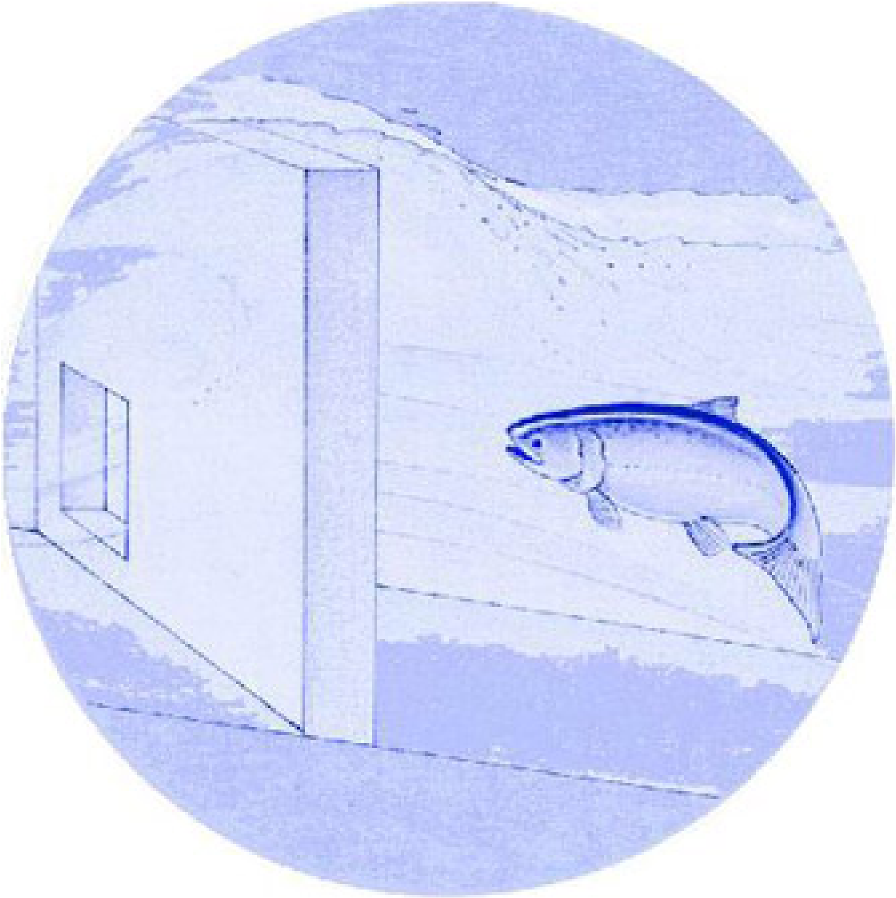
Spring Chinook Salmon Interactions Indices and Residual/Precocial Monitoring in the Upper Yakima Basin

Yakima/Klickitat Fisheries Project Monitoring and Evaluation
Report 5 of 7

Annual Report
2003 - 2004



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

Yakima/Klickitat Fisheries Project Monitoring and Evaluation

Annual Report 2003

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Executive Summary

Select ecological interactions and spring chinook salmon residual/precocial abundance were monitored in 2003 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 precocials). Residual spring chinook salmon do not migrate to the ocean during the normal emigration period and continue to rear in freshwater. Precocials are those salmon that precocially mature in freshwater. The purpose of sampling during 2003 was to continue monitoring interactions indices and residual/precocial distribution and abundance. All sampling that we report on here was conducted in the upper Yakima River during summer and fall.

- 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 was collected during the summer and fall, 1998-2003 in the upper Yakima Basin. The space and food competition indices were highest for spring 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.

- 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 the core microhabitat values 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 River Basin. We measured spring chinook salmon microhabitat variables during the summers of 1998 to 2003 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 decreased with increasing abundance of spring chinook, and the number of fish occupying optimal habitats increased with increasing abundance. Our data may indicate that space is not limiting chinook growth or survival in the upper Yakima basin or that chinook decrease their territorial behavior in response to increasing abundance of conspecifics. We will continue to measure microhabitat use and, along with the food and space competition indices, monitor any changes that may be associated with supplementation activities.

- We examined the hypothesis that the Cle Elum Supplementation Hatchery alters the assemblage of spring chinook salmon that precocially mature in freshwater. We counted the number of precocials on the spawning grounds between 1998 and 2003 while snorkeling in the upper Yakima River. The release of hatchery fish in the spring affected the natural abundance, distribution, age/size, and behavior of precocials observed on redds the following fall. The estimated number of age 0+, age 1+, and hatchery precocials observed on the spawning grounds between 1998 and 2003 during the peak of spawning ranged from 4 to 554, 16 to 42, and 11 to 52 respectively. Females that were spawned in the hatchery produced fewer precocials on redds two years later than females that spawned in the river ($P<0.05$). The lower number of hatchery precocials on the spawning grounds may be due to high mortality of precocials after they are released from the hatchery. During the peak of spawning, between 30% and 52% of all hatchery precocials observed on the spawning grounds within a year were in the lowest spawning reach examined, whereas only 0% to 9% of all age 0+ precocials and 0% to 15% of all wild age 1+ precocials were observed in this reach. Most hatchery precocials were observed downstream of spawning areas during the spawning season. Except for the year 2000, the hatchery precocials per female taken for hatchery broodstock was higher than naturally produced age 1+ precocials per female spawner and the absolute value of the differences was statistically significant ($P<0.05$), but the differences in means was not statistically different ($P>0.05$). The hatchery does not release age 0+ precocials, which is the predominant age of wild precocial, so it decreased the number of this age of precocial. Hatchery precocials were larger ($P>0.05$) and behaviorally dominated most interactions with wild precocials on redds. This could result in higher per-capita reproductive success because of better access to females. Altering natural rates of precocialism and precocial assemblages on the spawning ground poses ecological and genetic risks to wild fish.

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General Introduction

This report examines some of the factors that can influence the success of supplementation, which is currently being tested in the Yakima Basin using 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). 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 precocially 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 precocials (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, precocials, 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. Three areas 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 precocial salmon monitoring (abundance). This report is organized into three chapters to represent these three areas of investigation. Data were collected during the summer and fall, 2003 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). 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.

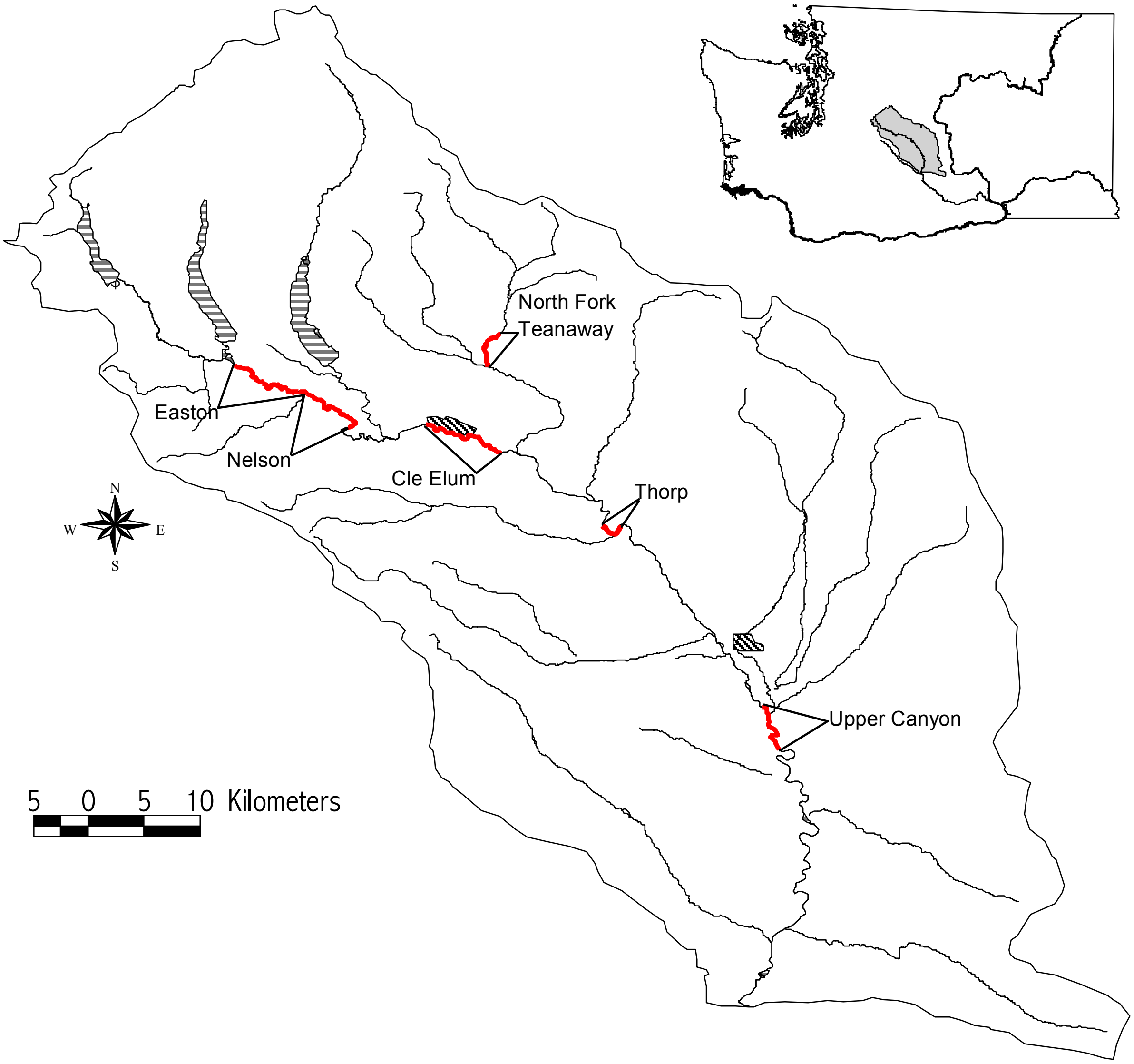

Figure 1. Locations of the study sections in the upper Yakima Basin, Washington. Study sections are identified as thickened sections of the river.

Acknowledgments

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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 was collected during the summer and fall, 1998-2003 in the upper Yakima Basin. The space and food competition indices were highest for spring 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.

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 occur 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 (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). We therefore 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.

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

Methods

Space Competition Index

A spatial competition index is calculated by multiplying a spatial overlap index by a competitor abundance index (1).

$$(\text{Spatial overlap index}) \quad \times \quad (\text{Sympatric abundance index}) \qquad (1)$$

The spatial overlap index is expressed as the percent of observations where the target taxon has at least one competitor overlapping it's "interaction space" (either the same species or a competitor species). "Interaction space" is defined as the average 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 tied 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 competitor abundance index is calculated as the ratio of competitor abundance/target taxon abundance when competitors were within interaction space.

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. Observations were made by having two snorkelers simultaneously snorkel each bank of a section. When conditions allowed, (i.e. shallow water or slow flows) snorkeling was conducted moving upstream, otherwise, observations were made while snorkeling downstream. 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 (Grant and Kramer 1990). Any spring chinook salmon that was more than 30 cm of another fish was counted as a single fish. Data was recorded on a PVC cuff fitted around the snorkelers arm.

Food Competition Index 1

The food competition index is calculated by multiplying a per capita competition index by an index of food consumption by the population of the competitor (1).

$$\text{(Per capita competition index)} \quad \times \quad \text{(Population consumption index)} \qquad (1)$$

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

$$\text{(overlap index)} \quad \times \quad \text{(food availability index)} \qquad (2)$$

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 3.

$$O_{jk} = 100 \times [1 - (1/2 \times \Sigma |p_{ij} - p_{ik}|)] \quad (3)$$

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. For instance, 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 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 growing period 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 line through the maximum stomach dry weights representing a range of fish lengths (Figure 1). 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 by the maximum fullness. This was then standardized to the proportion of the stomach that was empty (4).

$$1 - (\text{Observed fullness} / \text{maximum estimated fullness}) \quad (4)$$

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 (5).

$$(\text{Average stomach content weight}) \quad \times \quad (\text{competitor abundance index}) \quad (5)$$

The stomach content weights for each of the species sampled were averaged, regardless of fish size. The competitor abundance index was the abundance of species observed during night electrofishing in five main stem sections multiplied by our space competition index (6). Relative abundance was originally used as a measure of competitor abundance, however because this is dependant 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 be in very different locations.

$$(\text{number of species z observed}) \times (\text{space competition index}) \quad (6)$$

In summary, the food competition index is calculated by the product of equations 3, 4, 5, and 6.

Food competition index 2 modification

It is widely reported that an increase in water temperature results in an increase in gastric evacuation rate among salmonids. An incorporation of temperature into the food competition index could provide a better indication of food requirements over a 24hr period. A modification of the food competition index 1 was calculated in which temperature was used as a variable.

Rate of evacuation was determined by using Ruggerone's (1988) relationship for the evacuation rate (r_e) of coho. 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.

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

Where T is temperature (^{o}C) and MS is meal size in grams.
Gastric evacuation rates were determined using daily mean temperature (T) and mean monthly stomach wet weight (MS). Our stomach content weights were dry, so a conversion factor was used to approximate wet weight with the assumption that invertebrate dry weight is approximately 18% of total wet weight.

Daily meal was determined by dividing r_e into the mean monthly stomach wet weight and multiplying by 24hrs.

$$(MS/r_e) * 24\text{hrs}$$

Maximum daily meal was determined by using the maximum value from our stomach dry weight regression that corresponded to the mean fork length of predators within a given month and using that in the evacuation equation. Dividing the maximum daily meal into the daily meal and subtracting the resulting proportion from one, gives us a factor for the competition index that incorporates temperature in providing an estimate of stomach fullness.

$$1 - (\text{Daily meal}/ \text{Maximum daily meal}) \quad (7)$$

An index of competitor consumption was determined by multiplying daily meal and competitor abundance.

$$(\text{mean monthly daily meal}) \quad \times \quad (\text{competitor abundance index}) \quad (8)$$

The Per capita food competition index consist of the standard diet overlap described above (equation 3) multiplied by the new measure of stomach fullness (equation 7).

The food competition index is calculated by multiplying the per capita index by the index of competitor consumption (equation 8).

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. USBR Hydromet temperatures within the Cle Elum section were used on a number of dates where thermograph data was unavailable. No temperature data was found within the Cle Elum section for 1998. For that year hydromet data from near Umtanum creek, a site lower on the Yakima River mainstem, was compared to hydromet data at the Cle Elum site over a five-year period and a daily estimate made using a factor derived from the mean monthly difference between the two.

Field Sampling

To determine food availability for juvenile spring chinook salmon we sampled four mainstem sections and one tributary section during the summer and fall in the upper Yakima Basin. The mainstem 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 mainstem, 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 mainstem Teanaway River. Due to differences between the NFT and the mainstem 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 mainstem Yakima River.

Age 0+ spring chinook salmon were collected using several methods. During the day, fish were collected with a backpack electrofisher. When conditions did not favor electrofishing, 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. In 2003, we identified prey items to taxonomic levels identified in Table 1. We did this to determine the level of taxonomic resolution where results would be consistent. These levels were based upon degrees of overlap at higher taxonomic levels. If overlap was low at higher taxonomic levels then we did not identify prey items to lower levels. We subsampled the prey items at lower taxonomic levels and then applied those findings to the whole sample. Contents from each stomach were then dried at 80^0 C for 48 hours and weighed to the nearest 0.0001g. Non-nutritious items, such as caddisfly cases, sticks, and stones were removed from the sample prior to weighing.

Table 1. Taxonomic level of invertebrate identification 2003. Orders listed in the left column were taken only to the ordinal level. Genus listing in bold under their respective order headings belong to the family in bold type.

Order	Diptera		Ephemeroptera		Trichoptera	
	Family	Genus	Family	Genus	Family	Genus
Hemiptera	**Chironomidae**	acricotopus	**Baetidae**	acerpenna	**Hydropsychidae**	ceratopsyche
Hymenoptera	Tipulidae	bryophaenocladius	Siphlonuridae	baetis	Hydroptilidae	cheumatopsyche
Lepidoptera	Ceratapogonidae	cardiocladius	Heptageniidae	dipheter	Glossosomatidae	hydropsyche
Arachnid	Simuliidae	chaetocladius	Ephemerellidae	paracloeodea	Rrhyacophilidae	
Cladocera	Culicidae	chironominae	Leptophlebiidae	paracloeodes	Brachycentridae	
	Empedidae	chironomus	Ephemeridae	procleon	Limnephilidae	
	Thaumaleidae	cricotopus	Tricorythidae	procloeon	Polycentropodidae	
	Scyomyzidae	cricotopus/orthocladius			Phryganeidae	
	Dixidae	diamesinae			Philomotamidae	
	Chaoboridae	eukefferiella			Leptoceridae	
	Athericidae	eukiefferiella			Psychomyiidae	
	Brachyceridae	heleniella			Sericostomatidae	
	Phoridae	heterotrissocladius			Lepidostomatidae	
	Tabaniidae	metriocnemus			Hymenoptera formicidae	
	Doichopodidae	nanocladius			Hymenoptera other	
	Syrphidae	orthocladius				
	Muscidae	paracricotopus				
	Ephydridae	podonomini				
	Pelecorhynchidae	pseudoorthocladius				
	Psychodidae	psuedokiefferiella				
		rheopelopia				
		stempellinella				
		tanypodinae				
		thienemanniella				

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

We tested our assumption that low stomach fullness indicated low food availability by experimentally supplementing food abundance. Snorkelers would locate spring chinook or rainbow trout that were in feeding locations. A dispenser filled with freezed dried krill was attached to a long metal rod and used to release food in the water upstream of the feeding fish. Fish were fed until they were satiated or they left the area. The number of krill that a fish ate was recorded. In some instances we were able to net the fish that we were feeding and collect its stomach contents. We treated the stomach contents the same as in other sampling except that we weighed the krill separately from the other stomach contents.

Results

Space Competition Index

Space competition indices were highest for spring chinook (i.e., intraspecific competition) during all years (Table 2). The next highest index score were for rainbow trout, redside shiner, mountain whitefish, and hatchery spring chinook (Table 3). If all of the interspecific SCI values were added together, they would still be less than the SCI value for spring chinook salmon. High indices for rainbow trout are primarily due to high spatial overlap, whereas high indices for redside shiner is primarily due to localized high abundance (Table 3). SCI values for chinook salmon did not explain a significant amount of variation in growth or survival of chinook salmon and did not improve relationships using chinook salmon abundance alone (Figures 1 and 2).

Table 2. Space competition indices between age 0+ spring chinook salmon and other competitor species within the mainstem 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	
Average 1999-2003				
Species	Spatial overlap	Competitor abundance	Space comp.	Stdev
SPC	0.57	5.24	2.93	0.49
HSPC	0.04	0.28	0.03	0.05
RBT	0.21	0.61	0.16	0.15
MWF	0.06	0.49	0.04	0.05
RSS	0.04	1.68	0.09	0.13
SUK	4.9E-03	0.05	1.1E-04	1.7E-04
COHO	0.02	0.03	5.8E-04	6.6E-05

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

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

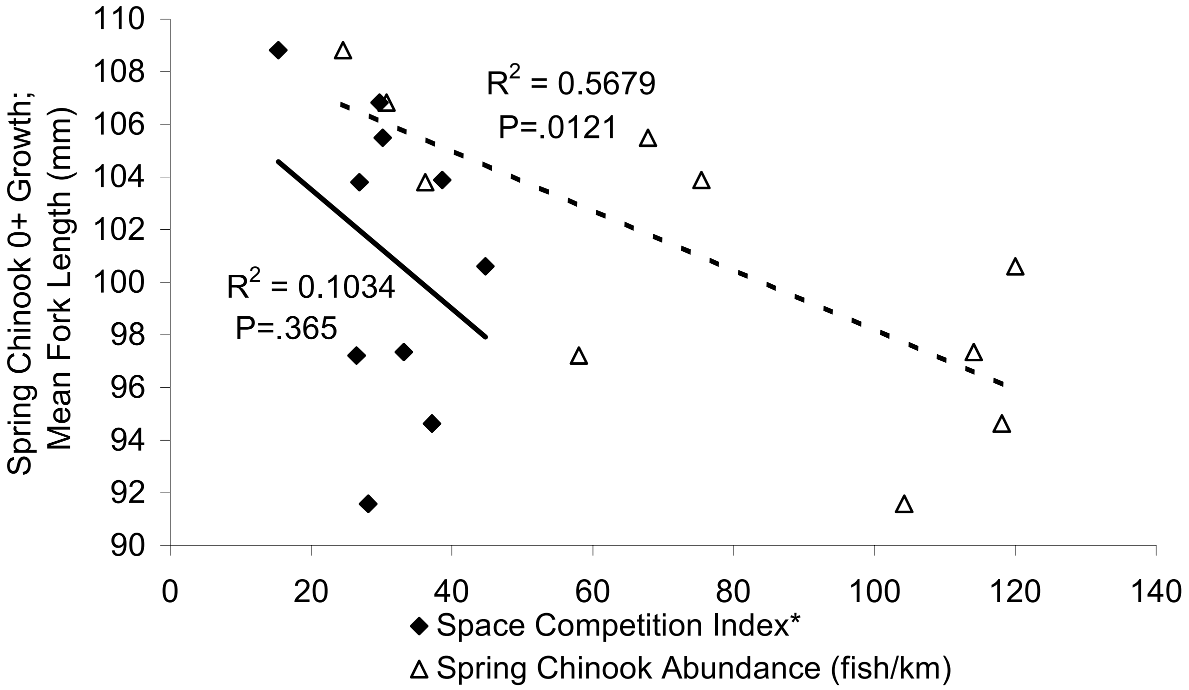

Figure 1. Age 0+ spring chinook growth in relation to spring chinook abundance (dashed line) and the space competition index (solid line), 1994-2003.
*multiplied by a constant for scaling purposes

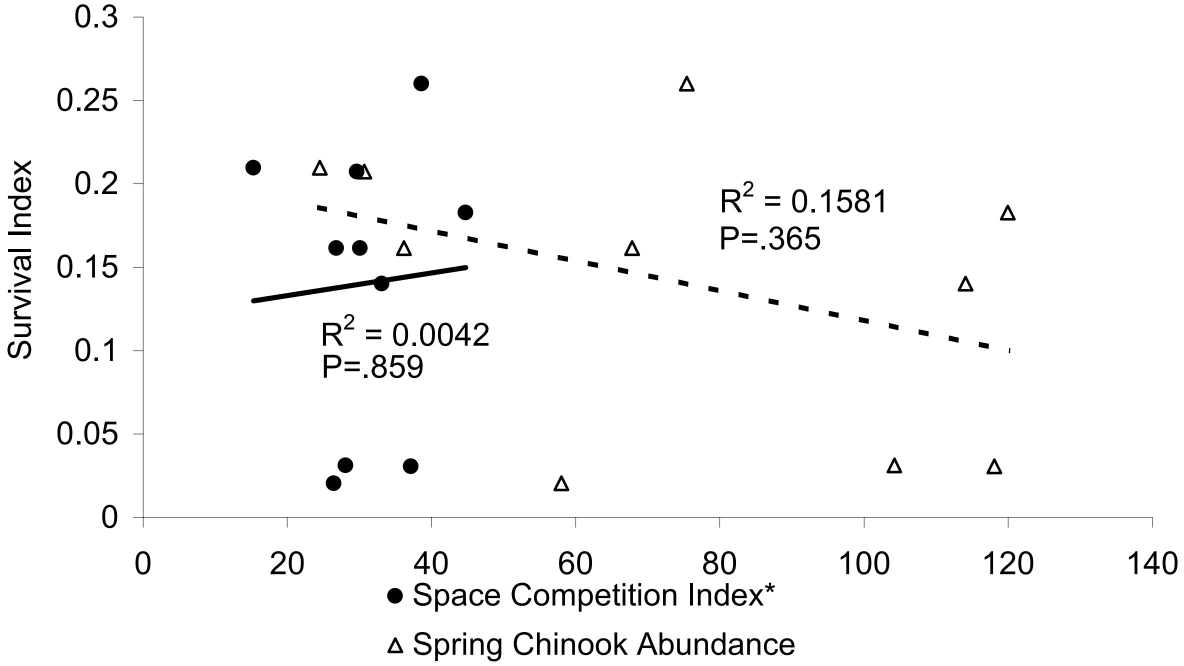

Figure 2. Age 0+ spring chinook salmon survival index in relation to Spring Chinook abundance (dashed line) and the space competition index (solid line), 1994-2003.
*multiplied by a constant for scaling purposes

The equation used to estimate maximum stomach fullness for spring chinook salmon (Figure 3) was derived using 2676 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).

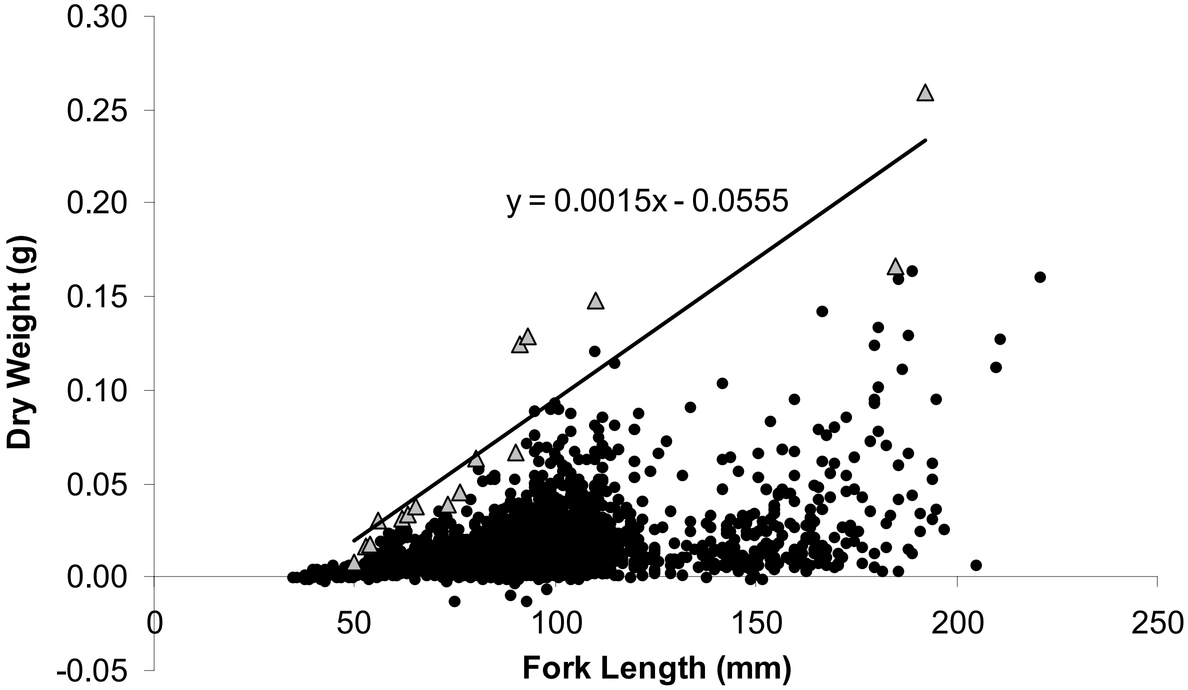

Figure 3. Dry weights of spring chinook salmon stomach contents plotted against spring chinook salmon fork length. The triangular points are the maximum weights that were used to fit the maximum stomach fullness regression line.

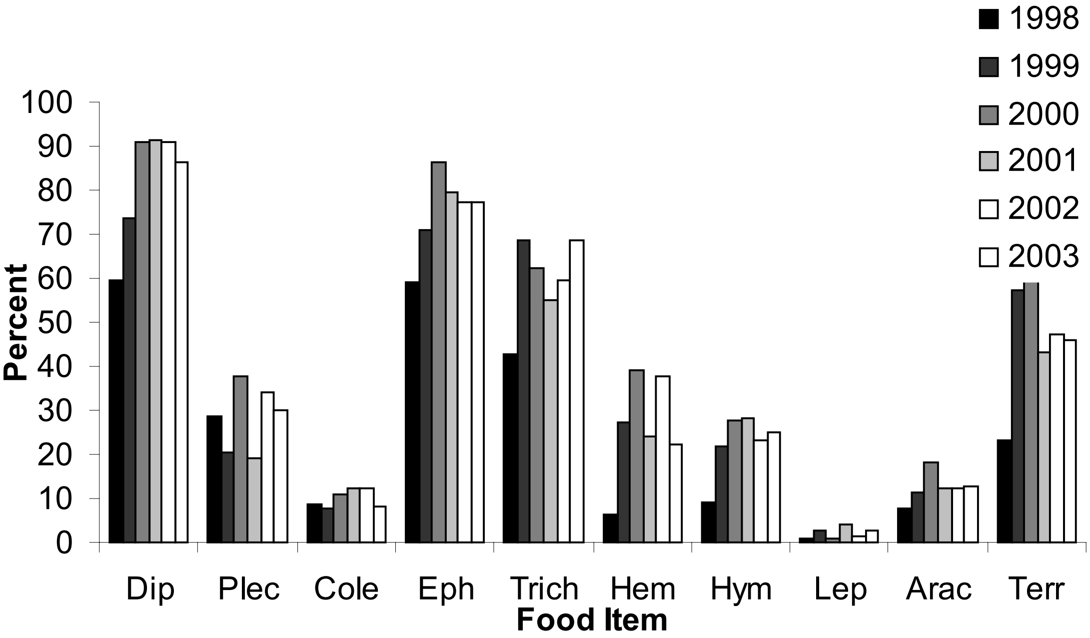

Figure 4. Occurrence frequency of food items found in age-0 spring chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

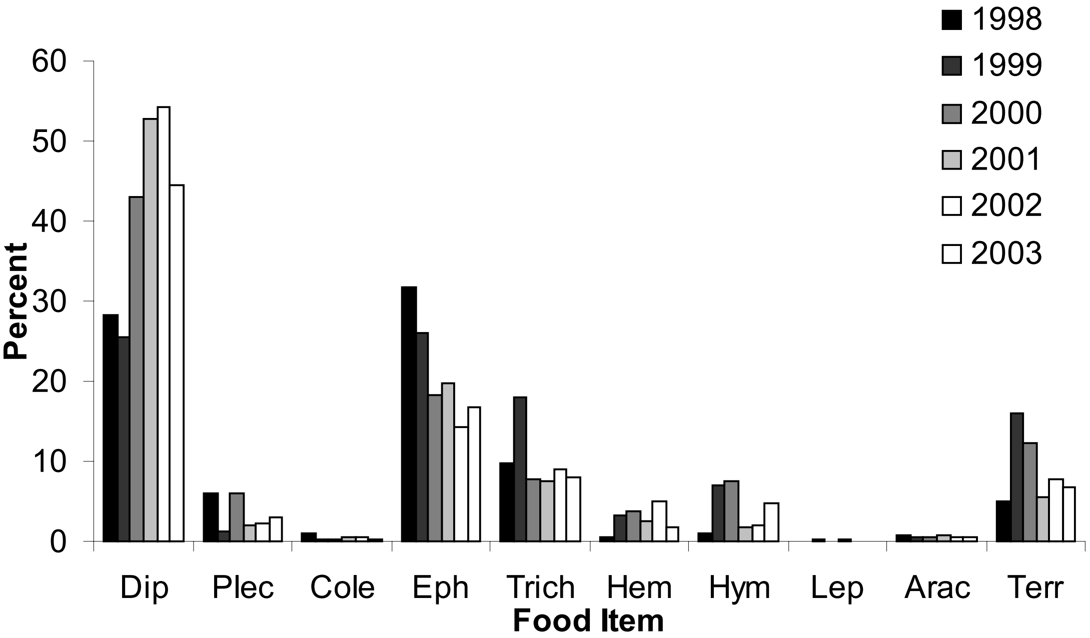

Figure 5. Percent composition of food items found in age-0 spring chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

Food Competition Index

Index 1

The competition index calculated for age-0 spring chinook salmon suggests that intraspecific competition for food was stronger than interspecific competition during most years (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. Rainbow trout was the second strongest competitor with spring chinook and mountain whitefish was third. The remainder of the species examined had relatively low index scores. The per capita index was highest for spring chinook salmon (Table 4).

Identification of stomach contents to family and lower taxonomic levels had a large impact on the per capita index (Table 4). The index for mountain whitefish was substantially reduced when prey items were identified to genus compared to order.

The intraspecific food competition index 1 for spring chinook explained similar, but slightly less, amounts of the variation in growth and survival than did spring chinook abundance alone (Figures 6 and 7).

Index 2

Index 2 explained more of the variation in growth and survival of age 0 chinook salmon than chinook salmon abundance alone or index 1 (Figures 6 and 7). The relationships between index 2 and growth and survival of chinook salmon were statistically significant ($P<0.05$) except when SCI was included in the survival comparison.

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

Time Period	1998		1999		2000		2001		2002		2003	
	n	%	n	%	n	%	n	%	n	%	n	%
0:01-4:00	n/a	n/a	8	6.9	28	23.8	10	10.9	5	20.7	61	23.0
4:01-8:00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	45	17.6	113	13.6
8:01-12:00	87	4.2	14	16.2	48	7.9	101	16.8	119	17.0	98	13.8
12:01-16:00	141	5.8	80	10.9	89	12.9	179	18.6	175	14.5	128	14.6
16:01-20:00	6	16.1	88	16.5	13	16.0	130	23.3	71	22.4	34	14.1
20:01-24:00	n/a	n/a	83	19.0	121	21.7	68	19.5	59	28.7	75	33.1
Average Day (7:59-20:00)		8.7		14.5		12.3		19.5		18.0		14.2
Average Night (20:01-4:00)		n/a		12.9		22.7		15.2		22.3		23.2
Average 24 hr* (0:01-24:00)		n/a		13.9		16.4		17.8		20.1		18.7

*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 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.

	Diet Overlap	1-Fullness SPC	Per Capita Index	Average dry wt (g)	Competitor Abundance	Space Comp. Index	Pop. Index 1
1998							
COHO	0	0.91	0	NA	0.01	0	0
CUT	0	0.91	0	NA	0.14	0	0
EBT	60.37	0.91	55.11	0.39	0.02	0	0
HSPC	0	0.91	0	NA	0	0	0
MWF	65.33	0.91	59.64	0.04	179.18	3.5E-02	14.31
RBT	74.76	0.91	68.25	0.02	56.84	2.0E-01	12.61
RSS	50.74	0.91	46.32	3.0E-03	1.13	2.7E-01	4.3E-02
SPC	100.00	0.91	91.30	4.4E-03	67.82	3.19	86.07
SUK	0	0.91	0	NA	83.03	0	0
1999							
COHO	0	0	0	NA	0.04	0	0
CUT	61.88	0.85	52.89	0.75	0	0	0
EBT	61.28	0.85	52.38	0.05	0.16	0	0
HSPC	84.68	0.85	72.38	0.03	0.40	1.2E-01	0.11
MWF	37.28	0.85	31.86	0.07	206.05	8.3E-02	40.61
RBT	69.84	0.85	59.70	0.06	71.53	3.4E-01	86.57
RSS	46.17	0.85	39.46	0.01	2.80	5.0E-02	4.6E-02
SPC	100.00	0.85	85.47	0.01	30.68	2.97	115.95
SUK	0	0	0	NA	80.30	0	0
2000							
COHO	0	0	0	NA	0	0	0
CUT	54.20	0.88	47.56	0.05	0.18	0	0
EBT	59.44	0.88	52.15	0.05	0.14	0	0
HSPC	66.75	0.88	58.56	0.03	0.86	5.8E-03	8.1E-03
MWF	55.70	0.88	48.87	0.09	183.59	1.2E-01	95.35
RBT	76.76	0.88	67.35	0.08	70.59	3.2E-01	116.68
RSS	72.49	0.88	63.60	0.03	3.97	2.4E-01	2.00
SPC	100.00	0.88	87.74	0.02	36.19	2.27	118.84
SUK	47.71	0.88	41.86	0.05	64.70	0	0
2001							
COHO	76.26	0.80	61.35	0.01	0.02	0	0
CUT	38.98	0.80	31.36	0.13	0.22	0	0
EBT	31.94	0.80	25.70	0.28	0.02	0	0
HSPC	49.00	0.80	39.42	0.04	5.10	4.4E-04	3.8E-03
MWF	72.52	0.80	58.35	0.08	248.45	4.7E-03	5.71

MWF^F	16.46	0.80	13.17	0.08	248.45	4.7E-03	1.30
RBT	63.15	0.80	50.81	0.07	68.21	9.4E-02	22.65
RSS	67.41	0.80	54.23	0.01	4.08	7.3E-03	2.0E-02
SPC	100.00	0.80	80.45	0.01	118.08	3.72	521.53
SUK	57.48	0.80	46.24	0.08	68.14	3.1E-04	8.4E-02
				2002			
COHO	86.98	0.82	71.36	0.01	0	6.3E-04	0
CUT	57.70	0.82	47.34	0.10	1.00	0	0
EBT	63.70	0.82	52.26	0.05	0.00	0	0
HSPC	50.16	0.82	41.15	0.07	0.25	1.2E-07	8.3E-08
MWF	63.32	0.82	51.95	0.07	177.71	6.7E-05	4.1E-02
MWF^F	8.97	0.82	7.35	0.07	177.71	6.7E-05	5.8E-03
RBT	77.12	0.82	63.27	0.08	60.59	1.5E-03	0.46
RSS	74.39	0.82	61.03	0.04	4.34	6.1E-05	5.8E-04
SPC	100.00	0.82	82.04	0.01	104.18	2.81	310.52
SUK	59.59	0.82	48.88	0.09	70.16	0	0
				2003			
COHO	72.58	0.86	62.31	0.02	0	5.4E-04	0
CUT	55.09	0.86	47.29	0.19	0.27	0	0
EBT	16.62	0.86	14.27	0.01	0.02	0	0
HSPC	58.72	0.86	50.41	0.06	0.59	3.3E-05	5.9E-05
MWF	62.70	0.86	53.82	0.06	196.99	2.4E-04	0.15
MWF^F	48.49	0.86	41.62	0.06	196.99	2.4E-04	0.11
MWF^g	35.66	0.86	30.61	0.06	196.99	2.4E-04	8.3E-02
RBT	75.41	0.86	64.73	0.06	60.87	1.8E-02	4.23
RBT^F	67.40	0.86	57.86	0.06	60.87	1.8E-02	3.78
RBT^g	61.08	0.86	52.43	0.06	60.87	1.8E-02	3.42
RSS	61.35	0.86	52.67	0.01	11.20	6.8E-04	4.4E-03
SPC	100	0.86	85.84	0.01	58.01	2.65	195.20
SUK	61.08	0.86	52.43	0.05	47.58	2.7E-05	3.1E-03
SUK^F	44.24	0.86	37.98	0.05	47.58	2.7E-05	2.2E-03
SUK^g	34.10	0.86	29.27	0.05	47.58	2.7E-05	1.7E-03
				Average 1998-2003^O			
COHO	78.61	0.83	65.00	0.01	0.01	1.9E-04	0
CUT	53.57	0.84	45.29	0.24	0.30	0	0
EBT	48.89	0.85	41.98	0.14	0.06	0	0
HSPC	61.86	0.84	52.38	0.05	1.44	2.2E-02	2.0E-02
MWF	59.47	0.85	50.75	0.07	198.66	4.0E-02	26.03
RBT	72.84	0.85	62.35	0.06	64.77	1.6E-01	40.53
RSS	62.24	0.85	52.93	0.02	4.59	9.4E-02	0.35
SPC	100.00	0.85	85.47	0.01	69.16	2.93	224.69
SUK	56.46	0.84	47.35	0.07	68.99	5.7E-05	1.5E-02

			Average 1998-2003^{g}				
MWF	33.82	0.85	28.86	0.07	198.66	4.0E-02	14.80
RBT	59.00	0.85	50.50	0.06	64.77	1.6E-01	32.83
RSS*	56.31	0.85	47.96	0.02	4.59	9.4E-02	0.32
SPC	100.00	0.85	85.46	0.01	69.16	2.93	224.69
SUK	21.01	0.84	17.62	0.07	68.99	5.7E-05	8.1E-03

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

Superscript (*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. Overlap values for years prior to 2003 were multiplied by a species specific factor, resulting in an overlap adjustment equal to the difference in magnitude between order and genus determined in 2003.

*data exits only to the ordinal and familial taxonomic level.

Table 5. Intra-specific per capita and population food competition indices 2 for 0+ spring chinook salmon.

	1-Percent Max	Diet Overlap	Per Capita Index 2	Daily Meal (g)	Abundance fish/km	Space Competition Index	Pop. Index 2 (10^4)
1998	0.96	100	96.46	3.58	67.82	3.19	7.47
1999	0.93	100	93.02	11.29	30.68	2.97	9.56
2000	0.91	100	91.03	13.37	36.19	2.27	10.02
2001	0.87	100	87.23	10.00	118.08	3.72	38.29
2002	0.87	100	86.59	10.40	104.18	2.81	26.37
2003	0.89	100	89.05	12.47	58.01	2.65	17.05

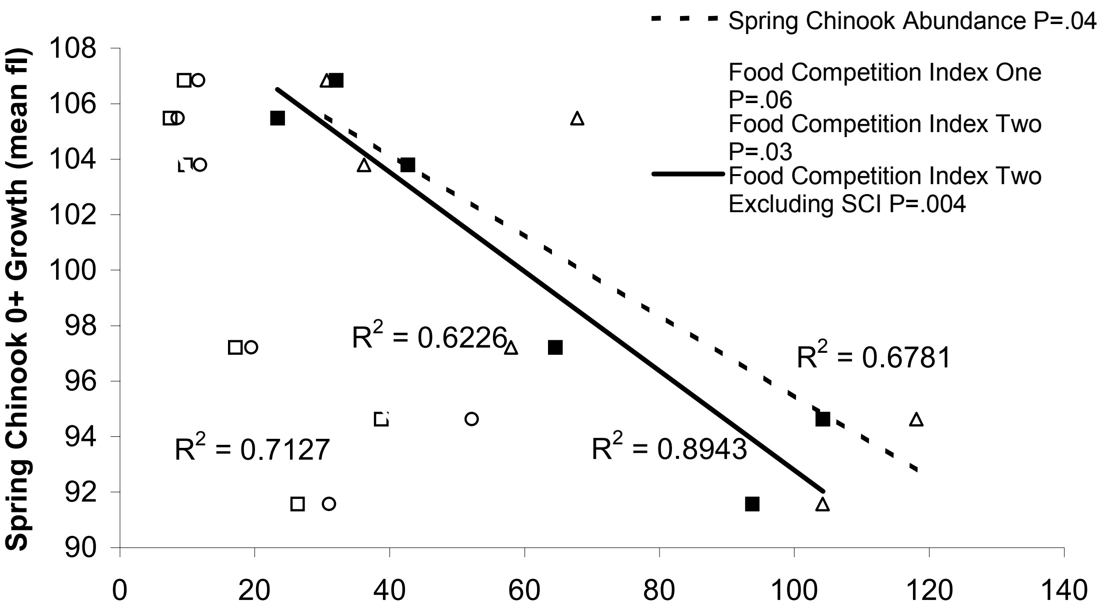

Figure 6. Spring chinook 0+ growth in the upper Yakima River, 1998-2003 in relation to food competition indices one, two and three.

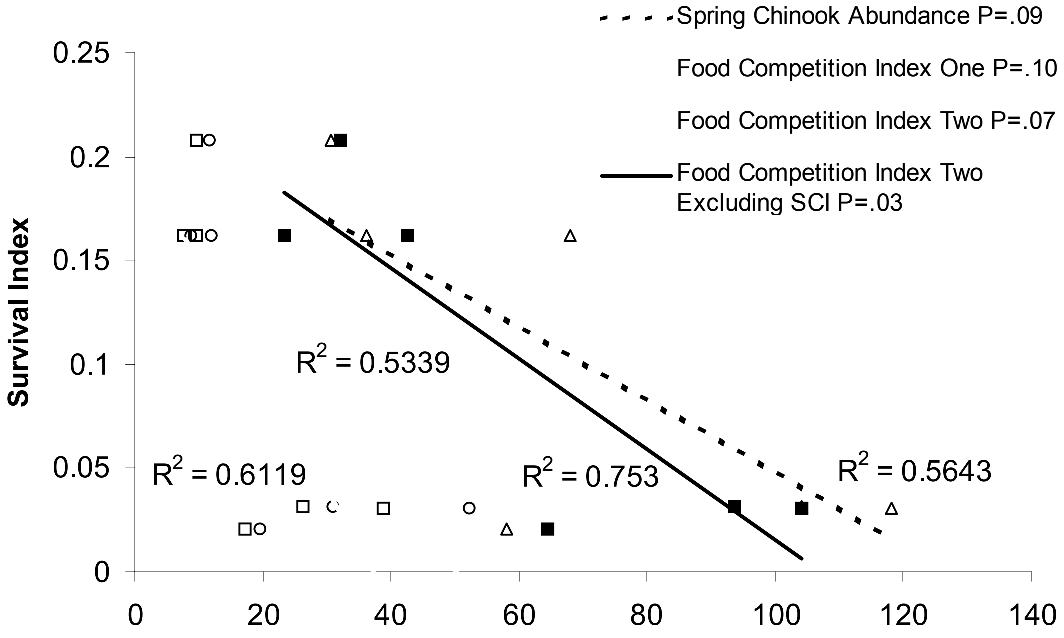

Figure 7. Spring chinook upper Yakima River survival index 1998-2003 in relation to food competition indices one, two, and three.

Table 6. Ranking of spring chinook competitor, food, and space indices by species averages 1998-2003. 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	85.46	SPC	224.69	SPC	2.93
2	COHO	65.34	RBT	32.83	RBT	0.16
3	HSPC	50.70	MWF	14.80	RSS	9.0E-02
4	RBT	50.50	RSS	0.32	MWF	4.0E-02
5	RSS	47.96	HSPC	0.02	HSPC	3.0E-02
6	CUT	45.21	SUK	0.01	COHO	5.80E-04
7	EBT	42.77	COHO	0	SUK	1.10E-04
8	MWF	28.86	CUT	0	CUT	0
9	SUK	17.62	EBT	0	EBT	0

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

Discussion

The 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 need to be resolved. For example, we found that 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 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 precocials.

The space and food competition indices were highest for spring chinook salmon, which suggests that intraspecific competition is stronger than interspecific competition. The food competition index 2 without the SCI explained 89% of the variation in chinook salmon growth and 75% of the variation in survival. 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 2003 (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 dependant growth and survival of spring chinook salmon is occurring in the upper Yakima River.

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 % upper limit of population size in five mainstem 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 estimates by the maximum likelihood capture efficiencies of small 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. 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.

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. 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 dependant impacts would be reduced. 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 plan to 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 to low levels so that adult salmon spawn low in the channel. These low flows are maintained through fry emergence so that redds are not dried out. This is appropriate when the numbers of fry are limiting the abundance of juveniles in the fall (e.g., <750 redds). However, when the number of redds are predicted to be sufficiently high, then the water flows in the summer may be more limiting to fall parr production then the number of fry produced. Thus, in years where spawning escapement is high flows might be targeted at enhancing fry-to-fall parr survival. Before any changes to flow management are implemented, the impacts to other species should also be assessed.

A water neutral approach to reducing density dependent impacts is to decrease the flow velocities by increasing the quantity and quality of bank habitat. This is particularly important in areas where large numbers of parr are rearing such as above the Teanaway River confluence.

The quantity of bank habitat might be increased by restoring access to areas above dams (e.g., Cle Elum Dam), blocked side channels, gravel pit ponds (e.g., Hanson Ponds), and low gradient tributaries (e.g., Teanaway). The quality of banks can be improved by increasing their complexity. Complexity might be enhanced by increasing riparian vegetation and large structures such as root wads and rocks.

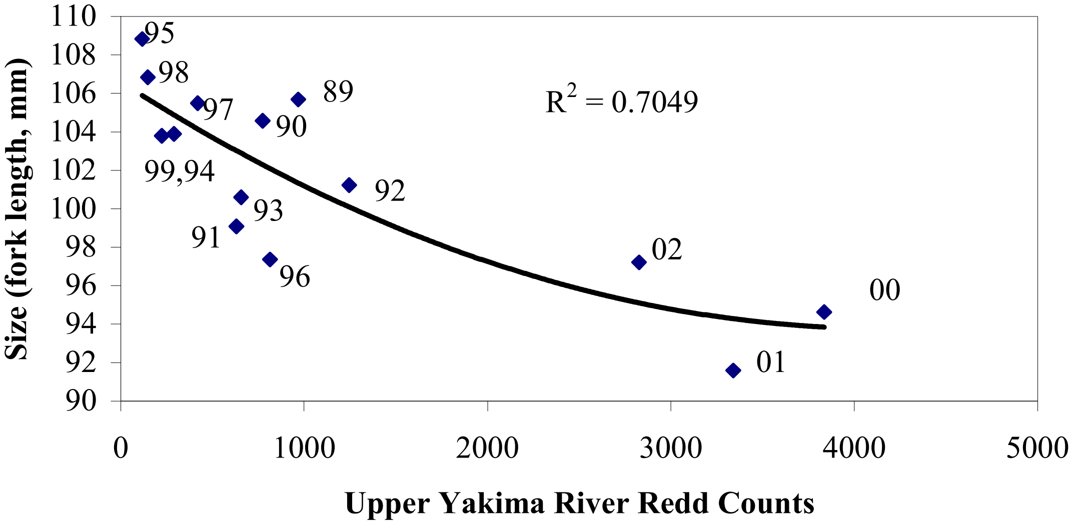

Figure 8. Size of age 0+ spring chinook salmon during September and October versus the number of redds that were produced the year prior. The dates are the year that redds were counted.

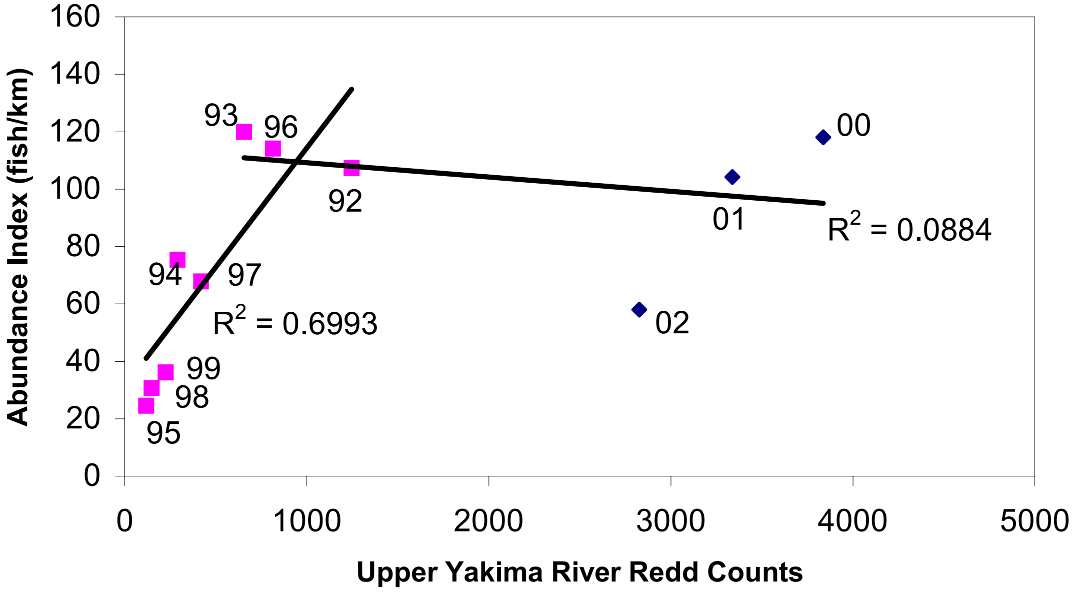

Figure 9. Abundance index of age 0+ spring chinook salmon during September and October versus the number of redds that were counted the year prior. The dates are the year that redds were counted.

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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 the core microhabitat values 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 River Basin. We measured spring chinook salmon microhabitat variables during the summers of 1998 to 2003 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 decreased with increasing abundance of spring chinook, and the number of fish occupying optimal habitats increased with increasing abundance. Our data may indicate that space is not limiting chinook growth or survival in the upper Yakima basin or that chinook decrease their territorial behavior in response to increasing abundance of conspecifics. We will continue to measure 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 in aquatic systems is defined as the maximum number of fish at their most demanding life-stage that can be supported by the available habitat. It is important to know what the carrying capacity of the system is in order to know whether supplementation mechanics are flawed or whether carrying capacity of the environment is limiting increased 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 with the number of parents. 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 habitats which 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 utilized 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 supplementation might change in response to an increase in the number of naturally produced spring chinook salmon if supplementation is successful. 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 coefficient of variation (CV) or 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 core 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.

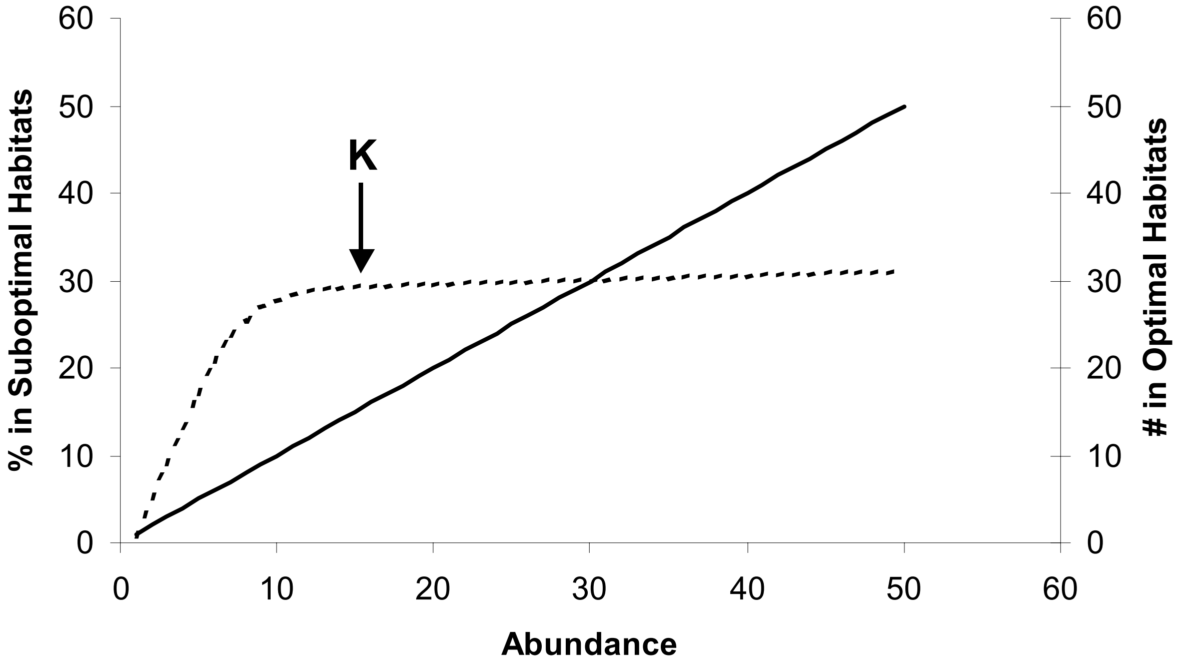

Figure 1. Hypothesized percentage of fish outside (solid line) and number of fish inside (dashed line) optimal habitat in relation to increasing abundance.

Methods

To adequately characterize the microhabitat use of age-0 spring chinook salmon and associated species, we measured multiple variables of fish that we observed by snorkeling 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 not sampled in 2002 but was sampled from 1999 to 2001 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 mainstem of the Teanaway River. The North Fork of the Teanaway River was not sampled in 1999 because pods of chinook were difficult to find due to a low spawner return in 1998. Microhabitat measurements were made during the months of July and August 1999 to 2001, August in 2002, and also early September during 1999 (Table 2). Later fall sampling, which was done in 1998, was not performed after 1998 because of difficulties in observing spring chinook salmon due to increased use of instream cover caused by cooler water temperatures (James et al. 1999). All analyses in this report were restricted to the mainstem Yakima River between July and September.

In each pod of fish, which is defined as all fish that are within 30 cm of each other and are assumed to interact (Pearsons et al. 1996), spring chinook salmon were counted and 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. 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. Microhabitat variables measured for spring chinook salmon, rainbow trout, redside shiners and mountain whitefish observed by snorkeling in the upper Yakima River Basin between 1998 and 2003.

Variable	Description
Position	Head, tail, left, right and average per pod
Length	Underwater visual fork length estimation (mm)
Total Depth	(m)
Focal Depth	Reported as % of water column in relation to total depth
Surface Velocity	(m/s)
60% Velocity	(m/s)
Focal Velocity	Velocity measured at the fish focal point (m/s)
Activity	Feeding, swimming, holding, interacting, resting

Table 2. Summary of dates and ranges of water temperatures (°C) measured during collection of 1998 to 2003 microhabitat data on spring chinook salmon in four study sections in the upper Yakima River Basin.

Section	Data	1998	1999	2000	2001	2002	2003
Cle Elum	Min	14	11	15	18	14	
	Max	17	14	18	19.5	16	
N. F. Teanaway	Min	15		17	16	13	17
	Max	15		21	22	21	20
Nelson	Min	14.5	14	13	14	14	16.5
	Max	19	15	18	17	19	20
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 (Table 1), 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 due to increased population density). Five of the microhabitat variables that were measured in 1998 (Table 1) were discontinued for the above reasons. Total water depth was measured and focal depth was recorded as the percent of the water column (total depth) above the focal point and was later converted to depth in meters from the water surface. Current velocities were measured for each marker with a Marsh-McBirney or Swoffer flow meter at three points in the water column; the surface, 60% of the water column, and at the fishes' focal point.

Microhabitat use of age-1+ spring chinook salmon, rainbow trout, and mountain whitefish were also characterized when they were associated with a pod. Because data was collected on these fish only when they were associated with spring chinook salmon, the data cannot be interpreted as being representative of their species. In the interest of long term monitoring, the microhabitat data were pooled by river section, species, and age class.

In 2001 we developed a new approach to evaluate the proportion of fish occupying suboptimal focal velocity, focal depth, and total depth. This approach standardizes for fish length. We created a scatter plot of each variable for each year and fitted a linear regression line using the least squares method (Figure 2,3,4). We then used the upper and lower 98% confidence levels of the slope and Y intercept in the linear regression equation of each of these three variables for 1998 (our baseline year) to solve for Y (microhabitat parameter) for each spring chinook length and plotted this line. This same line was then plotted for the 1999 to 2003 data. The idea is to compare the percent of spring chinook salmon that are using habitat outside of this zone for each year. In years of higher abundance of spring chinook salmon we would expect them to use habitat outside this zone at a higher proportion than years with lower abundance, 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. 2004).

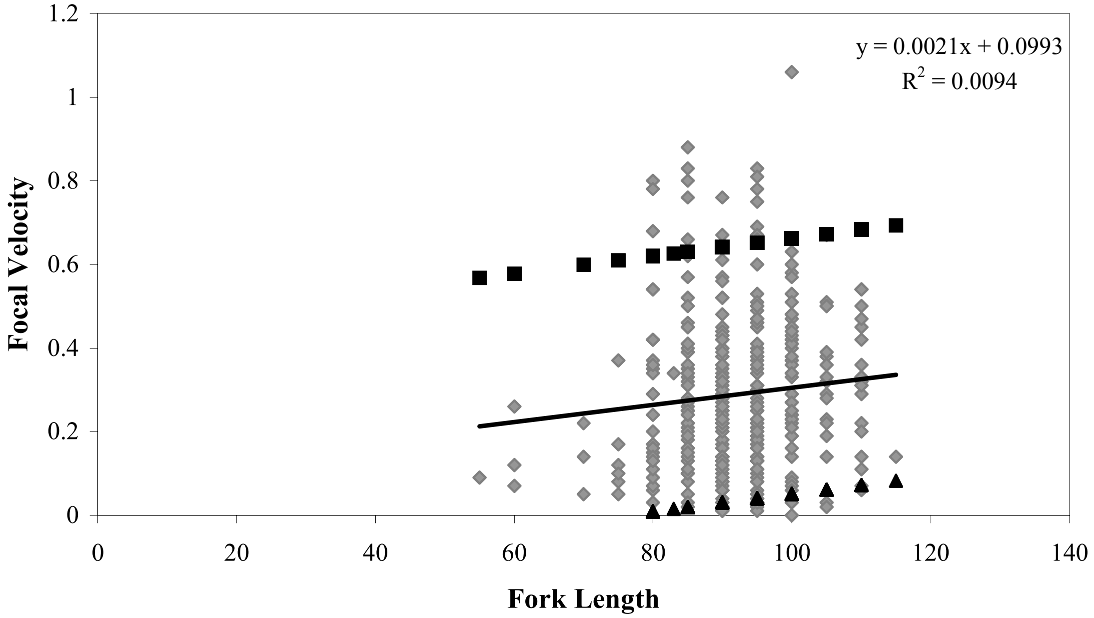

Figure 2. Relationship between spring chinook salmon length and focal velocity during 1998. Included are the linear regression line, and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

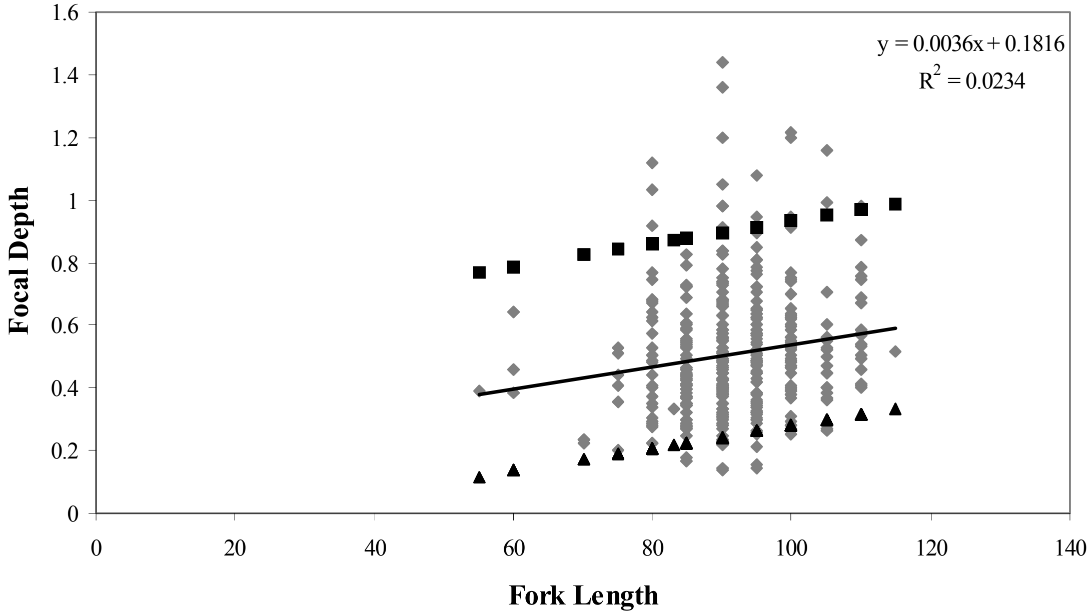

Figure 3. Relationship between spring chinook salmon length and focal depth during 1998. Included are the linear regression line, and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

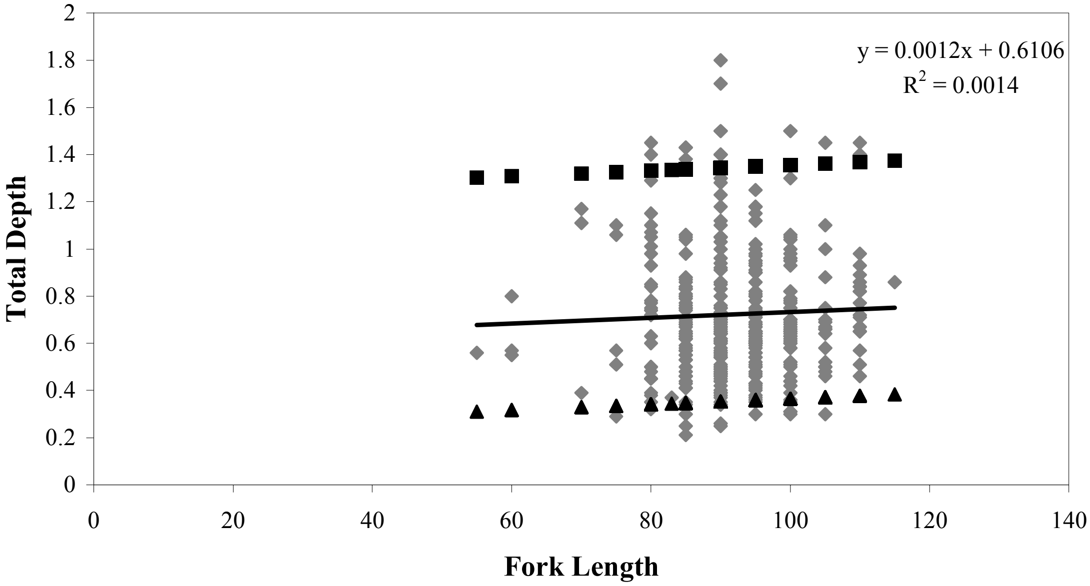

Figure 4. Relationship between spring chinook salmon length and total depth during 1998. Included are the linear regression line and boundaries of hypothetically optimal boundaries. The data points between the upper and lower boundaries represent 90 percent of the 1998 sample.

Results

None of the microhabitat variables showed a significant relationship between the proportion of chinook utilizing suboptimal microhabitats and chinook abundance (P>0.05). The percentage of age-0 spring chinook salmon occupying focal velocities and focal depths outside of the 1998 baseline data decreased with increasing abundance of chinook salmon per kilometer (Table 4, Figure 5). However, the percentage of age-0 spring chinook salmon occupying total depths outside of the 1998 baseline data was invariant with increasing abundance of chinook salmon per kilometer (Table 4, Figure 5). Focal depth was the most variable parameter followed by total depth. Focal velocity remained relatively stable for all years.

The estimated number of chinook salmon in optimal habitats was positively related to an index of abundance (P<0.001; Figure 6).

Table 3. Summary of microhabitat parameters used by age-0 spring chinook salmon during summer 1998 to 2003 in each study section in the upper Yakima River Basin.

	Focal Velocity (m/s)				Focal Depth (m)				Total Depth (m)			
	n	mean	stdev	cv	n	mean	stdev	cv	n	mean	stdev	cv
1998	364	0.29	0.187	64.841	376	0.51	0.206	40.369	376	0.72	0.287	39.671
1999	189	0.22	0.149	68.668	191	0.62	0.245	39.305	191	0.84	0.309	36.904
2000	135	0.23	0.199	87.518	137	0.84	0.440	52.307	137	0.87	0.446	51.563
2001	154	0.23	0.134	59.242	154	0.49	0.180	36.902	154	0.62	0.224	35.984
2002	302	0.21	0.140	65.248	302	0.48	0.167	34.548	302	0.62	0.184	29.754
2003	462	0.27	0.160	60.026	463	0.49	0.151	30.914	463	0.63	0.185	29.121
mean		0.24				0.57				0.72		
stdev		0.03				0.14				0.11		
cv		12.57				24.86				15.54		

Table 4. Percent of age-0 spring chinook focal velocities, focal and total depths greater than the 1998 fitted line during 1999 to 2002. 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.

Year	Focal Velocity	Focal Depth	Total Depth	Redd Count	SPC/Km	Mean Length (mm)
1998	10.2%	10.4%	9.6%	420	58	92
1999	6.9%	15.2%	9.4%	148	30	85
2000	9.6%	25.5%	10.9%	224	27	92
2001	3.9%	7.8%	9.7%	3,836	101	82
2002	1.3%	4.6%	3.6%	3,339	92	71
2003	5.6%	4.8%	4.1%	2,826	44	81

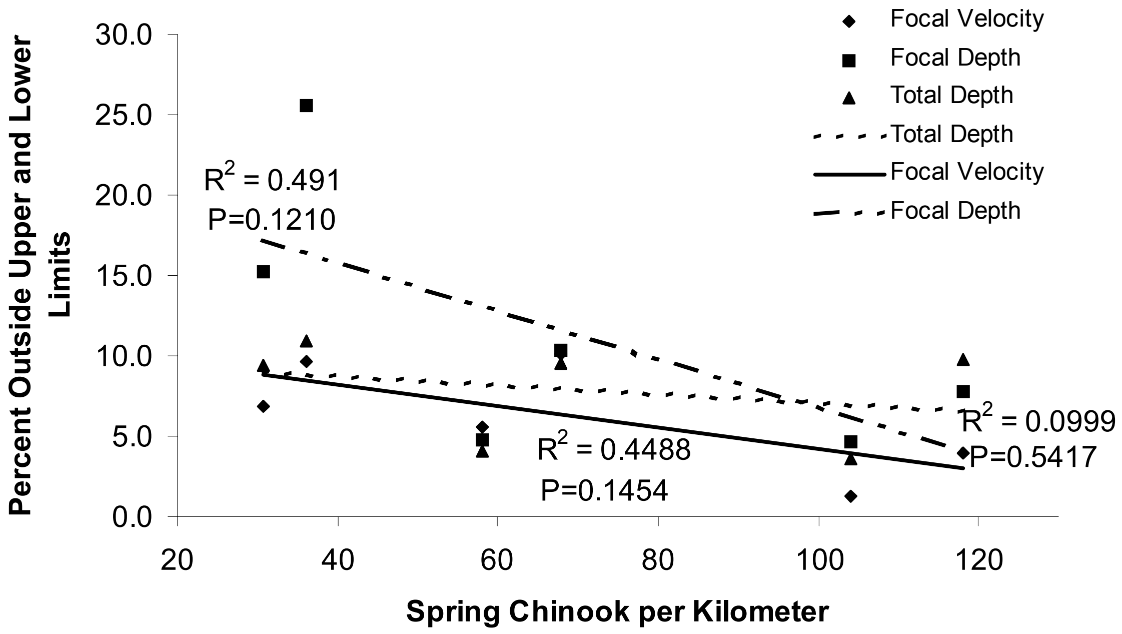

Figure 5. Relationship between the index of abundance of spring chinook salmon parr and the percent of focal velocities, focal depths, and total depths outside optimal values 1998 to 2003.

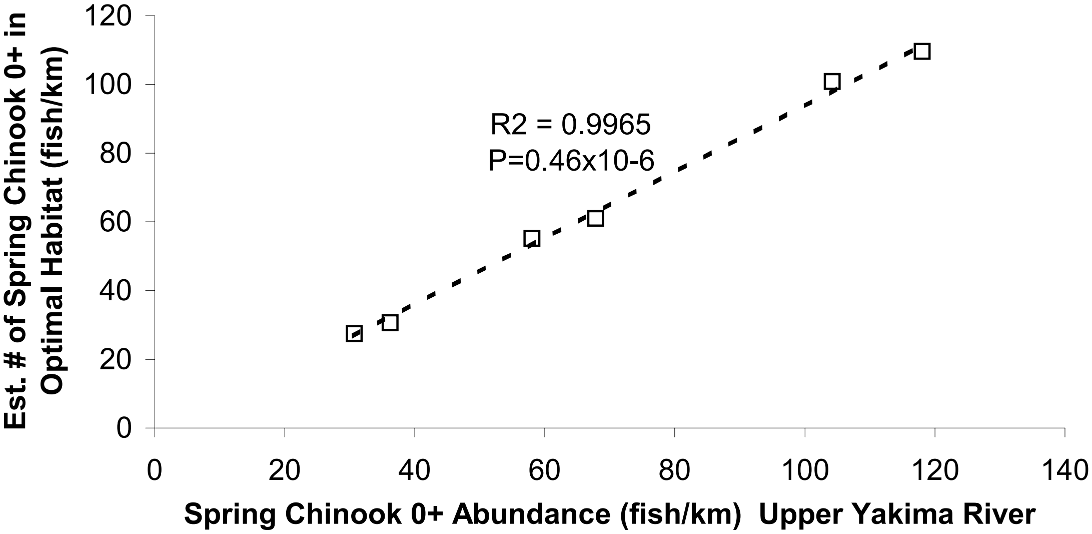

Figure 6. Relationship between spring chinook abundance index and the estimated number utilizing optimal habitat. Estimated number utilizing optimal habitat is the annual mean of the proportion within optimal of total depth, focal velocity, and focal depth measurements multiplied by the abundance index.

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, competition for space may be important at relatively low densities of fish and competition for food may be most important at high densities of fish.

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 dependant interactions are not important and that the environment is underseeded.

However, other analyses indicate that density dependant 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), or that some other factor such as food is the factor limiting growth and survival. No significant correlations were found between our space competition index and growth and survival, but strong correlations were found between our food competition index and growth and survival (Chapter 1 of this report).

Our results may also be an artifact of how we analyzed the data. None of our data was weighted for the number of fish in a pod. We will explore weighting the microhabitat data by number of fish to see if our findings change significantly. We will also explore the influence of abiotic factors, such as temperature and discharge, on the variation in microhabitat use.

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 2003. 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

Annual Differences in Precociously Mature Hatchery and Wild Spring Chinook Salmon on Spawning Grounds in the Yakima River

Abstract

We examined the hypothesis that the Cle Elum Supplementation Hatchery alters the assemblage of spring chinook salmon that precocially mature in freshwater. We counted the number of precocials on the spawning grounds between 1998 and 2003 while snorkeling in the upper Yakima River. The release of hatchery fish in the spring affected the natural abundance, distribution, age/size, and behavior of precocials observed on redds the following fall. The estimated number of age 0+, age 1+, and hatchery precocials observed on the spawning grounds between 1998 and 2003 during the peak of spawning ranged from 4 to 554, 16 to 42, and 11 to 52 respectively. Females that were spawned in the hatchery produced fewer precocials on redds two years later than females that spawned in the river ($P<0.05$). The lower number of hatchery precocials on the spawning grounds may be due to high mortality of precocials after they are released from the hatchery. During the peak of spawning, between 30% and 52% of all hatchery precocials observed on the spawning grounds within a year were in the lowest spawning reach examined, whereas only 0% to 9% of all age 0+ precocials and 0% to 15% of all wild age 1+ precocials were observed in this reach. Most hatchery precocials were observed downstream of spawning areas during the spawning season. Except for the year 2000, the hatchery precocials per female taken for hatchery broodstock was higher than naturally produced age 1+ precocials per female spawner and the absolute value of the differences was statistically significant ($P<0.05$), but the differences in means was not statistically different ($P>0.05$). The hatchery does not release age 0+ precocials, which is the predominant age of wild precocial, so it decreased the number of this age of precocial. Hatchery precocials were larger ($P>0.05$) and behaviorally dominated most interactions with wild precocials on redds. This could result in higher per-capita reproductive success because of better access to females. Altering natural rates of precocialism and precocial assemblages on the spawning ground poses ecological and genetic risks to wild fish.

Introduction

Although most chinook salmon are thought to be anadromous (Healey 1991), some salmon complete their entire life cycle in freshwater, even when they have access to the ocean. These salmon are generally small, male, precocially mature, short-lived and are referred to as residents, precocials, or minijacks (Gebhards 1960; Mullan et al. 1992; Zimmerman et al. 2003). This phenomenon has been observed in both stream and ocean type chinook (Unwin et al. 1999, Mullan et al. 1992). Although the incidence of precocial maturation in chinook salmon has been recognized since at least 1897 (Rutter 1902), the importance and management of this life-history has only recently become generally appreciated. Resident life histories have been observed in both natural (Flain 1970; Gebhards 1960, Mullan et al. 1992) and hatchery produced fish (Robertson 1957, Mullan et al. 1992, Larsen et al. 2004) and can occur as subyearling (Robertson 1957; Gebhards 1960; Mullan et al. 1992), yearling (Gebhards 1960; Mullan et al. 1992; Larsen et al. 2004), and perhaps under favorable conditions even older (Mullan et al. 1992; Unwin et al. 1999). The occurrence of precocialism in salmon has been credited to genetic factors and environmental and physiological cues (Bohlin et al. 1990; Thorpe 1987). It can be a valuable life-history strategy when population sizes are low or disturbances frequent and is commonly used by other anadromous species (Pearsons et al., in press). The sperm of precocial salmon has been shown to successfully fertilize eggs (Rutter 1904; Robertson 1957; Unwin et al. 1999) and some precocials may be able to spawn more than once (Bernier et al. 1993). It has been known for some time that hatcheries can produce chinook salmon precocials (Robertson 1957; Mullan et al. 1992), but there have been relatively few studies which have attempted to look at the consequences of releasing precocials.

In the Salmon River Drainage, Idaho, 2.6% of naturally produced salmon fingerlings from the Lemhi River showed precocious development and observations on Marsh and Elk Creek revealed that 4 to 30 yearling males were found in the bowls of redds where active spawning was occurring (Gebhards 1960). Taylor (1989) found incidences of precocialism among four chinook populations in Canada ranging from 0 to 29%. The higher incidences of precocialism were populations that were the farthest inland. Foote et al. (1990) found precocial rates among yearling males of an interior basin hatchery stock of 56%. They concluded that such wide differences in rates of precocialism were due to genetics because the growth rates of fish from the previous two studies were similar. In 1958, Gebhards (1960) found that age 0 precocials comprised 0.2% and age 1+ 0.9% of the population. Gebhards (1960) also concluded that age 1+ fish died after spawning, precocials were generally only found in areas where there was spawning activity, precocials were usually found in the bowl of the redd, and "the yearling males remained constantly within the redd."

Salmon hatcheries have the potential to unintentionally produce artificially high or low numbers of precocials, which can impact wild fish populations. Hatcheries may enhance precocious maturation of males by the dietary composition of the feed (Shearer and Swanson 2000) or the types of growth schedules that fish are placed on (Silverstein et al. 1998; Larsen et al. 2004). It is unclear whether the percentage of precocials produced naturally or in hatcheries differ, although evidence suggests that some hatcheries can produce high levels of precocials relative to natural systems (Larsen et al. 2004). However, relatively large hatchery programs can produce artificially high numbers of precocials because they release more fish than the natural environment produces. Artificially high numbers of precocials may harm wild populations through ecological and genetic mechanisms. Precocials may eat wild fish, compete for resources, and spread disease. They may also breed with wild fish and consequently lower fitness of offspring. Hatchery fish may pass on genes that are unfavorable in the natural environment and this may be particularly pronounced in precocials because they do not experience the selective pressures that migratory adults experience. In addition to potential impacts to wild fish, resident chinook salmon are undesirable to fisheries because they are generally too small for harvest. In fact, they can even reduce the quality of resident trout fisheries because they readily take to the hook and get in the way of trout. In short, production of artificially high numbers of precocials has the potential to limit the success of supplementation programs. In contrast, artificial reduction in their production may negatively impact the contribution of this valuable life-history strategy.

We sought to answer the following question: Does the Cle Elum Supplementation and Research Hatchery alter the distribution, abundance, age/size, and behavior of precociously maturing males in the natural environment? Approximately 19-25% of the hatchery production in the Yakima Basin has been precocial 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 precocial 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.

Methods

Precocial and residual spring chinook salmon were studied in the upper Yakima River mainstem and in the North Fork Teanaway River (see map in general introduction). These areas were selected because they are utilized intensively by spring chinook salmon for spawning and rearing and/or they were located near hatchery acclimation sites. The mainstem sections sampled for residual spring chinook salmon included; Nelson, a 7.2 km section of river below Easton Dam from the Washington Department of Fish and Wildlife access ramp (river km 314.6) to the I-90 bridge at river km 307.4, Cle Elum an 8.8 km section of river that flows past Cle Elum from river km 294.5 to river km 285.7, and Thorp, a 3.4 km section of river from the Clark flats acclimation site to the Thorp bridge. A 5 km section of the North Fork Teanaway River (NFT) between the mouth of Dickey Creek and the confluence of the North Fork and mainstem Teanaway River was also sampled. The sampling period for residual spring chinook salmon occurred primarily between July and September.

The abundance of residual spring chinook salmon was determined by counting fish while snorkeling. Observations were conducted in the Nelson, Cle Elum, NFT, and Upper Canyon sections during the months of July and August (Summer) and September (Fall) when water temperatures were at or above 14 ^{o} C (Table 1). Both banks of the section being sampled were snorkeled simultaneously. Observations were made by having two snorkelers snorkel each bank of a section. When conditions allowed, (i.e. shallow water or slow flows) snorkeling was conducted moving upstream, otherwise, observations were made while snorkeling downstream. Most of the snorkeling in the main channel occurred while moving downstream, whereas side channels were generally snorkeled while moving upstream. Only side channels were snorkeled in the Cle Elum section because of the dangerous conditions in the main channel. All spring chinook salmon encountered were enumerated. Size was visually estimated underwater. Fish with a length greater than 120 mm (FL) were considered age-1+ residuals based on size and growth rate data collected previously.

Sampling of precocials occurred throughout the mainstem Yakima River between Easton Dam and Town Diversion Dam, and the Cle Elum River (Cle River) from Cle Elum Dam to the Yakima River confluence. Observations were conducted in September and October to determine the presence and abundance of precocial spring chinook salmon. Two types of surveys were conducted. One type was to determine the change in precocial abundance in index areas through time and the other was to determine the abundance of precocials throughout the entire spawning area. We sampled temporally between 1998 and 2001 in the Easton, Nelson, and Cle Elum index sections of the upper Yakima River where high salmon redd densities have been observed in the past (Fast et al. 1991). Temporal surveys were limited to the Easton section in 2002 and 2003. Each section was floated one or more times 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 precocials were rarely observed on redds without anadromous fish present (Gebhards 1960; James et al. 1998). A snorkeler would then begin 5-10 meters downstream of the redd and snorkel upstream, counting all spring chinook encountered. Fish were categorized as either being on the redd (in the bowl), or associated with the redd (within 5 meters). In cases where a redd was snorkeled more than once, the observation with the highest precocial count was used for analysis.

We derived an estimate of the total number of precocials in the spawning areas of the upper Yakima Basin (second type of precocial survey) by snorkeling the majority of the spawning area in the upper Yakima Basin during the peak spawning time. The areas snorkeled were Easton Dam to Golf Course Road, South Cle Elum Bridge to Town Diversion Dam, and the Cle Elum River. The data from the surrounding reaches were extrapolated over the unsnorkeled reach. During years where more active redds were present than we could snorkel, we systematically sampled the active redds (e.g., every other redd) and then extrapolated average precocials per redd to the unsnorkeled redds.

We compared the average number of hatchery and naturally produced precocials that were produced per female parent. We divided the number of precocials on the spawning grounds during the peak of spawning by the number of female parents. 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 precocials two years later. We used the numbers of redds upstream of Roza Dam as the number of adults that could produce naturally produced precocials one (age 0+) or two (age 1+) years later (YN unpublished data). To calculate the number of precocials per female, we used the numbers of adults for the year prior to observation of age 0+ precocials, and the numbers of adults two years prior to observation of age 1+ precocials.

During surveys prior to 2002 we observed precocial salmon interacting on redds. In 2003, agonistic interactions among chinook salmon on eight redds in the Easton section and one redd in the Cle Elum section were recorded. A snorkeler would approach a redd in the same way as described above. After a 5 minute standardization period, agonistic interactions were recorded for 15 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 1 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 directed at it was termed the recipient. Contests were defined as a single or group of interactions between two fish. Contests are an uninterrupted series of interactions. Finally, dominance was assigned to an initiator fish that maintains/defends its position or a fish that moves another fish from an area previously occupied.

We estimated the number of hatchery precocials that were not on redds during the spawning season. Five sections of the upper Yakima River were sampled from the middle of September to the middle of October using a drift boat electrofisher as described by Pearsons et al. 2002. The electrofisher was turned off when we approached redds to avoid electroshocking fish on or near redds. The number of hatchery precocials netted during night electrofishing were expanded by our efficiency of capturing marked rainbow trout of a similar size. The estimated number of precocials in our index sites were then expanded by the site length that our site represented. In this way, we estimated the total number of precocials in the Yakima River from Roza Dam to the Cle Elum River confluence.

Analysis

Two tailed paired t-tests were used to compare the abundance of hatchery precocials vs. wild age 1+, and wild age 0+ and 1+ precocials combined. A P-value less than 0.05 indicates that there is a positive or negative difference in the mean number of precocials relative to wild precocials. We also compared the absolute value of the differences to see if the differences were significantly different from 0. A two sample t-test was used to compare mean sizes of age 0+, 1+, and hatchery precocials

Results

All residualized hatchery spring chinook salmon that we examined were precocial males (Table 1). In addition, many residualized hatchery fish exuded sperm when we handled them. We therefore treat hatchery residuals synonymously with precocial males. Between 11 and 20% of the wild male age 0+ chinook salmon that we sampled were precocial males (Table 1). Using 120 mm as a threshold for classifying precocials as age 0+ or age 1+ was supported by scale analysis (Table 2). There was little overlap between the size ranges of age 0+ and age 1+ fish. The size differences between age 0+ and wild age 1+, age 0+ and wild age 1+, and wild age 1+ and hatchery precocials were all significantly different ($P<0.05$).

Table 2. Proportions of age 0+ and hatchery precocials that were precocially maturing in the upper Yakima River.

	Wild spring chinook salmon				Hatchery spring chinook salmon			
Year	Collected	Male	Precocial	% Precocial	Collected	Male	Precocial	% Precocial
1999	0	0	0	n/a	32	32	32	100
2000	0	0	0	n/a	0	0	0	n/a
2001	107	55	9	16.4	9	9	9	100
2002	81	55	6	10.9	0	0	0	n/a
2003	141	71	14	19.7	4	4	4	100

Table 3. Fork lengths and ages of wild and hatchery precocial spring chinook salmon (SPC and HSPC respectively). Wild spring chinook collected within the upper Yakima River between August 24 and September 29, 1998. Hatchery spring Chinook collected within the upper Yakima River between the months of July and September 1999-2003

	Sample size	Minimum fork length	Maximum fork length	Mean fork length	Standard deviation
SPC 0+	7	83	124	108.1	13.21
SPC 1+	19	111	189	150.6	18.48
HSPC 1+	57	126	192	159.8	13.98

Distribution and abundance of precocials before spawning

Hatchery precocials were generally observed in greatest abundance immediately below acclimation sites. We observed hatchery precocials 2.5 km, 1.37 km, and 0.5 km above the Jack Creek acclimation site during the summer of 2000, 2001, and 2003 respectively.

The numbers of precocials decreased dramatically between the time of release and the end of September. For example, in a 200 m site below the acclimation site in the North Fork Teanaway in 2000 we observed 525 precocials on July 12, 210 on July 31, 161 on August 16, and none on September 27. We observed very few age 1+ precocials in the Yakima River during August, however they were much more abundant per female than naturally produced residuals (Table 3).

Table 3. Expanded peak counts of age 0+ parr and 1+ spring chinook salmon residuals relative to the number of anadromous female spawners. Counts were extrapolated from August counts within the Nelson, Cle Elum, and Thorp index sites. Expanded distance consists of 68 river kilometers beginning at the Easton Dam and ending at the Town Diversion northwest of Ellensburg.

Residual	# Wild		# Hatchery	# redds	# redds	Hfemales	Wild		Hatchery
observation yr	0+	1+	1+	0+	1+	1+	0+/redd	1+/redd	1+/female
1998*	718	31	NA	387	781	NA	1.86	0.04	NA
1999	1004	11	281	145	387	133	6.95	0.03	2.11
2000	807	27	427	185	145	199	4.37	0.19	2.15
2001	17883	0	57	3519	185	222	5.08	0	0.26
2002	4779	2	4	2906	3519	279	1.64	0.001	0.01
2003	8422	19	38	2614	2906	225	3.22	0.007	0.17
Average	5602	15	161	1626	1321	212	3.85	0.04	0.94
S.D.	6744	13	184	1549	1495	53	2.03	0.07	1.09

*The 1998 data set does not include the Thorp index site. Therefore, the 1998 expansion runs only from the Easton Dam to the confluence of the Teanaway River.

Abundance and distribution of precocials on the spawning grounds

The estimated number of age 0+, age 1+, and hatchery precocials observed on the spawning grounds during the peak of spawning ranged from 4 to 554, 16 to 42, and 11 to 52 respectively (Table 4, 5). The total number of wild precocials on the spawning grounds was higher than the number of hatchery precocials every year and the means and absolute differences were statistically higher ($P<0.05$). The mean number of hatchery and wild 1+ precocials were not significantly different ($P>0.05$) but the mean absolute differences were ($P<0.05$). The coefficient of variation was highest for age 0+ and lowest for wild age 1+ precocials. During the peak of spawning, between 30% and 52% of all hatchery precocials observed on the spawning grounds within a year were in the Thorp section, whereas only 0% to 9% of all age 0+ precocials and 0% to 15% of all wild age 1+ precocials were observed in this section (Table 4).

The release of hatchery fish in the spring affected the abundance and age structure of precocials observed on redds the following fall. In the spawning areas, we observed more hatchery precocials per female taken for hatchery broodstock (HP/F) than naturally produced age 0+ and 1+ precocials per female spawner (NP/F) in the wild combined during 1999 (Table 5), however, there were no statistical differences in the means or the absolute values of the differences between 1999 and 2003 ($P>0.05$). Except for the year 2000, HP/F was higher than age 1+ NP/F and the absolute value of the differences was statistically significant ($P<0.05$), but the difference in means was not statistically different ($P>0.05$). The hatchery does not release age 0+ precocials, so it decreased production of this age of precocial.

Table 4. The expanded number of wild (SPC) and hatchery (HSPC) precocials during the peak of spawning in stream sections.

Reach	Sample Date	Reach length (km)	SPC				HSPC	
			0+	0+/km	1+	1+/km	1+	1+/km
Easton	9/27/99	14.42	1	0.07	4	0.28	6	0.42
Nelson	9/26/99	13.31	0	0	11	0.82	2	0.14
Cle River	9/27/99	12.90	2	0.16	0	0	0	0
Cle Elum	9/28/99	13.59	1	0.11	0	0	1	0.11
Thorp	9/28/99	26.69	0	0	1	0.04	9	0.34
Total	**1999**		**4**		**16**		**18**	
Easton	9/28/00	14.42	16	1.13	0	0	4	0.28
Nelson	9/27/00	13.31	18	1.37	0	0	0	0
Cle River	9/25-9/26/00	12.90	87	6.74	42	3.26	2	0.16
Cle Elum	9/25/00	13.59	4	0.33	0	0	0	0
Thorp	9/28/00	26.69	2	0.09	0	0	5	0.18
Total	**2000**		**128**		**42**		**11**	
Easton	9/18/01	14.42	178	12.37	3	0.20	18	1.22
Nelson	9/23/01	13.31	3	0.25	0	0	0	0
Cle River	9/19-9/20/01	12.90	242	18.76	7	0.54	0	0
Cle Elum	9/20/01	13.59	106	7.78	7	0.52	7	0.52
Thorp	9/19/01	26.69	24	0.91	3	0.11	27	1.02
Total	**2001**		**554**		**20**		**52**	
Easton	9/23/02	14.42	32	2.23	8	0.52	1	0.07
Nelson	9/16/02	13.31	69	5.18	0	0	0	0
Cle River	9/20, 9/23/02	12.90	64	4.98	5	0.37	0	0
Cle Elum	9/17-9/18/02	13.59	56	4.09	10	0.77	7	0.51
Thorp	9/19/02	26.69	8	0.32	1	0.04	5	0.20
Total	**2002**		**229**		**24**		**13**	
Easton	9/26-/27/03	14.42	40	2.80	20	1.37	6	0.40
Nelson	9/26/03	7.29	34	4.67	0	0	0	0
Bullfrog	9/29-9/30/03	10.54	37	3.53	9	0.81	2	0.20
Cle River	9/27/03	12.90	19	1.50	1	0.10	4	0.30
Cle Elum	9/25/03	9.06	102	11.23	4	0.47	4	0.47
Thorp	9/24/03	26.69	24	0.90	2	0.07	7	0.26
Total	**2003**		**257**		**36**		**23**	

Table 5. The estimated number of precocials observed on the spawning grounds during the peak of spawning relative to the number of anadromous female spawners that had the potential to produce precocials.

Precocial	# Wild		# Hatchery	# redds	# redds	Hfemales	Wild		Hatchery
observation yr	0+	1+	1+	0+	1+	1+	0+/redd	1+/redd	1+/female
1999	4	16	18	145	387	133	0.031	0.041	0.138
2000	128	42	11	185	145	199	0.696	0.291	0.054
2001	554	20	52	3519	185	222	0.157	0.107	0.233
2002	229	24	13	2906	3519	279	0.079	0.007	0.048
2003	257	36	23	2614	2906	225	0.098	0.012	0.102
Average	234	28	23	1874	1428	212	0.212	0.092	0.115
S.D.	204	11	17	1594	1646	53	0.274	0.118	0.076
C.V.	87.2	39.8	71.2	85.1	115.2	25.0	129.2	129.2	65.7

Hatchery precocials were the most abundant in sections of the Yakima River that had the least amount of spawning activity. The Lower and Upper Yakima Canyon typically contain less than 1% of the upper Yakima Basin redds (YKFP unpublished data) and yet average 73% of the estimated number of precocials during the spawning season (Table 6).

Table 6. Estimated abundance of hatchery origin spring chinook salmon in mainstem Yakima River index monitoring sites.

	Yakima River Reach					
Year	LCYN	UCYN	EBURG	THORP	CELUM	Total
1999	87	127	98	69	0	381
2000	168	127	26	714	89	1,124
2001	6,581	1,594	736	1,665	0	10,576
2002	294	0	131	64	0	489
2003	1008	290	245	57	0	1601
Avg.	1,628	428	247	514	18	2,834
S.D.	2,793	660	284	703	40	4,356

LCYN = Lower Canyon, UCYN = Upper Canyon, EBURG = Ellensburg, THORP = Thorp, CELUM = Cle Elum sections

Among spawners on redds, 352 interactions were observed. (Table 7). When size difference affected dominance, larger fish dominated smaller ones, regardless of origin (Table 8). No interactions were observed between hatchery precocials and wild age 1+ precocials, presumably because of their low abundance. Fourteen interactions were observed between hatchery and wild age 0+ precocials. Hatchery precocials initiated 86% of these interactions and dominated 67% of the interactions (Table 8). Wild age 0+ and 1+ precocials used similar proportions and types of interactions, but hatchery precocials used fewer types of interactions and much higher proportions of crowding behavior (Table 9).

Table 7. Number of interactions observed on eight redds during the spawning season.

Date	Site	# Contests	Redd Index #								Active
			1	3	4	6	7	9	11	14	Redds Present
9/17/03	Cle Elum	3	9								na
9/19/03	Easton	22	49								2
9/21/03	Easton	15		29							4
9/22/03	Easton	26			37		47				1
9/23/03	Easton	33		13		52					2
9/24/03	Easton	23						31			3
9/25/03	Easton	25							35		6
9/26/03	Easton	34								50	6

Table 8. Behavioral interactions observed among spring chinook salmon precocials within the Cle Elum and Easton index sections of the upper Yakima River. Observations were conducted between September 17th and 26th 2003.

Observed interaction	% Dominance				% Dominance by size			
	Initiator	Recipient	Neither	n	L >S	S >L	Neither	n
SPC 0+ * SPC 0+	55	5	40	236	46.6	12.9	40.5	232
SPC 0+ * SPC 1+	0	38	63	8	37.5	0	62.5	8
SPC 0+ * ADULT	0	0	100	1	0	0	100	1
SPC 0+ * HSPC	0	0	100	2	0	0	100	2
SPC 0+ * JACK	22	33	44	9	33.3	22.2	44.4	9
SPC 1+ * SPC 0+	74	4	22	27	74.1	3.7	22.2	27
SPC 1+ * SPC 1+	29	0	71	7	25	0	75	4
SPC 1+ * ADULT	0	0	100	1	0	0	100	1
SPC 1+ * JACK	33	0	67	3	0	33.3	66.7	3
ADULT * SPC 0+	50	0	50	2	50	0	50	2
ADULT * SPC 1+	67	0	33	3	66.7	0	33.3	3
ADULT * HSPC	100	0	0	2	100	0	0	2
HSPC * SPC 0+	67	0	33	12	66.7	0	33.3	12
HSPC * HSPC	25	0	75	4	25	0	75	4
HSPC * JACK	0	0	100	1	0	0	100	1
JACK * SPC 0+	90	0	10	10	90	0	10	10
JACK * SPC 1+	67	0	33	6	66.7	0	33.3	6
JACK * HSPC	50	0	50	4	50	0	50	4
JACK * JACK	100	0	0	1	100	0	0	1

Summary of observations, regardless of specific contest. L-S indicates larger or smaller spring chinook within an observed interaction. All interactions are composed solely of spring chinook (SPC).

Table 9. Percentage of behavioral interactions types observed among precocial spring chinook salmon within the Cle Elum and Easton index sections of the upper Yakima River. Observations were conducted between September 17th and 26th 2003.

Contest	Sample	% Physical		% non-Physical		
Description	Size	Nip	Butt	Chase	Crowd	Threat
SPC 0+ * SPC 0+	236	34.7	2.1	24.6	30.9	7.6
SPC 0+ * SPC1+	8	0	0	0	100	0
SPC 0+ * HSPC	2	0	0	0	0	100
SPC 0+ Total	246	33.3	2.0	23.6	32.9	8.1
SPC1+ * SPC 0+	27	48.1	3.7	22.2	22.2	3.7
SPC 1+ * SPC 1+	7	42.9	0	28.6	28.6	0
SPC 1+ Total	34	47.1	2.9	23.5	23.5	2.9
HSPC * SPC 0+	12	41.7	0	0	58.3	0
HSPC * HSPC	4	25.0	0	0	75.0	0
HSPC Total	16	37.5	0	0	62.5	0

Discussion

Our results indicate that the natural 1) abundance, 2) distribution, 3) age/size, and 4) behavior, of precocially mature spring chinook salmon on the spawning grounds are being altered by the release of precocially mature hatchery fish. Despite the large numbers of precocials released and the high incidence of precocious male maturation (Larsen et al. 2004), there were fewer hatchery precocials on redds than wild precocials, and no significant difference in the number of precocials produced per female parent on the spawning grounds. The interannual abundance variation and difference that we observed in the abundance of hatchery and wild precocials on the spawning grounds was likely due to a combination of factors including: 1) the artificially high production of precocials in the hatchery environment, 2) the variable production of precocials in the river, 3) the variable survival rate of hatchery and wild fish after hatchery fish are released into the river, and 4) the proportion of surviving hatchery precocials that end up on the spawning grounds. The relatively large number of age 1+ precocials produced by the hatchery may be explained by the growth trajectories that hatchery fish experience and the relatively high survival rate of fish produced in hatcheries. Approximately 37-49% of the males produced by the Cle Elum hatchery were age 1+ precocials between 1999 and 2002 (Larsen et al. 2004). The percentage of hatchery precocials that was produced was relatively constant among the years that were examined and averaged 44%. This consistency in precocial production probably contributed to the lower variation in HP/F compared to NP/F on the spawning grounds. Larsen et al. (2004) hypothesized that the high incidence of age 1+ precocials 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+ (this report) and 1+ fish (Don Larsen, NOAA Fisheries, personal communication) that precocially 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 precocial production from other systems (Gebhards 1960, Mullan et al. 1992, Foote et al. 1991).

Although the rate of precocious male production was relatively constant for hatchery fish, the rate of production was likely to be more variable for wild fish. Emergence times and food abundance, which are both factors that are believed to influence precocious maturation, are much more variable in rivers than they are in the hatchery. In fact, the emergence times of hatchery fish are controlled by water temperature manipulations so that all of the fish can be ponded at the same time. In addition, the growth rates are set to meet certain size targets throughout the season.

The relatively high number of age 1+ hatchery precocials per female was also influenced by the relatively high egg-to-precocial survival that hatchery fish experience. Even if the percentage of precocial maturation was the same between hatchery and wild fish, the higher survival of fish in the hatchery contributes to higher numbers of precocious males per female. The egg-to-smolt survival rate in the hatchery is generally over 80%, compared to less than 10% for wild fish. Hatchery fish typically have a dramatically higher egg-to-smolt survival than wild fish.

However, hatchery fish typically have much lower survivals than wild fish when they are released into natural environments. Despite high survivals in the hatchery, the hatchery precocials seem to experience high mortality after release. For example, repeated snorkel counts of hatchery precocials in index sites of the North Fork Teanaway River indicated substantial declines through the summer; reaching zero during the spawning period. Mortality may be due to high angler exploitation, starvation, or predation. We cannot exclude the possibility that these fish may have moved out of our site as opposed to dieing. It has been documented that precocious males are moving downstream out of the spawning areas and some were detected as far downstream as John Day Dam on the Columbia River (Larsen et al. 2004). Precocials were collected migrating both downstream in the spring and upstream during the summer (Larsen et al. 2004). The downstream migrations occurred during the smolt out-migration period and the upstream migrations occurred at the time of adult spawning immigration. If precocials migrate downstream and then environmental conditions turn poor before they are able to migrate back upstream, then they are likely to die. The lower Yakima River becomes lethal for salmonids during the hot summer months when precocials might attempt to ascend the river. In the Umatilla River, precocials migrated at least 800 km and passed three dams before returning to the Umatilla River (Zimmerman et al. 2003). If mortality or movement in the river is reduced for hatchery fish (e.g., favorable flows and low angling), then alteration of the natural precocial assemblage could change in other ways.

Most of the hatchery precocials on the spawning grounds were observed in a section that had relatively little spawning activity, whereas the wild precocials were mainly in the areas with high spawning activity. The spawning area where most of the hatchery precocials were observed is at the lower end of the spawning distribution. It also happens to be located closest to the Yakima Canyon where the highest abundance of precocials that were not on the spawning grounds were observed. It is a mystery to us why sexually mature hatchery precocials, most of which are exuding sperm at the time of sampling, are located in areas away from where most of the spawning activity occurs. Some hypotheses include: lack of energetic capacity to swim back upstream to the spawning grounds; and inability to locate areas with spawning females after they had migrated downstream of spawning areas. We also observed that some hatchery precocials swam upstream of acclimation sites, but we do not know if naturally produced precocials do this too.

Hatchery fish are only released at age 1+. This eliminates the possibility that age 0+ hatchery precocials will have the potential to spawn. In the absence of hatchery releases, age 0+ precocials are generally more abundant in the spawning areas than age 1+ precocials, so the hatchery is altering the precocial assemblage to an older age and larger size and reducing the diversity of precocial strategies. This is in stark contrast to anadromous hatchery fish which typically mature earlier than wild fish and sometimes at a smaller size at age (Knudson et al. 2002). It is interesting to note that few incidences of precocial maturation at age 0+ have been observed in the hatchery (Larsen et al. 2004). In addition, attempts to experimentally produce age 0+ precocials by high feeding in the hatchery did not produce any precocials in 2002 (M. Farrell, personal communication). These fish emerged at a time that was the average for the population. It is possible that only the fish that emerge very early and experience good growth have the potential to precocially mature at age 0+. We detected differences in the absolute value of HP/F and 1+ NP/F but no difference in the means. This indicates that the differences were both positive and negative but not consistently one or the other. In other words, if the hatchery had not been built, then the natural number of age 1+ precocials would have been lower in 4 years and higher in 1 year.

The number of redds is likely to be an underestimate of the number of females that spawn in the Yakima River. Therefore, we also compared numbers of naturally produced precocials per female passing Roza Dam. The number of females passing Roza Dam is an upper limit to the number of natural females because it assumes complete survival until spawning, which is unlikely. Despite using an artificially high number of natural females, the conclusions were the same.

Hatchery precocials used a smaller repertoire of agonistic behaviors and were more likely to initiate and dominate interactions with wild precocials. Hatchery 1+ fish may be competitively superior to wild precocials because hatchery precocials are larger. Larger salmonids typically dominate smaller ones in behavioral contests (McMichael et al.1999). We have observed a number of instances where hatchery precocials displaced wild precocials from redds or from preferred locations on a redd. Behavioral dominance is important because dominant fish are more likely to be close to females and hence more able to fertilize eggs. Our behavioral results suggest that per capita fertilization rates of hatchery precocials should be higher than that of wild precocials. Ongoing work in the experimental spawning channel at the Cle Elum Supplementation and Research Facility will reveal if hatchery precocials fertilize more eggs than wild precocials (Schroder et al. 2003).

We have identified some issues that could potentially contribute to the underestimation of precocial numbers during our peak counts. We may underestimate the number of active redds by spooking adults or by floating at times when adults are temporarily away from their redds. However, we rarely observe precocials on redds without adults and this finding was also supported by work in the Salmon River drainage (Gebhards 1960). We may also underestimate the number of precocials because they may: 1) be hiding with hiding adults, 2) be hiding away from redds, 3) be scared off redds, 4) be moving between redds, and/or 5) spawn and die prior to our peak count. We have observed that repeated counts of precocials at three different times of the day in the same reach were similar. This suggests that either our counts are accurate or that our bias is consistent. However, counts were quite variable throughout the spawning season. In short, if we are underestimating the number of precocials on the spawning grounds then our numbers should be treated as indices.

Our study points out some challenges with integrating hatchery and wild populations while minimizing changes to natural populations. Many factors influence where and how many precocials will be on the spawning grounds, and many of these factors are outside of the control of hatchery managers. For instance, incidental harvest, flow rate, and water temperature may influence production and survival of precocials in the river and where hatchery precocials will be during the spawning season.

Management of the abundance and dominance of precocials can be accomplished in a variety of ways. There are a number of methods that could be used to minimize hatchery precocials. First and foremost is to reduce the hatchery production of artificially high numbers of precocials. This might be accomplished using techniques such as growth modulation (Larsen et al. 2004) and genetic selection (e.g., not using precocials in the broodstock). Second, precocials could be removed prior to release using methods similar to those used for steelhead residuals (Viola and Schuck 1995). Third, precocials that are released into the river could be selectively removed. For example, precocials could be removed through encouraging sport angling, removing at Roza Dam as they pass through the adult trap, and removed by underwater angling on the spawning grounds. Finally, production of smaller sized precocials is likely to result in more natural rates of dominance with wild fish.

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Appendix

The total number of precocials observed on or associated with redds was quite variable throughout the spawning season (Table 6). We could not detect a consistent pattern across years, even though the number of active redds generally followed a normal temporal distribution. During 2002 and 2003, daily counts in the Easton section were also quite variable, although the highest counts corresponded well with the time that we conducted our peak counts (Table 7, 8). In addition, the number of precocials observed were consistently low, particularly for age 1+ and hatchery precocials. The number of precocials observed within a single reach were similar throughout the day (Table 9).

Table 1. Temporal distribution of precocials on active redds in the Easton, Nelson, and Cle Elum index sites. The number observed on active redds (n), average number of precocials per active redd, and the percent of active snorkeled redds in which precocials were present are presented for each age class.

Date	Index Site	Active Redds Snorkeled	Age 0+			Age 1+			Age 1+ Hatchery		
			N	avg.	%	n	avg.	%	n	avg.	%
				1998							
9/29/98	Nelson	3	19	6.33	100	15	5.00	100	0	n/a	0
9/30/98	Nelson	3	6	2.00	67	11	3.67	67	0	n/a	0
10/1/98	Easton	6	15	2.50	67	8	1.33	50	0	n/a	0
10/5/98	Nelson	4	4	1.00	50	1	0.25	25	0	n/a	0
10/6/98	Cle Elum	5	37	7.40	80	20	4.00	80	0	n/a	0
10/12/98	Cle Elum	1	19	n/a	0	4	n/a	0	0	n/a	0
				1999							
9/20-9/23	All	28	6	0.21	18	13	0.48	32	22	0.80	36
9/26-9/28	All	25	2	0.08	8	9	0.36	16	5	0.20	16
				2000							
9/8-9/13	All	63	3	0.05	3	1	0.02	2	6	0.10	8
9/18-9/22	All	268	43	0.16	7	5	0.02	2	8	0.03	2
9/25-9/28	All	75	13	0.17	9	0	0.00	0	2	0.03	1
				2001							
9/10-9/13	All	24	45	1.88	58	4	0.17	13	0	n/a	0
9/18-9/23	All	52	72	1.38	37	2	0.04	4	4	0.08	6
9/24-9/28	All	53	78	1.47	40	2	0.04	4	10	0.19	13

Table 2. Temporal distribution of wild (SPC) and hatchery (HSPC) precocial spring chinook by age class and origin, from the Easton Dam to the Easton acclimation site 2002.

	Precocial daily totals					Precocials per redd			Frequency of occurrence		
DATE	SPC		HSPC	Active redds	Redds	SPC		HSPC	SPC		HSPC
	0+	1+	1+			0+	1+	1+	0+	1+	1+
9/9/02	3	1	0	7	7	0.43	0.14	0	42.9	14.3	0
9/10/02	2	0	0	10	10	0.20	0	0	10	0	0
9/11/02	3	0	0	10	10	0.30	0	0	10	0	0
9/12/02	1	1	0	12	12	0.08	0.08	0	8.3	8.3	0
9/13/02	0	0	0	13	13	0	0	0	0	0	0
9/16/02	8	2	0	18	18	0.44	0.11	0	16.7	5.6	0
9/17/02	2	0	0	25	25	0.08	0	0	4.0	0	0
9/18/02	3	0	0	43	43	0.07	0	0	4.7	0	0
9/19/02	5	0	0	56	56	0.09	0	0	8.9	0	0
9/20/02	10	0	0	65	65	0.15	0	0	10.8	0	0
9/23/02	12	0	0	27	27	0.41	0	0	18.5	0	0
9/24/02	9	0	0	33	33	0.27	0	0	12.1	0	0
9/25/02	1	0	0	24	24	0.04	0	0	4.2	0	0
9/26/02	3	0	0	9	9	0.33	0	0	11.1	0	0
9/27/02	4	2	0	15	15	0.27	0.13	0	20	6.7	0
9/30/02	4	3	0	4	4	1.00	0.75	0	25.0	50	0
10/01/02	0	0	0	2	2	0	0	0	0	0	0
Avg.	4.1	0.5	0.0	21.9	21.9	0.245	0.072	0	12.184	4.991	0

Table 3. Temporal distribution of wild (SPC) and hatchery (HSPC) precocial spring chinook by age class and origin, from the Easton Dam to the Easton acclimation site 2003.

	Precocial daily totals					Precocials per redd			Frequency of occurrence		
DATE	SPC		HSPC	Active redds	Redds	SPC		HSPC	SPC		HSPC
	0+	1+	1+			0+	1+	1+	0+	1+	1+
9/18/03	6	0	0	1	1	6.00	0	0	100	0	0
9/19/03	6	0	0	2	2	3.00	0	0	50	0	0
9/21/03	93	12	0	4	4	23.25	3	0	50	25	0
9/22/03	2	0	0	1	1	2.00	0	0	100	0	0
9/23/03	1	2	1	2	2	0.50	1	0.50	50	50	50
9/24/03	5	0	0	3	3	1.67	0	0	33.3	0	0
9/25/03	15	0	0	6	6	2.50	0	0	33.3	0	0
9/26/03	18	1	2	6	6	3.00	0.17	0.33	16.7	16.7	16.7
9/28/03	34	1	0	6	6	5.67	0.17	0	100	16.7	0
9/29/03	6	1	0	7	7	0.86	0.14	0	14.3	14.3	0
9/30/03	0	0	0	4	4	0	0	0	0	0	0
10/1/03	0	0	0	14	14	0	0	0	0	0	0
10/2/03	0	0	0	5	5	0	0	0	0	0	0
10/3/03	1	0	1	10	10	0.10	0	0.10	10	0	10
10/6/03	0	0	0	1	1	0	0	0	0	0	0
Avg.	12.5	1.1	0.3	4.8	4.8	3.24	0.30	0.06	37.17	8.17	5.11

Table 4. Multiple pass redd surveys conducted in the Nelson section, fall 2002

Time Period	Age 0+		Age 1+		Age 1+ Hatchery	
	n	per redd	n	per redd	n	per redd
Nelson 9/18/01						
10:00-12:00	28	1.75	1	0.06	1	0.06
13:00-15:00	35	1.75	1	0.05	6	0.30
15:45-17:00	37	1.85	0	0.00	2	0.10
Nelson 9/24/01						
10:00-12:00	3	0.11	0	0	0	0
13:00-15:00	4	0.13	0	0	0	0
15:45-17:00	3	0.10	0	0	0	0