Dworshak National Fish Hatchery Spring Chinook Salmon Density Study

Final Report

William Young
Nez Perce Tribe
&
Doug Nemeth & John Erhardt
USFWS Idaho Fish and Wildlife Conservation Office

Matt Campbell and Craig Steele
Idaho Fish Department of Fish and Game
Eagle Fish Genetics Laboratory

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EXECUTIVE SUMMARY

Dworshak National Fish Hatchery (DNFH) conducted a three-year trial to assess the impacts of increased spring Chinook rearing densities on adult returns. Although total adult returns were the final and most important metric, a variety of juvenile and adult life history metrics were also evaluated in a comparison between normal (control) and high (treatment) rearing densities. Chinook salmon at DNFH were reared in 1,280 ft^3 (8 x 80 x 2) raceways in B-bank fed by 1,250 gallons/minute (gpm) water consisting of 750 gpm reuse water from A-bank raceways and 500 gpm fresh water. The study design consisted of three replicates of three raceways at the standard (control – CL) density and three replicates of two raceways at a higher treatment (high density – HD) density with approximately equal numbers of juveniles in each replicate. This resulted in approximately 45,000 smolts/raceway in the CL group and 65,000 smolts/raceway in the HD treatment with final density indices of the CL and HD groups at 0.24 and 0.36, respectively. No significant differences in total adult recoveries, recovery rate (adults recovered/smolts released) or recoveries per raceway were identified between CL and HD releases over three brood years. The higher number of smolts released from the HD raceways returned significantly more adults per raceway, with a three-year average increase of 37% more recoveries. Given that the number of smolts released from the HD treatment group was 44% greater than that of the CL group, the overall recovery rate and recoveries per raceway were slightly diminished in the HD versus the CL groups, suggesting slightly reduced survival from the HD raceways. Adult recoveries from the HD groups for two brood years were similar (2012) and slightly higher (2014) than that of the CL groups. Recoveries from the HD groups for brood year 2013 was significantly lower than those from the CL groups and this largely explained the overall recovery rate differences observed for all three brood years combined. There was no significant difference in juvenile growth, size at release, disease incidence, mortality, or survival to Lower Granite Dam between the groups. Overall based on the three years of evaluation, increasing Chinook salmon rearing densities from 45,000 fish per raceway to 65,000 fish per raceway in the DNFH B-bank raceways would increase overall returns to the Snake River basin by approximately 1,000 adults given the average rate of return.

INTRODUCTION

The spring Chinook salmon production program at Dworshak National Fish Hatchery (DNFH) began in 1982 as part of the Lower Snake River Compensation Plan (LSRCP) to help mitigate for the loss of spring Chinook salmon from the Clearwater River due to the construction of the four lower Snake River hydropower facilities downstream from Lewiston, Idaho (U.S. Army Corp of Engineers-USACE 1981). The mitigation goal for the program is to return 9,135 adults above Lower Granite Dam annually as well as provide 36,540 adults annually for harvest downstream of Lower Granite Dam (LGR) in the Columbia and lower Snake rivers. In the original planning documents, the agencies estimated that Dworshak NFH would need to release 1.05 million smolts with a smolt-to-adult return (SAR) of 0.87 to reach these above LGR return goals (USACE, 1975). Additional information on the development and status of the LSRCP program can be found in Herrig (1990) and U.S. Fish and Wildlife Service (2020).

A program review conducted in 2011 (ISRP, 2011) revealed that the LSRCP spring Chinook salmon program rarely met the mitigation goals, and the DNFH program only met mitigation goals once from 1996 through 2009. With continued concern of the Clearwater River Basin co-managers and LSRCP over the inability of the program to meet the established adult mitigation goal, the Dworshak Complex Hatchery Evaluation Team (DCHET) conducted a detailed review of the production program to identify where improvements to fish cultural practices could be made.

Because DNFH Chinook have exhibited consistently high life stage survivals in the hatchery, the DCHET concluded that minor improvements to fish cultural practices had limited potential to significantly increase returns. An alternative option was to consider increasing total smolt production to increase returns. With limited rearing space and water available for additional rearing of LSRCP spring Chinook salmon, it was proposed to increase production by increasing the density of smolts using the available rearing space and water (Dworshak Complex Hatchery Evaluation Team, 2013). The DCHET developed a study designed to determine the maximum effective carrying capacity of spring Chinook salmon in raceways at DNFH. The initial strategy was to implement incremental increases in rearing density every three years. By the time the study design was completed in 2013, the co-managers agreed to conduct only the first three-year experiment using brood years 2012- 2014 (BY2012, BY2013 and BY2014). This study, utilizing half of the available LSRCP-owned raceways, compared raceways of standard (control) and high (treatment) densities in a replicate control/treatment design (Dworshak Complex Hatchery Evaluation Team, 2013).

METHODS

Study Design

Dworshak NFH has thirty 8’ x 80’ x 2’ concrete raceways in two separate “banks”, A-bank and B-bank, each bank with 15 raceways dedicated for Chinook salmon rearing. Under normal production protocols, smolts in all 30 raceways are reared to 20 fish per pound (fpp) with a Density Index (fish weight/area) of approximately 0.25 at the time of release. The density study experiment was conducted in B-Bank. A-bank raceways were not used in the experiment. B-bank water flow totaled 1,250 gpm water consisting of 750 gpm reuse water from A-bank raceways and 500 gpm fresh water (Table 1). The density experiment occurred over three brood years (BY) 2012, 2013, and 2014. The standard rearing density of 45,000 fish per raceway was set as the control (CL). The high density (HD) treatment groups’ density was increased by 20,000 smolts to 65,000 fish per raceway. The CL groups were reared in 9 raceways of three uniquely tagged replicates of three raceways each. The HD groups were reared in 6 raceways of three uniquely tagged replicates of two raceways each (Figure 1). Treatment and control groups were not randomly assigned but followed the layout in Figure 1. This design allowed for approximately equal numbers of fish among replicates and between treatments (390,000 Treatment vs. 405,000 control). All fish were reared to 20 fpp with final rearing density targets of 0.25 and 0.35 for the CL and HD groups, respectively. Flow index (fish weight/flow [L/minute]) targets varied due to loading weight differences between CL and HD raceways.

B-Bank Raceways

High Density (Treatment)						Standard Density (Control)								
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
HD1	HD1	HD2	HD2	HD3	HD3	CL1	CL1	CL1	CL2	CL2	CL2	CL3	CL3	CL3

Figure 1. Organization of the density experiment in the spring Chinook salmon B-Bank raceways at Dworshak National Fish Hatchery. Uniquely tagged replicate groups were designated as High Density (HD1 – HD3; 2 raceways per replicate) and Control (CL1 – CL3; 3 raceways per replicate).

Table 1. Rearing profile of the High Density and Control groups of spring Chinook salmon in the density experiment at Dworshak NFH. Flow rate was measured in gallons per minute (gpm) and rearing density is the number of fish per raceway.

Experimental Unit	Replicates/ raceways	Flow Rate (gpm)	Rearing Density	Density Index	Flow Index
High Density	3/6	1,250[1]	65,000	0.35	0.28
Control	3/9	1,250[1]	45,000	0.25	0.19

[1] The flow into B-Bank was 750 gpm re-use from A-Bank and 500 gpm fresh water.

Juvenile Metrics: Four juvenile metrics were compared to evaluate juvenile performance between the test groups for BY2012, BY2013 and BY2014: 1) mortality occurring in the hatchery, 2) growth rate occurring in the hatchery, 3) size-at-release and, 4) post-release survival from release to Lower Granite Dam (LGR) and Bonneville Dam (BON).

Mortality was calculated as the number of mortalities/number of fish being reared for each month from October – March. Total and average percent mortality were calculated in three control and three treatment raceways.

Length, weight and condition factor (CF= weight/length^3) were measured from a random sample of 300 fish per raceway each month from October – March to estimate growth rate of control and high-density rearing groups. Size at the final sampling time in March was used to represent the size at release. Results were compared using a two-way analysis of variance (ANOVA; year and treatment).

Juveniles from low- and high-density groups were representatively PIT-tagged prior to release to estimate survival to LGR and BON. Approximately 5,000 – 7,000 fish in two or three CL and two HD raceways were PIT tagged for brood years 2012 – 2014. Post-release survival was estimated using the *SURvival under Proportional Hazards (SURPH)* model (Lady et al. 2013).

Parentage-based tagging - All smolts reared and released were tagged with Parentage Based Tagging (PBT) methods (Steele et al. 2019). A baseline group of parents was developed by genotyping all males and females spawned at DNFH in each brood year. This parental baseline was used to assign all returning adult progeny to their parental spawning cross. Progeny from each spawn cross were tracked from spawn, to incubation, to replicate, to ensure that the integrity of the PBT family groups was maintained and adult recoveries could be assigned to CL or HD replicates with a high degree of certainty.

Parentage Assignments - Parentage was performed on returning offspring from CL and HD replicates using the software program SNPPIT v1.0 (Anderson 2010) with the broodstock as the parental baseline. SNPPIT performed parentage analysis using a combination of exclusionary and likelihood-based methods and has previously demonstrated to yield low type I and type II errors.

Sampling Returns - Returns from CL and HD groups from brood years 2012 – 2014 were identified in return years 2015 – 2019 (Table 2). Fin tissue samples were collected from returning fish sampled at three locations in the Snake Basin: 1) at the LGR adult trap from fish ladder; 2) during brood stock spawning at DNFH from adult collections and; 3) from returns in the Idaho Fish and Game (IDFG) sport fishing creel from harvested chinook salmon. The collections at the LGR trap were from a random sample of all returning Chinook salmon systematically captured (Harmon, 2003). All samples were analyzed using PBT and assigned to the release hatchery, release site and brood year of origin. Sampled fish identified as fish released from DNFH were further identified as being part of general production (A-bank) or identified from a specific replicate from the density experiment and are hereafter referred to as "recoveries".

Although the sample rate of fish trapped at LGR is known (generally around 20%) and could be expanded to estimate total returns, uncertainties around the sampling rates of the DNFH trapped/spawned fish and in the IDFG sport fishing creel would reduce precision of expanded results and introduce variation in the statistical tests. Most importantly, results of this treatment/control experiment were determined by a direct comparison of fish recoveries between the treatment and control groups, and not the magnitude of adult returns. Therefore, we did not attempt to estimate or expand total returns to the Snake River basin or calculate a smolt-to-adult return (SAR) but relied on a comparison of total recoveries from the three sampling points (LGR, DNFH, creel) under the assumption that CL and HD fish were recovered at the same rate and at their respective proportion in the returning population. The study was designed so that the number of smolts released in the CL and HD groups for each brood year were approximately equal.

Return years occurred over three consecutive years for each brood year (Table 2). Three metrics were used to evaluate the CL and HD groups: 1. Total recoveries; 2. Recovery rate and; 3. Recoveries/raceway.

Recovery rate was calculated as total recoveries divided by the number of juveniles released for each replicate of either the CL or HD group. Because PBT assignments tracked progeny to a replicate and not an individual raceway, recoveries per raceway was calculated as the number of fish recovered from each replicate divided by the number of raceways per replicate (average return per raceway).

Table 2. Brood years, release years and return years of 1-, 2- and 3-Ocean Chinook from the density study at Dworshak National Fish Hatchery.

Brood Year	Release Year	Ocean Age		
		1-Ocean	2-Ocean	3-Ocean
2012	2014	2015	2016	2017
2013	2015	2016	2017	2018
2014	2016	2017	2018	2019

DNA Extraction and SNP Genotyping – Collected fin tissue was preserved by placing it on a sheet of Whatman© paper to dry. Biological data including sex, date sampled/spawned, tag and mark information, length and cross information was recorded and matched to a genetic identification number.

Genomic DNA was extracted using the Nexttec Genomic DNA Isolation Kit from XpressBio (Thurmont, Maryland). Samples were genotyped with a standardized set of 292 Single Nucleotide Polymorphic (SNP) markers specifically developed to provide high resolving power for PBT of Chinook salmon in the Snake River basin (Steele *et al*. 2011) and a Y-specific allelic discrimination assay that differentiates sex in Chinook salmon. Genotyping was performed using Fluidigm 96.96 Dynamic Array IFCs (chips). Chip and genotyping protocols can be found in Steele *et al*. (2011). Following PCR Chips were imaged on a Fluidigm EP1 system and analyzed and scored using the Fluidigm SNP Genotyping Analysis Software version 3.1.1.

RESULTS

Juvenile Rearing

The CL replicates were reared in three raceways ranging from 43,075 to 47,896 smolts per raceway and the HD replicates were reared in two raceways ranging from 64,309 to 67,317 smolts per raceway (Table 3). Total release numbers for CL and HD groups differed by about 2,400 to 27,000 fish with an average of 3.5% fewer fish in the HD compared to the CL replicates. As a result, an average of 44.8% more smolts per raceway were reared in the HD raceways compared to the CL raceways (Table 3).

Table 3. Average and total number of juvenile Chinook salmon in control (CL) and high density (HD) groups released in brood year 2012, 2013, and 2014.

Brood Year	Group	Total Released	Average/replicate	Ratio of No. per Replicate[a]	Average/raceway	Ratio of No. per Raceway[a]
2012	CL	387,675	129,225	0.6%	43,075	50.9%
	HD	390,108	130,036		65,018	
2013	CL	431,064	143,688	-6.3%	47,896	40.5%
	HD	403,902	134,634		67,317	
2014	CL	405,324	135,108	-4.8%	45,036	42.8%
	HD	385,854	128,618		64,309	
			Averages	-3.5%		44.8%

[a] Ratio of number per replicate or raceway for CL and HD groups calculated as: ((HD/CL)-1) x 100

Juvenile Size at Release

Juvenile growth rate differences were determined by collecting monthly length, weight and CF measurements from October – March. Because monthly growth rates were not significantly different between the groups (data not shown), we only compared juvenile size in March, providing a comparison of size-at-release. A two-way ANOVA revealed significant differences among years for all three metrics ($p < 0.05$) and a single significant difference between the CL and HD groups in CF in BY2012 ($p < 0.01$; Table 6). Although a single statistically significant difference in CF was observed in one year, the consistent lack of differences between the two groups suggested that it was not biologically meaningful and no size-at-release differences were observed.

Although size at release did not meet the target of 20 fpp for any brood year, there was no significant difference in size between the HD and CL groups. FPP ranged from 21.3 in the HD group of BY2013 to 24.9 in the CL group of BY2012. The average FPP indicated that the CL fish were smaller in BY2013 and larger than HD fish in BY2012 and BY2014 (Table 4).

Final density index averaged 0.24 in the CL group and 0.36 in the HD group (Table 4), similar to the density targets of 0.25 and 0.35. Flow index averaged 0.19 in the CL group and 0.28 in the HD group (Table 4).

Table 4. . Mean fork length (FL), weight, condition factor (CF), fish per pound (FPP), final density index, density and flow index for juvenile Chinook salmon reared at control (CL) and high (HD) densities. Standard error – SE; millimeters - mm; grams – g; Kilograms – kg; cubic meters – m^3; liters – L; minutes – min. *Significant difference ($p < 0.01$).

Brood Year	Group	Mean (SE) FL (mm)	Mean (SE) Weight (g)	Mean (SE) CF	FPP	Total Weight (kg)	Density Index	Density (kg/m^3)	Flow index (kg/L/min)
2012	CL	115.9 (1.9)	18.2 (0.8)	1.148* (0.004)	24.9	786.8	0.23	21.7	0.17
	HD	117.6 (1.1)	19.1 (0.5)	1.163* (0.003)	23.7	1240.1	0.36	34.2	0.26
2013	CL	121.6 (2.6)	20.2 (1.5)	1.105 (0.017)	22.6	957.9	0.24	26.4	0.20
	HD	124.2 (3.0)	21.4 (1.4)	1.103 (0.010)	21.3	1438.3	0.38	39.6	0.30
2014	CL	120.8 (2.9)	20.2 (1.3)	1.118 (0.019)	22.5	910.9	0.24	25.1	0.19
	HD	118.8 (0.7)	19.1 (0.7)	1.105 (0.014)	23.7	1228.7	0.35	33.8	0.26

Hatchery Mortality

Total and average percent juvenile rearing mortality observed from October – March revealed no significant difference between the CL and HD groups (Table 5). Statistical analysis using a two-way ANOVA indicated significant differences among brood years ($p < 0.001$), but not between CL and HD groups ($p = 0.272$). Mortality was consistently higher in BY2014 relative to the other brood years for all replicates and all raceways.

Table 5. Total percent and average mortality for juvenile Chinook salmon reared at control (CL) and high (HD) densities from brood years 2012 – 2014. Total mortality and percent mortality were calcuated from October to March in three CL and three HD raceways.

Brood Year	Group	Raceway	Mortality Total	Mortality Percent	Mortality Mean (SE)
BY2012	CL	B22	93	0.217	0.285 (0.034)
		B27	140	0.321	
		B30	138	0.317	
	HD	B17	133	0.203	0.185 (0.018)
		B19	130	0.202	
		B20	97	0.150	
BY2013	CL	B22	324	0.690	0.506 (0.096)
		B27	221	0.460	
		B30	176	0.367	
	HD	B17	244	0.365	0.547 (0.204)
		B19	219	0.322	
		B20	645	0.955	
BY2014	CL	B22	2318	5.204	3.89 (0.715)
		B27	1306	2.744	
		B30	1735	3.721	
	HD	B17	2650	4.066	2.818 (0.632)
		B19	1332	2.018	
		B20	1546	2.371	

Juvenile Survival to Lower Granite and Bonneville dams

Post-release PIT tag detections at Lower Granite (LGR) and Bonneville (BON) dams estimated generally high survival of both the CL and HD release groups. Survival to LGR ranged from 73.5% to 85.6%, and survivals were similar between the CL and HD groups for each brood year (Table 6). Survival to BON was lower with no differences in survival between the groups in BY2013 and BY2014 (Table 6). Survival to BON for BY2012 demonstrated high standard errors for both groups and was not reliably accurate for a comparison.

Table 6. Estimated mean survival to Lower Granite (LGR) and Bonneville (BON) dams for PIT-tagged spring Chinook salmon juveniles reared at control (CL) and high density (HD) at Dworshak National Fish Hatchery. Estimates were generated using the SURvival under Proportional Hazards (SURPH) model. Standard errors in parenthesis below each survival estimate.

Brood Year	Density	LGR	BON
BY2012	CL	79.7 (0.0169)	NA[a] (0.3275)
	HD	85.6 (0.0225)	53.8 (0.1533)
BY2013	CL	77.7 (0.0304)	36.2 (0.0517)
	HD	78.3 (0.0359)	34.4 (0.0616)
BY2014	CL	74.4 (0.0149)	35.0 (0.1047)
	HD	73.5 (0.0129)	36.8 (0.1370)

[a]High standard error resulted from anomalous PIT tag detections, accuracy of this estimate unreliable.

Chinook Recoveries

The number of recoveries of returning progeny from CL and HD release groups were significantly different among brood years ($p < 0.001$), but not between CL and HD groups ($p = 0.486$) or brood year by group interactions ($p = 0.512$). Although 61 more fish were recovered in the CL group compared to the HD group for BY2013 (Table 7), similar numbers were recovered from the other two brood years and the BY2013 result could be at least partially explained by the higher number of smolts released from the CL group that year compared to the HD group (approximately 27,000, Table 3). These results indicated, given the study assumptions, that rearing Chinook salmon in six raceways (HD) produced the same amount of returning adults as rearing approximately the same number of Chinook salmon in nine raceways (CL). Therefore, the HD group had to produce more returning adults per raceway than the CL group.

Table 7. Dworshak National Fish Hatchery spring Chinook recoveries to the hatchery rack, Lower Granite Dam and in the Idaho sport fishery by brood year (BY), group and sex for control (CL) and high density (HD) release groups from brood years (BY) 2012, 2013 and 2014.

	BY2012		BY2013		BY2014	
Sex	CL	HD	CL	HD	CL	HD
Male	189	169	129	79	89	87
Female	172	185	116	105	86	92
Subtotal	361	354	245	184	175	179

The recovery rate (recoveries/number of fish released for each replicate *100) between the CL and HD groups were also not significantly different ($p = 0.486$) but did vary by brood year ($p < 0.001$; Table 8). On average, the difference in recovery rate was 5.1% lower in the HD compared to that of the CL across the three brood years. The lower recovery rate of the HD group resulted mainly from the larger differences observed in BY2013 (19.8% lower). In contrast, the recovery rate of the HD treatment was 7.4% greater in BY2014 and nearly identical in BY2012 (Table 8).

Comparing recoveries on a per raceway basis provided an effective way to evaluate the effect of increasing densities in the individual raceways. Total recoveries per raceway were significantly higher for the HD groups compared to the CL groups ($p = 0.003$; Table 8) indicating that increased rearing densities resulted in more returning fish. The HD treatment demonstrated an average increase of 11 recoveries/raceway (37.6%) relative to the CL group. Similar to the total recoveries and recovery rate, the poor performance of the HD group in BY2013 negatively influenced the results overall, although the HD group still had 12.7% more returns/raceway.

Table 8. Control (CL) and high density (HD) adult recoveries per replicate, average recovery rate and recoveries/pond (across replicates) of Dworshak Fish Hatchery Chinook salmon from brood years 2012 – 2014. These three metrics were standardized as the percentage difference relative to the control group ([HD – CL/CL] x 100).

		Average recoveries			Average percent difference		
Brood Year	Group	Average fish/ replicate	Average recovery rate (%)	Average recoveries/ raceway	Total return (%)	Recovery rate (%)	Recoveries/ raceway (%)
BY2012	CL	121	0.094	40	-2.2	-2.8	46.7
	HD	118	0.091	59			
BY2013	CL	82	0.057	27	-24.9	-19.8	12.7
	HD	61	0.046	31			
BY2014	CL	58	0.043	19	2.3	7.4	53.4
	HD	60	0.046	30			
				Average	-8.3	-5.1	37.6

Recovery rate = number of recoveries from a given replicate/number of smolts released from that replicate *100

There was no significant difference in age composition between the CL and HD groups (X^2 = 1.128; p = 0.569), with 2-ocean fish comprising 90% of the adult recoveries for both groups (Table 9). Sex composition differed between the groups, with a significantly higher average proportion female in the HD compared to the CL group (z = 2.036; p = 0.042; Table 9).

Table 9. Dworshak National Fish Hatchery spring Chinook salmon sampled during broodstock collection, Lower Granite Dam trapping, and Idaho sport fishery creel by brood year (BY), sex and ocean age for control and high density groups as determined by parentage-based tagging (PBT).

	Ocean	Male		Female	
	Age	Control	High Density	Control	High Density
BY12	1	28	15	0	0
	2	150	143	156	174
	3	9	11	15	10
	Subtotals	187	169	171	184
BY13	1	2	7	0	0
	2	125	72	116	104
	3	1	0	0	0
	Subtotals	128	79	116	104
BY14	1	11	12	0	0
	2	74	72	81	78
	3	4	3	3	12
	Subtotals	89	87	84	90
Totals		404	335	371	378

Cost analysis

An analysis was performed to estimate increased costs associated with increased production. Results are presented in Appendix 1.

DISCUSSION

The density study was initiated to improve spring Chinook returns upstream of LGR due to the chronic failure to achieve the LSRCP return target of 9,135 adults at DNFH. Releasing additional smolts is one potential means of increasing returns. Given limited space and water at DNFH, increased rearing densities was the best option for increasing production. This was not without risk as it had been demonstrated that Columbia River spring Chinook salmon reared at even low to moderate densities (exceeding 0.2) have been shown to produce fewer returns relative to those reared at a lower density (Banks, 1994). While other studies involving spring and fall Chinook and coho salmon have shown mixed results (Martin and Wertheimer, 1989; Olson and Paiya, 2013), they generally supported the conclusions that increased densities negatively affected returns and this negative response is more pronounced in spring Chinook (Banks, 1990) than fall Chinook (Banks and LaMotte, 2002) or coho (Ewing and Ewing, 1995). Consequently, it is important to evaluate rearing density differences and the interaction between increased densities and survival rate to identify the optimal combination of smolt output and survival needed to achieve an adult return goal.

The results presented here show that Chinook salmon reared in the HD B-bank raceways (HD density index 0.36; CL density index 0.24) did not experience any deleterious effects relative to the CL groups in the juvenile metrics: size at rearing, growth, mortality, or survival to LGR or BON. Density increases investigated at other hatcheries demonstrated negative effects on juvenile growth or mortality at higher rearing densities (Banks, 1994; Olson and Paiya, 2013), in addition to decreased adult returns, something not observed in this study.

Chinook returns (total recoveries) and recovery rate (recoveries/number of juveniles released) were not statistically different between the HD and CL groups indicating that increased rearing densities in the B-bank raceways at DNFH resulted in increased adult returns. Although not significantly different, the slightly lower average recovery rate in the HD group (5.1% lower) compared to the CL group suggested that the overall adult yield of the HD groups, a surrogate for survival, slightly underperformed relative to the CL groups. This was also evident when examining the average adult recovery per raceway, where the HD raceways had by an average of 37% more recoveries than the CL raceways. Because HD raceways produced 44% more smolts, this represented a reduction of 8.3% over what was expected given equal survival between the two groups.

Evaluating each brood year separately revealed significantly lower adult recoveries, recovery rate and recoveries/pond from the HD group in BY2013. Adult return metrics from the other two brood years for the HD groups ranged from slightly higher returns in BY2014 to slightly lower in BY2012. Consequently, this single brood year had a significant effect on the results of the study. Reasons for the difference were not evident. The juvenile metrics were similar, or in the case of juvenile mortality, were much lower in BY2013 compared to BY2014. Consequently, the difference may have resulted from delayed mortality or some other unmeasured factor, or was a sampling error or statistical anomaly. In spite of decreased performance from a rate perspective, overall returns from the HD group exceeded that of the CL in BY2013.

The flow index in the HD groups was 0.28, a level considerably higher than many other studies (Banks, 1994; Ewing et al. 1998; Banks and LaMotte, 2002) and this may have mitigated potential negative effects from the high-density rearing environment. General production fish reared in the A-bank raceways at DNFH have lower flow (750 gpm compared to 1,250 gpm in B-bank raceways) with similar flow indices to the HD raceways in this study. These suggest that higher densities may be tolerated given high enough flow.

Management Implications

The results of this study confirmed that it was possible to increase adult returns by increasing densities and rearing more smolts in existing space at DNFH. The lower recovery rates and recoveries per raceway indicated that survival was slightly lower in the high-density raceways. However, increasing adult returns, not increasing or even maintaining similar survival, was the main objective of the study. Applying high densities to all 15 B-bank raceways and projecting adult returns from a range of previously observed SARs revealed that a harvestable surplus of adults will result as long as SARs remain above 0.10% (Table 10). Applying the recent 2005 - 2014 ten-year average SAR of 0.58% would result in an estimated 1,000 additional adults available for harvest.

Table 10. Projected spring Chinook salmon adult returns per raceway and total adult returns from 15 raceways for control (CL) and high density (HD) production in Dworshak National Fish Hatchery B-bank raceways. The column "SAR Achieved" shows the number of years a particular SAR had been achieved from brood years 1981-2014. HD benefit was the difference in adult returns between CL and HD production after accounting for brood stock needs (brood stock: CL – 900 adults; HD – 1,320 adults; fecundity: 2,700 smolts/female) and represents the expected harvestable surplus at various SAR levels.

		Adult Return per raceway		Total Adult Return		HD Benefit
SAR Achieved	SAR %	CL	HD	CL	HD	Adult return difference
5	1.00%	450	619	5,850	7,968	2,118
2	0.90%	405	557	5,175	7,039	1,864
1	0.80%	360	495	4,500	6,110	1,610
2	0.70%	315	433	3,825	5,182	1,357
1	0.60%	270	372	3,150	4,253	1,103
1	0.50%	225	310	2,475	3,324	849
5	0.40%	180	248	1,800	2,395	595
4	0.30%	135	186	1,125	1,466	341
8	0.20%	90	124	450	538	88
5*	0.10%	45	62	-225	-391	-166

*All prior to 1991.

The two Chinook salmon raceway banks at DNFH are different in water source and flow. A-bank uses lower flows of first use water whereas B-bank uses higher flows with a portion of reuse water from A-bank. Consequently, A-bank may not respond similarly to higher densities and the reuse of high-density A-bank water may negatively affect B-bank. Previous studies have revealed that higher flows may mitigate for negative density effects (Banks, 1994; Ewing et al. 1998; Banks and LaMotte, 2002). However, the consequences of recycling A-bank water for B-bank production are uncertain without further studies. At this time, we would recommend proceeding cautiously with density increases in A-bank and not to necessarily expect similar results as revealed in this study using B-bank.

Since the conclusion of this study low-head oxygenators (LHOs) were installed in both A- and B-bank raceways. LHOs may mitigate for the minor negative effects associated with the high-density raceways and allow for higher densities in A-bank. Although the effects of the addition of LHOs to the raceways at DNFH is unknown, other studies indicated that Chinook salmon reared under higher flow indices and oxygen supplementation minimized or eliminated the negative effects of high rearing density on adult return rates (Clark et al. 2013).

Although no significant density effects were demonstrated in B-bank, the lower recovery rate observed in the BY2013 HD groups potentially indicated that some years may be negatively affected by density increases. Was this a random event and if so, how often would it occur? Data from this study indicated that it would be expected to occur in one out of three years. However, only three years of data is not nearly enough time to make definitive conclusions. Without control groups in the future, it will not be possible to determine if survival was negatively affected in any given year or how frequent the density affects would be expected to occurr. More frequent BY2013-like years would reduce the effectiveness of the high density rearing and bring back fewer adults. In spite of the lower recovery rates (survival) that occurred from BY2013, the main objective of the study was met, more adults back to the Snake River basin.

Finally, even the low densities of the CL and A-bank raceways are higher than what is regionally accepted for spring Chinook salmon (Banks, 1990; Ewing and Ewing, 1995). Spring Chinook smolts released from DNFH have some of the lowest survivals in the Snake River basin, even though they are closer to the ocean relative to other Snake Basin hatcheries. Numerous other factors likely negatively affect survival such as a reliance on surface water from the heavily managed North Fork Clearwater River. The presence and spawning of anadromous fish above the hatchery are likely disease vectors and hatchery juveniles are exposed to un-natural rearing profiles resulting from cold water releases from Dworshak Dam. However, it is not unreasonable to assume that adult survival wasn't already negatively affected by high densities and the increased densities investigated in this study had little impact.

A separate review of DNFH smolt output (past, present, and hypothetical), and observed SARs was performed by LSRCP (Rod Engle, personal communication) and provides additional insight into the interplay of smolts released and SARs needed to achieve the target return goal (Table 11). At the current smolt release number (target release goal is 1.35 million), an SAR of at least 0.7 would be necessary for achieving the in-basin mitigation goal. This SAR has only been achieved 10/34 times in the 1981-2014 timeframe, indicating that DNFH performance was generally below 0.7%. The mitigation goal could hypothetically be met by increasing production. However, increased production brings associated increases in rearing costs (feed, marking, labor, etc.) and brood-stock needs that removes fish available for harvest locally within the Clearwater River Basin. Increasing production and subsequently increasing rearing densities in a fixed rearing space is what this study explored. Increased production without impacting existing rearing parameters or densities would likely yield different and likely higher adult returns. This is a possibility at DNFH but involves additional costs beyond A and B bank and different infrastructure (unmodified Burrows ponds) not under the purview of the LSRCP program.

This study demonstrated that it was possible to increase production at DNFH using the existing space by increasing raceway densities. Applying the rearing densities of the HD raceways (65,000 smolts/raceway) to all 30 DNFH raceways would result in the total production of 1,950,000 smolts that would be at a level to meet the mitigation goals at an SAR of 0.5.

Table 11. Smolt-to-adult return (SAR) levels needed to meet LSRCP mitigation goals for spring Chinook salmon at Dworshak National Fish Hatchery at various total production capacities. This does not account for fixed rearing space or higher rearing densities at different production levels. The column "SAR Achieved" shows the number of years a particular SAR had been achieved during 1981-2014. Green shaded cells show combinations of smolts released and SAR that could meet mitigation goals. Graphic by Rod Engle (LSRCP).

Increasing Cost and Brood Needs

		DNFH Total Production				
SAR Achieved	**SAR %**	**1,050,000**	**1,350,000**	**1,650,000**	**1,950,000**	**2,250,000**
5	**1.00**	10,500	13,500	16,500	19,500	22,500
2	**0.90**	9,450	12,150	14,850	17,550	20,250
1	**0.80**	8,400	10,800	13,200	15,600	18,000
2	**0.70**	7,350	9,450	11,550	13,650	15,750
1	**0.60**	6,300	8,100	9,900	11,700	13,500
1	**0.50**	5,250	6,750	8,250	9,750	11,250
5	**0.40**	4,200	5,400	6,600	7,800	9,000
4	**0.30**	3,150	4,050	4,950	5,850	6,750
8	**0.20**	2,100	2,700	3,300	3,900	4,500
5	**0.10**	1,050	1,350	1,650	1,950	2,250

Increasing Performance

SUMMARY

Increased rearing densities did not result in negative effects on rearing Chinook salmon growth or in-hatchery survival metrics or juvenile survival to LGR.

Chinook reared at higher densities produced more returning fish than did fish reared at typical DNFH rearing densities. On a rate basis (number of fish returning/number of fish released), usual density and high-density groups performed similarly overall indicating that HD rearing will return more fish.

Although there was not a significant difference in recovery rate between groups, the slightly lower average recovery rate for the HD group (5.1% lower) than the CL group suggests that the overall adult yield of the HD groups slightly underperformed relative to the CL groups. This difference was influenced by a single brood year (BY2013), not consistent differences in all brood years.

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Appendix

SPAWNING and REARING COSTS

The details of the cost analysis are provided in Jones et al. (2014). In summary, eggs from seven adult females (and milt from seven males to maintain a 1:1 ratio) were needed to produce an additional 20,000 smolts for each raceway. Costs by task were estimated (Table 11) and production of an additional 20,000 smolts per raceway was estimated to cost about $2,600 (Jones et al. 2014). Tasks were completed by existing personnel.

Table 11. Estimated costs for producing an additional 20,000 spring Chinook salmon smolts at DNFH (Jones et al. 2014).

Task	Cost ($)
Spawning an additional seven females with seven males	385
Fish Health (sampling spawned female ovarian fluid for BKD	336
Egg incubation and care	246
Ponding	120
Feed and Feeding	1,115
Adipose clipping	400
Total per extra 20,000 smolts produced	2,602