# EVALUATION OF FALL CHINOOK AND CHUM SALMON SPAWNING BELOW BONNEVILLE, THE DALLES, JOHN DAY AND MCNARY DAMS

Annual Report 1998 - 1999

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# 1998-1999 EVALUATION OF FALL CHINOOK AND CHUM SALMON SPAWNING BELOW BONNEVILLE, THE DALLES, JOHN DAY AND McNARY DAMS

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OREGON DEPARTMENT OF FISH AND WILDLIFE
WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

ANNUAL PROGRESS REPORT

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| REPORT TITLE: | 1998-1999 Evaluation of Fall Chinook and Chum Salmon Spawning Below Bonneville, The Dalles, John Day and McNary Dams |
| PROJECT TITLE: | Evaluate Spawning Fall Chinook and Chum Salmon Below The Four Lowermost Columbia River Dams |
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# INTRODUCTION

This report describes work conducted by the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) from 1 October 1998 to 30 September 1999. The work is part of studies to evaluate spawning of fall chinook salmon (Oncorhynchus tshawytscha) and chum salmon (O. keta) below the four lowermost Columbia River dams under the Bonneville Power Administration's Project 99-003. The purpose of this project is twofold:

1) Document the existence of fall chinook and chum populations spawning below Bonneville Dam (river mile (RM) 145), The Dalles Dam (RM 192), John Day Dam (RM 216), and McNary Dam (RM 292) (Figure 1) and estimate the size of these populations.

2) Profile stocks for important population characteristics; including spawning time, genetic make-up, emergence timing, migration size and timing, and juvenile to adult survival rates.

Specific tasks conducted by ODFW and WDFW during this period were:

1) Documentation of fall chinook and chum spawning below Bonneville, The Dalles, John Day and McNary dams using on-water observations;

2) Collection of biological data to profile stocks in areas described in Task 1;

3) Determination of spawning population estimates and age composition, average size at return, and sex ratios in order to profile stocks in areas described in Task 1;

4) Collection of data to determine stock origin of adult salmon found in areas described in Task 1;

5) Determination of possible stock origins of adult salmon found in areas described in Task 1 using tag rates based on coded-wire tag recoveries and genetic baseline analysis;

6) Determination of emergence timing and hatching rate of juvenile fall chinook and chum below Bonneville Dam;

7) Determination of migration time and size for juvenile fall chinook and chum rearing in the area described in Task 6;

8) Investigation of feasibility of determining stock composition of juvenile fall chinook and chum rearing in the area described in Task 6;

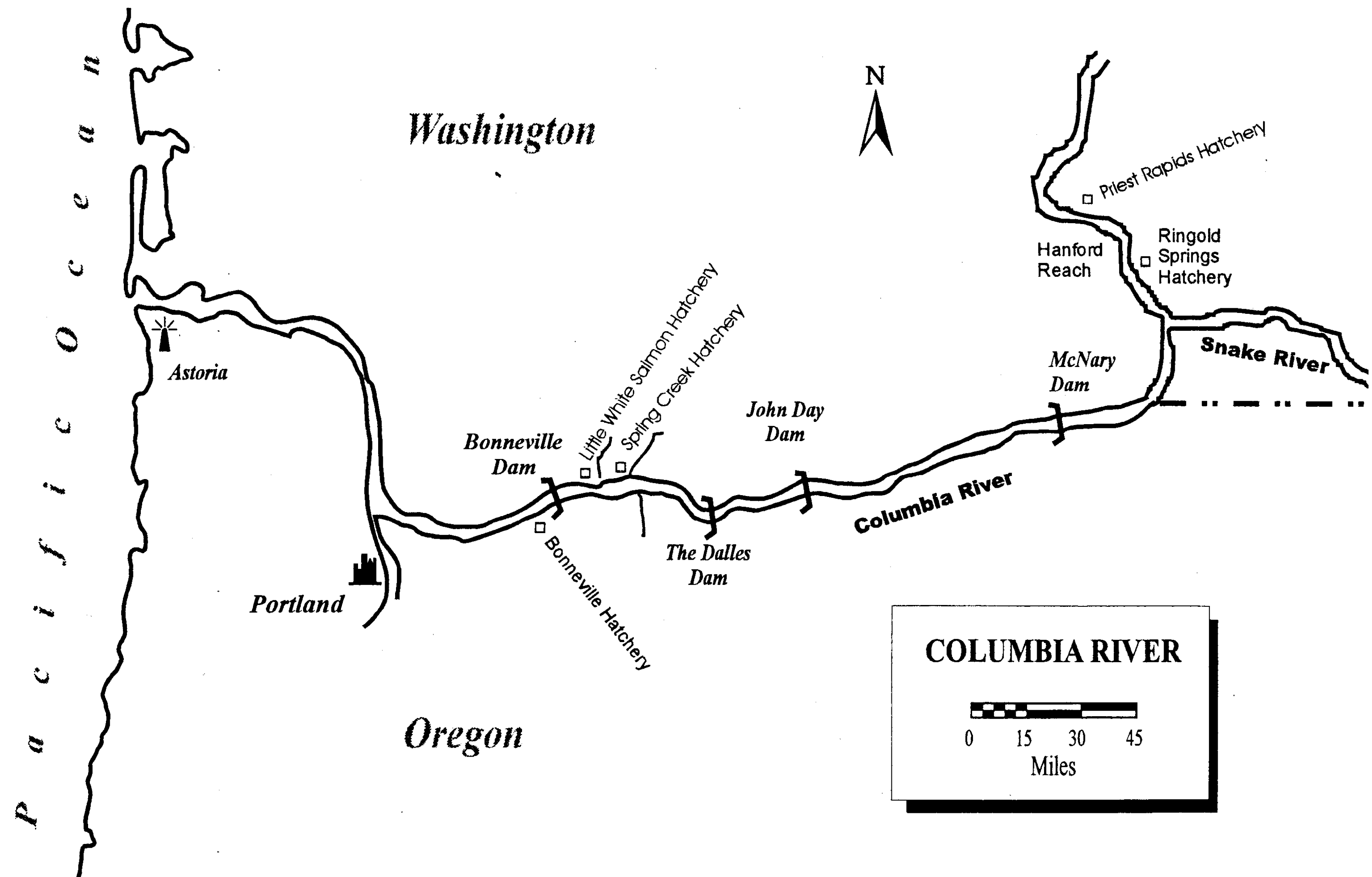


Figure 1. Location of dams, hatcheries, and production areas pertinent to the evaluation.

9) Documentation of stranding and entrapment in low-lying areas of juvenile fall chinook and chum rearing in the area described in Task 6;

10) Investigation of feasibility of coded-wire tagging juvenile fall chinook captured in the area described in Task 6 to determine juvenile to adult survival rate.

# METHODS AND MATERIALS

## Adult study

Spawning ground surveys of fall chinook and chum salmon below Bonneville, The Dalles, John Day, and McNary dams occurred from 26 October through 15 December 1998. The below Bonneville Dam study area is approximately two miles downstream from the dam, between river miles 141.0-143.5. The area includes Pierce and Ives Islands as well as the main channel of the Columbia River. Primary spawning areas are within the island complex and along the shorelines of the islands adjacent to the main channel of the Columbia River. The study area below The Dalles Dam included waters along both shorelines for two miles downstream of the dam. Both shorelines for approximately seven miles below the John Day and McNary dams were surveyed, including potential spawning habitat surrounding islands just below the John Day Dam. A weekly count of spawning redds and numbers of live and dead fish were made from the bow of a jet boat and by wading in shallow water. In addition, locations of newly formed spawning redds were recorded using global positioning system (GPS) receivers and some high elevation redds were marked with painted rebar.

Fish carcasses were examined and biological data was collected to profile stock for age composition, average size at return, and sex ratios. Scales from sampled fish were removed and analyzed to determine total age. To assist in determining stock origin of salmon found in the study areas, carcasses were inspected for fin clips. The snouts of fish with adipose fin clips were removed and kept for future coded-wire tag recovery and analysis.

To assist in determining whether fish had successfully spawned, female carcasses were examined for the presence of eggs. Except for the Bonneville fall chinook group, carcass tissue samples were collected from all populations for genetic stock identification (GSI). GSI work was not performed on the Bonneville fall chinook population since genetic baseline data for this group was completed in 1998.

A capture-recapture carcass tagging study known as the Worlund technique was used to assist in providing spawner population estimates (Appendix A). The mathematical model used to analyze data was developed by G. Paulik (prepared by

D. Worlund) of the University of Washington and is a use of the multiple release and recapture methods of G. Seber and G. Jolly (Biometrika Vol. 49, 1962).

Each week newly found fall chinook and chum carcasses were marked with a unique colored plastic tag and returned to their original location. The number of new tags issued and the number of tags recovered from previous week's tagging were recorded. Carcasses found with a tag were mutilated to identify them as a recovery. A population estimate was generated after tag data was analyzed by the above method.

**Juvenile study**

The juvenile portion of the study concentrated on areas where spawning occurred below Bonneville Dam in 1998. Investigations of emergence timing and hatching rates of fall chinook and chum salmon fry originally were to be conducted using emergent traps. Traps were to be placed over redds identified by GPS waypoints and marked with painted rebar the previous fall. After examining Bonneville Dam flow data and visiting prospective sampling areas in late winter, it was determined emergent trapping would not be possible. Depths over redds in the Ives and Pierce Islands area were seven to 15 feet and flows were in excess of 250 thousand cubic feet per second (kcfs). At such velocities it would be difficult to employ emergent traps and unsafe to maintain them.

To determine emergence timing an alternative to trapping was developed. Hatching and emergence dates were estimated by calculating them in temperature units (TU) measured in Celsius degree-days. The dates were calculated in TU from the initiation of spawning to hatching of eggs (500 $^{o}$ C. TU for chinook and 600 $^{o}$ C. TU for chum) and beginning and ending of emergence (1,000 $^{o}$ C. TU for chinook and 800 $^{o}$ C. TU for chum). Water temperatures used in TU calculations were taken from Bonneville Dam readings and from temperature gauges located in the Ives Island area and maintained by U. S. Fish and Wildlife Service.

Sampling to determine the time and size juveniles migrated from areas used for rearing began 17 February 1999. Surveys were conducted twice weekly through the end of July. Sampling took place in seven designated locations below Bonneville Dam (Figure 2). The locations were selected by reason of their proximity to redds identified during spawning ground surveys, representative habitat and seining accessibility. Specific sampling areas within the seven locations changed with variations in river flows.

Three types of gear were used to capture juvenile fish in the study area. Four foot deep stick seines with one eighth inch mesh in lengths of 18 and 28 feet and a

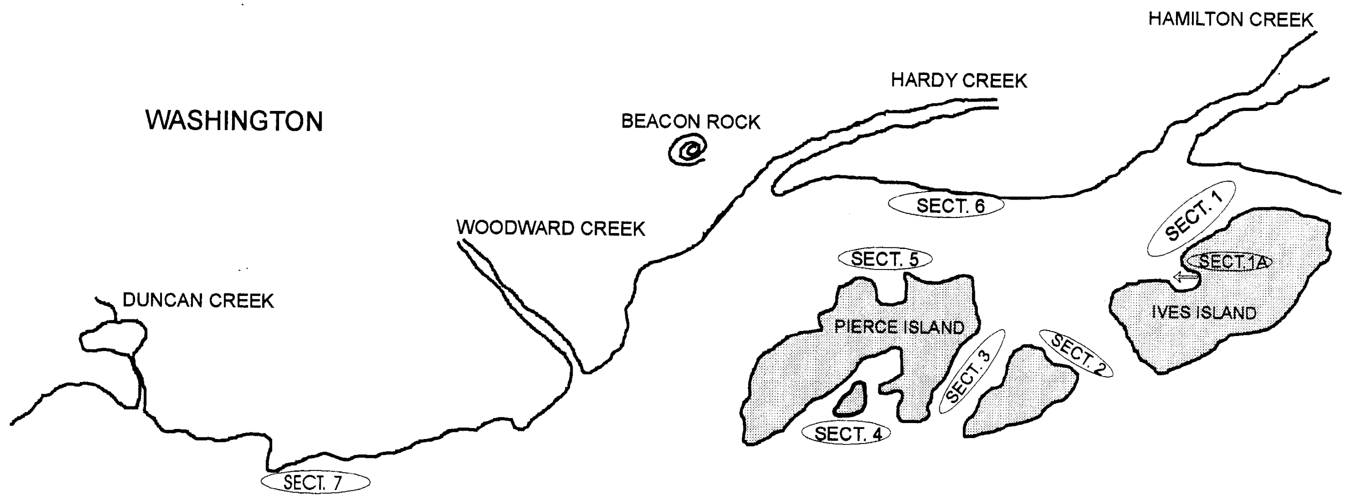


Figure 2. Location of juvenile sampling sections below Bonnevile Dam, 1999.

100 foot long, five foot deep beach seine with one sixteenth inch mesh, were fished along the shorelines. After being set the seines were immediately retrieved. In-water fishing time was approximately five minutes. Seines worked best in sections of the river with moderate velocities and free of snags and large obstructions. The third type of gear was a modified larvae tow referred to as a D-ring trap. The D-ring trap consists of a fixed frame with a three foot wide, five foot long conical net with two mm mesh. The trap was suspended in the river current from a piling upstream from known redd locations. Depending on the amount of debris in the water, the D-ring trap was fished below known redd locations for sets of 30 to 60 minutes.

Captured fish were dip-netted into a five-gallon bucket containing the anesthetic MS-222. Once anesthetized, fish were identified by species, measured for fork length, examined for fin clips, and developmental stage was noted (e.g., yolk-sac or button-up fry). Processing time was five to ten minutes per set. After data was collected, fish were returned to the site of capture. Beginning and ending times for each sampling session were recorded along with the number of sets fished and water temperatures in the study area. In addition, Bonneville Dam flows were recorded for the periods when sampling occurred.

When upriver juvenile chinook caught in the study area were not marked, the criterion used for differentiating chinook juveniles that were products of the study area from upriver natural production and hatchery releases was based on the length of the sampled fish. Chinook less than 50 mm were assumed to be products of the study area. This assumption was based on the fact that juvenile chinook emerge at a size range of 35-40mm, hatcheries above Bonneville Dam release chinook at sizes greater than 60 mm and wild chinook juveniles do not begin migrating until they are larger than 60mm. As study area juvenile chinook grew in size the length criterion used to differentiate them from untagged upriver hatchery and wild production increased. This method was believed to be effective until June when smolts of approximately the same size as study area juvenile chinook and presumably from the Hanford Reach of the Columbia River began migrating into the study area. Although there is little natural production of chum above Bonneville Dam and no chum hatchery programs, it could not determined whether chum captured in the study area were produced there since both Hamilton and Hardy Creek produce chum and are in close proximity to the study area.

In conjunction with juvenile sampling, qualitative stranding and entrapment surveys were made in low-lying areas surrounding the Ives/Pierce Island complex. Areas with stranding or entrapment potential were surveyed to determine the number of juvenile fall chinook and chum salmon stranded on substrate or trapped in isolated pools following decreases in Bonneville Dam discharge.

Table 1. Columbia River mainstem spawning ground surveys, 1998.

Below Bonneville Dam

Fall Chinook

| Date | Redds | Live | Dead | Sampled | CWT recoveries | GSI samples |
|---|---|---|---|---|---|---|
| 10/26/98 | 16 | 9 | 3 | 3 | 0 | 0 |
| 10/30/98 | 58 | 50 | 0 | 0 | 0 | 0 |
| 11/2/98 | 82 | 115+7Jks | 4 | 4 | 0 | 0 |
| 11/6/98 | 121 | 120 | 13 | 0 | 0 | 0 |
| 11/9/98 | 199 | 180+3Jks | 14 | 14 | 0 | 0 |
| 11/16/98 | 198 | 242 | 82 | 76 | 0 | 0 |
| 11/23/98 | 0 | 14 | 66 | 66 | 0 | 0 |
| 11/30/98 | 0 | 0 | 46 | 46 | 0 | 0 |
| 12/7/98 | 0 | 0 | 30 | 27 | 0 | 0 |
| 12/14/98 | 0 | 0 | 8 | 8 | 0 | 0 |
| Total | | | 266 | 244 | 0 | 0 |

Below Bonneville Dam

Chum

| Date | Redds | Live | Dead | Sampled | CWT recoveries | GSI samples * |
|---|---|---|---|---|---|---|
| 11/6/98 | 0 | 13 | 0 | 0 | 0 | 0 |
| 11/9/98 | 0 | 35 | 0 | 0 | 0 | 0 |
| 11/16/98 | 47 | 110 | 2 | 2 | 0 | 0 |
| 11/23/98 | 6 | 33 | 8 | 7 | 0 | 0 |
| 11/30/98 | 0 | 0 | 44 | 44 | 0 | 0 |
| 12/7/98 | 12 | 75 | 42 | 42 | 0 | 0 |
| 12/14/98 | 0 | 8 | 23 | 23 | 0 | 0 |
| Total | | | 119 | 118 | 0 | 0 |

Below The Dalles Dam

Fall Chinook

| Date | Redds | Live | Dead | Sampled | CWT recoveries | GSI samples |
|---|---|---|---|---|---|---|
| 10/27/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/3/98 | 0 | 0 | 2 | 2 | 0 | 1 |
| 11/10/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/17/98 | 0 | 0 | 2 | 1 | 0 | 0 |
| 11/24/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12/1/98 | 0 | 1 | 0 | 0 | 0 | 0 |
| 12/9/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | | 4 | 3 | 0 | 1 |

Below John Day Dam

Fall Chinook

| Date | Redds | Live | Dead | Sampled | CWT recoveries | GSI samples |
|---|---|---|---|---|---|---|
| 10/28/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/4/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/12/98 | 0 | 0 | 2 | 2 | 0 | 0 |
| 11/18/98 | 0 | 1 | 8 | 8 | 0 | 6 |
| 11/25/98 | 0 | 1 | 19 | 16 | 0 | 3 |
| 12/2/98 | 0 | 0 | 18 | 17 | 0 | 4 |
| 12/10/98 | 0 | 0 | 5 | 3 | 0 | 1 |
| 12/15/98 | 0 | 0 | 2 | 0 | 0 | 0 |
| Total | | | 54 | 46 | 0 | 14 |

Below McNary Dam

Fall Chinook

| Date | Redds | Live | Dead | Sampled | CWT recoveries | GSI samples |
|---|---|---|---|---|---|---|
| 10/29/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/5/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/13/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11/19/98 | 0 | 1 | 0 | 0 | 0 | 0 |
| 11/26/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12/3/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12/11/98 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | | 0 | 0 | 0 | 0 |

** Does not include 16 samples taken by WDFW geneticists.*

# RESULTS AND DISCUSSION

## Adult study

Table 1 shows the results of spawning ground surveys below the four lowermost Columbia River dams. Spawning of fall chinook and chum below Bonneville Dam was documented by counts of live fish, redds and post-spawning mortality. Based on spawning ground surveys, initiation of spawning below Bonneville Dam for fall chinook and chum salmon was set at 19 October and 12 November 1998, respectively. Peak spawning for both species was set at 16 November. At peak spawning for fall chinook there were 198 redds and 242 live fish counted. Peak spawning for chum saw 47 redds and 110 live fish. The dates determined as the end of spawning were 30 November for fall chinook and 14 December for chum. Spawning may have continued to occur after the above dates but by mid-December high water and turbid river conditions made surveying difficult and spawning activity could no longer be observed. Although there were several carcasses sampled below The Dalles Dam, no redds were found there or below McNary Dam. It appeared the areas surveyed below both dams had minimal spawning habitat. Although no redds and only two live fish were observed below the John Day Dam, 54 dead fall chinook were found and there appeared to be areas below the dam where spawning could potentially occur.

Below Bonneville Dam fall chinook spawning times seem to be similar to other late-spawning stocks of fall chinook in the Columbia and Snake rivers. Unlike early-spawning stocks such as tule fall chinook which spawn in September and October, late-spawning stocks begin spawning in early to mid November and often spawn into January. Below Bonneville Dam chum spawning times appear to be similar to those observed for populations found in nearby Hardy and Hamilton creeks.

Locations of redds below Bonneville Dam were recorded using GPS technology. A total of 206 GPS waypoints identifying fall chinook and chum redds were established in the study area. Figures 3 and 4 show approximate locations of these redds. The majority of chum redds were observed below the mouth of Hamilton Creek. Locations of fall chinook redds were found where suitable aggregate and adequate flows existed, including areas in the main river channel between Ives and Pierce islands in water depths up to ten feet deep.

Fall chinook and chum population estimates were made based on results of carcass tagging. A total of 244 fall chinook and 119 chum were tagged and there were 92 and 30 respective recoveries. Using these numbers and incorporating them into the aforementioned Worlund technique, population estimates of 554 returning fall chinook and 226 returning chum were obtained (Tables 2-5). The fall chinook estimate should be considered a minimum estimate since it is felt a number of returning fish spawned in the deeper main channel areas where carcasses could not be recovered.

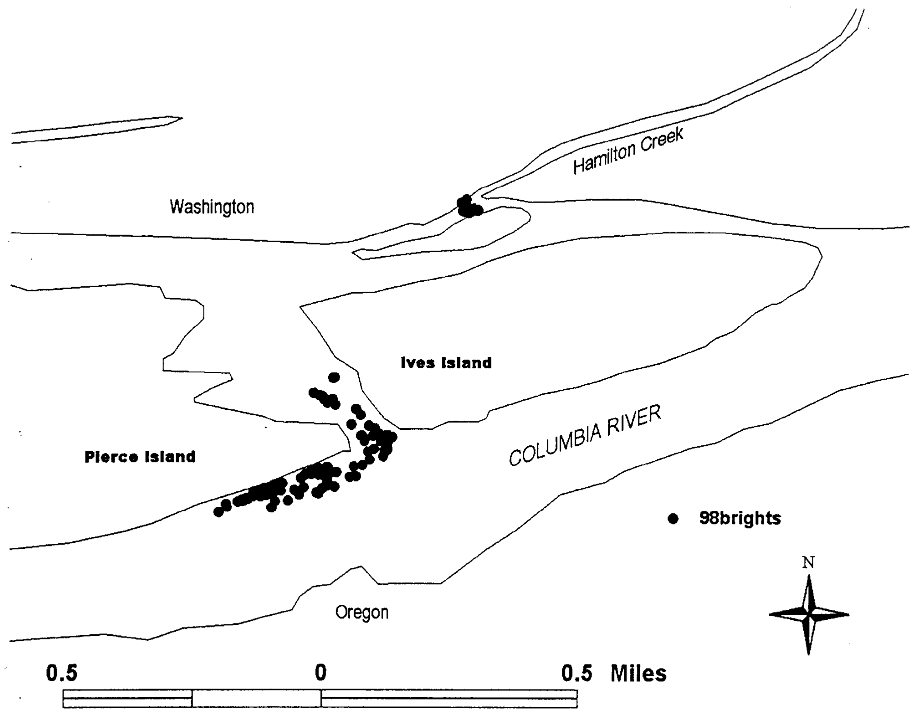


Figure 3. Location of fall chinook redds below Bonneville Dam,1998.

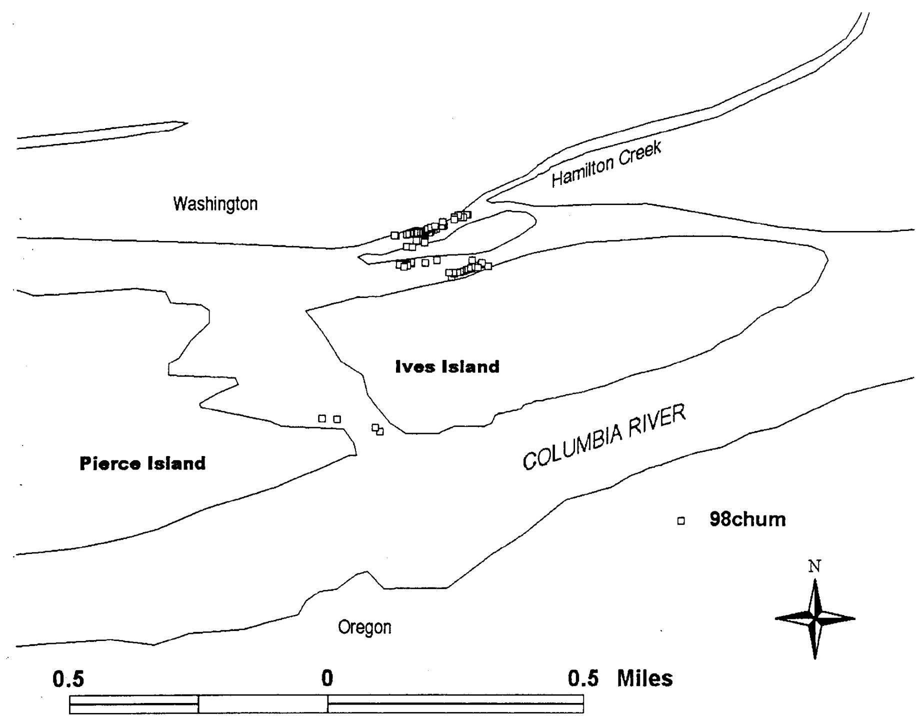


Figure 4. Location of chum redds below Bonneville Dam,1998.

Table 2. A summary of the carcass tagging used to estimate the population of fall chinook spawning in the Columbia River below Bonneville Dam, 1998.

| Period (I) | Date | Tag color | Number | Tag recoveries (by period) 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 26-Oct | Red Circle | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2-Nov | Orange Triangle | 4 | | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 9-Nov | Brown Square | 14 | | | 3 | 3 | 0 | 0 | 0 | 0 |
| 4 | 16-Nov | Yellow Circle | 76 | | | | 18 | 4 | 1 | 0 | 0 |
| 5 | 23-Nov | Blue Circle | 66 | | | | | 32 | 7 | 0 | 0 |
| 6 | 30-Nov | Red ½ Circle | 46 | | | | | | 12 | 4 | 0 |
| 7 | 7-Dec | Orange Circle | 27 | | | | | | | 5 | 0 |
| 8 | 14-Dec | Yellow ½ Circle | 8 | | | | | | | | 1 |
| 9 | 21-Dec | No Tags | 0 | | | | | | | | |

Table 3. Quantities used to calculate the total natural spawning population of fall chinook in the Columbia River below Bonneville Dam, 1998.

Worksheet A

| i | Ti | Zi | Ri. | R.i | Ci | Mi | Fi | Ni | si | ui | Bi | ~si | Di |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | 3 | | 5.196152 |
| 1 | 3 | 0 | 0 | 1 | 3 | 0.00 | 0.0000 | 3 | 0.333333 | 1 | 4 | 0.57735 | 6.928203 |
| 2 | 4 | 0 | 1 | 1 | 5 | 1.00 | 0.2000 | 5 | 0.25 | 1 | 14 | 0.5 | 28 |
| 3 | 14 | 0 | 1 | 6 | 15 | 1.00 | 0.0667 | 15 | 0.92236 | 1 | 327.13043 | 0.960396 | 340.6204 |
| 4 | 76 | 3 | 3 | 23 | 79 | 12.91 | 0.0380 | 340.0435 | 0.342923 | 0.232323 | 6.4750634 | 0.585596 | 11.05722 |
| 5 | 66 | 5 | 21 | 39 | 87 | 29.46 | 0.2414 | 122.0549 | 0.792355 | 0.712794 | 54.31746 | 0.890143 | 61.02102 |
| 6 | 46 | 8 | 36 | 16 | 82 | 59.00 | 0.4390 | 134.3889 | 0.602899 | 0.610169 | 38.441481 | 0.776465 | 49.5083 |
| 7 | 27 | 4 | 20 | 5 | 47 | 41.60 | 0.4255 | 97.76 | 0.185185 | 0.480769 | 2.6000 | 0.430331 | 6.041854 |
| 8 | 8 | 0 | 9 | 1 | 17 | 9.00 | 0.5294 | 17 | 0.125 | 1 | 16 | 0.353553 | 45.25483 |
| 9 | 0 | 0 | 1 | 0 | 1 | 2.00 | 1.0000 | 2 | | 1 | | | |
| | 244 | | | 92 | | | | | | | | | 553.628 |

Table 4. A summary of the carcass tagging used to estimate the population of chum spawning in the Columbia River below Bonneville Dam,1998.

| Period (I) | Date | Tag color | Number | Tag recoveries (by period) 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| 1 | 16-Nov | Yellow Circle | 2 | 1 | 0 | 0 | 0 | 0 |
| 2 | 23-Nov | Blue Circle | 8 | | 2 | 0 | 0 | 0 |
| 3 | 30-Nov | Red ½ Circle | 44 | | | 10 | 0 | 0 |
| 4 | 7-Dec | Orange Circle | 42 | | | | 17 | 0 |
| 5 | 14-Dec | Yellow Circle | 23 | | | | | 5 |
| 6 | 21-Dec | No Tags | 0 | | | | | |

Table 5. Quantities used to calculate the total natural spawning population of chum in the Columbia River below Bonneville Dam, 1998.

Worksheet A

| i | Ti | Zi | Ri. | R.i | Ci | Mi | Fi | Ni | si | ui | Bi | ~si | Di | SI-1*UI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | 0.217391 |
| | | | | | | | | | | | 2 | | 2.828427 | |
| 1 | 2 | 0 | 0 | 1 | 2 | 0 | 0.0000 | 2.0000 | 0.5 | 1.000000 | 8.000000 | 0.707107 | 11.31371 | |
| 2 | 8 | 0 | 1 | 2 | 9 | 1.00 | 0.1111 | 9.0000 | 0.25 | 1.000000 | 44.000000 | 0.5 | 88 | |
| 3 | 44 | 0 | 2 | 10 | 46 | 2.00 | 0.0435 | 46.0000 | 0.227273 | 1.000000 | 42.000000 | 0.476731 | 88.09994 | |
| 4 | 42 | 0 | 10 | 17 | 52 | 10.00 | 0.1923 | 52.0000 | 0.404762 | 1.000000 | 23.000000 | 0.636209 | 36.15164 | |
| 5 | 23 | 0 | 17 | 5 | 40 | 17.00 | 0.4250 | 40.0000 | 0.217391 | 1.000000 | 0.000000 | 0.466252 | 0 | |
| 6 | 0 | 0 | 5 | 0 | 5 | 5.00 | 1.0000 | 5.0000 | | 1.000000 | | | | |
| | 119 | | 30 | | | | | | | | | | 226.3937 | |

To assist in determining whether fish had successfully spawned, female carcasses were inspected for the presence of eggs. A total of 61 fall chinook and 72 chum carcasses were examined in the study area below Bonneville Dam. Body cavities contained few eggs and all carcasses appeared to be spawned out. Of the 15 female fall chinook carcasses found below The Dalles and John Day dams, 14 were considered to be spawned out and one was thought to be a prespawning mortality.

Vital statistics were developed to aid in determining stock origins of returning fish found spawning in the study areas. Vital statistics of fall chinook populations found below Bonneville and John Day dams include age compositions, mean fork lengths, and sex ratios (Tables 6-7). Fall chinook populations sampled below the dams showed similarities in age classes with other late-spawning stocks found in the Columbia River. Late-spawning fall chinook found primarily above Bonneville Dam typically return as age two through six fish. Comparing vital statistics of 1998 returning Bonneville Hatchery late-spawning fall chinook (Table 8) to those sampled the below Bonneville Dam, it is evident that similarities exist in size and general age and sex composition characteristics. In both populations age 3 fish are predominantly males and for age 4 fish females outnumber males.

Table 9 contains vital statistics of chum sampled below Bonneville Dam. In 1998, age composition statistics of chum sampled in the study area were similar to those of populations found in nearby Hardy Creek and the spring channel of Hamilton Creek. For the three groups four-year-old fish were the predominant age class.

To further assist in determining stock origin of salmon found below the four dams, carcasses were sampled for fin clips and other external marks. A total of 293 fall chinook and 118 chum were mark sampled below the four dams. No carcasses were found to have fin clips or other marks.

GSI sampling of chum carcasses found below Bonneville Dam and fall chinook carcasses found below The Dalles and John Day dams provided too few samples to assist in determining stock origin of the returning spawners since collection of the minimum sample size of 100 samples was not accomplished. A total of 16 samples were collected from chum below Bonneville Dam and 15 samples were collected from fall chinook populations above Bonneville Dam. Below Bonneville Dam fall chinook were sampled for GSI data by WDFW in 1996 and 1997. Analysis of 142 samples showed relatively small genetic differences between the samples from below Bonneville Dam and samples of other Columbia River late-spawning stock fall chinook. Chinook spawning below Bonneville Dam were considered to be genetically similar to other bright fall chinook populations such as those found in the Hanford Reach of the Columbia River, at Little White Salmon National Fish Hatchery and at ODFW’s Bonneville Hatchery.

Table 6. Estimated age composition, sex composition, and length of fall chinook salmon that spawned below Bonneville Dam, 1998.

| Age group | Number In Sample | | % In Sample | | Mean Length (cm) | | Length Range (cm) | |
|---|---|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females | Males | Females |
| 2 | 1 | 0 | 1.1 | 0.0 | 55 | - | 55 | - |
| 3 | 8 | 0 | 8.9 | 0.0 | 66 | 94 | 52-74 | - |
| 4 | 13 | 43 | 14.4 | 47.8 | 93 | 88 | 79-103 | 75-96 |
| 5 | 8 | 17 | 8.9 | 18.9 | 103 | 95 | 99-109 | 91-101 |
| Total | 30 | 60 | 33.3 | 66.7 | | | | |

Table 7. Estimated age composition, sex composition, and length of fall chinook salmon that spawned below John Day Dam, 1998.

| Age group | Number In Sample | | % In Sample | | Mean Length (cm) | | Length Range (cm) | |
|---|---|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females | Males | Females |
| 2 | 0 | 0 | 0.0 | 0.0 | - | - | - | - |
| 3 | 1 | 0 | 7.4 | 0.0 | 76 | - | 76 | - |
| 4 | 6 | 10 | 22.2 | 40.8 | 97 | 88 | 85-101 | 82-97 |
| 5 | 6 | 2 | 22.2 | 7.4 | 110 | 98 | 102-115 | 96-99 |
| Total | 13 | 12 | 51.8 | 48.2 | | | | |

Table 8. Estimated age composition, sex composition, and length of bright fall chinook salmon that returned to Bonneville Hatchery, 1998.

| Age group | % In Sample | | Mean Length (cm) | | Length Range (cm) | |
|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females |
| 2 | 5.0 | 0.0 | 60 | 64 | 48-67 | 64 |
| 3 | 36.0 | 8.0 | 69 | 70 | 62-80 | 64-79 |
| 4 | 11.0 | 32.0 | 88 | 87 | 79-96 | 68-100 |
| 5 | 1.0 | 7.0 | 89 | 90 | 81-100 | 72-100 |
| Total | 53.0 | 47.0 | | | | |

Table 9. Estimated age composition, sex composition, and length of chum salmon that spawned below Bonneville Dam, 1998.

| Age group | Number In Sample | | % In Sample | | Mean Length (cm) | | Length Range (cm) | |
|---|---|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females | Males | Females |
| 3 | 5 | 5 | 4.3 | 4.3 | 73 | 65 | 68-80 | 61-68 |
| 4 | 30 | 55 | 25.9 | 47.4 | 77 | 71 | 65-96 | 64-77 |
| 5 | 10 | 10 | 8.6 | 8.6 | 83 | 76 | 76-91 | 66-89 |
| 6 | 0 | 1 | 0.0 | 0.9 | - | 72 | - | 72 |
| Total | 45 | 71 | 38.8 | 61.2 | | | | |

## Juvenile study

Hatching and emergence times for 1998 brood salmon below Bonneville Dam are contained in Table 10. Hatching of fall chinook was estimated to have occurred from 26 November to 9 March 1999. Hatching of chum was estimated to have occurred from 19 February to 11 April 1999. Emergence of fall chinook began on 2March and continued through 12 May. Peak emergence of fall chinook took place 28 April. Emergence of chum below Bonneville Dam began 29 March and continued through 4 May. Peak emergence of chum took place 4 April.

Sampling for post-emergent fry took place in locations identified in Figure 3. Based on emergence estimates juvenile sampling began 17 February 1999. Sampling was terminated 30 July after it appeared that the majority of juveniles had migrated from the area. A total of 5,886 juvenile chinook and 36 chum were sampled during the 1999-sampling season. Catch rates of gear used to capture juvenile chinook are contained in Table 11.

Results of chum sampling are found in Table 12. Chum were most often caught in section seven of the study area. The first chum fry was caught and sampled on 12 March and was 39 mm in length. The last chum fry was caught and sampled on 4 May. All chum fry observed were in the buttoned-up stage. Chum fry ranged in size from 32 mm to 49 mm and mean length was 41.1 mm. The small number of chum observed and sampled may likely be due to the fact that juvenile chum are very elusive and will often reenter the substrate when sensing danger. In addition, chum migrate soon after emergence, spending little time rearing in freshwater.

Results of juvenile chinook sampling are contained in Table 13 and shows weekly changes in length distribution of juveniles sampled in the study area. The first chinook caught and sampled below Bonneville Dam was on 2 March and was a yolk-sac fry, 36 mm in length. Recently emerged fish ($\leq$50 mm) were present in the sample catch from 2 March to 13 July, indicating emergence took place over a longer period of time than TU estimates using observed spawning times suggested. Peak catch of fish 50 mm or less in length was 11 May, which generally agrees with the chinook peak emergence TU estimate of 28 April. Until upriver wild juvenile chinook began appearing in the sample in mid June, juvenile chinook found in the study area that were less than 60 mm in length were considered to be products of the study area. This assumption was based on data that showed upriver chinook hatchery releases consisted mainly of fish larger than 60 mm in length.

Juvenile chinook sampling data suggests that the study area chinook began migration when they attained a size greater than 60 mm in length. As the spring sampling season progressed, chinook less than 60 mm in length gradually made up more of the sample until their numbers peaked on or about May 11. After May 11 there was a gradual decrease in the catch of juvenile chinook less than 60 mm in re-

Table 10. Columbia River water temperatures (F°) and temperature units (C°) below Bonneville Dam, 1998-1999.

(Temperatures from Oct. 1-Nov. 5 were taken at Bonneville Dam, temperatures after Nov. 6 were taken from the USFWS gauge at Ives Island.)

| | OCTOBER | | NOVEMBER | | DECEMBER | | JANUARY | | FEBURARY | | MARCH | | APRIL | | MAY | | JUNE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TEMP | TU's | TEMP | TU's | TEMP | TU's | TEMP | TU's | TEMP | TU's | TEMP | TU's | TEMP | TU's | TEMP | TU's | TEMP | TU's |
| DAY | (F) | (C) | (F) | (C) | (F) | (C) | (F) | (C) | (F) | (C) | (F) | (C) | (F) | (C) | (F) | (C) | (F) | (C) |
| 1 | 68 | 20 | 58 | 14 | 48 | 9 | 40 | 4 | 39 | 4 | 40 | 4 | 44 | 7 | 50 | 10 | 57 | 14 |
| 2 | 68 | 20 | 58 | 14 | 48 | 9 | 40 | 4 | 39 | 4 | 40 | 4 | 44 | 7 | 50 | 10 | 57 | 14 |
| 3 | 67 | 19 | 58 | 14 | 48 | 9 | 39 | 4 | 39 | 4 | 40 | 4 | 44 | 7 | 50 | 10 | 57 | 14 |
| 4 | 67 | 19 | 58 | 14 | 48 | 9 | 40 | 4 | 39 | 4 | 40 | 4 | 44 | 7 | 50 | 10 | 57 | 14 |
| 5 | 67 | 19 | 58 | 14 | 47 | 9 | 40 | 4 | 38 | 4 | 40 | 5 | 44 | 7 | 50 | 10 | 57 | 14 |
| 6 | 66 | 19 | 54 | 12 | 47 | 8 | 40 | 4 | 38 | 4 | 40 | 5 | 44 | 7 | 50 | 10 | 55 | 13 |
| 7 | 66 | 19 | 53 | 12 | 47 | 8 | 40 | 4 | 38 | 3 | 40 | 5 | 44 | 7 | 50 | 10 | 55 | 13 |
| 8 | 66 | 19 | 53 | 12 | 47 | 8 | 40 | 5 | 38 | 4 | 40 | 5 | 44 | 7 | 50 | 10 | 55 | 13 |
| 9 | 66 | 19 | 53 | 11 | 46 | 8 | 40 | 4 | 38 | 4 | 41 | 5 | 44 | 7 | 50 | 10 | 55 | 13 |
| 10 | 66 | 19 | 51 | 11 | 46 | 8 | 40 | 5 | 38 | 4 | 41 | 5 | 44 | 7 | 50 | 10 | 55 | 13 |
| 11 | 66 | 19 | 52 | 11 | 46 | 8 | 40 | 5 | 38 | 3 | 41 | 5 | 44 | 7 | 50 | 10 | 55 | 13 |
| 12 | 65 | 18 | 52 | 11 | 46 | 8 | 40 | 5 | 38 | 3 | 41 | 5 | 45 | 7 | 50 | 10 | 55 | 13 |
| 13 | 64 | 18 | 52 | 11 | 45 | 7 | 40 | 4 | 38 | 4 | 41 | 5 | 45 | 7 | 50 | 10 | 57 | 14 |
| 14 | 64 | 18 | 52 | 11 | 45 | 7 | 40 | 4 | 38 | 4 | 41 | 5 | 46 | 8 | 50 | 10 | 57 | 14 |
| 15 | 64 | 18 | 52 | 11 | 45 | 7 | 40 | 5 | 38 | 4 | 41 | 5 | 46 | 8 | 50 | 10 | 57 | 14 |
| 16 | 64 | 18 | 52 | 11 | 44 | 7 | 40 | 5 | 38 | 4 | 41 | 5 | 46 | 8 | 52 | 11 | 57 | 14 |
| 17 | 63 | 17 | 51 | 11 | 44 | 7 | 40 | 5 | 38 | 4 | 41 | 5 | 46 | 8 | 52 | 11 | 59 | 15 |
| 18 | 62 | 17 | 51 | 11 | 44 | 7 | 40 | 4 | 38 | 4 | 41 | 5 | 46 | 8 | 52 | 11 | 59 | 15 |
| 19 | 62 | 17 | 51 | 10 | 43 | 6 | 40 | 5 | 38 | 4 | 41 | 5 | 46 | 8 | 52 | 11 | 59 | 15 |
| 20 | 62 | 17 | 51 | 10 | 41 | 5 | 40 | 5 | 38 | 4 | 42 | 6 | 46 | 8 | 52 | 11 | 59 | 15 |
| 21 | 60 | 16 | 50 | 10 | 40 | 5 | 40 | 5 | 38 | 4 | 42 | 6 | 48 | 9 | 52 | 11 | 59 | 15 |
| 22 | 60 | 16 | 50 | 10 | 40 | 4 | 40 | 5 | 38 | 3 | 42 | 6 | 48 | 9 | 52 | 11 | 59 | 15 |
| 23 | 60 | 16 | 50 | 10 | 40 | 4 | 40 | 5 | 39 | 4 | 43 | 6 | 50 | 10 | 54 | 12 | 61 | 16 |
| 24 | 60 | 16 | 50 | 10 | 40 | 4 | 40 | 5 | 39 | 4 | 43 | 6 | 50 | 10 | 55 | 13 | 61 | 16 |
| 25 | 60 | 16 | 50 | 10 | 40 | 5 | 40 | 5 | 39 | 4 | 43 | 6 | 50 | 10 | 55 | 13 | 61 | 16 |
| 26 | 60 | 16 | 50 | 10 | 40 | 5 | 40 | 4 | 39 | 4 | 43 | 6 | 50 | 10 | 55 | 13 | 61 | 16 |
| 27 | 60 | 16 | 50 | 10 | 40 | 5 | 40 | 4 | 39 | 4 | 43 | 6 | 50 | 10 | 55 | 13 | 61 | 16 |
| 28 | 60 | 16 | 49 | 10 | 40 | 5 | 40 | 4 | 39 | 4 | 43 | 6 | 50 | 10 | 55 | 13 | 61 | 16 |
| 29 | 60 | 16 | 49 | 10 | 40 | 5 | 40 | 4 | | | 44 | 6 | 50 | 10 | 57 | 14 | 61 | 16 |
| 30 | 59 | 15 | 49 | 9 | 40 | 5 | 40 | 4 | | | 44 | 7 | 50 | 10 | 57 | 14 | 61 | 16 |
| 31 | 58 | 14 | | | 40 | 5 | 40 | 4 | | | 44 | 7 | | | 57 | 14 | | |
| TOTAL | -- | 542 | -- | 335 | -- | 206 | -- | 138 | -- | 108 | -- | 165 | -- | 242 | -- | 344 | -- | 435 |
| AVE. | 63.2 | 17.5 | 52.2 | 11.2 | 43.7 | 6.6 | 40.0 | 4.5 | 38.4 | 3.9 | 41.5 | 5.3 | 46.5 | 8.1 | 52.1 | 11.1 | 58.1 | 14.6 |

REQUIRED TEMPERATURE UNITS (TU'S)

FALL CHINOOK

| | (C°) |
|---|---|
| EYE OUT | 250 |
| HATCHING | 500 |
| EMERGENCE | 1000 |

CHUM

| | |
|---|---|
| EYE OUT | 400 |
| HATCHING | 600 |
| EMERGENCE | 800 |

CUMULATIVE TU'S (C°) SINCE INITIATION AND END OF SPAWNING

FALL CHINOOK

| EVENT | DATE | EYED OUT | | HATCHING | | EMERGENCE | |
|---|---|---|---|---|---|---|---|
| | | DAY | TU'S | DAY | TU'S | DAY | TU'S |
| BEGIN SPAWNING | 10/19 | 11/3 | 249 | 11/26 | 503 | 3/2 | 1002 |
| PEAK SPAWNING | 11/16 | 12/12 | 253 | 2/1 | 500 | 4/28 | 999 |
| END SPAWNING | 11/30 | 1/9 | 252 | 3/9 | 502 | 5/12 | 1008 |

CHUM

| EVENT | DATE | EYED OUT | | HATCHING | | EMERGENCE | |
|---|---|---|---|---|---|---|---|
| | | DAY | TU'S | DAY | TU'S | DAY | TU'S |
| BEGIN SPAWNING | 11/12 | 1/3 | 403 | 2/19 | 602 | 3/29 | 799 |
| PEAK SPAWNING | 11/16 | 1/12 | 399 | 3/2 | 601 | 4/4 | 802 |
| END SPAWNING | 12/14 | 3/14 | 404 | 4/11 | 599 | 5/4 | 803 |

Table 11. Catch rates of juvenile chinook captured with stick and beach seines below Bonneville Dam, 1999.

| Week | Date | # chinook | # stick sets | # caught in stick | # beach sets | # caught in beach | Chinook per stick | Chinook per beach |
|---|---|---|---|---|---|---|---|---|
| 1 | 17-Feb | 0 | 6 | 0 | - | - | 0.0 | - |
| 2 | 23-Feb | 0 | 6 | 0 | - | - | 0.0 | - |
| 3 | 2-Mar | 1 | 6 | 1 | - | - | 0.2 | - |
| 3 | 5-Mar | 0 | 6 | 0 | - | - | 0.0 | - |
| 4 | 9-Mar | 4 | 6 | 4 | - | - | 0.7 | - |
| 4 | 12-Mar | 4 | 7 | 4 | - | - | 0.6 | - |
| 5 | 16-Mar | 0 | 7 | 0 | - | - | 0.0 | - |
| 5 | 19-Mar | 62 | 2 | 0 | 5 | 62 | 0.0 | 12.4 |
| 6 | 22-Mar | 20 | 3 | 2 | 6 | 18 | 0.7 | 3.0 |
| 6 | 26-Mar | 6 | 5 | 2 | 2 | 4 | 0.4 | 2.0 |
| 7 | 29-Mar | 19 | 4 | 6 | 5 | 13 | 1.5 | 2.6 |
| 7 | 2-Apr | 182 | 5 | 7 | 5 | 175 | 1.4 | 35.0 |
| 8 | 6-Apr | 55 | 3 | 5 | 6 | 50 | 1.7 | 8.3 |
| 8 | 9-Apr | 36 | 4 | 0 | 5 | 36 | 0.0 | 7.2 |
| 9 | 13-Apr | 37 | 2 | 2 | 7 | 35 | 1.0 | 5.0 |
| 9 | 16-Apr | 19 | 1 | 0 | 5 | 19 | 0.0 | 3.8 |
| 10 | 20-Apr | 166 | 6 | 0 | 5 | 166 | 0.0 | 33.2 |
| 10 | 23-Apr | 242 | 5 | 0 | 7 | 242 | 0.0 | 34.6 |
| 11 | 27-Apr | 204 | 5 | 9 | 5 | 195 | 1.8 | 39.0 |
| 11 | 30-Apr | 193 | 3 | 0 | 6 | 193 | 0.0 | 32.2 |
| 12 | 4-May | 187 | 3 | 0 | 6 | 187 | 0.0 | 31.2 |
| 12 | 7-May | 191 | 3 | 3 | 5 | 188 | 1.0 | 37.6 |
| 13 | 11-May | 276 | 3 | 0 | 5 | 276 | 0.0 | 55.2 |
| 13 | 14-May | 324 | 3 | 2 | 5 | 322 | 0.7 | 64.4 |
| 14 | 18-May | 256 | 3 | 10 | 5 | 246 | 3.3 | 49.2 |
| 14 | 21-May | 221 | 3 | 4 | 6 | 217 | 1.3 | 36.2 |
| 15 | 25-May | 310 | 3 | 51 | 6 | 259 | 17.0 | 43.2 |
| 15 | 28-May | 264 | 2 | 54 | 5 | 210 | 27.0 | 42.0 |
| 16 | 2-Jun | 183 | 3 | 58 | 5 | 125 | 19.3 | 25.0 |
| 16 | 4-Jun | 145 | 3 | 79 | 5 | 66 | 26.3 | 13.2 |
| 17 | 8-Jun | 195 | 4 | 107 | 5 | 88 | 26.8 | 17.6 |
| 17 | 11-Jun | 238 | 4 | 118 | 6 | 120 | 1.0 | 20.0 |
| 18 | 15-Jun | 391 | 5 | 159 | 4 | 232 | 31.8 | 58.0 |
| 18 | 18-Jun | 113 | 3 | 72 | 5 | 41 | 24.0 | 8.2 |
| 19 | 22-Jun | 165 | 5 | 50 | 6 | 115 | 10.0 | 19.2 |
| 19 | 25-Jun | 145 | 3 | 48 | 7 | 97 | 16.0 | 13.9 |
| 20 | 29-Jun | 125 | 3 | 25 | 7 | 100 | 8.3 | 14.3 |
| 20 | 2-Jul | 254 | 3 | 37 | 7 | 217 | 12.3 | 31.0 |
| 21 | 6-Jul | 144 | 3 | 0 | 6 | 144 | 0.0 | 24.0 |
| 21 | 9-Jul | 127 | 3 | 2 | 6 | 125 | 0.7 | 20.8 |
| 22 | 13-Jul | 48 | 3 | 6 | 6 | 42 | 2.0 | 7.0 |
| 22 | 16-Jul | 42 | 3 | 14 | 6 | 28 | 4.7 | 4.7 |
| 23 | 20-Jul | 13 | 4 | 0 | 6 | 13 | 0.0 | 2.2 |
| 23 | 23-Jul | 42 | 2 | 0 | 5 | 42 | 0.0 | 8.4 |
| 24 | 27-Jul | 20 | 2 | 1 | 7 | 19 | 0.5 | 2.7 |
| 24 | 30-Jul | 217 | 2 | 33 | 6 | 184 | 16.5 | 30.7 |

Table 12. Fork length information of juvenile chum sampled below Bonneville Dam, 1999.

| Date | Number | Fork length (mm) | Mean Fork Length (mm) |
|---|---|---|---|
| 17-Feb thru 9-March | 0 | | -- |
| 12-Mar | 2 | 39,39 | 39.0 |
| 16-Mar | 3 | 39,40,41 | 40.0 |
| 19-Mar | 0 | | -- |
| 22-Mar | 3 | 32,42,43 | 39.0 |
| 26-Mar | 1 | 40 | 40.0 |
| 29-Mar | 1 | 42 | 42.0 |
| 1-Apr | 13 | 37, 2 @ 39, 2 @ 40, 5 @ 42, 43, 45, 47 | 41.5 |
| 6-Apr | 3 | 2 @ 41, 42 | 41.0 |
| 9-Apr | 1 | 42 | 42.0 |
| 13-Apr | 1 | 42 | 42.0 |
| 16-Apr | 0 | | -- |
| 20-Apr | 4 | 40, 2 @ 41, 46 | 42.0 |
| 23-Apr | 2 | 39,49 | 44.0 |
| 27-Apr | 0 | | -- |
| 30-Apr | 0 | | -- |
| 4-May | 2 | 38,40 | 39.0 |
| 7-May thru 30-July | 0 | | -- |
| Total: | 36 | | 41.1 |

Table 13. Fork length information of juvenile chinook sampled below Bonneville Dam, 1999.

| | | | Number of chinook in millimeters. | | | | | | | | | Totals | | Mean Lengths | | | % Chf | Adipose Fin Clips* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Week** | **Date** | **Total** | **Range** | **30-39** | **40-49** | **50-59** | **60-69** | **70-79** | **80-89** | **90-100** | **> 100** | **≤ 50** | **51- 100** | **≤ 50** | **51-100** | **< 100** | **≤ 60mm** | **#** | **Mean Length** |
| 1 | 17-Feb | **0** | - | - | - | - | - | - | - | - | - | **0** | **0** | - | - | - | | | |
| 2 | 23-Feb | **0** | - | - | - | - | - | - | - | - | - | **0** | **0** | - | - | - | | | |
| 3 | 2-Mar | **1** | 36 | 1 | - | - | - | - | - | - | - | **1** | **0** | 36 | - | 36 | | | |
| 3 | 5-Mar | **0** | - | - | - | - | - | - | - | - | - | **0** | **0** | - | - | - | | | |
| 4 | 9-Mar | **4** | 39 - 56 | 1 | 1 | 2 | - | - | - | - | - | **3** | **1** | 44 | 56 | 47 | | | |
| 4 | 12-Mar | **4** | 36 - 50 | 3 | 1 | - | - | - | - | - | - | **4** | **0** | 40 | - | 40 | | | |
| 5 | 16-Mar | **0** | - | - | - | - | - | - | - | - | - | **0** | **0** | - | - | - | | | |
| 5 | 19-Mar | **62** | 43 -198 | - | 1 | 3 | 22 | 23 | 2 | 0 | 11 | **1** | **50** | 43 | 70 | 70 | 6% | 5 | 73 |
| 6 | 22-Mar | **20** | 40 -125 | - | 8 | 1 | 6 | 2 | - | - | 3 | **8** | **9** | 43 | 66 | 55 | 45% | | |
| 6 | 26-Mar | **6** | 39 - 65 | 1 | 2 | - | 3 | - | - | - | 0 | **3** | **3** | 42 | 64 | 53 | 50% | | |
| 7 | 29-Mar | **19** | 40 - 122 | - | 9 | 1 | 4 | 4 | - | - | 1 | **9** | **9** | 43 | 67 | 55 | 53% | 2 | 70 |
| 7 | 2-Apr | **182** | 35 -133 | 9 | 48 | 41 | 34 | 42 | 7 | - | 1 | **60** | **121** | 44 | 65 | 59 | 54% | 6 | 68 |
| 8 | 6-Apr | **55** | 36 - 80 | 5 | 22 | 5 | 12 | 9 | 2 | - | 0 | **28** | **27** | 41 | 61 | 55 | 58% | | |
| 8 | 9-Apr | **36** | 37 - 113 | 5 | 7 | 2 | 1 | 11 | 9 | - | 1 | **12** | **23** | 41 | 80 | 64 | 39% | 1 | 79 |
| 9 | 13-Apr | **37** | 32 - 197 | 4 | 20 | 2 | - | 5 | 2 | - | 4 | **24** | **9** | 42 | 74 | 61 | 70% | | |
| 9 | 16-Apr | **19** | 38 - 144 | 2 | 14 | 1 | 1 | - | - | - | 1 | **16** | **2** | 42 | 57 | 44 | 89% | | |
| 10 | 20-Apr | **166** | 36 - 88 | 13 | 127 | 13 | 6 | 2 | 5 | - | 0 | **145** | **21** | 41 | 66 | 46 | 92% | 1 | 88 |
| 10 | 23-Apr | **242** | 36 - 164 | 14 | 189 | 21 | 6 | 3 | 6 | 1 | 2 | **208** | **32** | 44 | 62 | 46 | 93% | 1 | 70 |
| 11 | 27-Apr | **204** | 37 - 153 | 4 | 152 | 19 | 3 | 7 | 10 | 3 | 6 | **160** | **38** | 44 | 64 | 46 | 86% | | |
| 11 | 30-Apr | **193** | 39 - 152 | 3 | 140 | 29 | 8 | 2 | 6 | - | 5 | **150** | **38** | 44 | 70 | 49 | 89% | | |
| 12 | 4-May | **187** | 37 - 178 | 2 | 117 | 38 | 3 | 1 | 12 | 1 | 13 | **126** | **48** | 45 | 70 | 50 | 84% | 1 | 69 |
| 12 | 7-May | **191** | 37 - 92 | 3 | 112 | 56 | 10 | 3 | 6 | 1 | 0 | **123** | **68** | 45 | 60 | 51 | 90% | | |
| 13 | 11-May | **276** | 38 - 93 | 3 | 239 | 29 | 3 | - | 1 | 1 | 0 | **248** | **28** | 45 | 55 | 45 | 98% | | |
| 13 | 14-May | **324** | 38-153 | 6 | 156 | 127 | 11 | 6 | 6 | 9 | 3 | **181** | **140** | 46 | 60 | 51 | 89% | 1 | 80 |
| 14 | 18-May | **256** | 39-151 | 6 | 124 | 60 | 13 | 10 | 27 | 13 | 3 | **142** | **111** | 48 | 64 | 57 | 74% | 4 | 76 |
| 14 | 21-May | **221** | 37-164 | 2 | 55 | 104 | 17 | 9 | 20 | 10 | 4 | **72** | **145** | 45 | 65 | 58 | 73% | 2 | 84 |
| 15 | 25-May | **310** | 37-109 | 15 | 59 | 131 | 67 | 15 | 8 | 13 | 2 | **84** | **224** | 46 | 64 | 58 | 66% | | |
| 15 | 28-May | **264** | 35-82 | 12 | 170 | 47 | 28 | 5 | 2 | - | 0 | **184** | **80** | 44 | 59 | 48 | 87% | | |
| 16 | 2-Jun | **183** | 38-111 | 6 | 63 | 59 | 39 | 10 | 2 | - | 4 | **71** | **108** | 45 | 59 | 53 | 70% | | |
| 16 | 4-Jun | **145** | 38-149 | 7 | 74 | 38 | 19 | 4 | 2 | - | 1 | **84** | **60** | 47 | 59 | 51 | 82% | 1 | 84 |
| 17 | 8-Jun | **195** | 38-101 | 3 | 59 | 77 | 30 | 10 | 7 | 8 | 1 | **67** | **127** | 47 | 67 | 57 | 71% | 6 | 84 |
| 17 | 11-Jun | **238** | 37-158 | 7 | 48 | 97 | 37 | 16 | 14 | 14 | 5 | **71** | **162** | 46 | 69 | 59 | 64% | 7 | 87 |
| 18 | 15-Jun | **391** | 39-145 | 2 | 52 | 139 | 111 | 53 | 23 | 8 | 3 | **61** | **327** | 46 | 67 | 57 | 49% | 8 | 86 |
| 18 | 18-Jun | **113** | 38-139 | 2 | 14 | 44 | 31 | 16 | 2 | 2 | 2 | **19** | **92** | 47 | 65 | 60 | 53% | 1 | 90 |
| 19 | 22-Jun | **165** | 39-88 | 2 | 12 | 43 | 60 | 36 | 12 | - | 0 | **17** | **148** | 46 | 67 | 64 | 35% | 3 | 85 |
| 19 | 25-Jun | **145** | 39-99 | 1 | 20 | 38 | 42 | 30 | 12 | 2 | 0 | **24** | **121** | 46 | 67 | 64 | 41% | | |
| 20 | 29-Jun | **125** | 45-100 | - | 3 | 10 | 45 | 33 | 25 | 8 | 1 | **4** | **120** | 47 | 71 | 72 | 10% | 2 | 87 |
| 20 | 2-Jul | **254** | 47-101 | - | 1 | 10 | 49 | 89 | 78 | 23 | 4 | **2** | **248** | 49 | 77 | 77 | 4% | 12 | 84 |
| 21 | 6-Jul | **144** | 47-99 | - | 2 | 4 | 9 | 47 | 48 | 34 | 0 | **2** | **142** | 48 | 83 | 81 | 4% | 5 | 92 |
| 21 | 9-Jul | **127** | 49-101 | - | 1 | 2 | 13 | 38 | 43 | 29 | 1 | **1** | **125** | 49 | 83 | 82 | 2% | 2 | 90 |
| 22 | 13-Jul | **48** | 48-105 | - | 1 | - | 7 | 12 | 21 | 6 | 1 | **1** | **46** | 48 | 81 | 80 | 2% | 1 | 83 |
| 22 | 16-Jul | **42** | 56-108 | - | - | 1 | 2 | 8 | 20 | 7 | 2 | **0** | **40** | - | 82 | 83 | 3% | | |
| 23 | 20-Jul | **13** | 76-108 | - | - | - | - | 5 | 3 | 4 | 1 | **0** | **12** | - | 85 | 85 | 0 | | |
| 23 | 23-Jul | **42** | 62-111 | - | - | - | 2 | 5 | 8 | 18 | 9 | **0** | **33** | - | 91 | 91 | 0 | 1 | 99 |
| 24 | 27-Jul | **20** | 83-112 | - | - | - | - | - | 12 | 5 | 3 | **0** | **17** | - | 89 | 89 | 0 | 1 | 86 |
| 24 | 30-Jul | **217** | 70-119 | - | - | - | - | 12 | 46 | 105 | 54 | **0** | **163** | - | 90 | 90 | 0 | 2 | 92 |
| **Totals:** | | 5,886 | | 144 | 2,123 | 1,294 | 754 | 583 | 509 | 325 | 152 | 2,416 | 3,318 | | | | 60% | 76 | |

*Adipose fin clips of fish <100mm.

presented less than 5 % of the population. As water temperatures increased during the spring rearing period below Bonneville Dam, the average size of chinook sampled in the study area increased. During the time period 20 April to 25 June mean length increased from 46 mm to 64 mm, a rate of 0.27 mm/day. It appears resident juvenile chinook reared below Bonneville Dam until they attained a size of approximately 60 to 80 mm in length, at which time they began migrating from the area. This was supported by the fact that relatively few of the chinook sampled were larger than 80 mm in length. Chinook found in the sample larger than 80 mm were most often associated with upriver hatchery releases since adipose-clipped chinook greater than 80mm in length would often appear in the sample soon after hatchery releases. Mean fork lengths of chinook smolts released in June from Priest Rapids and Ringold Springs hatcheries were 96 mm. (personal communication, Dan Bozorth, Manager, January 2000, WDFW).

Based on changes in the length distribution of chinook that were sampled below Bonneville Dam, it appears that fish rearing in the study area began migrating in late May. The data suggests peak migration from the study area most likely occurred in mid to late June. By mid-July few juvenile chinook were caught in the study area and it appeared migration of juvenile fall chinook below Bonneville was nearly complete. On 30 July, the last sampling day of the season, a relatively large number of juvenile chinook were sampled. The sample included two marked smolts and large number of juveniles greater than 100 mm in length. On 28 July, Bonneville Hatchery released approximately five million juvenile fall chinook and apparently some of those fish were carried into the study area by river current before migrating downstream.

Chinook migrating from upriver locations seemed to spend little time in the study area before continuing their migration. This was observed after the Spring Creek NFH releases and again with the later upriver chinook releases. Marked smolts that appeared in the study area after Spring Creek releases were present in the sample for approximately one week after liberation before continuing downstream. Marked fish from upriver releases in June and July averaged only 2.9% of the sample catch.

It is difficult to say whether variations in Columbia River flows had any effect on migration timing of juveniles from the study area. Fluctuations in flow did have an impact on the project's ability to catch juvenile salmon found below Bonneville Dam. Access to certain sampling areas within the designated sections of the study area changed with fluctuations in flow through the islands below Bonneville Dam and consequently sampling locations and methods changed in order to catch juvenile fish. In addition, it appears variations in flow may have had little effect on the ability of upriver migrating fish to gain access to the Ives and Pierce Island area. Regardless of flow conditions, marked fish were present in the sample after hatchery releases and during the upriver bright fall chinook spring migration.

To assist in determining stock composition of juvenile salmon using the rearing areas below Bonneville Dam all captured juveniles were examined for marks. Hatchery adipose-clipped juveniles were helpful in determining stock composition within the study area since they could be easily differentiated from resident fish by their fin clips and relatively large size. Numbers and mean lengths of marked juvenile chinook are presented in Table 14.

Adipose clipped chinook were first observed in the sample on 19 March 1999. The timing of their appearance in the study area and the sizes of the marked fish suggests they were part of a release from Spring Creek NFH made on 18 March. Marked chinook were again sampled on 2 April in an isolated area on the inside of Ives Island (section 1). Because of their size and appearance, it was assumed they were also part of the 19 March, Spring Creek NFH release and had held over in the sheltered area. Relatively large, marked chinook again appeared in the sample on 18 and 21 May. This coincided with Spring Creek's last release of the year. In addition to the Spring Creek NFH fish, larger marked yearling chinook periodically appeared in the study area most likely from upriver hatcheries and acclimation sites. From February through the end of May, marks and size of fish could easily distinguish resident chinook from migrating chinook smolts. After May and through July, the majority of adipose-clipped fish continued to be larger than resident wild chinook but some marked juveniles, which probably represented Hanford Reach wild production, were in the same size range as resident fish. During this period, the generally smaller unmarked migrating upriver wild chinook could not be distinguished from chinook rearing in the study area. Since there is no chum hatchery production above Bonneville Dam and Hardy and Hamilton Creek chum are not marked for assessment purposes, no marked chum were observed in the sampling.

Stranding and entrapment of juvenile salmon in shallow water areas was documented as having occurred in sections five and six of the study area below Bonneville Dam. Both sections were rearing areas for juveniles and in close proximity to chinook and chum redds. Section five, which lies along the south side of Pierce Island, contains pools where depths fluctuate with river flows.

Information on stranding and entrapment is documented below. There appears to be a relationship between decreases in flows and stranding and entrapment of juvenile fish rearing in sections five and six. All stranded or entrapped fish that were not mortalities were liberated into the river. Since areas where stranding or entrapment occurred are home to large numbers of predatory birds and evidence of their presence was observed after flows dropped, it is likely that predation took place after a stranding event.

**3/9/99, Section 5:**

3/5/99, flows averaged 294.2 kcfs, and water was flowing into pools. 3/6/99, the flows were gradually reduced. Water stopped flowing into pools on 3/6/99, 2:00 pm

Table 14. Marked juvenile chinook sampled below Bonneville Dam, 1999.

| Week | Date | Number of marks | Fork Length (mm) | Mean Length | Total Sampled Chinook | % Marked of Sample |
|---|---|---|---|---|---|---|
| 1 | 17-Feb | | | | 0 | |
| 2 | 23-Feb | | | | 0 | |
| 3 | 2-Mar | | | | 1 | |
| 3 | 5-Mar | | | | 0 | |
| 4 | 9-Mar | | | | 4 | |
| 4 | 12-Mar | | | | 4 | |
| 5 | 16-Mar | | | | 0 | |
| 5 | 19-Mar | 5 | 74, 2 @ 68, 2 @ 78 | 73 | 62 | 8.1 |
| 6 | 22-Mar | | | | 20 | |
| 6 | 26-Mar | | | | 6 | |
| 7 | 29-Mar | 2 | 63, 76 | 70 | 19 | 1.1 |
| 7 | 2-Apr | 6 | 52, 62, 66, 69, 78, 80 | 68 | 182 | 3.3 |
| 8 | 6-Apr | | | | 55 | |
| 8 | 9-Apr | 1 | 79 | 79 | 36 | 2.8 |
| 9 | 13-Apr | 2 | 128, 133 | 131 | 37 | 5.4 |
| 9 | 16-Apr | | | | 19 | |
| 10 | 20-Apr | 1 | 88 | 88 | 166 | 0.6 |
| 10 | 23-Apr | 1 | 70 | 70 | 242 | 0.4 |
| 11 | 27-Apr | | | | 204 | |
| 11 | 30-Apr | | | | 193 | |
| 12 | 4-May | 2 | 69, 151 | 110 | 187 | 1.1 |
| 12 | 7-May | | | | 191 | |
| 13 | 11-May | | | | 276 | |
| 13 | 14-May | 2 | 80, 142 | 110 | 324 | 0.6 |
| 14 | 18-May | 4 | 60, 77, 80, 85, | 76 | 256 | 1.6 |
| 14 | 21-May | 3 | 83, 84, 164 blue V.I. tag | 164 | 221 | 1.4 |
| 15 | 25-May | | | | 310 | |
| 15 | 28-May | | | | 264 | |
| 16 | 2-Jun | | | | 183 | |
| 16 | 4-Jun | 1 | 84 | 84 | 145 | 0.7 |
| 17 | 8-Jun | 6 | 72, 80, 85, 87, 90, 91 | 84 | 195 | 3.1 |
| 17 | 11-Jun | 7 | 84, 2 @ 86, 2 @ 87, 2 @ 88 | 87 | 238 | 2.9 |
| 18 | 15-Jun | 9 | 74, 80, 86, 87, 89, 2 @ 90, 94, 145 | 93 | 391 | 2.3 |
| 18 | 18-Jun | 2 | 90, 139 | 115 | 113 | 1.8 |
| 19 | 22-Jun | 3 | 84, 2 @ 85 | 85 | 165 | 1.8 |
| 19 | 25-Jun | | | | 145 | |
| 20 | 29-Jun | 2 | 85, 88 | 87 | 125 | 1.6 |
| 20 | 2-Jul | 12 | 72, 76, 79, 2 @ 82, 85, 2 @ 86, 88, 89, 90, 95 | 84 | 254 | 4.7 |
| 21 | 6-Jul | 5 | 86, 91, 93, 94, 97, (94 red v.i. tag, no clip.) | 92 | 144 | 3.5 |
| 21 | 9-Jul | 2 | 88, 91 | 90 | 127 | 1.6 |
| 22 | 13-Jul | 1 | 83 | 83 | 48 | 2.1 |
| 22 | 16-Jul | | | | 42 | |
| 23 | 20-Jul | | | | 13 | |
| 23 | 23-Jul | 2 | 99, 101 | 100 | 42 | 4.8 |
| 24 | 27-Jul | 2 | 86, 105 | 96 | 20 | 1.0 |
| 24 | 30-Jul | 6 | 89, 94, 102, 105, 108, 156, | 109 | 217 | 2.8 |
| | Total: | 89 | | | 5,886 | 1.5 |

at 280 kcfs. 3/9/99, stranding check at 11:00 am, flows at 207.1 kcfs. **Total stranded: 16 chinook, 4 coho (Mortality: 11 chinook, 2 coho).**

**<u>3/12/99, Section 6:</u>**
3/11/99, 9:00 am, flows were at 301.8 kcfs. 3/12/99, 9:00 am, stranding check, flows were at 226.1 kcfs, and there were standing pools of water.
**Total stranded: 3 chum (Mortality: 3 chum).**

**<u>4/2/99, Section 6:</u>**
4/1/99, 9:00 am, flows were at 307.7 kcfs. Over a 24 hour period flows were reduced to 270.9 kcfs. **Total stranded: 1 chum (Mortality: 1 chum).**

**<u>4/6/99, Section 6:</u>**
4/3/99, over an 8 hour period beginning at 4:00 pm and ending at 12:00 am flows averaged 292 kcfs. The flows were reduced to 265.9 kcfs on 4/6/99, stranding check at 5:00 am. **Total stranded: 2 chinook, 1 chum (Mortality: 2 chinook, 1 chum).**

**<u>4/23/99, Section 6:</u>**
4/21/99, flows were between 293-300.4 kcfs at 8:00 pm to 1:00 pm. 4/22/99, flows were reduced to a 271.1 kcfs at 11:00 am. **Total stranded: 2 chinook, 1 chum (Mortality: 2 chinook, 1 chum).**

**<u>5/11/99, Section 5:</u>**
5/10/99, 7:00 am, flows were at 308 kcfs. Flows were dropped to 277.1 kcfs over 24 hours. Stranding check at 7:00 am, 5/11/99.
**Total stranded: 110 chinook, 1 coho (Mortality: none).**

**<u>5/14/99, Section 5:</u>**
5/11/99, flows were up to an average of 297kcfs. Flows were lowered below 280 kcfs until stranding check at 9:00 am 5/14/99. **Total stranded: 133 chinook (Mortality: 1 chinook).**

**<u>7/2/99, Section 5:</u>**
7/1/99, 9:00 am, flows were at 311.5 kcfs. Over a 24 hour period flows were dropped to 279.2 kcfs. **Total stranded: 36 chinook (Mortality: none).**

**<u>7/14/99, Section 5:</u>**
7/8/99, flows were in the 290 kcfs range for 2 hours and then reduced to the 260 kcfs range. 7/9/99 flows were back to the 290 kcfs range for 2 hours then dropped to 261.6 kcfs at 9:00 am. **Total stranded: 14 chinook (Mortality: none).**

In order to determine a juvenile to adult survival rate for the naturally produced fall chinook below Bonneville Dam, we began investigating the feasibility of coded-wire tagging a portion of the population. Similar tagging projects performed by

WDFW have shown that the timing of an operation to tag wild fish is critical. Coded-wire tagging will probably need to be completed within a relatively small window of time. In tagging operations conducted by WDFW it was necessary to begin the tagging late enough in the rearing period when at least half the captured fish were large enough ($\geq$ 47 mm fork length) to receive a full length coded-wire tag, but before smoltification and subsequent migration occurred. For our project, it will also be necessary to capture juvenile chinook from areas that are free of smolts from earlier upriver chinook releases (e.g. Spring Creek NFH) and to terminate tagging before June when upriver fall chinook migration begins.

In FY 2000, we will begin determining the feasibility of capturing large numbers of juveniles from areas below Bonneville Dam least likely impacted by upriver releases. Since survival rate of fall chinook spawning and rearing below Bonneville Dam is unknown, it is difficult to determine the number of coded-wire tags necessary to estimate smolt to adult survival rate. Typically, a project would try to tag as many fish as possible. WDFW's goal for coded-wire tagging wild fall chinook in the Hanford Reach of the Columbia River was 200,000 fish. Because the population below Bonneville Dam is far smaller than the Hanford Reach population, a goal of 200,000 fish would not be feasible. Initially, our goal will be to coded-wire tag 10,000 juvenile fall chinook.

## SUMMARY AND CONCLUSIONS

A total of 293 returning fall chinook and 118 chum were sampled below Bonneville, The Dalles, John Day and McNary dams in 1998. No spawning salmon were observed below The Dalles, John Day and McNary dams. Peak redd counts below Bonneville Dam in 1998 for fall chinook and chum were 198 and 47 respectively. Peak spawning times below Bonneville Dam for both fall chinook and chum occurred 16 November. There were estimated to be a total of 554 fall chinook spawning below Bonneville Dam in 1998. The 1998 returning chum population below Bonneville Dam was estimated to be 226 spawners.

Temperature unit data suggests that below Bonneville Dam 1998 brood fall chinook emergence began on 2 March 1999 and ended 12 May 1999, with peak emergence occurring 28 April. 1998 brood juvenile chum emergence below Bonneville Dam began 29 March 1999 and continued through 4 May 1999. Peak chum emergence below Bonneville Dam took place 4 April. A total of 5,734 juvenile chinook $\leq$ 100 mm and 35 juvenile chum were sampled in the study area below Bonneville Dam. Due to the small number of chum sampled no conclusions can be made regarding migration timing from chum rearing areas. Results of juvenile chinook sampling corroborates the temperature unit estimate of peak emergence of 1998 brood fall chinook and suggests migration from rearing areas took place from late May 1999 through July 1999 when juvenile fall chinook were in the 60 to 80 mm fork length size range. In addition, juvenile sampling data seems to suggest that 1998 returning chinook continued to spawn below Bonneville Dam longer than was observed by spawning ground surveys.

Adult and juvenile sampling below Bonneville Dam provided information to assist in determining the stock of fall chinook and chum spawning and rearing below Bonneville Dam. Based on observed spawning time, adult age and sex composition, previous GSI analysis, juvenile emergence timing, juvenile migration timing and juvenile size at the time of migration, it appears fall chinook using the area below Bonneville Dam are part of the stock described as upriver bright fall chinook. Determination of stock of chum spawning and rearing below Bonneville dam could not be made this year since nearby Hamilton and Hardy Creek juvenile chum also frequent the study area and as of yet too few GSI samples from chum sampled in the study area are available to analyze.

## PLANS FOR FY 2000

We are planning to continue collecting data to determine the status of fall chinook and chum spawning below Bonneville, The Dalles, John Day and McNary dams. We are planning to collect data from the fish spawning below Bonneville, The Dalles, John Day and McNary dams to profile stocks and determine stock origins. We will continue to estimate emergence timing of juvenile fall chinook and chum below Bonneville Dam. We are planning to sample juvenile populations to determine migration time and size for juvenile fall chinook and chum rearing below Bonneville Dam. We will continue to determine juvenile stock composition. We will continue to monitor stranding and entrapment of juvenile chinook and chum below Bonneville Dam. We are planning to investigate the feasibility of coded-wire tagging juvenile fall chinook captured below Bonneville Dam to determine juvenile to adult survival rate and ocean distribution.

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# APPENDIX

# Carcass Tagging [1/]

General:

This method of estimating the size of a spawning population depends upon the following:

(1) Some idea as to when the carcasses are first present on the spawning ground.

(2) There are at least 5 tagging and sampling days during the spawning season.

(3) The tagging and sampling days are spread throughout the season.

(4) The lapse time between the first and second sampling days is about equal to the interval between the initial occurrence of spawners and the first sampling day.

(5) All recovered carcasses are either tagged and returned to the stream or are removed from the population.

(6) Numbered tags of the same (dull) color are used throughout the sampling period.

(7) Note: Other than the restriction in (4), the time lapse between sampling days need not be equal.

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*1/* This method was developed by G. Paulik of the University of Washington. It is an application of the more general multiple release and recapture techniques presented by G. Seber and G. Jolly in Biometrika; vol 49, 1962, and vol. 50, 1963. Prepared by D. Worlund,, Northwest Fisheries Center.

Model and Notation:

| | | Initial Occurrences | $1^{st}$ sampling | $2^{nd}$ sampling | Etc. | | |
|---|---|---|---|---|---|---|---|
| Time | | $t_0$ | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ |
| Number of fish dying during time interval | | $D_0$ | $D_1$ | $D_2$ | $D_3$ | $D_4$ | |
| Proportion of $D_o$ not disappearing during time interval | | $S_0$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | |
| Number of $D_i$ available | | | $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ |
| Total number of carcasses available | | | $N_1$ | $N_2$ | $N_3$ | $N_4$ | $N_5$ |
| Total carcasses recovered | | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| Number tags released | | | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| Number tags recovered from $C_i$ | | | $R_{1.}$ (=0) | $R_{2.}$ | $R_{3.}$ | $R_{4.}$ | $R_{5.}$ |
| Number tags recovered from $T_i$ | | | $R_{1.}$ (=0) | $R_{2.}$ | $R_{3.}$ | $R_{4.}$ | $R_{5.}$ |
| Number carcasses tagged <u>before</u> $i^{th}$ sample <u>and</u> recovered <u>after</u> the $i^{th}$ period. | $\Rightarrow$ | | $Z_1$ | $Z_2$ | $Z_3$ | $Z_4$ | $Z_5$ |
| Number of tagged carcasses available | $\Rightarrow$ | | (=0) $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
| Probability of recovering a carcass | $\Rightarrow$ | | $U_1$ | $U_2$ | $U_3$ | $U_4$ | $U_5$ |
| Proportion of population of carcasses that are tagged | $\Rightarrow$ | | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $f_5$ |

Estimating Equations:

An estimate of the total spawning population, E, is the sum of the estimated $D_i$.

$$\hat{E} = \hat{D}_o + \hat{D}_1 + \hat{D}_2 + \text{----------} + \hat{D}_{I-1}$$

Where I is the last sampling day.

Two basic quantities to be calculated (work sheet A) are $\hat{M}_i$ and $\hat{f}_i$ :

$$\hat{M}_i = \frac{Z_i}{R_{.i} / T_i} + R_{i.}$$

$$= \left[ \frac{T_i Z_i}{R_{.i}} \right] + R_{i.} \qquad (i = 2, 3, \text{----}, I\text{-}1)$$

And $$\hat{f}_i = \frac{R_{i.}}{C_i} \qquad (i = 1, 2, \text{----}, I)$$

Having these estimates one can then calculate (worksheet B):

$$\hat{N}_i = \frac{\hat{M}_i}{\hat{f}_I} \qquad (i = 2, 3, ----, I-1)$$

$$\hat{s}_i \quad \frac{\hat{M}_{i+1}}{\hat{M}_i - R_{i.} + T_i} \qquad (i = 1, 2, ----, I-2)$$

$$\hat{u}_i = \frac{C_i}{\hat{N}_i} \qquad (i = 2, 3, ----, I-1)$$

$$\hat{B}_i = \hat{N}_{i+1} - \hat{s}_i(\hat{N}_i - C_i + T_i) \qquad (i = 2, 3, ----, I-2)$$

Then $$\hat{D}_1 = \frac{\hat{B}_i}{\sqrt{\hat{s}_i}} \qquad (i = 2, 3, ----, I-2)$$

There is left to calculate $D_o$, $D_1$, and $D_{I-1}$ :

$D_1$ : Note:- $M_1 = R_{1.} = o$

Then $\hat{s}_1 = \frac{\hat{M}_2}{T_1}$

<u>Assume</u> $u_1 = u_2$

Then $\hat{N}_1 = \frac{C_1}{\hat{u}_1} = \frac{C_1}{\hat{u}_2}$

$\hat{B}_1 = \hat{N}_2 - \hat{s}_1(\hat{N}_1 - C_1 + T_1)$

and $\hat{D}_1 = \frac{\hat{B}_1}{\int \hat{s}_l}$

$D_o$: note: $- B_o = N_1$

Then $\hat{D}_o = N_1 \quad \frac{T_1 - T_o}{2(t2 - t1)} \quad (1n\ \hat{s}_1)$