

FISHERY RESEARCH



IDAHO NATURAL PRODUCTION MONITORING AND EVALUATION

Annual Progress Report
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Idaho Natural Production Monitoring and Evaluation

Project Progress Report

2005 Annual Report

Part 1—Project Overview

Part 2—Monitoring age composition of wild adult spring/summer Chinook salmon in the Snake River basin in 2005 to estimate smolt-to-adult return rates

Part 3—The stock-recruitment relationship for naturally produced spring/summer Chinook salmon in the Snake River basin

Part 4—Improve the precision of smolt-to-adult survival rate estimates for wild steelhead trout by PIT tagging additional juveniles

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PART 1—PROJECT OVERVIEW

The Idaho Natural Production Monitoring & Evaluation Project (INPMEP) is a long-term, large-scale research and monitoring effort conducted by the Idaho Department of Fish and Game (IDFG). The project goal is to understand the population dynamics and associated controlling factors of naturally produced anadromous salmonids that spawn upstream from Lower Granite Dam (LGD). Except for the spring Chinook salmon *Oncorhynchus tshawytscha* that spawn in the Clearwater River basin, all of Idaho's anadromous salmonids are listed under the Endangered Species Act (ESA). The Snake River stocks of summer steelhead trout *O. mykiss* and spring/summer Chinook salmon are still supported by natural reproduction and are thus the focal species of project investigations.

The INPMEP has been a dynamic effort. When demands and priorities have changed, the project has changed to meet them. In recent years, regional groups have recommended changes to the way research, monitoring, and evaluation efforts are conducted in the Columbia basin (e.g., ISRP 2005; NPCC 2005). Recovery planning efforts are underway for ESA-listed stocks. Under the authority of the Northwest Power and Conservation Council, subbasin management plans have been developed for all parts of the basin. All of these plans come with their imperatives for projects such as INPMEP. Existing data should be evaluated to provide the basis for any new efforts. Recent project reports and statements of work have reflected INPMEP efforts toward such evaluations with an emphasis on the new imperatives, such as fine-scale population description. This Project Overview was written to provide the context necessary for readers to understand current and proposed project work.

Project History

The INPMEP has been evolving for 20 years. It was originally established as the Idaho Habitat Evaluation for Offsite Mitigation Record, project number 1983-007-00. The initial goal was to evaluate the effectiveness of offsite habitat mitigation projects in Idaho funded by the Bonneville Power Administration (Petrosky and Holubetz 1985). It was IDFG's responsibility to monitor fish responses to the habitat changes, as describing physical habitat changes was the responsibility of the individual sponsors of habitat projects. After the initial inventory, the project expanded to include estimation of juvenile abundance at sites over a broad geographic area (general parr monitoring) and intensive studies at two stream reaches to measure parr density and stage-specific survival rates in order to link redd counts, juvenile abundance, and emigrant production (Petrosky et al. 1988).

Project objectives shifted emphasis in the early 1990s to monitoring the effectiveness of the Columbia Basin Fish and Wildlife Program in Idaho; habitat project effectiveness was then a secondary consideration to overall anadromous production monitoring (Rich et al. 1992). This shift was reflected in a change in project name and number to Idaho Habitat/Natural Production Monitoring, 1991-073-00. The general parr monitoring program became more complex as many cooperating agencies and projects contributed data. An additional objective was developed to describe adult-juvenile relationships by population type for both steelhead and Chinook salmon (e.g., wild B-run steelhead; Schrader and Petrosky 1994).

Project focus changed again with the listing of Snake River spring/summer Chinook and summer steelhead under the ESA in the mid 1990s. Some of the more intensive monitoring efforts were assumed by the Idaho Supplementation Studies (project 1989-098-00) and

Steelhead Supplementation Studies (now Idaho Steelhead Monitoring and Evaluation Studies [ISMES] project 1990-055-00) as part of their monitoring for supplementation studies. Project personnel began to collect, compile, and compare basinwide and stream-specific data regarding juvenile productivity and smolt-to-adult return (SAR) rates. They discovered a discrepancy between ocean ages determined by scales and by returns of tagged Chinook salmon, leading to a search for a more rigorous aging protocol (Kiefer et al. 2001). In 1996, project personnel began to collect fin tissue from Chinook carcasses and to archive these samples. There was also a lack of population-specific data on steelhead in Idaho, so an effort was developed to increase the number of passive integrated transponder (PIT) tags placed in fish from remote streams. General parr monitoring continued as before but was last summarized through 1999 (Hall-Griswold and Petrosky 2002).

Current Direction

The current project direction first appeared in its initial form in the 2001 report (Kiefer et al. 2001). The focus of INPMEP became to assess population characteristics, survival, and productivity of spring/summer Chinook salmon and steelhead in Idaho. Within the overall goal of INPMEP, we would like to answer several broad questions: What is the production of wild and natural juvenile anadromous salmonids in Idaho? How and why does this production vary? What are the numbers of spawning adults returning each year? How are adult returns structured across the landscape and in time? The answers will link salmon life stages in time and space, thus providing an understanding of population persistence.

Project Objectives

We have grouped project tasks into five objectives, as defined in the latest proposal and recent statements of work. The purpose of each objective involves enumerating or describing individuals within the life stages of anadromous salmonids (Figure 1). By understanding the transitions between stages and associated controlling factors, we hope to achieve a mechanistic understanding of population dynamics.

- Objective 1.** Correlate juvenile density of spring/summer Chinook to estimated abundance of the parental generation and the smolt migration. This objective is general trend monitoring that focuses on density of juvenile salmonids at selected sampling sites. The intent is to describe relationships on a basinwide scale and for individual populations where possible. Analyses will examine the productivity of Idaho's habitat for anadromous salmonids. Patterns in the data may suggest controlling factors.
- Objective 2.** Estimate 2005 adult escapement and describe age structure of the wild/natural spawning run of spring/summer Chinook above Lower Granite Dam. Abundance and age structure are important parameters in evaluating performance of fish populations. The first part of this objective relates back to Objective 1. The second part is essential for the completion of Objective 3.
- Objective 3.** Investigate aggregate life-cycle survival rates for wild and naturally produced spring/summer Chinook salmon populations above Lower Granite Dam. Objective 3 links life stages through time. This is an evaluation that interprets data

generated from other objectives. There are two components: a stock-recruit model (adult to juvenile) and estimation of smolt-to-adult return rates (juvenile to adult).

Objective 4. Increase precision of aggregate smolt-to-adult return rate estimates of wild steelhead that spawn above LGR. Project personnel place PIT tags in juvenile steelhead collected by angling at remote locations. This effort also provides population-specific data regarding migration characteristics of steelhead.

Objective 5. Describe genetic stock structure and composition of adult Snake River spring/summer Chinook salmon. The Interior Columbia Basin Technical Recovery Team (ICBTRT 2003) listed and prioritized research needs for population structure in the Snake River spring/summer Chinook ESU. Top priority is given to population-scale genetic data. Currently, INPMEP has archived tissues samples from spawning ground surveys since 1996. Genetic structure will serve as a foundation for future population research, e.g., straying rates, effective population sizes, and probability of genetic bottlenecks. The spatial coverage of the archive includes northeastern Oregon as well as the Clearwater and Salmon subbasins.

Report Topics

In this annual progress report, we will present our results for Objectives 2, 3, and 4. Part 2 of this report will detail results of INPMEP aging research and estimation of SAR rates for wild and naturally produced Chinook salmon (Objectives 2 and 3). Part 3 reports on the ongoing development of a stock-recruit model for the freshwater phase of spring/summer Chinook salmon in the Snake River basin (Objective 3). Part 4 is a summary of work done toward evaluating the juvenile emigration of wild steelhead (Objective 4). Data are still being developed for Objective 5 and a re-organization of Objective 1 is in progress to incorporate a probabilistic site-selection protocol. These objectives will not be addressed in this report. We will note here that it may be useful to provide a summary of key research results from all past reports in the Project Overview in the future.

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**PART 2—MONITORING AGE COMPOSITION OF WILD ADULT SPRING/SUMMER
CHINOOK SALMON IN THE SNAKE RIVER BASIN IN 2004 TO ESTIMATE SMOLT-TO-
ADULT RETURN RATES**

ABSTRACT

Accurate determination of the age structure is important for monitoring status and trends of wild adult spring/summer Snake River Chinook salmon *Oncorhynchus tshawytscha*. We determined age composition of the 2005 return and computed smolt-to-adult return (SAR) rates for the 1996-2004 migratory cohorts. The majority of the 2005 return (66.3%) spent two years in the ocean. Length distributions of all ocean-age classes overlapped adjacent ages; lengths of four-ocean fish were wholly contained within the length distribution of three-ocean fish. Data were complete for migratory years 1996-2001; data for migratory years 2002-2004 were incomplete. Annual estimates of SAR values varied over an order of magnitude (0.33%-3.79%), but 95% confidence intervals were broad (e.g., 0.3%<3.79%<7.56%). Three-ocean females outnumbered three-ocean males by 3.7:1 in 2005. The sex ratio at this age averaged 2:1 since migratory year 1998 and is consistent with historical records.

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INTRODUCTION

Age information is an important tool for management and recovery of Snake River spring/summer (SRSS) Chinook salmon *Oncorhynchus tshawytscha*. Accurate age data is essential to assign returning adults to a specific brood year and to estimate survival rates (smolt-to-adult return, SAR). Inaccurate age data can lead to serious errors in the management of populations (Zabel and Levin 2002).

Many agencies use scales to age Pacific salmon *Oncorhynchus* species. However, when Pacific salmon leave the ocean for their spawning migration, they cease feeding and scale material begins resorbing. Resorption results in the loss of annuli on the periphery of some scales, making accurate age determination difficult for salmon with long spawning migrations (Chilton and Bilton 1986), such as the migrations made by Snake River salmon stocks. In addition, scales may be damaged or regenerated, which makes them impossible to read. This project began to collect fin rays from carcasses to determine ocean ages in 1998. The original motivation for this effort was the mismatch of scale ages with known ocean ages of fish tagged as juveniles with passive integrated transponder (PIT) tags. Ocean ages based on fin rays have been >97% accurate in any given year based on known-age adults (Kiefer et al. 2001, 2002, 2004; Copeland et al. 2004).

In this report, we present the age structure of spring/summer Chinook salmon carcasses collected in 2005 throughout the Snake River basin upstream of Lower Granite Dam (LGD). These data were used to assign the run to age categories and to update and extend SAR rates previously estimated (migratory years [MY] 1998-2004). Additionally, we examined sex ratios and gender-specific length at age.

METHODS

Sampling

The study area encompasses streams in the Snake River basin upstream of LGD known to have spawning populations of spring/summer Chinook salmon. Field personnel sampled carcasses from representative spawning areas throughout the study area (Figure 2). In general, these reaches are a subset of the redd count transects described by Hassemer (1993).

Collection techniques were the same as used in past years (Copeland et al. 2004). Each carcass was measured to fork length (FL) and mid-eye to hypural length (MEHP). The dorsal fin was removed and inserted into a uniquely numbered, pre-labeled coin envelope. A 16 mm² piece of fin tissue with good color (excluding the adipose fin) was placed in 95% ethanol. Tissue samples were stored for future genetic analysis. Samples were transported to the Idaho Department of Fish and Game (IDFG) Fisheries Research Office in Nampa, Idaho. Fin rays were stored in a freezer until preparation for aging.

The majority of samples were collected on the spawning grounds from carcasses of wild adults. A few samples were collected from carcasses that floated down to adult trapping weirs. Hatchery personnel collected up to 30 dorsal fins from known-age (PIT tagged) hatchery adults at Rapid River, McCall, and Dworshak hatcheries. We used this set of known-age samples to estimate aging accuracy in the current year.

Fin Preparation

Laboratory technicians removed dorsal fins from the freezer and placed them in specially designed wooden racks to dry. The fin rays were adjusted so the base of the fin was perpendicular to the rays. After drying 24 hours, the technicians removed excess material (i.e. bones, loose skin, and flesh), then epoxied and placed them on waxed paper to harden overnight under a fume hood.

Laboratory technicians cut each epoxied fin into cross-sections by making eight to ten thin slices (1.2 mm) in each fin using a water-cooled, high-speed sectioning saw. Cross-sections were placed on a microscope slide to dry in the order in which they were sliced. Sections were affixed to the slides using a clear liquid mounting medium to improve resolution and preserve the sample.

Fin Aging

Mounted fin ray sections were aged using a compound microscope. Green, filtered, transmitted light illuminated opaque (dark) zones alternating with translucent (light) zones (Figure 3). Opaque zones represent material deposited during the periods of rapid growth, while translucent zones represent material deposited during periods of slow growth (Ferreira et al. 1999). The translucent (light) zones then are annuli between zones of ocean growth (Figure 3). It is harder to distinguish multiple freshwater annuli. Technicians counted the ocean annuli to age the fish.

We assembled a reference collection of known-age Chinook salmon to train readers and help personnel age hard-to-read fin rays. This reference collection was comprised of Chinook salmon tagged as juveniles with PIT or coded-wire tags and recovered as returning adults. New personnel were tested on fin rays from the reference collection until they achieved a 90% accuracy rate (out of 100) before they were allowed to read fin rays from the current year.

All samples were independently aged by at least two technicians. Fins were read again in a referee session if there was disagreement in age determination or if the determined age did not match what was expected for the fish's length based on experience. During a referee session, a camera was attached to the microscope to display the image on a television screen. Three trained personnel then viewed the fin together and arrived at a consensus age. In some cases, a consensus was not reached and the fin ray was classified as not readable. Referee sessions were more frequent at the beginning of the analysis to ensure that newly trained personnel were accurately aging the new fin rays and to discuss any abnormalities seen in growth patterns.

Ocean Age Proportions at Lower Granite Dam

Size and sex influence carcass recovery rates, so carcass samples may not represent the true composition of the population (Zhou 2002). We used video images to determine the length frequency distribution of wild adult spring/summer Chinook salmon passing LGD in 2005. This corrects for any length biases in the carcass sample, such as collecting a disproportionate number of larger fish. A video camera recorded adults passing the viewing window at LGD for 24 hours every third day from April through August. We randomly selected the initial start date

for recording videos from the anticipated first week of the migration. The start date established the video recording schedule for the rest of the season.

The length frequency distribution of the aggregate run was calculated based on samples from the videotapes. We estimated the number of viewing minutes necessary to obtain approximately 400 images. We randomly selected a 1-hour segment of each videotape for viewing. Images were examined for an adipose fin. Fish with a full adipose fin were assumed to be of natural origin. Chinook salmon missing all or part of the adipose fin were assumed to be of hatchery origin. The images of wild individuals were digitized and fork length was estimated from the number of pixels between the nose and caudal fin fork (I_F). Several vertical lines were placed on the LGD viewing window and we measured the pixels between them (I_L). The distance between the outer two lines is known (62.489 cm); therefore, the value of an image pixel is also known. We also used a correction factor (0.0988) to adjust for image distortion by the water to estimate the actual fork length of the digitized images. This correction factor was developed in the early stages of aging work. Fork length was estimated as:

$$FL = \left(62.489 \left(\frac{I_F}{I_L} \right) \right) - 0.098.$$

We assigned all individuals in the 2005 run passing LGD to a smolt year. First, we constructed a length frequency distribution by 5 cm increments using fork lengths estimated from video images:

$$p_i = \frac{v_i}{V},$$

where p_i is the proportion of the run in length category i , v_i is the number of images in length category i , and V is the number of images measured. Similarly, the age distribution of each length group was calculated based on the carcass samples:

$$a_{ij} = \frac{m_{ij}}{M_i},$$

where a_{ij} is the proportion of carcasses of length i at ocean age j , m_{ij} is the number of carcasses of length i at ocean age j , and M_i is the total number of carcasses of length i . The age distribution of the carcass sample was expanded to the aggregate run by multiplying the matrix of a_{ij} by the vector of p_i . These proportions were then summed for each age and multiplied by the number of wild spring/summer Chinook salmon passing LGD as estimated by the U.S. v. Oregon Technical Advisory Committee (TAC; S. Sharr, IDFG, personal communication):

$$n_j = N \sum_{i=1}^4 p_i a_{ij},$$

where n_j is the number of fish at ocean age j and N is the TAC escapement estimate.

Estimating Aggregate Smolt-to-Adult Return Rates

We combined the age assignments with smolt estimates (see Part 3 of this report) to estimate an aggregate SAR estimate for wild Snake River spring/summer Chinook salmon. To calculate a SAR for a particular MY, we used the sum of ocean returns from that cohort as the numerator and the estimate of wild smolts passing LGD as the denominator:

$$SAR_k = \frac{\sum_{l=1}^4 r_{k+l}}{S_k},$$

where SAR_k is the SAR of MY k , r_{k+l} is the return from that cohort in year $k+l$, and S_k is the estimate of smolts migrating in year k . The maximum value of l is 4, because that is the maximum ocean age we have observed in the past (Copeland et al. 2004). The SAR value is the estimate of the number of smolts migrating past LGD that return to LGD as adults. We used formulas from Fleiss (1981) to estimate the 95% confidence limits on SAR values. The lower limit is given by:

$$\frac{(2np + t_{\alpha/2}^2 - 1) - t_{\alpha/2} \sqrt{t_{\alpha/2}^2 - (2 + 1/n) + 4p(nq + 1)}}{2(n + t_{\alpha/2}^2)}$$

and the upper limit by:

$$\frac{(2np + t_{\alpha/2}^2 + 1) + t_{\alpha/2} \sqrt{t_{\alpha/2}^2 + (2 + 1/n) + 4p(nq + 1)}}{2(n + t_{\alpha/2}^2)},$$

where n is the number of smolts, p is the SAR value as a proportion, q is 1-SAR, and $t_{\alpha/2}$ is 1.96.

RESULTS AND DISCUSSION

Ocean Age Proportions in 2005

Field technicians and hatchery personnel collected three known-age naturally produced fish and 59 known-age hatchery fish in 2005. Laboratory technicians aged 100% of the known-age fish correctly. Of the known-age validation sample, there were six one-ocean fish, 45 two-ocean fish, and eight three-ocean fish. No known-age four-ocean fish were collected.

We examined fin rays from 440 carcass samples. Ages could not be determined for 15. These omissions will not create any biases as long as individuals dropped are a random sample within their length class (i.e. unreadable fin rays are not from older individuals in a given length group). An unusual number (28) of fish were observed to have a double freshwater mark, ten of which were PIT tagged as juveniles. We examined the complete tag history of these known-age fish from the regional PIT tag database (www.ptagis.org) to determine their passage route and timing through the dams on the lower Snake River. All were detected in the bypass system at LGD. Eight were returned to the river below LGD. The other two were routed to raceways below the dam but also could have returned to the river at some point. Four of the eight fish returned

to the river were recovered as jacks (early-maturing males); therefore, the putative second freshwater annulus likely was a growth check.

Technicians classified the majority (66.3%) of the carcasses aged in 2005 as two-ocean returns (Figure 4). All fish <60 cm FL were classified as one-ocean, but some individuals larger than 60 cm FL were also classified as one-ocean (Table 1). Length distributions of one- and two-ocean ages overlapped by 6 cm. The overlap zone between two- and three-ocean ages was more substantial at 26 cm, although three-ocean fish were more prevalent at longer lengths (Figure 4). The length distribution of four-ocean fish was encompassed within that of three-ocean fish (Figure 4). Because they were not larger than three-ocean fish, we surmise that four-ocean fish were slow growers that stayed longer in the ocean before maturing (Ricker 1981; Quinn 2005).

The average FL of two-ocean males and females in 2005 were identical (75.4 cm), whereas three-ocean males, on average, were much larger than females (95.7 cm versus 88.9 cm). We observed this in our previous report (Copeland et al. 2005). Development of the male kype and erosion of the female's tail during spawning may cause gender-specific differences in FL. Comparison of the length from the mid-eye-to-hypural bone (MEHP length) removes any influences these sex specific traits cause. We calculated differences between sexes in terms of fork and MEHP lengths using the data from Copeland et al. (2005). Two-ocean males were 2.5 cm larger than females in FL, but females were 0.3 cm longer in MEHP length. Three-ocean males were 8.1 cm larger than females in FL, but only 3.2 cm in MEHP length. Similarly, in 2005, average MEHP length of males was 2.2 cm shorter for two-ocean fish and 2.8 cm longer for three-ocean fish. We concluded that the gender differences we observed for three-ocean fish were real, but about half of that was due to the secondary sexual characteristics listed above.

We measured 387 unmarked salmon from video images as they passed LGD (Table 2). The overall length distribution of this sample was strongly unimodal with extended tails at both extremes (Figure 5) and is similar to the length distribution of carcass samples (Tables 1 and 2). The largest proportion was in the 70-79 cm groups (Table 2). Larger fish (>115 cm) were not present as they have been in the past (see Kiefer et al. 2001, 2002, 2004). In 2005, the largest Chinook salmon measured on the spawning grounds was 106 cm, and the largest length estimated of a spring/summer Chinook salmon passing through the LGD viewing window was 107 cm. After expanding the carcass data to reflect the aggregate run, we found 7% in the one-ocean age class, 66.3% in the two-ocean age class, and 25.7% in the three-ocean age class with the remaining 1% in the four-ocean age class (Table 3).

Larger, older fish tended to be females. There were no four-ocean males found on the spawning grounds, and the proportion of three-ocean females was high (79%, Table 4). Since INPMEP began carcass collections, the proportion of three-ocean females on the spawning grounds varied from 52% to 80%. Two-ocean females and males were more evenly split (Table 4). Similar trends were also found in hatchery fish (Brian Leth, IDFG, personal communication). Historically, wild Chinook salmon spawning in Idaho have had a sex ratio biased toward females, with the exception of a few populations (C. E. Petrosky, IDFG, unpublished data). Older ages in Chinook salmon spawning returns are dominated by females because of sex-specific maturation schedules (Healey 1991).

Aggregate Smolt-to-Adult Return Rates

Cohort age data were complete through MY 2001. Estimated SAR values (excluding jacks) ranged from a low of 0.33% for smolt year 1996 to a high of 3.69% for smolt year 1999 (Table 5). Please note these estimates are the percentage of smolts migrating past LGD that return to LGD as adults (LGD to LGD). Since 1998 was the first year for which this project had aging results, SAR estimates were calculated for MY 1996 without one-ocean returns. Age data were complete through three-ocean returns for MY 2002 and two-ocean returns for MY 2003. In 2006, TAC revised their previous adult escapement estimates (S. Sharr, IDFG, personal communication). Smolt numbers were also updated from 2002-2004 (Part 3). Incorporating these updated abundance estimates changed SAR estimates for 1996-2004 by $\leq 0.4\%$.

The SAR values calculated by the Comparative Survival Study (Berggren et al. 2005) for wild spring/summer Chinook salmon (also LGD to LGD) showed a similar trend to those presented here, but the values we computed were higher. For example, the greatest difference was between the MY 2000 values: Berggren et al. (2005) calculated SAR = 1.71% (95% CI: 1.25%—2.23%) versus our computation of 3.16% (95% CI: 0.3%—6.28%). Although the confidence intervals about our estimates are wide, the consistent difference between point estimates is troubling. Berggren et al. (2005) calculated SAR using PIT-tagged smolts. There could be additional mortality of PIT-tagged fish compared to untagged fish. PIT-tagged fish were not necessarily proportional to wild fish numbers from each drainage, and the way they were handled and transported was not necessarily reflective of the run at large, so there may be sampling error at the population level. The use of PIT-tagged individuals is particularly limiting because relatively few adults return to be detected, between 0.5% to 2.2% of the total cohort returns we used. The dearth of adult fish could exacerbate population-level sampling errors. Williams et al. (2005) found SAR values based on untagged SRSS Chinook salmon clearly exceeded those based only on PIT tag detections when returns were high. They concluded that SAR estimates based on PIT-tagged fish do not represent the survival of untagged fish. Lastly, Berggren et al. (2005) found that various weighting schemes (based on passage history) could influence the overall SAR value. Certainly, these issues should be considered when comparing their estimates to ours.

The process through which we calculated SAR values doubtlessly contained problems as well. Misclassification of hatchery fish could introduce a large bias in SAR estimates for wild fish because the hatchery returns were much larger than the wild escapement. Origin of salmon passing the viewing window at LGD was classified based on presence or lack of an adipose fin; therefore, the 'wild' category included unclipped hatchery fish, partially clipped fish with regenerated fins, and supplementation fish that deliberately were not marked. Because both adults and smolts were classified based on fin clips, misclassified fish were in both numerator and denominator of the SAR estimate. If their survival were equivalent to actual naturally produced fish, then the SAR is unbiased. However, hatchery fish typically do not survive as well as wild fish after release into the wild (Raymond 1988; Bouwes et al. 2002), which would introduce a negative bias, i.e. the estimate would be lower than actual survival. In spite of a potentially significant minority of unmarked hatchery fish, our SAR values were high. The strength of our SAR estimate is that it contains no assumptions regarding population representation or passage history. Its weakness is the wide confidence interval about each estimate.

CONCLUSIONS AND RECOMMENDATIONS

We continued to observe reduced length-at-age and unusual growth patterns in the aging data, such as split annuli and multiple freshwater annuli. Density-dependence in the freshwater phase (see Part 3) may cause slower growth and delayed smoltification. This may lead to decreased ocean growth and survival (Beamish et al. 2004) and influence adult fitness and escapement (Nicieza and Braña 1993). Split annuli and false annuli indicate fish experienced some type of stress. Stress affects growth. This may change the maturity schedule and survival assumptions on which run forecasts are based. The identity of unusual growth patterns should be verified.

The SAR estimates are a primary product of this research. Estimated SAR (LGD to LGD) for the aggregated Snake River spring/summer populations varied over an order of magnitude during our study period (0.33% to 3.79%). We are confident that SAR estimates were founded on precise and accurate age information. However, the effect of uncertainty in other inputs on SAR precision has never been assessed. In particular, data regarding the misclip rate should be obtained and its effect should be examined. A rigorous assessment of SAR estimation and the associated error will increase usefulness. We used one method to assess the uncertainty about SAR estimates. Others may be suitable, e.g., nonparametric bootstrap. It is tempting to choose the method that results in the smallest error bounds. This should be avoided, and the method that best approximates the actual error process should be used.

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Table 1. Number collected and proportion by ocean age for each 5 cm fork length group of wild Chinook salmon carcasses collected on spawning grounds in 2005.

Length Group	Number Collected	Ocean Age			
		1	2	3	4
<50	6	1.00	0.00	0.00	0.00
50-54	7	1.00	0.00	0.00	0.00
55-59	3	1.00	0.00	0.00	0.00
60-64	6	0.17	0.83	0.00	0.00
65-69	24	0.04	0.96	0.00	0.00
70-74	79	0.00	0.97	0.03	0.00
75-79	90	0.00	0.93	0.07	0.00
80-84	46	0.00	0.65	0.33	0.02
85-89	71	0.00	0.18	0.79	0.03
90-94	56	0.00	0.02	0.94	0.04
95-99	19	0.00	0.05	0.90	0.05
100-104	16	0.00	0.00	1.00	0.00
105+	2	0.00	0.00	1.00	0.00

Table 2. Number of images measured and estimated proportion in each 5 cm fork length group of wild adult spring/summer Chinook salmon passing Lower Granite Dam during 2005.

Length Group	Images Measured	Proportion
<50	6	0.016
50-54	9	0.023
55-59	7	0.018
60-64	18	0.047
65-69	46	0.119
70-74	89	0.230
75-79	83	0.214
80-84	37	0.096
85-89	41	0.106
90-94	21	0.054
95-99	24	0.062
100-104	3	0.008
105+	3	0.008

Table 3. Estimated proportion by ocean age and 5 cm fork length group, total proportion by age, and number by age of wild spring/summer Chinook salmon passing Lower Granite Dam in 2005.

Length Group	Ocean Age			
	1	2	3	4
<50	0.016	0.000	0.000	0.000
50-54	0.023	0.000	0.000	0.000
55-59	0.018	0.000	0.000	0.000
60-64	0.008	0.039	0.000	0.000
65-69	0.005	0.114	0.000	0.000
70-74	0.000	0.224	0.006	0.000
75-79	0.000	0.200	0.014	0.000
80-84	0.000	0.062	0.031	0.002
85-89	0.000	0.019	0.084	0.003
90-94	0.000	0.001	0.051	0.002
95-99	0.000	0.003	0.055	0.003
100-104	0.000	0.000	0.008	0.000
105+	0.000	0.000	0.008	0.000
Total Proportion	0.070	0.663	0.257	0.010
Number	610	5814	2255	90

Table 4. Number and proportion of age group that were male or female by return year based on carcass samples. Proportions are in parentheses.

Ocean Age	Sex	Return Year							
		1998	1999	2000	2001	2002	2003	2004	2005
1	F	na	2 (0.08)	0	1 (0.07)	2 (0.15)	1 (0.06)	2 (0.22)	2 (0.11)
	M	na	23 (0.92)	30 (1.00)	13 (0.93)	11 (0.85)	15 (0.94)	7 (0.78)	16 (0.89)
2	F	3 (0.38)	104 (0.54)	111 (0.46)	399 (0.50)	177 (0.50)	87 (0.56)	248 (0.56)	114 (0.49)
	M	5 (0.63)	90 (0.46)	132 (0.54)	400 (0.50)	174 (0.50)	67 (0.44)	191 (0.44)	120 (0.51)
3	F	118 (0.80)	23 (0.55)	17 (0.52)	52 (0.71)	214 (0.71)	306 (0.62)	68 (0.66)	130 (0.79)
	M	29 (0.20)	19 (0.45)	16 (0.48)	21 (0.29)	88 (0.29)	189 (0.38)	35 (0.34)	35 (0.21)
4	F	4 (0.25)	3 (0.50)	0	2 (0.67)	3 (0.50)	7 (0.78)	1 (0.25)	6 (1.00)
	M	12 (0.75)	3 (0.50)	0	1 (0.33)	3 (0.50)	2 (0.22)	3 (0.75)	0

Table 5. Number of smolts produced, number of adults returned by age, and estimated smolt-to-adult return (SAR) rate of the aggregated Snake River wild spring/summer Chinook salmon stock by migratory year. The 95% confidence bounds for the SAR estimates are in parentheses.

	Migratory Year								
	1996	1997	1998	1999	2000	2001	2002 ^a	2003 ^a	2004 ^a
Smolts (#)	419,826	161,157	599,159	1,560,298	1,344,382	500,700	1,128,539	1,455,845	1,501,332
<i>Returns at:</i>									
1-ocean	na	173	250	1670	1884	366	2438	1303	610
2-ocean	910	2288	7732	43,259	15,963	6880	18,755	5814	
3-ocean	484	456	1279	13,601	24,525	2160	2255		
4-ocean	0	34	308	674	51	90			
Total	1394	2950	9568	59,205	42,424	9495	23,448	7117	610
	0.33	1.83	1.60	3.79	3.16	1.90	2.08	0.49	0.04
SAR (%)	(0.02-0.65)	(0.06-3.16)	(0.03-3.16)	(0.03-7.56)	(0.03-6.28)	(0.04-3.76)	(0.04-4.12)	(0.02-0.95)	(0.01-0.07)

^a Adult return of cohort is not completed.

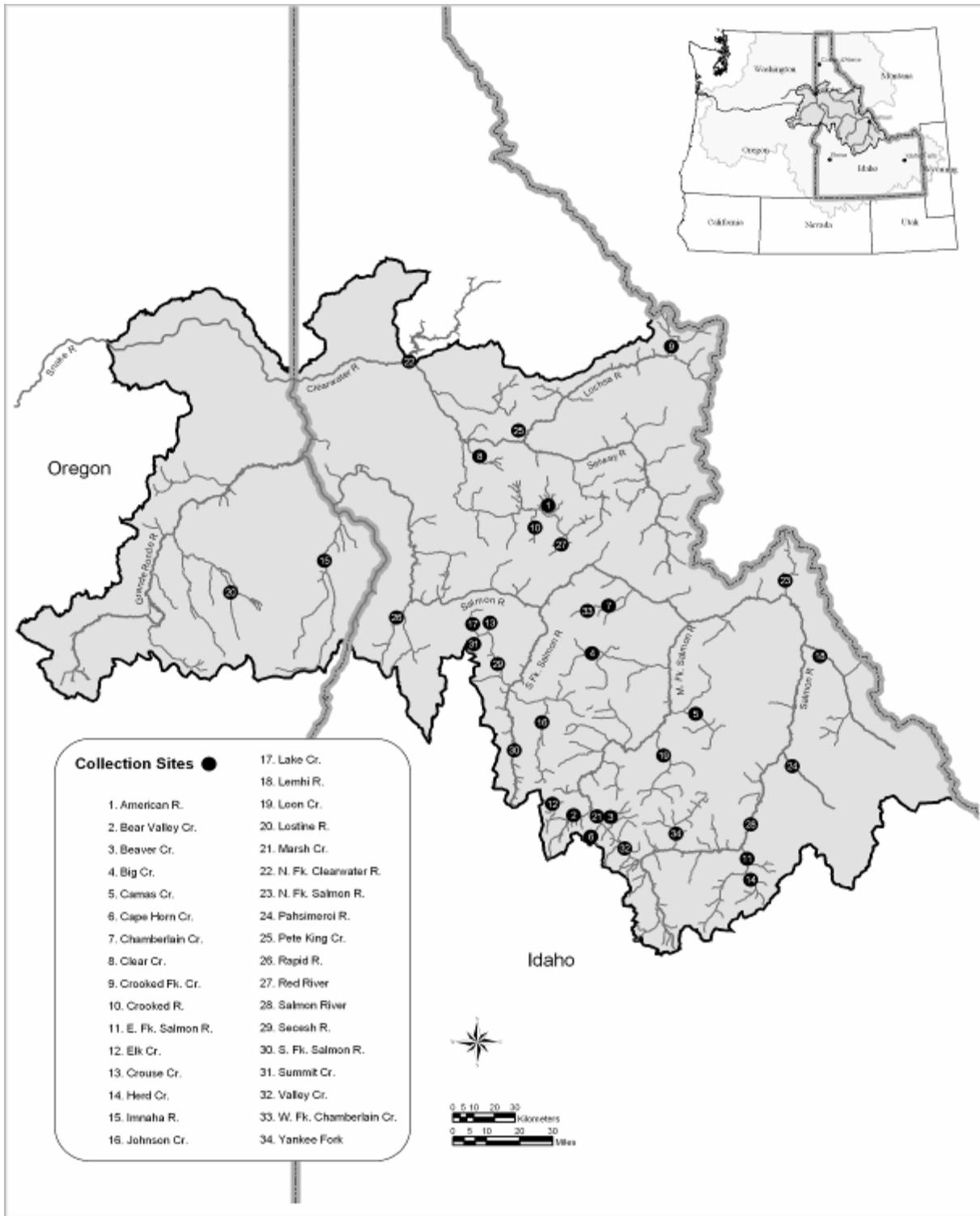


Figure 1. Location of sites where wild spring/summer Chinook salmon carcasses were collected in 2005.

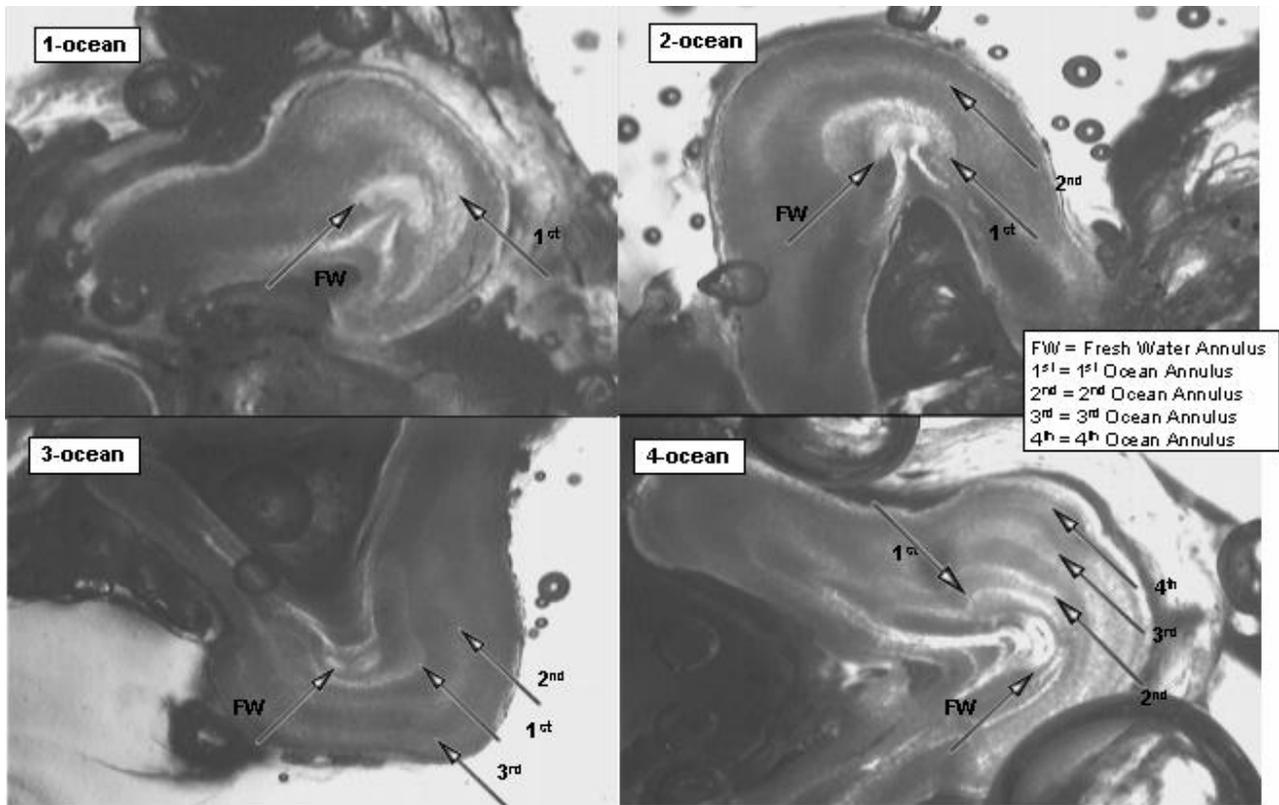


Figure 2. Example cross-sections illustrating the patterns typical of the four ocean ages observed in dorsal fin rays collected from carcasses of Snake River spring/summer Chinook salmon. Light was transmitted from below.

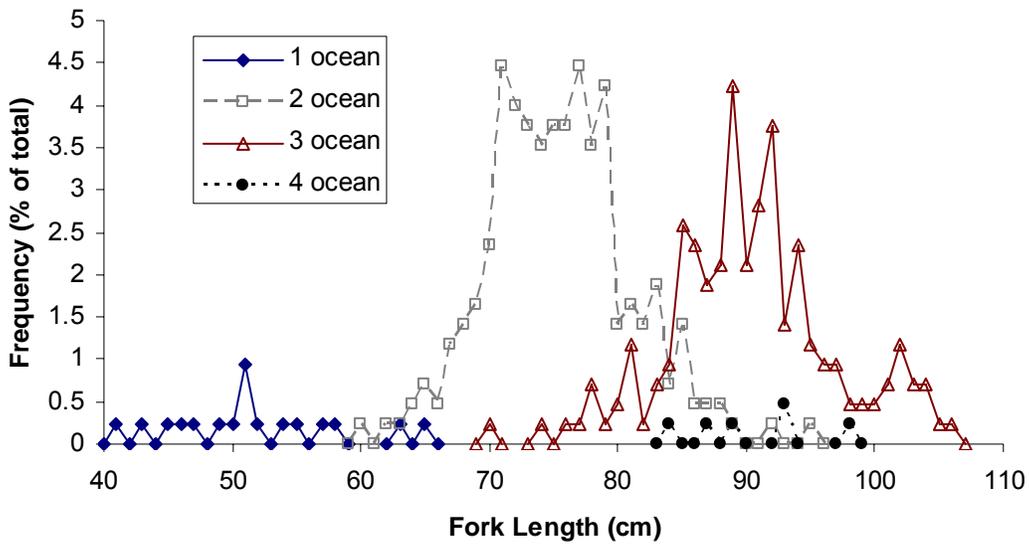


Figure 3. Length distribution by ocean age Snake River spring/summer Chinook salmon collected in 2005. Ages were determined from fin rays collected from carcasses (n = 425).

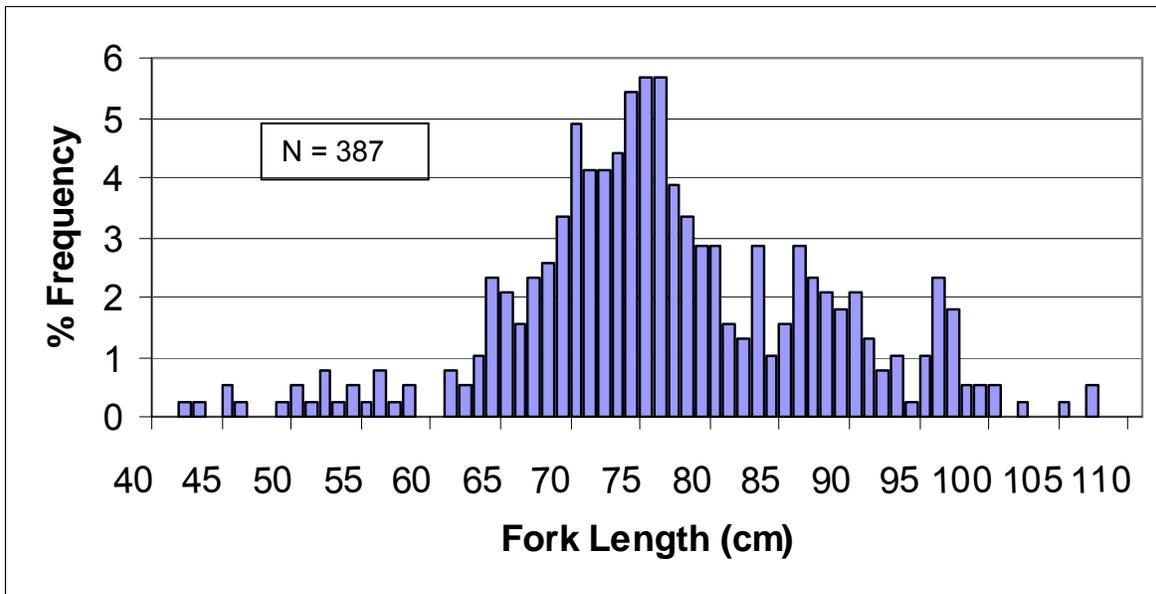


Figure 4. Length distribution of wild Snake River spring/summer Chinook crossing Lower Granite Dam in 2005 as measured from video images.

PART 3—THE STOCK-RECRUITMENT RELATIONSHIP FOR NATURALLY PRODUCED SPRING/SUMMER CHINOOK SALMON IN THE SNAKE RIVER BASIN

ABSTRACT

Stock-recruitment relationships are important to understanding how density-dependent forces affect abundance. Previously, I fit a Beverton-Holt curve to estimates of female spring/summer Chinook salmon *Oncorhynchus tshawytscha* available for natural reproduction above Lower Granite Dam during 1990-2002 versus the number of smolts produced. Here, I updated the Beverton-Holt stock-recruit model with data from the 2005 smolt migration and more recent estimates of detection efficiencies at Lower Granite Dam in 2002, 2003, and 2004. The estimated number of naturally produced smolts in 2005 (brood year 2003) was 1,828,522. Updated smolt estimates changed <0.3% of previous values. For the 1990–2003 brood years, intrinsic productivity was 441.6 smolts per female and asymptotic production was 1.8 million smolts, as estimated by nonlinear fit ($r^2 = 0.94$). Parameter estimates were more sensitive to changes in smolt abundance than female abundance. The effects of likely biases in the data, i.e. overestimation of smolt abundance, should be to reduce both parameter estimates by a similar percentage as the bias to the input data. Asymptotic smolt production predicted by the fitted model was much less than production observed in the 1960s. To understand why, we must investigate the processes that act to produce the observed function. I recommend several steps to refine and explore the model.

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INTRODUCTION

The relationship between parental abundance and subsequent recruitment of progeny is the focus of a significant portion of fisheries research and management efforts. A stock-recruitment analysis describes the demographic ability of a population to sustain itself, assuming all influential factors remain constant. This analysis is typically an empirical process simplifying the many intervening stages by aggregating life history stages (Hilborn and Walters 1992). The goal is to produce a predictive model, which is a description of the observed pattern, i.e. the regularities of the system under consideration (Rigler 1982). A mathematical model is chosen and fitted to the data, but such stock-recruit relationships often have had poor explanatory power (Hall 1988).

Sources of variation in survival of Pacific salmon *Oncorhynchus sp.* are split between freshwater and saltwater phases in approximately equal magnitudes (Bradford 1995). For threatened Snake River spring/summer (SRSS) Chinook salmon *O. tshawytscha*, survival during both freshwater and saltwater life stages must be understood for decision makers to effectively select measures to promote recovery. Stock-recruit data are also useful for evaluating the effectiveness of management effort such as habitat alterations (Bradford et al. 2005).

For salmon, smolt emigration is a convenient and meaningful stage to consider recruitment (Solomon 1985). Stock-recruitment relationships for Columbia River Basin Chinook salmon have been described using a Beverton-Holt (BH) function (NPPC 1986) or a Ricker function (Petrosky et al. 2001). In a BH function, the relationship is regulated by density-dependent mortality during the juvenile stage and is asymptotic in shape, with the asymptote representing carrying capacity (Beverton and Holt 1957). In a Ricker function, regulatory mechanisms cause declines in recruitment at higher stock densities (Ricker 1954). In general, most data sets have produced very poor fits to stock-recruitment relationships (Hall 1988). The most serious problem in a stock-recruitment analysis is error in estimation of adult and recruit abundance (Hilborn and Walters 1992). The Columbia River hydrosystem presents an opportunity to estimate the stock-recruitment inputs using the efficient counting systems present at the dams in the system. Here, I updated the BH stock-recruit model of Kiefer et al. (2004) with data from the 2005 smolt migration and more recent estimates of detection efficiencies at Lower Granite Dam (LGD) in 2002, 2003, and 2004. In addition, I conducted a sensitivity analysis to examine the impacts of potential biases on model output.

METHODS

Smolt production in 2005 was estimated using fish passage data collected at LGD. Passage data consisted of daily counts of wild smolts collected and estimated daily collection efficiencies (probability of detection at the dam). Daily smolt migration number was estimated by dividing the daily count by estimated collection efficiency for that day. I obtained the daily numbers of wild Chinook salmon smolts collected at LGD from the Fish Passage Center website (<http://www.fpc.org/smoltqueries/CurrentDailyData.asp>). The estimated daily smolt collection efficiencies at LGD were provided by the Northwest Fisheries Science Center (Steve Smith, personal communication). Efficiencies were estimated using procedures detailed in Sandford and Smith (2002). Daily estimates were summed for the year. Because the daily efficiencies for 2002, 2003, and 2004 had been re-estimated, I recomputed smolt numbers for those years.

I used a BH function for the analysis. Previous work showed the BH function fit better than the Ricker function (Copeland et al. 2004). The number of females available for natural reproduction (FANR) for the brood years 1990-2003 and the number of smolts produced by brood years (BY) 1990-2002 had been previously estimated by Kiefer et al. (2004) and Copeland et al. (2004). To these data, I added the smolt estimate from the 2005 migration (BY 2003) and updated the smolt estimates for BY 2000, 2001, and 2002. The stock-recruit model was refit using the BH formula (Ricker 1975):

$$R = \frac{1}{\alpha + \beta / P}$$

where P = parent year spawning escapement (i.e. FANR), R = recruits (smolts) produced by parent year spawning escapement (P), and α and β are fitted parameters representing the slope at the origin and the asymptote. In this formulation, α is the inverse of asymptotic production and β is the inverse of slope at the origin (Quinn and Deriso 1999).

Model parameters were estimated in two ways. I fitted the model directly using iterative nonlinear regression (Gauss-Newton algorithm) and by using Paulik's transformation (Ricker 1975):

$$\frac{P}{R} = \beta + \alpha P$$

in which the dependent variable (P/R) is now a productivity rate. Following transformation, the model parameters were estimated using least squares linear regression.

The sensitivity analysis proceeded in two stages. The primary input variables were FANR and abundance of naturally produced smolts. I changed each input value $\pm 10\%$ for each variable in turn, while holding the other variable constant. The model was then refit using Paulik's transformation as above, and the new parameter estimates were calculated. The percentage changes to the parameter estimates (α and β) were computed. The second stage of the sensitivity analysis focused on the values that were used to estimate the model inputs: FANR and smolt abundance. The purpose of this stage was to consider likely biases that may occur to the input variables. To estimate FANR, five other values are required: number of adult Chinook salmon passing LGD, proportion of females, number of fish retained in hatcheries, harvest estimates from above LGD, and natural mortality between LGD and the spawning grounds (Kiefer et al. 2004). I changed each of these by $\pm 10\%$ in turn while holding the others constant, excepting hatchery take (i.e. I assumed hatchery take was known without error). The percentage change in FANR was recorded after each manipulation. For smolt abundance, I examined the likely influence of unmarked hatchery smolts on model output using migratory year 2003 as an example. A misclip rate of 3% is considered acceptable. A small number of supplementation fish are also released without adipose clips, so I considered that up to 5% of hatchery production was unmarked. I further assumed that survival of marked and unmarked hatchery fish was similar. To estimate the number of unmarked hatchery fish, I divided the number of hatchery smolts counted at LGD by 0.95 and subtracted the number of clipped smolts counted.

RESULTS

The estimated number of smolts exiting the system via LGD during migratory year 2005 was 1,828,522. This estimate covers the period March 26 to August 12, 2005. Copeland et al. (2004) previously estimated FANR for BY 2003 at 26,126, which includes hatchery strays. Applying this value to the estimated recruitment gave a productivity estimate of 70.0 smolts per female. This was the third lowest productivity since 1990 (Figure 6). There were changes in the estimated efficiency of the smolt bypass system at LGD for 2002, 2003, and 2004. The updated smolt estimates changed <0.3% from the previous estimates. The smolt estimate from MY 2005 completed the data for the 1990-2003 brood years (Table 6). The nonlinear model fit the data very well (Figure 7, $r^2 = 0.941$). The linear model gave an almost identical fit to the data ($r^2 = 0.939$), although the parameter estimates were slightly different (e.g., intrinsic productivities were 441.6 vs. 414.2 smolts/female; Table 7). The parameter estimates from the nonlinear fit were higher than were those from the linear fit. Note previous r^2 values (Copeland et al. 2004, 2005) for nonlinear estimates were corrected for values of the mean, whereas the values given in this report are raw r^2 , i.e. model sums of squares divided by total sums of squares. The latter value more accurately shows how much variation in the data was explained by the model.

The fitted stock-recruit relationship was influenced more broadly by changes to the smolt estimate than the FANR estimate (Figure 8). A 10% decrease to FANR caused an 11% increase in the estimated productivity but no changes to asymptotic production. The difference between the curves is greatest at an escapement of approximately 4,000 and would be around 44,000 smolts. A 10% decrease in smolt abundance caused a 10% decrease to both estimated productivity and asymptotic production. The difference between curves increased with FANR to 155,000 at the maximum observed FANR. The FANR estimate was most influenced by variables that determined the initial input of females into the system: the count at LGD and the sex ratio (Table 8). Sources of mortality (harvest and migratory losses) had less effect. To assess the likely effect of unclipped hatchery smolts on stock recruit parameter estimates, I used the 2003 migration data. Based on data from the Fish Passage Center, I estimated that 5,183,335 and 1,455,845 hatchery and natural smolts, respectively, passed LGD (assuming that the bypass system is as effective at collecting hatchery smolts as naturally produced fish). Assuming that only 95% of the hatchery fish are actually marked with an adipose clip, this means that 272,807 unmarked hatchery fish were counted as part of the natural production—18.7% of the total. If this percentage was relatively constant from BY 1990 to BY 2003, then this bias would result in a reduction in the productivity and asymptote estimates of equal magnitude.

DISCUSSION

The complete data set now includes 14 pairs of estimates. The 2005 smolt migration (2003) was the highest in the data series (Table 6). This was also the third highest FANR. Consequently, 2003 had the third lowest productivity (smolts/female), with the lowest productivities being produced by the two greater escapements. The updated daily collection efficiencies did not change smolt abundance greatly from estimates reported previously. The wide range in values allowed a very powerful analysis.

The models generated were very precise ($r^2 > 0.90$). The parameters estimated here have not changed greatly from previous versions. Asymptote estimates have increased slightly. The flattening on the right-hand side of the plot has become more pronounced with the last two

years. Productivity estimates from linear versus nonlinear fits have converged with the last few iterations going from 411.8 and 481.0 in Copeland et al. (2004) to 414.2 and 441.6 in this report.

Myers et al. (1999) found that maximum reproductive rates, the number of adult spawners produced per parental spawner per year at low density, of most fish species were almost always between 1 and 7, with chinook salmon being somewhat of an outlier at 7.32. They used data on adult spawners of both sexes and note that values for Columbia River populations appear to be much higher (but it is hard to estimate “natural” rates because of dam-induced mortality). If we assume that the smolt sex ratio is 1:1, then it would take an SAR of >3% to achieve the average adult productivity of the species for this stock. Median SAR (1998–2002 migratory years) is 1.90% (Part 2); therefore, SRSS Chinook salmon are not as resilient as the intrinsic smolt productivity given here might indicate. Bjornn (1990) estimated production rate of SRSS Chinook in the 1960s to be five adult recruits per parent (i.e. 10 per female) and that productivity declined by about 80% since the late 1970s through the mid 1980s. Bjornn (1990) further estimated that full seeding for spring Chinook in the Snake River basin was approximately 20,000 spawners (10,000 females). This spring escapement was exceeded by brood years 2001-2003 (see Kiefer et al. 2004 and Copeland et al. 2004), the years that show flattening in the stock recruit curve. I caution that this relationship (and Bjornn’s) should be interpreted cautiously with thought to the limited time period of the available data relative to the true potential productivity of this system (Lichatowich 1999). If Bjornn’s (1990) estimate is accurate, then perhaps reduced productivity resulted from impacts to summer-run populations and lost life history diversity (Lichatowich and Moberg 1995).

Previously, I proposed that the production by 2002 and 2003 would provide a valuable test of model predictions and utility (Copeland et al. 2004). The 2002 data point agreed very well (Copeland et al. 2005). The 2003 data point was outside the 90% prediction interval computed by Copeland et al. (2004; 42.7–68.6 smolts/female). The use of a more rigorous standard (i.e. the 95% interval) would give a wider prediction interval.

The shape of the stock-recruit model was robust to likely biases in the data. I focused on consistent errors for the sensitivity analysis and assumed that random error would increase only the variation about the fitted curve and not change its shape. The most influential potential bias was in smolt abundance and was almost certainly negative. The Fish Passage Center removes some unclipped hatchery smolts from their estimates by the use of a coded-wire tag detector at LGD (FPC 2004); this bias was probably not as great as I assumed in the sensitivity analysis. Bias in FANR was most likely via nonrepresentative sex ratios. Because these stocks are protected, it is not surprising that sources of mortality were not as important to FANR. Dam counts and hatchery take should be relatively precise and unbiased, given the intensive attention that goes into those efforts.

CONCLUSIONS AND RECOMMENDATIONS

In summary, the Beverton-Holt model described the data very well. Curve shape appeared robust and the parameter estimates reasonable. The estimated model should be refined as necessary. The best use of this information is as a starting point to generate plausible hypotheses regarding population regulation in this system. This work has been an exercise in inductive pattern description. To achieve understanding, a program of deductive hypothesis testing and mechanistic model building is necessary. With these points in mind, I will make two recommendations:

- 1) Examine selected data points for likely errors. The examination of data quality via the sensitivity analysis was rather coarse. Use standard regression diagnostics to identify influential data points and focus on these. Obtain information regarding misclip rates at hatcheries and the percentage of production that is marked with coded-wire tags. Recompute FANR estimates using the most recent escapement estimates. Incorporate a reasonable error structure into the model.
- 2) Develop a list of reasonable hypotheses for reductions in stock productivity. I have already thought of several (Table 9) but certainly have not exhausted all the plausible possibilities. These hypotheses and their predictions can be ranked based on an evaluation of the literature and extant data. Note that none of the hypotheses in Table 9 is mutually exclusive and may be interactive. Therefore, the relevant question is, "what is the likely magnitude of additive and multiplicative effects?" Given the nature of the question, the appropriate evaluation should be via model selection procedures (Burnham and Anderson 2002).

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Table 6. Abundance of females available for natural reproduction (FANR) and naturally-produced smolts by brood year.

Brood Year	FANR	Smolts
1990	4,976	527,000
1991	2,916	627,037
1992	6,826	627,942
1993	8,514	1,558,786
1994	1,043	419,826
1995	497	161,157
1996	1,556	599,159
1997	11,885	1,560,298
1998	3,726	1,344,382
1999	1,630	490,534
2000	8,733	1,128,539
2001	51,902	1,455,845
2002	31,415	1,501,322
2003	26,126	1,828,522

Table 7. Comparison of estimates of the parameters of the Beverton-Holt curves (intrinsic productivity and asymptotic production) from nonlinear and linear models fit with 1990-2003 data. The 95% confidence limits are in parentheses.

Model	Intrinsic Productivity	Asymptotic Production
Nonlinear	441.6 (263.3—1,369.0)	1,779,359 (1,390,821—2,475,248)
Inverse	414.2 (239.2—1,545.3)	1,666,667 (1,436,782—1,984,127)

Table 8. Percent change in number of females available for natural reproduction with a 10% change in the value of each input, as all other inputs are held constant.

Input Variable	Change to Input Variable	
	-10%	+10%
Dam count	-18.1%	+18.1%
Sex ratio	-18.1%	+18.1%
Harvest	+6.0%	-6.0%
Migration mortality	+7.4%	-9.0

Table 9. Candidate hypotheses explaining density dependence observed in smolt production of Snake River spring/summer Chinook salmon populations during 1990-2005.

Hypothesis	Explanation
Marine-derived nutrients	Lack of adult carcasses reduces carrying capacity of infertile spawning streams (Naiman et al. 2002).
Retreat to core areas	Current spawners home to relatively small patches of habitat (Thurow 2000; Isaak and Thurow 2006).
Invasion of predators and competitors	Introduced species and hatchery-produced fish compete with and prey on young salmon (Levin et al. 2002; Weber and Fausch 2003).
Hatchery strays	Hatchery strays are not effective spawners (Fleming and Gross 1993).
Habitat loss	Reduction of off-channel habitat in spawning and rearing areas (Pollock et al. 2004).
Temperature stress	Global warming and loss of tree cover via forest fires and grazing raise water temperatures at critical times (Flebbe 1997; Schoennagel et al. 2005).
Drought/low flows	High escapements are coincident with drought. Stream flow is critical to juvenile survival in the interior Columbia basin (Arthaud et al., in preparation).
Life history diversity	Loss of local adaptations and temporal variations in movement lead to a reduction in occupied habitat and regional productivity (Adkison 1995; Lichatowich and Mobrand 1995).

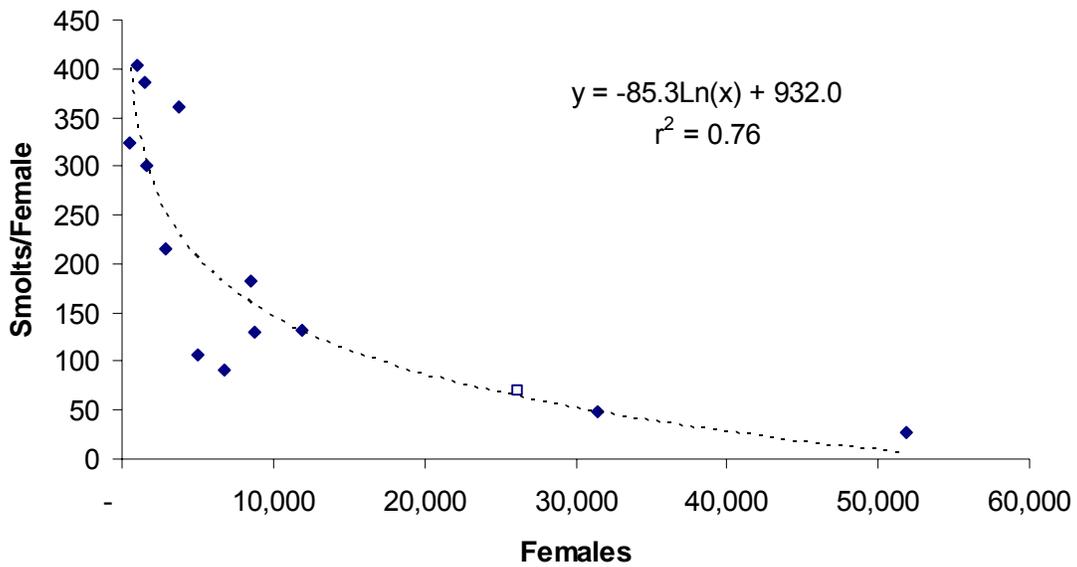


Figure 5. Observed productivity (smolts/female) plotted against abundance of parental females for the brood years 1990-2003. The 2003 point is hollow. The dotted line is fitted to the data.

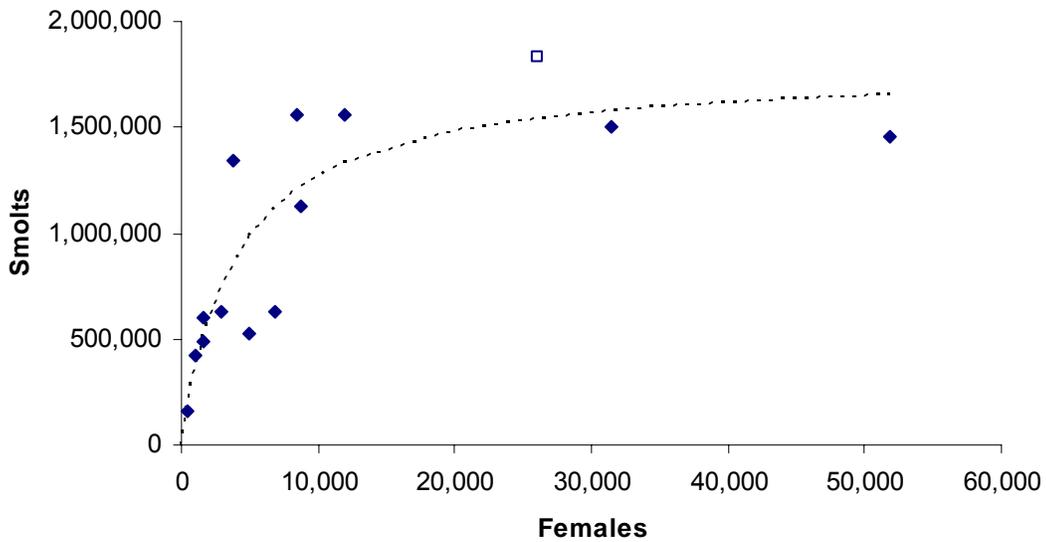


Figure 6. Number of smolts by parental female abundance for brood years 1990-2003. The dotted line is the Beverton-Holt function fit by a nonlinear algorithm. The 2003 point is hollow. See Table 7 for the parameter estimates.

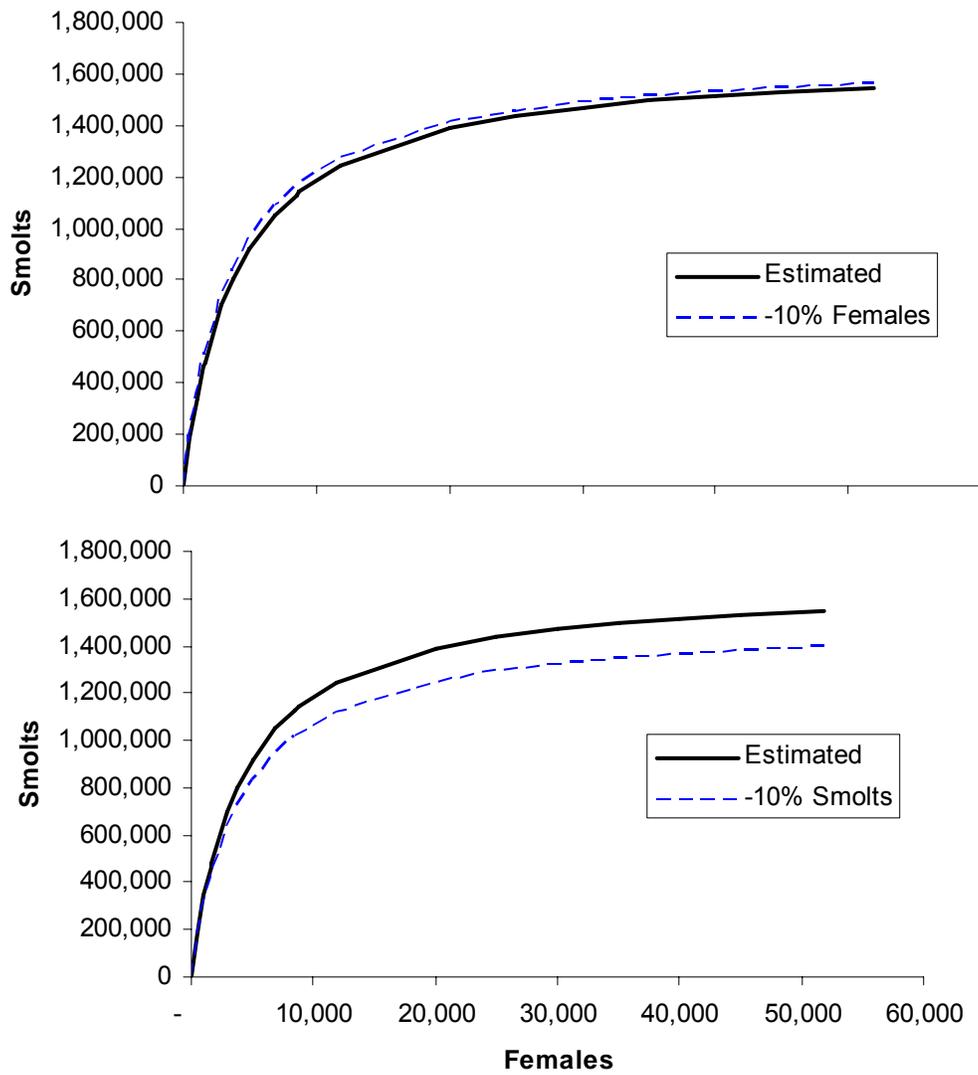


Figure 7. Results of the sensitivity analysis. The solid line is the Beverton-Holt curve fit from the observed data. The dashed line is the curve fit after one of the input variables was reduced by 10%.

**PART 4—IMPROVE THE PRECISION OF SMOLT-TO-ADULT SURVIVAL RATE ESTIMATES
FOR WILD STEELHEAD TROUT BY PIT TAGGING ADDITIONAL JUVENILES**

ABSTRACT

We placed 2,805 PIT tags in wild *Oncorhynchus mykiss* juveniles during summer 2005. The 2005 juvenile spring emigration from all populations sampled was unimodal in timing with a peak on May 5, although there were several subsidiary peaks. Overall detection rate in 2005 of fish tagged in 2004 was 18.2% but varied from 9.7% to 26.2% among populations. The proportion of fish tagged in 2003 that delayed emigration to 2005 also varied among populations (1.4%-45.0%). We hypothesized that migratory characteristics of a local population are the result of interactions between growth potential and the ease of movement to the migratory corridor. Several seasons of data have been collected at the current set of sites, allowing valid comparisons over time. We recommend this effort continue as part of Idaho Steelhead Monitoring and Evaluation Studies beginning in 2007. A summary will be prepared covering all Idaho Natural Production Monitoring and Evaluation Project steelhead tagging activities from 1998-2006 for the 2007 annual report.

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INTRODUCTION

Much research on protected anadromous salmonid stocks in the Columbia River basin has focused on downstream juvenile survival and smolt-to-adult return rates (SAR) (e.g., Raymond 1988). To facilitate this research, the National Marine Fisheries Service developed the passive integrated transponder (PIT) tag during the 1980s (Prentice et al. 1990a). These tags allow the individual identification of tagged fish as they migrate past the dams of the Columbia River hydrosystem without subsequent handling (Prentice et al. 1990b). Using this information, researchers can compute valid and reliable survival estimates for both juveniles and adults (Newman 1997; Skalski et al. 1998).

Fish passage downstream through a dam in the Columbia hydrosystem can be accomplished by several routes (Muir et al. 2001). Survival estimates must be calculated separately for each route. Subdividing detections by route has reduced sample size, thus decreasing the precision and usefulness of subsequent survival estimates. Hence, there is a need to increase the number of PIT-tagged smolts, especially for wild steelhead trout *Oncorhynchus mykiss* (Newman 1997).

Little specific information exists about the populations that comprise the Snake River stock (ICBTRT 2003). In Idaho, many of the spawning and rearing stream reaches for wild steelhead are in rugged and remote wilderness areas that must be sampled with light, mobile gear such as electrofishing or angling. Most headwater streams in Idaho are very infertile and have low conductivity, rendering electrofishing ineffective (Petrosky and Holubetz 1987). Previous work by project personnel has shown that hook-and-line sampling with artificial flies can be effective at collecting juvenile steelhead (R. Kiefer, Idaho Department of Fish and Game, personal communication).

In 1998, the Idaho Natural Production Monitoring and Evaluation Project (INPMEP) initiated efforts to increase the number of PIT-tagged steelhead smolts available to estimate downstream smolt survival and SAR. Our objectives in this report were two-fold: 1) to summarize the results of fieldwork in 2005 and 2) to update our previous detection estimates based on new detections made during the 2005 emigration.

METHODS

Fieldwork in 2005 was conducted in five streams: North Fork Moose Creek; Chamberlain Creek; Camas Creek and its major tributary, Yellowjacket Creek; and Lemhi River (Figure 9). These areas had high catch rates of young *O. mykiss* and detection rates >10% based on previous data (except Yellowjacket Creek and Lemhi River). All streams were believed to have minimal hatchery influence (except Lemhi River).

Wild steelhead trout juveniles were captured by angling with artificial flies during July and August 2005. Each angler carried a five-gallon bucket half filled with water to store captured fish temporarily while fishing. Water in the bucket was changed at least every 15-20 min when <10 fish were in the bucket and about every 10 min when >10 fish were in the bucket. Anglers transferred fish from buckets to submerged perforated plastic live-boxes (1.0 m x 0.5 m x 0.7 m) placed at approximately 1 km intervals throughout the stream.

We held captured fish in live-boxes overnight and tagged them the following morning. The delay allowed the fish to recover from collection stress and provided the coolest water temperatures for tagging. We anesthetized the fish and injected PIT tags into the body cavity using a 12-gauge hypodermic needle and modified syringe. Needles and PIT tags were sterilized by soaking them in a 70% alcohol solution for at least 10 min before tagging. Wild steelhead trout 65-249 mm FL were tagged while all others were released. Steelhead <65 mm FL were too small to tag. Wild steelhead trout >250 mm FL were most likely nonmigratory resident fish (Partridge 1985). After tagging, fish were returned to a live-box and allowed to recover at least 1 h before release. At the completion of fieldwork, project personnel uploaded PIT tag data to the Columbia River Basin PIT Tag Information System (PTAGIS).

Unique detection records from adult and juvenile detector sites in the Columbia River hydrosystem were obtained from the PTAGIS database (<http://www.psmfc.org/pittag/>) in October 2005. The PTAGIS reports provided information on tagging dates, capture method, FL at release, release site, interrogation site, and date detected. To maintain continuity with past reports, interrogation reports from the four main smolt collection facilities (LGD, Little Goose, Lower Monumental, and McNary dams) were used to determine detection rates for migratory year (MY) 2004.

To summarize fieldwork in 2005, we reported numbers tagged by stream. We also report the detections in MY 2005. The majority of these fish were tagged in 2004 but some were tagged during 2003 and 2002 in Bargamin Creek, Horse Creek, Middle Fork Salmon River, Rapid River, Sulphur Creek, and Whitebird Creek. Therefore, we updated all detection rates for populations previously sampled by this project. The detection rate for each stream was calculated by dividing the number detected by the total number of fish tagged in that stream in a particular year:

$$d_{ij} = \frac{\sum_{k=1}^3 D_{i,j+k}}{T_{ij}}$$

for stream i sampled in year j , where d is the detection rate, D is the number of fish detected in the hydrosystem in year $j+k$, and T is the number of fish tagged. We also presented data on population-specific arrival times into the hydrosystem during 2005. For each of these streams, the dates were calculated when the 10th, 50th, and 90th percentile of total PIT tag detections occurred.

RESULTS

A total of 2,805 PIT tags were placed in wild *O. mykiss* juveniles in 2005. The crew tagged 143 fish in the Lemhi River (mean fork length = 172 mm; Figure 10). In Chamberlain Creek, 1145 fish were tagged (mean fork length = 137 mm). There were 18 individuals previously tagged that were captured. There were 707 fish tagged in North Fork Moose Creek (mean fork length = 154 mm). Twenty-seven previously-tagged individuals were also captured. In Camas Creek, 413 individuals were tagged (mean fork length = 174 mm). Only seven were recaptures from previous work. Lastly, 397 fish from Yellowjacket Creek were tagged (mean fork length = 152 mm). Seventeen fish were recaptures.

During the spring of 2005, juvenile detections for INPMEP-tagged fish totaled 851. Overall detection rate in 2005 of fish tagged in 2004 was 18.7%. Some individuals detected in 2005 (32%) were tagged prior to 2004. Of these, nine were tagged in 2002 and 197 were tagged in 2003. We used the latter values to update detection rates we previously estimated (Table 10).

The 2005 juvenile migration was unimodal in timing, although there were several subsidiary peaks evident in the distribution (Figure 11). The major peak was May 5. The last minor peak was reached on May 23, after which emigrant numbers quickly dropped. Only four tagged individuals were detected after May 31. Median date of arrival at LGD varied among populations. The timing of individual populations was extremely consistent; median arrival dates ranged from May 4 to May 11 (Figure 12). Data for migrants from Brushy Fork, Whitebird Creek, and East Fork Salmon River are not presented because <10 detections were recorded. Using the difference between the 10th and 90th percentile dates as an index of migration period, population migration periods varied from 8 to 22 days. Migrants from Moose Creek had the earliest 10th percentile date, April 25. The latest 90th percentile date was for the Chamberlain Creek population (May 23).

DISCUSSION

Detection rates of steelhead juveniles tagged by this project have varied among populations. Overall detection rate during MY 2005 for fish tagged in 2004 (18.7%) was above average for this project (median = 15.4%, range = 11.9%-21.7% during MY 1999-2005). Migration in 2001 had a higher overall detection rate. However, not all populations have been sampled every year; therefore, annual changes in the aggregate detection rate could be confounded by population differences. For tagging conducted during the summer of 2004, the highest detection rate came from Camas Creek and the lowest from East Fork Salmon River. Comparing Camas, North Fork Moose, Chamberlain, and Yellowjacket creeks over the last three years, Camas consistently has the highest detection rate, whereas Chamberlain and Yellowjacket are the lowest. Note that detection rate is a function of the probabilities of survival and emigration, as well as the efficiency of the detection system at LGD. If one assumes that probability of detection at LGD is similar among populations for a specific migratory year, then population detection rate carries information regarding the juvenile life history of a particular population relative to the others. Unfortunately, the tendency of individuals to residualize and remain in their natal stream is confounded with their chances of surviving.

We detected a number of fish that held over past their anticipated migratory year (i.e. tagged in 2003 but migrated in 2005). These fish were a large proportion of the total detections from North Fork Moose Creek. Byrne (2005) found that steelhead populations in the Clearwater drainage tend to take longer to smolt than in the Salmon drainage. However, holdovers were a sizable minority of several populations in the Salmon drainage, particularly from areas high in the Middle Fork drainage. Incidence of holdovers on a population level was up for the 2005 migratory year, but a greater proportion of the total 2005 detections were holdovers (32%). That is because tagging efforts were scaled back last year (five populations sampled during 2004), but tagged fish were still emigrating from previously sampled populations (10 sampled during 2003).

Migration timing did not vary greatly among populations in 2005. Overall, the migration was temporally limited, because migration timing was very similar among populations, as it was in 2004 (see Copeland et al. 2005). Initiation of migration was earlier for North Fork Moose

Creek similar to our previous findings (Copeland et al. 2004, 2005), but other population differences were likely masked. Previously, a multimodal distribution was observed when several populations are considered together (e.g., Copeland et al. 2004; Mensik et al. undated). Presumably, the limited migration timing observed in 2005 was due to poor snowpack and low flows in early spring 2005.

It seems obvious that there are differences in how the populations function in terms of anadromy. Even adjacent reaches may have populations with widely varying characteristics, the best example being Camas and Yellowjacket creeks. The length frequency data presented here imply underlying differences in growth and age structure. We hypothesize that migratory characteristics of a local population are the result of interactions between growth potential and the ease of movement to the migratory corridor. This is an important aspect of biodiversity for these steelhead populations, and migration characteristics were identified by the ICBTRT (2003) as a data need.

RECOMMENDATIONS

The efforts by INPMEP personnel have resulted in information on previously unsampled steelhead populations, especially in the Salmon basin. These data provide a valuable complement to data from the Idaho Steelhead Monitoring and Evaluation Studies (ISMES), which has greater emphasis in the Clearwater basin. However, populations sampled by INPMEP changed frequently, which impaired the utility of the data. The currently sampled sites now have several seasons of data collected. We recommend this limited effort continue as part of ISMES beginning in 2007. For the next INPMEP annual report, a program summary will be prepared covering all INPMEP steelhead tagging activities from 1998-2006. Length data were not presented in previous reports; these data should be part of the summary.

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Table 10. Stream-specific detection rates (%) for steelhead parr tagged by this project during 2002—2004 and percent of fish tagged in 2003 that migrated in 2005 (holdovers). Italicized values for 2002 and 2003 were updated from those reported by Copeland et al. (2005).

Stream	Tagging Year			Holdovers (%)
	2002	2003	2004	
Bargamin Creek	11.7	<i>17.0</i>	^a	21.2
Camas Creek	23.7	<i>23.4</i>	26.2	5.0
Chamberlain Creek	17.3	<i>12.6</i>	12.7	8.8
EF Salmon River	^a	^a	9.7	na
Horse Creek	<i>17.6</i>	<i>15.9</i>	^a	12.8
MF Salmon River	<i>20.1</i>	<i>24.7</i>	^a	29.2
NF Moose Creek	16.1	<i>22.9</i>	24.8	22.9
Rapid River	^a	<i>20.2</i>	^a	20.9
Sulphur Creek	<i>21.0</i>	<i>22.1</i>	^a	45.0
Whitebird Creek	6.1	<i>4.2</i>	^a	1.4
Yellowjacket Creek	8.3	17.5	11.5	11.6

^a No tagging.

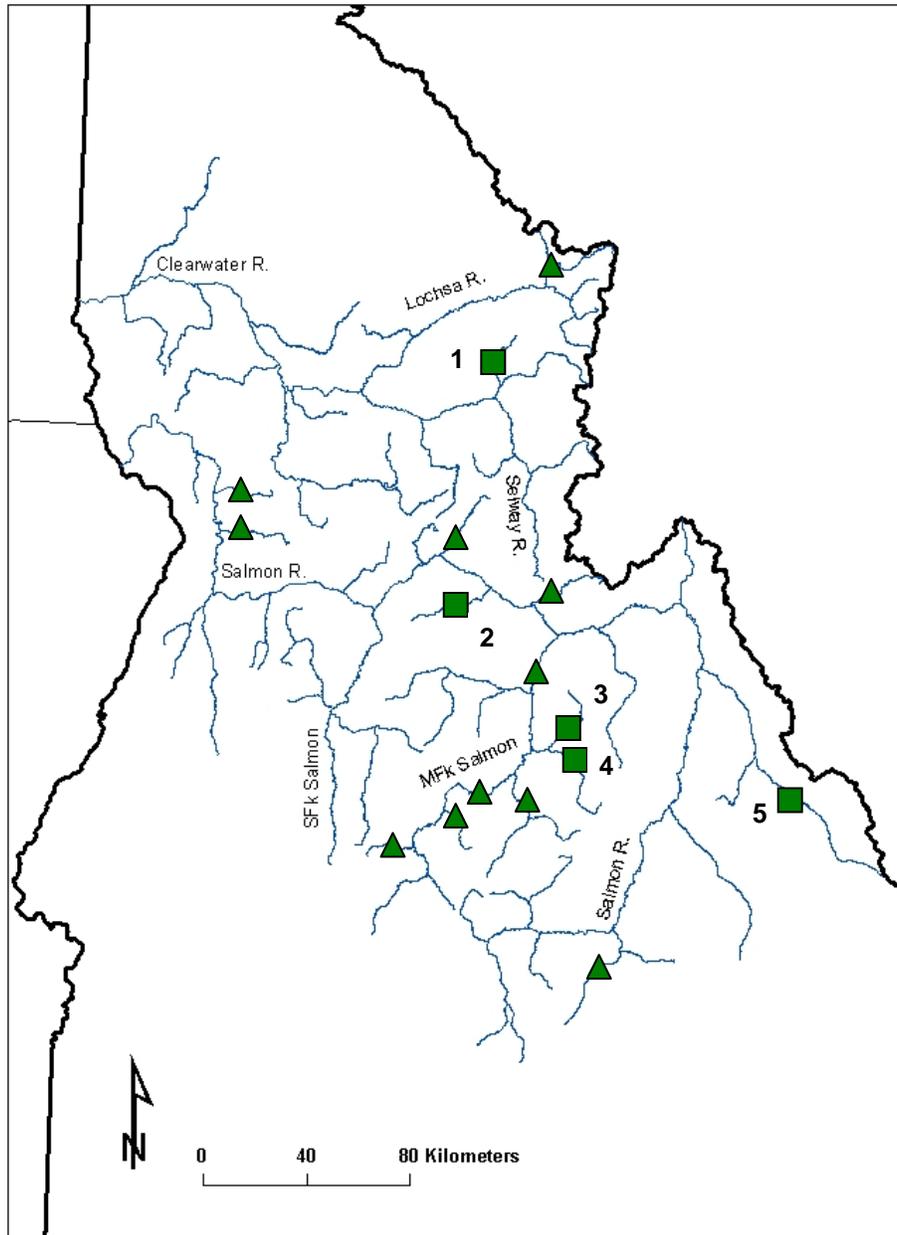


Figure 8. Locations where INPMEP personnel collected steelhead parr by angling in 2005 (squares; 1 = North Fork Moose Creek, 2 = Chamberlain Creek, 3 = Yellowjacket Creek, 4 = Camas Creek, 5 = Lemhi River). Previously sampled sites are represented by triangles.

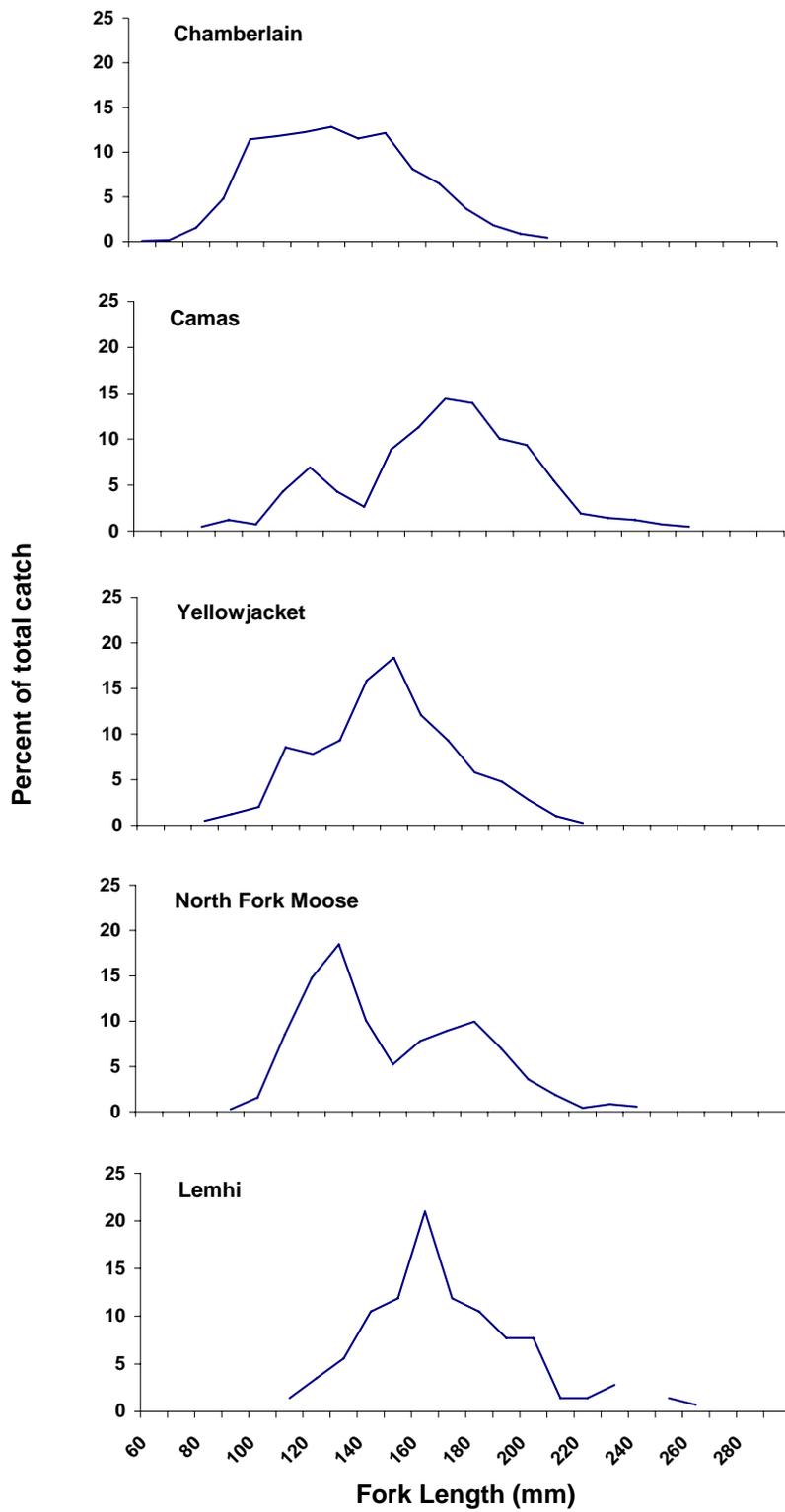


Figure 9. Length distribution of steelhead juveniles tagged during 2005 by population.

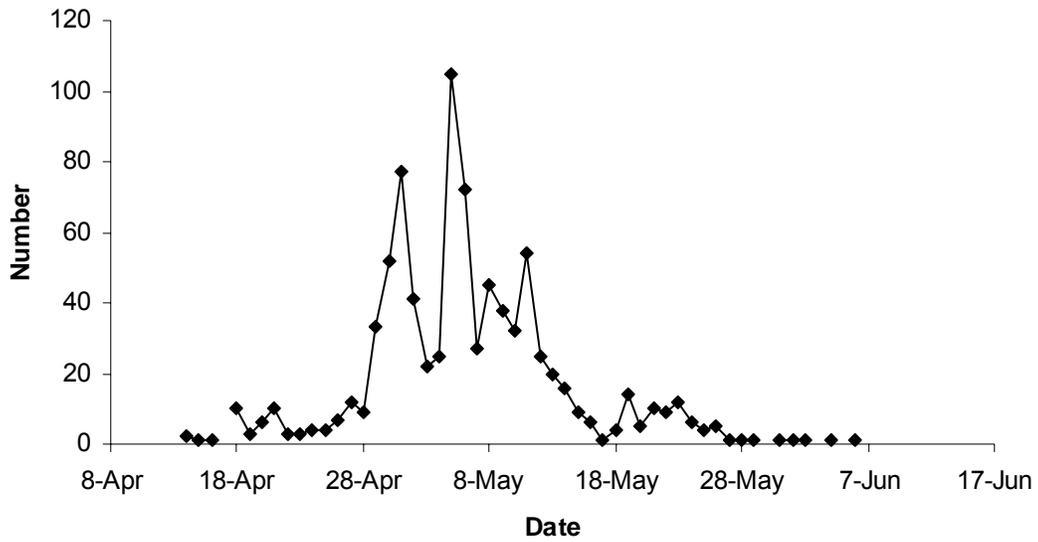


Figure 10. Date of arrival at Lower Granite Dam in 2005 of steelhead smolts tagged by project personnel.

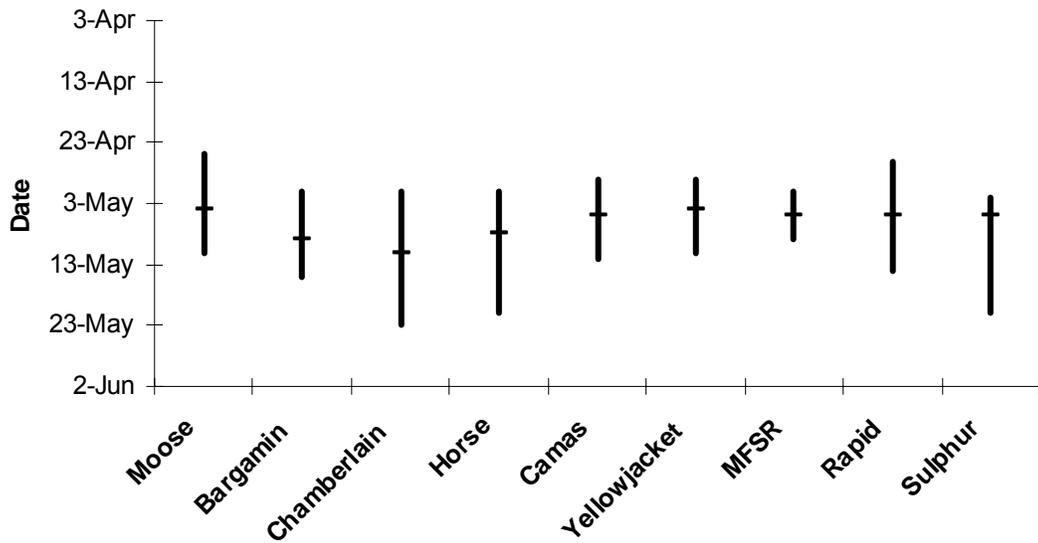


Figure 11. Population-specific arrival times at Lower Granite Dam in 2005. The vertical bar spans the 10th and 90th percentiles. The hash mark denotes the median arrival time. Streams are arranged from left to right by distance from Lower Granite Dam. MFSR°= Middle Fork Salmon River.

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