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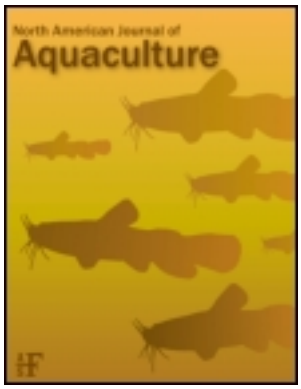

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Hatchery Steelhead Smolt Release Size Effects on Adult Production and Straying

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ARTICLE

Hatchery Steelhead Smolt Release Size Effects on Adult Production and Straying

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Abstract
Studies have demonstrated higher postrelease survival for larger hatchery steelhead *Oncorhynchus mykiss* smolts than for smaller ones. However, the ideal release size should also maximize adult returns and minimize interactions of hatchery fish with wild fish. We conducted a study over five release years with paired groups of anadromous hatchery steelhead smolts reared to target sizes of either 90 g (small size) or 113 g (large size). After stream release, we monitored out-migration travel times and survival to a downstream dam using freeze-brand marks in a subsample of each release group. Steelhead smolts that out-migrate quickly may interact less with wild fish. Across all release groups, travel time was about 3 d slower for small-sized smolts than for large ones, but this difference was not statistically significant, and there was no significant difference in the percentage of brands detected at the dam between the two smolt sizes. Coded wire tag recovery was used to compare smolt-to-adult survival (SAS), the number of adults produced per 100 kg of smolts released, and the percentage of adults that strayed. Across all years, large-sized smolts had an average SAS of 1.31% compared with 0.92% for small-sized smolts, a statistically significant difference of 42.0%. The average number of adult steelhead produced per 100 kg of smolts released also was higher for the large-sized group (11.4 adults/100 kg of smolts) over the small-sized group (10.1 adults/100 kg of smolts), though the 12.8% difference was not statistically significant. Adults originating from large-sized smolt releases strayed at a rate of 13.1% compared with a 7.9% rate for the small-sized smolt groups, a difference that was statistically significant. In this study, larger hatchery steelhead smolts had a higher survival after release; however, we found tradeoffs between management objectives associated with maximizing adult production and those aimed at minimizing ecological risks.

The body size of smolts of steelhead *Oncorhynchus mykiss* (anadromous Rainbow Trout) originating from hatchery releases has long been believed to affect their postrelease survival and therefore the number of adult returns (Larson and Ward 1955; Wagner et al. 1963; Tipping 1997). Juveniles released at a larger size generally survive to maturity at a higher rate. However, when faced with determining the appropriate release size, hatchery managers must consider more than just survival rates. For example, growing steelhead smolts to a larger size increases feed costs and may reduce the overall number of fish the hatchery facility can rear. Smolt release size may also affect the degree to which hatchery fish affect wild stocks, an important consideration given the recent emphasis on reducing ecological and genetic impacts of hatchery programs (APRE 2004; Pearsons 2008; Paquet et al. 2011). For example, the number of hatchery steelhead smolts that residualize in freshwater (i.e., fail to migrate seaward) is known to be dependent on smolt size (Jonasson et al. 1995; Viola and Schuck 1995; Hausch and Melnchuk 2012). Residual steelhead may adversely affect natural fish populations through predation or competition. Size at release could also affect how quickly smolts out-migrate—shorter out-migration times reduce opportunities for hatchery fish to interact with wild fish—and the ability of smolts to imprint on their release waters and return to those locations as adults. Hatchery steelhead adults that stray to other locations rather than return to their release site may spawn with natural fish, and thereby reduce the fitness of the natural population (Araki et al. 2007).

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In release year 1986, a study was initiated in a northeast Oregon hatchery steelhead program to investigate whether an increase in the target release size of yearling smolts from an average of 90 g (11.1 fish/kg [5 fish/lb]) to 113 g (8.8 fish/kg [4 fish/lb]) would potentially increase adult returns and reduce hatchery and wild fish interactions, including straying of adult fish. The study was successfully completed but it was not published. Although earlier studies on release size are informative, conclusions from them are confounded by the low number of adult returns (e.g., $n \leq 16$ per release group: Tipping 1997), sizes of released fish that were much smaller than those typical of today (i.e., 5.5–35 fish/lb: Larson and Ward 1955; Wagner et al. 1963) or releases of differing sizes of fish that were not paired to the same location and date. In this paired-release study the numbers of smolts released were large, and many adult returns subsequently were counted. Moreover, this study is the first to address whether smolt release size impacts adult straying. In light of growing concerns about the consequences of hatchery salmonids spawning in the wild (e.g., Araki et al. 2008) this study places the question of an ideal steelhead smolt release size in a new context. Thus, despite being dated, we believe the data herein provides managers with valuable new information for determining the appropriate release size for hatchery steelhead smolts.

METHODS

Experiments were conducted from release years (RY) 1986 through 1991 (excluding 1988) using yearling smolts reared at the Irrigon Fish Hatchery (IFH), operated by Oregon Department of Fish and Wildlife and located along the Columbia River approximately 11.2 km from the town of Irrigon, Oregon (Figure 1). Fish were released from acclimation ponds at the Wallowa Fish Hatchery (WFH) in the Grande Ronde River basin. Wallowa Fish Hatchery broodstock for smolts produced at IFH come from marked (presumably hatchery origin) returns to WFH, located on Spring Creek approximately 1 river kilometer (rkm) upstream from the mouth, and from marked WFH stock adult returns at a weir located just upstream from the mouth of Deer Creek. Irrigon hatchery is supplied with well water at temperatures that range from about 10.5°C to 13.9°C.

Eggs from broodstock collected at both locations were incubated at WFH to the eyed stage and then transferred to IFH for hatching and rearing. Fry were initially reared in indoor tanks before being transferred in July to concrete outdoor raceways measuring 30.5 m long × 6.0 m wide × 1.1 m deep. There were two raceways for each size-group. For the small-sized group, 51,000–54,000 fish were reared in each raceway, whereas raceways for the large-sized group held 41,000–45,000 fish. Targeted maximum raceway densities for both size-groups was about 19.5 kg/m^3. In midsummer, steelhead were marked with an adipose fin clip, and in autumn, approximately 25,000 fish from each raceway received a left-ventral fin clip and a coded wire tag (CWT; Table 1), resulting in two CWT codes for each size-group. However, for the 1986–1987 releases the two codes were spread evenly between the two raceways, rather than each assigned uniquely to one raceway. Therefore, we considered CWT-derived metrics from those years to be one replicate, whereas the following years had two replicates. After coded-wire-tagging, fish were fed BioMoist pellets (Bioproducts, Warrenton, Oregon) at rates that were adjusted based on monthly water temperatures and estimates of fish size to achieve a targeted release size of either 90 or 113 g.

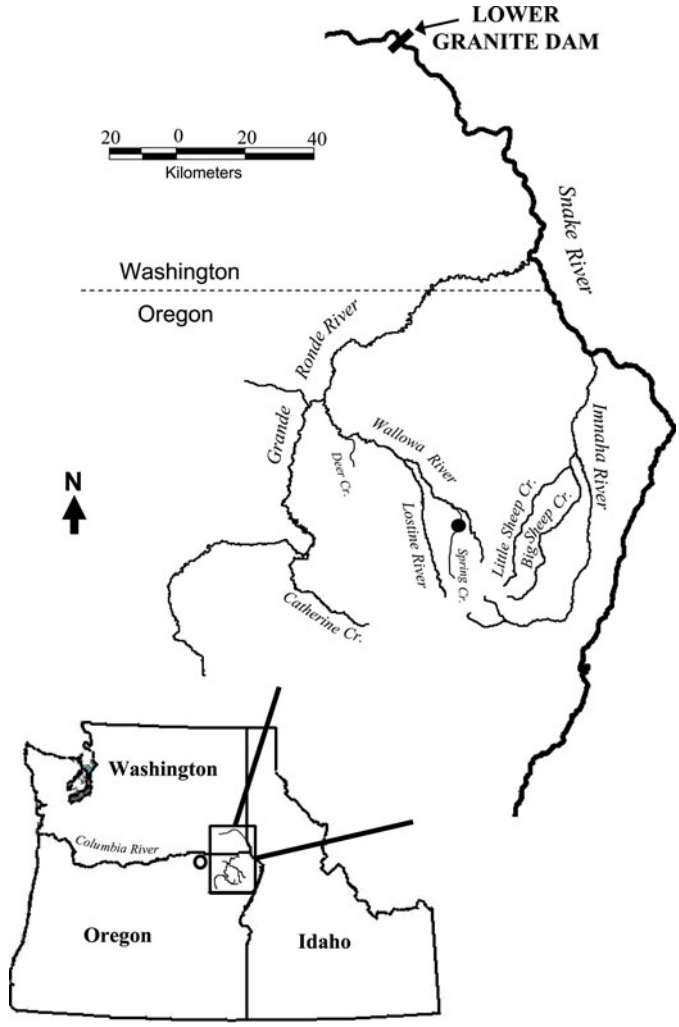

FIGURE 1. Location of the Wallowa Fish Hatchery and associated acclimation facility (dark circle) on Spring Creek in the Grande Ronde River basin of northeastern Oregon. An open circle marks the location of the Irrigon Fish Hatchery.

To compare the rates of smolt passage at Lower Granite Dam (LGD) and the days of migration to the dam, between 29,000 and 51,000 smolts from each size-group were freeze-branded each year in February or March using a silver-tipped branding rod cooled in a canister containing liquid nitrogen, and each group received a unique brand (Table 1). Out-migrating juveniles were sampled hourly from April to November at a trap located on

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TABLE 1. Release characteristics and the number of tagged fish released and subsequently recovered from groups of yearling steelhead smolts that were released at two sizes. Fork lengths (mm), weights (g), and condition factors (K) are averages. Brands are freeze brands; CWT = coded wire tags.

		Release					Number recovered	
Year	Size-group	Number (×1,000)	FL (SD)	Weight (SD)	K	Number branded (×1,000)	CWT	Brands
1986	Large	55.0	224 (20)	115 (36)	0.99	29.7	1,075	3,548
	Small	52.4	201 (20)	83 (27)	0.98	29.9	541	1,540
1987	Large	46.6	231 (19)	124 (33)	0.99	29.1	483	971
	Small	50.0	213 (20)	96 (28)	0.97	29.1	540	169
1989	Large	53.4	223 (18)	119 (30)	1.04	49.9	224	10,173
	Small	53.0	203 (18)	86 (23)	1.01	49.9	110	10,884
1990	Large	53.0	218 (18)	108 (27)	1.02	49.7	889	14,900
	Small	52.8	202 (18)	86 (23)	1.02	50.3	628	12,078
1991	Large	57.5	222 (18)	116 (29)	1.05	40.9	829	18,030
	Small	53.8	212 (18)	101 (26)	1.04	41.0	649	18,141
Mean	Large		224	116.4	1.02			
	Small		206	90.4	1.00			

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the dam's juvenile fish bypass system and were identified and enumerated by the freeze-brand mark using protocols described by the Fish Passage Center (1994).

A week before stream release from acclimation ponds in mid to late April, at least 100 randomly selected fish from both release groups, identified by using freeze brands, were weighed (g) and measured for FL (mm), from which Fulton's condition factor (K = weight/length^3 × 10^5: Anderson and Neumann 1996) was calculated.

We estimated annual steelhead smolt-to-adult survival (SAS) rates and a stray rate index (SRI) for each release group using CWT recoveries from in-basin and out-of-basin locations. The estimated number of adult recoveries in a capture area equals the actual number of CWT recoveries multiplied by a sampling rate expansion factor, and the total number of adults produced from each release group is the summation of adults captured in all areas (Johnson 1990). Smolt-to-adult survival is the percentage of smolts estimated to have been captured as adults from all locations, and SRI is the estimated number of adult steelhead CWTs recovered in a river basin other than the Grande Ronde River basin into which they were released, divided by the estimated number of captured adults. We cannot consider the SRI to be a true straying rate because some adults that were harvested in out-of-basin fisheries may have returned to the Grande Ronde River basin had they not been captured. In-basin recoveries came mostly from adults trapped in fish ladders at Wallowa Hatchery acclimation facilities, where all hatchery adults were collected, and from fisheries in the Grande Ronde River basin. Gender of adults trapped at the ladder was recorded, then the release group and year of release was determined from the CWT. Out-of-basin CWT recoveries were downloaded from the Regional Mark Information System database (www.rmpc.org), which summarizes expanded recoveries throughout all fisheries and hatchery returns in the Pacific Coast region of North America. We report the total number of adults produced per 100 kg of smolts released as an indicator of the smolt size that most efficiently produces adults. Scaling adult production in this manner accounts for the greater number of smolts that can be reared to the 90-g release size.

A paired t-test was used to analyze differences in travel time and survival to LGD, and percent SAS and SRI, between the two fish sizes at release. All data sets passed tests for normality (Shapiro–Wilk). The paired t-test does not assume equal variances (Zar 1984), thus this assumption was not tested. Smolt release size could influence the gender and age composition of returning adults if one strategy produced more individuals that failed to migrate after release (i.e., residualize), because there is a correlation between body size and residualism (Hausch and Melnchuk 2012) and residuals are mostly males (Viola and Schuck 1995). Therefore, we also used the paired t-test to examine differences in the percentage of returning adults that were males and the percentage that returned after 1 year of ocean residence rather than after 2 years. Results were considered significant at P-values less than 0.05.

RESULTS

The weight-at-release goal for small-sized groups (90 g) and large-sized groups (113 g) was difficult to meet precisely, as average annual weight at release of the small-sized group ranged between 83 and 101 g and those of the large-sized group ranged between 108 and 124 g (Table 1). However, over the course of the study the average weight of the small-sized group was 90.4 g and that of the large-sized group was 116.4 g; both were within 3.0% of the goals. Smolt FLs and condition factors at the time of release averaged 206 mm and 1.00 for small-sized groups, and

224 mm and 1.02 for large-sized groups. Annual branded smolt recoveries at LGD for calculating smolt out-migration metrics ranged between 169 and 18,141, and we estimated that annual CWT recoveries, from which SAS and SRI were derived, ranged between 110 and 1,075.

After stream release, steelhead smolt groups took an average of 10.3–33.2 d to reach LGD (Table 2). Large-sized smolts had shorter migration times in four of five release years, and when averaged across all release years the small-sized smolts arrived at LGD about 3 d later than the large-sized group; however, this difference was not significant ($P = 0.084$). There was no consistent pattern in the percentage of branded smolts from the two size-groups that were sampled at LGD; a greater percentage of the large-sized groups were sampled in 1987 and 1990, the small-sized groups were sampled at a greater percentage in 1986 and 1989, and sampling was nearly identical in 1991. Across all study years there was no significant difference in the percentage detected between the two groups ($P = 0.972$).

Percent SAS varied greatly by year. Survival rates for the large-sized group ranged between 0.42% and 1.95%, and for the small-sized group they ranged between 0.21% and 1.18%, but SAS was higher for large-sized groups in four of the five release years (Table 2). Across all years, large-sized smolts had an average SAS of 1.31% compared with 0.92% for small-sized smolts, a statistically significant ($P = 0.006$) difference of 42.0%. The average number of adult steelhead produced per 100 kg of smolts released was also higher from the large-sized group (11.4 adults/100 kg of smolts) over the small-sized group (10.1 adults/100 kg of smolts), though the 12.8% difference was not statistically significant ($P = 0.179$).

The estimated annual number of CWT recoveries in stray locations ranged between 9 and 68 per release group. Adults originating from large-sized smolt releases showed a greater propensity to stray in each release year (Table 2). Across all release years, the SRI for release groups of large-sized smolts averaged 13.1% compared with 7.9% for small-sized smolt groups, and the 66% difference was statistically significant ($P = 0.004$).

Gender was determined from 1,122 adults and age composition from 5,968 adults. We found no apparent effect of release size on either the gender or age of returning adults. Of the adults that returned from large-sized groups, 54.9% (SE = 2.5) were male and 63.8% (SE = 4.8) returned after 1 year of ocean residence, whereas adults originating from small-sized smolt releases were 54.1% (SE = 2.66) males and 60.3% (SE = 4.8) returned after one ocean year. There was no statistically significant difference in either gender ($P = 0.664$) or age at return ($P = 0.183$).

DISCUSSION

Results from this study support the commonly held belief that postrelease survival is higher for larger hatchery steelhead smolts than for smaller ones, because smolts that were targeted for release at 113 g exhibited a 42% higher SAS compared with those targeted for a 90-g release size. But, we measured only a 12.8% average difference in returning adults per 100 kg of smolts released, which suggests that SAS rates alone do not provide managers, who wish to maximize adult production, with adequate information for determining the appropriate release size. To illustrate this point, consider a plausible hypothetical result in which the average difference in our measured SAS rates narrowed to 26%; in that instance the adults produced per 100 kg of smolts would be roughly equal (assuming targeted release sizes were met), and managers would need to consider other factors in order to choose the ideal release size. If, for example, the number of adults available for broodstock is limited, as may be the case in hatchery programs that collect natural-origin adults for broodstock, then a larger release size may be preferred. Rearing fewer smolts to a larger size may also save on costs associated with marking (e.g., fin-clipping) and tagging fish. However, rearing smolts to a size of 91 g rather than 133 g could save as much as 33% in feed costs (Tipping 1997).

Two metrics in this study, out-migration travel time and SRI, may provide information about potential ecological interactions between our study fish and wild fish. Travel times to LGD were not significantly different between large- and small-sized smolts, suggesting that rearing smolts to a larger size would not reduce interactions with wild fish during the out-migration. In contrast, the SRI suggests a greater potential for adults produced from release groups of large-sized smolts to interact with natural-origin adults. Imprinting on release waters occurs at the smolt stage (Hasler et al. 1978); therefore, a greater level of smolt development due to rearing juveniles to a larger size would, in theory, reduce straying. We did not have access to laboratory equipment to measure physiological indices of smolt development, such as gill ATPase activity and plasma thyroxine levels; however, during prerelease sampling we visually assessed smolt development based on skin silvering and the presence of parr marks (Hoar 1976), and classified each fish as being either parr, intermediately smolted, or smolts. Most fish in every release group were judged to be intermediately smolted, and no more than 6% of any group were classified as parr, but in every release year the large-sized group had a higher percentage classified as smolts (L. R. Clarke, unpublished data). Since the smolt development measurements and SRI values do not agree, we are uncertain as to why adults from the large-sized group exhibited a greater propensity to stray.

The literature suggests that hatchery steelhead smolts residualize either because slow in-hatchery growth rates result in fish that are physiologically unprepared to out-migrate to the ocean upon stream release, or because males reach the onset of sexual maturation before release (Berejikian et al. 2012; Hausch and Melnchuk 2012). Concerning the former, studies suggest that steelhead juveniles 180–190 mm in length are less likely to out-migrate than are larger conspecifics (Tipping 1997; Sharpe et al. 2007). As to the latter, studies have reported early male maturation in both the larger and smaller males within a cohort (Tipping et al. 2003; Sharpe et al. 2007). Though this

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TABLE 2. Metrics derived from freeze brand recoveries of out-migrating steelhead smolts recovered at Lower Granite Dam on the Snake River and coded wire tag recoveries of adult steelhead that were released at either a large or small size; SAS = smolt-to-adult survival, SRI = stray rate index. Percent SAS, adults produced per 100 kg of smolts, and SRI are unreplicated values in 1986 and 1987, and averages and SE from two replicate raceways from 1989 to 1991.

Release year	Group	Outmigration: Travel time (d) (SD)	Outmigration: Percent detected	% SAS (SE)	Adults per 100 kg of of smolts (SE)	% SRI (SE)
1986	Large	29.2 (8.6)	5.1	1.95	17.2	16.2
	Small	33.2 (10.7)	11.9	1.03	12.3	6.7
1987	Large	10.3 (4.2)	3.3	0.97	7.7	7.7
	Small	14.4 (13.8)	0.5	1.03	10.7	5.2
1989	Large	26.0 (11.2)	20.4	0.42 (0.02)	3.5 (0.22)	7.9 (0.02)
	Small	30.6 (14.5)	21.8	0.21 (0.05)	2.4 (0.61)	4.1 (0.01)
1990	Large	26.2 (14.6)	30.0	1.68 (0.15)	15.6 (1.02)	18.9 (0.07)
	Small	24.4 (13.8)	24.0	1.18 (0.13)	13.8 (0.16)	12.1 (0.00)
1991	Large	26.8 (9.8)	44.0	1.53 (0.32)	13.2 (2.80)	14.8 (0.02)
	Small	29.3 (11.7)	44.2	1.13 (0.01)	11.2 (0.38)	11.3 (0.01)
Mean	Large	23.7	20.6	1.31	11.4	13.1
	Small	26.4	20.5	0.92	10.1	7.9

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study did not include quantification of residualism rates in the two size-groups, our prerelease measurements showed that no more than 2.0% of any large-sized smolt release group was less than 180 mm FL, whereas between 4.3% and 11.0% of small-sized groups were below that threshold, suggesting that release groups of small-sized fish may have produced more residuals from individuals that had not matured to the smolt stage and did not out-migrate. However, we also cannot exclude the possibility that more robust in-hatchery growth from the large-sized release group resulted in a greater percentage of males that were sexually mature, and therefore residualized, after release.

Smolts for this study were released into the stream approximately 988 rkm from the ocean and had to endure either an out-migration past eight dams on the Snake and Columbia rivers or the stress associated with being collected at LGD and transported by barge 460 rkm downstream to below Bonneville Dam. Hypothetically, either out-migration pathway could impart a greater mortality on smaller smolts, thereby possibly reducing the SAS of the release groups of small-sized fish. If this were true, then our study results may not be applicable to hatcheries that release steelhead smolts into coastal streams. Since Tipping (2011) found survival differences between large- and small-sized hatchery Chinook Salmon *O. tshawytscha* juveniles released upstream of four Columbia River dams, but no survival differences between the two size-groups when releases occurred below those dams, we cannot rule out the possibility that our large- and small-sized smolts experienced differential out-migration mortality.

The percentage of freeze-branded out-migrating smolts detected at LGD trended higher in later years of this study, but this should not be interpreted as an improvement in out-migration survival over the course of the study, because each year an unknown and variable percentage of fish traveled over the dam's spillway or passed through the turbines, where they were not trapped and counted (Smith et al. 1993). Only fish that were guided into the dam's juvenile bypass facility could be counted, and upgrades to the guidance mechanisms during the study years may have improved the efficiency of this process. Therefore, within-year comparisons of the percent of brands detected between the two release groups are informative, but between-year comparisons are not.

Choosing the preferred release size for steelhead smolts is not a simple decision, even when only hatchery production-related factors are considered (e.g., rearing limitations, costs, adult production), and it becomes more complex when release size is linked to concerns about ecological impacts of hatchery fish. In this study we found tradeoffs associated with a larger release size of 113 g, though ultimately Wallowa Hatchery program managers adopted the larger-sized smolt goal. For more information on processes and criteria to aid hatchery managers that must weigh the risks and rewards of decisions such as size at release, we suggest papers by Bjornn (1986), Ham and Pearsons (2001), Currens and Busack (2004), and Lorenzen et al. (2010). Finally, studies with Pacific salmon have shown that seasonal in-hatchery growth and lipid accumulation can affect rates of early male maturation (Larsen et al. 2006, 2013), and a more natural growth profile may improve survival to adulthood (Clarke et al. 2012). McMillan (2009) found similar influences of growth and lipid accumulation on early male maturation in wild *O. mykiss* populations. Thus, we suggest that future studies with hatchery steelhead focus on ways to reach a desirable hatchery steelhead smolt release size while mimicking the growth patterns observed in natural populations.

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