Three Stocks, One Story: An evaluation of different hatchery stocks reared and released at Warm Springs National Fish Hatchery

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Abstract *- Hatchery spring Chinook salmon (Oncorhynchus tshawytscha) eggs from Round Butte State Fish Hatchery (RBH) and Parkdale Fish Hatchery (PFH) were reared and released at Warm Springs National Fish Hatchery (WSNFH). To assess stock performance, stocks were monitored for size, condition factor, on-station survival, pre-release precocial rate, juvenile survival, migration timing, release to adult return survival rates, size, age structure, and external mark identification accuracy. Although on-station survival and growth did not show significant differences, return timing and survival was earlier and higher for WSNFH stock fish. While RBH and PFH stock fish contributed to harvest benefits, there is some level of genetic risk to the Warm Springs population if fish from RBH or PFH stock are incorporated into the WSNFH population during spawning. Segregating RBH and PFH stock adult returns based on external marks had an overall 11% error rate. This evaluation provides managers with a better understanding of the short and long-term benefits and risks of supplementing the Warm Springs NFH program with non-Warm Springs stock fish during years of production shortfalls.*

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INTRODUCTION

The Warm Springs National Fish Hatchery (WSNFH) stocks salmon within the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) reservation to increase tribal harvest opportunities. The current focus of the Warm Springs National Fish Hatchery is to produce spring Chinook salmon (*Oncorhynchus tshawytscha*) for tribal harvest in the Deschutes and Columbia River Basins and for on-reservation distribution to tribal members. The hatchery began operation in 1978 with an initial collection of broodstock from the wild Warm Springs River spring Chinook population. The hatchery has been managed as an integrated hatchery program, with one of the goals being to maintain genetic and phenotypic similarity between the hatchery and wild population. Another goal of the hatchery is to minimize impacts to the wild fish populations in the Warm Springs River.

The current juvenile release goal for the hatchery is 750,000 fish, however over the past decade the release numbers have been variable. During years of production shortfalls, consideration has been given to augmenting the hatchery production with eggs or juveniles from other hatchery programs. The resulting progeny released into the Warm Springs River is intended to increase adult returns and tribal harvest opportunities when those fish return as adults. In recent years, eggs from Round Butte Hatchery (RBH) and juveniles from the Parkdale Hatchery Hood River Program (PFH) have been transferred to WSNFH, where they were reared and released. To maintain the WSNFH genetic stock, any releases from non-WSNFH stocks are differentially marked (e.g., left ventral clip) so that upon adult return these stocks can be segregated out from the WSNFH broodstock production.

The main benefit of importing non-WSNFH stock fish during years of shortfalls is an increase in the likelihood of meeting the annual juvenile release goal. The assumption is that the increased juvenile release numbers would also lead to an increase in adult returns in out-years, thereby increasing harvest opportunities. The production goal of at least 2,250 adults returning to the mouth of the Deschutes River allows for a harvest and escapement of 630 hatchery adults for broodstock (> 60 cm in total length assuming 90% pre-spawning survival and 60% female) at WSNFH (USFWS 2004). The facility has produced an estimated mean of 2,280 adults annually based on CWT data for the most recent ten-year dataset of complete adult returns (brood years 2006 – 2015). Co-managers estimate that current conditions provide an annual average of 518 harvest benefits to the Tribes and non-Tribal sport fishers and escapement of 1,762 to the hatchery resulting in a mean smolt-to-adult survival rate (SAR) of 0.42% (Silver et al. 2023).

When considering whether to rear and release non-WSNFH stock fish (i.e., RBH or PFH), managers must consider the risks and benefits of such actions. The integrated population of spring Chinook salmon reared at WSNFH is the best representative of the historic Deschutes River lineage of spring Chinook salmon (Smith et al. 2014). Round Butte hatchery stock originated from wild spring Chinook (presumably Warm Springs River fish) collected downstream at Sherars Falls on the Deschutes River. The RBH program has not been managed as an integrated program; no wild fish are incorporated into the hatchery program. The PFH program's initial broodstock was of RBH origin, but in more recent years the program has tried to develop a more localized Hood River broodstock from subsequent adult returns of Hood River releases. Based on genetic analyses (Smith et al. 2016) the WSNFH, RBH, and PFH populations "exhibit significantly different allele frequencies ... an indication of divergence among the populations" (see memo 6/29/18 from C. Smith, USFWS). Rearing and releasing RBH or PFH stock fish at WSNFH poses some level of genetic risk to the Warm Springs population, with the risk being greater from importing PFH stock compared to importing RBH stocks. The genetic risk to the integrated WSNFH stock increases with the number and frequency of egg/juvenile transfers from those stocks.

The 2006 Hatchery Review Team concluded that the importation of spring Chinook salmon from RBH posed disease, genetic (natural spawning of hatchery fish), and ecological (e.g. competition) risks to the WSNFH-stock of spring Chinook salmon (USFWS 2006, page 29). To prevent incorporating imported stock into the WSNFH population, non-WSNFH stock adults (as indicated by the presence of an external mark) are removed from the adult population upon their return to the Hatchery. The Hatchery Review Team also recognized that if the additional risks and logistics associated with rearing non-WSNFH stock cannot be reduced or eliminated, the practice should be discouraged (USFWS 2006, page 32).

While there is limited information on non-WSNFH-stock performance of fish reared and released at WSNFH, preliminary studies indicate non-WSNFH-stock fish may survive at a lower rate. An analysis of coded-wire tag recoveries of RBH-stock fish reared and released at WSNFH from brood years (BYs) 2007, 2009, and 2017 showed that the RBH-stock fish returned at a statistically significantly lower rate than WSNFH-stock fish (proportional degree of difference: 40% lower for BY 2007, 65% lower for BY 2009, and 67% lower for BY 2017). In BY 2015, ~120,000 PFH juveniles were reared and released. No Age 3 fish were recovered, and the Age 4 and Age 5 adult return rate was 71% lower than WSNFH stock fish.

It is not known whether the lower survival trends of non-WSNFH-stock releases will continue or what the reasons for lower survival rates might be. Differential marking (left ventral clipping of non-WSNFH stock fish) may subject fish to additional handling stress (Sharpe et al. 1998; Wertheimer et al. 2002). An evaluation of hatchery performance of ventral fin clipped fish and adipose fin clips/coded-wire tagged fish was conducted for three BYs (1987-89) at WSNFH. Spring Chinook salmon marked with a ventral fin clip performed as well as fish marked with an adipose fin clip/coded-wire tag; but sample sizes were small and survival to adult was low for all groups (Olson and Cates 2004). In addition, a recent study found that out-of-basin Hood River stock reared at Carson NFH were smaller, had lower gill NA, K-ATPase levels, and higher minijack rates than Carson stock fish (Spangenberg et al. 2015). The authors stated that their findings "... emphasize that broodstock transfer among hatchery facilities to fulfill short-term production goals may result in either positive or negative long-term consequences for a hatchery program depending on the specific stock and facility."

Monitoring of the on-hatchery and off-hatchery performance of non-WSNFH-stock fish reared and released from WSNFH will provide managers with a better understanding of the short-term and long-term benefits and risks of supplementing the WSNFH program with non-WSNFH-stock fish during years of production shortfalls.

In 2018, only 246 WSNFH-stock adults returned to the hatchery. The low return was the result of only approximately 133,000 brood year 2014 juveniles being released (4-year-old returns in 2018). The low WSNFH-stock adult returns led to WSNFH requesting and receiving eyed-up eggs (embryos) from both RBH and PFH to augment hatchery production. As of December 1, 2018, the estimated inventory of eggs from each stock being incubated at WSNFH was:

- Warm Springs Stock: 252,638
- Round Butte Stock: 249,186
- Parkdale Stock: 153,538

The BY 2018 production program at WSNFH provided an opportunity to evaluate the relative performance of the three hatchery stocks of spring Chinook salmon reared under similar conditions with the following objectives:

1. Monitor on-hatchery growth and survival profile.
2. Monitor pre-release precocial rate.
3. Monitor downstream migration survival and timing.
4. Monitor release to adult return rates and age structure.
5. Identify variables that might contribute to any observed differences in return rates.

METHODS

The overall study design can be described as a “common garden” experiment roughly based on the study conducted by Spangenberg et al. 2015 to test the null hypothesis that spring Chinook Salmon from WSNFH, RBH, and PFH stock will have similar growth rates, survival, precocity, juvenile survival, migration timing, adult return rates and age structure when reared under similar conditions (i.e., rearing density, daily feeding, raceway cleaning, etc.) at WSNFH.

All fish were marked with an adipose fin-clip and coded-wire tagged (CWT) in late April 2019; each stock received a differential CWT code. The RBH and PFH stocks received an additional ventral clip mark later that year to allow hatchery managers to segregate broodstock upon their subsequent return as adults. The RBH stock received a left-ventral clip and PFH fish received a right-ventral clip (Table 1).

Monitoring stock on-hatchery growth and survival profile began in early May 2019 when fish were moved from the indoor incubation area at WSNFH to the outdoor raceways until March 2020. Each month, one hundred fish were randomly collected with a dipnet from a single raceway of each stock. Fish were held in an aerated 5-gallon bucket, lightly sedated in 60 ppm MS-222, measured for fork length (mm) and weight (g), revived in another aerated 5-gallon bucket, and returned to their corresponding raceway. Monthly hatchery mortality records for all raceways were used to estimate on-hatchery survival.

In February 2020, a representative number of fish from each stock was PIT tagged prior to release (Table 1). Fork lengths (mm) were collected from the PIT tagged fish at the time of tagging. Coinciding with PIT tagging activities, a sample of 300 fish from each stock were arbitrarily selected and visually inspected for evidence of precociousness. Assuming 50% of the population was male, presence of milt and yellow fin coloration would provide an estimate of the stock's precocial rate.

Table 1. Number of brook year 2018 juveniles marked and tagged for release from Warm Springs NFH.

Stock:	Mark(s)	CWT Tagged	PIT Tagged
WSNFH	Adipose	281,133	8,944 split between ponds 7 and 12
RBH	Adipose, Left-ventral	230,310	6,566 split between ponds 20 and 21
PFH	Adipose, Right-ventral	135,798	3,884 split between ponds 16 and 17

All fish were force released into the Warm Springs River in early April 2020. Downstream detections of PIT tagged fish at Bonneville Dam and the lower river trawl were monitored for travel time and to estimate their survival to Bonneville Dam. Migration timing was calculated from the day of release to the first day of detection at Bonneville Dam (for those fish detected at Bonneville).

Upstream PIT detections at Bonneville Dam were monitored for return timing and rates. Fish returning upstream at age-2 (i.e., fish detected in an adult fishway the same year as their release) were used to estimate rate of precocious maturation in males. To exclude late out-migrating juveniles, fish detected during the month of May were not included in the analysis. Adult ladder detections in subsequent years (2021-2023) were used to compare overall return rates and return timing.

Coded-wire tags were recovered from a representative subsample of the adult returns (2021-2023) to WSNFH. Unexpanded recoveries for the three stocks of fish were used to compare age at return, release to adult recovery rates at WSNFH, and the accuracy of LV/RV external marks.

RESULTS

On-Hatchery Growth and Survival

Growth Rate

Spring Chinook growth was observed from ponding in May 2019 to pre-release in March 2020 (Table 2). While growth rate over time was similar for all stocks (Table 2, Figure 1), a one-way ANOVA was performed to evaluate if there was an overall difference in mean fork length between the three stocks. Tukey post-hoc analyses revealed RBH-stock fish were significantly smaller than the WSNFH and PFH-stock fish at both ponding and before release (ANOVA: $F_{(2, 297)} = 69.09$, $P = <0.001$; $F_{(2, 297)} = 7.94$, $P = <0.001$). There was no statistically significant difference in mean lengths between WSNFH and PFH-stock fish at either event (Table 2, Figure 2).

Mean weight followed the same trend as mean FL at ponding. At pre-release, the mean (± 95% CI) weight of WSNFH-stock (19.3 ± 1.6 g) was significantly greater (ANOVA: $F_{(2, 297)} = 5.11$, $P = <0.001$) than both RBH (16.6 ± 0.9 g) and PFH-stock fish (17.0 ± 1.1 g) which were not significantly different from one another.

Table 2. Mean FL (mm; ± 95% CI) of stocks reared at WSNFH at ponding (May 2019) and pre-release (March 2020).

Stock	Ponding	Pre-Release	Absolute Growth Rate (mm/day)	Mean Size at Release (fish/lb)
WSNFH	68 ± 1 [a]	118 ± 3 [a]	0.17	24.8
RBH	61 ± 1 [b]	111 ± 2 [b]	0.17	24.3
PFH	67 ± 1 [a]	115 ± 2 [a]	0.16	23.3

[a,b] Within a column, means without a common superscript significantly differ (One-way ANOVA to compare mean FL for each stock by sample event. $P < 0.001$)

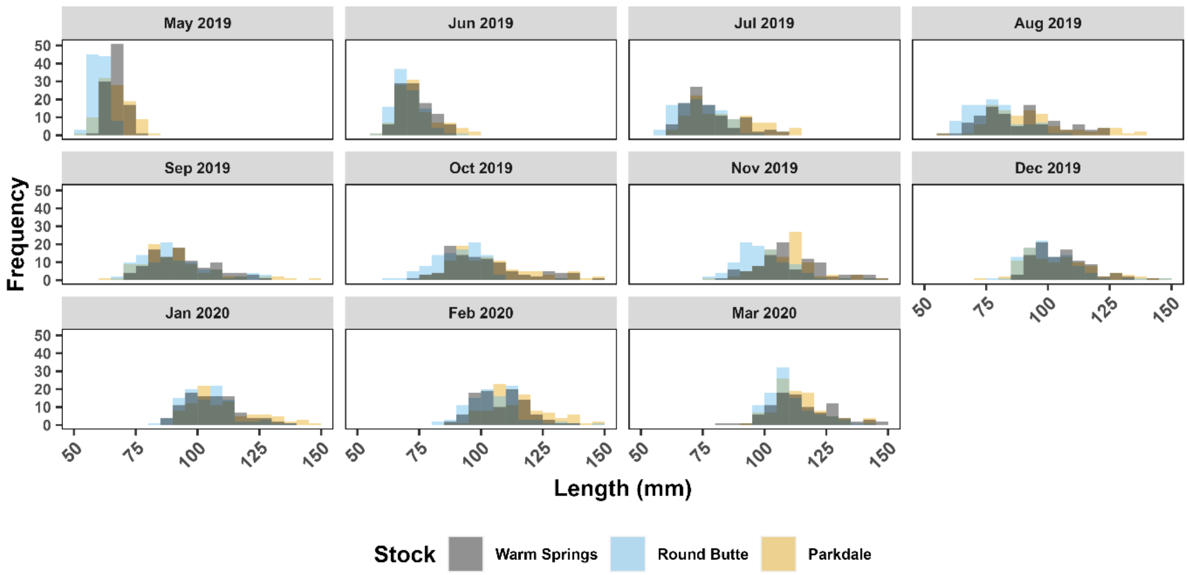

Figure 1. Monthly FL (mm) frequency distribution of Spring Chinook at WSNFH.

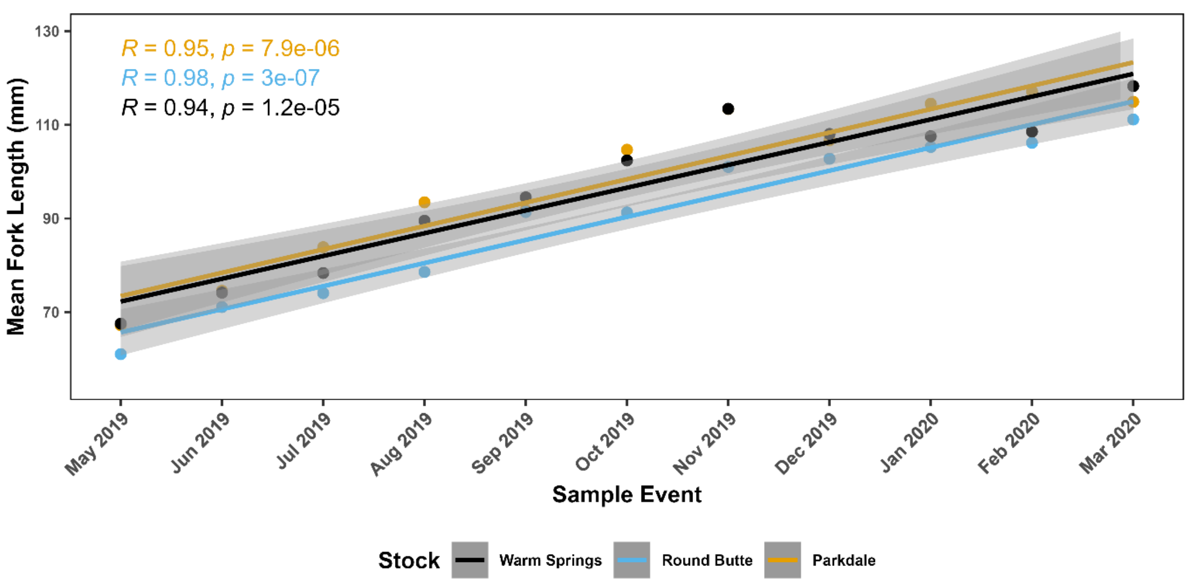

Figure 2. Mean FL (mm) for Parkdale, Round Butte, and Warm Springs-stock spring Chinook salmon fish from BY 2018 reared at Warm Springs NFH from May 2019 to March 2020. Mean FL of RBH-stock was significantly lower ($P < 0.001$) than PFH and WSNFH-stocks when they were ponded (May 2019) and before they were released (March 2020). Growth rate was not statistically different among stocks.

Condition Factor

Fulton's condition factor (K) did not significantly differ between stocks (Two-way ANOVA - without interaction between stock and sample event: $F_{(2, 3,287)} = 1.80$, $P = 0.166$), but it was significantly different among sample events (ANOVA: $F_{(10, 3,287)} = 101.27$, $P < 0.001$), peaking in September and October. Although there is no linear relationship between condition factor and time, overall condition factor increased for RBH-stock and decreased PFH and WSNFH-stock between ponding and pre-release.

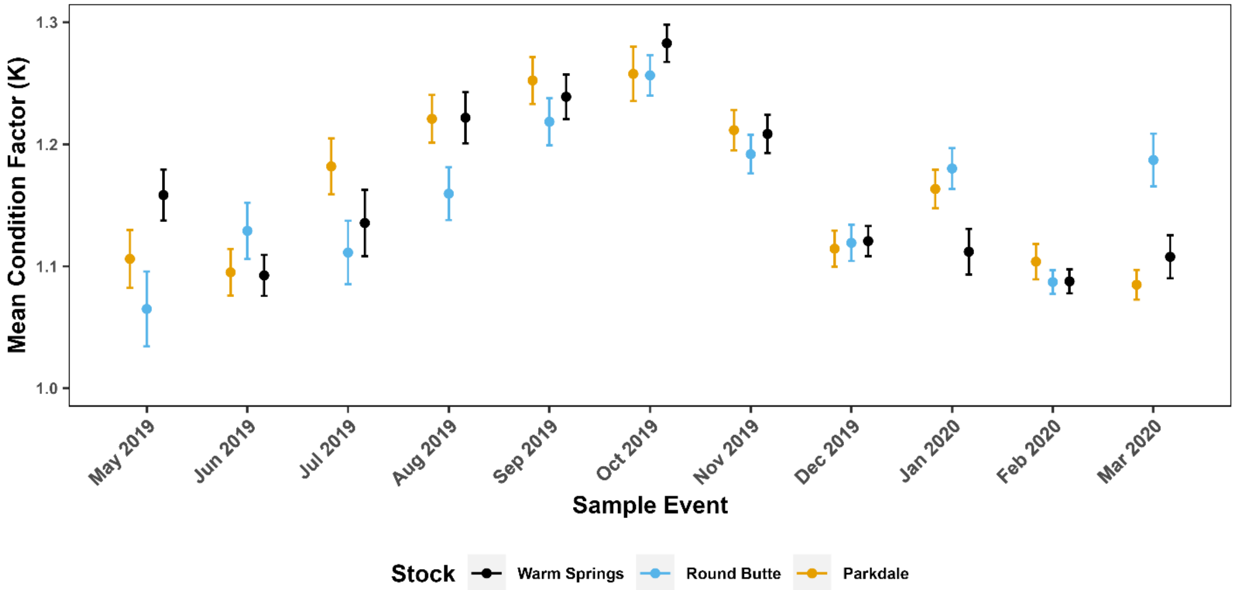

Figure 3. Monthly mean Fulton's condition factor (K; ± 95% CI) of stocks reared at WSNFH from ponding (May 2019) to pre-release (March 2020).

Mortality Rate

On-station mortality rate was lowest for PFH and highest for RBH. A Pearson's Chi-Square test of independence was performed to examine the relationship between mortality rate and stock. Our results indicated mortality rate differed by stock ($X^2_{2,\ 662,264}$ = 83,434, P <0.001). However, the differences in mortality rates among stocks were of very low magnitude due to our large sample size (Table 3).

Mortality was highest in the summer and lowest in the fall and winter (Figure 4). From June to August 2019, the mean maximum water temperature each month was above 17° C. Beginning in fall (September 2019), maximum temperatures began to drop along with mortality and stayed below 5° C from November 2019 to February 2020. A binomial regression with mortality as a function of mean high temperature and stock showed maximum temperature may influence mortality rates (Figures 4 and 5).

Table 3. Beginning and ending inventory of all fish by stock reared at WSNFH at ponding (May 2019). and pre-release (March 2020).

Stock	Beginning Inventory (May 2019)	Ending Inventory (April 2020)	Total Mortality	Mortality Rate % (95% CI)
WSNFH	287,717	281,133	6,584	0.22 (0.22 – 0.23)
RBH	235,828*	230,310	5,518	0.23 (0.23 – 0.24)
PFH	138,719*	135,798	2,921	0.21 (0.20 – 0.22)

*Beginning inventory includes pond inventory adjustments (October 2019)

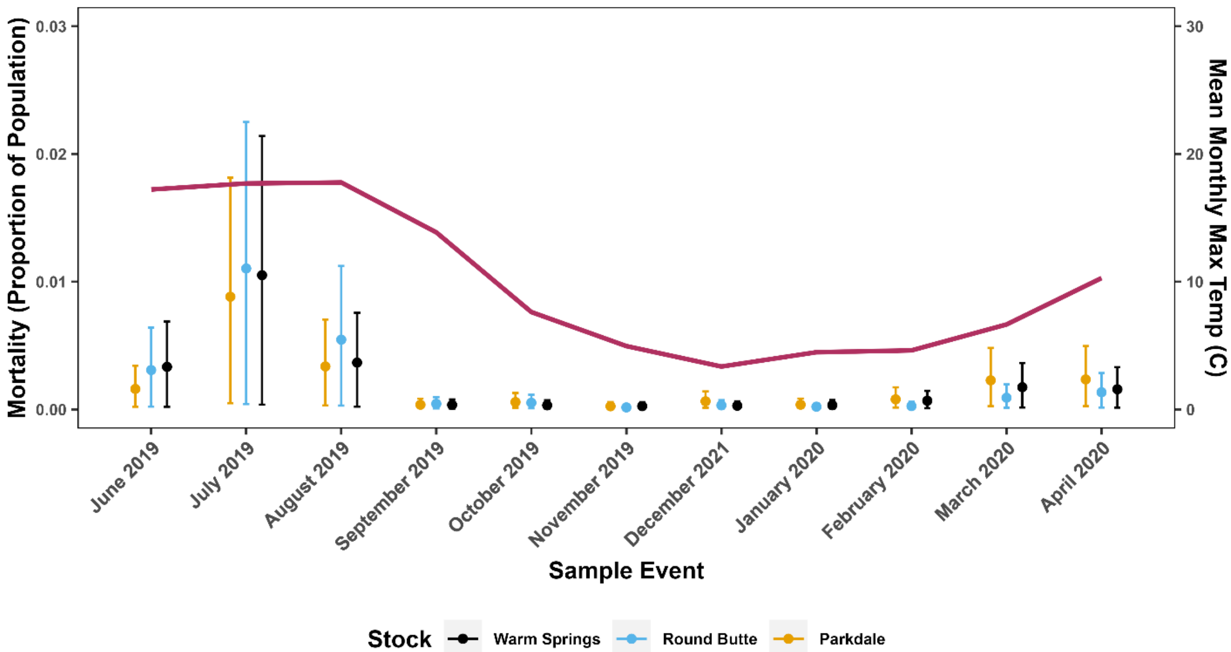

Figure 4. Proportion of mortalities (± 95% CI) in the population by stock each month from ponding (May 2019) to pre-release (March 2020). Mean monthly maximum temperature (°C) is indicated by red line on secondary y axis.

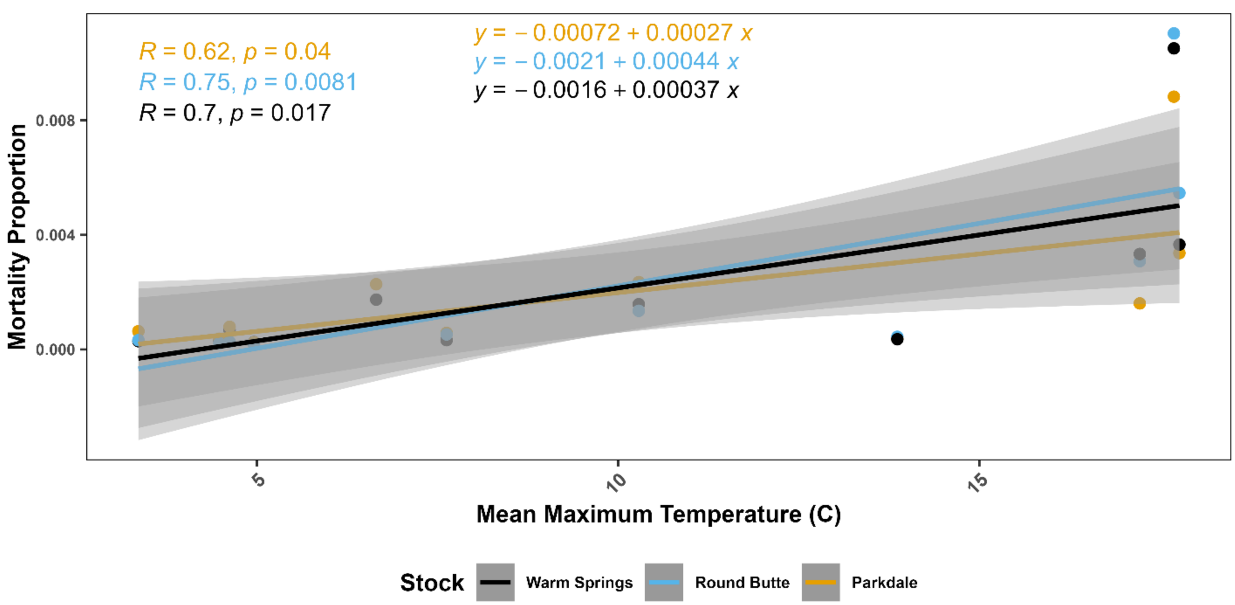

Figure 5. Proportion of mortalities in the population as a function of mean high temperature and stock month from ponding (May 2019) to pre-release (March 2020).

Precocity

Fish were checked for precocity during PIT tagging activities two months before they were released. Assuming half of handled fish were male, the precocial rate was no greater than 0.4% (upper 95% CI). A Pearson's Chi-Square test indicated precocity rate was not dependent on stock ($X^2_{2,\ 9,239}$ = 1.39, P <0.498).

Table 4. Juvenile fish by stock checked for precocity two months before release from Warm Springs NFH.

Stock	Sample Date	Total Fish Handled	Male	Precocial	% Precocial (95% CI)
WSNFH	2/3/2020	7,989	3,995	4	0.10 (0.03 - 0.26)
RBH	2/4/2020	6,590	3,295	1	0.03 (0.00 - 0.17)
PFH	2/5/2020	3,897	1,949	2	0.10 (0.01 - 0.37)

Off-Station Timing and Survival

Juvenile Travel Time/Survival

Brood year 2018 juveniles were force-released from WSNFH on April 8, 2020, into the Warm Springs River (water temperature = 8.3° C). Fish migrated downstream from the Warm Springs River to the Deschutes River, into the Columbia River where they passed The Dalles Dam and Bonneville Dam before entering the Pacific Ocean. The detection rate of PIT tagged fish at Bonneville Dam is a function of a) migration survival from release to Bonneville Dam and b) the detection efficiency of the PIT antenna arrays at the dam. All stocks had detections at Bonneville Dam's Juvenile Fish Bypass Facility in as few as 4.5 days with the 90th percentile passing in fewer than 30 days after their release. There was no significant association between stock and detection rate (Pearson's Chi-Square test of independence $X^2_{(2,\ 19{,}394)} = 1.57$, $P = 0.455$) or travel time (One-way ANOVA $F_{(2,\ 1{,}704)} = 0.90$, $P = 0.408$).

Median juvenile survival estimates Bonneville Dam are based on a scale of 0 - 1 with 1 being 100% survival to Bonneville Dam. There was a significant association between stock and survival rate (Pearson's Chi-Square test of independence $X^2_{(2,\ 19{,}394)} = 125.73$, $P < 0.05$) where WSNFH fish survived at a higher rate (0.67) than PFH (0.53) and RBH (0.50) fish. Post hoc comparisons of rates of survival by stock (Bonferroni correction) revealed that higher rates of survival were seen among WSNFH fish, 0.67 (0.43 – 0.98 CI). In comparison, juvenile survival to Bonneville Dam was statistically similar among PFH and RBH fish (~0.5).

Table 5. Brood Year 2018 juvenile travel time and survival estimates from release to Bonneville Dam (BONN). Median travel time includes range, 10th and 90th percentiles in days. Median juvenile survival estimates (90% Credible Intervals) are based on MARK, MCMC estimation method run on 10/31/2023.

Stock	PIT Tagged	Detected at BONN (%)	Median Travel Time	Range	10th	90th	Median Juvenile Survival (90%CI)
WSNFH	7,944	764 (9.6%)	16	(4.5 - 44)	10	26	0.67 (0.43 – 0.98)
RBH	6,566	594 (9.0%)	18	(4.5 - 44)	10	25	0.50 (0.30 – 0.82)
PFH	3,884	350 (9.0%)	16	(4.5 - 43)	10	27	0.53 (0.30 – 0.89)

Adult Returns to Bonneville Dam

Overall, PFH-stock fish returned significantly later to Bonneville Dam than WSNFH-stock; for all stocks, Age-3 fish returned significantly later than Ages-4 and 5 fish. A two-way ANOVA showed both stock and age-at-return were statistically significant ($F_{(2, 100)} = 5.80$, $P < 0.01$, ($F_{(2, 100)} = 11.50$, $P < 0.001$, respectively), the effect of stock on age-at-return and vice versa had no significant interaction ($F_{(3, 100)} = 5.80$, $P = 0.88$).

- Age 2 Minijacks: All stocks had PIT tagged minijacks detected at Bonneville Dam; median passage was in July 2020 (Table 6).
- Age 3 Jacks: Warm Springs NFH-stock were detected returning to Bonneville Dam at a rate of 0.09%, 3 times higher than both RBH (0.03%) and PFH-stocks (0.03); median passage of all stocks occurred in June 2021 (Table 6).
- Age 4 Adults: Warm Springs NFH-stock were detected returning to Bonneville Dam at a rate of 0.43%, 2.4 times higher than RBH-stock (0.18%) and 5.4 times the rate of PFH-stock (0.08%), RBH-stock was detected 2.3 times the rate of PFH-stock; median passage of WSNFH and RBH was in early to mid-May and PFH in mid-June 2022 (Table 6).
- Age 5 Adults: Three WSNFH-stock fish were detected in early May and one RBH-stock fish was detected in early June at Bonneville Dam in 2023, zero PFH-stock fish were detected (Table 6).

Table 6. Median first detection date and expanded PIT return to Bonneville Dam by stock and age. Expansion rate based on number of fish PIT tagged/number of fish released. Age-2 minijacks are not included in the adult analysis.

Stock	Age	Detections	Expanded Detections	Return Rate % (Expanded/Released)	Median Return Date
WSNFH	Age-2 (Minijack)	9	319	0.11	July 2
	Age-3 (Jack)	7	248	0.09	June 4[a]
	Age-4	34	1,204	0.43	May 9[b,a]
	Age-5	3	106	0.04	May 16
RBH	Age-2 (Minijack)	4	140	0.06	July 9
	Age-3 (Jack)	2	70	0.03	June 11
	Age-4	12	421	0.18	May 19
	Age-5	1	35	0.01	June 2
PFH	Age-2 (Minijack)	3	105	0.08	July 20
	Age-3 (Jack)	1	35	0.03	June 27[b]
	Age-4	3	105	0.08	June 14
	Age-5	0	0	0	-

[a,b] Common superscript indicates significant differences (pairwise comparisons made with Tukey's Honestly Significant Difference).

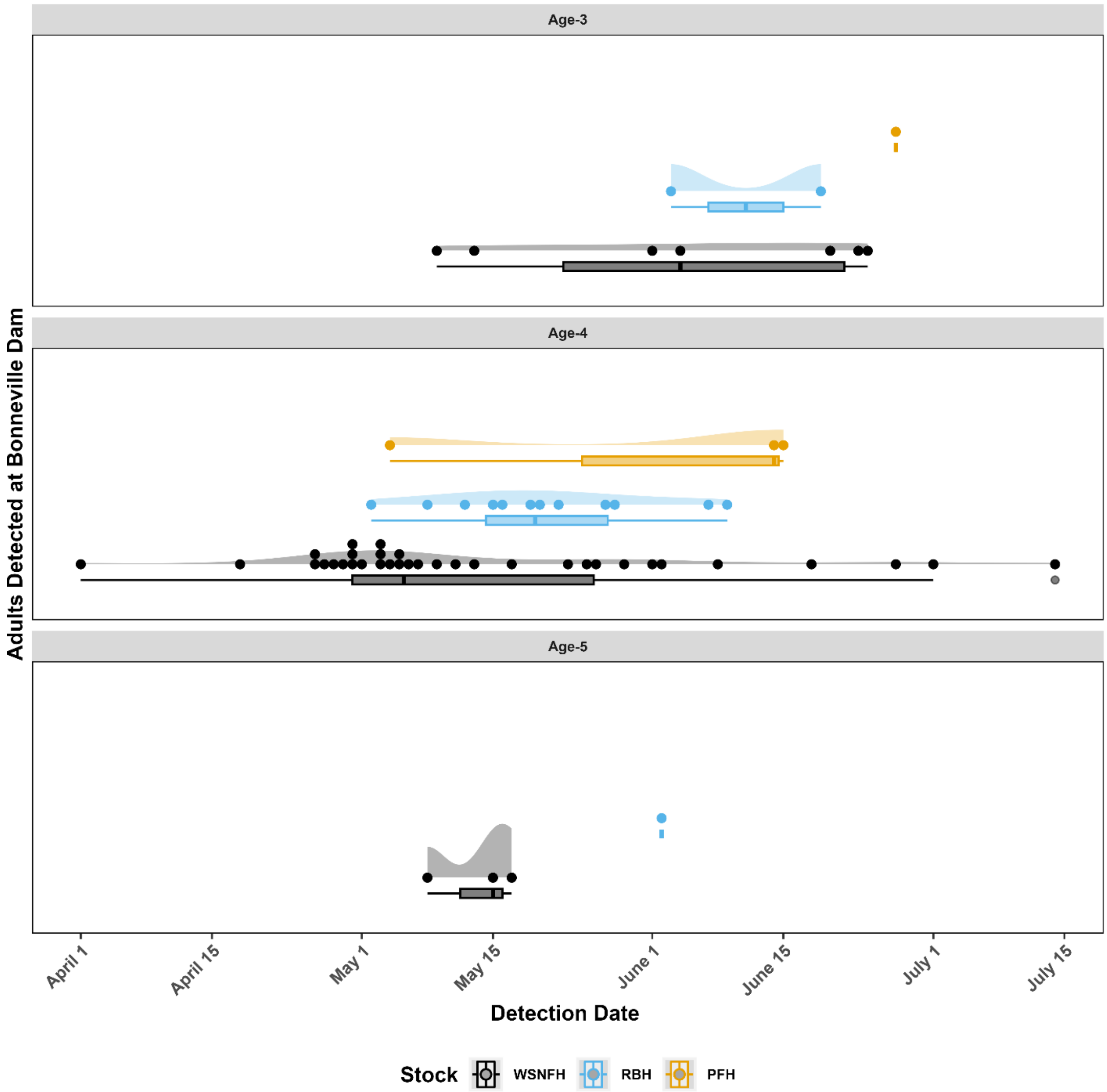

Figure 6. Distribution of returning adult detection dates at Bonneville Dam by age for WSNFH, RBH, and PFH stocks. Boxplots represent the minimum, maximum, median, first quartile and third quartile of detections by day of year. Median detection dates are provided in Table 6, column 6, with the WSNFH+Age-4 condition having the broadest range of return dates. WSNFH-stock fish have the earliest median return dates and PFH stock have the latest.

Adult Returns to WSNFH

Age Composition

Collecting CWTs provides additional information for multiple stocks returning to the hatchery as adults. Each stock released from WSNFH has a unique CWT which can be used to calculate the age at return for each fish. Most of all stocks return to the facility as age-4 adults (WSNFH 87%, RBH 91%, and PFH 88%;Table 7, Figure 7). A Chi-square test of independence between age-at-return and stock did not yield significance.

Table 7. Estimated age structure of BY18 hatchery spring Chinook returns to WSNFH by Warm Springs, Round Butte, and Parkdale stock released at WSNFH.

Stock	Age-2	Age-3	Age-4	Age-5	Est. CWT Return
WSNFH	15	57	533	6	611
RBH	4	15	240	4	263
PFH	7	3	96	3	109

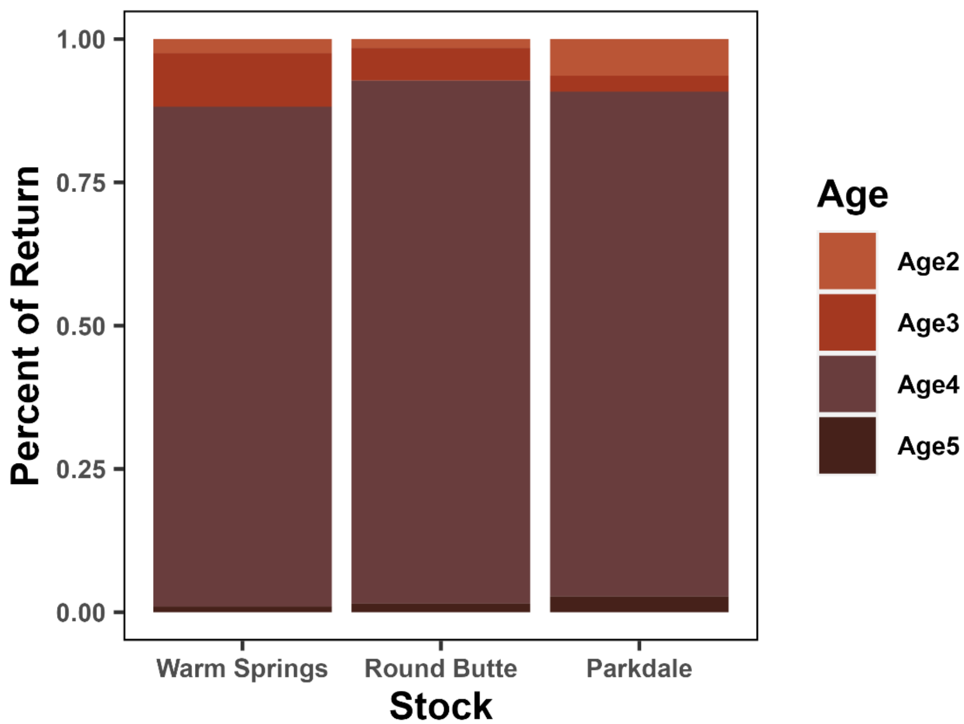

Figure 7. Proportion of age-at-return to WSNFH for stocks reared and released from WSNFH. (see Table 7).

Size at Return

Coded Wire Tags can also provide information for length of returning adult females to the hatchery. There was only one Age-3 female with a length recorded and analysis could not be conducted. For Ages-4 and 5, the mean length of WSNFH-stock was significantly smaller than PFH and RBH-stock (one-way ANOVA $F_{(2, 495)} = 26.75$, $P < 0.001$). There was no statistically significant difference between lengths of PFH and RBH-stock (Table 8; Figure 8).

Table 8. Mean FL (cm; ± 95% CI) of adult females spawned or surplused at WSNFH.

Stock	Age-3	Age-4	Age-5
WSNFH	64 (--)	70 (69 – 70)	72 (68 – 75)
RBH	--	73 (72 – 74)	78 (75 – 81)
PFH	--	73 (72 - 75)	80 (72 – 89)

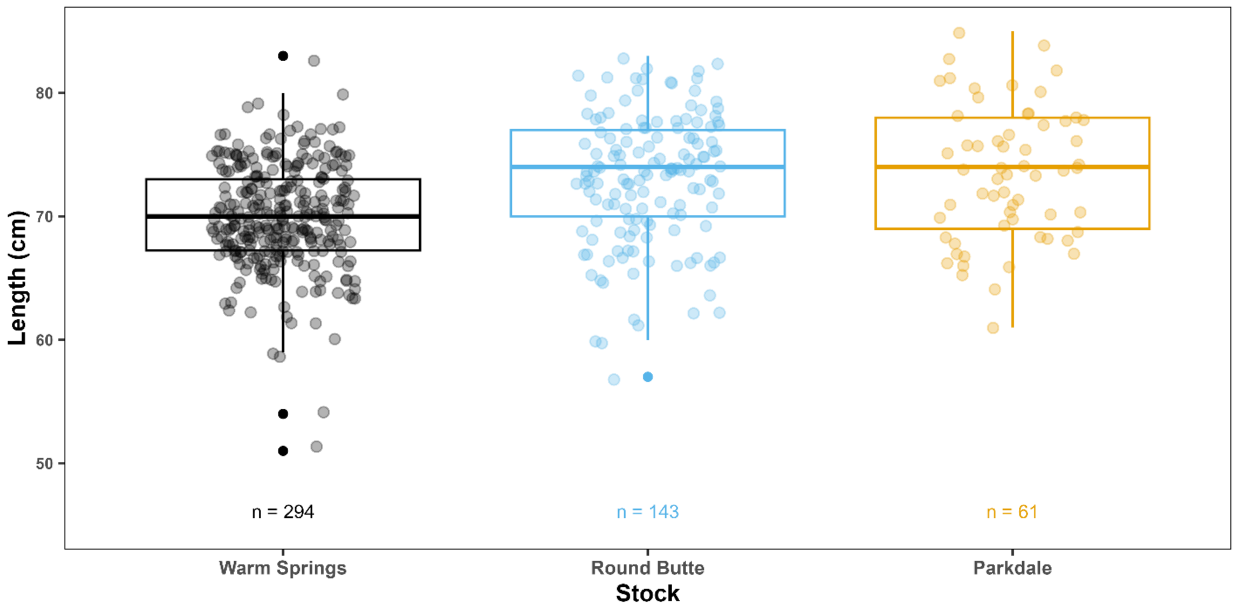

Figure 8. Box plots illustrating the distribution of female fork lengths (cm) for Age-4 and Age-5 fish returning to WSNFH. Boxplots represent the minimum, maximum, median, first quartile and third quartile of female length by stock. Mean length of WSNFH-stock was significantly (*P* < 0.001) lower than PFH and RBH-stock.

Stock Assessment/Smolt-to-Adult Survival Rate

Coded-wire tag recoveries and hatchery returns are used to estimate the contribution of Warm Springs NFH spring Chinook salmon to various fisheries and calculate the Smolt-to-Adult Survival Rate (SAR). Throughout the Columbia Basin, CWT recoveries are recorded and summarized to estimate the number of adult spring Chinook salmon that are harvested or stray to other basins. Fish from PFH-stock were estimated to have contributed to the Columbia River/Freshwater Sport fishery at almost two times the rate of WSNFH-stock (WSNFH 10%, 72/703; RBH 13%, 45/337; PFH 19%, 31/160). An estimated seven WSNFH-stock strayed to the Pelton Fish Trap while five RBH-stock and two PFH strayed to the Round Butte Hatchery as jacks. All other recoveries were reported as harvest or returns to WSNFH. Age-5 totals only include returns to WSNFH due to Regional Mark Processing Center reporting delays (Table 9).

Hatchery performance based on SAR is assessed by calculating the proportion of released smolts to the estimated number of adults that were harvested, strayed, or returned to the hatchery. A Chi-square test of independence was performed to examine the relationship between stock and SAR. The relationship between these variables was significant, ($X^2_{(2, 641,482)}$ = 119.68, P < 0.001). Adults from the WSNFH-stock have a significantly higher SAR than both RBH and PFH-stock while RBH-stock and PFH-stock are not significantly different from one another (Figure 9). Round Butte Hatchery-stock SAR was 0.15% and PFH-stock SAR was 0.12%; stocks were 40% and 52%, respectively, lower than the WSNFH-stock (0.25%).

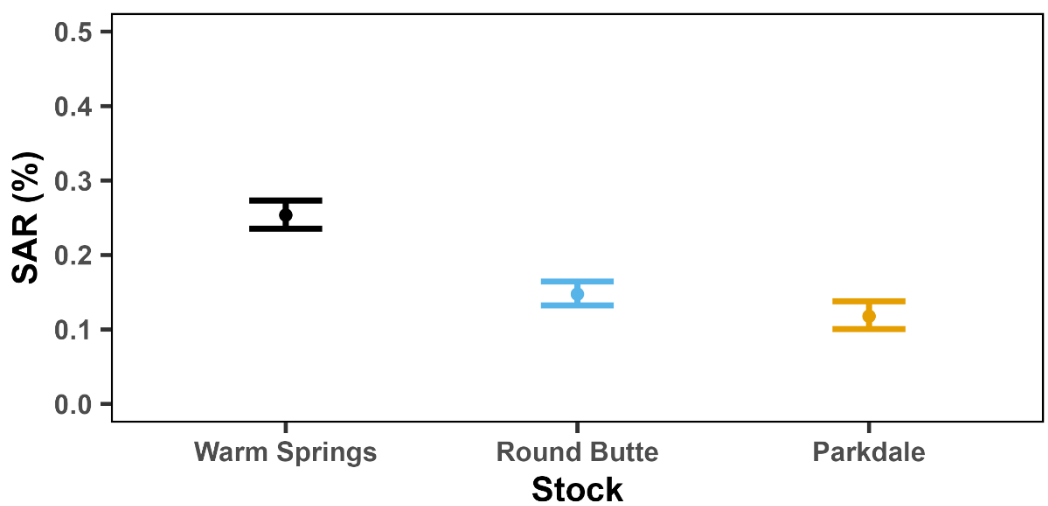

Figure 9. Estimated smolt-to-Adult Survival Rate (SAR) of juveniles reared and released from WSNFH to adult returns by stock (SAR and 95% CI; see Table 9 column 10).

Table 9. Estimated returns by age based on expanded CWT recoveries for three BY18 stocks released from WSNFH. Binomial proportion confidence interval (± 95%) is based on the proportion of released fish to estimated adult returns. Age-5 totals only include returns to the Warm Springs NFH due to Regional Mark Processing Center (RMIS) reporting delays. Data from CRIS RDTS1 File; original downloaded from RMIS TS1 REC Report 20210103.

Stock	Return Year - Age	Ocean Troll	Columbia River/Freshwater Sport	Columbia River Gillnet	Pelton Fish Trap	RBH Hatchery Returns	WSNFH Hatchery Returns	Total	Smolt-to-Adult Survival Rate (± 95%)
Warm Springs Tag Code: 05-63-33 Release: 277,213	2020 -Age 2 (Mini Jack)	0	0	0	0	0	15	15	
	2021 -Age 3 (Jack)	0	6	0	7	0	57	70	
	2022 -Age 4 (Adult)	3	66	10	0	0	533	612	
	2023 -Age 5 (Adult)	--	--	--	--	--	6	6	
	Total	**3**	**72**	**10**	**7**	**0**	**611**	**703**	**0.25% (0.24 – 0.27)**
Round Butte Tag Code: 05-63-34 Release: 228,471	2020 -Age 2 (Mini Jack)	0	0	0	0	0	4	4	
	2021 -Age 3 (Jack)	0	6	9	0	5	15	35	
	2022 -Age 4 (Adult)	0	39	15	0	0	240	294	
	2023 -Age 5 (Adult)	--	--	--	--	--	4	4	
	Total	**0**	**45**	**24**	**0**	**5**	**263**	**337**	**0.15% (0.13 – 0.16)**
Parkdale Tag Code: 05-62-11 Release: 135,798	2020 -Age 2 (Mini Jack)	0	0	0	0	0	7	7	
	2021 -Age 3 (Jack)	0	0	0	0	2	3	5	
	2022 -Age 4 (Adult)	0	31	18	0	0	96	145	
	2023 -Age 5 (Adult)	--	--	--	--	--	3	3	
	Total	**0**	**31**	**18**	**0**	**2**	**109**	**160**	**0.12% (0.10 – 0.14)**

Run Reconstruction

Run reconstruction draws upon methods detailed in Lovtang et al. (2011) to estimate the age distribution and contribution of adults returning to the mouth of the Deschutes River. Annual age estimates are based on the proportion of readable CWT tags sampled at the hatchery (Tables 7 and 10). In 2021, an estimated 79 WSNFH and 4 RBH-stock fish returned as jacks. Tribal creel sampling did not take place in 2021 and we were unable to generate a harvest estimate. In 2022, most fish returned as 4-year-olds with an estimated 27 WSNFH-stock fish harvested during the limited tribal harvest season. Fish that were not harvested or used for spawning were surplused and donated to the Tribes (169 WSNFH, 267 RBH and 82 PFH). The oldest of the fish returned in 2023 as 5-year-olds. Two WSNFH-Stock fish were harvested during the limited tribal season. Fish that were not harvested or used for spawning were surplused and donated to the Tribes (16 WSNFH, 4 RBH and 3 PFH).

Table 10. Run reconstruction by stock of BY18 hatchery spring Chinook salmon from the Warm Springs River. There was no sport harvest in any year and no tribal creel survey in 2021 due to COVID-19 health precautions. Run reconstructions performed 12/16/2021, 1/6/2023, and 12/20/2023.

Location	Hatchery Stock	Disposition	Age 3	Age 4	Age 5	Total
To WSNFH	WSNFH	Upstream	0	0	9	9
		Surplus	0	169	16	178
		Mortality	0	301	1	302
		Spawned/Green	79	164	3	167
	RBH	Upstream	0	7	0	7
		Transfer to RBH	4	0	0	4
		Surplus	0	267	4	271
		Mortality	0	1	0	2
	PFH	Surplus	0	82	3	85
Harvest	WSNFH	Tribal	--	27	2	29
	RBH	Tribal	--	0	0	0
	PFH	Tribal	--	0	0	0
Total	WSNFH		79	661	31	771
Estimated	RBH		4	275	4	283
Return	PFH		0	82	3	85

External Mark Accuracy by Stock

Each stock received a unique CWT code and differential fin marks (ADLV/ADRV/AD) to identify their stock of origin when they returned to the hatchery as adults. Based on visual identification of adult returns at the hatchery and subsequent reading of coded-wire tags there was an overall 11% error rate in visual identification of stocks by fin marks. Of the total 92 visual call errors, 85 (92%) were RBH and PFH stocks misidentified as WSNFH stock (Table 11).

- Error rate was lowest for Warm Springs fish (2%), of the 498 coded-wire tagged Warm Springs fish that returned as adults, 491 (99%) were identified correctly (AD clip); 7 (1%) were misidentified as Round Butte (ADLV clip) and zero were misidentified as Parkdale (ADRV clip). The seven incorrectly identified WSNFH-stock fish were surplused.
- Error rate for Round Butte fish was (24%), of the 222 Round Butte coded-wire tagged fish that returned as adults, 168 (76%) were identified correctly (ADLV clip); 9 (4%) were misidentified as Parkdale (ADRV clip) and 45 (20%) were misidentified as Warm Springs (AD clip) fish. Five males and three females were spawned, eleven were surplused, and twenty-six died in the brood ponds.
- Error rate was highest for Parkdale fish (35%), Of the 89 Parkdale coded-wire tagged fish that returned as adults, 58 (65%) were identified correctly (ADRV clip); 8 (9%) were misidentified as Round Butte fish (ADLV clip), and 23 (26%) were misidentified as Warm Springs (AD clip) fish. Three males were spawned, six were surplused, and fourteen died in the brood ponds.

Table 11. External mark identification accuracy for BY18 (release year 2020) Warm Springs, Round Butte, and Parkdale stock returning to the WSNFH as adults. Data retrieved from CRiS Biosample File 3/12/2024.

CWT Stock	Visual Call AD Only WSNFH	Visual Call ADLV RBH	Visual Call ADRV PFH	Total Return	Incorrectly Identified by External Mark	Error Rate (Incorrectly Identified/Total CWT Return)
WSNFH	**491**	7	0	498	7	2%
RBH	45	**168**	9	222	54	24%
PFH	23	8	**58**	89	31	35%
Total	**559**	**183**	**67**	**809**	**92**	**11%**

DISCUSSION

All three stocks reared and released from WSNFH provided adult fish for harvest opportunities in the Deschutes and Columbia River Basins and were distributed to on-reservation tribal members. However, we observed differences among these three stocks when we compared their survival and return migration timing. Many factors such as pre-release size, juvenile growth rate, precociousness, and downstream migration rate may contribute to variations. Our evaluation compared the on-station juvenile performance for all three stocks (e.g., size, growth, mortality) and found it was similar among the three stocks. Differences between the stocks began to appear off-station after release when juvenile WSNFH-stock fish had a higher survival rate to Bonneville Dam. These differences persisted as WSNFH-stock fish returned as adults earlier in the year and at a higher rate, suggesting characteristic differences between these stocks that become apparent in the river and ocean environments.

Juvenile Performance

Larger fish are inversely related to predation rate (Claiborne et al. 2011), have better feeding opportunities, and migrate faster downstream (Zabel and Achord 2004; Beckman et al. 2017). Our findings suggest that mean fish lengths among stocks did not significantly impact adult return rates. Despite similarities in length between WSNFH-stock and PFH-stock fish, the latter exhibited delayed returns and lower SAR. Conversely, RBH-stock fish, although smaller than PFH-stock fish, displayed earlier returns and a higher SAR. These results underscore the complexity of factors influencing adult return rates beyond mere size differences among stocks.

The significant difference in mean weight observed among WSNFH, RBH, and PFH-stock fish before release suggests potential advantages for WSNFH-stock fish. With WSNFH-stock fish exhibiting the highest SAR, it is plausible that their greater weight contributed to increased resilience against starvation and enhanced ability to swiftly migrate downstream compared to RBH and PFH-stock fish.

Growth rate has also been shown to affect SARs; elevated growth rates produce larger smolts with higher rates of survival than smaller smolts (Martin and Wertheimer 1989; Beckman et al. 1999; Zabel and Achord 2004). However, elevated growth rates may also stimulate early maturation in males (Larsen et al. 2004). We observed similar growth rates and estimated a precocity rate of less than 0.5% with no dependence on stock.

The condition factor (a function of length and weight) for all three stocks followed a pattern of growth comparable to "the wild fish template," relatively high growth in the summer, reduced growth through the winter, and increased growth again in the spring. This seasonal change in growth before release has been correlated with higher SARs (Beckman et al. 2017). The condition factor did not significantly differ between stocks; it was highest at the end of the summer and dropped through December when fish were on a limited diet due to cold temperatures. Condition factor began to increase again in March before their April release amid warming temperatures.

While there were statistical differences in on-station mortality rates among stocks, on-station mortality was very low for all stocks, less than 0.5% from marking to release. Mortality peaked for all stocks in the summer. This could indicate a common environmental factor such as warm water temperatures affecting all stocks rather than specific factors unique to individual stocks. While warm water temperatures during the summer months (above 17° C) may contribute to a higher growth response, prolonged exposure to warmer temperatures can cause stress and reduce their resilience to additional stressors such as disease (Sullivan et al. 2000; Richter and Kolmes 2005). Further stress can come from ventral fin marking operations to differentiate stocks. While the lack of a ventral fin does not appear to impair salmonid adult returns (Wertheimer et al. 2002; Bumgarner et al. 2009), psychological disturbance, confinement, and handling increases cortisol levels for a short time (Sharpe et al. 1998).

The dynamics of water temperature, growth rate, condition factor, and precocity exhibited consistent patterns across all stocks. External factors such as environmental conditions or management practices beyond the controlled on-station environment may manifest among stocks after their release. Smolt migration timing and survival may be a useful indicator for predicting ocean survival and subsequent adult returns to the hatchery (Scheuerell et al. 2009). While there was no significant association between stock and detection rate or travel time to Bonneville Dam, median juvenile survival estimates to Bonneville Dam revealed a significant association between stock and survival rate, with the highest survival observed for WSNFH-stock fish.

Adult Returns

Columbia River spring Chinook migrate upstream in April and May when river temperatures are lower and hold over summer in cold water refuges or at the hatchery before spawning. Detections at Bonneville Dam indicated that WSNFH-stock returned at a higher rate than RBH and PFH-stock fish which may be due to better juvenile survival of WSNFH-stock. Parkdale Fish Hatchery-stock passed Bonneville Dam significantly later than WSNFH-stock fish. In 2022, the median passage date at Bonneville Dam for Age-4 WSNFH-stock was May 9, RBH was May 19, and PFH was a month later on June 14. Parkdale Fish Hatchery is located in the Hood River Basin, which is closer to the Pacific Ocean and has cooler water temperatures relative to the Deschutes Basin (EPA 2021). One of the goals of Parkdale Fish Hatchery is to re-establish and maintain a naturally sustaining spring Chinook salmon population in the Hood River sub-basin. The initial source for the Parkdale Fish Hatchery were Deschutes stock spring Chinook salmon. Since 2005, their broodstock consists of adults returning to Hood River from late July through spawning in October (CTWS and ODFW 2017). The later return of PFH-stock adults indicates the hatchery is attaining a broodstock that is better adapted to the specific conditions of the Hood River which are different from the Warm Springs River (i.e., migration and spawn timing, temperature tolerance).

The stock assessment evaluated the contribution of adult returns to various fisheries, utilizing the SAR to gauge the overall performance of each stock. In terms of survival, the WSNFH-stock demonstrated significantly higher success compared to RBH and PFH-stock. For example, for every 100,000 juvenile fish released, approximately 250 WSNFH, 150 RBH, or 120 PFH-stock fish will return as adults. Low survival rates are influenced by a multitude of factors, such as susceptibility to predators or harvest, environmental stressors, availability of food, migratory path, or genetic adaptations. The low SAR and increased harvest rate of PFH-stock adults in the Columbia River may be attributed to our observation that PFH returned to Bonneville Dam later in the year; their protracted presence in the lower river (August) could overlap with the fall Chinook fishery and lead to a greater susceptibility of harvest opportunities.

Adults that returned to the mouth of the Deschutes River were harvested by the Tribes or returned to the WSNFH where they were surplused (donated to the Tribes or disposed of), held for brood, (spawned, green, or pre-spawn mortalities), or transported elsewhere. While returning WSNFH-stock females had a higher SAR, they were significantly smaller than RBH and PFH-stock. Fecundity is strongly associated with female length in that larger females have a greater number of eggs and thus higher reproductive potential (Malick et al. 2023). Fecundity can also be influenced environmental conditions, food availability, and individual genetics. Fish from RBH and PFH-stock that survived the migration back upstream to WSNFH may have been more robust, but WSNFH-stock may be better adapted to the conditions in the Warm Springs River.

The accuracy of identifying the stock origin of returning adults based on external fin marks presents challenges, with an overall 11% error rate observed. Most of these visual call errors (92%) potentially stem from the regeneration of ventral fins. This discrepancy raises concerns, notably as only 65% of PFH-stock fish were correctly identified by visual mark, resulting in the inadvertent spawning of three males with WSNFH-stock females. Such misidentifications can have substantial outcomes, including the inadvertent transportation of fish upstream for natural spawning or unintentional spawning with wild broodstock at WSNFH. Conversely, the uncertainty associated with partial marks may lead to the unnecessary surplus of WSNFH-stock fish, highlighting the importance of accurately recognizing stock origin for the effective management of adult returns.

Risks, Recommendations, and Logistics

The current strategy for the Warm Springs NFH is closely linked to maintaining the genetic integrity of spring Chinook salmon native to the Warm Springs River. In recent years, the CTWSRO has implemented a wild spring Chinook supplementation program in the Warm Springs River. Some wild spring Chinook salmon are held at the hatchery for spawning and rearing, while some adult hatchery fish are transported upstream to the native spawning grounds. In addition, the hatchery has spawned wild with WSNFH-stock hatchery fish to prevent divergence among the two populations. The resulting crossed progeny have been incorporated into both the hatchery program and into the wild supplantation program. While the increased adult returns bring harvest benefits and support tribal distribution, differences among stock performance should be considered when importing non-WSNFH stock fish during years of shortfall.

Moreover, rearing and releasing RBH and PFH stock spring Chinook at WSNFH requires differential marking for juveniles to segregate them from the WSNFH population when they return as adults. It is important to recognize the potential risks associated with segregated rearing and sorting adult returns along with additional logistical demands to mitigate for these risks (Table 12). Such considerations are vital for maintaining the genetic integrity and overall health of spring Chinook salmon populations in the Warm Springs River Basin.

Table 12. Risks, Recommendations and Logistical considerations for rearing and releasing RBH and PFH stock fish at WSNFH.

Risk	Recommendation	Logistics
Potential mislabeling or mixing of stocks before AD/CWT operations (eggs, tanks) or mixing of stocks during transport to Little White Salmon NFH before differential fin marks (LV/RV) are applied.	Clear communication during moves and transfers. Label stocks in two locations (i.e., label in tank and outside of tank, tape, flag, plastic disc, etc.). Regularly QA/QC CRiS database to ensure accuracy, schedule check-ins between Hatchery and CRFWCO each week.	Segregate rearing until fish are both CWT and ventrally marked (at WSNFH nursery and ponds, during transport, and at LWSNFH). Schedule time for QA/QC.
Introduction of diseased or recently sick or stressed fish to WSNFH population. Infection of imported stock with disease from WSNFH-stock.	Work with donor hatchery fish pathologist to assess fish health before transfer. Take biosecurity measures to reduce opportunities for cross contamination. Assume imported stocks are carriers of *Flavobacterium pychrophylum* and *Renibacterium salmoninarum*	House imported stock far away from the WSNFH-stock, preferably in the third bank.

Risk	Recommendation	Logistics
Stress and injury may result from additional ventral fin marking operations. Potential misclipping of ventral fin (i.e., removing the left ventral fin instead of the right ventral fin).	Carefully conduct handling and tagging operations with an experienced crew. Hatchery, CRFWCO and Fish Health staff coordinate early in the year to coordinate marking and tagging schedules with feeding regimes and to ensure adequate time for recovery before/after transport and release.	Schedule additional ventral marking while fish are at LWSNFH, ensure correct mark is applied. Order separate CWT tag codes for each stock by January. Proportionally represent all stocks during PIT tagging.
Inaccurate recognition of LV/RV external marks. LV/RV may regenerate and be falsely identified as WSNFH-stock. LV/RV may be falsely applied to WSNFH-stock leading to loss of potential spawning production.	Surplus returning adults with ADLV/RV at catch pond, do not mix into brood ponds. Read CWTs before spawning. Record visual mark of all fish when snout is collected. Cross reference visual marks (Fish Removal File) with CWT (Biosample File) in CRiS to assess accuracy. Cull eggs if necessary.	Set up mobile snout dissection area and microscope to read CWT before spawning, additional spawning time needed to process CWTs. Include fish health number with biosample to identify female/male's eggs that were inadvertently spawned with PFH or RBH. Check with marking crew to assess clip quality post marking.
LV/RV marked fish could be requested to be transferred and spawned at their hatcheries of origin. The CWT returns to WSNFH may be reported incorrectly as returns to RBH or PFH at the end of the season.	Include reporting responsibilities before fish transfer request is approved.	Coordinate with all Hatcheries and agencies requesting a fish transfer.

Risk	Recommendation	Logistics
Unintentional mixing of stocks during spawning, potentially leading to reduction in fitness of Warm Springs population. This risk increases with the number and frequency of egg/juvenile transfers from RBH and PFH stocks, this risk is compounded by having a wild supplementation program taking place on station.	Use differential CWTs and fin marks (LV/RV) to identify stock origin. Evaluate feasibility of genotyping broodstock sometime prior to eggs from all crosses being pooled. Pedigree reconstruction could then be used to identify inadvertently spawned Round Butte or Parkdale fish, and their eggs could be handled accordingly. Surplus returning adults with LV/RV at catch pond, do not transport or mix into brood ponds. Read CWTs before spawning, especially wild origin x WSNFH mix fish. Cull eggs if necessary. Develop Hazard Analysis Critical Control Point (HACCP) Plan to identify critical points of risk, their limits, and monitoring procedures to prevent WSNFH-stock fish from becoming less fit in their natural environment. Do not rear stocks from other hatchery sources every year. Place lowest priority on accepting PFH-stock fish.	Set up mobile snout dissection area and microscope to read CWT before spawning, additional spawning time needed to process CWTs. Include fish health number with biosample to identify female/male's eggs that were inadvertently spawned with PFH or RBH. Discuss egg/juvenile transfers with HET including regional geneticist before requesting or planning transfers. Spawn all fish – genotype later and cull if necessary. If Round Butte Hatchery would like to incorporate Warm Springs stock into their population, they will need an MOU with long term goals.
Natural spawning by hatchery-origin fish from a different hatchery program.	Do not release ADLV/RV fish upstream. Separate out returning adults with ADLV/RV before upstream transport.	Additional time to check adult fish for external ADLV/RV marks when the catch pond is being emptied.

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