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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 2002**

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## Executive Summary

Select ecological interactions and spring chinook salmon residual/precocial abundance were monitored in 2002 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 2002 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. We developed and monitored space and competition indices for fish that have the potential to compete with juvenile spring chinook salmon during the summer and fall, 1998-2002. The space competition index was highest for spring chinook salmon, but the population food competition index was highest for mountain whitefish. Preliminary analyses revealed that competition indices for spring chinook salmon were the only indices that correlated well with spring chinook growth or survival. We suspect that our index of resource overlap may be too coarse to accurately reflect food competition and recommend identifying prey items to finer taxonomic levels in the future.
- 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 2002 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. Contrary to our expectations, the proportion of spring chinook salmon in sub optimal habitats decreased with increasing abundance of spring chinook. 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 2002 while snorkeling. The release of hatchery fish in the spring affected the natural distribution, abundance, and age structure of precocials observed on redds the following fall. 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. During the peak of

spawning, between 38% and 52% of all hatchery precocials observed on the spawning grounds within a year were in the Thorp section, whereas only 0% to 4% of all age 0+ precocials and 0% to 15% of all wild age 1+ precocials were observed in this section. 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. Except for year 2000, age 1+ HP/F was higher than age 1+ NP/F. The hatchery does not release age 0+ precocials, so it decreased production of this age of precocial. It appears that hatchery precocials experience high mortality after they are released into the river and pose ecological and genetic risks to wild fish.

All findings in this report should be considered preliminary and subject to further revision as more data and analytical results become available.

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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). 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, 2002 in index sections of the upper Yakima Basin (Figure 1). 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.

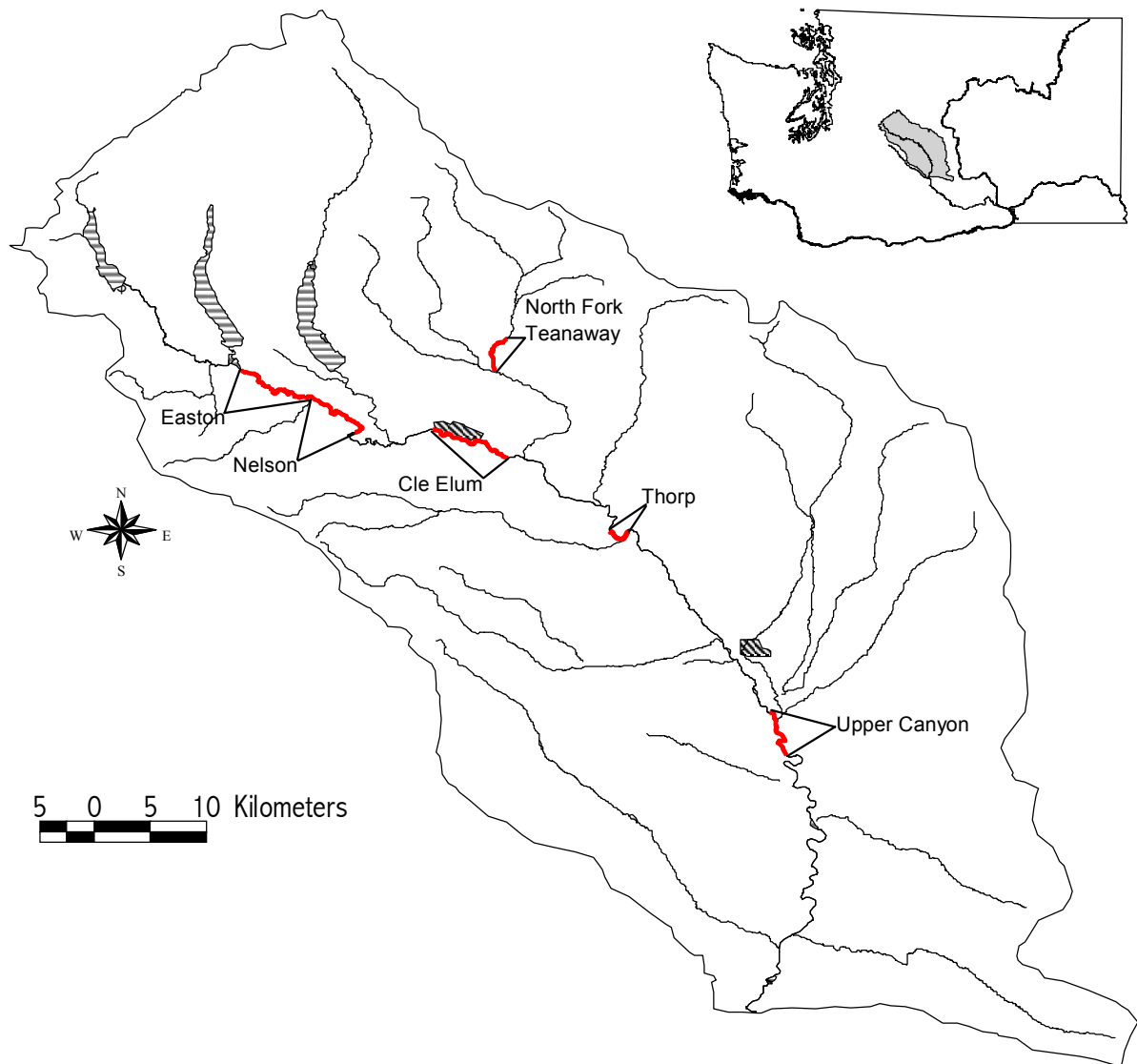


Figure 1. Locations of the study sections in the upper Yakima Basin, Washington. Study sections are identified as thickened sections of the river.

## **Acknowledgments**

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## **Literature Cited**

Busack, C., B., Watson, Pearsons, T., C., Knudsen, S., Phelps, and M. Johnston. 1997. Yakima fisheries project spring chinook supplementation monitoring plan. Bonneville Power Administration, Portland, OR. DOE/BP-64878-1.

# Chapter 1

## **A simple method to index competition strength/potential 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. We developed and monitored space and competition indices for fish that have the potential to compete with juvenile spring chinook salmon during the summer and fall, 1998-2002. The space competition index was highest for spring chinook salmon, but the population food competition index was highest for mountain whitefish. Preliminary analyses revealed that competition indices for spring chinook salmon were the only indices that correlated well with spring chinook growth or survival. We suspect that our index of resource overlap may be too coarse to accurately reflect food competition and recommend identifying prey items to finer taxonomic levels in the future.

### **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*), redbreasted sunfish (*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). Redbreasted sunfish have been shown to displace spring chinook salmon from preferred habitat (Hillman 1989) and are competitively superior to another cold-water salmonid, steelhead trout, at temperatures above 18°C (Reeves et al 1987). Spring chinook salmon parr in the upper Yakima River are frequently observed in close association with redbreasted sunfish, 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

### *Food Competition Index*

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).

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

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

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

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.

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

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 was averaged, regardless of fish size. The competitor abundance index was the relative abundance of each species (6).

$$(\text{number of species } z \text{ observed}) / (\text{total number of all species observed}) \quad (6)$$

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

## 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. We did this to determine the level of taxonomic resolution where results would be consistent. Contents from each stomach were then dried at 80<sup>0</sup> 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.

Stomach content removal methods for rainbow trout were identical to those used for spring chinook salmon, however, mountain whitefish and redbreast 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 freeze-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.

### ***Space Competition Index***

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

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

The spatial overlap index is expressed as the percent of observations where the target taxon has at least one competitor overlapping its “interaction space” (either the same species or a competitor species). “Interaction space” is defined as the 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/spring target taxon abundance when competitors are 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). 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.

## Results

Over 2000 stomach samples were used to derive the equation in Figure 1 that was used to estimate maximum stomach fullness for spring chinook salmon. Spring chinook salmon mainly consumed insects of the following orders; Diptera, Ephemeroptera, and Trichoptera (Figures 2 and 3). The mean gut fullness of spring chinook salmon was relatively low (Table 1). In general, gut fullness increased throughout the day and peaked around dusk (Table 1).

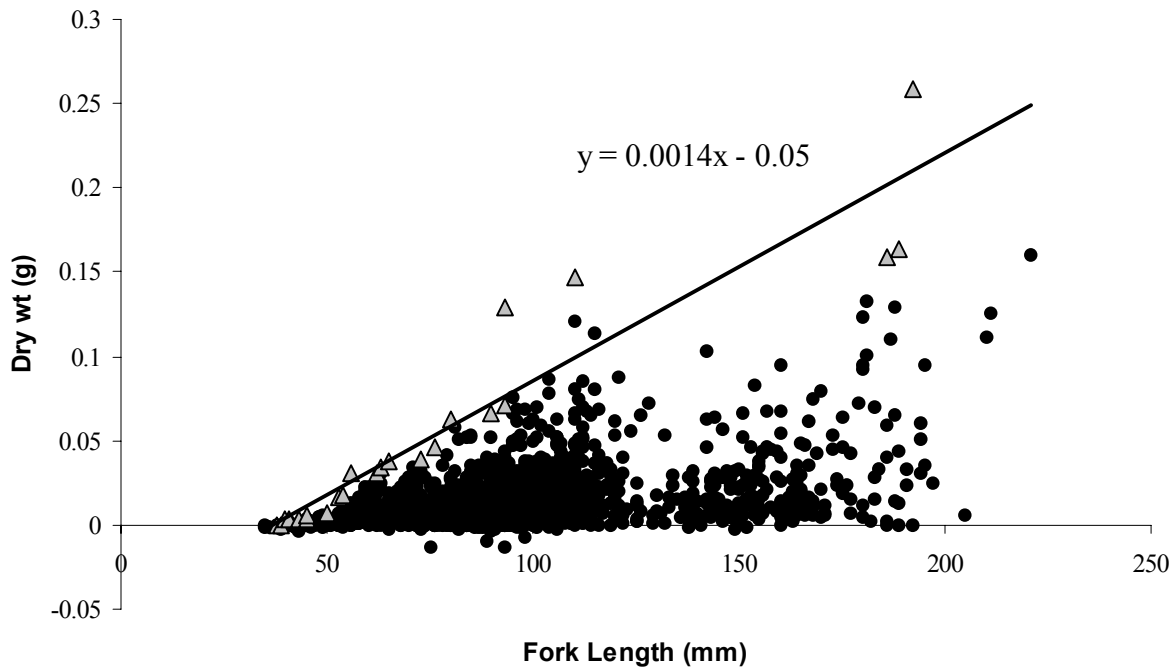


Figure 1. Dry weights of spring chinook salmon stomach contents plotted against spring chinook salmon fork length. The triangular points are the maximum weights used to generate the equation used to determine maximum stomach fullness.

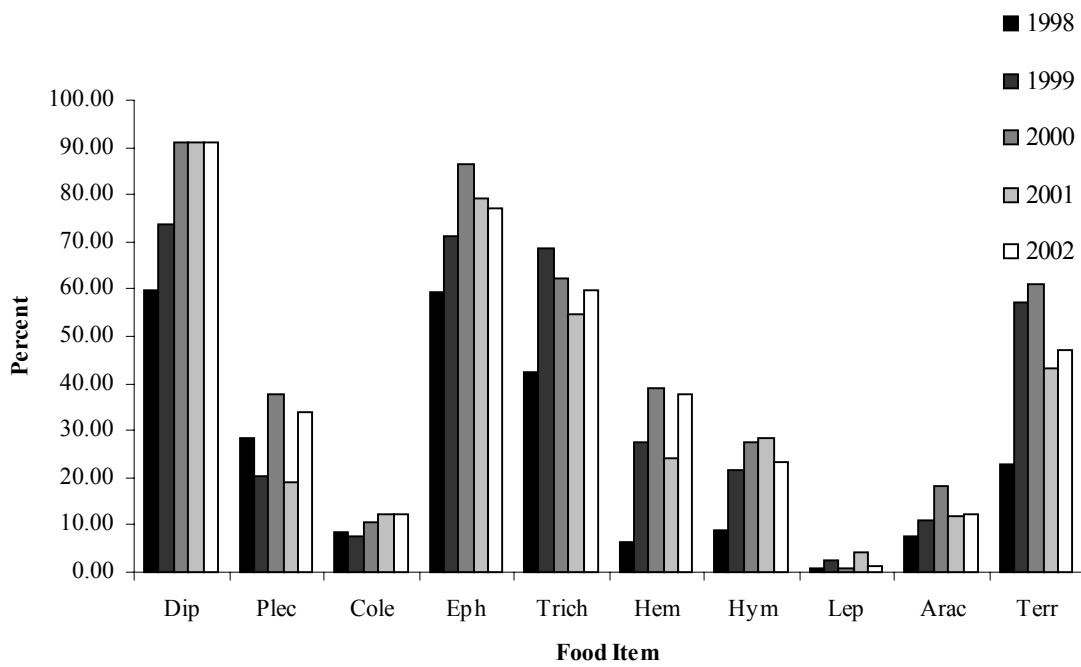


Figure 2. Occurrence frequency of food items found in age-0 spring chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

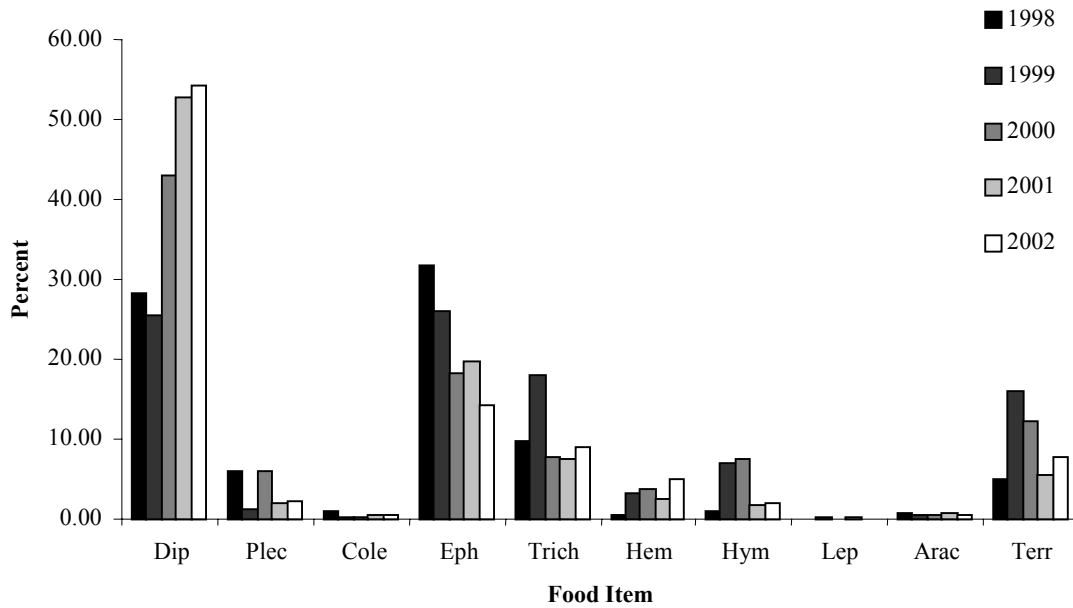


Figure 3. Percent composition of food items found in age-0 spring chinook salmon. Dip=Diptera, Plec=Plecoptera, Cole=Coleoptera, Eph=Ephemeroptera, Tri=Trichoptera, Hem=Hemiptera, Hym=Hymenoptera, Lep=Lepidoptera, Arac=Arachnid, Terr=Terrestrial

### *Food Competition Index*

The competition index calculated for age-0 spring chinook salmon suggests that interspecific competition for food was higher than intraspecific competition (Table 2). The per capita index was highest for spring chinook salmon, whereas the population competition index was highest for whitefish during all years (Table 3).

Identification of stomach contents to family had a large impact on the index (Table 2). The index for mountain whitefish was substantially reduced when prey items were identified to family compared to order.

Table 1. Average stomach fullness by time for wild spring chinook greater than or equal to 50 mm within the mainstem Yakima River.

Time	1998		1999		2000		2001		2002	
	n	%	n	%	n	%	n	%	n	%
0:01-4:00	0	n/a	8	7.2	28	25.0	10	11.5	5	21.6
4:01-8:00	0	n/a	0	n/a	0	n/a	0	n/a	46	18.0
8:01-12:00	87	4.4	14	17.0	48	8.2	101	17.2	120	17.5
12:01-16:00	141	6.1	80	11.4	89	13.5	179	19.1	179	14.7
16:01-20:00	6	16.8	88	17.3	13	16.8	130	24.1	74	22.2
20:01-24:00	0	n/a	83	20.0	121	22.7	68	20.4	62	29.7
Average Day (7:59-20:00)		9.1		16.4		15.3		20.2		18.1
Average Night (20:01-4:00)		n/a		13.6		23.8		16.0		23.1

Table 2. Per capita and population food competition indices 1998-2002 between 0+ spring chinook salmon (SPC) and competitor species, all time periods. An index of zero represents a species with no observed spatial overlap and/or competitor abundance within a given year.

Species	Diet overlap	1-fullness SPC	Per capita index	Average dry wt (g)	Stdev dry wt (g)	Competitor abundance	Population index
<b>1998</b>							
COHO	0	0.91	0	NA	NA	NA	0
CUT	0	0.91	0	NA	NA	NA	0
EBT	60.37	0.91	54.89	0.39	0.03	NA	0
HSPC	0	0.91	0	NA	NA	NA	0
MWF	65.33	0.91	59.40	0.04	0.03	61.84	139.41
RBT	74.76	0.91	67.97	0.02	0.03	11.24	12.48
RSS	50.74	0.91	46.14	3.0E-03	2.7E-03	0.09	0.01
SPC	100.00	0.91	90.93	4.4E-03	0.01	15.29	6.06
SUK	0	0.91	0	NA	NA	NA	0
<b>1999</b>							
COHO	0	0.84	0	NA	NA	NA	0
CUT	61.88	0.84	51.72	NA	NA	NA	0
EBT	61.28	0.84	51.22	0.05	0.06	0.14	0.39
HSPC	84.68	0.84	70.78	0.03	0.04	NA	0
MWF	37.28	0.84	31.16	0.07	0.07	52.98	122.69
RBT	69.84	0.84	58.37	0.06	0.15	19.35	67.01
RSS	46.17	0.84	38.59	0.01	0.00	0.42	0.13
SPC	100.00	0.84	83.58	0.01	0.02	6.77	8.43
SUK	0	0.84	0	NA	NA	NA	0
<b>2000</b>							
COHO	0	0.85	0	NA	NA	NA	0
CUT	54.20	0.85	45.90	NA	NA	NA	0

EBT	59.44	0.85	50.33	0.05	0.08	0.14	0.37
HSPC	66.75	0.85	56.52	0.03	0.02	NA	0
MWF	55.70	0.85	47.16	0.09	0.08	48.26	208.31
RBT	76.76	0.85	65.00	0.08	0.09	11.51	57.45
RSS	72.49	0.85	61.38	0.03	0.05	2.19	4.48
SPC	100.00	0.85	84.68	0.02	0.02	5.74	8.00
SUK	47.71	0.85	40.40	0.05	0.05	7.96	15.91
<b>2001</b>							
COHO	76.26	0.80	60.84	0.01	0.01	NA	0
CUT	38.98	0.80	31.10	0.13	0.00	0.16	0.64
EBT	31.94	0.80	25.49	0.28	0.29	0.01	0.07
HSPC	49.00	0.80	39.09	0.04	0.04	NA	0
MWF	72.52	0.80	57.86	0.08	0.07	53.72	258.35
MWF	16.46*	0.80	13.13	0.08	0.07	53.72	58.63
RBT	63.15	0.80	50.39	0.07	0.09	6.69	23.46
RSS	67.41	0.80	53.78	0.01	0.01	0.31	0.21
SPC	100.00	0.80	79.79	0.01	0.06	23.33	27.49
SUK	57.48	0.80	45.86	0.08	0.09	10.65	41.50
<b>2002</b>							
COHO	86.98	0.82	71.21	0.01	0.01	NA	0
CUT	57.70	0.82	47.24	0.10	0.07	0.24	1.08
EBT	63.70	0.82	52.15	0.05	0.06	NA	0
HSPC	50.16	0.82	41.06	0.07	0.04	NA	0
MWF	63.32	0.82	51.84	0.07	0.06	42.30	146.97
MWF	8.97*	0.82	7.34	0.07	0.06	42.30	20.81
RBT	77.12	0.82	63.14	0.08	0.21	6.95	35.66
RSS	74.39	0.82	60.91	0.04	0.02	1.47	3.22
SPC	100.00	0.82	81.87	0.01	0.01	20.81	22.02
SUK	59.59	0.82	48.78	0.09	0.10	5.25	24.08
<b>Average 1998-2002</b>							
COHO	81.62		66.03	0.01		NA	0
CUT	53.19		43.99	0.25		0.10	0.43
EBT	55.34		46.81	0.17		0.06	0.17
HSPC	62.65		51.86	0.04		NA	0
MWF	58.83		49.48	0.07		51.82	175.14
RBT	72.33		60.97	0.06		11.15	39.21
RSS	62.24		52.16	0.02		0.90	1.61
SPC	100.00		84.17	0.01		14.39	14.40
SUK	54.93		45.02	0.08		7.95	27.16

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

\*Overlap values calculated from samples of both SPC and the competitor species MWF in which gut contents were identified to invertebrate family rather than order. These values are for comparison only and are not included in the overall average.

### *Space Competition Index*

Space competition indices were highest for spring chinook (i.e., intraspecific competition) during all years (Table 3, 4). The next highest index score was for rainbow trout and then redbside shiner (Table 3). High indices for rainbow trout are primarily due to high spatial overlap, whereas high indices for redbside shiner is primarily due to localized high abundance (Table 3).

Table 3. 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
<b>1998* n = 325</b>			
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
<b>1999 n = 151</b>			
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
<b>2000 n = 205</b>			
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
<b>2001 n = 1306</b>			
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

Average 1999-2002				
Species	Spatial overlap	Competitor abundance	Space comp.	Stdev
SPC	0.57	5.29	2.99	0.53
HSPC	0.05	0.35	0.03	0.06
RBT	0.22	0.71	0.19	0.15
MWF	0.06	0.59	0.05	0.05
RSS	0.04	2.01	0.11	0.13
SUK	0.001	0.07	1.6E-04	2.2E-04
COHO	0.03	0.02	6.3E-04	NA

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

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

Table 4. Ranking of spring chinook competitor, food, and space indices by species averages 1998-2002. Index values of zero indicate a lack of observed spatial overlap and/or competitor abundance.

Rank	Per Capita Food		Population Food		Space competition	
1	<b>SPC</b>	<b>84.17</b>	MWF	175.14	<b>SPC</b>	<b>2.99</b>
2	COHO	66.03	RBT	39.21	RBT	0.15
3	RBT	60.97	SUK	27.16	RSS	0.11
4	RSS	52.16	<b>SPC</b>	<b>14.40</b>	MWF	0.05
5	HSPC	51.86	RSS	1.61	HSPC	0.03
6	MWF	49.48	CUT	0.43	COHO	6.3E-04
7	EBT	46.81	EBT	0.17	SUK	1.6E-04
8	SUK	45.02	COHO	0	CUT	0
9	CUT	43.99	HSPC	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 = redbside 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 use in calculating the food competition index likely underestimated the abundance of hatchery spring chinook precocials.

The space competition and the per capita food indices were highest for spring chinook salmon, but the population food competition index was highest for mountain whitefish. Preliminary analyses revealed that competition indices for spring chinook salmon were the only indices that correlated well with spring chinook growth or survival. We found that the size of age 0+ spring chinook was negatively related to the number of redds that produced them (Figure 4). In addition, above about 750 redds we did not observe a relationship between number of redds and the number of fry the following Fall (Figure 5). These findings suggest that density dependant growth and survival of spring chinook salmon is occurring in the upper Yakima River. Below about 750 redds we found a positive relationship between survival and the number of redds that produced them (Figure 5).

The lack of strong correlations with mountain whitefish suggest that our population food competition index needs refinement. As discussed earlier, we believe that identifying prey items to the lowest practicable level will lower the competition index for mountain whitefish substantially

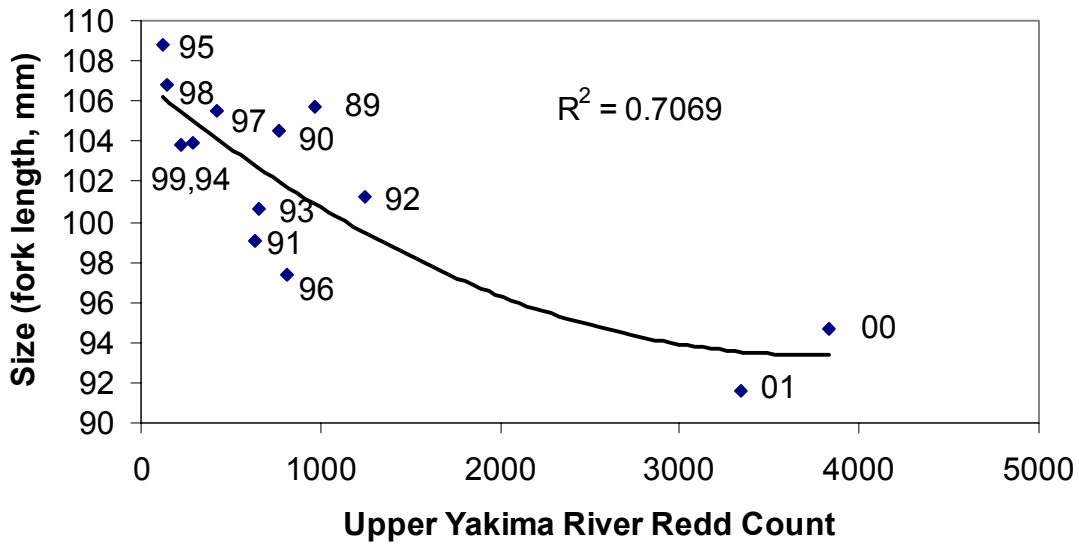


Figure 4. Size of age 0+ spring chinook salmon during September and October versus the number of redds that were produced the year prior. The dates are the year that redds were counted.

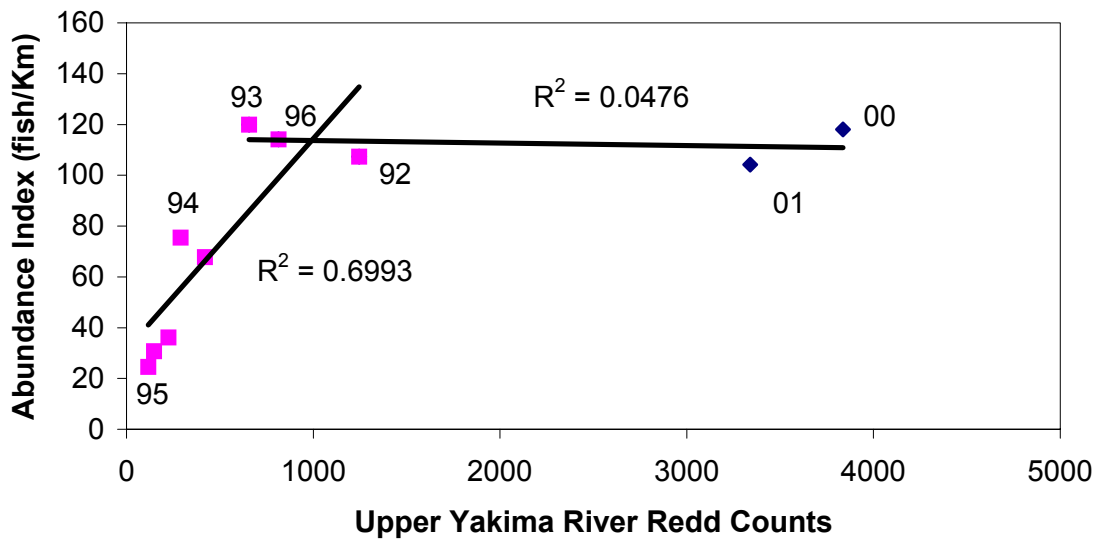


Figure 5. Abundance index of age 0+ spring chinook salmon during September and October versus the number of redds that were counted the year prior. The dates are the year that redds were counted.

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## Chapter 2

### Microhabitat Utilization of Spring Chinook Salmon

#### Abstract

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 2002 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. Contrary to our expectations, the proportion of spring chinook salmon in sub optimal habitats decreased with increasing abundance of spring chinook. 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 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). 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). 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) 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 wanted to develop a way to monitor the range of microhabitats used within schools or pods of these fish by comparing the microhabitat values of the purported dominant fish within a pod and the fish that was furthest downstream within the pod (the purported most subordinate fish) as well as the difference in values for the fish at each outer edge of the pod. We expect that when densities are lower, the differences between these values would be less than when densities are higher.

This report summarizes the continuation of data collected since 1998 (James et al. 1999).

## **Methods**

To adequately characterize the microhabitat use of age-0 spring chinook salmon and associated species, we measured multiple variables surrounding 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 during 1999 to 2001 because of difficulties in

observing spring chinook salmon due to increased use of instream cover caused by cooler water temperatures (James et al. 1999). 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, redbreasted shiners and mountain whitefish observed by snorkeling in the upper Yakima River Basin between 1998 and 2002.

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
*Substrate	Dominant and subdominant recorded using the Wentworth scale (Cummins 1962)
*Habitat Type	Deep pool, shallow, pool, deep run, shallow run, run, low gradient riffle, pocket pool (Frissell 1986)
*Overhead Cover	Visual estimation of percent cover and distance to cover (m)
*Instream Cover	Distance to marker (m) and cover type; wood, rock, aquatic vegetation, overhanging vegetation, undercut bank, water depth, and turbulence
*Distance to Bank	(m)

\*Microhabitat variables discontinued after the 1998 sampling season.

Table 2. Summary of dates and ranges of water temperatures (°C) measured during collection of 1998 to 2002 microhabitat data on spring chinook salmon in four study sections in the upper Yakima River Basin.

Section	Dates	Year	Water Temperature (°C)
Nelson	July 21	1998	14.5 – 16.0
Nelson	August 6	1998	16.5 – 18.0
Nelson	August 10	1998	16.0 – 19.0
Nelson	August 25-27	1998	15.0 – 18.5
Nelson	September 15-17	1998	16.0 – 17.0
Cle Elum	August 18-19	1998	16.5 – 18.5
Cle Elum	August 31-Sept. 3	1998	17.0 – 19.5
Cle Elum	Sept. 22	1998	14.0
Upper Canyon	Sept. 8-10	1998	15.0 – 19.0
N. F. Teanaway	August 11-12	1998	15.0 – 22.0
Nelson	July 29-30	1999	14-16
Nelson	August 2-3	1999	14-16
Nelson	August 25-26	1999	15-18
Cle Elum	August 10-12	1999	11.5-12
Cle Elum	September 2	1999	11-12
Cle Elum	September 7	1999	11.5-14
Thorp	August 23-25	1999	13-14
Thorp	September 10	1999	11-13
Nelson	July 26-27	2000	13-18
Cle Elum	August 8	2000	15-16
Cle Elum	August 17	2000	18
Cle Elum	August 21	2000	16-17.5
Thorp	August 22	2000	15.5-16.5
N. F. Teanaway	July 31	2000	17-21
Nelson	August 8	2001	16-17
Nelson	August 13	2001	14
Cle Elum	August 2	2001	18-19.5
Cle Elum	August 20	2001	19-19.5
Thorp	July 31	2001	16-19
Thorp	August 9	2001	15-17
Thorp	August 21	2001	17
N. F. Teanaway	August 6	2001	16-22
Nelson	August 5-6	2002	14-16
Nelson	August 14	2002	16.5-19
Nelson	August 21	2002	16-17.5
Cle Elum	August 12	2002	15
Cle Elum	August 15	2002	14-16
Cle Elum	August 20	2002	16
Cle Elum	August 28	2002	15.5-16
N. F. Teanaway	August 7	2002	16-17.5
N. F. Teanaway	August 13	2002	13-21
N. F. Teanaway	August 22	2002	17.5-19
N. F. Teanaway	August 28	2002	18

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, WDFW unpublished data) 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 1999 to 2002 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 Swiffer 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 grouped and analyzed by river section, species, and age class. By using these index sections, we hope to detect potential changes that may occur as supplementation proceeds.

In 2001 we decided on a new approach to compare the data in order to track yearly changes in 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 1). We then used the upper 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 2002 data. The idea is to compare the percent of spring chinook salmon that are using habitat that fall above this line for each year. In years of higher abundance of spring chinook salmon, we would expect them to use habitat above this line at a higher proportion than years with lower abundance if habitat is limited.

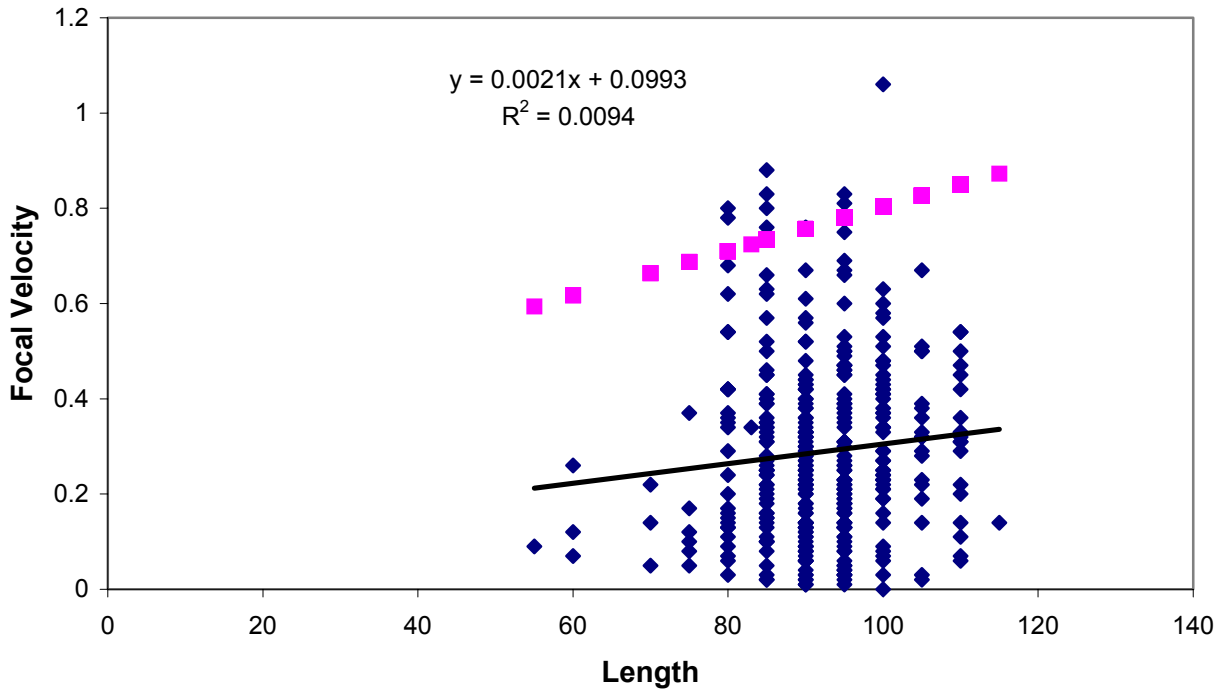


Figure 1. Relationship between spring chinook salmon length and focal velocity during 1998. Included are the linear regression line (in black), and the upper 98% confidence line. The lower 98% confidence line lies below the x-axis and is not shown.

## Results

Age-0 spring chinook salmon were found in a relatively small portion of the available habitat and exhibited preference for specific microhabitat criteria. General summer microhabitat use by spring chinook salmon is summarized in Table 3. No age-0 spring chinook salmon were observed in the North Fork Teanaway River in 2000, where only one redd was counted in 1999.

Single factor ANOVA's were used to determine if differences exist between sections with respect to summer microhabitat variables (Table 4). All variables, with the exception of 60% velocity and focal velocity, were found to be statistically different between sections. Therefore we did not combine any of the sections in order to show their respective differences.

Table 3. Summary of microhabitat parameters used by age-0 spring chinook salmon during summer 1998 to 2002 in each study section in the upper Yakima River Basin. Depths were measured in meters (m). Velocities are reported as meters/second (m/s).

Variable	N	Mean	Std Dev	Std Error	Min	Max	Coefficient of Variation
Nelson 1998							
Total Depth	171	0.87	0.31	0.02	0.29	1.80	0.35
Focal Depth	152	0.28	0.19	0.02	0.05	0.94	0.68
Surface Velocity	163	0.47	0.31	0.02	0.04	1.45	0.66
60% Velocity	163	0.32	0.23	0.02	0.00	1.06	0.71
Focal Velocity	148	0.28	0.21	0.02	0.00	1.06	0.74
Cle Elum 1998							
Total Depth	185	0.63	0.22	0.02	0.21	1.50	0.36
Focal Depth	169	0.17	0.17	0.01	0.03	1.16	1.00
Surface Velocity	184	0.38	0.25	0.02	0.00	1.10	0.67
60% Velocity	182	0.34	0.22	0.02	0.00	1.08	0.63
Focal Velocity	168	0.27	0.17	0.01	0.01	0.88	0.63
North Fork Teanaway 1998							
Total Depth	82	0.64	0.16	0.02	0.29	0.96	0.25
Focal Depth	83	0.45	0.17	0.02	0.00	0.74	0.38
Surface Velocity	83	0.15	0.16	0.02	0.00	0.59	1.00
60% Velocity	80	0.14	0.14	0.02	0.00	0.60	1.01
Focal Velocity	77	0.12	0.12	0.01	0.00	0.49	1.01
Nelson 1999							
Total Depth	112	0.90	0.34	0.03	0.29	1.90	0.38
Focal Depth	101	0.66	0.25	0.03	0.19	1.60	0.38
Surface Velocity	111	0.31	0.24	0.02	0.02	1.03	0.78
60% Velocity	112	0.29	0.21	0.02	0.00	0.95	0.71
Focal Velocity	101	0.23	0.16	0.02	0.00	0.81	0.69
Cle Elum 1999							
Total Depth	70	0.70	0.22	0.03	0.34	1.40	0.32
Focal Depth	64	0.53	0.23	0.03	0.22	1.35	0.42
Surface Velocity	68	0.21	0.17	0.02	0.02	0.72	0.84
60% Velocity	68	0.22	0.17	0.02	0.00	0.88	0.79
Focal Velocity	62	0.19	0.13	0.02	0.00	0.50	0.71
Thorp 1999							
Total Depth	28	0.98	0.24	0.04	0.65	1.50	0.24
Focal Depth	26	0.71	0.19	0.04	0.27	1.15	0.27
Surface Velocity	28	0.55	0.20	0.04	0.30	0.98	0.36

60% Velocity	28	0.37	0.20	0.04	0.08	0.81	0.54
Focal Velocity	26	0.26	0.15	0.03	0.00	0.59	0.57

Nelson 2000

Total Depth	59	1.05	0.59	0.08	0.43	3.00	0.56
Focal Depth	59	1.03	0.58	0.08	0.40	2.99	0.57
Surface Velocity	58	0.28	0.25	0.03	0.01	0.91	0.88
60% Velocity	54	0.25	0.20	0.03	0.03	0.80	0.79
Focal Velocity	58	0.21	0.17	0.02	0.02	0.59	0.80

Cle Elum 2000

Total Depth	69	0.73	0.20	0.02	0.45	1.35	0.27
Focal Depth	69	0.71	0.19	0.02	0.44	1.33	0.27
Surface Velocity	68	0.33	0.24	0.03	0.02	1.04	0.73
60% Velocity	68	0.31	0.24	0.03	0.00	0.95	0.80
Focal Velocity	68	0.25	0.23	0.03	0.01	1.27	0.92

Thorp 2000

Total Depth	10	0.66	0.25	0.08	0.26	1.20	0.38
Focal Depth	10	0.64	0.25	0.08	0.25	1.18	0.39
Surface Velocity	10	0.31	0.26	0.08	0.02	0.76	0.82
60% Velocity	10	0.28	0.23	0.07	0.05	0.68	0.81
Focal Velocity	10	0.20	0.11	0.04	0.01	0.36	0.56

Nelson 2001

Total Depth	44	0.73	0.19	0.03	0.31	1.16	0.26
Focal Depth	44	0.58	0.17	0.03	0.25	1.04	0.29
Surface Velocity	44	0.59	0.31	0.05	0.07	1.28	0.52
60% Velocity	44	0.43	0.27	0.04	0.03	1.00	0.63
Focal Velocity	44	0.26	0.16	0.02	0.01	0.67	0.61

Cle Elum 2001

Total Depth	59	0.57	0.19	0.02	0.27	1.08	0.34
Focal Depth	52	0.44	0.13	0.02	0.18	0.76	0.30
Surface Velocity	59	0.44	0.13	0.02	0.18	0.76	0.30
60% Velocity	59	0.31	0.19	0.03	0.01	0.81	0.63
Focal Velocity	52	0.22	0.11	0.02	0.01	0.54	0.50

Thorp 2001

Total Depth	62	0.60	0.25	0.03	0.17	1.38	0.42
Focal Depth	60	0.47	0.21	0.03	0.10	1.03	0.44
Surface Velocity	62	0.45	0.33	0.04	0.00	1.27	0.73
60% Velocity	62	0.38	0.27	0.03	0.00	1.13	0.72
Focal Velocity	60	0.21	0.13	0.02	0.02	0.58	0.64

North Fork Teanaway 2001

Total Depth	42	0.42	0.17	0.03	0.20	0.74	0.40
Focal Depth	41	0.33	0.13	0.02	0.16	0.67	0.40
Surface Velocity	42	0.28	0.13	0.02	0.06	0.59	0.44
60% Velocity	42	0.24	0.10	0.02	0.04	0.42	0.55
Focal Velocity	41	0.19	0.11	0.02	0.04	0.42	0.55

Nelson 2002

Total Depth	176	0.63	0.22	0.02	0.20	1.40	0.35
Focal Depth	176	0.49	0.19	0.01	0.17	1.33	0.40
Surface Velocity	176	0.45	0.24	0.02	0.00	1.05	0.53
60% Velocity	176	0.35	0.20	0.01	0.01	0.91	0.57
Focal Velocity	176	0.24	0.13	0.01	0.00	0.63	0.56

Cle Elum 2002

Total Depth	130	0.60	0.11	0.01	0.32	0.89	0.19
Focal Depth	126	0.47	0.12	0.01	0.18	0.75	0.25
Surface Velocity	130	0.28	0.21	0.02	0.00	0.92	0.77
60% Velocity	130	0.25	0.21	0.02	0.00	0.98	0.82
Focal Velocity	126	0.18	0.14	0.01	0.00	0.56	0.78

North Fork Teanaway 2002

Total Depth	104	0.52	0.13	0.01	0.21	0.88	0.25
Focal Depth	104	0.42	0.13	0.01	0.17	0.84	0.31
Surface Velocity	104	0.27	0.14	0.01	0.00	0.68	0.54
60% Velocity	104	0.23	0.12	0.01	0.00	0.58	0.51
Focal Velocity	104	0.20	0.11	0.01	0.00	0.56	0.56

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Table 4. Results of ANOVA tests comparing summer microhabitat variables between study sections for age-0 spring chinook salmon in the upper Yakima River Basin during 1998 to 2002. Depths were measured in meters (m). Velocities were measured in meters/second (m/s). Lengths were measured in millimeters (mm).

Variable	<i>df</i>	F	<i>P</i>
Nelson, Cle Elum 1998			
Total Depth	340	128.47	<0.0001
Focal Depth	319	36.20	<0.0001
Surface Velocity	332	21.68	<0.0001
60% Velocity	332	0.35	<0.57
Focal Velocity	314	0.26	<0.62
Length	315	7.39	<0.01
Nelson, Cle Elum, Thorp 1999			
Total Depth	207	13.38	<0.0001
Focal Depth	188	7.77	<0.001
Surface Velocity	204	23.84	<0.0001
60% Velocity	205	6.15	<0.01
Focal Velocity	186	2.60	<0.081
Length	189	6.38	<0.01
Nelson, Cle Elum, Thorp 2000			
Total Depth	135	10.96	<0.0001
Focal Depth	135	10.89	<0.0001
Surface Velocity	133	0.57	<0.57
60% Velocity	129	0.75	<0.48
Focal Velocity	133	0.84	<0.44
Length	134	41.40	<0.0001
Nelson, Cle Elum, Thorp 2001			
Total Depth	162	7.88	<0.001
Focal Depth	153	9.00	<0.001
Surface Velocity	162	8.93	<0.001
60% Velocity	162	3.13	<0.051
Focal Velocity	153	1.63	<0.21
Length	151	4.67	<0.011
Nelson, Cle Elum 2002			
Total Depth	304	3.43	<0.066
Focal Depth	300	1.89	<0.18
Surface Velocity	304	42.54	<0.001
60% Velocity	304	16.00	<0.001
Focal Velocity	300	14.40	<0.001
Length	300	2.65	<0.106

Tables 5 to 9 shows the mean absolute differences between the head (most upstream in the pod) and tail (most downstream in the pod) and between left and right positions for five different microhabitat parameters measured in all sites during 1998 to 2002. These data illustrate relatively small and consistent differences.

Table 5. Mean absolute differences between head/tail (H/T) microhabitat positions and between left/right (L/R) positions held by age-0 spring chinook salmon in the upper Yakima River Basin in 1998.

Positions	N	Total Depth	Focal Depth	Surface Velocity	60% Velocity	Focal Velocity
Nelson						
H/T	38	0.15	0.15	0.15	0.08	0.11
L/R	33	0.21	0.16	0.22	0.19	0.2
Cle Elum						
H/T	31	0.05	0.1	0.13	0.11	0.13
L/R	29	0.11	0.13	0.18	0.17	0.13
North Fork Teanaway						
H/T	12	0.04	0.05	0.03	0.07	0.03
L/R	13	0.06	0.14	0.05	0.06	0.05

Table 6. Mean absolute differences between head/tail (H/T) microhabitat positions and between left/right (L/R) positions held by age-0 spring chinook salmon in the upper Yakima River Basin in 1999.

Positions	N	Total Depth	Focal Depth	Surface Velocity	60% Velocity	Focal Velocity
Nelson						
H/T	13	0.19	0.17	0.10	0.10	0.11
L/R	17	0.11	0.14	0.10	0.27	0.10
Cle Elum						
H/T	9	0.06	0.05	0.07	0.06	0.03
L/R	8	0.11	0.10	0.06	0.05	0.11
Thorp						
H/T	3	0.13	0.16	0.04	0.12	0.06
L/R	3	0.05	0.22	0.11	0.22	0.02

Table 7. Mean absolute differences between head/tail (H/T) microhabitat positions and between left/right (L/R) positions held by age-0 spring chinook salmon in the upper Yakima River Basin in 2000.

Positions	N	Total Depth	Focal Depth	Surface Velocity	60% Velocity	Focal Velocity
Nelson						
H/T	7	0.10	0.10	0.11	0.02	0.05
L/R	11	0.17	0.16	0.11	0.12	0.18
Cle Elum						
H/T	12	0.10	0.11	0.16	0.13	0.16
L/R	6	0.09	0.09	0.16	0.20	0.15
Thorp						
H/T	2	0.18	0.19	0.34	0.26	0.16
L/R	2	0.28	0.28	0.37	0.35	0.03

Table 8. Mean absolute differences between head/tail (H/T) microhabitat positions and between left/right (L/R) positions held by age-0 spring chinook salmon in the upper Yakima River Basin in 2001.

Positions	N	Total Depth	Focal Depth	Surface Velocity	60% Velocity	Focal Velocity
Nelson						
H/T	5	0.04	0.06	0.08	0.17	0.08
L/R	5	0.04	0.10	0.11	0.04	0.06
Cle Elum						
H/T	12	0.04	0.05	0.06	0.09	0.08
L/R	9	0.06	0.10	0.12	0.13	0.22
Thorp						
H/T	10	0.07	0.08	0.22	0.16	0.19
L/R	14	0.14	0.19	0.25	0.16	0.27
North Fork Teanaway						
H/T	2	0.05	0.03	0.11	0.03	0.04
L/R	5	0.06	0.06	0.09	0.04	0.07

Table 9. Mean absolute differences between head/tail (H/T) microhabitat positions and between left/right (L/R) positions held by age-0 spring chinook salmon in the upper Yakima River Basin in 2002.

Positions	N	Total Depth	Focal Depth	Surface Velocity	60% Velocity	Focal Velocity
Nelson						
H/T	33	0.12	0.12	0.13	0.11	0.08
L/R	23	0.11	0.16	0.15	0.13	0.14
Cle Elum						
H/T	26	0.08	0.06	0.17	0.12	0.11
L/R	27	0.10	0.07	0.16	0.13	0.18
North Fork Teanaway						
H/T	12	0.05	0.04	0.06	0.08	0.07
L/R	16	0.08	0.07	0.09	0.10	0.10

Summer microhabitat used by age-1+ spring chinook salmon, age-0 rainbow trout, age-1+ rainbow trout, and age-0 mountain whitefish are summarized in Tables 10 to 14.

Table 10. Summary of microhabitat used by age-1+ spring chinook salmon, age-0 and age-1+ rainbow trout, and mountain whitefish in the upper Yakima River Basin during summer 1998 (all sections pooled). Depths were measured in meters (m). Velocities are reported as meters/second (m/s).

Variable	N	Mean	Std Dev	Std Error	Min	Max	Coefficient of Variation
Age-1+ Spring Chinook Salmon Upper Yakima River							
Total Depth	14	0.86	0.31	0.08	0.47	1.60	0.36
Focal Depth	14	0.24	0.16	0.04	0.06	0.53	0.67
Surface Velocity	13	0.79	0.48	0.13	0.06	1.65	0.61
60% Velocity	13	0.52	0.26	0.07	0.11	1.04	0.50
Focal Velocity	13	0.43	0.23	0.07	0.04	0.83	0.53
Age-0 Rainbow Trout Upper Yakima River							
Total Depth	27	0.43	0.13	0.03	0.29	0.68	0.30
Focal Depth	27	0.10	0.07	0.01	0.03	0.27	0.70
Surface Velocity	27	0.35	0.16	0.03	0.04	0.74	0.46
60% Velocity	27	0.28	0.15	0.03	0.03	0.58	0.54
Focal Velocity	27	0.21	0.12	0.02	0.01	0.40	0.57
Age-1+ Rainbow Trout Upper Yakima River							
Total Depth	12	0.81	0.41	0.12	0.36	1.45	0.51
Focal Depth	12	0.67	0.35	0.10	0.30	1.31	0.53
Surface Velocity	11	0.63	0.40	0.12	0.17	1.27	0.63
60% Velocity	11	0.41	0.30	0.09	0.04	0.92	0.74
Focal Velocity	11	0.30	0.26	0.08	0.02	0.79	0.86
Age-1+ Rainbow Trout North Fork Teanaway River							
Total Depth	14	0.63	0.16	0.04	0.31	0.87	0.26
Focal Depth	14	0.53	0.15	0.04	0.28	0.78	0.29
Surface Velocity	14	0.25	0.23	0.06	0.00	0.65	0.92
60% Velocity	14	0.19	0.19	0.05	0.00	0.57	0.98
Focal Velocity	14	0.16	0.13	0.04	0.00	0.35	0.84
Age-0 Mountain Whitefish Upper Yakima River							
Total Depth	2	0.99	0.01	0.01	0.98	1.00	0.01
Focal Depth	2	0.89	0.01	0.01	0.88	0.90	0.01
Surface Velocity	2	0.50	0.05	0.04	0.46	0.53	0.10
60% Velocity	2	0.73	0.11	0.07	0.65	0.80	0.15
Focal Velocity	2	0.55	0.17	0.12	0.43	0.67	0.31
Age-0 Mountain Whitefish North Fork Teanaway River							
Total Depth	6	0.56	0.09	0.04	0.45	0.72	0.16
Focal Depth	6	0.55	0.10	0.04	0.45	0.72	0.18
Surface Velocity	6	0.34	0.11	0.05	0.15	0.49	0.32
60% Velocity	6	0.35	0.11	0.04	0.28	0.57	0.30
Focal Velocity	6	0.17	0.09	0.04	0.11	0.43	0.53

Table 11. Summary of microhabitat used by age-1+ spring chinook salmon, age-0 and age-1+ rainbow trout, and mountain whitefish in the upper Yakima River Basin during summer 1999 (all sections pooled). Depths were measured in meters (m). Velocities are reported as meters/second (m/s).

Variable	N	Mean	Std Dev	Std Error	Min	Max	Coefficient of Variation
Age-1+ Spring Chinook Salmon Upper Yakima River							
Total Depth	37	1.00	0.27	0.05	0.47	1.60	0.27
Focal Depth	37	0.75	0.25	0.04	0.13	1.30	0.34
Surface Velocity	36	0.69	0.40	0.07	0.03	1.48	0.57
60% Velocity	37	0.46	0.27	0.04	0.00	1.03	0.59
Focal Velocity	37	0.37	0.21	0.03	0.01	0.83	0.57
Age-0 Rainbow Trout Upper Yakima River							
Total Depth	19	0.64	0.16	0.04	0.43	0.90	0.25
Focal Depth	19	0.54	0.15	0.03	0.26	0.79	0.28
Surface Velocity	16	0.19	0.22	0.05	0.00	0.73	1.12
60% Velocity	18	0.13	0.13	0.03	0.01	0.55	1.02
Focal Velocity	18	0.12	0.10	0.02	0.01	0.33	0.81
Age-1+ Rainbow Trout Upper Yakima River							
Total Depth	20	0.99	0.26	0.06	0.49	1.40	0.26
Focal Depth	20	0.79	0.21	0.05	0.39	1.10	0.26
Surface Velocity	20	0.77	0.42	0.09	0.14	1.70	0.55
60% Velocity	20	0.54	0.26	0.06	0.13	1.03	0.48
Focal Velocity	20	0.42	0.26	0.06	0.07	1.09	0.63
Age-0 Mountain Whitefish Upper Yakima River							
Total Depth	3	0.48	0.09	0.05	0.37	0.55	0.20
Focal Depth	3	0.47	0.11	0.06	0.35	0.55	0.23
Surface Velocity	3	0.22	0.18	0.11	0.01	0.33	0.83
60% Velocity	3	0.18	0.17	0.10	0.01	0.35	0.93
Focal Velocity	3	0.13	0.11	0.06	0.01	0.22	0.83

Table 12. Summary of microhabitat used by age-1+ spring chinook salmon, age-0 and age-1+ rainbow trout, and mountain whitefish in the upper Yakima River Basin during summer 2000 (all sections pooled). Depths were measured in meters (m). Velocities are reported as meters/second (m/s).

Variable	N	Mean	Std Dev	Std Error	Min	Max	Coefficient of Variation
Age-1+ Spring Chinook Salmon Upper Yakima River							
Total Depth	5	1.46	0.61	0.27	1.00	2.50	0.42
Focal Depth	5	1.43	0.61	0.27	0.99	2.49	0.43
Surface Velocity	4	1.15	0.77	0.39	0.48	2.21	0.67
60% Velocity	3	1.09	0.42	0.24	0.85	1.58	0.39
Focal Velocity	4	0.66	0.35	0.18	0.36	1.17	0.54
Age-1+ Spring Chinook Salmon North Fork Teanaway River							
Total Depth	44	0.47	0.10	0.02	0.25	0.64	0.22
Focal Depth	44	0.45	0.10	0.02	0.24	0.61	0.22
Surface Velocity	44	0.55	0.26	0.04	0.09	1.28	0.47
60% Velocity	44	0.41	0.16	0.02	0.12	0.75	0.40
Focal Velocity	44	0.30	0.21	0.03	0.02	0.95	0.70
Age-0 Rainbow Trout Upper Yakima River							
Total Depth	14	0.67	0.10	0.03	0.54	0.90	0.15
Focal Depth	14	0.65	0.10	0.03	0.52	0.89	0.16
Surface Velocity	14	0.30	0.29	0.08	0.02	0.86	0.98
60% Velocity	14	0.24	0.19	0.05	0.01	0.64	0.82
Focal Velocity	14	0.19	0.20	0.05	0.01	0.82	1.08
Age-1+ Rainbow Trout Upper Yakima River							
Total Depth	16	0.79	0.26	0.06	0.47	1.45	0.33
Focal Depth	16	0.77	0.26	0.06	0.46	1.45	0.34
Surface Velocity	16	0.50	0.33	0.08	0.09	1.06	0.66
60% Velocity	16	0.48	0.30	0.08	0.07	1.10	0.63
Focal Velocity	16	0.37	0.29	0.07	0.00	0.99	0.79
Age-1+ Rainbow Trout North Fork Teanaway River							
Total Depth	11	0.47	0.10	0.03	0.33	0.68	0.20
Focal Depth	11	0.45	0.10	0.03	0.32	0.67	0.22
Surface Velocity	11	0.56	0.28	0.08	0.25	1.10	0.50
60% Velocity	11	0.37	0.21	0.06	0.13	0.87	0.59
Focal Velocity	11	0.22	0.12	0.04	0.08	0.53	0.54
Age-0 Mountain Whitefish Upper Yakima River							
Total Depth	4	0.80	0.28	0.14	0.48	1.12	0.35
Focal Depth	4	0.79	0.28	0.14	0.47	1.11	0.35
Surface Velocity	4	0.40	0.31	0.15	0.09	0.83	0.77
60% Velocity	4	0.44	0.24	0.12	0.18	0.76	0.54
Focal Velocity	4	0.28	0.19	0.09	0.12	0.55	0.69

Table 13. Summary of microhabitat used by age-1+ spring chinook salmon, age-0 and age-1+ rainbow trout, and mountain whitefish in the upper Yakima River Basin during summer 2001 (all sections pooled). Depths were measured in meters (m). Velocities are reported as meters/second (m/s).

Variable	N	Mean	Std Dev	Std Error	Min	Max	Coefficient of Variation
Age-1+ Spring Chinook Salmon Upper Yakima River							
Total Depth	3	0.92	0.04	0.02	0.88	0.96	0.04
Focal Depth	3	0.83	0.04	0.02	0.79	0.86	0.04
Surface Velocity	3	1.26	0.18	0.10	1.11	1.46	0.14
60% Velocity	3	0.73	0.17	0.10	0.55	0.88	0.23
Focal Velocity	3	0.24	0.24	0.14	0.04	0.51	1.01
Age-0 Rainbow Trout Upper Yakima River							
Total Depth	19	0.52	0.22	0.05	0.16	0.86	0.43
Focal Depth	19	0.42	0.18	0.04	0.10	0.70	0.42
Surface Velocity	19	0.30	0.13	0.03	0.05	0.53	0.43
60% Velocity	19	0.19	0.12	0.03	0.00	0.40	0.62
Focal Velocity	19	0.15	0.11	0.02	0.00	0.33	0.72
Age-0 Rainbow Trout North Fork Teanaway River							
Total Depth	12	0.38	0.21	0.06	0.16	0.80	0.54
Focal Depth	12	0.32	0.18	0.05	0.10	0.64	0.58
Surface Velocity	12	0.26	0.16	0.05	0.03	0.46	0.61
60% Velocity	12	0.18	0.11	0.03	0.01	0.38	0.61
Focal Velocity	12	0.17	0.10	0.03	0.01	0.31	0.61
Age-1+ Rainbow Trout Upper Yakima River							
Total Depth	6	0.79	0.22	0.09	0.54	1.14	0.28
Focal Depth	6	0.71	0.20	0.08	0.49	1.03	0.28
Surface Velocity	6	1.05	0.21	0.09	0.73	1.40	0.20
60% Velocity	6	0.80	0.22	0.09	0.48	1.09	0.27
Focal Velocity	6	0.19	0.18	0.07	0.00	0.42	0.96
Age-1+ Rainbow Trout North Fork Teanaway River							
Total Depth	3	0.72	0.13	0.07	0.59	0.84	0.17
Focal Depth	3	0.65	0.11	0.06	0.53	0.76	0.17
Surface Velocity	3	0.32	0.11	0.06	0.22	0.43	0.32
60% Velocity	3	0.32	0.06	0.04	0.28	0.39	0.19
Focal Velocity	3	0.20	0.16	0.09	0.04	0.35	0.78

Table 14. Summary of microhabitat used by age-1+ spring chinook salmon, age-0 and age-1+ rainbow trout, and mountain whitefish in the upper Yakima River Basin during summer 2002 (all sections pooled). Depths were measured in meters (m). Velocities are reported as meters/second (m/s).

Variable	N	Mean	Std Dev	Std Error	Min	Max	Coefficient of Variation
Age-0 Rainbow Trout Upper Yakima River							
Total Depth	22	0.60	0.22	0.05	0.32	1.12	0.36
Focal Depth	22	0.42	0.23	0.05	0.52	1.01	0.55
Surface Velocity	22	0.35	0.18	0.04	0.01	0.65	0.52
60% Velocity	22	0.25	0.16	0.03	0.00	0.68	0.65
Focal Velocity	22	0.19	0.14	0.03	0.00	0.45	0.77
Age-0 Rainbow Trout North Fork Teanaway River							
Total Depth	19	0.44	0.07	0.02	0.30	0.60	0.17
Focal Depth	19	0.37	0.10	0.02	0.18	0.54	0.27
Surface Velocity	19	0.27	0.18	0.04	0.09	0.67	0.64
60% Velocity	19	0.27	0.17	0.04	0.10	0.69	0.63
Focal Velocity	19	0.20	0.14	0.03	0.00	0.53	0.67
Age-1+ Rainbow Trout Upper Yakima River							
Total Depth	3	0.77	0.31	0.18	0.56	1.12	0.40
Focal Depth	3	0.63	0.34	0.20	0.34	1.01	0.54
Surface Velocity	3	0.45	0.18	0.11	0.25	0.61	0.41
60% Velocity	3	0.36	0.31	0.18	0.10	0.71	0.86
Focal Velocity	3	0.18	0.17	0.10	0.06	0.37	0.95
Age-1+ Rainbow Trout North Fork Teanaway River							
Total Depth	20	0.53	0.11	0.03	0.40	0.87	0.22
Focal Depth	19	0.46	0.12	0.03	0.31	0.87	0.26
Surface Velocity	20	0.33	0.27	0.06	0.06	1.29	0.83
60% Velocity	20	0.25	0.16	0.04	0.03	0.59	0.65
Focal Velocity	20	0.17	0.11	0.03	0.02	0.38	0.66
Age-0 Mountain Whitefish Upper Yakima River							
Total Depth	3	0.48	0.13	0.08	0.33	0.59	0.28
Focal Depth	3	0.48	0.13	0.08	0.33	0.59	0.28
Surface Velocity	3	0.43	0.08	0.05	0.36	0.52	0.20
60% Velocity	3	0.39	0.10	0.06	0.28	0.46	0.25
Focal Velocity	3	0.18	0.13	0.07	0.04	0.28	0.69
Age-0 Mountain Whitefish North Fork Teanaway River							
Total Depth	7	0.49	0.13	0.05	0.33	0.68	0.26
Focal Depth	7	0.46	0.13	0.05	0.33	0.65	0.28
Surface Velocity	7	0.43	0.16	0.06	0.19	0.72	0.38
60% Velocity	7	0.37	0.15	0.06	0.20	0.65	0.41
Focal Velocity	7	0.18	0.10	0.04	0.04	0.28	0.57

The percentage of age-0 spring chinook salmon occupying focal velocities greater than the 1998 baseline data was lower in 1999, 2000 and 2001 (Table 15). Focal depth was the most variable parameter followed by total depth. Focal velocity remained relatively stable for all years. There was a negative relationship between the estimated number of spring chinook salmon per kilometer and the percentage of microhabitat variables greater than the 1998 baseline data (Figure 2).

Table 15. 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	2.7%	2.7%	2.7%	420	58	92
1999	1.6%	8.4%	5.8%	148	30	85
2000	1.5%	17.5%	8.8%	224	27	92
2001	0.0%	1.3%	0.6%	3,836	101	82
2002	0.0%	2.6%	0.3%	3,339	92	71

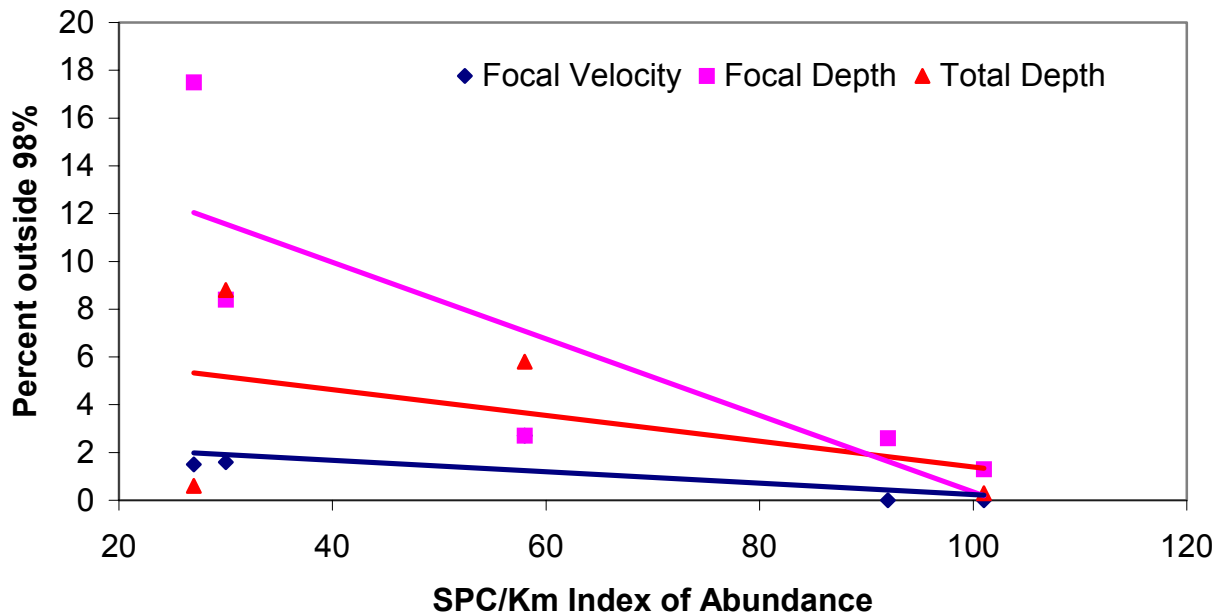


Figure 2. Relationship between the index of abundance of spring chinook salmon parr and the percent of focal velocities, focal depths, and total depths outside the fitted line of the 98% confidence level for 1998 to 2002.

## Discussion

We did not see an increase in the use of higher focal velocities in 2001 or 2002, which were years with high age-0 spring chinook salmon densities, relative to 1998 to 2000 which had much lower spring chinook salmon densities (Table 15). Instead, our data showed a negative relationship between density and focal velocities (Figure 2). This was somewhat surprising because we expected to see a higher proportion of fish using velocities higher than their normal range in a year with many more fish potentially competing for the same space. Contrary to our expectations, the proportion of age 0+ spring chinook salmon that utilized “sub optimal” 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 sub optimal 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.

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.

Focal depth was quite variable, especially in 2000, and may not be a useful parameter for comparisons. In the future, we plan to report focal depth as the percent of the water column rather than a measurement of actual depth in order to standardize for reaches over varying total depths.

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 2002. 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.

Although significant overlaps were found in some of the microhabitat variables between age-0 spring chinook and other fishes, the data can be misleading. Because microhabitat variables for other species were only sampled when they were associated with spring chinook salmon, it cannot be considered a representative sample. If the other species were sampled representatively, it is likely that we would not see nearly the degree of overlap as is shown in our data.

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## **Chapter 3**

# **Precocially Mature Hatchery and Wild Spring Chinook Salmon on the Spawning Grounds**

### **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 2002 while snorkeling. The release of hatchery fish in the spring affected the natural distribution, abundance, and age structure of precocials observed on redds the following fall. 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. During the peak of spawning, between 38% and 52% of all hatchery precocials observed on the spawning grounds within a year were in the Thorp section, whereas only 0% to 4% of all age 0+ precocials and 0% to 15% of all wild age 1+ precocials were observed in this section. 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. Except for year 2000, age 1+ HP/F was higher than age 1+ NP/F. The hatchery does not release age 0+ precocials, so it decreased production of this age of precocial. It appears that hatchery precocials experience high mortality after they are released into the river and pose 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 or precocials (Mullan et al. 1992). Resident life histories have been observed in both natural (Flain 1970; Gebhards 1960) and hatchery produced fish (Robertson 1957, Mullan et al. 1992, James 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). Approximately 25% of the hatchery production in the Yakima Basin has been precocial males (Larsen et al., in review) and some of these fish are observed on the spawning grounds approximately four months after they are released from acclimation sites. It can be a valuable

life history strategy when population sizes are low or disturbances frequent and is commonly used by other anadromous trout (Pearsons et al., in press).

Salmon hatcheries have the potential to unintentionally produce artificially high numbers of resident fish, which can impact wild fish populations. Hatcheries may enhance precocial maturation of males by the kinds of diets that are fed to fish (e.g., high fats) or the types of growth schedules that fish are placed on. It is unclear whether the percentage of resident fish produced naturally or in hatcheries differ. However, relatively large hatchery programs can produce artificially high numbers of resident fish because they release more fish than the natural environment produces. Artificially high numbers of resident fish may harm wild populations through ecological and genetic mechanisms. Resident fish 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 resident fish 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 resident fish has the potential to limit the success of supplementation programs.

We sought to answer the following question: Does the Cle Elum hatchery alter the distribution, abundance, and age/size structure of precocially mature males in the natural environment?

## 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 intensively utilized 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 WDFW 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 °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 (WDFW, unpublished data).

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 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). 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 (James et al. 1998). A snorkeler would then begin 5-10 meters downstream of the redd and snorkel upstream, counting and enumerating 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. Some behavioral observations were made during the time of spring chinook salmon spawning.

We compared the average number of hatchery and naturally produced precocials that were produced by female parents. 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 or two years later. The number of redds is likely to be an underestimate of the number of females that spawn because of inefficiencies in field methods. 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.

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.

## 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 precocials. Between 11 and 16% of the wild age 0+ chinook salmon that we sampled were precocial males (Table 1).

Table 1. Proportions of age 0+ and hatchery precocials that were precocially maturing in the upper Yakima River.

Year	Wild spring chinook salmon				Hatchery spring chinook salmon			
	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

### *Distribution and abundance of precocials before spawning*

Hatchery precocials were generally observed in greatest abundance immediately below acclimation sites, however they were found as far downstream as John Day Dam (Larsen et al. In Review). Precocials were collected migrating both downstream in the spring and upstream during the summer (Larsen et al. In Review). The downstream migrations occurred during the smolt outmigration period and the upstream migrations occurred at the time of adult spawning immigration. We observed hatchery precocials 2.5 km, and 1.37 km above the Jack Creek acclimation site during the summer of 2000 and 2001 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 precocials during August, however they were much more abundant per female than naturally produced residuals (Table 2).

Table 2. Expanded peak counts of age 0+ and 1+ spring chinook salmon residuals relative to the number of anadromous female spawners, (YKFP redd counts within index reaches). 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 observation yr	# Wild		# Hatchery	# redds	# redds	Hfemales	Wild		Hatchery
	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
Average	5038	14	192	1428	1003	208	3.98	0.05	1.13
S.D.	7381	14	197	1646	1429	60	2.24	0.08	1.16

\*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 3). During the peak of spawning, between 38% and 52% of all hatchery precocials observed on the spawning grounds within a year were in the Thorp section, whereas only 0% to 4% of all age 0+ precocials and 0% to 15% of all wild age 1+ precocials were observed in this section.

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 4). Except for the year 2000, HP/F was higher than age 1+ NP/F. The hatchery does not release age 0+ precocials, so it decreased production of this age of precocial. Hatchery precocials were larger than both age classes of the naturally produced precocials and hatchery precocials were observed interacting aggressively with smaller wild precocials. The hatchery precocials often displaced wild precocials during these contests.

The total number of precocials observed on or associated with redds was quite variable throughout the spawning season (Table 5). We could not detect a consistent pattern across years, even though the number of active redds generally followed a normal temporal distribution. During 2002, 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 6). 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 7).

Table 3. 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
<b>Total</b>	<b>1999</b>		<b>4</b>		<b>16</b>		<b>18</b>	
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
<b>Total</b>	<b>2000</b>		<b>128</b>		<b>42</b>		<b>11</b>	
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
<b>Total</b>	<b>2001</b>		<b>554</b>		<b>20</b>		<b>52</b>	
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
<b>Total</b>	<b>2002</b>		<b>229</b>		<b>24</b>		<b>13</b>	

Table 4. 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 observation yr	# Wild		# Hatchery	# redds	# redds	Hfemales	Wild		Hatchery
	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
Average	229	25	24	1689	1059	208	0.241	0.112	0.118
S.D.	235	12	19	1778	1644	60	0.308	0.127	0.087

Table 5. 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.	%
<b>1998</b>											
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
<b>1999</b>											
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
<b>2000</b>											
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
<b>2001</b>											
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 6. 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.

DATE	Precocial daily totals				Precocials per redd			Frequency of occurrence			
	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 7. 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

Table 8. Estimated abundance of hatchery origin spring chinook salmon in mainstem Yakima River index monitoring sites.

Year	Yakima River Reach					Total
	LCYN	UCYN	EBURG	THORP	CELUM	
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
Avg.	1,783	462	248	628	22	3,143
S.D.	3,200	757	328	756	45	4,966

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

## Discussion

Our results indicate that the natural distribution, abundance, and age of precocially mature spring chinook salmon on the spawning grounds is being altered by the release of precocially mature hatchery fish. This alteration is likely to be caused by the hatchery release strategy, growth trajectory in the hatchery, and differential survival of fish in natural and hatchery environments. 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 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. In review). 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+.

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 area where most of the hatchery precocials were observed is at the lower end of spawning distribution. It also happens to be located closest to the Yakima Canyon where the highest abundance of precocials that are not on the spawning grounds are 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.

The large number of age 1+ precocials produced by the hatchery may be explained by the growth trajectories that hatchery fish experience (Larsen et al. In review). Approximately 50% of the males produced by the Cle Elum hatchery are age 1+ precocials. Larsen et al. (in review)

hypothesized that the high incidence of age 1+ precocials is 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 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. 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 and reaching zero during the spawning period. Mortality may be due to high angler exploitation, starvation, or predation. It is also possible that precocials are moving out of the spawning areas. 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 will be magnified further.

Although the number of hatchery precocials on the spawning grounds was generally higher per parent than naturally produced age 1+ precocials, the number of precocials produced per parent may be similar. If hatchery and wild fish produce different proportions of precocials, then we would expect to see higher female:male sex ratios in returning anadromous fish that had higher rates of precocialism. This assumes that either the number of precocials that survive to spawn is small relative to the smolt population or that precocials die after the spawning season. The first assumption is true for both age 0+ and 1+ precocials. The second assumption is likely to be true for age 1+ precocials but unknown for age 0+ precocials. In support of the second assumption, few if any of the spring chinook salmon smolts that have been aged at the Chandler Juvenile Fish Facility have been older than 1+ and hardly any of the PIT tagged fish that have been released from the hatchery have been detected the year after release (YKFP unpublished data). The sex ratio of hatchery and wild fish adults are not significantly different which suggests that rates of precocialism are similar (Knudson et al. 2002). The disparity between precocialism rates and precocials per female is likely to be due to differential survival in the hatchery and natural environments.

Hatchery 1+ fish may be competitively superior to wild precocials because hatchery precocials are larger. We have observed a number of instances where hatchery precocials displaced wild precocials from redds. 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 underestimating the number of precocial counts 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. 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 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.

We recommend the following changes to the evaluation of residuals and precocials:

- monitor distribution and relative abundance of residuals in June as soon after release as possible to maximize potential of determining peak relative abundance. Survey the areas above and below acclimation sites and the maximum elevation in Jack Creek;
- do snorkel counts at the peak of spawning throughout the spawning areas of the Upper Yakima Basin, American River, and Naches Basin;
- do temporal surveys in the Easton reach while microhabitat measurements are being taken and discontinue other temporal surveys;
- collect ecological information at times other than the peak of spawning (e.g., scales for age – length determination, representative length sample, stomach contents, % mature, behavioral observations of precocials on redds).

Management of the abundance of precocials can be accomplished in a variety of ways. First and foremost is to reduce the hatchery production of precocials. This might be accomplished using techniques such as growth modulation and genetic selection (e.g., not using precocials in the broodstock). Second, precocials could be removed prior to release. 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.

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