two stocks that would lead to variation in stomach fullness.

The results did support the hypothesis that stated that stomach fullness differs between years (Figure 6). For instance, stomach fullness of salmon in 2009 was significantly greater than in 2010, 2011, and 2012. This was possibly related to the higher precipitation and faster flow rates in 2010, 2011, and 2012 than in 2009 (NOAA, 2016; USGS, 2016). Piccolo *et al.* (2008) found that in another species of salmon, Coho salmon, as the rates of flow increased, the fish became less likely to catch prey. This may be a result of the prey items moving quicker due to the faster flow rates, which would cause the fish to have less time to notice the prey (Piccolo *et al.*, 2008). It is reasonable to believe that this finding would also occur for Chinook salmon because both Chinook and Coho salmon drift feed (Piccolo *et al.*, 2008; Neuswanger *et al.*, 2014). Drift feeding is a strategy that many fish use while foraging (Neuswanger *et al.*, 2014). In this method, the fish watch for prey drifting in moving water (Neuswanger *et al.*, 2014).

Overall, the results supported the hypothesis that fish will have fuller stomachs in later months than earlier months (Figure 7). For example, stomach fullness in August and September is significantly greater than in June and July, which may be related to environmental differences between the months. For instance, August and September were both warmer than June and July (USGS, 2016). This may have affected the prey species in the area. Studies have observed that there tends to be higher abundance of salmon prey in warmer waters (Limm and Marchetti, 2009). It is important to note that while the later months of August and September contained fish with fuller stomachs than earlier months, October (the latest month in this study) was not significantly different than any of the other months.

Stomach Contents:

While the various stock and production type combinations consumed similar prey items, the results did support the first hypothesis, which stated that stomach contents would differ between these stock and production type combinations. For example, the WCF hatchery fish were significantly more likely to eat nonfood items than WCF wild fish (Figure 11). However, there was no significant difference in stomach contents between these fish and the UCR hatchery and wild salmon. Since UCR fish had to travel further than WCF fish to reach the estuary, it is possible that the UCR hatchery fish had more experience with identifying prey items resulting in no significant difference in the consumption of nonfood items.

The results supported the hypothesis that stated that hatchery fish would have eaten more nonfood items than wild fish (Figure 10). This variation may have resulted mostly from the differences between WCF hatchery fish and WCF wild fish, which were significantly different from each other, as described above. The hatchery fish may have not been able to identify live prey as well as the wild fish, especially if their prior experiences had not exposed them to the available prey items (Sosiak *et al.*, 1979). Also, hatchery fish may have had more trouble capturing live prey due to behavioral differences and may have settled for more nonfood items than the wild fish. When salmon are foraging, they can mistake nonfood items for prey, causing them to spend time and energy in capturing and handling these items (Neuswanger *et al.*, 2014). This can lead to the fish having a harder time foraging, and can cause them to use energy chasing after these nonfood items (Neuswanger *et al.*, 2014). Since hatchery fish consumed more nonfood items, which contain no nutritional value, they may have been at a disadvantage both energetically and nutritionally compared to wild fish.

One of the items classified as nonfood was plastic. Plastics can enter an estuary directly from land due to runoff, as well as from rivers and the ocean (Sadri and Thompson, 2014). This movement of small pieces of plastics greatly depends on water currents and wind direction (Sadri and Thompson, 2014). These plastics can negatively affect many species. For instance, seabirds often mistake plastic for prey (Derraik, 2002). Fish and sea turtles have also been known to eat plastics (Derraik, 2002). Studies have found that consumption of plastics by aquatic animals can lead to a decrease in the amount of food eaten, a decrease in reproduction, severe internal damage, and death (Derraik, 2002). Overall, the ingestion of plastic often puts these animals at a disadvantage when compared to animals that eat less plastic.

Wild fish were significantly more likely than hatchery fish to consume fish, supporting the hypothesis that stated that the stomach contents would differ between wild and hatchery fish (Appendix Table 2). This may have occurred because wild and hatchery subyearling Chinook salmon often occupy different parts of the Columbia River Estuary (Weitkamp *et al.*, 2015). Studies have found that wild salmon usually occupy more shallow areas of the estuary, while hatchery fish stay in deeper waters (Weitkamp *et al.*, 2015). This may have caused wild and hatchery fish to come into contact with different prey items, resulting in the small differences in stomach contents seen.

In support of the next hypothesis, UCR salmon were significantly more likely than WCF fish to eat amphipods and insects (Appendix Table 2). This difference between stocks may have arose from differing prey availability in the different parts of the Columbia River basin. For instance, insects tend to be more abundant in freshwater systems, so UCR fish, which had to travel the furthest through freshwater, may have had more access to insects than the WCF fish.

The results also indicated that stomach contents varied between years (Appendix Tables 2 and 3). For instance, fish in 2012 were less likely to eat nonfood items compared to those in 2008, 2009, and 2011. Originally, I thought that more precipitation would lead to more runoff, resulting in more nonfood items, such as plastics, being washed into the rivers and estuary. With this line of thought, 2012 should have had the most amount of nonfood consumed, but the opposite happened (NOAA, 2016). Instead, flow rates may have impacted the amount of nonfood items in the estuary in 2012. Neuswanger *et al.* (2014) found that Chinook salmon captured more nonfood items than prey when flow rates were slow. Since, 2012 had the fastest flow rate, it is possible that many of the nonfood items were quickly washed out to the ocean, resulting in the salmon having less time to consume them.

Stomach contents varied between months, as well. For instance, fish in May and October ate significantly more amphipods compared to the fish in the months of June and September (Appendix Tables 2 and 4). This may have occurred because precipitation was higher in May and October than in June and September (NOAA, 2016). Studies have found that amphipods, which often occupy algae, move away from the algae and into the water column when it rains (Blockely *et al.*, 2007). During these periods of precipitation, salmon would have an easier time catching amphipods, since larger abundances of this prey species would be readily available to the fish.

Overall, the results showed that hatchery and wild salmon ate very similar amounts of food, and very similar prey items. The similarities in diet support the idea that there is the possibility for competition for food between hatchery and wild fish. If competition is occurring, then it is important for hatcheries to consider environmental factors and determine whether or not there are enough resources available to support both wild and hatchery fish. Currently, fisheries highly manage the number of salmon fished, through limiting where and when fishing for Chinook salmon can occur (ODFW, 2016). They also manage how many fish people can remove from the population, as well as place size minimums on the salmon that can be fished (ODFW, 2016). On the other hand, the amount of fish released are not managed to the same extent. Hatcheries release a consistent target number of fish from year to year, and they do not adjust this number depending on the environment and food availability (pers. com. Laurie Weitkamp). I recommend that hatchery managers should consider the current carrying capacity of the rivers and estuary when determining how many fish to release in a specific year. This may help decrease any competition that may arise between wild and hatchery fish.

APPENDIX

Table 1: The p-values for different stomach fullness comparisons, including wild to hatchery, UCR to WCF, between various years, and between various months. P-values less than 0.05 were significant, and are highlighted yellow.

	Comparisons	p-value	Significance
Wild/Hatchery	Wild to Hatchery	0.059	No
Stock	UCR to WCF	0.533	No
Year	2007 to 2008	0.467	No
	2007 to 2009	0.082	No
	2007 to 2010	0.671	No
	2007 to 2011	0.536	No
	2007 to 2012	0.667	No
	2008 to 2007	0.467	No
	2008 to 2009	0.338	No
	2008 to 2010	0.152	No
	2008 to 2011	0.102	No
	2008 to 2012	0.491	No
	2009 to 2007	0.082	No
	2009 to 2008	0.338	No
	2009 to 2010	0.001	Yes
	2009 to 2011	0	Yes
	2009 to 2012	0.031	Yes
	2010 to 2007	0.671	No
	2010 to 2008	0.152	No
	2010 to 2009	0.001	Yes
	2010 to 2011	0.764	No
	2010 to 2012	0.177	No
	2011 to 2007	0.536	No
	2011 to 2008	0.102	No
	2011 to 2009	0	Yes
	2011 to 2010	0.764	No
	2011 to 2012	0.050	Yes
	2012 to 2007	0.667	No
	2012 to 2008	0.624	No
	2012 to 2009	0.031	Yes
	2012 to 2010	0.177	No
	2012 to 2011	0.50	Yes
Month	May to June	0.811	No
	May to July	0.787	No
	May to August	0.232	No

	May to September	0.238	No
	May to October	0.516	No
	June to May	0.811	No
	June to July	0.938	No
	June to August	0.014	Yes
	June to September	0.006	Yes
	June to October	0.350	No
	July to May	0.787	No
	July to June	0.938	No
	July to August	0.005	Yes
	July to September	0.002	Yes
	July to October	0.314	No
	August to May	0.232	No
	August to June	0.014	Yes
	August to July	0.005	Yes
	August to September	0.931	No
	August to October	0.174	No
	September to May	0.238	No
	September to June	0.006	Yes
	September to July	0.002	Yes
	September to August	0.931	No
	September to October	0.179	No
	October to May	0.516	No
	October to June	0.350	No
	October to July	0.314	No
	October to August	0.174	No
	October to September	0.179	No

Table 2: The p-values for each prey type for the different comparisons (ex. years 07,08 refers to the comparison of each prey type between 2007 and 2008). CR stands for crustaceans. P-values less than 0.05 were significant, and are highlighted yellow.

Prey Item		Amphipod	Cladocera	Corophium	Crab Larvae	Fish
% Correct		92.2	98	73.6	82.6	91.4
Wild/Hatchery		0.191	0.522	0.435	0.741	0.05
Stocks		0.013	0.264	0.64	0.165	0.286
Years	07,08	0.602	1.0	0.003	0.062	0.753
	07,09	0.170	0.998	0.963	0.153	0.318
	07,10	0.594	1.0	0.487	0.002	0.05
	07,11	0.019	0.998	0.150	0	0
	07,12	0.027	1.0	0.195	0.250	0.002
	08,09	0.514	0.999	0	0.001	0.762
	08,10	0.896	1.0	0	0	0.278
	08,11	0.103	0.999	0	0	0.011
	08,12	0.150	1.0	0	0.005	0.082
	09,10	0.335	0.998	0.344	0.022	0.209
	09,11	0.163	1.0	0.019	0.002	0.001
	09,12	0.248	0.995	0.033	0.642	0.007
	10,11	0.041	0.998	0.351	0.152	0.053
	10,12	0.061	1.0	0.470	0.007	0.413
	11,12	0.731	0.995	0.730	0	0.086
Month	5,6	0.002	0.999	0.075	0.999	0.999
	5,7	0.001	0.999	0.019	0.999	0.999
	5,8	0.002	1.0	0.037	0.999	0.999
	5,9	0.004	0.999	0.594	0.999	0.999
	5,10	0.168	0.999	0.200	0.999	0.999
	6,7	0.957	1.0	0.137	0.253	0.060
	6,8	0.994	0.997	0.431	0.283	0.382
	6,9	0.461	1.0	0	0	0.022
	6,10	0.002	1.0	0.195	0.027	0.002
	7,8	0.955	0.995	0.494	0.039	0.326
	7,9	0.564	1.0	0	0	0.645
	7,10	0.001	1.0	0.004	0.002	0.042
	8,9	0.573	0.995	0	0	0.161
	8,10	0.002	0.997	0.026	0.065	0.009
	9,10	0.004	1.0	0.024	0.056	0.061
		Insects	Nonfood	Other CR	Other non-CR	Shrimp

% Correct		65.5	81.1	95	94.2	94.2
Wild/Hatchery		0.617	0.031	0.401	0.380	0.664
Stocks		0	0.150	0.755	0.232	0.084
Years	07,08	0.909	0.399	0.326	1.0	0.998
	07,09	0.348	0.534	0.845	0.998	0.998
	07,10	0.224	0.835	0.388	1.0	0.998
	07,11	0.831	0.687	0.183	0.998	0.998
	07,12	0.927	0.276	0.120	0.998	0.998
	08,09	0.401	0.630	0.333	0.998	0.879
	08,10	0.154	0.421	0.610	1.0	0.822
	08,11	0.943	0.493	0.057	0.998	0.940
	08,12	0.812	0.028	0.035	0.998	0.481
	09,10	0.004	0.605	0.419	0.998	0.582
	09,11	0.238	0.719	0.132	0.039	0.735
	09,12	0.079	0.005	0.066	0.126	0.177
	10,11	0.057	0.819	0.051	0.998	0.839
	10,12	0.116	0.106	0.014	0.998	0.516
	11,12	0.560	0.008	0.900	0.217	0.142
Month	5,6	0.837	0.999	0.999	0.999	0.999
	5,7	0.484	0.999	1.0	0.999	1.0
	5,8	0.240	0.999	1.0	0.999	0.999
	5,9	0.374	0.999	0.999	0.999	0.999
	5,10	0.066	0.999	0.999	0.999	0.999
	6,7	0.158	0.146	0.997	0.758	0.997
	6,8	0.007	0.026	0.997	0.957	0.855
	6,9	0.033	0.017	0.012	0.139	0.253
	6,10	0	0.269	0.197	0.060	0.003
	7,8	0.093	0.307	1.0	0.757	0.997
	7,9	0.485	0.337	0.996	0.018	0.997
	7,10	0.001	0.981	0.997	0.003	0.996
	8,9	0.306	0.936	0.997	0.034	0.242
	8,10	0.055	0.423	0.997	0.008	0.002
	9,10	0.006	0.457	0.710	0.464	0.004

Table 3: Comparisons between years for each prey item (ex. Fish caught in 2007 were more likely to have eaten amphipods than fish caught in 2012).

Year		Amphipod	Cladocera	Corophium	Crab Larvae	Fish
2007	More likely than:	2012, 2011		2008	2011, 2010	2012, 2011, 2010
	Less likely than:					
2008	More likely than:				2012, 2011, 2010, 2009	2011
	Less likely than:			2012, 2011, 2010, 2009, 2007		
2009	More likely than:	2011		2008	2011, 2010	2012, 2011
	Less likely than:			2012, 2011	2008	
2010	More likely than:	2011		2008		
	Less likely than:				2012, 2008, 2007	2007
2011	More likely than:			2009, 2008		
	Less likely than:	2010, 2007			2012, 2009, 2008, 2007	2009, 2008, 2007
2012	More likely than:			2009, 2008	2011, 2010	
	Less likely than:	2007			2009, 2008	2009, 2007
		Insects	Nonfood	Other Crustaceans	Other Non-crustaceans	Shrimp
2007	More likely than:					
	Less likely than:					
2008	More likely than:		2012	2012		
	Less likely than:					
2009	More likely than:	2010	2012			
	Less likely than:			2011		
2010	More likely than:			2012		
	Less likely than:	2009				
2011	More likely than:		2012		2009	
	Less likely than:					
2012	More likely than:					
	Less likely than:		2011, 2009, 2008	2010, 2008		

Table 4: Comparisons between months for each prey item (ex. Fish caught in May (5) were more likely to have eaten amphipods than fish caught in September (9)). 5 corresponds with May, 6 corresponds with June, 7 corresponds with July, 8 corresponds with August, 9 corresponds with September, and 10 corresponds with October.

Month		Amphipod	Cladocera	Corophium	Crab Larvae	Fish
5	More likely than:	9, 8, 7, 6				
	Less likely than:			8, 7		
6	More likely than:			9		
	Less likely than:	10, 5			10, 9	10, 9
7	More likely than:			10, 9, 5		
	Less likely than:	10, 5			10, 9, 8	10
8	More likely than:			10, 9, 5	7	
	Less likely than:	10, 5			9	10
9	More likely than:				8, 7, 6	6
	Less likely than:	10, 5		10, 8, 7, 6		
10	More likely than:	9, 8, 7, 6		9	7, 6	8, 7, 6
	Less likely than:			8, 7		

		Insects	Nonfood	Other Crustaceans	Other Non-crustaceans	Shrimp
5	More likely than:					
	Less likely than:					
6	More likely than:	10, 9, 8				
	Less likely than:		9, 8	9		10
7	More likely than:	10				
	Less likely than:				10, 9	
8	More likely than:		6			
	Less likely than:	6			10, 9	10
9	More likely than:	10	6	6	8, 7	
	Less likely than:	6				10
10	More likely than:				8, 7	9, 8, 6
	Less likely than:	9, 7, 6				

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