Spring Chinook Salmon Competition/Capacity and Residual/Precocious Male Monitoring in the Upper Yakima Basin

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This report covers one of many topics under the Yakima/Klickitat Fisheries Project’s Monitoring and Evaluation Program (YKFPME). The YKFPME is funded under two BPA contracts, one for the Yakama Nation and the other for the Washington Department of Fish and Wildlife (Contract number 00042861, Project Number 1995-063-25). A comprehensive summary report for all of the monitoring and evaluation topics will be submitted after all of the topical reports are completed. This approach to reporting enhances the ability of people to get the information they want, enhances timely reporting of results, and provides a condensed synthesis of the whole YKFPME. The current report was prepared by the Washington Department of Fish and Wildlife.
Executive Summary

During the summer and fall of 2010 continued monitoring occurred in an effort to help evaluate the factors that contribute to, or limit supplementation success. Monitored variables included: spring Chinook micro and meso-habitat selection, and precocious male abundance and distribution in the upper Yakima River Basin. This work was conducted as part of the Yakima/Klickitat Fisheries Project’s supplementation monitoring program. Abstracts of the topics covered in this report are listed below.

Chapter 1. Methods to compare the abundance and distribution of rearing spring Chinook fry in the upper Yakima River Basin are necessary to identify factors that limit natural production. However, because large portions of the upper Yakima would be difficult to sample using other methods, snorkeling surveys may be the most practical and cost effective method of generating estimates of abundance and distribution. Snorkeling surveys were conducted in three study reaches in the upper Yakima River in the summer of 2010 to assess the efficacy of snorkeling as an effective method for developing spring Chinook abundance indices that could be compared between reaches. Preliminary results suggest that snorkeling may be a viable method. Additional data will be required to determine if sufficient power to detect differences in abundance, and effective methods to determine sampling efficiencies can be attained.

Chapter 2. The carrying capacity of a watershed is one of the main factors in determining whether supplementation is a viable technique of increasing natural production. Preliminary analysis suggests that density dependent mechanisms affecting spring Chinook survival exist in the upper Yakima River after spawning and prior to or during the fall parr stage and potentially prior to the summer rearing period. We collected and measured spring Chinook fry throughout the Yakima and Cle Elum rivers in the early spring and into early summer to determine if size differentials could be detected between reaches in the early rearing periods. We also used newly developed snorkeling protocols in three study reaches in the upper Yakima River to index spring Chinook abundance and distribution. We measured the distance and frequency of feeding and agonistic strikes, characterized spring Chinook focal positions by measuring environmental factors such as depth and velocity, and attempted to index the ratio of food availability and energy required to hold at known positions.

Chapter 3. Artificial propagation of Chinook salmon (Oncorhynchus tshawytscha) has the potential to alter the abundance and distribution of males that precociously mature in freshwater and thereby influence ecological and genetic interactions in the natural environment. We investigated the abundance and distribution of precociously mature, hatchery and natural origin male spring Chinook salmon during the spawning season (e.g., four to seven months after release from the hatchery) in the Yakima River. We counted the number of precocious males on the spawning grounds while snorkeling during the peak of spawning and electro-fished to determine abundance and distribution of precocious males away from redds. The abundance of hatchery origin precocious males on redds was less than 0.003% of the number of fish released and were less abundant on redds than natural origin precocious males ($P<0.01$). Between 1999 and 2010, the mean abundance of hatchery age 1 precocious males observed on the spawning grounds was 26 fish and ranged between 0 and 78 fish annually. Hatchery and natural origin precocious males were both found throughout the spawning range during the spawning season, However,
differences in distribution between origins were detected ($P < 0.05$). Hatchery precocious males were proportionately more abundant in the lowest sampling reach and less abundant in a tributary with no hatchery facilities. In addition, most hatchery precocious males were found downstream of spawning areas during the spawning season. It appears that many precociously mature fish released from the hatchery migrate downstream and fail to migrate back to the spawning grounds or die within the Yakima River prior to spawning time. Thus, hatchery precocious males in the Yakima River do not contribute favorably to harvest and may pose ecological risks to non-target taxa, but most of these fish have a low probability of contributing genes to future generations.
# Table of Contents

Executive Summary ................................................................................................................................................. i

Table of Contents .................................................................................................................................................. iii

General Introduction

Chapter 1. Development and assessment of methods to measure abundance and distribution of rearing spring Chinook salmon in the upper Yakima River basin.........................8

Chapter 2. Rearing spring Chinook abundance and meso-scale habitat measures in three reaches of the upper Yakima River Basin.................................................................19

Chapter 3. Abundance and distribution of hatchery and natural origin precociously mature male spring Chinook salmon in the Yakima River.......................................................35
General Introduction

This report examines factors that can influence the success of supplementation, which is currently being tested in the Yakima Basin using the upper Yakima stock of spring Chinook salmon. Supplementation success in the Yakima Basin is defined relative to four topic areas: natural production, genetics, ecological interactions, and harvest (Busack et al. 1997). The success of spring Chinook salmon supplementation in the Yakima Basin is dependent, in part, upon fish culture practices and favorable physical and biological conditions in the natural environment (Busack et al. 1997; James et al. 1999; Johnson et al. 2008). Shortfalls in either of these two topics (i.e., failure in culturing many fish that have high long-term fitness or environmental conditions that constrain spring Chinook salmon production) will cause supplementation success to be limited. For example, inadvertent selection or propagation of spring Chinook that residualize or precociously mature may hinder supplementation success. Spring Chinook salmon that residualize (do not migrate during the normal migration period) may have lower survival rates than migrants and, additionally, may interact with wild fish and cause unacceptable impacts to non-target taxa. Large numbers of precocious males (nonanadromous spawners) may increase competition for females and significantly skew ratios of offspring sired by nonanadromous males, which could result in more nonanadromous spring Chinook in future generations. Conditions in the natural environment (e.g., flow, temperature, and/or available habitat) may also limit the success of spring Chinook supplementation.

The tasks described below represent various subject areas of juvenile spring Chinook salmon monitoring but are treated together because they can be accomplished using similar methods and are therefore more cost efficient than if treated separately. Topics of investigation we pursued in this work were: 1) evaluation of methods to monitor rearing Chinook abundance and distribution; 2) carrying capacity monitoring (meso and microhabitat) and 3) residual and precocious male salmon monitoring (abundance and distribution). This report is organized into three chapters to represent these topics of investigation. Data were collected during the summer and fall in index sections of the upper Yakima Basin (Figure 1). Previous results on the topics in this report were reported in James et al. (1999), and Pearsons et al. (2003; 2004; 2005; 2006; 2007) and Johnson et al. (2008). 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. Survey reaches within the upper Yakima basin. Drift boat electrofishing survey reaches included: lower canyon, upper canyon, Ellensburg, Thorp, and the Cle Elum. Snorkeling surveys were conducted in the Thorp and Cle Elum reaches as well as the Bullfrog, Nelson, Easton and the Cle Elum River.
Acknowledgments

We are thankful to the many people that helped make this report a reality. In particular, we are thankful to those members of the Ecological Interactions Team and Cascade Aquatics who helped collect and enter the data. Anthony Fritts provided helpful edits to the report, and Molly Kelly created Figure 1. We also thank Patty Smith who administered funding of this work. This work was funded by the Bonneville Power Administration as part of the implementation of the Yakima/Klickitat Fisheries Project’s monitoring plan.

Literature Cited


Chapter 1

Development and assessment of methods to measure abundance and distribution of rearing spring Chinook salmon in the upper Yakima River basin.

Abstract

Methods to compare the abundance and distribution of rearing spring Chinook fry in the upper Yakima River Basin are necessary to identify factors that limit natural production. However, because large portions of the upper Yakima would be difficult to sample using other methods, snorkeling surveys may be the most practical and cost effective method of generating estimates of abundance and distribution. Snorkeling surveys were conducted in three study reaches in the upper Yakima River in the summer of 2010 to assess the efficacy of snorkeling as an effective method for developing spring Chinook abundance indices that could be compared between reaches. Preliminary results suggest that snorkeling may be a viable method. Additional data will be required to determine if sufficient power to detect differences in abundance, and effective methods to determine sampling efficiencies can be attained.

Introduction

Methods to compare abundance and distribution of rearing spring Chinook fry in the upper Yakima River Basin are necessary to identify factors that limit natural production (Johnson et al. 2008). However, because large portions of the upper Yakima are difficult to sample using boat-based electrofishing and waters are too deep to effectively sample using a backpack electrofisher, snorkeling surveys may be the most practical and cost effective method of generating estimates of abundance and distribution.

Snorkeling surveys are widely used to monitor fish populations in streams and to estimate both relative and total abundance (Slaney and Martin 1987). Given adequate conditions, snorkeling is a quick and inexpensive technique for estimating population numbers (Zubick and Fraley 1988; Hillman 1992). Further, snorkeling has been suggested as an effective census technique in larger fluvial systems when electrofishing may be less than ideal (Schill and Griffith 1984) and has been recently used for annual monitoring efforts in larger systems such as the Okanogan Basin (Arterburn et al. 2008) and the lower American River in California (FFC 2006). Snorkeling surveys are also largely passive, which may be beneficial when ESA listed species such as steelhead \((Oncorhynchus mykiss)\) overlap with target species.

It is unknown if snorkeling surveys are feasible in all areas of the upper Yakima River Basin. The upper Yakima changes dramatically in the early spring with increasing flows to meet
downstream irrigation demands and again in the fall when flows are decreased to prevent post spawning redd desiccation. Although upstream snorkeling surveys have been successfully conducted in the main-stem Yakima (Pearsons 1994, Johnson et al. 2009) none have been attempted in the Cle Elum River where flows are often highest. Additionally, differences in temperature have been shown to decrease snorkel survey efficiencies (Hillman 1992), and water temperatures are low well into the early summer in much of the upper Basin.

Our objective is to determine if we can physically conduct snorkeling abundance estimates in the upper Yakima River Basin that are comparable between reaches. Our goals are to provide a standardized protocol for indexing abundance both spatially and temporally throughout the basin with known efficiency. This chapter documents our progress in determining the feasibility and efficacy of these methods in the upper Yakima River.

Methods

Study area

Our study area in 2010 consisted of two contiguous reaches of the Yakima River which are similar in flow, gradient, and temperature, and a third section located in the Cle Elum River with very different flow, gradient, and temperatures. Beginning with the upstream boundary at Easton Dam (rmk 326), the study reaches were: Easton (10.7 km), Nelson (7.3 km) and Cle Elum (12.2 km; rkm 186) (Figure 1). The Easton and Nelson reaches have fairly consistent flow velocity over the summer period that is generally less than one meter per second, which is considered unrestrictive to rearing juvenile Chinook (Johnson et al. 2008; Pearsons et al. 2007). The Cle Elum River reach experiences low flows up until early June when discharge from Lake Cle Elum is increased significantly to meet summer irrigation demands (SOAC 1999).
Figure 1. Survey reaches within the upper Yakima Basin. Snorkeling surveys in 2010 were conducted in the Easton and Nelson reaches of the main-stem Yakima River, and in the Cle Elum River between the Cle Elum Dam and the Cle Elum River confluence with the Yakima.

**Abundance/Sampling units**

Each reach was divided into sampling units by general habitat type (Table 1). Sampling units were limited to 100m in length in order to avoid sampling bias due to snorkeler fatigue. Revisions to the 100m site lengths were made when our habitat units were only slightly longer than the maximum sampling unit length (e.g., 105 meters). Unit borders were marked by GPS during a preliminary survey at the beginning of each year so that the sampling units could be easily located and refined prior to sampling. Two independent crews conducted surveys daily. Each crew was systematically rotated through the sampling reaches for the duration of the study. Survey sites within each reach were selected randomly without replacement.
Table 1. Definition of habitat types used to classify sampling sites within the Easton and Nelson reaches of the upper Yakima River 2010.

<table>
<thead>
<tr>
<th>Habitat Unit</th>
<th>Depth</th>
<th>Appearance of water surface</th>
<th>Substrate types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Riffle</td>
<td>&gt; 0.5 m</td>
<td>Swift current, turbulent, unbroken surface</td>
<td>Generally cobbles</td>
</tr>
<tr>
<td>Glide</td>
<td>&gt; 0.5 m</td>
<td>Slow current, unbroken surface</td>
<td>All types possible</td>
</tr>
<tr>
<td></td>
<td>uniform depth</td>
<td>Slow current</td>
<td>All types possible</td>
</tr>
<tr>
<td>Pool</td>
<td>&gt; 1.5 m</td>
<td>Slow current, unbroken surface</td>
<td>All types possible</td>
</tr>
<tr>
<td>Rapid</td>
<td>0-2 m</td>
<td>Swift current, very turbulent, broken surface</td>
<td>Large boulders or bedrock, frequently breaking water surface</td>
</tr>
<tr>
<td>Riffle</td>
<td>&lt; 0.5 m</td>
<td>Swift current, turbulent, unbroken surface</td>
<td>Generally cobbles</td>
</tr>
<tr>
<td>Run</td>
<td>0.5-1.5 m</td>
<td>Moderate current, unbroken surface</td>
<td>All types possible</td>
</tr>
</tbody>
</table>

Crews sampled the upstream locations first, using the preliminary survey GPS locations to locate the approximate upstream boundary of each survey site. Once on site, boundaries were refined immediately prior to sampling to ensure the best break point between habitat units. Adjusted site boundaries were re-marked using GPS. Surveyors walked the bank to the lower boundary of the site or floated to the bottom and waited a period of five minutes before beginning the upstream survey. One snorkeler on each bank then worked upstream parallel to one another identifying and enumerating all fish encountered. Data were recorded on a cuff made from a six-inch length of four-inch I.D. PVC pipe. After both snorkelers had completed the parallel bank survey they then floated downstream adjacent to one another recording all fish within their focal range. When channel width exceeded the focal range, center channel surveys were extrapolated over the difference. Focal range, in meters, was measured daily in each reach by moving a scale silhouette of a sub-yearling Chinook away from the snorkeler until parr marks were no longer visible while under water (Thurow 1994). Snorkeling was conducted in water temperatures between 9.0 and 19.0 degrees Celsius.

It has been suggested that because rearing spring Chinook are strongly associated with bank habitats center channel surveys are likely unnecessary in estimating abundance (Pearsons et al. 1994). This finding is supported by a subsequent multiyear dataset that found approximately eighty percent of rearing Chinook within five meters of the bank, and in flows less than one m/s (Pearsons et al. 2007). This suggests that bank-only surveys should be sufficient in most upper basin areas. We compared estimates of abundance between bank and center channel habitats in the same survey sites to determine if center channel surveys would contribute significantly to our overall total counts.

Decker and Hagen (2007) suggested that a linear relationship between spawner and fry abundance indicated little density dependent competition. We hypothesized that if our estimates were an adequate index of abundance and our sampling sites were below rearing capacity for spring Chinook, newly emerged fry would remain within their reach of origin and we would observe a relationship between mean abundance and the number of redds the previous year within our study reaches. We compared the number of redds in each of our sampling reaches the year prior to our surveys (YKFP unpublished data) to mean observed abundance the following
year. We used a Pearson product moment statistic and considered the relationship significant if
the p-value was less than 0.05.

We conducted a small feasibility study to determine if mark-re-sight surveys could be
used to determine snorkeling efficiency. If snorkeling efficiency is highly variable due to
differences in flow, temperature, or visibility then frequent measures of efficiency are necessary.
In this case, the independent methods used to determine efficiency may be impractical due to the
additional effort required to attain them. To evaluate this, sub-yearling Chinook were collected
along the banks of three study sites with lengths comparable to our standard survey sites.
Collected fish were held in a 0.06g/l to 0.04g/l solution of Bismarck Brown biological stain
(Mallinckrodt Baker, Inc., Phillipsburg, New Jersey) for a period of five to seven minutes and
then released. Snorkeling surveys were conducted approximately 24 hours later and the number
of marked and unmarked Chinook recorded by two snorkelers under water. Efficiencies were
estimated by comparing the total number of fish observed to a Petersen mark-recapture estimate
modified for small sample size (Chapman 1951). Temple and Pearsons (2007) provide a detailed
description of this estimator. Our methods are consistent with those used to determine
snorkeling efficiencies in the lower Thompson River (Decker and Hagen (2007).

Results

Water temperatures during sampling ranged between 9.0 and 19.0 degrees Celsius (mean,
14.5; SD, 2.3). Temperatures at sampling were significantly different between survey reaches
(ANOVA: $F_{2, 147} = 29.0, P < 0.01$; Figure 2.

![Figure 2. Mean temperature at the time of sampling in Easton, Nelson, and Cle Elum River survey reaches. Snorkeling surveys were conducted between July 6 and September 1 2010.](image)
Temperature was not significantly correlated with our observed spring Chinook abundance in surveys conducted in water temperatures below 19 degrees (n = 260, $R^2 < 0.01$, $P = 0.14$), below 14 degrees (n = 81, $R^2 < 0.01$ $P = 0.58$), or below 10 degrees Celsius (n = 12, $R^2 = 0.06$, $P = 0.43$). Visibility ranged from 0.8 to 3.2 (mean, 2.0; SD, 0.6). Sampling temperatures were not significantly different between main channel and side channel survey sites in the Cle Elum River reach (t-test: $P = 0.24$). Visibility was significantly different between reaches (ANOVA: $F_{2, 137} = 304.4$, $P < 0.01$). Detectable differences were found between all reaches, with greatest visibility in the Cle Elum River reach (Tukey test: $P < 0.05$; Figure 3). However, despite detectable differences in visibility between study reaches, visibility was not correlated with observed abundance ($R^2 = 0.02$, $P = 0.07$).

![Visibility vs. Study Reach](image)

**Figure 3.** Mean visibility within the Easton, Nelson, and Cle Elum River sampling reaches. Snorkeling surveys were conducted between July 6 and September 1 2010.

We did not detect a significant difference in site counts from bank habitats only and those inclusive of center channel counts (t-test: $P = 0.74$). Center channel counts accounted for an average of 8.3 percent of the total site counts and were highly variable (SD, 21.4). Based on these data and similar results from previous years, bank counts were considered independent replicates in subsequent analysis. Mean observed abundance was not significantly correlated with the number of redds the previous fall ($R^2 = 0.20$, $P = 0.27$). Based upon a relationship between observed spring Chinook density and redd density in previous years surveys (Johnson et al. 2009) observed densities in 2010 in the Easton, Nelson, and CER reaches were 61, 258, and 27 percent greater than expected respectively. Mean efficiency estimates from spring Chinook mark recapture estimates were highly variable (mean, 5.8; SD, 7.2; Table 2).
Figure 3. Relationship between the number of spring Chinook redds observed (YKFP unpublished data) and the relative number of rearing parr the following summer for brood years 2007-2008 (dashed line) and 2007-2009 (solid line) in upper Yakima River Basin survey reaches.

Table 2. Summary of mark re-sight snorkeling estimates. Re-sight surveys occurred approximately 24 hours after individuals were marked.

<table>
<thead>
<tr>
<th>Site</th>
<th>Temp. (deg. C)</th>
<th>Site length(m)</th>
<th>Spp</th>
<th>Marked</th>
<th>Unmarked visuals</th>
<th>Marked visuals</th>
<th>Estimate</th>
<th>% Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>16</td>
<td>45</td>
<td>Spc</td>
<td>13</td>
<td>23</td>
<td>1</td>
<td>n/a</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>16</td>
<td>45</td>
<td>Rbt</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>n/a</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>52</td>
<td>Spc</td>
<td>24</td>
<td>8</td>
<td>2</td>
<td>274</td>
<td>3.6</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>52</td>
<td>Rbt</td>
<td>12</td>
<td>8</td>
<td>2</td>
<td>142</td>
<td>7.0</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>52</td>
<td>All</td>
<td>36</td>
<td>16</td>
<td>4</td>
<td>258</td>
<td>7.8</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
<td>44</td>
<td>Spc</td>
<td>20</td>
<td>21</td>
<td>4</td>
<td>181</td>
<td>13.8</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
<td>44</td>
<td>Coho</td>
<td>40</td>
<td>43</td>
<td>28</td>
<td>108</td>
<td>65.5</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
<td>44</td>
<td>Rbt</td>
<td>15</td>
<td>4</td>
<td>2</td>
<td>111</td>
<td>5.4</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
<td>44</td>
<td>All</td>
<td>75</td>
<td>68</td>
<td>34</td>
<td>236</td>
<td>43.2</td>
</tr>
</tbody>
</table>
Discussion

Our sampling temperatures were often lower than 14 degrees Celsius; a level at which Hillman et al. (1992) observed a decrease in snorkeling efficiency as high as fifty percent. Contrary to those findings, we did not detect any relationship between temperature and mean abundance by reach; nor did we detect a significant relationship between temperature and abundance in sites sampled less than 14 degrees, or in sites sampled less than 10 degrees Celsius. Based on these results, we conclude that although temperature can bias snorkeling estimates of abundance, the number of sites sampled below critical levels of ten degrees Celsius were negligible in our analysis of abundance between reaches.

Underwater visibility, or focal range, is another factor to consider that may affect observer efficiency and the quality of underwater counts. Like the temperature factor, visibility must be accounted for in underwater counts of fish. This is especially true in the early spring, when visibility has been found to be low in some areas (Pearsons et al. 1994; WDFW unpublished data). Although most rearing spring Chinook are found within the focal ranges we observed, we have detected slight decreases in measured abundance with decreasing visibility in previous years (Johnson et al. 2008). Establishing methods to measure snorkeling efficiency will help to determine if these factors will affect our ability to monitor rearing Chinook abundance both spatially and temporally in the Upper Yakima River Basin.

Similar to findings in previous years, we observed a statistically insignificant number of rearing spring Chinook in center channel habitats. These findings are consistent with the observations of Pearsons et al. (1994) and Johnson et al. (2009). This suggests that in most areas of the upper Yakima Basin, center channel snorkels are likely unnecessary for detecting overall differences in Chinook abundance between reaches. However, when Chinook were observed in center channel habitats they represented an average twenty three percent of the total site count. If the sampling goal is to measure true abundance rather than an index of abundance, center channel snorkels should be retained in areas where habitat is available (e.g., when subsurface woody debris is present, or in pool-type habitats). For our purposes an index is likely sufficient. Additionally, flows are often restrictive to Chinook rearing just a short distance from the bank in much of the upper Yakima and Cle Elum rivers during the late spring and summer time period (Pearsons et al. 2007). We intend to continue our evaluation of center channel habitat use by including off channel habitats and pools when conducting surveys in the summer of 2011.

Our 2010 estimates were far greater than expected relative densities based on the relationship developed using 2008 and 2009 mean site estimates by reach. However our estimates appear to reflect other in-basin and mixed basin estimates conducted on the same population during subsequent life stages. WDFW spring Chinook parr estimates in the fall of 2010 were approximately 1.5 times larger than expected (G. Temple, WDFW, personal communication) and preliminary 2011 smolt counts at the Chandler Fish Handling Facility near Prosser (YKFP 2011) appear to be more than four times the ten year average (brood years 1998-2007; YN 2009). It is possible that unusually mild incubation conditions may have resulted in a relaxation of factors normally affecting the Chinook population during an early life stage. Although mild flow conditions are a likely contributor to observed survival of rearing spring Chinook from the 2007 brood, it is currently unknown what specific factors are limiting the population in other years. We speculate that high survival may result in limited available habitat in some study reaches resulting in increased downstream movement. This would violate our
assumption of primary habitat use near the point of emergence, and our ability to develop redd-to-parr indices between study reaches. We will continue to collect relative abundance data from a number of upper Yakima Basin study reaches to evaluate the efficacy of such indices, and will continue to develop methods to evaluate the true efficiency of our estimates.

Acknowledgments

We thank the many people who co-labored in collecting field data. This includes Trenton De Boer, Nick Mankus, Cole Barrett, Kyle Hatch, Zack Mays, and Timothy Webster. Molly Kelly constructed Figure 1. Patty Smith provided administrative support. This work is part of the Yakima/Klickitat Fisheries Project and was funded by the Bonneville Power Administration through a contract to the Washington Department of Fish and Wildlife.

References


Chapter 2

Rearing spring Chinook abundance and habitat type in the upper Yakima River Basin.

Abstract

The carrying capacity of a watershed is one of the main factors in determining whether supplementation is a viable technique of increasing natural production. Preliminary analysis suggests that density dependent mechanisms affecting spring Chinook survival exist in the upper Yakima River sometime after spawning, prior to the fall parr stage, and potentially prior to the summer rearing period. We collected and measured spring Chinook fry throughout the Yakima and Cle Elum rivers in the early spring and into early summer to determine if size differentials could be detected between reaches in the early rearing periods. We also used newly developed snorkeling protocols in three study reaches in the upper Yakima River to index spring Chinook abundance and distribution. We measured the distance and frequency of feeding and agonistic strikes, characterized spring Chinook focal positions by measuring environmental factors such as depth and velocity, and attempted to index the ratio of food availability and energy required to maintain known positions in the stream channel.

Introduction

The carrying capacity of a watershed is an important factor in determining whether supplementation is a viable technique of increasing natural production. Carrying capacity can be defined as the maximum number of individuals the habitat can support. In the Yakima River Basin, carrying capacity can limit the number of naturally produced spring Chinook salmon Oncorhynchus tshawytscha even when supplementation mechanics are operating perfectly (Busack et al. 1997).

Preliminary analysis suggests that density dependent mechanisms affecting spring Chinook survival exist in the upper Yakima River after spawning and prior to or during the fall parr stage (Johnson et al. 2009), and perhaps prior to the summer rearing period (Johnson et al. 2008). If the Yakima River is at capacity in some years, then supplementation efforts can only serve to increase the number of naturally produced smolts when natural production is below that capacity. Therefore, identifying the factors that limit natural production is critical if restoration efforts aimed at maintaining or increasing natural production are to achieve their intended biological goals.

There are many potential limitations to rearing spring Chinook growth and survival in the Yakima Basin. Pearsons et al. (2007) speculated that the limiting factors for juvenile spring Chinook salmon in the upper Yakima Basin may differ depending upon past habitat alteration and present flow management. Factors limiting growth and survival are likely multiple, and may differ both temporally and spatially throughout the upper Yakima River. For example, temporal
habitat limitations may exist at multiple life history stages as food and space requirements of the fish change, and spatial limitation may occur when flows are increased to satisfy irrigation needs by reducing the habitat usable to fish.

Reach specific estimates of spring Chinook abundance and distribution are thought necessary to identify factors limiting natural production in the upper Yakima River Basin (Johnson et al. 2008). We collected and measured spring Chinook fry throughout the Yakima and Cle Elum rivers in the early spring and into early summer to determine if size differentials could be detected among river reaches in the early rearing periods. We also used newly developed snorkeling protocols in three study reaches in the upper Yakima River Basin to index spring Chinook abundance and distribution, and compared meso-scale habitat measures to those indices.

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). Further, the variation of microhabitats used by a species and life stage of fish is typically positively related to the density of that species/life stage as well as the density of competitor species (Allee 1982; Ross 1986; Grant and Kramer 1990; Robertson 1996). Our sampling goals were to identify a range of microhabitat conditions at and around rearing spring Chinook holding positions in order to characterize habitat suitability in terms of energy expenditure and benefit, while at the same time accounting for seasonal growth. Although knowing the temporal and spatial dynamics of rearing Chinook abundance at the reach scale will allow us to evaluate productivity through development of stock recruit relationships, it may not be sufficient to identify the specific factors that are limiting production. Comparisons of the types of microhabitat utilized and the ranges used between high and low productivity sites may allow us to identify these factors.

Methods

Study area

Our study area in 2010 consisted of two contiguous reaches of the Yakima River which are similar in flow, gradient, and water temperature, and a third section located in the Cle Elum River with very different flow, gradient, and water temperature. Beginning with the upstream boundary at Easton Dam (rkm 326), the study reaches were: Easton (10.7 km), Nelson (7.3 km) and Cle Elum (12.2 km; rkm 298) (Figure 1). The Easton and Nelson reaches have fairly consistent flow velocity over the summer period that is generally less than one meter per second, which is considered unrestrictive to rearing juvenile Chinook (Johnson et al. 2008; Pearsons et al. 2007). The Cle Elum River reach experiences low flows up until early June when discharge from Lake Cle Elum is increased significantly to meet summer irrigation demands (SOAC 1999).
Figure 1. Survey reaches within the upper Yakima basin. Snorkeling surveys in 2010 were conducted in the Easton and Nelson reaches of the main-stem Yakima River, and in the Cle Elum River between the Cle Elum Dam and the Cle Elum River confluence with the Yakima.
Early spring fry size

We collected and measured spring Chinook fry throughout the Yakima and Cle Elum Rivers in the early spring and into early summer to identify areas of potential growth limitation. Spring Chinook fry lengths were collected via backpack electrofishing at 41 sites within 19 primary reaches of the upper Yakima river between Roza Dam (rmk 205) and Easton Dam (rmk 326), in the mainstem of the Teanaway river (rmk 282), and in the Cle Elum River between the confluence of the Cle Elum River with the Yakima (rmk 298) and the Cle Elum Dam approximately 12.8 km upstream (Figure 1). Lengths were collected between March 16 and June 18, 2010. Sites were sampled at approximately two week intervals throughout the sampling period. We indexed growth between sampling periods by dividing the difference in mean length between sampling periods by the number of days between sampling periods. We used mean daily water temperatures near our sampling sites (USBR 2011) to calculate accumulated thermal units through the incubation and early rearing period (September 15, 2009 to June 15, 2010).

Abundance/Sampling units

We performed relative abundance snorkeling estimates of juvenile Chinook in the Easton, Nelson, and Cle Elum reaches (see chapter one of this report). Briefly, each reach was divided into sampling units by general habitat type (Table 1.). Sampling units were limited to 100 m in length in order to avoid sampling bias due to snorkeler fatigue. Exceptions to site length were made when our habitat units were only slightly longer than the maximum sampling unit length (e.g., 105 meters). Unit borders were marked by GPS during a preliminary survey at the beginning of each year so that the sampling units could be easily located and refined prior to sampling. Two independent crews conducted surveys daily. Each crew was systematically rotated through the sampling reaches for the duration of the study. Survey sites within each reach were selected randomly without replacement. Due to the low likelihood of spring Chinook parr crossover between banks (Johnson et al 2009, chapter one of this report) each bank survey was considered independent.
Table 1. Definition of habitat types used to classify sampling sites within the Easton and Nelson reaches of the upper Yakima River 2010.

<table>
<thead>
<tr>
<th>Habitat Unit</th>
<th>Depth</th>
<th>Appearance of water surface</th>
<th>Substrate types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Riffle</td>
<td>&gt; 0.5 m</td>
<td>Swift current, turbulent, unbroken surface</td>
<td>Generally cobbles</td>
</tr>
<tr>
<td>Glide</td>
<td>&gt; 0.5 m uniform depth</td>
<td>Slow current, unbroken surface</td>
<td>All types possible</td>
</tr>
<tr>
<td>Pool</td>
<td>&gt; 1.5 m one deep spot</td>
<td>Slow current, unbroken surface</td>
<td>All types possible</td>
</tr>
<tr>
<td>Rapid</td>
<td>0-2 m</td>
<td>Swift current, very turbulent broken surface</td>
<td>Large boulders or bedrock, frequently breaking water surface</td>
</tr>
<tr>
<td>Riffle</td>
<td>&lt; 0.5 m</td>
<td>Swift current, turbulent, unbroken surface</td>
<td>Generally cobbles</td>
</tr>
<tr>
<td>Run</td>
<td>0.5-1.5 m</td>
<td>Moderate current, unbroken surface</td>
<td>All types possible</td>
</tr>
</tbody>
</table>

Crews sampled the upstream locations first, using the preliminary survey GPS locations to locate the approximate upstream boundary of each survey site. Site boundaries were refined immediately prior to sampling to insure the best break point between habitat units and were re-marked using GPS. Surveyors walked the bank to the lower boundary of the site or floated to the bottom and then waited a period of five minutes before beginning the upstream survey. One snorkeler on each bank then swam upstream parallel to one another identifying and enumerating all fish encountered. Data were recorded on a cuff made from a six-inch section of four-inch I.D. PVC pipe. After both snorkelers had completed the parallel bank survey, they then floated downstream adjacent to one another recording all fish within their focal range. When channel width exceeded the measured focal range, center channel surveys were extrapolated over the difference. Visibility (focal range) was measured daily in each reach by moving a scale silhouette of a Chinook away from the snorkeler (under water) until parr marks were no longer visible (Thurow 1994). Snorkeling was conducted in water temperatures between 9.0 and 19.0 degrees Celsius.

**Territory size**

Snorkeling observations were made in the main-stem Yakima River to observe and record age-0 spring Chinook salmon territory size. Using a clipboard, observers recorded direction and distance of juvenile Chinook salmon movements relative to the focal position. Underwater stopwatches were used to time each observation. Observations in 2010 ranged in duration from 1.4 to 6.2 minutes, terminating when the target Chinook left the observer’s view. The holding position of the fish was defined as its focal position, and was variable throughout most observations. Movements were recorded onto a two-dimensional datasheet graph, which represented distance in body lengths, and direction relative to the focal point (Figure 2). The direction of a fish movement was classified as top, bottom, left or right, with each consisting of a ninety-degree range centered at the focal point (Figure 2). Movements were classified as either feeding or agonistic depending upon whether the focal fish 1) obtained a food item, or 2) moved aggressively as an instigator or in response to an intruding Chinook. Feeding strikes were denoted by a dark circle or point on the datasheet, and agonistic strikes with an “x”.

23
Figure 2. Graphical representation of the data sheets used in recording age-0 Chinook salmon territory size. Data is recorded in units of focal fish body length (BL).

**Flow Ratio and Microhabitat**

Flow ratio (Pearsons et al. 2006) is a parameter designed to index the ratio of food availability and energy required to hold at a known focal position. This ratio is defined as the highest flow velocity within two body lengths of the focal position divided by the focal point velocity. A flow ratio greater than one indicates at least one adjacent velocity greater than the focal point velocity. We measured velocities at two body lengths to either side and above and below the observed spring Chinook focal positions. Core microhabitat variables were measured around the each observed focal position. These included the estimated length of the observed Chinook, focal point velocity, the focal depth, total depth, and temperature.
Results

*Early spring fry size*

A total of 4,269 fry lengths were collected throughout the sampling period. Mean change in daily growth by river reach ranged between 0.07 and 0.52 mm/day and averaged 0.26 mm/day. Change in length was negatively correlated with upstream distance of the sampling reach ($R^2 = 0.86, P < 0.01$; Figure 1).

![Figure 1. Relationship between calculated spring Chinook daily growth and upstream river kilometer. Sampling was conducted at two week intervals between March 16 and June 18 2010.](image)

Accumulated thermal units explained 64 percent of the variation in growth ($R^2 = 0.64, P < 0.01$) and was highly correlated with river mile ($R^2 = 0.66, P < 0.01$). Mean length of rearing spring Chinook was similar in the Cle Elum River and in the main-stem Yakima above the Cle Elum River confluence, but was significantly greater below the confluence (Figure 2).
Figure 2. Difference in mean length of age 0 spring Chinook collected bi-weekly between March 16 and June 18 2010.

**Abundance/Sampling units**

A total of 125 sites were surveyed in the three study reaches between July 6 and August 31, 2010 (Table 2) for a total of 250 total replicates. Nine replicates were removed due to incomplete data. Differences in abundance among habitat types were detected (ANOVA: $F_{5, 243} = 3.3, P < 0.01$), with run-type and riffle-type habitats having significantly fewer spring Chinook juveniles than pool-type habitats (post-hoc multiple comparisons, $P < 0.05$, Figure 3). Run-type and riffle-type habitats had significantly fewer spring Chinook juveniles than pool-type habitats. Significant differences in mean abundance were also detected between study reaches (Kruskal-Wallis ANOVA: $H_{2, 251} = 11.6, P < 0.01$; Figure 4).
Table 2. Physical parameters of 2010 snorkeling survey sites by sampling reach.

<table>
<thead>
<tr>
<th>Habitat Classification</th>
<th>n</th>
<th>Mean site length (m)</th>
<th>SD</th>
<th>n</th>
<th>Site width (m)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cle Elum River</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep Riffle</td>
<td>13</td>
<td>97.9</td>
<td>7.5</td>
<td>3</td>
<td>27.6</td>
<td>11.7</td>
</tr>
<tr>
<td>Glide</td>
<td>1</td>
<td>80.0</td>
<td>n/a</td>
<td>1</td>
<td>17.7</td>
<td>n/a</td>
</tr>
<tr>
<td>Pool</td>
<td>5</td>
<td>51.5</td>
<td>25.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rapid</td>
<td>4</td>
<td>89.5</td>
<td>13.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Riffle</td>
<td>13</td>
<td>87.1</td>
<td>17.9</td>
<td>5</td>
<td>10.8</td>
<td>6.5</td>
</tr>
<tr>
<td>Run</td>
<td>9</td>
<td>92.4</td>
<td>13.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Easton</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep Riffle</td>
<td>10</td>
<td>59.9</td>
<td>19.6</td>
<td>10</td>
<td>18.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Glide</td>
<td>5</td>
<td>90.0</td>
<td>17.3</td>
<td>5</td>
<td>26.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Pool</td>
<td>9</td>
<td>53.0</td>
<td>16.7</td>
<td>9</td>
<td>20.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Rapid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Riffle</td>
<td>7</td>
<td>69.9</td>
<td>29.5</td>
<td>7</td>
<td>23.3</td>
<td>7.7</td>
</tr>
<tr>
<td>Run</td>
<td>13</td>
<td>82.8</td>
<td>19.7</td>
<td>13</td>
<td>21.4</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>Nelson</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep Riffle</td>
<td>12</td>
<td>78.8</td>
<td>22.6</td>
<td>12</td>
<td>29.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Glide</td>
<td>1</td>
<td>100.0</td>
<td>n/a</td>
<td>1</td>
<td>28.7</td>
<td>n/a</td>
</tr>
<tr>
<td>Pool</td>
<td>7</td>
<td>50.0</td>
<td>20.2</td>
<td>7</td>
<td>27.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Rapid</td>
<td>8</td>
<td>65.4</td>
<td>19.6</td>
<td>8</td>
<td>34.0</td>
<td>5.3</td>
</tr>
<tr>
<td>Riffle</td>
<td>7</td>
<td>77.6</td>
<td>22.1</td>
<td>7</td>
<td>37.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Run</td>
<td>14</td>
<td>84.8</td>
<td>22.1</td>
<td>14</td>
<td>31.2</td>
<td>4.8</td>
</tr>
</tbody>
</table>
Figure 3. Spring Chinook abundance by habitat classification in sites sampled between July 6 and August 31, 2010. Error bars represent 95 percent confidence intervals.

Figure 4. Mean observed abundance of juvenile spring Chinook per linear bank meter in 2010 sampling reaches. Error bars represent ninety-five percent confidence intervals.
**Territory size**

Territory size (log transformed) was significantly correlated with fish fork length (mm) (Spearman rank R: $r_{sp} = 0.60, P < 0.01$; Figure 5).

![Scatter plot showing the relationship between territory size (log transformed) and fork length.](image)

$R^2 = 0.3113$

Figure 5. Relationship between spring Chinook fork length (mm) and observed territory size in the spring and summer of 2006-2009 (black points) and 2010 (white points).

The proportions of feeding strikes were significantly different between categorical distances (1-4 body lengths) from the focal position (Friedman ANOVA: $\chi^2_{3, 390} = 599.7, P < 0.01$; Figure 6). Agonistic strikes were also significantly different between categorical distances (1-4 body lengths) from the focal position (Friedman ANOVA: $\chi^2_{3, 190} = 102.5, P < 0.01$; Figure 6). The observed ratios of agonistic to feeding strikes increased with increasing distance from the focal position, but were not significantly different (Friedman ANOVA: $\chi^2_{4, 3} = 1.6, P = 0.67$; Figure 7).
Figure 6. Proportion of rearing spring Chinook feeding and agonistic strikes with increasing distance from the observed focal position in body lengths 2006-2010.

Figure 7. Mean ratio of agonistic strikes per feeding strike with increasing distance from the observed focal position 2006-2010.
Flow ratio and physical microhabitat

Flow ratio was greater than one in 80 percent of observations (mean, 1.2; SD, 0.4). Mean water velocity within two body lengths of Chinook focal positions was significantly greater above significantly lower below the focal position (Repeated-measures ANOVA: $F_{4, 284} = 20.1, P < 0.01$; Post-hoc LSD test, $P < 0.01$). Flow ratio and fish length were not correlated ($R^2 < 0.01, P = .50$). A summary of microhabitat variables measured around Chinook focal positions is presented in table 4.

Table 4. Summary of physical parameters measured at observed spring Chinook focal positions.

<table>
<thead>
<tr>
<th></th>
<th>Temp °C</th>
<th>Spc length (mm)</th>
<th>Focal depth (m)</th>
<th>Total depth (m)</th>
<th>Focal velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>74</td>
<td>74</td>
<td>74</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Mean</td>
<td>15.8</td>
<td>74.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>SD</td>
<td>0.7</td>
<td>7.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Discussion

Our results suggest, as expected (e.g. Quinn 2005), that productivity is greater in downstream areas throughout the spring and early summer likely due to warmer temperatures through the incubation and early rearing period. It is currently unknown to what extent fry migrate to lower areas of the basin. It is also unknown if these areas remain productive in terms of potential growth and survival as growth occurs and annual flow conditions change in the early summer. For example, flow alterations may reduce habitat availability, predation may be greater, temperatures may be too high in summer, and competition for suitable habitat may increase. Greater than average estimates of summer and fall parr abundance and subsequent smolt estimates the following spring suggest survival was unusually high for progeny from the 2009 brood year adults. Factors such as a low number of springtime freshets may mean that the numbers observed are not representative (i.e., selection pressures acting on the population in a more normative year may have been relaxed in the fry-to-parr stage in 2010). A review of annual peak flows in the upper Yakima River (USGS 2011) suggests that 2010 had the lowest frequency of high flow events in the last 100+ years. Additional years will be required to identify both spatially and temporally, specific density dependant factors believed to be affecting survival.

We observed greater rearing spring Chinook abundance than could be explained by differences in redd density the previous fall (see figure in chapter one of this report). We speculate that unusually high survival throughout the winter of 2010 and spring of 2011 may have resulted in increased competition for available habitat and/or a more volitional distribution of fry into downstream habitat. In a more normative flow year, spring freshets or early summer flow management practices may result in a thinning of the population. Areas of the upper Yakima such as the Nelson reach (which has consistently lower number of spawners than adjacent reaches) may be limited by spawning density. In years where upstream rearing habitat is not fully seeded the number of rearing parr may be correlated with the number of reds (our assumption when below spawner capacity). However, if survival is high and upstream habitats
reach capacity an increase in downstream movement into previously unoccupied but suitable rearing habitat may occur. It’s interesting to note that our findings were reflected in subsequent fall parr and spring smolt abundance estimates. This supports the contention that population dynamics can be monitored at earlier life stages in the upper Yakima River Basin.

Territory size continued to be strongly associated with spring Chinook length, which is consistent with the findings of others (Grant and Kramer 1990, Keeley and Grant 1995). These data suggest that territory may be a reasonable microhabitat metric to measure the degree of competition for space. Previous work in the Yakima Basin was unsuccessful in linking calculated territory based on local abundance to fall abundance (Pearsons et al. 2007). However, the spatial scale of those measures may have been either too large to detect changes in territorial behavior, or measured after any subsequent mortality or out-migration had already occurred. We will continue to develop the Yakima Basin relationship between Chinook length and territory size in 2011. Chinook decreased the frequency of defense and foraging with increased distance from the holding position. This is consistent with our expectations that increased effort would be required to defend and utilize space away from the position of holding. The frequency of defense may be just as important as the size of the observed territory when evaluating limiting factors. For example, if food is a limiting factor, then we may observe highly defended areas of high food availability and smaller territory size, and areas of low food availability where the individual is forced to defend a larger area. These two scenarios may be energetically equivalent for the individual. We expected larger Chinook would be found in areas with the greatest food availability for the least energetic cost and that higher flow would equate to greater food availability. We did not detect a significant relationship between flow ratio and Chinook length in 2010. We will continue to investigate flow ratio as a metric of indexing food availability and energy expenditure at Chinook holding positions. Ranges of focal depth, total depth, and focal velocity during our observations were within the ranges of previous years. We will continue to monitor and refine our set of physical microhabitat measures around the focal position of rearing spring Chinook in order to compare these variables to abundance at the reach scale.

**Acknowledgments**

We thank the many people who co-labored in collecting field data. This includes Trenton De Boer, Nick Mankus, Cole Barrett, Kyle Hatch, Zack Mays, and Timothy Webster. Molly Kelly constructed Figure 1. Patty Smith provided administrative support. This work is part of the Yakima/Klickitat Fisheries Project and was funded by the Bonneville Power Administration through a contract to the Washington Department of Fish and Wildlife.
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Chapter 3

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

Abstract

Artificial propagation of Chinook salmon (*Oncorhynchus tshawytscha*) has the potential to alter the abundance and distribution of males that precociously mature in freshwater and thereby influence ecological and genetic interactions in the natural environment. We investigated the abundance and distribution of precociously mature, hatchery and natural origin male spring Chinook salmon during the spawning season (e.g., four to seven months after release from the hatchery) in the Yakima River. We counted the number of precocious males on the spawning grounds while snorkeling during the peak of spawning and electro-fished to determine abundance and distribution of precocious males away from redds. The abundance of hatchery origin precocious males on redds was less than 0.003% of the number of fish released and were less abundant on redds than natural origin precocious males ($P<0.01$). Between 1999 and 2010, the mean abundance of hatchery age 1 precocious males observed on the spawning grounds was 26 fish and ranged between 0 and 78 fish annually. Hatchery and natural origin precocious males were both found throughout the spawning range during the spawning season. However, differences in distribution between origins were detected ($P < 0.05$). Hatchery precocious males were proportionately more abundant in the lowest sampling reach and less abundant in a tributary with no hatchery facilities. In addition, most hatchery precocious males were found downstream of spawning areas during the spawning season. It appears that many precociously mature fish released from the hatchery migrate downstream and fail to migrate back to the spawning grounds or die within the Yakima River prior to spawning time. Thus, hatchery precocious males in the Yakima River do not contribute favorably to harvest and may pose ecological risks to non-target taxa, but most of these fish have a low probability of contributing genes to future generations.

Introduction

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

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

Artificially high numbers of precocious males that are released into rivers may harm wild populations through ecological and genetic mechanisms (Pearsons and Hopley 1999; Pearsons 2002; Pearsons and Temple 2007). Hatchery precocious males may eat wild fish, compete for resources, and spread disease (Pearsons et al. 2007b; 2009). They may also breed with wild fish and consequently lower the fitness of offspring because of the domesticating effects of artificial propagation (Schröder et al. 2006; Blankenship 2007). Hatchery fish may pass on genes that are unfavorable in the natural environment and may be particularly pronounced in precocious males because they do not experience the selective pressures that migratory adults experience and they may be the result of hatchery selection (Garant et al. 2003). In addition to potential impacts to wild fish, resident Chinook salmon are undesirable to fisheries because they are generally too small for harvest and can interfere with fisheries on other species by being caught more easily than targeted species such as resident trout. In short, production of artificially high numbers of precocious males has the potential to limit the success of supplementation programs. In contrast, artificial reduction in their production may negatively impact the population by reducing traits that are associated with precocious maturation such as fast growth.
The primary objective of this study was to evaluate the abundance and distribution of hatchery spring Chinook salmon precocious males during the spawning season in the Yakima River. The goal of the hatchery program in the Yakima River is to increase natural production and to provide harvest opportunity while keeping adverse genetic and ecological impacts within specified biological limits (Bonneville Power Administration 1996; Fast and Craig 1997; Bosch 2004). As such, the program strives to minimize differences between the hatchery and natural spawning fish to decrease the risk of long-term fitness impacts. Previous research indicated that the Yakima Supplementation and Research Facility has produced and released an average of 129,249 precocious males/year into the upper Yakima basin between 1999 and 2008 (Larsen et al. 2004a; Larsen et al. 2008; Yakima/Klickitat Fisheries Project, Unpublished data). The estimate of precocious male abundance was derived by multiplying the percent of fish that exhibited physiological indicators of precocious maturation by the total numbers of fish released. It was not clear whether the spawning grounds would be swamped with large numbers of precocious males or whether these fish would die or fail to migrate to the spawning grounds prior to the spawning season. Our goals were to 1) estimate the abundance of hatchery origin precocious males on the spawning grounds, and 2) quantify the distribution of hatchery precocious males on and away from the spawning grounds. We also present information about the abundance and distribution of natural origin precocious males so that we can determine how hatchery precocious males might differ.

**Methods**

**Study Area and Hatchery Program**

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

Artificial propagation of spring Chinook salmon in the upper Yakima Basin began with brood stock collection in 1997 and yearling smolt releases in 1999 as part of the Yakima/Klickitat Fisheries Project (YKFP). Approximately 689,458 Chinook salmon smolts have been released annually in the upper Yakima River from 1999 to 2010 (YKFP unpublished data). Broodstock for the spring Chinook program were natural origin upper Yakima stock collected at a trapping facility at Roza Dam. Chinook were spawned and juveniles were reared at the Cle Elum Supplementation and Research Facility (CESRF) in Cle Elum, Washington (Larsen et al. 2004a; Knudsen et al. 2006; Pearsons et al. 2007c). Yearlings were transported to one of three acclimation sites during January and February. Easton and Clark Flat acclimation sites are located on the Yakima River and the Jack Creek acclimation site is on the North Fork of the Teanaway River (Figure 1). The Easton and Jack Creek acclimation sites are located at the
upper end of the Chinook spawning distribution in the Yakima and Teanaway Rivers, and the Clark Flats acclimation site is located near the lower end of the annual spawning distribution in the Yakima River. Prior to release, Chinook in each acclimation site were sampled to determine the rate of precocious maturation (Larsen et al. 2004a, 2008). Hatchery spring Chinook were allowed to volitionally migrate out of the acclimation sites between March 15th and May 31st. Chinook were approximately 120 mm fork length (FL) when released. Fish that remained in the acclimation sites were forced out in mid to late May.

Due to a high rate of precocious male maturation in the hatchery, a production scale growth modulation program was established in 2002 (release year 2004) to evaluate the efficacy of reducing the incidence of precocious male maturation (Larsen et al. 2006). Half of all hatchery-reared Chinook in brood years (BY) 2002-2004 were reared under low growth conditions and half were reared using normal hatchery protocol. Larsen et al. (2004b) reported 29% of the low growth reared males and 43% of the normally reared males precociously matured; a 33% reduction in precocious male maturation. However, preliminary estimates indicated that the low growth fish did not survive as well as the normally reared fish. Normal rearing practices were reestablished for all hatchery-reared Chinook in BY 2005.
Figure 1. Survey reaches within the upper Yakima basin. Drift boat electrofishing survey reaches included: lower canyon, upper canyon, Ellensburg, Thorp, and the Cle Elum. Snorkeling surveys were conducted in the Thorp and Cle Elum reaches as well as the Bullfrog, Nelson, Easton and the Cle Elum River.

Abundance and Distribution

Sampling of precocious males on the spawning grounds occurred throughout the main stem Yakima River between Easton Dam and Town Diversion Dam, and the Cle Elum River from Cle Elum Dam to the Yakima River confluence between 1999 and 2010 (Figure 1). These areas represent the vast majority of the spawning area in the upper Yakima River and generally account for over 99% of Chinook redds counted annually (YKFP, unpublished data). Annual counts of precocious males occurred during the peak of spawning, which generally occurred during the last half of September. The sampling area consisted of six reaches (Figure 1). These reaches, beginning at the downstream end at approximately river kilometer (rkm) 256 were: Thorp (26.6 rkm long), Cle Elum (9.1 rkm long), the Cle Elum River (12.2 rkm long), Bullfrog (10.2 rkm long), Nelson (7.3 rkm long), and Easton (10.7 rkm long). The Bullfrog reach was first sampled in 2003. Excluding the Bullfrog reach, all reaches together make up 87 percent (66 rkm) of the total spawning area above the Town Diversion Dam (Figure 1).

We counted the number of precocious males on active redds by snorkeling. Each reach was floated with an inflatable raft and spring Chinook redds were flagged and numbered. Upon reaching a redd we determined the presence or absence of anadromous salmon. We only snorkeled those redds with anadromous fish on the redds and termed them ‘active redds’. Previous work demonstrated that precocious males were rarely observed on redds without anadromous fish present (Gebhards 1960; James et al. 1999). A snorkeler would then begin 5-10 meters downstream of the redd and snorkel upstream, counting all spring Chinook encountered. Fish were categorized as either being on the redd (in the bowl), or associated with the redd (within 5 meters). We combined the abundance of fish in these two categories in our analysis, however, most of the fish we counted were on redds. Hatchery origin residuals (e.g., non-migrants) were differentiated from natural origin spring Chinook by the presence of an adipose clip. During years when more active redds were present than we could snorkel (2000-2006), we systematically sampled the active redds (e.g., every other redd).

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

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

**Hatchery line**

We collected hatchery origin spring Chinook present in the system in the fall during our nighttime electrofishing recapture runs. These were brought back to the lab, checked for sex, precocity, gonad weight, and scanned for a coded-wire tag. If a coded-wire tag was present, its location indicated whether the hatchery Chinook was a supplementation line, or hatchery control line fish. Only Chinook originating from the Clark Flat Acclimation Site were possible hatchery control line origin. These were identified by the presence of a red elastomer mark behind the eye (YKFP 2010).

**Analysis**

An ANOVA was used to compare the estimated annual abundance of precocious males by age class and origin. If test results were significant at a 0.05 level, Tukey post-hoc comparisons were made to determine which comparisons were significant. A two-tailed Mann-Whitney U-test was used to compare the abundance of hatchery fish collected on and away from redds. Comparisons of spatial distributions on the spawning grounds were evaluated using contingency table G-tests of independence. The mean abundance in each reach from 1999-2010 for each age and origin of spring Chinook salmon were tested. We interpreted significant differences ($P < 0.05$) as differences in spatial distribution. Pearson product moment correlation statistics were used to explore various relationships of precocious male abundance. Non-parametric tests were used when data did not meet parametric test assumptions and could not be adequately transformed. All tests were performed in STATISTICA version 8.0 (StatSoft 2007), or in Excel using methods provided by Zar 1999. Previous work determined that the majority of residual males are precociously mature (Pearsons et al. 2008); therefore we consider all hatchery residuals encountered in the system as precociously mature males.

**Results**

The estimated number of natural origin age 0, natural origin age 1, and hatchery precocious males on the spawning grounds during the peak of spawning ranged from 5 to 718, 0 to 92, and 0 to 78 between 1999 and 2010 respectively (Table 1). Differences among age and origin of precocious male abundance were detected (ANOVA: $F_{2,33} = 12.0, P < 0.01$). Post-hoc analysis determined that natural production age 0 precocious males were greater in abundance than both natural and hatchery production age-1 males (Tukey test: $P < 0.01$). There were no detectable differences in abundance between age 1 natural and hatchery production precocious males (Tukey test: $P = 0.99$). Age 0 precocious males were found on a greater proportion of
redds sampled than either age 1 or hatchery origin (ANOVA: $F_{2, 33} = 9.0, P < 0.01$; Tukey test: $P < 0.01$), and were in greater in number per active redd (ANOVA: $F_{2, 33} = 15.4, P < 0.01$; Tukey test: $P < 0.01$), (Table 2.).

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

<table>
<thead>
<tr>
<th>Survey year</th>
<th>Active redds</th>
<th>(%) Redds surveyed</th>
<th>(%) Spawning area sampled</th>
<th>Observed</th>
<th>Age 0</th>
<th>Age 1</th>
<th>Hatchery</th>
<th>Estimated total</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>36</td>
<td>100</td>
<td>87</td>
<td>4</td>
<td>11</td>
<td>17</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>2000</td>
<td>316</td>
<td>66</td>
<td>87</td>
<td>103</td>
<td>42</td>
<td>8</td>
<td>128</td>
<td>42</td>
</tr>
<tr>
<td>2001</td>
<td>276</td>
<td>62</td>
<td>87</td>
<td>336</td>
<td>11</td>
<td>26</td>
<td>555</td>
<td>21</td>
</tr>
<tr>
<td>2002</td>
<td>304</td>
<td>81</td>
<td>87</td>
<td>138</td>
<td>15</td>
<td>8</td>
<td>228</td>
<td>25</td>
</tr>
<tr>
<td>2003</td>
<td>230</td>
<td>78</td>
<td>100</td>
<td>204</td>
<td>25</td>
<td>19</td>
<td>267</td>
<td>35</td>
</tr>
<tr>
<td>2004</td>
<td>1662</td>
<td>27</td>
<td>100</td>
<td>195</td>
<td>16</td>
<td>21</td>
<td>718</td>
<td>65</td>
</tr>
<tr>
<td>2005</td>
<td>655</td>
<td>99</td>
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<td>357</td>
<td>17</td>
<td>0</td>
<td>360</td>
<td>17</td>
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<tr>
<td>2006</td>
<td>198</td>
<td>90</td>
<td>100</td>
<td>148</td>
<td>2</td>
<td>0</td>
<td>177</td>
<td>3</td>
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<tr>
<td>2007</td>
<td>92</td>
<td>100</td>
<td>100</td>
<td>55</td>
<td>0</td>
<td>0</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>173</td>
<td>82</td>
<td>100</td>
<td>69</td>
<td>55</td>
<td>42</td>
<td>85</td>
<td>67</td>
</tr>
<tr>
<td>2009</td>
<td>105</td>
<td>99</td>
<td>100</td>
<td>87</td>
<td>15</td>
<td>34</td>
<td>88</td>
<td>15</td>
</tr>
<tr>
<td>2010</td>
<td>499</td>
<td>48</td>
<td>100</td>
<td>133</td>
<td>42</td>
<td>12</td>
<td>280</td>
<td>92</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Survey year</th>
<th>Active redds</th>
<th>Presence/Active redd</th>
<th>Abundance/Active redd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Age 0</td>
<td>Age 1</td>
</tr>
<tr>
<td>1999</td>
<td>36</td>
<td>0.11</td>
<td>0.14</td>
</tr>
<tr>
<td>2000</td>
<td>316</td>
<td>0.18</td>
<td>0.10</td>
</tr>
<tr>
<td>2001</td>
<td>276</td>
<td>0.31</td>
<td>0.03</td>
</tr>
<tr>
<td>2002</td>
<td>304</td>
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<td>0.03</td>
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<td>0.31</td>
<td>0.06</td>
</tr>
<tr>
<td>2004</td>
<td>1662</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>2005</td>
<td>655</td>
<td>0.24</td>
<td>0.02</td>
</tr>
<tr>
<td>2006</td>
<td>198</td>
<td>0.75</td>
<td>0.04</td>
</tr>
<tr>
<td>2007</td>
<td>92</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>173</td>
<td>0.08</td>
<td>0.21</td>
</tr>
<tr>
<td>2009</td>
<td>105</td>
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<tr>
<td>2010</td>
<td>499</td>
<td>0.15</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Hatchery precocious males were distributed differently than natural origin age 0, and natural origin age 0 and age 1 combined on the spawning grounds (G-test; $P < 0.05$). A significant difference was not detected between natural origin age 0 and natural origin age 1 fish, or between natural origin age 1 and hatchery precocious males (G-test; $P > 0.05$; Figure 2). An average of 24 percent of all hatchery precocious males observed on the spawning grounds were in the lowest spawning reach examined, whereas only 4 percent of natural origin age 0, and 10 percent of natural origin precocious males were observed in this reach (Figure 2.).

![Figure 2. Mean proportion ($p$) of natural and hatchery origin precocious males by reach within the upper Yakima River at the peak of spawning activity 1999-2010. Error bars represent 95 percent confidence intervals with negative boundaries of zero.](image)

Estimated total abundance of hatchery origin spring Chinook salmon away from redds at the time of spawning ranged between 0 and 102 fish/km among sampling reaches (Table 3). The lower and upper Yakima Canyon averaged 64% of the estimated number of precocious males away from redds (Figure 3). The annual abundance of hatchery precocious males were significantly correlated with the number observed on redds ($R^2 = 0.39; P = 0.03$; Figure 4).
Table 3. Estimated abundance of hatchery origin spring Chinook salmon (HSPC) away from redds in the main stem Yakima River in the fall of 2010. The maximum number of fish netted (n) in one of two electrofishing surveys completed in consecutive weeks is presented (LCYN is the Lower Canyon, UCYN is the Upper Canyon, EBURG is Ellensburg, THORP is Thorp, and CELUM is Cle Elum). Capture probability was generated using rainbow trout of approximately the same size range as hatchery spring Chinook salmon.

<table>
<thead>
<tr>
<th>Section</th>
<th>n</th>
<th>Capture prob.</th>
<th>Section est.</th>
<th>Section km</th>
<th>HSPC/km</th>
<th>Reach km</th>
<th>Total est.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCYN</td>
<td>27</td>
<td>0.2274</td>
<td>119</td>
<td>4.8</td>
<td>25</td>
<td>19.2</td>
<td>475</td>
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<tr>
<td>UCYN</td>
<td>17</td>
<td>0.1723</td>
<td>99</td>
<td>5.2</td>
<td>19</td>
<td>13.4</td>
<td>254</td>
</tr>
<tr>
<td>EBURG</td>
<td>3</td>
<td>0.1305</td>
<td>23</td>
<td>4.2</td>
<td>5</td>
<td>21.2</td>
<td>116</td>
</tr>
<tr>
<td>THORP</td>
<td>1</td>
<td>0.1167</td>
<td>9</td>
<td>5.7</td>
<td>2</td>
<td>24.1</td>
<td>36</td>
</tr>
<tr>
<td>CELUM</td>
<td>0</td>
<td>0.0881</td>
<td>0</td>
<td>7.4</td>
<td>0</td>
<td>16.2</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>881</td>
</tr>
</tbody>
</table>

Figure 3. Proportional abundance ($p$) of hatchery spring Chinook sampled away from redds in the fall of 2010, and the mean proportional abundance between 1999 and 2010. Significant differences were detected between the two lowest abundance sites (UCYN and CELUM) and the site with greatest abundance (LCYN).
Figure 4. Relationship between the estimated numbers of hatchery spring Chinook (Hspc) precocious males on and off the spawning grounds 1999-2010. Estimates from off the spawning grounds have been Box-Cox transformed (Box and Cox, 1964) to meet conditions of a near-normal distribution.

**Discussion**

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

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

Most of the hatchery precocious males that we encountered were located downstream of spawning areas. The lower and upper Yakima Canyon typically contain less than 1% of the upper Yakima Basin redds (Yakama Nation, unpublished data) and yet averaged 64% of the estimated number of hatchery precocious males during the spawning season. Many of the hatchery precocious males on the spawning grounds were observed in a reach that had relatively little spawning activity, whereas the natural origin precocious males were mainly in the areas with high spawning activity. The spawning area where many of the hatchery precocious males were observed was at the lower end of the spawning distribution. It also happens to be located closest to the Yakima Canyon where the highest abundance of precocious males that were not on the spawning grounds was observed. In the Wenatchee River, very few hatchery precocious males were observed on the spawning grounds, but a considerable number were captured migrating upstream at a location downstream of the spawning areas (Murdoch et al. 2007). These fish may have also distributed themselves below the main spawning areas as we observed in the Yakima Watershed. This behavior is in contrast to natural origin precocious males that are rarely observed moving upstream past dams in the Yakima or Wenatchee watersheds, suggesting that natural origin precocious males have adopted a strategy of remaining on or near the spawning grounds and thus conserving energy and promoting growth and testes development. Some hypotheses as to why sexually mature hatchery precocious males, most of which are exuding milt at the time of sampling, are located in areas away from where most of the spawning activity occurs include: lack of energetic capacity to swim back upstream to the spawning grounds; inappropriate downstream migration behavior for their life-history strategy; late migration timing; and inability to locate areas with spawning females after they had migrated downstream of spawning areas. Younger salmon, such as precocious males and jacks, typically migrate back to the spawning grounds later than older salmon (Knudsen et al. 2006; Murdoch et al. 2007) and may migrate during unfavorable environmental conditions.

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

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

We have identified some issues that could potentially contribute to the underestimation of precocious male numbers during our peak snorkel counts. We may have underestimated the number of active redds by spooking adults or by floating at times when adults are temporarily away from their redds. However, we rarely observed precocious males on redds without adults being present and this finding was also supported by work in the Salmon River drainage (Gebhards 1960). Gebhards (1960) concluded that precocious males were generally only found in areas where there was spawning activity and were usually found in the bowl of the redd, and “the yearling males remained constantly within the redd.”

Other reasons include the possibility that precocious males may have been hiding away from the redds, were scared off the redds, were moving between redds, or were present in greater numbers before or after our peak count. Additional snorkeling efforts along the banks in 1998 and 2007 did not find hatchery precocious males in hiding areas such as undercut bank in the vicinity of spawning areas, and multiple reach surveys conducted in 2007 and 2008 did not suggest greater numbers of precocious males on the spawning grounds the week before or after our peak of spawning surveys. We have also observed that repeated counts of precocious males at three different times of the day in the same reach were similar. This suggests that either our counts were accurate or that our bias was consistent. However, our estimates of fish away from redds, that were generated from electrofishing were higher in some years than those generated from snorkeling in the Thorp reach, suggesting that snorkeling may underestimate abundance.

In short, if we underestimated the number of precocious males on the spawning grounds then our numbers should be treated as indices.

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

The consequences of eliminating a large proportion of hatchery males from the spawning population may be quite important, but currently the consequences of this unintended outcome are uncertain. Reduction of hatchery precocious males may be beneficial to the natural spawning population because of the potential reduction in domesticating effects that might be caused by hatchery rearing (Garant et al. 2003). Alternatively, reducing the genetic contribution of fish that have traits related to precocious maturation, such as fast growth, may impact the population in negative ways. Indeed, we found that age 0 precocious males were larger than immature fish (Pearsons et al. 2007b; Pearsons et al. 2009). Further research is needed to understand the importance of precocious males to natural spawning populations and the potential domesticating impacts of hatchery precocious males to natural populations.

Releasing large numbers of precocious males could also increase ecological risks to target and non-target taxa (e.g., McMichael et al. 1999). Any impacts that may have occurred within the first five years of hatchery releases were within the management containment objectives for the YKFP (Pearsons and Temple 2007). Hatchery precocious males have been shown to share similar food and space with other salmonids in the Yakima River, but indices designed to evaluate competition with natural origin spring Chinook salmon in the main stem Yakima River suggests that competition is relatively low (Pearsons et al. 2007b). Furthermore, low incidences of piscivory have been documented in the upper Yakima watershed (Johnson et al. 2008).

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