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ARTICLE

Determining Optimum Size at Release for Hatchery-Origin Tucannon River Spring Chinook Salmon Using PIT Tags

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Abstract

The Tucannon River spring Chinook Salmon *Oncorhynchus tshawytscha* hatchery program has consistently failed to reach the program target adult (age 4 and older) smolt-to-adult return (SAR) rate of 0.87%. This has resulted in the hatchery program falling short of meeting its hatchery adult return goal of 1,152 fish. To determine whether hatchery fish released at a larger size would increase the number of returning adults, we released 95,256 PIT-tagged, hatchery-origin spring Chinook Salmon with known FLs (range = 73–212 mm) categorized into five length-classes (<120, 120–139, 140–159, 160–179, and ≥180 mm FL) over eight brood years (2006–2013) to examine how size at release affected the smolt-to-adult survival (SAS) rate to the Columbia–Snake River system and the SAR rate to the Tucannon River. We used this information to determine an optimum size range at release to maximize adult returns to the Tucannon River and determine whether the program target SAR of 0.87% was achieved by any of the length-classes. Return of hatchery adults (age 4 and older) for both SAS and SAR peaked for the 140–159-mm length-class. Smaller size at release resulted in lower survival, whereas fish larger than this size range matured prematurely either as minijacks or jacks and the majority never made it back to the Tucannon River. Based on this study, to maximize adult returns, hatchery smolts from the Tucannon River spring Chinook Salmon hatchery program should be released in the 140–159-mm range. None of the length-classes came close to reaching the adult SAR target of 0.87% (SAR for fish that were 140–159 mm at release was 0.15%). The expectation that changes to smolt size will lead to reaching the 0.87% SAR target is unrealistic for this population under current hatchery rearing and environmental conditions.

The Tucannon River population of spring Chinook Salmon *Oncorhynchus tshawytscha* is currently listed as threatened under the Endangered Species Act (ESA) as part of the Snake River spring/summer Chinook Salmon evolutionarily significant unit (NMFS 1992a, 1992b). A hatchery supplementation program was initiated as part of the Lower Snake River Compensation Plan (LSRCP) in 1985 using endemic-origin Tucannon River spring Chinook Salmon to mitigate for losses due to the construction and operation of four hydroelectric dams in the lower Snake River. To date, this program has consistently failed to reach the program target adult (age 4 and older) smolt-

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to-adult return (SAR) rate of 0.87% (Gallinat et al. 2008). This has resulted in the program not meeting the hatchery adult return goal of 1,152 fish (Gallinat et al. 2008). The LSRCP spring Chinook Salmon hatchery programs have only met the 0.87% SAR target approximately 20% of the time (ISRP 2014), prompting the question of whether changes in hatchery practices could aid in achieving the target SAR.

Hatchery adult return abundance could be improved through increased production, higher survival of current production, or some combination of both. Any effort to increase production for this ESA-listed population would require collecting more broodstock from already-limited adult returns. Thus, the alternative of identifying methods to increase survival of current hatchery releases may be a more viable alternative. A variety of methods, including exercise experiments (Evenson and Ewing 1993; Hoffnagle et al. 2006), seminatural rearing conditions (Fuss and Byrne 2002; Fast et al. 2008), and density reduction (Martin and Wertheimer 1989; Hopley et al. 1993; Banks and LaMotte 2002), has been employed at various fish hatcheries in an effort to increase survival of hatchery-reared fish. Most of these strategies are difficult to implement at large production hatcheries due to space and personnel limitations; furthermore, the benefits of these methods have been limited and success has been inconsistent (Evenson and Ewing 1993; Hopley et al. 1993; Hoffnagle et al. 2006; Fast et al. 2008). Because of these inconsistencies, the general paradigm used by fish hatcheries to increase survival of hatchery fish has been to increase the size at release (Hager and Noble 1976; Tipping 1986; Martin and Wertheimer 1989).

Numerous obstacles along the migration corridor can impede salmon survival. Decreased water velocity (e.g., reservoirs) after dam construction has resulted in smolt emigration to the ocean taking twice as long as emigration under free-flowing conditions (Williams et al. 2005). Hatchery fish may also have difficulty adjusting to and locating food in the natural environment after release, resulting in high postrelease mortality (Rondorf et al. 1985). Releasing fish at a larger size would likely increase smolt survival (Tipping 1997; Zabel and Achord 2004), but this may also increase the number of precocious males and possibly change the age structure of the returning adult population (Bilton et al. 1982; Larsen et al. 2013), leading to a reduction in the number of full-size anadromous adults (Beckman et al. 2017).

To investigate the effect of hatchery juvenile size on overall survival and number of returns, we utilized PIT tags to avoid bias (e.g., large fish recovered more than smaller fish, females recovered more than males, etc.) associated with in-river carcass recoveries (Zhou 2002; Murdoch et al. 2010). A network of interrogation systems that can passively detect fish with PIT tags is currently in place within juvenile bypass systems and adult fishways at hydroelectric dams throughout the Columbia and Snake River basins (Burke and Jepson 2006). Instream interrogation was accomplished via antenna arrays installed in the Tucannon River (see Zydlewski et al. 2006).

The original intent of this study was to examine two distinct target release-size groups (30 g versus 50 g) from brood years (BYs) 2006–2010; however, there were length overlaps between the two groups during some of the years, which complicated the analysis. Therefore, we examined 95,256 PIT-tagged, hatchery-origin Tucannon River spring Chinook Salmon with known FLs (FL range = 73–212 mm) categorized into five length-classes (<120, 120–139, 140–159, 160–179, and ≥180 mm FL) over eight BYs (2006–2013) and tabulated the returning adults by age. Total (ages 2–5) and adult (age 4 and older) smolt-to-adult survival (SAS) rates were defined as the total number of fish that were detected returning to the Columbia and Snake River watersheds (Bonneville Dam and upstream) within those age-groups. The primary goal, however, was to increase the number of adults returning to the Tucannon River, so total (ages 2–5) and adult (age 4 and older) SAR rates were defined as PIT tag detections in the Tucannon River. The results of this study were used to determine an optimum size range at hatchery release that would return the most adults to the Tucannon River in an effort to help rebuild this ESA-listed population. Finally, we determined whether the program target SAR of 0.87% was achieved by any of the length-classes.

METHODS

The Tucannon River is a third-order stream in southeastern Washington State and flows into the Snake River between Little Goose and Lower Monumental dams approximately 622 river kilometers (rkm) from the mouth of the Columbia River (Figure 1). Natural- and hatchery-origin returning adults from the 2006–2013 run years were collected for broodstock at the Tucannon Fish Hatchery (TFH) adult trap located at rkm 59 on the Tucannon River (measured from its confluence with the Snake River). Broodstock were then transported to Lyons Ferry Hatchery (LFH), which is located on the Snake River (Figure 1). The LFH was used for broodstock holding and spawning, egg incubation, and early rearing to about age 1. The LFH facility is supplied with constant-temperature (11°C), pathogen-free well water. Adults were spawned during the end of August through September, with egg incubation during September and October, and fry were ponded in concrete raceways (3.1 × 1.1 × 30.5 m) in December. From December to October of the following year, all fish were reared together under identical conditions.

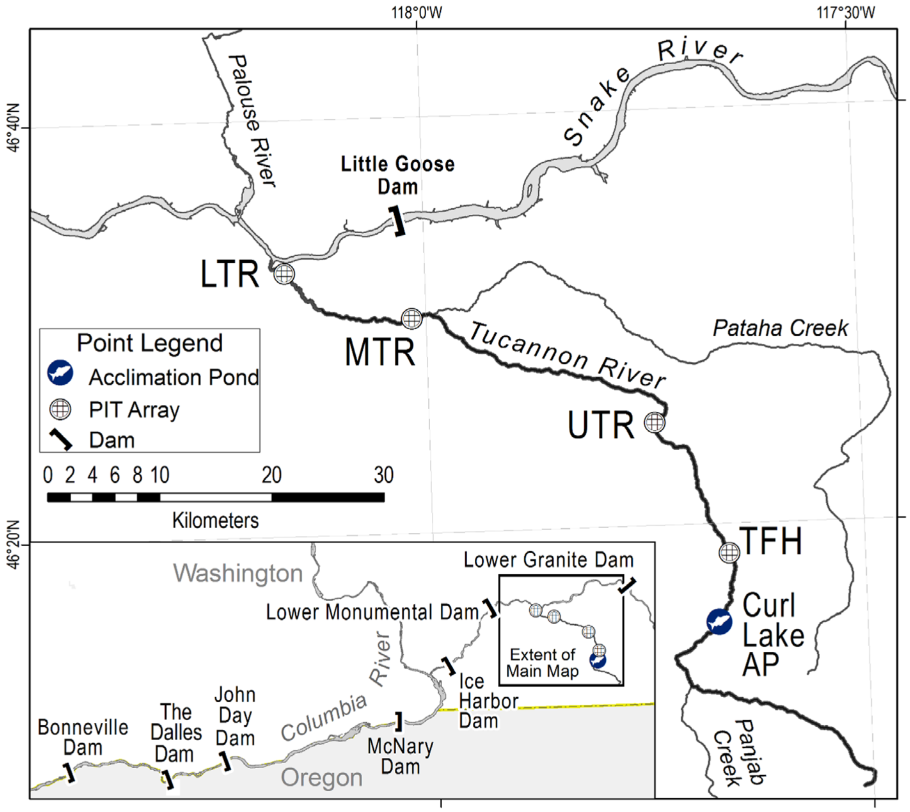

FIGURE 1. Locations of the lower Tucannon River (LTR), middle Tucannon River (MTR), upper Tucannon River (UTR), and Tucannon Fish Hatchery (TFH) instream PIT tag arrays on the Tucannon River within the Snake River basin, Washington, USA. The locations of the major hydroelectric dams on the Snake and Columbia rivers that are discussed in this paper are also shown.

For all fish, coded wire tags (CWTs) were applied in the snout during mid-September, 1 year after spawning. For BYs 2006–2010, the 30-g target size-group was tagged with a unique CWT and a purple visible implant elastomer (VIE) tag (Northwest Marine Technology, Shaw Island, Washington) behind the left eye, whereas fish from the 50-g target size-group were given a different CWT and a blue VIE tag behind the left eye. The VIE tag allowed for external visual identification of fish from each group after they were combined for acclimation and volitional release. For the 2011–2013 BYs, fish were tagged with a CWT only. Fish in this study were not adipose clipped, thus excluding them from mark-selective sport harvest upon return. After tagging, the two study groups were reared separately with similar rearing densities, raceway cleaning frequency, and commercial feed (Bio-Oregon, Longview, Washington). Feeding rates were adjusted in an effort to obtain, on average, the final target release sizes (30 and 50 g for BYs 2006–2010; 38 g for BYs 2011–2013). The fish were transferred to TFH in October, approximately 2–3 weeks after tagging. Fish were placed into 12.2-m-diameter circular ponds (0.6 m deep), 4.6- × 1.5- × 35.1-m raceways, or 3.1- × 0.9- × 24.4-m raceways for a period of 3–4 months. At TFH, river water was used as the main water source, with well water added at times to keep temperatures above 4.4°C, to prevent outbreaks of erythrocytic inclusion body syndrome, which had been previously documented. Flow index was monitored monthly at both facilities and rarely exceeded 80% of allowable loading.

In January, a subsample from each BY was PIT-tagged before being transferred to the Curl Lake Acclimation Pond. During PIT tagging, fish were placed into a recirculated, unbuffered anesthetic solution (45–60 mg/L) of tricaine methanesulfonate (Western Chemical, Ferndale, Washington). The PIT tags (12.0 × 2.1 mm, 134 kHz ISO) were injected into the body cavity posterior to the pectoral fin at or near the ventral midline by experienced taggers according to standard protocols (Prentice et al. 1990; CBFWA 1999). At the time of tagging, the PIT tag code and FL (mm) were recorded and stored on a laptop computer running PITTAG4 software (Pacific States Marine Fisheries Commission, Portland, Oregon). Fish from BYs 2006–2008 were PIT-tagged by Washington Department of Fish and Wildlife (WDFW) personnel, totaling 2,000, 500, and 525 fish, respectively. The PIT tagging for BYs

2009–2013 was performed under a contract with Biomark (Boise, Idaho), totaling 25,000, 23,000, 15,000, 15,000, and 15,000 fish, respectively.

In early February, fish were transferred to the Curl Lake Acclimation Pond, which is a 0.85-ha, natural-bottom lake with a mean depth of 2.7 m and a pond volume estimated at 22,203 m^3. Water temperatures while fish were acclimating ranged between 4.4°C and 12.8°C. Fish that died prior to release were scanned for PIT tags, and tagged mortalities were removed from the release files. Volitional release ended in late April of each year, and any remaining fish were forced out of the pond. Final release numbers of fish with PIT tags and associated FLs were 1,983, 500, 513, 24,871, 22,763, 14,904, 14,862, and 14,860 for BYs 2006–2013, respectively. The total number of released PIT-tagged fish used in the analyses is provided in Table 1. The PIT tag release files were uploaded to the PIT Tag Information System (www.PTAGIS.org) database, and subsequent detections (passive recapture) were downloaded for analysis (PTAGIS 2012).

Main-stem PIT tag arrays are located in the juvenile bypass and adult ladders at many of the dams along the Columbia and Snake rivers (Figure 1). During the study period, PIT tag antennas in the fish ladders were operational at Bonneville, McNary, and Ice Harbor dams. Although some fish are able to pass the dams undetected (e.g., navigation locks), cumulative detection efficiency was greater than 98% (Tenney et al. 2014, 2015, 2016). There are also instream PIT tag antenna arrays (Figure 1) on the lower Tucannon River (LTR; rkm 2.2), on the middle Tucannon River (MTR; rkm 17.8), on the upper Tucannon River (UTR; rkm 44.4) and at TFH (rkm 59.2). The LTR array was installed in 2005, the MTR and UTR arrays were installed in 2011, and the TFH array was installed in 2012. Thus, returning PIT-tagged fish could be detected at LTR throughout the study period, with potential backup detections at the other sites. The PIT tag antenna arrays in the Tucannon River consisted of six antennas (0.9 × 6.1 m; enclosed in 10.2-cm-diameter PVC pipe) anchored flat to the bottom of shallow (<0.5 m at the deepest spot during low flows) sections of the river, comprising three rows (except at TFH, where only two rows were deployed). Each row of antennas spanned the entire stream width, depending on flows. Tag detections were downloaded from a FishTracker FS1001M stationary multiplex transceiver (Biomark) and were uploaded to PTAGIS. Detection efficiencies at LTR during the returning adult spring Chinook Salmon migration period (using detections at LTR from the three rows of antennas) ranged from 69% to 100%, with most years having detection efficiencies greater than 90% (Joseph D. Bumgarner, WDFW, personal communication). When PIT tag detections from both the LTR and MTR arrays were used, PIT tag detection efficiency averaged 98% (range = 95–100%).

Fish were assumed to be mature during the year in which they returned to freshwater after being in the marine environment. The SAS and SAR rates were calculated based on the final detection of a PIT-tagged fish and based on the location of the antenna: detections from Bonneville Dam and sites upstream of Bonneville Dam were used for SAS calculation, and detections in the Tucannon River were used for calculation of SAR rates. The SAR detections constituted a subset of the SAS detections.

We analyzed the number of PIT-tagged fish that were detected as returning to the Columbia–Snake River system and to the Tucannon River by using generalized linear models (GLMs) that were framed to predict the probability of success of trials. For analyses of PIT-tagged fish, success depended on the detection of returning fish in a region and age category, and trials depended on the specific group of fish for which we wanted to evaluate the detection probability (in the primary analyses, all releases).

We assumed that the number of successes for each combination of unique explanatory variables came from a

TABLE 1. Total number and proportion of hatchery-origin Tucannon River spring Chinook Salmon that were PIT-tagged by length-class from brood years (BYs) 2006–2013 for the 30-, 50-, and 38-g target release-size goals.

	30-g target, BYs 2006–2010		50-g target, BYs 2006–2010		38-g target, BYs 2011–2013		Total, BYs 2006–2013	
Length-class (mm)	Number tagged	Percent	Number tagged	Percent	Number tagged	Percent	Number tagged	Percent
<120	23,319	92.25	465	1.83	23,052	51.66	46,836	49.17
120–139	1,859	7.35	9,354	36.90	13,735	30.78	24,948	26.19
140–159	94	0.37	8,163	32.20	4,614	10.34	12,871	13.51
160–179	7	0.03	6,333	24.98	2,791	6.25	9,131	9.59
≥180	0	0.00	1,036	4.09	434	0.97	1,470	1.54
Totals	25,279	100.00	25,351	100.00	44,626	100.00	95,256	100.00

quasi-binomial distribution. In preliminary tests, we often detected significant overdispersion (relative to a binomial distribution) and thus elected to use the quasi-binomial distribution in all cases. The probability of success for each tagged fish, π_i, was modeled as a function of predictors using a logit link function:

$$\text{logit}(\pi_i) = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 x_{i,1} + \ldots + \beta_k x_{i,k}. \quad (1)$$

Here, $x_{i,j}$ represent explanatory variables. These explanatory variables were "dummy" (0–1) variables indicating which level of a categorical variable applied to the *i*th group of fish. In our primary analyses, we used fish released from each BY (2006–2013) and included the categorical explanatory variables LC (length-class of fish at PIT tagging) and BY. The LC was represented by five classes of FL (<120, 120–139, 140–159, 160–179, and ≥180 mm). We did not include the interaction of LC and BY because this is aliased with overdispersion.

Tests for effects of each categorical factor (variable) were performed via a chi-square likelihood-ratio test evaluating whether the full baseline model, including the variable (and all other variables under consideration), fit better than a reduced model from which that variable was dropped. Variables that were not significant ($P > 0.05$) were not included in the final model.

Analysis was conducted using R version 4.1.0, and the GLM function of the stats package was used for fitting models (R Core Team 2013). Chi-square tests for comparing models used the ANOVA function of the stats package.

We analyzed subsets of the PIT tag returns to quantify probabilities of the return of fish at different ages and different locations. The location and age in which we are interested determine what a "success" is, and the number of trials is determined by what the probability is conditioned upon. As one example, we assessed the probability that a smolt would return as an adult to the Tucannon River based on the number of PIT-tagged fish (trials) and the number recovered as adults in the Tucannon River. For simplicity of wording, all probabilities of return to a region imply return and detection, and "recovery" means that a fish with a PIT tag is detected. More specifically, we define the following probabilities and the associated successes and trials for the PIT tag data in our primary analyses:

1. SAS_T: the probability that a released fish returns to the Columbia–Snake River system (any location, any age), where successes are any returning PIT-tagged fish detected in the system and trials are all tagged fish.
2. SAR_T: the probability that a released fish returns (any age) to the Tucannon River, where successes are PIT-tagged fish detected in the Tucannon River and trials are all tagged fish.
3. SAS_A: the probability that a released fish returns as an age 4 or older adult to the Columbia–Snake River system (any location), where successes are any age 4 or older PIT-tagged fish detected in the system and trials are all tagged fish.
4. SAR_A: the probability that a released fish returns as an age 4 or older adult to the Tucannon River, where successes are age 4 or older PIT-tagged fish detected in the Tucannon River and trials are all tagged fish.

We further explored causes for patterns in these results by defining "trial" based on fish known to have returned to the Columbia–Snake River system (either all such returns or the returns of age 4 and older adults) and "success" as the return of such fish to the Tucannon River. The details of these additional models and results are presented in Appendix 1.

During 2006–2010, the size of fish released was deliberately manipulated with target sizes of 30 and 50 g. Although the mean sizes of fish in the two target categories were significantly different from one another in all years, there was substantial variation within target categories and among years in the actual sizes of the fish at release (Appendix 2). In addition, the size distribution was broader for BYs 2006–2010 than in later years. In a preliminary analysis, we found that the target size did not explain variation in returns above and beyond that explained by LC (Appendix 2). Given the difference in size distributions for BY 2010 and earlier BYs versus later years, we also repeated our main analysis separately for the two groups of BYs, in each case finding similar effects of LC (Appendix 2). We therefore used data from all years without reference to the target size in our primary analyses.

RESULTS

For all of the primary PIT tag models, both LC and BY were highly significant ($P \leq 0.001$). The total probability of Tucannon River spring Chinook Salmon returning to the Columbia–Snake River system increased continuously with stocking length category (Figure 2; Tables 2 and 3, SAS_T analysis). Although the total probability of returns to the Tucannon River also increased with LC, the probability was nearly equal for the two largest LCs (Figure 3; Tables 2 and 3, SAR_T analysis). The probability of return to the Tucannon River was notably lower and, excluding the highly uncertain return rates for BYs 2007 and 2008, ranged from one-half to one-tenth of the returns to the Columbia–Snake River system (Table 4). Probabilities of returns to the Columbia–Snake River system and to the Tucannon River varied substantially among years (Tables 2 and 4). The highest estimated total return rate to the Columbia–Snake River system (for releases in the 140–159-mm category) was nearly 0.03 in the first BY

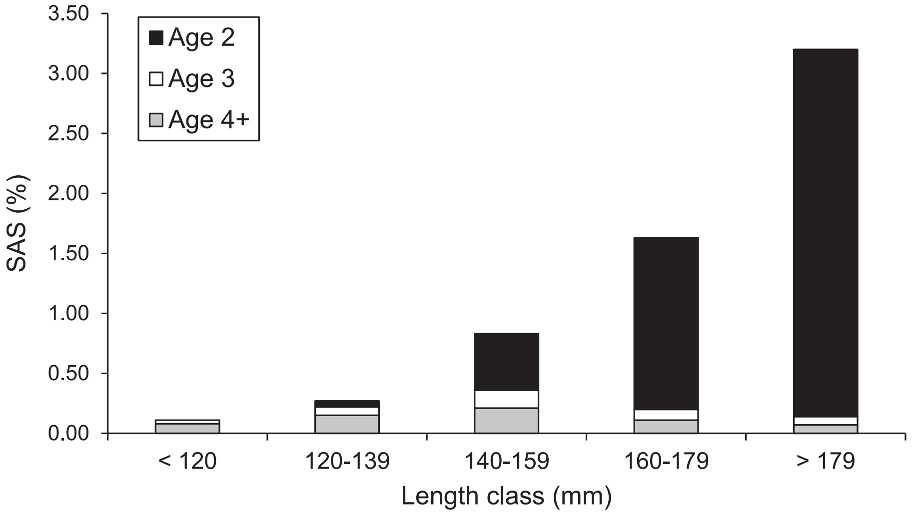

FIGURE 2. Smolt-to-adult survival (SAS) for hatchery-origin Tucannon River spring Chinook Salmon of ages 2, 3, and 4+ (4 and older) from brood years 2006–2013 that were categorized by length (mm FL) at release and were detected as returning to the Columbia–Snake River system based on PIT tag detections.

TABLE 2. Parameter estimates and SEs for primary analyses of PIT-tagged Chinook Salmon detections. Parameters are those of the linear model for the logit of the probability of detecting returns (equation 1). The four variables analyzed (SAS_T, SAR_T, SAS_A, and SAR_A) are described in the text. The estimate of the intercept gives the estimated logit for the baseline length-class (<120 mm) and brood year (BY; 2006). The estimates given for the other length-classes and BYs represent the difference from the logit of the baseline category.

	SAS_T		SAR_T		SAS_A		SAR_A	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	−5.87	0.28	−6.74	0.47	−5.91	0.36	−7.03	0.61
120–139 mm	0.97	0.23	0.63	0.24	0.68	0.24	0.56	0.28
140–159 mm	2.22	0.22	1.46	0.25	1.18	0.26	1.15	0.31
160–179 mm	2.86	0.21	1.65	0.26	0.64	0.36	0.61	0.44
≥180 mm	3.41	0.27	1.68	0.51	0.01	1.00	−17.63	$>1\times10^3$
BY 2007	−1.05	0.65	−17.56	$>1\times10^3$	−0.24	0.76	−18.68	$>1\times10^3$
BY 2008	−19.34	$>1\times10^3$	−17.64	$>1\times10^3$	−17.97	$>1\times10^3$	−18.71	$>1\times10^3$
BY 2009	−1.68	0.27	−0.66	0.47	−1.36	0.36	−0.34	0.61
BY 2010	−0.77	0.24	−0.45	0.46	−1.97	0.41	−0.95	0.65
BY 2011	−0.71	0.31	0.24	0.48	−0.73	0.38	0.34	0.63
BY 2012	−0.67	0.27	−0.13	0.48	−1.41	0.40	−0.75	0.67
BY 2013	−1.74	0.28	−1.09	0.50	−1.73	0.40	−1.39	0.71

(2006), and excluding the highly uncertain zero return rate for BY 2008, the lowest rate was less than 0.005 in the last BY (2013), whereas the return rate varied without clear trend in the intervening years (Table 4, SAS_T analysis). The probability of returns to the Tucannon River showed a similar proportional range of variation among BYs (excluding the highly uncertain zero-detection BYs), but with only a rough correspondence in which years had the most success (Table 4, SAR_T analysis).

Return rates of adults (age 4 and older) from released fish peaked for the 140–159-mm LC and declined with further increases in size (Figures 2 and 3). This pattern was seen both for all returns (SAS_A) and for returns to the Tucannon River (SAR_A; Tables 2 and 3, SAS_A and SAR_A analyses). Although our models allowed for overdispersion, effectively allowing random variation in the size dependence of return rates among BYs, examination of the data for each BY (Appendix 1) suggests similar patterns of size dependence of return rates for BYs that produced sufficient returns over multiple size-classes to allow this to be evaluated. For the BY (2011) for which we illustrated probabilities of returns with LC, nearly all age 4 fish that returned to the Columbia–Snake River system also returned to the Tucannon River, as indicated by the

TABLE 3. Calculated probability of detected Chinook Salmon return for the SAS_T, SAR_T, SAS_A, and SAR_A analyses (see text for definitions) based on the parameter estimates in Table 2. For these calculations, for different length-classes the parameter for brood year 2011 was used. Results were calculated using the inverse logit, $\pi = \exp(x)/[1 + \exp(x)]$, where x is the logit of π defined by equation (1). Probabilities were calculated for different length-classes for only a single brood year to illustrate the magnitude of effects, given that the effects on logits were additive. The value in bold italics represents an estimate from a length-class with zero detections and low sample sizes, with highly uncertain length-class effect (based on a parameter with SE >1,000; see Table 2).

Length-class (mm)	SAS_T	SAR_T	SAS_A	SAR_A
<120	0.0014	0.0015	0.0013	0.0013
120–139	0.0037	0.0028	0.0026	0.0022
140–159	0.0127	0.0064	0.0042	0.0040
160–179	0.0238	0.0077	0.0025	0.0023
≥180	0.0406	0.0080	0.0013	***0.0000***

similar probabilities for SAS_A and SAR_A in Table 3. The absolute probabilities differed more in some years, but the similar LC dependence of return rates for age 4 and older adults to the Columbia–Snake River system and the Tucannon River is supported by an ancillary analysis treating returns to the Columbia–Snake River system as trials and returns to the Tucannon River as successes, which did not find a significant effect of LC (Appendix 1). The return rates at older ages were less than half the total return rate in most years and LCs (Tables 3 and 4). Return rates of older adults also varied substantially among BYs. There was a rough but not perfect correspondence in temporal patterns in return probabilities among BYs (1) when comparing overall return rates to the system and return rates to the Tucannon River for older adults and (2) when comparing the return rates of older adults with the return rates of all ages (Tables 2 and 4). Although return rates to the Tucannon River were nearly as high as those to the Columbia–Snake River system overall in most years, there were a few BYs for which the estimated probability of return of age 4 and older adults to the Tucannon River was substantially lower than that to the overall system (Table 4). The ancillary analysis using age 4 and older returns and returns to the Tucannon River as successes found a significant effect of BY (Appendix 1), confirming that the relative return rates to the Columbia–Snake River system overall and the Tucannon River did have different patterns over BYs for age 4 and older fish.

DISCUSSION

We observed an increasing trend in both SAS_T and SAR_T with size at release. However, we were surprised at the large number of fish—primarily minijacks and jacks—that returned to the Columbia–Snake River system (SAS_T), only to seemingly vanish and not return to the Tucannon River (SAR_T). The last detections of these fish were primarily at McNary Dam (36.8%), Ice Harbor Dam (32.7%), and The Dalles Dam (17.8%). The final fate (i.e., mortality, straying, etc.) of these missing fish is unknown.

The greater survival at a larger release size may be due to the ability of the larger fish to avoid predation (primarily by Northern Pikeminnow *Ptychocheilus oregonensis* and Smallmouth Bass *Micropterus dolomieu*), or they may be better able to survive other obstacles along the migration corridor to successful emigration. Monzyk et al. (2009) found that size-selective mortality was evident for both hatchery- and natural-origin spring Chinook Salmon smolts, with larger individuals experiencing higher survival. Larger individuals in a population also tend to have faster migration times (Beckman et al. 1998; Zabel 2002), which may provide a shorter duration of exposure to predators and other migration hazards. Though not specifically examined in this paper, emigrating smolts from the original 50-g target release-size group in our study arrived 7 d faster, on average, to Bonneville Dam than fish from the 30-g group (Gallinat and Ross 2012, 2013).

Larger smolts may also have benefited from continuing to have a survival advantage as they migrated into the Columbia River estuary and nearshore marine environment. Predation pressure on these smolts would be expected to continue as millions of hatchery- and natural-origin juveniles pass through the estuary, competing for limited food resources. There is also evidence that fish size can be related to smoltification (Beckman et al. 1999), and the smaller fish may have not completed the smoltification process within the necessary time frame to promote migratory urge, ultimately leading to lower saltwater tolerance (Zaugg et al. 1986). We did not have the funding for Na^+, K^+ ATPase analysis, which would have been informative in determining the level of smoltification in our study. Larger smolts, especially early maturing males, also might not migrate far offshore, thus affecting their marine distribution (Chamberlin et al. 2011) and resulting in spatial survival differences.

The 140–159-mm LC in our study returned the most age 4 and older adults to the Tucannon River. Based on length–weight data from BYs 2006–2013, TFH fish of this size range would weigh between 33 and 49 g (WDFW, Snake River Lab, unpublished data). This is in contrast to the study by Feldhaus et al. (2016), which found no performance benefit between small (18–23-g) and large (30–38-g) spring–summer Chinook Salmon smolts in the Imnaha River. Those authors reported significantly higher out-migration survival differences to Lower Granite Dam for the large smolts released at 30–38 g compared to the smolts released at 18–23 g, but the survival advantage did not translate to greater numbers of returning adults, as SARs were not significantly different between the two groups (Feldhaus et al. 2016). They went on to suggest the

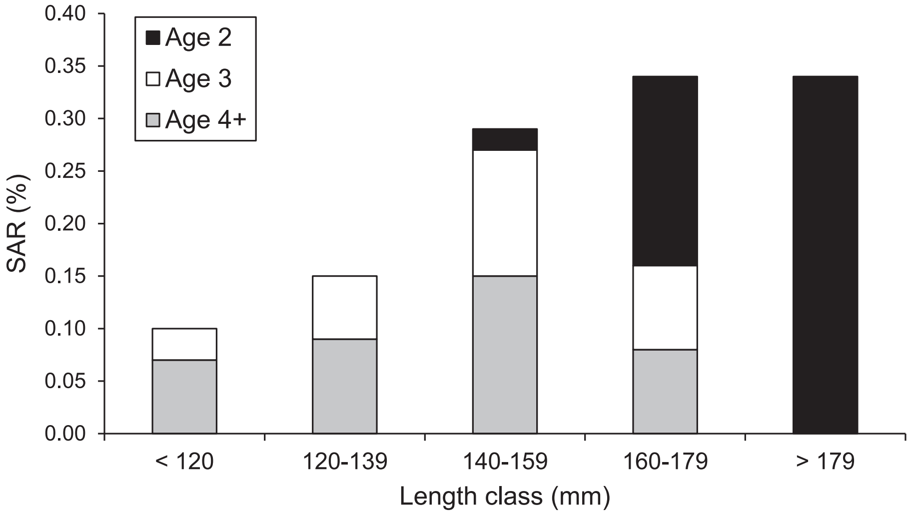

FIGURE 3. Smolt-to-adult returns (SAR) for hatchery-origin Tucannon River spring Chinook Salmon of ages 2, 3, and 4+ (4 and older) from brood years 2006–2013 that were categorized by length (mm FL) at release and were detected as returning to the Tucannon River based on PIT tag detections.

TABLE 4. Calculated probability of detected Chinook Salmon return for the SAS$_T$, SAR$_T$, SAS$_A$, and SAR$_T$ analyses (see text for definitions) based on parameter estimates in Table 2. Results were calculated using the inverse logit, $\pi = \exp(x)/[1 + exp(x)]$, where x is the logit of π defined by equation (1). Probabilities were calculated for different brood years using only a single length-class to illustrate the magnitude of effects, given that the effects on logits were additive. For these calculations, for different brood years the parameter for the 140–159-mm length-class was used. The values in bold italics represent estimates from brood years with zero detections and low sample sizes, with highly uncertain brood year effects (based on parameters with SEs >1,000; see Table 2).

Brood year	SAS$_T$	SAR$_T$	SAS$_A$	SAR$_A$
2006	0.0288	0.0052	0.0092	0.0029
2007	0.0096	***0.0000***	0.0072	***0.0000***
2008	***0.0000***	***0.0000***	***0.0000***	***0.0000***
2009	0.0050	0.0027	0.0023	0.0020
2010	0.0128	0.0033	0.0012	0.0011
2011	0.0136	0.0067	0.0044	0.0041
2012	0.0141	0.0046	0.0022	0.0013
2013	0.0049	0.0017	0.0016	0.0007

possibility of there being a size threshold beyond which survival benefits that are associated with increased size are asymptotic or even decreasing (Feldhaus et al. 2016). We did not find that to be the case in our study for total adult returns (SAS$_T$), but we did find that the 140–159-mm LC appeared to be the threshold for returning age 4 and older fish to the Tucannon River. Beyond this size range, adult returns dropped precipitously with increased length at release, with no age 4 and older adults returning from smolts greater than 179 mm at release. It should be noted that our study used PIT tag detections of fish associated with a FL, whereas the Feldhaus et al. (2016) study was based on raceway group rather than individual fish with known FLs and used CWT estimates from recovered adults, which may have resulted in biased estimates.

One problem that would need to be addressed is that 75–80% of the fish tagged in this study were smaller than 140 mm and only 14% were within the 140–159-mm LC. Even when fish were reared with a 38-g release goal for BYs 2011–2013, only 10% of the fish were within that LC. No hatchery can produce "cookie cutter" fish. However, to maximize hatchery adult (age 4 and older) returns to the Tucannon River, greater effort would be needed to grade and sort fish so that a greater proportion of the hatchery releases are within the 140–159-mm LC to return more hatchery-origin adults.

The Tucannon River spring Chinook Salmon hatchery program is a conservation program for which the goal is not only to produce fish for supplementation of the natural population, but also to preserve the genetic diversity and integrity of the population (Fisch et al. 2015). This program has the expectation that adult fish of hatchery origin will spawn in the natural environment, providing the opportunity for traits derived from the hatchery program to be integrated with natural-origin fish. The high number of minijacks and jacks in the larger-sized release group presents a concern given the potential to integrate this trait into the natural population. The age and size at sexual maturity for Chinook Salmon have heritability values of 0.49–0.57 for males and 0.39–0.41 for females (Hankin et al. 1993). This genetic contribution is considered as one way that hatchery rearing can change salmon populations (Hankin et al. 2009; Ford et al. 2012).

Additionally, Ford et al. (2012) found that lower fitness of hatchery fish could be attributed in large part to a younger age at sexual maturity of male hatchery-origin fish. To counter this, hatchery spawning practices should favor using larger, older individuals as broodstock to mimic the mate selection that occurs in nature (Johnson and Friesen 2013).

Changing the current hatchery feeding regime could possibly be used to reduce precocial male maturation. In the hatchery environment, there typically is not a decrease in available food during the winter months like there is in the natural environment. Hatchery feeding regimes that include fasting during the winter months have been suggested as a tool to mimic conditions experienced by natural salmon populations (Larsen et al. 2001; Beckman et al. 2017). Spangenberg et al. (2014) found that reduced growth during selected months (August–January) resulted in lower rates of precocial male maturation. Food availability and high growth rates in the hatchery environment cause a shift to maturity at younger ages and a resulting loss of some life history diversity, as many fish that would have matured as precocious parr and yearlings in the natural environment mature and die in the hatchery environment before they are released (Mullan et al. 1992). It is clear that the hatchery environment contributes to the success of a program as determined by SAR. Beckman et al. (2017) found significant differences in SAR among Hood River-stock spring Chinook Salmon juveniles reared at three different hatchery facilities and released at a common site. Understanding the mechanisms for these differences would likely enhance our ability to develop new hatchery management strategies that are appropriate for spring Chinook Salmon.

Since the conclusion of this study, WDFW fisheries managers and tribal co-managers agreed to increase the release size of Tucannon River spring Chinook Salmon to 38 g/fish, which is larger than the program had historically targeted (30 g) but is on the lower end of the optimum size range of 140–159 mm (33–49 g). Although these larger smolts are likely to increase the numbers of minijacks and jacks, the results from this study indicate that there will also be higher numbers of returning adult spawners in the river contributing to future natural production, which is one objective of the program. While the minijacks and jacks are a concern, we have shown that a large proportion of those individuals never make it back to the Tucannon River. In addition, the majority of minijacks and jacks that do return can be removed at the TFH adult trap. Unfortunately, as previously mentioned, the adult trap is located high in the river and, on average, about 30% of the annual run remains below the trap. Therefore, the contribution of minijacks and jacks in this portion of the river is still a concern but has been difficult to determine since carcass recovery from these ages is low. Given that both genetic and environmental mechanisms likely prompt a higher rate of returning minijacks and jacks, the long-term impact to natural production of releasing larger-sized hatchery fish should continue to be examined.

Our evaluation of size at release was prompted by a hatchery program target of achieving an average SAR of 0.87%—a target that we have been unable to achieve. We found no evidence supporting the notion that increasing the size of smolts released, even to a size that does not normally occur in nature, will ever allow us to consistently reach this rate. The mean hatchery-origin SAR for BYs 1985–2004 (pre-study period) was 0.20%. Based on that SAR, it would take 576,000 hatchery smolts on an annual basis to reach the return goal of 1,152 adults. Producing that many hatchery smolts is unrealistic for this listed population; therefore, unless survival rates drastically change, the hatchery adult return goal of 1,152 will never be met and the hatchery program, as it currently stands, will continue to fail. Our study could be recreated at other hatchery facilities to determine whether our findings hold true or whether there are regional or hatchery differences in survival rates. As mentioned earlier, overall the LSRCP spring Chinook Salmon programs have only met the 0.87% SAR target about 20% of the time. There are likely stock differences (e.g., spring race versus summer race) or other currently unknown reasons that explain why only a few of the LSRCP hatchery programs have been able to meet the target SAR while the majority of the programs cannot. This observation should prompt a reexamination of LSRCP program management expectations based on current hydrosystem migration corridor and marine survival rates and limitations to increasing the survival of hatchery-produced fish.

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Appendix 1: Analyses Treating Returns to the Columbia–Snake River System as Trials

In the analysis considering all Chinook Salmon that were detected as returning to the Columbia–Snake River system as trials and all fish that returned to the Tucannon River as successes, both brood year (BY) and length-class (LC) were significant ($P < 0.05$). When the analysis was restricted to trials defined by fish returning at age 4 or older, BY was highly significant ($P < 0.001$) but LC was not ($P = 0.94$); hence, LC was excluded from the final model. The parameter estimates showed that for the analysis of all returns, LC had a strong effect, with return rates to the Tucannon River declining with the length at which fish were released—in stark contrast to the absence of discernable effect of initial LC for fish that returned at age 4 or older. These results confirmed our interpretation of the primary results: that the negative influences on return rate to the Tucannon River for fish stocked at greater lengths were driven by failure of those fish, when they returned at younger ages to the Columbia–Snake River, to also return to the Tucannon River. Note that in Table A.1.1, no estimates are reported (NA) for BY 2008 (because no age 4 and older returns occurred) or for any of the LCs for the age 4 and older returns (because LC was not included in the model).

TABLE A.1.1. Parameter estimates and SEs for trials defined as a PIT-tagged Chinook Salmon detection in the Columbia–Snake River system, with success defined as a detection in the Tucannon River. Parameters are those of the linear model for the logit of the probability of detecting returns (equation 1). The two variables analyzed distinguish whether trials were defined as all returns to the system or only age 4 and older fish. The estimate of the intercept gives the estimated logit for the baseline length-class (<120 mm) and brood year (BY; 2006). The estimates given for the other length-classes and BYs represent the difference from the logit of the baseline category. "NA" indicates no estimate.

	All returns		Age 4 and older returns	
Parameter	Estimate	SE	Estimate	SE
Intercept	0.12	0.74	−0.85	0.69
120–139 mm	−1.11	0.58	NA	NA
140–159 mm	−2.05	0.56	NA	NA
160–179 mm	−2.66	0.58	NA	NA
≥180 mm	−3.10	0.79	NA	NA
BY 2007	−16.19	$>1\times10^3$	−17.72	$>1\times10^3$
BY 2008	NA	NA	NA	NA
BY 2009	2.09	0.71	2.72	0.87
BY 2010	1.04	0.67	2.64	1.03
BY 2011	1.98	0.80	3.29	1.01
BY 2012	1.18	0.70	1.25	0.87
BY 2013	1.07	0.72	0.56	0.88

Appendix 2: Variability in Target Sizes for Brood Years 2006–2010 and Evaluation of an Additional Effect due to Target Size and Separate Analysis by Brood Year Group

During 2006–2010, the size of fish released was deliberately manipulated with target sizes of 30 and 50 g. Although the average lengths of fish in the two size categories were significantly different from one another in all years, the actual length distributions for the two size categories substantially overlapped within years and varied within a size category among years (Figure A.2.1). Given this variation, we believe that analyzing the data using the same length categories for all years, based on actual lengths of fish at release rather than the target size categories, was reasonable (Table A.2.1). Nevertheless, it is possible that the conditions used to achieve the target sizes could have had influences on the fish beyond what was reflected by their length category. To evaluate this possibility, we repeated our primary analyses, but included target size category as an additional categorical variable (30 g, 50 g, or neither [for brood years {BYs} after 2010]). Note that no parameter estimates can be obtained for the "neither" category because this category is aliased with BY (i.e., the category was only present in BY 2011 and later BYs, when the other two categories were not present).

The effect of the target size variable was not significant for SAS_T, SAR_T, SAS_A, or SAR_A ($P = 0.24$, 0.17, 0.28, and 0.29, respectively). In general, the effects of BY and length-class (LC) were similar with and without the use of target size (compare Tables 2 and A.2.2).

We also repeated the main categorical analysis reported in Table 2 separately for the two groups of BYs (2006–2010 and 2011–2013; Tables A.2.3 and A.2.4). This showed that the qualitative patterns of LC effects reported in the main text held when the two groups of BYs were examined separately (compare Table 2 with Tables A.2.3 and A.2.4).

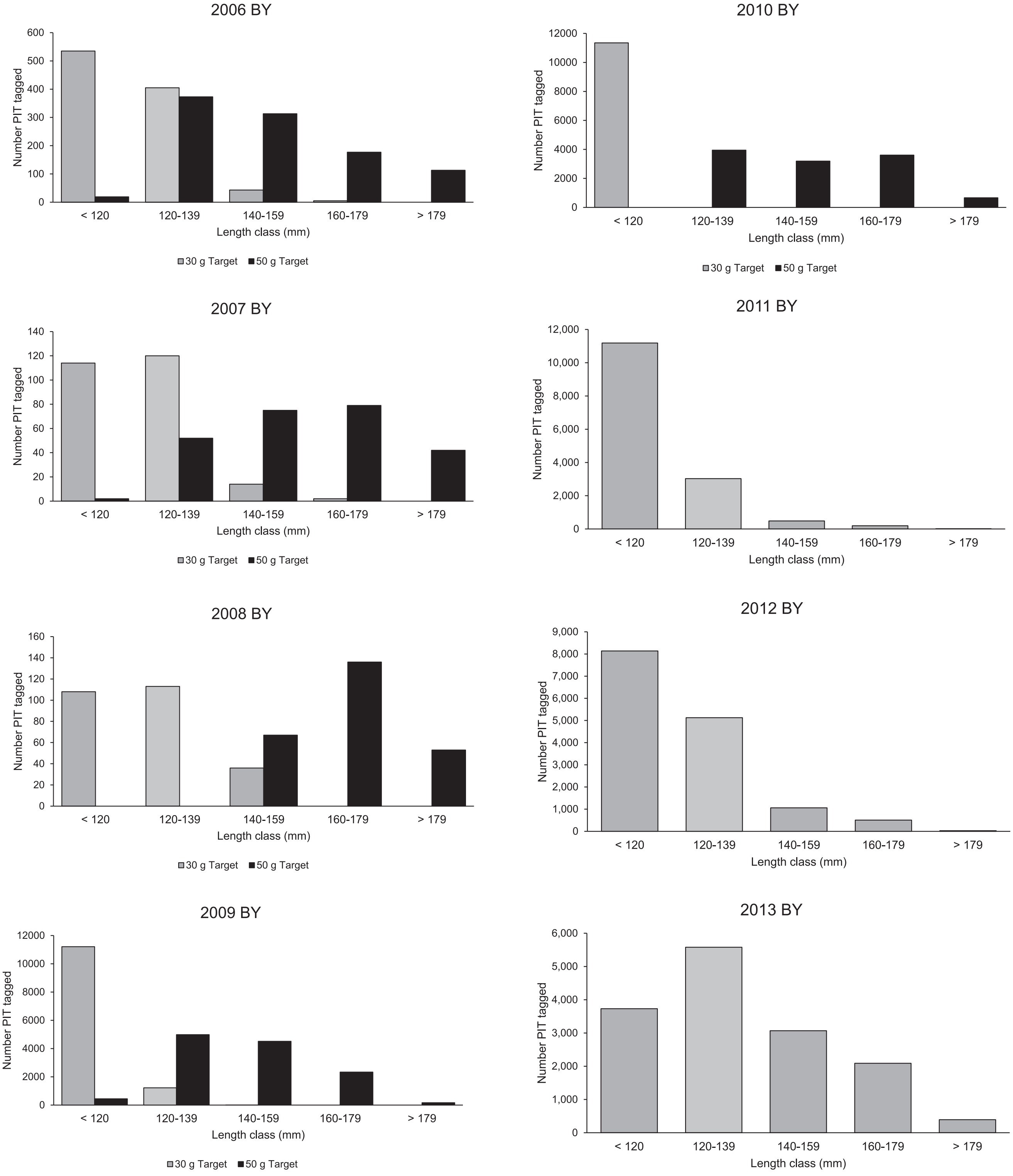

FIGURE A.2.1. Length (mm FL) distributions of PIT-tagged, hatchery-origin Tucannon River spring Chinook Salmon for brood years (BYs) 2006–2013 used in the analysis.

TABLE A.2.1. Passive integrated transponder detections of hatchery-origin Tucannon River spring Chinook Salmon by length-class (mm) at the time of PIT tagging and age at return to the Columbia–Snake River system, which was used in calculating smolt-to-adult survival (SAS), and detections of returns to the Tucannon River for calculating smolt-to-adult return (SAR) for brood year (BY) 2006–2013 releases.

		SAS detections					SAR detections				
Length-class (mm)	Number PIT-tagged	Age 2	Age 3	Age 4	Age 5	Total	Age 2	Age 3	Age 4	Age 5	Total
BY 2006, 30-g release-size target											
<120	535	1	1	1	0	3	0	0	1	0	1
120–139	405	0	2	2	0	4	0	0	0	0	0
140–159	43	0	0	0	0	0	0	0	0	0	0
160–179	5	1	0	0	0	1	0	0	0	0	0
≥180	0	0	0	0	0	0	0	0	0	0	0
Totals	988	2	3	3	0	8	0	0	1	0	1
BY 2006, 50-g release-size target											
<120	19	0	0	0	0	0	0	0	0	0	0
120–139	373	0	0	5	1	6	0	0	2	0	2
140–159	313	5	1	1	0	7	1	0	0	0	1
160–179	177	3	1	0	0	4	0	0	0	0	0
≥180	113	8	1	0	0	9	2	0	0	0	2
Totals	995	16	3	6	1	26	3	0	2	0	5
BY 2007, 30-g release-size target											
<120	114	0	0	0	0	0	0	0	0	0	0
120–139	120	0	0	0	0	0	0	0	0	0	0
140–159	14	0	0	0	0	0	0	0	0	0	0
160–179	2	0	0	0	0	0	0	0	0	0	0
≥180	0	0	0	0	0	0	0	0	0	0	0
Totals	250	0	0	0	0	0	0	0	0	0	0
BY 2007, 50-g release-size target											
<120	2	0	0	0	0	0	0	0	0	0	0
120–139	52	0	0	0	0	0	0	0	0	0	0
140–159	75	0	0	1	0	1	0	0	0	0	0
160–179	79	1	0	0	0	1	0	0	0	0	0
≥180	42	1	0	1	0	2	0	0	0	0	0
Totals	250	2	0	2	0	4	0	0	0	0	0
BY 2008, 30-g release-size target											
<120	108	0	0	0	0	0	0	0	0	0	0
120–139	113	0	0	0	0	0	0	0	0	0	0
140–159	36	0	0	0	0	0	0	0	0	0	0
160–179	0	0	0	0	0	0	0	0	0	0	0
≥180	0	0	0	0	0	0	0	0	0	0	0
Totals	257	0	0	0	0	0	0	0	0	0	0
BY 2008, 50-g release-size target											
<120	0	0	0	0	0	0	0	0	0	0	0
120–139	0	0	0	0	0	0	0	0	0	0	0
140–159	67	1	0	0	0	1	0	0	0	0	0
160–179	136	1	0	0	0	1	0	0	0	0	0
≥180	53	1	0	0	0	1	0	0	0	0	0
Totals	256	3	0	0	0	3	0	0	0	0	0
BY 2009, 30-g release-size target											
<120	11,212	0	0	7	0	7	0	0	6	0	6
120–139	1,221	0	0	0	0	0	0	0	0	0	0
140–159	1	0	0	0	0	0	0	0	0	0	0
160–179	0	0	0	0	0	0	0	0	0	0	0

TABLE A.2.1. Continued.

		SAS detections					SAR detections				
Length-class (mm)	Number PIT-tagged	Age 2	Age 3	Age 4	Age 5	Total	Age 2	Age 3	Age 4	Age 5	Total
≥180	0	0	0	0	0	0	0	0	0	0	0
Totals	12,434	0	0	7	0	7	0	0	6	0	6
BY 2009, 50-g release-size target											
<120	444	0	0	0	0	0	0	0	0	0	0
120–139	4,982	2	1	6	0	9	0	1	6	0	7
140–159	4,512	7	5	11	0	23	1	4	10	0	15
160–179	2,335	15	0	6	0	21	2	0	4	0	6
≥180	164	1	0	0	0	1	0	0	0	0	0
Totals	12,437	25	6	23	0	54	3	5	20	0	28
BY 2010, 30-g release-size target											
<120	11,350	0	3	4	2	9	0	3	3	2	8
120–139	0	0	0	0	0	0	0	0	0	0	0
140–159	0	0	0	0	0	0	0	0	0	0	0
160–179	0	0	0	0	0	0	0	0	0	0	0
≥180	0	0	0	0	0	0	0	0	0	0	0
Totals	11,350	0	3	4	2	9	0	3	3	2	8
BY 2010, 50-g release-size target											
<120	0	0	0	0	0	0	0	0	0	0	0
120–139	3,947	2	3	3	0	8	0	3	3	0	6
140–159	3,196	24	3	3	0	30	1	3	2	0	6
160–179	3,606	92	2	2	0	96	14	2	2	0	18
≥180	664	30	0	0	0	30	3	0	0	0	3
Totals	11,413	148	8	8	0	164	18	8	7	0	33
BY 2011, 38-g release-size target											
<120	11,185	0	6	15	1	22	0	6	14	1	21
120–139	3,029	3	0	7	0	10	0	0	6	0	6
140–159	485	3	1	2	0	6	0	1	2	0	3
160–179	193	0	0	0	0	0	0	0	0	0	0
≥180	12	0	0	0	0	0	0	0	0	0	0
Totals	14,904	6	7	24	1	38	0	7	22	1	30
BY 2012, 38-g release-size target											
<120	8,137	1	4	5	0	10	0	4	3	0	7
120–139	5,127	5	6	5	0	16	0	4	2	0	6
140–159	1,060	11	7	4	0	22	0	5	3	0	8
160–179	508	7	3	1	0	11	1	3	1	0	5
≥180	30	0	0	0	0	0	0	0	0	0	0
Totals	14,862	24	20	15	0	59	1	16	9	0	26
BY 2013, 38-g release-size target											
<120	3,730	0	0	1	0	1	0	0	0	0	0
120–139	5,579	1	6	7	0	14	0	6	4	0	10
140–159	3,069	9	2	5	0	16	0	2	2	0	4
160–179	2,090	11	2	1	0	14	0	2	0	0	2
≥180	392	4	0	0	0	4	0	0	0	0	0
Totals	14,860	25	10	14	0	49	0	10	6	0	16

TABLE A.2.2. Parameter estimates and SEs for a modification of the primary analyses of PIT-tagged Chinook Salmon detections that included an additional variable, target size. Parameters are those of the linear model for the logit of the probability of detecting returns (equation 1). The four variables analyzed (SAS$_\text{T}$, SAR$_\text{T}$, SAS$_\text{A}$, and SAR$_\text{A}$) are described in the main text. The estimated intercept is the logit for the baseline length-class (<120 mm), brood year (BY; 2006), and target size (30 g). The estimates given for the other length-classes, BYs, and target size category (50 g [T50]) represent the difference from the logit of the baseline category. An estimate for the "neither" target size category could not be obtained and is not included in the table.

	SAS$_\text{T}$		SAR$_\text{T}$		SAS$_\text{A}$		SAR$_\text{A}$	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	−6.00	0.30	−6.89	0.44	−7.10	0.41	−6.00	0.34
120–139 mm	0.84	0.24	0.47	0.24	0.45	0.22	0.56	0.24
140–159 mm	2.05	0.25	1.23	0.28	0.98	0.26	0.99	0.30
160–179 mm	2.68	0.25	1.41	0.29	0.43	0.34	0.45	0.38
≥180 mm	3.22	0.30	1.43	0.49	−17.80	$>1\times10^3$	−0.21	0.93
BY 2007	−1.05	0.61	−17.66	$>1\times10^3$	−17.84	$>1\times10^3$	−0.22	0.69
BY 2008	−19.13	$>1\times10^3$	−18.41	$>1\times10^3$	−18.52	$>1\times10^3$	−17.76	$>1\times10^3$
BY 2009	−1.70	0.25	−0.70	0.42	−0.38	0.40	−1.40	0.33
BY 2010	−0.80	0.22	−0.50	0.41	−0.99	0.43	−2.01	0.37
BY 2011	−0.48	0.35	0.47	0.47	0.46	0.43	−0.58	0.38
BY 2012	−0.41	0.35	0.15	0.48	−0.60	0.47	−1.23	0.41
BY 2013	−1.40	0.37	−0.75	0.52	−1.19	0.50	−1.50	0.43
T50	0.36	0.31	0.46	0.35	0.32	0.30	0.36	0.33

TABLE A.2.3. Parameter estimates and SEs for the primary analyses of PIT-tagged Chinook Salmon detections but restricted to include only brood years (BYs) 2006–2010. Parameters are those of the linear model for the logit of the probability of detecting returns (equation 1). The four variables analyzed (SAS$_\text{T}$, SAR$_\text{T}$, SAS$_\text{A}$, and SAR$_\text{A}$) are described in the text. The estimate of the intercept gives the estimated logit for the baseline length-class (<120 mm) and BY (2006). The estimates given for the other length-classes and BYs represent the difference from the logit of the baseline category.

	SAS$_\text{T}$		SAR$_\text{T}$		SAS$_\text{A}$		SAR$_\text{A}$	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	−6.04	0.29	−6.85	0.34	−5.93	0.46	−7.00	0.65
120–139 mm	1.09	0.30	0.75	0.26	0.73	0.40	0.59	0.42
140–159 mm	2.26	0.27	1.46	0.23	1.08	0.40	1.01	0.41
160–179 mm	3.14	0.25	1.80	0.23	0.80	0.49	0.72	0.50
≥180 mm	3.70	0.28	2.02	0.37	0.29	1.15	−19.02	$>1\times10^3$
BY 2007	−1.08	0.54	−19.58	$>1\times10^3$	−0.25	0.85	−19.68	$>1\times10^3$
BY 2008	−20.33	$>1\times10^3$	−19.66	$>1\times10^3$	−18.01	$>1\times10^3$	−19.73	$>1\times10^3$
BY 2009	−1.64	0.22	−0.62	0.31	−1.34	0.41	−0.33	0.61
BY 2010	−0.79	0.20	−0.44	0.31	−1.97	0.46	−0.96	0.65

TABLE A.2.4. Parameter estimates and SEs for the primary analyses of PIT-tagged Chinook Salmon detections but restricted to include only brood years (BYs) 2011–2013. Parameters are those of the linear model for the logit of the probability of detecting returns (equation 1). The four variables analyzed (SAS_T, SAR_T, SAS_A, and SAR_A) are described in the text. The estimate of the intercept gives the estimated logit for the baseline length-class (<120 mm) and BY (2011). The estimates given for the other length-classes and BYs represent the difference from the logit of the baseline category.

	SAS_T		SAR_T		SAS_A		SAR_A	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	−6.49	0.27	−6.47	0.34	−6.63	0.16	−6.69	0.25
120–139 mm	0.86	0.33	0.54	0.47	0.63	0.22	0.53	0.38
140–159 mm	2.27	0.33	1.52	0.55	1.35	0.27	1.42	0.48
160–179 mm	2.29	0.39	1.36	0.72	0.21	0.51	0.12	1.05
≥180 mm	2.49	0.75	−15.70	$>1 \times 10^3$	−17.59	$>1 \times 10^3$	−16.10	$>1 \times 10^3$
BY 2012	0.08	0.29	−0.35	0.44	−0.68	0.22	−1.10	0.40
BY 2013	−0.80	0.33	−1.23	0.55	−0.99	0.25	−1.77	0.50