

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 2006 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 2006 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, 1998-2006 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, redbreast 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 a leveling off of the 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. 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. We evaluated the incidence of predation of residualized hatchery spring Chinook salmon on natural origin *Oncorhynchus mykiss* and Chinook salmon in the Yakima River Basin. Residual spring Chinook were sampled between July and September 1999 to 2004, and between April and September 2005 to 2006. 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 residuals 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 residual 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 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 1999-2006 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. However, 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. 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 was over 8 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 approximately 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 20% of transect locations were habitable in the summer and 90% in the fall in these sections. 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 30% 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. The percent of habitable locations 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. We urge caution in the using the data that we present on the habitat

transects because they are likely to be biased. Transects that were very deep were not measured across the whole transect during 2005 and therefore could not be used in the analysis. These data should be considered preliminary until published in a peer-reviewed journal.

Table of Contents

Executive Summary	i
Table of Contents	iv
General Introduction	1
Chapter 1 Indices of competition strength among stream fish: examples from the Yakima Basin	4
Chapter 2 The Use of Microhabitat Utilization of Spring Chinook Salmon as an Indicator of Density Dependence	30
Chapter 3 Influence of Chinook Salmon Growth Modulation in a Supplementation Hatchery Program to Reduce Composition of Precociously Mature Males in the Yakima River.....	50
Chapter 4 Incidence of Predation by Hatchery Spring Chinook Salmon on Natural Origin <i>Oncorhynchus mykiss</i> and Chinook Salmon.....	83
Chapter 5 Do juvenile salmonids benefit from supplemental Chinook salmon carcasses provided by hatchery supplementation?	89
Chapter 6 The influence of stream discharge and velocity on juvenile spring Chinook salmon habitat and food availability	98

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). 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, 2006 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). 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.

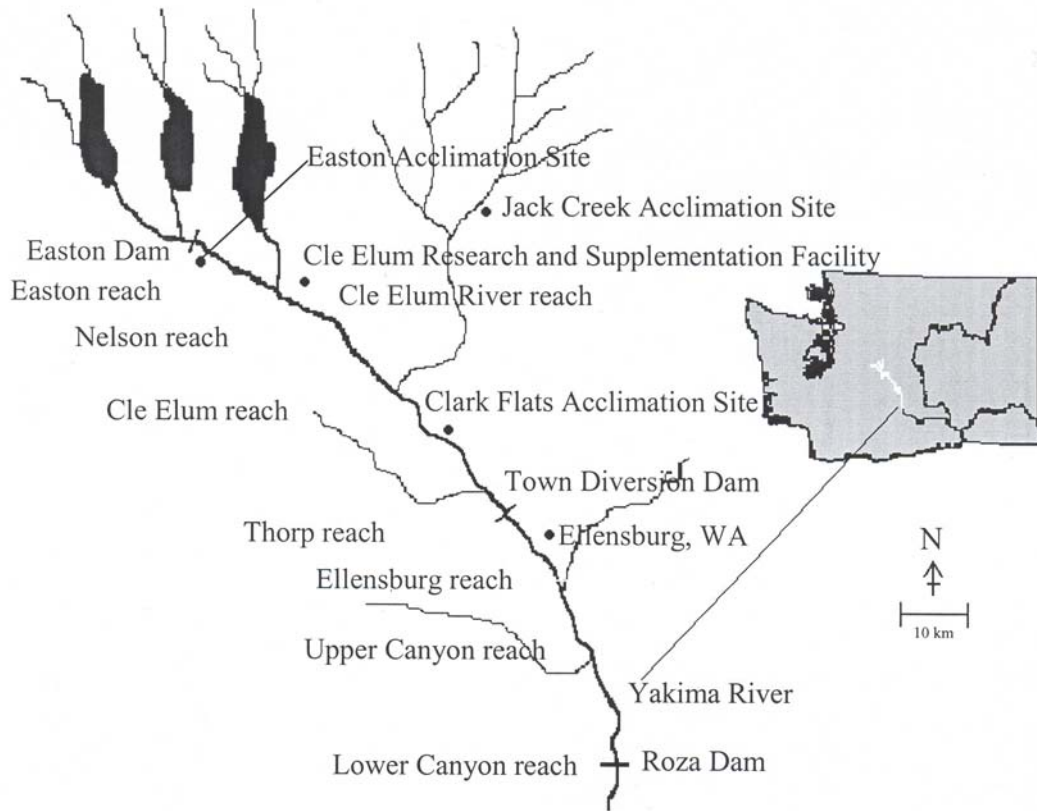


Figure 1. Locations of the study sections in the upper Yakima Basin, Washington

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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, 1998-2006 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, redbside 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)

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*), redbase 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°C (Reeves et al. 1987). Spring Chinook salmon parr in the upper Yakima River are frequently observed in close association with redbase 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).

$$\text{Space Competition Index} = (\text{Spatial overlap index}) \times (\text{Sympatric abundance index}) \quad (1)$$

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 substantial 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 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° 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 watershed (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 the 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).

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

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

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

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.

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

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 1). 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.

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

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).

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

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.

$$(\text{number of species } z \text{ observed}) \times (\text{space competition index}) \quad (7)$$

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 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:

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

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 because a relationship for Chinook salmon is 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.

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

Gastric evacuation rates were determined using daily mean temperature (T , °C) and mean monthly stomach wet weight (MS, in grams). We converted stomach content dry weights to wet weights using a linear regression model of samples 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., do to 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 80⁰ 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	Order	Family	Genus
Arachnid			Ephemeroptera	Ameletidae	
Cladocera				Baetidae	Acentrella
Coleoptera					Acerpenna
Diptera	Athericidae				Baetis
	Brachyiceridae				Callibaetis
	Ceratopogonidae				Dipheter
	Chaoboridae				Fallceon
	Chironomidae				Heterocloeon
		Acricotopus			Labiobaetis
		Brillia			Paracloeodes
		Bryophaenocladus			Procloeon
		Cardiocladus			Unk
		Chaetocladus			
		Chironominae		Ephemerellidae	
		Chironomus		Ephemeridae	
		Cladopelma		Heptageniidae	
		Cricotopus		Leptophlebiidae	
		Cricotopus/Orthocladus		Siphonuridae	
		Cricotopus/Paratrachocladus		Tricorythidae	
		Diamesa		Unk	
		Endochironomus	Hemiptera	Aphididae	
		Epoicocladus		Other	
		Eukiefferiella	Hymenoptera		
		Goeldichironomus		Andrenidae	
		Guttipeloplia		Apidae	
		Halocladus		Braconidae	
		Heleniella		Cephalidae	
		Heterotrissocladus		Ceraphronidae	
		Hydrobaenus		Chalcididae	
		Krenosmittia		Cynipidae	
		Limnophyes		Diapriidae	
		Metriocnemus		Encyrtidae	
		Microchironomus		Eulophidae	
		Microspectra		Eupelmidae	
		Monodiamesia		Figitidae	
		Nanocladus		Formicidae	
		Orthocladus		Heloridae	
		Pagastia		Ichneumidae	
		Paracladopelma		Parasitic Wasps	
		Paracricotopus		Platygasteridae	
		Parakiefferiella		Pompilidae	
		Parametriocnemus		Proctotrupidae	
		Paratanytarsus		Pteromalidae	
		Parochlus		Sphecidae	
		Parorthocladus		Unk	
		Phaenopsectra	Lepidoptera		
		Podonomini	Plecoptera	Capniidae	
		Polypedilum		Chloroperlidae	
		Pothastia		Leuctridae	
		Procladius		Nemouridae	
		Pseudochironomus		Perlodidae	
		Pseudokiefferiella		Pteronarcidae	
		Pseudorthocladus		Unknown	
		Pseudosmittia	Trichoptera	Brachycentridae	
		Rheopelopia		Glossosomatidae	
		Rheotanytarsus		Helicopsychidae	
		Smittia		Hydropsychidae	
		Stempellinella			Ceratopsyche
		Stictochironomus			Cheumatopsyche
		Synorthocladus			Hydropsyche
		Tanypodinae			Unk
		Thienemanniella			
		Tokunagaia		Hydroptilidae	
		Tvetenia		Lepidostomatidae	
		Zavrelia		Leptoceridae	
		Unknown		Limnephilidae	
	Culicidae			Philopotamidae	
	Deuterophlebiidae			Phryganeidae	
	Dixidae			Polycentropodidae	
	Dolichopodidae			Psychomyiidae	
	Empididae			Rhyacophilidae	
	Ephydriidae			Sericostomatidae	
	Muscidae			Uenoidae	
	Pelecorhynchidae			Unk	
	Phoridae		Terrestrial		
	Psychodidae		fish		
	Sciomyzidae		eggs		
	Simuliidae		Other		
	Syrphidae				
	Tabanidae				
	Thaumaleidae				
	Tipulidae				
	Unk				

Stomach content removal methods for rainbow trout were identical to those used for spring Chinook salmon, however, mountain whitefish and redbreasted 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, redbreasted 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 redbreasted 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

Average 1999-2006

Species	Spatial overlap	Competitor abundance	Space comp.	Stdev
SPC	0.55	4.49	2.67	0.98
HSPC	0.02	0.15	0.01	0.04
RBT	0.20	0.45	0.12	0.13
MWF	0.05	0.33	0.03	0.04
RSS	0.05	1.16	0.07	0.11
SUK	3.19E-03	0.03	4.54E-05	1.01E-04
COHO	0.01	0.01	1.32E-04	2.58E-04

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

*1998 space competition index calculations lack samples from within the Thorp index section.

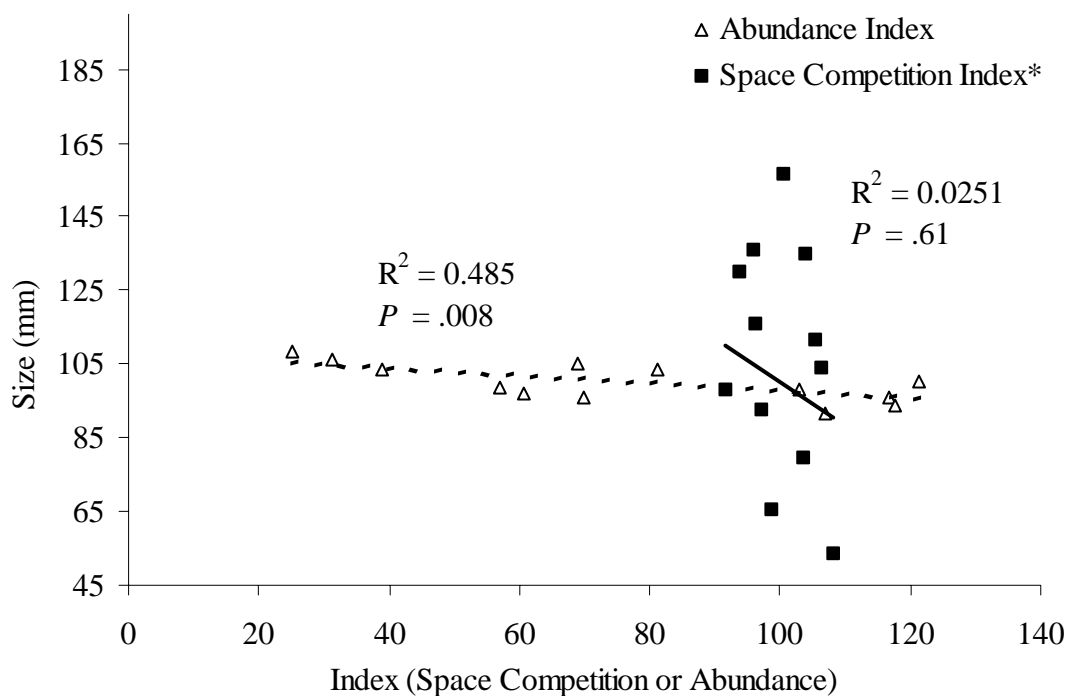


Figure 1. Age 0 spring Chinook salmon growth (fork length in millimeters) in relation to spring Chinook salmon abundance (dashed line) and the space competition index (solid line), 1994-2006.

* SCI multiplied by a constant for scaling purposes

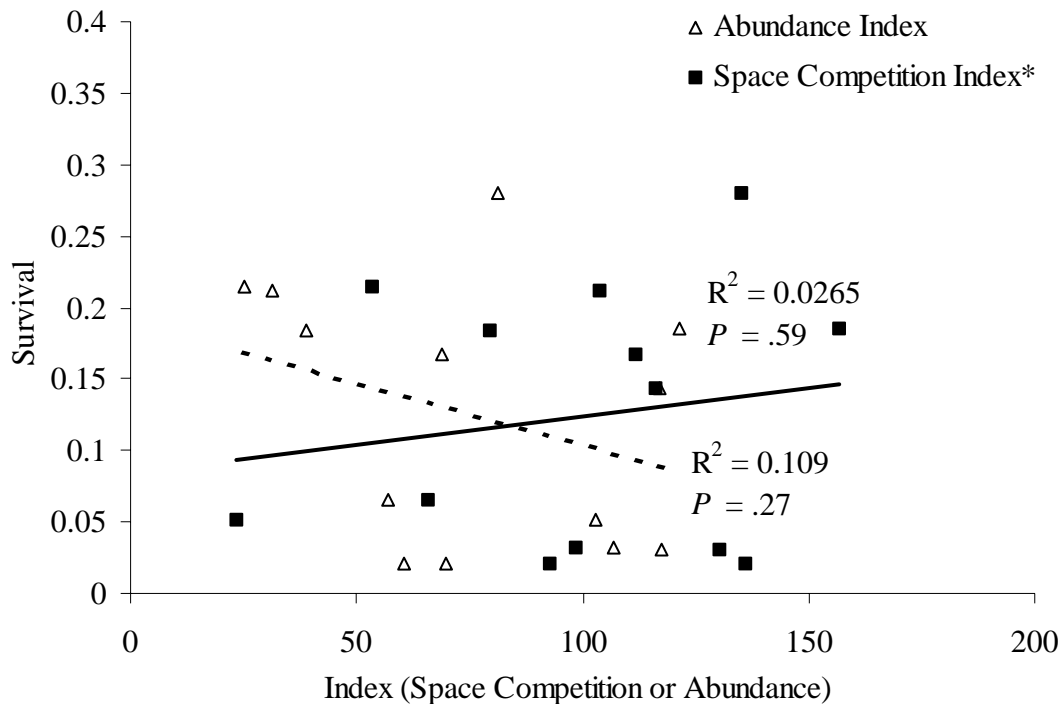


Figure 2. Age 0 spring Chinook salmon survival index in relation to Spring Chinook salmon abundance (dashed line) and the space competition index (solid line), 1994-2006.

* SCI 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 4196 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 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 this finding was reversed (Figures 6 and 7). The food competition index in 2006 was the highest that we have observed (Table 5). The relationships between the intraspecific index, and growth and survival of Chinook salmon were statistically significant ($P < 0.05$).

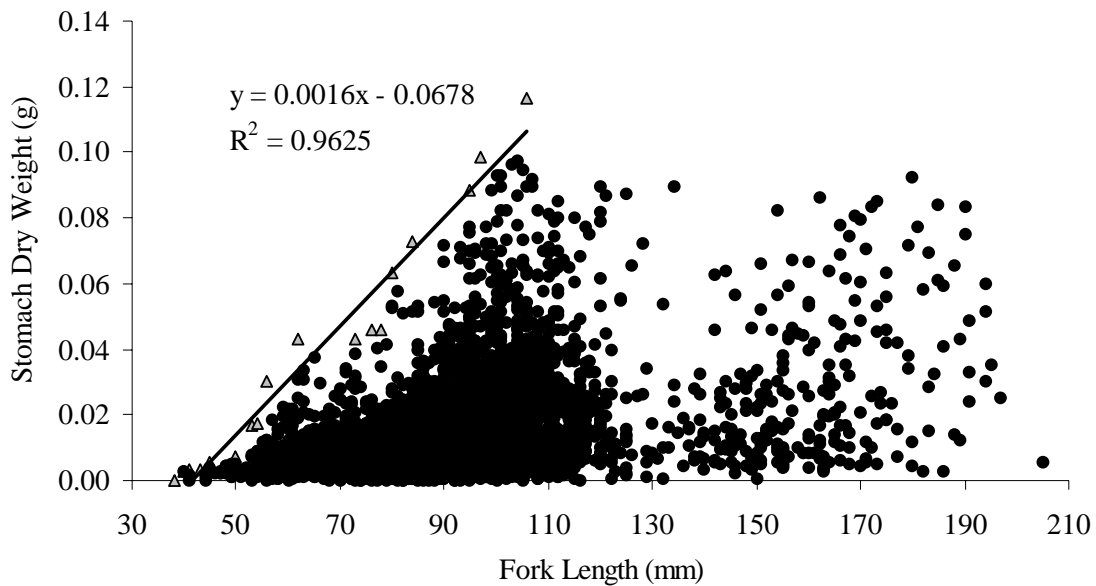


Figure 3. Dry weights of spring Chinook salmon stomach contents plotted against spring Chinook salmon fork length. The triangular points are the maximum weights that were used to fit the maximum stomach fullness regression line.

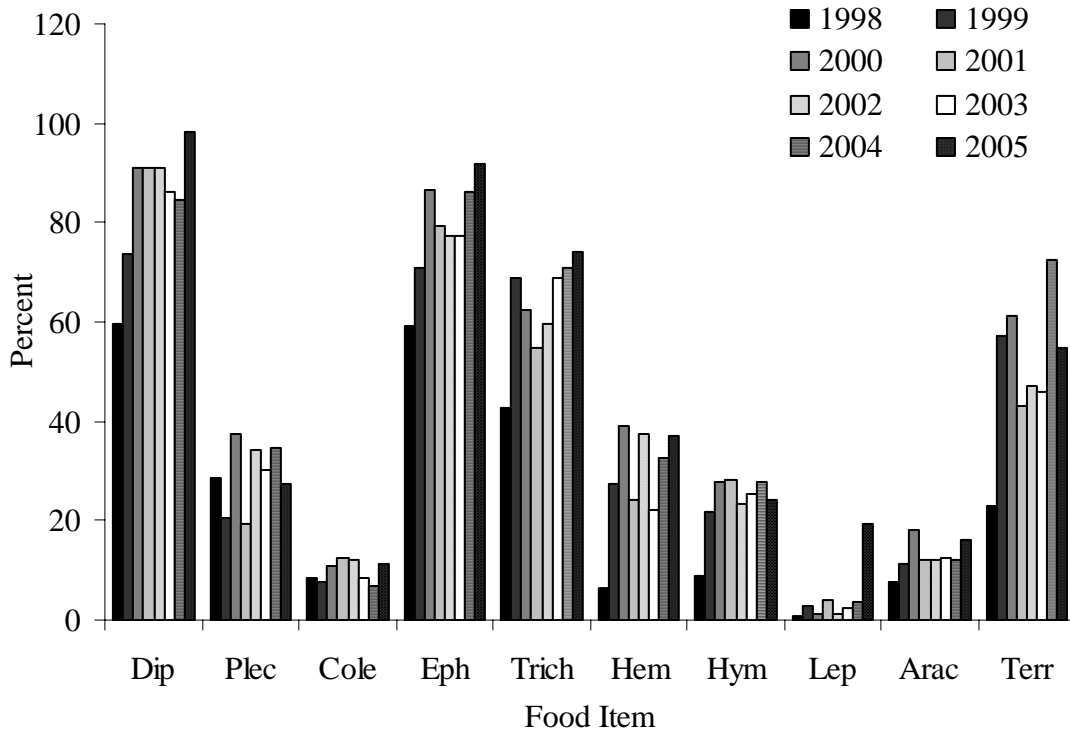


Figure 4. Occurrence frequency of food items found in age-0 spring Chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

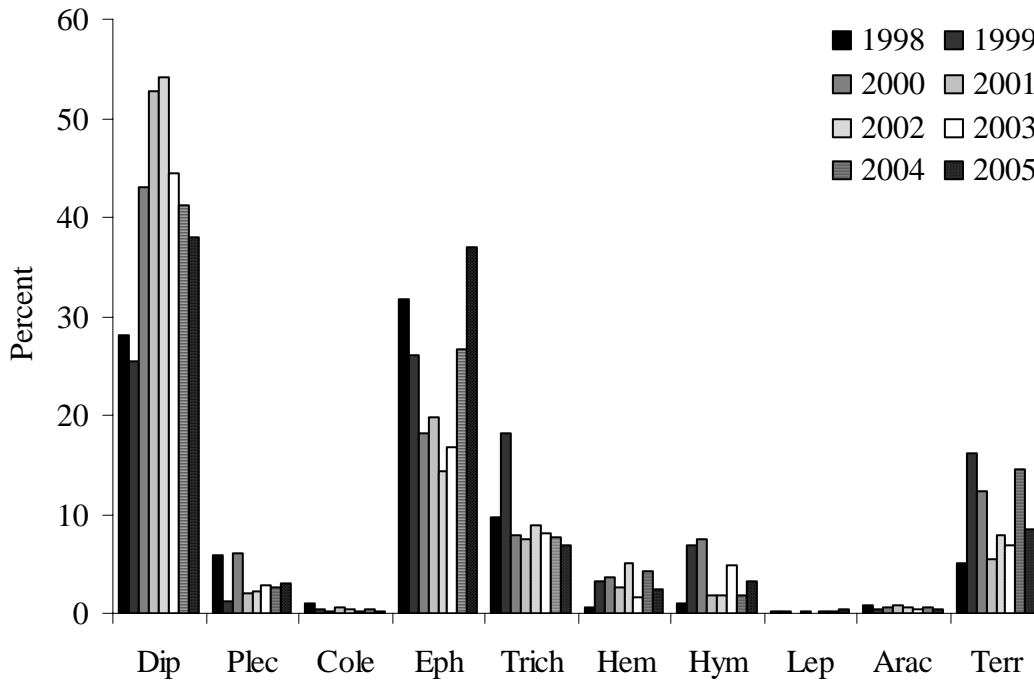


Figure 5. Percent composition of food items found in age-0 spring Chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

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

year	Time Period												Average %		
	0:01-4:00		4:01-8:00		8:01-12:00		12:01-16:00		16:01-20:00		20:01-24:00		Day	Night	24hr
	%	n	%	n	%	n	%	n	%	n	%	n			
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

*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
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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 = redbside 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 (grams)	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	20.67	102.84	212.62

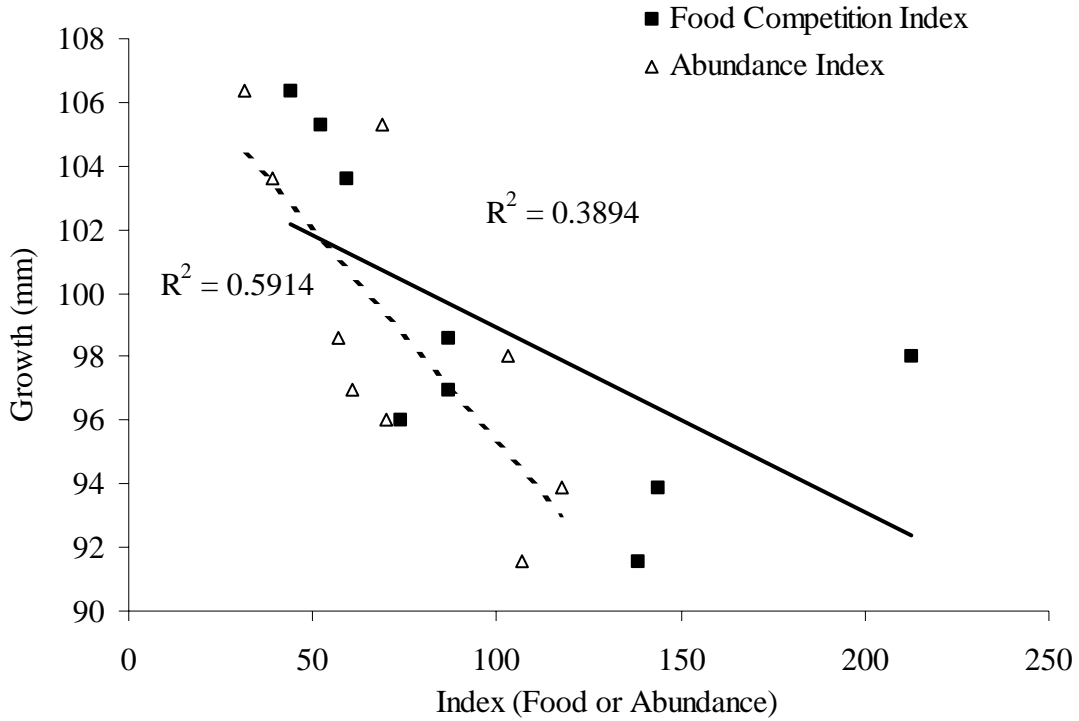


Figure 6. Spring Chinook age 0 mean fork length (mm) in the upper Yakima River, 1998-2006 in relation to abundance and the intra-specific food competition indices.

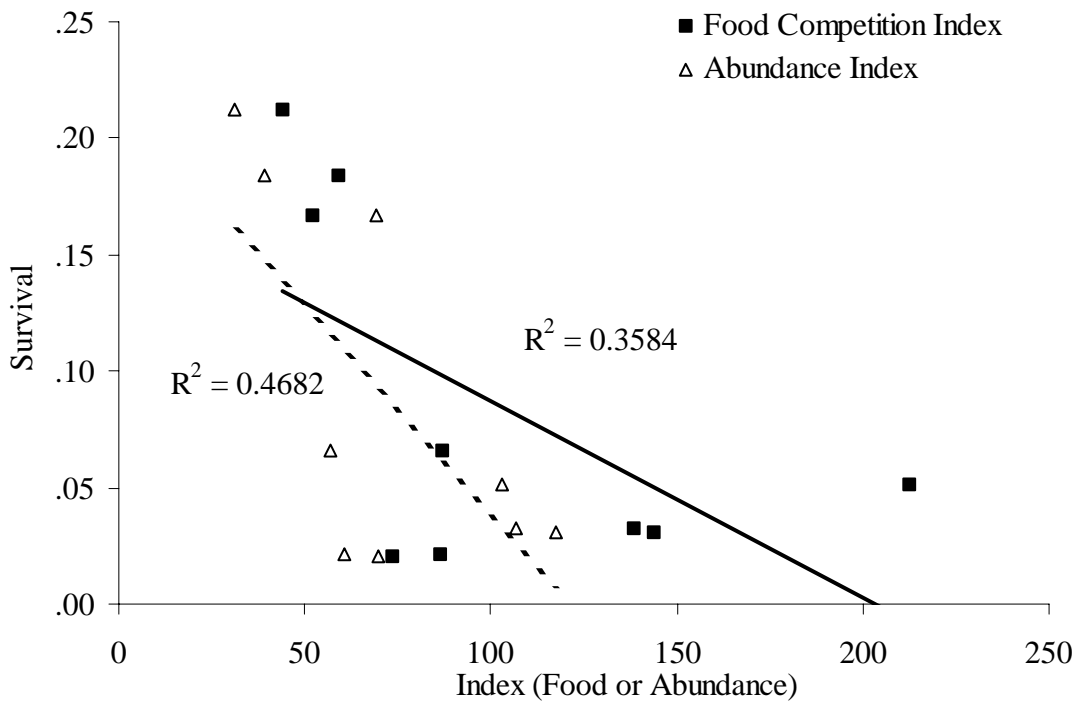


Figure 7. Spring Chinook upper Yakima River survival index (parr abundance index/redds in the previous year) 1998-2006 in relation to abundance and intra-specific food competition indices.

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 = reddsider 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 (Figure 8). In addition, above approximately 750 redds we did not observe a relationship

between number of redds and an index of the number of parr the following Fall (Figure 9). Below approximately 750 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.

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 750 redds. However, supplementation may increase the number of fall parr when natural escapement (without hatchery influence) is less than 750 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 is 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).

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. 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 (e.g., <750 redds). 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 than 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.

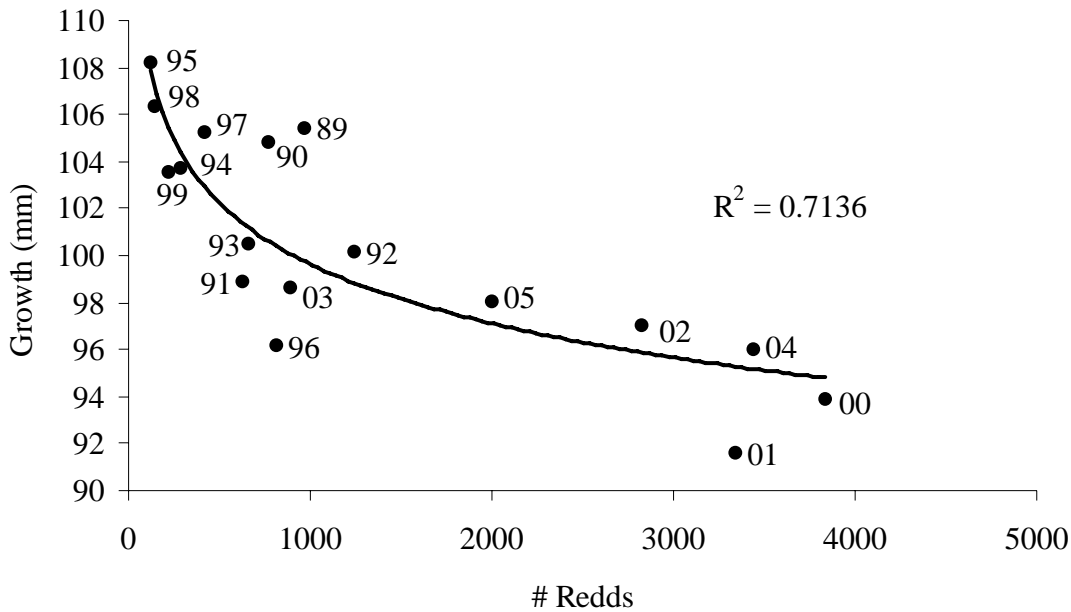


Figure 8. Size of age 0 spring Chinook salmon during September and October versus the number of redds that were produced the year prior. The dates are the year that redds were counted.

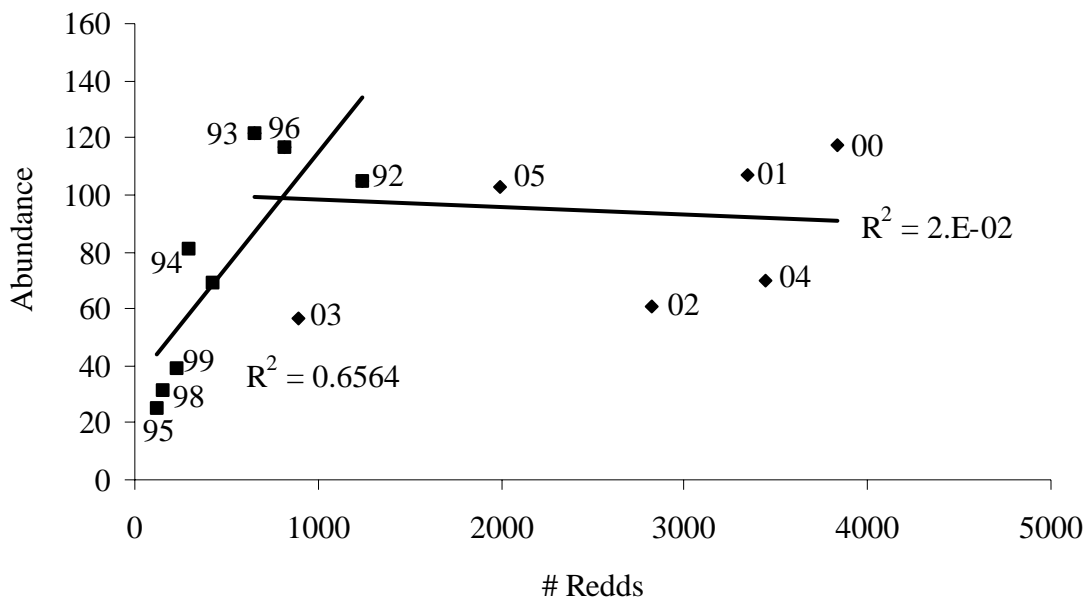


Figure 9. Abundance index of age 0 spring Chinook salmon during September and October versus the number of redds that were counted the year prior. The dates are the year that redds were counted.

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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 a leveling off of the 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. 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). 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.

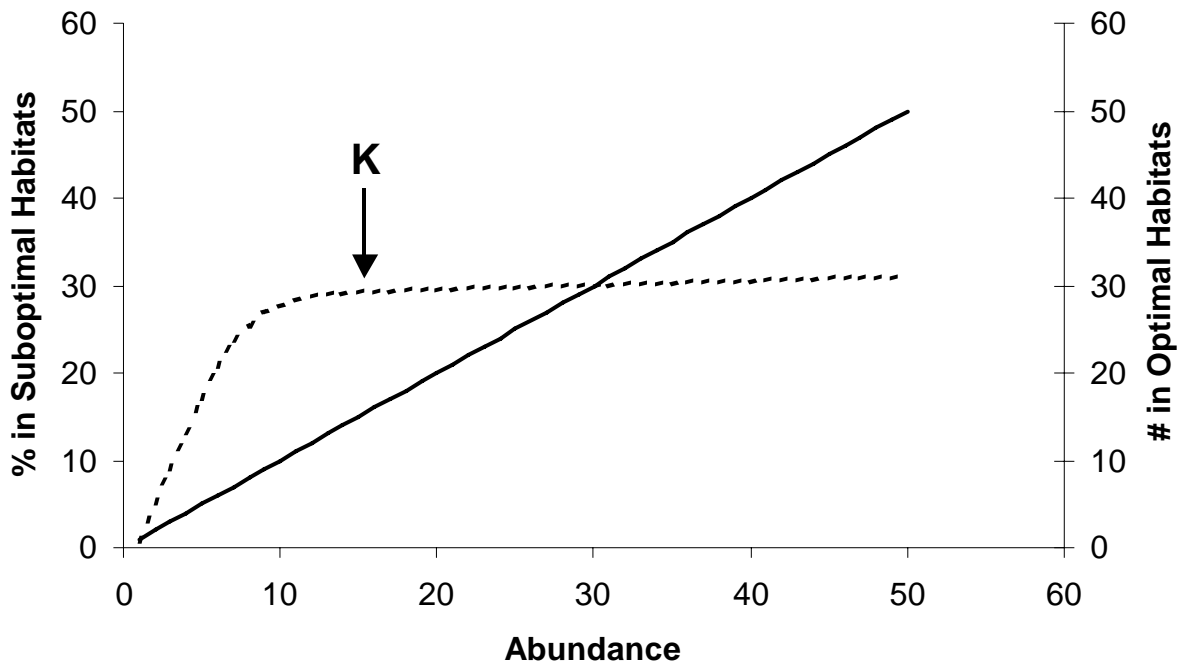


Figure 1. Hypothesized percentage of fish outside (solid line) and number of fish inside (dashed line) optimal habitat in relation to increasing abundance.

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 river bottom)
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 2006 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
Cle Elum	Min	14	11	15	18	14		18	13	14.5
	Max	17	14	18	19.5	16		21	19	19
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
	Max	19	15	18	17	19	20	20.5	17	19
Thorp	Min		11	15.5	15		16			
	Max		14	16.5	19		19			
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 Swiffer 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.

During 2005 and 2006, 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:

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

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 (Temple et al. 2006).

We estimated territory size of Chinook salmon by measuring the surface area (1999-2005) or volume (2005 and 2006) 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.

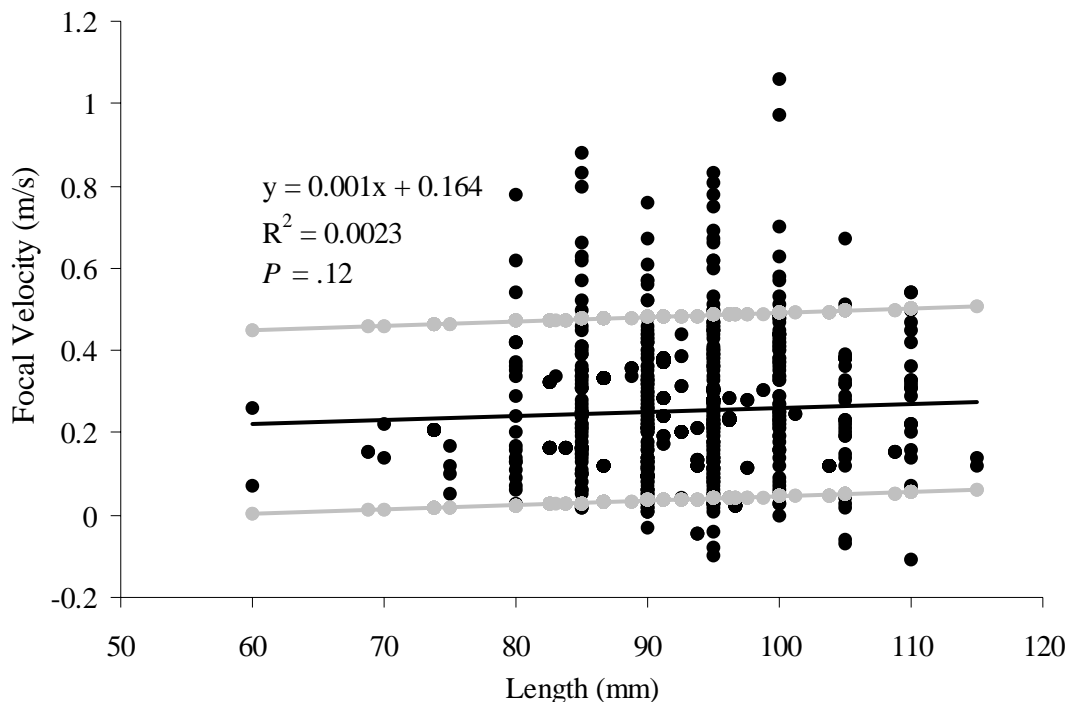


Figure 2. Relationship between spring Chinook salmon length and focal velocity during 1998. Included are the linear regression line, and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

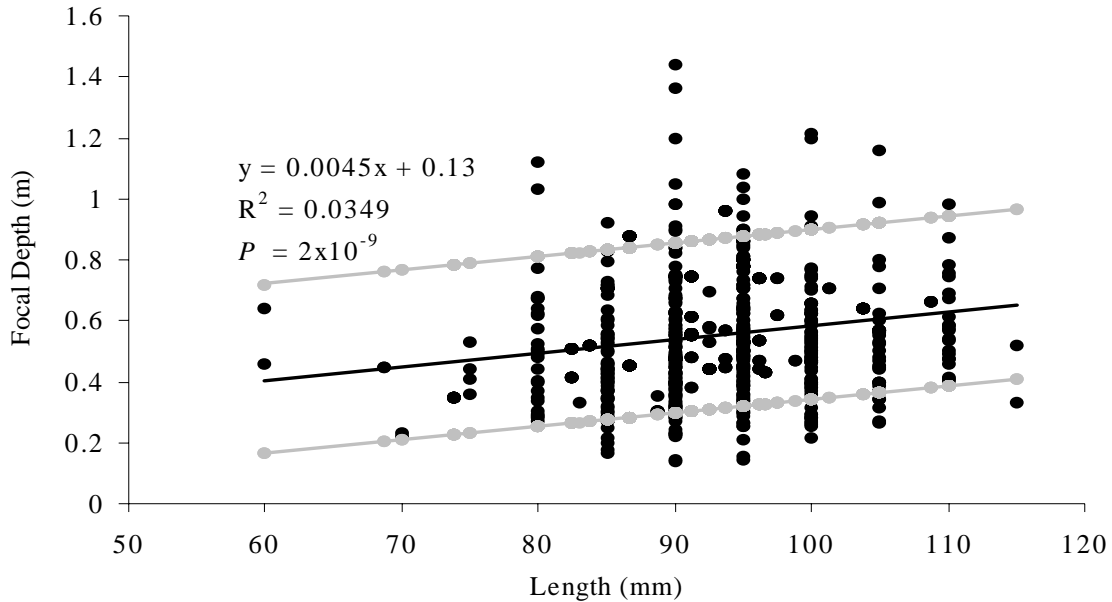


Figure 3. Relationship between spring Chinook salmon length and focal depth during 1998. Included are the linear regression line, and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

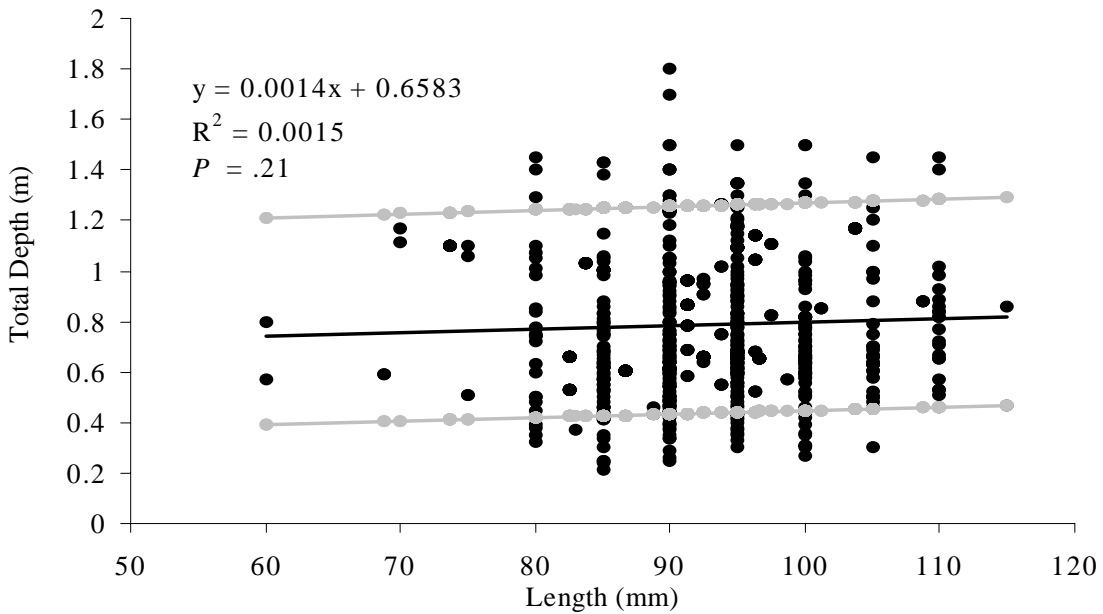


Figure 4. Relationship between spring Chinook salmon length and total depth during 1998. Included are the linear regression line and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

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 1998-2006. (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			

Additional snorkeling observations were made in the Cle Elum and Nelson sections of the main-stem Yakima River between July 11th and August 30th, to observe and record age-0 spring Chinook salmon territory size. Using an underwater stopwatch and clipboard, observers recorded direction and distance of movements from the current focal position in timed observations. The holding position of the subject 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.).

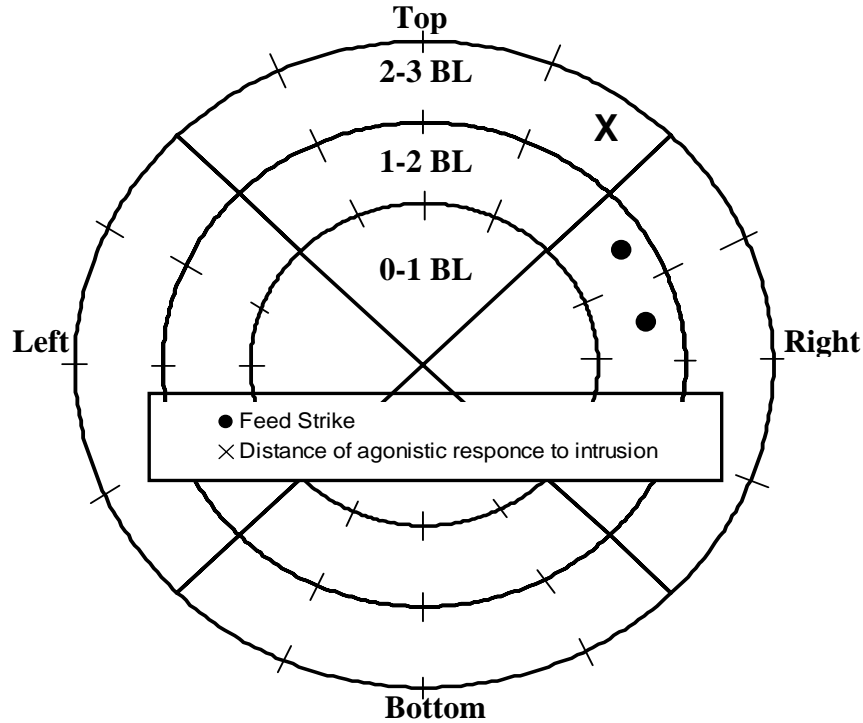


Figure 5. Graphical representation of the recording of observed age-0 spc territory size.

Direction 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 and agonistic interaction (e.g., chase, threat). Observations ranged in length from one minute to twenty minutes, terminating when the subject left the observer's view.

Results

None of the microhabitat variables showed a significant 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 5). The estimated number of Chinook salmon in optimal habitats was positively related to an index of abundance ($P < 0.001$; Figure 6). There was not a significant relationship between our fall abundance index and territory area (Figure 7), but there was between fish length and territory volume (Figure 8).

The highest flows adjacent to the focal position of the fish were 2 body lengths above the top of the fish (Figure 9). 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 10) and between fish length and cover index (Figure 12), but not a significant relationship between flow ratio and cover (Figure 11).

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 13). The highest frequency of food strikes occurred above the fish and rarely occurred below the fish (Figure 13).

Table 3. Summary of microhabitat parameters used by age-0 spring Chinook salmon during summer 1998 to 2005 within index sites of the upper Yakima Basin. All variables are weighted to account for pod density.

Year	Focal Velocity (m/s)				Focal Depth (m)				Total Depth (m)			
	n	mean	stdev	cv	n	mean	stdev	cv	n	mean	stdev	cv
1998	997	0.25	0.15	57.37	1010	0.55	0.17	31.86	1010	0.79	0.26	32.88
1999	446	0.20	0.13	63.10	449	0.67	0.23	34.81	449	0.90	0.31	34.85
2000	436	0.19	0.13	68.57	439	0.90	0.36	40.32	438	0.92	0.37	39.75
2001	377	0.21	0.11	52.04	377	0.48	0.13	27.95	377	0.64	0.19	29.64
2002	1344	0.17	0.11	61.18	1344	0.46	0.12	25.27	1344	0.63	0.15	24.30
2003	1206	0.20	0.13	62.78	1207	0.50	0.14	27.94	1207	0.73	0.19	25.45
2004	567	0.24	0.13	54.50	569	0.48	0.14	30.35	569	0.63	0.18	28.63
2005	405	0.17	0.10	61.00	405	0.50	0.10	19.92	405	0.65	0.13	20.83
2006	1158	0.14	0.12	80.00	1158	0.41	0.16	39.84	1158	0.58	0.23	39.32
mean		0.20				0.55				0.72		
stdev		0.03				0.15				0.12		

Table 4. Percent of age-0 spring Chinook focal velocities, focal and total depths outside 1998 fitted lines during 1999-2006, 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	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	3,836	118	94
2002	4.2	5.3	6.0	3,339	107	92
2003	9.9	6.7	6.9	2,826	61	97
2004	6.6	13.2	14.2	890	57	99
2005	5.7	1.0	3.5	3,444	70	96
2006	2.2	10.1	17.5	1,996	103	98

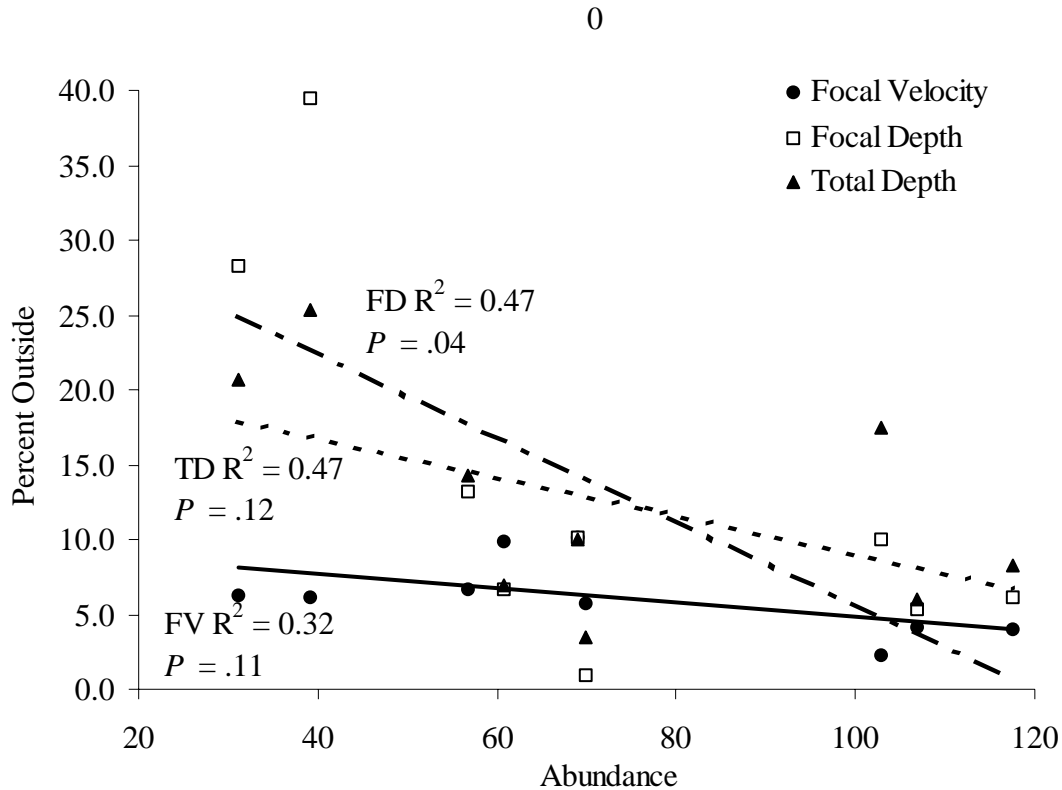


Figure 5. Relationship between the index of abundance of spring Chinook salmon parr (fish/km) and the percent of focal velocities, focal depths, and total depths outside optimal values 1998 to 2006.

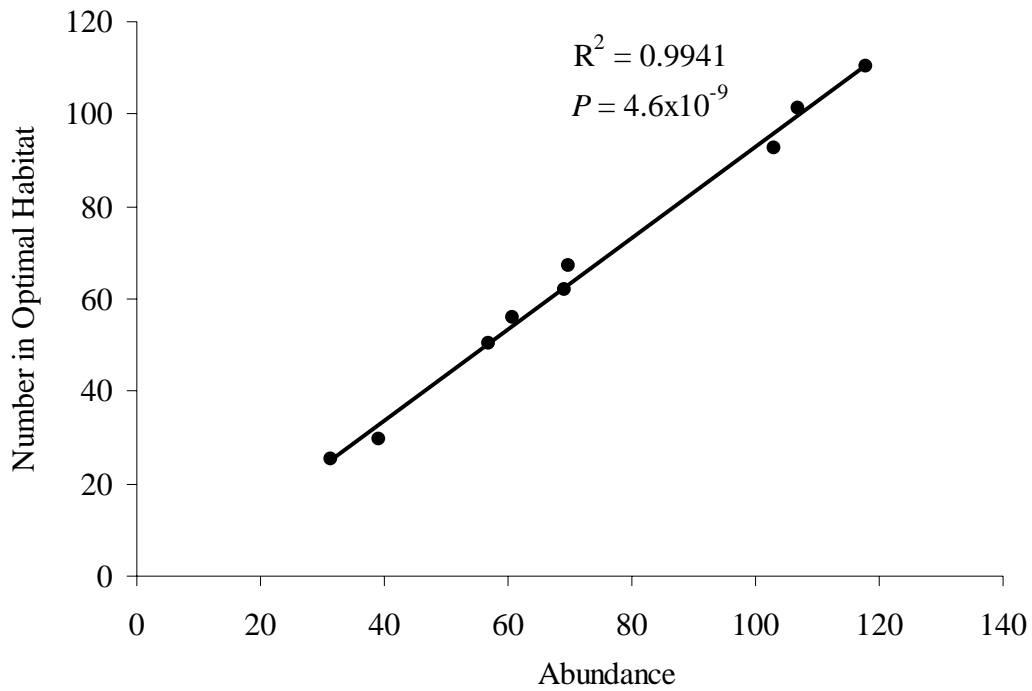


Figure 6. Relationship between spring Chinook abundance index (fish/km) and the estimated number using optimal habitat. Estimated number utilizing optimal habitat is the annual mean of the proportion within optimal of total depth, focal velocity, and focal depth measurements multiplied by the abundance index.

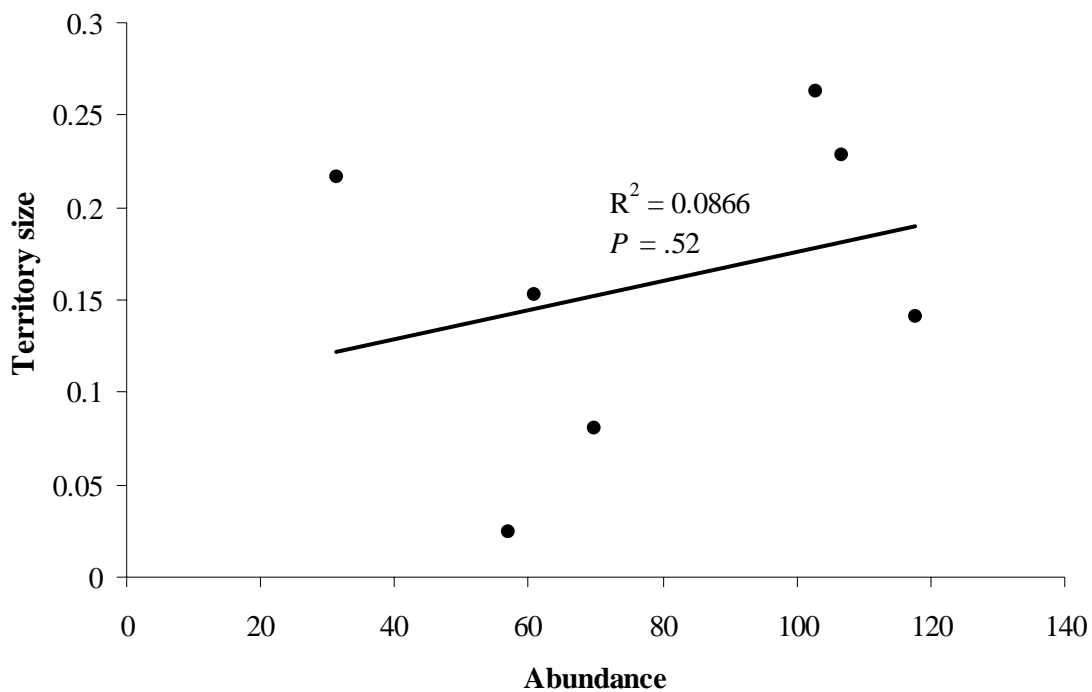


Figure 7. Relationship between annual spring Chinook salmon abundance estimates (fish/km) and planar elliptical territory size (m^2) 1999-2005.

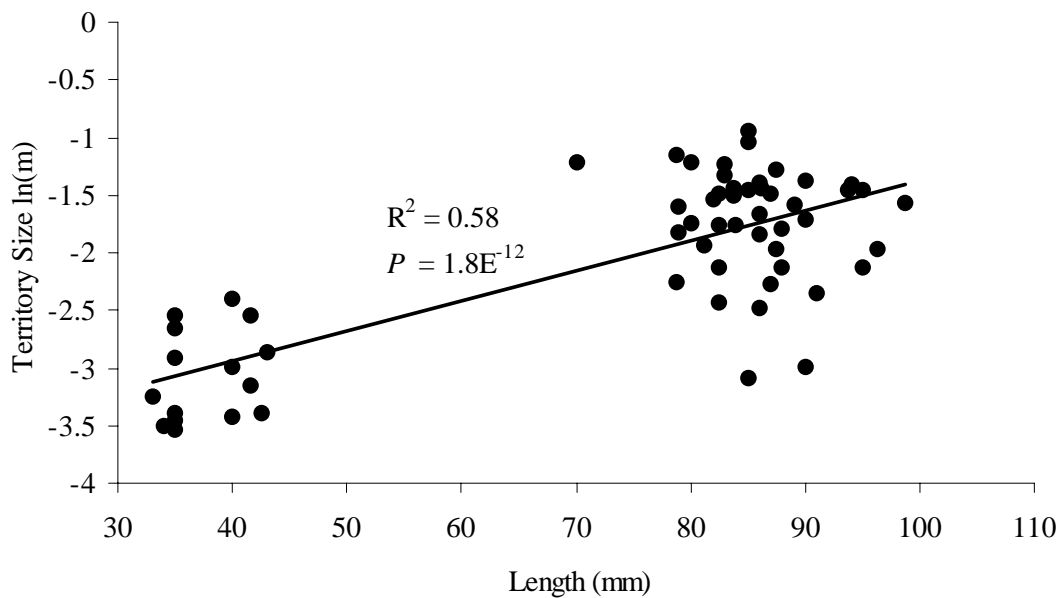


Figure 8. Relationship between total length (mm) and volumetric territory size (m^3) 2005-06.

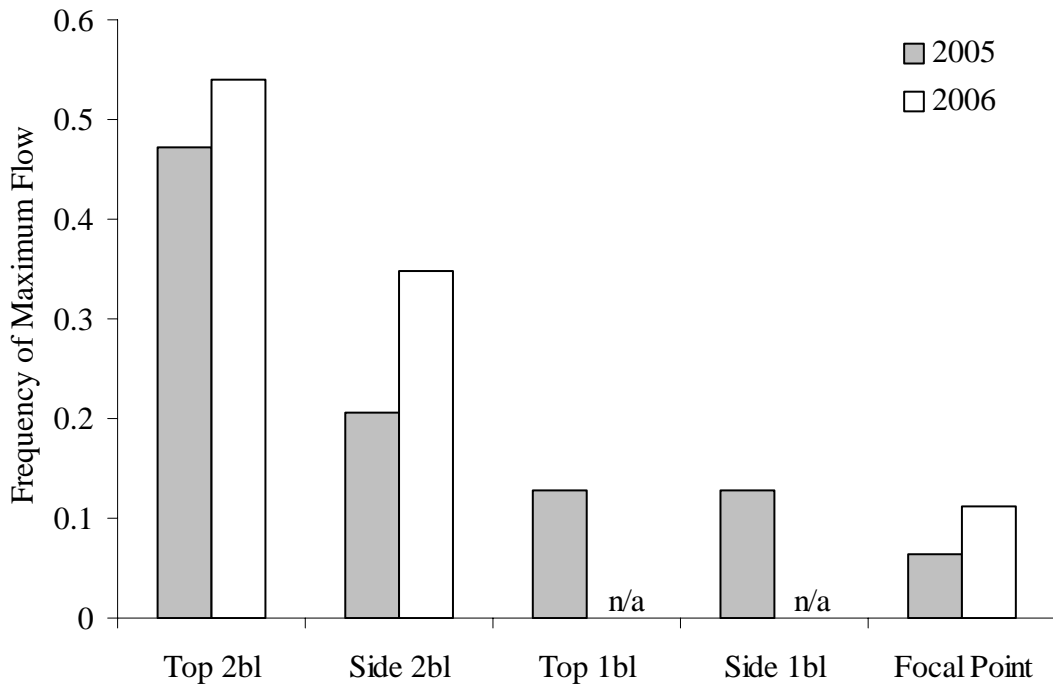


Figure 9. Frequencies of maximum flows at zero, one, or two body lengths from the focal point.

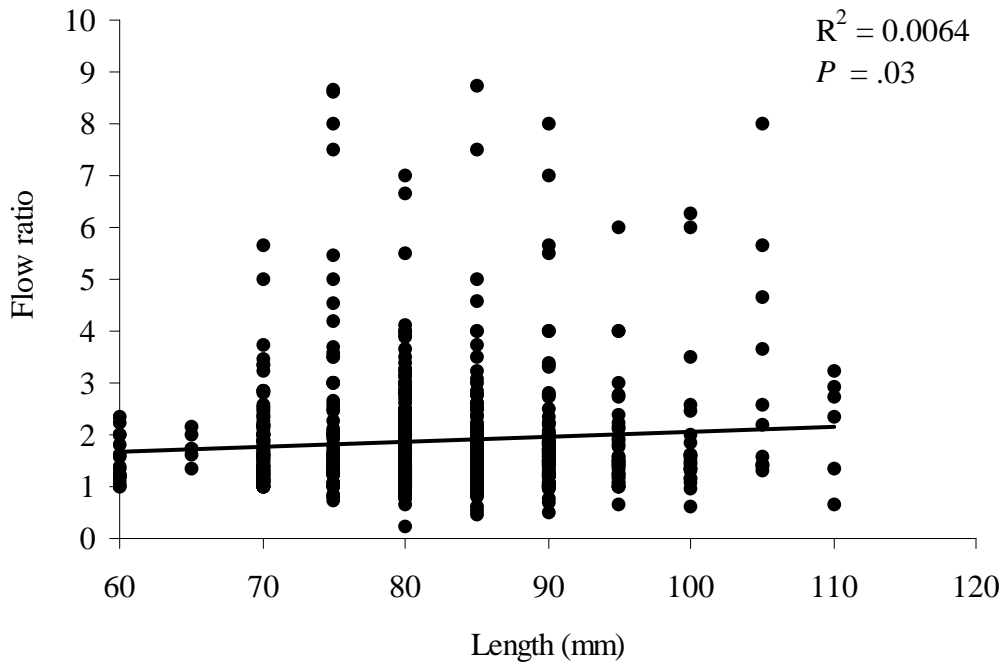


Figure 10. Relationship between flow ratio and spring Chinook length (mm) 2005-2006.

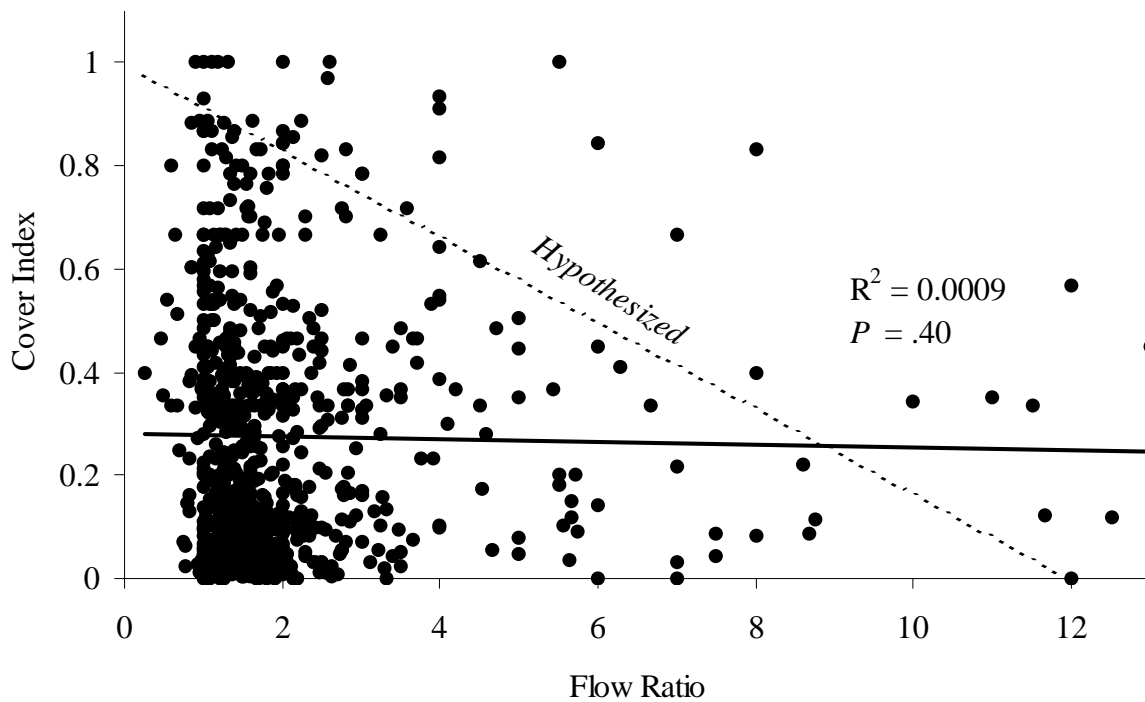


Figure 11. Actual and hypothesized relationship between flow ratio and the cover index, 2005-2006.

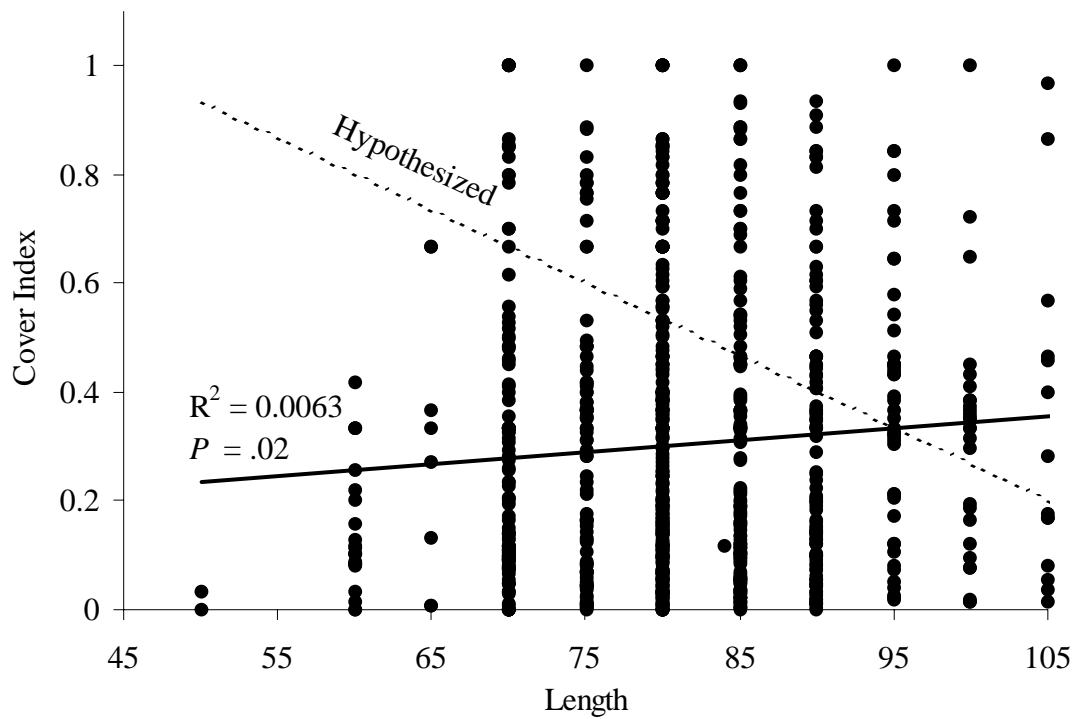


Figure 12. Actual and hypothesized relationship between spring Chinook length (mm) and the cover index 2005-2006.

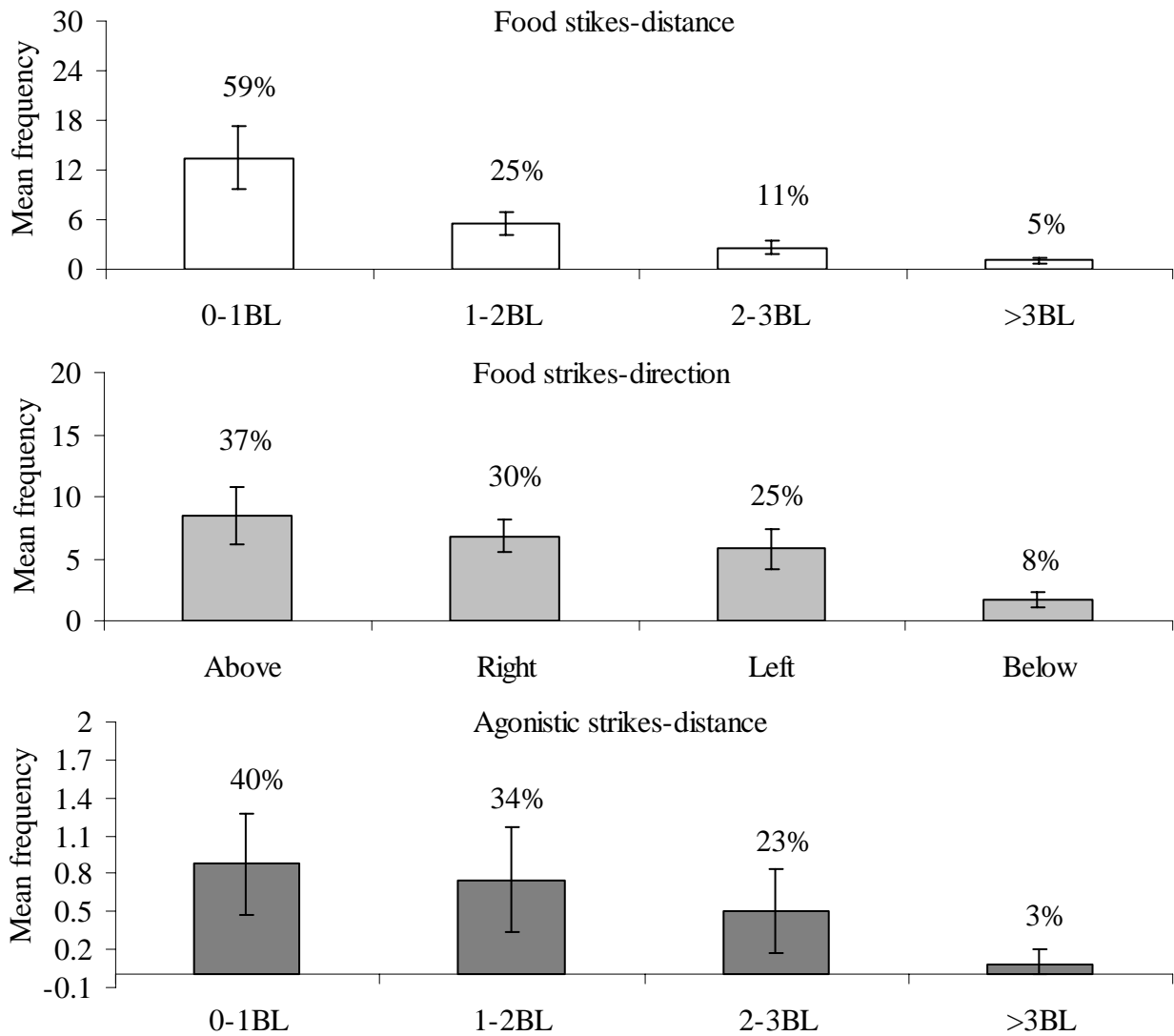


Figure 13. Frequency of age-0 spring Chinook food strikes by direction, and frequency of food and agonistic strikes by distance expressed in body lengths, e.g. 0-1BL = zero to one body length. Feeding strike observations n = 70, agonistic strike observations n = 24.

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 dependent interactions are correlated with growth and survival (Chapter 1 of this report). 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.

During 2005 and 2006, 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

Influence of Chinook Salmon Growth Modulation in a Supplementation Hatchery Program to Reduce Composition of Precociously Mature Males in the Yakima River

Abstract

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.

Introduction

Previous work has shown that a spring Chinook salmon (*Oncorhynchus tshawytscha*) supplementation program in the Yakima Basin produces large numbers of precocious males but that these fish were not abundant on the spawning grounds. Approximately 19-25% of the spring Chinook hatchery production in the Yakima Basin has been precocious males (Larsen et al. 2004) and some of these fish are observed on the spawning grounds approximately four months after they are released from acclimation sites. Using an annual precocious male average of 22% and the total number of fish released, Larsen et al. (2004) 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 similar methods and new data from Larsen et al. 2004b to calculate the number of precocious males released, 99,964 were released in 2003, 147,573 in 2004, and 162,648 in 2005* (Don Larsen, personal communication*).

Demographic and behavioral variables of hatchery and natural origin male spring Chinook salmon that precociously matured in the Yakima River were compared (Pearsons et al. 2005). Hatchery origin precocious males were less abundant on redds, and larger than natural origin precocious males. The hatchery did not release age 0 precocious males, which was the predominant age of natural origin precocious males. The estimated number of wild age 0, wild age 1, and hatchery age 1 precocious males observed on the spawning grounds between 1999 and 2003 ranged from 5 to 555, 16 to 42, and 11 to 53 respectively. Between 29% and 52% 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 wild age 0 and 0% to 15% of all wild age 1 precocious males were observed in this reach. In addition, most hatchery precocious males were found downstream of spawning areas during the spawning season. Larger precocious males behaviorally dominated smaller ones on redds and the types of agonistic interactions of hatchery and wild fish were generally similar. There was no difference in the estimated number of hatchery and wild precocious male progeny on redds produced per female parent, which suggests that the hatchery did not significantly alter the abundance of precocious males on the spawning grounds.

Larsen et al. (2004) hypothesized that the high incidence of age 1 precocious males was due to high growth during two critical time periods. They found that the fish produced at the Cle Elum Hatchery had high growth during both of these critical periods. This was quite different from the average growth of the fish in the Yakima River. The proportion of wild age 0 (Pearsons et al. 2005) and age 1 fish (Don Larsen, NOAA Fisheries, personal communication) that precociously mature in the river appear to be much lower than that of the hatchery. This finding is also supported by other assessments of hatchery and wild rates of precocious male production from other systems (Gebhards 1960; Mullan et al. 1992; Foote et al. 1991).

Growth modulation of half the hatchery-reared fish was instituted to evaluate the efficacy of reducing the incidence of precocious maturation (Larsen et al. 2004b). The other half-of-the 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 fish and 29% of the low growth reared fish precociously matured, a 33% reduction in precocious male maturation. Our objective was to evaluate whether the abundance, distribution, size, or behavior of hatchery and natural origin precocious males differed by instituting growth modulation.

Methods

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 (Figure 1). These areas represent the vast majority of the spawning in the upper Yakima River and generally account for over 99% of the redds counted annually (www.ykfp.org). Counts of precocious males occurred during the peak of spawning, which generally occurred at the end of September. The sampling area consisted of four reaches that were surveyed in their entirety in all years, and two reaches in which a portion was not surveyed in years prior to 2003. In each of these two reaches extrapolations from data collected in an adjacent portion of the reach or “section” were made. The boundaries, beginning with the most downstream reach were: the Thorp reach, from the Town Diversion north of Ellensburg, at approx. rkm 256, upstream 26.6 kilometers to the Teanaway Game ramp; the Cle Elum reach, upriver 13.7 kilometers to the Cle Elum River confluence; the Nelson reach, 12.8 kilometers upstream to the WDFW boat launch; the Easton reach, 10.7 kilometers upstream to the Easton Dam at rkm 326; and the Cle Elum River reach from the Cle Elum River confluence, 12.2 kilometers upstream to the Cle Elum Dam (Figure 1). A sixth reach, surveyed since 2003 and termed Bullfrog, consisted of the 10.2 km of river previously within the Nelson and Cle Elum reaches over which extrapolations were made in preceding years. Areas that were sampled, over which no extrapolations were necessary, make up 78 percent (59.7 rkm) of the spawning area above the Town Diversion Dam. 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 a 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). Fish size was visually estimated underwater. Hatchery origin residuals were differentiated from wild spring Chinook by the presence of an adipose clip. During years where more active redds were present than we could snorkel, 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 first calculating the ratio of age and origin specific precocious males on or associated per active redd within each of the surveyed reaches. We then applied these ratios to the number of redds, if any, that were deemed active at the time of the survey but were not snorkeled. From this total we then calculated the number of precocious males per river kilometer within each survey site and expanded our counts, when necessary, over the distance that was not snorkeled within a reach. Reach expansions were necessary in both the Cle Elum and Nelson reaches in all years prior to 2003.

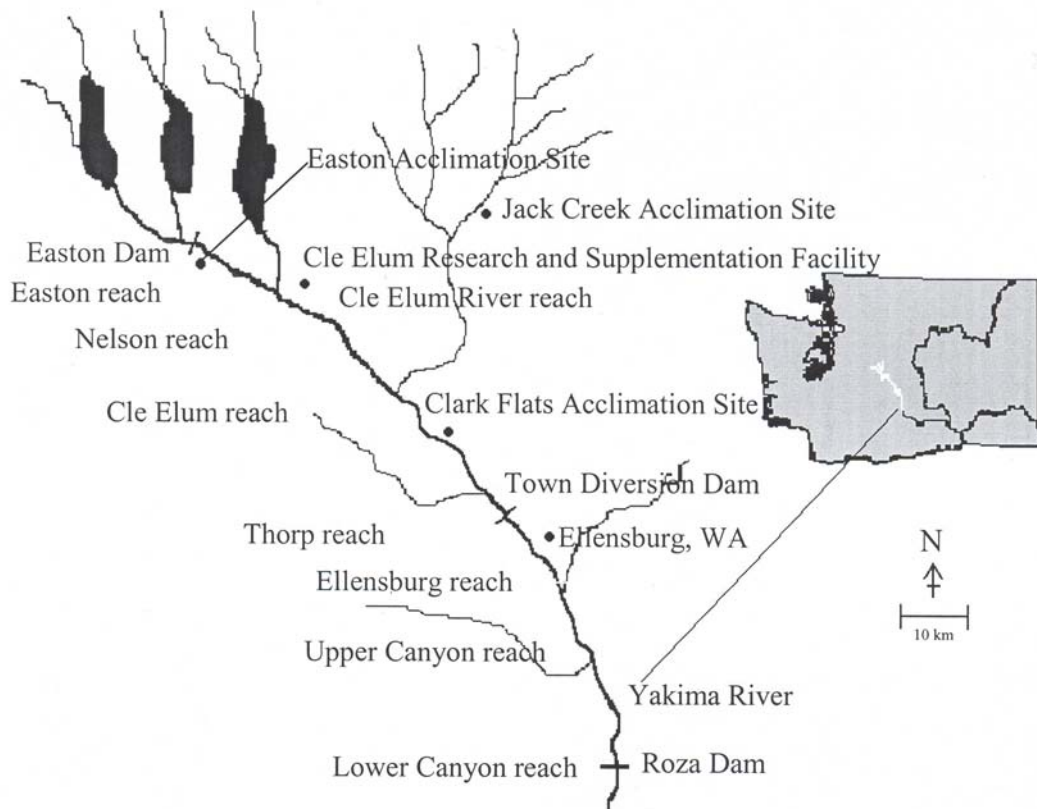


Figure 1. Locations of study reaches and hatchery facilities in the upper Yakima Basin, Washington.

We 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 Temple et al. (2006). 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 in spawning areas to avoid electroshocking fish on or near redds. We could not perform valid mark-recapture estimates of hatchery spring Chinook due to low recapture efficiency of marked fish. We applied the capture efficiency of similar sized rainbow trout to the number of hatchery spring Chinook netted during the mark runs to generate an abundance estimate. Capture efficiencies were generated from log-likelihood mark-recapture models. Thus, the number of hatchery precocious males netted during electrofishing were expanded by our efficiency of capturing marked rainbow trout of a similar size for a given year and section. The estimated numbers of precocious males in our index sections were then expanded over the remainder of the reach that each section represented. In this way, we estimated the total number of precocious males in the Yakima River from Roza Dam to the Cle Elum River confluence.

Precocity, Size, and Age

Hatchery and wild fish that were less than 300 mm were collected to determine the incidence of precocious maturation, gender, 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. (2004) to visually assess gender and precocious 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 in the field and scale samples were collected from fish during 1998. Scales were projected with a microfiche projector and were aged by counting annuli. Fish with a length greater than 120 mm (FL) were considered age 1 residuals based on preliminary size and age data.

Behavioral dominance

Prior to 2003, we observed precocious male Chinook interacting on redds, but had not documented our observations. Beginning in September of 2003, agonistic interactions among spring Chinook salmon were recorded within our survey reaches in the upper Yakima River (Table 6). In order to observe interactions on a given redd, a snorkeler would first approach in the same manner described previously. After a five-minute acclimation period, agonistic interactions were recorded for fifteen minutes. The types of interactions were recorded as nip (contact with mouth open), butt (contact with mouth closed), chase (no contact, swimming after another fish at least one body length), threat (no contact; for example fin flares, opercle flares, swimming side by side), and crowd (no clear threat but physical presence moved the other fish away). The fish that started an interaction was termed the initiator and the fish that was the receiver of an interaction was termed the recipient. The relative size of the initiator and the recipient (large, small, or equal) was recorded. Finally, dominance was assigned to the fish that maintained/defended its position or a fish that moved another fish from an area previously occupied.

Analysis

To determine if the hatchery production influenced the number of precocious males that would ordinarily occur on the spawning grounds, we compared the average number of hatchery and naturally produced precocious males that were produced per female parent. We divided the estimated number of precocious males on the spawning grounds during the peak of spawning each year by the number of female parents that had the potential to produce them. We used the number of females collected for broodstock at Roza Dam and spawned at the Cle Elum Hatchery as the number of females that could produce hatchery precocious males two years later. We used the numbers of redds upstream of Roza Dam as the number of females that could produce natural origin precocious males one (age 0) or two (age 1) years later (Yakama Nation, unpublished data, www.ykfp.org). We also used the number of females that passed Roza Dam as the number of potential females to bracket the number of potential wild spawners. Redd counts are likely to

underestimate wild spawners and passage counts are likely to overestimate wild spawners. To calculate the number of precocious males per female, we used the numbers of adults for the year prior to observation of age 0 precocious males, and the numbers of adults two years prior to observation of age 1 precocious males. An ANOVA with main factors of age and origin (age 0, age 1, and hatchery), and time (before and during growth modulation) was used to test for differences in precocious males/female. The interaction term of this ANOVA tested for whether the precocious males/female of each age and origin were different before and during growth modulation.

We compared the range of annual estimates of precocious male abundance, size, and distribution for 1999-2003 to the 2004-2006 estimates. A two-sample t-test was used to detect differences in the aforementioned variables. A G-test was used to determine if there were distributional differences of precocious males in five different main stem river sections.

Samples sizes of behavioral interaction data were too small to compare differences between 2003 and 2004. Interactions between age classes were not observed in 2005 and 2006 because of the limited amount of time spent snorkeling on redds. Samples were pooled to investigate general patterns of behavior. We used a Wilcoxon matched pairs test to evaluate potential differences in dominance by age and origin, and size of precocious males observed interacting on redds. Contest outcomes were averaged for each redd and then paired by both competitor age and origin or by size. Significant results indicated a difference in observed dominance between contestants. Descriptive comparisons of interaction types between spring Chinook salmon of differing age class and origin were evaluated. Small sample sizes and the characteristics of the data precluded rigorous statistical testing.

Results

Nearly all of the residualized hatchery fish collected were precociously maturing and approximately 22% of the wild age 0 males were precociously maturing (Table 1). The mean size of precocious males was within the range observed during previous years (Table 2). 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 (Table 3, Figure 2). In contrast, no hatchery precocious males were observed on redds during 2005 and 2006. We did not detect a significant difference in hatchery origin precocious male abundance during the years before and during growth modulation (one tailed t-test; $P=0.46$), however the power of the test was quite low. We would have to observe no hatchery precocious males on the redds for 14 years in order to detect a significant difference. Significant differences were also not detected for natural origin age 0 and age 1 fish before and during the years of growth modulation ($P>0.05$). The estimated abundance of precocious males away from redds in 2004 was the second highest that we have recorded, in 2005 the abundance was average, and in 2006 the abundance was the lowest. We did not detect a significant difference in abundance away from redds in the years before and during growth modulation (one-tail t-test $P = 0.265$).

The distribution of hatchery precocious males away from the redds was still highest in the Canyon reaches (Table 4). The highest proportion of precocious males on redds were not in the lowest section but in the highest (Easton, Figure 3). No detectable differences were found in distribution of age 0, age 1 and hatchery precocious males before and during growth modulation (G-test $P>0.05$). The hatchery and wild age 0 precocious progeny per female in 2004 was the highest that we have observed, but in 2005 and 2006 it was the lowest we have observed for

hatchery precocious males (Table 5, Figure 4). However, we did not detect significant differences in the precocious males/female for any age and origin before or during the years of growth modulation (ANOVA Interaction term $P=0.60$). Furthermore we did not detect significant differences in abundance of precocious males/female among age classes or origins between 1999 and 2006 (ANOVA $P=0.17$).

Table 1. Proportions of wild age 0 and hatchery age 1 spring Chinook salmon that were precociously maturing in the upper Yakima River.

Year	Wild spring Chinook salmon			Hatchery spring Chinook salmon				
	Collected	Male	Precocious	% Precocious	Collected	Male	Precocious	% Precocious
1999					32	32	32	100
2001	107	55	9	16.4	9	9	9	100
2002	81	55	6	10.9				
2003	141	71	14	19.7	7	7	7	100
2004	239	109	40	36.7	126	126	122	96.8
2005	225	104	31	29.8	14	14	14	100
2006	129	95	19	20.0				

Table 2. Fork lengths (mm) of sexually mature precocious wild and hatchery spring Chinook males collected during the spawning season (between late August and October) in the upper Yakima River.

Year	n	Min length	Max length	Mean length	Stdev length
Age 0 Wild Spring Chinook					
1999	13	88	114	104.1	8.43
2000	2	95	101	98	4.24
2002	1	85	85	85	n/a
2003	24	84	115	100.8	9.07
2004	56	80	156	104.4	12.08
2005	36	68	115	90.2	12.52
2006	20	75	104	91.7	7.37
Age 1 Wild Spring Chinook					
1999	5	132	210	158.2	30.49
2000	3	126	168	143.3	21.94
2001	5	124	203	151.6	35.7
2002	1	146	146	146	n/a
2003	6	120	150	135.2	13
2004	6	129	173	145.3	17.56
2005	0	n/a	n/a	n/a	n/a
2006	1	n/a	n/a	193.0	n/a
Age 1 Hatchery Spring Chinook					
1999	26	147	230	193	22.89
2000	50	140	245	173.2	26.35
2001	311	140	298	186.5	15.39
2002	13	156	204	182.7	16.45
2003	35	168	221	190	12.23
2004	62	128	220	184.5	15.63
2005	42	162	206	185.5	10.31
2006	1	n/a	n/a	187	n/a

Table 3. Number and extrapolations of wild and hatchery origin precocious males by age class observed within river sections and reaches at the peak of spawning activity in the upper Yakima River.

Section	Snorkeled		Observed		Total	Section km	Fish per km	Reach km	Reach total
	yes	no	on	associated					
1999 Age 0 Wild Spring Chinook									
Thorp	5	0	0	0	0	26.6	0	26.6	0
Cle Elum	12	0	1	0	1	9.1	0.11	13.7	2
Cle Elum River	6	0	2	0	2	12.2	0.16	12.2	2
Nelson	4	0	0	0	0	7.3	0	12.8	0
Easton	9	0	1	0	1	10.7	0.09	10.7	1
1999 Age 1 Wild Spring Chinook									
Thorp	5	0	1	0	1	26.6	0.04	26.6	1
Cle Elum	12	0	0	0	0	9.1	0	13.7	0
Cle Elum River	6	0	0	0	0	12.2	0	12.2	0
Nelson	4	0	6	0	6	7.3	0.82	12.8	11
Easton	9	0	3	1	4	10.7	0.37	10.7	4
1999 Age 1 Hatchery Spring Chinook									
Thorp	5	0	4	5	9	26.6	0.34	26.6	9
Cle Elum	12	0	1	0	1	9.1	0.11	13.7	2
Cle Elum River	6	0	0	0	0	12.2	0	12.2	0
Nelson	4	0	1	0	1	7.3	0.14	12.8	2
Easton	9	0	3	3	6	10.7	0.56	10.7	6
2000 Age 0 Wild Spring Chinook									
Thorp	22	4	2	0	2	26.6	0.08	26.6	2
Cle Elum	29	58	1	0	3	9.1	0.33	13.7	5
Cle Elum River	110	0	85	2	87	12.2	7.13	12.2	87
Nelson	16	16	5	0	10	7.3	1.37	12.8	18
Easton	30	31	7	1	16	10.7	1.49	10.7	16
2000 Age 1 Wild Spring Chinook									
Thorp	22	4	0	0	0	26.6	0	26.6	0
Cle Elum River	110	0	42	0	42	12.2	3.44	12.2	42
Cle Elum	29	58	0	0	0	9.1	0	13.7	0
Nelson	16	16	0	0	0	7.3	0	12.8	0
Easton	30	31	0	0	0	10.7	0	10.7	0
2000 Age 1 Hatchery Spring Chinook									
Thorp	22	4	4	0	5	26.6	0.19	26.6	5
Cle Elum	29	58	0	0	0	9.1	0	13.7	0
Cle Elum River	110	0	2	0	2	12.2	0.16	12.2	2
Nelson	16	16	0	0	0	7.3	0	12.8	0
Easton	30	31	2	0	4	10.7	0.37	10.7	4

2001 Age 0 Wild Spring Chinook									
Thorp	14	6	14	3	24	26.6	0.90	26.6	24
Cle Elum	10	37	15	0	71	9.1	7.83	13.7	107
Cle Elum River	104	0	226	16	242	12.2	19.83	12.2	242
Nelson	16	13	1	0	2	7.3	0.27	12.8	4
Easton	26	50	56	5	178	10.7	16.62	10.7	178
2001 Age 1 Wild Spring Chinook									
Thorp	14	6	2	0	3	26.6	0.11	26.6	3
Cle Elum	10	37	1	0	5	9.1	0.55	13.7	8
Cle Elum River	104	0	7	0	7	12.2	0.57	12.2	7
Nelson	16	13	0	0	0	7.3	0	12.8	0
Easton	26	50	1	0	3	10.7	0.28	10.7	3
2001 Age 1 Hatchery Spring Chinook									
Thorp	14	6	17	2	27	26.6	1.01	26.6	27
Cle Elum	10	37	1	0	5	9.1	0.55	13.7	8
Cle Elum River	104	0	0	0	0	12.2	0	12.2	0
Nelson	16	13	0	0	0	7.3	0	12.8	0
Easton	26	50	3	3	18	10.7	1.68	10.7	18
2002 Age 0 Wild Spring Chinook									
Thorp	35	2	8	0	8	26.6	0.30	26.6	8
Cle Elum	22	29	16	0	37	9.1	4.08	13.7	56
Cle Elum River	59	13	51	1	64	12.2	5.24	12.2	64
Nelson	39	7	29	3	38	7.3	5.21	12.8	67
Easton	91	7	29	1	33	10.7	3.08	10.7	33
2002 Age 1 Wild Spring Chinook									
Thorp	35	2	1	0	1	26.6	0.04	26.6	1
Cle Elum	22	29	3	0	7	9.1	0.77	13.7	11
Cle Elum River	59	13	4	0	5	12.2	0.41	12.2	5
Nelson	39	7	0	0	0	7.3	0	12.8	0
Easton	91	7	7	0	8	10.7	0.75	10.7	8
2002 Age 1 Hatchery Spring Chinook									
Thorp	35	2	5	0	5	26.6	0.19	26.6	5
Cle Elum	22	29	2	0	5	9.1	0.55	13.7	8
Cle Elum River	59	13	0	0	0	12.2	0	12.2	0
Nelson	39	7	0	0	0	7.3	0	12.8	0
Easton	91	7	1	0	1	10.7	0.09	10.7	1
2003 Age 0 Wild Spring Chinook									
Thorp	20	0	21	3	24	26.6	0.90	26.6	24
Cle Elum	37	16	71	0	102	9.1	11.25	9.1	102
Bullfrog	47	3	35	0	37	10.2	3.64	10.2	37
Cle Elum River	24	7	15	0	19	12.2	1.56	12.2	19
Nelson	23	4	29	0	34	7.3	4.66	7.3	34

Easton	29	20	30	0	51	10.7	3.73	10.7	51
2003 Age 1 Wild Spring Chinook									
Thorp	20	0	2	0	2	26.6	0.08	26.6	2
Cle Elum	37	16	3	0	4	9.1	0.44	9.1	4
Bullfrog	47	3	8	0	9	10.2	0.89	10.2	9
Cle Elum River	24	7	0	1	1	12.2	0.08	12.2	1
Nelson	23	4	0	0	0	7.3	0	7.3	0
Easton	29	20	11	0	19	10.7	1.87	10.7	19
2003 Age 1 Hatchery Spring Chinook									
Thorp	20	0	7	0	7	26.6	0.26	26.6	7
Cle Elum	37	16	3	0	4	9.1	0.44	9.1	4
Bullfrog	47	3	2	0	2	10.2	0.20	10.2	2
Cle Elum River	24	7	0	3	4	12.2	0.33	12.2	4
Nelson	23	4	0	0	0	7.3	0	7.3	0
Easton	29	20	4	0	7	10.7	0.56	10.7	7
2004 Age 0 Wild Spring Chinook									
Thorp	94	29	5	0	21	26.6	0.79	26.6	21
Cle Elum	222	49	16	0	88	9.1	9.67	9.1	88
Bullfrog	540	180	42	1	172	10.2	16.86	10.2	172
Cle Elum River	0	37	13	0	13	12.2	1.78	12.2	13
Nelson	149	79	29	1	87	7.3	7.13	7.3	87
Easton	209	74	85	3	337	10.7	31.50	10.7	337
2004 Age 1 Wild Spring Chinook									
Thorp	94	29	6	0	25	26.6	0.94	26.6	25
Cle Elum	222	49	2	0	11	9.1	1.21	9.1	11
Bullfrog	540	180	0	0	0	10.2	0	10.2	0
Cle Elum River	0	37	0	0	0	12.2	0	12.2	0
Nelson	149	79	2	0	6	7.3	0.49	7.3	6
Easton	209	74	6	0	23	10.7	2.15	10.7	23
2004 Age 1 Hatchery Spring Chinook									
Thorp	94	29	3	0	13	26.6	0.49	26.6	13
Cle Elum	222	49	1	0	6	9.1	0.66	9.1	6
Bullfrog	540	180	1	0	4	10.2	0.39	10.2	4
Cle Elum River	0	37	1	0	1	12.2	0.14	12.2	1
Nelson	149	79	4	0	12	7.3	0.98	7.3	12
Easton	209	74	11	0	42	10.7	3.93	10.7	42
2005 Age 0 Wild Spring Chinook									
Thorp	33	0	26	0	26	26.6	1	26.6	26
Cle Elum	88	0	48	3	51	9.1	6	9.1	51
Bullfrog	259	0	120	1	121	10.2	12	10.2	121
Cle Elum River	99	3	52	0	54	12.2	4	12.2	54
Nelson	51	0	43	0	43	7.3	6	7.3	43

Easton	120	2	63	1	65	10.7	6	10.7	65
2005 Age 1 Wild Spring Chinook									
Thorp	33	0	5	0	5	26.6	0	26.6	5
Cle Elum	88	0	0	0	0	9.1	0	9.1	0
Bullfrog	259	0	3	0	3	10.2	0	10.2	3
Cle Elum River	99	3	5	0	5	12.2	0	12.2	5
Nelson	51	0	2	0	2	7.3	0	7.3	2
Easton	120	2	2	0	2	10.7	0	10.7	2
2005 Age 1 Hatchery Spring Chinook									
Thorp	33	0	0	0	0	26.6	0	26.6	0
Cle Elum	88	0	0	0	0	9.1	0	9.1	0
Bullfrog	259	0	0	0	0	10.2	0	10.2	0
Cle Elum River	99	3	0	0	0	12.2	0	12.2	0
Nelson	51	0	0	0	0	7.3	0	7.3	0
Easton	120	2	0	0	0	10.7	0	10.7	0
2006 Age 0 Wild Spring Chinook									
Thorp	11	0	5	2	7	26.6	0.26	26.6	7
Cle Elum	52	5	33	0	36	9.1	3.98	9.1	36
Bullfrog	65	5	54	12	71	10.2	6.97	10.2	71
Cle Elum River	27	0	6	2	8	12.2	0.66	12.2	8
Nelson	11	0	4	0	4	7.3	0.55	7.3	4
Easton	13	9	30	0	51	10.7	4.74	10.7	51
2006 Age 1 Wild Spring Chinook									
Thorp	11	0	0	0	0	26.6	0	26.6	0
Cle Elum	52	5	0	0	0	9.1	0	9.1	0
Bullfrog	65	5	0	0	0	10.2	0	10.2	0
Cle Elum River	27	0	0	0	0	12.2	0	12.2	0
Nelson	11	0	0	0	0	7.3	0	7.3	0
Easton	13	9	2	0	3	10.7	0.32	10.7	3
2006 Age 1 Hatchery Spring Chinook									
Thorp	11	0	0	0	0	26.6	0	26.6	0
Cle Elum	52	5	0	0	0	9.1	0	9.1	0
Bullfrog	65	5	0	0	0	10.2	0	10.2	0
Cle Elum River	27	0	0	0	0	12.2	0	12.2	0
Nelson	11	0	0	0	0	7.3	0	7.3	0
Easton	13	9	0	0	0	10.7	0	10.7	0

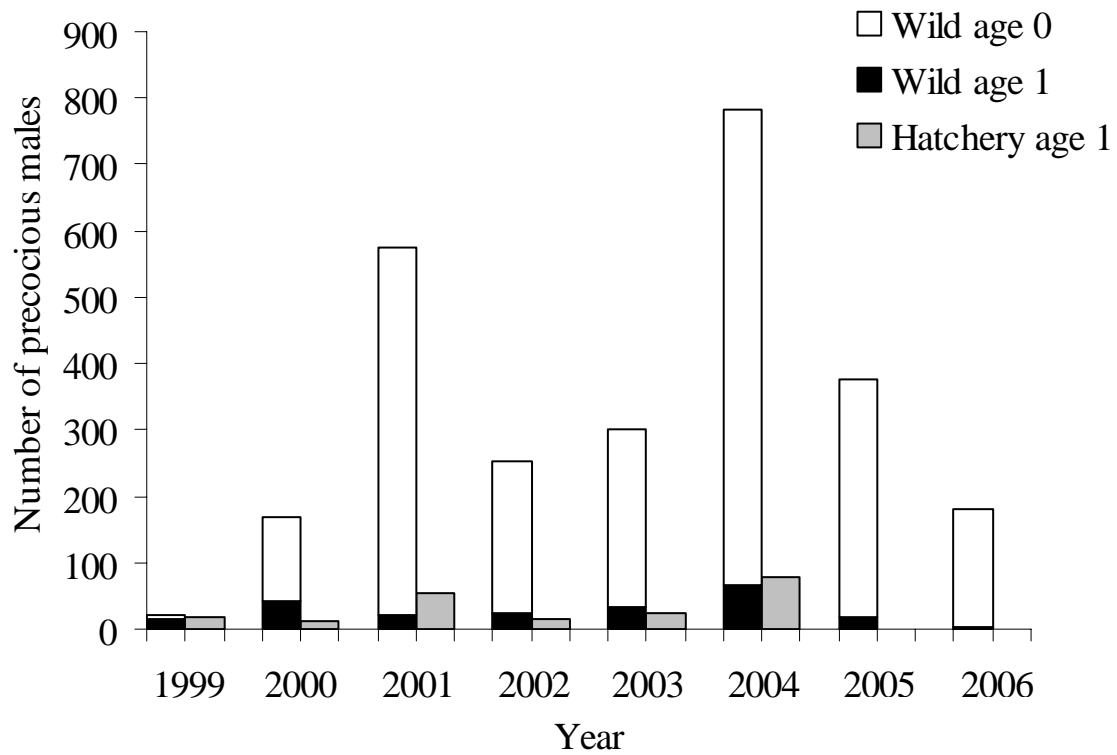


Figure 2. Estimated number of precocious males on the spawning grounds during the peak of spawning activity 1999-2006.

Table 4. Estimated abundance of hatchery origin spring Chinook salmon away from redds in the main stem Yakima River. “n” captured is a mean of the number of fish netted on the left and right bank, sampled over two consecutive nights per section (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 prob.	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 ^a	160 ^a	4.8	33.3	19.2		639
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

^a Generated from a modified Peterson estimate

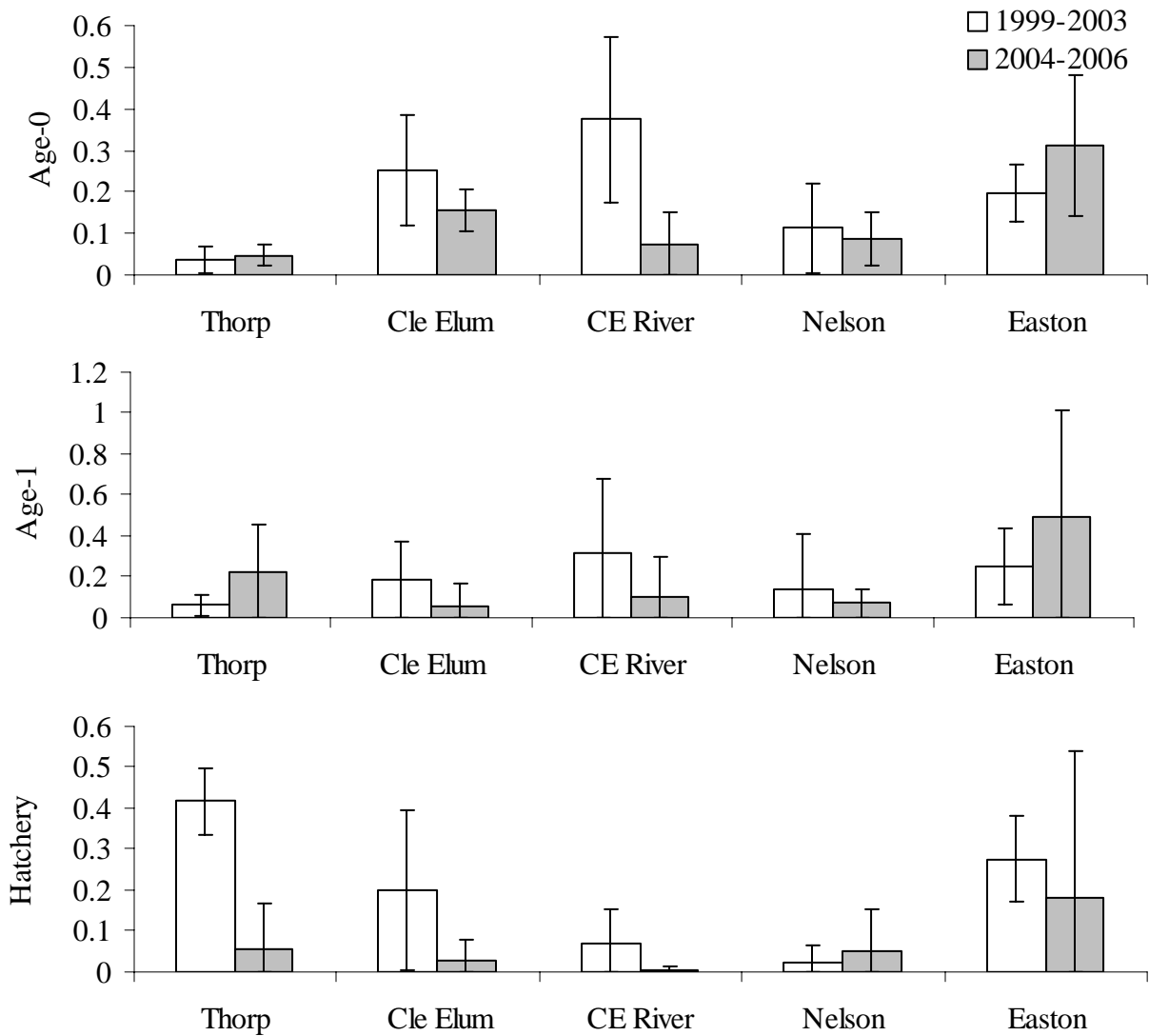


Figure 3. Distribution of spring Chinook par at the peak of spawning activity before implementation of the hatchery growth modulation (1999-2003), and after (2004-2006), by age and origin. Distribution is presented as the mean proportion ($\pm 2SE$) of spring Chinook par observed in each reach. Easton and the Cle Elum River are the most upstream locations, and Thorp is the most downstream location.

Table 5. Include mean and CI for 2004-2006. Estimated number of precocious male spring Chinook per redd and per female estimated to have passed Roza Dam. Redd and female counts are either one or two years removed from the estimated number of precocious males depending upon age class. Hatchery females are the number of females taken for brood from the Roza facility two years prior to observation of their offspring within the study area.

Observation year	n	Upper Yakima redd count	Potential F parents	Precocious males/redd	Precocious males/F
Age 0 Spring Chinook					
1999	5	147	207	0.03	0.02
2000	128	212	312	0.6	0.41
2001	555	3,770	6527	0.15	0.09
2002	228	3,260	6469	0.07	0.04
2003	267	2,816	5057	0.09	0.05
Mean	236.6	2041.0	3714.4	0.2	0.1
CI	179.5	1518.7	2812.4	0.2	0.1
2004	707	868	874	0.81	0.81
2005	360	3414	5630	0.11	0.06
2006	177	1996	3093.1	0.09	0.06
Mean	414.7	2092.7	3199.0	0.3	0.3
CI	304.6	1443.6	2693.0	0.5	0.5
Age 1 Spring Chinook					
1999	16	413	655	0.04	0.02
2000	42	147	207	0.29	0.2
2001	21	212	312	0.1	0.07
2002	25	3,770	6527	0.01	4.0E-03
2003	35	3,260	6469	0.01	0.01
Mean	27.8	1560.4	2834.0	0.1	0.1
CI	9.3	1574.3	2935.5	0.1	0.1
2004	66	2,816	5057	0.02	0.01
2005	17	868	874	0.02	0.02
2006	3	3414	5630	8.8E-04	5.3E-04
Mean	28.7	2366.0	3853.7	1.4E-02	1.0E-02
CI	37.4	1506.5	2938.0	1.2E-02	1.1E-02
Age 1 Hatchery Spring Chinook					
1999	19	-	133	-	0.14
2000	11	-	199	-	0.06
2001	53	-	222	-	0.24
2002	14	-	279	-	0.05
2003	24	-	225	-	0.11
Mean	24.2	-	211.6	-	0.1
CI	14.8	-	46.3	-	0.1
2004	75	-	261	-	0.29

2005	0	-	201	-	0
2006	0	-	246	-	0
Mean	25	-	236	-	0.1
CI	49.0	-	35.3	-	0.2

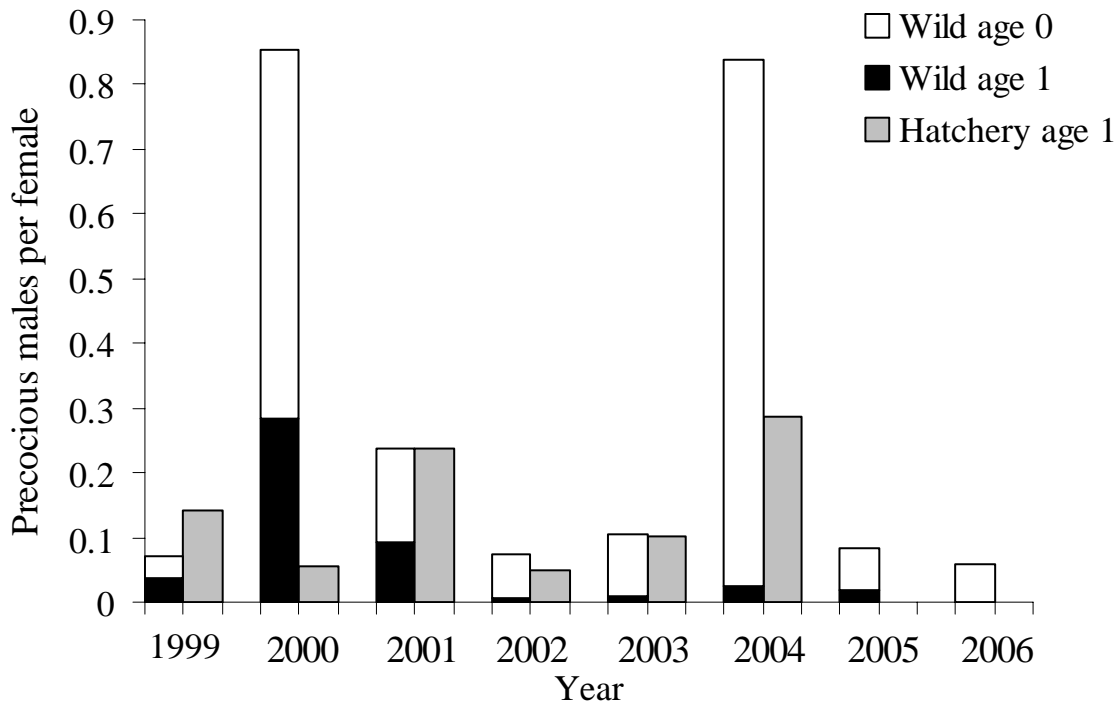


Figure 4. Estimated number of precocious male progeny on the spawning grounds, at the peak of spawning activity, per female spawner. Wild female parents were estimated using redd counts.

Agonistic interactions among precocious males were recorded while visually observing 10 redds in 2003, 20 redds in 2004, 4 redds in 2005 and 3 redds in 2006. Five redds were sampled twice in 2004, however these were considered independent due to temporal separation of 5-7 days and different numbers of precocious males on the redds. The composition of total fish present, and within the observed focal group of each redd is summarized in Table 6. Agonistic interactions during 2005 were only seen between wild age 0 fish. Larger fish were dominant in both hatchery age 1 by wild age 0, and wild age 1 by wild age 0 contests (Table 7; Figure 5; $P < 0.05$). Contests between hatchery and wild age 1 spring Chinook were too few to conduct adequate tests. A difference was observed in the frequency of interaction types initiated by wild age 0 and age 1 and directed towards each other, but no difference of interaction type was detected between age class and origin either independently or within the proportion of contact and non-contact interactions (Table 8; Figure 6; $P > 0.05$)

Table 6. Composition of spring Chinook salmon on redds while behavioral interactions were observed. The focal grouping includes those fish that were observed. The total encompasses all of the fish on the redd. “Spc” and “Hspc” denote either wild or hatchery origin spring Chinook respectively, with the number indicating age. “SpcF” and “SpcM” denote spring Chinook adult females and males respectively. Observation number (Obs #) may be cross-referenced with both Tables 7 and 8.

Site	Date	Redd #	Obs #	Mean Focal					Mean Total					
				Spc 0	Spc 1	Hspc	SpcF	SpcM	Spc 0	Spc 1	Hspc	SpcF	SpcM	
Cle Elum	9/17/03	1	1	3						4		1		
Cle Elum	9/15/04	2	2	1	1			1		1	1		1	2
Cle Elum	9/20/04	2	3	3			1	1		3			1	1
Cle Elum	9/15/04	3	4	2			1			2			1	
Cle Elum	9/20/04	3	5	3		1		6		3		1	1	6
Cle Elum	9/15/04	4	6	3				3		3				3
Cle Elum	9/20/04	4	7	2	1	2		3		2	1	2	1	3
Cle Elum	9/20/04	5	8			1		3		1		1	1	5
Cle Elum	9/20/04	6	9	3			2	4		3			2	6
Nelson	9/13/04	7	10	2			1			2			1	
Nelson	9/21/04	7	11	1		1		2		2		1	1	2
Nelson	9/13/04	8	12	3	2					5	2			
Easton	9/19/03	9	13	5	1					7	1		1	1
Easton	9/21/03	10	14	6						14			1	2
Easton	9/23/03	10	15	4	2					8	2		1	1
Easton	9/22/03	11	16	5	1					9	1		1	3
Easton	9/22/03	12	17	6	6					6	6		1	5
Easton	9/23/03	13	18	5			1			9			1	
Easton	9/24/03	14	19	6	1					7	2		1	3
Easton	9/25/03	15	20	5	1					9	1		1	1
Easton	9/26/03	16	21	8		2		3		18		2	1	4
Easton	9/13/04	17	22	3	1	1				8	2	1		
Easton	9/13/04	18	23	3	2					3	2			
Easton	9/14/04	19	24	3	2	3				3	2	3	1	2
Easton	9/16/04	20	25	4	1					5	1		1	1
Easton	9/17/04	21	26	5	1	1				5	1	1		
Easton	9/17/04	22	27	7						7	1			
Easton	9/29/04	23	28	6	1	1	1	1		6	2	1	1	3
Easton	9/29/04	24	29	3	3		1	1		3	3		1	1
Easton	9/29/04	25	30	1	1	2	1	5		1	1	2	1	5
Easton	10/3/05	100	31	10						10			1	3
Easton	10/3/05	104	32	5						13			1	1
Easton	10/4/05	112	33	5	2					5	2		1	2
Easton	10/5/05	105	34	3						3				1
Easton	9/26/06	17	1	6	0	0	1	0		6	0	0	1	0
Easton	9/27/06	3	2	4	0	0	1	0		4	0	0	2	1

Easton	10/4/06	21	3	2	0	0	0	0	4	0	0	0	0
Easton	10/5/06	21	4	3	0	0	0	0	3	0	0	0	0

Table 7. Behavioral interactions observed among spring Chinook salmon on active redds at the time of spawning. Spc 0, spc 1 and Hspc are natural origin age 0, natural origin age 1 and hatchery origin age 1 spring Chinook respectively. The fish that began an interaction was termed the initiator, while the receiving fish was termed the recipient. Large (L) and small (S) indicate the relative size of the competitors. Dominance was assigned to the fish that maintained or defended its position, or moved another fish from an area previously occupied. The dominant fish was to the left of the “>”. “Neither” was defined as no clear dominant. “Jack” were 2 year old males. Percentage totals may be slightly less than or greater than 100 in cases where table formatting prevents the presentation of an extended number of figures.

Date	Observation	Contests	Interactions per Contest	% Dominance			% Dominance by size		
				Initiator	Recipient	Neither	L > S	S > L	Neither
Spc 0 x Spc 0									
9/17/03	1	3	3.0	83	0	17	33	50	17
9/19/03	13	22	2.2	47	17	36	58	6	36
9/21/03	14	13	1.8	42	15	42	46	12	42
9/22/03	16	13	1.7	56	0	44	52	4	44
9/22/03	17	7	2.0	64	0	36	64	0	36
9/23/03	18	12	1.1	88	0	13	88	0	13
9/23/03	15	24	1.7	62	0	38	19	43	38
9/24/03	19	10	1.7	68	0	32	38	30	32
9/25/03	20	21	1.5	79	0	21	76	3	21
9/26/03	21	13	1.3	77	8	15	69	15	15
9/13/04	10	33	1.4	49	19	32	16	53	32
9/13/04	12*	3 ²	1.7	50	17	33	50	25	25
9/13/04	22	6	1.3	100	0	0	83	17	0
9/13/04	23	7	1.5	83	0	17	69	14	17
9/15/04	6	12	1.6	53	22	26	61	13	26
9/16/04	25*	14 ⁸	1.4 ^{1.1}	60	0	40	31	25	44
9/17/04	26*	13 ¹⁰	1.5 ^{1.4}	78	0	21	0	80	20
9/17/04	27*	12 ³	1.1 ^{1.0}	46	8	46	68	19	13
9/20/04	5	4	1.8	71	0	29	71	0	29
9/20/04	7	7	2.4	53	3	44	56	0	44
9/20/04	3	6	2.0	17	46	38	33	29	38
9/20/04	9	1	2.0	50	50	0	25	25	50
9/29/04	28*	18 ¹⁴	2.3 ^{1.8}	61	0	39	8	62	30
9/29/04	29*	4 ³	2.3 ^{2.3}	38	8	54	0	44	56
10/3/05	100	18	2	71	3	25	61	5	34
10/3/05	104	23	2	67	0	33	63	0	37
10/4/05	105	6	1	100	0	0	100	0	0
10/5/05	112	34	1.1	84	9	7	90	0	10
9/26/06	1	9	1.5	66.7	0	33.3	66.7	0.0	33.3
9/27/06	2	36	1	44.4	2.8	52.8	33.3	13.9	52.8

10/4/06	3	7	1	42.9	14.3	42.9	57.1	0.0	42.9
10/5/06	4	15	1	60	0	40	60.0	0.0	40.0
Avg.		14.2	1.7	62.8	7.6	29.6	51.4	18.4	30.2

Spc 0 x Spc 1

9/22/03	16	1	1.0	0	0	100	0	0	100
9/22/03	17	3	1.0	0	33	67	33	0	67
9/23/03	15	4	1.0	0	50	50	50	0	50
9/13/04	12	3	1.0	0	33	67	33	0	67
9/14/04	24	1	1.0	0	0	100	0	0	100
9/16/04	25	4	1.0	0	75	25	75	0	25
9/17/04	26	2	1.0	0	50	50	50	0	50
9/21/04	11	1	1.0	0	0	100	0	0	100
9/29/04	28	6	1.2	8	0	92	0	8	92
9/29/04	29	1	1.0	100	0	0	0	100	0
Avg.		2.6	1.0	10.8	24.2	65.0	24.2	10.8	65.0

Spc 1 x Spc 0

9/22/03	16	2	2.5	42	0	58	42	0	58
9/22/03	17	5	1.6	77	0	23	77	0	23
9/23/03	15	6	1.0	100	0	0	100	0	0
9/24/03	19	4	1.0	75	25	0	75	25	0
9/25/03	20	4	1.0	100	0	0	100	0	0
9/13/04	12	6	1.6	22	47	31	22	47	31
9/13/04	22	14	1.4	100	0	0	100	0	0
9/13/04	23	5	1.0	100	0	0	100	0	0
9/14/04	24	1	1.0	100	0	0	100	0	0
9/16/04	25	16	1.0	100	0	0	100	0	0
9/20/04	7	1	1.0	100	0	0	100	0	0
9/21/04	11	1	1.0	0	100	0	0	100	0
9/29/04	28	9	1.4	39	43	19	39	43	19
9/29/04	29	3	1.3	67	17	17	67	17	17
Avg.		5.5	1.3	72.9	16.5	10.5	72.9	16.5	10.5

Spc 1 x Spc 1

9/22/03	17	3	2.3	28	0	72	28	0	72
9/13/04	12	7	1.3	57	21	21	57	21	21
9/14/04	24	3	1.0	67	0	33	33	33	33
9/29/04	29	3	1.7	33	33	33	67	0	33
Avg.		4.0	1.6	46.2	13.7	40.1	46.2	13.7	40.1

Hspc x Spc 0

9/26/03	21	8	1.5	79	0	21	79	0	21
9/13/04	22	1	1.0	100	0	0	100	0	0
9/14/04	24	3	1.0	100	0	0	100	0	0
9/17/04	26	4	1.5	75	0	25	75	0	25

9/20/04	5	9	1	70	9	22	70	9	22
9/21/04	11	1	2.0	50	0	50	50	0	50
9/29/04	28	2	2.0	25	0	75	25	0	75
Avg.		4	1.5	71.3	1.2	27.5	71.3	1.2	27.5
Spc 0 x Hspc									
9/26/03	21	1	2.0	0	0	100	0	0	100
9/13/04	22	2	1.0	0	0	100	0	0	100
9/17/04	26	2	1.0	0	50	50	50	0	50
9/20/04	8	1	1.0	0	100	0	100	0	0
9/29/04	28	1	1.0	0	100	0	100	0	0
Avg.		1.4	1.2	0	50	50	50	0	50
Hspc x Spc 1									
9/14/04	24	3	1.0	0	0	100	0	0	100
9/29/04	28	1	1.0	100	0	0	n/a	n/a	n/a
Avg.		2	1.0	50	0	50	n/a	n/a	n/a
Spc 1 x Hspc									
9/13/04	22	1	1.0	0	0	100	0	0	100
9/14/04	24	4	1.0	100	0	0	50	50	0
Avg.		2.5	1.0	50	0	50	25	25	50
Hspc x Hspc									
9/26/03	21	2	2.0	25	0	75	25	0	75
9/20/04	7	1	4.0	0	0	100	0	0	100
Avg.		1.5	3.0	12.5	0	87.5	12.5	0	87.5
Jack x Spc 0									
9/22/03	16	1	1.0	100	0	0	100	0	0
9/24/03	19	7	1.0	100	0	0	100	0	0
9/26/03	21	2	1.0	50	0	50	50	0	50
9/20/04	3	3	1.0	67	0	33	67	0	33
9/20/04	9	4	1.0	75	0	25	75	0	25
Avg.		3.4	1.0	78.3	0	21.7	78.3	0	21.7
Spc 0 x Jack									
9/21/03	14	1	1.0	50	0	50	0	50	50
9/22/03	16	2	1.0	50	50	0	50	50	0
9/22/03	17	1	3.0	0	33	67	33	0	67
9/24/03	19	2	1.0	0	50	50	50	0	50
9/29/04	30	1	1.0	0	0	100	0	0	100
Avg.		1.4	1.4	20	26.7	53.3	26.7	20.0	53.3
Jack x Spc 1									
9/22/03	17	5	1.0	60	0	40	60	0	40
9/23/03	15	1	1.0	100	0	0	100	0	0
Avg.		3	1.0	80	0	20	80	0	20
Spc 1 x Jack									

9/22/03	17	2	1.5	50	0	50	0	50	50
				Jack x Hspc					
9/26/03	21	3	1.3	67	0	33	67	0	33
9/20/04	8	1	1.0	0	0	100	0	0	100
Avg.		2	1.2	33.3	0.0	66.7	33.3	0.0	66.7
				Hspc x Jack					
9/26/03	21	1	1.0	0	0	100	0	0	100
				Jack x Jack					
9/26/03	21	1	1.0	100	0	0	100	0	0
9/20/04	9	4	1.3	50	13	38	50	13	38
Avg.		2.5	1.1	75	6.3	18.8	75	6.3	18.8

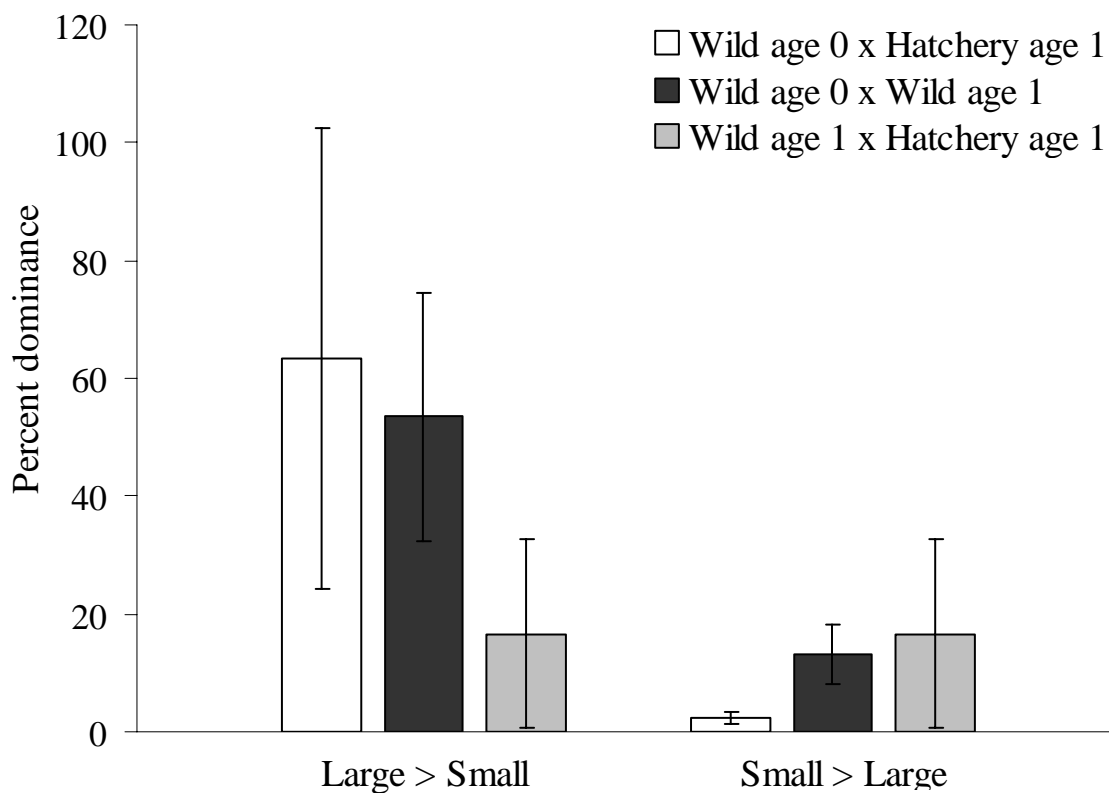


Figure 5. Mean percent dominance by size of competing spring Chinook observed across redds in 2003 and 2004 by age and origin. Data represent only those contests in which dominance by size was observed (e.g., equal size competitors or equal observed dominance is not represented). Error bars represent 95% confidence intervals.

Table 8. Behavioral interaction types observed among spring Chinook salmon on active redds at the time of spawning. Spc 0, Spc 1 and Hspc are natural origin age 0, natural origin age 1 and hatchery origin age 1 spring Chinook salmon respectively.

Date	Observation	Contests	Interactions per contest	% Contact		% Non-Contact		
				Nip	Butt	Chase	Crowd	Threat
Spc 0 x Spc 0								
9/17/03	1	3	3	11.1	0	61.1	27.8	0
9/19/03	13	22	2.2	19.0	0	41.6	32.6	6.8
9/21/03	14	13	1.8	14.1	7.7	15.4	62.8	0
9/22/03	16	13	1.7	34.6	7.7	36.5	13.5	7.7
9/22/03	17	7	2	45.2	0	31.0	23.8	0
9/23/03	18	12	1.1	37.5	12.5	25.0	0	25
9/23/03	15	24	1.7	39.2	0	10.42	36.5	13.9
9/24/03	19	10	1.7	48.3	0	5.00	31.7	15
9/25/03	20	21	1.5	44.4	2.4	29.37	17.5	6.3
9/26/03	21	13	1.3	61.5	0	15.4	23.1	0
9/13/04	10	33	1	20.7	1	17.7	58.1	2.5
9/13/04	12	3	2	16.7	0	0	66.7	16.7
9/13/04	22	6	1	27.8	0	72.2	0	0
9/13/04	23	7	2	11.9	0	38.1	50	0
9/15/04	6	12	2	19.4	0	30.6	50	0
9/16/04	25	14	1	26.2	0	20.2	53.6	0
9/17/04	26	13	1	7.7	0	71.8	20.5	0
9/17/04	27	12	1	0	0	12.5	87.5	0
9/20/04	5	4	2	11.1	16.7	44.4	27.8	0
9/20/04	7	7	2	0	0	0	78.6	21.4
9/20/04	3	6	2	8.3	0	16.7	75	0
9/20/04	9	1	2	0	50	0	50	0
9/29/04	28	18	2	14.1	0	32.4	30.6	23
9/29/04	29	4	2	0	0	8.3	79.2	12.5
10/3/05	100	18	2	28.2	0	66.2	5.6	0
10/3/05	104	23	2	26.8	0	49.3	19.6	4.3
10/4/05	105	6	1	0	0	66.7	33.3	0
10/5/05	112	34	1.1	29.4	0	50.0	20.6	0
9/26/06	1	9	1.5	0	0	33.3	66.7	0
9/27/06	2	36	1	0	0	72.2	25	2.8
10/4/06	3	7	1	14.3	0	42.9	42.9	0
10/5/06	4	15	1	13.3	0	53.3	26.7	6.7
Avg.		13.3	1.6	19.7	3.1	33.4	38.7	5.1
Spc 0 x Spc 1								
9/22/03	16	1	1	0	0	100	0	0

9/22/03	17	3	1	0	0	100	0	0
9/23/03	15	4	1	0	0	100	0	0
9/13/04	12	3	1	0	0	0	100	0
9/14/04	24	1	1	0	0	0	100	0
9/16/04	25	4	1	0	0	0	100	0
9/17/04	26	2	1	0	0	0	100	0
9/21/04	11	1	1	0	0	0	100	0
9/29/04	28	6	1	8.3	0	0	91.7	0
9/29/04	29	1	1	0	0	0	100	0
Avg.		2.6	1.0	0.8	0.0	30.0	69.2	0.0

Spc 1 x Spc 0

9/22/03	16	2	2.5	41.7	16.7	41.7	0	0
9/22/03	17	5	1.6	50	0	36.7	13.3	0
9/23/03	15	6	1	83.3	0	0	0	16.7
9/24/03	19	4	1	0	0	0	100	0
9/25/03	20	4	1	75	0	25	0	0
9/13/04	12	6	1.5	8.3	0	8.3	83.3	0
9/13/04	22	14	1.4	35.7	7.1	50	7.1	0
9/13/04	23	5	1	0	0	20	80	0
9/14/04	24	1	1	0	0	100	0	0
9/16/04	25	16	1	18.9	0	21.6	53.0	2.7
9/20/04	7	1	1	0	0	0	100	0
9/21/04	11	1	1	100	0	0	0	0
9/29/04	28	9	1.4	14.8	0	11.1	53.7	20.4
9/29/04	29	3	1	0	0	33	33	33
Avg.		5.5	1.2	30.6	1.7	24.8	37.4	5.2

Spc 1 x Spc 1

9/22/03	17	3	2.3	38.9	0	27.8	33.3	0
9/13/04	12	7	1	0	0	28.6	50	21.4
9/14/04	24	3	1	0	33.3	66.7	0	0
9/29/04	29	3	2	0	0	11.1	77.8	11.1
Avg.		4	1.6	9.7	8.3	33.5	40.3	8.1

Hspc x Spc 0

9/26/03	21	8	1.5	33.3	0	0	66.7	0
9/13/04	22	1	1	0	0	100	0	0
9/14/04	24	3	1	0	0	100	0	0
9/17/04	26	4	2	16.7	0	33.3	50	0
9/20/04	5	9	1	5.6	0	5.6	77.8	11.1
9/21/04	11	1	2	50	0	0	0	50
9/29/04	28	2	2	25	0	0	25	50
Avg.		4.0	1.5	18.7	0	34.1	31.3	15.9

Spc 0 x Hspc

9/26/03	21	1	2	0	0	0	0	100
9/13/04	22	2	1	0	0	0	100	0
9/14/04	24	1	1	0	0	100	0	0
9/17/04	26	2	1	0	0	0	100	0
9/20/04	8	1	1	0	0	0	100	0
9/29/04	28	1	1	0	0	0	0	100
Avg.		1.3	1.2	0.0	0.0	16.7	50.0	33.3
Hspc x Spc 1								
9/14/04	24	3	1	0	0	0	100	0
9/29/04	28	1	1	0	0	0	100	0
Avg.		2	1	0	0	0	100	0
Spc 1 x Hspc								
9/13/04	22	1	1	0	0	0	100	0
9/14/04	24	4	1	0	0	75	25	0
Avg.		2.5	1	0	0	37.5	62.5	0
Hspc x Hspc								
9/26/03	21	2	2	25	0	0	75	0
9/20/04	7	1	4	0	0	0	0	100
Avg.		1.5	3	12.5	0	0	37.5	50
Jack x Spc 0								
9/22/03	16	1	1	0	0	0	100	0
9/24/03	19	7	1	0	0	0	86	14
9/26/03	21	2	1	0	0	50	50	0
9/20/04	3	3	1	0	0	0	100	0
9/20/04	9	3*	1	0	0	33.3	66.7	0
Avg.		3.2	1.0	0.0	0.0	16.7	80.5	2.9
Spc 0 x Jack								
9/21/03	14	1	1	50	0	0	50	0
9/22/03	16	2	1	0	0	0	50	50
9/22/03	17	1	3	0	0	0	100	0
9/24/03	19	2	1	0	0	0	100	0
9/29/04	30	1	1	0	0	0	100	0
Avg.		1.4	1.4	10	0	0	80	10
Jack x Spc 1								
9/22/03	17	5	1	0	20	20	60	0
9/23/03	15	1	1	0	0	0	100	0
Avg.		3	1	0	10	10	80	0
Spc 1 x Jack								
9/22/03	17	2	1.5	0	0	25	75	0
Jack x Hspc								
9/26/03	21	3	1.3	0	0	0	100	0
9/20/04	8	1	1	0	0	0	100	0

Avg.		2	1.2	0	0	0	100	0
				Hspc x Jack				
9/26/03	21	1	1	0	0	0	100	0
				Jack x Jack				
9/26/03	21	1	1	0	0	0	100	0
9/20/04	9	4	1.3	0	0	63	38	0
Avg.		2.5	1.1	0	0	31.3	68.8	0

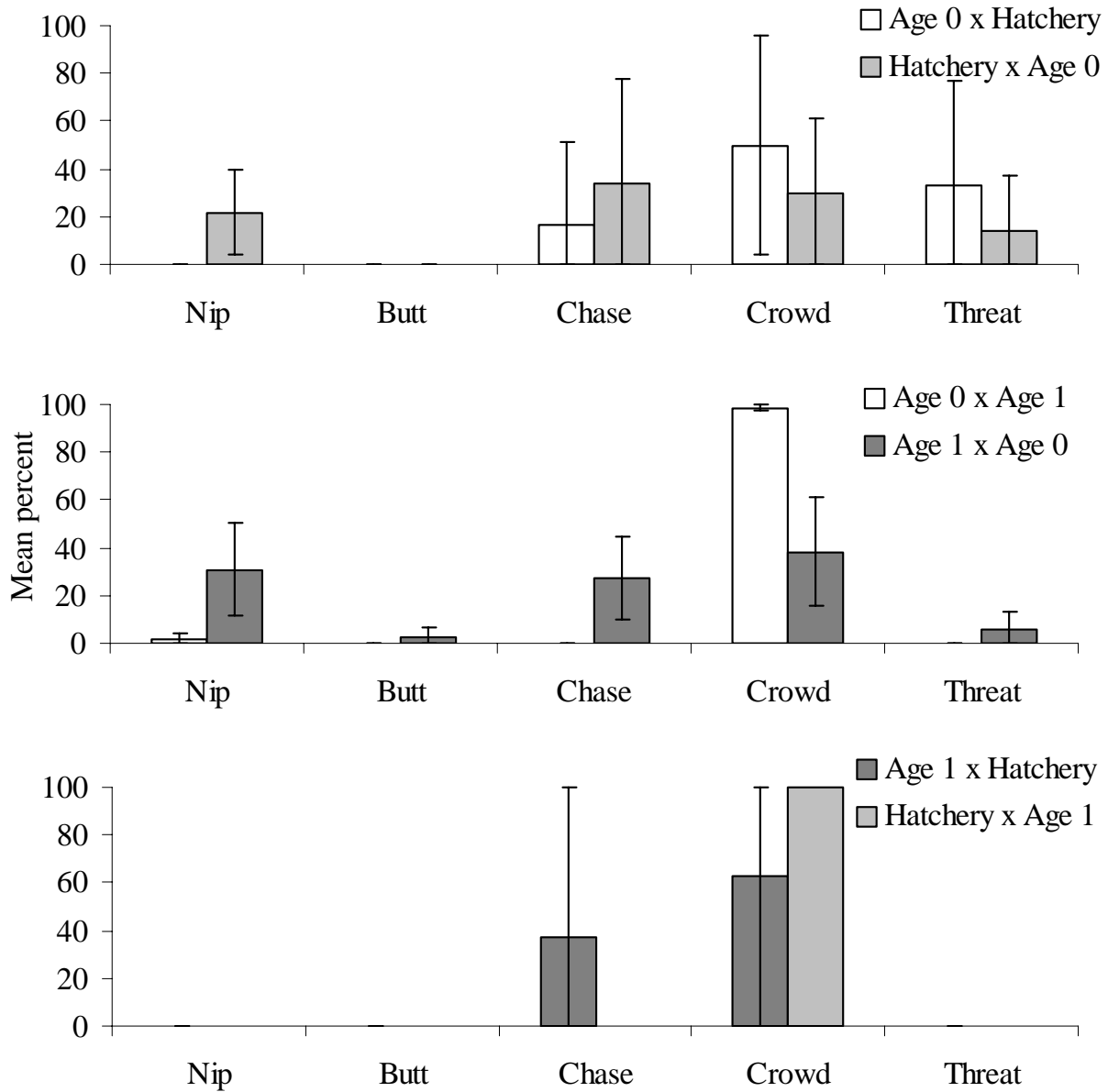


Figure 6. Mean percentage and 95% confidence interval of each interaction type observed among juvenile spring Chinook during 2003 and 2004. Means are calculated on the mean interaction type observed on each redd.

Discussion

Despite the reduction in the number of hatchery precocious males released (Larsen et al. 2004b), we did not detect reductions in the abundance of precocious or residualized males on or off the spawning grounds between 2004 and 2006. We observed considerable annual variation in the abundance of precocious males on and off redds. It is possible that precocious males in 2004 had higher survival in the river or migrated to a lesser degree than in previous years. Very small differences in survival could explain the large numbers of precocious males in 2004 because such a small fraction of the precocious males survive to spawn time. Thus, it is possible that growth modulation would have reduced the number of precocious males in previous years that we studied. The opposite pattern was seen in 2005 and 2006, where we did not count any hatchery precocious males on the spawning grounds. However, there were 1077 (2005) and 8 (2006) precocious males that were inhabiting areas far downstream of spawning areas. It should be noted that our ability to detect statistically significant differences was very low because of high annual variation and small number of replicate years. Thus it is possible that true differences occurred, but could not be detected. It appears that at least 15-30 more years of replicate sampling would be necessary to detect a statistically significant result, if a true difference exists.

Fish that were reared using the growth modulation were smaller at release than the conventionally reared fish. The release of smaller fish may have contributed to production of immature residualized Chinook salmon and also reduced competitive dominance in a small number of contests with wild age 1 precocious males. However, the lengths and proportion of residualized fish that were precocious males during growth modulation does not support the conjecture that smaller fish residualized. Almost all of the residual fish were precociously maturing and they were of similar size as fish in years prior to growth modulation.

Hatchery precocious males continue to be most abundant in areas downstream of spawning locations. The Lower and Upper Yakima Canyon typically contain less than 1% of the upper Yakima Basin redds (Yakama Nation, unpublished data) and yet averaged most of the estimated number of precocious males during the spawning season. Some hypotheses as to why sexually mature hatchery precocious males, most of which are exuding sperm 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; or inability to locate areas with spawning females after they had migrated downstream of spawning areas.

Hatchery precocious males used similar agonistic behaviors and were more likely to initiate and dominate interactions with wild precocious males. 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). However, the production and release of smaller precocious males may decrease the dominance of hatchery precocious males. Interactions between hatchery and natural origin fish were rarely size matched so we don't know which fish is dominant when size is controlled. 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 females and hence more able to fertilize eggs. Dominant fish are better able to choose which locations pose the best chance for spawning success. Our behavioral results suggest that per capita fertilization rates of hatchery precocious males should be higher than that of wild precocious males. However, sneaking strategies may also be successful. Evaluation of these strategies is outside the scope of this manuscript.

Ongoing work in the 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).

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Chapter 4

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

Abstract

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. We evaluated the incidence of predation of residualized hatchery spring Chinook salmon on natural origin *Oncorhynchus mykiss* and Chinook salmon in the Yakima River Basin. Residual spring Chinook were sampled between July and September 1999 to 2004, and between April and September 2005 to 2006. 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 residuals 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 residual 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 (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 their 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. 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).

Residual spring Chinook were sampled between July and September 1999 to 2006. Additional samples were collected in 2005 and 2006 between April and July. 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 for each residual. 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. 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 1999-2006. Percent sample consists of 4 percent in April, 5 percent in May, 13 percent in June, 48 percent in July, 22 percent in August, and 8 percent in September across years (1999-2005). Although attempts were made, no fish were captured after June in 2006.

Year	n	Fork length (mm)			Presence/Absence (%)		
		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
Total/Mean	292	166	133	195	0.2	99.6	0.2
Collected before June 1							
2005	31	132	96	168	0	93.5	6.5
2006	36	105	82	144	0	100	0

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

Table 2. Hatchery spring Chinook found to have fish present in the gut 1999-2006

Section	Date	Predator		Number of		Prey size
		Length (mm)	Prey Type	Prey	Prey	
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 an unfortunate loss of sample in the lab, estimates both prey items around 40 mm in length and deep bodied.

Table 3. Mean length (mm) of potential prey. 1983-89 spring Chinook lengths presented are YKFP 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					
Month	Year	n	Mean			Month	Year	n	X length (mm)	Min	Max
			Length (mm)	Min	Max						
February	1989	-	36								
March- April	1983	25	34								
March-July	1984	237	35*								
June	2005	18	69.7	60	85	June	1995	307	26.2	21	31
July						June	1996	68	25.8	21	30
August	2005	35	81.4	69	97	July	1995	5	25.4	23	27
September	2005	68	97.9	80	116	July	1996	183	24.7	22	29
October	2005	70	89.6	78	108	July	2005	26	40.5	30	48
April	2006	127	39.1	34	48	July	2006	145	40.8	26	70
May	2006	515	43.7	31	59	Sept.	2006	127	69.8	44	105

*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 not

sampled until July, August, or September, except in 2005 and 2006 when earlier collections were made. 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.

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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 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 1999-2006 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. However, 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. 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 salmon

(Schindler et al. 2003), but this relationship has rarely been demonstrated (Naiman et al. 2002). 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 kisutch* 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. 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 carcass material or eggs in the field (2004-2006). Fish were measured for length (FL mm) and weight (g). 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 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 1 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 Temple et al. (2006).

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 was not detected in the field, 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.

Year	Spring Chinook			Rainbow Trout		
	# 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
Total/Mean	2125	0.13	0.34	1821	2.06	0.22

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

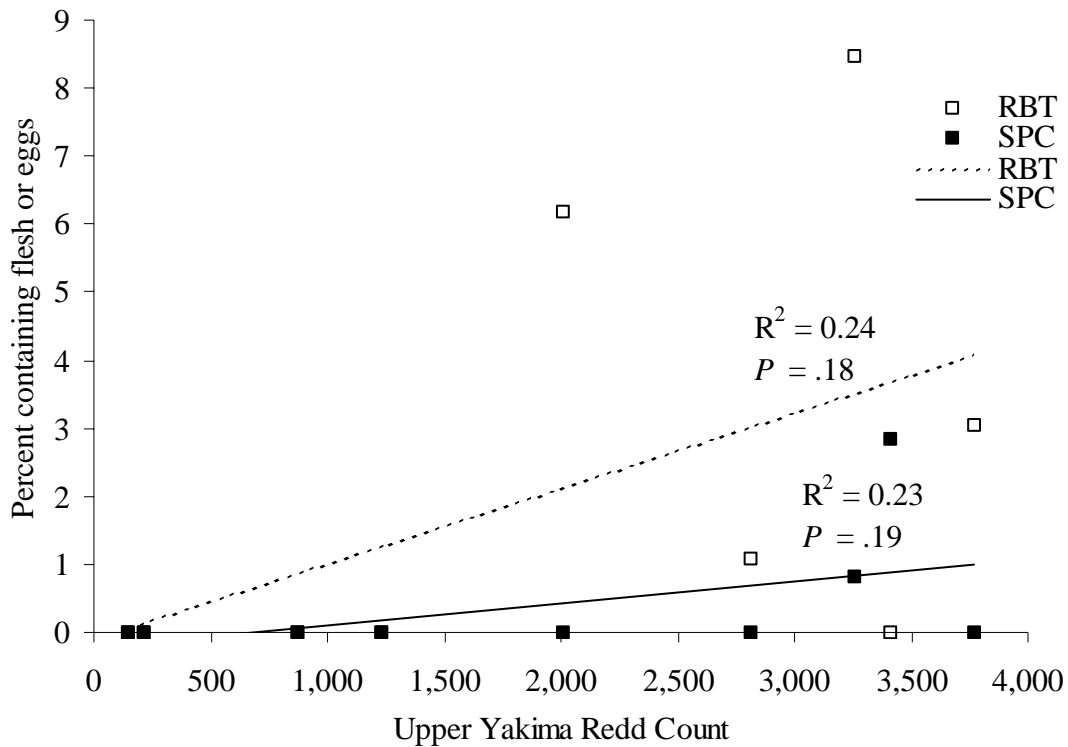


Figure 1. The relationship between the estimated number of redds and the percent of rainbow trout and spring Chinook salmon containing carcass flesh or eggs.

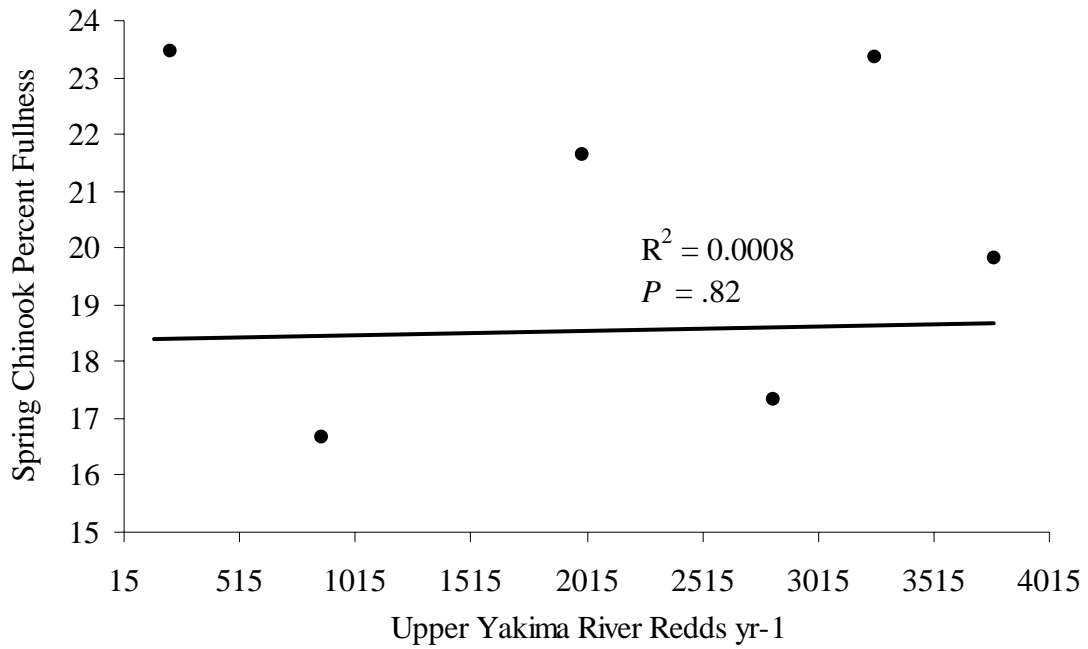


Figure 2. Spring Chinook percent fullness vs. upper Yakima spring Chinook redd counts the previous year.

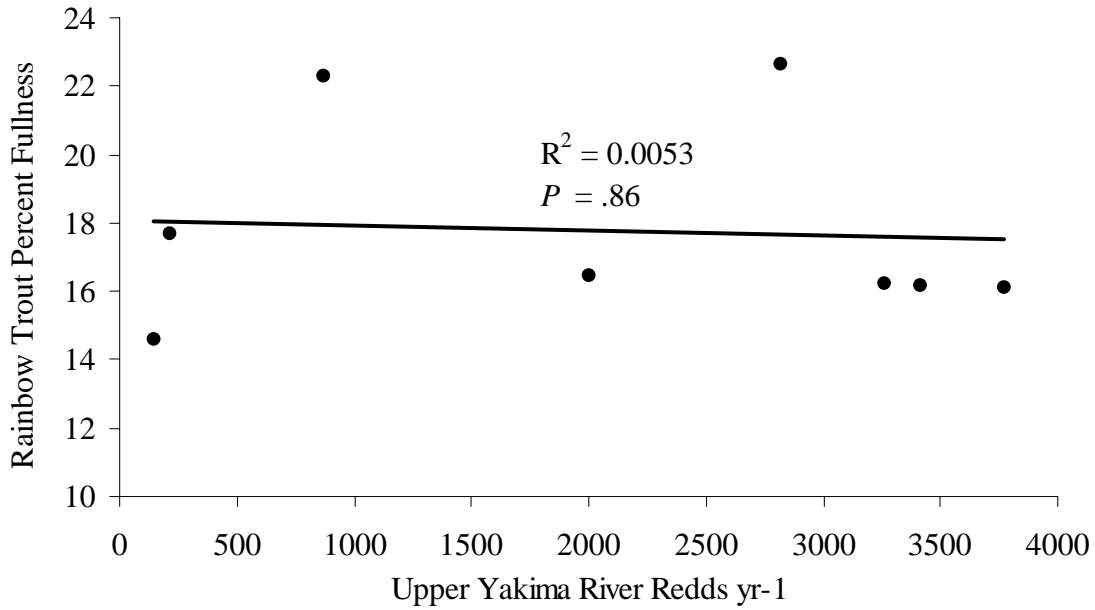


Figure 3. Rainbow trout percent fullness vs. upper Yakima spring Chinook redd counts the previous year.

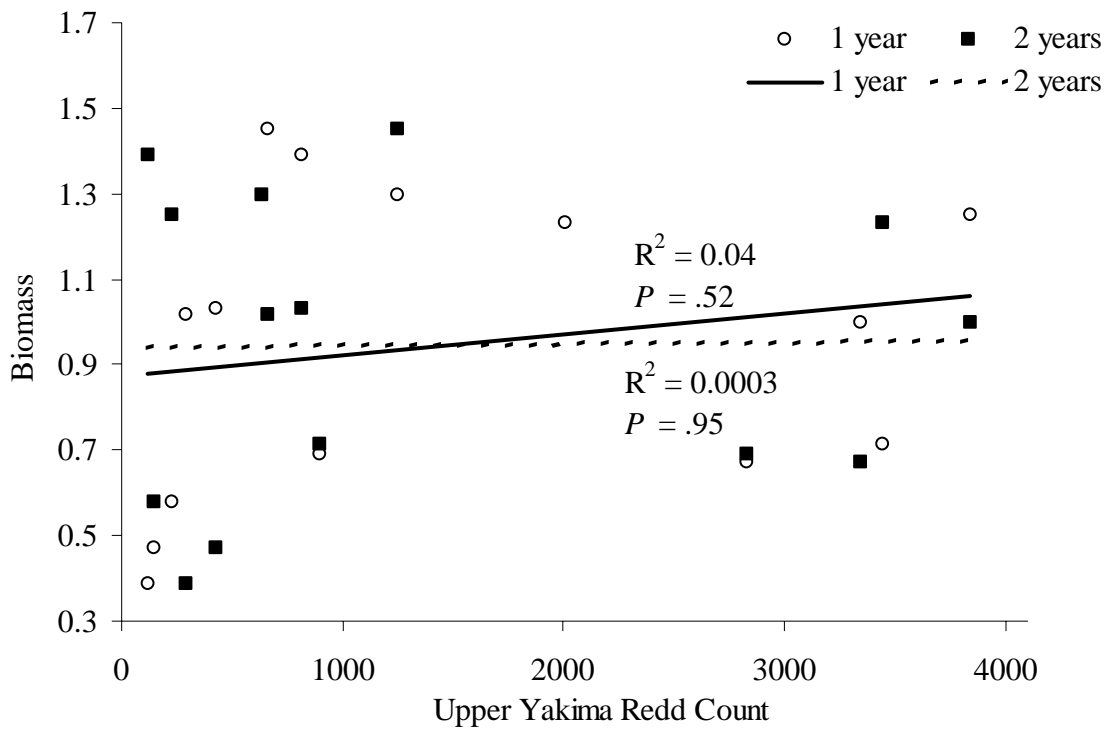


Figure 4. The relationship between upper Yakima River redd counts and the spring Chinook salmon biomass index (kg/km) delayed 1 or 2 years.

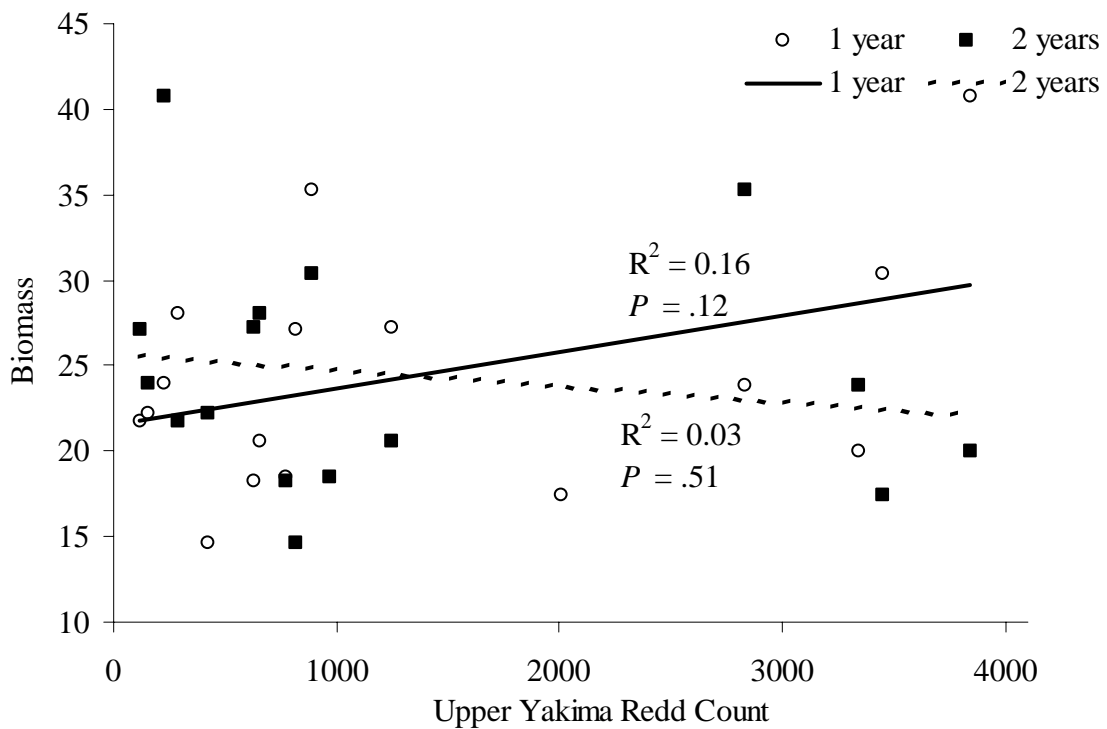


Figure 5. The relationship between upper Yakima River redd counts and the age 1 rainbow trout biomass index (kg/km) delayed 1 or 2 years.

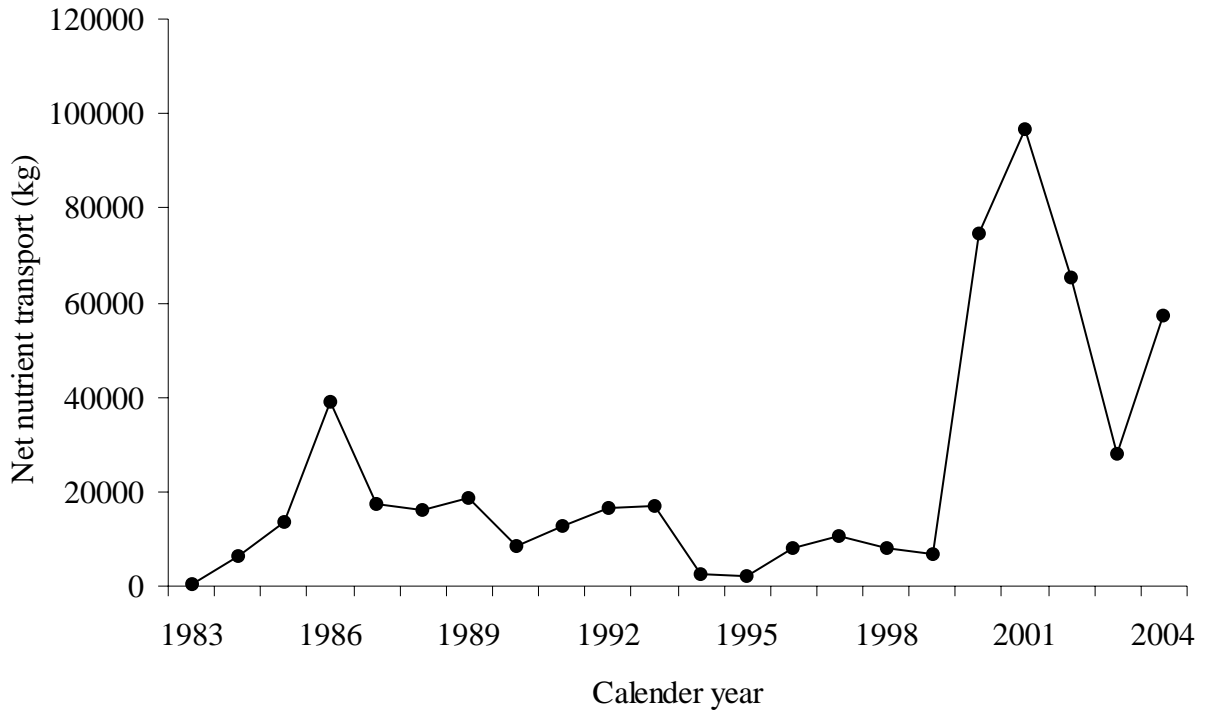


Figure 6. Net transport of nutrients from adult spring Chinook salmon (adult biomass – smolt biomass) into the Yakima River basin.

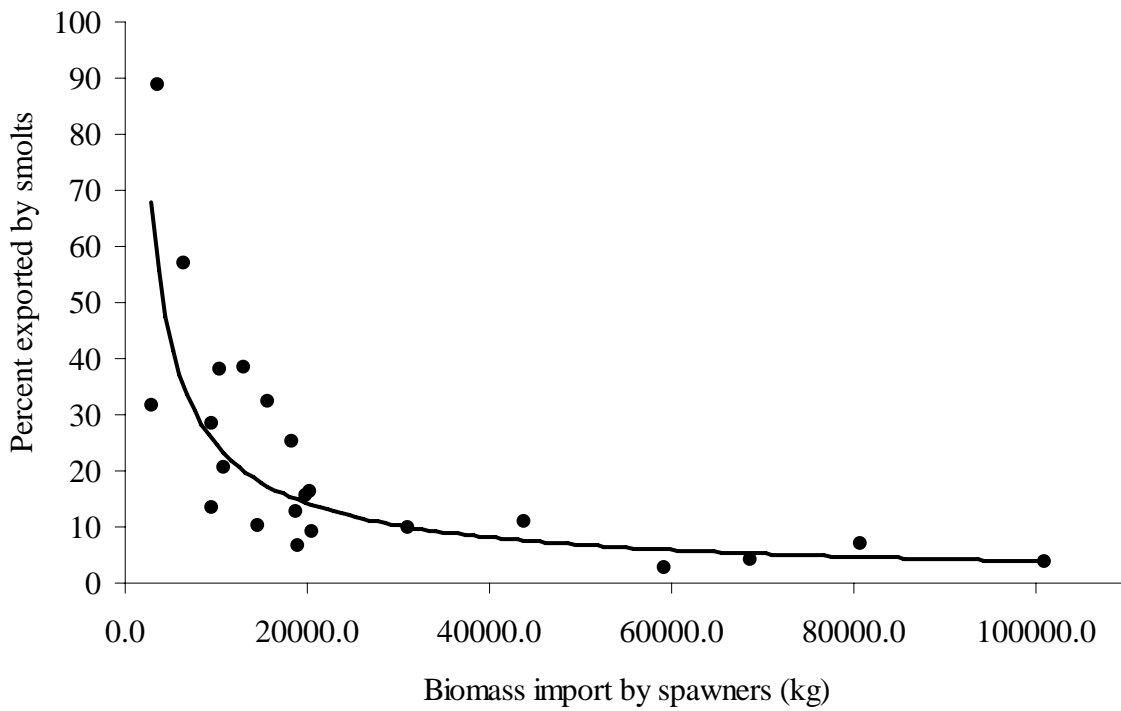


Figure 7. Percent of the spring Chinook salmon adult nutrients that are exported by smolts from the same brood year.

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). 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 was over 8 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 approximately 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 20% of transect locations were habitable in the summer and 90% in the fall in these sections. 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 30% 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. The percent of habitable locations 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. We urge caution in the using the data that we present on the habitat transects because they are likely to be biased. Transects that were very deep were not measured across the whole transect during 2005 and therefore could not be used in the analysis. 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).

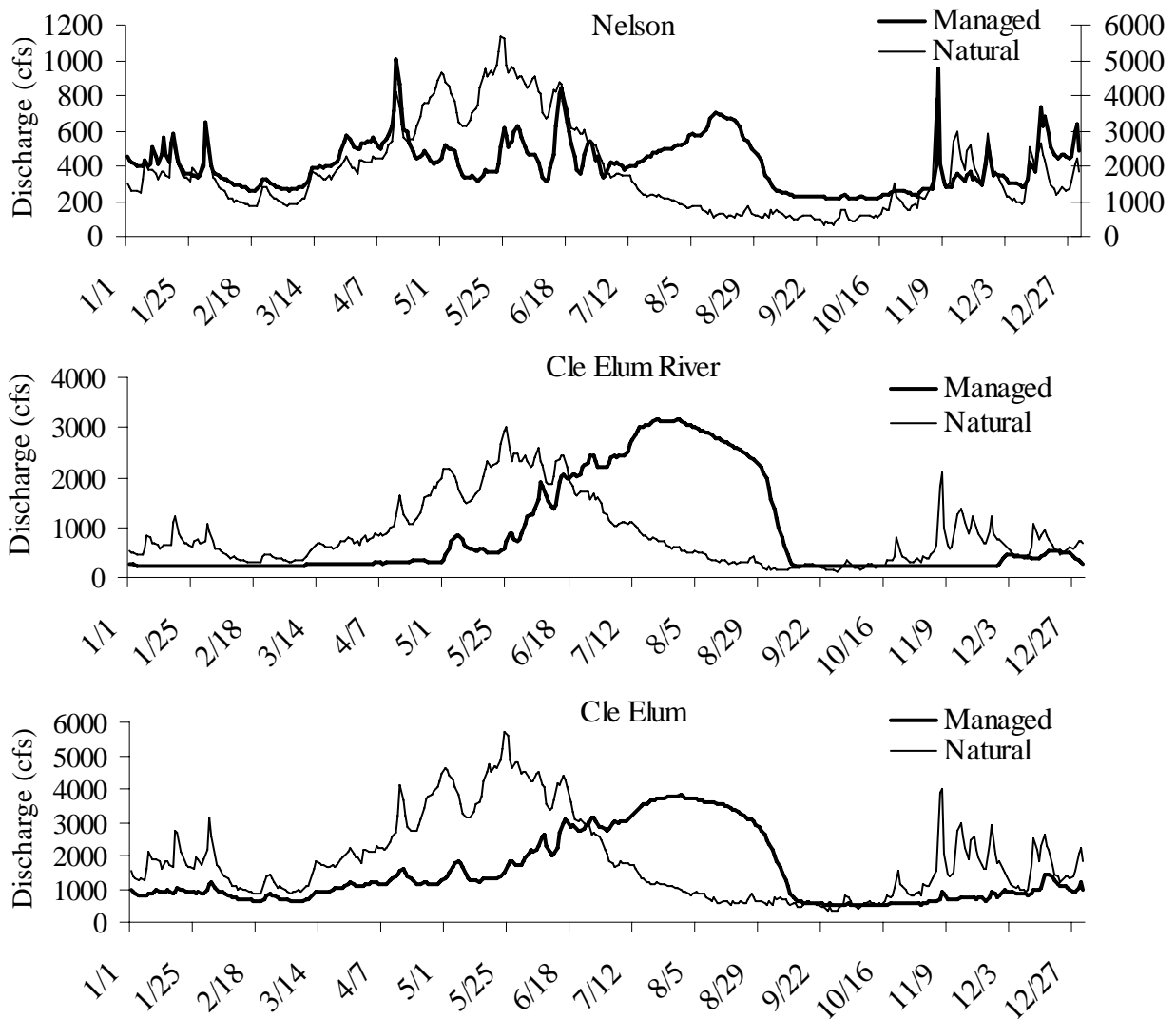


Figure 1. Managed and modeled natural discharge in the Yakima River at Nelson and Cle Elum, and in the Cle Elum River, 1998-2006. Modeled natural flows were not available for the Easton section so scaled data from the modeled natural discharge of the Cle Elum section are presented for comparison.

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 (food). 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 increasing 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 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, our data set 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. Finally we drew maps to assist interpretation of the transect data.

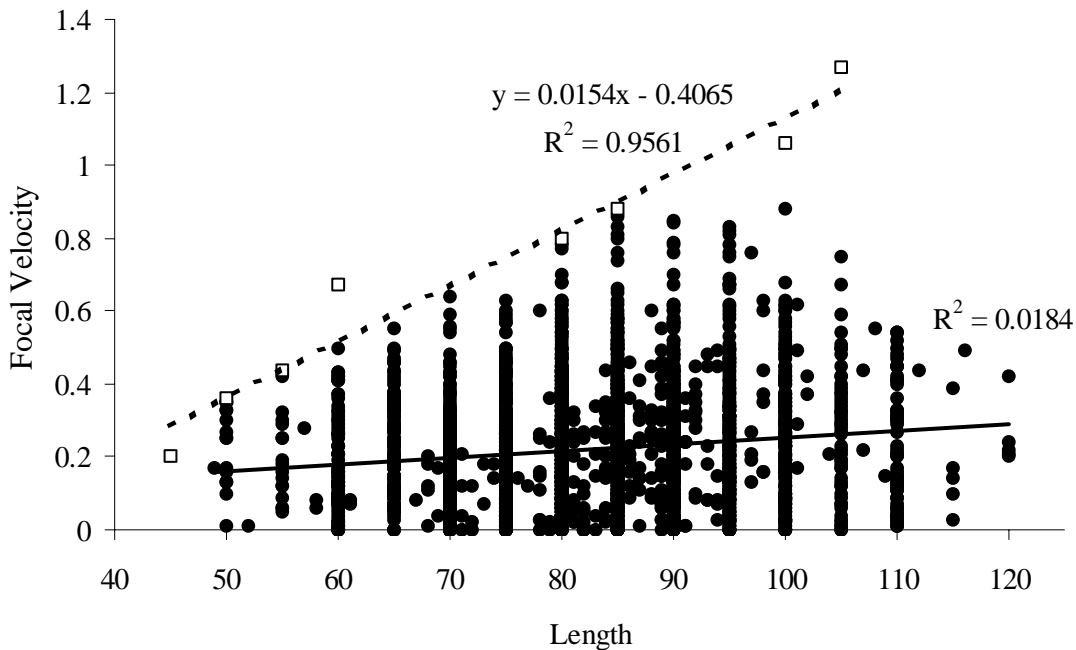


Figure 2. Maximum (dashed line) and mean velocities (m/s) (solid line) measured at age 0 spring Chinook focal positions by size (mm) 1998-2006.

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).

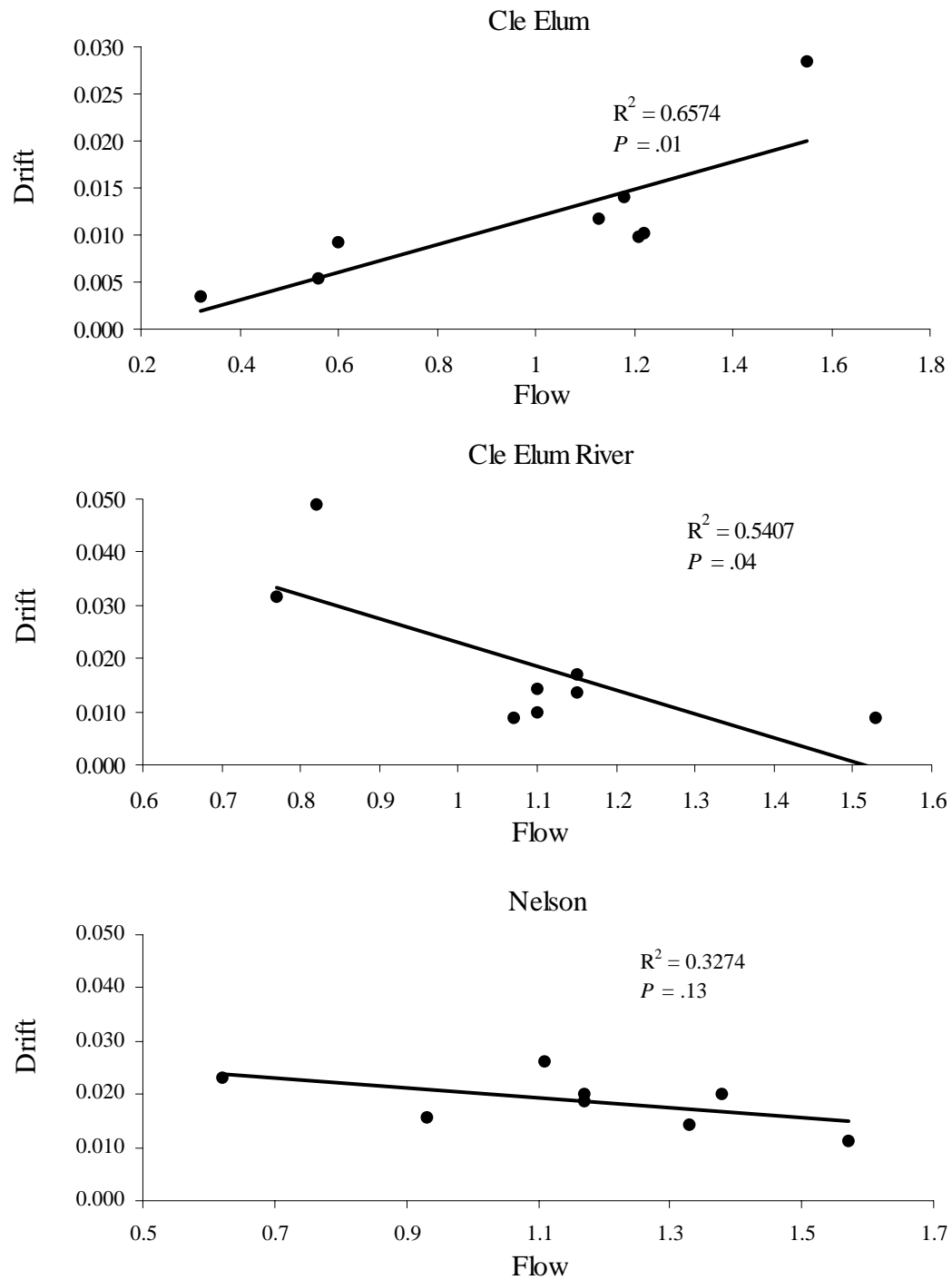


Figure 3. Relationship between flow velocity (m/s) and the rate of invertebrate drift (dry weight, g/hr) at main stem Yakima and Cle Elum River study sites during the summer, 2005.

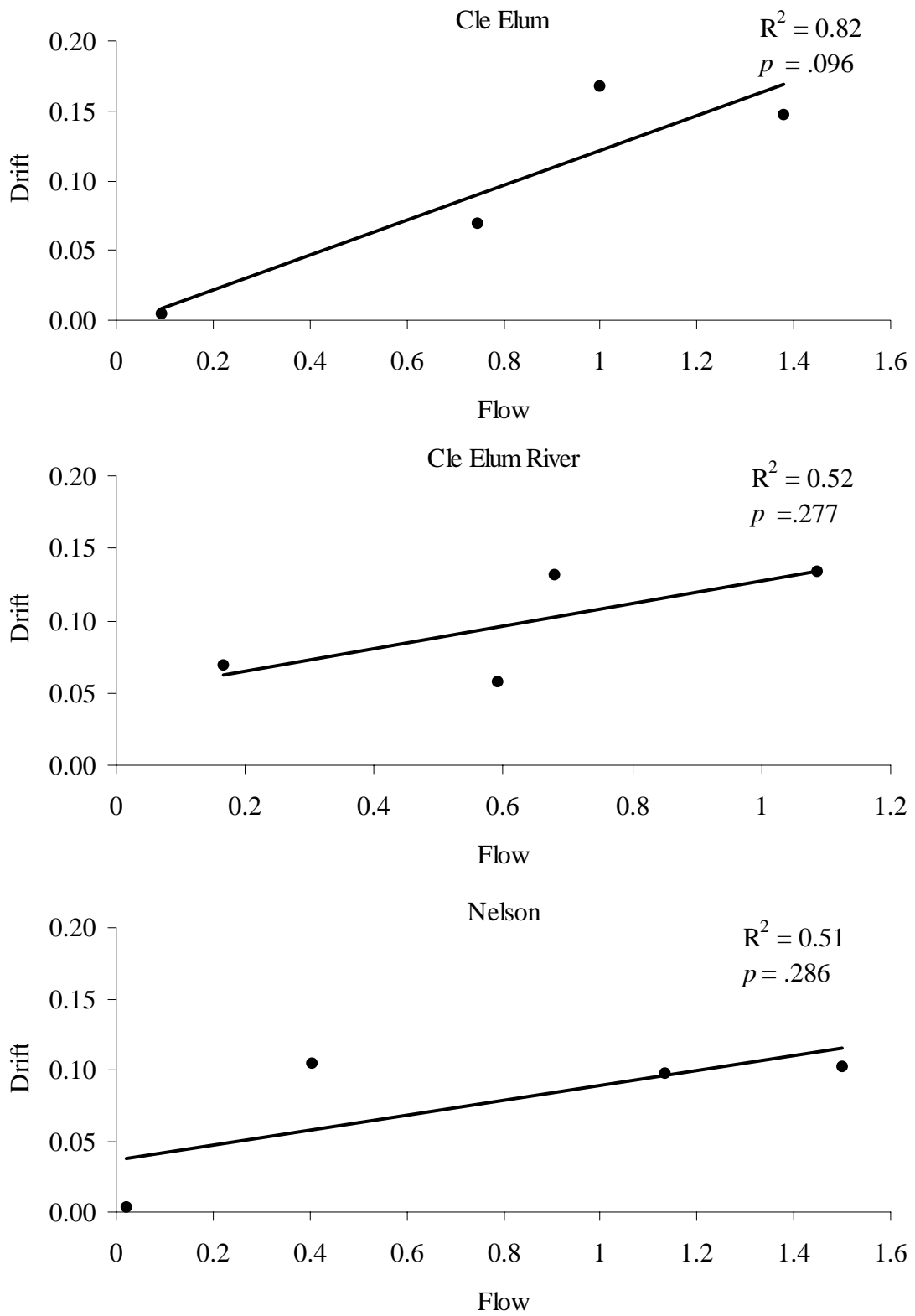


Figure 4. Relationship between flow velocity (m/s) and the rate of invertebrate drift (dry weight, g/hr) at main stem Yakima and Cle Elum River study sites during the summer, 2006.

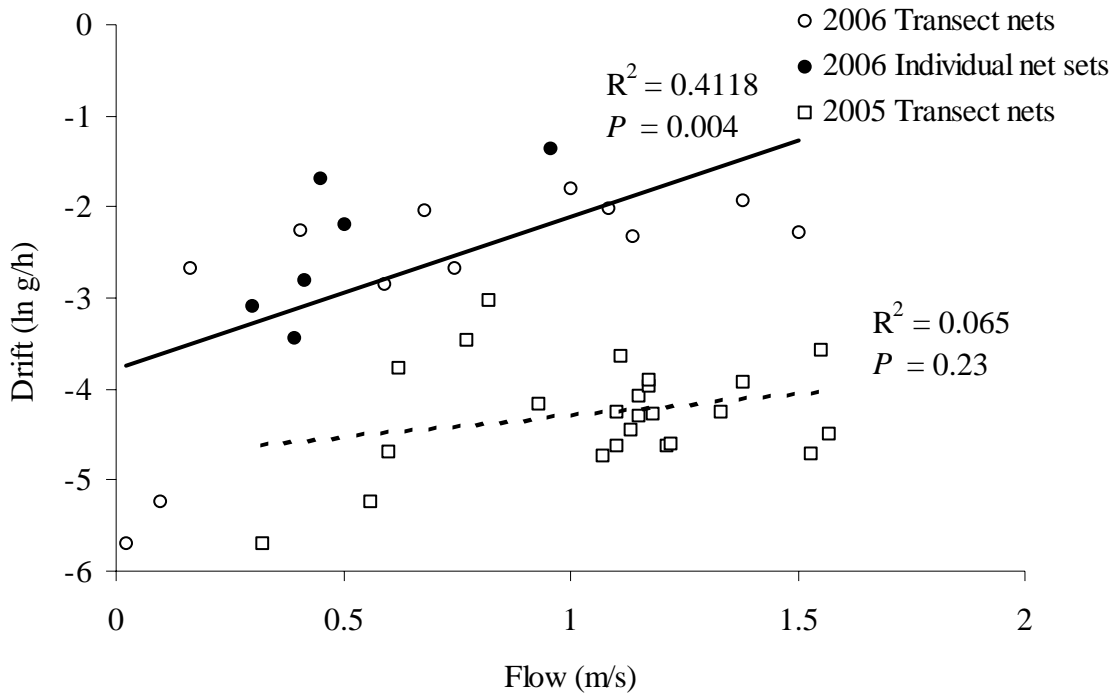


Figure 5. Relationship between flow velocity (m/s) and the rate of invertebrate drift (dry weight, g/hr) at main stem Yakima and Cle Elum River study sites during the summer, 2006 (solid line) and 2005 (dashed line).

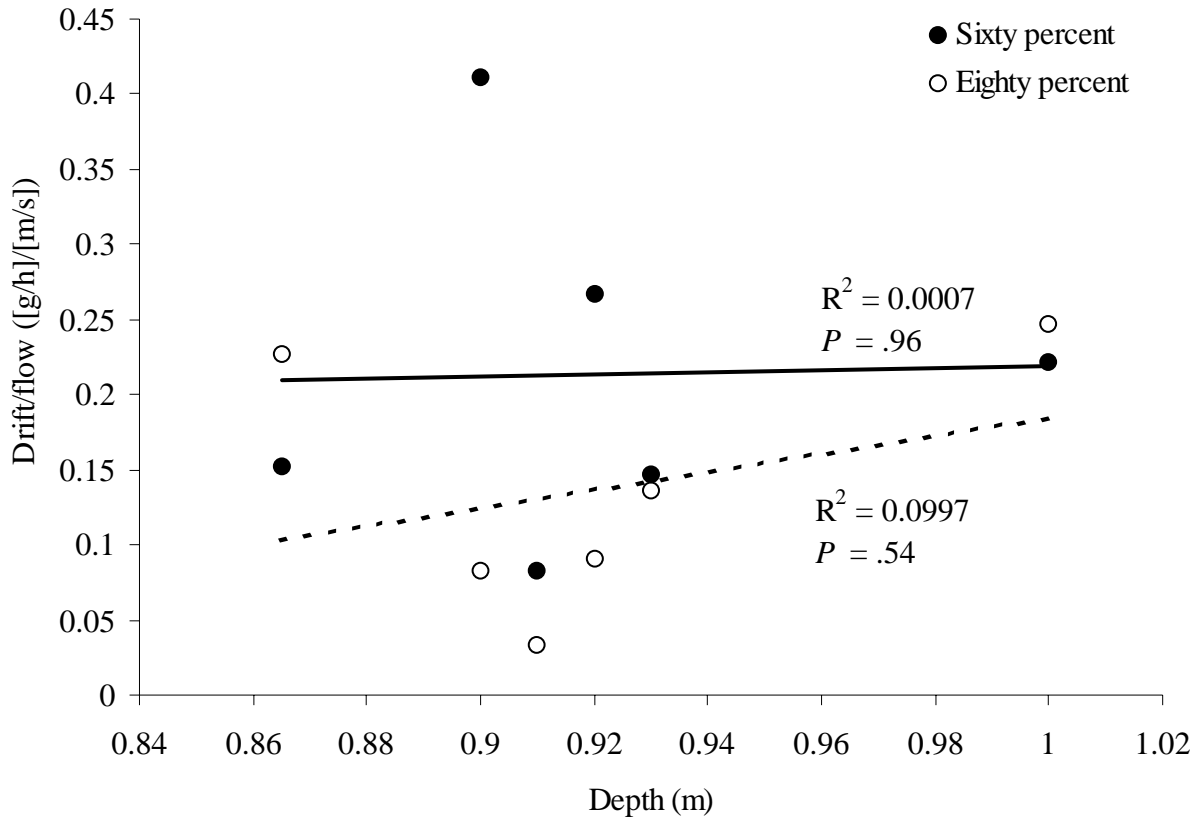


Figure 6. Relationship between invertebrate drift and total depth at 60 percent of the water column (dark line, measured from the water surface), and at 80 percent of the water column (dashed line) 2006.

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 was over 8 times higher in the Cle Elum and Cle Elum River sections during the summer than during the fall (Table 1). The habitable area in these sections was approximately 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 (Table 2). Approximately 20% 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 by about 2 times but decreased the percent of the locations that were habitable by over 4 times, resulting in approximately 100% less habitable areas at artificially high summer 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 30% 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. The percent of habitable locations 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, 2005-2006.

Site	Mean Temperature (C°)	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

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

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

Table 3. Summary of physical parameters measured along transects in the summer and fall of 2005 and 2006.

Site	n	Mean		Mean*	
		Width (m)	SD	Depth (m)	SD
Summer 2005					
Cle Elum	9	35.22	32.7	0.43	0.17
Cle Elum River	13	37.54	16.18	0.41	0.16
Nelson	24	32.02	6.07	0.47	0.1
Mean		34.93	18.32	0.44	0.14
Fall 2005					
Cle Elum	22	37.73	20.72	0.43	0.14
Cle Elum River	27	28.67	10.16	0.41	0.12
Nelson	25	29.08	6.7	0.41	0.11
Mean		31.82	12.53	0.42	0.12
Summer 2006					
Cle Elum	11	50.6	16.5	0.78	0.31
Cle Elum River	15	52.8	19.0	0.81	0.18
Nelson	15	30.6	6.3	0.52	0.18
Mean		44.7	13.9	0.7	0.2
Fall 2006					
Cle Elum	11	48.0	9.5	0.44	0.11
Cle Elum River	15	31.0	7.9	0.38	0.12
Nelson	15	28.9	7.1	0.50	0.22
Mean		36.0	8.2	0.4	0.2

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 (Steingrimssohn 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%).

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 different 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.

The habitable area was similar in 2005 and 2006, despite different discharges and wetted area between the two years. This was because the percentage of maximum habitable locations was lower in summer 2006 than 2005.

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 (see Chapter 1) 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 urge 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. Since the results were similar between 2005 and 2006, it is unlikely that the bias was strong. We intend to continue to reduce the potential for bias in future years.

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 than 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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