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**POST-RELEASE ATTRIBUTES AND SURVIVAL OF  
HATCHERY AND NATURAL FALL CHINOOK SALMON  
IN THE SNAKE RIVER**

Annual Report 1998



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ANNUAL REPORT 1998

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## EXECUTIVE SUMMARY

This report summarizes results of research activities conducted primarily in 1997 and 1998. The findings in these chapters represent the efforts of both this project and the collaboration between this project and other researchers working on fall chinook salmon. These chapters communicate significant findings that will aid in the management and recovery of fall chinook salmon in the Columbia River Basin.

Genetic analyses of juvenile chinook salmon PIT tagged in the Snake River in 1997 showed that 64% of fish recovered at Little Goose Dam were fall chinook salmon; the remaining 36% were spring/summer chinook salmon. A total of 639 fish were PIT tagged between 6 May and 15 July, and averaged 76 mm fork length. Of these fish, 122 (19.1%) were detected at Little Goose Dam. A total of 26 (4.1%) PIT-tagged fish residualized in reservoirs and emigrated in 1998 as yearlings. Survival for both subyearlings and yearlings combined was 39.3%.

Post-release attributes and survival were evaluated for yearling and subyearling hatchery supplementation releases made in the Snake River in 1997. Yearlings traveled rapidly to Lower Granite Dam after being released at Pittsburg Landing in April. Larger subyearlings traveled faster and arrived earlier at Lower Granite Dam than did smaller subyearlings. Growth was fastest, and change in condition factor was greatest, for smaller subyearlings than for larger subyearlings and yearlings. There was no significant relation between gill ATPase activity and subyearling travel time. Survival from release to Lower Granite Dam was highest for yearlings and larger subyearlings. Releasing a subyearling chinook salmon > 92 mm fork length earlier in the spring might reduce the difference in smolt-to-adult returns between subyearlings and yearlings documented in other studies.

We divided subyearling chinook salmon captured in the Snake River from 1995 to 1998 into three cohorts based on date of fry emergence, and then tested the relation between cohort survival and flow and temperature. Cohort 1 was generally PIT tagged in May and detected at Lower Granite Dam in July. Cohort 2 was tagged in May but passed Lower Granite Dam later in July. Cohort 3 was tagged in June and detected in August. Cohort survival ranged from 0.669 to 0.085, and was highest for cohort 1. Flow was positively related to survival while temperature

was negatively related to survival. Fish migrating under higher flows and cooler temperatures may experience less delay and predation. The change in life history timing caused by the construction of the Hells Canyon Complex of dams may be one factor that led to the decline of Snake River fall chinook salmon.

Point abundance electrofishing was used to determine use of different rearing habitats by fall chinook salmon in the free-flowing Snake River. Lateral gradient and water velocity were important variables determining fall chinook salmon use of rearing habitats. Substrate, embeddedness, and vegetation were less important. Using a statistical model developed from data from the Hanford Reach of the Columbia River, we were 90% accurate in predicting the presence of fall chinook salmon in the sites we sampled, but were only 13% accurate in predicting their absence. This may be due to the low numbers of fall chinook salmon in the Snake River. In general, use of rearing habitats by fall chinook salmon was similar between the Snake River and the Hanford Reach.

Temperature-sensing radio tags were used to determine the thermal history of juvenile fall chinook salmon migrating through Little Goose Reservoir in 1998. Laboratory tests confirmed that these tags would be suitable for use in Little Goose Reservoir. Thermal data was collected using fixed-site radio receivers and intensive mobile tracking, and water temperatures were measured using a bathythermograph. Fish were exposed to higher water temperatures as they migrated downstream through the reservoir, primarily in the top 10 m of the water column. Longitudinal temperature differences were greater than seasonal differences. Temperatures experienced by fish were similar to available water temperatures, and we found no evidence of thermal refugia in Little Goose Reservoir.

Morphology of juvenile salmon was studied to develop a tool to distinguish between subyearling fall chinook, subyearling spring chinook, and yearling spring chinook salmon at lower Snake River dams during the summer outmigration. Subyearling fall chinook salmon had smaller heads and eyes, deeper bodies, and shorter caudal peduncles than yearling spring chinook salmon. Subyearling spring chinook salmon exhibited both fall and yearling spring-like characteristics. Statistical analyses showed that morphological characteristics were not sufficient to classify groups of chinook salmon, therefore scale and genetic

analyses are the only means to definitively determine run composition of summer migrants in the lower Snake River.

The absolute and relative abundance, length at age, and diet composition of smallmouth bass, and the consumption of juvenile fall chinook salmon *Oncorhynchus tshawytscha* by smallmouth bass *Micropterus dolomieu* was estimated in the Hells Canyon Reach of the Snake River during 1996 and 1997. The absolute abundance of smallmouth bass  $\geq 175$  mm was 43,248 fish for the entire 109 km Hells Canyon Reach. The relative abundance of smallmouth bass 150-249 mm was significantly higher above (upstream section) the Salmon River confluence than below (downstream section) during 1996 and 1997, and the relative abundance of smallmouth bass  $\geq 250$  mm was greater upstream than downstream during 1996. There was no significant difference between relative abundance in the downstream and upstream sections for smallmouth bass  $\geq 250$  mm during 1997. Mean annual growth increments for 2 to 8-year-old smallmouth bass were 16 to 58 mm in the Snake River. Smallmouth bass consumed significantly more crayfish in the upstream section and significantly more fish in the downstream section. Fifty-two PIT-tagged fall chinook salmon were recovered in smallmouth bass stomach samples during 1996 and 1997, and 62% of these were collected within the 1 km of the release site at Pittsburg Landing, Idaho. Monthly consumption rates at the release site were highest (1.143 hatchery fall chinook/bass/day) using the Adams gastric evacuation model. The estimated consumption rates of juvenile fall chinook salmon using the Wisconsin bioenergetics model were lower than those from the Adams gastric evacuation model. A total loss of 9,282 PIT tagged hatchery fall chinook salmon and 5,102 wild fall chinook salmon to smallmouth bass during 1996 and 1997 was estimated using the Adams model. Using the Wisconsin bioenergetics model, a total loss of 2,112 PIT tagged hatchery fall chinook salmon and 1,326 wild fall chinook salmon to smallmouth bass was estimated during 1996 and 1997. It is speculated that high discharge, low water temperatures, and high turbidity during the residence time of juvenile fall chinook salmon in the Hells Canyon Reach of the Snake River explains the low occurrence of fall chinook salmon in the diets of smallmouth bass.

## ACKNOWLEDGEMENTS

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**CHAPTER ONE**

Report on Subyearling Chinook Salmon  
PIT Tagged in the Snake River, 1997

by

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## Introduction

Snake River fall chinook salmon *Oncorhynchus tshawytscha* have declined in abundance over the last three decades and were listed as threatened under the Endangered Species Act (USFWS 1988) in 1992 (NMFS 1992). Fishery managers are attempting to recover the Snake River fall chinook salmon population through summer flow augmentation and supplementation (NMFS 1995). The goal of our study is to provide fishery managers with data and analyses to assess early life history and survival for subyearling Snake River fall chinook salmon. These include run timing, race information, survival estimates, and the extent of residualism. This chapter is a brief summary of data collected during 1997.

## Study Area

The Snake River originates in Yellowstone Park, Wyoming and drains about 240,300 km<sup>2</sup>. It flows across southern Idaho and then in a northern direction forming the border between Idaho, Oregon, and Washington. We sampled subyearling chinook salmon in a 167 km free-flowing reach that is presently used for spawning and rearing downstream of Hells Canyon Dam (Figure 1). Lower Granite Dam is the first dam encountered by fish downstream of the Hells Canyon Reach, and has a fish bypass system equipped with a PIT-tag monitoring system (Prentice et al. 1990a). A subsample of subyearling chinook salmon passing Lower Granite Dam are routed through the fish bypass system where they are electronically scanned for Passive Integrated Transponders (PIT) tags (Prentice et al. 1990b) and then routed back to the river. Five of the seven dams downstream of Lower Granite Dam also have similar bypass systems.

## Methods

Natural subyearling fall chinook salmon were collected with a beach seine for PIT-tagging and survival studies in the Snake River (Connor et al. 1997). Seining sites were located between RK 357 and RK 227 (Figure 1). Seining was done weekly starting in April and continued until water temperatures reached 20°C or the catch neared zero. Natural chinook salmon were aged at capture based on fork length and PIT tagged if they were  $\geq 60$  mm

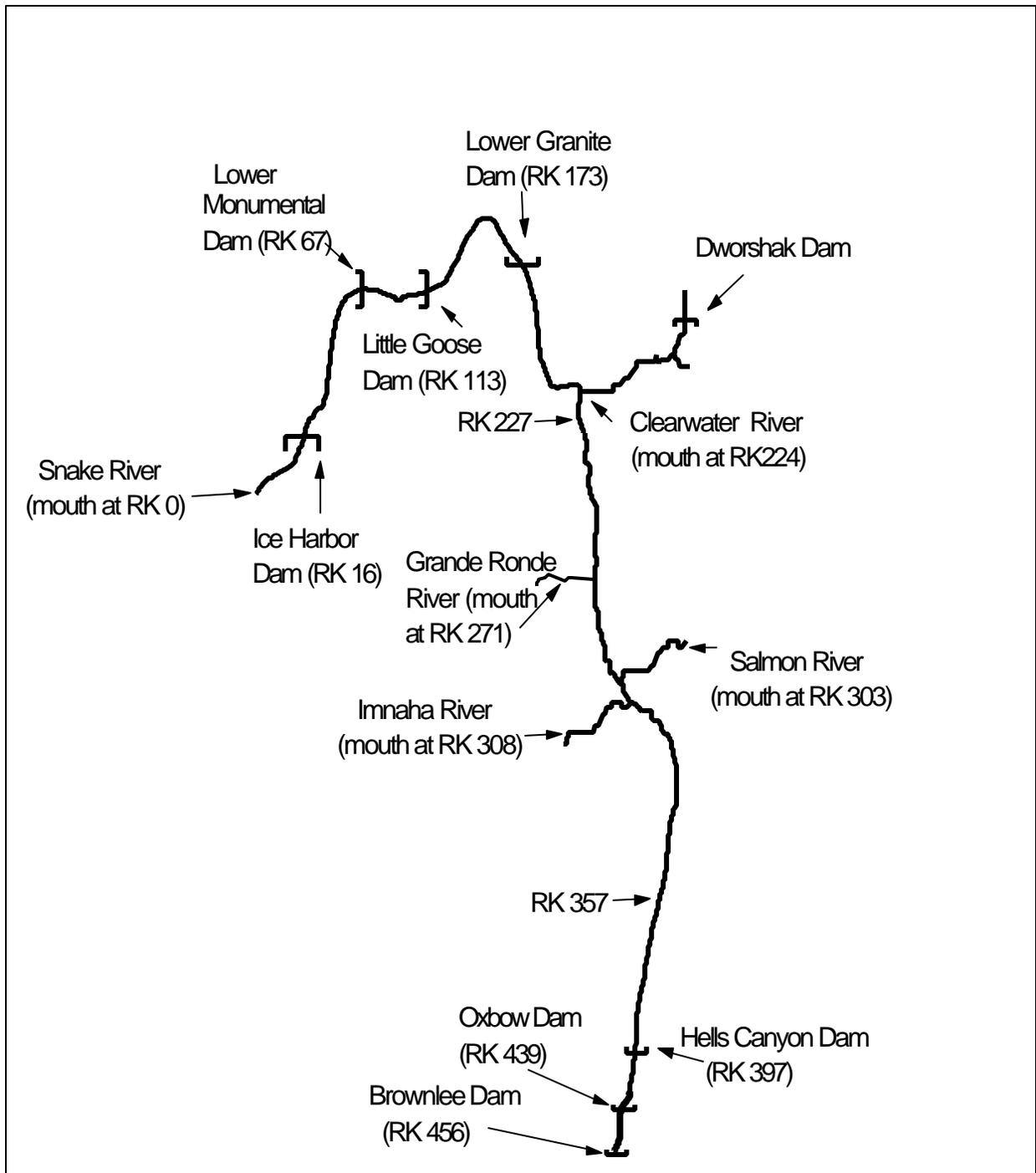


Figure 1. Snake River study area in 1997 including locations of the seining area (RK 357 to RK 227), major tributaries, and dams.

fork length. In-season assessment of fish race was done as described by Connor et al. (1997).

A subsample of PIT-tagged natural salmon was recaptured at Little Goose Dam (Figure 1) in 1997 using a separation-by-code hardware and software system (Downing et al. unpublished protocol, National Marine Fisheries Service). A scale was taken from each recaptured fish for aging (Jearld 1983) and the fish was frozen for subsequent race identification as described by Connor et al. (1997).

We used the single release version of the Cormack/Jolly-Seber survival probability model (Cormack 1964; Jolly 1965; Seber 1965; Burnham et al. 1987) to estimate survival to the tailrace of Lower Granite Dam for subyearling chinook salmon. This model was also used to estimate detection probability at Lower Granite Dam. We assumed that detection of a fish at a PIT-tag detection site did not affect the probability of its detection at downstream sites, or its survival to a downstream site. It was also assumed that the single release model accurately estimated sampling variability. Iwamoto et al. (1994) found that all of the above model assumptions were satisfied and precise survival estimates were obtained for PIT-tagged hatchery reared yearling spring chinook salmon. We also made a general assessment of the effects of residualism on the survival probability estimates. This was done by treating each residual (i.e., a fish released in 1997 that was detected in 1998) as if it was detected and removed from the river at Lower Granite Dam in 1997. This provided an estimate of survival, but not an estimate of detection probability.

## **Results and Discussion**

Subyearling fall chinook salmon composed 64% of the PIT-tagged natural fish recaptured at Little Goose Dam in 1997 (Table 1). This indicates that a large percentage (i.e., 36%) of the subyearlings we PIT tagged in 1997 were spring/summer chinook salmon. One of these spring/summer chinook salmon was a yearling, while the remainder was subyearlings. There is no proven method for identifying the race of tagged fish that were not recaptured at Little Goose Dam. Consequently, in the following results, we make no further reference to subyearling chinook salmon race. All fish are simply referred to as subyearlings.

Table 1. **C**Number of PIT-tagged natural subyearling chinook salmon detected and recaptured at Little Goose Dam in 1997. The percentage of subyearlings (0) and yearlings (1) determined by aging, and the percentage of fall chinook salmon versus spring/summer chinook salmon determined by genetic analyses, are also given.

Number detected	Number recaptured	Recaptured fish			
		Age(%)		Race(%)	
		0	1	Fall	Spring/summer
101	75	98.7	1.3	64.0	36.0

We Pit tagged 639 subyearling chinook salmon in 1997 between 6 May and July 15 (Table 2). The average fork length of PIT-tagged subyearling chinook salmon was 76 mm. Water temperature during tagging averaged 15.4°C. A total of 122 (19.1% of all fish tagged) PIT-tagged fish were detected at Lower Granite Dam between 4 June and 13 October (Table 3). The peak date of detection was 2 July.

A total of 26 (4.1% of all fish tagged) of the subyearling chinook salmon that were PIT tagged in the Snake River in 1997 residualized in reservoirs in the Snake or Columbia rivers and survived to be detected migrating seaward as yearlings in 1998 (Table 4). Survival of PIT-tagged subyearling chinook salmon from release to the tailrace of Lower Granite Dam was 35.2% in 1997 (Table 5). Adding the 26 detections that were made for yearling emigrants increased the survival estimate to 39.3%.

The data presented in this chapter increases the information on emigration timing and survival for subyearling chinook salmon produced naturally in the Snake River. This information was provided to, and used by, fishery managers to help them make flow decisions in 1997. In addition, it has been relied upon by the Plan for Analyzing and Testing Hypotheses (PATH) workgroup for their decision analysis report on Snake River fall chinook salmon.

Table 2. **C**Number of natural subyearling chinook salmon that were PIT tagged and released in the Snake River in 1997, and the mean fork length (mm+SE) and mean water temperature when the fish were tagged (°C+SE).

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Number	Range of release dates	Mean fork length (mm+SE)	Mean water temperature (°C+SE)
639	6 May to 15 July	76+0.44	15.4+0.07

---

Table 3. **C**Number and dates of detection at Lower Granite Dam for PIT-tagged natural subyearling chinook salmon that were released in the Snake River in 1997.

---

Number detected	Percent detected	Peak date of detection	Range of detection dates
122	19.1	2 July	4 June to 13 October

---

Table 4. **C**Number of first detections by dam for natural subyearling chinook salmon that were PIT tagged in the Snake River as subyearlings in 1997, and detected in 1998 after overwintering in Snake or Columbia river reservoirs. Abbreviations: no. = number; % = number of detections/number of fish tagged.

Lower Granite		Little Goose		Lower Monumental		McNary		Total	
no.	%	no.	%	no.	%	no.	%	no.	%
12	1.9	3	0.5	4	0.6	7	1.1	26	4.1

Table 5. **C**Detection and survival probability estimates at Lower Granite Dam for groups of PIT-tagged natural subyearling chinook salmon released in the Snake River in 1997. Detection probability is a measure of fish guidance efficiency at Lower Granite Dam and survival probabilities are estimates of survival from release to the tailrace of the dam.

Group	Probability estimates	
	Detection (+SE)	Survival (+SE)
Subyearling emigrants	0.521 $\pm$ 0.042	0.352 $\pm$ 0.030
Subyearling and yearling emigrants	NA	0.393 $\pm$ 0.030

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**CHAPTER TWO**

Post-Release Attributes and Survival of Lyons Ferry  
Hatchery Fall Chinook Salmon Released in the Snake River  
at Pittsburg Landing, 1997

by

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## Introduction

Snake River fall chinook salmon *Oncorhynchus tshawytscha* were listed as threatened under the Endangered Species Act (ESA; United States Fish and Wildlife Service 1988) in 1992 (National Marine Fisheries Service 1992). Supplementation of natural stock with hatchery fish was proposed as an interim recovery measure for the Snake River stock (Bevan et al. 1994; NMFS 1995). Supplementation has been defined by a number of researchers and varies by the situation under study (Miller et al. 1990; Steward and Bjornn 1990). As an interim recovery measure for Snake River fall chinook salmon, supplementation consists of releasing yearling and subyearling fall chinook salmon reared at Lyons Ferry Hatchery to artificially increase the abundance of fish in the free-flowing Snake River. Such releases were made in 1997 at Pittsburg Landing on the Snake River. The objective of this chapter is to summarize post-release attributes including dispersal, growth rate, condition factor, level of smoltification (i.e., ATPase activity), and survival of seaward emigrants past Lower Granite Dam.

## Study Area

The Snake River originates in Yellowstone Park, Wyoming and drains about 240,300 km<sup>2</sup>. It flows across southern Idaho and then in a northern direction forming the border between Idaho, Oregon, and Washington. Pittsburg Landing (river km (RK) 346; Figure 1) is a remote campground and boat launch administered by the U.S. Forest Service in Hells Canyon National Recreation Area. The U.S. Army Corps of Engineers built a temporary facility at this site to acclimate fish prior to release. In 1997, the acclimation facility consisted of 15 fish tanks divided into four groups of four (i.e., four-tank clusters), however, one cluster only contained three tanks. Each tank was 6 m in diameter and 5 m deep and supplied with river water passed through stacked columns to maintain dissolved gas concentration in a suitable range. A detailed description of the acclimation facility is given by Key et al. (1999).

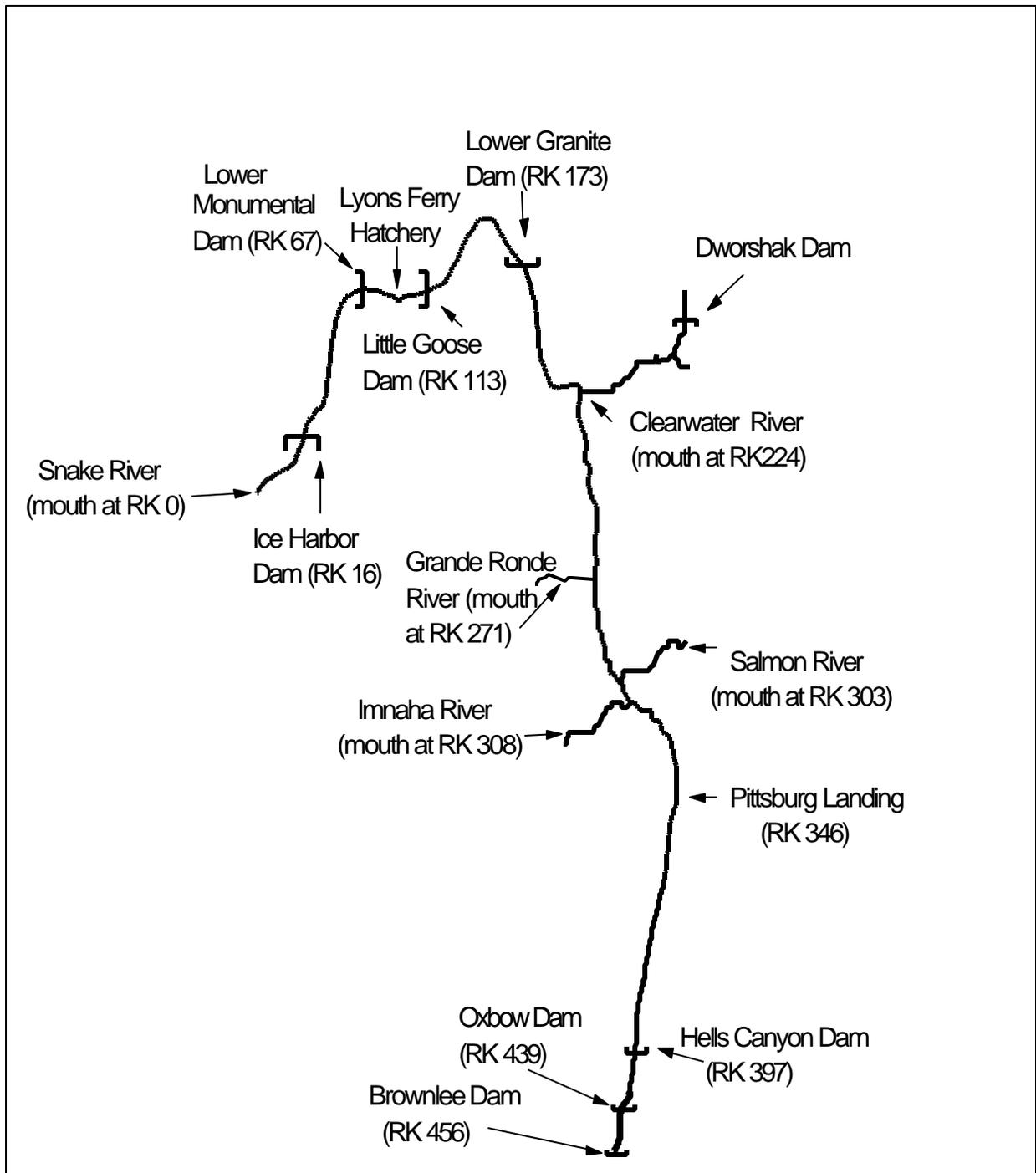


Figure 1. Snake River study area including the location of Pittsburg Landing, major tributaries, and dams.

## Methods

### *Pre-release Data Collection*

Transport and culture practices prior to release of hatchery yearling fall chinook salmon in the Snake River are described in detail by Key et al. (1999). In 1997, approximately 150,000 Lyons Ferry Hatchery yearling fall chinook salmon were tagged with coded-wire and green elastomer tags, and adipose fin-clipped prior to transport to Pittsburg Landing. Transport of fish to Pittsburg Landing began on 28 February and ended 6 March, 1997. Each of the 15 tanks contained about 10,000 fish.

One tank was selected to represent each tank cluster in 1997. Seven days prior to release, Passive Integrated Transponders (PIT tags; Prentice et al. 1990a) were placed in 2,468, 2,500, 2,495, and 2,498 randomly collected yearlings from each of the four representative tanks. Yearlings were not fed for 24 h prior to being tagged. Yearlings were tagged between 7 and 10 April. Fork length was measured to the nearest millimeter for every yearling that was PIT tagged and 10% of each release group was weighed to 0.1 g. Condition factor ( $K$ ) was calculated as  $\text{weight}/\text{length}^3 \times 10^5$  (Piper et al. 1982). Yearlings were acclimated for about 6 weeks.

Yearling fall chinook salmon were released from 14 to 17 April in 1997. All yearlings in each tank cluster were released on a separate day at dusk. A total of 10 non-lethal gill ATPase samples (Schrock et al. 1994) were collected from yearlings of each release group the week of release. The vials containing gill clips were damaged during transport and only 4 to 9 of samples were analyzed per release group. The acclimation tanks were checked daily for mortalities; mortality usually occurred within 24 h after tagging.

Subyearling chinook salmon were reared at Lyons Ferry Hatchery to provide four release groups of three different fork length treatments (i.e., means =  $92 \pm 0.71$  mm,  $85 \pm 0.48$  mm,  $71 \pm 0.00$  mm). Size was controlled by the hatchery manager through feeding rate. Prior to tagging subyearlings were graded to avoid tagging fish < 65 mm fork length. Some fish < 65 mm were incidentally tagged as a result of the tagging rate required to mark 5,500 fish per day. These fish were excluded from

subsequent results and analysis to avoid bias associated with tagging mortality.

Subyearlings were not fed for 24 h prior to being tagged. On each of four days (June 11-14), about 2,500 fish of each fork length treatment were measured to the nearest millimeter and 10% were weighed. Every fish was then PIT tagged and mixed evenly between two trucks. Subyearlings were transported to Pittsburg Landing, acclimated to ambient river temperature, and released at dusk.

A total of 25 non-lethal gill ATPase samples were collected from subyearlings from each release group on each day of release, and 19 to 25 of these were successfully analyzed. Pre-release mortality was high (7.0%) for the first release group of 71-mm subyearlings because the taggers did not adjust their rate of tagging, and tag placement to account for small fish size. The tagging procedure was modified after the first release group and the mortality due to tagging decreased to low levels thereafter. To avoid bias in the results caused by poor tagging protocol, the first release group of 71-mm subyearlings was omitted from all analyses of post-release attributes.

#### *Analysis of Post-release Attributes*

Hatchery yearling and subyearling fall chinook salmon that were guided into the fish bypass systems by submersible traveling screens at Lower Granite, Little Goose, Lower Monumental, and McNary dams were monitored for PIT tags (Prentice et al 1990b). Subsamples of PIT-tagged yearlings and subyearlings were recaptured at Little Goose Dam using a separation-by-code system (Downing et al. unpublished protocol, National Marine Fisheries Service). Fork lengths and weights were measured on all tagged fish that were recaptured at Little Goose Dam, and non-lethal ATPase samples were collected from up to 20 tagged fish per release. All fish recaptured at Little Goose dam were transported and released below Bonneville Dam by barge or truck.

Information from PIT-tagged hatchery yearling and subyearling fall chinook salmon recaptured at Little Goose Dam was tabulated by release group. Information included median recovery date, mean fork length, mean growth rate, mean condition factor  $K$ , and mean ATPase activity. Changes in mean  $K$  ( $\Delta K$ ) and mean ATPase activity ( $\Delta \text{ATPase}$ ) were calculated for each

release group by subtracting mean  $K$  or mean ATPase activity at release from mean  $K$  or mean ATPase activity at recapture.

The single release version of the Cormack/Jolly-Seber survival probability model (Cormack 1964; Jolly 1965; Seber 1965; Burnham et al. 1987) was used to estimate survivals to the tailrace of Lower Granite Dam for PIT-tagged hatchery yearling and subyearling fall chinook salmon. It was assumed that a detection of a fish at a PIT-tag detection site did not affect the probability of its detection at downstream sites, or its survival to a downstream site. It was also assumed that the single release model accurately estimated sampling variability. Iwamoto et al. (1994) found that all of the above model assumptions were satisfied and precise survival estimates were obtained for PIT-tagged hatchery reared yearling spring chinook salmon.

Various relations between independent and dependent variables were tested using simple least-squares regression (SYSTAT 1994). Analysis of variance (ANOVA) was also used to test for differences in means for various variables.

## Results

Mean fork length of tagged yearlings for release groups ranged from 149 mm to 158 mm (mean = 155 mm),  $K$  was 1.1 for all four groups, ATPase activity averaged 24.1, and mortality ranged from 0.2 to 0.9% (Table 1). Mean fork lengths of tagged subyearlings were similar between release groups for each size treatment (Table 2). The  $K$  values for 92-mm, 85-mm, and 71-mm subyearlings ranged from 1.1 to 1.3. ATPase activity for the release groups ranged from 17.2 to 34.8, and mortality ranged from 0.0 to 7.0% (Table 2). After omitting release 1 of 71-mm subyearlings from analyses, there was no significant relation between fork length and pre-release mortality ( $N = 15$ ;  $r^2 = 0.111$ ;  $P = 0.225$ ).

Post-release dispersal through the free-flowing Snake River and Lower Granite Reservoir was similar within release groups of yearlings, and within release groups of fork length treatments for subyearlings (Table 3). However, there were marked differences between yearlings and subyearlings, and between subyearlings of different fork lengths (Table 3). Yearlings

Table 1. **C**Information for Lyons Ferry Hatchery yearling fall chinook salmon that were acclimated, PIT tagged, and released at Pittsburg Landing on the Snake River in 1997. ATPase activity is expressed as  $\mu\text{mol Pi} \cdot (\text{mg protein})^{-1} \cdot \text{h}^{-1}$ .

Release group	Number tagged	Date of tagging	Mean fork length (mm $\pm$ SE)	Mean K ( $\pm$ SE)	Weeks acclimated	Release date	ATPase ( $\pm$ SE)	Pre-release mortality (%)
1	2,468	7 April	149 $\pm$ 1.21	1.1 $\pm$ 0.01	6.4	14 April	25.1 $\pm$ 2.25	0.9%
2	2,500	8 April	157 $\pm$ 0.34	1.1 $\pm$ 0.01	5.7	15 April	25.0 $\pm$ 3.42	0.4%
3	2,495	9 April	155 $\pm$ 0.35	1.1 $\pm$ 0.01	5.9	16 April	24.3 $\pm$ 1.57	0.3%
4	2,498	10 April	158 $\pm$ 0.35	1.1 $\pm$ 0.01	6.0	17 April	22.0 $\pm$ 0.76	0.2%

Table 2. **C**Information for subyearling fall chinook salmon that were PIT tagged at Lyons Ferry Hatchery and then trucked for release at Pittsburg Landing on the Snake River in 1997. ATPase activity is expressed as  $\mu\text{mol Pi} \cdot (\text{mg protein})^{-1} \cdot \text{h}^{-1}$ .

Release group	Number tagged	Date of release	Mean fork length (mm+SE)	Mean K (+SE)	Mean ATPase (+SE)	Pre-release mortality (%)
1	505	11 June	92+0.35	1.3+0.02	20.2+1.60	0.9
2	501	12 June	94+0.32	1.2+0.02	17.2+1.39	0.4
3	499	13 June	91+0.35	1.2+0.02	17.2+1.22	0.6
4	505	14 June	91+0.35	1.2+0.02	19.6+1.88	0.8
1	2,485	11 June	85+0.16	1.1+0.01	34.7+3.01	1.0
2	2,500	12 June	86+0.15	1.1+0.01	34.8+2.82	0.2
3	2,496	13 June	86+0.14	1.1+0.01	34.3+2.16	0.6
4	2,471	14 June	84+0.17	1.1+0.01	29.2+2.67	1.6
1	2,184	11 June	71+0.10	1.1+0.01	20.3+1.79	7.0
2	2,322	12 June	71+0.09	1.1+0.01	21.8+1.43	1.2
3	2,262	13 June	71+0.09	1.1+0.01	24.7+2.25	0.9
4	2,184	14 June	71+0.09	1.1+0.01	19.2+2.02	0.0

Table 3. Median dates of passage at Lower Granite Dam, and median travel times for PIT-tagged Lyons Ferry Hatchery yearling and subyearling fall chinook salmon released at Pittsburg Landing on the Snake River in 1997.

Release group	Number detected	Median date of passage (d)	Median travel time (d)
Yearlings (mean fork length at release = 155 $\pm$ 2.10 mm)			
1	756	21 April	7
2	819	21 April	6
3	662	22 April	6
4	844	22 April	5
Subyearlings (mean fork length at release = 92 $\pm$ 0.71 mm)			
1	146	5 July	24
2	152	9 July	27
3	150	10 July	26
4	162	9 July	25
Subyearlings (mean fork length at release = 85 $\pm$ 0.48 mm)			
1	723	12 July	31
2	735	13 July	31
3	760	16 July	32
4	739	17 July	33
Subyearlings (mean fork length at release = 71 $\pm$ 0.00 mm)			
2	488	5 August	53
3	466	9 August	57
4	479	6 August	53

traveled rapidly to Lower Granite Dam after being released at Pittsburg Landing. The early passage date at Lower Granite Dam for yearlings was expected since they were released earlier than subyearlings. The median date of passage for larger subyearlings was earlier than for smaller subyearlings (Table 3). There was a significant positive relation between fork length at release and travel time for subyearlings ( $N = 11$ ;  $r^2 = 0.96$ ;  $P < 0.01$ ).

Post-release growth,  $K$ , and  $\hat{K}$  were similar within release groups of yearlings, and within release groups of subyearlings of the same fork length (Table 4). However, there were marked differences in these same attributes between yearlings and subyearlings, and among subyearlings of different fork lengths (Table 4). Yearlings had the slowest growth rate between release and recapture at Little Goose Dam. Growth rate for subyearlings was slower for larger subyearlings than for smaller subyearlings, and there was a significant negative relation between travel time and growth rate ( $N = 11$ ;  $r^2 = 0.81$ ;  $P < 0.01$ ). Larger fish were more active emigrants and spent less time rearing and feeding than smaller fish. The change in  $K$  was largest for 71-mm subyearling release groups. The  $K$  values for the four release groups of 71-mm subyearlings increased, while there was little change in  $K$  for 92- and 85-mm fish (Table 4). Again, this is probably related to differences in the migratory, rearing, and feeding behavior among the three fork length treatments of subyearlings.

ATPase activity of yearlings increased between release and recapture (range of increase: 2.2 to 8.6; Table 4). ATPase activity changes were both negative and positive, and generally the smallest, for 92-mm subyearlings. ATPase activities for 85-mm subyearlings were highest at recapture (mean: 47.1), and showed the greatest increase (range of increase: 10.0 to 18.0; Table 4). The 71-mm subyearlings had the lowest mean ATPase activities, and an increase intermediate to the other size groups. There were significant differences (ANOVA;  $N = 9$ ;  $P < 0.01$ ) among the means of the 92-mm ( $n = 3$ ; mean = 34.3), 85-mm ( $n = 3$ ; mean = 47.1), and 71-mm ( $n = 3$ ; mean = 30) subyearlings, but the correlation between fork length and ATPase was weak ( $N = 9$ ;  $r = 0.44$ ). The relation between ATPase activity (Table 4) and travel time (Table 3) for subyearlings was insignificant ( $N = 9$ ;  $r^2 = 0.30$ ;  $P = 0.125$ ).

Table 4. **C**Information for PIT-tagged Lyons Ferry Hatchery yearling and subyearling fall chinook that were recaptured at Little Goose Dam in 1997. ATPase activity is expressed in  $\mu\text{mol Pi} \cdot (\text{mg protein})^{-1} \cdot \text{h}^{-1}$ .

Release group	N	Mean FL (mm $\pm$ SE)	Mean growth (mm/d $\pm$ SE)	Mean K ( $\pm$ SE)	Mean ATPase ( $\pm$ SE)	$\Delta K$	$\Delta$ ATPase
Yearlings (mean fork length at release = 155 $\pm$ 2.10 mm)							
1	37	168 $\pm$ 1.9	0.2 $\pm$ 0.03	1.0 $\pm$ 0.01	24.4 $\pm$ 2.0	-0.1	+4.2
2	35	174 $\pm$ 3.4	0.2 $\pm$ 0.03	1.0 $\pm$ 0.01	25.8 $\pm$ 2.5	-0.1	+8.6
3	40	166 $\pm$ 1.7	0.3 $\pm$ 0.03	1.0 $\pm$ 0.01	23.5 $\pm$ 2.3	-0.1	+6.3
4	42	165 $\pm$ 2.1	0.3 $\pm$ 0.03	1.0 $\pm$ 0.01	21.8 $\pm$ 2.1	-0.1	+2.2
Subyearlings (mean fork length at release = 92 $\pm$ 0.71 mm)							
1	31	121 $\pm$ 1.4	1.0 $\pm$ 0.04	1.1 $\pm$ 0.02	-----	-0.2	----
2	29	123 $\pm$ 1.3	1.1 $\pm$ 0.03	1.2 $\pm$ 0.02	34.8 $\pm$ 2.5	0.0	+0.1
3	32	121 $\pm$ 1.0	1.1 $\pm$ 0.04	1.1 $\pm$ 0.02	34.2 $\pm$ 5.5	-0.1	-0.6
4	28	123 $\pm$ 1.4	1.1 $\pm$ 0.04	1.2 $\pm$ 0.02	33.8 $\pm$ 3.0	0.0	+4.6
Subyearlings (mean fork length at release = 85 $\pm$ 0.48 mm)							
1	32	119 $\pm$ 1.2	1.1 $\pm$ 0.05	1.1 $\pm$ 0.01	49.3 $\pm$ 12.1	0.0	+14.6
2	33	121 $\pm$ 2.4	1.2 $\pm$ 0.05	1.1 $\pm$ 0.02	52.8 $\pm$ 16.2	0.0	+18.0
3	32	118 $\pm$ 1.6	1.2 $\pm$ 0.05	1.1 $\pm$ 0.02	-----	0.0	----
4	30	123 $\pm$ 2.1	1.3 $\pm$ 0.04	1.2 $\pm$ 0.02	39.17 $\pm$ 3.0	+0.1	+10.0
Subyearlings (mean fork length at release = 71 $\pm$ 0.00 mm)							
2	39	135 $\pm$ 2.3	1.4 $\pm$ 0.03	1.2 $\pm$ 0.01	28.4 $\pm$ 2.0	+0.1	+6.6
3	32	144 $\pm$ 4.0	1.4 $\pm$ 0.04	1.3 $\pm$ 0.02	27.6 $\pm$ 2.2	+0.2	+2.9
4	41	132 $\pm$ 2.6	1.3 $\pm$ 0.05	1.3 $\pm$ 0.02	30.9 $\pm$ 1.8	+0.2	+11.7

Survival probability estimates for PIT-tagged hatchery fall chinook salmon to the tailrace of Lower Granite Dam were similar within release groups of yearlings, and within release groups of subyearlings of the same fork length (Table 5). Yearlings survived at the highest rate. There was a significant positive relation between fork length and survival for subyearlings ( $N = 11$ ;  $r^2 = 0.98$ ;  $P < 0.01$ ; Table 5). Plotting survival probability against fork length of all release groups of yearlings and subyearlings suggests that the relation between hatchery fall chinook salmon fork length and survival may be asymptotic (Figure 2).

### **Discussion**

Supplementing the natural population with hatchery fish is one interim measure currently being used to assist in the recovery of the Snake River fall chinook salmon population. Supplementation was advocated by the Snake River Salmon Recovery Team (Bevan et al. 1994) and NMFS (1995). The Recovery Team and NMFS recommended outplanting Lyons Ferry Hatchery subyearling fall chinook salmon to mimic the life history of natural fall chinook salmon in the Snake River above Lower Granite Dam. Conversely, the Washington Department of Fisheries advocated outplanting yearling fall chinook salmon based on higher smolt-to-adult survival from on-station releases (Bugert et al. 1997). A compromise was reached among the federal agencies, state agencies, and the tribes that gave the yearling program first priority at Lyons Ferry Hatchery. An annual production goal of 900,000 yearlings was established, half of which was to be outplanted above Lower Granite Dam.

Portable acclimation facilities are being used at Pittsburg Landing in the Hells Canyon Reach, at Captain John Creek on the Snake River, and at Big Canyon Creek on the Clearwater River. Although yearling fall chinook salmon is the primary age class being used for supplementation, our research using subyearlings is necessary because NMFS recommended that the supplementation program be weaned from a dependency on yearling releases (NMFS 1995). Presently, Lyons Ferry Hatchery fish are in short supply, so determining the optimal size at release will allow for the development of the most efficient supplementation strategy for fall chinook salmon.

Table 5.C Survival probability estimates to the tailrace of Lower Granite Dam for PIT-tagged Lyons Ferry Hatchery yearling and subyearling fall chinook salmon released at Pittsburg Landing on the Snake River in 1997.

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Release group	Survival probability ( $\pm$ SE)
Yearlings (mean fork length = 155 $\pm$ 2.10 mm)	
1	0.908 $\pm$ 0.023
2	0.923 $\pm$ 0.022
3	0.926 $\pm$ 0.027
4	0.943 $\pm$ 0.023
Subyearlings (mean fork length = 92 $\pm$ 0.71 mm)	
1	0.806 $\pm$ 0.045
2	0.856 $\pm$ 0.063
3	0.804 $\pm$ 0.057
4	0.834 $\pm$ 0.062
Subyearlings (mean fork length = 85 $\pm$ 0.48 mm)	
1	0.687 $\pm$ 0.029
2	0.658 $\pm$ 0.026
3	0.657 $\pm$ 0.024
4	0.607 $\pm$ 0.022
Subyearlings (mean fork length = 71 $\pm$ 0.00 mm)	
2	0.397 $\pm$ 0.022
3	0.372 $\pm$ 0.022
4	0.401 $\pm$ 0.023

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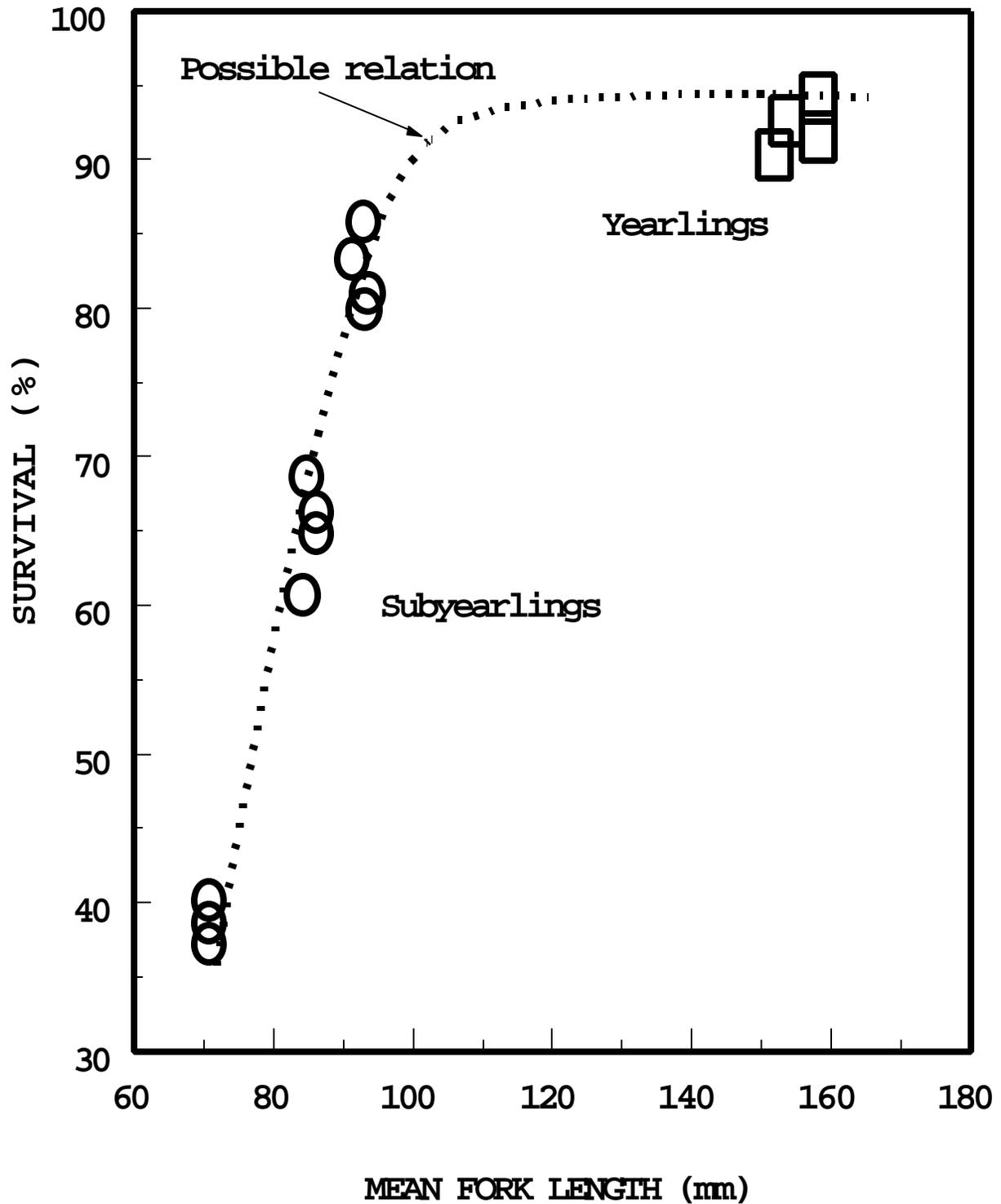


Figure 2.-Fork length of Lyons Ferry Hatchery yearling and subyearling fall chinook salmon that were released at Pittsburg Landing in 1997, and survival for each release group.

In 1997, we found marked differences in the post-release attributes and survival of 155-mm yearlings and 92-, 85-, and 71-mm subyearlings. Yearlings dispersed downstream rapidly and survived at high rates. Travel time to Lower Granite Dam was indirectly related to fork length of subyearling chinook salmon; the 92-mm fish emigrated faster than the 85- or 71-mm fish. The fork length versus survival analyses presented in this paper demonstrated a strong, possibly asymptotic relation between fork length and survival. Larger fish traveled to Lower Granite Dam faster than smaller fish, were less susceptible to predation, and may have been exposed to higher flows and cooler water during seaward migration. This study was repeated in 1998 and flow and temperature effects will be incorporated into a final survival analysis. The 1997 results suggest that releasing a subyearling chinook salmon > 92-mm fork length earlier in the spring might reduce the difference in smolt-to-adult returns between subyearlings and yearlings documented by Bugert et al. (1997).

In 1997, this study directly increased the number of fall chinook salmon that were released in the Snake River basin. This direct increase in the number of juveniles outplanted should produce an increase in the number of returning adults. If these adults are allowed to spawn naturally, then a short-term increase in the natural population of fall chinook salmon should be realized.

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**CHAPTER THREE**

Subyearling Chinook Salmon Early Life History  
Timing and Survival in the Snake River, 1995 to 1998

by

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## Introduction

Historically, the Snake River was considered in some years to be the most important producer of fall chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River Basin (Fulton 1968). Limited spawning occurred as far upstream as Shoshone Falls at river kilometer (RK) 977 (Fulton 1968). The historic core population of Snake River fall chinook reportedly spawned in the 48-km reach of river between Marsing, Idaho (RK 685) and Swan Falls Dam (RK 733; Haas 1965).

The spawning area near Marsing, Idaho became inaccessible to spawners with the completion of the Hells Canyon Complex of dams in 1967. Available spawning habitat was reduced further by the completion of the lower four Snake River dams (1962 to 1975). The present-day population of Snake River fall chinook salmon spawns in the margins of its historic range primarily in the unimpounded Snake, Grande Ronde, and Clearwater rivers (Garcia 1998).

Fall chinook salmon have an ocean-type life history (Healey 1991). The juveniles migrate seaward within two to three months after emerging from the gravel. Water temperatures near Marsing, Idaho were warmer during the egg incubation period than in most of the areas presently used for spawning. Fall chinook salmon fry near Marsing emerged from the gravel primarily in early April (Connor et al. 1997). The historic passage distribution for subyearling smolts as they left the Snake River was compressed and passage occurred from late May to early July (Mains and Smith 1956). Presently, fall chinook salmon fry emerge, rear, and migrate seaward later than they did historically. For example, in 1995 subyearling smolts passed Lower Granite Dam in a protracted fashion beginning in June, peaking in July, and ending in November (Connor et al. 1997). The change in early life history timing is the result of cold water temperatures during egg incubation in the remaining river reaches that are available for spawning (Connor et al. 1997).

S Snake River fall chinook salmon were listed as **A**threatened under the Endangered Species Act (ESA) in 1992 (USFWS 1987; NMFS 1992). I propose that the change in early life history timing is one factor that contributed to ESA listing. Smolts are now exposed to lower flows and warmer water temperatures than historically. Testing my hypothesis is difficult because there is no survival information for smolts prior to 1995. The

effects of early life history timing on survival could be studied if fish from different emergence cohorts could be marked to estimate their survival. The objectives of this study were to: 1) develop a method to separate subyearling chinook salmon captured along the Snake River into three cohorts based on date of fry emergence, and 2) test the relation between subyearling chinook salmon survival and flow and water temperature during seaward migration.

### **Study Area**

We collected subyearling chinook salmon along the Snake River between RK 365 and RK 224 (Figure 1). The majority of the study area was within Hells Canyon, which extends from Hells Canyon Dam to mouth of the Grande Ronde River (Figure 1). The Snake River within Hells Canyon is confined by steep-sided cliffs, and its channel is relatively narrow and large rapids are common. Downstream of Hells Canyon the Snake River broadens and the rapids become less common.

There are three main fall chinook salmon spawning areas located within the study area. These areas are the Snake River upstream of the Salmon River confluence, the Snake River from the Salmon River confluence to the head of Lower Granite Reservoir, and the Grande Ronde River (Garcia 1998). Fall chinook salmon fry emerge first in the Snake River upstream of the Salmon River confluence, second below the Salmon River confluence, and third in the Grande Ronde River. Fry disperse downstream from spawning areas leading to mixed-cohort rearing in the mainstem Snake River.

Lower Granite Dam is located at RK 173, and is the first dam fish encounter downstream of Hells Canyon (Figure 1). Subsamples of subyearling chinook salmon passing Lower Granite Dam are routed through the fish bypass system where they are electronically scanned for Passive Integrated Transponders (PIT) tags (Prentice et al. 1990a; 1990b) and then routed back to the river. Five of the seven dams downstream of Lower Granite Dam also have fish bypass systems that are equipped PIT-tag monitoring systems.



Figure 1.C The Snake River basin with the location of major tributaries and dams shown. The dotted rectangle encloses the current spawning areas used by fall chinook salmon.

## Methods

### *Data Collection*

Subyearling chinook salmon, which were predominantly fall-run fish (W. P. Connor, U. S. Fish and Wildlife Service, unpublished data), were collected using a 30.5-m long beach seine (Connor et al. 1998) as they reared along the 141-km stretch of the Snake River between RK 365 and RK 224. Fish were collected using an opportunistic sampling design that allowed us to capture adequate numbers of fish for analyses, in spite of low fish abundance, variable river flows, and time constraints. Prior to sampling, we selected from 18 (in 1995) or 15 (from 1996 to 1998) permanent sampling sites. Permanent sites were composed of low velocity pockets of water adjacent to sandy or cobble shorelines at least 100-m long.

After selecting permanent sites, we divided the Snake River into three reaches. This was done to provide a sampling unit that could be covered in one day. These reaches extended from RK 365 to RK 304, from RK 304 to RK 270, and from RK 270 to RK 224. Sampling began in April and was continued weekly until water temperature reached approximately 20°C, or catch neared zero. Each permanent site was sampled one day a week by setting the beach seine three times (flows permitting). Permanent sites within the lower reach were sampled on the first day of sampling, sites in the middle reach were sampled on the second day, and upper reach sites were sampled on the third day. Permanent sites within each reach were sampled in random order.

Approximately 21 d after peak fry emergence, we began supplementing our catch with additional seine hauls made at non-permanent sites. This supplemental sampling continued for three weeks. The physical characteristics of the sites used for supplemental sampling varied widely and included small beaches, cobble bars, and backwaters. Supplemental sampling was done within each reach after permanent sampling was completed for the day, or by adding days to the sampling schedule.

All subyearling chinook  $\geq$  60-mm fork length were anesthetized, PIT tagged, and allowed to recover as described by Connor et al. (1998). The PIT-tagged fish were released where they were collected to resume rearing, dispersal, and eventual seaward migration. Subsamples of PIT-tagged fish were detected at dams downstream of the study area from April until December.

## *Data Analysis*

Catch data was pooled within each year. The emergence date of each fish was back calculated based on fork length at capture, mean observed growth rate (W. P. Connor, unpublished data), and a mean fork length of 38 mm at emergence (Arnsberg et al. 1992). The data was grouped into three cohorts per year to approximate the life history of fish from the three spawning areas described previously. It also served as a means of forming replicate groups of fish within years. Cohort 1 represented fish from the Snake River above the Salmon River, cohort 2 represented fish below the Salmon River, and cohort 3 represented fish from the Grande Ronde River.

I used the single release version of the Cormack/Jolly-Seber survival probability model (Cormack 1964; Jolly 1965; Seber 1965; Burnham et al. 1987) to estimate survival to the tailrace of Lower Granite Dam for subyearling chinook salmon. No survival estimate was made for cohort 3 in 1995 because of problems that occurred at Lower Granite Dam during the passage of fish. I made three assumptions when using the single release approach. First, I assumed that detection of a subyearling chinook salmon at a PIT-tag detection site did not affect its probability of subsequent detection at downstream sites. Secondly, I assumed that detection at a PIT-tag detection site did not affect the probability of subsequent survival for a fish through downstream river reaches. Thirdly, I assumed that detected fish suffered no significant post-detection bypass mortality before remixing with non-detected fish.

An aligned ranks test (SAS 1989) was used to test the null hypothesis that median survival was equal among cohorts. I used a randomized block design to factor out the year effect. I then made pairwise comparisons between cohorts using the aligned ranks test. All comparisons were made at  $\alpha = 0.05$ .

I calculated exposure indices for flow and water temperature for each cohort. The indices were calculated as the mean daily flows and temperatures that occurred in Lower Granite Reservoir between the median date the cohort was PIT tagged, and the date 5% of the cohort passed Lower Granite Dam.

A Pearson correlation coefficient (SYSTAT 1994) was calculated to test the strength of association between the flow

and water temperature exposure indices. The effects of flow and water temperature were tested separately on survival using ordinary least-squares regression (SYSTAT 1994). Flow was transformed as  $-1/\text{flow}^8$ . Water temperature was transformed as  $-\text{temperature}^8$ . The null hypotheses for the regressions were  $H_1$ : survival is not related to flow, and  $H_2$ : survival is not related to temperature. Both hypotheses were tested at  $\alpha = 0.05$ .

## Results

A range of 463 to 2,056 subyearling chinook salmon were PIT tagged along the Snake River from 1995 to 1998 (Table 1). The number of PIT-tagged fish that were detected at Lower Granite Dam ranged from 122 to 9,546 (Table 1). Adequate numbers of fish were PIT tagged each year to allow the data to be divided into three cohorts per year based on the estimated emergence dates of each fish.

### *Cohort Separation*

The number of subyearling chinook salmon in each of the three cohorts was similar within years, but varied among years according to the total number of fish that were tagged (Table 2). The approach used to separate each year of data into three cohorts worked well based on the dates each cohort was PIT tagged and released, and then detected passing Lower Granite Dam. The first cohorts always comprised fish that were tagged, released, and detected earlier than the second cohorts, which in turn were tagged, released, and detected earlier than fish in the third cohorts. Subyearling chinook salmon from cohort 1 were PIT tagged and released in May and were detected passing Lower Granite Dam in July (Table 2). Fish from cohort 2 were also released in May, but they were detected later in July than fish from cohort 1 (Table 2). Subyearling chinook salmon from the third cohort were tagged in June and were detected in August (Table 2). The distribution of release and tagging dates and

Table 1. Number of subyearling chinook salmon that were PIT tagged and released along the Snake River, and the number of tagged fish that were detected at Lower Granite Dam, 1995-1998.

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Year	Number tagged	Number detected
1995	1,370	440
1996	463	145
1997	639	122
1998	2,056	546

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Table 2. Sample sizes and the median julian dates of emergence, release, and detection for each subyearling chinook salmon cohort that was PIT tagged and released along the Snake River, 1995-1998.

Event	Cohort					
	1		2		3	
	n	median	n	median	n	median
<b>1995</b>						
Emergence	456	118	456	128	458	138
Release	456	151	456	155	458	164
Detection	145	196	156	205	139	219
<b>1996</b>						
Emergence	154	106	154	131	155	149
Release	154	129	154	157	155	177
Detection	54	189	62	206	29	218
<b>1997</b>						
Emergence	213	122	213	137	213	149
Release	213	149	213	168	213	176
Detection	65	183	47	198	10	223
<b>1998</b>						
Emergence	684	112	684	123	608	139
Release	684	140	684	146	608	167
Detection	205	190	195	215	143	225

detection dates tended to be skewed and there was some overlap in the tails of each distribution (Figure 2).

### *Estimating Cohort Survival*

Estimated survival to the tailrace of Lower Granite Dam for the cohorts ranged from 0.669 (0.051) to 0.085 (0.048; Table 3). The blocking approach effectively adjusted for the year effect ( $F = 2.77$ ;  $P = 0.1504$ ). There was a significant overall difference in survival among the three cohorts (Figure 3;  $F = 15.00$ ;  $P = 0.0077$ ). Survival for cohorts 1 and 2 was not significantly different ( $P = 0.2729$ ). Survival was significantly different between cohorts 1 and 3 ( $P = 0.0031$ ) and between cohorts 2 and 3 ( $P = 0.0083$ ; Figure 3).

### *Flow, Temperature, and Survival*

Flow exposure indices ranged from 2,258 to 4,920 m<sup>3</sup>/sec (Table 4). Water temperature exposure indices ranged from 10.9 to 18.0 °C (Table 4). Cohorts 1 and 2 were exposed to higher flows and cooler water temperatures during seaward migration than cohort 3. Flow and water temperatures exposure indices were highly correlated ( $r = -0.747$ ;  $P = 0.008$ ). Therefore, I opted not to use a multiple regression approach to test the relation between survival and flow and water temperature.

Separate regressions using the transformed flow and water temperature exposure indices as independent variables, and survival as the dependent variable, revealed significant relations. Flow was positively related to survival (Figure 4;  $N = 11$ ; intercept = 0.05966; slope = 0.0003;  $r^2 = 0.74$ ;  $P = 0.003$ ). Water temperature was negatively related to survival (Figure 5;  $N = 11$ ; intercept = 0.6510; slope = 0.005;  $r^2 = 0.75$ ;  $P = 0.001$ ).

## **Discussion**

Small sample sizes of fish prevented me from testing the three assumptions (Burnham et al. 1987) inherent to single-release survival modeling. If the detection of subyearling chinook salmon at one dam affected their probability of subsequent detection at downstream dams, then survival was underestimated. If detection at a dam affected the probability

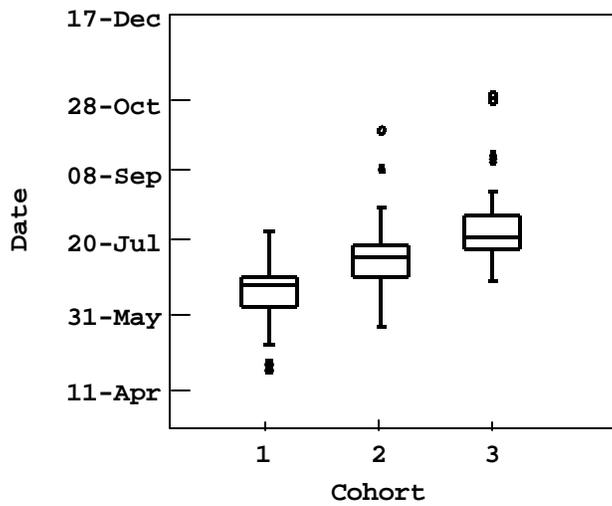
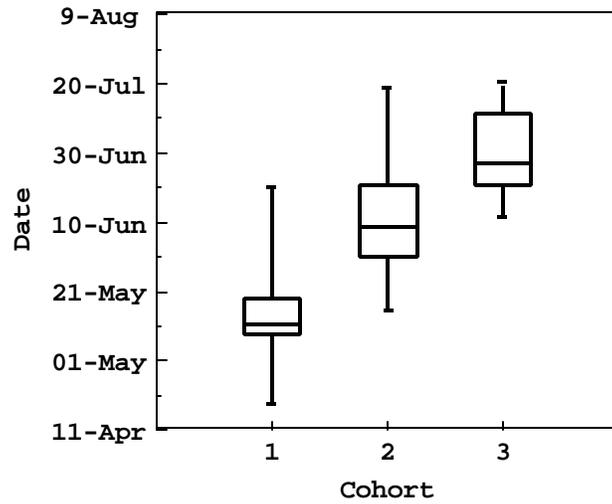


Figure 2. Can an example of the release (top) and detection date distributions (bottom) for subyearling chinook salmon that were PIT tagged and released along the Snake River and then detected as they passed Lower Granite Dam, 1996.

Table 3. Estimated survival (standard error in parentheses) to the tail race of Lower Granite Dam for each cohort of subyearling chinook salmon that was PIT tagged and released along the Snake River, 1995-1998.

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Estimated Survival (SE) by cohort			
Year	1	2	3
1995	0.669(0.051)	0.668(0.085)	-----
1996	0.568(0.061)	0.591(0.059)	0.279(0.053)
1997	0.613(0.053)	0.361(0.050)	0.085(0.048)
1998	0.657(0.028)	0.612(0.028)	0.404(0.03)

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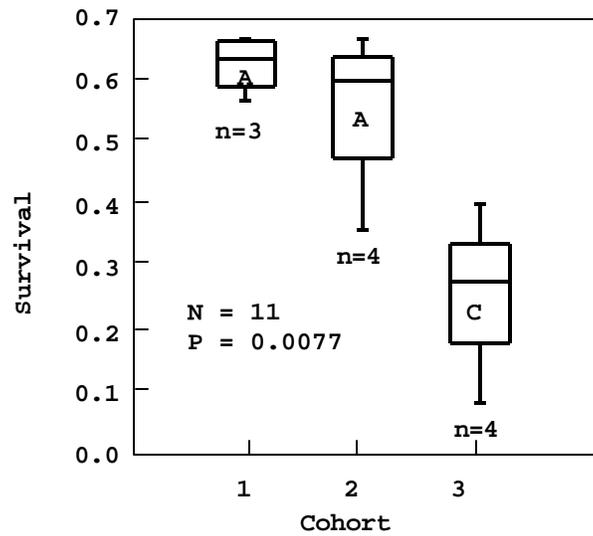


Figure 3. Estimated survival to the tail race of Lower Granite Dam grouped across years by cohort for subyearling chinook salmon that were PIT tagged and released along the Snake River, 1995-1998. The *P* value from an aligned ranks test is given, and the letters within the box plots indicate the outcome of pairwise comparisons ( $\alpha=0.05$ ).

Table 4. Flow (m<sup>3</sup>/sec) and water temperature (°C) exposure indices calculated using data from Lower Granite Reservoir for the period each cohort of PIT-tagged Snake River subyearling chinook salmon was passing downstream through the reservoir, 1995-1998.

Exposure index	Cohort		
	1	2	3
<b>1995</b>			
Flow	3,587	3,192	-----
Temperature	14.5	15.0	-----
<b>1996</b>			
Flow	3,881	4,172	2,258
Temperature	10.9	14.2	16.5
<b>1997</b>			
Flow	4,920	4,461	2,262
Temperature	12.9	14.7	18.0
<b>1998</b>			
Flow	4,477	3,785	2,527
Temperature	13.4	14.2	15.6

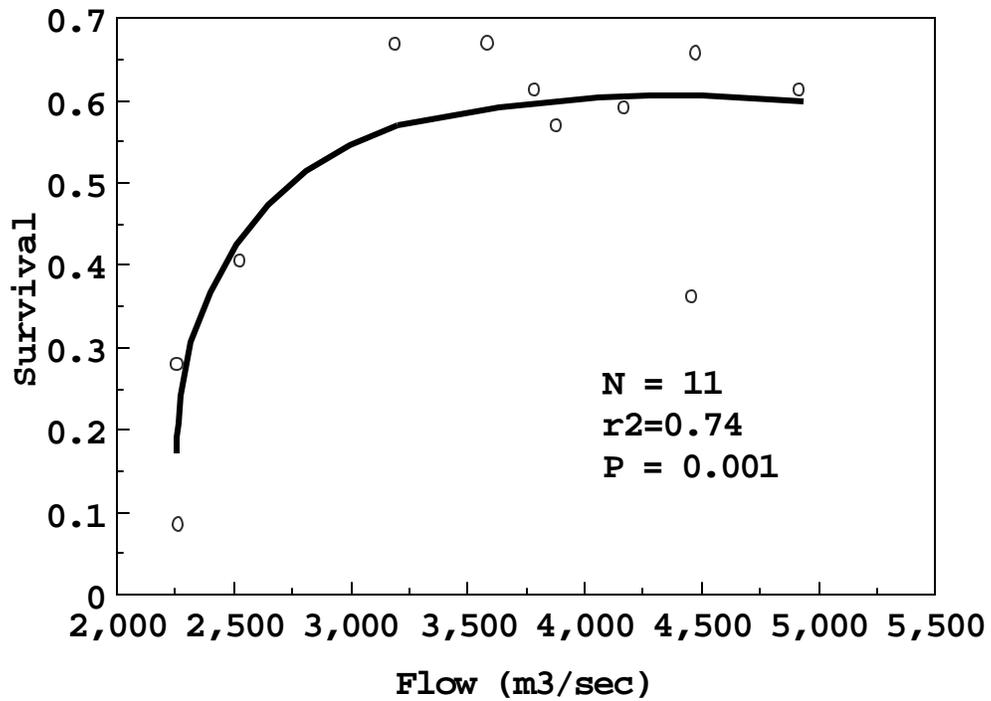


Figure 4. Relation between water flow (m<sup>3</sup>/sec) in Lower Granite Reservoir and estimated survival to the tailrace of Lower Granite Dam for subyearling chinook salmon that were PIT tagged along the Snake River, 1995-1998.

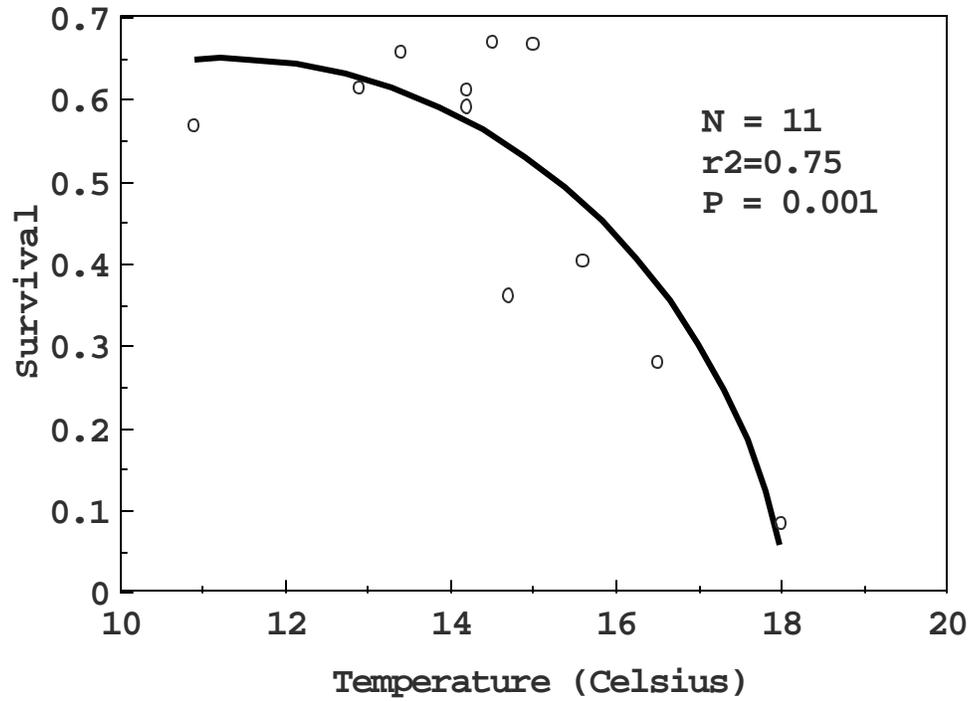


Figure 5. Relation between water temperature ( $^{\circ}\text{C}$ ) in Lower Granite Reservoir and estimated survival to the tailrace of Lower Granite Dam for subyearling chinook salmon that were PIT tagged along the Snake River, 1995-1998.

of subsequent survival through downstream river reaches, then my estimates are biased high. Significant post-detection bypass mortality before fish remixed with non-detected fish would also result in overestimates of survival. Goodness of fit tests were used to test the three assumptions during a study of wild yearling and hatchery subyearling chinook salmon survival that was conducted in my study area. The assumptions were not violated (Iwamoto et al. 1994; Smith et al. 1997).

Differences in survival between cohorts of subyearling chinook salmon released along the Snake River from 1995 to 1998 can be traced back to emergence timing. Earlier emerging fish migrated seaward earlier and passed through Lower Granite Reservoir under higher flows and cooler water temperatures than later emerging and emigrating fish. Hatchery subyearling fall chinook salmon that were released in the Snake River under high flows and low temperatures survived better than fish that were released under lower flows and warmer temperatures (Smith et al. 1997). Detection rates for natural subyearling chinook salmon PIT tagged in the Snake River from 1992 to 1995 were positively related to flow and negatively related to water temperature (Connor et al. 1998). The cohort survival results presented in this paper are consistent with previous studies. I conclude that the change in life history timing caused by the construction of Hells Canyon Complex of dams was one factor that led to the decline of the Snake River fall chinook salmon population.

Possible explanations for the significant relations between flow and survival were reviewed by Connor et al. (1998). These authors proposed that high flows may positively affect survival of seaward migrating subyearling chinook salmon by preventing delays in passage. In theory, delays in passage could cause disorientation of emigrants, increased exposure time to predators, reversal of smoltification, and disease (Park 1969; Raymond 1979; Berggren and Filardo 1993). In the future it would be valuable to determine if the time at large between the tagging and detection of a cohort was related to survival.

Studies were also reviewed (Connor et al. 1998) that demonstrated the effect of water temperature on consumption of subyearling chinook salmon by predators in the Columbia and Snake rivers (Poe et al. 1991; Vigg and Burley 1991; Vigg et al. 1991; Curet 1994; Anglea 1997). The number of subyearling chinook salmon eaten by northern pikeminnow (*Ptychocheilus*

*oregonensis*), smallmouth bass (*Micropterus dolomieu*), walleye (*Stizostedion vitreum*), and channel catfish (*Ictalurus punctatus*) increased with water temperature. The significant relation I found between water temperature and survival of subyearling chinook salmon may be the result of high rates of predation at warmer water temperatures.

The goal of the ESA is to restore viable self-perpetuating populations of mammals, birds, and fishes in their native habitats (USFWS 1988). Summer flow augmentation (NMFS 1995) is one method being used to recover Snake River fall chinook salmon. Summer flow augmentation increases flow and decreases water temperature in Lower Granite Reservoir (Connor et al. 1998). The regression results for cohort survival support the need for continued summer flow augmentation.

Supplementation with hatchery fish (Miller et al. 1990; Steward and Bjornn 1990) is another method being used to recover Snake River fall chinook salmon. The results of cohort analysis in this paper may be useful for supplementation planning. Among spawning areas in the margins of the historic range, those that foster earlier fry emergence may produce more surviving smolts per spawner than those that foster later emerging fry. Releasing hatchery fish into the Snake River upstream of the Salmon River confluence might result in the highest possible smolt-to-adult return rate.

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**CHAPTER FOUR**

Nearshore Habitat Use by Subyearling Fall Chinook Salmon  
in the Snake River

by

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## Introduction

With the listing of Snake River fall chinook salmon *Oncorhynchus tshawytscha* as "threatened" under the Endangered Species Act (NMFS 1992), there has been increased interest in defining attributes of primary rearing habitats. Studies of habitat use by subyearling fall chinook salmon conducted in the Snake River have primarily used beach seining in the free-flowing reaches (Key et al. 1994a; Key et al. 1994b) and reservoirs (Bennett et al. 1992; Curet 1993). Beach seining is limited by the range of velocities and substrates that can be effectively sampled, and therefore can bias estimates of habitat use. Deep, rocky, and swift habitats must be sampled with gear other than beach seines. In 1998, we used electrofishing to sample a wider range of habitats than had been sampled in the past. The objective of this study was to better define subyearling fall chinook salmon rearing habitat in the Snake River, and to compare habitats used to those used by fall chinook salmon in the Hanford Reach of the Columbia River.

## Study Area

Our 1998 habitat study was conducted in the free-flowing Snake River between river kilometer (RK) 233 and RK 398. The river was divided into upper and lower sampling reaches, with the lower reach extending from Asotin (RK 233.8) to just above the confluence with the Grand Ronde River (RK 278.3), and the upper reach extending from above Cougar Rapids (RK 294.1) to Pittsburg landing (RK 346.0; Figure 1). River kilometer information was calculated from the mouth of the Snake River, and was obtained from U.S. Army Corps of Engineers navigation charts.

## Methods

### *Point Shock Abundance Sampling*

Point shock abundance sampling (Persat and Copp 1990) was used to collect fish in shoreline habitats during three periods in 1998: May 5-15, June 7-11, and June 20-25. Samples were collected from the lower reach for each time period, whereas the upper reach was only sampled on the third trip.

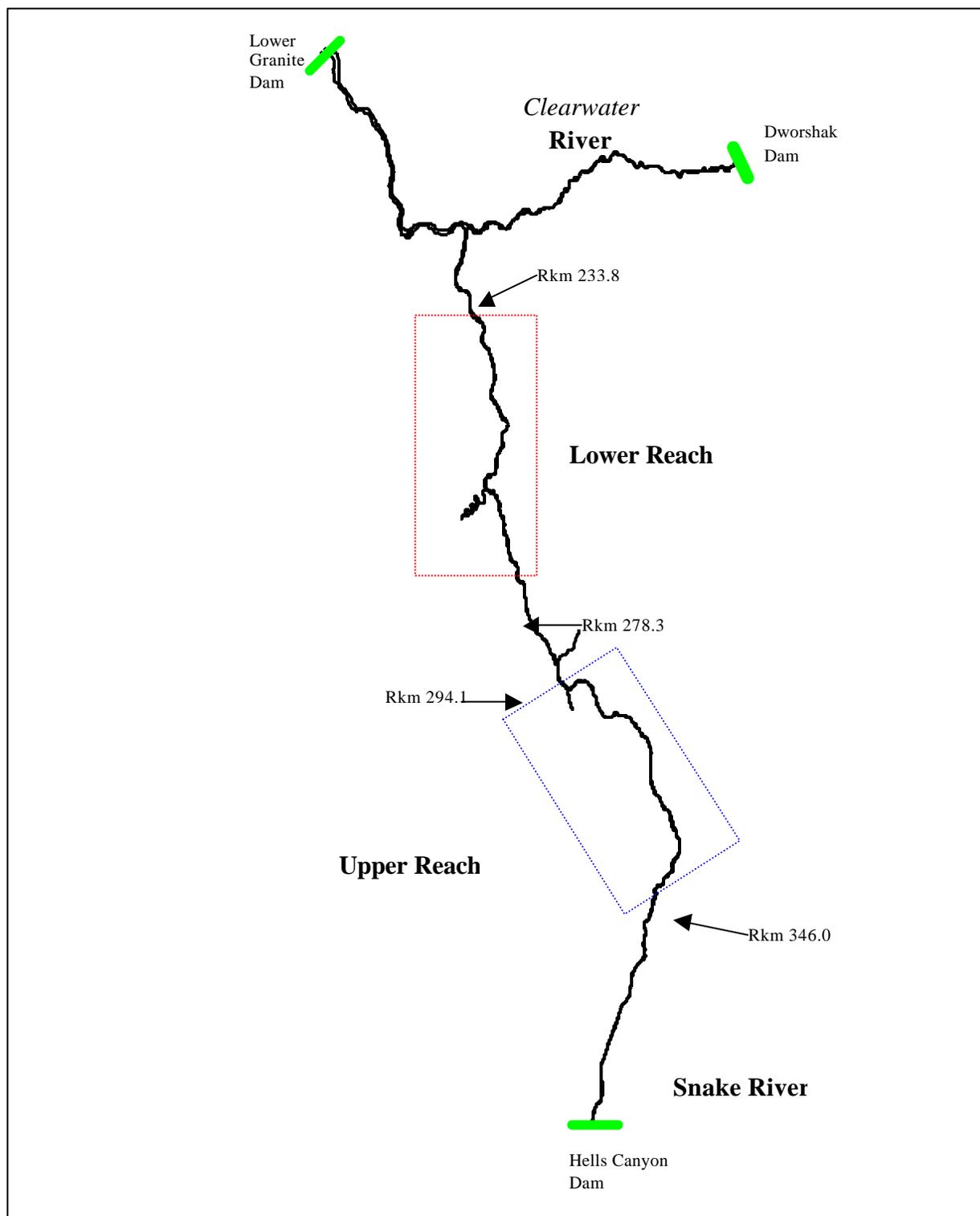


Figure 1.-Snake River sampling reaches used during fall chinook salmon habitat surveys in 1998.

Data was collected using a 5.5 m Smith-Root electrofishing boat with a 1.02 m umbrella anode array and electrical output of 2 amps at 60 pulses/s DC. Samples were collected by driving directly towards the shoreline and shocking areas 2-5 m from shore, or until the boat was no longer able to go forward because of shallow depth. When the area of interest was reached, an 8-s shock was initiated and the boat's forward momentum stopped. This allowed a localized area to be shocked with minimal forewarning to fish. At the end of the shock, a buoy was set to mark the area where fish were caught or seen, or the center of the shocked area if no fish were seen.

### *Site Selection*

A method of site selection was used that included some of the more uncommon habitats, avoided unnecessary duplication, and minimized sample bias. Three matrices were constructed to create different combinations of habitat variables to guide sampling efforts, and included 1) velocity X depth, 2) velocity X substrate, and 3) depth X substrate. Sites were selected and sampled to collect information for each matrix cell. Effort was expended to sample the habitat combination in each cell at least once, with three or more samples being preferred. Sampling in a reach was completed when no new sites could be found to fill empty or partially filled cells in the three matrices.

### *Catch*

Subyearling fall chinook salmon were targeted for collection. Stunned fish were collected with dipnets, sorted by species, and enumerated. Captured fall chinook salmon were anesthetized with 26 mg/L of tricaine methanesulfonate (MS-222), weighed to the nearest 0.1 g, and measured to the nearest 1 mm. Incidental fish were identified to species; larger specimens were released so as not to harm or stress the fall chinook salmon. All fish were allowed to recover for approximately 15 min before release.

Fish seen, but not caught, were visually identified, enumerated, and noted as "seen". If we were unable to adequately identify the species of fish, the fish was designated as "unknown" and its size and general appearance were noted if it was chinook-like. All large fish (e.g. Catostomidae) were identified visually and noted as "seen" so that effort could be concentrated on collecting subyearling fall chinook salmon.

## *Habitat*

Various habitat measurements were collected at each point-shock sample site. Water temperature was measured to the nearest 0.1°C at the point of shock, and at 1 m, and 15 m from shore. Water velocity was measured using a current meter at the point of shock and at 15 m from the shore. Water depth and flow direction were collected concurrent with velocity measurement. Distance of point of shock to the shore was measured to the nearest 1 cm. At the point of shock, substrate type was visually assessed and assigned a code based on a Wentworth classification modified from Orth (1983; Table 1). Embeddedness of substrate was also visually assessed and assigned a code following Platts et al. (1983; Table 2). Presence of inundated vegetation and overhanging cover was noted. Vegetation was defined as absent, sparse, medium, or dense. Sparse vegetation was defined as vegetation that covered up to 10% of the substrate, medium vegetation covered 10-50% of the underlying substrate, and dense vegetation covered more than 50% of the substrate. Our vegetation classifications did not account for height and stem density, or if the vegetation created velocity breaks. Water turbidity was measured every 2 h in Nephelometric Turbidity Units (NTU). Location of each point-shock sample was determined using a Global Position System (GPS).

## *Analysis*

The total number of point-shock samples and fall chinook salmon caught and seen were tallied for each reach and trip. Subyearling chinook salmon catch and effort in the different habitats sampled were summarized and compared graphically. The first and second sampling trips were combined for analysis for the lower reach, but trip three was not included because no chinook were caught. The upper reach was analyzed separately from the lower reach.

The probability of catching one or more subyearling chinook salmon in the different habitats sampled was statistically computed using a predictive model that was developed for fall chinook salmon in the free-flowing Hanford Reach of the Columbia River (USGS, unpublished data). Individual habitat variables such as velocity, depth, and distance from shore were transformed using the natural log, inverse, and square root to normalize distributions. The transformation that best improved the normality for each variable was selected. A factor analysis was then conducted because many of the variables were highly

Table 1.-Substrate codes, particle sizes, and descriptions used to classify dominant substrate during juvenile fall chinook salmon habitat surveys in the Snake River, 1998.

Code	Particle size (mm)	Description
1	<1	Fines to coarse sand
2	>1-2	Very coarse sand
3	>2-4	Fine gravel
4	>4-8	Medium gravel
5	>8-16	Coarse gravel
6	>16-32	Small pebble
7	>32-64	Large pebble
8	>64-256	Cobble or rubble
9	>256	Boulder
10		Bedrock cliffs

Table 2.-Embeddedness codes and descriptions used to classify embeddedness of dominant substrates during juvenile fall chinook habitat surveys in the Snake River, 1998.

Code	Description
1	Dominant substrates have between 0 and 25 percent of their edges obscured by finer substrates.
2	Dominant substrates have between 25 and 50 percent of their edges obscured by finer substrates.
3	Dominant substrates have between 50 and 75 percent of their edges obscured by finer substrates.
4	Dominant substrates have between 75 and 100 percent of their edges obscured by finer substrates.

correlated with each other. The factors were rotated using the varimax rotation to distribute the variance equally among the factors and improve interpretation. The related factor scores were then used in a test data set to classify fish presence or absence using a discriminant analysis and a calibration function developed for the Hanford Reach (USGS, unpublished data). All analyses were done using SAS (1994).

## Results

A total of 589 point shock abundance samples were collected resulting in 107 wild and 3 hatchery subyearling fall chinook salmon caught or seen (Table 3). The average catch-per-unit-effort (CPUE) was 0.18 subyearling fall chinook salmon per point abundance sample. Most fall chinook salmon, 96%, were caught on sampling trips 1 and 2 in the lower reach. Of the 589 sites sampled, 519 (87%) contained no fish, and 70 sites (13%) had one or more salmon. The upper reach was only sampled during trip three and only four chinook salmon were caught. Because of the low catch in the upper reach, no further analysis was conducted. Average fork length of subyearling fall chinook salmon was 54.0 mm for trip 1, 75.8 mm for trip 2, and 66.5 mm for trip 3. Incidental fish caught in both reaches on the Snake River are reported in Appendix 1.

Subyearling fall chinook salmon were more abundant at sites where sand was the dominant substrate, however, substrate did not seem to be a significant factor determining habitat use (Figure 2). CPUE was highest over sand (0.41), but chinook were also caught over all other major available substrate types, except bedrock cliffs, with CPUEs of at least 0.2. Very coarse sand to coarse gravel substrates (codes 2-5) were not sampled due to lack of availability in the Snake River.

Subyearling fall chinook salmon were associated with highly embedded substrates. The highest sampling effort (48%) was in areas that were 75-100% embedded (code 4), resulting in 76% of the catch and a CPUE of 0.42 (Figure 3). Areas with 0-25% embeddedness (code 1) accounted for 28% of the effort but only 8% of the catch (CPUE 0.08).

CPUE was higher in areas of medium vegetation cover, and lower, but approximately equal, where vegetation was absent or sparse (Figure 4). Where vegetation was classified as sparse, small amounts of terrestrial grasses and forbs were dominant.

Table 3.-Number of wild and hatchery subyearling fall chinook salmon caught by electrofishing in the upper and lower reaches of the Snake River for each sampling period in 1998.

Reach	Sampling period	Total shocks	Total wild fall chinook salmon	Total hatchery fall chinook salmon
Lower	5 May - 15 May	190	79	0
Lower	7 June - 11 June	191	25	2
Lower	20 June - 25 June	108	0	0
Upper	20 June - 25 June	100	3	1
Total		589	107	3

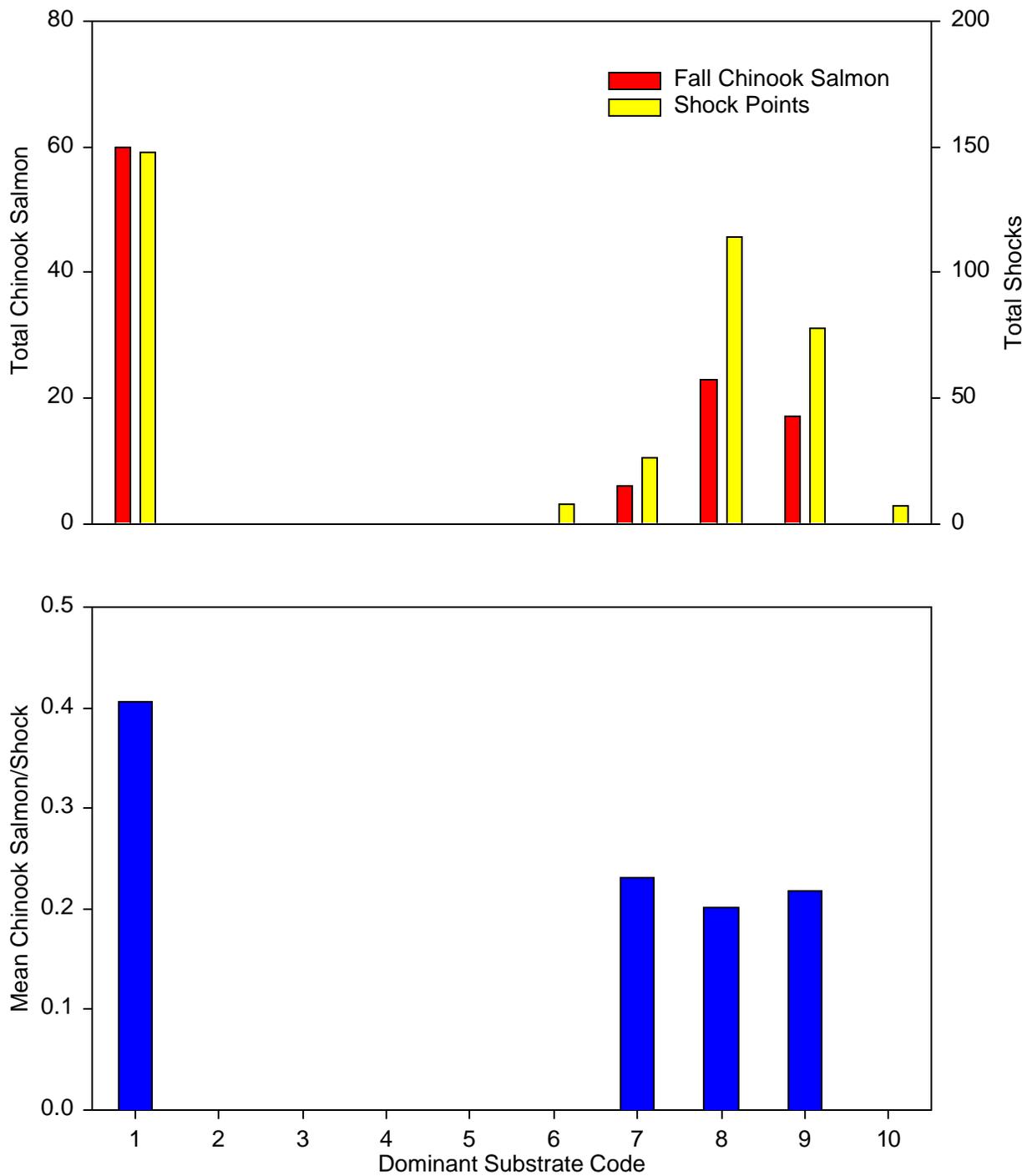


Figure 2.-Comparison of subyearling chinook salmon, point abundance samples collected, and mean chinook/shock for dominant substrates at point abundance sites in the lower reach of the free-flowing Snake River, 1998.

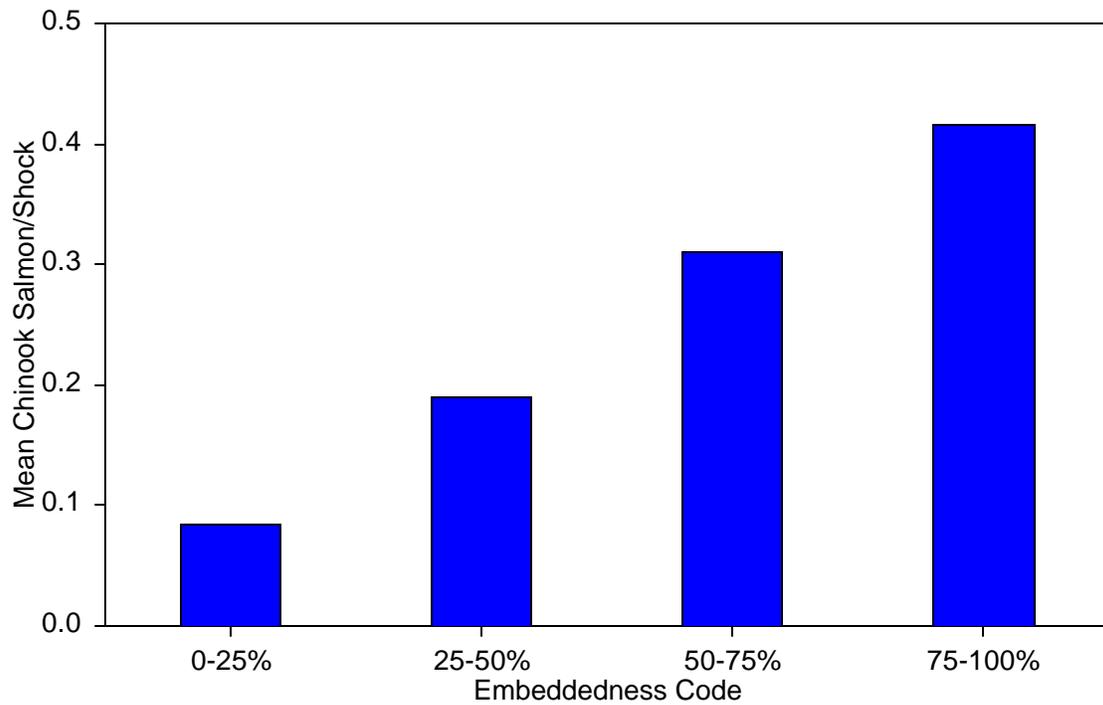
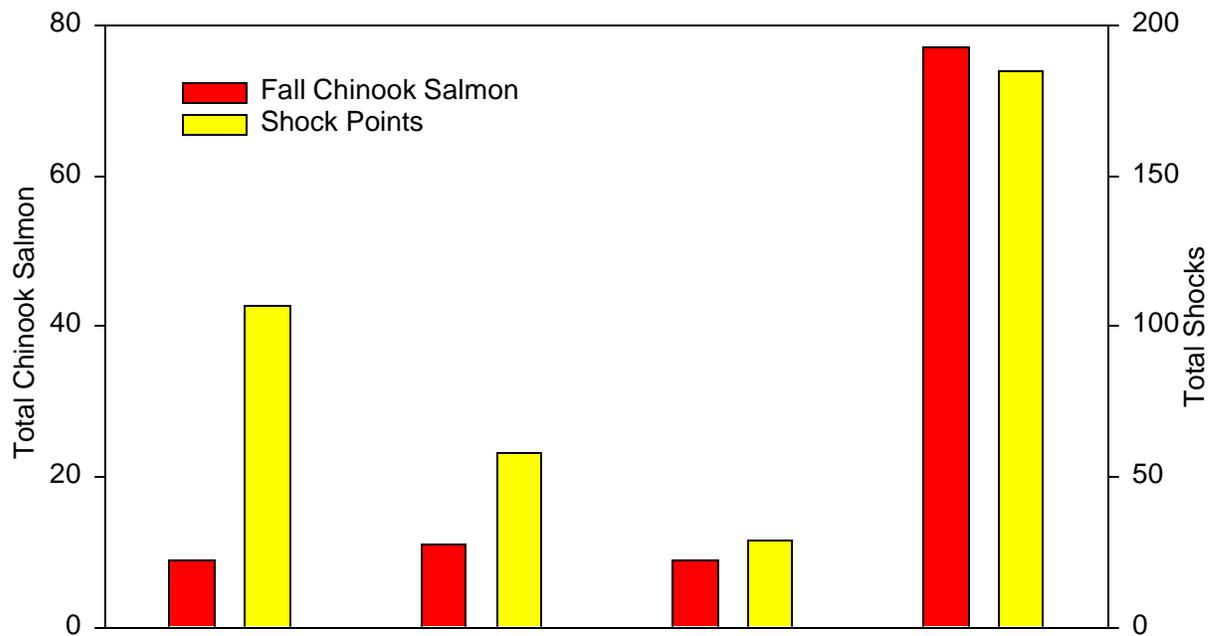


Figure 3.-Comparison of subyearling chinook salmon, point abundance samples collected, and mean chinook/shock for embeddedness at point abundance sites in the lower reach of the free-flowing Snake River, 1998.

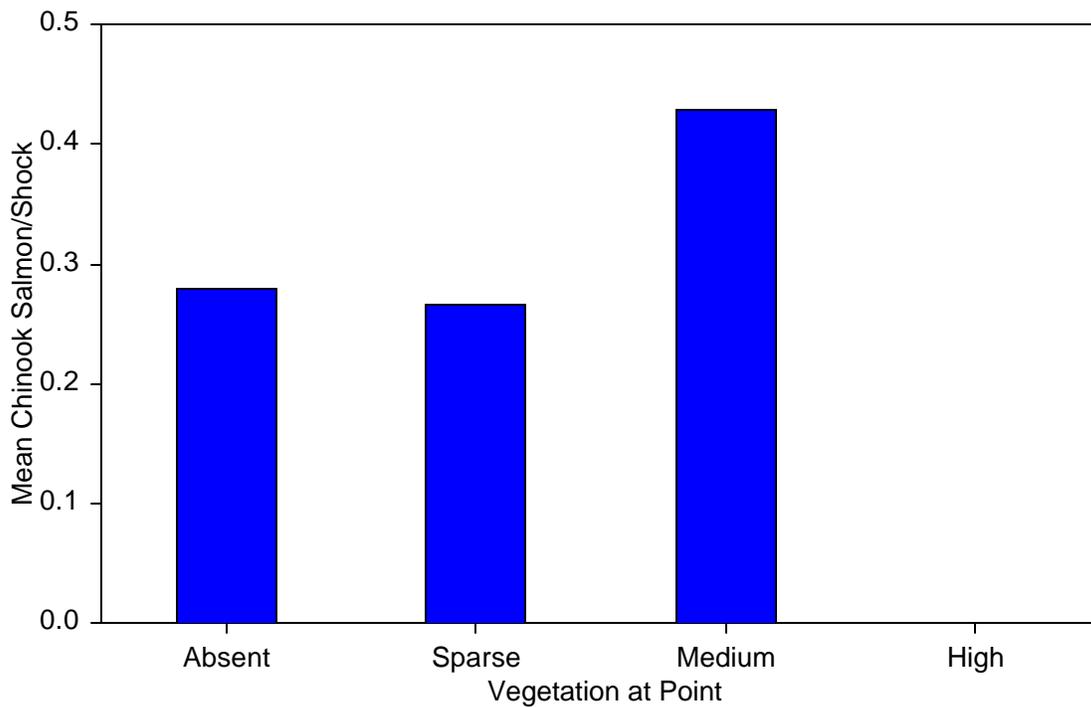
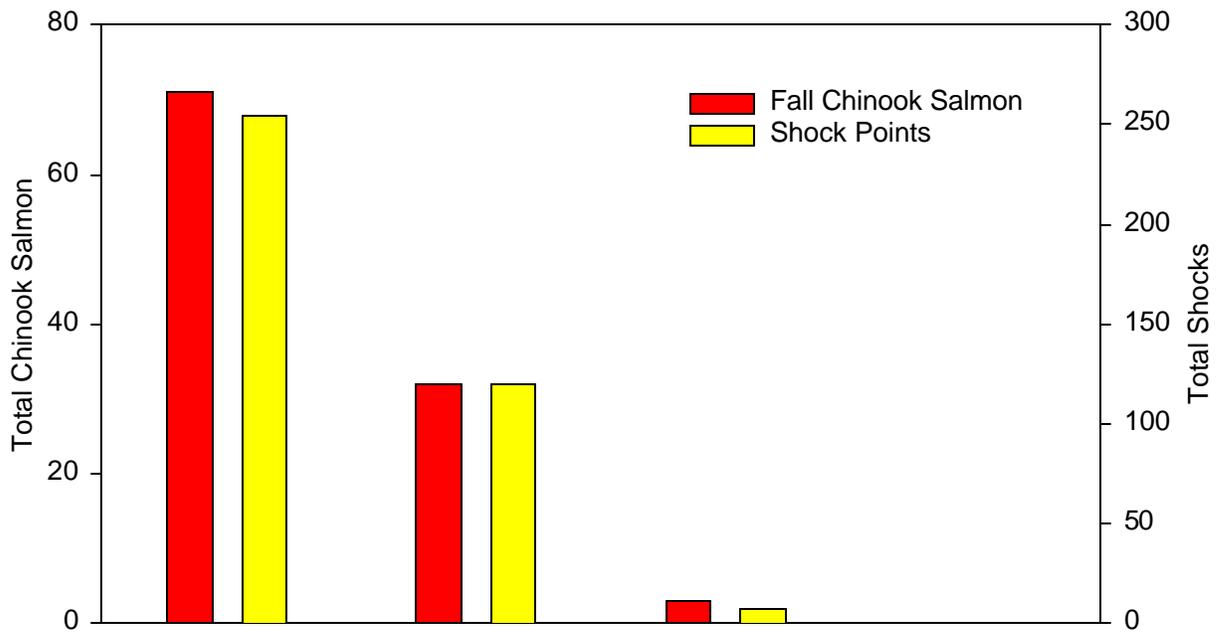


Figure 4.-Comparison of subyearling chinook salmon, point abundance samples collected, and mean chinook/shock for vegetation at point abundance sites in the lower reach of the free-flowing Snake River, 1998.

Medium vegetation was usually represented by groupings of inundated bushes or trees, which created velocity breaks. Medium vegetation was present in only seven point abundance sample sites, however, and was generally not available.

The gradient between the shore and point of shock, or slope, influenced the habitat selection of subyearling fall chinook salmon. We caught fish over slopes up to 55%, although most of the catch was associated with slopes 20% or less (Figure 5). Of the total catch, 91.5% was over slopes of 20% or less, and represented 73% of the effort in these areas.

Velocity at point of shock was another factor that influenced fall chinook salmon habitat selection. Most of the catch (97%) was in areas with velocities of 0.35 m/s, or less, (Figure 6). No subyearling fall chinook salmon were caught in velocities greater than 0.55 m/s. Most of the effort (78%) was concentrated in areas with velocities of 0.35 m/s, or less. CPUE was more than twice as high where velocity was below 0.35 m/s than at higher velocities.

Using our statistical habitat model for the Hanford Reach, we were 90% accurate in predicting the presence of one or more subyearling fall chinook salmon in our sample sites (Table 4). In contrast, we were only 13% accurate in predicting where fall chinook salmon would not be present. Of the total habitat sampled, 87% was predicted to have 1 or more fall chinook salmon, but only 18% of our sample sites had subyearlings present. Conversely, 13% of the total habitat samples was predicted to have no catch, but based on our sampling, 82% of point-shock sites had no fish.

## **Discussion**

Habitat use by subyearling fall chinook salmon in the lower reach of the free-flowing Snake River was similar to that of subyearlings rearing in the Hanford Reach of the Columbia River. The use of nearshore rearing habitats by juvenile fall chinook is determined largely by gradient, velocity, and substrate, and to a lesser degree by embeddedness and vegetation. It is difficult to make conclusions about any one variable since all are interrelated. The shape of the channel (gradient) determines water velocities, and water velocity is the main determinant of substrate and embeddedness. These in turn

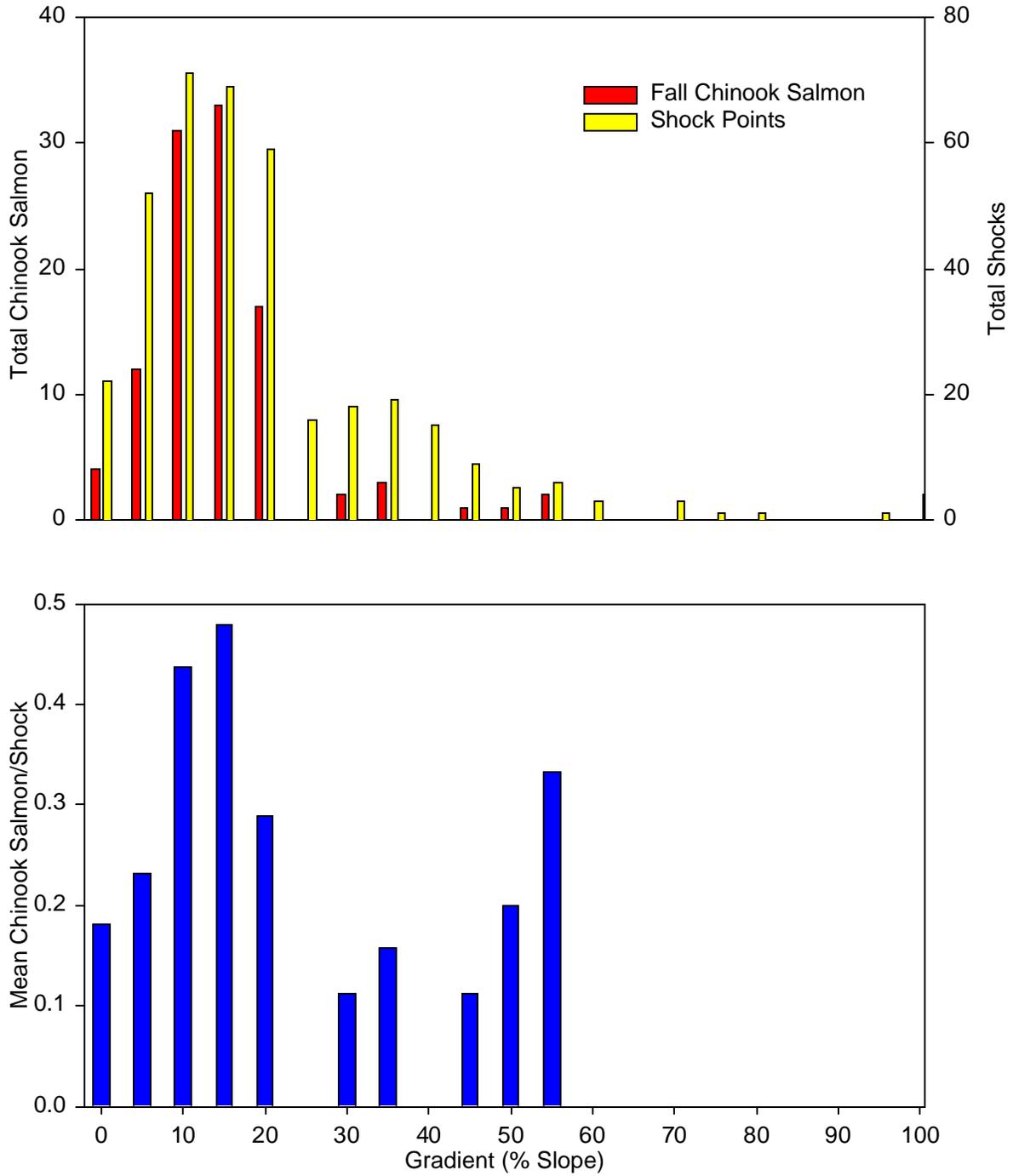


Figure 5.-Comparison of subyearling chinook salmon, point abundance samples collected, and mean chinook/shock for gradient at point abundance sites in the lower reach of the free-flowing Snake River, 1998.

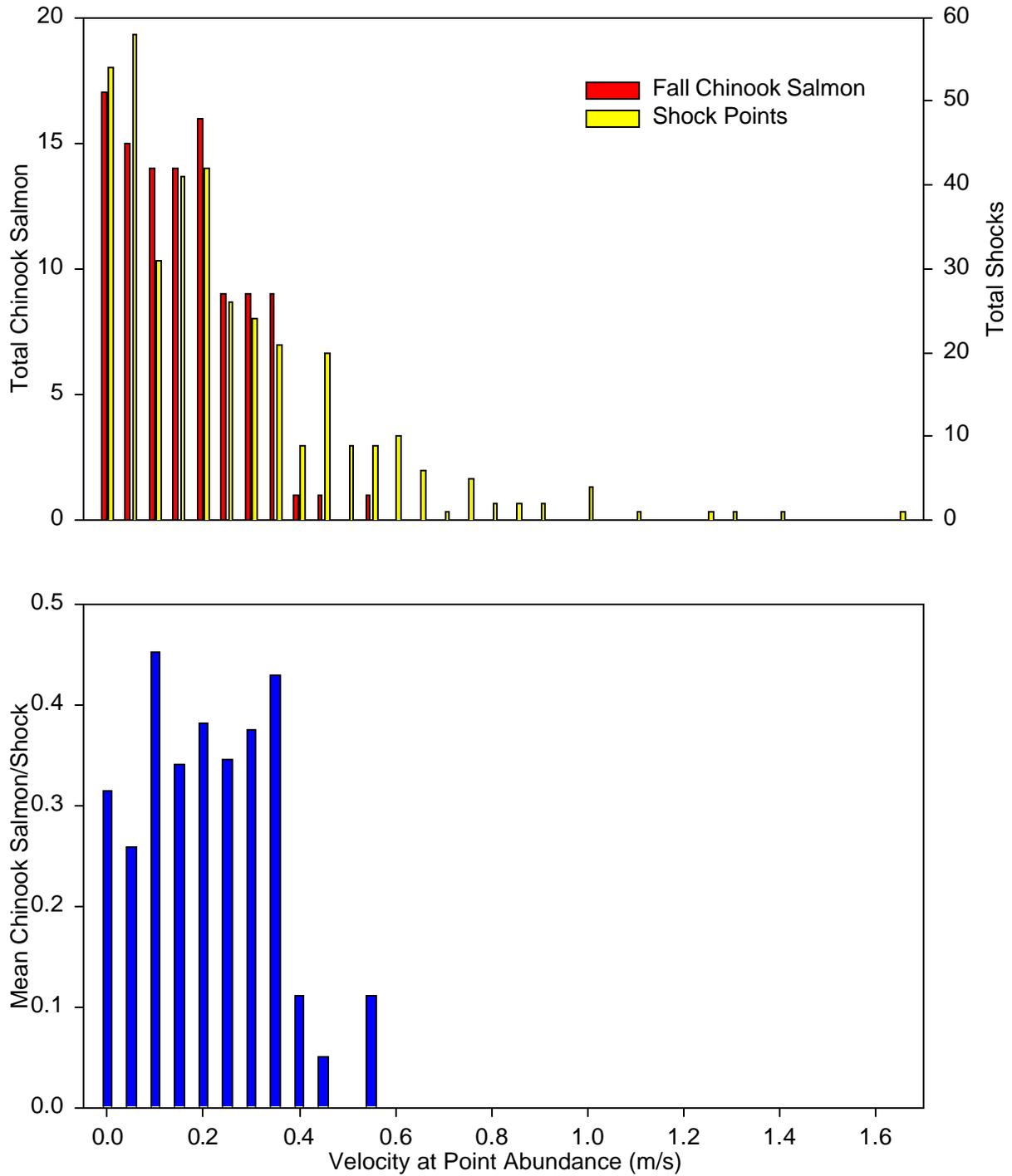


Figure 6.-Comparison of subyearling chinook salmon, point abundance samples collected, and mean chinook/shock for velocity at point abundance sites in the lower reach of the free-flowing Snake River, 1998.

Table 4.-Prediction of presence and absence of juvenile fall chinook salmon in habitats sampled in the Snake River in 1998. The discriminant analysis-based model was developed from Hanford Reach fall chinook salmon habitat and catch data.

Actual Group	Predicted Group			Total
	Contained no fish	Contained 1 or more fish		
Contained no fish	Number	42	272	314
	Percent	13.38	86.62	100.00
Contained 1 or more fish	Number	7	60	67
	Percent	10.45	89.55	100.00
Total percent	Number	49	332	381
	Percent	12.86	87.14	100.00

determine the type of vegetation that grows during times of bank dewatering.

Subyearling fall chinook salmon were most abundant in the Snake River over sandy substrates, but were also found over almost all available substrate types except bedrock cliffs. When chinook salmon were caught in areas where boulders were the dominant substrate, the boulders were widely spaced and heavily embedded. No chinook salmon were caught in man-made boulder areas such as rip-rap. Key et al. (1996) also reported little use of boulders and rip-rap, but otherwise found chinook over all available substrates in the Hanford Reach with greatest abundance over coarse gravel. Key et al. (1994a; 1994b) using beach seines reported finding subyearling chinook over habitats with a wide range of percent fine substrates in both the free-flowing Snake River and the Hanford Reach. Curet (1993) reported that subyearling chinook rearing in Lower Granite and Little Goose reservoirs exhibited a strong preference for sandy areas, and showed a moderate avoidance of areas containing cobble. However, effort over different substrate types was not reported. Bennett et al. (1993) also found most subyearling chinook over sandy substrates in Little Goose Reservoir. However, since Curet (1993), Bennett et al. (1993), and Key et al. (1994a; 1994b) used beach seines to collect subyearling fall chinook salmon, results from these studies were limited to areas that were conducive to seining and do not represent the range of habitats available.

Water velocity was another determinant of subyearling fall chinook salmon use of nearshore habitats. We found that most chinook salmon were caught in areas with velocities of 0.35 m/s, or less. Key et al. (1996) also caught greater numbers of fall chinook in areas with lower water velocities (0.2 m/s) in the Hanford Reach. Everest and Chapman (1972) found the greatest densities of subyearling summer chinook where velocities were less than 0.5 m/s in streams habitats. Indeed, our increased catch of fall chinook salmon over more embedded substrates may be a function of lower velocity and not an actual effect of embeddedness. Slower water velocity habitats may be energetically profitable for juvenile fall chinook salmon, while still allowing for feeding on prey items in the drift.

The role of vegetation in determining subyearling fall chinook abundance in the Snake River should be interpreted carefully. Sparse vegetation consisted of submerged terrestrial grasses and forbs, and did not create velocity breaks or

refugia. Only a few areas were sampled where we classified vegetation as "medium". It is likely that medium vegetation was used as velocity breaks in areas with high nearshore velocities rather than for cover from predators. Data we collected in the Hanford Reach in 1999 revealed that fall chinook salmon selected habitats based on conditions other than the presence or absence of vegetation (USGS, unpublished data). We believe that the same holds true for fall chinook salmon rearing in the Snake River.

Shallow nearshore water with low gradient is an important habitat criterion for subyearling fall chinook salmon rearing in the free-flowing Snake River. Bennett et al. (1993) reported that areas with low gradients were characteristic of rearing areas in Little Goose Reservoir. In the Hanford Reach, the highest mean numbers of subyearling fall chinook salmon were caught over gradients of 35-40% measured at 7.6 m from shore (Key et al. 1996). Dauble et al. (1989) also found that shallow nearshore areas were preferred by subyearling fall chinook. Additionally, Key et al. (1994b) proposed that shallow nearshore waters may be important to chinook salmon by providing warmer water temperatures for faster growth and lower risk of predation from large piscivorous fish.

The total catch of subyearling fall chinook salmon was significantly lower in the Snake River (110 fish) as compared to the Hanford Reach (1,541 fish). The latter was sampled in 1994 and 1995 at roughly half the effort (Key et al. 1996). This difference resulted in total point abundance samples without catch of chinook in the Snake River to be 88%, as compared to 33% in the Hanford Reach. Statistical analysis of the presence of fish in rearing areas in the Snake River showed high predictability of areas where subyearling fall chinook were actually caught. The high number of zero catches in habitats in the Snake River where the model predicted fish presence could be the result of the low number of fall chinook salmon in the Snake River. If so, then there is more suitable rearing habitat available in the Snake River than is currently being used.

The results of this study suggest that subyearling fall chinook salmon habitat use is similar between the free-flowing Snake River and the Hanford Reach of the Columbia River. Habitat variables such as gradient and velocity seem to be most important in determining fish presence. Substrate and embeddedness do not seem to be important criteria for habitat

selection, except for avoidance of bedrock cliffs and man-made boulder areas.

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**CHAPTER FIVE**

Thermal Exposure of Juvenile Fall Chinook Salmon  
Migrating Through Little Goose Reservoir, 1998

by

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## Introduction

Hydroelectric development in the Columbia River basin has resulted in the impoundment of much of the Snake River. One of the negative effects of this development is an altered thermal regime in the river. While annual maximum water temperatures in reservoirs may not be different from free-flowing reaches, temperatures peak later and stay elevated longer in reservoirs (Karr et al. 1998). High water temperatures can delay adult arrival timing at spawning sites, and can increase predation on juvenile salmon as a result of increased predator metabolism (Poe et al. 1991; Vigg and Burley 1991).

The life history of juvenile Snake River fall chinook salmon *Oncorhynchus tshawytscha* may make them particularly vulnerable to high, late-summer temperatures. Fall chinook salmon migrate seaward as subyearlings after rearing near natal areas for 2-3 months. Most fall chinook salmon migrate through the impounded lower Snake River (four dams) during the months of July and August when reservoir temperatures are routinely above 20°C. This is near the upper incipient lethal temperature of 24°C for juvenile spring chinook salmon (Brett 1952). The effects of chronic exposure to sublethal temperatures on fall chinook salmon migratory behavior, disease resistance, and predator avoidance remain unexplored. Answers to these questions may affect recovery efforts for this Endangered Species Act listed stock (NMFS 1992).

Information on thermal histories of juvenile fall chinook salmon migrating through lower Snake River reservoirs is unavailable. Applying water temperature data collected at fixed-site monitoring stations to fisheries data may not be accurate since there is no way of knowing how these temperatures compare to those experienced by the fish. However, recent advances in miniature electronics have resulted in the production of temperature-sensing radio transmitters suitable for use in fish as small as 120 mm fork length. To the best of our knowledge, these tags have not been used in field applications, but may make it possible to obtain thermal histories on migrating salmon.

This study was initiated to 1) determine the suitability of temperature-sensing radio tags for field use, 2) obtain thermal histories from juvenile fall chinook salmon in Little Goose Reservoir, and 3) determine if temperatures selected by juvenile

fall chinook salmon were different from those generally available in the reservoir.

## Methods

Little Goose Reservoir is located on the lower Snake River in eastern Washington (Figure 1). The reservoir was created in 1970 with the completion of Little Goose Dam (Snake River kilometer (RK) 112.8), and is approximately 60.3 km long. Lower Granite Dam (RK 173) is the only dam upriver of Little Goose Dam before the free-flowing Hells Canyon Reach, where Snake River fall chinook salmon spawn naturally (Connor et al. 1993). We divided Little Goose Reservoir into three reaches for our study: Reach 1 extended from Lower Granite Dam downstream to Rice Bar (RK 149.8), Reach 2 extended from Rice Bar to Central Ferry (RK 131.7), and Reach 3 extended from Central Ferry to Little Goose Dam.

### *Laboratory Procedures*

Miniature temperature-sensing radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA) were used to collect thermal histories from juvenile fall chinook salmon. Transmitters were 17 mm long, 6 mm in diameter, weighed 1.7 g in air, and had a life span of 8 to 10 d. The transmitters operated on unique frequencies, and had pulse intervals (in milliseconds) which varied directly with temperature. The manufacturer provided equations for each tag to convert pulse interval to temperature.

Laboratory tests were conducted at the Columbia River Research Laboratory (CRRL) to determine tag performance before field application. We evaluated tag accuracy, tag response time, quality of manufacturer's conversion equations, output accuracy, and time to output stabilization. Tag accuracies were determined at 19, 20, 21, and 22.0°C, the anticipated range of field temperatures, by comparing stabilized output temperatures to temperatures measured by a thermometer. Tag response time to stabilization was recorded for temperature changes (0.5, 1.0, 2.0, 4.0, 6.0, and 8.0°C) between 7 and 23°C. Three test tags were placed in an insulated container of water for 10 min and allowed to stabilize at an initial temperature. Stable water temperatures were maintained within  $\pm 0.1^\circ\text{C}$ , and were measured with a mercury thermometer meeting ANSI/SAMA accuracy requirements. The tags were then transferred to a test container with a different water temperature and the pulse intervals were recorded for 10 min. The tags were then immediately returned to the initial container. This test was repeated for all changes in water

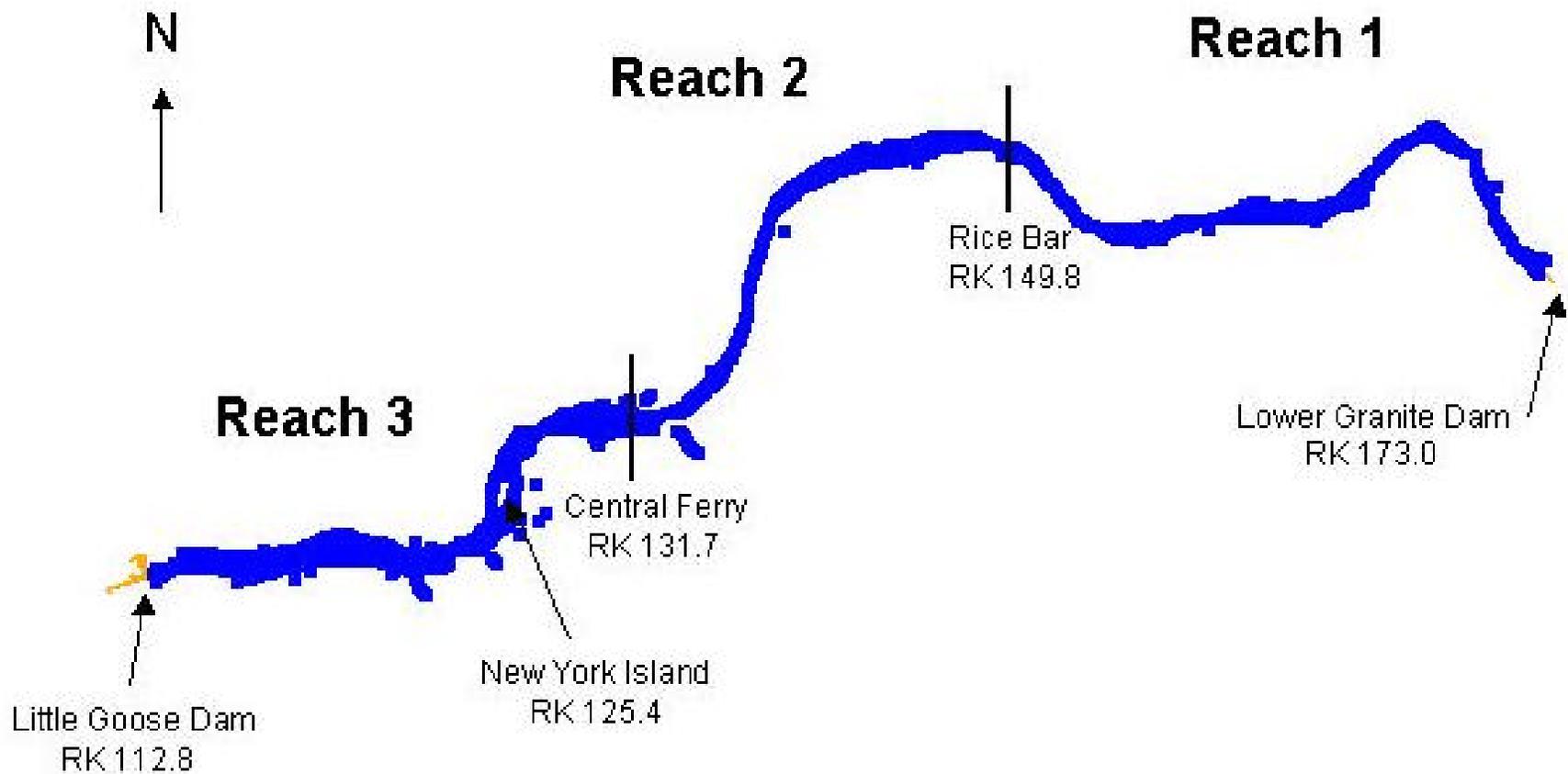


Figure 1.-Map of Little Goose Reservoir on the Snake River showing study reaches and important landmarks in river kilometers (RK).

temperature. Regression analysis was then used to determine the relationship between temperature and the recorded pulse interval. Our regression equations were compared to those provided by the manufacturer by determining if slopes and intercepts were significantly different (SAS 1996).

Response time to stabilization was also evaluated by surgically implanting tags in juvenile chinook salmon. Two fish were implanted as described in Adams et al. (1998) and allowed to recover for 24 h after surgery. Test fish were exposed to temperature changes of 0.5, 1.0, 2.0, 4.0, 6.0, and 8.0°C, with one fish tested over a range of 15 to 7°C and the other tested from 15 to 23°C. Tag output was recorded for 15 minutes. To standardize our stabilization time estimates, tag output was first graphed. A mean and standard deviation (STD) was calculated for the tail portion of the output curve, which represented stabilization. Critical value lines were created at  $\pm 2$  STD to create an approximate 95% confidence interval around the mean. When the output value crossed the appropriate critical value line, the output was considered stabilized, and time was measured to that point.

### *Field Procedures*

To obtain thermal histories from in-river migrants, we tagged naturally-produced juvenile fall chinook salmon collected at the Lower Granite Dam juvenile fish collection facility between 8 July and 31 August 1998. Fish selected for tagging were at least 120 mm fork length (FL) and had no visible signs of injury or stress. Fish were anesthetized in a 100 mg/L solution of buffered tricaine methanesulfonate (MS-222) and weighed and measured. A temperature-sensing radio transmitter with a unique frequency was then gastrically implanted in the fish using the technique described by Burger et al. (1985). After tagging, fish were allowed to recover for approximately 24 h before being released into the Lower Granite Dam tailrace via the PIT-tag bypass pipe.

Ten groups of 6 to 7 tagged fish were released at regular intervals spread over five 10-d periods (Period 1: July 10 - July 19, Period 2: July 20 - August 1, Period 3: August 2 - August 14, Period 4: August 15 - August 28, Period 5: August 29 - September 15). One fish from each release group was tracked by boat as it migrated through the reservoir. The fish with the strongest signal was selected and tracked continuously for 48 h. Each hour, a fish location and a temperature profile were collected for the selected fish. The radio signal was received by a data-logging receiver (Lotek Engineering Inc., Newmarket, Ontario, Canada), which recorded

the transmitter date, time, frequency, signal strength, and pulse rate (milliseconds). Pulse rates were later converted to temperature for analysis. The location of the fish was determined by using a six-element Yagi antenna to direct the boat towards the signal. When the boat passed directly over the fish, the signal strength would drop abruptly. At this point, the boat was stopped, the latitude and longitude were recorded and the location entered as a waypoint into a real-time differentially corrected global positioning system receiver (GPS, maximum error  $\leq 16$  m). This method produced an estimated tag location within 6 m of the actual tag location (Banach and Steward 1997). While the boat operator held this position, a second crew member lowered a bathythermograph (Ocean Sensors, Inc., San Diego, California, USA) to obtain a temperature and depth profile at the fish location. Surface temperature was measured with a stick thermometer.

Reservoir temperatures were monitored with a second bathythermograph (BT) during the study. Twenty-five transects were set up throughout the reservoir from Lower Granite Dam to Little Goose Dam. The bathythermograph was lowered at five locations along each transect (south shoreline, 25% channel width, 50% channel width, 75% channel width, and north shoreline). Shoreline drops were made as near to shore as possible while staying within water 3-4 m deep. Data was collected from each transect at approximately 10-d intervals.

Fish movement and temperature exposure were also monitored by fixed-site receivers connected to stationary antenna arrays. Stationary antenna arrays were similar to that used by Venditti and Kraut (1999). These arrays were used to confirm mobile collection data, monitor the movement and temperature exposure of the other tagged fish, and monitor temperature exposure of fish in the forebay of Little Goose Dam.

### *Data Analysis*

Mobile tracking and fixed-site detection records were used to construct thermal histories for each fish. Fish temperature records that were outside of the range (19-27 °C) recorded by BT temperature profiles were considered inaccurate and discarded from analyses. Mobile temperature data from fish in Reach 3 were combined with fixed-site data from New York Island and Little Goose forebay to increase sample sizes in that reach. Mean water temperatures experienced by fish were examined for longitudinal (reach) and seasonal (time period) differences using two-way analysis of variance (ANOVA; SAS 1996). The

percent of records occurring in 1°C temperature classes was also calculated for each reach and time period.

Mean water temperatures measured by the BT were examined for longitudinal (reach) and seasonal (time period) differences using two-way ANOVA. We compared the frequency distributions of water temperatures used by tagged fish with the distributions of BT-measured temperatures, by reach and time period, using chi-square analysis. *t*-tests were used to compare temperature differences within the water column.

Our comparison of transmitter and BT temperature was limited by signal attenuation of the transmitters; we were unable to effectively detect fish that had sounded to a depth greater than 10 m. Therefore, we compared transmitter temperatures to both BT temperatures from the whole water column, and BT temperatures from only the top 10 m of the water column.

## Results

### *Laboratory tests*

The regression equations produced at CRRL for temperature transmitter output did not differ from those provided by the manufacturer (slope and intercept values did not differ significantly,  $P < 0.05$ ). Therefore, the manufacturer's regression equations were used to derive temperatures from radio tag outputs. Temperature-sensing radio tags were found to be very accurate in laboratory tests. The difference between water temperatures measured by radio tags and the stick thermometer averaged  $\pm 0.03^\circ\text{C}$  (range  $\pm 0.00$  to  $0.07^\circ\text{C}$ ). In *in vitro* tests, the response time for tags to stabilize after a change in temperature ranged from 47 s ( $0.5^\circ\text{C}$  change) to 1 min 15 s ( $8.0^\circ\text{C}$  change). When tags were implanted in fish, stabilization times ranged from 2 min 16 s ( $0.5^\circ\text{C}$  change) to 4 min 34 s ( $6.0^\circ\text{C}$  change). Response times generally increased directly with the magnitude of the temperature change.

### *Field tests*

A total of 69 juvenile fall chinook salmon were tagged with temperature-sensing radio transmitters and released into Little Goose Reservoir. There were 10 releases of 6-7 fish per release. The mean size of radio-tagged fish increased seasonally from 134 mm and 32.0 g

to 170 mm and 65.0 g (Table 1). Tag retention during the 24-h recovery period was 99% (one spit tag), and there were no mortalities.

The overall percentage of radio-tagged fish detected by mobile tracking and at the four fixed-site antenna arrays was 80%. Fifty-three percent of tagged fish were detected during mobile tracking and 41% were detected at fixed-sites. The percentage of radio-tagged fish detected at individual fixed-site arrays was 35% at New York Island, 36% at the forebay barges, 41% at Little Goose Dam, and 39% at exit locations below Little Goose Dam.

Ten fish were tracked as primary fish. However, it was often necessary to monitor other fish if the primary fish could not be located or did not move for a period of 4 h. The number of temperature records collected on individual primary fish ranged from 435 to 9,928 (mean=4,422). The number of temperature records collected on alternate fish ranged from 1 to 660 (mean=103). The high number of records obtained on fish during mobile tracking (Figure 2) indicated that fish generally traveled through the reservoir in the top 10 m of the water column.

Analysis of BT temperature records indicated that vertical differences in temperatures in the water column were minimal (Figure 3). Temperatures were typically highest in the top 1 m, and were generally uniform from 1 m to the bottom. Mean surface water temperature (21.4°C) was significantly greater than mean water column temperature (20.6°C;  $t = -2.65$ ,  $P = 0.0302$ ). Mean temperature below 10 m was 20.6°C, whereas mean temperature above 10 m was 20.8°C. The mean temperature above 10 m was significantly greater than mean temperature below 10 m ( $t = 37.99$ ,  $P = 0.0001$ ).

Juvenile fall chinook salmon were exposed to higher water temperatures as they migrated downstream through Little Goose Reservoir (Table 2). The percent of tagged fish found in water temperatures from 21°C to 22°C was 6.1% in Reach 1, 18.1% in Reach 2, and 43.7% in Reach 3. Mean temperature exposure in Reach 3 (22.3°C) was significantly higher than in Reach 1 (20.5°C) or Reach 2 (20.6°C). Two-way ANOVA showed that the reach and time period variables, as well as the interaction term, were all significant ( $P < 0.0001$ ), however, the reach variable explained a greater amount of model variance ( $F =$

Table 1. - Release dates, number of fish released (*N*), and mean fork lengths and weights, with standard deviations in parentheses, of radio-tagged juvenile fall chinook salmon released into Little Goose Reservoir during July-September, 1998.

Release number	Release date	<i>N</i>	Length (mm)	Weight (g)
1	7/10	7	139 (8.8)	35.7 (6.7)
2	7/12	7	137 (10.8)	35.1 (8.6)
3	7/20	6	136 (12.2)	33.1 (10.5)
4	7/22	7	139 (10.0)	35.1 (6.9)
5	8/01	7	139 (6.8)	34.3 (8.0)
6	8/04	7	146 (5.4)	41.2 (4.3)
7	8/15	7	154 (6.7)	48.7 (6.5)
8	8/17	7	154 (9.3)	49.1 (9.0)
9	8/29	7	164 (4.0)	59.3 (5.3)
10	8/31	7	168 (10.3)	64.7 (12.0)
Overall	--	69	148 (8.4)	43.6 (7.8)

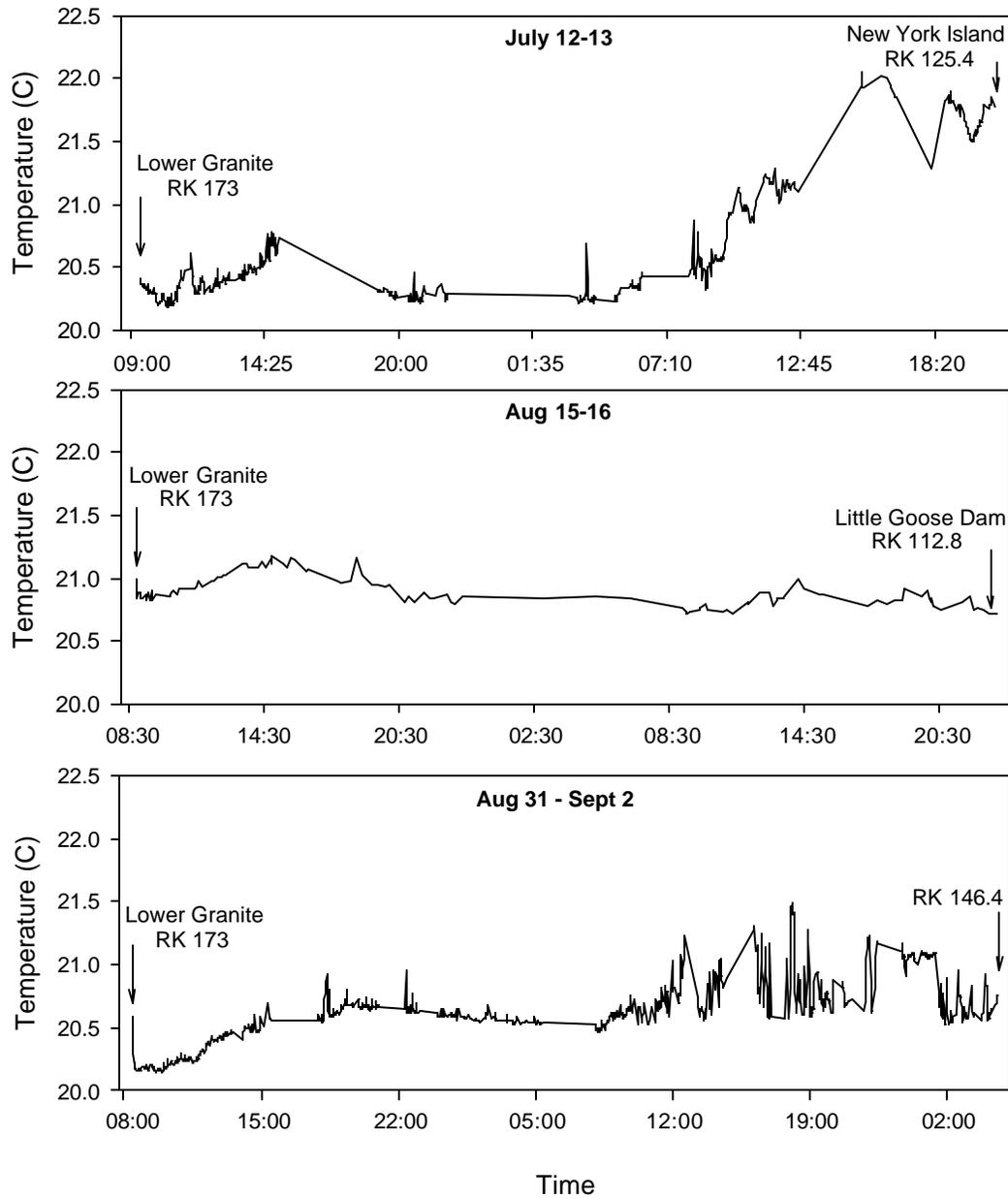


Figure 2.-An example of thermal histories collected from individual fish in Little Goose Reservoir from three different time periods in 1998. Starting and ending locations are shown for each fish.

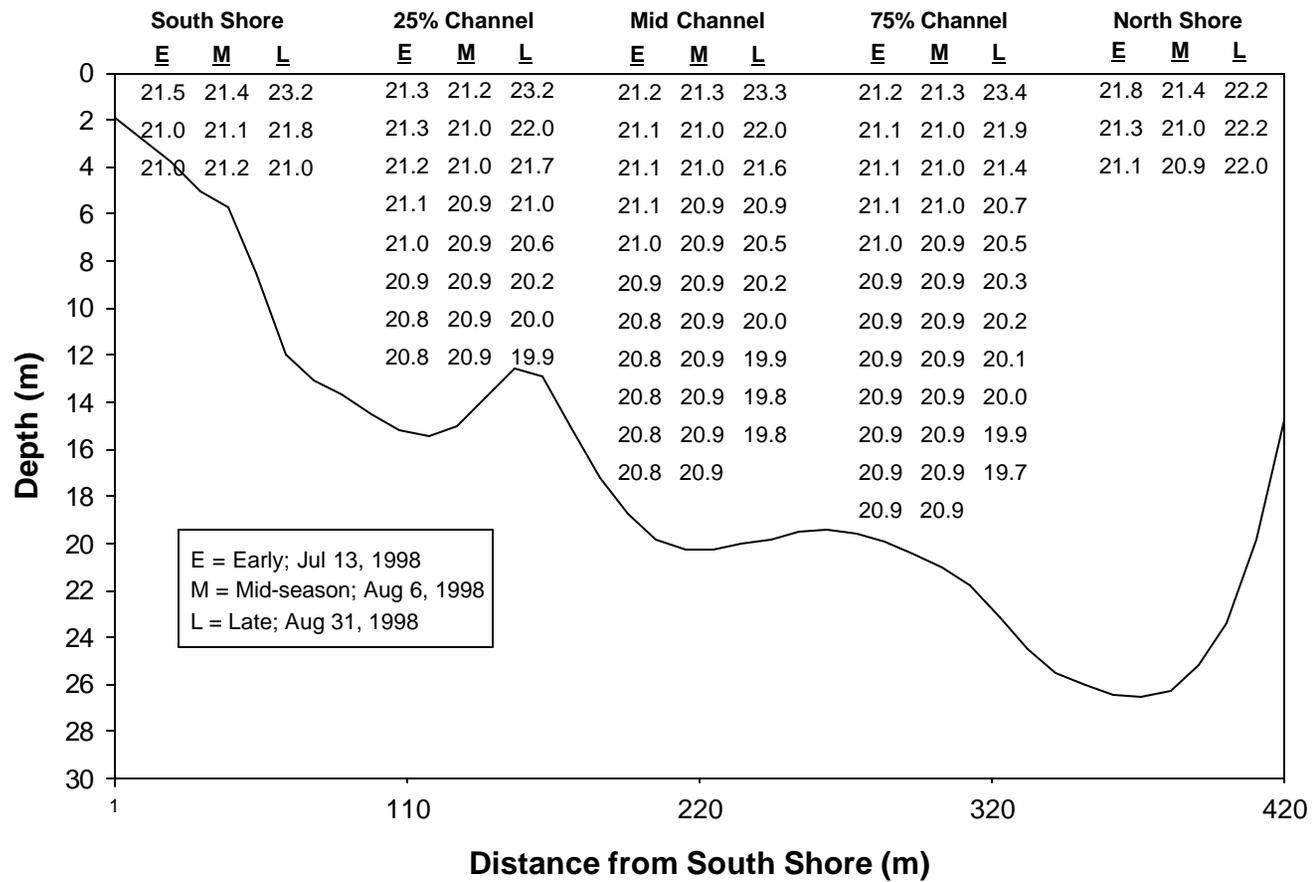


Figure 3.-An example of thermal profiles collected along a cross section of Little Goose Reservoir at river kilometer 90.0 in 1998. Temperatures (C) were collected with a bathythermograph except for the surface temperature, which were collected with a stick thermometer.

Table 2.-Mean temperatures (°C) experienced by juvenile fall chinook salmon implanted with temperature-sensing radio transmitters in Little Goose Reservoir, 1998. Temperatures are shown by river reach and time period. Sample sizes represent the number of temperature records used to calculate the mean and are shown in parentheses.

Time period	Reach 1	Reach 2	Reach3
Jul 10 - Jul 19	20.8 (1,562)	21.1 (313)	21.0 (1,526)
Jul 20 - Aug 1	20.8 (1,313)	21.4 (1,057)	23.6 (2,248)
Aug 2 - Aug 14	20.5 (8,162)	20.7 (1,247)	24.3 (1,876)
Aug 15 - Aug 28	20.4 (5,946)	20.3 (4,783)	21.6 (7,277)
Aug 29 - Sep 15	20.5 (16,691)	20.7 (929)	---

10,931,  $P < 0.0001$ ) than time period ( $F = 2,179$ ,  $P < 0.0001$ ) or the interaction term ( $F = 1,621$ ,  $P < 0.0001$ ).

Longitudinal and seasonal changes in water temperature in Little Goose Reservoir were similar to those observed for radio-tagged fish. Water temperatures were highest in the lower portion of the reservoir (Reach 3) and exhibited a seasonal peak in early to mid August (Table 3). Two-way ANOVA revealed that longitudinal temperature variation ( $F = 6,529$ ,  $P < 0.0001$ ) was greater than season variation ( $F = 2,962$ ,  $P < 0.0001$ ) during our study period. There was a significant interaction between reach and time period variables, but it accounted for less variation than the main effect variables ( $F = 929$ ,  $P < 0.0001$ ).

Temperatures experienced by fish migrating through Little Goose Reservoir were variable in relation to available water temperatures. During July 10-19 and August 2-14 (Periods 1 and 3), fish selected temperatures similar to available temperatures (Table 4). Fish selected warmer temperatures from July 20 to August 1 (Period 2), but selected cooler water over that generally available during the latter half of August and early September (Periods 4 and 5). Comparisons of mobile BT and radio-tagged fish temperature distributions, by time period, were all significantly different ( $P < 0.0001$ ) using chi-square analysis.

## Discussion

Our laboratory tests confirmed that temperature-sensing radio tags had sufficient accuracy and precision for use in our intended field study. Furthermore, the individual regression equations provided by the manufacturer proved accurate for the expected range of temperatures encountered in the field. The time for tags to stabilize (response time) was usually a couple of minutes depending on the change in temperature experienced. We considered this amount of time to be inconsequential since we collected data on individual fish for up to 48 h. In addition, the range of temperatures experienced by fish in Little Goose Reservoir was typically less than 1°C.

Temperatures measured in Little Goose Reservoir using a bathythermograph showed that the reservoir was well mixed and not thermally stratified, and contained no areas of thermal refugia where fish might escape higher water temperatures. Generally, there was not a wide range of temperatures for fish

Table 3.-Mean water column temperatures (°C) from bathythermograph transects in Little Goose Reservoir, 1998. Temperatures are shown by river reach and time period. Sample sizes represent the number of temperature records used to calculate the mean and are shown in parentheses.

Time period	Reach 1	Reach 2	Reach3
Jul 10 - Jul 19	20.9 (792)	20.8 (4,710)	21.0 (6,202)
Jul 20 - Aug 1	19.7 (2,466)	20.7 (4,288)	20.9 (5,368)
Aug 2 - Aug 14	20.1 (1,661)	21.2 (2,557)	21.3 (4,954)
Aug 15 - Aug 28	20.1 (2,268)	20.1 (4,413)	20.8 (4,231)
Aug 29 - Sep 15	20.0 (2,574)	20.3 (3,442)	20.5 (4,800)

Table 4.-Percent frequency of temperatures in two degree classes for five time periods in 1998 as measured with a bathythermograph (BT) for the whole water column and temperature-sensing radio transmitters (Fish). BT and Fish temperature distributions were significantly different ( $P < 0.0001$ ) from each other, for each time period, as determined by chi-square analysis.

Data source	Temperature class (°C)			
	19-21	21-23	23-25	25-27
<b>Jul 10 - Jul 19</b>				
BT	85.3	14.7	0.0	0.0
Fish	85.0	11.4	2.2	1.4
<b>Jul 20 - Aug 1</b>				
BT	82.9	16.4	0.6	0.1
Fish	56.8	38.9	2.4	1.9
<b>Aug 2 - Aug 14</b>				
BT	92.1	7.9	0.0	0.0
Fish	91.3	8.5	0.1	0.1
<b>Aug 15 - Aug 28</b>				
BT	52.1	47.9	0.0	0.0
Fish	88.1	11.6	0.1	0.2
<b>Aug 29 - Sep 15</b>				
BT	60.1	39.0	0.9	0.0
Fish	93.1	6.9	0.0	0.0

to choose from. The highest temperatures were in the top 1 m of the water column, and were the result of solar warming. While we found that water below 10 m was significantly cooler than water above 10 m, the difference was only 0.2°C. This was likely the result of our large sample size (N = 41,909), which can increase the chance of finding a significant difference between two means (Cody and Smith 1997), and is probably not biologically significant.

Water temperatures increased both seasonally and longitudinally in Little Goose Reservoir during our study, and may negatively affect juvenile fall chinook salmon migratory behavior and survival. Temperatures were highest in the forebay of Little Goose Dam where smolts can be delayed for a week or more during their migration (Venditti and Kraut 1999). This delay increases fish exposure to high temperatures that can increase the risk of disease and predation (Vigg and Burley 1991). High temperatures may also reduce gill ATPase activity, a measure of smoltification that has been associated with migratory behavior in chinook salmon (Zaugg 1989; Beeman et al. 1991). One consequence to Snake River juvenile fall chinook salmon of migrating during the seasonally warmest water temperatures of the year is reduced survival. High water temperatures have been associated with low survival for both wild and hatchery Snake River fall chinook salmon (Connor - this report; Muir et al. 1998).

Although average annual water temperature has not changed due to hydroelectric development, peak summer temperatures have been delayed by as much as 30 d (Jaske 1969). Because reservoirs have a higher heat storage capacity than rivers, it takes longer for temperatures to drop following peak temperatures. Our results indicate that longitudinal differences in mean water temperature in Little Goose Reservoir are more significant than those resulting from seasonal fluctuations. In 1998, we recorded surface temperatures as high as 26.7°C in the forebay of Little Goose Dam. It appears that the risks associated with higher water temperature will be greatest in the surface waters of the forebay during and after peak summer temperatures.

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**CHAPTER SIX**

Morphological Differences Between Juvenile Fall and Spring  
Chinook Salmon Migrating Through the Lower Snake River

by

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## Introduction

Declines in the populations of Snake River fall and spring chinook salmon *Oncorhynchus tshawytscha* prompted their listing as threatened under the Endangered Species Act (ESA) in 1992 (NMFS 1992), and increased interest in identifying run characteristics. Spring and summer chinook salmon are considered to be a single evolutionarily significant unit (ESU; National Marine Fisheries Service, unpublished), and will hereafter be referred to as spring chinook salmon. Fall chinook salmon have an ocean-type life history that is characterized by seaward migration in the summer within 2-3 months of fry emergence (Taylor 1990; Healey 1991). In contrast, spring chinook salmon display a stream-type life history which is accompanied by rearing in tributaries for a year before initiating seaward migration in the spring as yearlings (Healey 1991). Yearling and subyearling chinook salmon migrations are generally temporally segregated, but some yearling spring chinook salmon also migrate during the summer (Achord et al. 1996). Late migrating yearlings comprised 12-78% of the summer outmigration past Lower Granite Dam—the upper-most dam on the lower Snake River—from 1992 to 1997. This is based on the number of yearling and subyearling chinook salmon that pass the dam from June 1 through late October (Fish Passage Center, unpublished data). This overlap necessitates having criteria to separate the two runs to allow for the estimation of population attributes such as run size and timing.

Currently, personnel monitoring the smolt outmigration classify juvenile chinook salmon as subyearlings or yearlings under the assumption that all subyearling chinook salmon are of the fall run, while yearlings are of the spring run. This would seem reasonable considering the life history differences of the two runs. However, genetic samples collected from juvenile Snake River chinook salmon since 1991 have shown that while all yearlings are of the spring run, in some years (e.g. 1993) subyearling spring chinook salmon dominate the subyearling population (Marshall et al. 1999). The presence of subyearling spring chinook salmon in the summer migrant population invalidate the assumption that all subyearlings are of the fall run, and complicate efforts to distinguish between the two runs.

Current methods used to distinguish between fall and spring chinook salmon at smolt monitoring facilities are highly subjective. Fish length is used to separate larger yearling from smaller subyearling chinook salmon when size differences

exist. However, subyearling chinook salmon are often just as large as yearlings at lower Snake River dams. The principal means used to separate the two runs is based on subjective morphological differences observed by smolt monitoring personnel. Head, eye, and body characteristics are the primary discriminators, but have not been statistically validated. Morphology has also been used by others to distinguish between many populations and runs of Pacific salmon (Carl and Healey 1984; Taylor and McPhail 1985; Taylor 1986; Swain and Holtby 1989; Beeman et al. 1994). The objective of this study was to determine if morphological characters could be used to distinguish juvenile Snake River fall chinook salmon from spring chinook salmon during the summer migration.

### Methods

Subyearling chinook salmon were collected and tagged with passive integrated transponders (PIT tags; Prentice et al. 1990) as they reared along a 137-km reach of the Snake River between river kilometers 224 and 361 from 1991 to 1997 (Connor et al. 1998). PIT-tagged fish were released where they were collected. We subsequently recaptured a portion of PIT-tagged fish each year at Lower Granite or Little Goose dams on the Snake River in eastern Washington. Fish were obtained from bypass facilities as described in Matthews et al. (1977) during the summer migration from June through October. Fin-clipped spring chinook salmon and PIT-tagged subyearling chinook were targeted for collection to obtain fish of known origin. A portion of PIT-tagged fish were sacrificed to determine their run using starch-gel electrophoresis and genotypic sorting (Marshall et al. 1999). Only known-run fish were used in analyses. Scales were collected from sample fish and analyzed according to Jearld (1983) to determine fish age.

A subjective 3x4-level morphological code was assigned to each fish to classify fish run based on head shape, eye diameter, and body depth (Table 1). These three characters were selected based on morphological differences between spring and fall chinook salmon perceived by personnel monitoring smolts at Lower Granite Dam. Codes of 1 and 2 were indicative of spring-like characteristics, whereas codes of 3 and 4 described fall-like features. Head, eye, and body codes were summed to derive an overall score for each fish, which ranged from 3 (most spring-like) to 12 (most fall-like). Fish with a score of 3 to 7 were classified as spring chinook salmon, and fish with a

Table 1.—Morphological codes used to describe head, eye, and body characteristics for classifying juvenile chinook salmon run.

Code	Head	Eye	Body
1	Blunt	Large diameter	Long and shallow
2	Less blunt	Medium diameter	Shallow
3	Less pointed	Small diameter	Medium deep
4	Pointed	Small diameter and down-turned	Deep

score of 8 to 12 were classified as fall chinook salmon. The division between 7 and 8 ensured that fish with a score of 7 had at least two spring-like characteristics, and fish with a score of 8 had at least two fall-like characteristics. There were only two fish for which this did not hold, and they were excluded from analyses.

In addition to assigning a morphological code, all fish were anesthetized and immediately photographed for more rigorous morphological analyses. Fins were held out with pins to better show insertion points on the body. A 150-mm ruler was placed next to each fish to provide a standard reference scale. Morphometric information was obtained from photographs by digitizing landmarks in an X-Y coordinate space (Winans 1984) from a truss system on each fish (Strauss and Bookstein 1982). Sixteen landmarks were chosen to form the truss system, as in Beeman et al. (1994) although an additional point was added to measure eye diameter (Figure 1). Distances between landmarks were calculated using the Pythagorean theorem and a computer, and resulted in 35 morphometric characters. Character measures were adjusted using the scale in each photograph so that digitized distances corresponded to 2-dimensional distances on each fish.

Principal components analysis was used to reduce the 35 morphometric characters to a smaller data set of uncorrelated variables to simplify interpretation of shape differences, and to facilitate the separation of fish races using discriminant function analysis. All data were log transformed (base 10), and principal components (PCs) were calculated using the variance-covariance matrix since all measures were in the same units (Bookstein et al. 1985). The second (PC2) and third (PC3) principal components were sheared using the method of Humphries et al. (1981) as reformulated by Rohlf and Bookstein (1987) to adjust for the effects of fish size in shape analyses. The first principal component was assumed to represent general size and was not sheared. Univariate normality of sheared PC2 and PC3 was evaluated by examining normal probability plots (SAS 1996).

Discriminant function analysis of sheared PC2 and PC3 scores was used to classify fish into one of three groups: 1) subyearling fall chinook salmon ( $N = 299$ ), 2) subyearling spring chinook salmon ( $N = 127$ ), and 3) yearling spring chinook salmon ( $N = 388$ ). The prior probability of group membership was set proportional to group sample size. Homogeneity of the within-

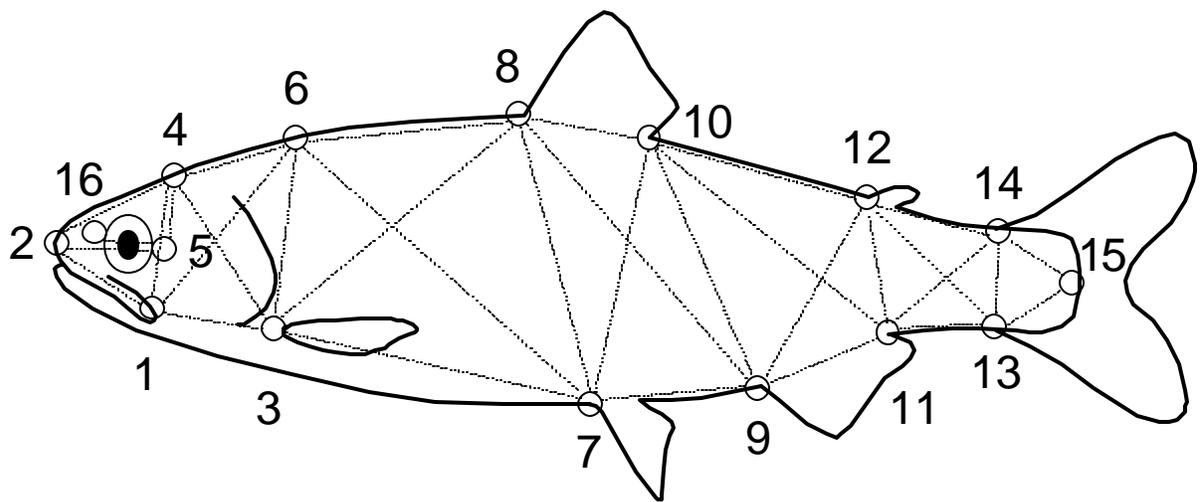


Figure 1.-Locations of 16 landmarks(open circles) and 35 morphometric characters (broken lines) used to develop a truss network. Landmarks are from Beeman et al. (1994) with the exception of point 16, which is located at the most anterior point of the eye.

group variance-covariance matrices was tested using Bartlett's modification of the likelihood ratio test to determine whether linear or quadratic discriminant functions were appropriate (SAS 1996).

The classification results of the discriminant function using all data in a training set were compared to those using a cross-validation classification procedure. In this method, an individual was removed from the data set, and a discriminant function was calculated using the remaining individuals. The excluded individual was then classified to a particular group according to the function. This process was repeated for each individual in the data set, and classifications were tabulated for each group. Since prior probabilities of group membership were unequal, classification rates were tested against those expected by chance using Cohen's *kappa* statistic (Titus et al. 1984). The value of *kappa* ranges from zero to one; with zero indicating no improvement over random chance, while a value of one results from perfect assignment. An intermediate value of *kappa*, such as 0.70, indicated that classification based on the discriminating variables is 70% better than chance assignment. Ninety-five percent confidence intervals (CI) and the probability of *kappa* being significantly different from zero were also calculated.

## Results

The first three principal components, which accounted for 92.1% of the total variation in morphometric measurements, were retained for analyses. These principal components were retained based on the amount of variability they explained and their interpretability. Normal probability plots revealed that both sheared PC2 and PC3 scores were approximately normal. The first principal component, which explained 85% of the variation, was highly correlated with fork length ( $r = 0.98$ ;  $N = 814$ ), and the similarity of signs and magnitudes of loadings on this component indicated it explained differences due to size (Table 2). Sheared PC2 and PC3 accounted for 4.4 and 2.8% of the total variation, respectively. The contrasts of signs and loadings of these components indicated that they contained mainly shape information (Table 2).

Shape differences between the three groups of fish existed primarily in the head, mid-body, and caudal peduncle regions. Highly negative loadings on sheared PC2 summarized differences

Table 2.—Loadings of juvenile chinook salmon morphometric characters on the first three principal components. Percent of variation explained by each principal component is shown at the bottom of each column. Refer to Figure 1 for character descriptions.

Character	PC1	Sheared PC2	Sheared PC3
1-2	0.149	-0.111	-0.214
1-3	0.172	-0.039	-0.038
2-3	0.165	-0.056	-0.102
2-4	0.136	-0.241	-0.198
2-5	0.139	-0.203	-0.304
4-5	0.128	-0.315	-0.061
4-6	0.184	0.094	0.071
2-6	0.164	-0.046	-0.052
1-6	0.167	-0.022	-0.008
3-4	0.169	-0.005	-0.036
1-4	0.135	-0.224	-0.119
3-6	0.176	0.087	-0.011
3-7	0.172	0.061	0.073
6-8	0.169	0.049	0.049
6-7	0.177	0.105	0.019
3-8	0.174	0.077	0.060
7-8	0.193	0.215	0.009
7-9	0.178	-0.059	0.098
8-10	0.175	0.021	0.027
8-9	0.186	0.098	0.043
7-10	0.189	0.203	0.018
9-10	0.189	0.162	0.043
9-11	0.170	0.114	-0.079
10-12	0.164	0.140	0.015
9-12	0.175	0.185	0.009
10-11	0.178	0.091	0.017
11-12	0.192	0.066	0.085
11-13	0.142	-0.286	0.318
12-14	0.166	-0.351	0.372
12-13	0.176	-0.189	0.184
11-14	0.153	-0.190	0.325
13-14	0.181	-0.013	0.071
14-15	0.197	0.189	-0.340
13-15	0.192	0.138	-0.158
5-16	0.099	-0.391	-0.468
Variation explained	85.0%	4.4%	2.8%

in head shape and peduncle length, while highly positive loadings on two body measures summarized variation in body depth (Table 2; Figure 2). Subyearling fall chinook salmon were well separated from yearling spring chinook salmon using this component, having smaller heads and eyes, deeper bodies, and shorter caudal peduncles (Figure 3). Subyearling spring chinook salmon were intermediate to fall and yearling spring chinook in these areas, but were more like subyearling fall chinook salmon.

Sheared PC3 explained additional variation in the head and caudal peduncle regions beyond that of sheared PC2. Subyearling spring chinook salmon were separated from subyearling fall chinook and yearling spring chinook on sheared PC3, but the latter two were poorly separated from each other on sheared PC3 (Figure 3). Additional interpretable shape differences on sheared PC3 showed that subyearling spring chinook salmon had a deeper and more truncated caudal peduncle, and a shorter maxillary than subyearling fall chinook and yearling spring chinook salmon (Figure 2).

Morphological characteristics were useful in separating subyearling fall chinook and yearling spring chinook salmon using discriminant function analysis, but the classification of subyearling spring chinook salmon was poor. A quadratic function was used because of significant differences between the within-group variance-covariance matrices. Training set and cross-validation classifications were identical, indicating no bias between the two methods. Both subyearling fall chinook and yearling spring chinook salmon correct classification rates exceeded 80%, but subyearling spring chinook salmon were classified with only 26% accuracy (Table 3). Incorrectly classified subyearling spring chinook salmon were evenly split between the subyearling fall chinook and yearling spring chinook groups. The *kappa* indicated that correct classifications were only 59% better than that expected by random chance, but were significantly different from zero (*kappa* = 0.59, 95% CI = 0.54 to 0.64,  $P < 0.0001$ ).

A separate PC and discriminant analysis using only subyearling fall and yearling spring chinook salmon was run to determine if removal of subyearling spring chinook salmon from the three-group analysis improved classifications and the *kappa* statistic. In this two-group analysis, subyearling fall chinook were classified with 84% accuracy, and 90% of yearling spring chinook salmon were correctly classified (Table 3). The *kappa* indicated assignments were 75% better than random chance (*kappa*

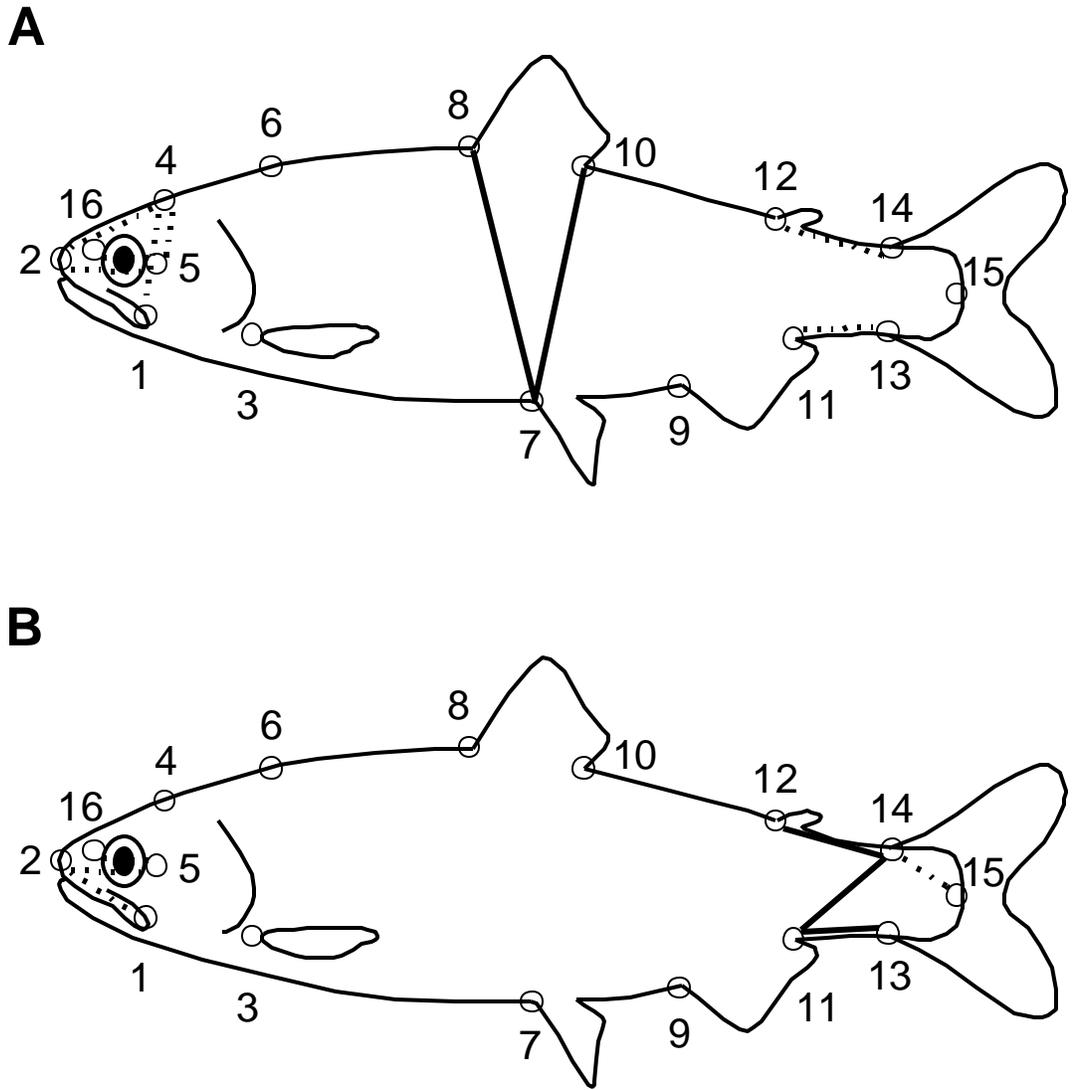


Figure 2.- Morphometric characters with important loadings on sheared PC2 (A) and sheared PC3 (B). Solid lines denote positive loadings and broken lines denote negative loadings.

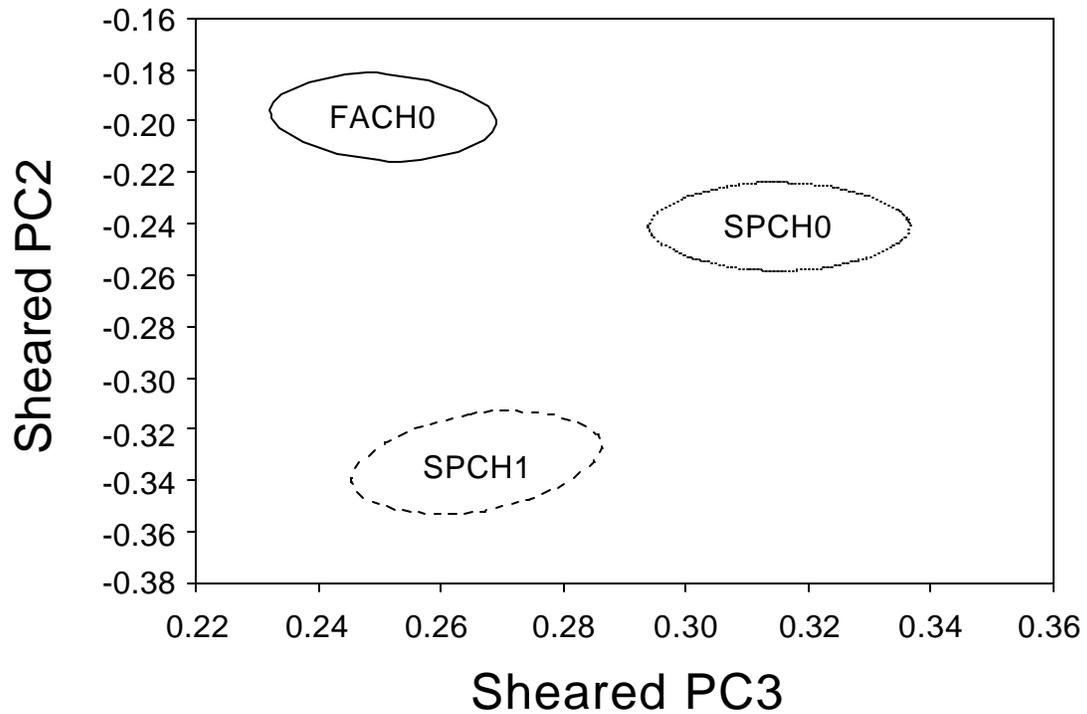


Figure 3.-Ninety-five percent confidence ellipses for bivariate means of sheared PC2 and PC3 scores for three groups of juvenile chinook salmon. Groups are abbreviated FACH0 for subyearling fall chinook, SPCH0 for subyearling spring chinook, and SPCH1 for yearling spring chinook salmon.

Table 3.—Classification of group membership of juvenile chinook salmon using a quadratic discriminant function developed using sheared principal components scores of morphometric measurements. Prior probability of group membership and *kappa* are shown as well. Actual groups are abbreviated FACH0 for subyearling fall chinook, SPCH0 for subyearling spring chinook, and SPCH1 for yearling spring chinook.

Actual group	Number classified into each group			Total	% correct
	FACH0	SPCH0	SPCH1		
<b>Three-group training set</b>					
FACH0	246	14	39	299	82
SPCH0	48	33	46	127	26
SPCH1	35	16	337	388	87
<b>Three-group cross-validation set</b>					
FACH0	245	15	39	299	82
SPCH0	48	33	46	127	26
SPCH1	35	16	337	388	87
Probability of membership	0.3673	0.1560	0.4767		
<i>kappa</i> = 0.54					
<b>Two-group training set</b>					
FACH0	254	---	45	299	85
SPCH1	36	---	352	388	91
<b>Two-group cross-validation set</b>					
FACH0	252	---	47	299	84
SPCH1	37	---	351	388	90
Probability of membership	0.4352	---	0.5648		
<i>kappa</i> = 0.75					

= 0.75, 95% CI = 0.70 to 0.80,  $P < 0.0001$ ), and represented a substantial improvement over that of the three-group analysis that included subyearling spring chinook salmon.

The scores from the subjective 3x4-level morphological codes were useful for classifying group membership of subyearling fall chinook and yearling spring chinook salmon, but performed poorly for classifying subyearling spring chinook salmon. Eighty-eight percent of subyearling fall chinook salmon had morphological scores  $\geq 8$  and were classified correctly, while 81% of yearling spring chinook salmon were correctly classified with scores  $\leq 7$  (Table 4). Subyearling spring chinook salmon were assigned fall-like morphological codes and classified to the fall run 64% of the time, whereas correct assignment to the spring run was only 36%. The *kappa* calculated for fall and pooled spring-run salmon indicated that morphological score-based classifications of fish run were 53% better than random chance (*kappa* = 0.53, 95% CI = 0.48 to 0.59,  $P < 0.0001$ ).

## Discussion

Morphometrics were useful in separating subyearling fall chinook salmon from yearling spring chinook salmon, and would be a valuable tool in separating the two runs if subyearling spring chinook salmon were not present. Both the statistical approach and the simple morphological score yielded similar results (i.e., over 80% accuracy) in classifying subyearling fall and yearling spring chinook salmon. The *kappa* statistic indicated that statistical analyses were more powerful in truly differentiating subyearling fall and yearling spring chinook salmon than was the subjective morphological code. However, while use of the morphological code may classify fish with lower accuracy, its simplicity may make it more useful at smolt monitoring facilities when few subyearling spring chinook salmon are present during the summer outmigration.

Our statistical analyses validate, and provide a basis for, the morphological differences between the fall and spring runs that smolt monitoring personnel perceived. However, both approaches were inadequate in identifying subyearling spring chinook salmon. The development of the morphological code was based on the assumption that subyearling fall and yearling spring chinook salmon would be the only two groups passing lower

Table 4.—Classification of juvenile chinook salmon run based on morphological scores. Fish with scores  $\geq 8$  were classified as fall-run, and fish with scores  $\leq 7$  were classified as spring-run. To calculate *kappa*, it was necessary to pool yearling and subyearling spring chinook salmon into one group. Actual groups are abbreviated FACH0 for subyearling fall chinook, SPCH0 for subyearling spring chinook, and SPCH1 for yearling spring chinook.

Actual group	Number classified into each group		Total	% correct
	Fall-run	Spring-run		
FACH0	261	36	297	88
SPCH0	81	46	127	36
SPCH1	73	315	388	81
Probability of membership	0.3658	0.6342		
<i>kappa</i> = 0.53				

Snake River dams, and seemed logical at the time considering the two life histories.

The results of this study were complicated by the presence of subyearling spring chinook salmon. A subyearling smolt strategy has been documented for spring chinook salmon in the Rogue River, Oregon (Cramer and Lichatowich 1978; Buckman and Ewing 1982), but this life history is not the norm for spring chinook salmon in the Snake River (Stephen Achord, National Marine Fisheries Service, personal communication). While subyearling spring chinook salmon may number in the thousands in any given migration year, yearlings migrating out of the Snake River typically number in the millions (FPC 1991-1995, 1998), thus minimizing the proportion of subyearling spring chinook salmon in the yearling population. However, subyearling spring chinook salmon can be large contributors to the summer subyearling chinook salmon population. Subyearling spring chinook salmon made up 62% of the subyearling chinook sample that were electrophoretically validated in 1993 (Marshall et al. 1999), and the spring chinook contribution ranged from 5-50% in the other years of this study. We suggest that the cause for these high percentages of spring chinook salmon in the subyearling population is two-fold. First, it is possible that some subyearling spring chinook salmon are washed out of tributaries and into the mainstem Snake River during periods of high winter flows. The more productive main-stem Snake River may contribute to higher growth rates and smoltification in their first summer of life. Second, the high numbers of subyearling spring chinook salmon may be an artifact of the currently depressed fall chinook population in the Snake River. While there may be a small portion of the spring chinook salmon population that migrates as subyearlings, historically they probably represented an insignificant fraction of the subyearling fall chinook salmon population when fall chinook salmon were more abundant.

Snake River fall chinook salmon morphology does not fit the observation that juvenile salmonids become more slender and elongate during the parr-smolt transformation (Folmar and Dickhoff 1980, Hoar 1988). Snake River fall chinook salmon are unique in that they are probably the farthest inland population with an ocean-type life history. It has also been shown that inland coho salmon *O. kisutch*, with greater distances to migrate, are more slender than coastal counterparts; perhaps conferring an energetic advantage during migration (Taylor and McPhail 1985). While yearling spring chinook salmon in the

Snake River adhere to the "inland" portion of this paradigm, subyearling fall chinook do not. One reason for the deep bodies of Snake River fall chinook salmon may be related to growth opportunities in rearing areas. Juvenile fall chinook salmon rearing in nearshore habitats in the free-flowing Snake River grow an average of 1.4 mm/d and have condition factors of 1.3 to 1.4 (Connor et al. 1994). This exceeds average growth rates of 0.33-1.32 mm/d reported for juvenile fall chinook salmon in freshwater and estuarine habitats elsewhere (Reimers 1973; Healey 1980; Kjelson et al. 1982). Tributaries to the Snake River that support spring chinook salmon are cooler and not as productive as the mainstem Snake River (Stephen Achord, National Marine Fisheries Service, personal communication), and fish rearing there would have lower growth rates (e.g., 0.17-0.33 mm/d; Healey 1991) and condition factors. This would be consistent with the observation that stream-type chinook salmon are generally associated with rivers of lower growth opportunity than are ocean-type chinook (Taylor 1990).

Snake River fall chinook salmon morphology may also be genetically determined to some extent. Clarke et al. (1992) demonstrated that chinook salmon life history is under genetic control, and that an ocean-type pattern of development was expressed independent of environmental cues—in this case photoperiod. If a robust body form develops independently of rearing environment and distance to the ocean, but rather attends an ocean-type development pattern, then this would explain why Snake River fall chinook salmon have deep bodies despite rearing so far inland. This idea is further supported by Major and Mighell (1969) who found that subyearling fall chinook salmon migrating from the Yakima River, Washington, had deeper bodies than yearling spring chinook salmon despite rearing more than 560 km from the ocean. It is likely that the morphological differences observed between Snake River fall and yearling spring chinook salmon represent a genotype-environment interaction, which has been noted in other salmonids (Riddell et al. 1981; Carl and Healey 1984; Clarke et al. 1992; Clarke et al. 1994).

Our study revealed two developmental phenomena in Snake River spring chinook salmon. First was a switch from a yearling to subyearling outmigration strategy for at least a portion of the spring chinook salmon that reared in the mainstem Snake River. Subyearling spring chinook salmon in mainstem habitats benefited from the high growth opportunity similar to fall chinook salmon, and subsequently migrated in their first summer

of life. This developmental conversion (Smith-Gill 1983) was previously demonstrated for stream-type chinook salmon by Clarke et al. (1992), and may provide diversity to this stock. The second phenomenon was the expression of both subyearling fall and yearling spring chinook salmon morphologies by subyearling spring chinook salmon. This would not be expected if all fish were exposed to the same rearing conditions. However, the rearing history and origin of each fish prior to PIT tagging was not known. It is possible that the differences observed in subyearling spring chinook salmon morphology were due to the time fish spent in tributaries before entering the mainstem Snake River, and the temperatures of those tributaries. Temperature can control many aspects of smoltification (see review by Folmar and Dickhoff 1980), and a fish's thermal history prior to entering the mainstem Snake River may influence its morphology as well.

The morphological variability observed in subyearling spring chinook salmon may be an artifact of the combination of spring and summer chinook salmon into a single ESU in the Snake River. While these two runs are genetically similar, they exhibit both geographic and temporal segregation, as well as coexistence in the Snake River (Matthews and Waples 1991). Spring chinook salmon typically spawn earlier in headwater tributaries, whereas summer chinook salmon spawn later and farther downstream. Consequently, there may be some life history differences between populations from these two runs. Growth potential may be higher for summer chinook salmon, and there may be a tendency for at least part of the population to migrate as subyearlings. This is common for summer chinook salmon in the upper Columbia River basin, which migrate seaward as subyearlings, but this idea has been discounted for Snake River summer chinook salmon (Matthews and Waples 1991). However, it is possible that the subyearling spring chinook salmon that exhibited fall-like, or subyearling spring-like, morphology could have been summer, rather than spring chinook salmon.

Juvenile chinook salmon migrating through the Lower Snake River are classified as yearlings or subyearlings based on size, subjective morphological features, and time of year. Designation of fish run by age is not adequate for describing run composition and timing. Given the presence of subyearling spring chinook salmon and the difficulty identifying them using morphology, we believe the only way to accurately determine run composition for summer migrants at lower Snake River dams is by

collecting scale and genetic samples. This has become more practical with the advent of non-lethal DNA analysis, which can be used to determine fish run with accuracy similar to that of electrophoresis (Rusty Rodriguez, U.S. Geological Survey, personal communication).

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**CHAPTER SEVEN**

Smallmouth Bass Predation on Juvenile Fall Chinook Salmon  
in the Hells Canyon Reach of the Snake River, Idaho

by

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## Introduction

The role of predation in the survival of juvenile salmonids *Oncorhynchus spp.* in several parts of the Columbia River Basin has been examined (Poe et al. 1991; Ward et al. 1995). Predation studies in the Columbia River in the 1980's implicated the northern pikeminnow *Ptychocheilus oregonensis*, smallmouth bass *Micropterus dolomieu*, walleye *Stizostedion vitreum*, and channel catfish *Ictalurus punctatus* as aquatic predators of emigrating juvenile salmon (Poe et al. 1991; Rieman et al. 1991). Rieman et al. (1991) estimated an annual loss of 2.7 million juvenile salmon to aquatic predators in John Day Reservoir during the mid-1980's. The northern pikeminnow was the primary piscivorous predator, accounting for 78% of loss of salmonids in the Columbia Basin (Poe et al. 1991), however, smallmouth bass accounted for 7% of the loss of the late migrating subyearling fall chinook salmon *O. tshawytscha* in Lower Granite Reservoir on the Snake River (Anglea 1997). Other research in the Columbia River basin also suggests that smallmouth bass may be a substantial predator of subyearling fall chinook salmon (Curet 1993; Tabor et al. 1993), although substantial annual variations in consumption occur (Naughton 1998).

Smallmouth bass were historically distributed throughout eastern North America and have been introduced throughout the world (Coble 1975). Smallmouth bass were thought to have first been stocked into the Snake River Basin in the late 1800's to provide angling opportunities (Munther 1970). Lampman (1949) reported that fish and game personnel of Oregon and Washington stocked bass in the early 1920's in various waters of the Pacific Northwest. Smallmouth bass were actively stocked in the Snake River by the Idaho Fish and Game Department in 1941, and are now found throughout the Hells Canyon Reach of the Snake River.

Smallmouth bass are opportunistic predators that consume prey items as they are encountered (Pflug and Pauley 1984), and have been implicated as a predator on salmonids in reservoirs and after hatchery releases (Warner 1972). Smallmouth bass inhabit littoral zones with low water velocities (<15cm/s Munther 1970; Rankin 1986). Subyearling fall chinook salmon also rear in littoral habitat with low water velocities (Mains and Smith 1956; Curet 1993). The potential for habitat overlap in these nearshore areas where subyearlings rear and smallmouth bass forage is high. Tabor et al. (1993) attributed a high

salmonid predation rate for smallmouth bass (59% of diet) in the Hanford Reach of the Columbia River to prey abundance, prey size, and habitat overlap.

Snake River fall chinook salmon were historically distributed from the mouth of the Snake River to a natural barrier at Shoshone Falls, Idaho, River Kilometer (Rkm) 990 (Haas 1965). Swan Falls Dam was the first impoundment to inundate spawning and rearing habitat in 1901, eliminating 320 km of habitat in the upper river. Following construction of Swan Falls Dam, most spawning occurred in the 48-km reach from the dam to Marsing, Idaho. From the late 1950's through the mid-1970's, dam construction continued both in the lower Snake River and the portion downstream of Swan Falls Dam, leaving a remnant 160 km reach of free-flowing river (Rkm 238 to Rkm 398) for spawning and rearing downstream of Hells Canyon Dam (Irving and Bjornn 1981). With each successive impoundment, spawning habitat has decreased for the mainstem spawning fall chinook salmon and numbers of returning adults have declined. In April of 1992, the National Marine Fisheries Service (NMFS) listed Snake River fall chinook salmon as threatened under the Endangered Species Act (USFWS 1988; NMFS 1992). Recovery efforts are underway to evaluate the potential of supplementing the natural population with hatchery fish (Muir et al. 1996). Supplementation is an interim recovery method used to bolster natural populations, and though controversial, has been advocated by the NMFS in the Snake River Salmon Recovery Plan Draft Recovery Plan for Snake River Salmon (NMFS 1995).

In 1987, federal, state and tribal agencies agreed to evaluate release sites, determine appropriate stocks to release, and conduct research to improve supplementation methods for upper Columbia River fish runs, including Snake River fall chinook salmon (Anonymous 1987). The primary goal of the Columbia River Fish Management Plan (1987) was to provide management guidelines to rebuild depressed fish runs. To meet the goals of the Columbia River Fish Management Plan, research was conducted to understand the in-river survival and travel times of post-release hatchery subyearling fall chinook salmon in the Snake River. Predation of subyearling fall chinook salmon by smallmouth bass has been suggested to account for some mortality during rearing (Gray and Rondorf 1986; Tabor et al. 1993).

Most predation studies in the Columbia River basin have been focused on reservoirs, as well as passage-related problems

at hydroelectric projects (Poe et al. 1991; Ward et al. 1995; Anglea 1997; Naughton 1998). The need to examine predation in other areas of the basin has been noted, especially in salmonid rearing areas (Gray and Rondorf 1986; Tabor et al. 1993). The potential for smallmouth bass predation on subyearling fall chinook in the free-flowing Hells Canyon Reach of the Snake River could be significant, considering the habitat use of both species, water temperatures, residence time, and the smaller size of subyearling fall chinook salmon.

Management of smallmouth bass populations outside the historical distribution has presented challenges for fisheries managers trying to balance a nonnative sportfish with dwindling native species, such as endangered salmonids in the Pacific Northwest (Pflug and Pauley 1984; Gray and Rondorf 1986; Tabor et al 1993). The good intentions of state fish agencies to provide angling opportunities may currently conflict with recovery efforts for endangered salmonid stocks. A better understanding of smallmouth bass populations and the dynamics surrounding the interactions with native salmonid fishes is needed to facilitate co-management of these species in the future.

The goal of this study was to address smallmouth bass predation on juvenile fall chinook salmon in the Hells Canyon Reach of the Snake River. Our study objectives were to 1) estimate absolute abundance, relative distribution, length at age, and growth increments of smallmouth bass in the Hells Canyon Reach of the Snake River, and 2) estimate subyearling fall chinook salmon consumption and total loss by smallmouth bass using gastric evacuation rate and bioenergetic methods.

### **Study Area**

The study area includes 109 km of the free-flowing Snake River from Asotin, Washington (Rkm 237) to Pittsburg Landing, Idaho (Rkm 346; Figure 1). The Snake River flows through Hells Canyon in a northwesterly direction through a semi-arid environment with steep canyon walls of basalt. The overall mean gradient of the Hells Canyon Reach is 1.1 m/km and mean width is 143 m. Substrates consist of bedrock, large boulders, cobble, and sand.

We subdivided the Hells Canyon Reach into two sections based on gradient, water temperatures, and turbidity. One study

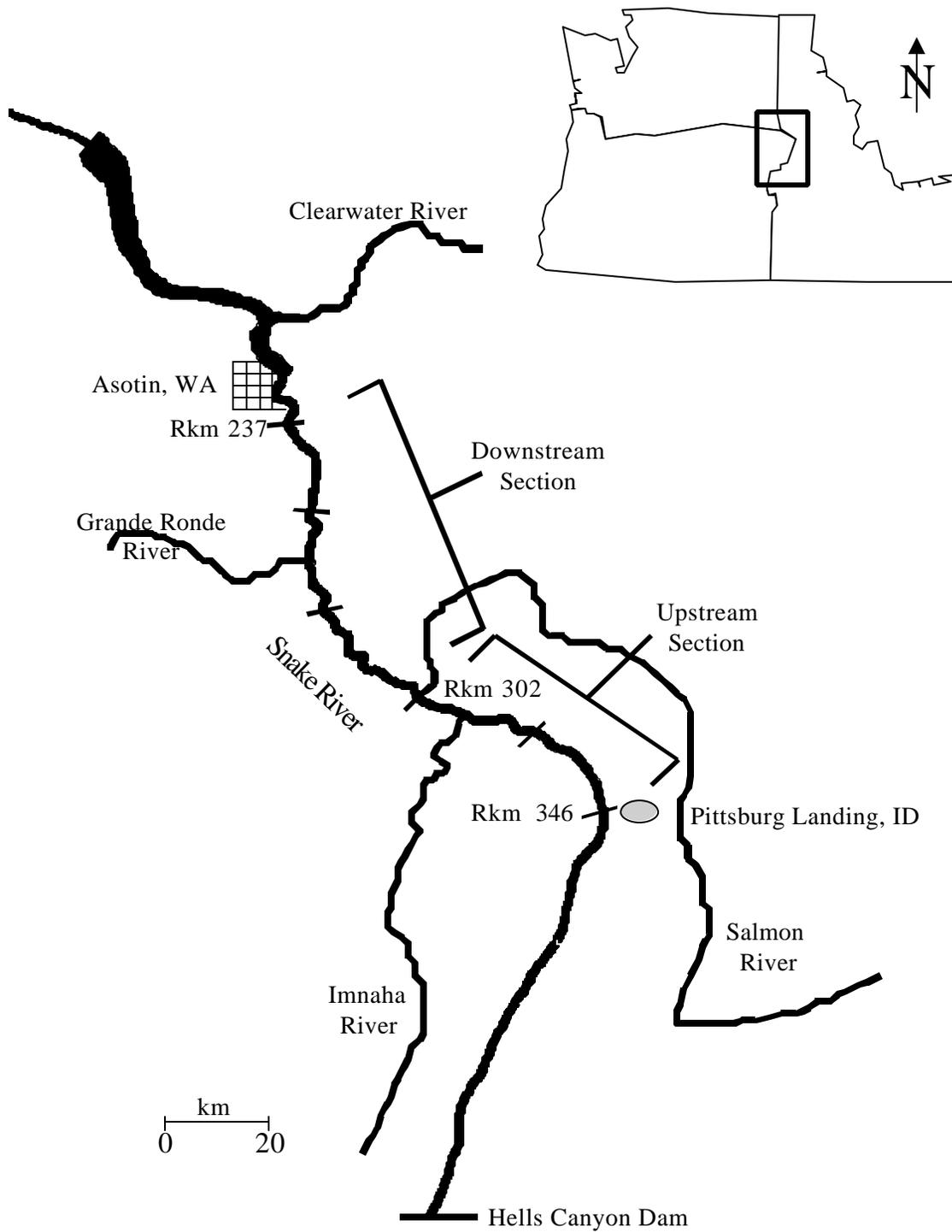


Figure 1. Hells Canyon reach of the Snake River from Pittsburg Landing, Idaho (Rkm 346) to Asotin, Washington (Rkm 237).

section was upstream from the confluence of the Salmon River and the other was downstream of the confluence of the Salmon River. The upstream section was 43 km long and had a gradient of 1.7m/km, and the downstream section was 66 km long and had a gradient of 0.7 m/km (Figure 1). Estimated widths of the Snake River ranged from 83 to 159 m in the upstream section, and 114 to 216 m in the downstream section. Water temperature and turbidity can differ between the areas upstream and downstream of the confluence of the Salmon River as a result of the differences between the discharges from the Salmon River and Hells Canyon Dam on the mainstem Snake River.

## Methods

### *Smallmouth Bass Abundance*

*Absolute abundance.*—We estimated the absolute abundance of smallmouth bass by conducting a mark-recapture study during the late summer of 1997, when water temperatures, turbidities, and flows were similar between the two study sections. A stratified random sampling design, based on river gradients and canyon topography, was used for the two sections of the Hells Canyon Reach (Figure 1). The upstream section was divided into three strata: open, canyon, and chute. The open strata were defined by gradients  $>1.50$  m/km and longitudinal slopes  $\leq 25^\circ$ . The canyon strata had gradients between 1.00-1.50 m/km and slopes of 26-33°. The chute was defined by gradients  $>2.00$ m/km and a slope  $\geq 34$ . We sampled six randomly selected longitudinal transects measuring between 325 m and 1,165 m in length in each section, comprising approximately 9% of the length of the upstream section and 8% of the downstream section. In the upstream section, we sampled two longitudinal transects in the open strata (out of a total of 15 longitudinal transects), three longitudinal transects in the canyon strata (out of a total of 23 longitudinal transects), and one longitudinal transect in the chute strata (out of a total of 5 longitudinal transects). In the downstream section, we sampled six longitudinal transects (out of a total of 66 longitudinal transects) using a simple random sampling design, as all of the downstream section was of an open habitat type. A single mark-recapture method was used for the Rkm 256 longitudinal transect, as we were only able to sample a single mark-recapture effort. For all other longitudinal transects multiple census methods were used to estimate absolute abundance.

Absolute abundance sampling was conducted during daytime for the area upstream of the confluence of the Grande Ronde River (Rkm 271), and both during the day and night in the area downstream of the Grande Ronde River. Night electrofishing for smallmouth bass is recommended to maximize catch per unit effort (Paragamian 1989), however for this study, night electrofishing was considered too hazardous for the area upstream of the Grande Ronde River.

Smallmouth bass were captured using a Smith-Root electrofishing boat set at 600 V DC at 60 pulses/s to produce 3-4 amps in the water. Electrofishing was conducted in a downstream direction parallel to the shoreline, using one dipnetter. We measured the shoreline distance (m) of each longitudinal transect using an electronic distance meter and estimated cross-channel widths using discharge to width equations derived from Instream Flow Incremental Methodology cross sections (Connor et al. 1994). All smallmouth bass captured were retained in a livewell, and fish  $\geq 175$  mm fork length were tagged with a numbered anchor tag inserted posterior to the dorsal fin above the lateral line. After processing, fish were released alive into the middle of the area electrofished. At least 7 d passed between each mark-recapture period.

*Relative abundance.*—During the smallmouth bass predation sampling (Objective 2), we collected relative abundance data of smallmouth bass using a stratified random sampling design. Predation sampling was conducted from June to October, 1996 and from May to October, 1997. We collected smallmouth bass for 5 continuous days, except in October when we sampled for 3 d. Sampling was initiated at Pittsburg Landing, Idaho (Rkm 346) and progressed downstream to Asotin, Washington (Rkm 237). A sample day was composed of electrofishing six randomly selected longitudinal transects in downstream manner for at least 5 min. Three transects were electrofished with a minimum of 2 h between sampling periods during the morning period, and three transects were electrofished with a minimum of 2 h between sampling periods during the evening period.

#### *Smallmouth Bass Analysis*

*Absolute abundance.*— For the multiple-census longitudinal transects, we used the Schnabel estimator (1938) modified by Overton (1965) to analyze the data:

$$\hat{N}_k = \frac{\sum_{t=1}^n (C_t \cdot M_t)}{(\sum_{t=1}^n r_t) + 1}$$

where:  $\hat{N}_k$  = population estimate for  $k$  longitudinal transects,  
 $C_t$  = number of fish collected in each sample period  $t$ ,  
 $M_t$  = number of fish marked and released in each sample period  $t$ ,  
 $r_t$  = number of marked fish collected in each sample period  $t$ .

A direct Petersen index method as modified by Chapman (1951) was used for the single mark recapture longitudinal transect:

$$\hat{N}_k = \frac{(M+1)(C+1)}{r+1} - 1,$$

where:  $\hat{N}_k$  = population estimate for  $k$  longitudinal transect,  
 $M$  = number of fish marked and released in the first period,  
 $C$  = number of fish collected in the second period,  
 $r$  = number of marked fish collected in the second period.

For both the Schnabel and Petersen models, we assumed that tagged fish retained their tags, tagged and untagged fish were equally susceptible to recapture, no mortality resulted from tagging, tagged fish were randomly incorporated into the population, and the population was closed (Van Den Avyle 1993). We calculated a population estimate for each longitudinal transect and then standardized the number of smallmouth bass estimated in each longitudinal transect to 1 km. A grand population mean for each section was estimated from an average of the longitudinal transect means (smallmouth bass/km) within a section, multiplied by the length of a section. We used a stratified population estimator to calculate the grand mean for each section (Scheaffer et al. 1996):

$$\bar{y}_{st} = \frac{1}{N} \sum_{i=1}^L N_i \bar{y}_i,$$

where:  $\bar{y}_{st}$  = grand mean for river section  $st$ ,  
 $N$  = total number of longitudinal transects,  
 $N_i$  = number of longitudinal transects for the  $i^{\text{th}}$  stratum,  
 $\bar{y}_i$  = population estimate for the  $i^{\text{th}}$  stratum.

Variance was calculated using the formula

$$\hat{v}(\bar{y}_{st}) = \frac{1}{N^2} \sum N_i^2 \left( \frac{N_i - n_i}{N_i} \right) \left( \frac{s_i^2}{n_i} \right),$$

where:  $\hat{v}(\bar{y}_{st})$  = estimated variance for the river section  $s$ ,  
 $N$  = total number of longitudinal transects in section,  
 $N_i$  = number of longitudinal transects in the  $i^{\text{th}}$  stratum  
 $n_i$  = number of longitudinal transects sampled in the  $i^{\text{th}}$  stratum,  
 $s_i^2$  = variance for the  $i^{\text{th}}$  stratum.

We combined the absolute abundance estimates for each section for an expanded population estimate for the entire 109 km reach of the Snake River.

We estimated the number of smallmouth bass in the 150-174 mm size class by calculating their relative abundance during the predation sampling in the fall of 1997. The proportion of the 150-174 mm smallmouth bass size class was then added to the absolute abundance estimate for smallmouth bass  $\geq 175$  mm. We calculated the abundance of smallmouth bass 150-249 mm, and  $\geq 250$  mm in length, by multiplying the percent abundance in each length class by estimated abundance for smallmouth bass  $\geq 150$  mm from the mark-recapture data.

*Relative abundance.*—A catch per unit effort (CPUE) index was calculated for two size classes of smallmouth bass using the formula:

$$CPUE_i = C_i / T_i$$

where: CPUE<sub>i</sub> = catch per unit effort (minute) for the i<sup>th</sup> sample,  
C<sub>i</sub> = number of fish caught for the i<sup>th</sup> sample,  
T<sub>i</sub> = time sampled in minutes for the i<sup>th</sup> sample.

The two size classes of smallmouth bass were: 150-249 mm and ≥250 mm. To calculate each size class frequency by week, we pooled the catch, and divided by the pooled electrofishing time to calculate the CPUE by week sampled.

We compared CPUE for 150-249 mm and ≥250 mm size classes of smallmouth bass between the two sections of the Snake River upstream and downstream of the Salmon River. We used an aligned ranks one-way analysis of variance using the Friedman approach (Lehman and D' Abera 1983;  $P < 0.05$ ), with sample week included as a blocking variable, to test the hypothesis that:

H<sub>0</sub> : There is no difference in the relative abundance of smallmouth bass in the Snake River between the sections upstream and downstream of the confluence of the Salmon River.

H<sub>A</sub> : There is a difference in the relative abundance of smallmouth bass in the Snake River between the sections upstream and downstream of the confluence of the Salmon River.

*Age and growth.*—We analyzed scales to determine length at age and growth increments of smallmouth bass collected in the spring of 1997 in the sections upstream and downstream of the Salmon River in Hells Canyon. Scales were removed from smallmouth bass at the extension of the pectoral fin ventral to the lateral line. Scale samples were divided into size classes using length at age data from Keating (1970). Scale samples were randomly selected, cleaned between finger tips with water, and mounted between glass slides for reading. Scales were aged using a microfiche 46X reader. Each scale was read at least twice to determine focus, annuli, and scale margin and recorded on a strip of paper. Scale growth increments were digitized and loaded into DISBCAL (Frie 1982) scale analysis program. Back-

calculated mean length at age ( $L_n$ ) was determined using the Frazer-Lee formula (Carlander 1982):

$$L_n = a + S_n / S_c (L_c - a)$$

where:  $a$  = intercept value of best straight line relationship,  
 $S_n$  = scale measurement to an annulus,  $n$ ,  
 $S_c$  = scale measurement to margin of scale,  
 $L_c$  = length of fish at capture (mm).

We used a standard intercept value (35 mm) suggested by Carlander (1982) due to low numbers of young-of-the-year smallmouth bass in our sample.

#### *Consumption of Fall Chinook Salmon by Smallmouth Bass*

*Smallmouth bass collection.*—We collected smallmouth bass in the morning and the evening of each sample day during daytime hours (Objective 1). When hatchery fall chinook salmon were released at Pittsburg Landing, electrofishing for smallmouth bass commenced the following morning at sunrise, which was typically 9 to 13 h after the release. Releases of PIT-tagged fall chinook salmon at Pittsburg Landing occurred weekly from June 6 to July 10 during 1996 ( $n = 20,954$ ), and from May 28 to July 8 during 1997 ( $n = 42,293$ ) by the U.S. Fish and Wildlife Service and NMFS (Appendix 2). Weekly release sizes of PIT-tagged fall chinook salmon ranged from 1,214 to 8,118.

*Dietary collection and analysis.*—We collected stomach contents of smallmouth bass  $\geq 150$  mm using a modified lavage technique (Seaburg 1957). Smallmouth bass stomach contents were washed into a 425  $\mu\text{m}$  mesh filter, placed in a labeled Whirlpac bag, flooded with water, and immediately frozen on dry ice.

In the laboratory, stomach contents were thawed and prey items identified to the lowest practical taxon. Prey items were enumerated and weighed. Digested prey weights were measured by first blotting the prey item for 30 s, and then weighing each item the nearest 0.001 g. Prey items were placed into four main groups: insects, crustaceans, fish, and other prey items. Members of the class Insecta were identified and weighed as a group, and representatives of the more common orders were noted. Items from the class Crustacea were identified to order, and

fishes were identified to genus or species. Diagnostic bones were used to identify digested fish using methods described in Hansel et al. (1988). Vertebra shape was used to classify well-digested fish parts between salmonid and nonsalmonid fish.

Live weights of prey chinook salmon subsequently used in the analysis were estimated using length (mm) to weight (g) regression equations developed by Vigg et al. (1991). Fork lengths of undigested chinook prey were measured to the nearest mm. Digested specimens were measured nape to tail, or measurements of diagnostic bones were used to calculate undigested lengths (Hansel et al. 1988; Vigg et al. 1991).

We analyzed the diet of smallmouth bass  $\geq 150$  mm by year and month in each section sampled. Additionally, we divided diet data into two size classes (150–249 mm, and  $\geq 250$  mm) to account for possible differential predation rate between size classes of smallmouth bass. Hatchery fall chinook salmon with PIT tags recovered in stomach samples were identified by date and location of release (William Connor, USFWS, Ahsahka, Idaho unpublished data). We used a MANOVA (Hair et al. 1995) to compare the general diets (percent weight) for smallmouth bass  $\geq 150$  mm between the upstream and downstream sections in the Snake River. We pooled diet data for smallmouth bass  $\geq 150$  mm for 1996 and 1997 and calculated percent weights of smallmouth bass diet data by transect. Data expressed as percentages (0 to 100%) form a binomial distribution. Therefore, we transformed data using the arcsine of the square root to meet the underlying assumption of normality (Zar 1984). We considered differences significant if  $P \leq 0.05$ , and reported Pillai's trace statistic as the test statistic (Hair et al. 1995). We used a canonical analysis to determine which variables were driving the separation between groups, and ANOVA to reveal which dietary items differed between locations.

*Daily consumption: Adams model.*—We estimated daily consumption using a simple meal turnover-time adapted from Adams et al. (1982) and modified by Naughton (1998); (Roger Tabor, USFWS Olympia Washington, personal communication) where:

$$C = n / N; \quad (1)$$

where: C = consumption rate of subyearling fall chinook salmon (prey/smallmouth bass/day),

n = number of subyearling fall chinook consumed within 24 h of capture, and  
 N = total number of smallmouth bass sampled (including empty stomachs).

Weights of digested fall chinook salmon at collection were compared to estimated weights of live fish derived from regression equations (Vigg et al. 1991) after a 24-h digestion period. Prey weights heavier than estimated live weight after a 24-h digestion period were included in the calculation of a daily consumption rate. Prey weights lighter than the calculated live weight after 24-h digestion were not used in the calculation of daily consumption rates, because we assumed those prey fish were consumed during a period greater than 24 h. To estimate the portion (g) of meal evacuated from the stomach of smallmouth bass (E), we used the algorithm from Rogers and Burley (1991):

$$E = S \cdot \left( 1 - e^{-0.005tS^{-0.29}e^{0.15T}W^{0.23}} \right)^{1.95}; \quad (2)$$

where: E = weight evacuated (g),  
 t = time (hours),  
 S = meal weight (g),  
 T = temperature (°C) at capture, and  
 W = smallmouth bass weight (g).

The meal weight was calculated by the method of Vigg et al. (1991):

$$S = O_i + O_j + D_k, \quad (3)$$

where: S = meal weight (g),  
 O<sub>i</sub> = the calculated original weight of fall chinook salmon at ingestion,  
 O<sub>j</sub> = the calculated original weight of any other prey fish that was digested that was within 10% of the original weight,  
 D<sub>k</sub> = the digested weight of other prey items in sample.

*Daily consumption: Wisconsin model.*—We modified the bioenergetics model referred to by Ney (1993) as the Wisconsin model and software of Hanson et al. (1997), based on a balanced energy equation (Warren and Davis 1967):

$$C = (R + A + S) + (F + U) + (S + G) \quad (4)$$

where: C = consumption of prey items,  
R = respiration,  
A = active metabolism,  
S = specific dynamic action,  
F = egestion,  
U = excretion,  
S = somatic growth,  
G = gametic growth.

We used algorithms for consumption (Thornton and Lessem 1978), respiration, and egestion-excretion (Kitchell et al. 1977) described in Roell and Orth (1993). We did not model gametic energy storage (G) in the bioenergetics simulations because reproductive energy storage in smallmouth bass is not well known (Roell and Orth 1993). Smallmouth bass physiological parameters used were from Roell and Orth (1993) and Shuter and Post (1990; Appendix 3). We used estimated energy density values ( $\text{cal kg}^{-1}$ ) from Cummins and Wuychuck (1971), Petersen and Ward (1999), Shuter and Post (1990), and Rondorf et al. (1985; Appendix 4). Non-chinook fish were estimated as weighted mean from the diet data analysis: 75% cottids  $1308 \text{ cal kg}^{-1}$  ( $5475 \text{ J kg}^{-1}$ ; Petersen and Ward 1999) and 25% centrarchids  $1000 \text{ cal kg}^{-1}$  ( $4186 \text{ J kg}^{-1}$ ; Shuter and Post 1990). Daily mean water temperatures were supplied by Idaho Power Company, Boise, Idaho. Water temperatures were collected using thermographs located at Rkm 304, 309, 325, 347, and 368 in the upstream section and Rkm 251, 265, 272, 290 in the downstream section.

We applied the Wisconsin bioenergetics model to the upstream and downstream sections of the Hells Canyon Reach of the Snake River separately, due to different water temperatures in each section. Wisconsin model simulations were run using an "average" sized smallmouth bass within each of two size classes: 150-249 mm and  $\geq 250$  mm. A mean start and final length in each size class was generated using age at length tables (Objective 1). We used smallmouth bass age 2 to 4 for the 150-249 mm size

class and smallmouth bass  $\geq$ age 5 for the  $\geq$ 250 mm size class. Average-size smallmouth bass (mm FL) in each size class were converted to average weight (g) using the length weight equation developed from smallmouth bass captured during 1996-1997 in the Snake River,  $\text{Log } W = -4.971 + 3.04 \log \text{FL}$  ( $r^2 = 0.95$ ). Starting and ending weights for average-size 150-249 mm smallmouth bass used in the bioenergetics model simulations were 85 g to 154 g (upstream section) and 76 g to 155 g (downstream section). Starting and ending weights for average-size  $\geq$ 250 mm smallmouth bass used in the bioenergetics model simulations were 299 g to 370 g (upstream section) and 364 g to 462 g (downstream section).

We estimated the number fall chinook salmon consumed by an average smallmouth bass in each size class (150-249 mm and  $\geq$ 250 mm) by first summing daily weight of chinook salmon consumed (g), by month and location, generated by a simulation run. Total grams consumed by month by an average-sized smallmouth bass were then multiplied by the percentage of subcategories of juvenile chinook salmon found in the diet samples: wild, hatchery, and spring chinook salmon. Monthly numbers of fall chinook salmon consumed by smallmouth bass in each subcategory were calculated by dividing the weight of chinook consumed in each subcategory by the mean weight of the chinook salmon in each subcategory, using the length weight equation for chinook salmon (Vigg et al. 1991).

*Total loss of subyearling fall chinook salmon: Adams model.*—We used a method similar to Rieman et al. (1991) to estimate the total loss of juvenile fall chinook salmon to smallmouth bass in the Hells Canyon Reach of the Snake River:

$$L_{ij} = \sum N_{ki} C_{ij} P_j \quad (5)$$

where:

$L_{ij}$  = the loss of fall chinook salmon in the section  $i$  in the month  $j$ ,  
 $N_{ki}$  = the number of smallmouth bass in size class  $k$  in the section  $i$ ,  
 $C_{ij}$  = consumption of fall chinook salmon in section  $i$  in month  $j$ , and  
 $P_j$  = the number days in the month  $j$ .

Time periods were months and defined as the days between June 1-June 25 ("June"), and the days between June 26 - July 15 ("July"). A predation cutoff was established on July 15 due to low numbers of fall chinook salmon in the free-flowing section and water temperatures higher than 20°C. (William Connor, USFWS, Ahsahka, Idaho, personal communication).

*Total loss of subyearling fall chinook salmon: Wisconsin model.*—We estimated the total loss of juvenile fall chinook salmon by using the equation:

$$L = \sum N_{k i} C_{k i} W_{l i k} \quad (6)$$

where:

$N_{k i}$  = number of smallmouth bass in size class  $k$  in section  $i$ ,

$C_{k i}$  = grams of fall chinook salmon consumed in subcategory  $l$  in size class  $k$  in section  $i$ ,

$W_{l i k}$  = average weight (g) of the average size fall chinook salmon consumed in subcategory  $l$  in size class  $i$ .

Time periods used in calculating total loss with Wisconsin model were the same as in the above Adams model.

## Results

### *Smallmouth Bass Population Attributes*

*Absolute abundance.*—We tagged 654 smallmouth bass ranging in length from 175 mm to 408 mm, in 12 longitudinal transects throughout the Hells Canyon Reach from 15 July 1997 to 6 October 1997. We recaptured 97 smallmouth bass from all longitudinal transects for an overall mean recapture rate of 15% (0-28%). No smallmouth bass were recaptured at the Rkm 281 longitudinal transect, so the Rkm 281 transect was not used in the estimate of the population abundance for the downstream section of the Hells Canyon Reach (Appendix 5). No movement among longitudinal transects was detected during the sampling period. We estimated the population of smallmouth bass  $\geq 175$  mm in the upstream section to be 16,254 (266 - 32,912; 95% CI), and the population in the downstream section to be 26,994 (412 - 55,007; 95% CI; Table 1).

Table 1.-Estimated population abundance and density of four length classes of smallmouth bass in the upstream (Rkm 303 to Rkm 346) and downstream (Rkm 237 to Rkm 302) sections in the Snake River during 1997.

Sections	Length	Population	95%	Sample unit		Density
	Class (mm)	Estimate	CI <sup>a</sup>	(fish/km)	Hectares	(fish/ha)
Upstream <sup>b</sup>	≥ 150	17,458		406	435	40
	≥ 175	1,6254	266-32,912	378		37
	150-249	12,570		292		29
	≥ 250	4,888		114		11
Downstream	≥ 150	29,040		440	1,122	26
	≥ 175	26,994	412-55,007	409		24
	150-249	20,909		317		19
	≥ 250	8,131		123		7

<sup>a</sup> CI indicates confidence interval

<sup>b</sup> location includes 1 km section at release site

The expanded population estimate for smallmouth bass  $\geq 175$  mm for the entire Hells Canyon Reach was 43,248 (678 - 87,919; 95% CI), which equated to 397 fish/km, or 28 fish/ha.

We estimated the abundance of smallmouth bass  $\geq 150$  mm as 17,458 and 29,040 fish in the upstream and downstream sections, respectively (Table 1). In the upstream section, we estimated the number of smallmouth bass in the 150-249 mm size class to be 12,570 and the number of smallmouth bass  $\geq 250$  mm to be 4,888. In the downstream section, we estimated 20,909 smallmouth bass were 150-249 mm, and 8,131 were  $\geq 250$  mm. Seven percent of the catch of smallmouth bass was in the 150-174 mm size class. During the mark-recapture electrofishing, an average of 72% of the smallmouth bass were 150-249 mm and 28% of the smallmouth bass were  $\geq 250$  mm from both the upstream and downstream sections.

*Relative abundance.*—The highest relative abundance, based on CPUEs of smallmouth bass, was from the section upstream of the confluence of the Salmon River for both 1996 and 1997 (Figures 2 and 3). The highest CPUE by week (1.96 fish/min) was for the 150-249 mm size class during the week of 9 July 1997 (Figure 2). The highest CPUE by week sampled was for the  $\geq 250$  mm size class (1.13 fish/min) during the week of 28 June 1996 in the upstream section (Figure 3). We rejected the null hypothesis that there was no difference in relative abundance of smallmouth bass between upstream and downstream sections of the Snake River for three of the four tests. We concluded that there were more smallmouth bass estimated by CPUE in the upstream section for 150-249 mm size class during 1996 ( $P=0.005$ ) and 1997 ( $P=0.018$ ), and for fish  $\geq 250$  mm during 1996 ( $P=0.005$ ). We did not find a significant difference between river sections in the relative abundance for smallmouth bass  $\geq 250$  mm in 1997 ( $P=0.527$ ).

*Age and Growth.*—We aged 150 smallmouth bass scales collected in the Snake River in 1997 (Appendices 6 and 7). Lengths at age 1 were 79 mm and 80 mm in the upstream and downstream sections, respectively. Mean annual growth increments (fork length) for age 2 to 8 smallmouth bass in the upper section ranged from 58 to 16 mm (Table 2). Mean annual growth increments (fork length) for age 2 to 9 smallmouth bass in the downstream section ranged from 54 to 13 mm. Growth increments for age classes  $\geq 4$  in the upstream section were lower than in the downstream section (Table 2).

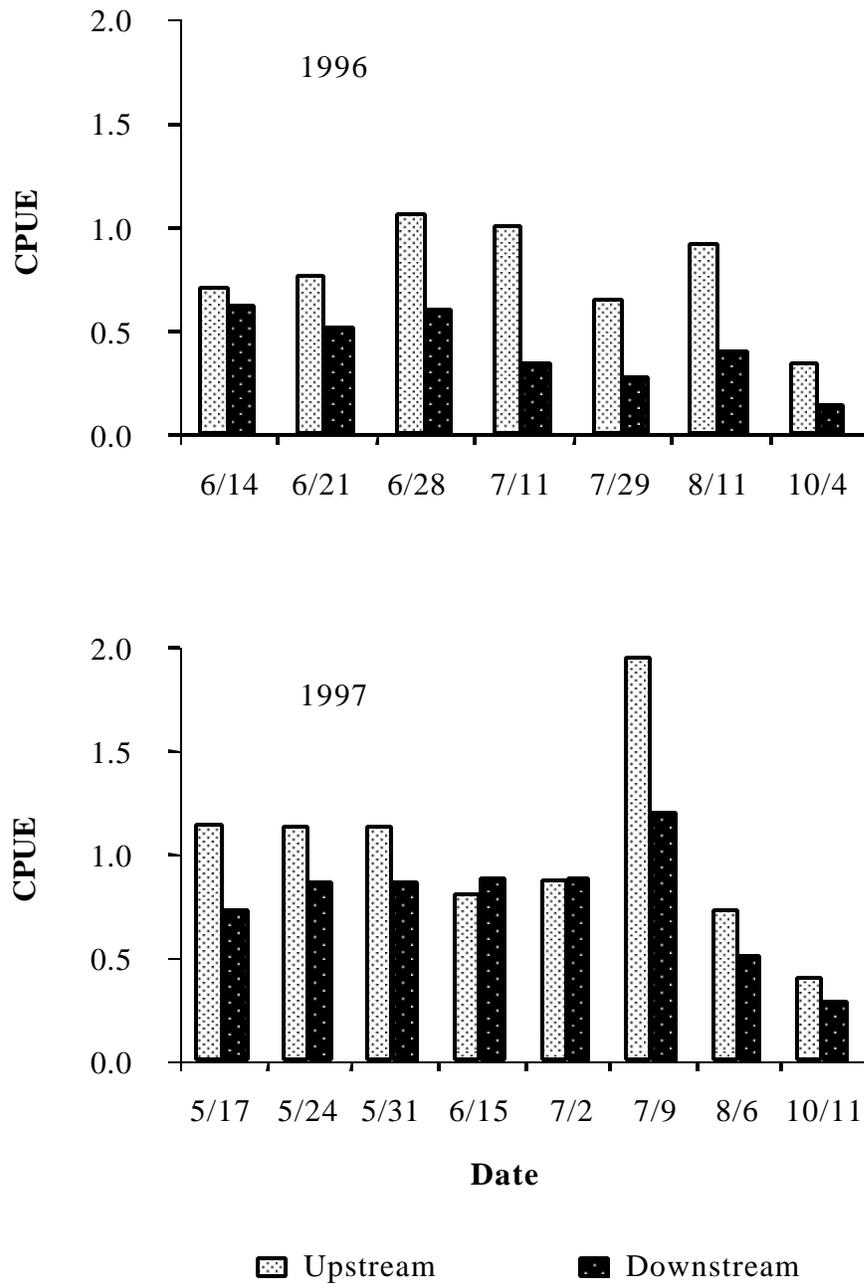


Figure 2. Catch per unit effort (fish/minute) for 150 to 249 mm smallmouth bass captured in the Hells Canyon reach of the Snake River (Rkm 237 to Rkm 346) during 1996 and 1997.

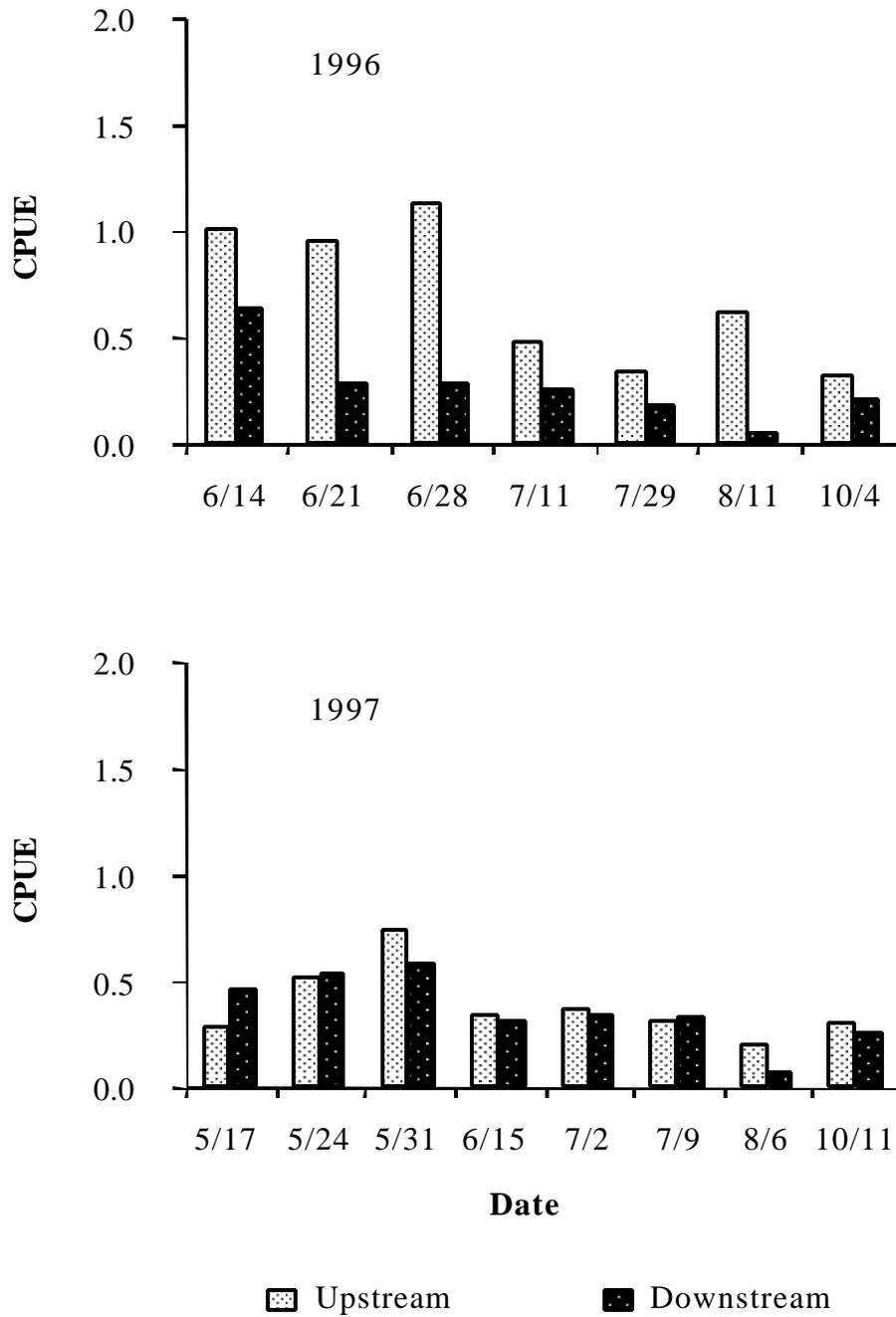


Figure 3. Catch per unit effort (fish/minute) for  $\geq 250$  mm smallmouth bass captured in the Hells Canyon reach of the Snake River (Rkm 237 to Rkm 346) during 1996 and 1997.

Table 2.-Estimated back-calculated age at length and weighted growth increments of smallmouth bass from the upstream (Rkm 303 to Rkm 346) and the downstream (Rkm 237 to Rkm 302) sections of the Snake River during 1997.

	Cohort								
	1	2	3	4	5	6	7	8	9
	<b>Upstream</b>								
Length at age FL (mm) <sup>a</sup>	79	137	193	228	258	284	303	319	-
Growth increment FL (mm) <sup>a</sup>	79	58	56	35	30	27	19	16	-
Length at age TL (mm) <sup>b</sup>	82	142	201	237	268	296	315	332	-
Growth increment TL (mm) <sup>b</sup>	82	60	59	36	31	28	19	17	-
	<b>Downstream</b>								
Length at age FL (mm) <sup>a</sup>	80	127	182	230	269	305	327	342	355
Growth increment FL (mm) <sup>a</sup>	80	47	54	48	39	37	21	16	13
Length at age TL (mm) <sup>b</sup>	84	133	189	239	280	318	340	356	369
Growth increment TL (mm) <sup>b</sup>	84	49	57	50	41	38	22	16	13

<sup>a</sup> Fork length

<sup>b</sup> Total length



### *Smallmouth Bass Diet Composition*

We collected 1,358 smallmouth bass for dietary analysis in 1996 of which 1,219 contained food items. In 1997, we collected 1,754 smallmouth bass of which 1,445 contained food items. Highest numbers of smallmouth bass collected were in the 150-249 mm size class; during 1996 and 1997, 60% ( $n = 733$ ) and 74% ( $n=1,070$ ) of smallmouth bass were in the 150-249 mm size class, respectively (Figure 4). Percent weights of prey items consumed by smallmouth bass  $\geq 150$  mm are summarized in Appendices 8 through 14.

In the section of Snake River upstream of the confluence of the Salmon River, including the release site, the most abundant prey item by weight for smallmouth bass  $\geq 150$  mm during 1996 (56.9%) and 1997 (70.2%) was crustaceans, followed by other fish (1996: 28.4%; 1997: 19.9%; Figure 5). Chinook salmon composed 1.9% of the dietary items by weight in 1996 and 0.8% in 1997. For the section of the Snake River downstream of the confluence of the Salmon River, other fishes were the most common prey item by weight during both 1996 and 1997, composing approximately 49% of the diet, followed by crustaceans at 39%. Juvenile chinook salmon composed 0.3% (by weight) of the diet in 1996 and were absent in 1997.

We found an overall significant difference in diet composition of smallmouth bass  $\geq 150$  mm between the upstream and downstream sections of Snake River during 1996 and 1997 (Pillai's Trace  $F = 15.57$ ;  $df = 383$ ;  $P = 0.0001$ ). Crayfish were consumed by smallmouth bass in greater proportion (percent weight) in the upstream section than in the downstream section. A canonical analysis using standardized canonical coefficients revealed that crayfish were driving the separation of the groups, followed by fish. Smallmouth bass consumed fish in greater proportions (percent weight) in the downstream section than the upstream section. Analysis of variance showed that crayfish ( $F = 46.88$ ;  $P = 0.0001$ ) and fish ( $F = 9.49$ ;  $P = 0.0022$ ) were significant contributors to the model. Other prey items ( $F = 0.10$ ;  $P = 0.7567$ ) did not contribute significantly to the model.

A total of 52 PIT tags were recovered from smallmouth bass stomach samples in 1996 and 1997 (Appendices 15 and 16). In 1996, 18 PIT tags were collected in smallmouth bass stomachs at the release site in the Snake River and 10 PIT tags were

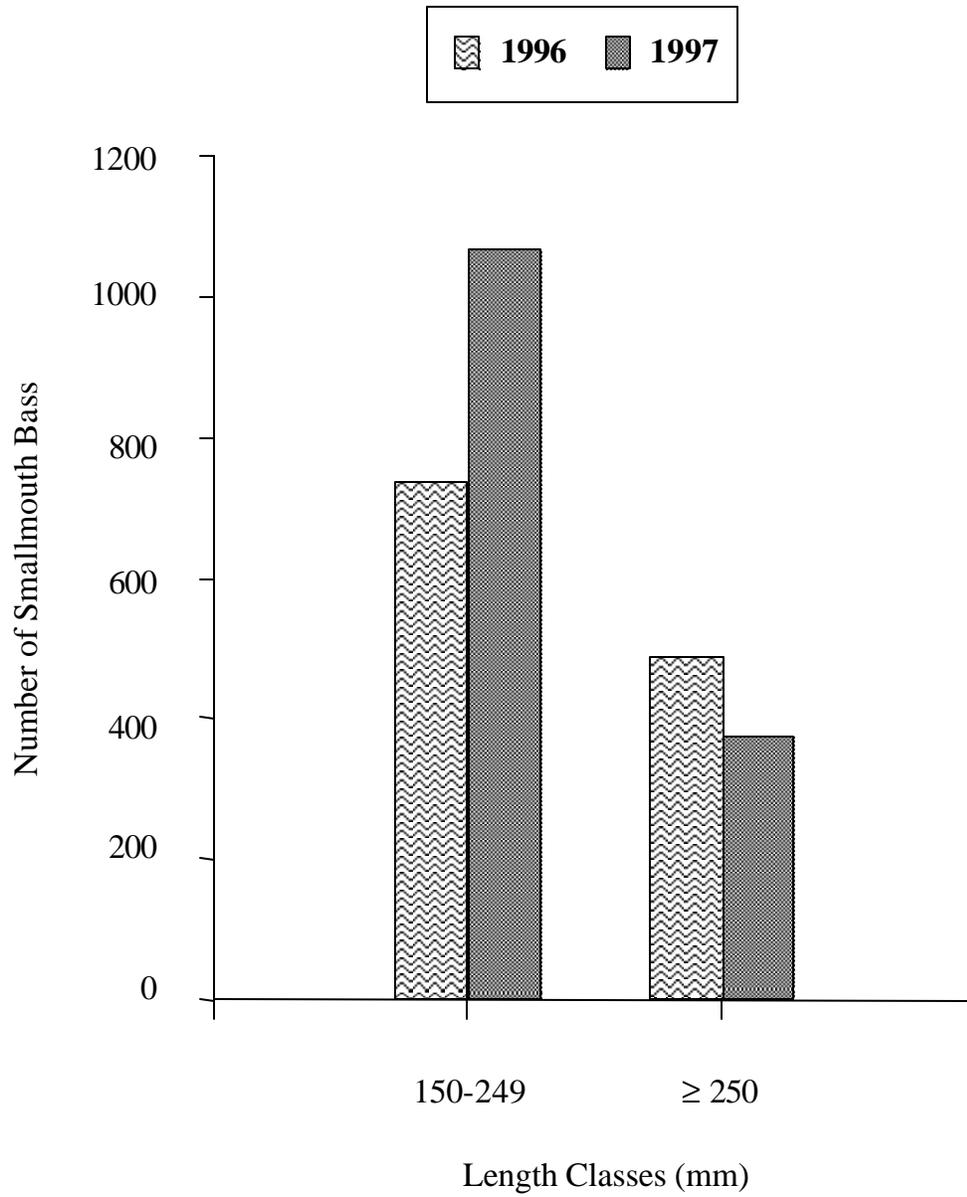


Figure 4. Length frequency of smallmouth bass sampled in the Snake River from Asotin, Washington to Pittsburg Landing, Idaho (Rkm 237 to Rkm 346) during 1996 and 1997 for dietary analysis.

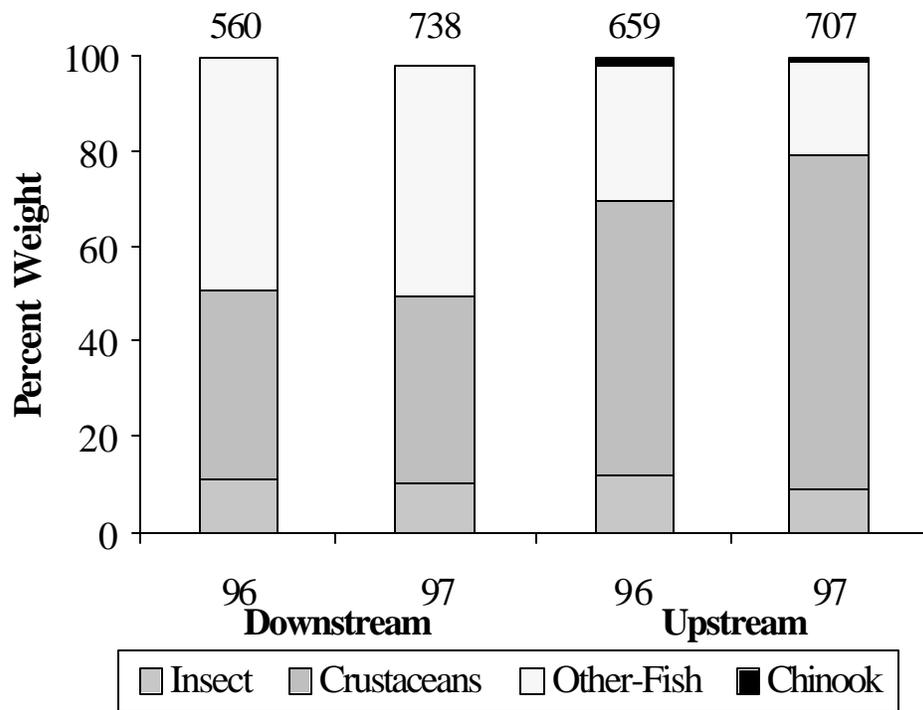


Figure 5. General dietary composition of smallmouth bass  $\geq 150$  mm sampled in the Snake River from Asotin Washington, to Pittsburg Landing, Idaho during 1996 and 1997. Upstream section included release site at Pittsburg Landing, Idaho (Rkm 346). Numbers above bars represent number of stomach samples examined.

collected from smallmouth bass stomachs 1 to 65 km downstream from the release site. Time from release to recapture in smallmouth bass stomach samples ranged from 9 h to about 22 d. During 1997, we recovered 24 PIT tags from smallmouth bass, of which 14 were collected at the release site in the Snake River, and 10 PIT tags were collected from 6 to 99 km downstream from the release site. Time from release to recapture ranged from 12 h to about 6 d.

### *Spatial and Temporal Trends in Smallmouth Bass Diets*

*Release site.*—During June 1996, crustaceans were the most abundant prey item by weight (45.1%) for smallmouth bass  $\geq 150$  mm followed by chinook salmon (40.1%; Figure 6). During July 1996, the most abundant prey item was chinook salmon (38.8%).

During 1996, we collected 34 smallmouth bass from June through July at the Pittsburg Landing release site; 56% (n=19) were from 150-249 mm bass and 44% (n=15) were from smallmouth bass  $\geq 250$  mm (Figure 6). For 150-249 mm smallmouth bass, the most abundant prey item by weight was chinook salmon (46.6%) followed by crustaceans (36.0%). The most abundant prey item for smallmouth bass  $\geq 250$  mm was crustaceans (42.6%) followed by chinook salmon (36.5%).

Crustaceans were the dominant prey item of smallmouth bass  $\geq 150$  collected during the months of May and June in 1997 (70.6% and 64.9%, respectively; Figure 6). Other fish contributed 25.8% in May and 31.4% in June, 1997. Chinook salmon were not found in smallmouth bass stomachs in May and June, 1997. In July 1997, chinook salmon (48.8%) was the most prevalent prey item by weight followed by crustaceans (40.3%) and insects (10.8%). During August 1997, crustaceans (59.8%) and insects (40.3%) composed the entire diet.

From May to August, 1997, we collected 49 smallmouth bass at Pittsburg Landing; 75% (n=37) were 150-249 mm and 24% (n=12) were  $\geq 250$  mm (Figure 6). For the 150-249 mm smallmouth bass, crustaceans were the dominant prey item (54.2%) followed by chinook salmon (24.2%). Stomach items from smallmouth bass  $\geq 250$  mm were dominated by crustaceans (64.4%) followed by other fish (35.1%). Chinook salmon were not found in smallmouth bass  $\geq 250$  mm in 1997.

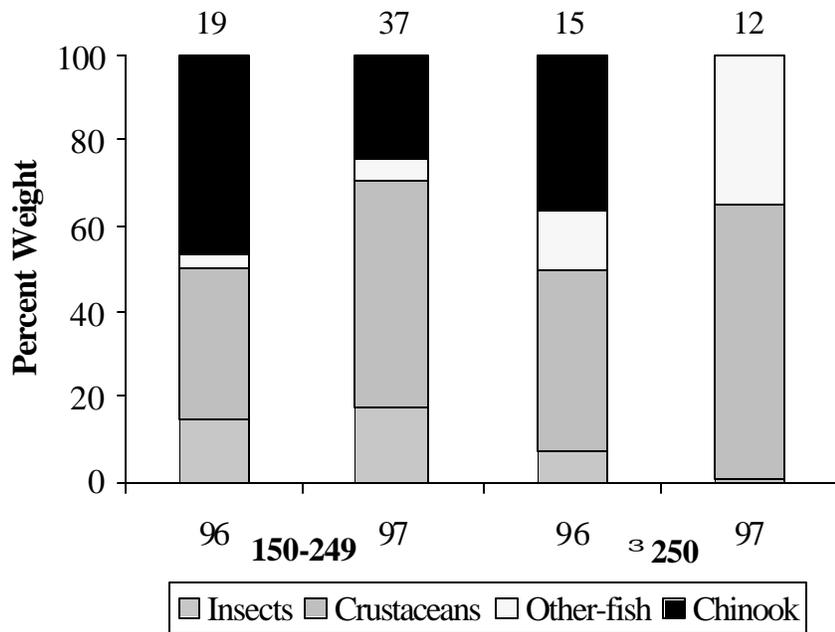
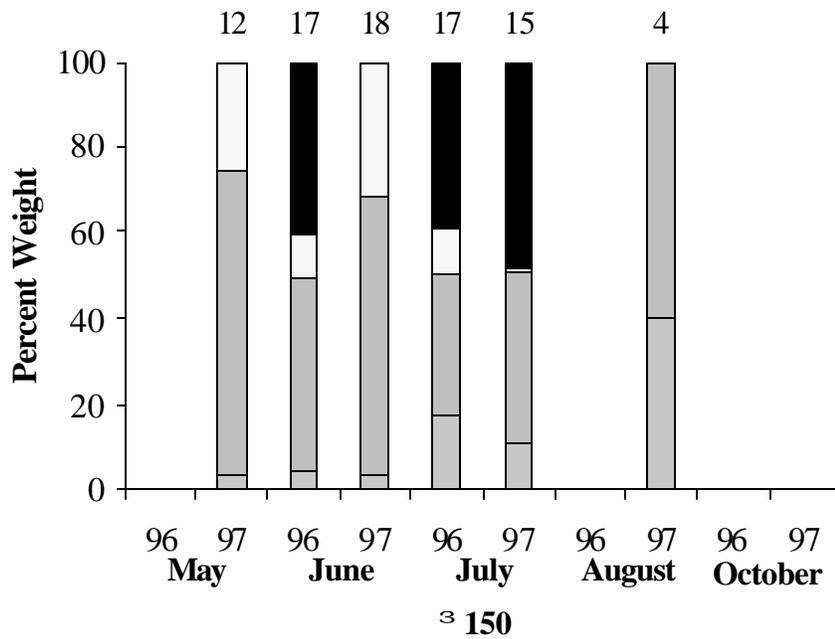


Figure 6. Diet composition of smallmouth bass  $\geq 150$  mm by month sampled and length class at Pittsburg Landing, Idaho (Rkm 346) on the Snake River during 1996 and 1997. Numbers above bars indicate the number of stomach samples examined.

*Upstream section.*—During 1996, crustaceans were the most abundant prey item by weight and accounted for more than 50% of the diet by weight for all months (Figure 7). In June, other fish accounted for 42.4%, and chinook salmon accounted for 0.7% of the diet by weight. In July, other fish constituted 22.8%, and chinook salmon 1.5%, of the diet by weight. In August, insects made up 36.4% of the diet by weight. For the month of October, other fish composed 30%, and insects 2.9%, of the diet by weight. No chinook salmon were found in the August and October samples of smallmouth bass.

During 1996, we collected 625 smallmouth bass, of which 58% (n=361) were 150-249 mm and 42% (n=264) were  $\geq 250$  mm (Figure 7). For 150-249 mm smallmouth bass, crustaceans (56.8%) were the most abundant prey item by weight, followed by insects (24.6%), and other fish (17.7%). Chinook salmon were not found in 150-249 mm smallmouth bass stomachs sampled in the upstream section during 1997. The most abundant prey item in smallmouth bass  $\geq 250$  mm was crustaceans (57.6%), followed by other fish (33.0%). Chinook salmon made up 1.1% of the diet, by weight, for smallmouth bass  $\geq 250$  mm.

During 1997, crustaceans were the most abundant prey item by weight for all months ( $\geq 62.4\%$ ) except October, for smallmouth bass  $\geq 150$  mm (Figure 7). From May through July, 1997, other fish were the second most common prey item by weight. Chinook salmon were found in the diet of smallmouth bass during June, 1997, and accounted for 0.3% of the diet by weight.

We collected 658 smallmouth bass from May to October during 1997 in the upstream section, of which 74% (n=484) were 150-249 mm and 26% (n=174) were  $\geq 250$  mm (Figure 7). Of 150-249 mm bass, crustaceans accounted for 65.5% of the total weight of prey items, followed by other fish (18.3%), insects (15.7%), and chinook salmon (0.2%). For bass  $\geq 250$  mm, crustaceans were the dominant prey item (76.0%), followed by other fish (20.9%), and insects (3.1%). Chinook salmon were not found in the stomachs of smallmouth bass  $\geq 250$  mm.

*Downstream section.*—During June, 1996, crustaceans (50.4%) were the most common prey item followed by other fish for smallmouth bass  $\geq 150$  mm (37.8%; Figure 8). Chinook salmon composed 0.3% of diet in June. During July (53.1%) and August (49.1%) 1996, the most common prey group was other fish. Crustaceans were the second most common prey item from July

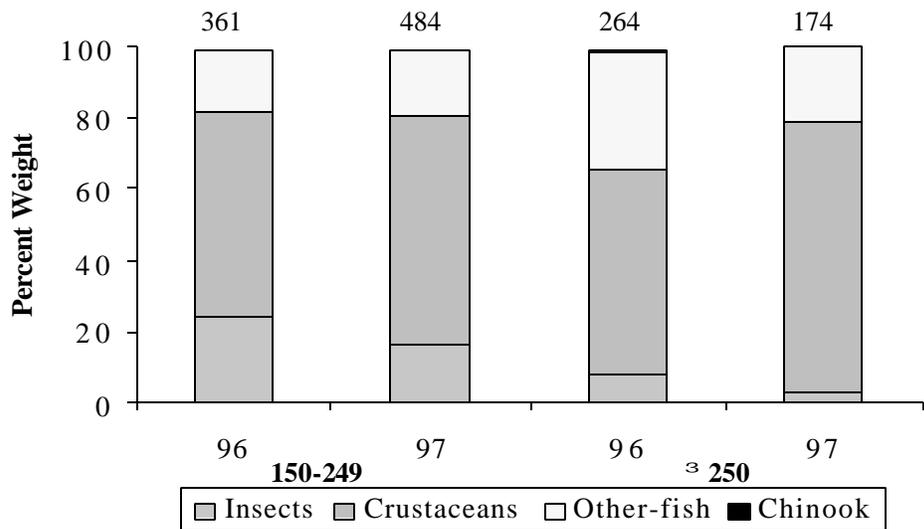
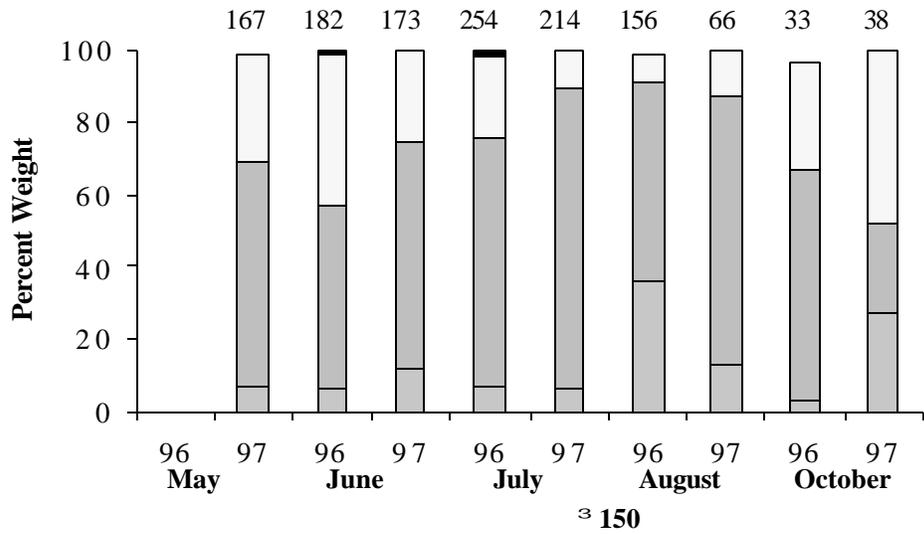


Figure 7. Diet composition of smallmouth bass  $\geq 150$  mm by month sampled and length class in the section of the Snake River upstream of the confluence of the Salmon River during 1996 and 1997. Numbers above bars indicate the number of stomach samples examined.

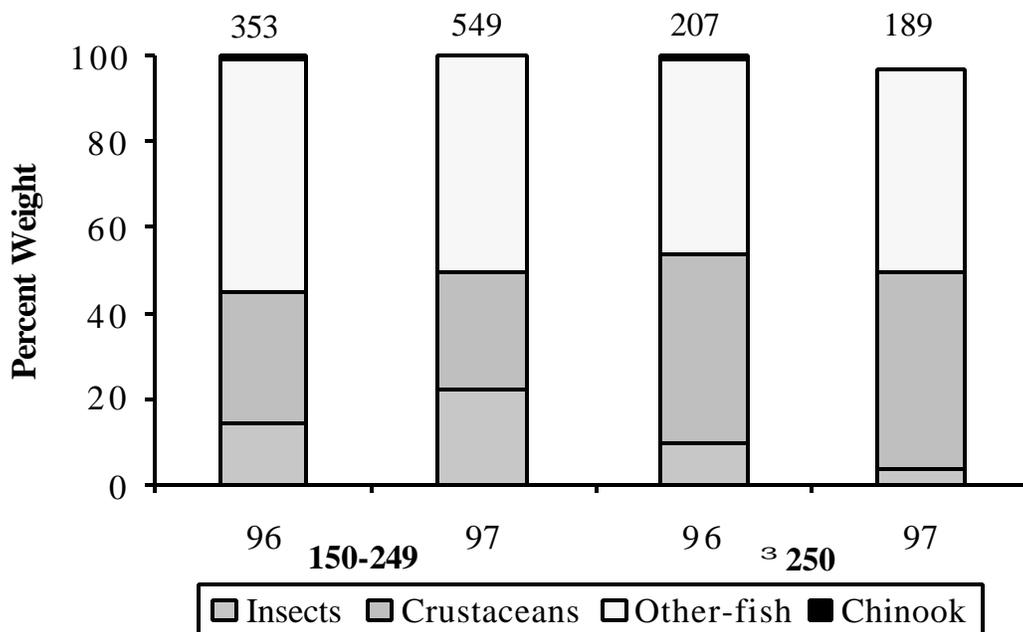
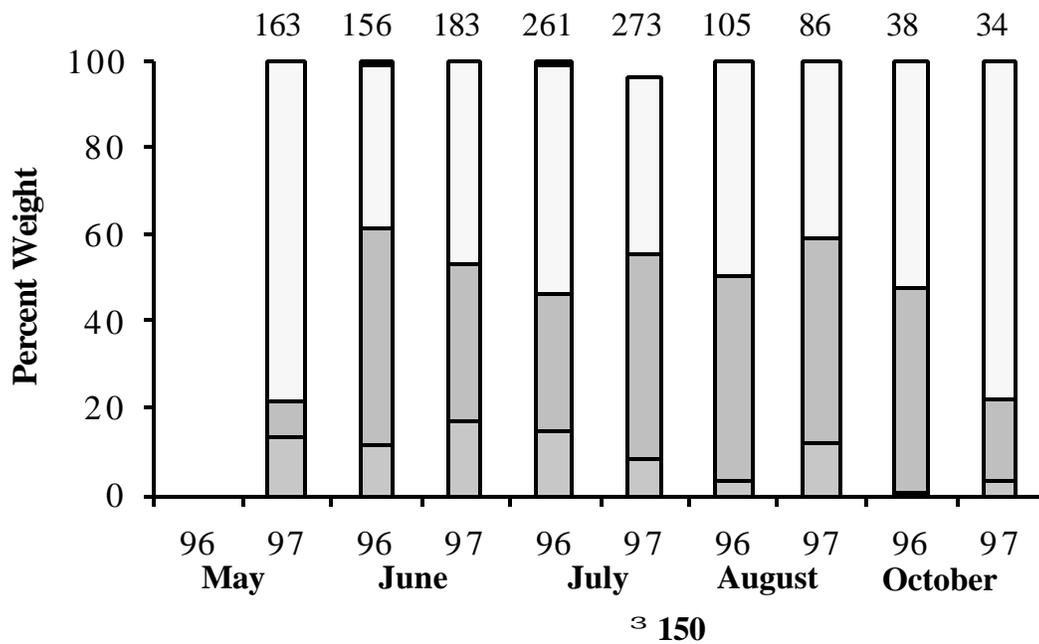


Figure 8. Diet composition of smallmouth bass  $\geq 150$  mm by month sampled and length class in the section of the Snake River downstream of the confluence of the Salmon River during 1996 and 1997. Numbers above bars indicate the number of stomach samples examined.

through October, 1996, making up 30.8% (July), 47.7% (August), and 46.7% (October) of the diet. Chinook salmon constituted 0.5% of the diet for July and were not found in August or October stomach samples of smallmouth bass.

In 1996, we collected 560 smallmouth bass, of which 63% (n=353) were 150-249 mm and 37% (n=207) were  $\geq 250$  mm (Figure 8). Other fish were the most common prey item by weight for the 150-249 mm and the  $\geq 250$  mm size classes, composing 54.2% and 46.0% of the diet, respectively. Crustaceans were the second most common prey item by weight during 1996, constituting 30% of the diet for 150-249 mm bass and 44.3% for smallmouth bass  $\geq 250$  mm. Chinook salmon accounted for  $\leq 0.1\%$  of the diet of 150-249 mm and  $\geq 250$  mm smallmouth bass.

During May, 1997, other fish (78.7%) was the dominant prey item by weight for smallmouth bass  $\geq 150$  mm, followed by insects (13.8%). During June, 1997, other fish (46.9%) were the most common prey item. During July (46.2%) and August (47.0%), 1997, crustaceans were the most abundant prey item by weight of smallmouth bass. In October, other fish (77.3%) were the dominant prey item by weight.

We collected 738 smallmouth bass from May to October in 1997 of which 74% (n=549) were 150-249 mm and 26% (n=189) were  $\geq 250$  mm (Figure 8). For 150-249 mm smallmouth bass, other-fish (50.7%) were the most common prey item by weight, followed by crustaceans (26.6%). For smallmouth bass  $\geq 250$  mm, other fish (47.7%) were the most prevalent prey item followed by crustaceans (45.6%). Chinook salmon were not found in the smallmouth bass stomachs downstream section during 1997.

#### *Numerical Consumption-Adams Model*

*Hatchery fall chinook salmon.*—Estimates of mean consumption rate of PIT-tagged hatchery fall chinook salmon by 150-249 mm and  $\geq 250$  mm smallmouth bass ranged from 0 to 1.143 fall chinook salmon/smallmouth bass/day (fc/smb/d; Figure 9; Appendices 17 and 18). Mean consumption was highest at the release site for all months and both years, except in June, 1997, for 150-249 mm smallmouth bass (Figure 9). The highest estimated consumption rates were observed during June, 1996 (0.933 fc/smb/d) for 150-249 mm bass and during July, 1997 (1.143 fc/smb/d) for smallmouth bass  $\geq 250$  mm at the release site. Consumption was generally lower in sections downstream from the release site

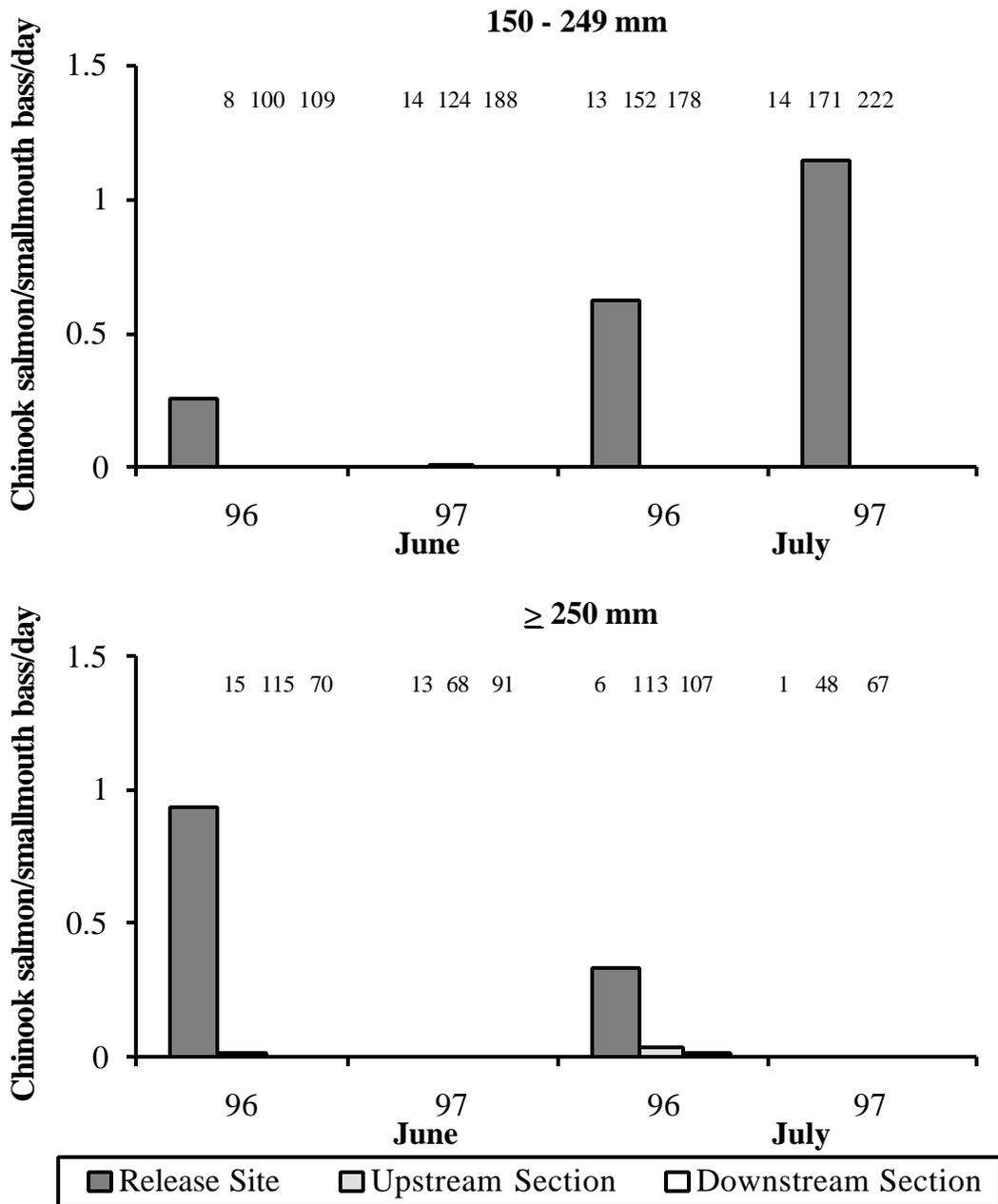


Figure 9. Mean daily consumption (fc/smb/d) of hatchery fall chinook salmon by 150-249 mm and  $\geq 250$  mm smallmouth bass using the Adams model. Smallmouth bass were collected in the Snake River from Asotin, Washington to Pittsburg Landing, Idaho during June and July 1996 and 1997. Numbers above bars indicate the number smallmouth bass sampled.

during a given month. The highest consumption rates for 1996 (0.027 fc/smb/d) and 1997 (0.008 fc/smb/d), excluding the release site, were recorded in the upstream section for both size classes of smallmouth bass.

*Wild fall chinook salmon.*—Estimates of mean consumption rate of wild fall chinook salmon were <0.01 fc/smb/d during 1996 (Figure 10; Appendices 19 and 20). During 1997, no smallmouth bass were captured with ingested wild fall chinook salmon. For 150-249 mm smallmouth bass, estimated consumption rates in the downstream section for June and July, 1996 ranged from 0.006 fc/smb/d to 0.009 fc/smb/d, respectively (Figure 10). For smallmouth bass  $\geq 250$  mm, a consumption rate of 0.008 fc/smb/d was calculated for the upstream section only in June, 1996 (Figure 10).

#### *Consumption-Wisconsin Model*

*Hatchery fall chinook salmon.*—Mean daily consumption of hatchery fall chinook salmon by smallmouth bass ranged from 0 to 0.0277 fc/smb/d for both size classes (Figure 11; Appendices 17 and 18). Consumption was highest at the release site during both months and for both size classes. We calculated that no smallmouth bass  $\geq 250$  mm consumed any hatchery fall chinook salmon during 1997 (Figure 11).

*Wild fall chinook salmon.*—Mean daily consumption of wild fall chinook salmon by 150-249 mm smallmouth bass calculated for the upstream section during 1996 ranged from 0 fc/smb/d to 0.0031 fc/smb/d (Figure 12; Appendices 19 and 20). For smallmouth bass  $\geq 250$  mm, monthly consumption in June, 1996 for both the upstream and downstream sections ranged from 0 to 0.0034 fc/smb/d (Figure 12). We calculated that no wild fall chinook salmon were consumed during July, 1996 or during all of 1997.

#### *Estimated Loss of Fall Chinook Salmon-Adams Model*

*Hatchery fall chinook salmon.*—We estimated that 5,347 (1996) and 3,935 (1997) hatchery subyearling fall chinook salmon were consumed by smallmouth bass from June through August (Tables 3 and 4). The highest loss of hatchery fall chinook salmon in 1996 was in July (4,490 hatchery fall chinook salmon), whereas in 1997, the highest loss was in June, (3,268 hatchery fall chinook salmon).

*Wild fall chinook salmon.*—We estimated the consumption of 5,102 wild subyearling fall chinook salmon by smallmouth bass using

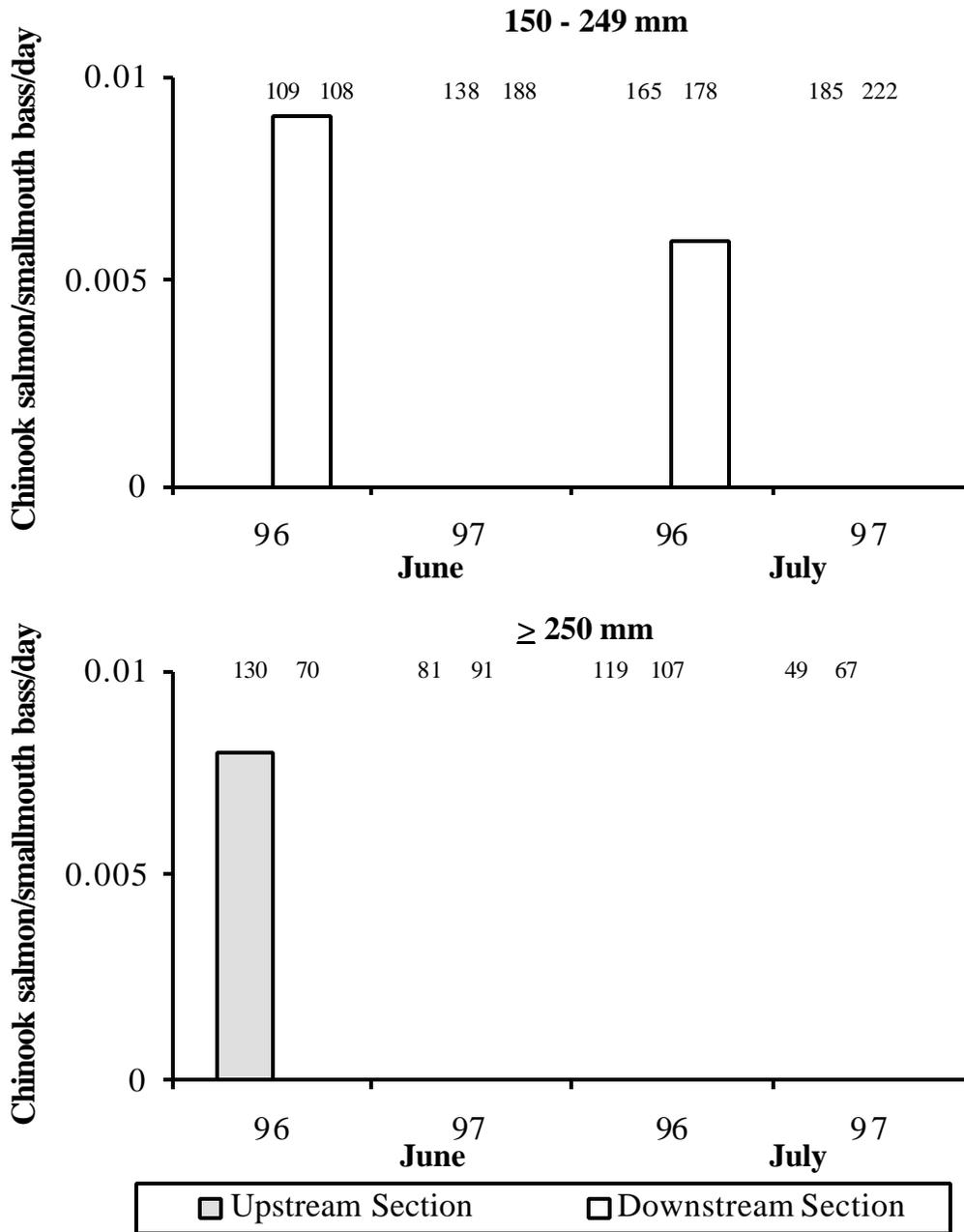


Figure 10. Mean daily consumption (fc/smb/d) of wild fall chinook salmon by 150-249 mm and  $\geq 250$  mm smallmouth bass using the Adams model. Smallmouth bass were collected in the Snake River from Asotin, Washington to Pittsburg Landing, Idaho during June and July 1996 and 1997. Numbers of bars indicate the number of smallmouth bass sampled.

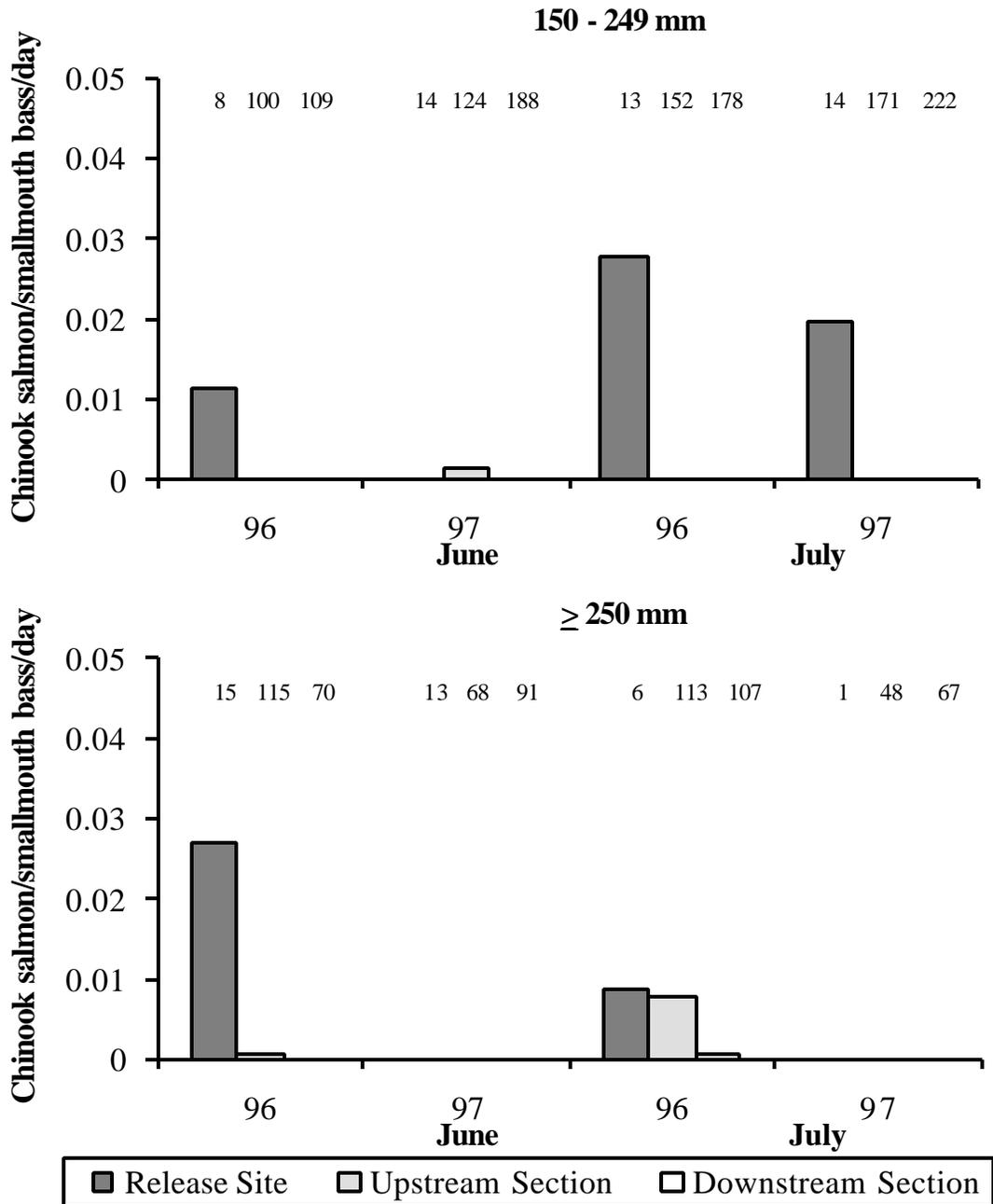


Figure 11. Mean daily consumption (fc/smb/d) of hatchery fall chinook salmon by an average 150-249 mm and  $\geq 250$  mm smallmouth bass using the Wisconsin model. Smallmouth bass were collected in the Snake River from Asotin, Washington to Pittsburg Landing, Idaho during June and July 1996 and 1997. Numbers above bars indicate the number of smallmouth bass sampled.

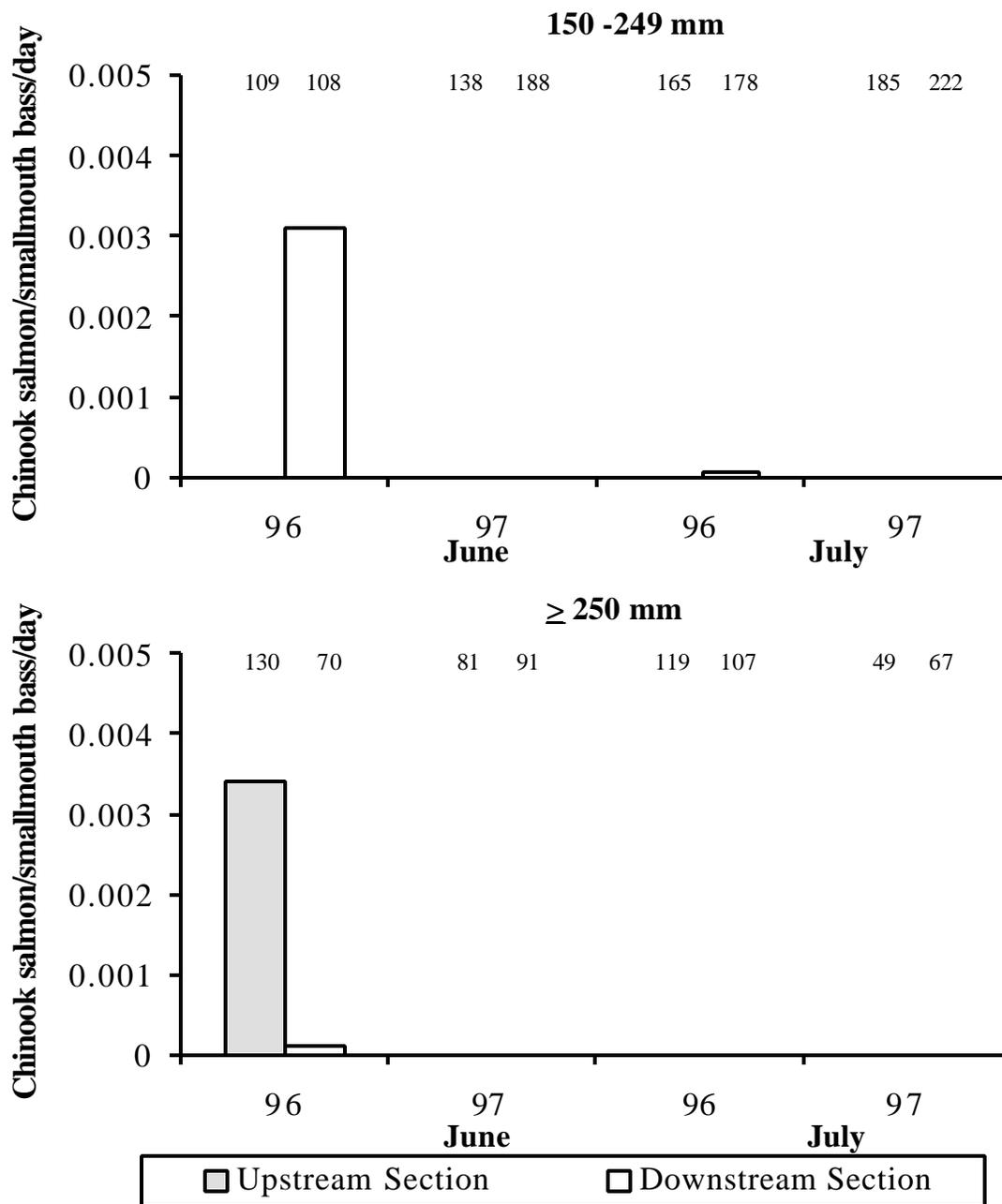


Figure 12. Mean daily consumption (fc/smb/d) of wild fall chinook salmon by an average 150-249 mm and  $\geq 250$  mm smallmouth bass using the Wisconsin model. Smallmouth bass were collected in the Snake River from Asotin, Washington to Pittsburg Landing, Idaho during June and July 1996 and 1997. Numbers above bars indicate the number of smallmouth bass sampled.

Table 3.-Estimated number of hatchery subyearling fall chinook salmon consumed by smallmouth bass  $\geq 150$  mm predation in the Hells Canyon reach of the Snake River (Rkm 237 to Rkm 346) during 1996 using the Adams and Wisconsin models.

Location	Length	Loss	Loss
	Class (mm)	Adams Model	Wisconsin Model
<b>June 1996</b>			
Release site	150 - 249	146	40
	$\geq 250$	213	37
Upstream section	150 - 249	0	0
	$\geq 250$	498	24
Downstream section	150 - 249	0	0
	$\geq 250$	0	0
<b>Monthly Total</b>		<b>857</b>	<b>101</b>
<b>July 1996</b>			
Release site	150 - 249	359	161
	$\geq 250$	76	20
Upstream section	150 - 249	0	0
	$\geq 250$	2,535	723
Downstream section	150 - 249	0	17
	$\geq 250$	1,520	117
<b>Monthly Total</b>		<b>4,490</b>	<b>1,038</b>
<b>1996 Total</b>		<b>5,347</b>	<b>1,139</b>

Table 4.-Estimated number of hatchery subyearling fall chinook salmon consumed by smallmouth bass  $\geq 150$  mm predation in the Hells Canyon reach of the Snake River (Rkm 237 to Rkm 346) during 1997 using the Adams and Wisconsin models.

Location	Length	Loss	Loss
	Class (mm)	Adams Model	Wisconsin Model
<b>June 1997</b>			
Release site	150 - 249	0	0
	$\geq 250$	0	0
Upstream section	150 - 249	3,268	623
	$\geq 250$	0	0
Downstream section	150 - 249	0	0
	$\geq 250$	0	0
<b>Monthly Total</b>		<b>3,268</b>	<b>623</b>
<b>July 1997</b>			
Release site	150 - 249	667	91
	$\geq 250$	0	0
Upstream section	150 - 249	0	0
	$\geq 250$	0	0
Downstream section	150 - 249	0	0
	$\geq 250$	0	0
<b>Monthly Total</b>		<b>667</b>	<b>91</b>
<b>1997 Total</b>		<b>3,935</b>	<b>714</b>

the Adams method from June through August, 1996 (Table 5). The highest monthly loss (54%) of wild fall chinook salmon was during June, 1996. All of the loss of wild fall chinook salmon during July occurred in the downstream section. Total loss for 1997 was negligible; no fall chinook salmon were found during diet analyses in 1997.

#### *Estimated Loss of Fall Chinook Salmon-Wisconsin Model*

*Hatchery fall chinook salmon.*—Using the Wisconsin model, we estimated the consumption of hatchery fall chinook salmon by smallmouth bass was 1,139 in 1996 and 714 in 1997 (Tables 3 and 4). In 1996, 91% of the loss to smallmouth bass predation occurred during the month of July, (Table 3), while in 1997, most of the estimated loss to smallmouth bass predation (87%) occurred during the month of June (Table 4).

*Wild fall chinook salmon.*—The estimated consumption of wild fall chinook salmon by smallmouth bass in 1996 was 1,326 (Table 5). During 1996, 59% of the total loss to smallmouth bass predation occurred in the downstream section during June. The loss of wild fall chinook salmon was not calculated for 1997.

## **Discussion**

### *Smallmouth Bass Abundance and Density*

Our estimate of absolute abundance of 43,248 smallmouth bass  $\geq 175$  mm, or 397 smallmouth bass/km, represents the only known estimate of absolute abundance for the 109 km free-flowing Snake River downstream of Pittsburg Landing, Idaho. We estimated 16,254 (378 smallmouth bass/km) and 26,994 (409 smallmouth bass/km) smallmouth bass  $\geq 175$  mm in the upstream and downstream sections of Snake River, respectively, which are similar to those reported for Lower Granite Reservoir on the Snake River. Anglea (1997) and Naughton (1998) reported estimates of 395 and 406 smallmouth bass/km (smallmouth bass  $\geq 168$  mm) from Lower Granite Reservoir, respectively. Naughton (1998) however, estimated 237 smallmouth bass/km (smallmouth bass  $\geq 168$  mm) in the Snake River arm of Lower Granite Reservoir compared to our 409 smallmouth bass/km in the adjacent downstream section of the Hells Canyon Reach of Snake River. We speculate the difference in absolute abundance between Naughton's study (1998) and our estimate of abundance (smallmouth bass/km) could be a

Table 5.-Estimated number of wild subyearling fall chinook salmon consumed by smallmouth bass  $\geq 150$  mm predation in the Hells Canyon reach of the Snake River (Rkm 237 to Rkm 346) during 1996 using the Adams and Wisconsin models.

Location	Length	Loss	Loss
	Class (mm)	Adams Model	Wisconsin Model
<b>June 1996</b>			
Upstream section	150 - 249	0	0
	$\geq 250$	451	196
Downstream section	150 - 249	2,302	777
	$\geq 250$	0	8
<b>Monthly Total</b>		<b>2,753</b>	<b>981</b>
<b>July 1996</b>			
Upstream section	150 - 249	0	0
	$\geq 250$	0	0
Downstream section	150 - 249	2,349	345
	$\geq 250$	0	0
<b>Monthly Total</b>		<b>2,349</b>	<b>345</b>
<b>1996 Total</b>		<b>5,102</b>	<b>1,326</b>

result of more suitable habitat and lower exploitation rates in the free-flowing Snake River.

Zimmerman and Parker (1995) reported an increasing trend in relative densities of smallmouth bass as sampling progressed upstream from the Lower Columbia River through Lower Granite Reservoir on the Snake River. The increasing trend in smallmouth bass relative abundance was attributed to higher water temperatures, smaller and deeper reservoirs, lower exploitation rates, and more suitable habitat characteristics in the Snake River. We found a similar trend in densities of smallmouth bass within the Hells Canyon Reach, and also between our study and previous studies in Lower Granite Reservoir. We estimated the density of smallmouth bass in the downstream section was 24 fish/ha and 37 fish/ha in the upstream section for smallmouth bass  $\geq 175$  mm. In Lower Granite Reservoir, Anglea (1997) reported 3.4 smallmouth bass/ha (smallmouth bass  $> 191$  mm), whereas Naughton (1998) reported 12.5 smallmouth bass/ha (smallmouth bass  $\geq 168$  mm). Our smallmouth bass density estimates are at the lower end of the range of 16 to 164 smallmouth bass/ha reported by Carlander (1977) in lotic systems throughout North America.

We anticipated that smallmouth bass relative abundance would be higher in the section of the Snake River upstream of the confluence of the Salmon River due to more suitable habitat characteristics, higher number of degree days, and lower exploitation rates (Schriever and Cochnauer 1996). Our results indicate higher smallmouth bass relative abundance (CPUE) in the upstream section of the Snake River for 150-249 mm smallmouth bass during 1996 and 1997, and smallmouth bass  $\geq 250$  mm during 1996. Although no differences were found in relative abundance of smallmouth bass in the  $\geq 250$  mm size class during 1997, we speculate that this lack of difference could be a result of lower exploitation rates and redistribution of populations associated with the abnormally high flows in 1997.

Our estimates of relative abundance and point estimates of absolute abundance of smallmouth bass were contradictory when comparing our study sections above and below the Salmon River confluence. No statistical test was run on the absolute abundance data and confidence intervals associated with our estimated absolute abundance for the two sections overlap, thus the apparent difference may not be real. Although we stratified our smallmouth bass absolute abundance estimates by general

habitat types, based on gradients and valley geomorphology, a stratification design based on a finer scale (such as substrate), as well as more longitudinal transects, may have improved our estimates of absolute abundance by capturing a greater portion of the variability.

Conducting a mark-recapture study in a large, remote river, such as the Snake River, can present logistical complications and sampling bias not experienced in smaller systems. Lyons (1991) suggested that electrofishing for smallmouth bass in large, deep rivers could bias the abundance estimate low as result of smallmouth bass in deeper pools not being recruited to electrofishing gear; thus a portion of the population will go unsampled. Therefore, we consider our estimates of smallmouth bass abundance to be conservative, but similar to others reported for the Snake River.

#### *Age and Growth*

Our estimates of smallmouth bass length at age (fork length mm) are similar to the results found by Keating (1970) for the Hells Canyon Reach of the Snake River. We estimated the length at first annulus formation of 79 mm and 80 mm for the upstream and downstream sections of the Snake River, respectively, whereas Keating estimated 84 mm and 82 mm for the same sections in the late 1960's. In a study conducted by Anglea (1997) on Lower Granite Reservoir, first annulus formation was at 78 mm, but his estimated subsequent growth increments were higher than those in our study sections.

As with Keating's (1970) research, we found larger increments of growth in the upstream section than in the downstream section for the first 3 years of growth. For ages 4 to 6, smallmouth bass in the downstream section grew faster than those in the upstream section. Annual degree-days ( $\geq 10^{\circ}\text{C}$ ) were similar during 1996 and 1997, and to those in the 1960's. During 1996 and 1997, annual degree-days averaged 1,571 for the upstream section and 1,256 for the downstream section. Keating (1970) reported 1,330 degree-days in the downstream section and 1,554 degree-days in the upstream section during the 1960's. He attributed slower growth of the large size classes of smallmouth bass in the upstream section to increased intraspecific and interspecific competition.

We hypothesize that the higher rate of growth of mature-sized smallmouth bass in the downstream section is a reflection of the prey availability and diet. Coble (1967) suggested that

food supply and quality may influence growth rates more than water temperature in mature smallmouth bass. Anglea (1997) suggested that the higher abundance of crayfish after impoundment of Lower Granite Reservoir on the Snake River could have stimulated higher growth. Mature smallmouth bass in our downstream section may have higher growth increments than smallmouth bass in the upstream section, even though they are exposed to fewer thermal units, because their diets comprise a larger portion of fish that are higher in energy and more easily digested.

#### *The Importance of Juvenile Fall Chinook Salmon in the Diet of Smallmouth Bass*

We found low incidence of predation on juvenile fall chinook salmon by smallmouth bass in all areas of the free-flowing Snake River, except at the Pittsburg Landing release site following the release of hatchery fall chinook salmon during 1996 and 1997. In our study, percent weight (0 to 48.8%) of fall chinook salmon in the diets of smallmouth bass  $\geq 150$  mm was highest directly after a hatchery release and decreased downstream (0 to 0.8%). Overall, chinook salmon composed 1.4% of the diet in the upstream section, including the release site, and 0.2% of the diet in the downstream section. Other smallmouth bass dietary studies in the Pacific Northwest have found various degrees of predation on juvenile salmonids. A study in the Snake River arm of Lower Granite Reservoir during 1996 and 1997 reported <0.1% to 5% salmonids in the diet of smallmouth bass (n=8,609; Naughton 1998). Pflug and Pauley (1984) reported that smallmouth bass (n=685) in Lake Sammamish, Washington fed on juvenile salmon primarily during the May smolt outmigration. Predator-prey studies conducted in the mid-1980's in John Day Reservoir on the Columbia River (Poe et al. 1991) found smallmouth bass (n=4,811) were the least important predator on juvenile salmon, accounting for approximately 4% of the diet by weight. Poe et al. (1991) also reported that most of the predation occurred during July and August, when subyearling fall chinook salmon were emigrating, thus concentrating the losses on later emigrating stocks of salmon. In the upper section of McNary Reservoir on the Columbia River, Tabor et al. (1993) reported 59% of the diet of smallmouth bass (n=92) was composed of juvenile salmon, and speculated a large portion of the salmonids in the diet were subyearling fall chinook salmon.

Although juvenile fall chinook salmon accounted for a small portion of the overall diet of smallmouth bass in our study,

hatchery fall chinook salmon were abundant in diet samples immediately after release at Pittsburg Landing. Other studies have documented the response of smallmouth bass to hatchery stocked juvenile salmonids. Warner (1972) reported substantial predation of smallmouth bass on juvenile Atlantic salmon *Salmo salar* directly after hatchery release in Maine lakes. Tabor et al. (1993) attributed high percentages of juvenile Pacific salmon in the diets of smallmouth bass to high densities and habitat overlap between juvenile Pacific salmon and smallmouth bass. We believe the discrepancy between our results and those of Tabor et al. (1993) is a result of much higher densities of juvenile fall chinook salmon in the Hanford Reach of the Columbia River, compared to the low numbers found in the Hells Canyon Reach of the Snake River. In the sections downstream of Pittsburg Landing, few juvenile fall chinook appeared in smallmouth bass diet samples. We attribute this low occurrence of hatchery juvenile fall chinook salmon in smallmouth bass diets to low densities of prey as hatchery fall chinook salmon move downstream and disperse.

Coble (1975) suggested that prey fish were an important component in the diets of older smallmouth bass. We found that smallmouth bass in both the 150-249 mm and the  $\geq 250$  mm size classes preyed upon fall chinook salmon, however, we could not detect a trend in predation of juvenile salmonids with increasing size of smallmouth bass. Anglea (1997) found an increase in predation on salmonids as the size of smallmouth bass increased in the Snake River. Naughton (1998) and Poe et al. (1991) however, found little difference in predation among size classes.

#### *Food Habits of Smallmouth Bass*

Our study represents the only recent, comprehensive dietary analysis of smallmouth bass in the Hells Canyon Reach of the Snake River. Our study, and others in the Pacific Northwest, demonstrate that smallmouth bass are opportunistic predators that consume prey items as they are encountered, and the availability and abundance of prey items is reflected in the diet (Coble 1975; Pflug and Pauley 1984; Tabor et al. 1993; Poe et al. 1991). Pflug and Pauley's (1984) study on Lake Sammamish, Washington reported a high occurrence of fish in the diets of smallmouth bass. Poe et al. (1991) found smallmouth bass fed primarily on fish (77.6%) and crayfish (21.3%) in the John Day Reservoir, Washington. In the riverine environment of the Hells Canyon Reach, Keating (1970) reported that smallmouth bass diets (n=72) were composed of crayfish (58%), fish (13%),

and insects (21%). During 1996 and 1997 in our study, diets of smallmouth bass were composed primarily of crayfish (63%) and fish (26%) in the upstream section (n=1366 smallmouth bass), and fish (49%) and crayfish (39%) in the downstream section (n=1298 smallmouth bass).

The opportunistic feeding behavior of smallmouth bass is demonstrated by the high percent weight of hatchery fall chinook salmon in the diet immediately after hatchery releases. Additionally, we found a large insect component in the diet of smallmouth bass during August, 1996 when a rangeland fire burned in the upstream section. During this time, smallmouth bass  $\geq 150$  mm consumed 58% insects by percent weight, primarily grasshoppers, compared to 11% insects in the downstream location during the same sample week. We believe terrestrial insects (grasshoppers) were flushed from shoreline areas into the water as the rangeland fire burned down to the Snake River, thus becoming available to smallmouth bass.

We found significant differences in the proportion of major prey items in diets of smallmouth bass between the upstream and downstream sections during 1996 and 1997. Smallmouth bass preyed significantly more on crayfish in the upstream section than the downstream section, and the diets of smallmouth bass in the downstream section were significantly higher in fish and insects. The difference in diet of smallmouth bass between the two sections could be a result of difference in prey abundance and availability between the two sections.

#### *Consumption of Fall Chinook Salmon*

We found low rates of predation by smallmouth bass on juvenile fall chinook salmon during 1996 and 1997 for both hatchery and wild fall chinook salmon downstream from the release site ( $< 0.03$  salmon/predator/day). The highest rates of consumption were found at the Pittsburg Landing release site directly after releases of hatchery fall chinook salmon. We believe the high consumption rates at Pittsburg Landing were a short-term response resulting from high densities of disorientated prey.

Vigg et al. (1991) suggested that many factors influence consumption rates of smallmouth bass, but water temperature was considered the single most important factor. Smallmouth bass exist in water temperatures ranging from 12 to 31°C (Ferguson 1958; Barans and Tubbs 1973) and the final preferendum is

approximately 28°C (Coble 1975). Smallmouth bass become active in water temperatures >10°C (Munther 1970) and begin actively feeding at approximately 15°C (Carlander 1977). Water temperatures in the Hells Canyon Reach varied between the upstream and downstream sections. Water temperatures reached 15°C in the upstream section by June 3, 1996 and May 13, 1997. In the downstream section, water temperatures reached 15°C by June 24, 1996 and June 17, 1997. Maximum water temperatures of 22°C occurred during August for both years in both sections. Water temperatures were therefore in the lower range of preferred water temperatures and below the final preferendum of smallmouth bass during 1996 and 1997. The low consumption rates of fall chinook salmon downstream from the release site could be a result of less than optimum water temperatures for smallmouth bass, thus lowering smallmouth bass metabolic demands and consumption rates.

#### *Total Loss of Fall Chinook Salmon*

We believe that the loss of juvenile fall chinook salmon from predation by smallmouth bass could account for a small portion of the mortality encompassed in survival estimates of juvenile fall chinook salmon to Lower Granite Reservoir. We hypothesized that predation of hatchery fall chinook salmon by smallmouth bass would be highest at the release site when disorientated juvenile salmonids were released in high densities. Total loss of hatchery fall chinook salmon to predation by smallmouth bass in the 109 km Hells Canyon Reach during 1996 was estimated at 26% (Adams model) and 5% (Wisconsin model). During 1997, the total loss of hatchery fall chinook salmon to smallmouth bass predation in the Hells Canyon Reach was estimated at 9% (Adams model) and 2% (Wisconsin model).

Predation on wild subyearling fall chinook salmon by smallmouth bass was low and infrequent in this study. We believe the low numbers of wild fall chinook salmon consumed by smallmouth bass during 1996, and the absence of predation in 1997, could be related to habitat differences used by fall chinook salmon and smallmouth bass in the free-flowing sections. Both smallmouth bass and juvenile fall chinook salmon are known to use littoral zones with reduced velocities (Mains and Smith 1956; Curet 1993; Munther 1970; Rankin 1986). However, smallmouth bass have a tendency to use nearshore habitat associated with rocky substrate and structure (Munther 1970, Coble 1975), while juvenile fall chinook salmon are thought to use habitats over sandy substrates (Dauble et al. 1989; Bennett

et al. 1992; Curet 1994). We believe the Hells Canyon Reach may provide sufficient preferred habitat for each species, and that habitat overlap is limited during fall chinook rearing. Thus, encounters between smallmouth bass and fall chinook salmon may be limited to when fall chinook salmon are migrating downstream over rocky substrate. Tabor et al. (1993) attributed the high consumption of fall chinook salmon by smallmouth bass in the upper section of McNary Reservoir to habitat overlap between juvenile salmon and smallmouth bass. However, in McNary Reservoir, smallmouth bass and fall chinook may be using available habitats differently than in the Hells Canyon Reach due to different geomorphologic characteristics.

Along with lower water temperatures, high discharge and the associated high turbidities could dampen the effect of predation by smallmouth bass on fall chinook salmon. High flow years in the Snake River basin, such as 1996 and 1997, are generally associated with lower water temperatures and higher turbidities than low flow years. Smallmouth bass are considered visual predators (Carlander 1977) and higher turbidities could decrease the reactive distance of smallmouth bass to a prey item, thus decreasing foraging efficiency (Vinyard and O'Brien 1976). Cada et al. (1997) suggested that reduced velocities and associated lower turbidities in the reservoirs of the Columbia River Basin may lower survival of juvenile salmon. Additionally, Gregory and Levings (1998) found that juvenile salmon are less likely to encounter, and be lost to, predators in turbid water. During 1996 and 1997, turbidities in the downstream section of the Hells Canyon Reach through mid-June (Appendices 21 and 22) were higher than what Gregory (1993) defined as turbid water ( $\geq 23$  NTU). Thus, we believe turbidity and water temperatures conditions during 1996 and 1997 in the Snake River helped to moderate predation of juvenile fall chinook salmon by smallmouth bass.

Mean survival estimates of PIT-tagged fall chinook salmon from Pittsburg Landing to Lower Granite Dam (Rkm 173) were 32% and 44% in 1996 and 1997, respectively (Williams and Bjornn 1998; Connor unpublished data). Our estimates of loss of PIT-tagged fall chinook salmon due to smallmouth bass predation followed a similar trend of higher mortality in 1996 than in 1997. Connor (unpublished data) found that larger fall chinook salmon had faster travel times to Lower Granite Dam and higher survival than smaller chinook salmon. He attributed the increased survival of larger fall chinook salmon to decreased exposure to predation due to faster travel time.

## Consumption Model Comparisons

Using both a field model, based on gastric evacuation (Adams model), and a bioenergetics model, based on a mass-balanced equation (Wisconsin model), has been suggested as a good method to corroborate and address consumption in fish (Ney 1993). In this study, the Wisconsin model, using seasonal growth of smallmouth bass, was a more conservative model and predicted total losses of juvenile fall chinook salmon to smallmouth bass predation that were 59 to 69% less than the Adams model.

Ney (1993) suggests that the bioenergetics approach is based on a sound method that accounts for energy pathways, but that the model is susceptible to errors in the input parameters and internal functions. We used coefficients for the physiological rate equations from a model for adult largemouth bass *Micropterus salmoides* (Roell and Orth 1993) because Hanson et al. (1997) advocated using physiological parameters from adult fish of similar species to model adult fish for which no parameters are available. Borrowing coefficients from similar species is common in bioenergetics modeling, however, this approach has been suggested as a weakness of bioenergetics modeling by Ney (1993). The bioenergetics model estimates a "p-value" that is defined as a proportion of the maximum consumption at which a fish needs to feed to attain an observed growth over time (Hanson et al. 1997). We estimated "p-values" from bioenergetics simulations that ranged from 0.15 to 0.24, which suggests that the Wisconsin model underestimated consumption. Low estimated "p-values" could be a result of using coefficients derived for largemouth bass. Additionally, we did not model reproductive energy storage, which would lead to underestimating consumption by not accounting for the energy needed to produce gametes.

The Adams model, which is based on an evacuation rate equation derived from laboratory digestion rates, has been criticized for not fully representing field conditions (Bromley 1994). The evacuation equation developed by Roger and Burley (1991) uses only salmonids as prey items, and does not account for differential digestion rates among prey items, especially hard to digest prey items, such as crayfish. Differential digestion rates among prey items for smallmouth bass is untested and may create errors, which will be incorporated into consumption rates.

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Appendix 22. Weekly water temperature ( $^{\circ}\text{C}$ ), turbidity (NTU), and discharge (cm/sec) during 1997 in the downstream (Rkm 237 to Rkm 303) and upstream (Rkm 303 to Rkm 346) sections of the Hells Canyon Reach of the Snake River.

Appendix 1.-Total number of incidental fish caught by electrofishing in the free-flowing area of the Snake River in 1998.

Common name	Scientific name	Total catch
Carp	<i>Cyrinus carpio</i>	84
Chiselmouth	<i>Acrocheilus alutaceus</i>	64
Dace	<i>Rhinichthys spp.</i>	6
Fall chinook salmon	<i>Oncorhynchus tshawytscha</i>	110
Largemouth bass	<i>Micropterus salmoides</i>	4
Largescale sucker	<i>Catostomus macrocheilus</i>	1227
Mountain whitefish	<i>Prosopium williamsoni</i>	47
Northern pikeminnow	<i>Ptychocheilus oregonensis</i>	31
Peamouth	<i>Mylocheilus caurinus</i>	22
Rainbow trout	<i>Oncorhynchus mykiss</i>	110
Redside shiner	<i>Richardsonius balteatus</i>	1
Sculpins	<i>Cottidae</i>	42
Smallmouth bass	<i>Micropterus dolomieu</i>	86
Spring chinook salmon	<i>Oncorhynchus tshawytscha</i>	20
Unknown		114

Appendix 2. Population estimates for each longitudinal transect, transect length, and estimated fish per km used to estimate population of smallmouth bass  $\geq 175$  mm in the Hells Canyon Reach of the Snake River in 1997.

Transect	Rkm	Habitat type	Estimate	Transect	
				length (m)	Fish / km
1	344	Open	195	325	600
2	342	Canyon	390	1165	335
3	337	Canyon	560	981	571
4	329	Open	177	630	281
5	318	Canyon	147	503	292
6	305	Chute	52	566	92
7	292	Open	74	883	82
8	281	Open	NA <sup>a</sup>	NA	NA
9	266	Open	649	992	654
10	256	Open	159	431	361
11	247	Open	323	630	512
12	243	Open	250	577	434

<sup>a</sup> No recaptured smallmouth bass

Appendix 3. Back-calculated fork lengths at age and annual growth increments from smallmouth bass collected during the spring of 1997 in the upstream section (Rkm 303 to Rkm 346) on the Snake River.

Year			Mean Fork Length (mm)							
Class	Cohort	Number	1	2	3	4	5	6	7	8
1996	1	1	88							
1995	2	15	77	145						
1994	3	30	78	140	198					
1993	4	6	86	149	202	248				
1992	5	7	79	123	183	227	257			
1991	6	2	71	126	190	239	278	300		
1990	7	10	80	125	180	216	253	281	302	
1989	8	4	75	130	195	226	260	285	305	319
Weighted Mean			79	137	193	228	258	284	303	319
Increment of growth			79	58	56	35	30	27	19	16
Number		75	75	74	59	29	23	16	14	4



Appendix 4. Back-calculated fork lengths at age and annual growth increments for smallmouth bass collected during the spring of 1997 in the downstream section (Rkm 237 to Rkm 303) of the Snake River.

Year			Mean Fork Length (mm)								
Class	Cohort	Number	1	2	3	4	5	6	7	8	9
1996	1	0	0								
1995	2	1	85	127							
1994	3	37	81	123	175						
1993	4	12	80	136	183	218					
1992	5	14	76	124	189	228	262				
1991	6	8	83	138	192	245	281	307			
1990	7	2	90	141	194	231	267	299	327		
1989	8	0	0	0	0	0	0	0	0	0	
1988	9	1	87	129	203	257	281	303	327	342	355
Weighted Mean			80	127	182	230	269	305	327	342	355
Increment of growth			80	47	54	48	39	37	21	16	13
Number		75	75	75	74	37	25	11	3	1	1

Appendix 5. Summary of releases of PIT tagged subyearling fall chinook salmon at Pittsburg Landing, Idaho Rkm 345.8 in 1996 and 1997. Releases of fall chinook salmon occurred at dusk (William Connor, USFWS, Ahsahka, Idaho, unpublished data).

Release date	Number of fall chinook salmon released	Cumulative number of salmon released
<b>1996</b>		
06/06/96	1,189	1,189
06/13/96	7,989	9,178
06/20/96	8,118	17,296
06/27/96	1,214	18,510
07/03/96	1,220	19,730
07/10/96	1,224	20,954
<b>1997</b>		
05/28/97	6,955	6,955
05/30/97	6,946	13,901
06/3/97	1,262	15,163
06/10/97	1,245	16,408
06/11/97	5,174	21,582
06/12/97	5,323	26,905
06/13/97	5,257	32,162
06/14/97	5,160	37,322
06/17/97	1,243	38,565
06/24/97	1,239	39,804
07/01/97	1,251	41,055
07/08/97	1,238	42,293

Appendix 6. Values used in Wisconsin bioenergetics model to estimate consumption of juvenile fall chinook salmon by smallmouth bass in the Hells Canyon Reach of the Snake River, Idaho (Rkm 237 to Rkm 346). Values and description are from Roell and Orth (1993) and Hanson et al. (1997).

Parameter	Description	Value
<b>Consumption</b>		
CA	Intercept of the mass dependence function at maximum consumption (g / g / d)	0.33
CB	Coefficient of mass dependence	-0.325
CQ	Water temperature C at CK1 of the maximum consumption	10
CTO	Water temperature C at CK2 of the maximum consumption	26
CTM	Water temperature C >CTO at CK3 of the maximum consumption	28
CTL	Water temperature C at CK4 of the maximum consumption	33
CK1	Proportion of maximum consumption at CQ	0.1
CK2	Proportion of maximum consumption at CTO	0.98
CK3	Proportion of maximum consumption at CTM	0.98
CK4	Proportion of maximum consumption at CTL	0.01
<b>Respiration</b>		
RA	Intercept for maximum standard respiration	0.008352
RB	Slope for the maximum standard respiration	-0.355
RQ	Slope for standard respiration dependence on temperature	2.1
RTO	Optimum water temperature for standard respiration	33
RTM	Maximum water temperature for standard respiration	38
ACT	Activity multiplier of standard respiration at > 10 C	1.3
SDA	Proportion of assimilated energy lost to specific dynamic action	0.17
<b>Egestion/Excretion</b>		
FA	Proportion of consumed energy egested	0.15
UA	Proportion of the assimilated energy excreted	0.088

Appendix 7. Energy densities of prey items and smallmouth bass used in the Wisconsin bioenergetics model to estimate consumption of juvenile fall chinook salmon in the Hells Canyon Reach of the Snake River, Idaho (Rkm 237 to Rkm 346).

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Prey item	Energy density		Source
	(cal / g)	(J / g)	
Insect	869	3,636	Cummins and Wuycheck 1971
Crayfish	1,077	4,508	Cummins and Wuycheck 1971
Non-chinook fish	1,231	5,153	Petersen and Ward 1999; Shuter and Post 1990
Chinook salmon	1,030	4,312	Rondorf et al. 1985
Other prey	988	4,136	Cummins and Wuycheck 1971
Smallmouth bass	1,000	4,186	Shuter and Post 1990

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Appendix 8. List of hatchery fall chinook salmon with passive integrated transponders (PIT tags) recovered from smallmouth bass digestive tracts during diet collection, 1996. All hatchery fall chinook salmon were released at Pittsburg Landing, Idaho, Rkm 345.8.

PIT tag code	Hatchery fall chinook salmon		Time to recovery d:h:min	Recapture Rkm	Distance from release (km)
	release day and time	recapture day and time			
<b>June</b>					
223238532E	6/13/96 20:00	6/14/96 05:00	00:09:00	345	0
22160E5E6E	6/13/96 20:00	6/14/96 05:00	00:09:00	345	0
41552E4613	6/13/96 20:00	6/14/96 05:00	00:09:00	345	0
2232067F36	6/20/96 19:55	6/21/96 08:08	00:12:13	345	0
2232214B39	6/20/96 19:55	6/21/96 08:08	00:12:13	345	0
2232357E1D	6/20/96 19:55	6/21/96 08:08	00:12:13	345	0
4157286F69	6/20/96 19:55	6/21/96 08:08	00:12:13	345	0
4170227F1B	6/20/96 19:55	6/21/96 08:08	00:12:13	345	0
22422A3F0F	6/20/96 19:55	6/21/96 04:40	00:20:45	344	1
41574B0269	6/20/96 19:55	6/22/96 04:00	01:20:05	323	22
415A0C484E	6/20/96 19:55	6/23/96 05:15	02:09:20	309	36
4157563419	6/20/96 19:55	6/23/96 03:30	02:19:35	302	43
<b>July</b>					
4157624A02	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
4165604A47	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
4165612E33	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
4157283211	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
415A2D0468	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
4156684E4C	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
415703463C	6/27/96 20:00	6/28/96 05:15	00:09:15	345	0
416C532A5B	6/27/96 20:00	6/28/96 06:45	00:10:45	344	1
416E2B6644	6/27/96 20:00	6/28/96 10:30	00:14:30	336	9
2230451478	6/6/96 20:55	6/29/96 05:10	22:08:15	320	25

Appendix 8 continued.

PIT tag code	Hatchery fall chinook salmon		Time to recovery d:h:min	Recapture Rkm	Distance from release (km)
	release day and time	recapture day and time			
4157073A68	6/20/96 19:55	6/30/96 15:55	00:09:20	291	54
4156186209	6/13/96 20:00	7/1/96 05:25	17:09:25	280	65
2230047D12	7/10/96 20:00	7/11/96 09:05	00:13:05	345	0
201519062C	7/10/96 20:00	7/11/96 09:05	00:13:05	345	0
223022063B	7/10/96 20:00	7/11/96 09:05	00:13:05	345	0
22301C1A5E	7/10/96 20:00	7/13/96 05:20	02:09:20	311	34

Appendix 9. List of hatchery fall chinook salmon with passive integrated transponders (PIT tags) recovered from smallmouth bass digestive tracts during diet collection, 1997. All hatchery fall chinook salmon were released at Pittsburg Landing, Idaho, Rkm 345.8.

PIT tag code	Hatchery fall chinook salmon		Time to recovery d:h:min	Recapture Rkm	Distance from release (km)
	release day and time	recapture day and time			
<b>June</b>					
5105466A3F	5/30/97 20:00	5/31/97 19:35	00:11:35	325	20
50607D664E	6/13/97 19:40	6/15/97 04:55	01:09:15	345	0
50586A610F	6/13/97 19:40	6/15/97 04:55	01:09:15	345	0
50606A02A7B	6/13/97 19:40	6/15/97 04:55	01:09:15	345	0
5063403E28	6/13/97 19:40	6/15/97 04:55	01:09:15	345	0
50586C6669	6/13/97 19:40	6/17/97 05:10	03:09:00	300	45
50523E1931	6/14/97 20:10	6/18/97 08:55	03:12:45	274	71
5055173662	6/12/97 20:35	6/19/97 05:30	06:08:55	254	91
505236370D	6/14/97 23:05	6/19/97 05:50	04:18:45	246	99
<b>July</b>					
5079521A61	7/1/97 20:00	7/2/97 09:05	00:13:05	339	6
505B22612A	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
505E1F4963	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
5060181410	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
505F2E6F45	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
50550B3461	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
505D6E7252	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
505D7A6A0A	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
50550C1629	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
50594C2D32	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
505F377445	7/8/97 17:30	7/9/97 05:05	00:11:35	345	0
50585F7F7A	7/8/97 17:30	7/9/97 11:00	00:17:30	339	6

Appendix 10. Percent weight of prey items consumed by smallmouth bass  $\geq 150$  mm collected in the Hells Canyon Reach of the Snake River (Rkm 237 to Rkm 346) from June through October, 1996 and May through October, 1997.

		Prey Items				
River		Insects	Crustaceans	Other-fish	Chinook	Other
Section	n	% Wt	% Wt	% Wt	% Wt	% Wt
<b>1996</b>						
Upstream <sup>a</sup>	659	12.3	56.9	28.4	1.9	0.4
Downstream	560	11.3	39.1	49.1	0.3	0.1
<b>1997</b>						
Upstream <sup>a</sup>	707	8.9	70.2	19.9	0.8	2.0
Downstream	738	10.8	38.4	48.9	0.0	2.0
<b>1996 and 1997</b>						
Upstream <sup>a</sup>	1,366	10.8	62.8	24.7	1.4	0.3
Downstream	1,298	11.1	38.9	49.0	0.2	0.8

<sup>a</sup> location includes release site

Appendix 11. Percent weight of prey items consumed by three size classes of smallmouth bass collected at Pittsburg Landing, Idaho (Rkm 345) in the section of the Snake River upstream of the confluence of the Salmon River from June through July, 1996.

		Prey Items				
Month	n	Insects % Wt	Crustaceans % Wt	Other-fish % Wt	Chinook % Wt	Other % Wt
<b><sup>3</sup> 150 mm</b>						
June	17	4.5	45.1	10.3	40.1	0
July	17	17.8	32.7	10.7	38.8	0
Total	34	9.4	40.5	10.5	39.6	0
<b>150-249 mm</b>						
June	6	19.6	53.5	0.0	26.9	0.0
July	13	13.0	30.6	3.8	52.6	0.0
Total	19	14.5	36.0	2.9	46.6	0.0
<b><sup>3</sup> 250 mm</b>						
June	11	2.5	44.0	11.7	41.8	0.0
July	4	26.1	36.5	22.7	14.7	0.0
Total	15	7.1	42.6	13.8	36.5	0.0

Appendix 12. Percent weight of prey items consumed by three size classes of smallmouth bass collected at Pittsburg Landing, Idaho (Rkm 345) in the section of the Snake River upstream of the confluence of the Salmon River from May through August, 1997.

		Prey Items				
Month	n	Insects % Wt	Crustaceans % Wt	Other-fish % Wt	Chinook % Wt	Other % Wt
<sup>3</sup> 150 mm						
May	12	3.6	70.6	25.8	0.0	0.0
June	18	3.8	64.9	31.4	0.0	0.0
July	15	10.8	40.3	0.0	48.8	0.1
August	4	40.2	59.8	0.0	0.0	0.0
Total	49	6.7	60.5	23.7	9.1	0.0
<b>150-249 mm</b>						
May	10	4.9	64.5	30.6	0.0	0.0
June	9	23.8	76.2	0.0	0.0	0.0
July	14	11.3	37.4	0.0	51.2	0.0
August	4	40.2	59.8	0.0	0.0	0.0
Total	37	16.8	54.2	4.8	24.2	0.0
<sup>3</sup> 250 mm						
May	2	0.0	88.1	11.8	0.0	0.0
June	9	0.5	63.0	36.5	0.0	0.0
July	1	0.0	100.0	0.0	0.0	0.0
August	0	0.0	0.0	0.0	0.0	0.0
Total	12	0.5	64.4	35.1	0.0	0.0

Appendix 13. Percent weight of prey items consumed by three size classes of smallmouth bass collected in the section of the Snake River upstream of the confluence of the Salmon River (Rkm 303 to Rkm 345) from June through October, 1996.

		Prey Items				
Month	n	Insects % Wt	Crustaceans % Wt	Other-fish % Wt	Chinook % Wt	Other % Wt
<b><sup>3</sup> 150 mm</b>						
June	182	6.2	50.6	42.4	0.7	0.2
July	254	7.4	68.1	22.8	1.5	0.2
August	156	36.4	54.4	8.4	0.0	0.7
October	33	2.9	63.8	30.0	0.0	3.3
Total	625	12.4	57.4	29.0	0.8	0.4
<b>150-249 mm</b>						
June	90	19.3	59.3	20.7	0.0	0.6
July	151	18.6	58.9	22.6	0.0	0.0
August	103	49.0	43.5	4.8	0.0	2.7
October	17	4.7	93.0	2.3	0.0	0.0
Total	361	24.6	56.8	17.7	0.0	0.8
<b><sup>3</sup> 250 mm</b>						
June	92	1.9	47.7	49.5	0.9	0.0
July	103	2.5	72.1	22.9	2.2	0.2
August	53	31.8	58.4	9.8	0.0	0.0
October	16	2.5	57.4	36.1	0.0	4.0
Total	264	8.0	57.6	33.0	1.1	0.2

Appendix 14. Percent weight of prey items consumed by three size classes of smallmouth bass collected in the section of the Snake River upstream of the confluence of the Salmon River (Rkm 302 to Rkm 346) from May through October, 1997.

Month	n	Prey Items				
		Insects % Wt	Crustaceans % Wt	Other-fish % Wt	Chinook % Wt	Other % Wt
<b>♂ 150 mm</b>						
May	167	6.7	62.5	30.1	0.0	0.8
June	173	12.1	62.4	25.1	0.3	0.0
July	214	6.2	83.4	10.4	0.0	0.1
August	66	13.1	74.1	12.8	0.0	0.0
October	38	27.0	24.6	48.4	0.0	0.0
Total	658	9.1	71.0	19.6	0.1	0.2
<b>150-249 mm</b>						
May	125	11.4	45.0	42.0	0.0	1.7
June	117	21.8	68.5	9.0	0.7	0.0
July	168	10.4	72.8	16.7	0.0	0.1
August	52	25.0	63.8	11.2	0.0	0.0
October	22	24.4	39.3	36.3	0.0	0.0
Total	484	15.7	65.5	18.3	0.2	0.3
<b>♂ 250 mm</b>						
May	42	2.7	77.3	20.0	0.0	0.0
June	56	3.3	56.9	39.7	0.0	0.1
July	46	2.2	93.3	4.4	0.0	0.0
August	14	1.5	84.1	14.4	0.0	0.0
October	16	29.7	7.4	62.9	0.0	0.0
Total	174	3.1	76.0	20.9	0.0	0.0

Appendix 15. Percent weight of prey items consumed by three size classes of smallmouth bass collected in the section of the Snake River downstream of the confluence of the Salmon River (Rkm 237 to Rkm 303) from June through October, 1996.

		Prey Items				
Month	n	Insects % Wt	Crustaceans % Wt	Other-fish % Wt	Chinook % Wt	Other % Wt
<b><sup>3</sup> 150 mm</b>						
June	156	11.2	50.4	37.8	0.3	0.3
July	261	15.4	30.8	53.1	0.5	0.1
August	105	3.1	47.7	49.1	0.0	0.0
October	38	0.8	46.7	52.5	0.0	0.0
Total	560	11.3	39.1	49.1	0.3	0.1
<b>150-249 mm</b>						
June	102	17.7	27.9	54.1	0.3	0.0
July	168	14.9	26.8	57.1	1.0	0.2
August	69	8.2	48.1	43.6	0.0	0.1
October	14	2.7	34.6	62.7	0.0	0.0
Total	353	14.1	30.9	54.2	0.7	0.1
<b><sup>3</sup> 250 mm</b>						
June	54	6.7	66.0	26.4	0.3	0.6
July	93	15.8	33.7	50.3	0.2	0.1
August	36	0.3	47.5	52.1	0.0	0.0
October	24	0.6	48.4	51.0	0.0	0.0
Total	207	9.5	44.3	46.0	0.1	0.2

Appendix 16. Percent weight of prey items consumed by three size classes of smallmouth bass collected in the section of the Snake River downstream of the confluence of the Salmon River (Rkm 237 to Rkm 303) from May through October, 1997.

Month	n	Prey Items				
		Insects % Wt	Crustaceans % Wt	Other-fish % Wt	Chinook % Wt	Other % Wt
<b>≅ 150 mm</b>						
May	162	13.8	7.5	78.7	0.0	0.0
June	183	16.7	36.4	46.9	0.0	0.0
July	273	8.9	46.3	41.1	0.0	3.8
August	86	12.5	46.8	40.7	0.0	0.0
October	34	3.5	19.1	77.3	0.0	0.0
Total	738	10.8	38.4	48.9	0.0	2.0
<b>150-249 mm</b>						
May	112	26.7	3.7	69.6	0.0	0.0
June	132	46.6	21.9	31.5	0.0	0.0
July	211	18.3	27.3	54.3	0.0	0.2
August	75	20.2	37.4	42.4	0.0	0.1
October	19	17.4	45.2	37.4	0.0	0.0
Total	549	22.6	26.6	50.7	0.0	0.1
<b>≅ 250 mm</b>						
May	50	6.9	9.6	83.5	0.0	0.0
June	51	5.6	44.3	55.7	0.0	0.0
July	62	3.0	58.2	32.8	0.0	6.0
August	11	0.6	61.3	38.1	0.0	0.0
October	15	0.9	13.8	85.3	0.0	0.0
Total	189	3.5	45.6	47.7	0.0	3.2

Appendix 17. Estimated consumption of hatchery subyearling fall chinook salmon by smallmouth bass  $\geq 150$  mm (fc/smb/d) in the Hells Canyon Reach of the Snake River (Rkm 237 to Rkm 346) during 1996 using the Adams and Wisconsin models.

Location	Length Class (mm)	Consumption	Consumption
		Adams Model fc/smb/d	Wisconsin Model fc/smb/d
<b>June 1996</b>			
Release site	150 mm-249mm	0.250	0.01150
	$\geq 250$ mm	0.933	0.02700
Upstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.009	0.00400
Downstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.000	0.00000
<b>July 1996</b>			
Release site	150 mm-249mm	0.615	0.02770
	$\geq 250$ mm	0.333	0.00890
Upstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.027	0.00760
Downstream section	150 mm-249mm	0.000	0.00004
	$\geq 250$ mm	0.009	0.00007

Appendix 18. Estimated consumption of hatchery subyearling fall chinook salmon by smallmouth bass  $\geq 150$  mm (fc/smb/d) in the Hells Canyon Reach of the Snake River (Rkm 237 to Rkm 346) during 1997 using the Adams and Wisconsin models.

Location	Length Class (mm)	Consumption	Consumption
		Adams Model fc/smb/d	Wisconsin Model fc/smb/d
<b>June 1997</b>			
Release site	150 mm-249mm	0.000	0.0000
	$\geq 250$ mm	0.000	0.0000
Upstream section	150 mm-249mm	0.008	0.0015
	$\geq 250$ mm	0.000	0.0000
Downstream section	150 mm-249mm	0.000	0.0000
	$\geq 250$ mm	0.000	0.0000
<b>July 1997</b>			
Release site	150 mm-249mm	1.143	0.0195
	$\geq 250$ mm	0.000	0.0000
Upstream section	150 mm-249mm	0.000	0.0000
	$\geq 250$ mm	0.000	0.0000
Downstream section	150 mm-249mm	0.000	0.0000
	$\geq 250$ mm	0.000	0.0000

Appendix 19. Estimated consumption of wild subyearling fall chinook salmon by smallmouth bass  $\geq 150$  mm (fc/smb/d) in the Hells Canyon Reach of the Snake River (Rkm 237 to Rkm 346) during 1996 using the Adams and Wisconsin models.

Location	Length Class (mm)	Consumption	Consumption
		Adams Model fc/smb/d	Wisconsin Model fc/smb/d
<b>June 1996</b>			
Upstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.008	0.00340
Downstream section	150 mm-249mm	0.009	0.00310
	$\geq 250$ mm	0.000	0.00009
<b>July 1996</b>			
Upstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.000	0.00000
Downstream section	150 mm-249mm	0.006	0.00008
	$\geq 250$ mm	0.000	0.00000

Appendix 20. Estimated consumption of wild subyearling fall chinook salmon by smallmouth bass  $\geq 150$  mm (fc/smb/d) in the Hells Canyon Reach of the Snake River (Rkm 237 to Rkm 346) during 1997 using the Adams and Wisconsin models.

Location	Length Class (mm)	Consumption	Consumption
		Adams Model fc/smb/d	Wisconsin Model fc/smb/d
<b>June 1997</b>			
Upstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.000	0.00000
Downstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.000	0.00000
<b>July 1997</b>			
Upstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.000	0.00000
Downstream section	150 mm-249mm	0.000	0.00000
	$\geq 250$ mm	0.000	0.00000

Appendix 21. Weekly water temperature (°C), turbidity (NTU), and discharge (cm / s) during 1996 in the downstream (Rkm 237 to Rkm 303) and upstream (Rkm 303 to Rkm 346) sections of the Hells Canyon Reach of the Snake River.

Date	Downstream Section			Upstream Section		
	Weekly Avg WT <sup>a</sup> ° C	Turbidity NTU	Weekly Avg DC <sup>b</sup> m <sup>3</sup> /sec	Weekly Avg WT <sup>a</sup> ° C	Turbidity NTU	Weekly Avg DC <sup>c</sup> M <sup>3</sup> /sec
04/15/96	9.4		2,338	9.9		1,401
04/22/96	9.5		2,636	10.6		1,554
04/29/96	9.7		1,879	11.4		968
05/06/96	10.0		1,405	12.2		726
05/13/96	10.1		2,778	13.1		706
05/20/96	10.9		2,789	13.9		884
05/27/96	12.5		2,903	14.4		1,236
06/03/96	13.5		3,645	15.7		1,330
06/10/96	14.3		3,767	17.4		1,169
06/17/96	14.2	34	2,726	17.9	6	926
06/24/96	15.0	12	1,859	18.0	5	629
07/01/96	17.5	8	1,690	19.0	3	547
07/15/96	20.0	4	1,084	20.4	3	566
07/22/96	21.1		906	21.2		528
07/29/96	21.5	3	841	21.5	2	518
08/05/96	20.8		782	21.4		519
08/12/96	21.7	3	678	21.7	2	437
08/19/96	21.2		526	21.5		316
08/26/96	21.3		563	21.5		355
09/02/96	19.8		401	20.7		209
09/09/96	20.0		408	20.8		227
09/16/96	18.5		666	19.6		512
09/23/96	17.0		702	18.4		523
09/30/96	17.0		655	17.8		505
10/07/96	16.8	3	651	17.3	2	502
10/14/96	14.6		598	15.9		413
10/21/96	11.7		462	14.6		271
10/28/96	10.8		459	13.5		267
11/04/96	9.5		450	11.9		267
11/11/96	8.7		453	10.7		269
11/18/96	7.0		697	9.6		299

<sup>a</sup> Weekly mean water temperature °C

<sup>b</sup> Weekly mean discharge m<sup>3</sup>/s from Anatone gage, Washington U.S.G.S.

<sup>c</sup> Weekly mean discharge m<sup>3</sup>/s from Hells Canyon Dam, Idaho U.S.G.S.

Appendix 22. Weekly water temperature ( $^{\circ}\text{C}$ ), turbidity (NTU), and discharge (cm / sec) during 1997 in the downstream (Rkm 237 to Rkm 303) and upstream (Rkm 303 to Rkm 346) sections of the Hells Canyon Reach of the Snake River.

Date	Downstream Section		Upstream Section			
	Weekly Avg WT <sup>a</sup> $^{\circ}\text{C}$	Turbidity NTU	Weekly Avg DC <sup>b</sup> $\text{m}^3/\text{sec}$	Weekly Avg WT <sup>a</sup> $^{\circ}\text{C}$	Turbidity NTU	Weekly Avg DC <sup>c</sup> $\text{m}^3/\text{sec}$
04/15/97	9.8		2,209	9.8		1,261
04/22/97	10.7		3,093	11.7		1,622
04/29/97	11.2		2,791	12.4		1,550
05/06/97	11.9		2,681	13.2		1,172
05/13/97	11.5	72	3,876	15.7	18	914
05/20/97	11.8	80	3,342	17.3	12	904
05/27/97	12.8	46	2,984	17.0	8	901
06/03/97	13.0		3,495	17.0		1,058
06/10/97	14.2		3,819	17.8		1,438
06/17/97	15.9	23	3,495	18.8	10	1,672
06/24/97	17.2		2,489	19.6		1,355
07/01/97	17.5	8	1,875	19.7	9	931
07/08/97	18.3	6	1,262	19.9	6	506
07/15/97	20.0		1,009	20.7		454
07/22/97	21.1		950	21.4		531
07/29/97	21.6		903	21.9		547
08/05/97	22.1	5	853	22.3	4	552
08/12/97	21.8		835	22.4		566
08/19/97	22.3		793	22.7		569
08/26/97	22.0		764	22.5		569
09/02/97	21.8		742	22.3		563
09/09/97	21.1		764	21.8		587
09/16/97	19.7		1,051	20.6		835
09/23/97	19.2		1,041	19.8		844
09/30/97	17.9		969	18.4		788
10/07/97	15.7	3	981	16.7	4	788
10/14/97	14.1		1,008	14.8		752
10/21/97	11.6		539	13.1		345
10/28/97	10.4		595	12.1		346
11/04/97	9.9		575	11.4		343
11/11/97	8.3		541	10.2		343
11/18/97	7.5		544	9.3		343

<sup>a</sup> Weekly mean water temperature  $^{\circ}\text{C}$

<sup>b</sup> Weekly mean discharge  $\text{m}^3/\text{s}$  from Anatone gage, Washington U.S.G.S.

<sup>c</sup> Weekly mean discharge  $\text{m}^3/\text{s}$  from Hells Canyon Dam, Idaho U.S.G.S.