Size-at-Release of Imnaha River Chinook Salmon Hatchery Smolts: Does Size Matter?

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INTRODUCTION

The Imnaha River Chinook salmon (*Oncorhynchus tshawytscha*) population has been supplemented with hatchery salmon since the 1982 brood year, when wild Imnaha River adults were first captured and spawned in captivity. This supplementation program has been operated under the auspices of the U.S. Fish and Wildlife Service's Lower Snake River Compensation Plan (LSRCP) program. This Imnaha River Chinook salmon hatchery supplementation program has been operated by the Oregon Department of Fish and Wildlife (ODFW) with the following production and program objectives:

- Prevent extinction of Imnaha River salmon populations and ensure a high probability of population persistence into the future.
- Establish adequate broodstock to meet annual production needs and to meet the long-term mitigation goal of 490,000 smolt releases.
- Meet the LSRCP mitigation goal of 3,210 hatchery adult returns to the Imnaha Basin.
- Reestablish historic tribal and recreational fisheries.
- Minimize impacts of the hatchery program on resident stocks.
- Maintain genetic and life-history characteristics of natural Chinook salmon populations in the Imnaha River.
- Operate the hatchery program so that genetic and life history characteristics of hatchery Chinook mimic those of wild Chinook, while achieving mitigation goals.

Data collected from research and monitoring activities are used to design and adapt culture practices to most effectively meet these management objectives. Based on the age structure of hatchery and natural spring Chinook adults from the 1982-1987 brood year returns captured at the Imnaha River weir, there was evidence that age composition differed between hatchery and natural adults (Figure 1). This finding suggested that the Imnaha River hatchery spring Chinook program was failing to meet the objective that genetic and life history characteristics of hatchery Chinook mimic those of wild Chinook.

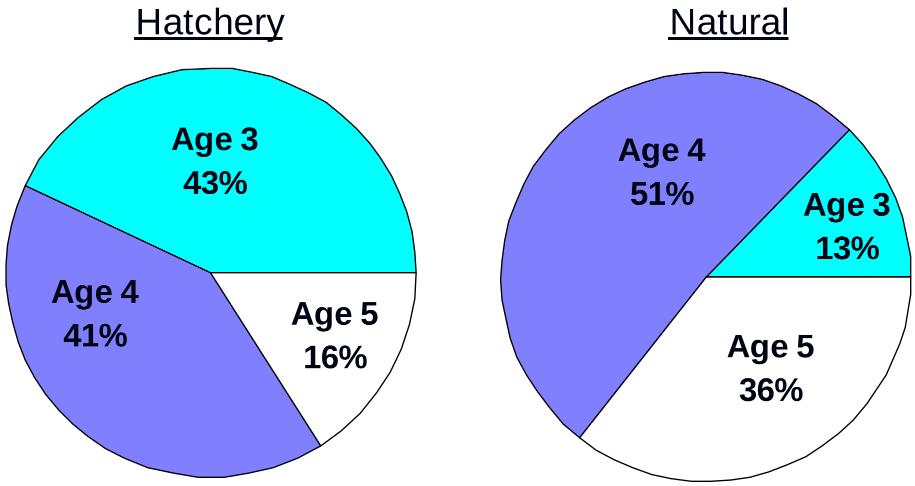

Figure 1. Age structure of adult hatchery and natural spring Chinook adults from the 1982-1987 brood years captured at the Imnaha River weir.

Based on these findings, a long term study was initiated to determine if smaller smolts could better meet the program objective of producing hatchery fish that mimic the life history characteristics of naturally produced Imnaha River spring Chinook salmon. The first study objective was to compare life history characteristics (e.g., age and size at maturity and run timing) between large and small smolts. A second study objective, that directly addresses the mitigation goal requirement, was to identify optimum rearing and release strategies that will produce the maximum survival to adulthood for hatchery-produced Chinook salmon smolts. We determined and compared the following performance metrics between large and small smolts: juvenile survival rates to Lower Granite Dam (LGD), smolt-to-adult return (SAR) rate to LGD, harvest rate, stray rate, smolt-to-adult survival (SAS) rate, and the number of adults produced per 10 kg of smolts released.

STUDY AREA AND METHODS

The smolts used for this study were offspring of hatchery- and natural-origin adults collected at the Imnaha River Weir/Acclimation Site, located at rkm 85. The Imnaha River Supplementation Program uses endemic Imnaha River Chinook salmon. The adults were spawned and reared at Lookingglass Fish Hatchery (LFH), located on Lookingglass Creek, a tributary of the Grande Ronde River at rkm 138. At smoltification, the smolts were transported to the Imnaha River Acclimation Site in April, nearly two years after their parents were collected, and released to migrate to the ocean and return upon maturation (Figure 2).

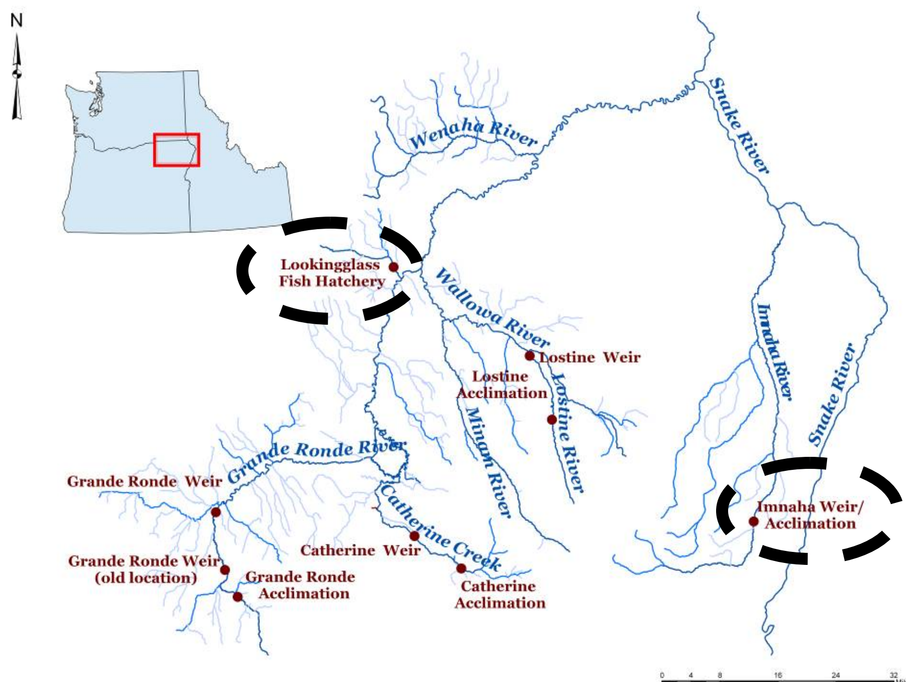

Figure 2. Map of the Grande Ronde and Imnaha River Basins and locations of the Imnaha Weir/Acclimation Site and Lookingglass Hatchery.

Experimental treatments were conducted with paired releases of large and small smolts from brood years (BY) 1988-1998. The 1991 BY was excluded because of high mortality due to bacterial kidney disease. The target size varied among BYs - for large smolts the target was 30 or 38 g/fish (12 or 15 fish/lb) and 18 or 23 g/fish (20 or 25 fish/lb) for small smolts. The 38 g large smolt target consisted of brood years 1988 and 1990 and the 30 g large smolt target was from BYs 1989 and 1992-1998. The 23 g small smolt target was for BYs 1988-1990, and the 18 g small smolt target was for BYs 1992-1998.

Additionally, rearing density varied among BYs due to low returns and the resulting reduced availability of adults for broodstock during some return years. We accounted for these differences in rearing density by separating the BYs into high density (> 40,000 smolts/raceway, or >14.5 kg/m^3) and low density (< 30,000 smolts/raceway, or < 9 kg/m^3) years (Table 1). Outdoor raceways at LFH are 30.5 m X 3 m and 1 m deep (95 m^3). High density smolt releases were conducted with BYs 1988-1993 and low density smolt releases occurred with BYs 1994-1998. The number of smolts/raceway in the high density release years ranged from 44,346-85,796 smolts and 6,613-26,796 smolts for the low density releases.

Smolt survival to LGD was based on detections of passive integrated transponder (PIT) tags and was limited to the 1992-1998 BYs because PIT tag technology was not available prior to 1992. Recovery information for each coded-wire tag (CWT) code group was obtained from the Regional Mark Information System (RMIS) CWT recovery database (Pacific States Marine Fisheries Commission). The observed and estimated number of hatchery salmon from each CWT code recovered in ocean and mainstem river fisheries, as well as the fish collected in sport, commercial and tribal harvests, strays collected in and out of the Snake River Basin, and those returning to their expected spawning or collection location were summarized from the RMIS database. Estimated CWT recoveries in the RMIS database were expanded from observed recoveries based on sampling rates at each recovery location. The RMIS database does not expand for recoveries observed in the Imnaha Basin. Therefore, we estimated total CWT marked hatchery adults from each code group (observed from weir collections and spawning ground recoveries) returning to the Imnaha River based on total escapement to each stream, sampling rate, and the proportion of each cohort marked with CWTs. Smolt-to-adult survival (SAS) rate was defined as the total estimated number of adults from a BY release group that were harvested, strayed, and/or returned to the LSRCP compensation area above LGD. The smolt-to-adult return (SAR) was defined as the estimated total number of adults returns from a BY release group that returned to the LSCRP compensation area over LGD. Age composition (% maturing at ages 3, 4 and 5) was calculated from all CWT recoveries. We defined strays as any fish captured outside of its direct migration route to its expected spawning or collection location. The number of smolts/10 kg was calculated by using the mean weight of the smolts at liberation.

RESULTS AND DISCUSSION

The first step in our analysis was to compare the performance of paired releases of large and small smolts without the density effect. There was no difference in downstream survival to LGD

Table 1. Spring Chinook salmon release metrics for each raceway of large and small smolts reared at high or low density and released from the Imnaha River Acclimation site, 1988-1998 brood years.

Brood year	Density group	Size group	Rearing pond	Target fish/ pound	Mean weight (g)	Rearing density (kg/m^3)	Number of CWT's released	Total smolts released
1988	High	Large	12	12	36.6	22.3	51,281	51,669
			13	12	35.5	21.7	51,597	52,013
		Small	14	20	25.1	21.6	56,611	73,337
			15	20	24.4	21.8	56,514	76,018
1989	High	Large	16	15	29.9	18.1	41,582	51,557
			17	15	28.0	18.7	40,770	56,848
		Small	14	20	20.5	19.3	42,804	79,654
			15	20	20.5	19.2	42,834	79,611
1990	High	Large	17	12	41.3	21.5	43,315	44,346
			18	12	40.2	21.4	45,075	45,256
		Small	16	20	21.6	21.8	85,110	85,796
1992	High	Large	14	15	29.9	18.3	49,471	52,075
		Small	15	25	17.6	17.4	81,997	84,013
			16	25	18.9	18.7	80,404	83,900
1993	High	Large	13	15	26.1	15.4	49,576	50,222
			14	15	25.8	14.8	47,084	48,723
		Small	9	25	20.4	18.7	77,200	77,952
			16	25	20.8	17.9	72,015	72,959
1994	Low	Large	3	15	25.5	4.2	13,635	13,839
			4	15	27.9	4.6	13,376	13,890
		Small	5	25	23.8	3.0	10,695	10,877
			6	25	23.3	6.3	22,643	22,915
			7	25	22.3	6.0	22,069	22,840
1995	Low	Large	6	15	30.7	3.6	9,742	9,896
			7	15	32.9	2.6	6,390	6,613
		Small	3	25	22.6	3.4	12,749	12,834
			4	25	20.1	5.1	20,782	21,568
1996	Low	Large	1	15	29.3	2.4	6,619	6,997
			2	15	30.3	5.0	12,670	14,022
			3	15	31.7	5.3	13,328	14,171
		Small	4	25	19.9	2.2	9,000	9,494
			5	25	20.0	4.5	18,028	19,056
			6	25	19.6	2.2	8,596	9,513
			7	25	19.9	4.7	18,691	19,874

Table 2. continued

Brood year	Density group	Size group	Rearing pond	Target fish/ pound	Mean weight (g)	Rearing density (kg/m^3)	Number of CWT's released	Total smolts released
1997	Low	Large	10	15	28.9	4.6	11,942	13,395
			11	15	28.6	4.7	12,287	13,997
			12	15	27.9	8.8	24,570	26,796
			13	15	27.9	4.6	12,756	13,997
			14	15	26.5	4.2	12,051	13,308
			15	15	27.9	4.9	12,992	14,872
		Small	8	25	18.5	4.9	21,239	22,385
			9	25	18.7	4.8	20,212	21,787
1998	Low	Large	7	15	27.0	6.0	18,097	18,894
			10	15	28.9	6.0	15,972	17,590
		Small	2	25	23.0	4.1	14,880	15,245
			3	25	22.1	4.8	18,232	18,600
			4	25	21.3	4.7	18,178	18,624
			5	25	21.1	4.6	17,659	18,618
			6	25	22.1	4.9	18,207	18,617
			8	15	24.7	5.1	16,948	17,581
			9	15	24.9	5.2	16,108	17,585
			16	25	21.9	4.8	18,001	18,633

between large and small smolts ($P = 0.07$; Figure 3). Large smolts survived at a mean rate of 67.4% and small smolts at a mean rate of 65.6%. Survival to LGD varied significantly among BYs ($P < 0.0001$; Figure 4).

Small smolts tended to return at an older age than larger smolts, with a lower percentage of smaller smolts returning at ages 3 and 4 and a greater percentage returning at age 5. However, there was no statistical difference in age composition of adult returns between treatment groups ($P \geq 0.22$; Figure 5).

Although mean survival rates were consistently higher for smaller smolts, size at release did not result in significant differences in harvest, stray, SAR or SAS rates between release groups ($P \geq 0.23$; Table 2). Among brood years, there was highly significant annual variation in SAS rates (Figure 6). The 1989-1994 BYs had mean SAS rates that ranged from 0.02-0.26%, well below that LSRCP SAR goal of 0.65%. Mean SAS rates for the 1988 and 1995-1998 BYs ranged from 0.60-2.67. This overall variation and pattern in brood year SAS rates was similar to that seen in other Snake River Chinook salmon hatchery programs, including Rapid River stock released from LFH, indicating regional causes for the poor survival years of the late 1980s and early 1990s.

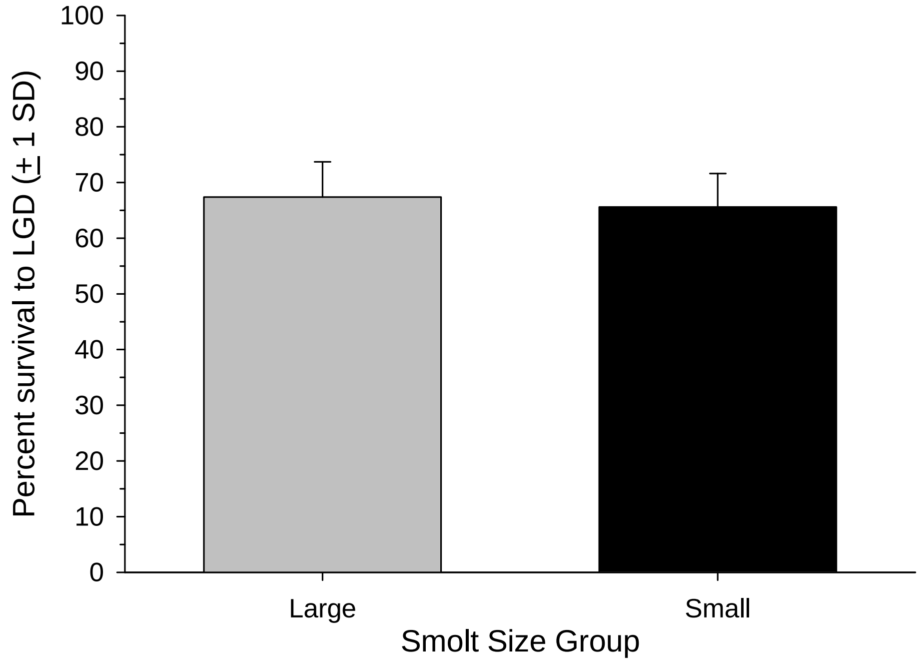

Figure 3. Mean percent survival to Lower Granite Dam (LGD) of large and small PIT-tagged Chinook salmon smolts released from the Imnaha River Acclimation Site, 1992-1998 brood years.

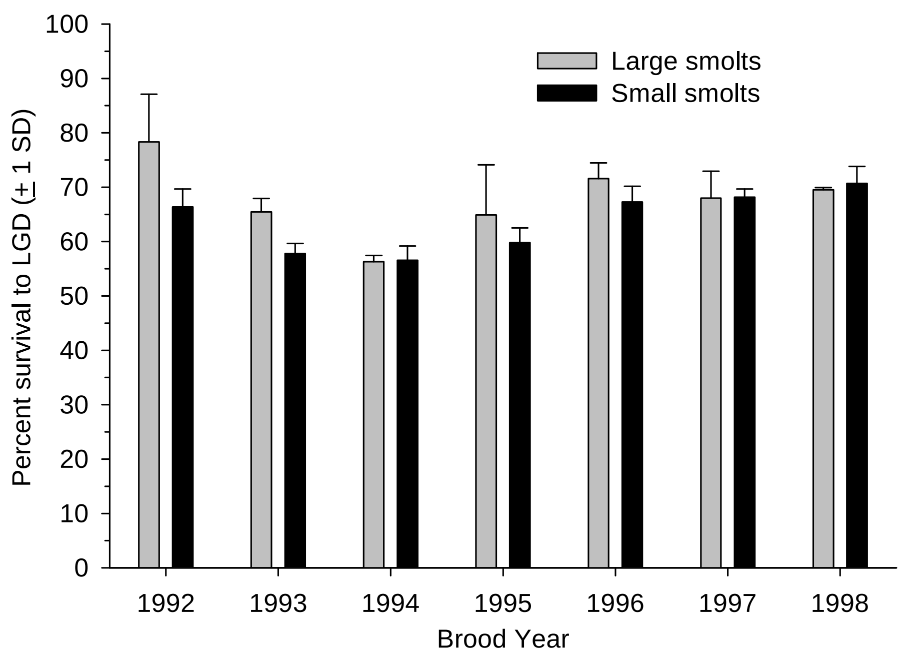

Figure 4. Mean annual percent survival to Lower Granite Dam of large and small smolts released from the Imnaha River Acclimation Site (LGD), 1992-1998 brood years.

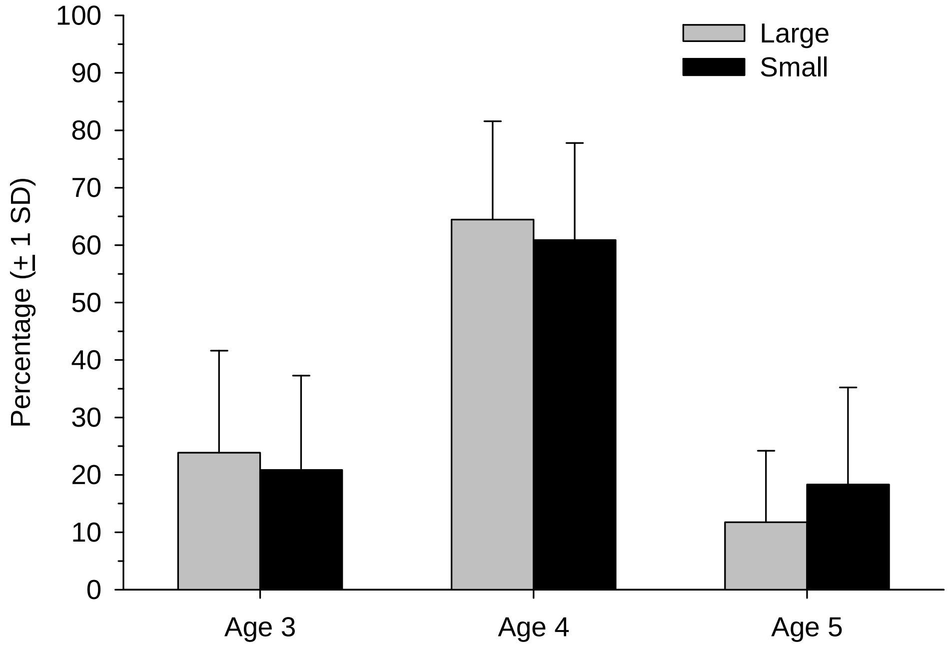

Figure 5. Age composition of age 3-5 adult returns from large and small smolt releases of Chinook salmon into the Imnaha River.

Table 2. Smolt-to-adult survival (SAS) rate (%) for large and small smolt releases from brood years 1988-1990 and 1992-1998.

Rate	Large smolts (mean 30 g/fish)	Small smolts (mean 21 g/fish)	P-value
Harvest	0.027	0.060	0.23
Stray	0.013	0.016	0.97
SAR	0.780	1.10	0.42
Total SAS	0.82	1.17	0.43

A mean of 2.8 adults returned for every 10 kg of smolts released from the large release group and 5.5 adults returned / 10 kg released from the small smolt release group (P = 0.02; Figure 7). This is consistent with the finding that there were no significant differences in survival rates between large and small smolt releases. If a larger number of small smolts are released than large smolts, and SAS is similar, it is logical that equal weight (= greater numbers) of small smolts released would result in a larger number of adult returns.

Next, we compared large and small smolt releases within the high density (BY 1988-1993) and low density (BY 1994-1998) rearing years. Smolt survival estimates, based on PIT tag detections, from the Imnaha River acclimation site to LGD for the high density experimental phase were limited to BY 1992-1993 (Figure 8). There were no significant differences in smolt

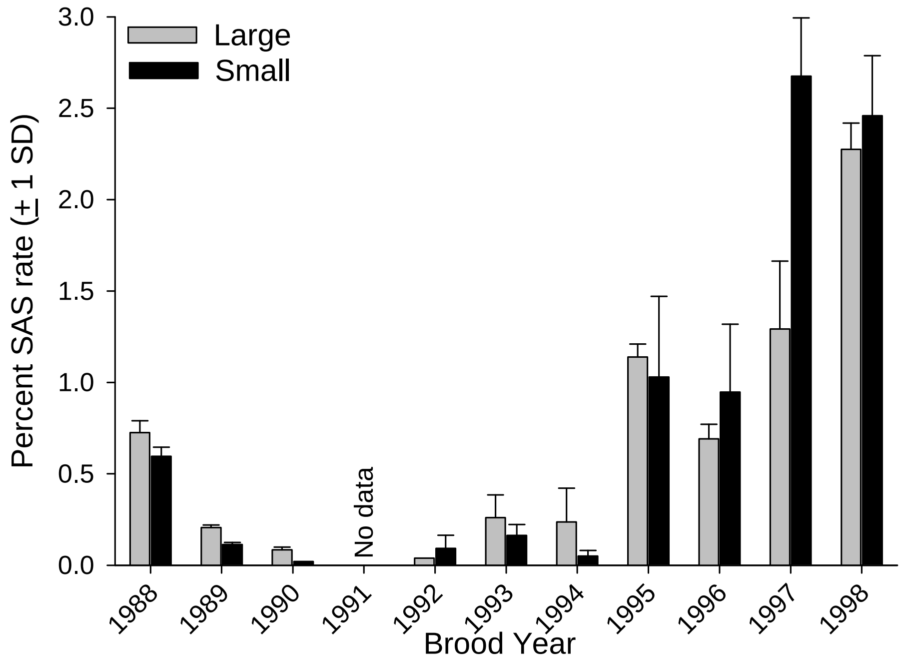

Figure 6. The percent smolt-to-adult survival (SAS) for large and small smolt releases, 1988-1998 brood years.

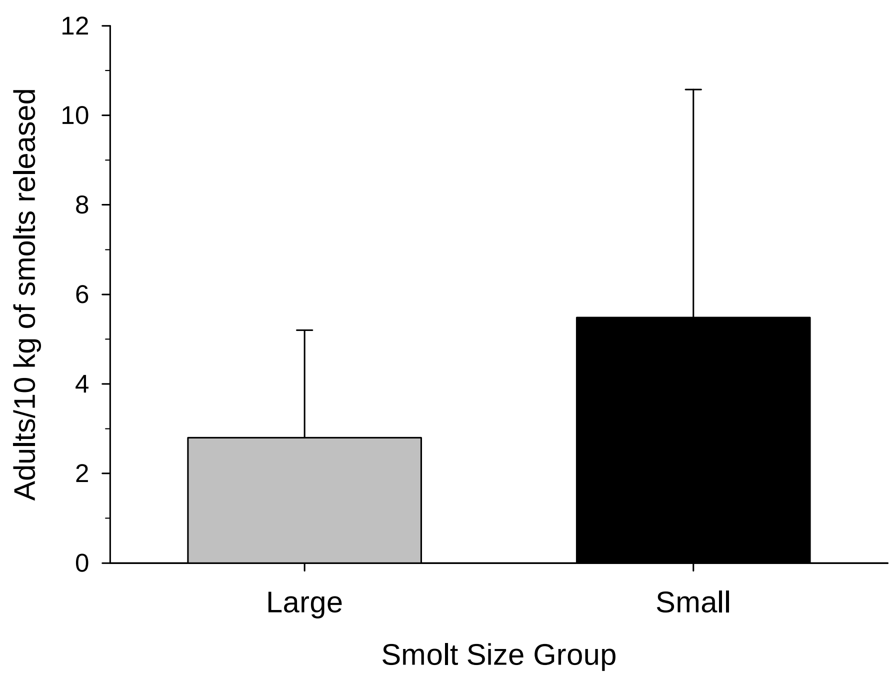

Figure 7. Adult returns per 10 kg of large and small smolts released, 1988-1998 brood years.

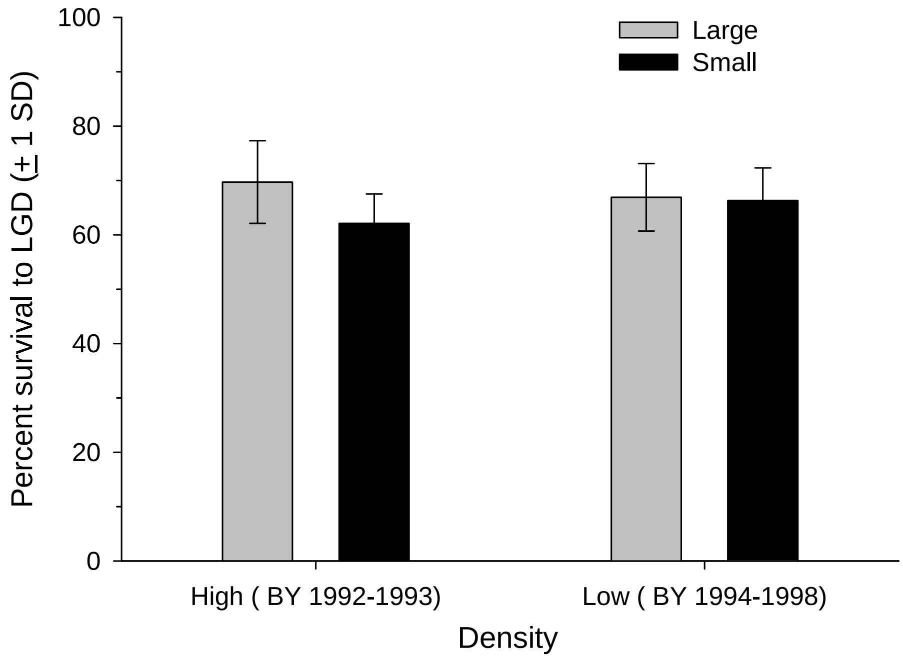

Figure 8. Percent survival of PIT-tagged large and small smolts from the Imnaha River acclimation site to Lower Granite Dam during high (1992-1993) and low density (1994-1998) rearing years.

survival rates between large and small smolt releases for either the high or low density release years ($P \geq 0.21$).

There were no significant differences in adult age composition for either the high density release years (Figure 9) or the low density release years ($P \geq 0.09$; Figure 10). Similarly, mean SAS rates were not significantly different between large and small smolts from either the high or low density releases (Figure 11).

There was significant variation in SAS rates among brood years for smolt release groups during both the high and low density rearing years ($P < 0.001$; Figure 12). The SAS rates for high density rearing years (BY 1988-1993) were lower than SAS rates observed during the low density experimental rearing years (BY 1994-1998). The overall pattern observed in our data for SAS rates from 1988-1998 was similar to data presented by the Idaho LSRCP program at the 2010 LSRCP review over the same time period, in Rapid River stock smolt releases from LFH, and is similar to trends observed for Chinook populations in the entire Columbia Basin, suggesting that regional variables (e.g., survival in the Columbia River, ocean conditions) are significant factors influencing the observed SAS patterns.

For both the high and low density rearing years, there were no significant differences in harvest, stray, or SAR rates between large and small smolts ($P > 0.30$). For all experimental groups, harvest and stray rates were less than 0.1%. The SAR rates for smolt release groups from the high density rearing years were less than half the SAR rates for the low density release groups

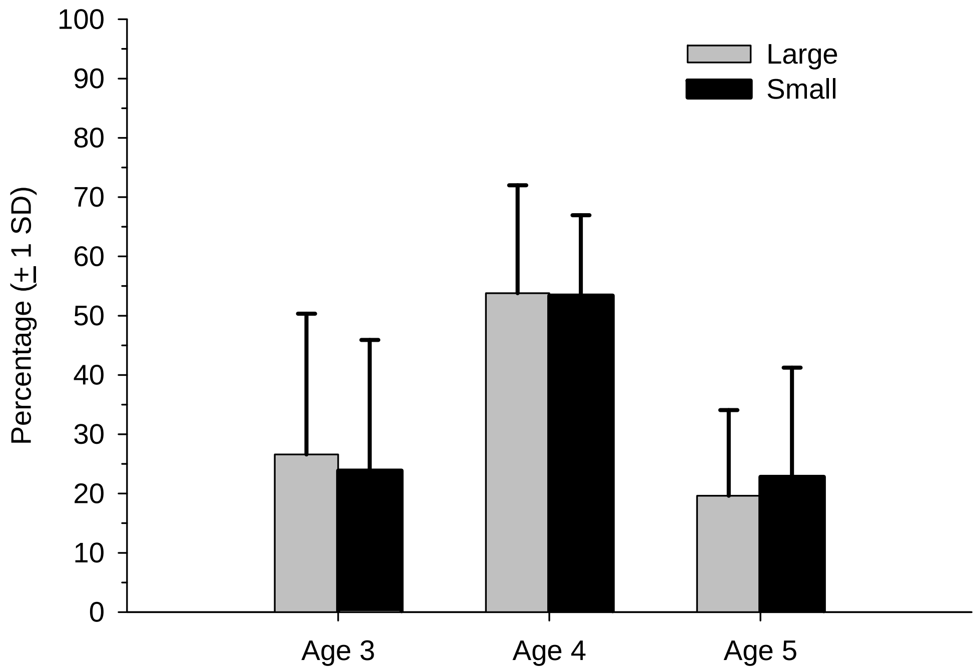

Figure 9. Age composition of adult returns from large and small smolt releases during high density rearing years, 1988-1993.

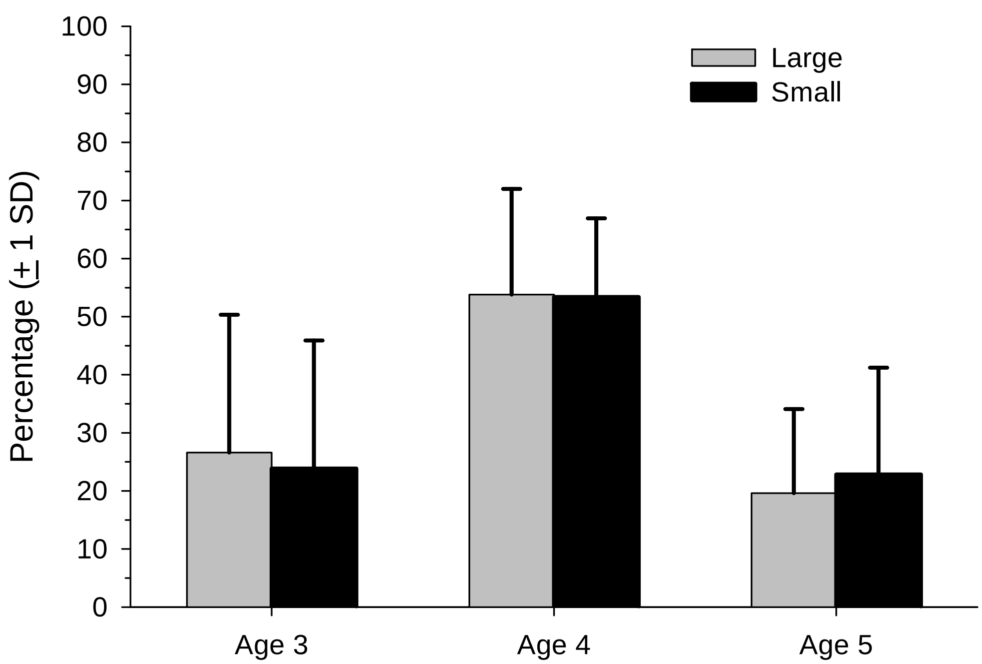

Figure 10. Age composition of adult returns from large and small smolt releases during low density rearing years, 1994-1998.

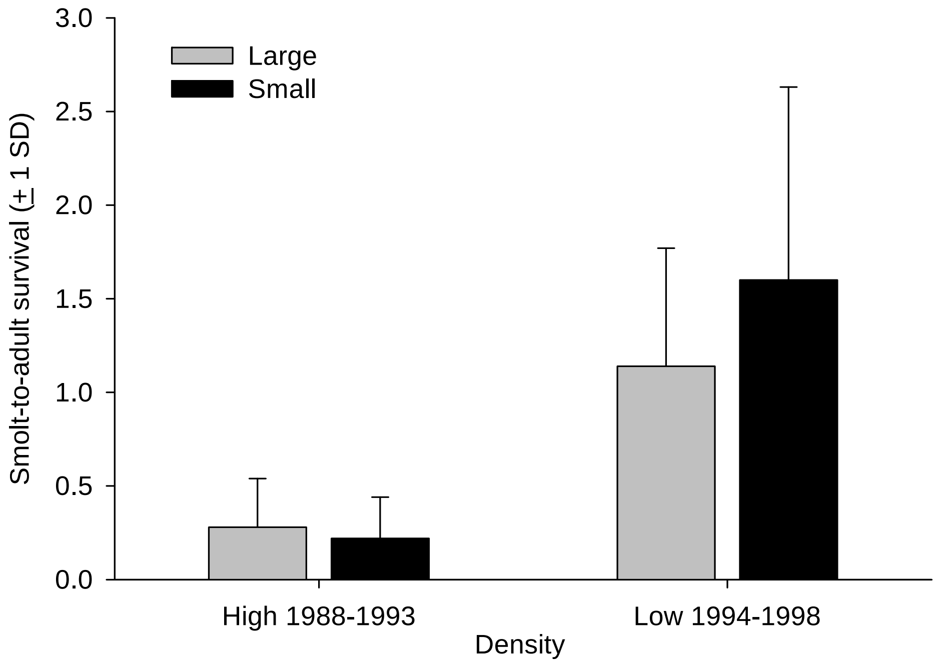

Figure 11. Smolt-to-adult survival (SAS) rates of large and small smolt releases during the high (BY 1988-1993) and low (BY 1994-1998) density rearing years.

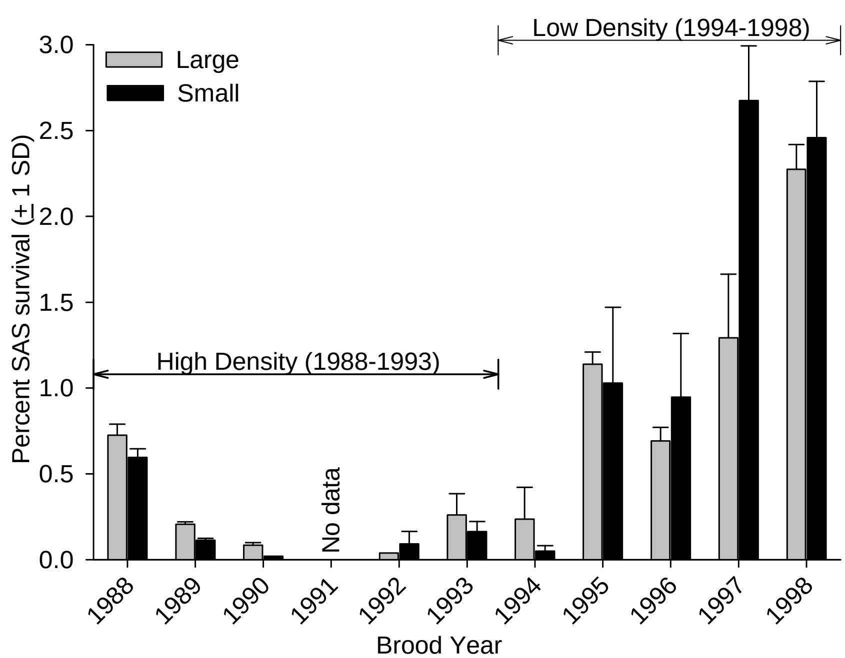

Figure 12. Smolt-to-adult survival (SAS) for large and small smolt releases during high (BY 1988-1993) and low (BY 1994-1998) density rearing years.

Table 3. Harvest, stray, smolt-to-adult return (SAR) and total smolt-to-adult survival (SAS) rates for large and small smolts released during high and low density rearing years.

	High density BY 1988-1993			Low density BY 1994-1998		
Rate	Large smolts	Small smolts	P-value	Large smolts	Small smolts	P-value
Harvest	0.001	0.002	0.37	0.042	0.087	0.31
Stray	0.007	0.005	0.51	0.017	0.021	0.97
SAR	0.281	0.209	0.58	1.082	1.525	0.30
SAS	0.288	0.216	0.51	1.142	1.633	0.31

(Table 3). Within each of the high and low density rearing years, there were significant differences in harvest, stray, and SAR rates among brood years ($P < 0.001$).

For the high density rearing years there was no difference in the number of adults that returned per 10 kg of smolts released for either size of smolt ($P = 0.5$); 0.89 adults returned per 10 kg of large smolts and 0.96 adults returned per 10 kg of small smolt (Figure 13). However, for the low density rearing years, there was a significantly greater number of adult returns per 10 kg of smolts released from the small smolt releases (7.60 adults / 10 kg released) than for the large smolts (3.98 adults / 10 kg released; $P = 0.01$).

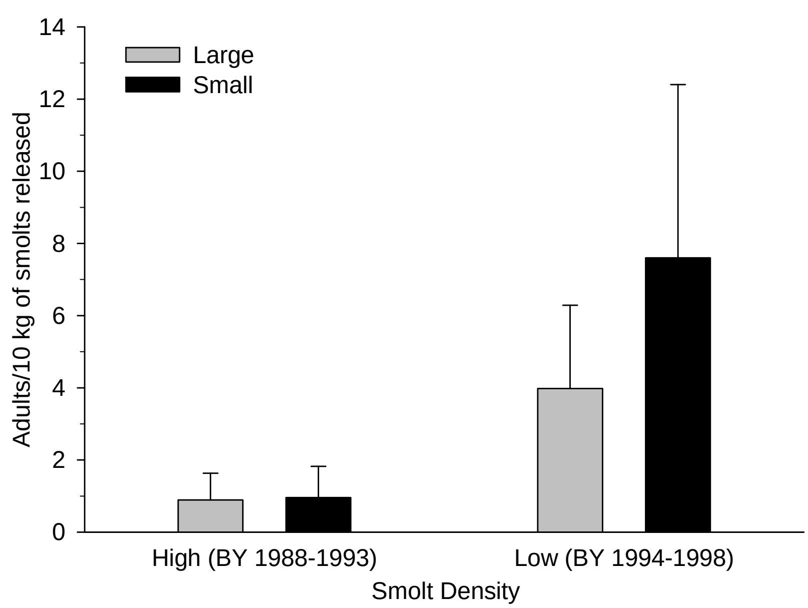

Figure 13. Adult returns per 10 kg of smolts released for experimental releases of large and small smolts from high (BY 1988-1993) and low (BY 1994-1998) density rearing years of Imnaha River Chinook salmon.

SUMMARY AND CONCLUSIONS

We found that PIT-tagged smolts survived at a similar rate to LGD, regardless of release size or rearing density. Differences in size-at-release or rearing density did not result in observed differences in age composition, harvest, stray, SAR, or SAS rates. For all experimental groups, brood year (or smolt migration year) had a greater effect on the response variables than smolt size or rearing density. For this study, similar SAR and SAS rates between smolt size release groups resulted in about twice as many adult returns/kg from the small smolt releases compared to large smolt releases. Additionally, Imnaha River hatchery spring Chinook appear to have a very low stray rate.

From a management perspective, these findings reconfirm the importance of annual variation on smolt and adult survival metrics. Based on these results, which appear to be unique to the Imnaha River spring Chinook salmon program, in space poor and egg rich years, like those we expect to continue experiencing at Lookingglass Hatchery, one potential strategy for maximizing the number of adult returns is to release more small smolts rather than fewer, large smolts. However, it is important to consider that this study occurred during a time when smolts migrating through the Columbia River hydrosystem were experiencing maximum transport (i.e., barged). Until a consistent "spread-the-risk" strategy is adopted, where half of the migrating smolts are transported and half migrate in-river, the best overall release strategy may be to spread the risk and release both large and small smolts.