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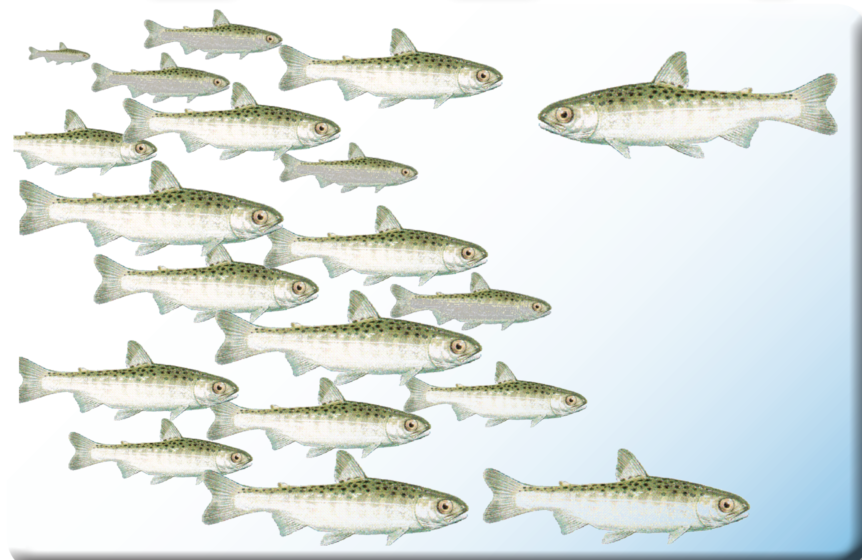
Green River Juvenile Salmonid Production Evaluation: 2016 Annual Report



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Washington Department of
Fish and Wildlife
Fish Program
Science Division

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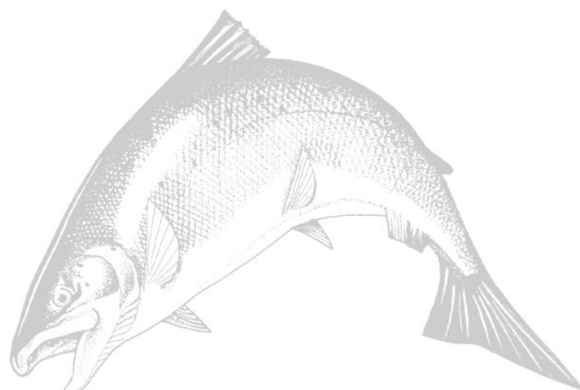

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Acknowledgements

Measuring juvenile salmon production from large river systems like the Green River involves a tremendous amount of work. Developing these estimates was possible due to the long hours of trap operation provided by our dedicated scientific technicians: Bob Green and Matt Pollack. Logistical support was provided by Wild Salmon Production Evaluation Unit biologist Josh Weinheimer.

A number of other individuals and agencies contributed to this project. Bill Mosby, the adjacent landowner, provided access to the trap site. Mike Wilson, manager of the WDFW Soos Creek hatchery, provided logistical support and a secure staging site near the trap. Aaron Bosworth and Nathanael Overman, WDFW Region 4, provided Chinook spawner survey data.

The juvenile salmonid production study on the Green River was initiated in 2000. This study was funded by the Washington State legislature between 2000 and 2002, by the Washington Salmon Recovery Funding Board (SRFB) between 2002 and 2007, by Tacoma Water between 2008 and 2011 and by the Army Corp of Engineers (USACE), the King County Flood Control District Cooperative Watershed Management Grant Program (WIRA 9), and Tacoma Water between 2013 and 2016.

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Executive Summary

This report provides the 2016 results from the juvenile salmonid monitoring study conducted on the Green River in central Puget Sound, Washington. The primary objective of this study was to estimate the juvenile abundance of natural-origin Chinook salmon in the Green River. Additional objectives were to estimate the number of juvenile migrants and life history characteristics of other salmonid species. Juvenile salmonids were captured in a five-foot screw trap located at river mile 34.5 (55 rkm). Catch was expanded to a total migration estimate using a time-stratified approach that relied on release and recapture of marked fish throughout the outmigration period.

The trap was operated from January 13 through June 26, 2016. During this period, the trap fished 86% of the time. We estimated the freshwater production (juvenile abundance) of Chinook (subyearling), coho, pink and steelhead. (Table 1).

Table 1. Catch, freshwater production, fork length (mm), and out-migration timing of natural-origin juvenile salmonids caught in the Green River screw trap in 2016. Data represent freshwater production above the juvenile trap, which is located at river mile 34.5.

Species/Life Stage	Catch	Production (% CV)	Avg Fork Length (± 1 S.D.)	Median Migration Date
Chinook – Subyrlg	2,898	57,214 (11.70%)	63.77 (± 20.92)	11-May
Chinook – Yrlg	0			
Coho – Yrlg	1,755	62,074 (15.65%)	113.76 (± 11.0)	29-Apr
Pink	152,259	3,137,795 (6.55%)	36.48 (±2.96)	25-Mar
Steelhead – Smolt	541	32,936 (37.69%)	169.02 (±16.63)	18-May
Chum	77,443 [b]			31-Mar [a]

[a] This is median catch date which is not adjusted for trap efficiency and therefore serves as an index of migration timing.
[b] Unable to distinguish between natural origin and hatchery production.

Chinook salmon spawn above and below the juvenile trap. A basin-wide production estimate was derived by applying estimated survival above the trap to spawning below the trap; a screw trap fished in Big Soos Creek estimated production from that tributary. Egg-to-migrant survival of Green River Chinook for the 2016 outmigration (2015 brood) was estimated to be 0.81%, yielding a basin-wide production estimate of 76,570 juveniles. Included in this estimate was an estimate of 16,987 Chinook migrating from Big Soos Creek with an egg-to-migrant survival of 2.8% This estimate was generated by a screw trap located just above the hatchery and operated by the Muckleshoot Indian Tribe.

Juvenile migrant Chinook in the Green River are predominantly subyearlings. Outmigration timing of subyearling Chinook was bimodal. The fry (≤45 mm fork length) represented 37% of all subyearling migrants and peaked in mid-February, parr migrants (>45 mm fork length) represented 63% of the migration and remained in the system above the trap site and the majority migrated from mid-May thru the remainder of the trapping season.

Introduction

This report provides the 2016 results from the juvenile salmonid production evaluation conducted on the Green River in central Puget Sound, Washington. Throughout this report, the number of juvenile migrants will be referred to as "freshwater production" because they are the offspring of naturally spawning salmon and steelhead in the Green River. The Green River study was initiated in 2000 with a focus on freshwater production and survival of Chinook salmon but has also provided description of the abundance and juvenile life history of coho, chum, pink and steelhead in this watershed. Information on Green River Chinook and steelhead contribute to ongoing status evaluations for Puget Sound Chinook and steelhead, both listed as *threatened* under the Endangered Species Act by the National Marine Fisheries Service (NMFS). In addition, freshwater production estimates for all species provide a baseline to evaluate impacts of the Additional Water Storage (AWS) project for Howard Hanson dam. In 2011, 2012 and 2013, the Green River juvenile trap results also contributed to the Genetic Mark Recapture (GMR) program conducted by WDFW Fish Science to validate escapement methodologies in Puget Sound watersheds, including the Green River (Seamons et al. 2012).

Under NMFS Listing Status Decision Framework, listing status of a species under the Endangered Species Act (ESA) will be evaluated based on biological criteria (abundance, productivity, spatial distribution, and diversity) and threats to population viability (i.e., harvest, habitat, etc) (Crawford 2007, McElhany et al. 2000). The Green River supports a demographically independent population of Chinook salmon (Ruckelhaus et al. 2006). Puget Sound steelhead were listed as *threatened* in May of 2007. Winter-run steelhead in the Green River were designated as a demographically independent population within the Central and South Sound Major Population Group (Myers et al. 2015).

The Green River watershed is distinguished by a number of factors including canyon geomorphology in a portion of the upper watershed, dikes and development in the lower watershed, regulated flows from Howard Hanson Dam, and large-scale hatchery production. The productivity of salmonid populations, including Chinook salmon, is influenced by the cumulative effect of these natural and human-influenced features. From 2000 to present, a juvenile fish trap has operated in the main stem Green River (river mile 34.5, rkm 55), approximately one half mile upstream from the mouth of Big Soos Creek. The trap is located upstream of Big Soos Creek in order to avoid the capture of large numbers of hatchery fish released annually from Soos Creek hatchery. This study has produced a long-term data set on juvenile migrants produced by naturally spawning Chinook salmon as well as other salmonids in the Green River.

The combination of juvenile and spawner abundance data for Green River Chinook salmon allows brood-specific survival to be partitioned between the freshwater and marine environment. Spawner abundance is currently derived from redd counts obtained by WDFW Region 4 staff. Monitoring freshwater production over a range of spawner abundances should provide a measure of watershed capacity and stock productivity through the spawner-recruit function. This information will be critical to identifying the relative impacts of harvest, habitat, and hatchery stressors on this stock.

Results from the Green River juvenile salmonid production evaluation also provide baseline data useful for assessing impacts of a large-scale water storage project at Howard Hanson reservoir. In the mid-1990s U.S. Army Corps of Engineers and Tacoma Water began planning for the Howard Hanson Dam (HHD) Additional Water Storage (AWS) Project. The project includes raising the reservoir surface elevation in order to increase water storage for domestic use. The final design for the project was developed between 1999 and 2001. Construction began in 2001 and is finished. The final significant component remaining to complete the project is the construction of the juvenile salmon collection and transport facility in the pool above HHD. Juvenile migrant trapping in the Green River was considered important for evaluating the impacts and success of mitigation elements from the AWS project on the abundance, freshwater survival, and migration timing of juvenile Chinook. Currently there are no adult salmon being trapped for transport and release above the dam. Once the juvenile collection facility has been constructed and adult salmon released above the dam, the trapping data will allow us to determine if production increases as fish recolonize the approximately 106 miles of river and stream habitat above the dam.

Objectives

The primary objective of this study was to estimate the abundance of juvenile migrants produced by naturally spawning Chinook salmon in the Green River. Additional objectives were to estimate the number of juvenile migrants produced by other salmonid species and to describe their juvenile life history. This report includes results from the 2016 field season.

Methods

Trap Operation

A floating rotary screw trap (5-ft or 1.5-m diameter) was used to capture juvenile migrants on the Green River (Seiler et al. 2002). The trap was located on the left bank at river mile 34.5 (rkm 55), approximately 3,200 ft (975-m) upstream of the Highway 18 bridge (Figure 1).

In 2016, the trap operated between January 13 and June 26 for a total of 3,413 of 3,954 possible hours (86% of the time). Over the course of the season, trapping was suspended 32 times; the duration of outages ranged from 8.0 to 118.0 hours. Trapping was suspended once for high water, three times for hatchery fish releases and, 28 times during day time periods late in the trapping season when catches were low and recreational use of the river was high.

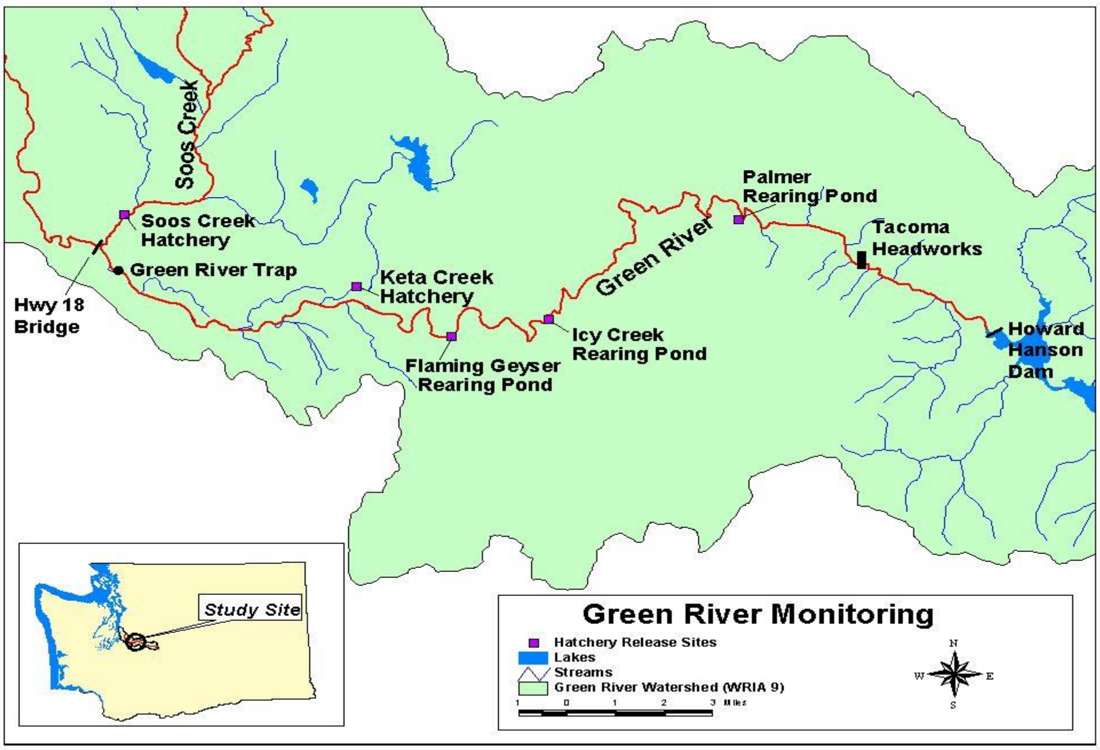

Figure 1. Location of Green River screw trap in relation to existing hatchery release sites and Howard Hanson Dam.

Fish Collection

The trap was checked for fish at dawn and dusk each day and at additional times when required by heavy debris loads or large catches. At the end of each trapping period, all captured fish were sorted by species and mark status (adipose fin clips or coded-wire tags) and then enumerated. Fork length (FL) was measured from a subsample of natural-origin Chinook, coho and steelhead smolts on a daily basis. Subyearling Chinook were length sampled at a rate of approximately 21%.

Chinook were enumerated as subyearlings and yearlings. Based on previous years data yearling Chinook emigrate between February and April and range in size from 76 to 156 mm FL. Subyearling Chinook emigrate between January and July, range between 34 mm and 107 mm FL.

Subyearlings are distinguished from yearling migrants by the body size and date of migration. During the time period that yearlings typically migrate, subyearling migrants average in size between 39 mm and 50 mm FL. For the purpose of analysis, subyearling migrants were further partitioned into "fry" and "parr," two freshwater rearing strategies observed in the Green River as well as other watersheds in Puget Sound (Kinsel et al. 2008, Kiyohara and Zimmerman 2011, Topping and Zimmerman 2011). Fry migrants were less than 46 mm fork length (FL) and emigrate after minimal to no rearing in freshwater. Parr migrants were longer than 45 mm FL, and became the dominant component of the catch by late April. Based on their size, parr migrants have reared in freshwater for some period of time prior to emigration.

Coho were enumerated as either fry or smolts (yearlings). Defining characteristics of coho fry were a bright orange-brown color, elongated white anal fin ray, small eye and small size (under 60 mm FL). Yearling coho were larger in size (approximately 90 to 160 mm FL), with silver sides, black tips on the caudal fin and large eye compared to the size of the head.

Trout were enumerated by two different age classes: parr and smolt. Parr were trout that were not "smolted" in appearance, typically between 50 and 150 mm FL, dark in color (brown with spots on the tail), and caught throughout the trapping season. Smolts were chrome in appearance, larger in size (90 to 225 mm FL) with many spots along the dorsal surface and tail. Smolts were assigned as either steelhead or cutthroat based on mouth size and presence or absence of red coloration on the ventral surface of the gill covers.

Origin was assigned based on the mark status of each species and known marks of hatchery fish released above the trap (Table 2). Hatchery releases above the screw trap in 2016 included Chinook, coho, chum and summer and winter steelhead. Coho and steelhead were assigned to origin based on the presence (natural) or absence (hatchery) of an adipose fin. A group of wild brood hatchery reared steelhead released above the trap were not ad-clipped but were tagged with a blank wire CWT. Therefore, every unmarked steelhead captured in the trap was electronically scanned for the presence of a CWT. Chum could not be assigned to origin because all hatchery chum were unmarked.

A group of over one million otolith marked only (no external mark) subyearling hatchery Chinook were planted in Palmer Ponds on February 24th and 29th for rearing and acclimation prior to release on June 25th, when the screw trap finished fishing for the season. Because these fish were not externally marked, their release was delayed to avoid the problem of differentiating them from naturally produced Chinook salmon. However, due to concerns that the fish reared at Palmer Ponds were escaping the hatchery facility, trap operators attempted to identify non-externally marked hatchery fish based on their larger size. Discriminating hatchery- from natural-origin fish is generally easiest early in the season, when hatchery fish are significantly larger than natural fish. However, by the end of April, size distributions of the two groups begin to merge as the natural fish catch up in size to the hatchery fish, challenging visual identification. Due to the large number of Chinook salmon with the bigger body size characteristic of hatchery fish encountered during May and June, we lethally sampled N = 30 non-externally marked fish on June 10 2016 to evaluate otolith marks. In selecting this sample, we targeted the largest Chinook salmon in the catch, attempting to confirm trap operators' ability to visually identify hatchery fish.

Table 2. Number of hatchery fish by mark type released above the Green River screw trap in 2016. Fish released below the trap are not included in this table as they do not impact the quality of the freshwater production estimate.

Species	Brood Year	Release Location	Ad-clip + CWT	CWT only	Ad-Clip only	Non-externally marked
Chinook – Subyrlg	2015	Palmer Pond				1,210,000[1]
Chinook – Yrlg	2014	Icy Creek	100,694		110,600	444
Coho – Yrlg	2014	Keta Creek	15,777		284,716	676
Chum - Subyrlg	2015	Keta Creek				2,904,641
Summer steelhead	2015	Icy Creek			32,557	
Winter Steelhead	2015	Icy Creek		10,000		

[1] This release was thermally otolith marked, with a goal of 100% marking.

Trap Efficiency Trials

Trap efficiency trials were conducted for Chinook, coho, and steelhead with maiden-caught fish of natural origin throughout the season. Captured fish were anesthetized with tricaine methanesulfonate (MS-222) and marked with either Bismarck-brown dye or a partial caudal fin clip. Small Chinook (January to early-May) were marked with Bismarck Brown dye, whereas the large Chinook parr, coho, and steelhead were marked with a partial caudal fin clip. The fin clip position alternated between upper and lower caudal fin in order to check for delayed migration of marked fish. After recovery in freshwater for the day, marked fish were released at one of two upstream locations at dusk. The release locations have served as the primary release locations over the many years of this project. The first location was 150 m upstream of the trap and the second location was the Neely Bridge site, located approximately a third of a mile above the trap site.

Freshwater Production Estimate

Freshwater production is the number of juvenile migrants leaving freshwater in a given year. In most cases, freshwater production corresponds to a single brood year of spawners; however, for some species (e.g., steelhead), freshwater production may represent more than one brood year.

Freshwater production was estimated using a single partial-capture trap design (Volkhardt et al. 2007). Data were stratified by time over the outmigration period in order to accommodate for temporal changes in trap efficiency. The general approach was to estimate (1) missed catch, (2) efficiency strata, (3) time-stratified abundance, (4) extrapolated migration outside the trapping season, and (5) total abundance.

(1) Missed catch. Total catch ($\hat{u}$) was the actual catch (n_i) for period *i* summed with missed catch ($\hat{n}_i$) during periods of trap outages.

Equation 1

$$\hat{u}_i = n_i + \hat{n}_i$$

Missed catch for a given period *i* was estimated as:

Equation 2

$$\hat{n}_i = \overline{R} * T_i$$

where:

$\overline{R}$ = Mean catch rate (fish/hour) from adjacent fished periods, and

T_i = time (hours) during the missed fishing period.

Variance associated with $\hat{u}_i$ was the sum of estimated catch variances for this period. Catch variance was:

Equation 3

$$Var(\hat{u}_i) = Var(\hat{n}_i) = Var(\overline{R}) * T_i^2$$

where:

Equation 4

$$V(\overline{R}) = \frac{\sum_{i=1}^{i=k} (R_i - \overline{R})^2}{k(k-1)}$$

(2) Efficiency strata. A *G*-test (Sokal and Rohlf 1981) was used to determine whether adjacent efficiency trials were statistically different. *A priori* pooling prior to the G-test occurred for efficiency trials with expected frequencies of less than five (Sokal and Rohlf 1981). Of the marked fish released in each efficiency trial (*M)*, a portion are recaptured (*m*) and a portion are not seen (*M-m*). If the *seen:unseen* [*m*:(*M-m*)] ratio differed between trials, the trial periods were considered as separate strata. However, if the ratio did not differ between trials, the two trials were pooled into a single stratum. A *G*-test determined whether adjacent efficiency trials were statistically different ($\alpha = 0.05$). Trials that did not differ were pooled and the pooled group compared to the next adjacent efficiency trial. Trials that did differ were held separately. Pooling of time-adjacent efficiency trials continued iteratively until the *seen:unseen* ratio differed between time-adjacent trials. Once a significant difference is identified, the pooled trials are assigned to one strata and the significantly different trial is the beginning of the next stratum.

(3) Time-stratified abundance. Abundance for a given stratum *h* ($\hat{U}_h$) was calculated from maiden catch ($\hat{u}_h$), marked fish released (M_h), and marked fish recaptured (m_h). Abundance was estimated with a Bailey estimator (Carlson et al. 1998, Volkhardt et al. 2007).

Equation 5

$$\hat{U}_h = \frac{\hat{u}_h (M_h + 1)}{m_h + 1}$$

Variance associated with the Bailey estimator was modified to account for variance of the estimated catch during trap outages (derivation in Appendix A):

Equation 6

$$V(\hat{U}_h) = V(\hat{u}_h)\left(\frac{(M_h + 1)(M_h m_h + 3M_h + 2)}{(m_h + 1)^2 (m_i + 2)}\right) + \left(\frac{(M_h + 1)(M_h - m_h)\hat{u}_h(\hat{u}_h + m_h + 1)}{(m_h + 1)^2 (m_h + 2)}\right)$$

(4) Extrapolated migration. Migration outside the trapping period ($\hat{N}_e$) was estimated based on an assumed number of days (*t*) outside the trapping period that the migration occurred. Extrapolation was used for Chinook salmon (January 1 – July 31) due to their extended outmigration period and the low levels of catch occurring at the beginning and end of the trapping season. Extrapolation was calculated based on the estimated daily migration ($\hat{N}_d$) for the first *k* days of trapping (and the last *k* days of trapping).

Equation 7

$$\hat{N}_e = \frac{\sum_{d=1}^{d=k} \hat{N}_d}{k} * \frac{t}{2}$$

Variance associated with the extrapolated migration was:

Equation 8

$$V(\hat{N}_e) = \frac{\sum_{d=1}^{d=k} (\hat{N}_d - \overline{N})^2}{k(k-1)} * \left(\frac{t}{2}\right)^2$$

(5) Total abundance. Total abundance of juvenile migrants was the sum of in-season stratified estimates and extrapolated estimates.

Equation 9

$$\hat{N}_T = \sum_{h=1}^{h=k} \hat{U}_h + \sum \hat{N}_e$$

Variance was the sum of variances associated with all in-season and extrapolated estimates:

Equation 10

$$V(\hat{N}_T) = \sum_{h=1}^{h=k} V(\hat{U}_h) + \sum V(\hat{N}_e)$$

Confidence intervals were calculated from the variance:

Equation 11

$$\hat{N}_{95\%ci} = \hat{N}_T \pm 1.96\sqrt{V(\hat{N}_T)}$$

Coefficient of variation was:

Equation 12

$$CV = \frac{\sqrt{V(\hat{N}_T)}}{\hat{N}_T}$$

Daily migration estimates were calculated from the daily catch and the trap efficiency for strata *h*:

Equation 13

$$\hat{U}_d = \frac{\hat{u}_{dh}}{e_h}$$

Where:

Equation 14

$$e_h = \frac{\hat{u}_h}{\hat{U}_h}$$

Freshwater Life History Diversity

Juvenile length statistics and median migration dates were summarized for all species. Median migration date was the date that 50% of juvenile migrants were estimated to have passed the trap and was derived from daily migration data. If daily migration estimates were not available for a species (e.g., no production estimate due to low trap efficiency), median catch date was reported as a proxy for median migration date. The use of catch data to estimate migration timing should be viewed with caution as catch numbers have limited meaning without trap efficiency information.

In order to describe abundance and migration of the two subyearling Chinook strategies, the subyearling Chinook production was divided into fry and parr migrants. For a given statistical week, the proportion of Chinook within each size class (≤ 45 mm FL, > 45 mm FL) was applied to the migration estimate for that week.

Egg-to-Migrant Survival for Subyearling Chinook

Freshwater productivity of subyearling Chinook was estimated as juveniles/female and egg-to-migrant survival. Juvenile migrants were estimated as described above. Female spawners were based on foot, boat, and aerial surveys of Chinook redds conducted by WDFW Region 4 and the Muckleshoot Indian Tribe(Footen et al. 2011). These estimates assume one female per redd (personal communication, Nathanael Overman, WDFW Region 4). Egg-to-migrant survival was the number of juvenile migrants divided by potential egg deposition (P.E.D.). Potential egg deposition was the product of female spawners estimated above the trap site and a Chinook fecundity estimate of 4,500 eggs per female. Fecundity was the long-term average of Chinook fecundity measured at Soos Creek Hatchery (personal communication, Mike Wilson, WDFW Hatchery Division).

Basin-wide Abundance of Subyearling Chinook

A portion of the Chinook spawning occurs below the juvenile trap in the mainstem Green River and above the hatchery rack on Soos Creek. In order to make a basin-wide abundance estimate for juvenile migrant Chinook, egg-to-migrant survival above the trap was applied to the estimated number of eggs deposited in the lower river below the trap. Soos Creek juvenile Chinook production was estimated separately with a screw trap operated by the Muckleshoot Indian Tribe. Egg deposition was estimated as described above. Soos Creek juvenile Chinook production was estimated separately with a screw trap operated by the Muckleshoot Indian Tribe. Egg deposition was estimated as described above.

Smolt to adult return rate for Chinook Salmon

In order to understand patterns of marine survival, we estimated smolt to adult return rate (SAR) for Green River Chinook salmon. This analysis required age data obtained from scale samples, escapement estimates and the hatchery mark rate among Chinook salmon spawning naturally in the Green River. Escapement and hatchery mark rate data were used to estimate the total number of naturally produced adult Chinook salmon returning to the area upstream of the smolt trap (river mile 34.5), including Newaukum Creek. Age data, restricted to samples collected from unmarked fish, were used to allocate adults from each return year to the corresponding brood year. The scale samples were collected from areas both upstream and downstream of the smolt trap, so our approach assumes a common age structure in both locations. For each outmigrant year class, total adult returns were calculated by summing the number of natural-origin adult Chinook salmon returning to the Green River upstream from the screw trap at age 3, 4, 5, 6. SAR was calculated by dividing the total number of natural-origin adult returns from all age classes by the total natural origin juvenile abundance from above the trap site. Our metric of adult returns was based on escapement to the spawning grounds, and does not account for variation in harvest over the years of study. For comparison, the same approach was used to evaluate the hatchery Chinook stock returning to the Soos Creek Salmon hatchery with data queried from the Regional Mark Information System (RMIS).

Results

Subyearling Chinook

The total estimated catch of non-externally marked Chinook ($\hat{u}$ = 3,033) included 2,898 captures in the trap and an estimated missed catch during trap outage periods of 135 (Table 3, Appendix B). In 2016, the hatchery origin Chinook fry released from Palmer Pond were otolith marked but not adipose fin clipped (ad-marked), or Coded Wire Tagged (CWT). The volitional release was started on June 25th, the same day the screw trap finished trapping for the season. The outlet of Palmer Pond is fitted with a drum screen that is designed to prevent fish from escaping. However, the screen appeared to allow some fish to escape. Shortly after the hatchery Chinook were transferred to Palmer Ponds on February 24th and 29th, we began capturing subyearling Chinook that were larger (and heavier) than the majority of the natural-origin Chinook we had been capturing prior to that point, suggesting that some hatchery fish were escaping. Of the 2,898 non-externally marked Chinook encountered during the entire season, the technicians working the trap initially visually identified 2,116 of them as having the larger size characteristic of hatchery fish. However, the vast majority (97%) of these larger, possibly hatchery fish were encountered on or after April 25, when visual identification proved problematic given the similar size and shape of the hatchery and natural origin fish. Furthermore, of the N = 30 otoliths examined from putative hatchery fish sampled on June 10 2016, N = 27 of them were unmarked, undermining our confidence in our ability to visual identify hatchery fish. With no way to positively identify the hatchery fish visually, we decided to include all non-externally marked Chinook salmon in the count of naturally produced juveniles (see discussion section), (Table 2, Appendix B). We presume the production estimate described below contains an unknown number of non-externally marked hatchery fish, and view our estimate as an upper bound.

We conducted a total of 87 efficiency trials with release numbers ranging between 1 and 119 fish and used a total of 2,310 chinook. Efficiency releases were performed from two locations, the first was the traditional site 150 m upstream of the trap, used every year, and the second was at the Neely Bridge located approximately a third of a mile above the trap location. Individual trials thru the early part of the season when the fish were being stained with Bismark Brown were combined because of the low number and sporadic nature of the recoveries. Individual trials performed later in the season when the mark changed to a caudle fin clip were combined by statistical week, with a minimum of 5 recoveries. Statistical weeks with less than 5 recoveries were combined with the subsequent statistical week, forming 8 groups prior to stratification. The *G*-test pooled the 8 groups into 4 strata, with trap efficiencies ranging between 2.7% and 15.8% (Table 3).

The trapping season of January 13 through June 26 encompassed the majority of the subyearling Chinook migration. A total of 49,739 subyearlings were estimated to have migrated during the trapping season. However, some fish migrated both before and after our trapping season, which was evident by the catch of Chinook migrants on our first and last days of trapping. A total of 624 Chinook were estimated to have migrated prior to the trapping season and 6,852 migrants were estimated following the trapping season. This extrapolation assumed migration began January 1 and ended July 31, 2016.

A total of 57,214 ± 13,341(±95% C.I.) unmarked subyearling Chinook were estimated to have migrated past the screw trap between January 1 and July 31, 2016. Coefficient of variation for this estimate was 11.70%.

Table 3. Catch, marked and recaptured fish, and estimated abundance of subyearling Chinook migrants at the Green River screw trap2016. Release groups were pooled to form four strata. Missed catch and associated variance were estimated for periods that the trap did not fish.

		Catch					Abundance	
Strata	Date	Actual	Missed	Variance	Marked	Recaptured	Estimated	Variance
Before	1/1-1/13		18				624	7.77E+01
1	1/15-4/24	686	61	1.12E+02	513	14	25,597	4.07E+07
2	4/25-5/22	468	19	1.11E+01	174	16	5,013	1.31E+06
3	5/23-5/29	429	0	0.00E+00	423	67	2,675	1.01E+05
4	5/30-6/26	1,315	55	3.66E+02	1200	99	16,454	2.69E+06
After	6/27-7/31		571				6,852	1.11E+04
Season Total		2,898	724	4.89E+02	2,310	196	57,215	4.48E+07

Freshwater productivity of natural-origin Chinook for brood year 2016 above the trap site was estimated to be 36 juveniles per female and an egg-to-migrant survival of 0.81%. This calculation was based on the number of subyearling Chinook passing the trap ($\hat{N}_T$ = 57,214), 1,570 redds assuming 1 female spawner per redd above the trap site (personal communication, Nathanael Overman, WDFW Region 4), and an estimated P.E.D above the trap site of 7,065,000 eggs. We note that estimated egg survival was likely lower because the number of natural origin subyearling Chinook passing the trap was probably inflated by non-marked Chinook escaping from Palmer Ponds. Even so, we estimated the lowest egg to migrant survival rate since the beginning of the monitoring project.

Basin-wide abundance of subyearling unmarked Chinook was estimated to be 76,570 juvenile migrants. This included 57,214 migrants from above the trap, 2,369 juveniles from the main stem below the trap and 16,987 from Big Soos Creek. This production is the lowest estimated since the project began in 2000. The low production can be attributed to the multiple high flow events during egg incubation. Flows measured at the USGS Auburn flow gauge (12113000) reached levels that exceeded 8000 CFS on five days between November 18 and January 12. The largest event occurred in early December with a peak flow over 10,000 CFS. In addition to the poor production the high flow scouring effects resulted in the poorest egg-to-migrant survival we have estimated since 2000 (Table 4).

However, we note that the methods for estimating production from Big Soos Creek have changed over the years and would therefore affect inter-annual comparisons of the basin-wide estimate. Previous estimates of Chinook production from Big Soos Creek either assumed a carrying capacity of 275,000 (trap years 2001–2003) or applied egg-to-migrant survival measured at the main stem trap to estimated egg deposition above the hatchery rack (trap years 2004 – 2012). Only in trap years 2000 (operated by WDFW) and 2013-2016 (operated by Muckleshoot Indian Tribe) has Chinook production from Big Soos Creek been measured directly. Comparisons of egg to migrant survive between the Green River above the trap and Soos Creek for the years that production was directly measured indicates that egg to migrant survival is much higher in Soos Creek that in the Green River. Several factors likely contribute to the higher survival. Soos Creek is lower gradient than the Green River reducing the amount of potential redd scour during periods of high water. The Soos Creek screw trap is located much closer to the spawning area, minimizing the distance and time the migrants have to travel before reaching the trap, reducing the potential for predation. Given these differences, only the years that were directly measured were included in the total basin production estimates (Table 4).

The median migration date for subyearling Chinook was on May 11 (Table 5). The fry migration peaked in early to mid-February corresponding to an increase in flow. A second much smaller fry migration peak occurred in mid-March closer to the typical fry migration peak timing. The parr migrants peaked three times with two small peaks occurring in mid-March and mid-April. The main peak occurred in early to mid-June, closer to the typical parr migration peak timing. An estimated 37% (21,285) of the Chinook migrated as fry and 63% (35,929) migrated as parr. The migration periods of fry and parr overlapped between late January and early May (Table 6, Figure 2).

The seasonal average length of subyearling Chinook was 63.77 ± 20.92 mm FL (± 1 S.D.; Appendix C). The weekly average lengths of the subyearling Chinook showed little increase (approximately 5 mm) during the early portion of the season, (January 15- March 27). Chinook subyearling body size increased substantially thru the end of trapping season (April-June), averaging a 3 mm FL increase per week. The largest size increase occurred between April 11 and April 24 with an increase of 17 mm (Figure 3, Appendix C).

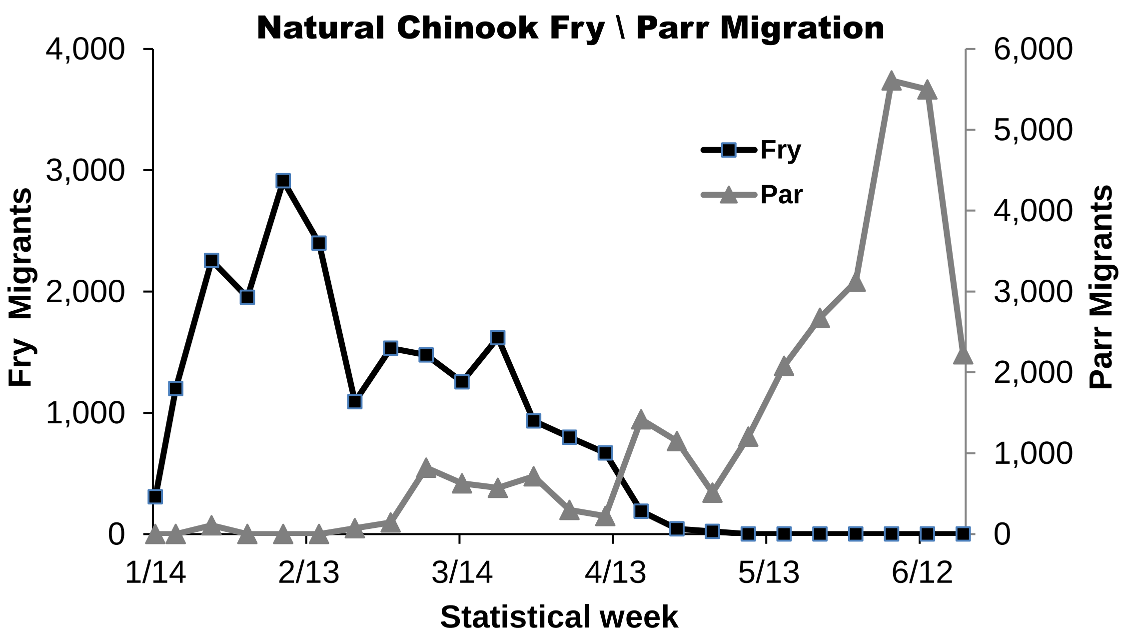

Figure 2. Weekly migration of sub- yearling Chinook migrants of natural-origin at the Green River screw trap in 2016. Subyearling migrants are partitioned into two freshwater rearing strategies fry (<45-mm FL) and parr (> 45-mm FL) migrants.

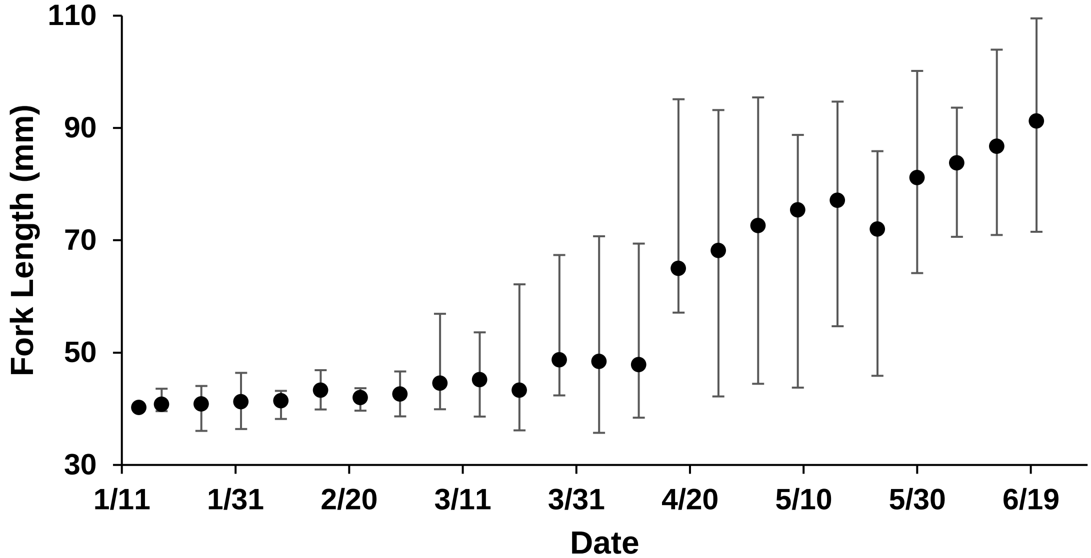

Figure 3. Fork length (mm) of subyearling Chinook migrants of natural origin captured in the Green River screw trap in 2016. Data are mean, minimum, and maximum values.

Table 4. Abundance of juvenile subyearling migrant Chinook salmon in the Green River. Abundance is partitioned into regions above the juvenile trap site, below the juvenile trap site within the Green River, and above Soos Creek hatchery rack. Note that the methods for estimating production from Big Soos Creek have changed over the years (see text of results for details)

Trap	Above Trap				Below Trap			Soos Crk			Total Green
Year	Redds	Deposition	Production	Survival	Redds	Deposition	Production	Females	Deposition	Production	Production
2000	1,835	8,257,500	475,207	5.75%	826	3,717,000	213,908	1,616	7,272,000	275,125	964,240
2001	1,425	6,412,500	809,616	12.63%	936	4,212,000	531,790	1,580	7,110,000		1,341,406
2002	2,167	9,751,500	584,151	5.99%	480	2,160,000	129,392	995	4,477,500		713,543
2003	2,324	10,458,000	449,956	4.30%	2,314	10,413,000	448,020	1,239	5,575,500		897,977
2004	1,793	8,068,500	236,650	2.93%	1,038	4,671,000	137,001	720	3,240,000		373,650
2005	2,738	12,321,000	470,334	3.82%	827	3,721,500	142,062	623	2,803,500		612,397
2006	966	4,347,000	99,796	2.30%	82	369,000	8,471	598	2,691,000		108,267
2007	1,792	8,064,000	127,491	1.58%	883	3,973,500	62,821	313	1,408,500		190,312
2008	1,486	6,687,000	400,763	5.99%	438	1,971,000	118,125	676	3,042,000		518,888
2009	2,107	9,481,500	196,115	2.07%	282	1,269,000	26,248	504	2,268,000		222,362
2010	218	981,000	55,547	5.66%	57	256,500	14,524	759	3,415,500		70,070
2011	706	3,177,000	254,182	8.00%	71	319,500	25,562	461	2,074,500		279,744
2012	333	1,498,500	90,260	6.02%	19	85,500	5,150	190	855,000		95,410
2013	1,127	5,071,500	492,737	9.72%	109	490,500	47,656	682	3,069,000	468,119	1,008,512
2014	774	3,483,000	396,623	11.39%	43	193,500	22,035	149	670,500	101,748	520,406
2015	1,008	4,536,000	396,944	8.75%	84	378,000	33,079	128	576,000	76,037	506,060
2016	1,570	7,065,000	57,214	0.81%	65	378,000	2,369	152	684,000	16,987	76,570

Smolt to adult return rate of Chinook Salmon

Estimating the survival from juvenile outmigration to return as adults will aid recovery efforts by providing information on population dynamics. SAR ranged 10-fold (0.14% and 1.5%) for brood years 2002 through 2011 (Table 7). Natural origin juveniles survived at a higher rate six out of eleven years than hatchery origin non-ad marked CWT juveniles released from Soos Creek Hatchery (Figure 4). As data accumulate in future years, we will continue to explore this pattern and the mechanisms the influence SAR rates for both hatchery and natural origin Chinook.

Table 5. Abundance (estimate, 95% confidence interval, coefficient of variation), fork length (average, standard deviation), and median migration date for natural-origin Chinook produced above the Green River juvenile trap, migration years 2000-2016.

	Abundance				Fork Length		Migration Timing
Migration Year	Estimate	Lower C.I.	Upper C.I.	CV	Average	St.Dev.	Median Date
2000	475,207	324,315	626,098	16.2	51.4	16.53	13-Mar
2001	809,616	641,195	978,038	10.61	45	12.32	16-May
2002	584,151	343,533	824,769	21.02	46.8	12.52	20-Apr
2003	449,956	265,175	634,738	20.98	47.1	12.41	10-Mar
2004	236,650	201,917	271,382	7.49	48.8	16.42	25-Mar
2005	470,334	410,369	530,300	6.5	52.7	18.11	8-Mar
2006	99,796	79,088	120,504	10.59	57.7	21.22	28-May
2007	127,491	107,242	147,740	8.1	69.9	23.47	5-Mar
2008	400,763	361,048	440,477	5.06	54.1	17.16	28-Mar
2009	196,118	171,529	220,706	6.4	54.7	17.49	2-Apr
2010	55,547	39,445	71,648	14.79	67.3	21.43	9-Jun
2011	254,182	225,327	283,037	5.79	51	13.29	2-Apr
2012	90,260	68,450	112,069	10.92	63.3	19.35	28-Apr
2013	492,737	420,077	565,397	6.28	48.1	14.41	21-Mar
2014	396,623	231,236	562,010	21.25	61.1	18.66	5-Mar
2015	396,944	290,947	502,941	13.60	45.4	14.60	7-Feb
2016	57,214	43,873	70,556	11.70	63.8	20.92	11-May

Table 6. Abundance of natural-origin fry and parr subyearling migrants of Green River Chinook, migration year 2000 to 2016.

	Fry Migrants			Parr Migrants		
Trap Year	Migration Interval	Abundance	% of Migration	Migration Interval	Abundance	% of Migration
2000	1/01-4/29	266,481	56.10%	3/11-7/31	208,726	43.90%
2001	1/01-5/20	379,174	46.80%	3/8-7/31	430,442	53.20%
2002	1/01-5/23	357,602	61.20%	3/3-7/31	226,550	38.80%
2003	1/01-5/27	413,358	91.90%	2/16-7/13	36,598	8.10%
2004	1/01-4/29	136,144	57.50%	3/21-7/31	100,506	42.50%
2005	1/01-4/26	391,274	83.20%	2/20-7/31	79,061	16.80%
2006	1/01-5/01	29,946	30.00%	2/18-7/31	69,850	70.00%
2007	1/01-5/07	88,439	69.40%	3/21-7/31	39,053	30.60%
2008	1/01-6/08	251,815	62.80%	3/15-7/31	148,948	37.20%
2009	1/01-5/13	119,406	60.90%	2/6-7/31	76,709	39.10%
2010	1/01-4/20	5,559	10.00%	2/11-7/31	49,988	90.00%
2011	1/01-6/12	128,472	50.50%	2/7-7/31	125,710	49.50%
2012	1/01-5/13	42,133	44.81%	2/27-7/31	48,127	55.19%
2013	1/23-6/2	357,952	72.45%	1/23-7/14	134,785	27.55%
2014	1/01-5/11	319,241	80.49%	2/3-7/31	77,382	19.51%
2015	1/01-5/3	383,580	96.63%	2/2-7/31	13,364	3.37%
2016	1/1-5/8	21,285	37.20%	1/31-7/31	35,929	62.80%

Table 7. Smolt to adult return (SAR) for adult Chinook in the Green River, brood years 2002-2011. Juvenile freshwater production and adult return estimates restricted to the area upstream from the smolt trap. Does not include age 2 (jack) returns.

Brood Year	Juvenile Freshwater Production	Age 3	Age 4	Age 5	Age 6	Total	Survival to return
2002	449,956	314	1,341	95	0	1,750	0.39%
2003	236,650	573	718	67	0	1,357	0.57%
2004	470,334	702	3,025	0	0	3,726	0.79%
2005	99,796	152	77	63	0	292	0.29%
2006	127,491	52	633	4	0	689	0.54%
2007	400,763	151	309	107	0	567	0.14%
2008	196,118	57	978	40	0	1,076	0.55%
2009	55,547	408	394	42	0	845	1.52%
2010	254,182	54	493	50	0	597	0.23%
2011	90,260	162	586	64	0	813	0.90%

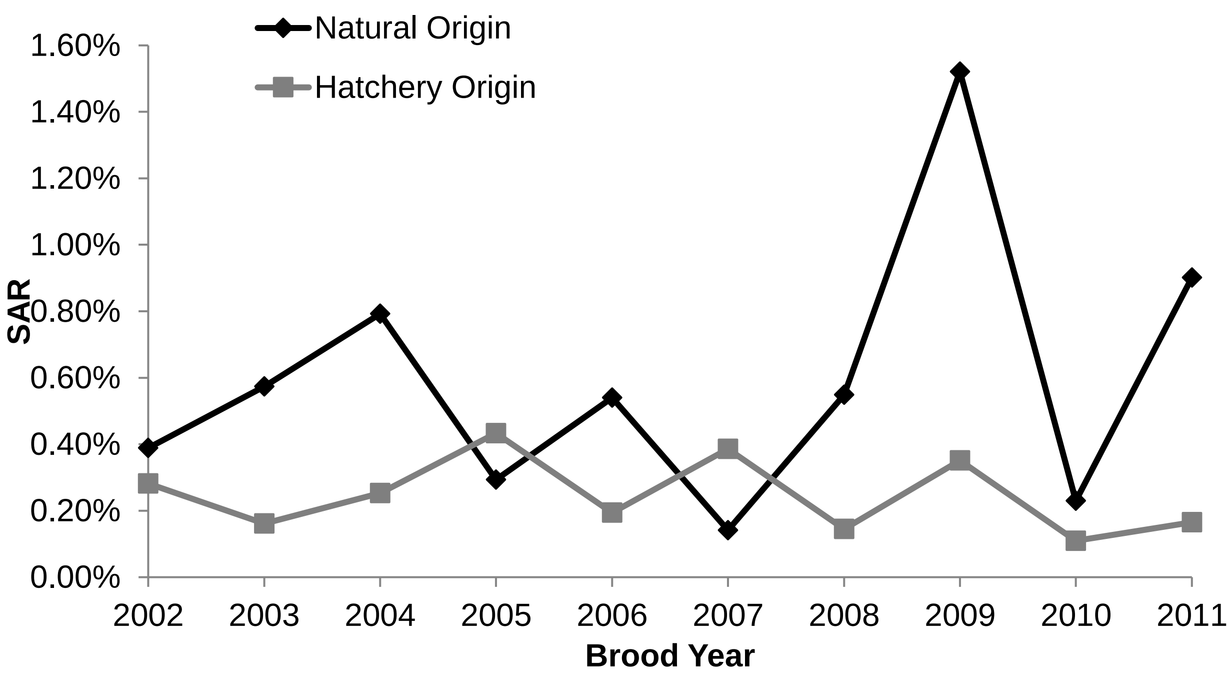

Figure 4. Smolt to adult return rate (SAR) of natural origin vs hatchery origin Chinook from the Green River, brood years 2002-2011. Does not include age 2 (jacks) returns or account for harvest.

Yearling Chinook

No natural-origin Chinook yearlings were captured. In total, 581 hatchery-origin yearling Chinook were captured (467 Ad-mark and 114 Ad-CWT).

Coho Smolts

The total estimated catch of natural-origin coho smolts ($\hat{u}$ =2,019) included 1,755 captures in the trap and an estimated missed catch during trap outage periods of 264 fish. Coho smolts were captured thru out the season with individuals captured on both the first and last days of the season. Table 8, Appendix D). In total, 5,374 hatchery coho were captured between January 19 and June 20 (5,179 Ad-mark and 195 Ad-CWT). Seventy one efficiency trials using natural origin coho were conducted over the trapping season. All efficiency trials were pooled to form a single strata with an efficiency of 3.19%.

We estimated a total of 62,074 ± 19,036 (95% C.I.) natural-origin coho smolts migrated past the screw trap (Table 8). Coefficient of variation for this estimate was 15.65%.

Table 8. Catch, marked and recaptured fish, and estimated abundance of natural-origin coho smolts at the Green River screw trap in 2016. Release groups were pooled to form a single strata. Missed catch and associated variance were calculated for periods that the trap did not fish.

		Catch					Abundance	
Strata	Date	Actual	Missed	Variance	Marked	Recaptured	Estimated	Variance
1	1/14-6/26	1,755	264	1.54E+04	1,444	46	62,074	9.43E+07

The median migration date for coho smolts was April 29. The first coho smolt was captured on January 14, our first day of trapping. Daily estimated migration of coho averaged 56 smolts per day through April 1 (Figure 5). Peak daily migration occurred on April 16 when 5,134 smolts were estimated to have passed the trap in a single night. Daily estimated migration declined gradually through May and early June. The last natural-origin coho smolt was captured on June 26, 2016.

The seasonal average length of coho smolts was 113.8 ± 11.4 mm FL (± 1 S.D.; Appendix E). The weekly averages were smaller early in the season averaging 103.2 mm thru early April and increasing abruptly to average 117 mm thru May and gradually decreasing in size through the remainder of the season (Figure 6).

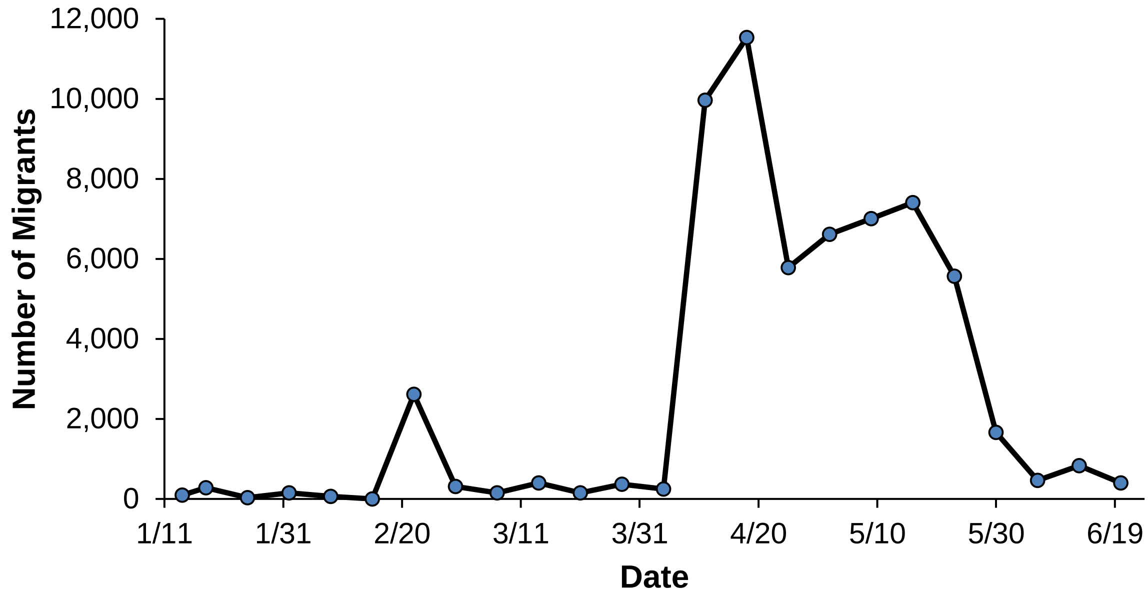

Figure 5. Weekly migration of natural-origin coho smolts rearing above the Green River screw trap in 2016.

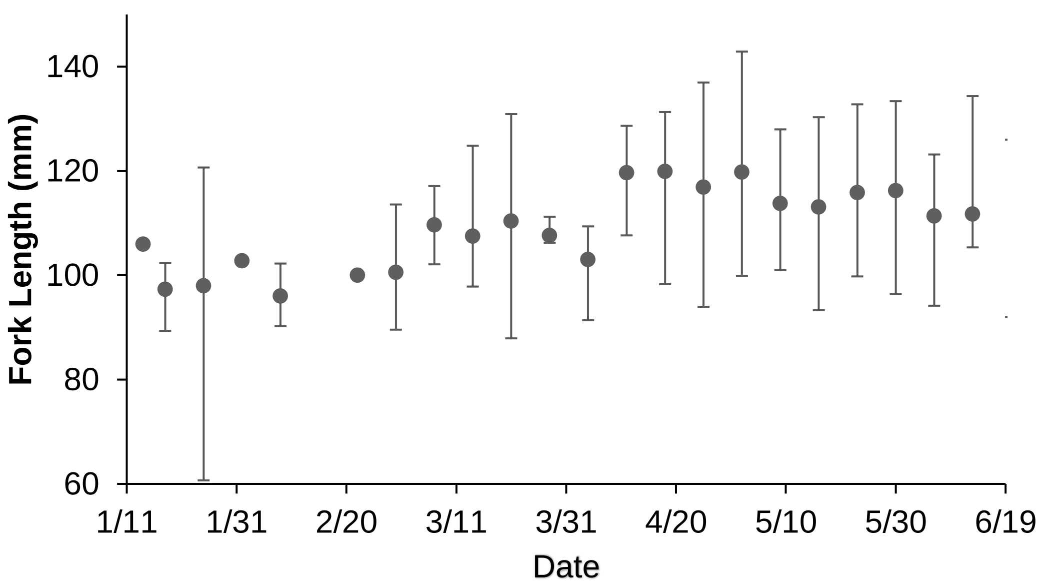

Figure 6. Fork lengths (mm) of natural-origin coho captured in the Green River screw trap in 2016. Data are mean, minimum, and maximum values by week.

Steelhead Smolts

The total estimated catch of natural-origin steelhead smolts ($\hat{u}$ = 552) included 541 captures in the trap and 11 missed catch estimated for trap outage periods (Table 9, Appendix D). In total, 306 CWT-only hatchery steelhead were captured between March 25 and June 9. Twenty-one trap efficiency trials using natural origin steelhead were conducted over the trapping season with 357 marks released and 5 recovered. We estimated a total of 32,936 ± 24,330(95% C.I.) natural-origin steelhead smolts migrated past the screw trap (Table 9). Coefficient of variation for this estimate was 37.69%.

Table 9. Catch, marked and recaptured fish, and estimated abundance of natural-origin steelhead smolts at the Green River screw trap in 2016. Release groups were pooled to form a single strata. Missed catch and associated variance were calculated for periods that the trap did not fish.

		Catch					Abundance	
Strata	Date	Actual	Missed	Variance	Marked	Recaptured	Estimated	Variance
1	1/14-6/26	541	11	1.14E+01	357	5	32,936	1.54E+08

The median migration date for steelhead smolts was May 18. The first natural-origin steelhead was captured on January 17. Daily estimated migration of steelhead averaged 31 smolts per day through April 1. Peak daily migration occurred on May 20 when 3,282 smolts were estimated to have passed the trap in a single night. Daily estimated migration declined gradually through May and early June. The last natural-origin steelhead smolt was captured on June 7, 2016.

Over the season, a total of 541 unmarked steelhead were measured (fork length), 100% of the total catch. Individuals ranged from 135 to 288 mm, and averaged 169.0 mm for the season (Figure 7).

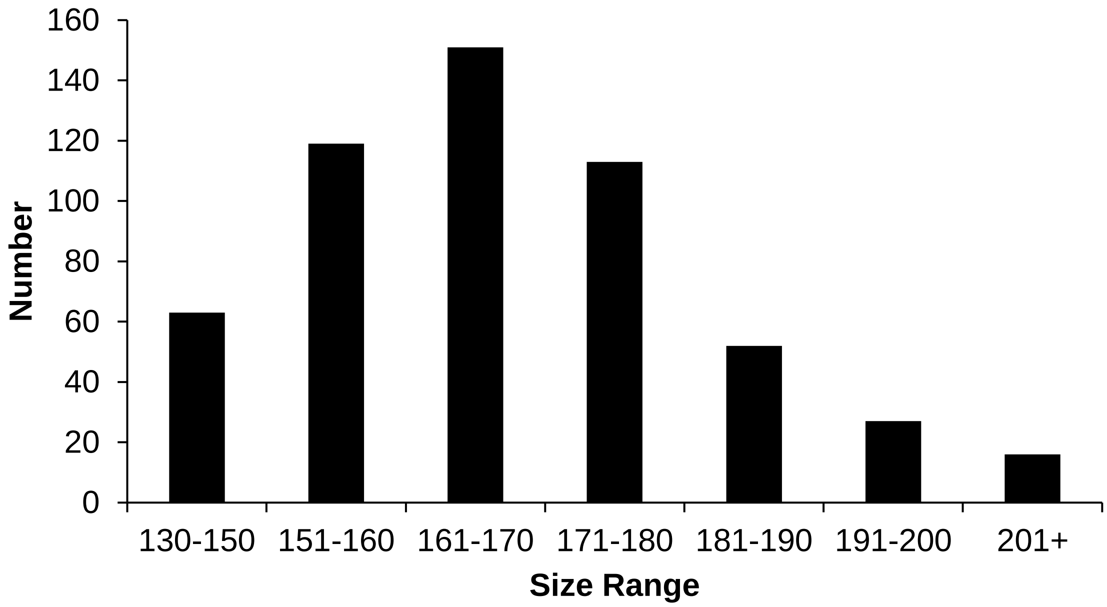

Figure 7. Length frequency of natural-origin steelhead fork length (mm) at the Green River screw trap in 2016.

Length samples were collected on 541 natural-origin steelhead smolts captured, scales and weights were collected on 538 individuals to determine the age structure and body size of natural-origin steelhead smolts. The sample included 444 readable and 94 regenerated or upside down samples (Table 10).

Table 10. Age, average length (mm) and average weight of natural-origin steelhead smolts collected at the Green River juvenile trap, migration years 2011-2016.

Smolt Age	1+			2+			3+			4+		
Year	Ave FL	%	Ave Wgt (g)	Ave FL	%	Ave Wgt (g)	Ave FL	%	Ave Wgt (g)	Ave FL	%	Ave Wgt (g)
2011	158.2	26%		180.1	67%		189.9	7%				
2012	158.6	53%		171.7	47%		206.5	1%				
2013	157	40%	39.8	177	59%	56.7	189	1%	78.8			
2014	161.4	61%	27.9	182.2	37%	41.2	211.1	1%	59.7	224	0%	101.3
2015	158.7	59%	40.1	185.8	38%	60.1	190	3%	78.5			
2016	164.6	37%	43.7	170.3	61%	49.8	188.1	2%	77.7	232.5	1%	124.4

Chum

The total estimated catch of unmarked chum fry ($\hat{u}$ =79,376) included 77,443 captures in the trap and 1,933 missed catch estimated for trap outage periods (Appendix D). Chum migrants were captured between January 30 and June 25, 2016. Captured chum could not be separated into natural and hatchery origin because chum released from Keta Creek hatchery were unmarked. No production estimate was calculated.

Pink

The total estimated catch of wild pink fry ($\hat{u}$ =153,366) included 152,259 captures in the trap and an estimated 1,107 missed catch during trap outage periods (Appendix D). Pink migrants were captured from the beginning of trapping until May 11, 2016. The daily migration steadily increased thru the early part of the season and peaked on the night of March 23 with over 359,884 fry estimated to have pasted the trap in a single night (Figure 8).

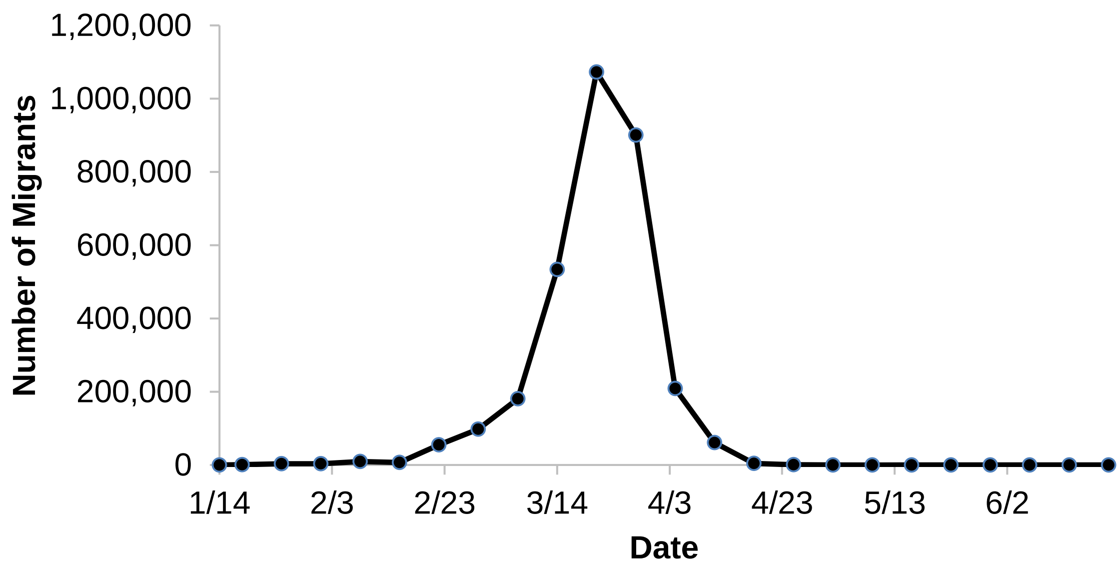

Figure 8. Weekly migration of pink fry originating from above the Green River screw trap in 2016. Data are number of juvenile migrants by week.

Thirteen trap efficiency trials were conducted using pink fry, which were subsequently pooled into two strata. We estimated a total of 3,137,795 ± 402,683 (95% C.I.) pink fry. Coefficient of variation for this estimate was 6.55%.

Other Species

In addition to species and age classes described above, catch during the trapping season included 79 coho fry, 236 trout parr, 29 cutthroat smolts and 2 cutthroat adults. (Appendix D). Non-salmonid species captured included Eulachon (*Thaleichthys pacificus*), sculpin (*Cottus* spp.), three-spine sticklebacks (*Gasterosteus aculeatus*), longnose dace (*Rhynichthys cataractae*), and lamprey ammocoetes.

Discussion and Synthesis

This report provides the freshwater production estimates for subyearling Chinook salmon coho salmon, and steelhead trout smolts emigrating from the Green River in 2016. No natural-origin yearling Chinook smolt were captured. In addition to abundance estimates, we provide summaries of body length, age, and outmigration timing that describe the duration of time that juvenile salmonids are using freshwater habitat for rearing.

Assumptions for Basin-Wide Chinook Estimate

The basin-wide estimate of Chinook freshwater production, including that from Soos Creek, relies on two assumptions. The first assumption is that the relative proportion of spawners estimated above and below the Green River juvenile trap is accurate. Redd surveys in 2015 were conducted on a weekly basis throughout the watershed and the relative number of redds observed above and below the trap was not likely to be biased by time or visibility. Therefore, the redd counts above and below the juvenile trap provide a reasonable approach for estimating juvenile production below the trap.

The second assumption is that egg-to-migrant survival of Chinook salmon is comparable above and below the juvenile trap. For estimation purposes, our calculation of egg-to-migrant survival is no different than juveniles per female because the same fecundity is applied to each female spawner. However, differences in watershed geomorphology, land use, spawner distribution and relative reproductive success of natural and hatchery-origin spawners add uncertainty to the assumption that freshwater productivity is comparable above and below the trap. The juvenile production estimated from the mainstream Green River below the trap was relatively small and represented 3% of the total production compared to that directly measured from the Green River and tributaries above the trap (75%) and Big Soos Creek (22%).

In previous years, to estimate production from Big Soos Creek, we had applied egg-to-migrant survival measured at the mainstem trap to the estimated egg deposition above the hatchery rack or assumed production from the creek was at carry capacity. However, starting in 2013 and continuing thru 2016, Big Soos Creek production was directly measured by the Muckleshoot Indian Tribe, substantially improving the quality of the basin-wide Chinook estimate.

Assumptions for Identification of Species and Origin

The estimate of natural-origin Chinook production assumes that juvenile fish were correctly identified to species and origin. Hatchery origin Chinook salmon are typically identified by the presence of an adipose-mark or coded-wire tag, and unmarked fish are assumed to be natural origin. However, in 2014 and continuing thru 2016, the primary hatchery mark strategy for the Palmer Pond release was an internal thermal otolith mark, with a goal of 100% marking. None of the 2014, 2015 or 2016 Palmer Pond releases were ad-marked; only in 2014 did a portion of the release receive CWT.

In 2016, the Palmer facility was not fish tight when the fish were transferred to the facility in late February and the juvenile trap began capturing Chinook that were escaping from the facility just days after planting. We attempted to identify the hatchery fish based on their larger size and rounder body shape. The difference in appearance is more pronounced early in the season before the natural origin chinook begin to grow and the hatchery fish have been fed and have grown. However, by mid-April the natural origin fish have begun to grow and the visual identification became less reliable. By the end of April, the number of fish identified by the trapping technicians as unmarked hatchery origin on a daily basis exceeded the number of natural migrants on a daily basis.

To check whether the visual identification was correct, in late April, we obtained an in-season modification to our ESA take permit to allow the deliberate sacrifice of 30 unmarked subyearling Chinook for otolith analysis. On the morning of June 10^{th}, N = 30 fish visually identified by the technicians as hatchery fish, were sacrificed. We deliberately sampled the largest fish, aiming to confirm our ability to visually identify hatchery fish. Otolith analysis identified three marked hatchery fish, an incidence of 10%. The fact that only 10% of the Chinook visually identified as hatchery fish were marked hatchery fish provided strong evidence that visual identification does not work, especially late in the season when the natural and hatchery origin fish are of similar size. In the future, if the Palmer Chinook are not externally marked (i.e., ad-marked or CWT), we plan to randomly sample over the entire period they are present upstream of the trap in Palmer Ponds for otolith analysis.

Freshwater Production of Chinook Salmon

The 2016 freshwater production estimate from above the trap location of unmarked subyearling Chinook was 57,214. As described above, this estimate includes an unknown number of hatchery-origin subyearling Chinook that escaped from Palmer Ponds as mentioned above. To explore the consequences of this issue on the production estimate, we applied the otolith sample results of 10% hatchery fish to the estimated catch of visually identified hatchery fish for the season (N = 2,189). Under this scenario, the estimated catch of hatchery fish would be reduced to N = 219 and the remainder (N = 1,970) assumed natural. Using this approach would estimate a natural production of 47,282 from above the trap.

However, the 30 fish were sampled for otoliths only on a single day (June 10) and not randomly selected over the entire period that hatchery Chinook were held at Palmer Ponds. Thus, we felt that the sample results did not accurately represent the true percentage of hatchery fish in our catch. For these reasons, we decided to include all non-externally marked fish in our production estimate, and acknowledge that our estimate of natural origin Chinook abundance is likely biased high. Even with some hatchery fish likely included the 2016 production estimate, 57,214 is the second lowest unmarked sub-yearling production estimate over all 17 years of this project (range = 56,000 to

810,000, Table4). Thus, regardless of the assumptions surrounding non-externally marked hatchery fish, 2016 yielded an exceedingly low abundance of juvenile Chinook salmon.

A downward trend in freshwater production is at least partly explained by a downward trend in Chinook escapement (Figure 9). However, we speculate that the reason behind poor production in 2016 can be explained by the multiple high water events during the egg incubation period. The freshwater productivity (0.81% egg-to-migrant survival and 36 juveniles/female) was the lowest observed over seventeen years of study. Furthermore, results from the three years of the GMR study showed that the GMR method of estimating adult spawner abundance above the trap site is 2,500 fish higher than the redd based estimate (Seamons 2012). If the GMR estimates are correct this would reduce the egg to migrant survival and production per female estimates compared to the redd based estimates.

Parr migrants were approximately 62.8% of the freshwater production above the Green River trap, which is among the highest observed, however the actual number of migrants was the second lowest. (Table 6). Parr production, which represents fish that have spent some time rearing in freshwater above the Green River trap, has ranged 32-fold (13,364 to 430,000 parr) over seventeen years of study. In comparison, fry production, which represents juveniles emigrating from freshwater soon after emergence, has ranged 74-fold (6,000 to 413,000 fry). Thus, there is much greater fluctuation in fry abundance than parr abundance.

Yearling Chinook migrants appear to be a minor component of the outmigration and in some years undetectable with use of a partial capture screw trap that failed to catch a single nature origin yearling. Our trap did encounter yearling hatchery-origin Chinook salmon, so the lack of natural-origin yearling Chinook salmon was not due to the inability of the fishing gear to capture them.

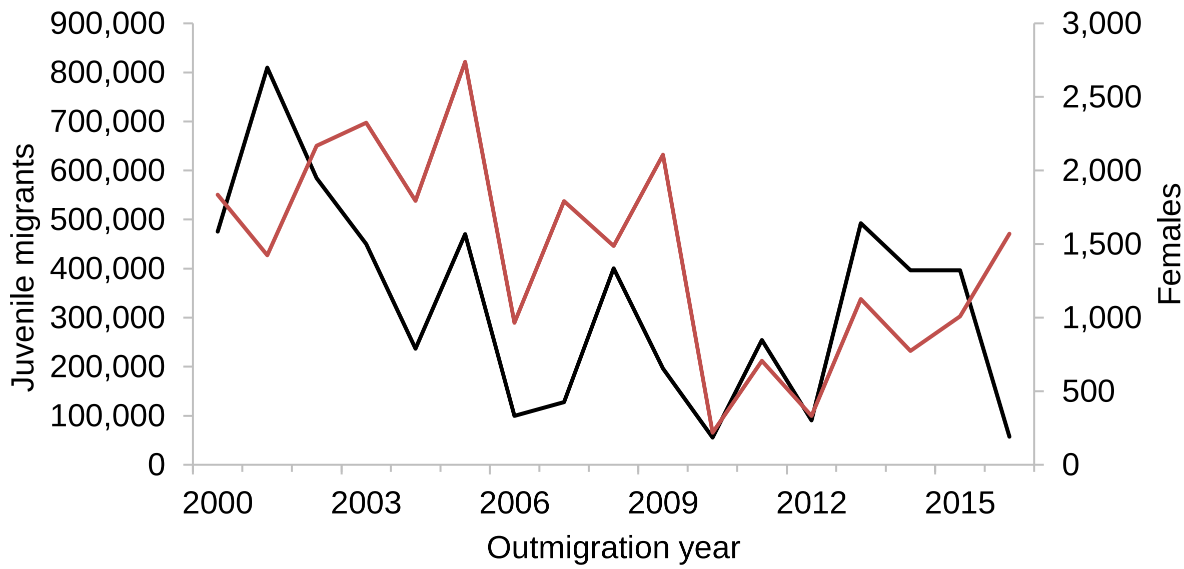

Figure 9. Number of subyearling Chinook migrants (black line) passing the Green River juvenile trap and the corresponding number of female spawners (Red line) above the juvenile trap, outmigration year 2000-2016.

Freshwater Production of Coho

Freshwater production of coho smolts above the Green River trap has been estimated for 14 of the 17 years of this study (Table 11). The 2016 freshwater production estimate of 62,074 coho smolts is similar to the average observed over the last 8 consecutive years we have estimated natural coho smolt productions (62,114).

The quality of the coho smolt estimates have varied widely among years and trends in these data should be interpreted with caution. In the first two years of the study (2000 and 2001), coho estimates were based on just one or two trap efficiency tests with hatchery fish and no associated variance was calculated. No estimates were generated for trapping years 2004 and 2005 because a large percentage of the coho released from the Keta Creek Hatchery (above the trap site) were unmarked, making positive identification of the natural-origin coho smolts impossible. In trapping year 2008, an abundance estimate was not made because recapture rates were so low that no reliable coho efficiency data were available.

Estimating the freshwater production of species with yearling migrants (i.e., coho and steelhead) has proven to be more challenging than for species with subyearling migrants (i.e., Chinook and pink). In general, larger body size of yearling migrants compared to subyearling migrants increases swimming strength and ability to avoid the trap. Slow water velocity at the trap location tends to reduce trap efficiency for yearling smolts, resulting in few recaptures of marked coho and steelhead smolts and low precision in our abundance estimates. The degree to which water velocity has limited catch has varied by year depending on the channel configuration above the trap. Over the last eight consecutive years we have been able to estimate coho production mainly because of the stability and consistency of the river channel at our trapping location. This location has provided a well-defined slot with good water velocities enabling the trap to capture enough coho smolts to generate these estimates.

A second challenge associated with estimating abundance for coho and steelhead smolts is the release of hatchery fish above the trap. The release timing of the hatchery fish typically coincides with the peak migration period for the natural-origin smolts of the same species. As a result, missed catch estimated during this period is high, as is the corresponding uncertainty (variance) of this catch. Hatchery yearling smolts (Chinook, coho, and steelhead) have a tendency to migrate downstream in large groups resulting in large catches that can overwhelm the live box of the juvenile trap. In order to accommodate for these catches, the trap is either completely lifted from the water (i.e., not fished) or is operated intermittently during the hatchery migration. Any periods of trap outages due to inundation by hatchery fish requires an estimate of missed catch, which increases the variance and reduces the precision of the annual abundance estimate. Catch of natural-origin smolts often increases during the hatchery fish migration, perhaps because the natural-origin fish are following the hatchery fish out of the system. This can result in high numbers of missed catch of coho and steelhead estimated during the outage period. This was the case for coho in 2016, as 13% of the total catch was estimated missed catch but not for the steelhead, as missed catch accounted for only 2% of the total natural origin steelhead catch. Virtually all of the estimated missed catch for coho occurred during the outages corresponding to hatchery fish release.

Table 11. Abundance (estimate, 95% confidence interval, coefficient of variation), fork length (average, standard deviation), and median catch or migration date for natural-origin coho smolts rearing above the Green River juvenile trap, migration years 2000-2016.

	Abundance				Fork Length		Migration Timing
Migration Year	Estimate	Lower C.I.	Upper C.I.	CV	Average	St.Dev.	Median Date
2000	32,769	---	---	---	115.1	20.37	5/11[a]
2001	55,113	---	---	---	114.3	13.68	5/16 [a]
2002	194,393	129,500	259,286	17.00%	99.5	12.76	5/12 [a]
2003	207,442	67,404	347,480	34.40%	104.3	12.4	5/1[b]
2004	---	---	---	---	105.8	12.3	5/8 [a]
2005	---	---	---	---	106.8	14.93	5/4 [a]
2006	31,460	21,143	41,777	16.70%	106.9	16	5/15
2007	22,671	14,735	30,607	17.90%	111.6	11.34	5/7
2008	---	---	---	---	105.1	11.95	5/9 [a]
2009	81,079	56,522	105,636	11.90%	103	10.9	5/5
2010	43,763	32,663	54,864	12.90%	115.9	11.21	5/8
2011	62,280	25,495	99,065	30.10%	109.4	11.4	5/7
2012	48,148	24,669	71,627	24.90%	106.1	12.68	5/7
2013	50,642	30,000	71,284	20.80%	103.5	16.75	5/9
2014	106,365	82,645	130,084	11.38%	104	13.13	5/11
2015	42,564	19,108	66,020	28.12%	104.9	11.76	5/2
2016	62,074	43,038	81,109	15.65%	113.8	113.76	4/29

a Median catch date.

b Abundance estimate includes an estimated 51,183 unmarked hatchery coho.

Freshwater Production of Steelhead

The abundance of steelhead smolts rearing above the Green River trap has been estimated for only 5 of the 17 years of this study (Table 12).

In 2016, steelhead smolts captured in the trap were similar in length and age as we observed in 2011 and 2012. In 2013, we began collecting weight measurements in addition to the scale and length samples to get a measure of the relative condition and fitness of the migrants. The percentage of age-1 smolts in 2012 and 2014 was higher than observed in either 2011 or 2013 and higher than would be expected based on typical 2-year smolt age for winter steelhead in western Washington rivers (Scott and Gill 2008). It is possible that this difference in age structure resulted from the two year cycle in which Green River pink salmon are extremely abundant in odd years but absent in even years. In 2012 and 2014, smolts had access to millions of pink salmon eggs the previous fall and millions of juvenile pink salmon fry in the spring immediately prior to downstream migration. Faster growth rates are associated with younger age at smolting (Beakes et al. 2010), and so it seems plausible that the food subsidy provided by pink salmon increased the proportion of age-1 smolts in 2012 and 2014. However, this trend did not hold true in 2016 with only 37% smolting at age-1, which was less than both 2013 (40%) and 2015 (59%). In 2016, the age structure of the steelhead smolts was more similar to odd (no pink salmon) years, with 61% migrating as age-2 smolts (Table 10).

Table 12. Abundance (estimate, 95% confidence interval, coefficient of variation), fork length (average, standard deviation), and median catch or migration date for natural-origin steelhead smolts rearing above the Green River juvenile trap, migration years 2000-2016.

	Abundance				Fork Length		Timing
Migration Year	Estimate	Lower C.I.	Upper C.I.	CV	Average	St.Dev.	Median Date
2000	---	---	---	---	171.5	29.12	5/12[a]
2001	---	---	---	---	176.6	20.2	5/17 [a]
2002	---	---	---	---	167.1	19.03	5/19 [a]
2003	---	---	---	---	173.8	20.44	4/19 [a]
2004	---	---	---	---	148.2	24.33	2/06 [a]
2005	---	---	---	---	153.3	19.05	1/25 [a]
2006	---	---	---	---	151.1	25.93	5/05 [a]
2007	---	---	---	---	157.1	19.8	4/29
2008	---	---	---	---	163.8	23.64	5/15 [a]
2009	26,174	10,151	42,198	19.40%	171.4	20.3	5/11
2010	71,710	49,317	94,103	15.90%	178.7	22.87	5/16
2011	---	---	---	---	175.1	18.4	5/08[a]
2012	---	---	---	---	166.1	17.9	5/16 [a]
2013	15,339	6,692	23,987	28.76%	169.1	17.73	5/11
2014	31,638	21,901	41,376	15.70%	171.2	18.3	5/5
2015					168.7	19.00	5/08[a]
2016	32,936	8,606	57,266	37.69%	169.0	16.63	5/18

a Median catch date

Appendix A

Variance of total unmarked smolt numbers, when the number of unmarked juvenile out-migrants, is estimated.

Author: Kristen Ryding, WDFW Biometrician

APPENDIX A.—Variance of total unmarked smolt numbers, when the number of unmarked juvenile out-migrants, is estimated.

The estimator for $\hat{U}_i$ is,

$$\hat{U}_i = \frac{\hat{u}_i\left(M_i+1\right)}{\left(m_i+1\right)}$$

the estimated variance of $\hat{U}_i$, $Var\left(U_i\right)$ is as follows,

$$Var\left(\hat{U}_i\right) = Var\left(\hat{u}_i\right)\left(\frac{\left(M_i+1\right)\left(M_i m_i+3M_i+2\right)}{\left(m_i+1\right)^2\left(m_i+2\right)}\right) + Var\left(\hat{U}_i\left|E\left(\hat{u}\right)\right.\right)$$

where $Var\left(\hat{U}_i\left|E\left(\hat{u}\right)\right.\right) = \dfrac{\left(M_i+1\right)\left(M_i-m_i\right)E\left(\hat{u}_i\right)\left(E\left(\hat{u}_i\right)+m_i+1\right)}{\left(m_i+1\right)^2\left(m_i+2\right)}$,

$E\left(\hat{u}_i\right)$ = the expected value of $\hat{u}_i$ either in terms of the estimator (equation for $\hat{u}_i$) or just substitute in the estimated value and, $Var\left(\hat{u}_i\right)$ depends on the sampling method used to estimate $\hat{u}_i$.

Derivation:

Ignoring the subscript i for simplicity, the derivation of the variance estimator is based on the following unconditional variance expression,

$$Var\left(\hat{U}\right) = Var\left(E\left(\hat{U}\left|u\right.\right)\right) + E\left(Var\left(\hat{U}\left|u\right.\right)\right).$$

The expected value and variance $\hat{U}$ given u is as before, respectively,

$$E\left(\hat{U}_i\left|u\right.\right) = \frac{u_i\left(M_i+1\right)}{\left(m_i+1\right)} \text{ and,}$$

$$Var\left(\hat{U}\left|u\right.\right) = \frac{u\left(u+m+1\right)\left(M+1\right)\left(M-m\right)}{\left(m+1\right)^2\left(m+2\right)}.$$

Substituting in $\hat{u}$ for u gives the following,

$$Var\left(\hat{U}\right) = Var\left(\frac{\hat{u}\left(M+1\right)}{\left(m+1\right)}\right) + E\left[\frac{\left(M+1\right)\left(M-m\right)\hat{u}\left(\hat{u}+m+1\right)}{\left(m+1\right)^2\left(m+2\right)}\right]$$

$$Var\left(\hat{U}\right) = \left(\frac{\left(M+1\right)}{\left(m+1\right)}\right)^2 Var\left(\hat{u}\right) + \frac{\left(M+1\right)\left(M-m\right)}{\left(m+1\right)^2\left(m+2\right)}\left[E\left(\hat{u}^2\right)+E\left(\hat{u}\right)\left(m+1\right)\right]$$

Note that,

$$E\left(\hat{u}^2\right) = Var\left(\hat{u}\right) + \left(E\hat{u}\right)^2$$

Substituting in this value for $E\left(\hat{u}^2\right)$,

$$Var\left(\hat{U}\right)=\left(\frac{(M+1)}{(m+1)}\right)^2 Var(\hat{u})+\frac{(M+1)(M-m)}{(m+1)^2(m+2)}\left[Var(\hat{u})+\left(E(\hat{u})\right)^2+E(\hat{u})(m+1)\right]$$

$$=\left(\frac{(M+1)}{(m+1)}\right)^2 Var(\hat{u})+\frac{(M+1)(M-m)}{(m+1)^2(m+2)}\left[Var(\hat{u})+E(\hat{u})\left[E(\hat{u})+m+1\right]\right]$$

$$Var\left(\hat{U}\right)=\left(\frac{(M+1)}{(m+1)}\right)^2 Var(\hat{u})+\frac{(M+1)(M-m)}{(m+1)^2(m+2)}Var(\hat{u})+\frac{(M+1)(M-m)E(\hat{u})\left[E(\hat{u})+m+1\right]}{(m+1)^2(m+2)}$$

$$Var\left(\hat{U}\right)=Var(\hat{u})\left(\frac{(M+1)^2}{(m+1)^2}+\frac{(M+1)(M-m)}{(m+1)^2(m+2)}\right)+\frac{(M+1)(M-m)E(\hat{u})\left[E(\hat{u})+m+1\right]}{(m+1)^2(m+2)}$$

$$Var\left(\hat{U}\right)=Var(\hat{u})\left(\frac{(M+1)^2}{(m+1)^2}+\frac{(M+1)(M-m)}{(m+1)^2(m+2)}\right)+Var\left(\hat{U}\middle|E(\hat{u})\right)$$

$$Var\left(\hat{U}\right)=\frac{(M+1)}{(m+1)^2}Var(\hat{u})\left(\frac{(M+1)(m+2)}{(m+2)}+\frac{(M-m)}{(m+2)}\right)+Var\left(\hat{U}\middle|E(\hat{u})\right)$$

$$Var\left(\hat{U}\right)=\frac{(M+1)}{(m+1)^2}Var(\hat{u})\left(\frac{Mm+2M+m+2+M-m}{(m+2)}\right)+Var\left(\hat{U}\middle|E(\hat{u})\right)$$

$$Var\left(\hat{U}\right)=Var(\hat{u})\left(\frac{(M+1)(Mm+3M+2)}{(m+1)^2(m+2)}\right)+Var\left(\hat{U}\middle|E(\hat{u})\right)$$

Appendix B

Daily catch and migration estimate for natural-origin, subyearling Chinook in the Green River, 2016.

APPENDIX B. ─Actual and estimated daily catches and migration for unmarked subyearling Chinook migrants in the Green River, 2016. Migration estimate is based on daily catch adjusted by the trap efficiency for each pooled time stratum.

Date	Time Fished Hours In	Time Fished Hours Out	Unmarked Sub-yearling Chinook Catch Actual	Estimated	Total	Migration
1/1-1/13	Pre-Trapping					624
1/14/2016	27.00		7	0	7	240
1/15/2016	24.00		0	0	0	0
1/16/2016	24.00		1	0	1	34
1/17/2016	24.00		1	0	1	34
1/18/2016	24.00		5	0	5	171
1/19/2016	24.00		0	0	0	0
1/20/2016	24.00		6	0	6	206
1/21/2016	24.00		1	0	1	34
1/22/2016	24.00		2	0	2	69
1/23/2016	24.50		12	0	12	411
1/24/2016	24.00		9	0	9	308
1/25/2016	24.00		3	0	3	103
1/26/2016	24.00		2	0	2	69
1/27/2016	24.00		5	0	5	171
1/28/2016	24.00		27	0	27	925
1/29/2016	26.50		8	0	8	274
1/30/2016	21.50		14	0	14	480
1/31/2016	24.00		10	0	10	343
2/1/2016	24.00		15	0	15	514
2/2/2016	24.00		10	0	10	343
2/3/2016	24.00		7	0	7	240
2/4/2016	24.00		5	0	5	171
2/5/2016	24.00		8	0	8	274
2/6/2016	24.00		9	0	9	308
2/7/2016	24.00		3	0	3	103
2/8/2016	24.00		10	0	10	343
2/9/2016	23.50		12	0	12	411
2/10/2016	24.50		26	0	26	891
2/11/2016	24.50		1	0	1	34
2/12/2016	24.00		8	0	8	274
2/13/2016	24.00		24	0	24	822
2/14/2016	24.00		4	0	4	137
2/15/2016	16.50	7.50	4	3	7	240

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APPENDIX B.─ continued.

	Time Fished		Unmarked Sub-yearling			
	Hours		Chinook Catch			
Date	In	Out	Actual	Estimated	Total	Migration
2/16/2016		24.00	0	10	10	343
2/17/2016		24.00	0	10	10	343
2/18/2016		24.00	0	10	10	343
2/19/2016		24.00	0	10	10	343
2/20/2016	9.00	15.00	3	6	9	308
2/21/2016	24.00		14	0	14	480
2/22/2016	24.00		9	0	9	308
2/23/2016	24.00		7	0	7	240
2/24/2016	24.00		4	0	4	137
2/25/2016	24.00		2	0	2	69
2/26/2016	24.00		2	0	2	69
2/27/2016	24.50		7	0	7	240
2/28/2016	24.00		3	0	3	103
2/29/2016	24.00		7	0	7	240
3/1/2016	24.00		9	0	9	308
3/2/2016	24.00		8	0	8	274
3/3/2016	24.50		10	0	10	343
3/4/2016	24.00		7	0	7	240
3/5/2016	24.00		5	0	5	171
3/6/2016	24.00		3	0	3	103
3/7/2016	24.00		10	0	10	343
3/8/2016	24.00		11	0	11	377
3/9/2016	24.00		6	0	6	206
3/10/2016	24.00		12	0	12	411
3/11/2016	24.00		1	0	1	34
3/12/2016	24.00		14	0	14	480
3/13/2016	24.50		13	0	13	445
3/14/2016	24.00		15	0	15	514
3/15/2016	24.50		9	0	9	308
3/16/2016	24.00		5	0	5	171
3/17/2016	24.00		15	0	15	514
3/18/2016	24.00		7	0	7	240
3/19/2016	23.50		1	0	1	34
3/20/2016	24.50		3	0	3	103
3/21/2016	24.00		21	0	21	720
3/22/2016	24.00		4	0	4	137

Table continued next page

APPENDIX B.─ continued.

Date	Time Fished Hours In	Out	Unmarked Sub-yearling Chinook Catch Actual	Estimated	Total	Migration
3/23/2016	24.00		7	0	7	240
3/24/2016	24.00		6	0	6	206
3/25/2016	24.00		17	0	17	583
3/26/2016	24.00		5	0	5	171
3/27/2016	24.00		4	0	4	137
3/28/2016	24.00		8	0	8	274
3/29/2016	24.00		4	0	4	137
3/30/2016	24.00		7	0	7	240
3/31/2016	24.00		8	0	8	274
4/1/2016	24.00		7	0	7	240
4/2/2016	24.00		10	0	10	343
4/3/2016	24.00		4	0	4	137
4/4/2016	24.00		2	0	2	69
4/5/2016	24.00		11	0	11	377
4/6/2016	24.00		6	0	6	206
4/7/2016	24.00		0	0	0	0
4/8/2016		24.00	0	4	4	137
4/9/2016		24.00	0	4	4	137
4/10/2016	24.00		5	0	5	171
4/11/2016	24.00		2	0	2	69
4/12/2016	24.00		2	0	2	69
4/13/2016	24.00		8	0	8	274
4/14/2016	24.00		5	0	5	171
4/15/2016	22.00		5	0	5	171
4/16/2016	14.00	14.00	0	3	3	103
4/17/2016	12.50	9.50	0	1	1	34
4/18/2016	24.50		5	0	5	171
4/19/2016	23.50		5	0	5	171
4/20/2016	24.00		5	0	5	171
4/21/2016	25.00		2	0	2	69
4/22/2016	24.00		6	0	6	206
4/23/2016	23.50		9	0	9	308
4/24/2016	24.00		15	0	15	514
4/25/2016	24.00		25	0	25	257
4/26/2016	23.50		17	0	17	175
4/27/2016	24.50		8	0	8	82

Table continued next page

APPENDIX B.─ continued.

Date	Time Fished Hours In	Out	Unmarked Sub-yearling Chinook Catch Actual	Estimated	Total	Migration
4/28/2016	24.00		10	0	10	103
4/29/2016	24.00		14	0	14	144
4/30/2016	24.00		36	0	36	371
5/1/2016	12.00	11.50	3	3	6	62
5/2/2016	12.50	12.00	2	3	5	51
5/3/2016	24.00		4	0	4	41
5/4/2016	24.00		3	0	3	31
5/5/2016	24.00		1	0	1	10
5/6/2016	24.00		11	0	11	113
5/7/2016	12.00	12.00	8	5	13	134
5/8/2016	24.00		15	0	15	154
5/9/2016	24.00		26	0	26	268
5/10/2016	15.50	8.50	31	1	32	329
5/11/2016	12.50	12.00	8	2	10	103
5/12/2016	14.00	10.00	9	2	11	113
5/13/2016	24.00		13	0	13	134
5/14/2016	24.00		15	0	15	154
5/15/2016	24.00		10	0	10	103
5/16/2016	24.00		46	0	46	474
5/17/2016	12.00	12.00	25	1	26	268
5/18/2016	11.50	12.50	32	1	33	340
5/19/2016	24.00		15	0	15	154
5/20/2016	11.50	12.50	56	1	57	587
5/21/2016	24.00		11	0	11	113
5/22/2016	24.00		14	0	14	144
5/23/2016	24.00		73	0	73	455
5/24/2016	24.00		87	0	87	542
5/25/2016	24.00		115	0	115	717
5/26/2016	24.00		46	0	46	287
5/27/2016	24.00		30	0	30	187
5/28/2016	24.50		40	0	40	249
5/29/2016	23.50		38	0	38	237
5/30/2016	10.50	13.50	37	0	37	444
5/31/2016	11.00	13.00	40	0	40	480
6/1/2016	12.00	12.00	19	0	19	228
6/2/2016	24.00		17	0	17	204

Table continued next page

APPENDIX B.─ continued.

Date	Time Fished Hours In	Out	Unmarked Sub-yearling Chinook Catch Actual	Estimated	Total	Migration
6/3/2016	12.00	12.00	45	4	49	588
6/4/2016	11.00	13.50	53	4	57	685
6/5/2016	10.00	14.00	37	4	41	492
6/6/2016	11.00	13.00	33	4	37	444
6/7/2016	11.00	13.00	44	4	48	576
6/8/2016	11.50	12.50	68	4	72	865
6/9/2016	11.50	12.50	50	4	54	649
6/10/2016	24.00		110	0	110	1,321
6/11/2016	10.50	13.50	13	5	18	216
6/12/2016	10.50	13.50	123	5	128	1,537
6/13/2016	24.00		85	0	85	1,021
6/14/2016	24.00		77	0	77	925
6/15/2016	24.00		124	0	124	1,489
6/16/2016	11.00	12.50	24	16	40	480
6/17/2016	24.50		28	0	28	336
6/18/2016	10.00	14.00	48	1	49	588
6/19/2016	10.50	13.50	55	0	55	661
6/20/2016	10.50	13.50	10	0	10	120
6/21/2016	24.00		12	0	12	144
6/22/2016	13.00	11.00	20	0	20	240
6/23/2016	10.50	13.50	28	0	28	336
6/24/2016	23.50		26	0	26	312
6/25/2016	11.50	14.00	55	0	55	661
6/26/2016	9.75		34	0	34	408
6/27-7/31	Post- Trapping					6,852
Total	3,413.25	541.00	2898	135	3,033	57,214

Appendix C

Fork length of natural-origin, subyearling Chinook in the Green River, 2016

APPENDIX C.─ Weekly mean fork length (mm), standard deviation (St. Dev.) range, and sample size of natural-origin subyearling Chinook caught in the Green River screw trap in 2016.

Week				Range		Number		Percent
Begin	End	Average	St.Dev.	Min	Max	Sampled	Caught	Sampled
1/14/2016	1/17/2016	40.22	1.30	39	43	9	9	100.00%
1/18/2016	1/24/2016	40.80	2.08	36	44	15	35	42.86%
1/25/2016	1/31/2016	40.86	2.42	36	46	22	69	31.88%
2/1/2016	2/7/2016	41.26	1.45	38	43	19	57	33.33%
2/8/2016	2/14/2016	41.45	2.04	38	45	22	85	25.88%
2/15/2016	2/21/2016	43.33	1.51	41	45	6	21	28.57%
2/22/2016	2/28/2016	42.00	2.25	38	46	16	34	47.06%
2/29/2016	3/6/2016	42.65	3.46	38	55	23	49	46.94%
3/7/2016	3/13/2016	44.57	4.30	38	53	28	67	41.79%
3/14/2016	3/20/2016	45.19	6.42	38	64	27	55	49.09%
3/21/2016	3/27/2016	43.35	5.45	37	62	23	64	35.94%
3/28/2016	4/3/2016	48.73	10.93	36	71	30	48	62.50%
4/4/2016	4/10/2016	48.45	12.83	39	70	11	24	45.83%
4/11/2016	4/17/2016	47.88	12.84	40	78	8	22	36.36%
4/18/2016	4/24/2016	65.00	13.94	39	90	34	47	72.34%
4/25/2016	5/1/2016	68.20	11.55	40	91	55	113	48.67%
5/2/2016	5/8/2016	72.65	10.99	41	86	23	44	52.27%
5/9/2016	5/15/2016	75.42	12.92	53	93	26	112	23.21%
5/16/2016	5/22/2016	77.13	14.75	51	91	16	199	8.04%
5/23/2016	5/29/2016	72.00	10.14	55	91	20	429	4.66%
5/30/2016	6/5/2016	81.17	9.79	68	91	6	248	2.42%
6/6/2016	6/12/2016	83.79	9.87	68	101	19	441	4.31%
6/13/2016	6/19/2016	86.74	9.68	67	105	81	441	18.37%
6/20/2016	6/26/2016	91.26	6.77	74	103	61	185	32.97%
Season Total		63.77	20.92	36	105	600	2,898	20.70%

Appendix D

Daily estimated catch of coho, chum and pink salmon, steelhead and cutthroat trout in the Green River, 2016

APPENDIX D.─ Daily estimated catches of coho, chum and pink salmon and steelhead and cutthroat trout caught in the Green River screw trap in 2016. Catch represents actual and estimated catch for a given day. Time in and out reflect time fished (in) and not fished (out) on a given day.

			Coho			Chum	Pink	Steelhead		Cutthroat	Trout
Date	Times		Smolts		Fry	Fry	Fry	Smolts		Smolt	Parr
	In	Out	Nat	Hat	Total	Total	Nat	Nat	Hat	Nat	Nat
1/14/2016	27.00	0.00	1	0	0	0	0	0	0	0	1
1/15/2016	24.00	0.00	2	0	0	0	1	0	0	0	2
1/16/2016	24.00	0.00	0	0	0	0	7	0	0	0	2
1/17/2016	24.00	0.00	0	0	0	0	2	1	0	0	1
1/18/2016	24.00	0.00	2	0	0	0	12	0	0	1	1
1/19/2016	24.00	0.00	0	1	0	0	3	0	0	0	3
1/20/2016	24.00	0.00	0	0	0	0	4	0	0	0	1
1/21/2016	24.00	0.00	0	0	0	0	8	0	0	0	0
1/22/2016	24.00	0.00	5	0	0	0	6	1	0	0	3
1/23/2016	24.50	0.00	0	1	0	0	19	0	0	0	4
1/24/2016	24.00	0.00	2	0	0	0	21	0	0	0	1
1/25/2016	24.00	0.00	0	0	0	0	8	2	0	1	0
1/26/2016	24.00	0.00	1	0	0	0	18	0	0	0	0
1/27/2016	24.00	0.00	0	0	0	0	12	0	0	0	1
1/28/2016	24.00	0.00	0	0	0	0	36	0	0	0	0
1/29/2016	26.50	0.00	0	0	0	0	29	0	0	0	0
1/30/2016	21.50	0.00	0	0	0	1	78	0	0	0	1
1/31/2016	24.00	0.00	0	0	1	1	65	1	0	0	1
2/1/2016	24.00	0.00	0	0	1	0	61	0	0	0	0
2/2/2016	24.00	0.00	0	0	0	2	51	0	0	0	3
2/3/2016	24.00	0.00	1	0	0	0	33	0	0	0	0
2/4/2016	24.00	0.00	3	0	0	1	23	0	0	0	0
2/5/2016	24.00	0.00	0	0	0	0	25	0	0	0	0
2/6/2016	24.00	0.00	0	0	0	0	31	0	0	0	0
2/7/2016	24.00	0.00	1	0	0	4	78	0	0	0	1
2/8/2016	24.00	0.00	1	0	1	0	68	0	0	1	3
2/9/2016	23.50	0.00	1	0	0	2	77	0	0	0	0
2/10/2016	24.50	0.00	0	0	0	16	208	0	0	0	1
2/11/2016	24.50	0.00	0	0	0	5	39	0	0	1	3
2/12/2016	24.00	0.00	0	0	0	9	60	0	0	0	0
2/13/2016	24.00	0.00	0	10	0	7	175	1	0	0	1
2/14/2016	24.00	0.00	0	10	0	2	173	0	0	0	1
2/15/2016	16.50	7.50	0	8	0	4	104	0	0	0	0
2/16/2016	0.00	24.00	0	8	1	6	88	1	0	0	2

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APPENDIX D.– continued.

Date	Times In	Times Out	Coho Smolts Nat	Coho Smolts Hat	Coho Fry Total	Chum Fry Total	Pink Fry Nat	Steelhead Smolts Nat	Steelhead Smolts Hat	Cutthroat Smolt Nat	Trout Parr Nat
2/17/2016	0.00	24.00	0	8	1	6	88	1	0	0	2
2/18/2016	0.00	24.00	0	8	1	6	88	1	0	0	2
2/19/2016	0.00	24.00	0	8	1	6	88	1	0	0	2
2/20/2016	9.00	15.00	0	7	1	5	44	1	0	0	2
2/21/2016	24.00	0.00	0	6	2	6	54	1	0	0	2
2/22/2016	24.00	0.00	3	13	1	22	105	1	0	0	3
2/23/2016	24.00	0.00	6	56	2	23	193	2	0	0	2
2/24/2016	24.00	0.00	32	332	0	3	62	5	0	2	15
2/25/2016	24.00	0.00	19	233	0	19	480	1	0	1	0
2/26/2016	24.00	0.00	17	167	0	15	434	5	0	1	43
2/27/2016	24.50	0.00	4	36	0	29	1,280	1	0	0	21
2/28/2016	24.00	0.00	4	28	0	34	1,995	0	0	0	6
2/29/2016	24.00	0.00	2	17	0	65	3,094	1	0	0	6
3/1/2016	24.00	0.00	4	9	0	34	1,578	0	0	0	2
3/2/2016	24.00	0.00	2	5	0	19	569	0	0	0	0
3/3/2016	24.50	0.00	0	4	0	29	495	0	0	0	2
3/4/2016	24.00	0.00	0	2	1	39	476	0	0	0	0
3/5/2016	24.00	0.00	1	2	1	50	907	0	0	0	1
3/6/2016	24.00	0.00	1	5	1	37	1,034	0	0	0	1
3/7/2016	24.00	0.00	2	4	0	107	1,261	0	0	0	2
3/8/2016	24.00	0.00	1	0	0	158	1,214	0	0	0	0
3/9/2016	24.00	0.00	1	8	0	167	925	0	0	0	0
3/10/2016	24.00	0.00	0	7	0	291	1,695	0	0	0	4
3/11/2016	24.00	0.00	0	1	1	134	1,266	0	0	0	2
3/12/2016	24.00	0.00	1	2	1	451	4,311	0	0	1	0
3/13/2016	24.50	0.00	0	4	2	677	4,432	0	0	0	3
3/14/2016	24.00	0.00	1	3	4	1,184	5,760	0	0	0	0
3/15/2016	24.50	0.00	1	3	3	995	5,420	0	0	0	6
3/16/2016	24.00	0.00	2	7	2	2,118	6,292	0	0	0	4
3/17/2016	24.00	0.00	1	6	3	1,076	6,122	0	0	0	4
3/18/2016	24.00	0.00	2	16	2	1,342	4,769	1	0	0	2
3/19/2016	23.50	0.00	4	5	2	877	9,551	1	0	0	0
3/20/2016	24.50	0.00	2	2	3	800	6,605	1	0	0	5

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APPENDIX D.─ continued.

Date	Times		Coho Smolts		Fry	Chum Fry	Pink Fry	Steelhead Smolts		Cutthroat Smolt	Trout Parr
	In	Out	Nat	Hat	Total	Total	Nat	Nat	Hat	Nat	Nat
3/21/2016	24.00	0.00	0	2	5	3,134	10,961	1	0	0	1
3/22/2016	24.00	0.00	0	3	2	747	3,775	0	0	0	1
3/23/2016	24.00	0.00	1	4	2	1,321	11,351	0	0	0	2
3/24/2016	24.00	0.00	0	2	3	6,309	2,500	0	0	0	2
3/25/2016	24.00	0.00	1	4	3	1,478	2,857	0	2	1	2
3/26/2016	24.00	0.00	1	2	4	619	4,567	0	5	0	1
3/27/2016	24.00	0.00	2	2	0	1,730	6,556	2	5	0	2
3/28/2016	24.00	0.00	0	0	1	637	5,609	2	6	0	3
3/29/2016	24.00	0.00	0	4	0	484	2,727	0	3	0	3
3/30/2016	24.00	0.00	1	3	2	408	4,804	5	13	0	2
3/31/2016	24.00	0.00	3	5	2	581	4,393	0	9	0	2
4/1/2016	24.00	0.00	2	2	0	575	3,469	1	4	0	0
4/2/2016	24.00	0.00	2	0	1	730	4,365	0	4	0	1
4/3/2016	24.00	0.00	4	1	2	621	2,607	1	3	2	3
4/4/2016	24.00	0.00	3	0	1	1,146	2,930	0	2	1	0
4/5/2016	24.00	0.00	1	0	1	6,492	1,466	1	7	2	3
4/6/2016	24.00	0.00	0	0	1	973	1,166	1	2	0	1
4/7/2016	24.00	0.00	0	0	0	145	205	0	9	0	3
4/8/2016	0.00	24.00	1	4	0	251	228	2	8	0	3
4/9/2016	0.00	24.00	1	4	0	251	228	2	8	0	3
4/10/2016	24.00	0.00	2	6	0	367	252	4	8	0	3
4/11/2016	24.00	0.00	4	0	0	686	333	0	10	1	2
4/12/2016	24.00	0.00	1	3	0	879	440	1	1	1	1
4/13/2016	24.00	0.00	3	2	0	5,355	454	0	0	0	0
4/14/2016	24.00	0.00	3	0	0	1,685	217	0	2	0	1
4/15/2016	22.00	0.00	23	219	0	980	149	0	0	0	1
4/16/2016	14.00	14.00	167	1,566	0	679	199	0	11	0	6
4/17/2016	12.50	9.50	123	1,115	0	258	94	2	6	0	4
4/18/2016	24.50	0.00	105	817	0	119	39	6	0	0	1
4/19/2016	23.50	0.00	47	489	0	55	16	10	2	0	6
4/20/2016	24.00	0.00	86	570	0	78	15	15	6	2	3
4/21/2016	25.00	0.00	32	396	0	35	12	3	1	0	2
4/22/2016	24.00	0.00	53	181	0	320	27	1	3	1	0
4/23/2016	23.50	0.00	27	107	0	2,369	18	2	3	2	1
4/24/2016	24.00	0.00	25	93	1	5,467	10	3	3	0	0

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APPENDIX D.─ continued.

Date	Times		Coho			Chum	Pink	Steelhead		Cutthroat	Trout
			Smolts		Fry	Fry	Fry	Smolts		Smolt	Parr
	In	Out	Nat	Hat	Total	Total	Nat	Nat	Hat	Nat	Nat
4/25/2016	24.00	0.00	37	115	1	1,360	8	3	1	2	1
4/26/2016	23.50	0.00	46	64	0	4,488	2	0	0	2	1
4/27/2016	24.50	0.00	28	38	0	558	5	1	1	0	0
4/28/2016	24.00	0.00	38	56	0	437	0	1	0	0	2
4/29/2016	24.00	0.00	13	22	0	604	0	1	0	0	1
4/30/2016	24.00	0.00	16	21	0	2,652	1	1	0	0	0
5/1/2016	12.00	11.50	10	19	0	866	0	0	0	0	0
5/2/2016	12.50	12.00	7	19	0	301	0	3	1	0	0
5/3/2016	24.00	0.00	27	63	0	164	0	6	0	0	0
5/4/2016	24.00	0.00	31	60	0	34	0	4	2	0	1
5/5/2016	24.00	0.00	25	43	0	26	0	1	2	0	0
5/6/2016	24.00	0.00	21	44	0	2,068	0	1	0	0	0
5/7/2016	12.00	12.00	28	26	0	1,891	0	2	2	1	0
5/8/2016	24.00	0.00	76	75	0	544	0	7	2	0	0
5/9/2016	24.00	0.00	64	58	0	986	0	3	0	0	1
5/10/2016	15.50	8.50	55	60	0	544	0	6	3	0	1
5/11/2016	12.50	12.00	30	27	0	181	1	2	1	0	0
5/12/2016	14.00	10.00	30	24	0	123	0	8	7	0	0
5/13/2016	24.00	0.00	27	20	0	42	0	15	4	0	0
5/14/2016	24.00	0.00	14	22	0	41	0	16	0	0	0
5/15/2016	24.00	0.00	8	6	0	16	0	6	19	0	0
5/16/2016	24.00	0.00	22	12	1	116	0	28	50	0	0
5/17/2016	12.00	12.00	21	18	0	122	0	18	22	0	0
5/18/2016	11.50	12.50	51	31	0	153	0	52	14	0	0
5/19/2016	24.00	0.00	24	12	0	51	0	16	2	0	0
5/20/2016	11.50	12.50	63	34	0	751	0	55	8	0	0
5/21/2016	24.00	0.00	39	17	0	144	0	32	9	0	0
5/22/2016	24.00	0.00	21	8	0	51	0	18	2	0	0
5/23/2016	24.00	0.00	51	28	0	291	0	48	9	0	1
5/24/2016	24.00	0.00	31	22	1	172	0	21	2	0	0
5/25/2016	24.00	0.00	41	36	0	83	0	12	4	0	0
5/26/2016	24.00	0.00	22	8	0	62	0	6	4	0	0
5/27/2016	24.00	0.00	17	15	0	53	0	11	2	0	0
5/28/2016	24.50	0.00	12	10	0	22	0	10	2	0	0
5/29/2016	23.50	0.00	7	5	0	16	0	6	2	1	0

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APPENDIX D.─ continued.

Date	Times		Coho Smolts		Fry	Chum Fry	Pink Fry	Steelhead Smolts		Cutts Smolt	Trout Parr
	In	Out	Nat	Hat	Total	Total	Nat	Nat	Hat	Nat	Nat
5/30/2016	10.50	13.50	7	7	0	27	0	9	1	0	0
5/31/2016	11.00	13.00	7	4	0	20	0	7	4	0	0
6/1/2016	12.00	12.00	2	3	0	19	0	7	2	0	0
6/2/2016	24.00	0.00	5	1	0	14	0	3	1	0	0
6/3/2016	12.00	12.00	14	4	0	48	0	6	3	0	0
6/4/2016	11.00	13.50	12	3	0	62	0	1	1	0	0
6/5/2016	10.00	14.00	7	6	0	29	0	0	0	0	0
6/6/2016	11.00	13.00	3	3	0	36	0	1	1	0	0
6/7/2016	11.00	13.00	5	3	0	28	0	2	0	0	0
6/8/2016	11.50	12.50	0	3	0	52	0	0	0	0	0
6/9/2016	11.50	12.50	0	1	0	44	0	0	1	0	0
6/10/2016	24.00	0.00	4	3	0	64	0	0	0	0	0
6/11/2016	10.50	13.50	1	1	0	13	0	0	0	0	0
6/12/2016	10.50	13.50	2	1	0	13	0	0	0	0	0
6/13/2016	24.00	0.00	3	0	0	10	0	0	0	0	0
6/14/2016	24.00	0.00	2	0	1	6	0	0	0	0	0
6/15/2016	24.00	0.00	7	2	4	16	0	0	0	0	0
6/16/2016	11.00	12.50	0	0	1	1	0	0	0	0	0
6/17/2016	24.50	0.00	0	0	0	0	0	0	0	0	0
6/18/2016	10.00	14.00	0	0	0	1	0	0	0	0	0
6/19/2016	10.50	13.50	15	0	1	6	0	0	0	0	0
6/20/2016	10.50	13.50	3	1	0	2	0	0	0	0	0
6/21/2016	24.00	0.00	2	0	0	2	0	0	0	0	0
6/22/2016	13.00	11.00	4	0	2	0	0	0	0	1	0
6/23/2016	10.50	13.50	0	0	0	0	0	0	0	0	0
6/24/2016	23.50	0.00	2	0	0	0	0	0	0	0	1
6/25/2016	11.50	14.00	0	0	1	2	0	0	0	0	0
6/26/2016	9.75	0.00	2	0	1	0	0	0	0	0	0
Total	3,413.3	541.0	2,019	7,842	84	79,376	153,366	552	337	29	260

Appendix E

Fork lengths of natural-origin coho smolts in the Green River, 2016

APPENDIX E.─Mean fork length (mm), standard deviation (St.Dev.), range, and sample size of natural-origin coho smolts in the Green River in 2016.

Week				Range		Number		Percent
Begin	End	Average	St.Dev.	Min	Max	Sampled	Caught	Sampled
1/14/2016	1/17/2016	106.00	7.00	98	111	3	3	100.00%
1/18/2016	1/24/2016	97.33	20.07	60	120	6	9	66.67%
1/25/2016	1/31/2016	98.00	na	98	98	1	1	100.00%
2/1/2016	2/7/2016	102.75	5.06	97	109	4	5	80.00%
2/8/2016	2/14/2016	96.00	0.00	96	96	2	2	100.00%
2/15/2016	2/21/2016			no samples				
2/22/2016	2/28/2016	100.00	10.16	89	113	6	85	7.06%
2/29/2016	3/6/2016	100.57	6.21	93	108	7	10	70.00%
3/7/2016	3/13/2016	109.67	15.04	100	127	3	5	60.00%
3/14/2016	3/20/2016	107.50	11.79	85	128	12	13	92.31%
3/21/2016	3/27/2016	110.40	2.19	109	114	5	5	100.00%
3/28/2016	4/3/2016	107.63	6.21	96	114	8	12	66.67%
4/4/2016	4/10/2016	103.00	9.11	91	112	5	6	83.33%
4/11/2016	4/17/2016	119.65	9.05	98	131	17	63	26.98%
4/18/2016	4/24/2016	119.94	9.91	97	140	48	375	12.80%
4/25/2016	5/1/2016	116.90	11.46	97	140	29	188	15.43%
5/2/2016	5/8/2016	119.79	8.52	107	134	28	214	13.08%
5/9/2016	5/15/2016	113.76	8.60	94	131	34	228	14.91%
5/16/2016	5/22/2016	113.07	9.44	97	130	42	241	17.43%
5/23/2016	5/29/2016	115.85	10.32	96	133	27	181	14.92%
5/30/2016	6/5/2016	116.24	7.89	99	128	17	54	31.48%
6/6/2016	6/12/2016	111.40	8.28	105	134	10	15	66.67%
6/13/2016	6/19/2016	111.75	10.18	96	130	16	27	59.26%
6/20/2016	6/26/2016	107.75	9.19	90	120	12	13	92.31%
Season Total		113.76	11.04	60	140	342	1,755	19.49%

References

Beakes, M.P., Satterthwaite, W.H., Collins, D.R., Merz, J.E., Titus, R.G., and Sogard, S.M. 2010. Smolt transformation in two California steelhead populations: effects of temporal variability in growth. Transactions of the American Fisheries Society **139**: 1263-1275.

Carlson, S.R., Coggins, L.G., and Swanton, C.O. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fishery Research Bulletin **5**: 88-102.

Crawford, B.A. 2007. Washington State framework for monitoring salmon populations listed under the federal Endangered Species Act and associated freshwater habitats. Governor's Forum of Monitoring Salmon Recovery and Watershed Health, Olympia, Washington.

Footen, B., Wildermuth, D., and Smith, D. 2011. 2010 Green River Chinook escapement report. Muckleshoot Indian Tribe and Washington Department of Fish and Wildlife.

Kinsel, C., Zimmerman, M.S., Kishimoto, L., and Topping, P. 2008. 2007 Skagit River salmon production evaluation, FPA 08-08. Washington Department of Fish and Wildlife, Olympia, Washington.

Kiyohara, K., and Zimmerman, M.S. 2011. Evaluation of juvenile salmon production in 2010 from the Cedar River and Bear Creek, FPA 11-12. Washington Department of Fish and Wildlife, Olympia, Washington.

McElhany, P., Ruckelshaus, M.H., Ford, M.J., Winwright, T., and Bjorkstedt, E. 2000. Viable salmonid populations and the recovery of evolutionary significant units. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-42, Northwest Fisheries Center, Seattle, Washington.

Myers, J.J., Hard, J.J., Connor, E.J., Hayman, R.A., Pess, G.R., and Thompson, B.E. 2015. Identifying populations of steelhead within Puget Sound Distinct Population Segment. NOAA Technical Memorandum: NMFS-NWFSC-128.

Ruckelhaus, M.H., Currens, K.P., Graeber, W.H., Fuerstenberg, R.R., Rawson, K., Sands, N.J., and Scott, J.B. 2006. Independent populations of Chinook salmon in Puget Sound. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-78.

Scott, J.B., and Gill, W.T. 2008. Onchorhynchus mykiss: assessment of Washington state's steelhead populations and programs, http://wdfw.wa.gov/publications/pub.php?id=00150. Washington Department of Fish and Wildlife, Olympia, Washington.

Seamons, T.R., Rawding, D., Topping, P., Wildermuth, D., Peterson, S., and Zimmerman, M.S. 2012. Spawner abundance estimates for Green River Chinook salmon. Submitted to the Pacific Salmon Commission Sentinel Stock Committee, Washington Department of Fish and Wildlife, Olympia, Washington.

Seiler, D.E., Volkhardt, G.C., Kishimoto, L., and Topping, P. 2002. 2000 Green River Juvenile Salmonid Production Evaluation. Washington Department of Fish and Wildlife, Olympia, Washington.

Sokal, R.R., and Rohlf, F.J. 1981. Biometry. W.H. Freeman and Company, New York.

Topping, P., and Zimmerman, M.S. 2011. Green River juvenile salmonid production evaluation: 2009 and 2010 annual report, FPA 11-01. Washington Department of Fish and Wildlife, Olympia, Washington.

Volkhardt, G.C., Johnson, S.L., Miller, B.A., Nickelson, T.E., and Seiler, D.E. 2007. Rotary screw traps and inclined plane screen traps. *In* Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. *Edited by* D.H. Johnson, B.M. Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O-Neil and T.N. Pearsons. American Fisheries Society, Bethesda, Maryland. pp. 235-266.