The influence of release strategy and migration history on capture rate of *Oncorhynchus mykiss* in a rotary screw trap

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Abstract

Rotary screw traps are used throughout the West Coast of North America to capture emigrating juvenile salmonids. Calibrating the capture efficiency of each trap is essential for valid estimates of fish passage. We released Passive Integrated Transponder (PIT) tagged *Oncorhynchus mykiss* upstream of a rotary screw trap in the South Fork John Day River, Oregon to estimate capture efficiency. We used three strategies for release of fish recently captured in the trap. We recaptured 28% of medium-size fish (86–145 mm fork length) and 14% of large-size fish (146–230 mm fork length) released during daylight 1.6 km upstream of the trap. We recaptured 33% of medium-size fish and 17% of large-size fish released during daylight 4.8 km upstream of the trap. We recaptured 42% of medium-size fish and 23% of large-size fish released at twilight 1.8 km upstream of the trap. A PIT antenna detected summer tagged parr (which were PIT tagged upstream 1–5 months before migration) as they approached the trap to evaluate potential bias from reduced recapture of recently trapped fish. We captured 53% of the medium-size first-time migrants and 40% of the large-size first-time migrants. Although average capture efficiencies of first-time migrants were greater than any of the three recently trapped fish strategies, twilight releases of recently trapped fish were least negatively biased, especially for medium-size fish.

Introduction

Extensive salmonid population monitoring across the West Coast of North America (Volkhardt et al. 2007) has been initiated in response to declining abundance (Nehlsen et al. 1991). Returns of adult anadromous salmonids are influenced by numerous factors in freshwater and marine life stages. Survival rates in migratory corridors and in the ocean are variable (Bilton et al. 1982; Achord et al. 2007) and may mask the influence of freshwater rearing areas on production. Hence, there is a need to determine abundance by life stage (Solazzi et al. 2000; Johnson et al. 2005) to measure effects of proximate factors, such as marine survival (Pyper et al. 2002). Most often such life history monitoring involves estimation of numbers of: 1) out-migrant juveniles emigrating from freshwater, and 2) adults returning to freshwater to spawn.

Abundance estimates of juveniles emigrating from rearing habitats require out-migrant traps, except in the few situations where census counts may be conducted at weirs. A common out-migrant trap throughout the West Coast of North America is the rotary screw trap (RST, E.G. Solutions Inc.[1], Corvallis, Oregon). RSTs can be nested inside weirs (Scace et al. 2007) to increase capture efficiency. This can potentially result in overcrowding of the holding box, causing mortality of biologically and economically valuable fishes (Music et al. 2010). Thus, RSTs are commonly used as a “stand-alone” gear that samples a portion of the channel profile, and captures a portion of the emigrant population. Valid estimates of capture efficiency are required for each RST in each location (Thedinga et al. 1994; Roper and Scarnecchia 2000) in order to estimate out-migrant abundance.

Capture efficiency varies depending on stream size, water velocity, water depth, cone rotation speed, and fish size (Roper and Scarnecchia 2000). The most commonly used method of estimating capture efficiency is to capture unmarked fish in the trap, apply a unique mark or tag, such as a Passive Integrated Transponder (PIT) tag (Schultz et al. 2006; Copeland and Venditti 2009), and release the marked fish upstream of the RST. The proportion of these marked fish (hereinafter referred to as “recent releases”) subsequently recaptured in the trap estimates capture efficiency for that sample period (Thedinga et al. 1994; Miller et al. 2000). This mark-recapture population estimation technique is subject to the assumptions of the Petersen estimate (Seber 1982). Violation of any of these assumptions can result in erroneous population estimates (Frith et al. 1995). The most pertinent, yet seldom evaluated, is the assumption of equal capture efficiency of marked and unmarked fish. For an estimate of catch efficiency to be unbiased the capture efficiency of “recent releases” which are fish captured in an RST, tagged, released upstream of the RST, and then make a second migration past the RST (usually occurring in < 24 hours) must equal the capture efficiency of fish approaching that RST for the first time (termed “unhandled naïve” by Scace et al. 2007).

Two protocols for “recent releases” may help meet the assumption of equal capture efficiency. The first protocol is to liberate recent releases close enough to an RST site so that mortality or delayed migration prior to returning to the RST site is minimized (Roper and Scarnecchia 2000; Volkhardt et al. 2007). The second protocol is to liberate recent releases at or after the end of civil twilight (when the sun is 6 degrees below the horizon line) each day. This protocol is based on the assumption that liberation after civil twilight will reduce predation and mimic natural movement patterns. There has been no evaluation of whether these protocols result in equal capture efficiency between recent releases and migrants that have not been previously captured in an RST. We evaluated these protocols by estimating capture efficiency for *Oncorhynchus mykiss* which were PIT tagged 1–5 months before their downstream migration (hereafter "summer tagged parr") and monitored by a PIT tag antenna immediately upstream of an RST.

The objectives of this study were three-fold: 1) compare estimates of the capture efficiency of an RST among recent releases made during daylight hours in two different locations and recent releases made after the end of civil twilight, 2) develop a size-structured model predicting capture efficiency for juvenile *O. mykiss*, 3) validate the accuracy of the model by comparing the model-predicted capture efficiency for recent releases against estimates of capture efficiency for summer tagged parr detected by an antenna as they approached an RST.

Methods

Site Description

This study was conducted in the South Fork John Day River (SFJD), a fifth-order basin located in Northeast Oregon (Figure 1). The SFJD supports a naturally reproducing population of *O. mykiss*, including resident and anadromous life history types. No hatchery stocking occurs in this basin, so all *O. mykiss* observed in this study were naturally produced. *O. mykiss* are widely distributed in the SFJD and its four main tributaries downstream of Izee Falls, an anadromous fish barrier (Figure 1). Emigration of juvenile *O. mykiss* from the SFJD is bimodal, with peaks in October-November and April-May. During fall 2005, we estimate that 3,966 *O. mykiss* migrated past this RST site (I. Tattam, unpublished data). The *O. mykiss* captured in the trap during this period ranged in fork length (FL) from 82–227 mm, with a mean of 140 mm.

We operated a 1.52 m diameter RST at river kilometer 10 of the SFJD (Figure 1). An RST comprises a partially submerged cone with an interior helical structure that is passively rotated by water pressure and funnels emigrant fish into a submerged holding box on the downstream end of the trap. The same type and size trap was used at the same location during fall (October-December) 2004 and fall (October-December) 2005. We conducted this calibration study during fall because flows are lower than during spring, allowing for placement of an in-stream PIT tag antenna. Stream discharge at this site during the 2005 release experiment ranged from 0.74–2.01 m^3/s (OWRD 2012). In-stream PIT tag antenna data were not available for 2005, hence we used the combination of antenna and RST data from 2004 to validate the predictive model we developed for recent releases in 2005.

The trap was situated at the head of a pool, and was adjusted both longitudinally and laterally to remain in the thalweg as discharge changed. Wetted width at this location was approximately six to eight m, depending on discharge. We monitored two operational variables: stream depth (a surrogate for discharge) and trap rotation speed (a surrogate for water velocity). Depth was measured with a staff gauge in the pool downstream of the trap. Speed was the number of seconds required for the cone of the trap (the mechanism by which fish are captured) to complete three full rotations. Depth and speed were recorded daily.

Comparison of capture efficiency estimates among different release strategies

During fall 2005 we used three different recent release strategies. All unmarked *O. mykiss* captured in the RST were tagged with intra-peritoneally injected 12-mm long full-duplex PIT tags (Prentice et al. 1990) and measured for FL. Retention rates for smaller Chinook salmon PIT tagged with these methods in a hatchery have been estimated at 99.9% over a four-week period, with mortality rates < 1% (Dare 2003). We assumed no tag-shed or tagging related mortality in our study. From October 14, 2005 through December 15, 2005; on each day that three or more unmarked *O. mykiss* were captured in the RST each fish was tagged and systematically assigned to one of three release strategies. For example, every 1st, 4th, 7th, etc., individual retrieved from the day's catch was transported 1.6 km upstream and immediately liberated during daylight hours (typically around 1100 hours). This daylight short-distance release strategy was labeled “A”. Fish assigned to release strategy “B” were transported 4.8 km upstream (long-distance) and immediately liberated during daylight hours a few minutes following the release of the other fish under strategy “A”. Finally, fish assigned to the release strategy “C” were transported 1.8 km upstream (short distance) and placed into a holding device equipped with a timer (see description in Miller et al. 2000) which was set to release them at the conclusion of civil twilight. A total of 848 *O. mykiss* were PIT tagged and released upstream of the SFJD RST on 37 days (daily release by strategy ranged from 1 to 51 individuals) during fall 2005 (Table 1). The RST was operated every night but one during this release experiment because a high volume of floating leaf debris prevented RST operation on that night. We excluded data from that day, as there was no potential for recapture on the night after release and most recaptures occurred on the first night following release.

We anticipated that FL would influence capture efficiency (e.g., Roper and Scarnecchia 2000). Thus we partitioned fish into three size categories within each recent release strategy: “small” (86–115 mm FL), “medium” (116–145 mm FL), and “large” (146–230 mm FL). We used Pearson correlation to test for collinearity among explanatory variables. Depth and speed were correlated ($r = 0.85$, $n = 38$, $P < 0.0001$). We eliminated depth, and analyzed trap rotation speed, since we had some control over speed as trap position was routinely adjusted to maximize it. We used logistic regression (SAS Procedure GenMod with logit link function) to model daily capture efficiency as a proportion and estimate significance of our strategies and other variables. Our model assumed a binomial distribution with an over-dispersion parameter to account for extra-binomial variation. Over-dispersion is typical for capture efficiency estimates, probably because fish do not behave as independent and identical units as a pure binomial model assumes.

Failure to account for over-dispersion could have resulted in erroneous error estimates. This model applies more weight to samples with a larger number of releases. The full model was:

$$\text{logit}(E) = \log(E/1-E) = B_0 + B_1 \cdot I_b + B_2 \cdot I_c + B_3 \cdot I_{small} + B_4 \cdot I_{medium} + B_5 \cdot speed + B_6 \cdot I_b \cdot I_{small} + B_7 \cdot I_b \cdot I_{medium} + B_8 \cdot I_c \cdot I_{small} + B_9 \cdot I_c \cdot I_{medium} + B_{10} \cdot I_b \cdot speed + B_{11} \cdot I_c \cdot speed + B_{12} \cdot I_{small} \cdot speed + B_{13} \cdot I_{medium} \cdot speed \qquad (1)$$

where E is capture efficiency (number recaptured · number released^{-1}). B's are fitted coefficients. I_b is the indicator (dummy variable, value 0 or 1) for release strategy B, I_c is the indicator for release strategy C (strategy A is represented when I_a=I_b=0, against which B and C are compared in turn), I_{small} is the indicator for the small FL group, I_{medium} is the indicator for the medium FL group (the small and medium size groups are individually compared with the large size group in this model), and speed is the number of cone rotations per second. Product signs denote first order interactions. The logit function represents a log odds ratio (log(E/1-E)) expression of E, allowing additive terms on the right side of equation (1) to be tested by analysis of deviance. We used drop-in-deviance F-tests (Ramsey and Schafer 2002) to sequentially compare reduced models with the full model (equation 1). Significant changes in deviance in reduced models represent significant effects on logit(E), and by association on E.

Size structured predictive model of E

We developed a size structured predictive model of E for release strategy C. These were of the form:

$$\text{logit}(E) = \log(E/1-E) = B_0 + B_1 \cdot I_{size} \qquad (2)$$

where I_{size} is an indicator for different size groups based on FL. B's are fitted coefficients. The size ranges of individuals released in strategy C and the summer tagged parr differed slightly (Figure 2). There were no summer tagged parr > 200 mm FL (Figure 2). To account for possible size based influences on the comparison of E between strategy C and summer tagged parr, we censored the 11 individuals in strategy C which were > 200 mm FL. Thus, the range of sizes was comparable between groups.

Validation of the predictive model for E

During fall 2004 we operated a PIT tag detection antenna (inner dimensions 30.5 cm high by 80.0 cm wide in the thalweg 78m upstream of the RST. The antenna was coupled to a Destron-Fearing[1] 2001F transceiver which recorded date and time of detection). The stream segment between the antenna and RST included two meanders and a turbulent riffle. The antenna detected 66% of summer tagged parr known to have migrated past the array (based on capture in the RST). Summer tagged parr were *O. mykiss* PIT tagged and released upstream of the RST during summer 2004. These individuals were primarily tagged in Black Canyon and Murderers creeks, and to a lesser extent, in the SFJD upstream of Black Canyon Creek to Izee Falls (Figure 1). Summer tagged parr were last handled 1–5 months prior to approaching the RST location. They were captured via seining or electrofishing, and were unlikely to have had prior experience with an RST. Thus, we assumed that the migratory behavior, diel migration timing, and probability of capture in the RST of these summer tagged parr were equal to that of *O. mykiss* which had never been captured before. Summer tagged parr were categorized into the same FL groups used in equation 1. For summer tagged parr captured in the RST, we used FL on the day of RST capture to group individuals. Additionally, we used FL data from summer tagged parr captured in the RST to estimate mean growth rates (mm/d) experienced by each specific tagging group (i.e., Black Canyon, Murderers, or upper SFJD) from tagging date to their recapture at the RST. For summer tagged parr which were not captured in the RST, we estimated FL of each individual on the day it migrated past the RST. We estimated FL of summer tagged parr that were detected, but not captured, as: ((FL when tagged in upper basin) + (mean daily growth rate · number of days at large)). This was a minor correction, increasing FL by a mean of 15% (range: 4–32%).

For summer tagged parr, E was estimated by the quotient of the number of *O. mykiss* captured at the RST divided by the total number detected migrating past the PIT array. We restricted this analysis to nights when both the RST and the PIT array were operational, as *O. mykiss* nearly always migrated past the PIT array and RST in the same night. *O. mykiss* detected at the PIT array on multiple days were censored as it was unknown whether they migrated past the RST during the study period. Estimates of E for summer tagged parr were compared against model-predicted 95% Confidence Intervals of E derived for two FL groups within strategy C. This comparison was made to determine whether strategy C (twilight-release, making a second migration past the RST) produced unbiased estimates of E for *O. mykiss*.

Results

Comparison of E among different release strategies

Drop-in-deviance tests found none of the first-order interactions (release strategy · size group, release strategy · speed, size group · speed) significantly contributed to the model ($F_{8,214} = 1.51$, $P = 0.16$). Trap rotation speed also did not significantly contribute to the model ($F_{1,215} = 1.31$, $P = 0.25$). Release strategy ($F_{2,217} = 4.7$, $P < 0.01$) and FL ($F_{2,217} = 12.2$, $P < 0.001$) were significant. Thus, we interpreted a reduced version of equation 1 with release strategy and FL as main effects.

Predicted E varied significantly among release strategies and FL (Figure 3). When analyzing FL, recent releases in the small FL group had significantly higher E than those in the large FL group ($P < 0.001$). Likewise, the E of recent releases in the medium FL group was significantly higher than those in the large FL group ($P < 0.001$). There was no significant difference in E between recent releases in the small and medium FL groups ($P = 0.81$). The E of recent releases under strategy A was significantly lower than for those under strategy C ($P = 0.005$). The E of recent releases with strategy B was not significantly different from those with strategy A ($P = 0.32$). We proceeded with our final size structured predictive model (equation 2) only for strategy C, because it was closest to our summer parr validation data (see below).

Size structured predictive model of E

We found no difference in E between small (86–115 mm) and medium (116–145 mm) FL groups, thus we combined these two FL groups into a small/medium group. The predicted E for the small/medium group was 0.45 (95% Confidence Interval: 0.36–0.55; Figure 3). The predicted E for the large group was 0.19 (95% Confidence Interval: 0.10–0.31; Figure 3). The size-structured binomial logistic model (equation 2) was over-dispersed, as indicated by an estimated over-dispersion parameter of 1.26.

Validation of the predictive model for E

Strategy C predictions were compared with averages for summer tagged parr. The observed E of summer tagged parr in the RST differed between FL groups. Estimated average E was 0.53 (24 captured of 45 available for capture) for summer tagged parr in the small/medium group and 0.40 (14 captured of 35 available for capture) in the large size group. For the small/medium group, the 95% Confidence Interval of E from the regression model (equation 2) for strategy C included the average estimate of E observed for summer tagged parr (Figure 3). The 95% Confidence Interval of E for the large group (equation 2) did not encompass the observed E for summer tagged parr (Figure 3).

Discussion

Time of release influenced E for *O. mykiss* in the South Fork John Day River. Daylight releases (strategy A or B) resulted in lower estimates of E than twilight releases (strategy C). Between daylight releases, transporting *O. mykiss* further upstream (strategy B) did not significantly change E compared to releases in close proximity to the trap (strategy A). Such daylight releases (strategies A and B) probably resulted in a daytime second migration past the RST. During fall 2004, recent releases with strategy A often migrated past the PIT antenna during daylight (I. Tattam, unpublished data). Conversely, natural downstream migration of salmonids occurs during darkness (Roper and Scarnecchia 1996). Of the summer tagged parr detected at the PIT tag antenna during fall 2004, 94% of detections occurred after evening civil twilight and before the beginning of civil twilight the following morning. Individuals migrating during daylight were seldom captured in the RST. Similarly, Cramer et al. (1992) found capture efficiency of juvenile Chinook in an RST to be 15 times higher at night than during daylight. We suspect that individuals migrating during daylight may have been lower in the water column, and less vulnerable to the RST which samples the upper portions of the column. Daytime out-migrants may also use visual clues to avoid the RST that are unavailable at night (Roper and Scarnecchia 1996). Migration timing, rather than loss of naivete, appeared to drive E in our study. Fish < 146 mm captured in the RST and released upstream at civil twilight (migrating past the trap during darkness) were recaptured at a rate comparable to fish approaching the trap for the first time. By altering diel migration timing, release strategies A and B produced biased estimates of E when compared to the E for naturally migrating summer tagged parr.

Fish length had a significant effect on rate of recapture in the RST. However, the relationship between E (as logit(E)) and FL is not linear. The recapture rate of recent releases in the small and medium FL groups was not significantly different when compared within any single release strategy (Figure 3). There is a threshold length, represented by the large size group in our study, above which *O. mykiss* have an increased ability to avoid capture in an RST (Figure 3). This decline in E for individuals ≥ 146 mm was also present for summer tagged parr, although to a lesser degree than for recent releases (Figure 3). Dambacher (1991) also found E to decrease with FL. However, he noted declining E beginning at a FL of only 106 mm when fishing a Humphreys trap. Trap placement, operation, stream flow, fish size, and species encountered will influence E uniquely in each trapping situation. For example, Thedinga et al. (1994) did not find any size-based differences in E when using a 2.4 m RST. However, the observed recapture rate was very low (3–6%, Thedinga el al. 1994), perhaps limiting the power to detect size differences in E. Future RST calibration efforts should anticipate size-based differences in E. If the number of recent releases is even among size groups, fewer large individuals will be recaptured. If fewer large individuals are recaptured, the estimate of E for the large size group will be less precise. Increasing the number of fish in the large size group released upstream of an RST is necessary to increase recaptures and hence increase the precision of the estimate of E. If few large wild out-migrants can be captured, releasing large hatchery-origin out-migrants upstream of an RST may be a strategy to increase recaptures. The capture efficiency of hatchery and wild out-migrants may differ (Roper and Scarnecchia 1996). Hence, statistically comparing capture efficiency of the two groups is necessary before applying capture efficiencies of hatchery fish to wild fish. Releasing hatchery fish may not be an option in basins managed for natural production, such as the South Fork John Day. Nonetheless, it may be a strategy to increase precision of efficiency estimates in basins that are managed for both natural and hatchery production.

Strategy C produced estimates of E comparable to the E observed for summer tagged parr. We found evidence that, at least for *O. mykiss* in the small and medium size groups, estimates of E for recent releases and summer tagged parr were not statistically different when using strategy C (Figure 3). These results are similar to those of Scace et al. (2007), who also employed a PIT tag antenna upstream of an RST. They found that when using a weir and RST in combination, E was high and comparable between summer tagged parr and twilight released Atlantic salmon smolts. Our results differed from Scace et al. (2007) for *O. mykiss* in the large size group. For large *O. mykiss*, we found a significant difference between estimates of E for summer tagged parr and recent releases (Figure 3). Therefore strategy C did not effectively duplicate the E of summer tagged parr *O. mykiss* in the large size group. Prior experience with the RST did not reduce the E of fish released under strategy C in the small and medium size groups as compared to summer tagged parr. Unless prior experience with the RST differentially influences large fish, we believe this likely did not cause the discrepancy in E.

The summer rearing location of large-sized *O. mykiss* may explain the difference in E between the recent release twilight group and summer tagged parr. Summer tagged parr were all PIT-tagged > 10 km upstream of the RST (Figure 1). We do not know from where the fish used for the recent release groups originated. However, it is plausible that some of these individuals originated from near the RST, and were simply making home-range movements when captured. *O. mykiss* were present in this location year-round (I. Tattam, personal observation). Small and medium-sized *O. mykiss* dominated the population size structure in upstream reaches of the SFJD and its tributaries. Larger *O. mykiss* dominated the population near the RST (Madriñán 2008). Thus, when unmarked *O. mykiss* in the small and medium size groups were captured in the RST, it is more likely that they were migrating several km or more to reach the RST (similar to the summer tagged parr), rather than just movement within their home range. Some of the large *O. mykiss* captured in the RST may have been released upstream within their original home range. In this scenario, they may not attempt a second migration past the RST. Alternatively, large individuals may have been more effective than small and medium size individuals at avoiding capture on a second migration past the RST. However, it seems as likely that location of origin, rather than enhanced trap avoidance on a second pass, influenced the difference in E between large-size recent releases and summer tagged parr. The apparent lack of directed migration by large *O. mykiss* released upstream of the RST indicates the importance of RST location within the stream network. If possible, an RST should be located in a stream section which is not continuously occupied by juvenile salmonids, so that only active migrants are captured. However, this may be impossible in small subbasins such as the SFJD.

Management Implications

Strategies A and B resulted in estimates of E that were lower than estimates of E from summer tagged parr. The estimated E for small and medium size groups in strategies A and B ranged from 28%–34%. The E from strategy C in these same size groups was 42%–44%. Strategy C best mimicked the E of summer tagged parr, which was 53% for the small/medium size group. If E is underestimated, population abundance will in turn be overestimated. An appropriate recent release strategy is crucial for population estimates and management. Our results suggest that for *O. mykiss* in the small and medium size groups, liberating recent releases at civil twilight created an estimate of E that is not statistically different from that of naturally migrating fish. Our results indicate that this release strategy will accurately estimate out-migrant abundance for the small and medium size groups. However, it remains unclear whether nighttime upstream releases will produce a valid estimate of E for *O. mykiss* in the large size group. Therefore, estimates of E should be qualified by time (Roper and Scarnecchia 2000) and fish length. Alternative methods of estimating E for large fish making their first approach to the trap should be further investigated. Emplacing PIT antennas or dual-frequency identification sonar immediately upstream of an RST may be two approaches.

The efficiency of any RST needs to be estimated in order to estimate out-migrant abundance. We found evidence that releasing marked *O. mykiss* upstream of an RST during daylight will result in biased estimates of out-migrant abundance. Releasing marked *O. mykiss* at twilight will create unbiased estimates of out-migrant abundance for small and medium size groups. Alternative trap calibration methods, preferably using an independent measure of migrating fish abundance should be considered. One option is to PIT tag juvenile salmonids upstream from the RST and use PIT antennas near the RST to detect migrants. Our results suggest this may be critical for an accurate estimate of E for large sized *O. mykiss*.

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Footnotes

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[1] Reference to trade names does not imply endorsement by the United States Geological Survey, Oregon Cooperative Fishery Research Unit, Oregon State University, or the Oregon Department of Fish & Wildlife.

TABLE 1.—Sample sizes of *Oncorhynchus mykiss* captured, marked with a PIT tag, and released upstream (M) of the South Fork John Day River rotary screw trap over 37 different days during fall 2005. The number of recaptures (R) and recapture rate of marked fish (E) are presented by size group and release strategy. Range is the minimum and maximum number of fish released by strategy on a single day. Strategy A was release during daylight 1.6 km upstream from the trap. Strategy B was release during daylight 4.8 km upstream of the trap. Strategy C was release at civil twilight 1.8 km upstream of the trap.

	Small (86–115 mm)			Medium (116–145 mm)			Large (146–230 mm)			
Strategy	M	R	E	M	R	E	M	R	E	Range
A	53	16	0.30	130	37	0.28	113	15	0.13	1–51
B	41	16	0.39	140	39	0.28	99	22	0.22	1–49
C	42	16	0.38	133	63	0.47	97	18	0.19	1–49
Total	136	48	0.35	403	139	0.34	309	55	0.18	3–149

FIGURE 1.—Map of the South Fork John Day River (SFJD) basin. Locations of release strategies (A, B, and C) used during fall 2005 are indicated. Dashed circles indicate the summer rearing locations where “summer tagged parr” were released 1–5 months prior to migration. Dashed arrow denotes streamflow direction. Inset shows the location of the SFJD basin in Oregon.

FIGURE 2.—Length-frequency histogram for *Oncorhynchus mykiss* migrating past a rotary screw trap on the South Fork John Day River. Summer tagged parr were tagged upstream of the trap during June-September 2004, 1–5 months before migration. Lengths for summer tagged parr were those observed or estimated when they migrated past the trap. Release strategy C fish were captured in the trap during October–December 2005, tagged and released upstream of the trap at civil twilight. Exclusions were those individuals removed from the final logistic regression model.

FIGURE 3.—Capture efficiencies for PIT tagged *Oncorhynchus mykiss* released upstream of the South Fork John Day River rotary screw trap during 2004–2005. Estimates are from two binomial logistic regression models of the effect of release strategy and size group on capture efficiency. Release strategy A (fish were released 1.6 km upstream during daylight), release strategy B (fish were released 4.8 km upstream during daylight), and release strategy C (fish were released 1.8 km upstream at civil twilight) occurred during fall 2005. Size groups for these releases were: Small = 86–115 mm FL, Medium = 116–145 mm FL, and Large = 146–230 mm FL. Striped bars compare capture efficiencies from the final binomial logistic regression model of strategy C (“Final C”) with observed capture efficiencies for summer tagged parr (“Summer Parr”). Summer tagged parr were detected migrating past a PIT antenna 78 m upstream of the

rotary screw trap during fall 2004. Size groups for this comparison were: Small/Medium = 86–145 mm FL, Large = 146–200 mm FL. Error bars are 95% Confidence Intervals.

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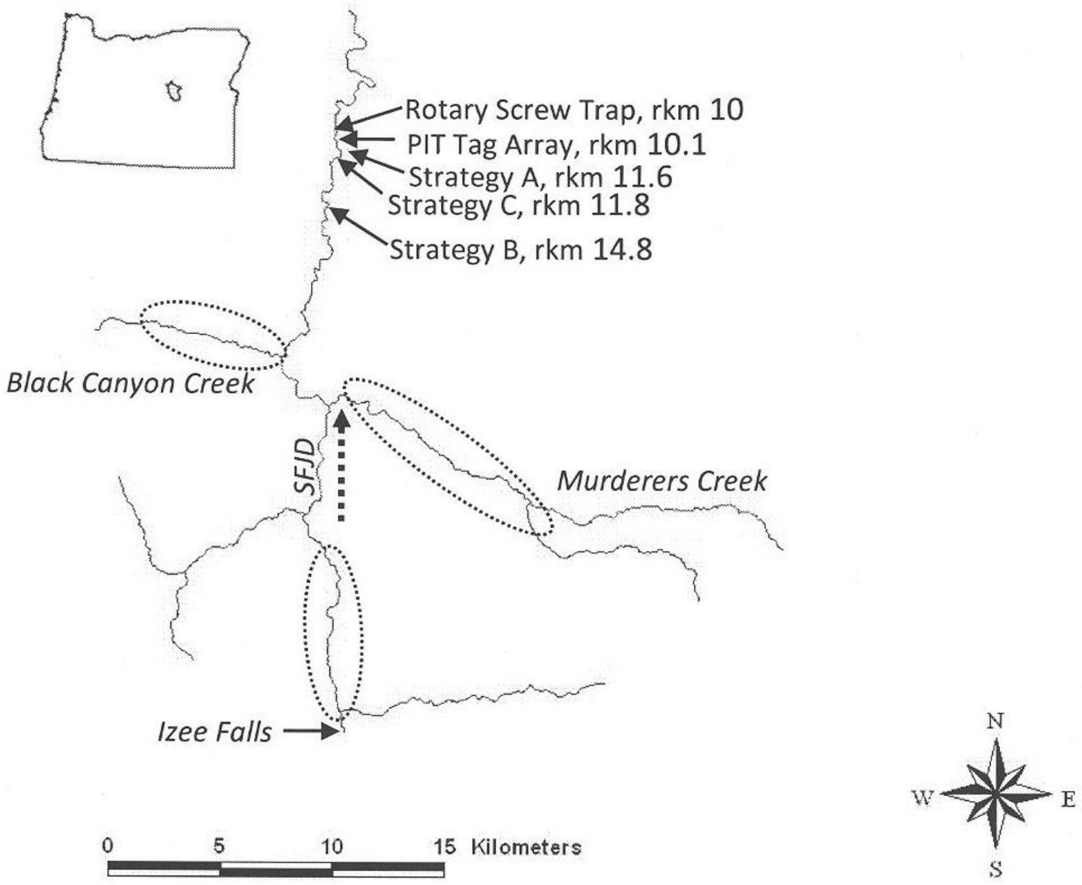

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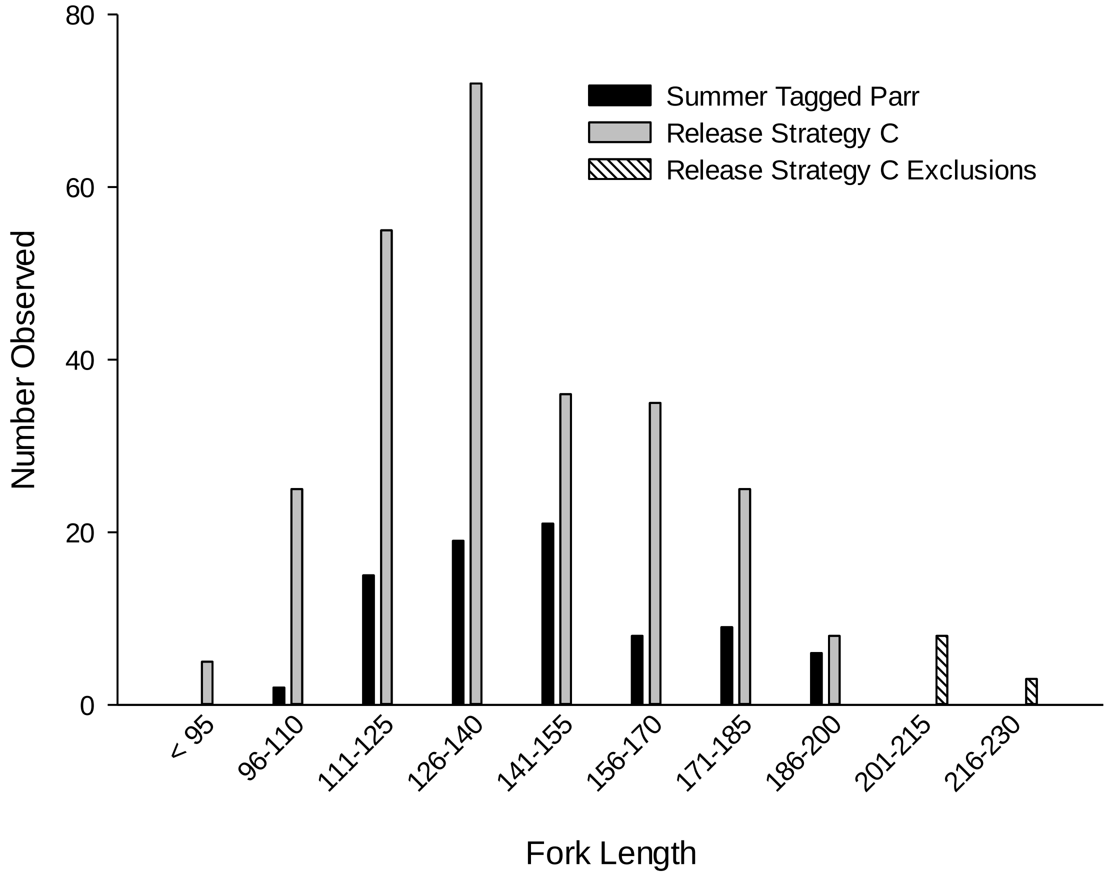
485 Tattam et al., Figure 2.



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Tattam et al., Figure 3.