Work Completed for Compliance with the 2008 Willamette Project Biological Opinion,
USACE funding: 2010

# PILOT HEAD-OF-RESERVOIR JUVENILE SALMONID MONITORING

Prepared for
***U. S. ARMY CORPS OF ENGINEERS***
***PORTAND DISTRICT – WILLAMETTE VALLEY PROJECT***
333 S.W. First Ave.
Portland, Oregon 97204

Prepared by
Fred R. Monzyk
Jeremy D. Romer
Ryan Emig
Thomas A. Friesen

**Oregon Department of Fish and Wildlife**
**Upper Willamette Investigations Program**
**Corvallis Research Lab**
**28655 Highway 34**
**Corvallis, Oregon 97333**

Cooperative Agreement: W9127N-10-2-0008
Task Order Number: 0001

September 2011

# Table of Contents

## List of Tables



## List of Figures

## Executive Summary

We operated 5-ft rotary screw traps near the head of Detroit, Foster, Cougar and Lookout Point reservoirs in order to collect spring Chinook salmon migrant information needed for the development of juvenile downstream passage options. The study objectives were to provide information on migration timing, size of migrants, and abundance of juvenile Chinook salmon and winter steelhead entering project reservoirs. Traps were located on the Breitenbush and North Santiam rivers upstream of Detroit Reservoir, the South Santiam River upstream of Foster Reservoir, the South Fork McKenzie River above Cougar Reservoir, and the Middle Fork Willamette River above Lookout Point Reservoir.

The South Fork McKenzie River trap was operational by mid-February 2010. We captured 28,074 subyearling Chinook salmon and 105 yearlings in the South Fork McKenzie trap. We estimated subyearling abundance to be 685,723 (95% CI ± 72,519) with peak fry migration into Cougar Reservoir in late April - early May. The mean fork length of subyearlings from March through May was 34 mm. Subyearlings did not show growth until June. Most yearlings were captured in February and March with a mean size of 86 mm FL.

Due to a delay in obtaining landowner easements and US Forest Service (USFS) Special Use Permits for the other trap sites, the bulk of fry emigration was missed this year for those populations. The Middle Fork Willamette trap upstream of Lookout Point Reservoir began operation on 25 June. We captured 86 subyearlings and only three yearlings during the six months of sampling. Subyearlings were larger in size than their South Fork McKenzie counterparts. We began operating the South Santiam trap on 10 May and collected a total of 101 subyearlings and no yearling Chinook salmon. We suspect we missed the majority of fry migration from this population. The size of subyearlings from the South Santiam tended to be larger than any other of the populations, indicating a possible earlier emergence date. We also collected 1,187 juvenile winter steelhead at this trap. Subyearling steelhead fry began to appear in late June. Two age classes were evident in the steelhead catch based on size. The North Santiam trap above Detroit began operating on 13 October and collected 276 subyearlings and no yearlings. Size of the captured subyearlings was comparable to subyearlings from the South Fork McKenzie River. The Breitenbush trap above Detroit began operation on 25 October and we only collected nine subyearlings and no yearlings. The low number of juveniles caught at this trap was due in part to the late installation and relatively few adult female Chinook salmon outplanted in the Breitenbush River the previous year.

## Introduction

Spring Chinook salmon (*Oncorhynchus tshawytscha*) and winter steelhead (*O. mykiss*) in the upper Willamette River Evolutionarily Significant Unit (ESU) were listed as threatened under the Endangered Species Act (NMFS 1999a; NMFS 1999b). As a result, the National Marine Fisheries Service (NMFS) must evaluate any action taken or funded by a federal agency to assess whether the actions are likely to jeopardize threatened and endangered species, or result in the destruction or impairment of critical habitat. The 2008 Willamette Project Biological Opinion (BiOp; NMFS 2008) outlined the impacts of the Willamette Valley Project (WVP) on Upper Willamette River (UWR) Chinook salmon and winter steelhead (NMFS 1999a; NMFS 1999b). The WVP consists of 13 dams and associated reservoirs managed jointly by the U.S. Army Corps of Engineers (USACE), Bonneville Power Administration, and Bureau of Reclamation, collectively known as the Action Agencies. The Biological Opinion detailed specific actions, termed Reasonable and Prudent Alternatives (RPAs) that would "…allow for survival of the species with an adequate potential for recovery, and avoid destruction or modification of critical habitat".

A number of RPAs in the Willamette Project BiOp are associated with downstream fish passage through project reservoirs and dams. These include RPAs 4.2 (winter steelhead passage), 4.7 (adult fish release sites above dams), 4.8 (interim downstream fish passage through reservoirs and dams), 4.9 (head-of-reservoir juvenile collection prototype), 4.10 (downstream juvenile fish passage through reservoirs), 4.12 (long-term fish passage solutions). Currently, numerous passage designs are under consideration to improve survival of downstream migrants. To guide the development of juvenile passage design alternatives, a basic understanding of the size, timing, and abundance of juvenile Chinook salmon that enter the reservoirs is needed.

Currently information is limited on migration timing and size of juvenile Chinook salmon and steelhead entering WVP reservoirs. The Bureau of Commercial Fisheries (later NMFS) conducted studies of juvenile spring Chinook salmon migrants on the South Fork McKenzie River prior to the completion of Cougar Dam (1959-1961). Trapping at the site of the present-day reservoir indicated that the majority of outmigrants were age-0 fry. Fry emigrated from March through June with an average size of 36mm FL. Limited trapping data from the South Fork McKenzie River in 2009 above Cougar Reservoir indicated a similar pattern (Mike Hogansen, ODFW, pers. comm.). Studies conducted by USACE on Fall Creek and the North Fork Middle Fork River from 2007-2009 showed that a majority of juvenile spring Chinook salmon entered the reservoir as fry in early spring (Greg Taylor, USACE, pers. comm.). There is no information on juvenile migrants above Detroit and Foster reservoirs.

In this study, we operated 5-ft rotary screw traps at the head of Detroit, Foster, Cougar and Lookout Point reservoirs to provide migrant information needed in developing juvenile downstream passage options. Traps were located on the Breitenbush and North Santiam rivers upstream of Detroit Reservoir, the South Santiam River above

Foster Reservoir, the South Fork McKenzie River above Cougar Reservoir, and the Middle Fork Willamette River above Lookout Point Reservoir.

This report fulfills a requirement under Cooperative Agreement Number W9127N-10-2-0008, covering activities of March 2010–March 2011. Activities were implemented by ODFW on behalf of the USACE to assist with meeting the requirements of the RPAs and measures prescribed in the Willamette Project BiOp of July 2008 (NMFS 2008). The USACE provided funding for monitoring activities. Primary tasks included: 1) develop monitoring infrastructure, including obtaining easements and permits for locating traps; 2) monitor juvenile salmonid outmigration to provide information on migration timing and size; and 3) estimate abundance of outmigrating UWR Chinook salmon. The data reported here covers field activities up to 31 December 2010.

## Methods

*Development of Monitoring Infrastructure (Task 1)*

The criteria used in selecting sites for placement of rotary screw traps included proximity to the head of the reservoir, ease of access from the stream bank for efficient installation, operation and removal, and proper cabling structures (e.g. trees, bridge abutments) for securing traps in place. Sites were located above Detroit Reservoir in the Breitenbush and North Santiam rivers, above Foster Reservoir in the South Santiam River, above Cougar Reservoir in the South Fork McKenzie River, and above Lookout Point Reservoir in the Middle Fork Willamette River (Figure 1).

*Juvenile Salmonid Outmigration Timing and Size (Task 2)*

We used 5-ft rotary screw traps to capture juvenile spring Chinook salmon migrating downstream. The South Santiam trap was located downstream of winter steelhead outplanting locations so information on juvenile steelhead migration could also be collected from this trap. Traps were operated continuously until catches drop to zero or stream flows were too low for trap operation. Occasionally, excessively high river flows precluded trap operations. Traps were normally checked and cleared of fish and debris once per day, with more frequent visits during storm events and periods of high debris transport.

Fish captured and removed from the traps were anesthetized with MS-222 and enumerated by species and age (e.g., age 0, age 1) or developmental stage (e.g., fry, parr, smolt). We measured fork length (mm) from a subsample of fish collected (~100/wk) and released all fish approximately 100 m downstream of the trapping site upon full recovery from anesthesia unless retained for trap capture efficiency tests.

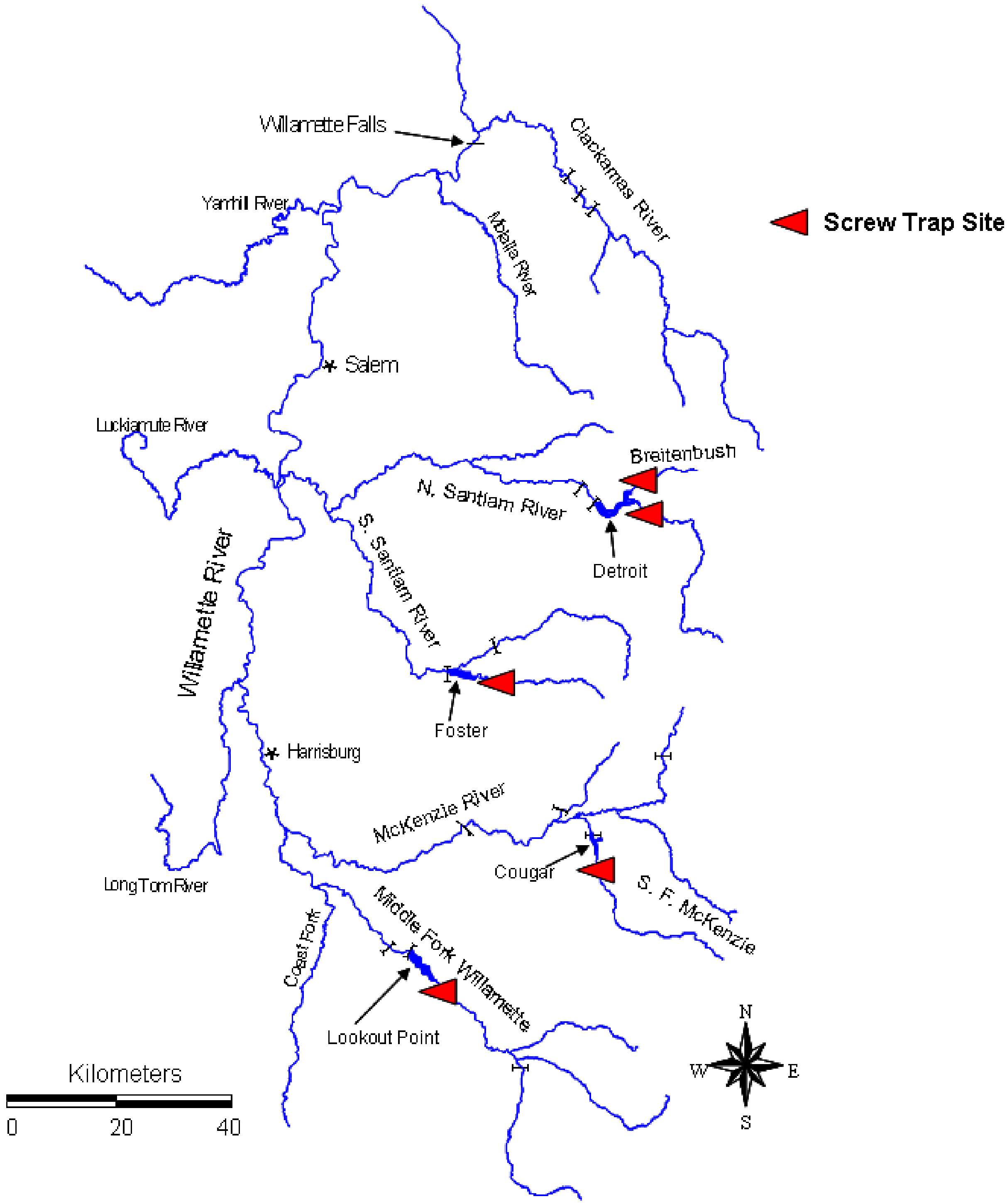


**Figure 1. Locations of 5-ft rotary screw traps above Willamette Project dams.**

*Abundance Estimates of Outmigrating Chinook Salmon (Task 3)*

We calculated trap capture efficiency using methods modified from Suring et al. (2009) and others. Capture efficiency was calculated weekly for each species and age class (based on relative size) by marking up to 50 fish from each species and age-class category (e.g., small clip from the caudal lobe or other marking technique for fry), and releasing the marked fish upstream approximately 0.5 km from the trap. Subsequent recaptures of marked fish were recorded. We calculated weekly abundance estimates of out-migrants by expanding trap catches using the following equations:

$N_m = c / e_m$
and
$e_m = r / m$,

where:

$N_m$ = weekly estimated out-migrants
$c$ = number of fish captured
$e_m$ = measured weekly trap efficiency
$r$ = number of recaptured marked fish
$m$ = number of marked fish released

Weekly abundance estimates were summed for season totals. During weeks when recaptures were infrequent (< five recaptures/week), recapture totals for an equal number of previous and subsequent weeks were pooled to obtain at least five recaptures. Population estimates generally were not calculated if fewer than five marked fish from a particular category were recaptured over the entire season, in which case the actual number caught was reported.

A bootstrap procedure was used to estimate the variance and construct 95% confidence intervals for each abundance estimate (Thedinga et al. 1994; 1000 iterations used for each calculation). This procedure uses trap efficiency as one parameter in the calculation of variance. A weighted value for trap efficiency then was used to calculate confidence intervals. Each weekly estimate of trap efficiency was weighted based on the proportion of total estimated migrants that each weekly estimate of migrants represented, using the equation:

$e_w = e_m * (N_m / N_t)$,

where:

$e_w$ = weighted weekly trap efficiency
$e_m$ = measured weekly trap efficiency
$N_m$ = weekly estimated migrants
$N_t$ = season total migrants.

The sum of the weighted trap efficiencies was used in the confidence interval calculations.

## Results and Discussion

*Development of Monitoring Infrastructure*

All rotary screw traps sites were below major spring Chinook salmon spawning areas located above the reservoirs. We developed long term easement agreements with private landowners for the South Santiam and North Santiam sites. All other sites are located on USFS property and required limited duration Special Use Permits.

The Breitenbush trap was located on U.S. Forest Service property directly upstream of the USGS gauging station (station 14179000) and was approximately 0.5 km from the head of Detroit Reservoir at full pool. The North Santiam trap was located on private property directly downstream of Coopers Ridge Road bridge and was approximately 5.8 km upstream of Detroit Reservoir when at full pool. The South Santiam trap was also located on private property near the town of Cascadia and was approximately 10 km upstream of Foster Reservoir at full pool. The South Fork McKenzie trap was located just downstream from the USGS gauging station (station 14159200) and was approximately 1 km upstream of Cougar Reservoir. The Middle Fork Willamette trap was located downstream of the town of Westfir, near the USFS seed orchard, approximately 5 km from Lookout Point Reservoir.

The South Fork McKenzie trap was already in place and operating before this study began (Table 1). The delay in obtaining landowner easements and USFS Special Use Permits for the other sites resulted in a lack of data for the bulk of fry emigration this year from the populations above these traps. Flows on the Breitenbush were too low for trap operation until 25 October. In addition, we delayed operation of the North Santiam trap until 13 October because of the proximity to the adult Chinook outplanting location. Operating this trap during the summer would have likely resulted in unwanted capture and take of adult spring Chinook salmon.

**Table 1. Installation date and location of rotary screw traps above project reservoirs.**

| Trap | Installation date | RKM | UTM (10T) |
|---|---|---|---|
| Breitenbush | 25 October[a] | 3 | 0568785 4955753 |
| North Santiam | 13 October[b] | 118 | 0575240 4949260 |
| South Santiam | 11 May | 78 | 0539897 4915479 |
| South Fork McKenzie | 10 February | 16 | 0562654 4877522 |
| Middle Fork Willamette | 24 June | 358 | 0537699 4846035 |

[a] trap installed on 27 July but not operational due to low stream flows
[b] delayed installation due to proximity to adult outplanting location

*Juvenile Salmonid Outmigration Timing and Size*

The delay this year in installing traps likely resulted in a lack of data for most of the subyearling migration with the exception of the South Fork McKenzie trap. The South Fork McKenzie trap collected large numbers of fry, some still with yolk sacs, indicating that fry migrate soon after emergence. Few parr were collected from late spring through the end of December at any trap site, suggesting that there is a substantial early spring fry migration in all the rivers above WVP dams. This was further substantiated by the observation of numerous fry at the head of Lookout Point Reservoir below the Middle Fork Willamette trap site in April (*see Life-History Characteristics of Spring Chinook Salmon Rearing in Willamette Valley Project Reservoirs -2010 report*).

Although fry migration was missed at most traps during 2010, the timing of fry emergence (and subsequent migration) can be estimated based on stream temperatures and the calculation of accumulated thermal units (ATU; Connor et al. 2003). The ATU value is calculated as the daily sum of mean stream temperature above 0°C starting from the time of egg deposition in the redd. Usually, embryonic development will result in fry emergence when ATU values reach 1000 (Connor et al. 2003, Geist et al. 2006; Groves et al 2008). Our calculating of ATU values for the rivers indicated that fry would likely emerge from the South Santiam and North Fork Middle Fork Willamette approximately a month earlier than fry from the South Fork McKenzie, North Santiam, and Breitenbush rivers (Figure 2).

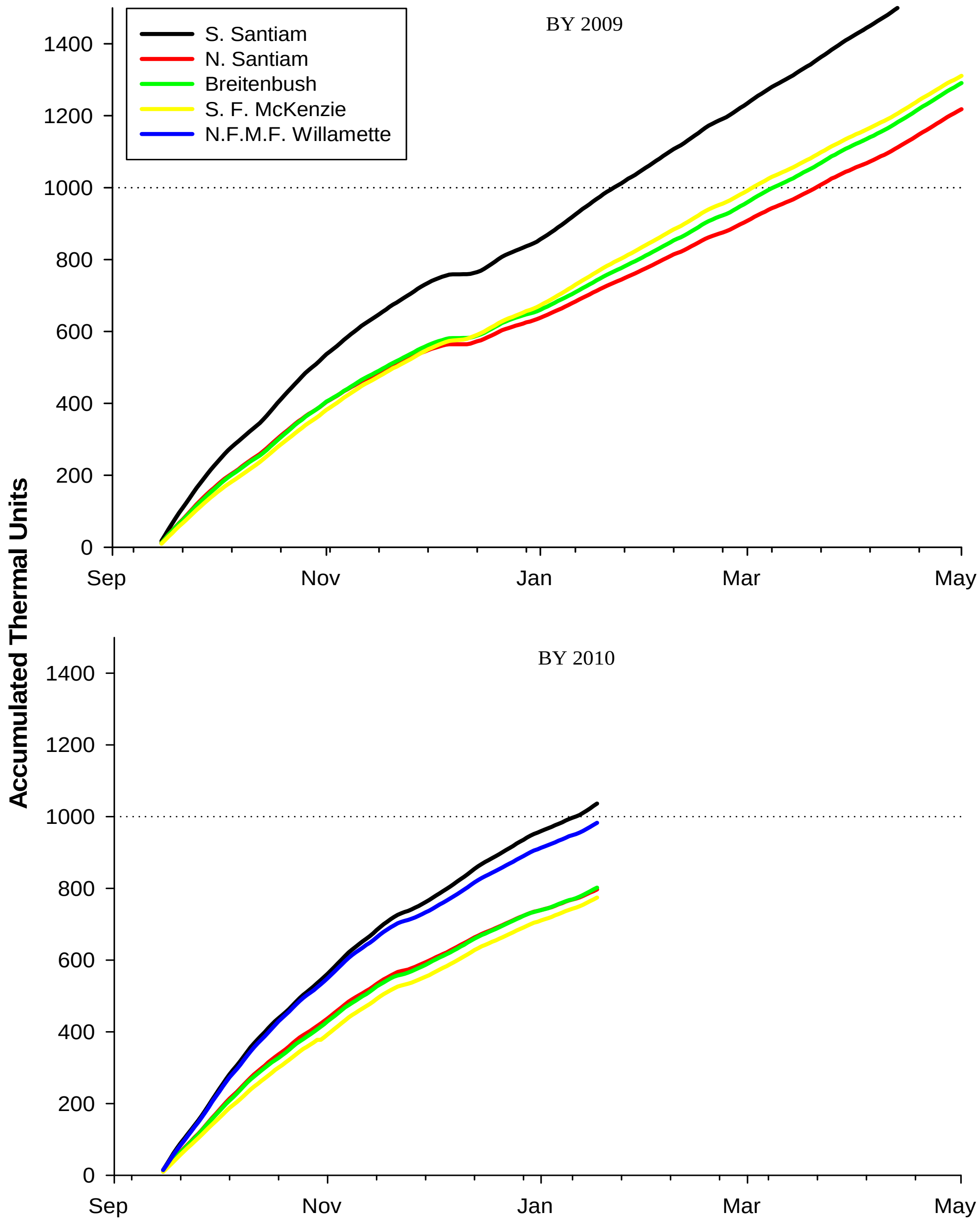


**Figure 2. Accumulated thermal units (ATU) and expected Chinook salmon fry emergence for the five rivers above project dams for the 2009 and 2010 brood years. ATU calculations made with standardized start date of egg incubation of 15 September. Dashed line references the accumulated 1000 thermal unit when fry are expected to emerge from redds. Temperature data for ATU calculations were from USGS gage stations (S. Santiam 14158000, N. Santiam 14178000, Breitenbush 14179000, S. F. McKenzie 14159200, N. F. Middle Fork Willamette 14147500). There was no temperature data for the N. F. Middle Fork Willamette station in 2009.**

*South Fork McKenzie*- We operated the South Fork McKenzie trap from 10 February through 31 December 2010 and captured 28,074 Chinook salmon subyearling and 105 yearlings. There was a distinct migration of subyearlings in early spring at this trap site. The first subyearling (fry) was captured on 12 February with daily catch rates increasing in March and peaking in late April (Figure 2). Subyearling catch decreased by June and remained low for the rest of the year. The median emigration date for subyearlings passing the trap was 1 May 2010 with over 90% of the subyearling catch occurring by 15 May 2010. The majority of fry migration observed in this study is consistent with results reported by the Bureau of Commercial Fisheries from studies conducted prior to dam completion (1959-1961) at a trap site that was approximately 1.5 km downstream from the current trap location. Given that we also observed a large fry migration at the trap site in 2009, this would indicate that fry outmigration is a strong life-history characteristic for this population of spring Chinook salmon.

The majority of yearling Chinook salmon were captured in February and March (Table 2). Yearlings collected in June and July contained parasitic copepods on their gills, indicative of time spent rearing in Cougar Reservoir. These individuals, as well as those captured later in the year, were likely precocious males returning to spawning areas upstream of the trap.

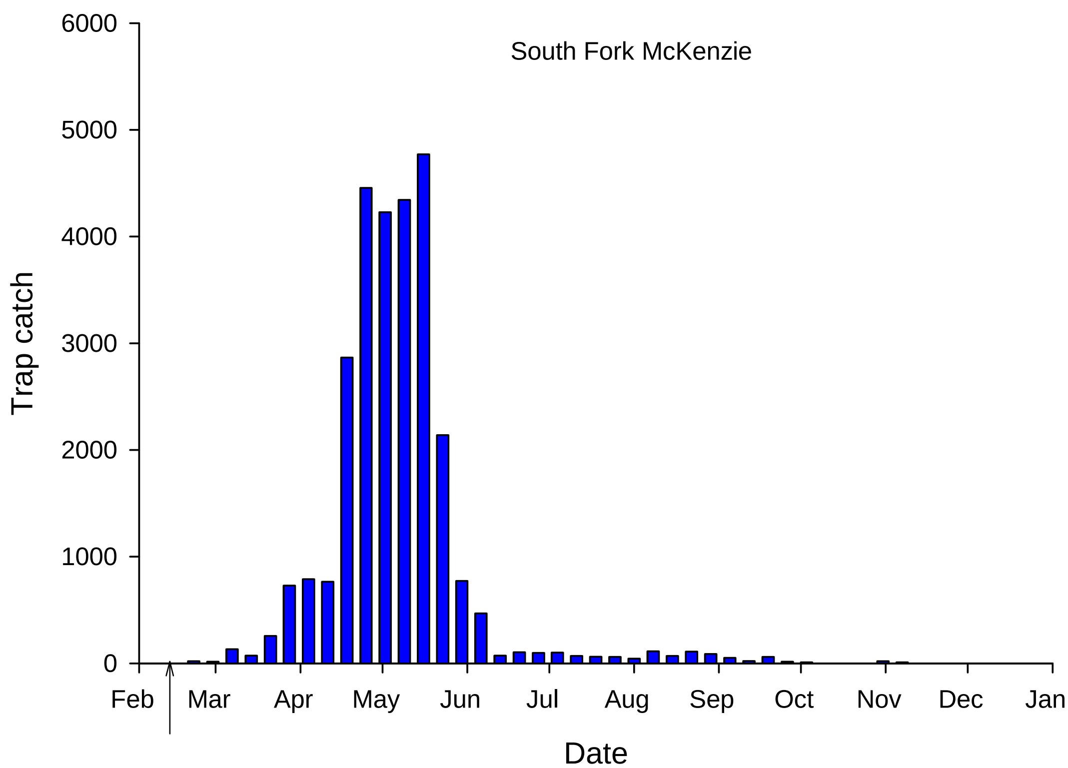


**Figure 3. Weekly catch of subyearling spring Chinook salmon at the South Fork McKenzie trap above Cougar Reservoir, 2010. Arrow on date axis indicates trap start date.**

**Table 2. Catch of juvenile spring Chinook salmon in the South Fork McKenzie screw trap above Cougar Reservoir, 2010.**

| | Trap catch | |
|---|---|---|
| Month | Subyearlings | Yearlings |
| Feb[a] | 39 | 27 |
| Mar | 1,738 | 51 |
| Apr | 11,836 | 11 |
| May | 12,736 | 4 |
| Jun | 851 | 5[b] |
| Jul | 268 | 4[b] |
| Aug | 412 | 0 |
| Sep | 117 | 2[c] |
| Oct | 33 | 1 |
| Nov | 20 | 1 |
| Dec | 23 | 0 |

[a] Month incomplete; trap operation started on 10 Feb 2010
[b] Parasitic copepods on gills, indicative of reservoir rearing
[c] Probable precocious males

The size of subyearling Chinook salmon ranged from 28 to 115 mm FL, and the mean fork length from March through May was 34 mm (Figure 4). Size remained constant during these months suggesting a protracted period of fry emergence in the South Fork McKenzie. Growth of the subyearling cohort was not evident until June (Figure 4). Yearling Chinook salmon fork lengths averaged 86 mm from February through May. The small number of yearlings captured after June likely did not rear in the river but rather came from Cougar Reservoir based on the presence of parasitic copepods on their gills.

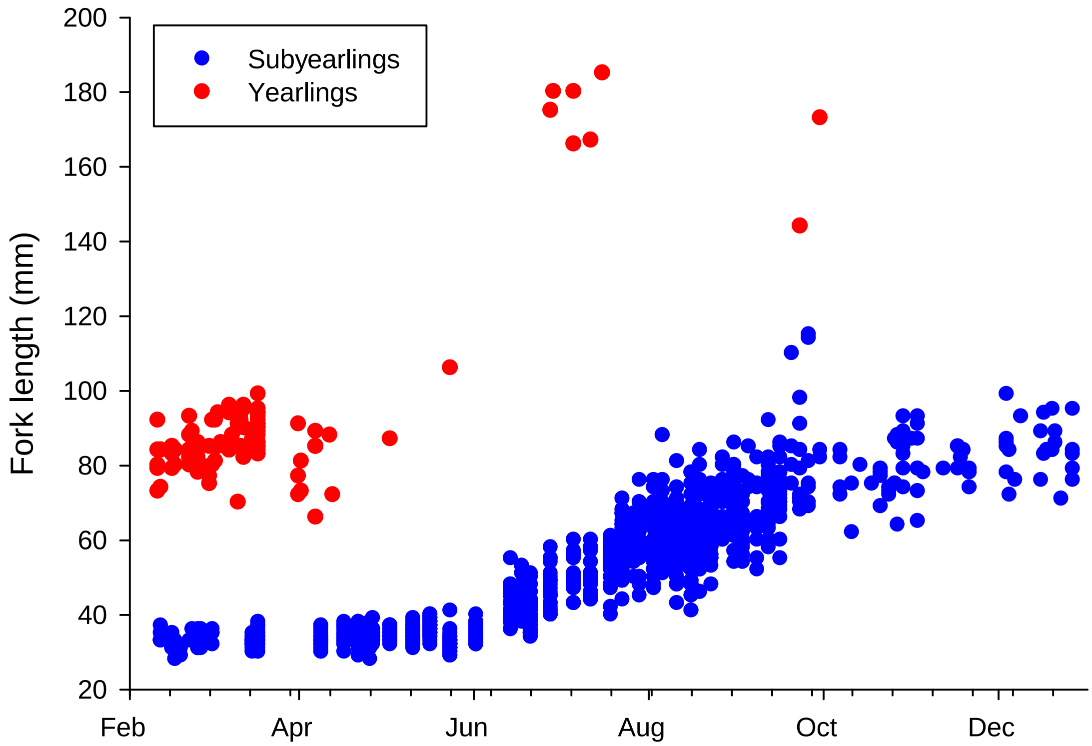


**Figure 4. Fork length of subyearling (blue) and yearling (red) Chinook salmon collected at the South Fork McKenzie trap, 2010.**

*Middle Fork Willamette*- We operated the Middle Fork Willamette trap from 25 June through 31 December 2010. We collected 86 subyearlings with most fish collected after October (Figure 5). Numerous fry were observed in Lookout Point Reservoir in April and May (see *Life-History Characteristics of Spring Chinook Salmon Rearing in Willamette Valley Project Reservoirs* -2010 report) prior to trap operation, indicating that a large portion of the subyearling migrant population was missed at the trap this year. A yearling was collected on 1 September 2010, most likely a precocious male. In addition, two individuals (198 and 258 mm FL), presumably yearling fish from Hill Creek Reservoir, were collected in early December.

The size of subyearlings collected in the Middle Fork Willamette tended to be larger than their counterparts in the South Fork McKenzie River (Figure 6). For example, the mean fork length of Middle Fork Willamette subyearlings in late June (n=5) was 70 mm compared to 46 mm for South Fork Mckenzie subyearling captured during the same time period. The larger size of subyearlings suggests that Middle Fork Willamette fry may emerge earlier than their South Fork McKenzie counterparts and hence, have more time to grow. Stream temperature was generally warmer in the Middle Fork Willamette River compared to the South Fork Mckenzie River, which also likely resulted in faster growth.

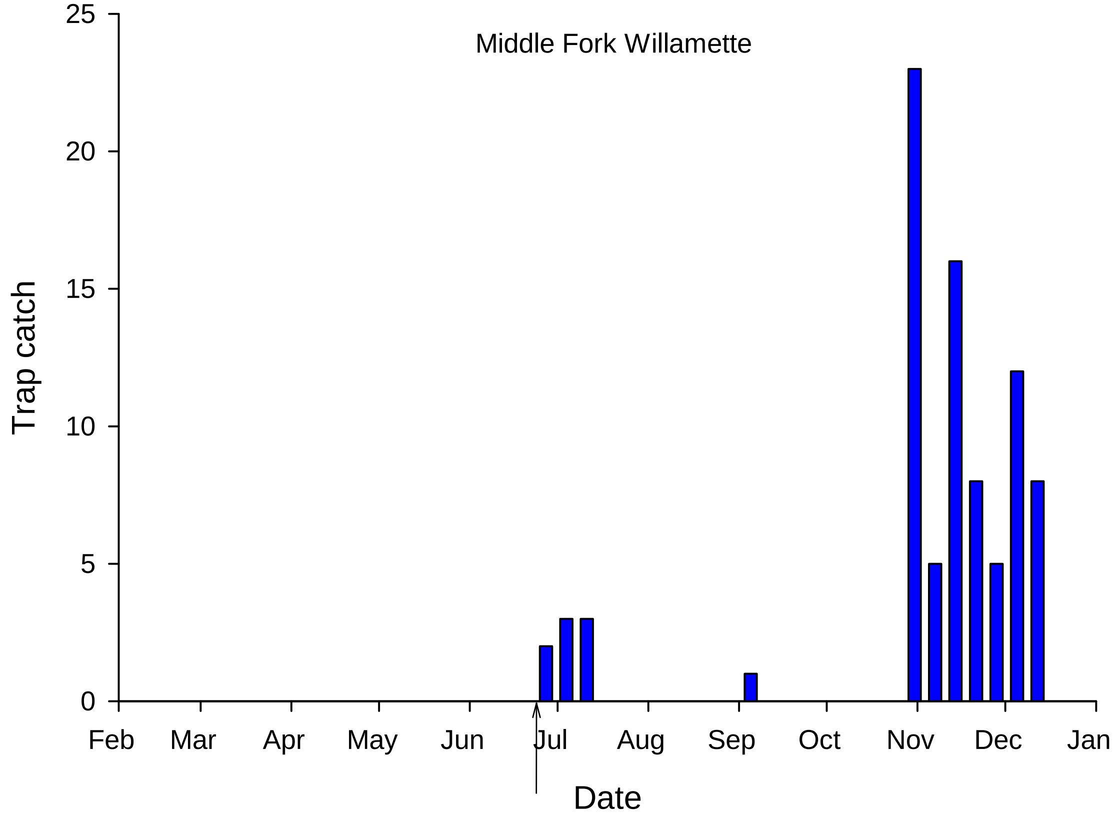


**Figure 5. Weekly catch of subyearling spring Chinook salmon at the Middle Fork Willamette trap above Lookout Point Reservoir, 2010. Arrow on date axis indicates trap start date.**

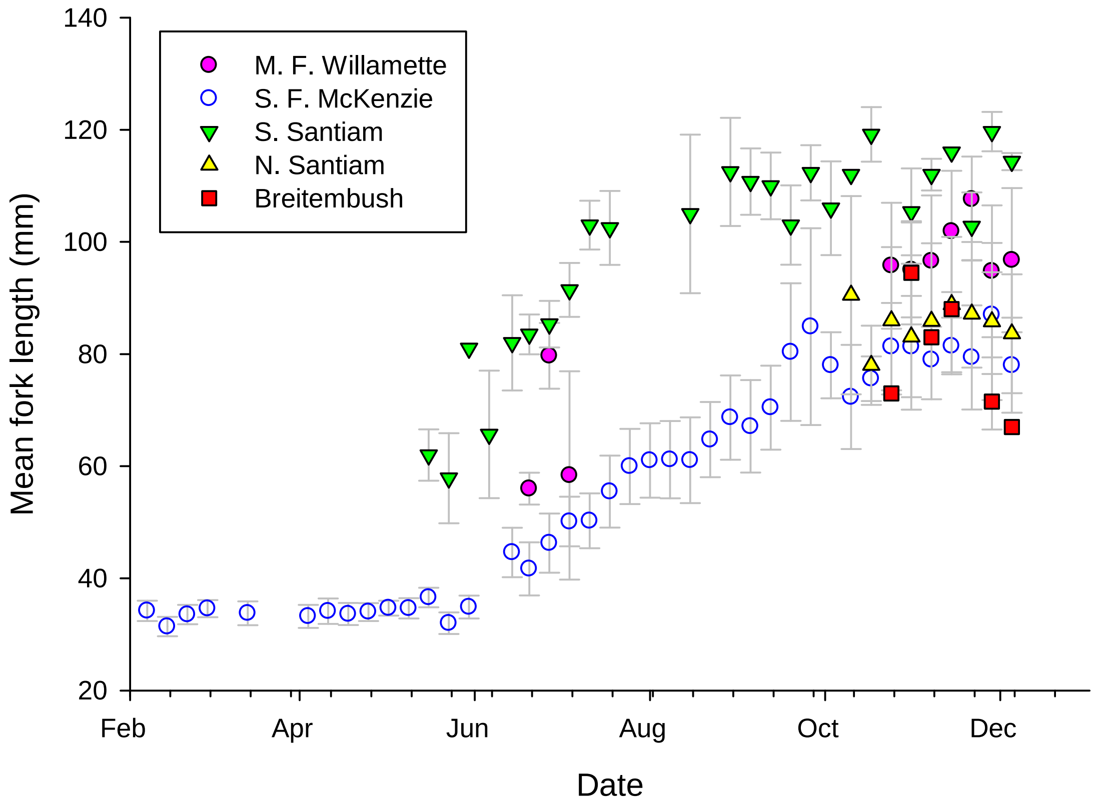


**Figure 6. Comparison of mean weekly fork lengths (mm) for subyearling Chinook salmon collected in rotary-screw traps above Willamette reservoirs, 2010. Error bars represent one standard deviation.**

*South Santiam River Chinook Salmon*- We operated the South Santiam trap from 10 May through 31 December 2010. A total of 101 subyearlings and no yearling spring Chinook salmon were collected (Figure 7). Catch rates were low but constant throughout the trap operation period. As with the Middle Fork Willamette trap, we suspect we missed the majority of subyearling migration at this trap. Subyearlings from the South Santiam River tended to be larger in size than subyearlings from all other populations sampled (Figure 6).

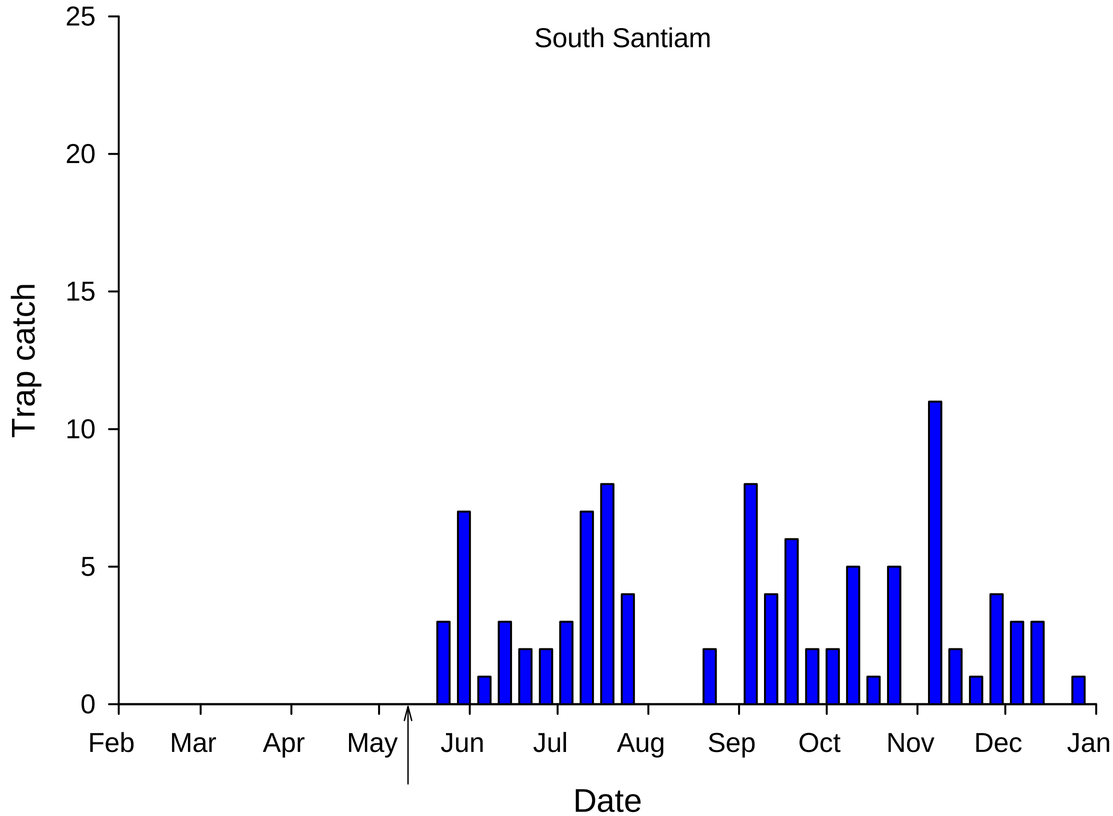


**Figure 7. Weekly catch of subyearling spring Chinook salmon at the South Santiam trap above Foster Reservoir, 2010. Arrow on date axis indicates trap start date.**

*South Santiam River Winter Steelhead*- In the South Santiam River, steelhead are sympatric with rainbow trout and only steelhead smolts can be visually differentiated from resident rainbow trout. For this reason, all juvenile *O. mykiss* were referred to as steelhead in this report, even though some fish were likely resident rainbow trout.

We collected 1,187 juvenile steelhead in the trap in 2010. Based on lengths, there appears to be at least two distinct year classes of juveniles (Figure 8). Subyearlings, presumably progeny from adult steelhead outplanted above Foster Reservoir, began appearing as fry in the trap in late June (<50 mm FL) with catch numbers peaking in late August/early September (Figure 9). This cohort appeared to reach a maximum length of 100mm by the end of the summer. An older year class of steelhead, presumably yearlings, was caught in the trap in lower numbers throughout the year.

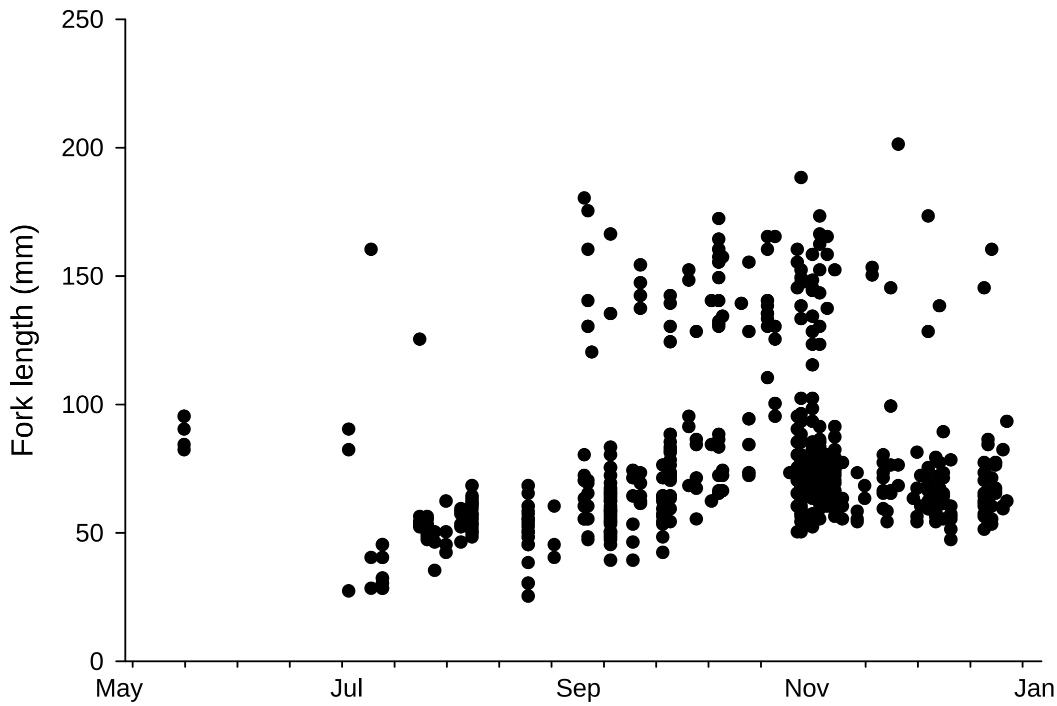


**Figure 8. Fork length of juvenile winter steelhead caught in the South Santiam trap above Foster Reservoir, 2010.**

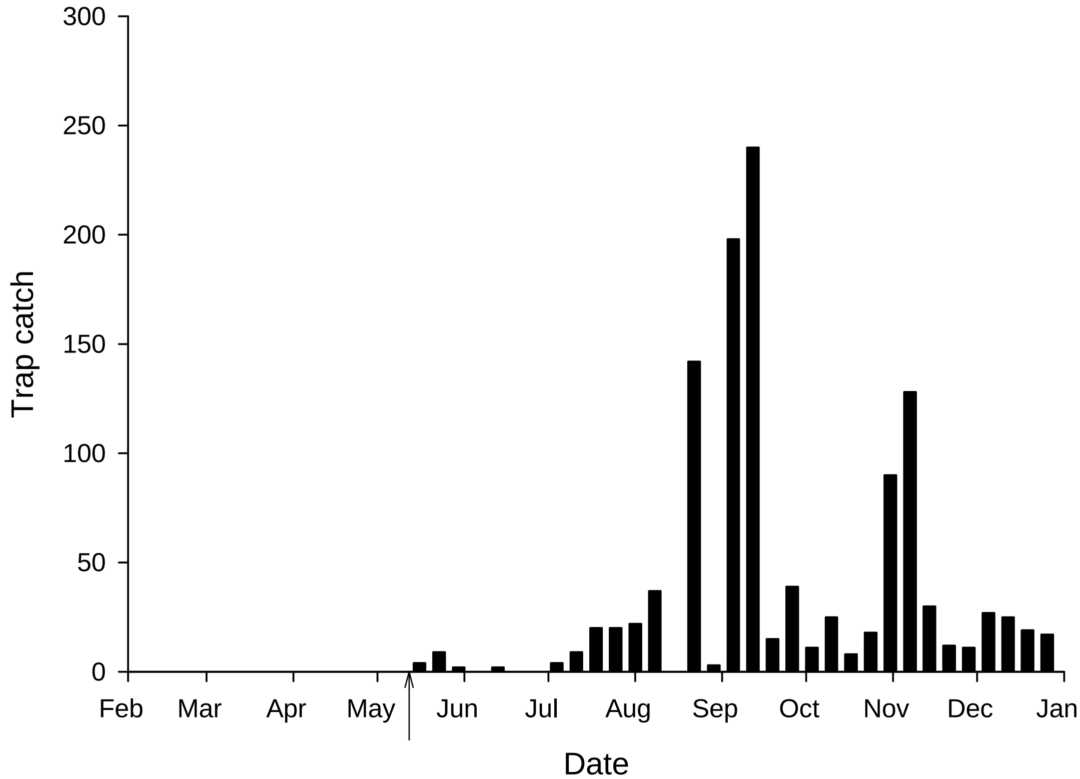

**Figure 9. Weekly catch of juvenile winter steelhead at the South Santiam trap above Foster Reservoir, 2010. Arrow on date axis indicates trap start date. Catch not adjusted for periods of trap stoppage.**

*North Santiam River*- We operated the North Santiam trap from 13 October through 31 December 2010 and collected 276 subyearlings and no yearling spring Chinook salmon (Figure 10). We did not operate this trap until October due to its proximity to the adult Chinook salmon outplant release site and our desire to avoid capturing adult fish that milled in the pool at the trap site. Daily catch rates in late October and early November were greater than other traps, suggesting a greater proportion of North Santiam subyearlings may reside in the river above the reservoir compared to other populations. The size of subyearling captured in the North Santiam River was similar to subyearlings in the Breitenbush and South Fork McKenzie rivers. Mean fork length of subyearlings was 86 mm and ranged from 46-137mm (Figure 6).

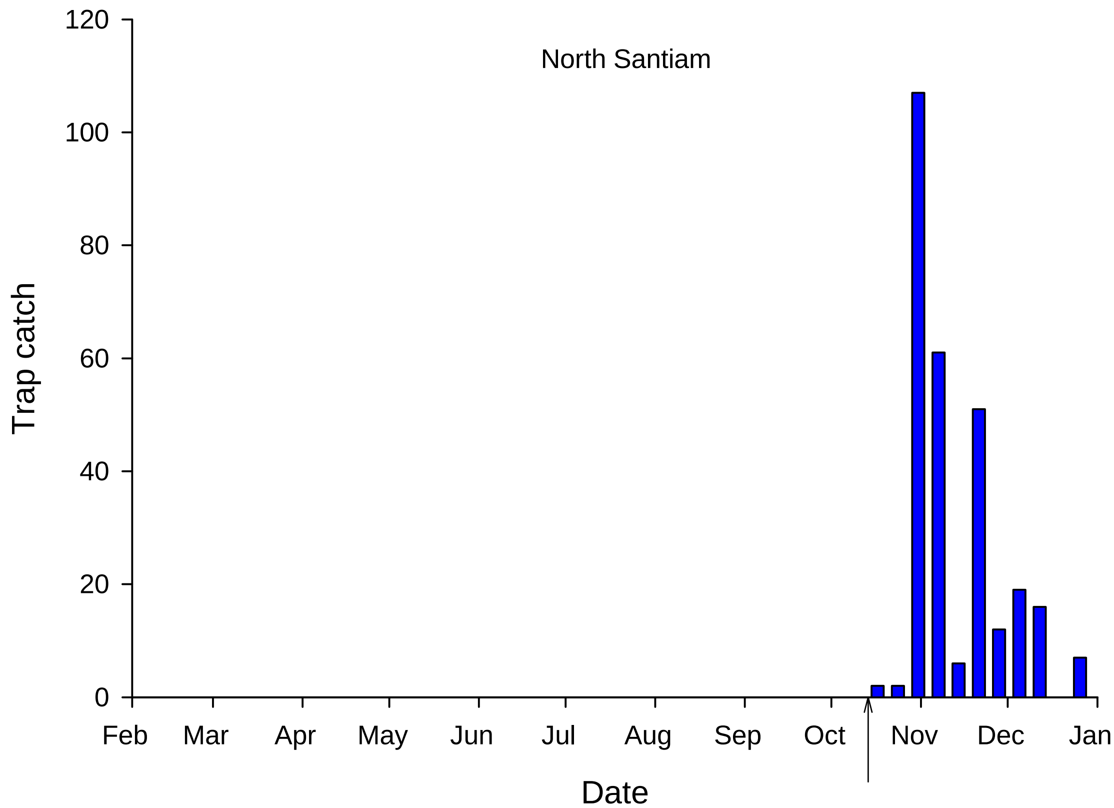


**Figure 10. Weekly catch of subyearling spring Chinook salmon at the North Santiam trap above Detroit Reservoir, 2010. Arrow on date axis indicates trap start date.**

*Breitenbush River*- We operated the Breitenbush River trap from 25 October through 31 December 2010. No yearlings and only nine subyearlings were collected. Like most other sites, we suspect we were unable to sample the fry outmigration due to the late installation of the trap. Another contributing factor to low juvenile catch rates was the limited numbers of female adult Chinook salmon outplanted above this trap site in 2009. Only 36 females were outplanted in the Breitenbush in 2009, considerably less than other rivers (Table 3).

**Table 3. Number of adult spring Chinook salmon outplanted above Willamette Valley Project dams in 2009. Progeny of these outplants would have produced the subyearling cohort in 2010.**

| | Outplants | | |
|---|---|---|---|
| River | Females | Total | Location |
| Breitenbush | 36 | 453 | Cleator Bend |
| North Santiam | 111 | 447 | Coopers Rd., Parrish Lk. Rd. |
| South Santiam | 172 | 425 | Gordon Rd., Riverbend, Res. |
| South Fork McKenzie | 630 | 1,280 | Various locations |
| NF Middle Fork Willamette | 358[a] | 1,253 | Mile post 6 |

[a] an additional 147 females were outplanted above Hills Creek Reservoir in the Middle Fork.

*Abundance Estimates of Outmigrants*

Estimates of abundance reported here were not corrected for periods when traps were stopped due to high flows or debris. Therefore, our estimates should be considered minimum estimates of population size. It is likely that many juveniles migrated past the trap sites during high flow periods when we could not operate traps. The amount of time a trap was stopped varied throughout the season and between traps.

The South Fork McKenzie trap had a sufficient number of trap efficiency recaptures of subyearling Chinook to calculate weekly population estimates. Trap efficiency ranged from 1.6 to 18% with and mean of 4.0% during the spring fry migration. We estimated a total of 685,723 (95% CI ± 72,519) subyearlings migrated out of the South Fork McKenzie River and into Cougar Reservoir between February and December 2010 (Figure 11). The vast majority of subyearlings (93%) migrated into Cougar Reservoir as fry with April and May comprising the peak months of emigration.

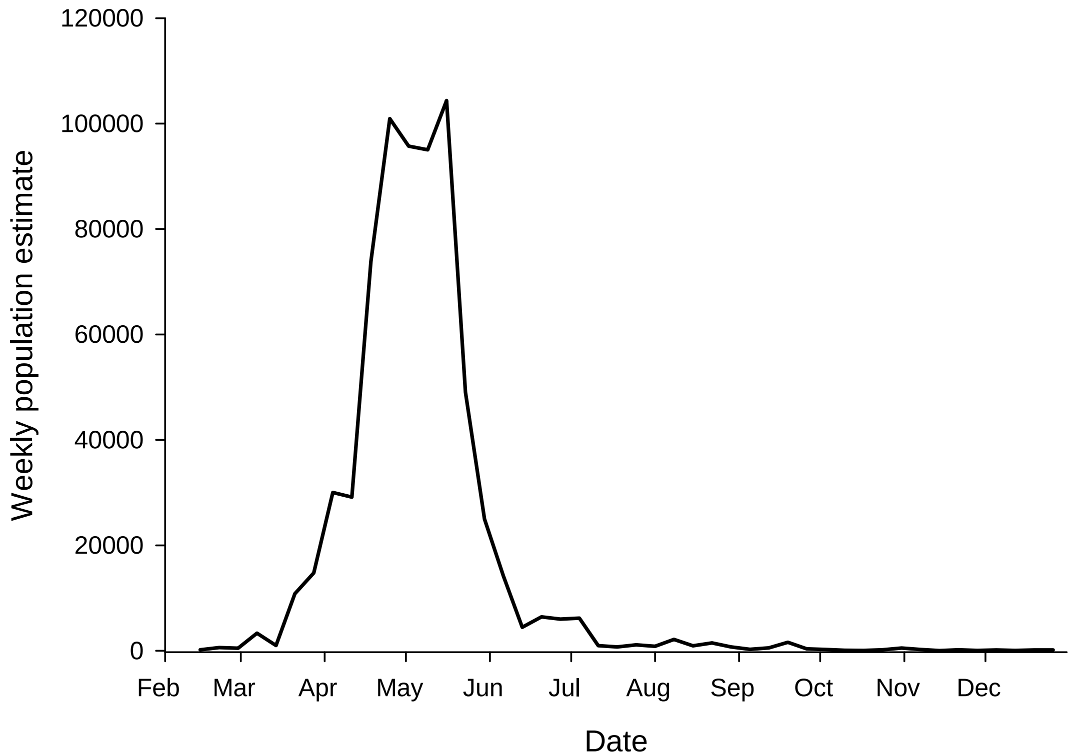


**Figure 11. Weekly population estimates for subyearling spring Chinook salmon migrating past the South Fork McKenzie trap in 2010.**

## Recommended Future Directions

We will continue to operate rotary screw traps at the same locations in 2011. Operations will begin in January to capture the beginning of fry emigration anticipated at some sites. In 2011, that we will have a more complete picture of outmigration now that monitoring sites have been developed and all traps are in place. In 2011, we also anticipate installing 8-ft rotary screw traps below WVP dams to monitor passage of juvenile spring Chinook salmon and winter steelhead out of the reservoirs.


## Acknowledgments

Many individuals and groups helped with this study. We thank Milt Moran of Cascade Timber Consulting, Inc. for allowing us access to the South Santiam trap site. We also thank Jim Morgan of Young and Morgan Timber Company for allowing us to install the North Santiam trap on their property, and Shari Monson (USFS) for helping us get a Special Use Permit for our traps located on Forest Service land. We would like to recognize seasonal biologists Chris Abbes, Dave Metz, Khoury Hickman, David Duckett, Kris Clemons, Shelly Goff, and Greg Gilham who diligently collected much of the field data at the trap sites this year.

## References


Connor, W. P., C. E. Piston, and A. P. Garcia. 2003. Temperature during incubation as one factor affecting the distribution of snake river fall chinook salmon spawning areas. Transactions of the American Fisheries Society, 132(6), 1236-1243.

Geist, D. R., C.S. Abernethy, K. D. Hand, V. I. Cullinan, J. A. Chandler, and P. A Groves. 2006. Survival, development, and growth of fall chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. Transactions of the American Fisheries Society 135 (6): 1462-1477.

Groves, P. A., J. A. Chandler, and T. J. Richter. 2008. Comparison of temperature data collected from artificial chinook salmon redds and surface water in the snake river. North American Journal of Fisheries Management 28 (3):766-80.

NMFS (National Marine Fisheries Service). 1999a. Endangered and threatened species: threatened status for two ESUs of steelhead in Washington and Oregon. Federal Register 64:14517-14528.

NMFS. 1999b. Endangered and threatened species: threatened status for three Chinook salmon evolutionarily significant units (ESUs) in Washington and Oregon, and endangered status of one Chinook salmon ESU in Washington. Federal Register 64:14307-14328.

NMFS. 2008. 2008-2023 Willamette River Basin Project Biological Opinion. NOAA’s National Marine Fisheries Service, Northwest Region, Seattle, WA. F/NWR/2000/02117.

Seber, G.A.F. 2002. The Estimation of Animal Abundance and Related Parameters, 2$^{nd}$ ed. Blackburn Press, Caldwell, NJ.

Suring, E., K.A. Leader, C.M. Lorion, B.A. Miller, D.J. Wiley. 2009. Salmonid Life Cycle Monitoring in Western Oregon streams, 2006-2008. Monitoring Program Report Number OPSW-ODFW-2009-2, Oregon Department of Fish and Wildlife, Salem.

Thedinga, J. F., M. L. Murphy, S. W. Johnson, J. M. Lorenz, and K. V. Koski. 1994. Determination of salmonids smolt yield with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. North American Journal of Fisheries Management 14:837-851.