Spring Chinook Salmon Interactions Indices and Residual/Precocious Male Monitoring in the Upper Yakima Basin

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Executive Summary

Select ecological interactions and spring Chinook salmon residual/precocious male abundance were monitored in 2007 as part of the Yakima/Klickitat Fisheries Project's supplementation monitoring program. Monitoring these variables is part of an effort to help evaluate the factors that contribute to, or limit supplementation success. The ecological interactions that were monitored were prey consumption, competition for food, and competition for space. Spring Chinook salmon life-history forms that have the potential to be influenced by supplementation and that pose ecological and genetic risks were monitored (residuals and precocious males). Residual spring Chinook salmon do not migrate to the ocean during the normal emigration period and continue to rear in freshwater. Precocious males are those salmon that precociously mature in freshwater. The purpose of sampling during 2007 was to continue monitoring interactions indices and residual/precocious male distribution and abundance. All sampling that we report on here was conducted in the upper Yakima River during summer and fall. Abstracts of the topics covered in this report are listed below.

Chapter 1. Studying an indirect interaction such as competition is very challenging and yet extremely important because of the impact that competition can have in structuring fish communities. Two competition indices were developed to assess the competition strength upon juvenile spring Chinook salmon: a food competition index to detect the effects of interference and exploitative competition; and a space competition index to detect the effect of interference competition. The main factors in the food competition index were food availability, food overlap, and competitor food consumption. The main factors in the space competition index were spatial overlap and abundance of sympatric competitors. We evaluated the utility of the indices by collecting data on stream fishes that have the potential to compete with juvenile Chinook salmon. Data were collected during the summer and fall, 1998-2007 in the upper Yakima Basin. The space and food competition indices were highest for spring Chinook salmon and next highest for rainbow trout. Other species or taxa (e.g., mountain whitefish, redside shiner, hatchery spring Chinook salmon residuals, eastern brook trout, sucker spp. coho salmon, and cutthroat trout) had considerably lower index scores. The ranking of competitors did not change following the supplementation of Chinook salmon. Preliminary analyses revealed that food competition indices for spring Chinook salmon were the only indices that correlated well with spring Chinook growth or survival, but correlations were not an improvement over those with spring Chinook abundance.

Chapter 2. The carrying capacity of a watershed is one of the main factors in determining whether supplementation is a viable technique of increasing natural production. We measured standard microhabitat values for age-0 spring Chinook salmon in four areas in the upper Yakima River Basin during the summers of 1998 to 2006 in an effort to index the carrying capacity of rearing space. If supplementation activities succeed in increasing the density of age-0 spring Chinook salmon and the resulting population exceeds the carrying capacity of the habitat, we expected to see an increase in the proportion of fish using suboptimal microhabitats and an asymptotic number of fish in optimal habitats. Contrary to our expectations, the proportion of spring Chinook salmon in sub optimal habitats did not increase with increasing abundance of spring Chinook salmon, and the number of fish occupying optimal habitats increased with increasing abundance. Our data may indicate that

space is not limiting Chinook salmon growth or survival in the upper Yakima basin or that Chinook salmon decrease their territorial behavior in response to increasing abundance of con-specifics. Alternatively, standard microhabitat variables may not measure the variables that are most important for microhabitat selection. We will explore new measures of microhabitat use and, along with the food and space competition indices, monitor any changes that may be associated with supplementation activities.

Chapter 3. Previous work has shown that a spring Chinook salmon supplementation program in the Yakima Basin produces large numbers of precocious males but that these fish were not abundant on the spawning grounds. Growth modulation of half the hatchery-reared fish was instituted to reduce the incidence of precocious maturation. In this study, we compared demographic and behavioral variables of hatchery and natural origin male spring Chinook salmon (*Oncorhynchus tshawytscha*) that precociously mature in the Yakima River. Comparisons were made between those years before growth modulation was started (1999-2003) and the years when it was instituted (2004-2006). We counted the number of precocious males on the spawning grounds while snorkeling during the peak of spawning, electrofished to determine abundance and distribution of precocious males away from redds, observed agonistic interactions while snorkeling, and collected Chinook to determine % precocity, size, and age. The abundance of hatchery origin precocious males on redds during 2004 was the highest that has been recorded, but still considerably less than the number of natural origin precocious males. In contrast, the abundance of hatchery origin precocious males on redds during 2005 and 2006 (n=0) was the lowest that has been recorded. The mean size of precocious males was within the range observed during previous years. In contrast to previous years, a small number of the residualized fish collected were immature. Preliminary results suggest that growth modulation might reduce the abundance of hatchery origin precocious males on the spawning grounds if factors that occur after release promote a low probability of surviving to or potential to reach the spawning grounds.

Chapter 4. Predation by hatchery fish is commonly thought to be one of the most potent ecological interactions that could impact wild fish populations. We evaluated the incidence of predation of hatchery spring Chinook salmon on natural origin *Oncorhynchus mykiss* and Chinook salmon in the Yakima River Basin. Spring Chinook were sampled between July and September 1999 to 2004, and between April and September 2005 to 2007. Fish were collected by backpack electrofishing, drift-boat electrofishing, and angling. Upon capture, stomach contents of Chinook salmon were evacuated using pulsed gastric lavage. We detected low incidence of piscivory by hatchery spring Chinook in the main stem Yakima River and none in the North Fork of the Teanaway River. However, prey fish of suitable sizes were present in the reaches where we collected hatchery spring Chinook salmon. Our data suggest that releasing hatchery fish at a size similar to natural origin conspecifics and using volitional release has the potential to decrease the incidence of predation by hatchery spring Chinook salmon.

Chapter 5. One of the potential benefits of a successful hatchery supplementation project is the increase in the amount of food provided by salmon carcasses that is available to natural origin fish. We found that supplementation increased the amount of marine derived nutrients in the upper Yakima watershed. In addition, adult spring Chinook salmon that return to the Yakima River provide a net increase of nutrients relative to the mass of spring Chinook salmon smolts that leave the Yakima Basin and this addition is amplified when higher abundances of adults return to the Yakima River. We evaluated the importance of Chinook salmon carcasses to juvenile salmonids (Chinook salmon and rainbow trout) in the Yakima River by 1) examining stomach contents of juvenile salmonids when carcass material was available, 2) evaluating stomach fullness of juvenile salmonids during the following summer rearing period, and 3) comparing spring Chinook salmon and rainbow trout biomass relative to the number of carcasses present one and two years prior. Averages from 1999-2007 revealed that less than 3% of spring Chinook salmon and rainbow trout contained flesh or eggs in their stomachs. Salmon and trout mainly fed on invertebrates during all periods. Furthermore, there was not a significant correlation between the number of salmon redds (an index of carcass abundance) and the incidence of flesh and eggs in fish stomachs, the stomach fullness during the summer and the number of redds one year prior, or the biomass and the number of redds one or two years prior ($P>0.05$). To date, we found little evidence to indicate that current ranges of abundances of salmon carcasses provided significant nutrient benefits to salmon or trout in the upper Yakima River. More dramatic increases in carcasses and/or increases in nutrient retention may be necessary before benefits to juvenile salmonids are detectable.

Chapter 6. It has been hypothesized that water discharge in the upper Yakima River is managed in a way that influences the upper limit of juvenile spring Chinook salmon abundance. Our goals were to 1) evaluate the relationship between abundance of drifting invertebrates and water velocity during high flows in the summer, and 2) determine the maximum percentage of habitat that is habitable by juvenile Chinook salmon during abnormally high (summer) and more natural low flow (fall) periods. Three different relationships between flow and drifting invertebrate abundance were detected in the three transects that were measured in 2005. First, there was a positive relationship between flow and drifting invertebrate abundance in the Cle Elum Transect ($P=0.01$). Second, there was a negative relationship between flow and drifting invertebrate abundance in the Cle Elum River Transect ($P=0.04$). Third, there was not a significant relationship between flow and drifting invertebrate abundance in the Nelson Transect ($P=0.13$). In 2006, all of the transects were positively related to flow, but none were statistically significant ($P>0.05$) until all samples were pooled ($P<0.05$). Habitable area for juvenile spring Chinook salmon differed between the summer and fall in all sections, but those sections that had the largest relative difference in discharge during the summer (relative to the fall) had the largest difference in habitable area. Mean discharge averaged over 10 times higher in the Cle Elum and Cle Elum River sections during the summer than during the fall. The habitable area in these sections was over 100% higher in the fall than the summer, even though the wetted area and discharge were substantially higher during the summer. The mean percent of habitable locations was higher in the fall than the summer in the Cle Elum and Cle Elum River sections. Approximately 15% of transect locations were habitable in the summer and 90% in the fall in these sections. In short, higher discharges increased wetted area but decreased the percent of the locations that were habitable by over 5 times, resulting in over 100% less habitable areas at artificially high summer discharge than more normal fall discharge. In contrast to the two other sections, the habitable area in the Nelson section was higher during the summer than the fall. Discharge was less than 2 times higher during the summer than the fall in the Nelson section. The higher area caused by the slightly higher discharge resulted in higher habitable area because the percent of habitable area was similar between the summer and fall. With the exception of the summer of 2007, the percent of habitable locations in the Nelson transects was always above 75% during both seasons. The Nelson transect had a much higher percentage of habitable locations than the other two transects during the summer and varied the least between seasons. These data should be considered preliminary until published in a peer-reviewed journal.

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General Introduction

This report examines some of the factors that can influence the success of supplementation, which is currently being tested in the Yakima Basin using the upper Yakima stock of spring Chinook salmon. Supplementation success in the Yakima Basin is defined relative to four topic areas: natural production, genetics, ecological interactions, and harvest (Busack et al. 1997). The success of spring Chinook salmon supplementation in the Yakima Basin is dependent, in part, upon fish culture practices and favorable physical and biological conditions in the natural environment (Busack et al. 1997; James et al. 1999; Pearsons et al. 2003; Pearsons et al. 2004; Pearsons et al. 2005; Pearsons et al. 2006; Pearsons et al. 2007). Shortfalls in either of these two topics (i.e., failure in culturing many fish that have high long-term fitness or environmental conditions that constrain spring Chinook salmon production) will cause supplementation success to be limited. For example, inadvertent selection or propagation of spring Chinook that residualize or precociously mature may hinder supplementation success. Spring Chinook salmon that residualize (do not migrate during the normal migration period) may have lower survival rates than migrants and, additionally, may interact with wild fish and cause unacceptable impacts to non-target taxa. Large numbers of precocious males (nonanadromous spawners) may increase competition for females and significantly skew ratios of offspring sired by nonanadromous males, which could result in more nonanadromous spring Chinook in future generations. Conditions in the natural environment may also limit the success of spring Chinook supplementation. For example, intra or interspecific competition may constrain spring Chinook salmon production. Spring Chinook salmon juveniles may compete with each other for food or space or compete with other species that have similar ecological requirements. Monitoring of spring Chinook salmon residuals, precocious males, prey abundance, carrying capacity, and competition will help researchers interpret why supplementation is working or not working (Busack et al. 1997). Monitoring ecological interactions will be accomplished using interactions indices. Interactions indices will be used to index the availability of prey and competition for food and space.

The tasks described below represent various subject areas of juvenile spring Chinook salmon monitoring but are treated together because they can be accomplished using similar methods and are therefore more cost efficient than if treated separately. Topics of investigation we pursued in this work were: 1) strong interactor monitoring (competition index and prey index), 2) carrying capacity monitoring (microhabitat monitoring); 3) residual and precocious male salmon monitoring (abundance); 4) performance of growth modulation in reducing precocious males during spawning; 5) incidence of predation by residualized Chinook salmon; and 6) benefits of salmon carcasses to juvenile salmonids. This report is organized into six chapters to represent these topics of investigation. Data were collected during the summer and fall, 2007 in index sections of the upper Yakima Basin (Figure 1). Previous results on the topics in this report were reported in James et al. (1999), and Pearsons et al. (2003; 2004; 2005; 2006; 2007). Hatchery-reared spring Chinook salmon were first released during the spring of 1999. The monitoring plan for the Yakima/Klickitat Fisheries Project calls for the continued monitoring of the variables covered in this report. All findings in this report should be considered preliminary and subject to further revision as more data and analytical results become available.

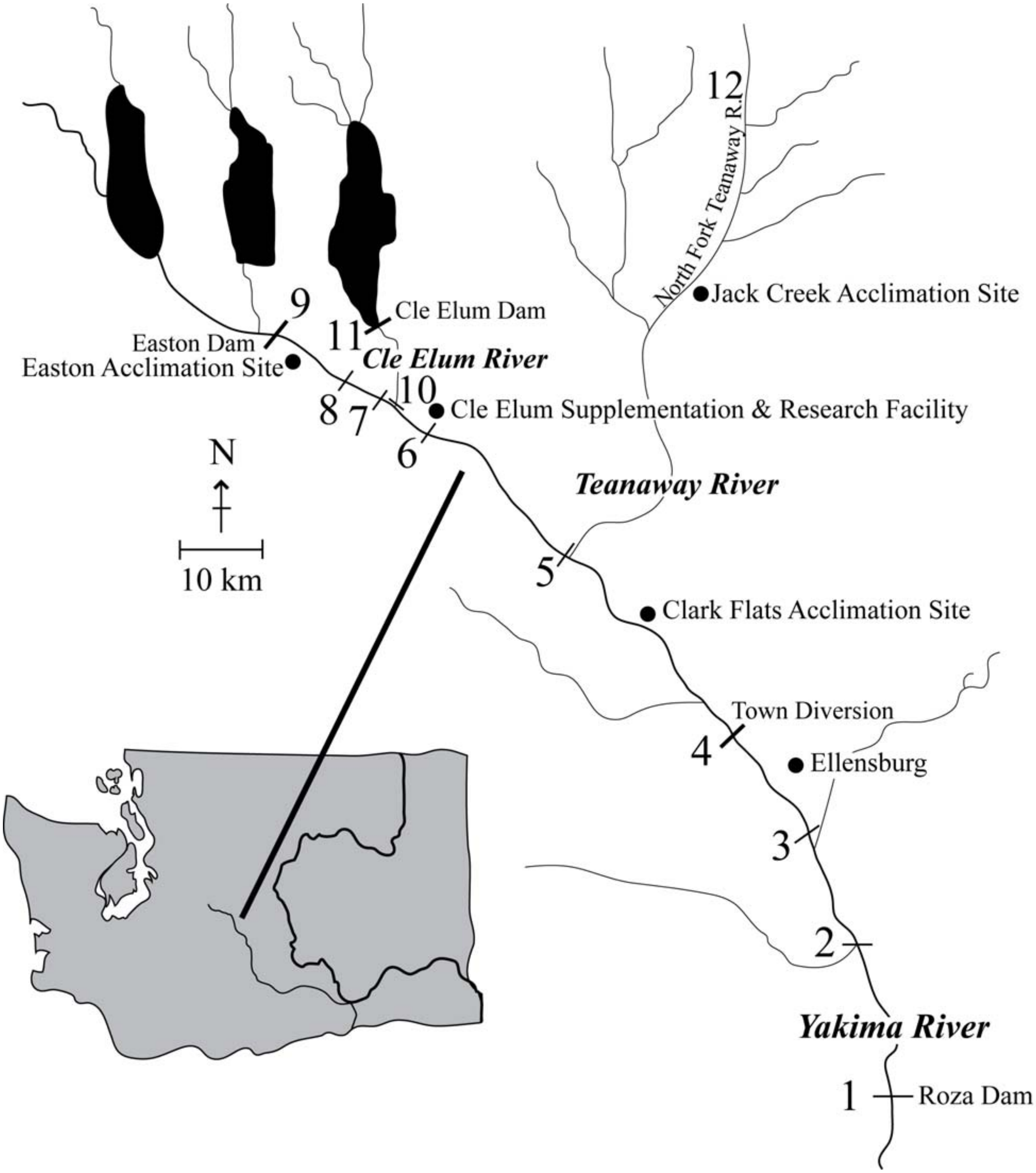

Figure 1. Locations of study sections in the upper Yakima Basin, Washington: lower canyon (points 1-2), upper canyon (points 2-3), Ellensburg (points 3-4), Thorp (points 4-5), Cle Elum (points 5-6), Bullfrog (points 6-7), Nelson (points 7-8), Easton section (points 8-9), Cle Elum River (points 10-11) and multiple sections of the North Fork Teanaway River (point 12).

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Chapter 1

Indices of competition strength among stream fish: Examples from the Yakima Basin

Abstract

Studying an indirect interaction such as competition is very challenging and yet extremely important because of the impact that competition can have in structuring fish communities. Two competition indices were developed to assess the competition strength upon juvenile spring Chinook salmon: a food competition index to detect the effects of interference and exploitative competition; and a space competition index to detect the effect of interference competition. The main factors in the food competition index were food availability, food overlap, and competitor food consumption. The main factors in the space competition index were spatial overlap and abundance of sympatric competitors. We evaluated the utility of the indices by collecting data on stream fishes that have the potential to compete with juvenile Chinook salmon. Data were collected during the summer and fall, 1998-2007 in the upper Yakima Basin. The space and food competition indices were highest for spring Chinook salmon and next highest for rainbow trout. Other species or taxa (e.g., mountain whitefish, redside shiner, hatchery spring Chinook salmon residuals, eastern brook trout, sucker spp. coho salmon, and cutthroat trout) had considerably lower index scores. The ranking of competitors did not change following the supplementation of Chinook salmon. Preliminary analyses revealed that food competition indices for spring Chinook salmon were the only indices that correlated well with spring Chinook growth or survival, but correlations were not an improvement over those with spring Chinook abundance.

Introduction

Studying an indirect interaction such as competition is very challenging and yet extremely important because of the impact that competition can have in structuring communities (Connell 1983; Schoener 1983). Competition for resources occurs if a species utilizes a common resource that is in short supply (exploitative competition) or if a species limits access to a critical resource (interference competition) (Birch 1957). Controlled field experiments are the best way to test competition, but logistically impractical when considering multiple species in a variety of ecological conditions during many years. Historically, resource overlap has been used as an indication or demonstration of competition particularly when there was interest in interaction among many species (Colwell and Futuyma 1971). The use of resource overlap indices during the 1970's resulted in many scientists to conclude that competition was extremely prevalent. However, without additional information, such as resource availability or behavioral interactions, overlap indices can be ambiguous (Colwell and Futuyma 1971; Sale 1974; Ross 1986). For example, high resource overlap between sympatric species is a good indication of competition only if resources are relatively scarce and important to the well being of the organisms. Conversely, low resource overlap is a good indication that significant competition is not occurring only when it can be demonstrated that the lack of overlap is due to innate differences in preferences and not interactive segregation. To overcome the ambiguity of interpretations associated with using just a resource overlap index we developed a composite index of competition that includes a per capita function of resource overlap and resource availability. In addition, the composite competition index includes an index of abundance and resource consumption so that population level competition can be indexed.

Interspecific competition among immature plants and animals is usually classified into competition for space or food (Connell 1983; Schoener 1983). Therefore, we developed a space competition and food competition index. We designed our food competition index to detect interference and exploitative competition and our space competition index was designed to detect interference competition. Salmonids use agonistic interactions to defend space against other fishes (Grant and Kramer 1990; McMichael et al. 1999) and must be within interaction range in order to interfere with other fish.

We illustrate the calculation and utility of the indices using data from species of stream fish that were hypothesized to be strong competitors in the Yakima Basin. Mountain whitefish (*Prosopium williamsoni*), redside shiner (*Richardsonius balteatus*), and rainbow trout (*Oncorhynchus mykiss*) are the most likely candidates to compete for food and/or space with spring Chinook salmon and limit spring Chinook salmon productivity in the upper Yakima Basin (Busack et al. 1997; Pearsons et al. 1998). Redside shiners have been shown to displace spring Chinook salmon from preferred habitat (Hillman 1989) and are competitively superior to another cold-water salmonid, steelhead trout, at temperatures above 18^{o}C (Reeves et al. 1987). Spring Chinook salmon parr in the upper Yakima River are frequently observed in close association with redside shiners, and interspecific interactions have been observed between these two species (Pearsons et al. 1996). Rainbow trout are also commonly associated with spring Chinook salmon in the upper Yakima River and their interactions sometimes result in displacement of spring Chinook salmon parr (Pearsons et al. 1996). In contrast, mountain whitefish are rarely associated with spring Chinook salmon but they may exploit food resources because they are very abundant and eat similar prey items as spring Chinook salmon (Daily 1971; Pearsons et al. 1996). We will index the severity of competition of these hypothetical competitors relying upon past observations of agonistic interactions and a combination of two metrics: resource overlap and resource availability (Busack et al. 1997). The indices will refer to the strength of competition with juvenile spring Chinook salmon.

Methods

Space Competition Index

We calculated a space competition index (SCI) by multiplying a spatial overlap index by a competitor abundance index (1).

Space Competition Index = (Spatial overlap index) x (Sympatric abundance index) (1)

The "spatial overlap index" is expressed as the percent of observations where the target taxon has at least one competitor overlapping its "interaction space" (either the same species or a competitor species). "Interaction space" is defined as the outer distance that a competitor will initiate agonistic interactions towards a competitor. This definition is analogous to a territory, but differs because the interaction space around an individual does not have to be anchored to a fixed locality. It is important to recognize that competition is indexed only at the time that observations are made. Prior unobserved interactions may result in interactive segregation. If prior unobserved interactions result in segregation beyond “interaction space”, then the index will indicate a low amount of interference competition. Thus, it is important to describe what times and life-stages the competition index applies. The “sympatric abundance index” is calculated as the ratio of competitor abundance divided by the target taxon abundance when competitors were within interaction space. The target species is natural origin, juvenile spring Chinook salmon.

Field Methods

Spatial overlap and competitor abundance were determined using underwater observations while snorkeling. Spring Chinook salmon and competitors were counted and age classes were determined (age 0, age 1, or adult). When possible we made observations when water temperatures were at or above 14^{o} C so that a greater proportion of the fish in the river could be observed by snorkelers (Hillman et al. 1992). Observations were made by having two snorkelers simultaneously snorkel each bank of a section of the river. When conditions allowed, (i.e. shallow water or slow flows) snorkeling was conducted moving upstream. If water velocities were too fast to snorkel upstream, then snorkelers would detect the presence of fish while floating downstream and then stop to make more detailed observations. Groups of fish that included spring Chinook salmon and were within 30 cm of another were considered a pod and were assumed to be within interaction space (Pearsons et al. 1996). This value also corresponds to territory sizes of salmonids of similar sizes in other watersheds (Grant and Kramer 1990). Any spring Chinook salmon that was more than 30 cm away from another fish was counted as a solitary fish. Data was recorded on a PVC cuff fitted around a snorkeler’s arm.

Interspecific Food Competition Index

We calculated an inter-specific food competition index by multiplying a per capita competition index by an index of food consumption by the population of the competitor (2).

$$\text{(Per capita competition index)} \quad \times \quad \text{(Population consumption index)} \qquad (2)$$

The per capita competition index is calculated by multiplying a food overlap index by a food availability index (2).

$$\text{(overlap index)} \quad \times \quad \text{(food availability index)} \qquad (3)$$

There are many mathematical expressions that have been proposed to index resource overlap. We chose to use Schoener’s (1970) index because it requires few assumptions and is among the most widely used niche overlap index (Crowder 1990). We also calculated the index to just two decimal places because confidence intervals of the index may be quite large (Ricklefs and Lau 1980; Crowder 1990). Diet overlap (O_{jk}) was calculated with formula 4.

$$O_{jk} = 100 \times [1 - (1/2 \times \Sigma\, |p_{ij} - p_{ik}|\ )] \qquad (4)$$

where p_{ij} is the proportion of resource *i* (food item) found in species *j*, and p_{ik} is the proportion of resource *i* (food item) found in species *k*.

Resource availability is very difficult to measure in many field situations. One of the difficulties in quantifying resource availability is determining what is actually available to the organism of interest. For example, traditional methods of sampling stream invertebrates may not reflect the amount of prey that is actually available to fish. Invertebrates that hide under rocks or that become active at night may not be available to fish that feed primarily during the day, but they would still be counted as "available" if traditional sampling methods, such as using drift nets, were used. This scenario would result in an overestimate of prey available to fish. To eliminate this potential problem we used the gut fullness of the organism to index the availability of prey. We assume that fish eat food in proportion to its availability if environmental conditions are suitable for growth. For instance, we assume that low stomach fullness during the summer when salmonids are growing indicates that food availability is low. We used Herbold's (1986) method to calculate stomach fullness. Gut fullness was determined by plotting stomach content dry weights against the fish fork length and fitting a regression line through the maximum stomach dry weights representing a range of fish lengths (Figure 3). Maximum stomach dry weights were included in the model fitting process if it was the heaviest value for a given length of fish and that it was heavier than the highest value for smaller fish. The equation of the line was then used to determine the maximum stomach fullness for each size class of fish. The stomach fullness was then calculated by dividing the observed fullness for each fish by the estimated maximum fullness for a fish of its size. This value was then standardized to the proportion of the stomach that was empty using equation 5.

$$1 - (\text{observed fullness} / \text{maximum estimated fullness}) \qquad (5)$$

The population consumption index of a competitor species was calculated by multiplying the average weight of the stomach contents by an index of competitor abundance (6).

$$(\text{average stomach content weight}) \quad \text{x} \quad (\text{competitor abundance index}) \qquad (6)$$

The stomach content weights for all sizes of each of the species sampled were averaged. The competitor abundance index was the abundance of species observed during night electrofishing in five main stem sections multiplied by our space competition index (7). Relative abundance was originally used as a measure of competitor abundance, however because this is dependent upon the abundance of many species, we chose to use absolute abundance from fall visual abundance estimates as a better indicator of competitor species abundance. We also multiplied the abundance of each species by the space competition index to account for habitat use. We assumed that a species that was closer to feeding locations of Chinook salmon was more likely to compete for food than a species that might typically occupy different locations in the channel.

$$(\text{abundance of species z observed}) \;\text{x}\; (\text{space competition index}) \qquad (7)$$

In summary, the interspecific food competition index (equation 2) is the product of equations 3 and 6.

Intraspecific Food Competition Index

Results from the interspecific index indicated that intraspecific competition was the strongest source of competition on Chinook salmon (see results). Therefore we developed a new index to refine the measurement of intraspecific competition. We indexed the total amount of food consumed by the Chinook salmon population by multiplying an abundance index by a per capita food consumption rate. The abundance index was the same as described for the interspecific food index, but the food consumption rate was estimated using a meal turnover method. Daily meal was determined by the following formula:

$$(MS/r_e) * 24 \text{ hours} \qquad (8)$$

Where MS is the mean monthly stomach wet weight and r_e is the rate of evacuation.
Rate of evacuation was determined by using Ruggerone's (1989) relationship for the evacuation rate of coho salmon that ate sockeye salmon fry because a relationship for Chinook salmon was not available. Because nearly all of the stomach samples in our data set consist solely of invertebrate prey items, the rate of evacuation was further modified by a factor of 0.43; a difference in gastric evacuation rate between invertebrates as determined by Brodeur & Pearcy (1987) and Ruggerone's relationship for gastric evacuation of sockeye salmon fry.

$$r_e=((0.133+0.021(T)-0.402(MS)) * 0.43 \qquad (9)$$

Gastric evacuation rates were determined using daily mean temperature (T, (^{o}C)) and mean monthly stomach wet weight (MS, in grams). Because we measured stomach contents in dry weight and the model input required wet weights, we converted stomach content dry weights to wet weights using a linear regression model of samples that we collected where dry and wet weights were available.

Temperatures for use in the relationship were daily means of hourly temperatures acquired from WDFW thermographs within the Cle Elum index site; a site most representative of the areas in which the majority of the stomach samples were collected. The U.S. Bureau of Reclamation (USBOR) Hydromet temperatures within the Cle Elum section were used on a number of dates where thermograph data was unavailable. No temperature data were found within the Cle Elum section for 1998. For that year Hydromet data from near Umtanum Creek, a site lower on the Yakima River main stem, was compared to Hydromet data at the Cle Elum site over a five-year period and a daily correction factor derived from the mean monthly difference between the two. Finally, the index of competitor consumption was determined by multiplying daily meal and competitor abundance.

Field Sampling

To determine food availability for juvenile spring Chinook salmon we sampled four main stem sections and one tributary section during the summer and fall in the upper Yakima Basin. The main stem sections included; Nelson, a 7.2 km section of river below Easton Dam between the WDFW access ramp (river km 314.6) and the I-90 bridge (river km 307.4), Cle Elum a 8.8 km section of river that flows past Cle Elum from river km 294.5 (South Cle Elum Bridge) to river km 285.7 (WDFW access ramp near the Teanaway River confluence), Thorp, a 3.4 km section between the Clark Flats acclimation site and the Thorp highway bridge, and Upper Canyon (UCAN) a 4.8 km section of river south of Ellensburg from Ringer road access (river km

238.2) to Bighorn (river km 233.4). Due to high flows and dangerous conditions in the main stem, snorkel sampling in the Cle Elum section was conducted in side-channels. The fifth section was a 5 km section of the lower North Fork Teanaway River (NFT) between the mouth of Dickey Creek and the confluence of the North Fork and main stem Teanaway River. Due to differences between the NFT and the main stem Yakima River, data collected in the NFT are currently used only in the calculation of maximum fullness of spring Chinook salmon. We sampled primarily during the day because Chinook salmon rearing in streams prey primarily on larval and adult insects and feed during the day (Healy 1991; Sagar and Glova 1988). However, samples have been consistently collected at night within the Cle Elum and Upper Canyon sections of the main stem Yakima River.

Age 0 spring Chinook salmon were collected using several methods. During the day, fish were collected with a backpack electrofisher. When electrofishing was inefficient in capturing fish (e.g., high water), fish were collected via hook and line using a dry fly or live bait. Sampling at night was primarily by drift boat electrofishing. Upon capture, the fish were anaesthetized and weighed to the nearest gram. Fork length was then measured (mm), and when possible stomachs were flushed using a modified gastric lavage technique (Giles 1980). After collection, the stomach contents were preserved in alcohol and invertebrates were identified to order and counted. During 2001 and 2002, we also identified invertebrates to family in stomachs of a subsample of spring Chinook salmon and mountain whitefish. Between 2003 and 2005, we identified prey items to taxonomic levels identified in Table 1. We did this to determine the level of taxonomic resolution where results would be consistent. These levels were based upon degrees of overlap at higher taxonomic levels. If overlap was low at higher taxonomic levels then we did not identify prey items to lower levels. We subsampled the prey items at lower taxonomic levels and then applied those findings to the whole sample. Contents from each stomach were then dried at 80^0 C for 48 hours and weighed to the nearest 0.0001g. Non-nutritious items, such as caddisfly cases, sticks, and stones were removed from the sample prior to weighing.

Table 1. Taxonomic level of invertebrate identification 2003-2005.

Order	Family	Genus
Arachnid		
Cladocera		
Coleoptera		
Diptera		
	Athericidae	
	Brachyceridae	
	Ceratopogonidae	
	Chaoboridae	
	Chironomidae	
		Acricotopus
		Brillia
		Bryophaenocladius
		Cardiocladius
		Chaetocladius
		Chironominae
		Chironomus
		Cladopelma
		Cricotopus
		Cricotopus/Orthocladius
		Cricotopus/Paratrichocladius
		Diamesa
		Endochironomus
		Epoicocladius
		Eukiefferiella
		Goeldichironomus
		Guttipelopia
		Halocladius
		Heleniella
		Heterotrissocladius
		Hydrobaenus
		Krenosmittia
		Limnophyes
		Metriocnemus
		Microchironomus
		Micropsectra
		Monodiamesia
		Nanocladius
		Orthocladius
		Pagastia
		Paracladopelma
		Paracricotopus
		Parakiefferiella
		Parametriocnemus
		Paratanytarsus
		Parochlus
		Parorthocladius
		Phaenopsectra
		Podonomini
		Polypedilum
		Potthastia
		Procladius
		Pseudochironomus
		Pseudokiefferiella
		Pseudorthocladius
		Pseudosmittia
		Rheopelopia
		Rheotanytarsus
		Smittia
		Stempellinella
		Stictochironomus
		Synorthocladius
		Tanypodinae
		Thienemanniella
		Tokunagaia
		Tvetenia
		Zavrelia
		Unknown
	Culicidae	
	Deuterophlebiidae	
	Dixidae	
	Dolichopodidae	
	Empididae	
	Ephydridae	
	Muscidae	
	Pelecorhynchidae	
	Phoridae	
	Psychodidae	
	Sciomyzidae	
	Simuliidae	
	Syrphidae	
	Tabanidae	
	Thaumaleidae	
	Tipulidae	
	Unk	
Ephemeroptera		
	Ameletidae	
	Baetidae	
		Acentrella
		Acerpenna
		Baetis
		Callibaetis
		Dipheter
		Fallceon
		Heterocloeon
		Labiobaetis
		Paracloeodes
		Procloeon
		Unk
	Ephemerellidae	
	Ephemeridae	
	Heptageniidae	
	Leptophlebiidae	
	Siphlonuridae	
	Tricorythidae	
	Unk	
Hemiptera		
	Aphididae	
	Other	
Hymenoptera		
	Andrenidae	
	Apidae	
	Braconidae	
	Cephidae	
	Ceraphronidae	
	Chalcididae	
	Cynipidae	
	Diapriidae	
	Encyrtidae	
	Eulophidae	
	Eupelmidae	
	Figitidae	
	Formicidae	
	Heloridae	
	Ichneumidae	
	Parasitic Wasps	
	Platygasteridae	
	Pompilidae	
	Proctotrupidae	
	Pteromalidae	
	Sphecidae	
	Unk	
Lepidoptera		
Plecoptera		
	Capniidae	
	Chloroperlidae	
	Leuctridae	
	Nemouridae	
	Perlodidae	
	Pteronarcidae	
	Unknown	
Trichoptera		
	Brachycentridae	
	Glossosomatidae	
	Helicopsychidae	
	Hydropsychidae	
		Ceratopsyche
		Cheumatopsyche
		Hydropsyche
		Unk
	Hydroptilidae	
	Lepidostomatidae	
	Leptoceridae	
	Limnephilidae	
	Philopotamidae	
	Phryganeidae	
	Polycentropodidae	
	Psychomyiidae	
	Rhyacophilidae	
	Sericostomatidae	
	Uenoidae	
	Unk	
Terrestrial		
fish		
eggs		
Other		

Stomach content removal methods for rainbow trout were identical to those used for spring Chinook salmon, however, mountain whitefish and redside shiners were preserved and gut contents were removed in the lab via dissection due to the inadequacy of gastric lavage techniques on these fish. Mountain whitefish were primarily captured in the Upper Canyon and Cle Elum sections at night with a drift boat electrofishing unit because of difficulty capturing these fish during the day. Prey items were identified to taxonomic levels in Table 1 with the aid of a dissecting microscope.

Results

Space Competition Index

Space competition indices (SCI) were highest for spring Chinook (i.e., intraspecific competition) during all years (Table 2). The next highest index scores were for rainbow trout, redside shiner, mountain whitefish, and hatchery spring Chinook salmon (Table 2). If all of the interspecific SCI values for other species were added together, they would still be less than the SCI value for spring Chinook salmon. High indices for rainbow trout are primarily due to high spatial overlap, whereas high indices for redside shiner are primarily due to localized high abundance (Table 2). SCI values for Chinook salmon did not explain a significant amount of variation in size or survival of Chinook salmon and did not improve relationships using Chinook salmon abundance alone (Figures 1 and 2). Size and survival of spring Chinook salmon were provided from another study.

Table 2. Space competition indices between age 0 spring Chinook salmon and other competitor species within the main stem Yakima River. An index of zero represents a species with no observed spatial overlap within a given year.

Species	Spatial overlap	Competitor abundance	Space competition index
	1998* n = 325		
SPC	0.48	6.69	3.19
HSPC	0	0	0
RBT	0.25	0.78	0.20
MWF	0.06	0.63	0.04
RSS	0.08	3.57	0.27
SUK	0	NA	0
COHO	0	NA	0
	1999 n = 151		
SPC	0.58	5.16	2.97
HSPC	0.17	0.74	0.12
RBT	0.30	1.14	0.34
MWF	0.07	1.25	0.08
RSS	0.04	1.19	0.05
SUK	0	NA	0
COHO	0	NA	0
	2000 n = 205		
SPC	0.55	4.10	2.27
HSPC	0.01	0.53	0.01
RBT	0.36	0.89	0.32
MWF	0.15	0.75	0.12
RSS	0.05	4.81	0.24
SUK	0	NA	0
COHO	0	NA	0
	2001 n = 1306		
SPC	0.59	6.27	3.72
HSPC	3.9E-03	0.11	4.4E-04
RBT	0.14	0.68	0.09
MWF	0.02	0.31	4.7E-03
RSS	0.02	0.47	0.01
SUK	2.3E-03	0.14	3.1E-04
COHO	0	NA	0
	2002 n = 599		
SPC	0.67	4.21	2.81
HSPC	0.003	3.4E-05	1.2E-07
RBT	0.05	0.027	0.001
MWF	0.02	0.004	6.7E-05
RSS	0.02	0.004	6.1E-05
SUK	0	NA	0
COHO	0.03	0.02	6.3E-04
	2003 n = 245		

SPC	0.53	4.99	2.65	
HSPC	0.02	1.6E-03	3.3E-05	
RBT	0.18	0.11	0.02	
MWF	0.03	0.01	2.4E-04	
RSS	0.03	0.02	6.8E-04	
SUK	0.01	2.2E-03	2.7E-05	
COHO	0.02	0.03	5.4E-04	
2004 n = 337				
SPC	0.55	3.40	1.88	
HSPC	0.01	0.01	7.7E-05	
RBT	0.30	0.31	0.09	
MWF	0.04	0.03	1.2E-03	
RSS	0.10	0.19	0.02	
SUK	0.01	4.1E-03	5.1E-05	
COHO	3.1E-03	4.9E-04	1.5E-06	
2005 n =156				
SPC	0.65	3.88	3.88	
HSPC	0.01	1.05E-03	6.71E-06	
RBT	0.08	0.01	8.90E-04	
MWF	0.02	2.19E-04	4.22E-06	
RSS	0.10	0.16	0.02	
SUK	0.01	3.21E-03	2.05E-05	
COHO	0.01	2.27E-03	1.45E-05	
2006 n = 270				
SPC	0.40	1.69	0.67	
HSPC	0	0	0	
RBT	0.17	0.12	0.02	
MWF	0.01	0.01	1.49E-04	
RSS	0.03	0.04	1.18E-03	
SUK	0	0	0	
COHO	0	0	0	
2007 n = 158				
SPC	0.66	3.90	2.59	
HSPC	0.01	0.35	2.2E-03	
RBT	0.30	1.17	0.36	
MWF	0.09	0.49	0.04	
RSS	0.05	0.14	0.01	
SUK	0.01	0.01	8.0E-05	
COHO	0	0	0	
Average 1999-2007				
Species	Spatial overlap	Competitor abundance	Space comp.	Stdev
SPC	0.57	4.43	2.66	0.93
HSPC	0.03	0.22	0.02	0.05
RBT	0.21	0.52	0.14	0.15
MWF	0.05	0.35	0.05	0.05
RSS	0.05	1.06	0.08	0.11
SUK	4.0E-03	0.04	1.4E-05	3.0E-05
COHO	0.01	0.01	2.1E-06	5.5E-06

COHO = coho salmon, CUT = cutthroat trout, EBT = eastern brook trout, HSPC = hatchery spring Chinook salmon, MWF = mountain white fish, RBT = rainbow trout, RSS = redside shiner, SPC = spring Chinook salmon, SUK = sucker spp.

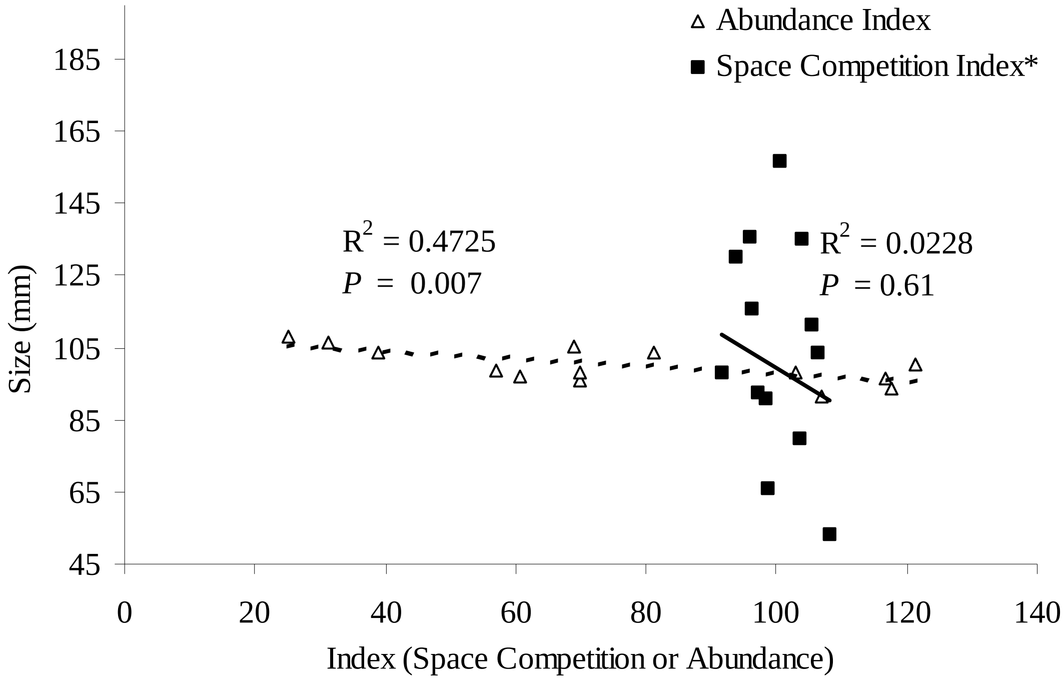

Figure 1. Age 0 spring Chinook salmon size (fork length in millimeters) in relation to spring Chinook salmon abundance (dashed line) and the space competition index (solid line), 1994-2007. * SCI was multiplied by a constant for scaling purposes.

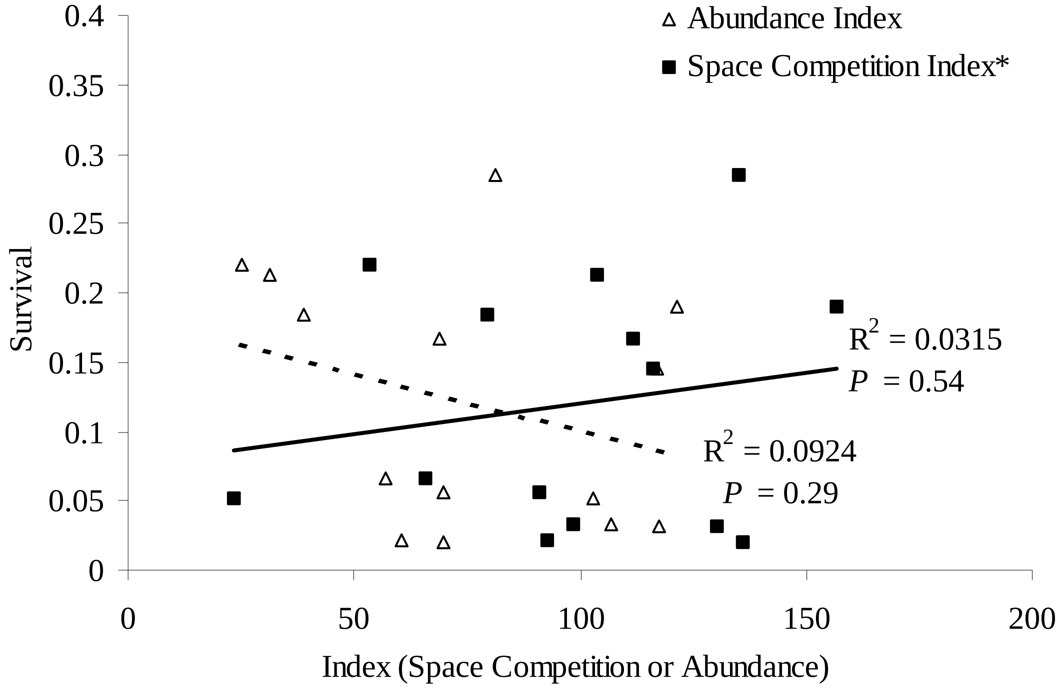

Figure 2. Age 0 spring Chinook salmon survival index in relation to Spring Chinook salmon abundance (dashed line) and the space competition index (solid line), 1994-2007.
* SCI was multiplied by a constant for scaling purposes.

Food Competition Index

The equation used to estimate maximum stomach fullness for spring Chinook salmon (Figure 3) was derived using 4,492 stomach samples. Spring Chinook salmon mainly consumed insects of the following orders; Diptera, Ephemeroptera, and Trichoptera (Figures 4 and 5). The mean gut fullness of spring Chinook salmon was relatively low (Table 3). In general, gut fullness increased throughout the day and peaked around dusk (Table 3).

Interspecific Competition

The competition index calculated for age-0 spring Chinook salmon suggests that intraspecific competition for food was stronger than interspecific competition for food during most years, particularly when prey taxa were identified to the lowest taxonomic level (Table 4). The index for spring Chinook salmon was higher than all other species for all years. However, in some years the combined interspecific indices for rainbow trout and mountain whitefish exceeded the intraspecific index for spring Chinook salmon when prey taxa were identified to Order (Table 4). Rainbow trout was the second strongest competitor and mountain whitefish was third. The index for mountain whitefish was reduced when prey items were identified to genus compared to order. The remainder of the species examined had relatively low index scores. The per capita index was highest for spring Chinook salmon (Table 4). A ranking of the food and space competition indices for each species is presented in Table 6.

Intraspecific index

The daily meal and abundance index varied substantially among years (Table 5). Prior to 2006, the intraspecific competition index explained more of the variation in growth and survival of age 0 Chinook salmon than Chinook salmon abundance alone. However, with the addition of data collected in 2006 and 2007 this finding was reversed (Figures 6 and 7). The food competition index in 2006 and 2007 were the highest that we have observed (Table 5). The relationships between the intraspecific index, and growth and survival of Chinook salmon were statistically significant (P<0.05).

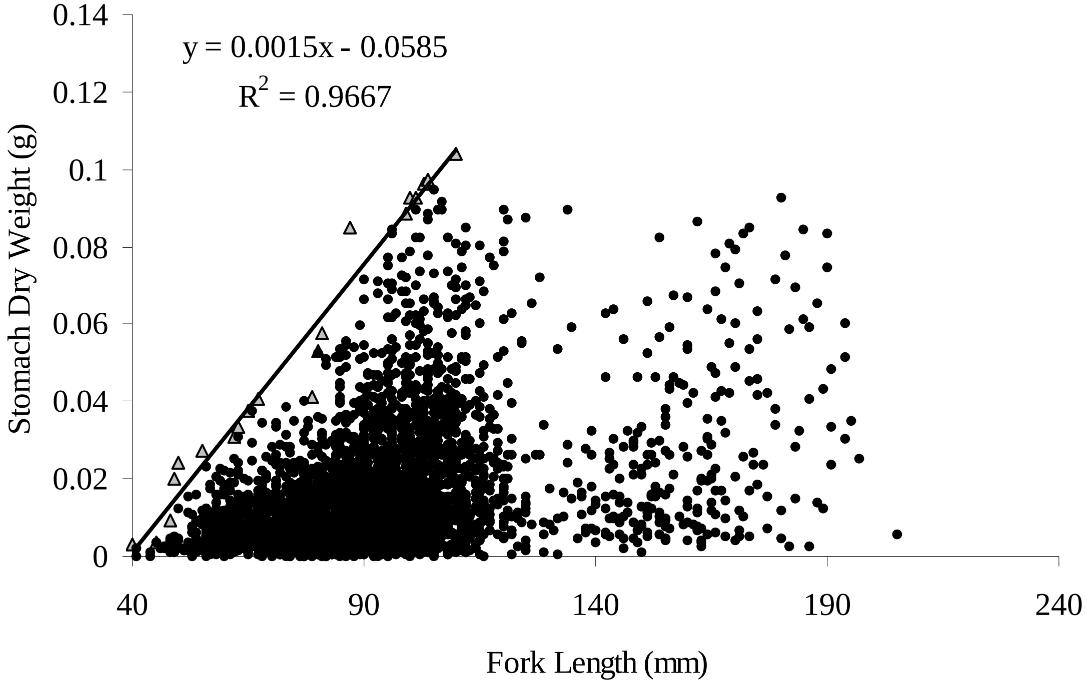

Figure 3. Dry weights of spring Chinook salmon stomach contents plotted against spring Chinook salmon fork length. The triangular points are the maximum weights that were used to fit the maximum stomach fullness regression line.

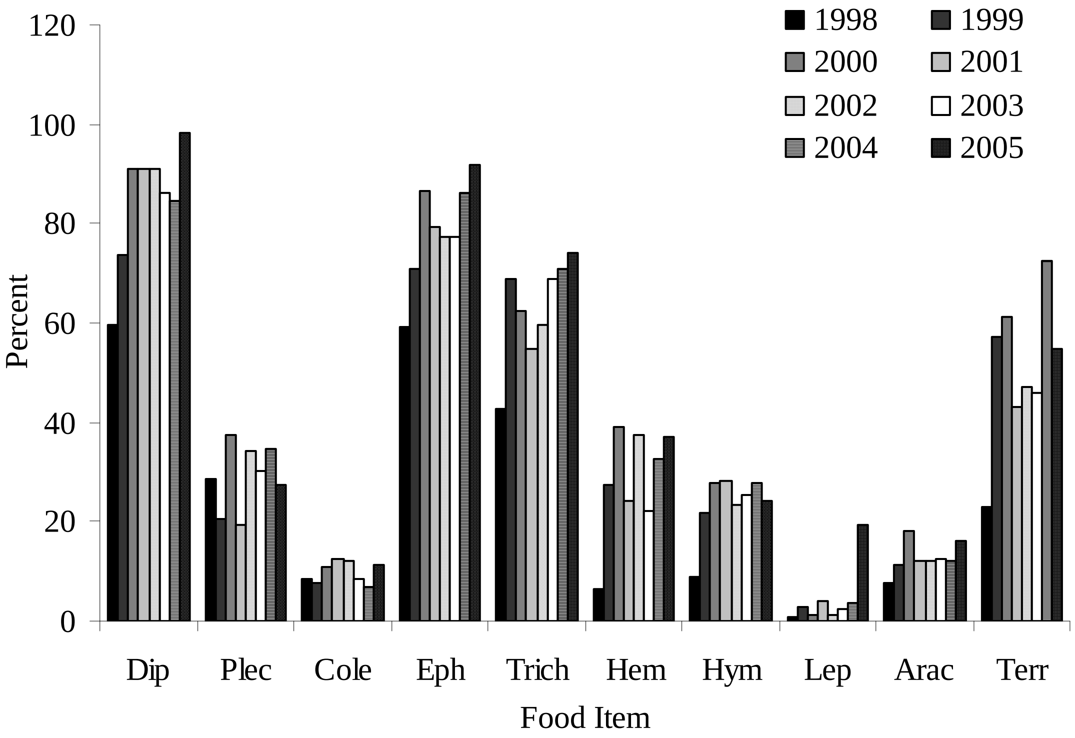

Figure 4. Occurrence frequency of food items found in age-0 spring Chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

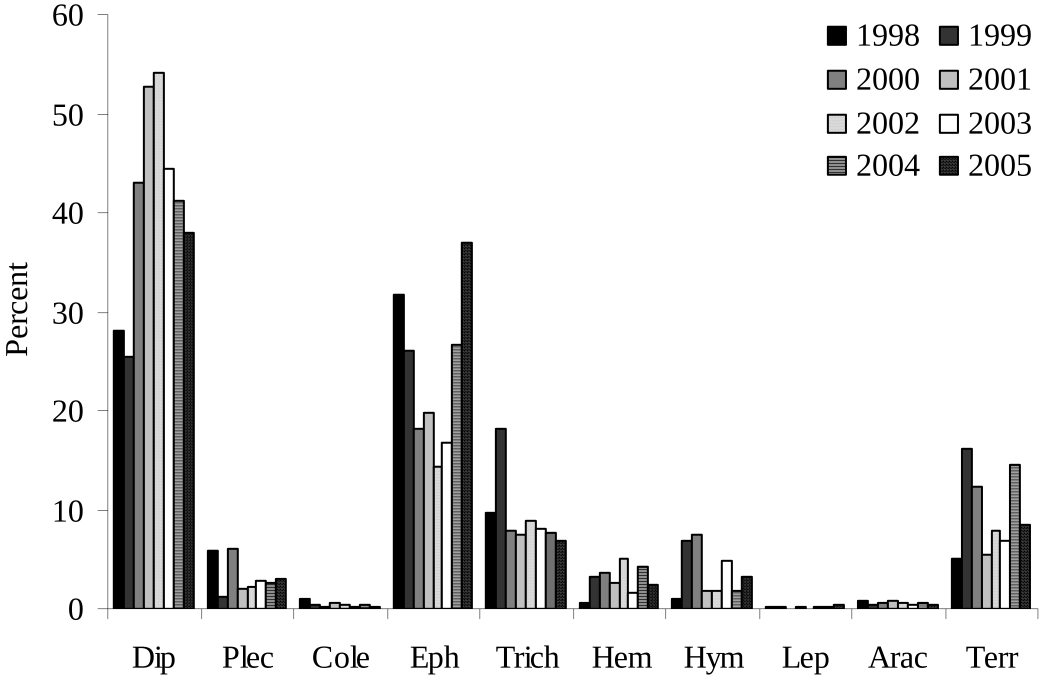

Figure 5. Percent composition of food items found in age-0 spring Chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

Table 3. Average stomach fullness by time for wild spring Chinook greater than or equal to 50 mm within the main stem Yakima River.

	Time Period														
	0:01-4:00		4:01-8:00		8:01-12:00		12:01-16:00		16:01-20:00		20:01-24:00		Average %		
year	%	n	%	n	%	n	%	n	%	n	%	n	Day	Night	24hr
98					4.3	84	6.2	129	17.1	6			9.2	na	9.2
99	8.0	7			17.8	13	12.7	69	16.9	81	19.4	80	15.8	13.7	15.0
2000	24.9	27			10.6	36	14.5	78	23.8	12	21.4	114	16.3	23.1	19.0
2001	11.1	10			19.3	101	20.9	179	25.6	128	20.4	67	21.9	15.8	19.5
2002	21.8	5	18.3	45	18.9	120	16.0	167	25.2	69	29.4	59	19.6	25.6	21.6
2003	23.6	61	14.3	111	14.5	95	15.6	119	15.3	34	33.5	74	14.9	28.5	19.5
2004	28.0	10	8.9	33	9.1	99	18.5	156	17.4	34	27.7	102	13.5	27.8	18.2
2005	21.5	9	9.2	44	8.8	83	11.8	164	13.4	116	34.6	30	10.8	28.1	16.6
2006	45.2	44	10.8	62	16.7	150	14.4	174	25.8	80	34.6	128	16.9	39.9	24.6
2007	30.3	10	21.9	45	39.2	95	30.0	34	23.2	74	31.7	70	30.8	28.0	29.4

*Average 24 hr percent fullness is incomplete for the years 1999-2001; no data exists for those years within the 4:01-8:00 time period.

Table 4. Per capita and population food competition indices between age 0 spring Chinook salmon (SPC) and competitor species during all time periods. An index of zero represents a species with no observed spatial overlap and/or competitor abundance within a given year. Superscripts (*O*), (*F*), and (*g*) represent calculations in which overlap values were determined by the identification of invertebrates to taxonomic levels of order, family, and genus respectively.

Species	Diet Overlap	1-Fullness SPC	Per Capita Index	Average dry wt (g)	Competitor Abundance	Space Comp. Index	Pop. Index
				1998			
COHO	0	0.9	0	NA	1.E-02	0	0
CUT	0	0.9	0	NA	0.2	0	0
EBT	60.4	0.9	54.5	0.39	3.E-02	0	0
HSPC	0	0.9	0	NA	0	0	0
MWF	65.3	0.9	59.0	4.E-02	171.1	4.E-02	15.3
RBT	74.8	0.9	67.5	2.E-02	58.6	0.2	12.9
RSS	50.7	0.9	45.8	3.E-03	1.2	0.3	4.E-02
SPC	100	0.9	90.3	4.E-03	69.0	3.2	86.74
SUK	0	0.9	0	NA	89.5	0	0
				1999			
COHO	0	0.8	0	0	3.E-02	0	0
CUT	61.9	0.8	52.0	0.75	0	0	0
EBT	61.3	0.8	51.5	5.E-02	0.1	0	0
HSPC	84.7	0.8	71.2	3.E-02	0.5	0.1	0.1
MWF	37.3	0.8	31.4	7.E-02	204.4	8.E-02	38.1
RBT	69.8	0.8	58.7	6.E-02	71.1	0.3	84.3
RSS	46.2	0.8	38.8	8.E-03	2.9	5.E-02	5.E-02
SPC	100	0.8	84.1	1.E-02	31.2	3.0	116.3
SUK	0	0.8	0	0	89.5	0	0
				2000			
COHO	0	0.8	0	0	0	0	0
CUT	54.2	0.8	44.1	5.E-02	0.2	0	0
EBT	59.4	0.8	48.4	5.E-02	9.E-02	0	0
HSPC	66.8	0.8	54.3	3.E-02	1.0	1.E-02	2.E-02
MWF	55.7	0.8	45.3	9.E-02	182.5	0.1	90.8
RBT	76.8	0.8	62.5	8.E-02	75.0	0.3	115.1
RSS	72.5	0.8	59.0	3.E-02	3.4	0.2	1.6
SPC	100	0.8	81.4	2.E-02	39.0	2.3	118.7
SUK	47.7	0.8	38.8	5.E-02	69.5	0	0
				2001			
COHO	76.3	0.8	61.4	9.E-03	2.E-02	0	0
CUT	39.0	0.8	31.4	0.13	0.1	0	0
EBT	31.9	0.8	25.7	0.28	1.E-02	0	0
HSPC	49.0	0.8	39.5	4.E-02	6.0	0	0

MWF	72.5	0.8	58.4	8.E-02	244.0	0	0
MWF[F]	16.5	0.8	13.3	8.E-02	244.0	0	0
RBT	63.2	0.8	50.9	7.E-02	73.3	9.E-02	23.4
RSS	67.4	0.8	54.3	1.E-02	4.6	1.E-02	3.E-02
SPC	100	0.8	80.6	1.E-02	117.6	3.7	520.6
SUK	57.5	0.8	46.3	8.E-02	73.4	3.E-04	9.E-02
			2002				
COHO	88.7	0.8	68.2	1.E-02	0	6.E-04	0
CUT	55.6	0.8	42.8	1.E-01	1.0	0	0
EBT	64.9	0.8	49.8	5.E-02	0	0	0
HSPC	51.2	0.8	39.3	7.E-02	0.3	1.E-07	9.E-08
MWF	63.6	0.8	48.9	7.E-02	179.8	7.E-05	4.E-02
MWF[F]	57.8	0.8	44.4	7.E-02	179.8	7.E-05	4.E-02
RBT	76.8	0.8	59.0	8.E-02	65.6	2.E-03	0.5
RBT[F]	39.6	0.8	30.5	8.E-02	65.6	2.E-03	0.2
RSS	75.0	0.8	57.6	4.E-02	4.3	6.E-05	5.E-04
SPC	100	0.8	76.8	1.E-02	106.8	2.8	298.0
SUK	58.3	0.8	44.8	9.E-02	77.0	0	0
			2003				
COHO	72.6	0.8	57.8	2.E-02	0	5.E-04	0
COHO[F]	59.3	0.8	47.2	2.E-02	0	5.E-04	0
COHO[G]	54.4	0.8	43.3	2.E-02	0	5.E-04	0
CUT	32.4	0.8	25.8	0.19	0.3	0	0
EBT	16.4	0.8	13.1	1.E-02	1.E-02	0	0
HSPC	59.2	0.8	47.1	6.E-02	0.7	3.E-05	7.E-05
HSPC[F]	53.1	0.8	42.2	6.E-02	0.7	3.E-05	6.E-05
MWF	62.7	0.8	49.9	6.E-02	185.4	2.E-04	0.1
MWF[F]	50.4	0.8	40.1	6.E-02	185.4	2.E-04	0.1
MWF[G]	36.8	0.8	29.3	6.E-02	185.4	2.E-04	7.E-02
RBT	75.4	0.8	60.0	6.E-02	65.0	2.E-02	4.5
RBT[F]	67.4	0.8	53.6	6.E-02	65.0	2.E-02	4.0
RBT[G]	59.7	0.8	47.5	6.E-02	65.0	2.E-02	3.6
RSS	61.4	0.8	48.8	1.E-02	11.6	7.E-04	4.E-03
SPC	100	0.8	79.6	1.E-02	60.7	2.7	189.5
SUK	60.8	0.8	48.4	5.E-02	52.3	3.E-05	3.E-03
SUK[F]	48.2	0.8	38.4	5.E-02	52.3	3.E-05	2.E-03
SUK[G]	36.2	0.8	28.8	5.E-02	52.3	3.E-05	2.E-03
			2004				
HSPC	53.8	0.8	42.9	6.E-02	2.3	8.E-05	5.E-04
HSPC[F]	52.5	0.8	41.8	6.E-02	2.3	8.E-05	5.E-04

HSPC[G]	51.7	0.8	41.2	6.E-02	2.3	8.E-05	5.E-04
MWF	76.7	0.8	61.2	7.E-02	186.8	1.E-03	1.0
MWF[F]	50.7	0.8	40.5	7.E-02	186.8	1.E-03	0.6
MWF[G]	37.5	0.8	30.0	7.E-02	186.8	1.E-03	0.5
RBT	72.3	0.8	57.7	9.E-02	72.4	9.E-02	35.7
RBT[F]	69.0	0.8	55.0	9.E-02	72.4	9.E-02	34.0
RBT[G]	59.7	0.8	47.6	9.E-02	72.4	9.E-02	29.4
RSS	29.0	0.8	23.1	1.E-02	9.8	2.E-02	5.E-02
RSS[F]	26.9	0.8	21.4	1.E-02	9.8	2.E-02	4.E-02
SPC	100	0.8	79.8	2.E-02	56.9	1.9	144.4
SUK	64.1	0.8	51.1	7.E-02	70.6	5.E-05	1.E-02
SUK[F]	45.9	0.8	36.6	7.E-02	70.6	5.E-05	1.E-02
SUK[G]	39.1	0.8	31.2	7.E-02	70.6	5.E-05	8.E-03
2005							
MWF	60.7	0.8	50.5	0.1	206.9	4.E-06	6.E-03
MWF[F]	31.8	0.8	26.4	0.1	206.9	4.E-06	3.E-03
MWF[G]	4.0	0.8	3.3	0.1	206.9	4.E-06	4.E-04
RBT	92.5	0.8	77.0	7.E-02	66.3	9.E-04	0.3
RBT[F]	68.8	0.8	57.2	7.E-02	66.3	9.E-04	0.2
RBT[g]	64.1	0.8	53.3	7.E-02	66.3	9.E-04	0.2
RSS	63.2	0.8	52.5	1.E-02	9.0	2.E-02	0.1
RSS[F]	52.9	0.8	44.0	1.E-02	9.0	2.E-02	8.E-02
RSS[G]	31.9	0.8	26.6	1.E-02	9.0	2.E-02	5.E-02
SPC	100	0.8	83.2	9.E-03	69.8	3.9	196.0
SUK	59.4	0.8	49.4	6.E-02	75.1	2.E-05	4.E-03
SUK[F]	29.4	0.8	24.4	6.E-02	75.1	2.E-05	2.E-03
SUK[G]	2.0	0.8	1.7	6.E-02	75.1	2.E-05	1.E-04
Average 1998-2005*[O]*							
COHO	39.6	0.8	31.2	7.E-03	1.E-02	2.E-04	0
CUT	34.7	0.8	28.0	0.2	0.3	0	0
EBT	49.1	0.8	40.5	0.1	4.E-02	0	0
HSPC	52.1	0.8	42.1	5.E-02	1.5	2.E-02	2.E-02
MWF	61.8	0.8	50.6	8.E-02	195.1	3.E-02	18.2
RBT	75.2	0.8	61.7	7.E-02	68.4	0.1	34.6
RSS	58.2	0.8	47.5	2.E-02	5.8	8.E-02	0.2
SPC	100	0.8	70.7	1.E-02	60.2	2.5	197.9
SUK	40.4	0.8	32.4	6.E-02	74.6	5.E-05	1.E-02
Average 2003-2005*[F]*							
MWF	44.3	0.8	35.7	0.1	193.0	5.E-04	0.25

RBT	68.4	0.8	55.3	0.1	67.9	4.E-02	12.8
SPC	100	0.8	70.7	1.E-02	60.2	2.5	197.9
SUK	41.2	0.8	33.1	0.1	66.0	3.E-05	5.E-03
			Average 2003-2005[G]				
MWF	26.1	0.8	20.9	0.1	193.0	5.E-04	0.18
RBT	61.2	0.8	49.5	0.1	67.9	4.E-02	11.1
SPC	100	0.8	70.7	1.E-02	60.2	2.5	197.9
SUK	25.8	0.8	20.5	0.1	66.0	3.E-05	3.E-03

COHO = coho salmon, CUT = cutthroat trout, EBT = eastern brook trout, HSPC = hatchery spring Chinook salmon, MWF = mountain white fish, RBT = rainbow trout, RSS = redside shiner, SPC = spring Chinook salmon, SUK = sucker spp.

Table 5. Intra-specific per capita and population food competition indices for age 0 spring Chinook salmon.

Year	Daily Meal (g)	Abundance Index (fish/km)	Food Comp. Index x10^{-1}
1998	7.58	69.02	52.30
1999	14.08	31.24	43.99
2000	15.12	39.04	59.03
2001	12.21	117.61	143.62
2002	12.94	106.77	138.19
2003	14.28	60.66	86.63
2004	15.28	56.86	86.88
2005	10.55	69.81	73.61
2006	15.74	102.84	161.87
2007	22.95	69.96	160.59

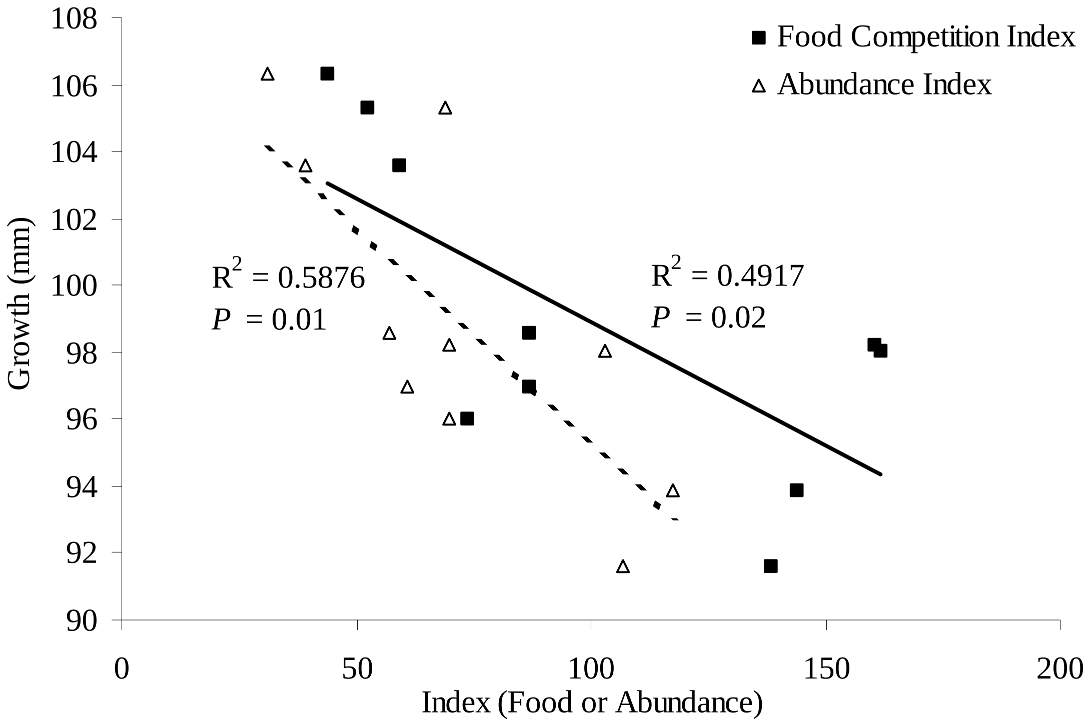

Figure 6. Spring Chinook age 0 mean fork length (mm) in the upper Yakima River, 1998-2007 in relation to abundance (dashed line) and the intra-specific food competition (solid line) indices.

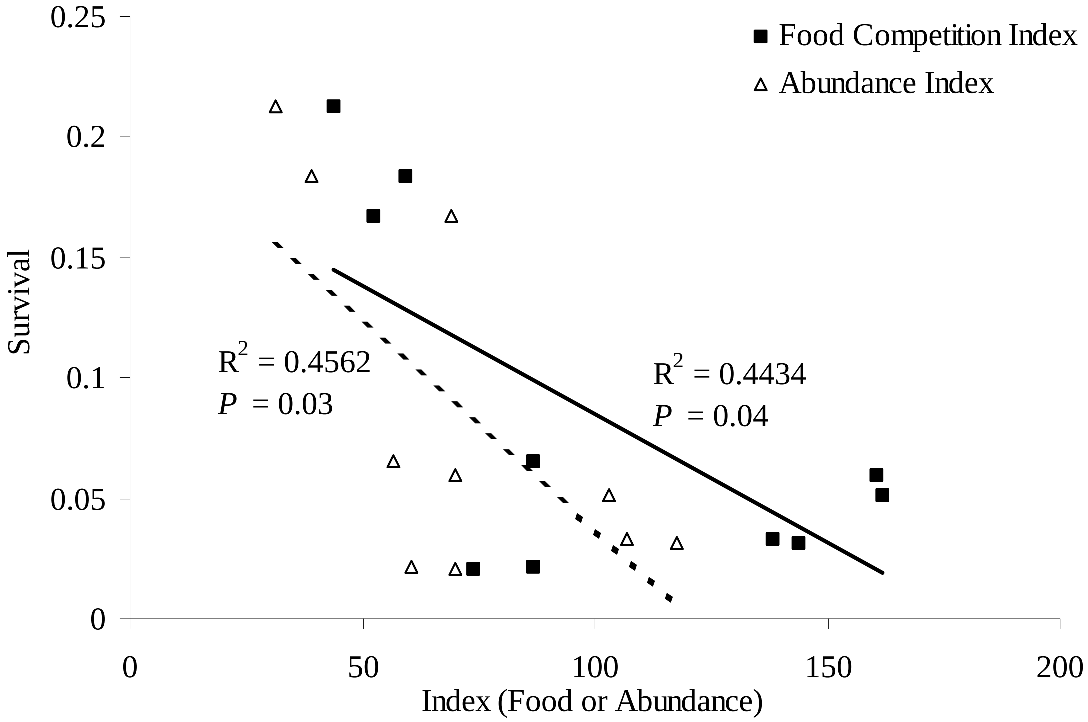

Figure 7. Spring Chinook upper Yakima River survival index (parr abundance index/redds in the previous year) 1998-2007 in relation to abundance and intra-specific food competition indices.

Table 6. Ranking of spring Chinook competitor, food, and space indices by species averages 1998-2005. Index values of zero indicate a lack of observed spatial overlap and/or competitor abundance.

Rank	Per Capita Food		Population Food		Space competition	
1	SPC	70.7	SPC	197.9	SPC	2.9
2	RBT	61.7	RBT	34.6	RBT	3.7E-02
3	MWF	50.6	MWF	18.2	RSS	1.6E-02
4	RSS	47.5	RSS	0.2	COHO	5.4E-04
5	HSPC	42.1	HSPC	2.E-02	MWF	4.8E-04
6	EBT	40.5	SUK	1.E-02	HSPC	7.7E-05
7	SUK	32.4	COHO	0	SUK	3.3E-05
8	COHO	31.2	CUT	0	CUT	0
9	CUT	28.0	EBT	0	EBT	0

COHO = coho salmon, CUT = cutthroat trout, EBT = eastern brook trout, HSPC = hatchery spring Chinook salmon, MWF = mountain white fish, RBT = rainbow trout, RSS = redside shiner, SPC = spring Chinook salmon, SUK = sucker spp.

Discussion

The interspecific competition indices had many desirable properties. For example, the indices facilitated the ranking of competition strength among intraspecific and interspecific competitors, allowed for investigation of competition at a variety of temporal and spatial scales, and allowed examination of total competition by adding the scores of multiple competitor species. In addition, the indices could be generated for most species without lethal sampling. This is particularly important where species are at very depressed levels, such as in places where species are listed under the Endangered Species Act.

Although the indices have many desirable properties, there are still a number of issues that should be considered. For example, taxonomic identification of stomach contents had a substantial effect on the food competition index. Therefore, it seems appropriate to identify stomach contents to the lowest practical level. In some instances, this may mean identifying prey items to species whereas in others to genus or family. Furthermore, the index of abundance that we used in calculating the food competition index likely underestimated the abundance of hatchery spring Chinook precocious males.

The ranking of interspecific competitors with spring Chinook salmon was similar among years and did not appear to be affected by supplementation. The space and food competition indices were highest for spring Chinook salmon, which suggests that intraspecific competition is stronger than interspecific competition. The intraspecific food competition index explained 81% of the variation in Chinook salmon growth and 55% of the variation in survival prior to 2006, but then the correlation dropped substantially in 2006. It is currently unknown why this deviation has occurred. Examination of a more extensive data set also supports the importance of intraspecific competition on growth and survival. We found that the size of age 0 spring Chinook was negatively related to the number of redds that produced them between 1990 and 2004 (Pearsons and Temple 2008). In addition, above approximately a threshold number of redds we did not observe a relationship between number of redds and an index of the number of parr the following Fall (Pearsons and Temple 2008). Below approximately this threshold number of redds we found a positive relationship between survival and the number of redds that produced them. These findings suggest that density dependent growth and survival of spring Chinook salmon is occurring in the upper Yakima River.

Although the space competition index was highest for spring Chinook salmon, the index did not explain much variation in Chinook growth and abundance. This suggests that either: food is the most important limiting factor, our space index is not a good measure of space competition, or space is being measured at the wrong scale. We believe that our index is a good measure of ranking potential competitors, but not a good way of explaining annual variation in growth or survival. Food may be abundant in the river, but there is a relatively small proportion of the wetted area in the summer that has flows that are slow enough for Chinook to be able to sustainably swim. This suggests that an intraspecific space competition index that measures space at a larger spatial scale might be more predictive. This approach is discussed in Chapter 6 of this report.

Preliminary results indicate that the current artificial configuration and management of the upper Yakima Basin may limit the success of the supplementation program. Additional numbers of spawners produced by the hatchery may not increase abundance of parr in the fall, when natural escapement produces over a threshold number of redds (Pearsons and Temple 2008). However, supplementation may increase the number of fall parr when natural escapement (without hatchery influence) is less than this threshold number of redds. Thus, the supplementation program may increase the annualized average number of fall parr by boosting abundance during the years when natural escapement is low. This should also increase the predictability of fall parr abundance. Large increases in abundance of fall parr are unlikely unless the factors contributing towards density dependence are addressed.

We used a model to predict the percent (%) upper limit of population size in five main stem Yakima River sections. The model uses fish size to predict territory size, and then stream area to determine how many territories can be supported (Grant and Kramer 1990). We used the average size of spring Chinook salmon measured during our main stem electrofishing surveys in September and October. During these surveys, which occur after water levels have been reduced substantially from summer irrigation flows, we also measure the average stream width. Estimates of Chinook salmon abundance were made by expanding our visual counts by the maximum likelihood capture efficiencies of similar sized rainbow trout (between 100 and 177 mm FL, but mainly 127-152 mm) during the past 4 years. The percent of the observed Chinook abundance was quite low and ranged from less than 1% to almost 6% of the modeled upper limit. If we restricted the area of suitable habitat to 0.5 - 1.0 m of bank habitat on both sides of the river (1-2 m total), then we more closely approximate the current capacity of the river environment. This is supported by our observations that most Chinook salmon are found within a few meters of the bank when discharge is high. If we are correct, then most of the river channel in the summer (e.g., over 90%) is uninhabitable for age 0 Chinook salmon. This is probably due to the artificially high water velocities in areas a few meters away from the bank (see Chapter 6 of this report).

If the goal of management is to increase the abundance and growth of Chinook salmon, then water discharges should be managed to be more normative during the summer. Most of the river channel is not used by spring Chinook salmon because of the artificially high water velocities during the summer in the Yakima River (Chapter 6 of this report). If flows were managed to be more like natural flows, then presumably a greater proportion of the channel would be suitable for Chinook salmon rearing and density dependent impacts would be reduced. Indeed, in the unregulated American River where flows are normative, spring Chinook parr have been observed throughout the width of the stream channel (WDFW, unpublished data). Current flow management may also contribute to lower availability of food to fish by stranding invertebrates during flip-flop and scouring flows during the summer.

A less beneficial strategy that may increase fall parr abundance is to focus flow management on the most limiting life-stage. Current water management in the basin is directed at protecting the life stages from the egg thru fry emergence. Flows are dramatically reduced from the abnormally high summer flow to more natural levels during spawning so that adult salmon spawn low in the channel. These low flows are maintained through fry emergence so that redds are not dried out. However, natural flows would typically increase in October. This is appropriate, for fry incubation when the numbers of fry are limiting the abundance of juveniles in the fall. However, it may not provide sufficient flows for other life-stages. When the number of redds are predicted to be sufficiently high, then the water flows in the summer may be more limiting to fall parr production then the number of fry produced. Thus, in years where spawning escapement is high, flows might be targeted at enhancing fry-to-fall parr survival. Before any changes to flow management are implemented, the impacts to other species should also be assessed.

A water neutral approach to reducing density dependent impacts is to decrease the flow velocities by increasing the quantity and quality of bank habitat. This is particularly important in areas where large numbers of parr are rearing such as above the Teanaway River confluence. The quantity of bank habitat might be increased by restoring access to areas above dams (e.g., Cle Elum Dam), blocked side channels, gravel pit ponds (e.g., Hanson Ponds), and low gradient tributaries (e.g., Teanaway). The quality of banks can be improved by increasing their complexity. Complexity might be enhanced by increasing riparian vegetation and large structures such as root wads and rocks.

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Chapter 2

The Use of Microhabitat Utilization of Spring Chinook Salmon as an Indicator of Density Dependence

Abstract

The carrying capacity of a watershed is one of the main factors in determining whether supplementation is a viable technique of increasing natural production. We measured standard microhabitat values for age-0 spring Chinook salmon in four areas in the upper Yakima River Basin during the summers of 1998 to 2006 in an effort to index the carrying capacity of rearing space. If supplementation activities succeed in increasing the density of age-0 spring Chinook salmon and the resulting population exceeds the carrying capacity of the habitat, we expected to see an increase in the proportion of fish using suboptimal microhabitats and an asymptotic number of fish in optimal habitats. Contrary to our expectations, the proportion of spring Chinook salmon in sub optimal habitats did not increase with increasing abundance of spring Chinook salmon, and the number of fish occupying optimal habitats increased with increasing abundance. Our data may indicate that space is not limiting Chinook salmon growth or survival in the upper Yakima basin or that Chinook salmon decrease their territorial behavior in response to increasing abundance of con-specifics. Alternatively, standard microhabitat variables may not measure the variables that are most important for microhabitat selection. We will explore new measures of microhabitat use and, along with the food and space competition indices, monitor any changes that may be associated with supplementation activities.

Introduction

The carrying capacity of a watershed is one of the main factors in determining whether supplementation is a viable technique of increasing natural production (Pearsons and Temple 2008). For example, supplementing a stock that is near carrying capacity will not produce a large increase in naturally produced fish. Carrying capacity can be described as the minimum number of adults to produce the maximum number of progeny (K_s) or the maximum number of fish at their most demanding life-stage that can be supported by the available habitat (K_r; Pearsons and Temple 2008). It is important to know what the carrying capacity of the system is in order to determine whether the capacity of the environment is likely to limit the numbers of naturally produced fish.

Unfortunately, carrying capacity is very difficult to measure due to different requirements for each life stage of the target taxa as well as biotic and abiotic variability between years (Neitzel and Johnson 1996). One of the most common methods to measure carrying capacity is to compare the number of progeny to the number of parents in a stock-recruitment relationship. This type of analysis requires many years of data and suffers from the possibility that the carrying capacity changed during the years that it took to collect the data. Grant and Kramer (1990) used territory size and basin area to predict upper limits of population density of juvenile salmonids in streams. However, their model was limited to shallow water habitats that are unlike those of many large rivers, including the upper Yakima River. Their model underestimates the number of fish that occupy deep-water habitats because the model does not incorporate water volume. The carrying capacity of the Yakima Basin can limit the number of naturally produced spring Chinook salmon *Oncorhynchus tshawytscha* even when supplementation mechanics are operating perfectly (Busack et al. 1997). Busack et al. (1997) described seven measures to index carrying capacity. One of these measures is an alteration of the patterns in microhabitat used by spring Chinook salmon parr, which is the topic of this chapter.

Different species and life stages of fishes show different preferences for specific microhabitat parameters (Lister and Genoe 1970; Hearn and Kynard 1986; Roper et al. 1994). The variation of microhabitats used by a species and life stage of fish is typically positively related to the density of that species/life stage as well as the density of competitor species (Allee 1982; Ross 1986; Grant and Kramer 1990; Robertson 1996). The microhabitat use of naturally produced juvenile spring Chinook salmon in the upper Yakima River Basin prior to supplementation could serve as a baseline data set of the preferred microhabitat as well as the range or variation of habitats used. Microhabitat use following successful supplementation might change in response to an increase in the number of naturally produced spring Chinook salmon. For example, under excessive population densities, many parr might be forced to use faster and/or deeper water with less structural complexity than would parr at lower densities (below carrying capacity; Busack et al. 1997). The magnitude of the difference between microhabitat values at higher salmon densities might be expected to be greater than they would at lower densities if carrying capacity is exceeded at the higher density. For example, the proportion of fish occupying suboptimal microhabitats would be expected to be greater for focal point velocity measures for age-0 spring Chinook salmon when salmon densities were greater. This may be due to some fish being forced to use less optimal microhabitats as the number of fish increases in limited environmental space. This approach must assume that preferred microhabitat locations are limited.

We measured standard microhabitat variables for age-0 spring Chinook salmon and other species and life-stages of fishes that occupy similar habitats in four areas in the upper Yakima Basin. In addition, we endeavored to develop a way to monitor the proportion of the population that occupied suboptimal microhabitats. We hypothesized that the proportion of fish occupying suboptimal microhabitats would increase as population size increased and that the number of fish occupying optimal microhabitats would increase with population size until an asymptote was reached (Figure 1). The point at which an asymptote was reached would represent the carrying capacity.

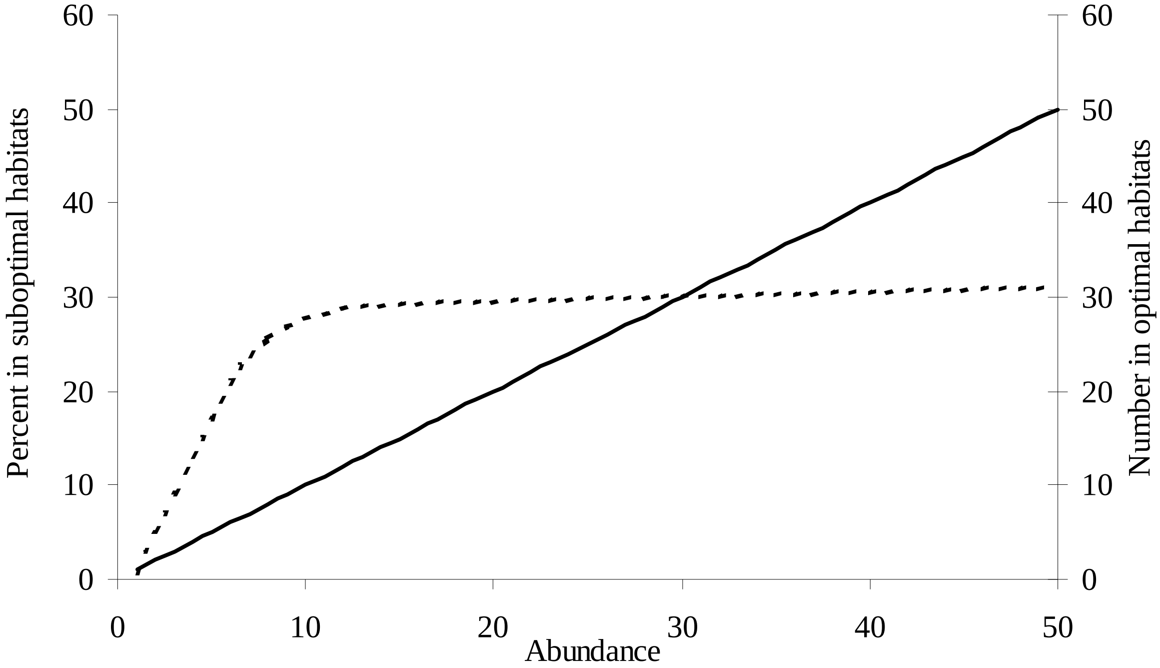

Figure 1. Hypothesized percentage of fish outside (solid line) and number of fish inside (dashed line) optimal habitat in relation to increasing abundance.

Methods

We characterized the microhabitat use of age-0 spring Chinook salmon in the Yakima watershed by measuring commonly reported variables and some new variables that are believed to be important as habitat quality. Fish were located by snorkeling. Spring Chinook salmon were frequently observed in groups of fish that we termed pods. In each pod of fish, which is defined as all fish that are within 30 cm of each other and have the potential to interact (Pearsons et al. 1996), spring Chinook salmon were counted and the extreme and average positions were recorded; which included head, tail, left, right, and average fish position. These positions within a pod were marked with painted washers placed where the fish were first observed. The average position was considered the general area where the majority of the fish were located. Fish lengths were estimated and focal depth and activity were recorded for the fish that held the head, tail, left, and right positions. Other fish within 30 cm of a spring Chinook salmon were counted as part of the pod. We applied the average microhabitat measurements (e.g., head, tail, left, and right) to the unmeasured fish on the inside of the pod. This was necessary to adequately weight the number of fish within the pod and because the head, tail, left, and right fish were the extreme measurements of a pod. Fish located more than 30 cm from a spring Chinook salmon but likely associated with the pod (i.e. were swimming in and out of the pod) were marked and measured separately.

Table 1. Description of microhabitat variables measured for spring Chinook salmon in the upper Yakima River Basin.

Variable(s)	Description
Distances	Distance (m) between fish located at key positions that represent pod boundaries: head, left, right, tail, center, and pod average.
Lengths	Estimated fork length estimation (mm) of fish holding key positions within the pod.
Depths	Total depth (m) of the water column, and focal depth (reported as a percent of the water column from the surface)
Velocities	Water velocities (m/s) measured at the surface, 60 percent of the water column from the water surface, the focal depth, and at a distance of two body lengths above, below, and to either side of the focal depth.
Cover types	In-stream and overhead cover types (e.g., Undercut bank, riparian, boulder, woody debris, depth)
Cover distances	Distance in meters to the nearest in-stream and overhead cover

Table 2. Summary of dates and ranges of water temperatures (°C) measured during collection of 1998 to 2007 microhabitat data on spring Chinook salmon in four study sections in the upper Yakima River Basin.

Section	Data	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Cle Elum	Min	14	11	15	18	14		18	13	14.5	13
	Max	17	14	18	19.5	16		21	19	19	19.9
N. F. Teanaway	Min	15		17	16	13	17	10	13		
	Max	15		21	22	21	20	20.5	19		
Nelson	Min	14.5	14	13	14	14	16.5	16.5	15	14	15.2
	Max	19	15	18	17	19	20	20.5	17	19	18.1
Thorp	Min		11	15.5	15		16				14.7
	Max		14	16.5	19		19				15.8
Upper Canyon	Min	15									
	Max	15									

Various physical parameters were measured for each fish location in 1998. A wide array of habitat variables were assessed, then a ‘core group’ of variables were selected from the larger group based on; 1) previous data collection efforts in the basin (Allen 2000, Pearsons et al. 2003) to enable use of a larger ‘pre-supplementation’ baseline data set, and 2) the descriptive value and statistical power of each variable to detect changes (i.e., shifts in microhabitat use, possibly do to increased population density). Five of the microhabitat variables that were measured in 1998 were discontinued because they did not meet the conditions above. Total water depth was measured and focal depth was recorded as the percent of the water column (total depth) at the focal point of the fish and was later converted to depth in meters from the water surface. Current velocities were measured for each marker with a Marsh-McBirney or Swoffer flow meter at three points in the water column; the surface, 60% of the depth measured from the water surface, and at the fishes' focal point. We also present water temperatures as background information (Table 2).

Between 2005 and 2007, we measured additional flow and cover variables because of the poor predictive performance of some of the other variables that we had previously measured (Pearsons et al. 2005; Table 1). We developed a new measure of velocity that was intended to index the amount of food available compared to the amount of energy it took to feed in that location. This new variable, termed "flow ratio," was the highest flow velocity within 2 body lengths of the focal position of the fish, divided by the focal point velocity of the fish. A flow ratio greater than 1 indicated that at least 1 adjacent velocity was greater than the focal point velocity. We measured focal point velocities at one and two body lengths to either side and above and below the focal position of the fish.

We also developed an index of cover. The cover index was a combination of three measures of predation cover; overhead, instream, and schooling. Overhead cover was intended to measure protection from predators that sight prey from above the water surface (e.g., birds). We assumed that fish that could be seen from above the water would be more susceptible to predation than those that couldn't. Therefore, we assessed whether a fish had cover directly above it. If cover was present, then we measured the distance between the overhead cover and the water surface. Overhead cover was indexed with the following equation:

$$\frac{\text{Absence or Presence }(0,1)}{\text{Distance in meters}+1}$$

Where the numerator is one if overhead cover was present and zero if overhead cover was not present.

Instream cover was intended to measure protection from instream predators such as fish. It was quantified by measuring the closest cover that could conceal the entire body of the fish from a larger predator. It was indexed with the following equation:

$$\frac{\text{Absence or Presence }(0,1)}{\text{Distance to cover (mm)}\big/\text{Body Length(mm)}}$$

Where the numerator is one if instream cover was present and zero if instream cover was not present.

Schooling cover was intended to measure protection from all predators. We assumed that large numbers of fish would provide a lower probability of being consumed than with smaller numbers of fish. We also assumed that pods of fish greater than 20 did not produce any additional schooling benefit than the benefit provided by 20 fish. However, we do not have data to support this assumption. Schooling cover was indexed with the following equation:

If; Pod density =1, then 0
If; Pod density = 20, then 1
Else; Pod density / 20

The final cover index was an average of the overhead, instream, and cover index. The maximum possible cover score was 1.

We made a number of hypotheses about the flow ratio and cover. We hypothesized that; 1) the use of cover would decrease as fish size increased (e.g., bigger fish are less susceptible to predators) and 2) that the flow ratio and cover index would be negatively related (food maximizing risk takers vs. risk avoiders).

We developed an approach to evaluate the proportion of fish occupying suboptimal focal velocity, focal depth, and total depth. This approach standardizes for fish length because fish are more capable of occupying faster and deeper water as they grow. We created a scatter plot of each of the three variables for 1998 (our baseline year which was also a year of low abundance), and fitted a linear regression line using the least squares method (Figure 2,3,4). We then manipulated the Y intercept of each regression line to create limits; above and below which five percent of the 1998 sample was excluded (e.g., 90% of all observations were within the bounds). These limits were then used to calculate the percent of data above and below the limits for each year. The idea was to compare the percent of spring Chinook salmon that were using habitat outside of this baseline zone for each year. In years of higher abundances of spring Chinook salmon we would expect them to use habitats outside this zone in higher proportions than years with lower abundances, if habitat is limited. Finally, we estimated the number of Chinook that occupied optimal microhabitats by using the proportion of fish within the optimum ranges as described above and multiplying that by an index of fall abundance (Pearsons et al. 2007).

We estimated territory size of Chinook salmon by measuring the surface area (1999-2005) or volume (2005-2007) of each pod that contained only spring Chinook and dividing the total area or volume by the number of spring Chinook salmon. Surface areas were estimated by measuring distances between head, tail, left, and right fish and then calculating an elliptical area. Volumes were calculated with the addition of a measurement between top and bottom fish. The shape of each pod was also recorded (Oval, Round, Triangular, Cube, Rectangular, Pyramid, Diamond) and then the volumes for these different shapes were calculated. We compared territory size to our fall abundance index and to the average size of fish in each pod.

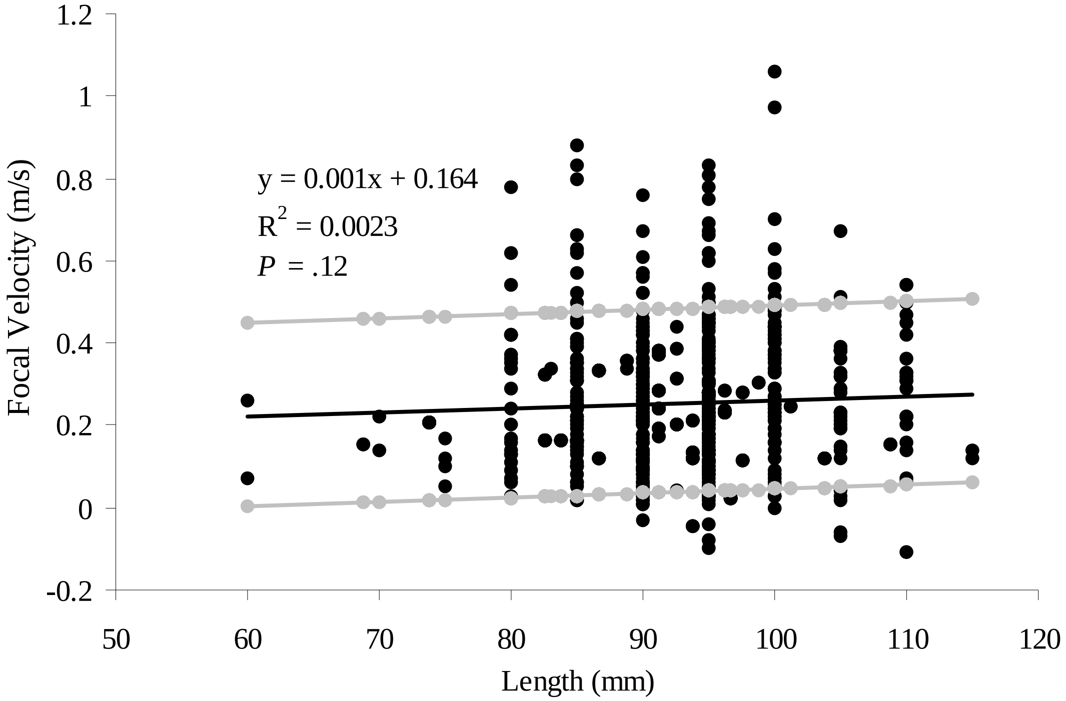

Figure 2. Relationship between spring Chinook salmon length and focal velocity during 1998. Included are the linear regression line, and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

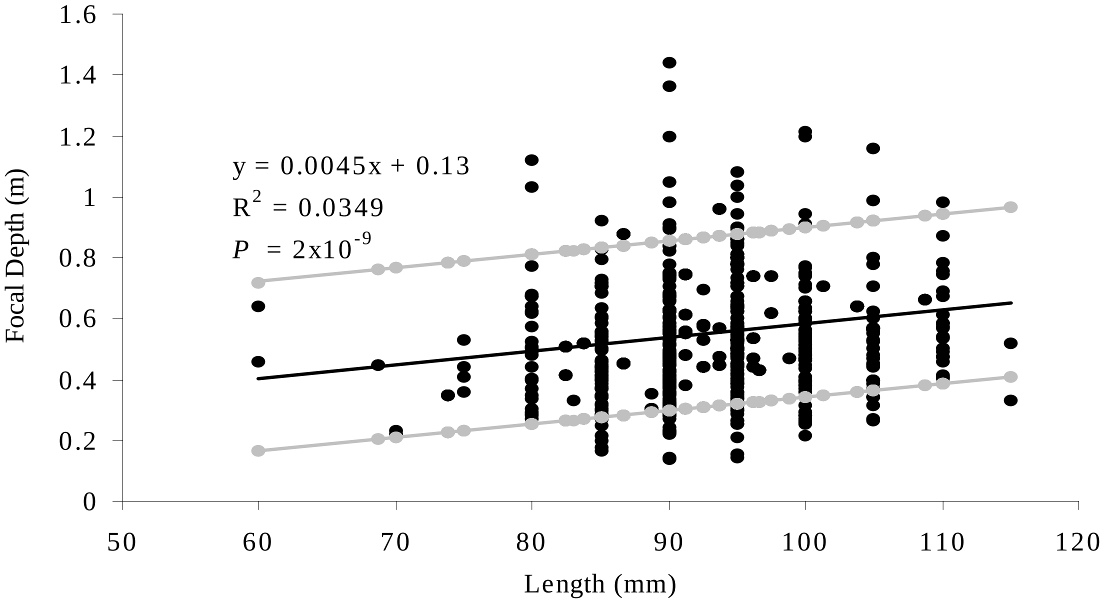

Figure 3. Relationship between spring Chinook salmon length and focal depth during 1998. Included are the linear regression line, and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

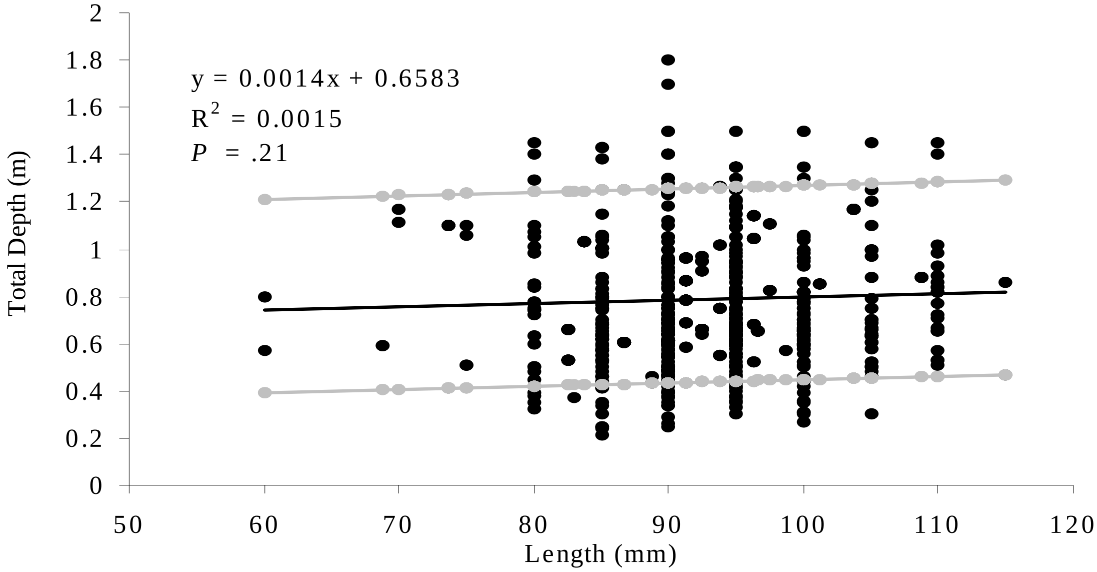

Figure 4. Relationship between spring Chinook salmon length and total depth during 1998. Included are the linear regression line and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

Measurements were taken in two sections of the Yakima River and in the North Fork of the Teanaway River (Table 1). The Nelson section of the Yakima River was sampled between the Washington Department of Fish and Wildlife (WDFW) access at the west end of Golf Course Road (about 300 m downstream of the mouth of Big Creek) and the low wooden bridge in the Elk Meadows subdivision. Side channels in the Cle Elum section of the Yakima River were sampled between the South Cle Elum Bridge and the WDFW access near the junction of highways 10 and 970. The Thorp section of the Yakima River was sampled between the Clark Flats acclimation site and the Thorp train bridge. The North Fork of the Teanaway River was sampled between the mouth of Dickey Creek and the confluence of the North Fork and main stem of the Teanaway River. All analyses in this report were restricted to the main stem Yakima River between July and September 1998-2007 (Table 3.)

Table 3. Microhabitat sampling months by section and date.

Year	Cle Elum	Nelson	NFT	Thorp	Upper Canyon
1998	Aug18-Sep03	Aug26-Aug26	Aug12-Aug12		Sep08-Sep08
1999	Aug10-Sep07	Jul29-Aug26			
2000	Aug08-Aug21	Jul26-Jul27	Jul31-Jul31	Aug22-Aug22	
2001	Aug02-Aug20	Aug08-Aug13	Aug06-Aug06	Jul31-Aug21	
2002	Aug12-Aug28	Aug05-Aug21	Aug07-Aug28		
2003	Aug18-Aug19	Aug12-Aug13	Aug14-Aug26	Aug27-Aug29	
2004	Aug19-Aug30	Aug09-Aug11	Aug12-Aug26		
2005	Aug18-Aug23	Aug17-Aug29	Aug15-Aug16		
2006	Aug10-Sep07	Aug27-Sep11			
2007	Jul23-Sep13	Aug14-Aug16		Sept20-Sept20	

Additional snorkeling observations were made in the Cle Elum and Nelson sections of the main-stem Yakima River between July 11th and August 30th 2006 to observe and record age-0 spring Chinook salmon territory size. In the following year, these observations were expanded to include the main-stem Yakima River near Easton. Observations were conducted between July 2nd and September 10th 2007. Using a clipboard, observers recorded direction and distance of juvenile Chinook salmon movements relative to the current focal position. Underwater stopwatches were use to time the observations. Observations ranged in length from one minute to twenty minutes, terminating when the subject left the observer's view. The holding position of the fish was considered the focal position, and was variable throughout most observations. Movements were recorded onto a two-dimensional datasheet graph, which represented distance in body lengths, and direction relative to the focal point (Figure 5.).

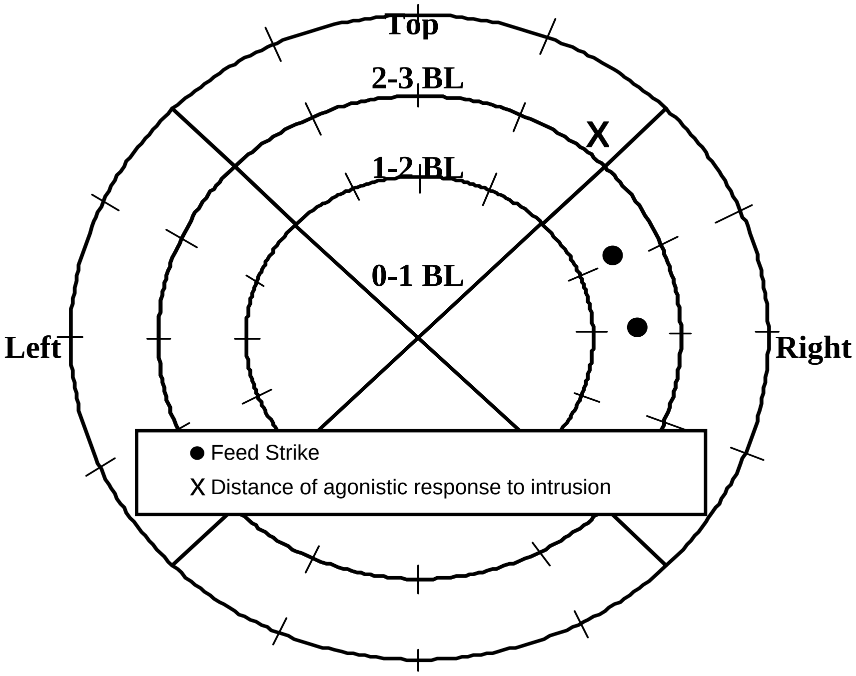

Figure 5. Graphical representation of the data sheets used in recording age-0 Chinook salmon territory size. Data is recorded in units of focal fish body length (BL).

The direction of a fish movement was classified as top, bottom, left or right, with each consisting of a ninety-degree range centered at the focal point (Figure 5). Movements were classified as either feeding or agonistic depending upon whether the focal fish obtained a food item, or the focal fish used agonistic behavior toward an intruder. The location of a food strike or an intruder was expressed relative to the focal position of the target fish. The location of the intruder was the farthest location from the focal fish that the focal fish initiated an agonistic interaction (e.g., chase, threat).

Results

None of the microhabitat variables showed a significant positive relationship between the proportion of Chinook utilizing suboptimal microhabitats and Chinook abundance (Table 3, 4, Figure 5). If anything, the percentage of age-0 spring Chinook salmon occupying focal velocities and depths outside of the 1998 baseline data decreased with increasing abundance of Chinook salmon per kilometer (Table 4, Figure 6). The estimated number of Chinook salmon in optimal habitats was positively related to an index of abundance ($P<0.001$; Figure 7). There was not a significant relationship between our fall abundance index and territory area (Figure 8), but there was between fish length and territory volume (Figure 9). Territory size measured as area was significantly correlated with territory size measured as a volume (Figure 15).

The highest flows adjacent to the focal position of the fish were 2 body lengths above the top of the fish (Figure 10). All subsequent analyses were conducted using measurements that were 2 body lengths from the focal position. There was a weak but significant relationship between flow ratio and fish size (Figure 11), flow ratio and cover (Figure 12), and between fish length and cover index (Figure 13).

Most of the feeding and initiation of agonistic interaction to an intruder occurred within two body lengths of the focal position of the fish (Figure 14). The highest frequency of food strikes occurred above the fish and rarely occurred below the fish (Figure 14).

Table 3. Summary of microhabitat parameters used by age-0 spring Chinook salmon during summer 1998 to 2007 within index sites of the upper Yakima Basin. All variables are weighted to account for pod density.

	Focal Velocity (m/s)				Focal Depth (m)				Total Depth (m)			
Year	n	mean	stdev	cv	n	mean	stdev	cv	n	mean	stdev	cv
1998	997	0.25	0.15	0.60	1010	0.55	0.17	0.31	1010	0.79	0.26	0.33
1999	446	0.20	0.13	0.65	449	0.67	0.23	0.34	449	0.90	0.31	0.34
2000	436	0.19	0.13	0.68	439	0.90	0.36	0.40	438	0.92	0.37	0.40
2001	377	0.21	0.11	0.52	377	0.48	0.13	0.27	377	0.64	0.19	0.30
2002	1344	0.17	0.11	0.65	1344	0.46	0.12	0.26	1344	0.63	0.15	0.24
2003	1206	0.20	0.13	0.65	1207	0.50	0.14	0.28	1207	0.73	0.19	0.26
2004	567	0.24	0.13	0.54	569	0.48	0.14	0.29	569	0.63	0.18	0.29
2005	405	0.17	0.10	0.59	405	0.50	0.10	0.20	405	0.65	0.13	0.20
2006	1158	0.14	0.12	0.86	1158	0.41	0.16	0.39	1158	0.58	0.23	0.40
2007	1318	0.14	0.10	0.70	1318	0.38	0.19	0.49	1318	0.68	0.32	0.47
mean		0.19				0.53				0.72		
stdev		0.04				0.15				0.12		

Table 4. Percent of age-0 spring Chinook focal velocities, focal and total depths outside 1998 fitted lines during 1999-2007, Redd counts from the previous year, visually estimated numbers of spring Chinook per kilometer in the upper Yakima River (Cle Elum and Thorp sections) during fall rainbow trout abundance estimates and mean lengths of spring Chinook sampled for microhabitat are included for comparison between years. All variables are weighted to account for pod density.

Year	Focal Velocity (%)	Focal Depth (%)	Total Depth (%)	Redd Count (yr-1)	Abundance Spc/km	Mean Length (mm)
1998	10.1	10.1	10.0	420	69	105
1999	6.3	28.3	20.7	148	31	106
2000	6.2	39.4	25.3	224	39	104
2001	4.0	6.1	8.2	3836	118	94
2002	4.2	5.3	6.0	3339	107	92
2003	9.9	6.7	6.9	2826	61	97
2004	6.6	13.2	14.2	890	57	99
2005	5.7	1.0	3.5	3444	70	96
2006	2.2	10.1	17.5	2019	103	98
2007	6.2	12.1	22.6	1250	69	98

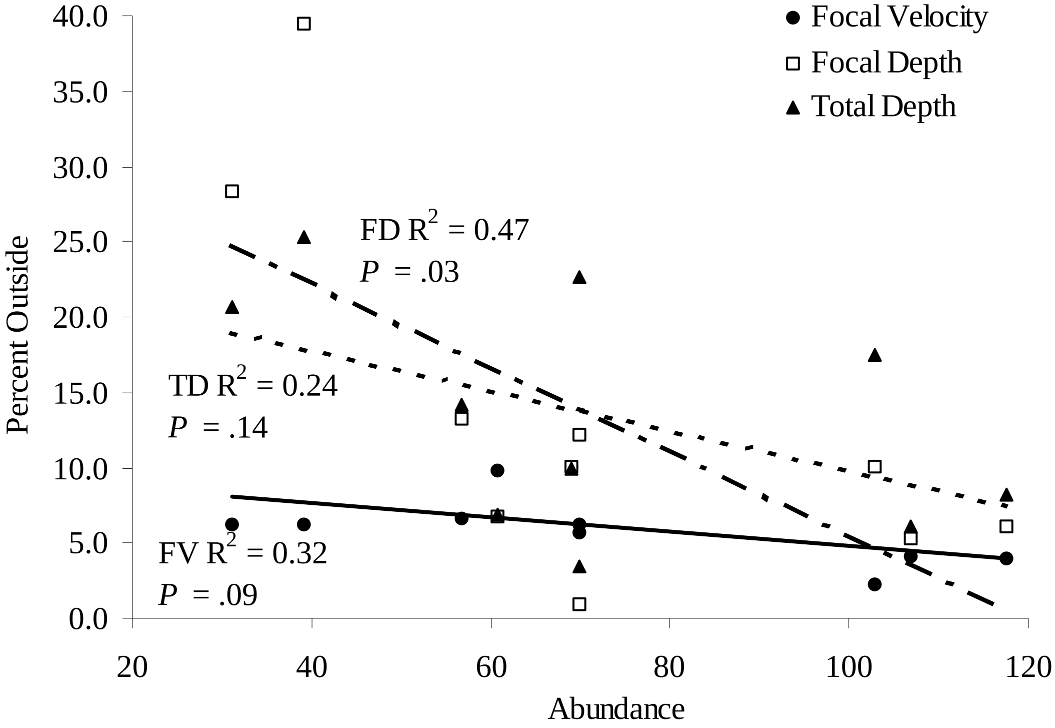

Figure 6. Relationship between the index of abundance of spring Chinook salmon parr (fish/km) and the percent of focal velocities, focal depths, and total depths outside optimal values 1998 to 2007.

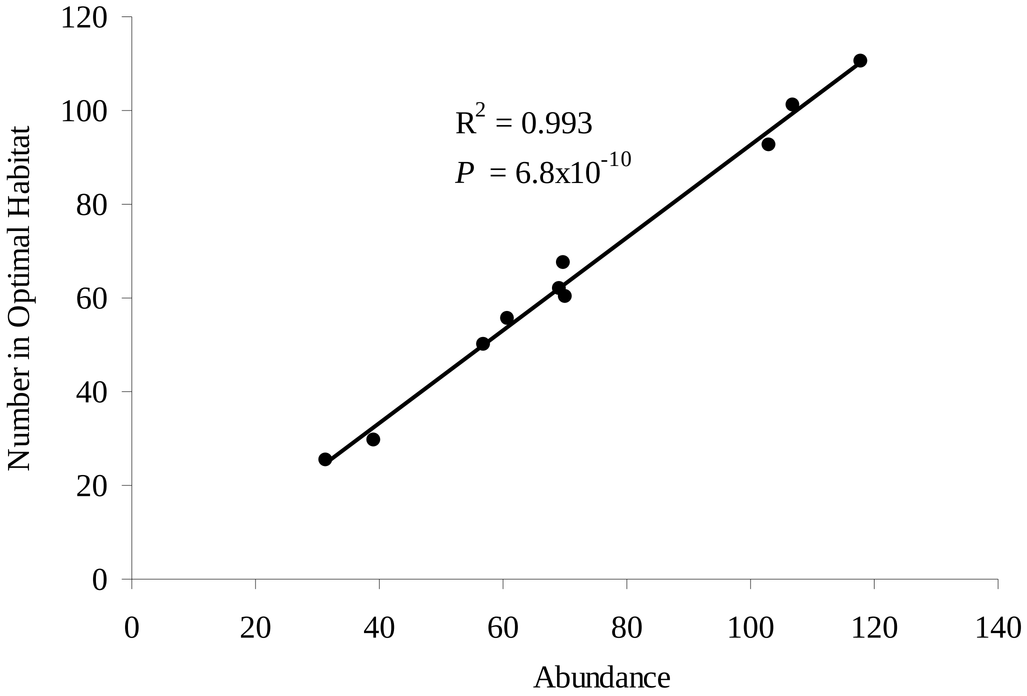

Figure 7. Relationship between spring Chinook abundance index (fish/km) and the estimated number fish using optimal habitat. Estimated number utilizing optimal habitat is the annual mean of the proportion within optimal of total depth, focal velocity, and focal depth measurements multiplied by the abundance index.

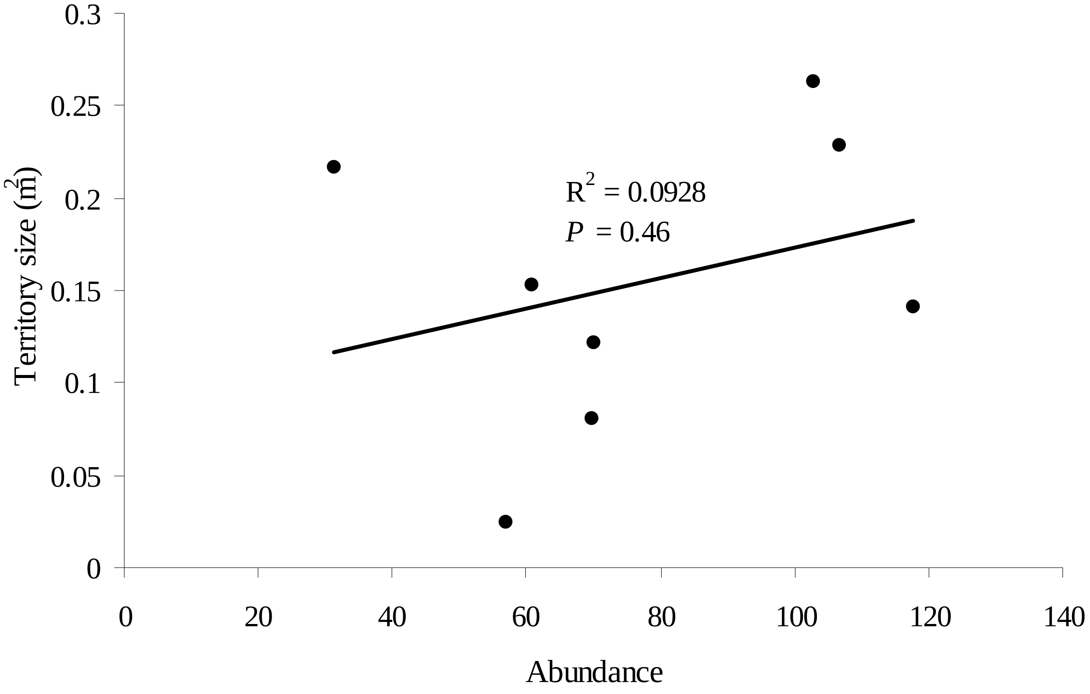

Figure 8. Relationship between annual spring Chinook salmon abundance estimates (fish/km) and planar elliptical territory size (m^2) 1999-2007.

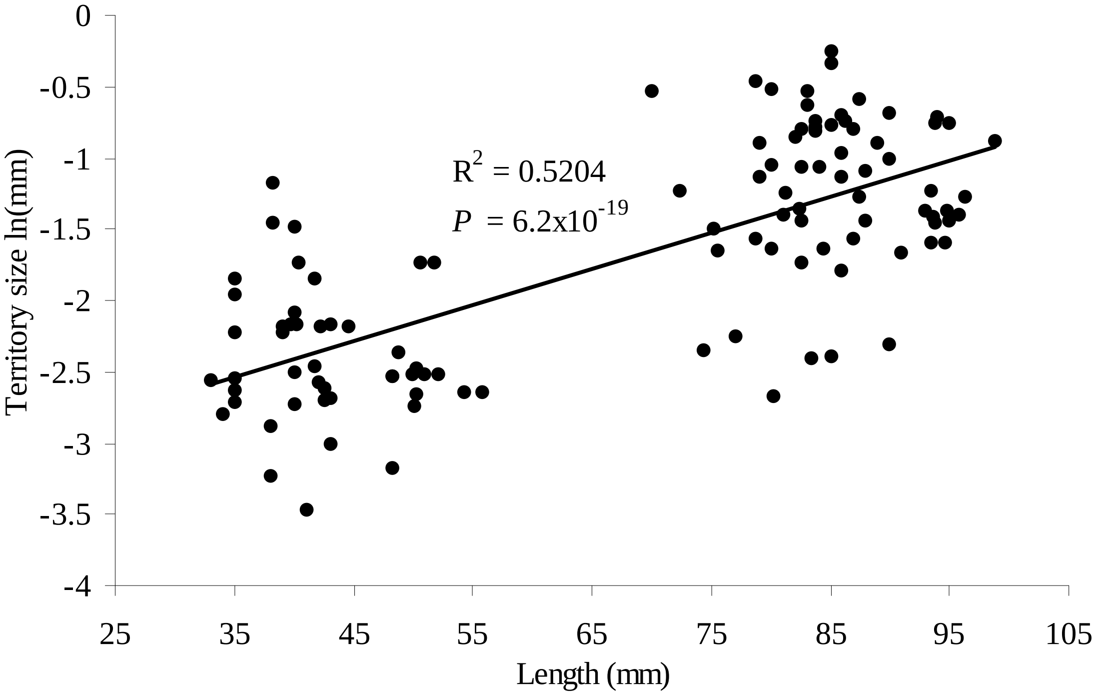

Figure 9. Relationship between total length (mm) and volumetric territory size (m^3) 2006-07.

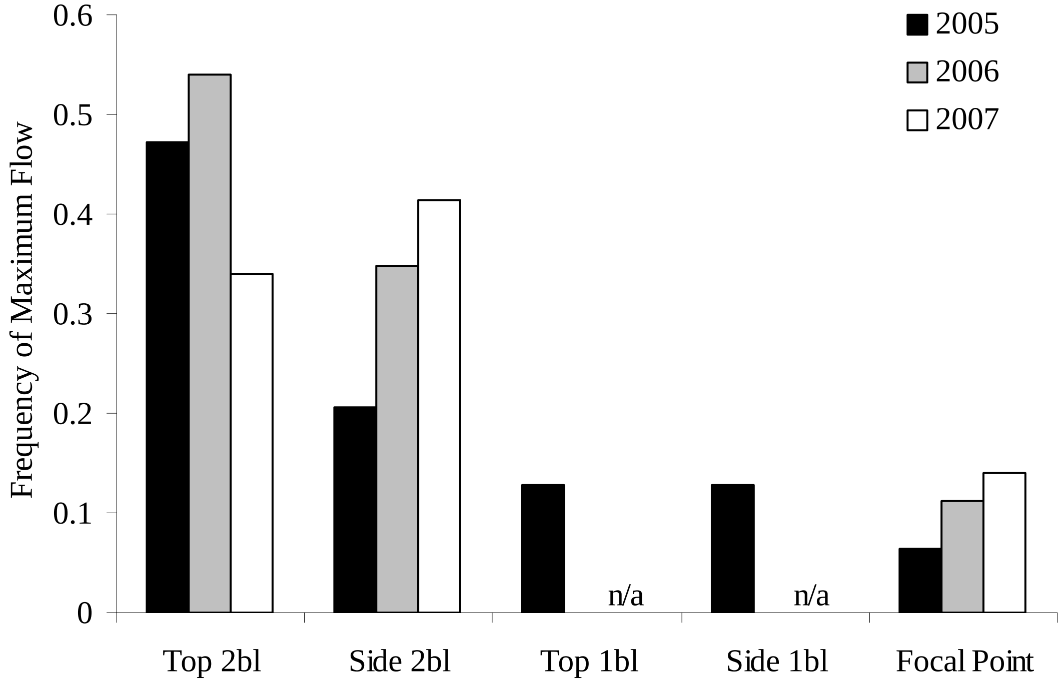

Figure 10. Frequencies of maximum flows at zero, one, or two body lengths from the focal point.

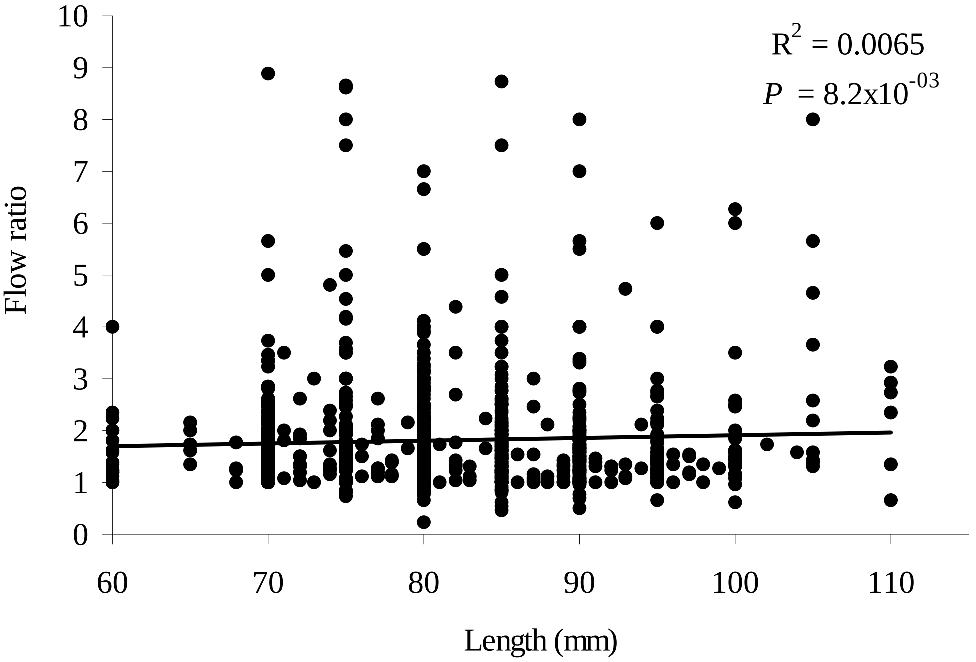

Figure 11. Relationship between flow ratio and spring Chinook length (mm) 2005-2007.

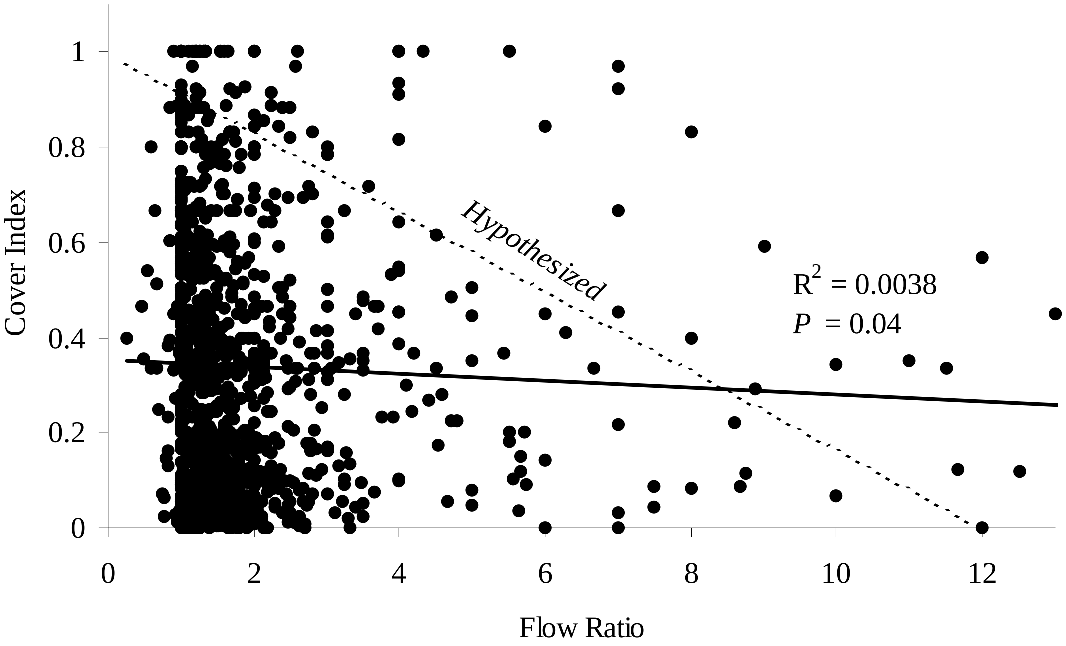

Figure 12. Actual and hypothesized relationship between flow ratio and the cover index, 2005-2007.

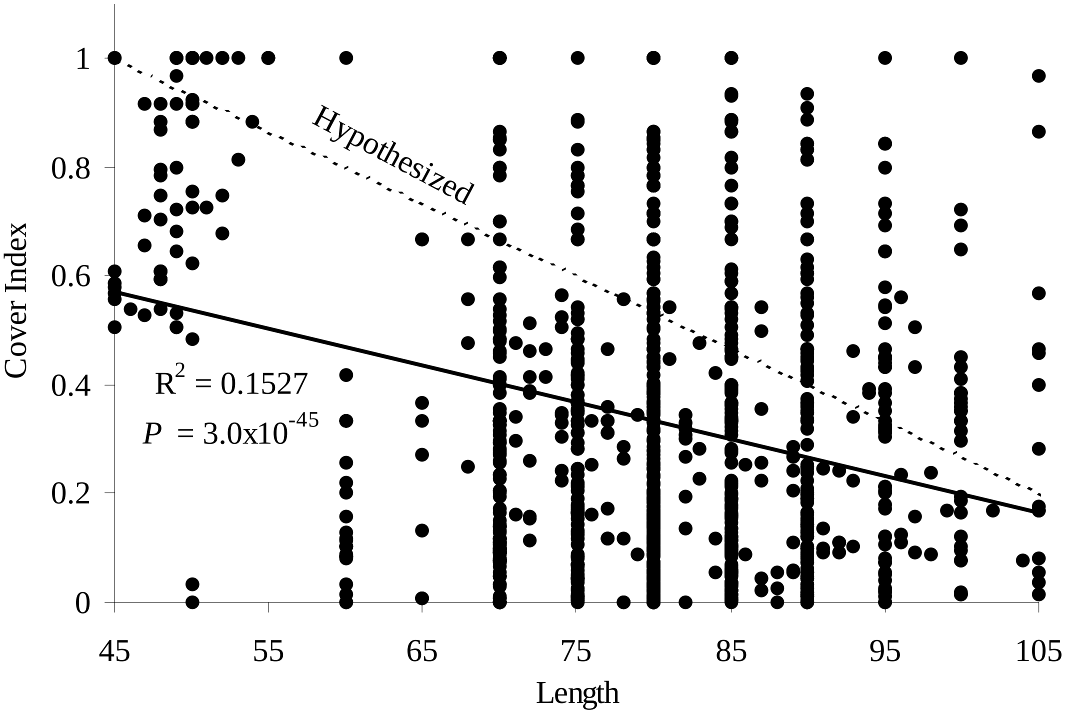

Figure 13. Actual and hypothesized relationship between spring Chinook length (mm) and the cover index 2005-2007.

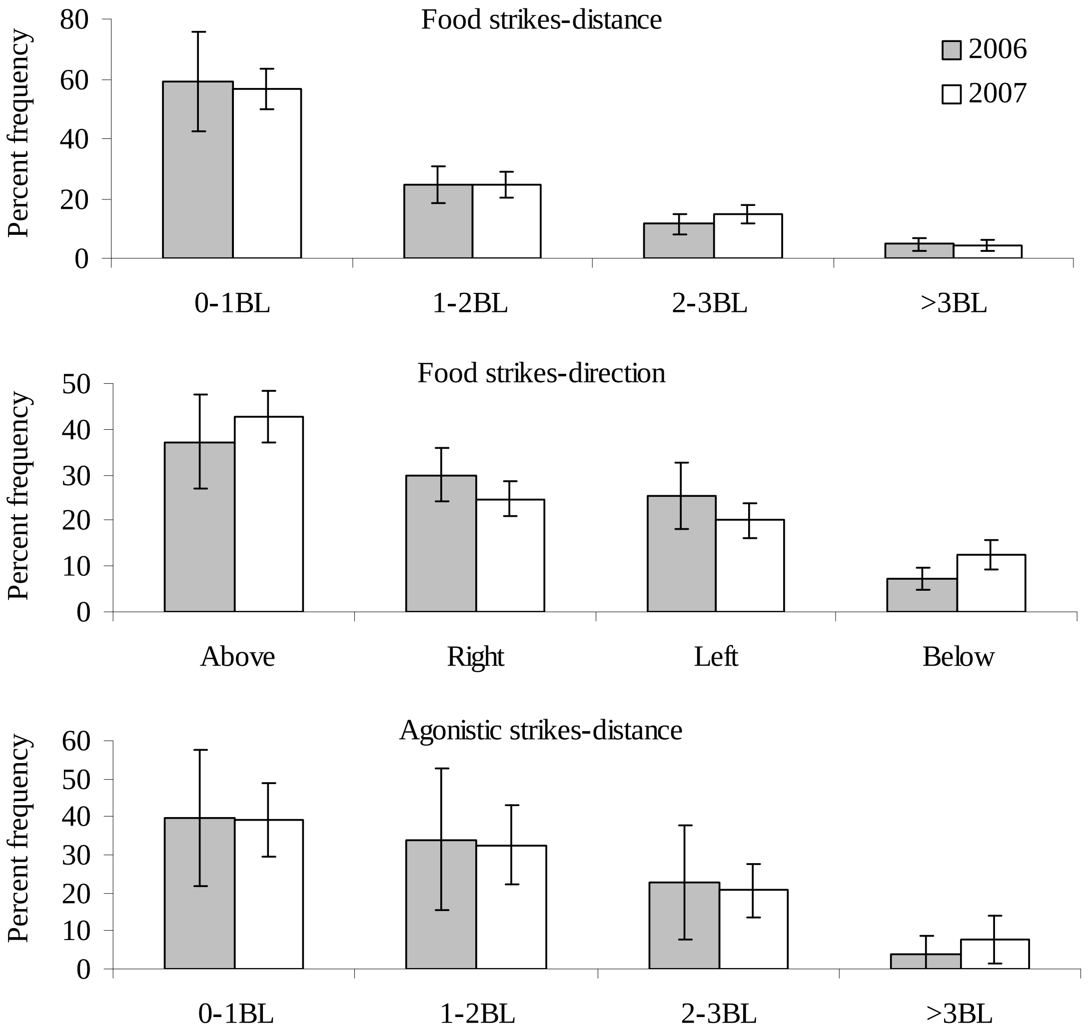

Figure 14. Frequency of age-0 spring Chinook food strikes by direction, and frequency of food and agonistic strikes by distance expressed in body lengths, e.g. 0-1BL = zero to one body length. Feeding strike observations n = 70 (2006) and n = 141 (2007), agonistic strike observations n = 24 (2006) and n = 79 (2007).

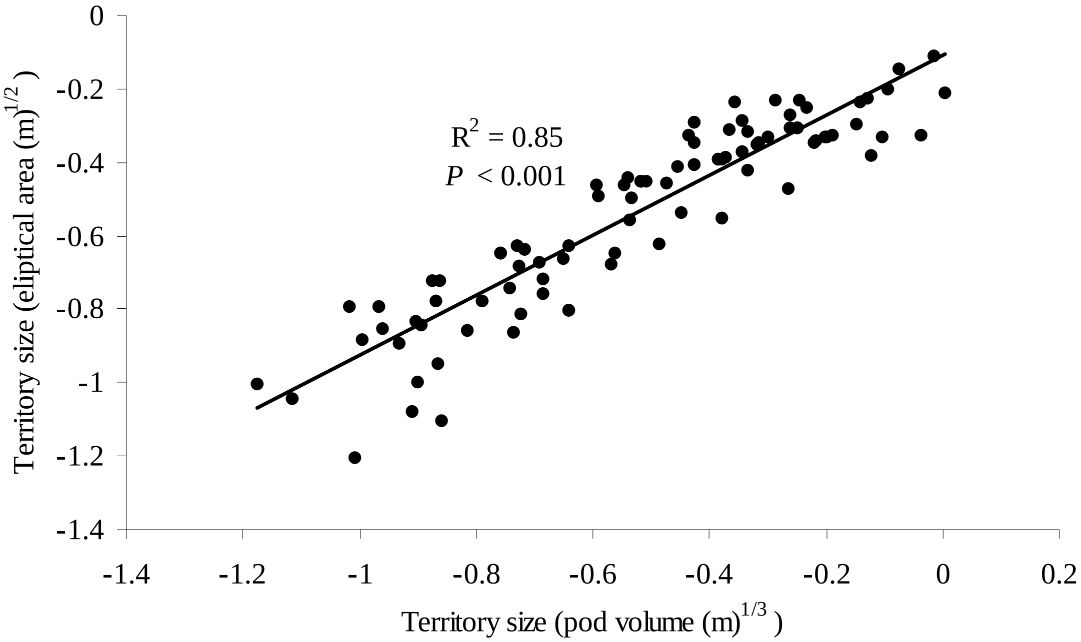

Figure 15. Relationship between linear territory distances derived from either calculated elliptical area or volume of spring Chinook pods.

Discussion

We did not see an increase in the use of suboptimal microhabitats with increasing age-0 spring Chinook salmon densities. This was somewhat surprising because we expected to see a higher proportion of fish using velocities and depths outside of their normal range in years with many more fish potentially competing for the same space (Figure 1). Contrary to our expectations, the proportion of age 0 spring Chinook salmon that utilized “suboptimal” microhabitats decreased with increasing salmon abundance. Low abundances of salmon may facilitate territorial behavior and large territory size. Dominant fish may be able to exclude subdominant fish from preferred microhabitats, resulting in many fish using suboptimal microhabitats. In contrast, increasing numbers of fish may make it more difficult to defend space. If very high numbers of fish are present, then the cost of defending space may become too high and fish will abandon territorial behavior. This could result in fewer fish excluded from optimal habitats and reduce competition for space. However, competition for food may become increasingly important as competition for space decreases due to increased density, and scramble competition for food increases. In summary, interference competition for space may be important at relatively low densities of fish and exploitative competition for food may be most important at high densities of fish. This hypothesis is contrary to the hypothesis posited by (Grant and Imre 2005).

Contrary to our original hypothesis (Figure 1), we also estimated an increase in the number of fish in optimal habitat with an increase in abundance. We had expected that as abundance increased that we would observe an increase in fish in optimal habitat until all of the optimal habitats were taken. One interpretation is that the observed relationship indicates that density dependent interactions are not important and that the environment is under-seeded. However, other analyses indicate that density is correlated with growth and survival (Chapter 1 of this report; Pearsons and Temple 2008). Alternative explanations include: Fish are changing their behavior and perhaps reducing the size of their territories as described above, the scale of habitat measurement was not limiting (Frissell et al. 1986), the microhabitat variables that we measured were not the habitat components that were most important to fish, or that some other factor such as food is the factor limiting growth and survival. Territory area did not appear to be declining relative to abundance of fish, because territory area was not significantly related to abundance (Figure 7). However, Chinook salmon use space in three dimensions, not in two. Unfortunately we only have a few years of data where pod volume was measured. In these years, we saw a significant relationship between fish size and territory volume. This finding supported that reported for territory area and fish size (Grant and Kramer 1990; Grant et al. 1998). No significant correlations were found between our space competition index and growth and survival (Chapter 1 of this report).

The microhabitat variables that we measured prior to 2005 may not have adequately described the habitat features that were most important to fish. We took most of our measurements on the focal positions of fish. However, fish are likely selecting habitat features that encompass more than just small focal positions. Juvenile salmonids are likely selecting habitats that provide the best growth for the least amount of survival risk. The best growth is achieved when large amounts of food are consumed and minimal energy of acquiring the food is expended. The highest amount of food for drift feeding salmonids is in the fastest water. Fast water is assumed to transport more invertebrates than slow water (Steingrimsson and Grant 1999). However, certain physical constraints limit the possible water velocities that juvenile salmonids can occupy. For example, focal point velocities must not exceed the sustainable swimming speed. Territorial salmonids expend the least amount of energy when they occupy slow focal velocities. The optimal feeding locations are in slow water velocity focal positions that are adjacent to fast water velocities. The velocities that we measured prior to 2005 only addressed the energetic cost of the fish's position. Ideally, we would have measured the amount of food passing through the territory size of the fish that we observed.

We found that adjacent velocities were frequently higher than focal point velocities, suggesting that fish are selecting habitats near velocity gradients and increasing their growth potential. We intend to develop a size-based model that can be used to predict what microhabitats are suitable for Chinook salmon in the Yakima River. To determine if our new approach of measuring microhabitat predicts the location where fish are found, we intend to systematically measure flow, depth, and cover along transects with and without fish and assess the degree to which modeled predictions match observations. The spacing of measurements will be the dimensions of the territory size of the average size Chinook salmon at the time of measurement.

We attempted to measure territory size in three ways. First, the size of a defended territory was calculated as the area of a circle using mean aggressive distance against an intruder as the radius (Keeley and Grant 1995; Keeley and McPhail 1998; Imre et al. 2002; 2004). Second, the feeding area was calculated as the area of a circle using the mean of the maximum foraging distances from a focal point as the radius. Third, the occupied area was calculated as the number of Chinook salmon in a pod divided by the size of the pod (Steingrimsson and Grant 1999; Grant et al. 1998). The three methods produced similar results; the territory size was approximately 2-3 body lengths in any direction of the fish.

Age-0 spring Chinook salmon in the upper Yakima River selected a fairly narrow range of microhabitat parameters in the study sites we examined during the summers of 1998 to 2006. The microhabitat values we report are similar to those presented by Allen (2000) for data they collected on age-0 spring Chinook salmon in the Yakima Basin in the summer of 1990 as well as those presented by Hillman et al. (1989) for data they collected in the Wenatchee River system during the summers (July and August) of 1986 and 1987.

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Chapter 3

Abundance and Distribution of Hatchery and Natural Origin Precociously Mature Male Spring Chinook Salmon in the Yakima River

Abstract

Artificial propagation of Chinook salmon (*Oncorhynchus tshawytscha*) has the potential to alter the abundance and distribution of males that precociously mature in freshwater and thereby influence ecological and genetic interactions in the natural environment. Previous research indicated that the Yakima Supplementation and Research Facility has produced and released an average of 124,573 precocious males per year into the upper Yakima Basin between 1999 and 2007. We investigated the abundance and distribution of precociously mature, hatchery origin and natural origin male spring Chinook salmon (*Oncorhynchus tshawytscha*) during the spawning season (e.g., four to seven months after release from the hatchery) in the Yakima River. We counted the number of precocious males on the spawning grounds while snorkeling during the peak of spawning, electrofished to determine abundance and distribution of precocious males away from redds, and collected Chinook to determine % precocity, size, and age. The abundance of hatchery origin precocious males on redds was less than 0.05% of the number of fish released and were less abundant on redds than natural origin precocious males ($P<0.05$). Between 1999 and 2007, the mean abundance of hatchery age 1 precocious males observed on the spawning grounds was 22 fish and ranged between 0 and 78 fish annually. Hatchery and natural origin precocious males were both found throughout the spawning range during the spawning season, but differences in distribution between origins were detected ($P<0.05$). Hatchery precocious males were proportionately more abundant in the lowest sampling reach and less abundant in a river with no hatchery facilities. In addition, most hatchery precocious males were found downstream of spawning areas during the spawning season. It appears that many precociously mature fish released from the hatchery migrate downstream and fail to migrate back to the spawning grounds or die within the Yakima River prior to spawning time. Thus, hatchery production of precocious males in the Yakima River do not contribute favorably to harvest and may pose ecological risks to non-target taxa, but most of these fish have a low probability of contributing genes to future generations.

Introduction

Artificial propagation of Chinook salmon (*Oncorhynchus tshawytscha*) has the potential to alter the age that fish mature and result in undesirable interactions with natural origin fish (Knudsen et al. 2006). This is a particular concern for conservation hatcheries where the goal is to increase natural production while maintaining the characteristics of the natural population (Mobrand et al. 2005). Although most Chinook salmon are anadromous (Healey 1991), some salmon complete their entire life cycle in freshwater, even when they have access to the ocean. These salmon are generally small, male, precociously mature, short-lived and are referred to as residents, precocious males, or minijacks (Gebhards 1960; Mullan et al. 1992; Zimmerman et al. 2003). Although the incidence of precocious male maturation in Chinook salmon has been recognized since at least 1897 (Rutter 1902), the importance and management of this life history has only recently become generally appreciated as population sizes are diminished and hatcheries are used for conservation. Resident life histories have been observed in both natural (Flain 1970; Gebhards 1960; Mullan et al. 1992) and hatchery produced fish (Robertson 1957; Mullan et al. 1992; Larsen et al. 2004a) and can occur as subyearling (Robertson 1957; Gebhards 1960; Mullan et al. 1992), yearling (Gebhards 1960; Mullan et al. 1992; Larsen et al. 2004a), and perhaps under favorable conditions even older ages (Mullan et al. 1992; Unwin et al. 1999). Estimates of precocious maturation have been reported between 0 and 93% (Gebhards 1960; Taylor 1989; Mullan et al. 1992; Foote et al. 1991; Shearer et al. 2006) although the high end of this range is from studies that have been performed in hatchery environments. It is less clear what the range of precocious maturation is in natural environments, but it is likely to be lower than the high ends of the range presented.

The occurrence of precocity in salmon has been credited to genetic factors and environmental and physiological cues (Thorpe 1987; Bohlin et al. 1990; Foote et al. 1991). Age-at-maturation has been shown to be heritable in salmon (Heath et al. 1994; Unwin et al. 1999). Furthermore, Foote et al. (1991) concluded that variation in precocious maturation rates observed in Canada (Taylor 1989; Foote et al. 1991) were due to genetics. The higher incidences of precocity that they observed were from populations that were the farthest inland and the growth rates of fish were similar. Hatcheries may enhance precocious maturation of males by the dietary composition of the feed (Shearer and Swanson 2000) or the types of growth schedules that fish are placed on (Silverstein et al. 1998; Larsen et al. 2004, 2006). Precocious maturation of some individuals may contribute to population viability particularly when population sizes are low or disturbances frequent and is commonly used by other anadromous species (Myers and Hutchings 1987; Foote and Larkin 1988; Pearsons et al. 2007a). When the spawning population size is small and there is genetic diversity among age classes, precocious males may contribute to genetic diversity and increase the probability that eggs are fertilized. The sperm of precocious male salmon has been shown to successfully fertilize eggs (Rutter 1902; Robertson 1957; Unwin et al. 1999) and some precocious males may be able to spawn in multiple years (Bernier et al. 1993). It has been known for some time that hatcheries can produce large numbers of precocious Chinook salmon (Robertson 1957; Mullan et al. 1992; Larsen et al. 2004a; Beckman and Larsen 2005), but there have been relatively few studies that have investigated the abundance and distribution of these fish in rivers during the spawning season.

Artificially high numbers of precocious males that are released into rivers may harm wild populations through ecological and genetic mechanisms (Pearsons and Hopley 1999; Pearsons 2002; Pearsons and Temple 2007). Hatchery precocious males may eat wild fish, compete for resources, and spread disease (Pearsons et al. 2007b; in press). They may also breed with wild fish and consequently lower fitness of offspring because of the domesticating effects of artificial propagation (Schroder et al. 2006; Blankenship 2007). Hatchery fish may pass on genes that are unfavorable in the natural environment and this may be particularly pronounced in precocious males because they do not experience the selective pressures that migratory adults experience and they may be the result of hatchery selection (Garant et al. 2003). In addition to potential impacts to wild fish, resident Chinook salmon are undesirable to fisheries because they are generally too small for harvest and they can interfere with fisheries on other species by being caught more easily than targeted species such as resident trout. In short, production of artificially high numbers of precocious males has the potential to limit the success of supplementation programs. In contrast, artificial reduction in their production may negatively impact the population by reducing traits that are associated with precocious maturation such as fast growth.

The primary objective of this study was to evaluate the abundance and distribution of hatchery spring Chinook salmon precocious males during the spawning season in the Yakima River. The goal of the hatchery program in the Yakima River is to increase natural production and to provide harvest opportunity while keeping adverse genetic and ecological impacts within specified biological limits (Bonneville Power Administration 1996; Fast and Craig 1997; Bosch 2004). As such, the program strives to minimize differences between the hatchery and natural spawning fish to decrease the risk of long-term fitness impacts. Previous research indicated that the Yakima Supplementation and Research Facility has produced and released an average of 124,573 precocious males/year into the upper Yakima Basin between 1999 and 2007 (Larsen et al. 2004a; Larsen et al. 2007; Yakima/Klickitat Fisheries Project, Unpublished data). The estimate of precocious male abundance was derived by multiplying the percent of fish that exhibited physiological indicators of precocious maturation by the total numbers of fish released. It was not clear whether the spawning grounds would be swamped with large numbers of precocious males or whether these fish would die or fail to migrate to the spawning grounds prior to the spawning season. Our goals were to 1) estimate the abundance of hatchery origin precocious males on the spawning grounds, and 2) quantify the distribution of hatchery precocious males on and away from the spawning grounds. We also present information about the abundance and distribution of natural origin precocious males so that we could determine how hatchery precocious males might differ.

Methods

Study Area and Hatchery Program

The Yakima River Basin is a large river system that drains into the Columbia River near Richland, Washington. The upper Yakima River Basin, which is the subject of this paper, is located upstream of Roza Dam (Figure 1). Historically large numbers of salmon returned to the upper Yakima Basin (Bonneville Power Administration 1996). The flows in the upper main stem are regulated by three dams located in the upper portion of the basin that are complete or partial barriers to upstream migration. These dams store water and release water when it is needed for agriculture irrigation. Peak flows during the spring have been truncated and flows are artificially high during the summer and then dramatically reduced to a constant level at the onset of spawning in September (Pearsons et al. 2007b). Chinook salmon spawning generally peaks during the latter half of September. The management of flows in the upper Yakima cause the annual differences in the hydrograph to be reduced.

Artificial propagation of spring Chinook salmon in the upper Yakima Basin began with brood stock collection in 1997 and yearling smolt releases in 1999 as part of the Yakima/Klickitat Fisheries Project (YKFP). Approximately 683,678 Chinook salmon smolts have been released annually in the upper Yakima River from 1999 to 2007 (Pearsons and Temple 2007; YKFP unpublished data). Broodstock for the spring Chinook program were natural origin upper Yakima stock collected at a trapping facility at Roza Dam. Chinook were spawned and juveniles were reared at a hatchery facility in Cle Elum, Washington (Larsen et al. 2004a; Knudsen et al. 2006: Pearsons et al. 2007d). Spring Chinook salmon yearlings were transported to acclimation sites during January and February and released during the spring from the Easton and Clark Flats acclimation sites on the Yakima River, and from the Jack Creek acclimation on the North Fork of the Teanaway River (Figure 1; Pearsons and Temple 2007). The Easton and Jack Creek acclimation sites are located at the upper end of the spawning distribution and the Clark Flats acclimation site is located near the bottom end of the spawning distribution. Fish were permitted to migrate out of the acclimation sites between March 15 and May 31 and averaged approximately 120 mm fork length (FL) when released. At the middle to end of May, all fish were forced out of the acclimations sites into the river. Prior to release, a representative sample of fish was sampled to determine the rate of precocious maturation (Larsen et al. 2004a, 2007).

Approximately 19-25% of the spring Chinook hatchery production in the Yakima Basin has been precocious males between 1999 and 2002 (Larsen et al. 2004a). Using an annual precocious male average of 22% and the total number of fish released, Larsen et al. (2004a) estimated that 85,640, 133,141, 166,815, and 184,398 precocious males were released into the upper Yakima River during 1999, 2000, 2001, and 2002, respectively. Using new precocious maturation data from Larsen et al. (2007) and smolt abundance from the Yakama Nation (YKFP Unpublished data), we calculate that 94,067 precocious males were released into the upper Yakima River in 2003, 151,764 in 2004, 84,053 in 2005, 95,063 in 2006 and 126,220 in 2007. Thus an average of 124,573 precocious males were released into the upper Yakima watershed between 1999 and 2007.

Due to the high number of precocious male production in the hatchery, growth modulation of half the hatchery-reared fish was instituted for brood years (BY) 2002 through 2004 (release year 2004 through 2006) to evaluate the efficacy of reducing the incidence of precocious maturation (Larsen et al. 2004b). The remaining fish were reared in the same way as they had been since the start of the supplementation program. Larsen et al. (2004b) reported 43% of the normal reared males and 29% of the low growth reared males precociously matured; a 33% reduction in precocious male maturation. However, preliminary estimates indicated that the low growth fish did not survive as well as the normal reared fish, so all fish were reared in the normal manner for BY 2005 (release year 2007).

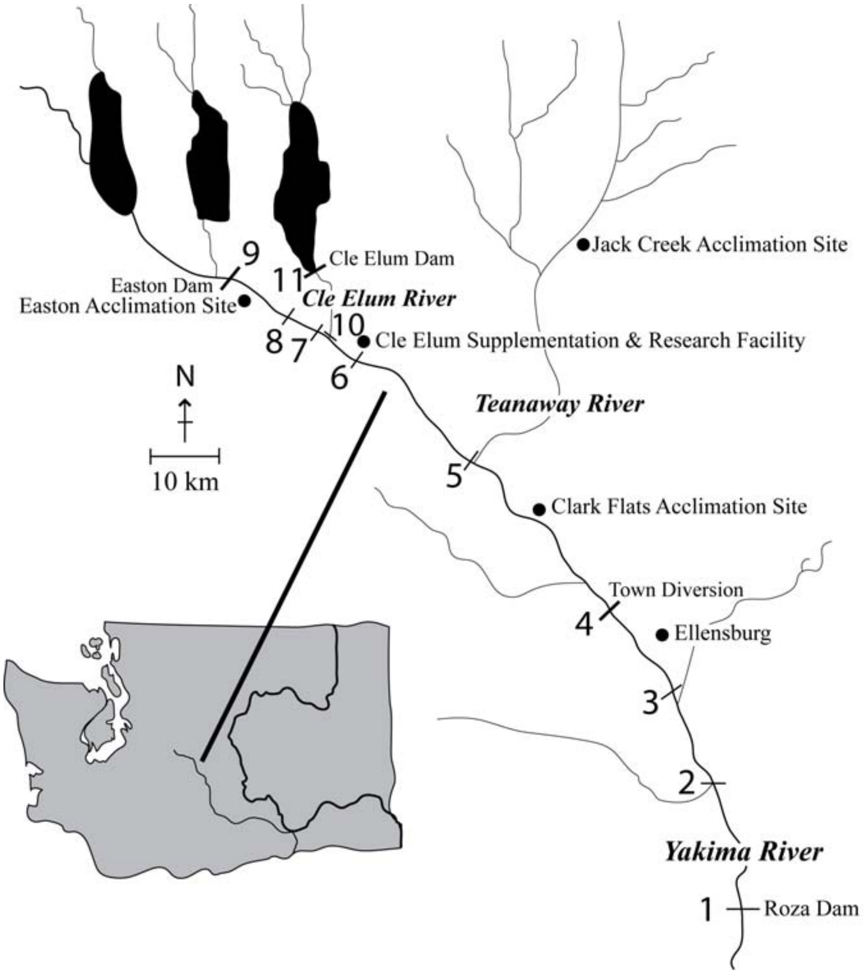

Figure 1. Survey reaches within the Upper Yakima basin. Drift boat electrofishing surveys occurred within the lower canyon (points 1-2), the upper canyon (points 2-3), the Ellensburg reach (points 3-4), the Thorp reach (points 4-5), and the Cle Elum reach (points 5-6). Snorkeling surveys were conducted in the Thorp and Cle Elum reaches as well as the Bullfrog reach (points 6-7), the Nelson reach (points 7-8), the Easton reach (points 8-9), and the Cle Elum River (points 10-11).

Abundance and Distribution

Sampling of precocious males on the spawning grounds occurred throughout the main stem Yakima River between Easton Dam and Town Diversion Dam, and the Cle Elum River from Cle Elum Dam to the Yakima River confluence between 1999 and 2007 (Figure 1). These areas represent the vast majority of the spawning area in the upper Yakima River and generally account for over 99% of the redds counted annually (www.ykfp.org, February 2008). Annual counts of precocious males occurred during the peak of spawning, which generally occurred during the last half of September. The sampling area consisted of six reaches (Figure 1). These reaches, beginning at the downstream end at approximately river kilometer (rkm) 256 were: Thorp (26.6 rkm long), Cle Elum (9.1 rkm long), the Cle Elum River (12.2 rkm long), Bullfrog (10.2 rkm long), Nelson (7.3 rkm long), and Easton (10.7 rkm long). The Bullfrog reach was first sampled in 2003. Excluding Bullfrog, all reaches together make up 87 percent (66 rkm) of the total spawning area above the Town Diversion Dam (Figure 1).

We counted the number of precocious males on active redds by snorkeling. Each reach was floated with an inflatable raft and salmon redds were flagged and numbered. Upon reaching a salmon redd we determined the presence or absence of anadromous salmon. We only snorkeled those redds with anadromous fish on the redds and termed them ‘active redds.’ Previous work demonstrated that precocious males were rarely observed on redds without anadromous fish present (Gebhards 1960; James et al. 1999). A snorkeler would then begin 5-10 meters downstream of the redd and snorkel upstream, counting all spring Chinook encountered. Fish were categorized as either being on the redd (in the bowl), or associated with the redd (within 5 meters). We combined the abundance of fish in these two categories in our analysis, however most of the fish we counted were on redds. Hatchery origin residuals (e.g., non-migrants) were differentiated from natural origin spring Chinook by the presence of an adipose clip. During years where more active redds were present than we could snorkel (all years but 1999 and 2007), we systematically sampled the active redds (e.g., every other redd).

We derived an estimate of the total number of precocious males by age class and origin in the spawning areas of the upper Yakima Basin by summing the abundance estimates of each of the six reaches. Abundance estimates in the reaches that were surveyed were calculated by multiplying mean abundance of precocious males per active redd by the number of active redds. We extrapolated the number of precocious males per river kilometer of adjacent sampled reaches to the length of reaches that were not sampled. Extrapolations of counts from both the Cle Elum and Nelson reaches were applied to the Bullfrog section prior to 2003.

We also estimated the number of hatchery precocious males that were not on redds during the spawning season. Five sections of the upper Yakima River were sampled at night from the middle of September to the middle of October using a drift boat electrofisher as described by Pearsons and Temple (2007) and Temple and Pearsons (2007). These sections represent approximately 29% of the area between the Cle Elum River and Roza Dam. The electrofisher was turned off when we approached redds to avoid electroshocking fish on or near redds. The numbers of hatchery precocious male Chinook netted during the electrofishing marking runs were expanded by maximum log-likelihood model recapture efficiencies for similar sized rainbow trout observed (177-203 mm). In sites where we could generate capture efficiencies for hatchery precocious male Chinook (e.g., mark-recapture), our observed rainbow trout electrofishing capture efficiency was within the 95% confidence interval (CI) of the hatchery origin spring Chinook electrofishing efficiency. Thus, we believe that size based efficiencies are reasonable ways of indexing abundance because fish size is one of the most important factors that influences electrofishing efficiency (Anderson 1995; Buttiker 1992).

Precocity, Size, and Age

Hatchery fish were collected to determine the incidence of precocious maturation, gender, size, and age; and natural origin fish that were less than 300 mm were collected to determine size and age. Fish were collected in the Yakima River prior to spawning by electrofishing and angling to determine the gender and incidence of precocious maturation. Fish were euthanized and their gonads examined. We used the methods described by Larsen et al. (2004a) to visually assess gender and precious maturation: “Immature females were identified by the gonad’s having an anterior thickening with a granular appearance, immature males by the gonad’s having a thin, clear, threadlike appearance with a diameter less than approximately 0.5

mm throughout the entire length, and precociously maturing males by the gonad's being opaque and having an anterior thickening of more than approximately 1.0-1.5 mm (depending on date) and a smooth surface texture." The fork length of each fish was measured and scale samples were collected from fish during 1998 and aged in the lab. Fish with a length greater than 120 mm (FL) were generally considered age 1 (fish having completed at least one full year of growth since hatching) residuals based on preliminary size and age data. Fish were also collected by angling on or near redds during the spawning season to determine whether they were mature.

Analysis

Non-parametric tests were used in statistical comparisons because our data did not meet the assumptions of parametric tests even when data transformations were performed (Zar 1999). A Friedman's test was used to compare the estimated annual abundance of hatchery precocious males to that of naturally produced age 1 precocious males, and both age 0 and age 1 precocious males combined. If test results were significant at a 0.05 level, Tukey-type post-hoc comparisons were made using methods presented by Zar (1999) to determine which comparisons were different. A two-tailed Wilcoxon paired test was used to compare the abundance of hatchery fish collected away from redds and on redds. A paired test was used to control for the high inter-annual variation of the abundance data. Comparisons of spatial distributions on the spawning grounds were evaluated using contingency table G-tests of independence (Zar 1999). The mean abundance in each reach from 1999-2007 for each age and origin of spring Chinook salmon were tested. We interpreted significant differences ($P<0.05$) as differences in spatial distribution. Pearson product moment correlation statistics were used to explore various relationships of precocious male abundance (Zar 1999). All tests were preformed in STATISTICA version 8.0 (Statsoft 2007).

Results

Nearly all of the residualized hatchery Chinook salmon that we collected in the river and examined prior to the spawning season were precociously maturing (187 out of 191) and all were males (191 out of 191). The four fish that were immature were all collected in 2004. In addition, many residualized hatchery fish that we did not lethally sample exuded milt when we handled them. We therefore treat hatchery residuals synonymously with precocious males in this study. Forty-six natural origin spring Chinook were captured from redds between 1998 and 2007. All of them were male and precociously mature. Scale analysis supported using 120 mm as a threshold for classifying naturally produced precocious males as age 0 or age 1 (Figure 3). There was little overlap between the size ranges of age 0 and age 1 fish. Length of mature age 0 fish was 10 mm longer than length of immature age 0 fish ($P<0.03$, paired t-test for years 2004-2007).

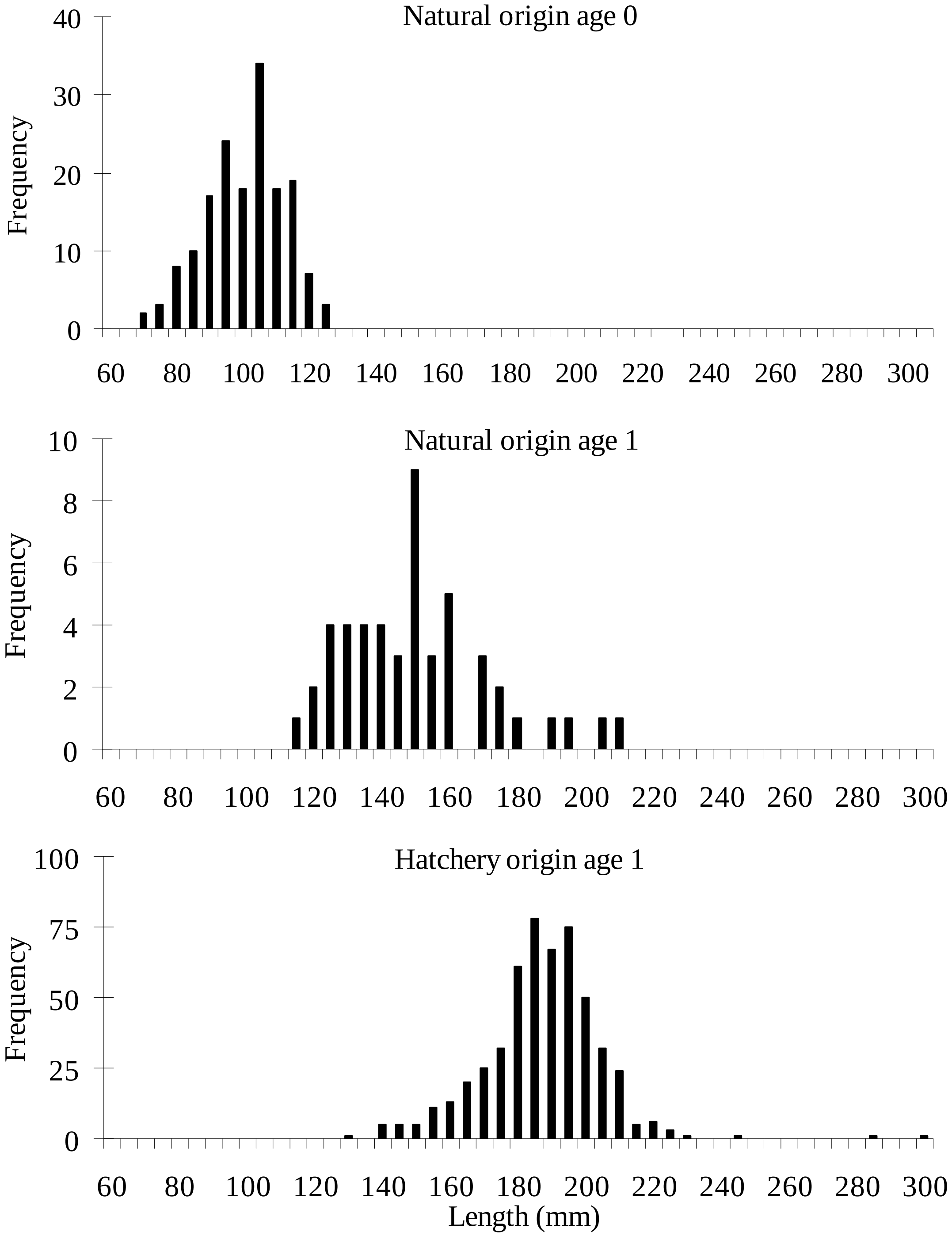

Figure 3. Length frequency of sexually mature precocious natural and hatchery origin spring Chinook salmon males collected during the spawning season (between late August and October) in the upper Yakima River 1998-2007. Ages of precocious male Chinook salmon prior to supplementation (1998) were determined by scale analysis.

The total number of hatchery precocious males estimated on the spawning grounds was less than 0.05% of the number that was released from the hatchery and was not significantly correlated with the number of precocious males released ($R^2 = 0.27$; $P = 0.15$). The estimated number of natural origin age 0, natural origin age 1, and hatchery precocious males on the spawning grounds during the peak of spawning ranged from 5 to 718, 0 to 65, and 0 to 78 between 1999 and 2007 respectively (Table 1). The total number of natural origin precocious males on the spawning grounds was significantly higher than the number of hatchery precocious males (Friedman's test; P<0.05), but the number of hatchery and natural origin age 1 precocious males were not significantly different (Tukey test; P>0.05). The means of the presence and abundance of natural (age 0 and age 1) and hatchery origin precocious males per active redd at the peak of spawning activity in the upper Yakima River are presented in Table 2.

Table 1. Number of observed and estimated totals of natural (age 0 and age 1) and hatchery origin precocious males by age class at the peak of spawning activity in the upper Yakima River. Estimated totals are extrapolations over redds and/or portions of reaches not sampled.

Survey year	Active redds	(%) Redds surveyed	(%) Spawning area sampled	Observed			Estimated total		
				Age 0	Age 1	Hatchery	Age 0	Age 1	Hatchery
1999	36	100	87	4	11	17	5	16	19
2000	316	66	87	103	42	8	128	42	11
2001	276	62	87	336	11	26	555	21	53
2002	304	81	87	138	15	8	228	25	14
2003	230	78	100	204	25	19	267	35	24
2004	1662	27	100	195	16	21	718	65	78
2005	655	99	100	357	17	0	360	17	0
2006	198	90	100	148	2	0	177	3	0
2007	92	100	100	55	0	0	55	0	0

Table 2. Means of the presence and abundance of natural (age 0 and age 1) and hatchery origin precocious males per active redd at the peak of spawning activity in the upper Yakima River.

Survey year	Active redds	Presence/Active redd			Abundance/Active redd		
		Age 0	Age 1	Hatchery	Age 0	Age 1	Hatchery
1999	36	0.11	0.14	0.19	0.14	0.44	0.53
2000	316	0.18	0.10	0.02	0.41	0.13	0.03
2001	276	0.31	0.03	0.04	2.01	0.08	0.19
2002	304	0.23	0.03	0.03	0.75	0.08	0.05
2003	230	0.31	0.06	0.06	1.16	0.15	0.10
2004	1662	0.05	0.01	0.01	0.43	0.04	0.05
2005	655	0.24	0.02	0	0.55	0.03	0
2006	198	0.75	0.04	0	0.89	0.02	0
2007	92	0.18	0	0	0.60	0	0

Hatchery and natural origin precocious males were both found throughout the spawning distribution during the spawning season, but differences in distribution between origins were detected. Hatchery precocious males were proportionately more abundant in the lowest sampling reach and less abundant in a river with no hatchery facilities (Figure 2). Hatchery precocious males were distributed differently than natural origin age 0, and natural origin age 0 and 1 combined on the spawning grounds (G-test; $P<0.05$) but a significant difference was not detected between natural origin age 0 and natural origin age 1 fish, or between natural origin age 1 and hatchery precocious males (G-test; $P>0.05$; Figure 2). Between 17% and 51% of all hatchery precocious males observed on the spawning grounds within a year were in the lowest spawning reach examined, whereas only 0% to 9% of all natural origin age 0 and 0% to 38% of all natural origin age 1 precocious males were observed in this reach (Figure 2). Proportions of natural and hatchery origin precocious males were also high in the Easton reach, which contains a hatchery release location.

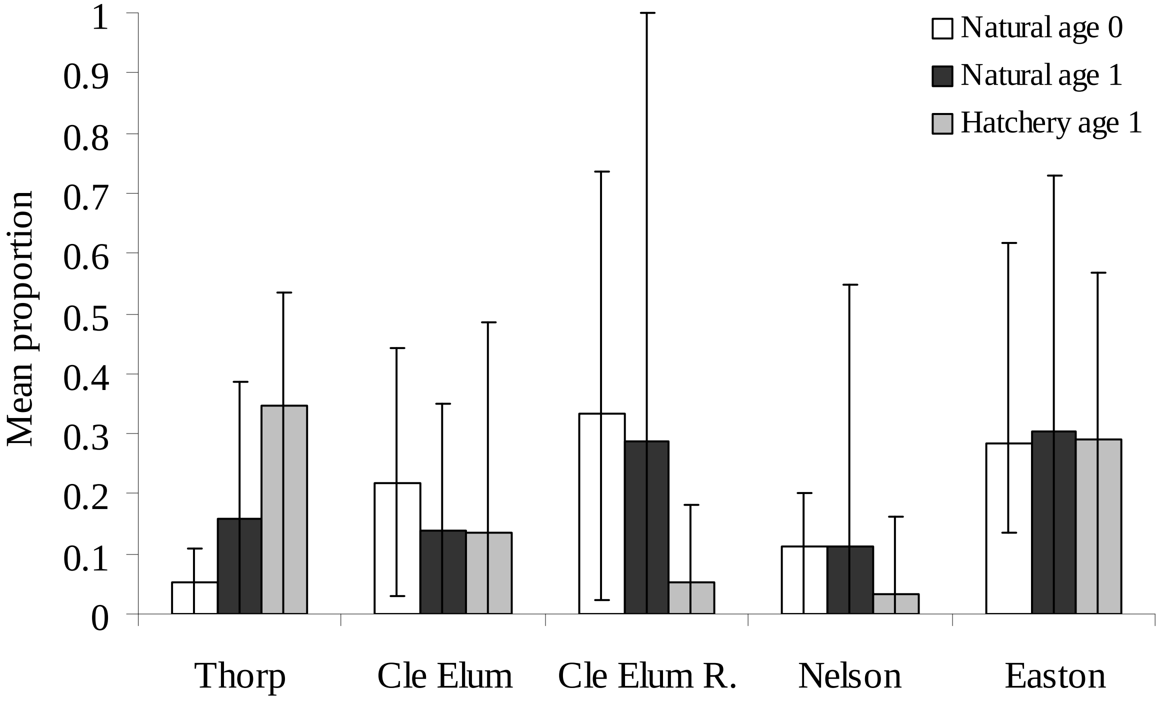

Figure 2. Mean proportion of natural and hatchery origin precocious males by reach within the upper Yakima River at the peak of spawning activity from 1999 to 2004 (years that hatchery precocious males were observed). Easton and the Cle River are the farthest upstream and Thorp is the farthest downstream. Error bars represent minimum and maximum proportions.

Hatchery precocious males that were not on redds, and collected by driftboat electrofishing, were more abundant than on redds (Wilcoxon: $P = 0.007$) and were the most abundant in reaches downstream of spawning areas. The Lower and Upper Yakima Canyon averaged 69% of the estimated number of precocious males off the redds during the spawning season (Table 3). The annual abundance of hatchery precocious males that were not on redds were not significantly correlated with the number of hatchery precocious males released from the hatchery ($R^2=0.21$; $P=0.22$) or the number on the spawning grounds ($R^2=0.34$; $P=0.10$).

Table 3. Estimated abundance of hatchery origin spring Chinook salmon (HSPC) away from redds in the main stem Yakima River. The mean number of fish netted (n) from the left and right banks, sampled over two consecutive nights per section during drift-boat electrofishing is presented (LCYN is the Lower Canyon, UCYN is the Upper Canyon, EBURG is Ellensburg, THORP is Thorp, and CELUM is Cle Elum). Capture probability was generated using rainbow trout of approximately the same size range as hatchery spring Chinook salmon.

Section	n	Capture probability	Section estimate	Section km	HSPC per km	Reach km	Total
				1999			
LCYN	6.5	0.25	26	4.8	5.4	19.2	104
UCYN	4	0.08	50	5.2	9.5	13.4	128
EBURG	1	0.05	20	4.2	4.8	21.2	101
THORP	2.5	0.14	18	5.7	3.1	24.1	76
CELUM	0	0.15	0	7.4	0	16.2	0
Total							408
				2000			
LCYN	7.5	0.15	50	4.8	10.4	19.2	200
UCYN	1.5	0.03	50	5.2	9.5	13.4	128
EBURG	1	0.19	5	4.2	1.3	21.2	27
THORP	13	0.07	186	5.7	32.6	24.1	787
CELUM	1	0.04	25	7.4	3.4	16.2	55
Total							1195
				2001			
LCYN	93.5	0.05	1958	4.8	406.2	19.2	7814
UCYN	28.5	0.05	628	5.2	119.8	13.4	1603
EBURG	12	0.08	150	4.2	35.7	21.2	756
THORP	13	0.03	433	5.7	76.0	24.1	1836
CELUM	0	0.03	0	7.4	0	16.2	0
Total							12009
				2002			
LCYN	3.5	0.04	88	4.8	18.2	19.2	349
UCYN	0	0.10	0	5.2	0	13.4	0
EBURG	4	0.15	27	4.2	6.3	21.2	134
THORP	2	0.12	17	5.7	2.9	24.1	71
CELUM	0	0.10	0	7.4	0	16.2	0
Total							554
				2003			
LCYN	21	0.07	300	4.8	62.2	19.2	1197
UCYN	8	0.07	114	5.2	21.8	13.4	292
EBURG	2	0.04	50	4.2	11.9	21.2	252
THORP	4	0.27	15	5.7	2.6	24.1	63
CELUM	0	0.07	0	7.4	0	16.2	0

Total							1804
2004							
LCYN	40	0.11	364	75.4	62.2	19.2	1451
UCYN	17	0.16	106	20.3	21.8	13.4	271
EBURG	11	0.09	122	29.1	11.9	21.2	616
THORP	3	0.08	38	6.6	2.6	24.1	159
CELUM	0	0.09	0	0	0	16.2	0
Total							2498
2005							
LCYN	37	0.23	162	4.8	33.6	19.2	646
UCYN	16	0.11	145	5.2	28	13.4	375
EBURG	1	0.08	12.5	4.2	3	21.2	63
THORP	0	0.04	0	5.7	0	24.1	0
CELUM	0	0.08	0	7.4	0	16.2	0
Total							1077
2006							
LCYN	1	0.18	1.18	4.8	0.25	19.2	5
UCYN	1	0.22	1.22	5.2	0.24	13.4	3
EBURG	0	0.11	0	4.2	0	21.2	0
THORP	0	0.17	0	5.7	0	24.1	0
CELUM	0	0.08	0	7.4	0	16.2	0
Total							8
2007							
LCYN	6	0.25	7.50	4.8	1.56	19.2	30
UCYN	6	0.13	6.78	5.2	1.30	13.4	17
EBURG	3	0.11	3.33	4.2	0.79	21.2	17
THORP	7	0.15	8.05	5.7	1.41	24.1	34
CELUM	0	0.07	0	7.4	0	16.2	0
Total							98

Discussion

Despite the large numbers of precocious males released from the hatchery (Larsen et al. 2004a; Beckman and Larsen 2005; Larsen et al. 2006), only a small fraction of these fish were observed on the spawning grounds and there were fewer hatchery precocious males on redds than natural origin precocious males. Hatchery precocious males may experience high mortality, migrate out of the study area after release, and/or fail to migrate back to the spawning grounds. Although the occurrence of some of these factors were observed in this or other studies (Larsen et al. 2004a; Beckman and Larsen 2005), we do not know the relative contribution of each of these factors towards the low abundance of precocious males on the spawning grounds. Mortality of hatchery precocious males may be due to high angler exploitation, starvation, or predation. There is considerable angling pressure focused on trout in the Yakima River and some anglers have commented about how many precocious Chinook males that they had caught, particularly during 2001. However, it is illegal to keep Chinook salmon in the upper Yakima River. Furthermore, studies have shown that hatchery origin fish released into the natural environment have lower survival than natural origin fish presumably because of their inability to find food or avoid predators (White et al. 1995; Weber and Fausch 2003). The high production of precocious males in the hatchery may make it difficult to reach the management goals of the supplementation program (Pearsons et al. 2007e).

It has been documented that some hatchery precocious males move downstream out of the spawning areas and have been detected as far downstream as Bonneville Dam on the Columbia River (Larsen et al. 2004a; Beckman and Larsen 2005). In the Umatilla River, precocious males migrated at least 800 km and passed three dams before returning to the Umatilla River (Zimmerman et al. 2003). Hatchery precocious males were collected migrating both downstream in the spring and upstream during the summer (Larsen et al. 2004a; Beckman and Larsen 2005). The downstream migrations occurred during the smolt out-migration period and the upstream migrations occurred at the time of adult spawning immigration. If precocious males migrate downstream and then environmental conditions turn poor before they are able to migrate back upstream, then they are likely to die. The lower Yakima River becomes lethal for salmonids during many of the hot summer months when precocious males might attempt to ascend the river. If the factors contributing to hatchery fish mortality in the river are reduced or the conditions in the river are favorable for migration back to the spawning grounds (e.g., favorable flows and low angling pressure), then presumably the number of hatchery precocious males on the spawning grounds could increase dramatically. However, the range of conditions that we evaluated in this study, which included both high and low flow years, provide a reasonable range of what can be expected in the future.

Most of the hatchery precocious males that we encountered were located downstream of spawning areas. The Lower and Upper Yakima Canyon typically contain less than 1% of the upper Yakima Basin redds (Yakama Nation, unpublished data) and yet averaged 69% of the estimated number of hatchery precocious males during the spawning season. Many of the hatchery precocious males on the spawning grounds were observed in a reach that had relatively little spawning activity, whereas the natural origin precocious males were mainly in the areas with high spawning activity. The spawning area where many of the hatchery precocious males were observed was at the lower end of the spawning distribution. It also happens to be located closest to the Yakima Canyon where the highest abundance of precocious males that were not on the spawning grounds was observed. In the Wenatchee River, very few hatchery precocious males were observed on the spawning grounds, but a considerable number were captured migrating upstream at a location downstream of the spawning areas (Murdoch et al. 2007). These fish may have also distributed themselves below the main spawning areas as we observed in the Yakima Watershed. This behavior is in contrast to natural origin precocious males that are rarely observed moving upstream past dams in the Yakima or Wenatchee watersheds, suggesting that natural origin precocious males have adopted a strategy of remaining on or near the spawning grounds and thus conserving energy and promoting growth and testes development. Some hypotheses as to why sexually mature hatchery precocious males, most of which are exuding milt at the time of sampling, are located in areas away from where most of the spawning activity occurs include: lack of energetic capacity to swim back upstream to the spawning grounds; inappropriate down stream migration behavior for their life-history strategy; late migration timing; and inability to locate areas with spawning females after they had migrated downstream of spawning areas. Younger salmon, such as precocious males and jacks, typically migrate back to the spawning grounds later than older salmon (Knudsen et al. 2006; Murdoch et al. 2007) and may migrate during unfavorable environmental conditions.

Cle Elum Hatchery origin fish are only released at age 1, which eliminates the possibility that age 0 hatchery precocious males will have the potential to spawn. In the absence of hatchery releases, age 0 precocious males are generally more abundant in the spawning areas than age 1 precocious males, so the hatchery is skewing the precocious male composition to an older age and larger size. This is in stark contrast to anadromous hatchery fish which typically mature earlier than wild fish and often at a smaller size-at-age (Knudsen et al. 2006). It is interesting to note that few incidences of precocious male maturation at age 0 have been observed in the Yakima hatchery (Larsen et al. 2004a). In addition, attempts to experimentally produce age 0 precocious males by high feeding rates in the hatchery did not produce any precocious males in 2002 (Farrell 2003). These fish emerged at the average emergence time of the population. It is possible that only the fish that emerge very early and experience good growth have the potential to precociously mature at age 0 (Larsen et al. 2007). However, because precocious males were not used in the broodstock, we cannot eliminate the possibility that genetics also influenced the absence of precocialism (e.g., Heath et al. 1994; Unwin et al. 1999). For example, the hatchery broodstock may contain a higher proportion of individuals that tend to produce offspring that mature at age 1 rather than age 0.

Hatchery age 1 fish may be competitively superior to wild precocious males because hatchery precocious males are larger. Larger salmonids typically dominate smaller ones in behavioral contests (McMichael et al. 1999). We have observed a number of instances where hatchery precocious males displaced wild precocious males from redds or from preferred locations on redds. Behavioral dominance is important because dominant fish are more likely to be close to spawning females and hence more able to fertilize eggs (Garant et al. 2003). Dominant fish are better able to choose which locations pose the best chance for spawning success. Our behavioral observations suggest that per capita fertilization rates of hatchery precocious males should be higher than that of wild precocious males. However, sneaking strategies of smaller individual may also be successful. Evaluation of these strategies is outside the scope of this manuscript, however Garant et al. (2003) found that mature Atlantic salmon (*Salmo salar*) parr of farm origin had higher reproductive success than wild origin parr. Ongoing work in an experimental spawning channel at the Cle Elum Supplementation and Research Facility will reveal if hatchery precocious males fertilize more eggs than wild precocious males (Schroder et al. 2003).

We have identified some issues that could potentially contribute to the underestimation of precocious male numbers during our peak snorkel counts. We may have underestimated the number of active redds by spooking adults or by floating at times when adults are temporarily away from their redds. However, we rarely observed precocious males on redds without adults being present and this finding was also supported by work in the Salmon River drainage (Gebhards 1960). Gebhards (1960) concluded that precocious males were generally only found in areas where there was spawning activity and were usually found in the bowl of the redd, and "the yearling males remained constantly within the redd." We may also have underestimated the number of precocious males because they may have: 1) been hiding with hiding adults, 2) been hiding away from redds, 3) been scared off redds, 4) been moving between redds, and/or 5) spawned and died prior to our peak count. Reasons 1-4 are not supported by snorkel observations that we conducted in 1998 and 2007. Hatchery precocious males were not observed in hiding areas, such as undercut banks, in the vicinity of spawning areas. We have also observed that repeated counts of precocious males at three different times of the day in the same reach were similar. This suggests that either our counts were accurate or that our bias was consistent. However, our estimates of fish away from redds, that were generated from electrofishing, were higher in some years than those generated from snorkeling in the Thorp reach, suggesting that snorkeling may underestimate abundance. In short, if we underestimated the number of precocious males on the spawning grounds then our numbers should be treated as indices.

Our study suggests that hatchery precocious males are unlikely to contribute a high proportion of genes in the Yakima Watershed when the number of anadromous adult returns is high, but contributions could be high when anadromous adult numbers are low. The highest abundance of hatchery precocious males that we estimated on the spawning grounds during any year was 78. This is a small proportion of the spawners when anadromous spawners number in the thousands, but relatively large when the abundance of spawners is in the hundreds. This range of anadromous fish abundance has been observed in the upper Yakima Watershed. In a separate DNA pedigree study conducted in an artificial spawning channel (Schroder et al. 2006), hatchery and natural origin precocious males of the upper Yakima spring Chinook salmon stock have been documented to sire offspring. In addition, precocious maturation appears to be highly heritable in Yakima spring Chinook salmon (Pearsons et al. 2007e). In short, it appears that the genetic contribution of hatchery precocious males on the spawning grounds is related to anadromous fish abundance and those factors that influence the abundance of precocious males on the spawning grounds. Variation in the precocious male contribution suggests that domestication risks may vary among years.

The consequences of eliminating a large proportion of hatchery males from the spawning population may be quiet important, but currently the consequences of this unintended outcome are uncertain. Reduction of hatchery precocious males may be beneficial to the natural spawning population because of the potential reduction in domesticating effects that might be caused by hatchery rearing (Garant et al. 2003). Alternatively, reducing the genetic contribution of fish that have traits related to precocious maturation, such as fast growth, may impact the population in negative ways. Indeed, we found that age 0 precocious males were larger than immature fish. Further research is needed to understand the importance of precocious males to natural spawning populations and the potential domesticating impacts of hatchery precocious males to natural populations.

Releasing large numbers of precocious males could also increase ecological risks to target and non-target taxa (e.g., McMichael et al. 1999). Any impacts that may have occurred within the first five years of hatchery releases were within the management containment objectives for the YKFP (Pearsons and Temple 2007). Hatchery precocious males have been shown to share similar food and space with other salmonids in the Yakima River, but indices designed to evaluate competition with natural origin spring Chinook salmon in the main stem Yakima River suggests that competition is relatively low (Pearsons et al. 2007b). Furthermore, low incidences of piscivory have been documented in the upper Yakima watershed (Pearsons et al. 2007b). In contrast, release of hatchery spring Chinook may be contributing to impacts to trout in the North Fork Teanaway River (Pearsons et al. 2007c).

Our study points out some challenges with integrating hatchery and wild populations while minimizing changes to natural populations. Many factors influence where and how many precocious males will be on the spawning grounds, and many of these factors are outside of the control of hatchery managers. For instance, incidental harvest, flow rate, and water temperature may influence production and survival of precocious males in the river and their location during the spawning season. In addition, the number of precocious males released was uncorrelated with the number that was observed approximately five months later. Knowledge about precocious males on the spawning grounds in other river basins should contribute towards more effective hatchery and fishery management. It appears that many precociously mature fish released from the hatchery migrate downstream and fail to migrate back to the spawning grounds or die within the Yakima River prior to spawning time. Thus, hatchery production of precocious males in the Yakima River do not contribute favorably to harvest and may pose ecological risks to non-target taxa, but most of these fish have a low probability of contributing genes to future generations. Despite the high production of hatchery precocious males, managers in the Yakima Basin have chosen to discontinue efforts to reduce precocious males because growth modulation reduced the survival of migrants; presumably because of their smaller size. The critical issue that was not directly addressed in this study was whether the hatchery changed the natural influence of precocious males in the target population. Until this issue is resolved, it is unclear how precocious males should be managed to conserve the upper Yakima Chinook population.

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Chapter 4

Incidence of Predation by Hatchery Spring Chinook Salmon on Natural Origin *Oncorhynchus mykiss* and Chinook Salmon

Abstract

Predation by hatchery fish is commonly thought to be one of the most potent ecological interactions that could impact wild fish populations. We evaluated the incidence of predation of hatchery spring Chinook salmon on natural origin *Oncorhynchus mykiss* and Chinook salmon in the Yakima River Basin. Spring Chinook were sampled between July and September 1999 to 2004, and between April and September 2005 to 2007. Fish were collected by backpack electrofishing, drift-boat electrofishing, and angling. Upon capture, stomach contents of Chinook salmon were evacuated using pulsed gastric lavage. We detected low incidence of piscivory by hatchery spring Chinook in the main stem Yakima River and none in the North Fork of the Teanaway River. However, prey fish of suitable sizes were present in the reaches where we collected hatchery spring Chinook salmon. Our data suggest that releasing hatchery fish at a size similar to natural origin conspecifics and using volitional release has the potential to decrease the incidence of predation by hatchery spring Chinook salmon.

Introduction

Among the ecological interactions between hatchery and wild fish, predation by hatchery fish is commonly thought to be one of the most potent ecological interactions that could impact wild fish populations. Some authors have reported high incidences of predation by hatchery origin salmonids (Sholes and Hallock 1979; Hawkins and Tipping 1999). One of the most frequently cited papers (e.g., White et al. 1995; Pearsons and Hopley 1999) about the potential for hatchery origin fish to eat wild origin fish is Sholes and Hallock (1979). Although their paper was not about predation, they presented information in their “Discussion and Conclusions” section about predation by hatchery origin fall-run Chinook salmon reared to yearlings on natural origin Chinook salmon. They estimated that “as many as 7.5 million naturally-produced salmon fingerlings were eaten by the yearlings.” They further estimated that this could result in a reduced catch of 12,750 fish in the ocean fishery. Although they do not present their methods or calculations, they did report that the yearlings did not migrate out of the Feather River (the stream of release) immediately, but stayed in the upper river. They reported that attempts were made to induce migration of the fish by producing short duration flushing flows. These attempts did not produce any noticeable effect upon the distribution and concentration of hatchery yearlings. Fish averaged 76 grams at release. Furthermore, they found that these fish averaged 1.3 salmon fingerlings per stomach.

The piscivory rates of migrating Chinook salmon captured at Bonneville Dam on the Columbia River were much lower than those found by Sholes and Hallock (1979). Muir et al. (1988) examined the gut contents of 130 yearling Chinook and 218 subyearling Chinook salmon collected at Bonneville Dam. These fish were likely a combination of hatchery and wild fish but they did not attempt to identify fish by origin. They found 0.8% and 2.2% of the yearling and subyearling Chinook salmon respectively had digested fish in their guts. These fish were not identified to species, but it is possible that some were salmonids.

These studies used different approaches to capturing Chinook salmon and as such captured Chinook that had different ecologies. The Sholes and Hallock (1979) study captured non-migrating fish and the other studies captured migrating fish. Residualized salmon are often more difficult to sample than migrants because they are generally less abundant and cannot be captured at a single location such as a migrant trap. It is likely that piscivory rates of migrant and non-migrant Chinook are different. The objective of this paper is to evaluate the incidence of predation of hatchery spring Chinook salmon on natural origin *Oncorhynchus mykiss* and Chinook salmon. More specifically, we compared piscivory rates of hatchery Chinook salmon that were collected before and after June 1. After June 1, Chinook salmon are considered residuals because they do not migrate during the typical time of outmigration, if at all.

Methods

Yearling spring Chinook salmon were volitionally released from three acclimation sites in the upper Yakima Basin between March 15 and May 31 as part of the Yakima/Klickitat Fisheries Project (Knudsen et al. 2006; Pearsons and Temple 2007). Most fish left acclimation sites during the month of April (YN, unpublished data). Beginning in April the water levels of the raceways were reduced by removing boards that constrain the flow at the downstream end of the raceways. Those fish that did not migrate by mid to late May were pushed into the river. The proportion of the release that was pushed out was typically less than 10% (Charles Strom, personal communication). Many fish precociously matured and many of these fish remained in the upper Yakima Basin (Larsen et al. 2004, Chapter 3 of this report).

Hatchery spring Chinook were sampled between July and September 1999 to 2004, and between April and September 2005 to 2007. Fish were collected by backpack electrofishing, drift-boat electrofishing, and angling. Upon capture, stomach contents of Chinook salmon were evacuated using pulsed gastric lavage. Stomach samples were 1) preserved in alcohol and examined in the lab or 2) examined for invertebrates or fish parts in the field. If fish parts were observed in the gut contents in the field, then they were preserved in alcohol and examined in the lab. Length (FL mm) and weight (g) were measured on all fish captured. Natural origin rainbow trout and Chinook salmon were also measured when captured.

We measured the length (FL mm) of naturally produced salmonids found in the Yakima River Basin to determine their potential risk of predation by hatchery spring Chinook. Length data was also mined from previous efforts that evaluated size at emergence. We calculated relative length by dividing the salmonid prey length by the length of hatchery spring Chinook salmon. Values less than 50% are considered to be potential prey (Pearsons and Fritts 1999).

Results

We detected no incidence of piscivory on salmonids by hatchery spring Chinook residuals after June 1 in either the main stem Yakima River or the North Fork of the Teanaway River (Table 1). The single prey fish that was detected in the stomach was a sculpin (Table 2). However, 3 fish were observed in stomachs of hatchery spring Chinook salmon prior to June 1 (Table 1). Two of these fish were likely to be salmonids (Table 2). The hatchery origin Chinook salmon ranged in size from a minimum of 82 mm to a maximum of 221 mm (Table 1). Prey sized age 0 Chinook salmon and rainbow trout were available throughout the duration of our stomach sample collections (Table 3). The relative size of potential prey/predator was generally less than 50% during July, but an increasing proportion of prey were not vulnerable to predation in September.

Table 1. Hatchery spring Chinook salmon mean length (mm) and percent food type found in the gut, April-September 1999-2007. Percent sample consists of 1 percent in March, 8 percent in April, 13 percent in May, 10 percent in June, 41 percent in July, 20 percent in August, and 7 percent in September across years (1999-2007). Although attempts were made, no fish were captured after June in 2006.

		Fork length (mm)			Presence/Absence (%)		
Year	n	Mean	Min	Max	Empty	Invertebrates only	Fish
Collected after June 1							
1999	44	162	126	194	0	100	0
2000	75	150	115	170	1.3	98.7	0
2001	64	162	129	221	0	98.4	1.6
2002	17	179	144	211	0	100	0
2003	14	170	148	185	0	100	0
2004	35	167	118	191	0	100	0
2005	43	174	154	195	0	100	0
2007	22	122	100	146	0	100	0
Total/Mean	314	161	129	189	0.2	100	0.2
Collected before June 1							
2005	31	132	96	168	0	93.5	6.5
2006	36	105	82	144	0	100	0
2007	20	120	92	144	10	90	0
Total/Mean	87	119	90	152	3	95	2

Hatchery spring Chinook collected after June 1st are considered residuals.

Table 2. Hatchery spring Chinook found to have fish present in the gut 1999-2007.

Section	Date	Predator Length (mm)	Prey Type	Number of Prey	Prey size
NFT	7/12/01	139	Cottid	1	fry
Cle Elum	4/12/05	99	Non-salmonid	1	~30 mm
Nelson	5/12/05	155	Salmonid	2	40 mm*

* Visual observation, prior to loss of sample in the lab. Estimates of both prey items were approximately 40 mm in length and the fish had deep bodies.

Table 3. Mean length (mm) of potential prey. The 1983-89 spring Chinook lengths presented are redd cap and fry trap data (Fast et al. 1991), 1995-96 rainbow trout lengths are weighted averages from WDFW redd caps.

Spring Chinook						Rainbow Trout					
Month	Year	n	Mean Length (mm)	Min	Max	Month	Year	n	Mean Length (mm)	Min	Max
February	89	-	36								
March-April	83	25	34								
March-July	84	237	35*								
April	06-07	227	38.3	30	48						
May	06-08	615	41	31	59						
June	05,07	60	59.6	40	85	June	95-96	375	187.5	21	31
July						July	95-96, 05-06	359	32.9	22	70
August	05	35	81.4	69	97						
September	05	68	97.9	80	116	September	06	127	69.8	44	105
October	05	70	89.6	78	108						

*median fork length

Discussion

Despite the presence of ample numbers of prey sized *O. mykiss* and Chinook salmon we found little evidence of substantial piscivory by residualized spring Chinook salmon in the Yakima Basin. This was in sharp contrast to the work on the Feather River where high rates of predation were detected (Sholes and Hallock 1979). The hatchery fish in our study were much smaller than those released into the Feather River. Our fish averaged 120 mm at release and those in the Feather River averaged approximately 184 mm at release (based on a length-weight regression of hatchery Chinook). Larger fish are able to eat larger prey fish and so the diversity of prey that a large fish can eat is larger than a small fish (Pearsons and Fritts 1999). Hatchery fish appeared to have been released in January and February and sampled in the same months in the Feather River. Our fish were volitionally released between March 15 and May 31 and sampled between April and September. Thus it is likely that the relative size of prey to predator would increase during the summer in the Yakima and make prey less susceptible to predators. Although both prey and predator are growing during this time, the prey fish are likely growing faster than the predators. Volitional release of the Yakima River fish may decrease the incidence of predation by keeping non-migrant fish out of the river when prey fish are particularly susceptible to predation. It appears that the Feather River fish were force released from the hatchery and that many fish were not ready to migrate at the time of stocking. The prey fish density in the Feather River may have been higher than it was in the Yakima, although we do not have data to support or refute this contention. Hawkins and Tipping (1999), suggested that the high incidences of predation that they observed in the Lewis River was the result of high prey fish densities. Finally, the predation work in the Feather River was conducted during one year, which may have been an abnormally high level of predation. Our work was conducted over many years. Our data suggest that releasing hatchery fish at a smaller size and using volitional release has the potential to decrease the incidence of predation by residual hatchery spring Chinook salmon.

It is possible that we failed to detect biologically significant levels of predation because of our small sample size. Even low incidences of predation can be biologically significant when the predator population is large or the prey population is small. Thus our results should not be used to suggest that predation by hatchery Chinook salmon is biologically insignificant, but rather provide a comparison to studies that have reported much higher levels of predation. Predation risks appear to be smallest after June 1 because piscivory rates are low and abundance of hatchery spring Chinook salmon is low. Estimates of abundance of in September and October ranged from 8 to 12,009 between 1999 and 2007 (Chapter 3 of this report) whereas approximately 800,000 fish were released into the upper Yakima Basin between March and May, 1999-2007.

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Chapter 5

Do juvenile salmonids benefit from supplemental Chinook salmon carcasses provided by hatchery supplementation?

Abstract

One of the potential benefits of a successful hatchery supplementation project is the increase in the amount of food provided by salmon carcasses that is available to natural origin fish. We found that supplementation increased the amount of marine derived nutrients in the upper Yakima watershed. In addition, adult spring Chinook salmon that return to the Yakima River provide a net increase of nutrients relative to the mass of spring Chinook salmon smolts that leave the Yakima Basin and this addition is amplified when higher abundances of adults return to the Yakima River. We evaluated the importance of Chinook salmon carcasses to juvenile salmonids (Chinook salmon and rainbow trout) in the Yakima River by 1) examining stomach contents of juvenile salmonids when carcass material was available, 2) evaluating stomach fullness of juvenile salmonids during the following summer rearing period, and 3) comparing spring Chinook salmon and rainbow trout biomass relative to the number of carcasses present one and two years prior. Averages from 1999-2007 revealed that less than 3% of spring Chinook salmon and rainbow trout contained flesh or eggs in their stomachs. Salmon and trout mainly fed on invertebrates during all periods. Furthermore, there was not a significant correlation between the number of salmon redds (an index of carcass abundance) and the incidence of flesh and eggs in fish stomachs, the stomach fullness during the summer and the number of redds one year prior, or the biomass and the number of redds one or two years prior ($P>0.05$). To date, we found little evidence to indicate that current ranges of abundances of salmon carcasses provided significant nutrient benefits to salmon or trout in the upper Yakima River. More dramatic increases in carcasses and/or increases in nutrient retention may be necessary before benefits to juvenile salmonids are detectable.

Introduction

One of the potential benefits of a successful hatchery supplementation project is the increase in the amount of food provided by salmon carcasses that is available to natural origin fish. If the recruitment rate of hatchery origin adults exceeds that of natural origin adults, then it is likely that the amount of food available to natural origin juveniles will be higher than natural levels. This is particularly true if the distribution of hatchery origin spawners is similar to natural origin spawners. Traditional hatchery programs might also increase nutrients if spawned out carcasses are distributed back into natural spawning areas. Many authors have suggested that the amount of nutrients provided by salmon carcasses is related to survival of juvenile salmonids (Schindler et al. 2003), but this relationship has rarely been demonstrated (Naiman et al. 2002). Some have suggested that there is a positive feedback between abundance of salmon carcasses, juvenile salmon production, and subsequent adult production (Wipfli et al. 2003; Scheurell et al. 2005). Elevated levels of food provided by supplementation programs could also dampen or outweigh the negative consequences of competitive or predatory interactions initiated by hatchery origin fish (Pearsons 2002). It has been documented that salmonids will directly consume the flesh and eggs that are present in dead salmon (Bilby et al. 1996; 1998). This is the most direct pathway that salmon carcasses can increase food availability to natural origin salmonids.

Salmon carcasses have been demonstrated to provide benefits to salmonids and their associated species (Stockner 2003; Wipfli 2003). Unfortunately, the numbers of salmon returning to streams is a small fraction of what occurred historically (Gresh et al. 2000) and many have suggested that the lack of carcasses has resulted in declines in salmonid productivity (Achord et al. 2003; Stockner 2003). Salmon carcasses primarily provide food to salmonids through two pathways; direct consumption of the carcass and eggs, and consumption of more numerous invertebrates that benefited from carcasses. Invertebrates primarily benefit from salmon carcasses by directly consuming carcass material and by increasing periphyton through the addition of dissolved nutrients into the water (Bilby et al. 1996).

Stream fishes with access to salmon carcasses and eggs generally grow faster than fishes at locations without this material. Artificially increasing availability of salmon carcass flesh and eggs by adding carcasses of hatchery coho salmon *Oncorhynchus kisutsh* to a small stream in southwestern Washington doubled the growth rate of juvenile coho salmon at this site relative to a nearby stream reach with low availability of carcasses (Bilby et al. 1998). Rapid increases in the proportion of carcass-derived N (as indicated by nitrogen stable isotope values) in the muscle tissue of the juvenile fish at the treated site and the abundance of eggs and flesh in their stomachs clearly indicated that the material derived from the carcasses was responsible for the accelerated growth rate. The fish residing at the site to which carcasses had been added contained nearly 20 times the amount of material in their stomachs than did fish collected on the same date from an area without carcasses; 60% to 95% of it salmon eggs and flesh. Spawning salmon also have been shown to elevate growth rates of fish in Alaskan streams. In the Wood River watershed in southwest Alaska, char and trout grew very rapidly while carcasses of sockeye salmon *O. nerka* were present (Eastman 1996). The body weight of one tagged char increased 58% in 36 days.

Large numbers of Chinook salmon carcasses have been stocked into the Naches subbasin, but the effects of the program have not been evaluated. Chinook salmon carcasses were also added to select reaches in Manastash Creek, but again, this study has not been reported upon yet. Rainbow trout and Chinook salmon readily consumed carcass analog material in Yakima Basin tributaries (Pearsons et al. 2003), suggesting that fish would use carcass material if it were available.

The objective of this study was to determine if juvenile salmonids in the upper Yakima Basin were using food provided by salmon carcasses. This is of particular interest in the Yakima Basin because it has the potential to increase the numbers of carcasses through hatchery supplementation. The upper Yakima stock of spring Chinook salmon is being supplemented as part of the Yakima/Klickitat Fisheries Project. The first hatchery origin 3-year old fish returned in 2000 and the first 4 year olds returned in 2001. We evaluated the importance of salmon carcasses to salmonids in the Yakima Basin by 1) examining stomach contents of juveniles when carcass material was available, 2) evaluating stomach fullness during the summer growing period, and 3) comparing spring Chinook and rainbow trout growth and survival relative to the number of carcasses present one and two years prior.

Methods

Juvenile spring Chinook salmon and rainbow/steelhead trout (*O. mykiss*) were captured in areas and at times that spring Chinook salmon were spawning, or after spawning when carcasses were available. Fish were collected by angling, backpack electrofishing, and drift boat electrofishing (Temple and Pearsons 2007). Upon capture, stomach contents of Chinook salmon were evacuated using pulsed gastric lavage. Stomach samples were 1) preserved in alcohol and examined in the lab (1998-2003), 2) examined for carcass material or eggs in the field (2004-2006), or 3) examined in the field and the lab (2007). Length (FL mm) and weight (g) of each fish were measured. The areas that were sampled were between the town of Easton and Town Diversion Dam near Ellensburg. Sampling took place between mid September and the end of October.

During the summer, when carcass material was not available, we sampled fish stomachs to determine if the % fullness increased after previous years of high spawner abundances. The methods and results are presented in Chapter 1 of this report. Additionally, we compared the stomach fullness to the number of spawners one year prior using a Pearson product moment correlation statistic. Lastly, we compared the biomass of juvenile salmonids during the fall to the number of redds created 1 and 2 years prior. Biomass estimates were derived from work described by Pearsons et al. (2007).

To determine if salmon provide a net nutrient benefit to the Yakima Basin, we compared adult biomass of fish returning to the Yakima Basin to the biomass of smolts leaving the Yakima Basin. Adult and smolt information was collected at Prosser Dam by the Yakama Nation between 1983 and 2006. Biomass was calculated as the product of abundance and mean weight. The net biomass was calculated by subtracting smolt biomass from the adult biomass that produced the smolts (2 years prior).

Results

Spring Chinook and rainbow trout rarely contained flesh or eggs in their stomachs (Table 1). There was one egg that was observed in the lab that was not detected in the field during 2007, so the field observations conducted in 2004-2006 may have underestimated the presence of small amounts of material. Salmon and trout mainly fed on invertebrates. Furthermore, there was not a significant correlation between the number of salmon redds and the incidence of flesh and eggs in fish stomachs (Figure 1; $P>0.05$), or the stomach fullness during the summer and the number of redds one year prior (Figure 2 and 3; $P>0.05$). Finally, we did not detect a significant relationship between juvenile Chinook salmon or rainbow trout biomass and the number of redds counted one or two years prior to biomass estimates (Figure 4 and 5; $P>0.05$).

Adult spring Chinook salmon that return to the Yakima River provide a net increase in marine derived nutrients relative to the mass of spring Chinook salmon smolts that leave the Yakima Basin (Figure 6). This nutrient addition occurred every year of the evaluation, but the addition was variable among years. One of the sources of variation was the beginning of the supplementation program, which has increased the number of adults. Furthermore, this net addition of nutrients increased with increasing numbers of adults (Figure 7).

Table 1. The percent of spring Chinook salmon and rainbow trout stomachs that contained carcass material or eggs.

	Spring Chinook			Rainbow Trout		
Year	# Stomachs	Flesh (%)	Eggs (%)	# Stomachs	Flesh (%)	Eggs (%)
1998	131	0	0	112	0	0
1999	222	0	0	254	0	0
2000	232	0	0	263	1.9	1.1
2001	246	0.8	0	165	8.5	0.6
2002	283	0	0	183	0.5	0.5
2003	418	0	0	331	0	0
2004	35	0	2.9	47	0	0
2004^{f}	295	0	0	348	0	0
2005^{f}	62	0	0	65	4	0
2006^{f}	201	0.5	0.5	53	5.7	0
2007	558	0.5	0	104	0	0
Total/Mean	2683	0.2	0.3	1925	1.9	0.2

*^{f} are stomach samples, which were subject only to visual inspection for flesh or egg content in the field.

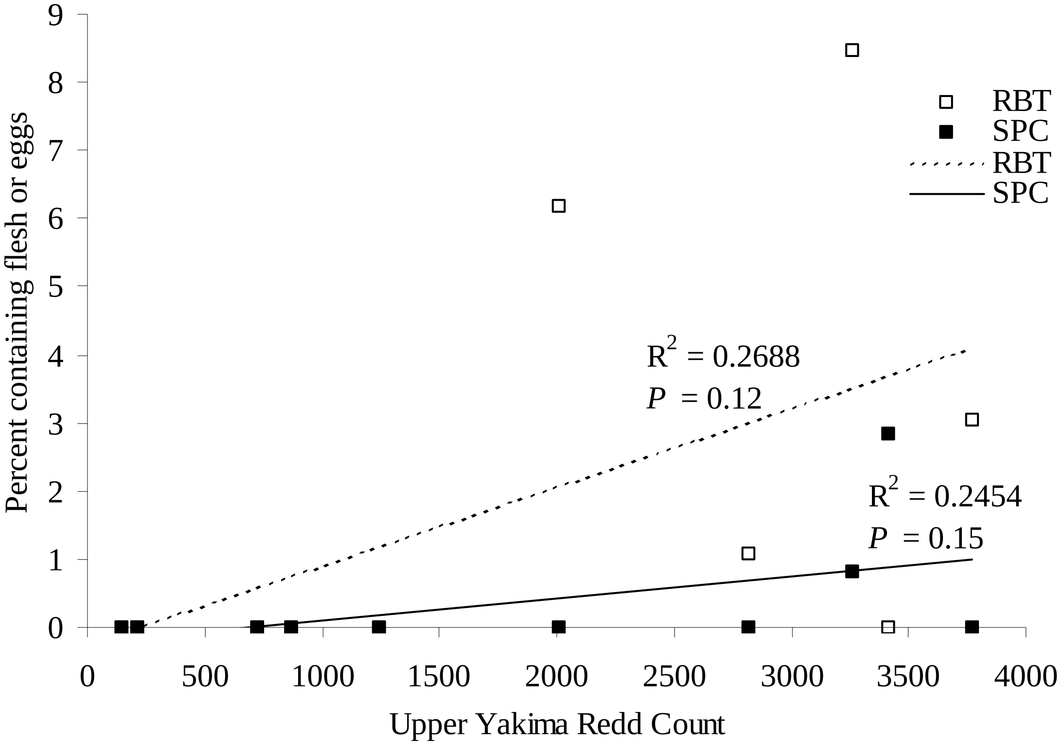

Figure 1. The relationship between the estimated number of redds and the percent of rainbow trout and spring Chinook salmon containing carcass flesh or eggs.

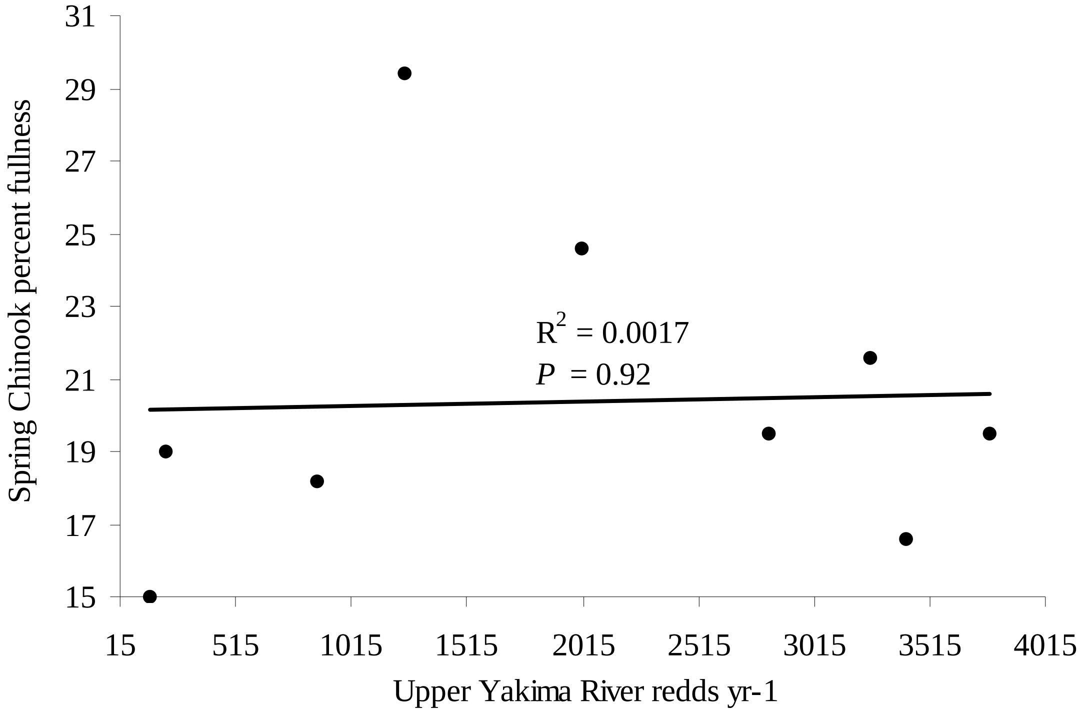

Figure 2. Spring Chinook percent fullness vs. upper Yakima spring Chinook redd counts the previous year.

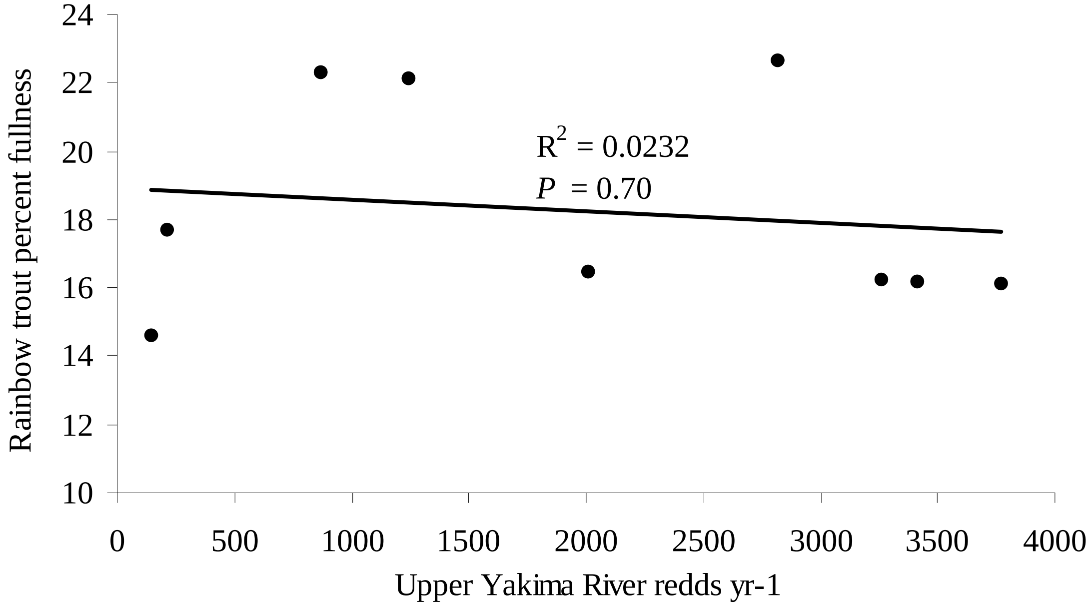

Figure 3. Rainbow trout percent fullness vs. upper Yakima spring Chinook redd counts the previous year.

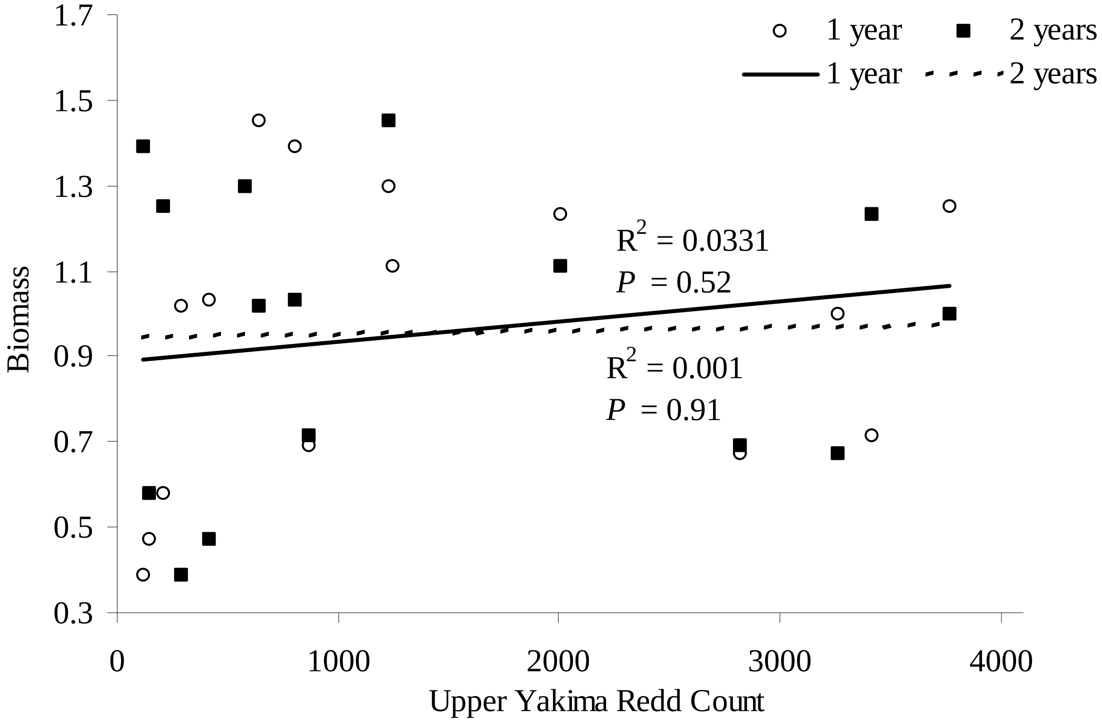

Figure 4. The relationship between upper Yakima River redd counts and the spring Chinook salmon biomass index (kg/km) delayed 1 or 2 years.

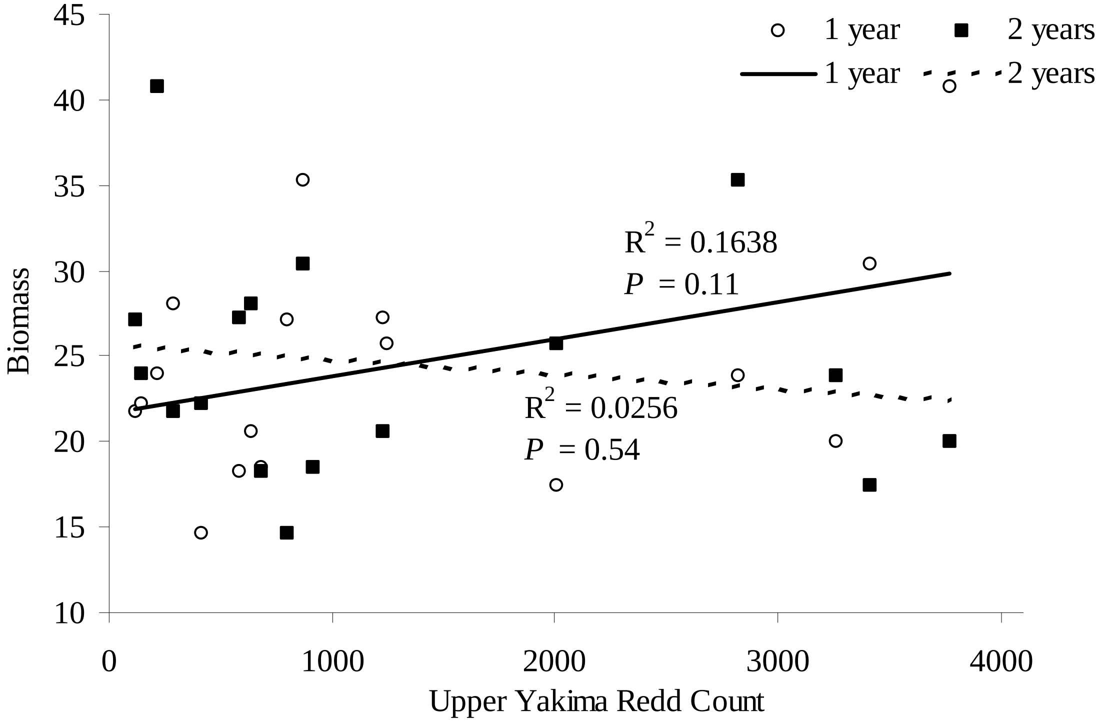

Figure 5. The relationship between upper Yakima River redd counts and the age 1 rainbow trout biomass index (kg/km) delayed 1 or 2 years.

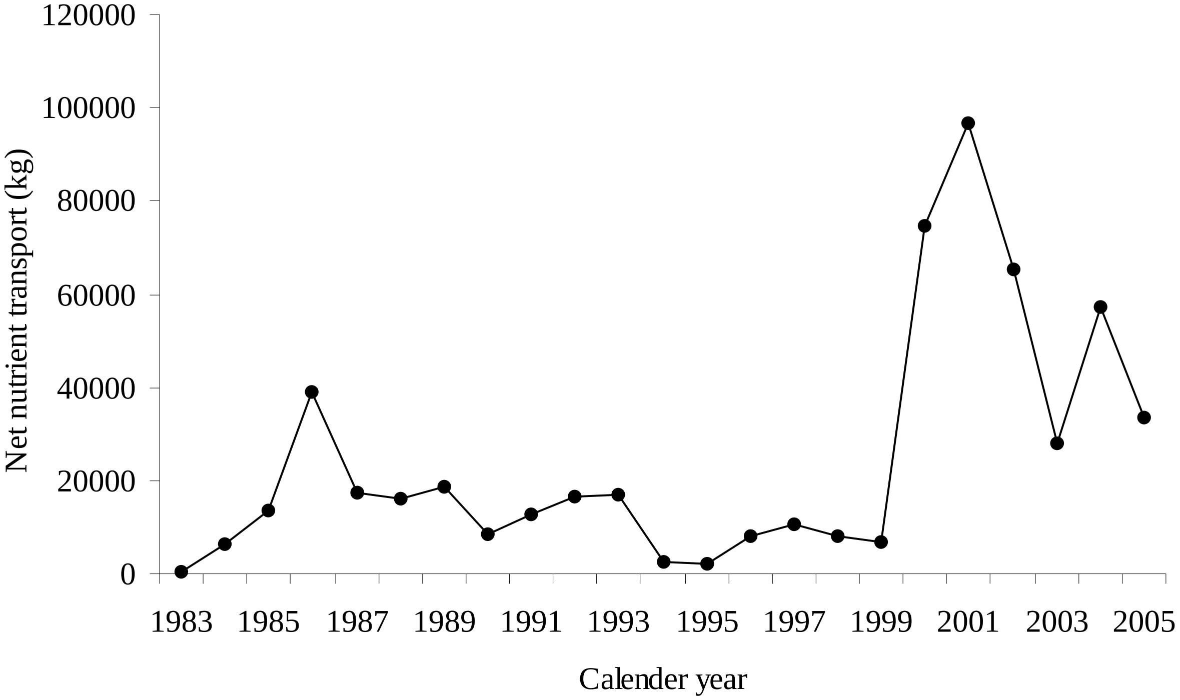

Figure 6. Net transport of nutrients from adult spring Chinook salmon (adult biomass – smolt biomass) into the Yakima River basin.

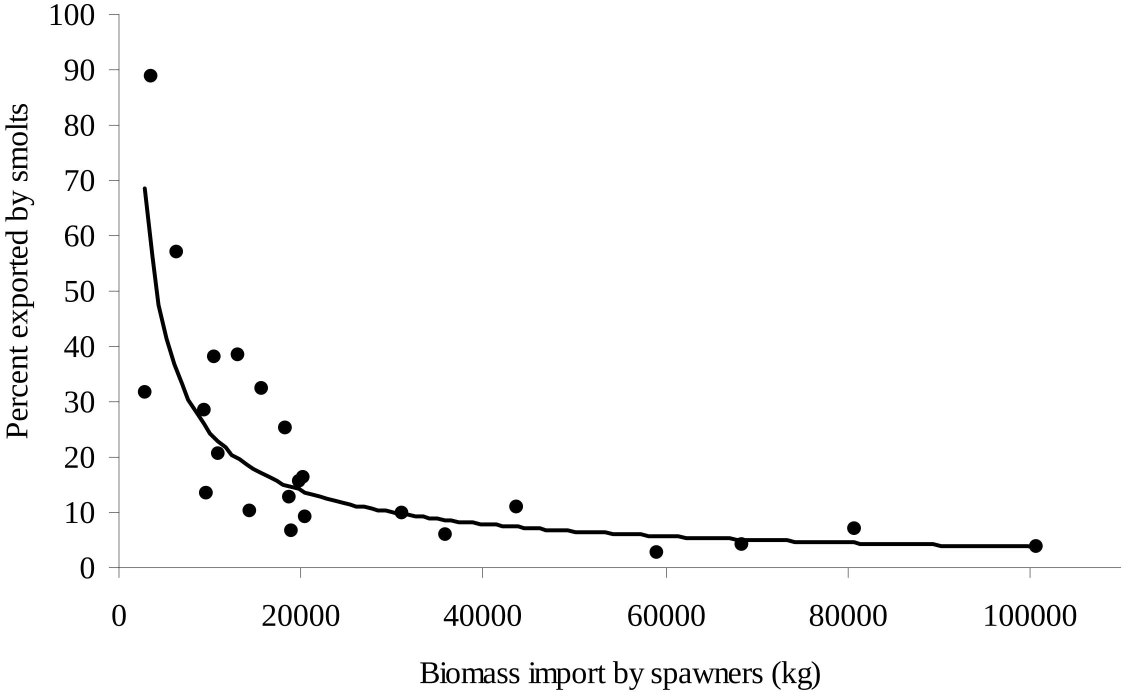

Figure 7. Percent of the spring Chinook salmon adult nutrients that are exported by smolts from the same brood year.

Discussion

We found little evidence to indicate that salmon carcass abundance across the range we encountered provided significant nutrient benefits to salmon or trout in the upper Yakima Basin. Although supplementation has increased the amount of nutrients available to juvenile salmonids, through an elevated adult recruitment rate, we were not able to detect measurable benefits to juvenile salmonids. One explanation for the lack of observed benefit may be that marine derived nutrients were not a factor limiting growth or survival. Alternatively, the number of carcasses may not be high enough to illicit a detectable response or that the environment is not able to retain the nutrients because of habitat simplification or water management. Finally, additional food production provided by salmon may not be biologically available to juvenile salmonids because of the unnaturally high flow regimes that occur during the summer (Chapter 6 of this report). However, preliminary results from a short-term study in the upper portions of Manastash Creek suggested that carcass additions did not increase trout growth or abundance (WDFW, unpublished data). We will continue to monitor the variables presented in this report to determine if cumulative benefits can be accrued from supplementing nutrients throughout the lifespan of a supplementation program (Pearsons 2002).

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Chapter 6

The influence of stream discharge and velocity on juvenile spring Chinook salmon habitat and food availability

Abstract

It has been hypothesized that water discharge in the upper Yakima River is managed in a way that influences the upper limit of juvenile spring Chinook salmon abundance. Our goals were to 1) evaluate the relationship between abundance of drifting invertebrates and water velocity during high flows in the summer, and 2) determine the maximum percentage of habitat that is habitable by juvenile Chinook salmon during abnormally high (summer) and more natural low flow (fall) periods. Three different relationships between flow and drifting invertebrate abundance were detected in the three transects that were measured in 2005. First, there was a positive relationship between flow and drifting invertebrate abundance in the Cle Elum Transect (P=0.01). Second, there was a negative relationship between flow and drifting invertebrate abundance in the Cle Elum River Transect (P=0.04). Third, there was not a significant relationship between flow and drifting invertebrate abundance in the Nelson Transect (P=0.13). In 2006, all of the transects were positively related to flow, but none were statistically significant (P>0.05) until all samples were pooled (P<0.05). Habitable area for juvenile spring Chinook salmon differed between the summer and fall in all sections, but those sections that had the largest relative difference in discharge during the summer (relative to the fall) had the largest difference in habitable area. Mean discharge averaged over 10 times higher in the Cle Elum and Cle Elum River sections during the summer than during the fall. The habitable area in these sections was over 100% higher in the fall than the summer, even though the wetted area and discharge were substantially higher during the summer. The mean percent of habitable locations was higher in the fall than the summer in the Cle Elum and Cle Elum River sections. Approximately 15% of transect locations were habitable in the summer and 90% in the fall in these sections. In short, higher discharges increased wetted area but decreased the percent of the locations that were habitable by over 5 times, resulting in over 100% less habitable areas at artificially high summer discharge than more normal fall discharge. In contrast to the two other sections, the habitable area in the Nelson section was higher during the summer than the fall. Discharge was less than 2 times higher during the summer than the fall in the Nelson section. The higher area caused by the slightly higher discharge resulted in higher habitable area because the percent of habitable area was similar between the summer and fall. With the exception of the summer of 2007, the percent of habitable locations in the Nelson transects was always above 75% during both seasons. The Nelson transect had a much higher percentage of habitable locations than the other two transects during the summer and varied the least between seasons. These data should be considered preliminary until published in a peer-reviewed journal.

Introduction

It has been hypothesized that water discharge in the upper Yakima River is managed in a way that influences the upper limit of juvenile spring Chinook abundance. Water is stored in three reservoirs, Keechelus, Kachess, and Cle Elum, and then most of the water is released during the summer to provide irrigation water far downstream. In essence, the upper Yakima River channel is used, among other things, as an irrigation canal to transport high volumes of water downstream. High summer flows are quite unlike natural runoff patterns that produce low flows in the summer (Figure 1).

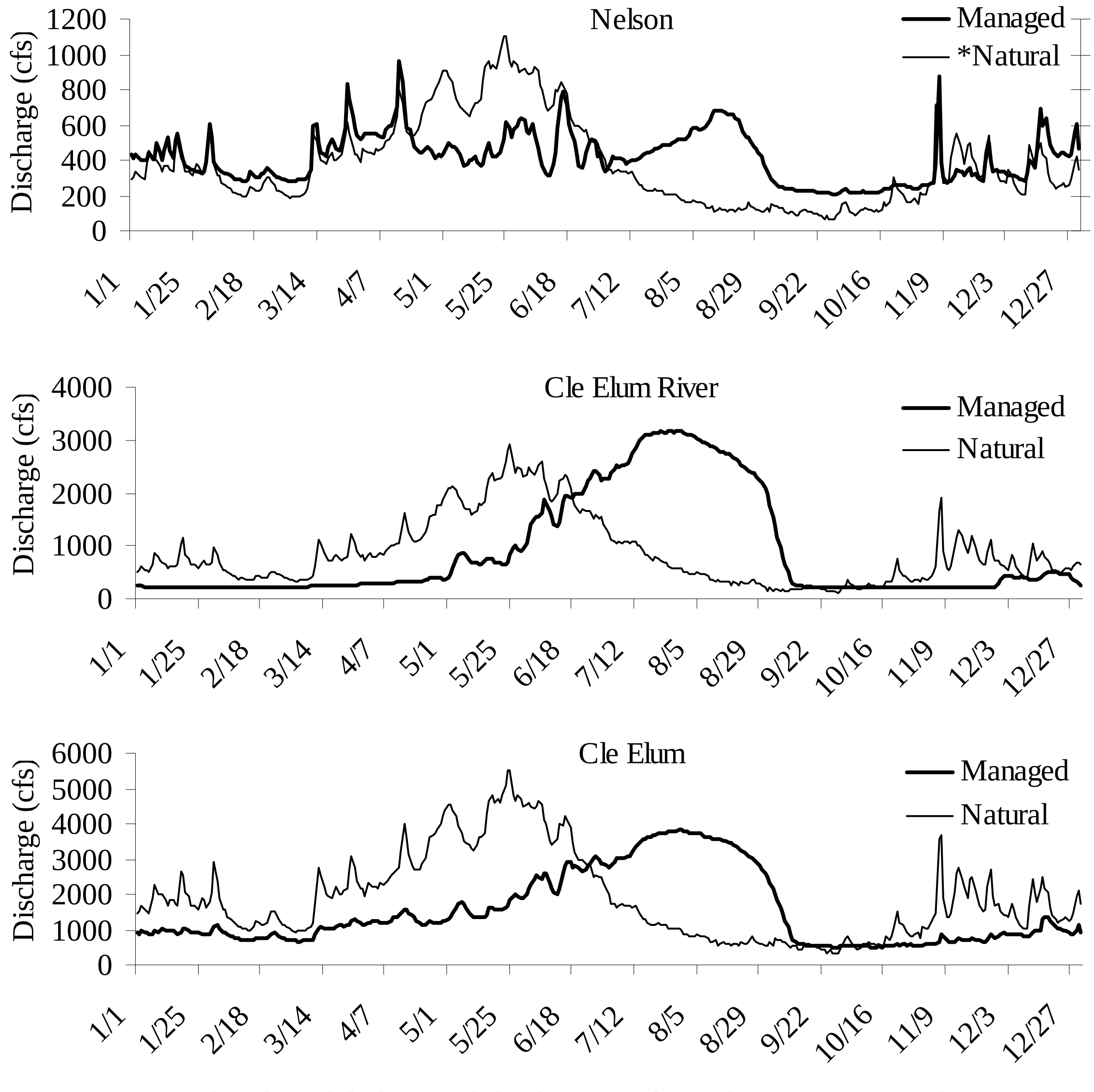

Figure 1. Managed and modeled natural discharge in the Yakima River at Nelson and Cle Elum, and in the Cle Elum River, 1998-2007. Modeled natural flows were not available for the Nelson section so scaled data from the modeled natural discharge of the Cle Elum section (secondary Y axis) are presented for comparison.

These unnatural flows are suspected to impact aquatic communities. For example, high flows may decrease the abundance of aquatic invertebrates by dislodging them from the stream bottom and scouring the stream bottom of periphyton. Furthermore, decreases in invertebrate abundance could decrease the abundance of fish that depend upon them for food, such as Chinook salmon. Juvenile Chinook salmon could also be precluded from using large areas of the river because water velocities are higher than what they could swim against. It is possible that food abundance for Chinook salmon is abundant in fast areas of the river that are uninhabitable by spring Chinook salmon. Thus, abundance of food might be high, but its availability to Chinook salmon may be low. Alternatively, high summer flows may increase the wetted area that is available to fish and contribute to increased abundance.

Our goals were to 1) evaluate the relationship between abundance of drifting invertebrates and water velocity during high flows in the summer, and 2) determine the maximum percentage of habitat that is habitable by juvenile Chinook salmon during high (summer) and low flow (fall) periods.

Methods

Drift net transects

We compared flow rate and drifting invertebrate dry weight by placing drift nets in a variety of different flows. Drift nets were placed along three transects perpendicular to flow in the Nelson and Cle Elum sections in the Yakima River, and the Cle Elum River section in the Cle Elum River during the summer, 2005-2006. Attempts were made to place the nets in similar environmental conditions except for flow. For example, we looked for locations that had uniform depths, substrate, and lack of overhead vegetation. Iron bar was pounded into the substrate and then nets were attached to the iron bar. Drift nets were set on August 10th, 11th, and 17th in the Cle Elum, Cle Elum River and Nelson river sections respectively during 2005 and on August 7th, 8th and 14th during 2006. Drift nets were 30 cm x 30 cm in dimension and had 500 micrometer mesh. Nets were operated for a span of four hours at times between 11:00 am to 5:30 pm. The middle of the net depth was at 60 percent of the water column (measured from the water surface) and velocity at that point, directly in front of the net, was measured using a flow meter. During 2006, two nets were also arranged at 60 and 80 percent of the water column to determine if drift abundance differed with water depth. At the end of the four-hour sampling period, net contents were removed and stored in alcohol until they could be processed in the lab. Lab processing included separating the fish food items from debris by soaking in sugar water and by removing invertebrates from their non-nutritional cases. Food items were placed in a drying oven for 48 hours and then weighed to the nearest 0.1 mg.

Depth and velocity transects

We endeavored to determine the percentage and amount of habitable area for juvenile spring Chinook salmon in three sections of the Upper Yakima River during two different flow regimes. Attempts were made to measure 15-30 transects in the Nelson, Cle Elum, and Cle Elum River sections during the summer and fall. These transects were set every 500 m and were perpendicular to the stream flow. Water depth, and velocity measurements at 0.6 and 0.8 of the depth from the water surface were made every half-meter, or every meter when water velocities were low. A location was classified as habitable if it had velocities that were less than or equal to the maximum focal point velocities that we have observed Chinook salmon using (Figure 2).

Measurements were not taken if velocities were greater than 1.0 m/s because they were deemed to be uninhabitable. Unfortunately, locations that were too deep to stand in were also not measured. This created the potential for bias, particularly during 2005, because some of the deep-water areas may have been habitable. Therefore, we eliminated transects that did not contain all the required measurements during 2005. Because of this, the data collected in 2005 is likely to be biased and should be interpreted with caution.

To reduce bias in 2006, we used streambed profiles from our fall transects, when water levels were low, to estimate the depths during the summer high flow period. We also used oranges in areas that we could not measure to assess areas that were above and below 1 m/s water velocity. Oranges were thrown into areas that could not be accessed, and the time for them to travel a measured distance (e.g., 10 m) was recorded. We estimated velocity as the travel distance of the orange divided by the time in seconds. We found that velocities measured using oranges were similar to that measured with the flow meter. Finally we drew maps to assist interpretation of the transect data.

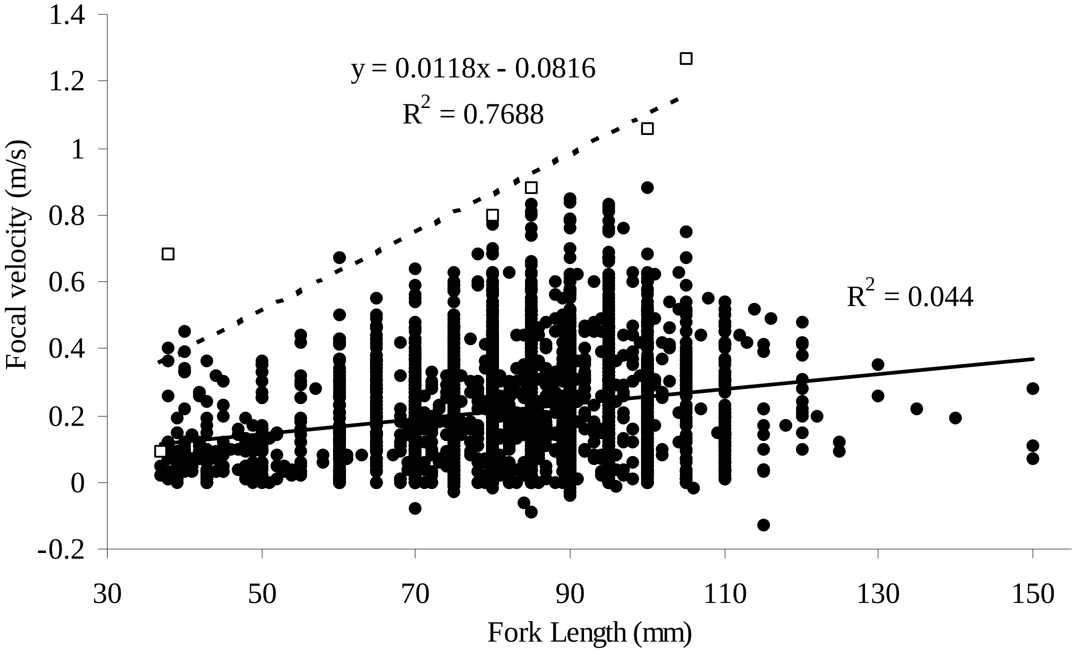

Figure 2. Maximum (dashed line) and mean velocities (m/s) (solid line) measured at age 0 spring Chinook focal positions by size (mm) 1998-2007.

Results

Drift net transects

Three different relationships between flow and drifting invertebrate abundance were detected in the three transects that were measured in 2005. First, there was a positive relationship between flow and drifting invertebrate abundance in the Cle Elum Transect (P=0.01, Figure 3). Second, there was a negative relationship between flow and drifting invertebrate abundance in the Cle Elum River Transect (P=0.04, Figure 3). Third, there was not a significant relationship between flow and drifting invertebrate abundance in the Nelson Transect (P=0.13, Figure 3). The ranges in velocities were highest in the Cle Elum transect, mainly due to the inclusion of slower water velocities. The slowest velocities in the other two transects were greater than 0.6 m/s.

During 2006, all of the relationships between flow and drifting invertebrate abundance were positive, although none were statistically significant (Figure 4). The lack of statistical significance is likely due to low statistical power resulting from low sample size. When we pooled all of the samples collected in 2006, a significant positive relationship was detected (Figure 5). It also appeared that the abundance of drift in our samples was higher in 2006 than 2005 (Figure 5). We did not detect a significant relationship between depth and drifting invertebrate abundance (Figure 6).

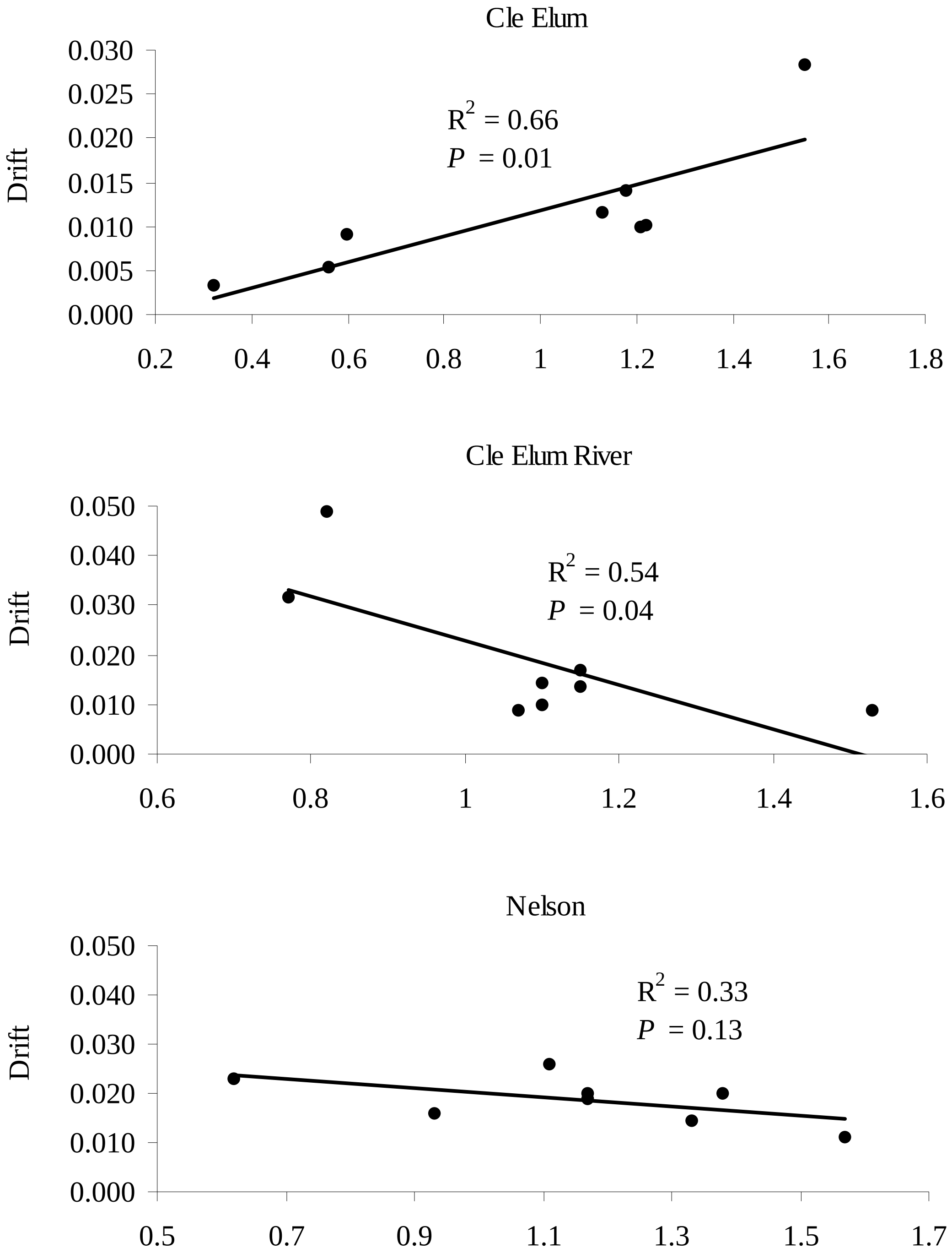

Figure 3. Relationship between flow velocity (m/s) and the rate of invertebrate drift (dry weight, g/hr) at main stem Yakima and Cle Elum River study sites during the summer, 2005.

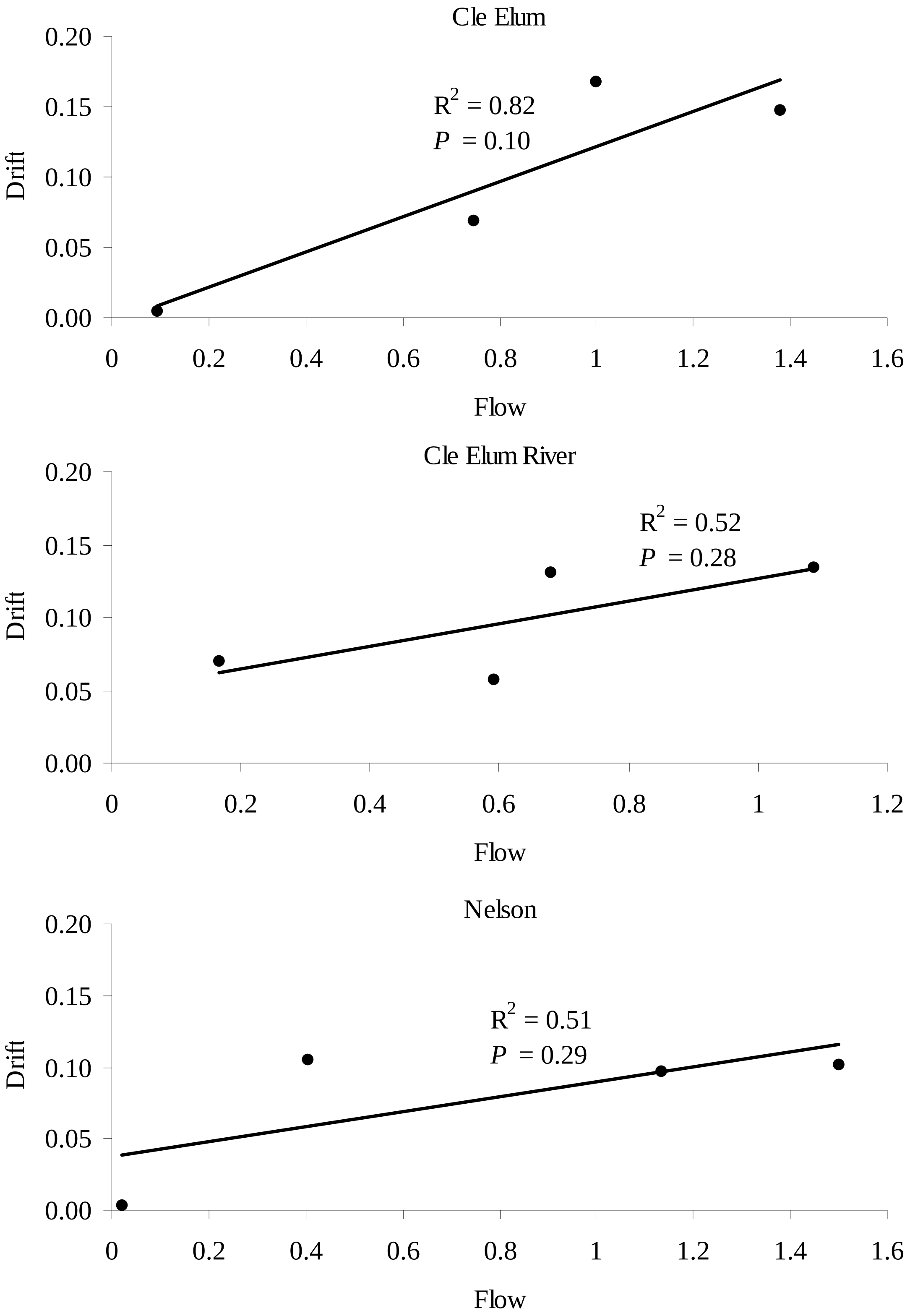

Figure 4. Relationship between flow velocity (m/s) and the rate of invertebrate drift (dry weight, g/hr) at main stem Yakima and Cle Elum River study sites during the summer, 2006.

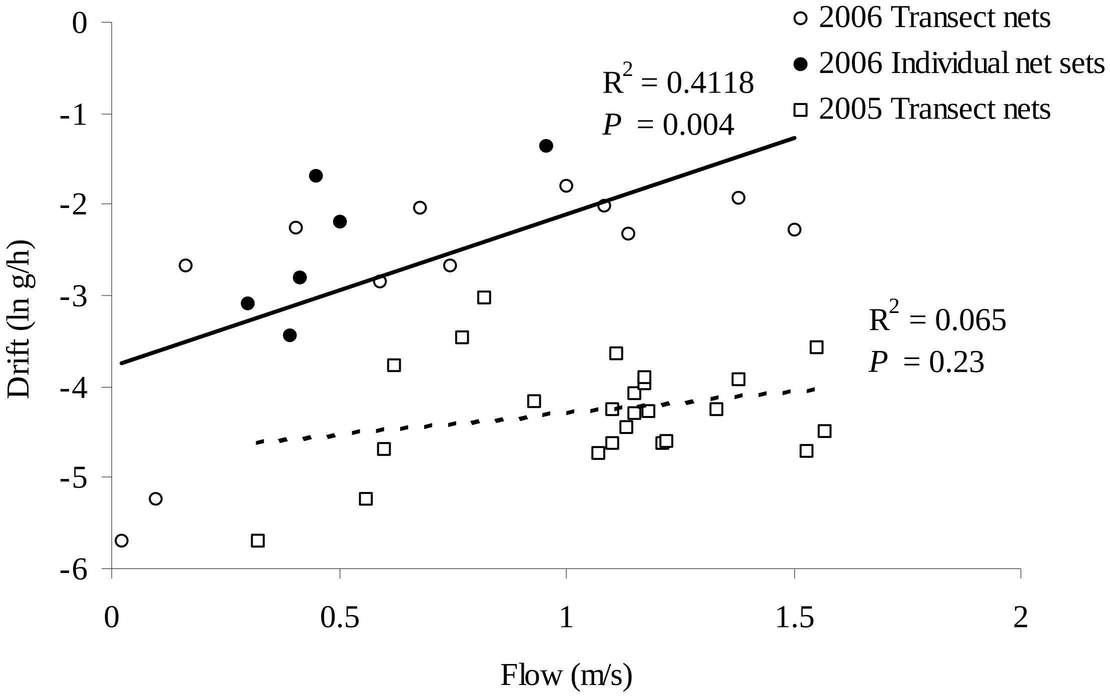

Figure 5. Relationship between flow velocity (m/s) and the rate of invertebrate drift (dry weight, g/hr) at main stem Yakima and Cle Elum River study sites during the summer, 2006 (solid line) and 2005 (dashed line).

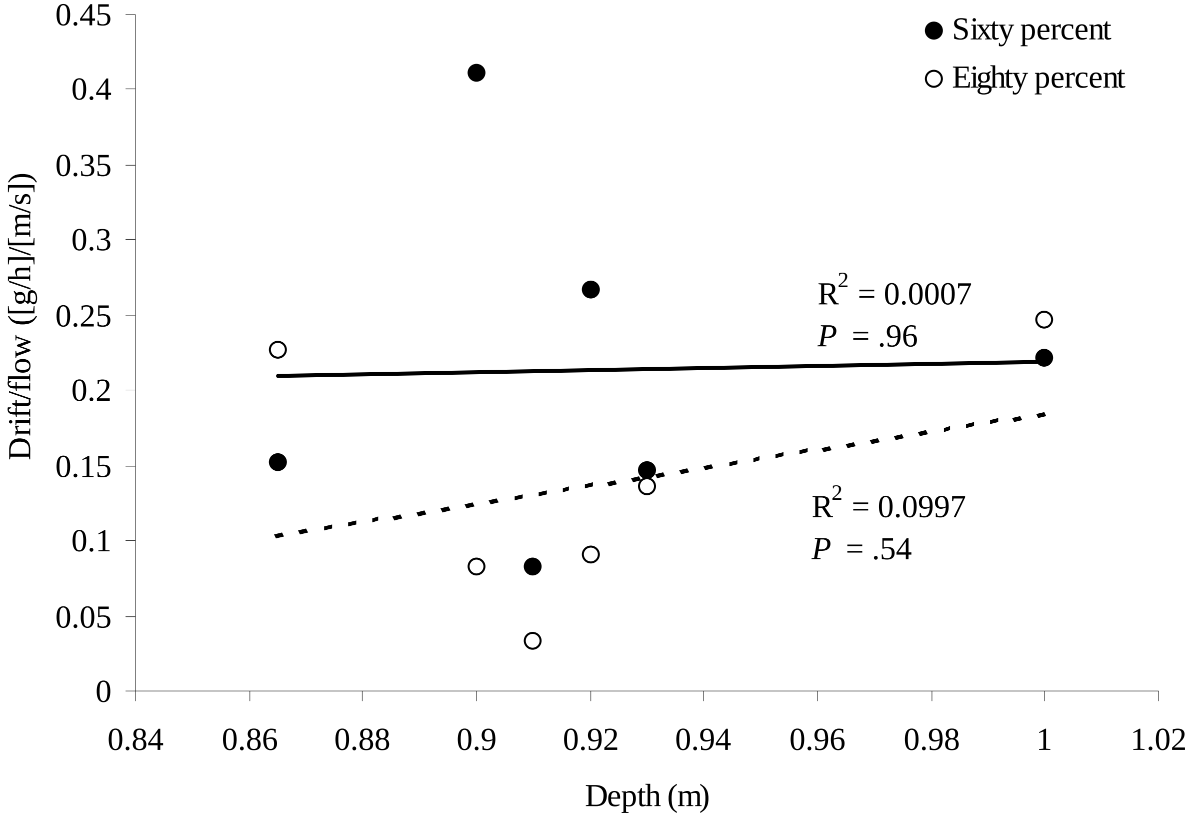

Figure 6. Relationship between invertebrate drift and total depth at 60 percent of the water column (dark line, measured from the water surface), and at 80 percent of the water column (dashed line) 2006.

Depth and velocity transects

Habitable area for juvenile spring Chinook salmon differed between the summer and fall in all sections, but those sections that had the largest relative difference in discharge during the summer (relative to the fall) had the largest difference in habitable area. Mean discharge averaged over 10 times higher in the Cle Elum and Cle Elum River sections during the summer than during the fall (Table 1; Figure 7). The habitable area in these sections was over 100% higher in the fall than the summer (Table 2; Figure 8), even though the wetted area and discharge were substantially higher during the summer. The mean percent of habitable locations was higher in the fall than the summer in the Cle Elum and Cle Elum River sections (Table 2; Figure 9). Approximately 15% of transect locations were habitable in the summer and 90% in the fall in these sections. The mean widths and depths of transects are presented in Table 3. In short, higher discharges increased wetted area but decreased the percent of the locations that were habitable by over 5 times, resulting in over 100% less habitable areas at artificially high summer discharge than more normal fall discharge.

In contrast to the two other sections, the habitable area in the Nelson section was higher during the summer than the fall (Table 2). Discharge was less than 2 times higher during the summer than the fall in the Nelson section (Table 1). The higher area caused by the slightly higher discharge resulted in higher habitable area because the percent of habitable area was similar between the summer and fall. With the exception of the summer of 2007, the percent of habitable locations in the Nelson transects was always above 75% during both seasons. The Nelson transect had a much higher percentage of habitable locations than the other two transects during the summer and varied the least between seasons.

Table 1. Yakima River temperature and discharge in the summer and fall, 2005-2007.

Site	Mean Temperature (C^o)	SD	Mean Discharge (m^3/s)	SD
		Summer 2005		
Cle Elum	15.9	0.6	89.9	1.4
Cle Elum River	14.9	0.4	79.1	0.5
Nelson	16.1	1.6	8.8	0.8
Mean	15.6	0.9	59.3	0.9
		Fall 2005		
Cle Elum	12	0.7	12.7	0.5
Cle Elum River	12	1.1	6.1	0.2
Nelson	11	0	5.2	0.02
Mean	11.6	0.6	8	0.2
		Summer 2006		
Cle Elum	14.0	0.7	109.5	0.3
Cle Elum River	16.4	0.5	91.4	0.6
Nelson	18.0	1.9	6.3	0.4
Mean	16.1	1.0	69.1	0.4
		Fall 2006		
Cle Elum	9.2	1.7	13.7	3.0
Cle Elum River	14.6	0.4	6.2	0.8
Nelson	13.8	0.2	5.9	0.4
Mean	12.5	0.8	8.6	1.4
		Summer 2007		
Cle Elum	15.7	1.1	113.1	0.6
Cle Elum River	13.9	0.4	98.6	0.7
Nelson	13.1	0.04	16.3	0.6
Mean	14.2	0.5	76.0	0.6
		Fall 2007		
Cle Elum	10.1	0.6	12.9	1.2
Cle Elum River	10.7	0.2	6.9	0.1
Nelson	10.9	0.2	5.9	0.3
Mean	10.6	0.3	8.6	0.5
		Mean Summer 2005-2007		
Cle Elum	15.2	1.0	104.2	12.5
Cle Elum River	15.1	1.3	89.7	9.9
Nelson	15.7	2.5	10.5	5.2
Mean	15.3	0.4	68.1	50.4

Mean Fall 2005-2007				
Cle Elum	10.4	1.4	13.1	0.5
Cle Elum River	12.4	2.0	6.4	0.4
Nelson	11.9	1.6	5.7	0.4
Mean	11.6	1.0	8.4	4.1

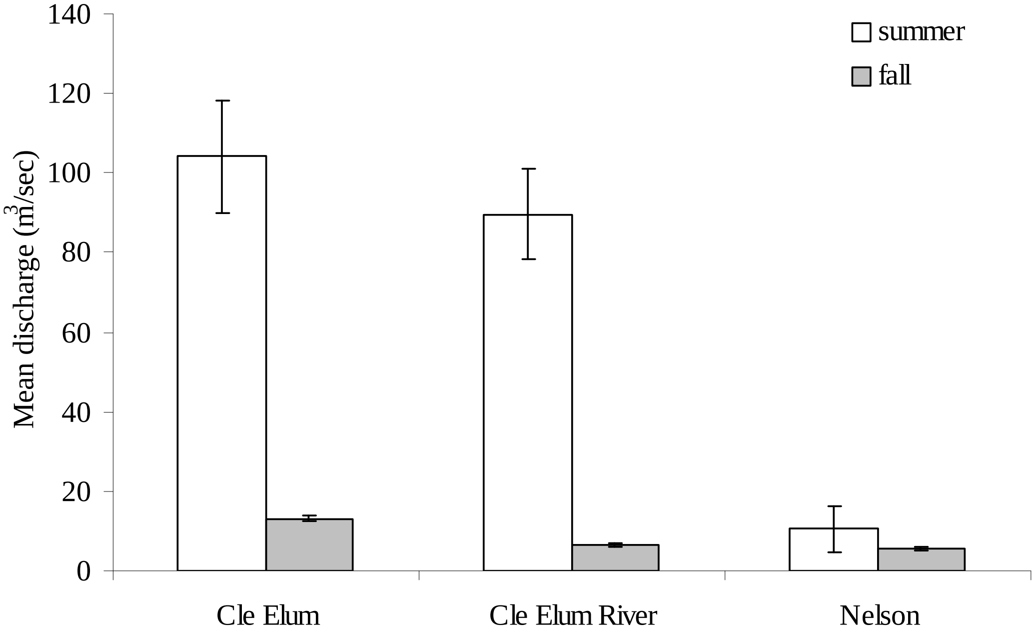

Figure 7. Mean discharges in upper Yakima and Cle Elum river study areas, summer and fall, 2005-2007

Table 2. Mean cross-sectional area, mean habitable area, and percentage of habitable velocities (< ~1 m/s), of measured transects during 2005, 2006 and 2007.

Site	n	Mean Area (m^2)	SD	Mean Habitable Area (m^2)	SD	Percent Habitable
			Summer 2005			
Cle Elum	9	31.8	9.8	8.0	5.0	25.1
Cle Elum River	13	22.8	8.5	3.3	2.6	14.3
Nelson	24	15.1	3.2	14.5	3.7	96.0
Mean		23.2	7.1	8.6	3.8	45.1
			Fall 2005			
Cle Elum	22	17.2	4.8	16.2	5.0	94.1
Cle Elum River	27	10.6	3.4	9.5	3.9	89.9
Nelson	25	11.2	2.9	10.8	3.3	95.9
Mean		13.0	3.7	12.2	4.1	93.3
			Summer 2006			
Cle Elum	11	54.4	11.3	6.9	6.5	12.7
Cle Elum River	15	41.3	10.2	6.5	5.9	15.8
Nelson	15	15.7	6.2	13.3	3.6	84.6
Mean		37.1	9.2	8.9	5.3	37.7
			Fall 2006			
Cle Elum	11	20.8	5	17.2	6.8	82.6
Cle Elum River	15	12.9	7.3	12.2	7.8	95.2
Nelson	15	13.5	6.4	10.4	3.5	77.1
Mean		15.7	6.2	13.3	6	85
			Summer 2007			
Cle Elum	15	53.5	15.3	6.6	6.0	12.4
Cle Elum River	15	45.0	8.8	4.7	6.2	10.4
Nelson	15	20.3	4.0	12.8	6.2	63.0
Mean		39.6	9.4	8.0	6.1	28.6
			Fall 2007			
Cle Elum	15	24.9	10.4	19.1	11.9	76.9
Cle Elum River	15	13.2	5.5	11.8	6.6	89.3
Nelson	15	15.6	5.6	14.7	5.9	94.3
Mean		17.9	7.1	15.2	8.1	86.8
			Mean Summer 2005-2007			
Cle Elum	3	46.6	12.8	7.2	0.7	16.7
Cle Elum River	3	36.4	11.9	4.8	1.6	13.5
Nelson	3	17.0	2.8	13.5	0.9	81.2
Mean		33.3	15.0	8.5	4.5	37.1
			Mean Fall 2005-2007			
Cle Elum	3	21.0	3.9	17.5	1.5	84.5

Cle Elum River	3	12.2	1.4	11.2	1.5	91.5
Nelson	3	13.4	2.2	12.0	2.4	89.1
Mean		15.5	4.7	13.5	3.4	88.4

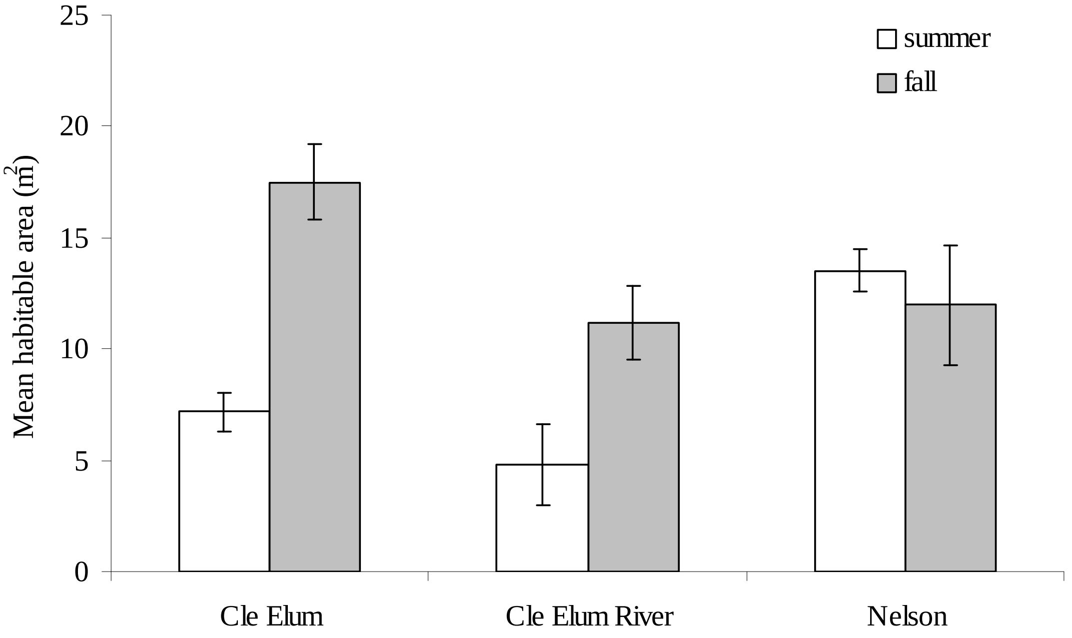

Figure 8. Mean habitable area in upper Yakima and Cle Elum river study sections, summer and fall, 2005-2007

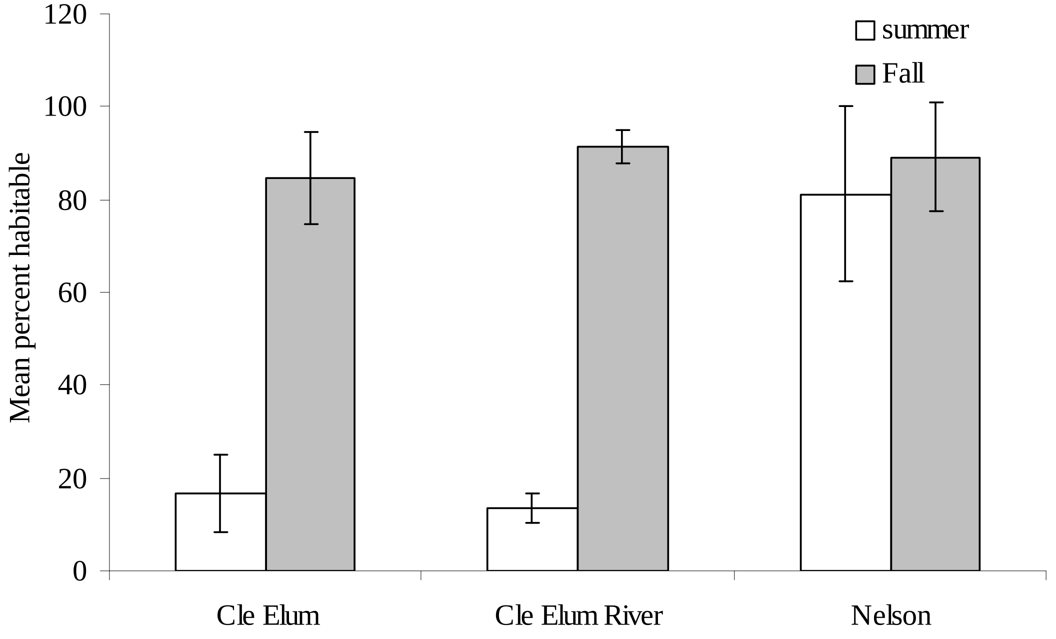

Figure 9. Mean percent habitable area of transects in the upper Yakima and Cle Elum river study sections, summer and fall, 2005-2007

Table 3. Summary of physical parameters measured along transects in the summer and fall of 2005-2007.

Site	n	Mean Width (m)	SD	Mean* Depth (m)	SD
		Summer 2005			
Cle Elum	9	35.2	32.7	0.4	0.2
Cle Elum River	13	37.5	16.2	0.4	0.2
Nelson	24	32.0	6.1	0.5	0.1
Mean		34.9	18.3	0.4	0.1
		Fall 2005			
Cle Elum	22	37.7	20.7	0.4	0.1
Cle Elum River	27	28.7	10.2	0.4	0.1
Nelson	25	29.1	6.7	0.4	0.1
Mean		31.8	12.5	0.4	0.1
		Summer 2006			
Cle Elum	11	50.6	16.5	0.8	0.3
Cle Elum River	15	52.8	19.0	0.8	0.2
Nelson	15	30.6	6.3	0.5	0.2
Mean		44.7	13.9	0.7	0.2
		Fall 2006			
Cle Elum	11	48.0	9.5	0.4	0.1
Cle Elum River	15	31.0	7.9	0.4	0.1
Nelson	15	28.9	7.1	0.5	0.2
Mean		36.0	8.2	0.4	0.2
		Summer 2007			
Cle Elum	15	63.3	16.2	0.8	0.1
Cle Elum River	15	53.2	10.6	0.9	0.2
Nelson	15	29.8	5.1	0.7	0.2
Mean		48.8	10.6	0.8	0.2
		Fall 2007			
Cle Elum	15	44.0	11.8	0.5	0.1
Cle Elum River	15	34.7	8.7	0.4	0.1
Nelson	15	29.7	6.4	0.5	0.2
Mean		36.2	9.0	0.4	0.1
		Mean Summer 2005-2007			
Cle Elum	3	49.7	14.1	0.7	0.2
Cle Elum River	3	47.8	9.0	0.7	0.3
Nelson	3	30.8	1.1	0.6	0.1
Mean	3	42.8	10.4	0.6	0.1
		Mean Fall 2005-2007			
Cle Elum	3	43.2	5.2	0.4	0.1

Cle Elum River	3	31.5	3.0	0.4	0
Nelson	3	29.2	0.4	0.5	0.1
Mean	3	34.6	7.5	0.4	0

Discussion

We had hypothesized that we would detect a positive relationship between water velocity and drifting invertebrate abundance at all of the transects we measured. If, invertebrate abundance was equally distributed across transects, then our hypothesis would be correct because drift abundance would be directly proportional to water velocity. However, if the benthic invertebrate abundance or drifting frequency varies with water velocity then it is possible to get the results that we did. It is possible that high velocities could decrease the abundance of benthic invertebrates by dislodging them or decreasing the amount of periphyton (e.g., invertebrate food) that could grow. In addition, areas of high flows may preclude invertebrates from living near the surface of the stream bottom (e.g., they may live far below the surface) and effectively decrease their abundance in the drift. Other studies have detected increases in drifting invertebrates with increasing velocities (Steingrimsson and Grant 1999).

Another possible explanation is that the higher velocity areas are also deeper which could result in greater dilution of the prey abundance. Although low density (e.g. highly diluted) is not beneficial to fish, it could explain why lack of positive relationships were observed in the two transects during 2005. The dilution factor did not explain the results that we observed in 2005, which isn't surprising because the depths at which nets were placed were similar (WDFW unpublished data). The lowest velocities in which nets were set was 0.3 m/s in 2005. It is possible that an increase in abundance of prey occurred at low flow velocities. We suspect that our results may also be influenced by transect placement. At least one of the transects was placed in an area that did not have perennial flow.

Our results in 2006 were consistent with our original hypothesis of higher food abundance with higher water velocity. In part, this was due to improved methods (driftnet sets included water velocities less than 0.6 m/s including 0 m/s). We were surprised that the pooled data was also consistent with the hypothetical relationship. We had expected that the high variation among transects would have swamped any pattern. Our 2006 data also suggests that dilution was not a strong factor influencing our transect results.

Our data indicate that food is prevalent in areas that are not habitable by juvenile Chinook salmon. Drift abundance was relatively high in areas that exceeded 1 m/s, but velocities above 1 m/s are uninhabitable by juvenile Chinook salmon during the summer (Chapter 2). Furthermore, less than 25% of wetted areas in the Cle Elum River and Cle Elum sections are habitable for juvenile Chinook salmon in the summer. In short, we speculate that the majority of food produced in the Yakima River main stem is unlikely to be available to juvenile Chinook salmon during the summer. This finding was unlikely to be true prior to flow management because prior to flow management most of the wetted area of the channel was habitable (e.g., > 80%) by juvenile Chinook salmon.

The cross-sectional stream area and the percentage of habitable transect locations were related to the magnitude of water discharges between years. The Nelson section had the lowest and least seasonally variable discharge. In contrast, the other two transects experienced high and seasonally variable discharges. There were at least two factors that could have contributed to increased percent habitability in the fall. One obvious factor was the decrease in discharge and the other factor was the increase in fish size. The upper limit of velocities that we used during the two seasons was based on the upper limits, for a given length of fish, that we have observed in the river. The differences in the velocity maxima were not very large between the summer and fall. Thus, it is unlikely that fish size was a strong factor contributing towards increased habitability in the fall. It is much more likely that the increased habitability was the result of decreasing flow in the Cle Elum and Cle Elum River sections. The discharge in the river is dramatically reduced in the fall to facilitate Chinook salmon spawning in areas that will stay wetted throughout egg incubation. Maximum habitable area could have increased with higher discharges if higher stream widths and depths could compensate for the low percentage of transects that were habitable. However, increases in widths and depths were not large enough to offset the low percentage of transects that were habitable in the Cle Elum and Cle Elum River sections. In contrast the smaller increase in summer flow in the Nelson section appeared to contribute to increased habitable area.

If habitable space limits the capacity of rearing spring Chinook salmon, then it is possible that current water management strategies during the summer could decrease abundance significantly in the Cle Elum River and below the Cle Elum River confluence. Habitable area during the fall is approximately 100% higher than the area in the summer. This difference is largely the result of unnaturally high flows during the summer. The discharges during the fall are similar to flows that would normally occur during the month of August (Figure 1). If habitable space limits the carrying capacity during August, then any fish in excess of current carrying capacity will die or emigrate. If this is true, then during high years of adult abundance (e.g., brood years 2000 and 2001), the majority of juvenile fish will die or emigrate because of the abnormally high flow regime. During years that double the number of adults spawn than can fully seed the current capacity of the environment, approximately half of the juvenile fish will die or emigrate because of the altered flow regime. Decreases in abundance would likely be due to mortality as opposed to displacement into suboptimal habitat or downstream locations. This speculation is supported by capacity relationships that are estimated after the summer high flows (Pearsons and Temple 2008) and by a correlation between our fall parr capacity estimates and smolts estimated at Chandler. Furthermore, we did not detect relationships between microhabitat used by juvenile Chinook and spawner abundance (Chapter 2).

In contrast, the altered flow regime in the Nelson section may slightly increase the habitable area. It is noteworthy that the Nelson section contains some of the highest spawning densities in the upper Yakima River. This may be related to larger amounts of rearing area for parr in the summer that contribute to higher survival and ultimately adult returns. It appears that the amount of rearing area is strongly related to stream discharge. However, it is also possible that the Nelson section is more favorable than other sections to other life-stages of salmon such as during adult holding.

We speculate that the limiting factors for juvenile spring Chinook salmon in the upper Yakima Basin may differ depending upon past habitat alteration and present flow management. The Cle Elum River and Cle Elum sections may currently be limited by the area of habitat that has flow that is < 1 m/s and perhaps the amount of bank habitat. In contrast, the Nelson section does not appear to be flow limited, but may be limited by the amount of bank habitat. The Nelson section has been channelized and few side channels remain. We have found that approximately 80% of juvenile Chinook salmon are within 5 m of a bank. This suggests that stream channels that are greater than 10 m wide (2 x 5 m) are relatively inefficient at producing rearing habitat for juvenile Chinook salmon. Prior to habitat channelization, the average channel width may have been substantially narrower than it is now because the flow would have been dispersed through multiple channels. The potential benefits of alternate habitat enhancement efforts could be modeled using the abundance of spawners and the potential benefits of adding bank habitat or flow reduction.

We urged caution in the using the data that we present on the habitat transects because they could be biased, particularly during 2005. Transects that were very deep were not measured across the whole transect and therefore could not be used in the analysis. This rarely occurred in 2006 and 2007. Since the results were similar between 2005, 2006, and 2007, it is unlikely that the bias was strong.

Summary

Most of the food and space for juvenile Chinook salmon in the Cle Elum and Cle Elum River sections during the summer is unavailable to them because of artificially high flows. Drifting food abundance generally increases with increasing flows, such that food abundance above 1 m/s is higher that that below 1 m/s. Artificially high summer discharges cause most areas to be above 1 m/s and juvenile Chinook salmon cannot live in velocities above 1 m/s. Thus although food abundance and space may be plentiful, it is not available to juvenile Chinook. In contrast, modest artificial increase of flow in the Nelson section has increased space, and potentially food, available to juvenile Chinook salmon. This suggests that less drastic changes to the natural hydrograph could substantially increase food and space available to Chinook salmon in the Cle Elum and Cle Elum River sections and thereby increase the carrying capacity of the river for this species. Increasing the carrying capacity of the river will increase the scope for increasing natural production associated with hatchery supplementation.

References

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