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A Comparison of the Survival and Migratory Behavior of Hatchery-Reared and Naturally Reared Steelhead Smolts in the Alsea River and Estuary, Oregon, using Acoustic Telemetry

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Abstract.—We tracked three groups of steelhead *Oncorhynchus mykiss* smolts implanted with acoustic transmitters to determine whether the degree of hatchery domestication or the juvenile rearing environment (hatchery raceway versus natural stream) influenced migration timing and survival in the Alsea River and estuary, Oregon. Two groups consisted of age-1 smolts reared in concrete raceways. One hatchery-reared group (traditional brood group) was derived from the traditional Alsea River broodstock initially developed in the 1950s. The second hatchery-reared group (new brood group) was derived from naturally reared Alsea River adult steelhead that were captured and spawned at the hatchery beginning in the winter of 2000–2001. The third group (naturally reared group) consisted of age-2 naturally reared smolts captured in a downstream migrant trap located in a tributary stream near the hatchery. We placed transmitters in 74 traditional brood smolts, 76 new brood smolts, and 72 naturally reared smolts. Thirty-one acoustic receivers were located throughout the Alsea River and estuary and in the ocean offshore of the river mouth to monitor smolt movement. We found no significant difference between groups in their survival to the head of tide or to the mouth of the estuary. Most smolts from all three groups were detected at the head of tide (87% of fish from the traditional brood group, 78% from the new brood group, and 84% from the naturally reared group). However, survival was poor in the lower estuary for all three groups; we estimated that only 37% of the traditional brood group, 45% of the new brood group, and 47% of the naturally reared group survived to the ocean. The timing of migration through the river was highly variable in all three groups, and we found no significant differences in the rate of downstream movement from the release site to the head of tide. Mean residence time within the estuary was similar for all groups, although smolts from the naturally reared group showed less variability in estuary residence time than hatchery-reared smolts.

Fishery management agencies in the Pacific Northwest have long relied on hatcheries to increase the number of steelhead *Oncorhynchus mykiss* available for harvest and to supplement declining natural rearing populations (Moring 1993; Mobrand et al. 2005; NMFS 2005). Poor smolt-to-adult survival rates for salmonids in the Pacific Northwest have been attributed to changing ocean conditions (Nickelson 1986; Pearcy 1992; Smith and Ward 2000) as well as high predation rates in estuarine or near-marine waters (Wood 1987; Collis et al. 2002; Melnychuk et al. 2007). In recent years, studies have also documented

several sources contributing to poor adult survival of hatchery steelhead, including the decrease in fitness resulting from domestication of hatchery-reared steelhead (Reisenbichler and Rubin 1999; Reisenbichler et al. 2004; Araki et al. 2007) and the negative impact of using of out-of-basin broodstock for hatchery programs (Chilcote et al. 1986; Chilcote 2003; Kostow 2004). Researchers have demonstrated genetic or behavioral differences resulting in predation mortality between hatchery and wild salmonids in laboratory studies (Johnsson and Abrahams 1991; Olla et al. 1994; Berejikian 1995; Alvarez and Nicieza 2003; Yamamoto and Reinhardt 2003). These studies suggest that increased predation may contribute to the decreased fitness seen in some domesticated stocks. This may be particularly true in the Pacific Northwest, where

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populations of birds and marine mammals that prey on juvenile salmonids have increased over the last three to four decades (Carter et al. 1995; Collis et al. 2002; Brown et al. 2005). However, few field studies have directly compared freshwater and estuarine postrelease survival and migration patterns for steelhead smolts with different histories of hatchery domestication. It is also unclear how these attributes in hatchery smolts differ from those in naturally reared smolts migrating within the same watershed.

In Oregon coastal streams, steelhead smolts migrate to the ocean in the spring, with the peak of the migration occurring in April and May. Naturally reared smolts are predominately age-2 smolts, although a small proportion of the smolt population may also include age-1 and age-3 smolts. In these streams, the average fork length of naturally reared steelhead smolts is typically 150–170 mm, although steelhead juveniles as small as 120 mm often exhibit morphological and physiological changes associated with smolting (body silvering, fin margin blackening, and a decline in condition factor) and are regularly observed migrating downstream each spring (Wagner 1974; Wedemeyer et al. 1980; Jepsen et al. 2006). In contrast, steelhead juveniles raised in Oregon coastal hatcheries grow more quickly and are normally released to migrate to the ocean as age-1 smolts. Although younger, these hatchery-reared smolts are generally larger than their naturally reared counterparts, averaging 180–200 mm fork length. Both naturally reared and hatchery-reared steelhead generally spend 1–3 years in the ocean before returning to the coastal rivers to spawn.

Many of the hatchery winter steelhead currently released in Oregon coastal streams originated from broodstock lines developed during the 1950s through 1970s. The parentage for many of these lines originated from out-of-basin fish, often from the early hatchery brood developed from the Alsea River (Wagner et al. 1963). In an effort to counteract the negative influence of domestication and out-of-basin broodstocks on the survival of hatchery-reared smolts, the Oregon Department of Fish and Wildlife (ODFW) has initiated a wild broodstock program in over 10 coastal rivers wherein naturally reared adult steelhead from within the river basin are brought into the hatcheries and used as broodstock. These programs were initiated to increase the number of adult steelhead returning to these rivers and to spread out the return time of the adult steelhead to improve the contribution to the fishery. It was also assumed that the straying of hatchery-reared fish to natural streams would pose a lower genetic risk to wild populations if within-basin broodstocks were used.

To date, the effect of wild brood programs on

steelhead populations in Oregon coastal streams has received little evaluation. Although benefits may result, the programs do pose some risk. Creating new broodstock programs from a small number of wild adult spawners may cause genetic changes that lower the effective population size (Ryman and Laikre 1991). Hulett et al. (2004) and Sharpe et al. (2007) advised of potential problems or unintended consequences associated with wild brood programs and emphasized the need to evaluate these programs both within the confines of the hatchery and also during the postrelease period as the smolts migrate to the ocean. Specifically, hatchery-reared steelhead juveniles from wild parents often show more variation in size at time of release, and consequently many fish do not migrate with the remainder of their cohort but instead residualize within the stream (Hulett et al. 2004; Reisenbichler et al. 2004; Sharpe et al. 2007).

We used acoustic telemetry to determine whether hatchery rearing and the degree of domestication in a hatchery broodstock influenced the migratory behavior and survival of winter steelhead smolts as they migrated through an Oregon coastal river and estuary. Three groups of smolts were evaluated; all were endemic to the river where the study took place. Two smolt groups were reared in a coastal hatchery and released as age-1 smolts as part of the normal production program; one hatchery group was the progeny of a traditional broodstock, whereas the second hatchery group was the progeny of naturally reared adult steelhead that had recently been captured and brought to the hatchery for spawning. The third group of fish consisted of the progeny of adult steelhead that spawned naturally in a tributary stream located near the hatchery. Because of the close proximity to the hatchery, some of these naturally reared smolts may be the progeny of hatchery adults that strayed into the tributary to spawn. Nevertheless, this third group represents fish that reared under natural conditions and migrated as age-2 smolts, the predominant age of smolting for steelhead in most Oregon coastal streams. Thus, the stream-reared smolts present a contrast to the two smolt groups that were raised in raceways under normal hatchery rearing practices. We recognize that this study cannot separate the effect of smolt age from rearing environment (stream versus hatchery). While naturally reared fish typically smolt at age 2, early studies with steelhead culture in Pacific Northwest hatcheries concluded that rearing fish to age-1 smolts was the most effective and practical method to produce healthy smolts. This practice has long been the normal rearing regime for steelhead in Oregon coastal hatcheries.

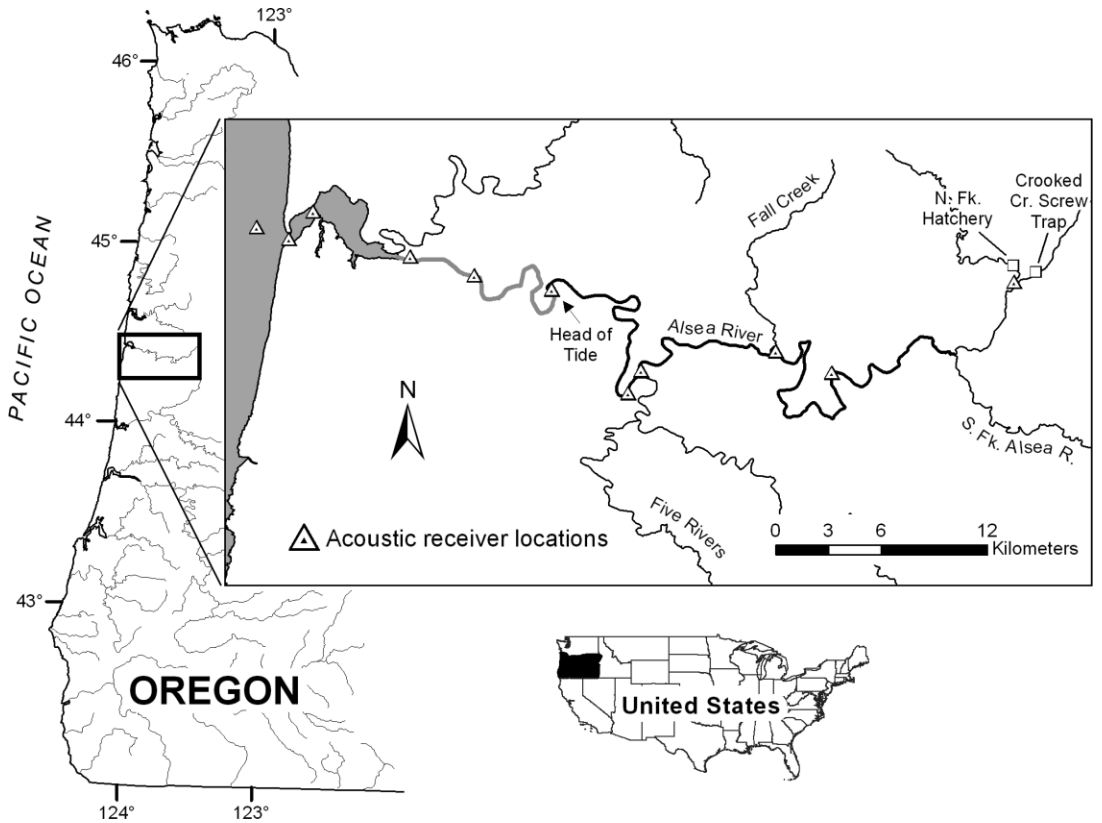


FIGURE 1.—Location of the Alsea River and estuary on the central Oregon coast. Diamonds denote locations of acoustic receiver detection arrays used to determine survival and migration timing of steelhead smolts. Four additional receivers (locations not pictured) were placed in secondary channels in the estuary to track estuarine movement.

Methods

Study Area

The Alsea River originates on the west slope of Oregon’s Coast Range mountains and flows into the Pacific Ocean near the town of Waldport, Oregon (44°26’N, 124°04’W; Figure 1). Average seasonal flows range between 3.5 m³/s (late summer) and 102 m³/s (winter). During the study (mid-March to May

2007), streamflows ranged from about 42.5 m³/s in mid-March and early April to 9.9 m³/s by mid-May (Figure 2). The average stream temperature in the main-stem Alsea River near the head of tide at river kilometer (rkm) 23.7 ranged from 10°C to 14°C in April 2007, when most of the smolts migrated through the river. River temperatures increased to 15–18°C in May (Figure 2). The Alsea River estuary covers an area of approximately 1,080 ha, and tidal flow extends about 21 km upstream from the estuary mouth (rkm 0) (Peterson et al. 1982). The lower 6 km of the estuary in Alsea Bay contain several subtidal channels traversing mud and sand flats, where the maximum width of the bay is approximately 1.5 km. Portions of the lower estuary return to a single channel that narrows to less than 0.5 km near rkm 3 and again at the estuary mouth (approximately 250 m wide at low tide and 370 m wide at high tide). The lower portion of Alsea Bay is shallow in most areas (2–3 m), although several deeper holes exist (>10 m), particularly near the mouth. The upper

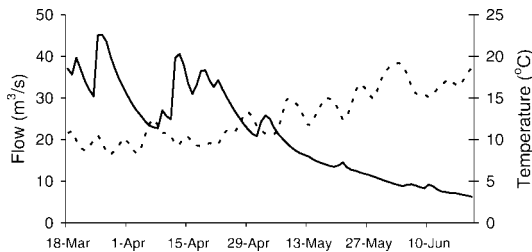


FIGURE 2.—Average daily river flow (m³/s; solid line) and temperature (°C; dashed line) in the lower main-stem Alsea River, Oregon, during spring 2007.

TABLE 1.—Number of acoustic tags implanted in each release group of Alsea River (Oregon) steelhead smolts and the mean size and range (fork length) of tagged fish in each group. Mean length of the naturally reared group was smaller than those of the two hatchery-reared groups (ANOVA: $P < 0.001$). The VEMCO V7-2L transmitters were used in all naturally reared smolts and in hatchery smolts under 170 mm; V7-2L transmitters were also implanted in 12 larger smolts (180–210 mm) from each hatchery group to evaluate differences in detection rate between V7-2L and V9-6L transmitters for fish of equal size.

Release group	Number of tags		Total smolts tagged	Fork length (mm)		
	V9-6L	V7-2L		Mean	SD	Range
Traditional brood	61	13	74	195	16	150–235
New brood	56	20	76	190	22	140–235
Naturally reared	0	72	72	168	17	140–214

part of the bay (above rkm 6) consists of a single constrained channel.

Treatment Groups

Acoustic transmitters were implanted in three groups of steelhead smolts. Two groups consisted of steelhead smolts raised at the North Fork Alsea Hatchery (rkm 85). One hatchery group (hereafter, traditional brood group) was the progeny of adults from the traditional Alsea River broodstock first developed in the 1950s (Wagner et al. 1963). Smolts from the second hatchery group (hereafter, new brood group) were the progeny of a broodstock developed beginning in the winter of 2000–2001. This new broodstock originated from naturally reared adult steelhead captured in the Alsea River by volunteer anglers. Although the original hatchery program called for naturally reared adults to be collected from the river each winter and used for this new broodstock, in some years there have been difficulties in catching and successfully holding enough of the naturally reared adults at the hatchery facility. Thus, some adult returns from the original releases of smolts from the new broodstock (F_1 generation) have been used along with naturally reared adults in order to produce enough smolts to meet hatchery production goals for the new broodline. As is common practice in all Oregon coastal hatchery programs, steelhead smolts from both groups were 1 year old at the time of release. The third group (hereafter, naturally reared group) consisted of steelhead smolts that reared naturally and were captured in Crooked Creek, a tributary that enters the North Fork Alsea River at rkm 84, just downstream of the North Fork Alsea Hatchery facility (Figure 1). Scale analysis indicated that all smolts in the naturally reared group that were implanted with acoustic tags were 2 years old.

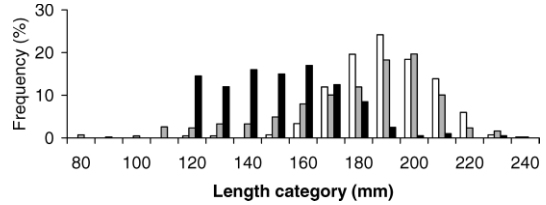


FIGURE 3.—Length frequency (fork length) of steelhead smolts in the traditional brood (open bars), new brood (gray bars), and naturally reared (black bars) groups. Tagged smolts from each group were representative of their respective populations, although smolts smaller than 140 mm did not receive transmitters.

Tagging Procedures

We implanted 74 acoustic transmitters in the traditional brood group, 76 transmitters in the new brood group, and 72 transmitters in the naturally reared group. Two sizes of VEMCO acoustic transmitters were used. The smaller V7-2L transmitters (7 × 20 mm, 1.6 g in air, expected battery life span = 80 d) were used in all naturally reared smolts and in hatchery smolts under 170 mm fork length. The V9-6L transmitters (9 × 20 mm, 3.3 g in air, expected battery life span = 65 d) were used in hatchery-reared smolts over 170 mm fork length. To evaluate differences in detection rates between the two transmitter sizes, we implanted twelve V7-2L transmitters in larger smolts (180–210 mm) from each of the two hatchery groups (Table 1). Both transmitters operated on a frequency of 69.0 kHz and transmitted at random intervals between 20 and 60 s. Each tag transmitted a unique identification code so that the identity of an individual fish detected by the receivers was known. To verify that all transmitters were working properly before placing the transmitters into the smolts, we first placed the transmitters in a bucket of water with a VEMCO VH40 hydrophone combined with a VEMCO VR28 receiver.

We kept the weight (in air) of the implanted tags at less than 5% of fish body weight to minimize possible behavioral or physiological changes in tagged fish (Lacroix et al. 2004; Welch et al. 2007). Given this criterion, we did not implant transmitters in smolts that were smaller than 140 mm fork length. Length frequency measurements of the two hatchery groups were taken 1 week prior to tagging (Figure 3). This information was used to determine the number of fish to be tagged within each size-group, with the goal of ensuring that the tagged fish were representative of the length frequency distribution of the hatchery populations. However, 1% of the smolts in the traditional brood group and 10% of the smolts in the new brood

TABLE 2.—Probability (SE in parentheses) of detection of VEMCO V9-6L and V7-2L transmitters by receiver arrays located in the Alsea River and estuary, Oregon. Estimates were generated using SURPH (Lady et al. 2001). All steelhead used in this analysis were hatchery reared and 180–210 mm fork length. Sample size was 24 smolts initially released with V7-2L transmitters and 67 smolts released with V9-6L transmitters. Smolts were tagged and released from North Fork Alsea Hatchery (river kilometer [rkm] 84.9).

Detection array location	rkm	Number of receivers	Tag	
			V9-6L	V7-2L
North Fork Alsea River (below Crooked Creek)	83.4	2	—	—
Main-stem Alsea River				
Campbell Park	66.8	2	0.98 (0.02)	1.00 (0.00)
Mouth of Fall Creek	50.4	2	0.97 (0.02)	1.00 (0.00)
Above Five Rivers	39.8	1	0.97 (0.02)	1.00 (0.00)
Below Five Rivers	38.7	1	0.97 (0.02)	1.00 (0.00)
Head of tide	23.7	3	0.96 (0.02)	1.00 (0.00)
Upper tidewater (Taylor's Landing)	13.0	2	0.96 (0.03)	1.00 (0.00)
Upper estuary (Oakland's Marina)	9.0	2	0.95 (0.03)	0.93 (0.06)
Lower estuary (101 bridge)	2.6	3	0.92 (0.06)	0.90 (0.09)
Alsea Bay mouth	0.2	4	1.00 (0.00)	1.00 (0.00)
Offshore of river mouth	—	5	—	—

group were smaller than 140 mm and thus were not represented by the tagged fish in the experiment. The mean fork length of tagged smolts was 195 mm for the traditional brood group and 190 mm for the new brood group.

Throughout the spring, all naturally reared smolts that were 140 mm fork length or larger were tagged upon capture in the Crooked Creek trap. A comparison of the length frequency of naturally reared smolts (defined as fish ≥ 120 mm) caught in the trap with the length frequency of smolts that were tagged indicated that 26% of the captured smolts were smaller than 140 mm and thus were not represented by the tagged fish in the experiment (Figure 3). This probably overestimates the untagged portion of the population as some naturally reared steelhead in the 120–140-mm size range do not undergo the process of smoltification and instead reside in the river for an additional year (Jepsen et al. 2006). The mean fork length of the naturally reared group implanted with transmitters was 168 mm.

Each fish implanted with an acoustic transmitter was anesthetized in an aerated bucket with buffered tricaine methanesulfonate (MS-222) at 75 mg/L for approximately 3–4 min and then was transferred to a surgical table, where a continuous flow of water with 50-mg/L buffered MS-222 was administered through the gills via a tube inserted into the fish's mouth. An incision was made on the ventral midline anterior to the pelvic fins, and the transmitter was inserted into the body cavity. After the transmitter was positioned in the body cavity, the incision was closed with three monofilament sutures and the fish was moved into a tank of aerated freshwater for recovery. New and sterilized surgical equipment and gloves were used for each fish to minimize the possibility of infection.

The hatchery smolts were tagged between 27 and 29 March 2007. After fish recovered from the anesthetic, they were placed in large net-pens within the hatchery raceways. Tagged fish were monitored in the net-pens until they were released into the raceways on the evening of 2 April 2007. No tagging mortalities were observed, and all fish appeared to be active and feeding prior to release. A volitional release of steelhead smolts (untagged and tagged fish) from the North Fork Alsea Hatchery began on 2 April 2007. Smolts were allowed to leave volitionally until 10 April 2007, when the remaining smolts were forced out of the raceways and the raceways were dewatered. By placing one of the acoustic receivers in the raceways, we determined that by 4 April 2007 only five tagged steelhead smolts remained in the raceways.

Naturally reared steelhead smolts captured in the downstream migrant trap in Crooked Creek were implanted with transmitters between 17 March and 18 April 2007. Individual smolts caught in the trap were tagged within 48 h of capture. Surgical procedures for smolts in the naturally reared group were identical to procedures described for smolts in the hatchery-reared groups. Once these fish recovered from the anesthetic, they were placed in a large net-pen in the stream. All naturally reared steelhead were held for 24 h after tagging and then were released.

Acoustic Receiver Locations

Prior to the commencement of tagging, 31 VEMCO VR2 acoustic receivers were deployed throughout the Alsea River (six locations), the estuary (six locations), and the ocean near the mouth of the estuary to track smolt movement (Figure 1; Table 2). Multiple receivers were used at most locations to form an array of

receivers that ensured a high detection rate for transmitters passing each location (Table 2). Most arrays were located to provide estimates of migration and survival rates through several zones from the release site to the ocean plume. Two additional receiver arrays not listed in Table 2 were placed in the back channels within the estuary; these arrays were not intended to provide full channel coverage but rather were used to increase our understanding of fish movement within the estuary. Most receivers were attached to a rope on an anchor-and-buoy rigging similar to that described by Clements et al. (2005). In the upper river, where pools were often less than 3 m deep, receivers were mounted to a weighted bracket so that they would stand upright and sit directly on the bottom of a pool. Receivers in the estuary were generally downloaded weekly, while river receivers were generally downloaded every other week. No transmitters were detected after June 20, and all receivers were removed from the river and estuary in early July, when transmitter batteries were predicted to have expired.

Analysis

The history of tag detections at each array site was initially examined for inconsistencies. One transmitter was found to have only been detected on a single event at one estuary receiver. We assumed that this detection represented a “false hit” and therefore removed it from the data set.

Receiver array efficiency.—To determine whether V7-2L and V9-6L transmitters were detected at different rates at receiver arrays, we generated estimates of detection probabilities for the V7-2L and V9-6L transmitters at each receiver array location using Survival under Proportional Hazards (SURPH) version 2.2b (Lady et al. 2001). To minimize potential bias from fish size or rearing history in this initial comparison of transmitter size, we limited the comparison to hatchery-reared fish with fork lengths of 180–210 mm. Sample size for this analysis was 24 smolts with V7-2L transmitters and 67 smolts with V9-6L transmitters. Because no significant difference was observed in detection probabilities between V7-2L and V9-6L transmitters in this study (see Table 2), transmitter size was not used as a variable in subsequent analyses of migration rate and survival. Thus, we compared survival probabilities and detection probabilities generated by SURPH based on detection observations for each release group regardless of transmitter size (i.e., within a release group, individuals with V7-2L and V9-6L transmitters were combined for analysis).

Fish movement.—We used a one-way analysis of variance (ANOVA) to test the hypothesis that migration rate between the release site and various locations in the river and estuary did not differ among the three groups (Snedecor and Cochran 1967). Prior to analysis, we used a natural logarithmic transformation on migration rate values to meet the assumptions of equal variances among groups and normal distribution of residuals. Mean migration rates are reported in tables and figures as back-transformed values. To ensure that only actively moving fish were included in this analysis, the first detection of a specific fish at one of the two receivers immediately downstream of the release site was considered to be the fish’s starting point (North Fork Alsea River array, rkm 83.4). Because of the volitional release from the hatchery raceways, this eliminated the uncertainty about when each fish left the hatchery raceways and began to move downstream.

We also developed a statistical model of fish downstream movement from the release point to the head of tide so that comparisons among fish groups and any relationship between fish length and migratory rate could be assessed. Plots of a fish’s location (rkm) versus time suggested that fish movement was generally nonlinear and that the downstream rate was nonuniform. To linearize the data for use in a statistical analysis, we used a Box–Cox transformation of the number of days from detection at the first receiver array to detection at the downstream receiver array location. The optimal transformation yielded a Box–Cox parameter (γ) value of -0.006 . This value of γ was sufficiently close to zero; therefore, the number of days after first detection + 1 was log transformed to create the response variable. The statistical model consisted of this response variable as a linear function of fish fork length, observed distance downstream at receiver arrays, group membership, and the interactions among these terms. The model was constrained to lack an intercept term, which ensured that the model represented all fish as having started their migration at the same time ($t = 1$, to accommodate the log transformation) at the first receiver location (distance = 0). All observations of fish at the receiver arrays were used in the model so that consecutive observations of a specific fish’s location in the river were not independent of one another. We accounted for this by using a mixed regression model, considering the series of each fish’s observations as a repeated measure, and specifying a first-order autoregressive covariance structure for the sequence of each fish’s observed locations.

We used the initial time of arrival at freshwater receivers to determine movement patterns over a 24-h cycle as fish moved downstream. The initial arrival

time of each fish at each freshwater receiver was compared with the sunrise and sunset tables for that day. The arrival time was then categorized as either day or night movement. We used the Pearson chi-square analysis to test the null hypothesis that night movement was independent of release group category (Gotelli and Ellison 2004).

We defined the duration of estuary residence as extending from a fish's last detection at the head-of-tide receiver array (rkm 23.7) to the fish's arrival (i.e., initial detection) at the receiver where it was detected last in the estuary. The arrival time at the final estuarine receiver was used rather than the departure time to ensure that if a fish died in the vicinity of the receiver and the transmitter continued to contact the receiver, we would not count that time as residency time. We compared each fish's arrival at (or departure from) an estuarine receiver array to evaluate whether the fish had moved upstream or downstream when it moved between receiver arrays. This information, in combination with the time of day of fish arrival at or departure from estuarine receiver arrays, was used to evaluate whether the fish was moving during daytime or nighttime and whether the tide was flooding or ebbing. This was done by using upstream or downstream movement as the response variable in a logistic regression analysis with release group, diel period (daytime or nighttime), and tide stage as the explanatory variables.

We used regression analysis (Snedecor and Cochran 1967) to determine the relationship between the duration of estuary residence and fish size for each of the release groups. We also used regression analysis to determine whether the duration of estuary residence was related to the date of fish entry into the estuary.

Smolt survival.—We used a Cormack–Jolly–Seber release–recapture design, where transmitter detections at the receiver array sites were considered recaptures (Cormack 1964; Jolly 1965; Seber 1965). Survival probabilities and receiver array detection estimates (capture probabilities) were generated using SURPH (Lady et al. 2001). We used a likelihood ratio test (Gotelli and Ellison 2004) to test the null hypotheses that survival to the head of tide and survival to the estuary mouth were independent of release group. To ensure that only actively moving fish were used in the analysis, tagged fish that were released but never detected by the receivers downstream of the release points were excluded from the data set. We found that 9 of the 72 tagged smolts (12.5%) in the naturally reared group either died or simply did not migrate to the first downstream receiver array located in the North Fork Alsea River just below the mouth of Crooked Creek, a distance of approximately 3 km. Conversely,

we found that only 5% and 2% of the smolts from the traditional brood and new brood groups were not detected at this same receiver array, which is 1.5 km directly downstream from the hatchery. To minimize any potential bias resulting from the initial release location (Crooked Creek versus North Fork Alsea Hatchery), we estimated survival using only smolts that were detected at this first downstream receiver array. Thus, the initial sample size for the survival analysis was 70, 71, and 63 fish for the traditional brood, new brood, and naturally reared groups, respectively.

We defined estuary survivors as fish that were last detected at the estuary mouth array (rkm 0.2) or offshore receiver array. Smolts that were detected at these arrays but that subsequently moved back upstream and were last detected at arrays higher in the estuary were assumed to be mortalities (15 fish). For purposes of the survival analysis in SURPH, we constructed case histories for these fish that reflected their last known location as their farthest detection downstream. Seven smolts that were last detected at the estuary mouth array were also assumed to have died prior to entering the ocean. The transmitters from these seven fish were repeatedly detected in the vicinity of the estuary mouth array over a period of 3–6 weeks. This pattern of movement was atypical of other smolts, and the array was in a location of high tidal exchange and a high concentration of predators. In constructing case histories for these seven fish, we coded their last detection at the lower estuary array (rkm 2.6) so that the SURPH program would not assume survival at the estuary mouth.

Results

Comparison of Transmitter Types

The probability of detection of V9-6L transmitters at all receiver array locations was 92% or greater. The probability of detection of V7-2L transmitters was 100% at all river array sites and 90% or higher at estuary array sites. The probability of detection was similar between transmitter types at all array locations (Table 2).

Transmitter size had no significant effect on the survival probability at the head of tide (likelihood ratio test: $P > 0.10$) or at the mouth of the estuary ($P > 0.50$; Table 3). Transmitter size also had no significant effect on the number of days it took hatchery-reared smolts of similar size (180–210 mm) to migrate to the head of tide or estuary mouth (Table 3).

Receiver Array Efficiency

Estimates of the probability of detection (capture probability) generated by the SURPH program for each release group at all receiver array locations are

TABLE 3.—Comparison of the effect of transmitter size on steelhead smolt survival probability (generated in SURPH; SE in parentheses) and number of days to head-of-tide and Alsea Bay mouth acoustic receiver arrays, Oregon (CI = confidence interval). To minimize the effect of fish size, only hatchery smolts with fork lengths of 180–210 mm were used for this analysis. Mean length of smolts implanted with VEMCO V7-2L and V9-6L transmitters was 196 mm for both groups.

Tag	Number released	Array location	Survival probability	Days to location		
				Mean	95% CI	Range
V7-2L	24	Head of tide	0.75 (0.09)	9.4	6.6–14.0	2.1–33.3
V9-6L	67	Head of tide	0.87 (0.04)	10.5	9.8–14.2	1.9–43.6
V7-2L	24	Estuary mouth	0.42 (0.10)	10.8	6.9–19.6	3.4–33.8
V9-6L	67	Estuary mouth	0.36 (0.06)	12.5	11.9–18.3	2.7–44.4

provided in Table 4. Detection probabilities were 96% or greater for all freshwater and upper tidewater array locations. Detection probabilities ranged between 82% and 100% for array locations in the estuary for the three release groups.

Fish Movement

Variation in migration timing through the river was high for all three groups. We found no significant difference among groups in the rate of movement to the mouth of Fall Creek (rkm 50.4; ANOVA: $P = 0.579$) or to the head of tide (ANOVA: $P = 0.696$; Table 5). The mean migration time through the river (to the head-of-tide array) was 9.7, 11.2, and 10.4 d for the traditional brood, new brood, and naturally reared groups, respectively (migration rate = 6.2, 5.3, and 5.7 km/d, respectively). However, movement through the river was not uniform. Fish from all groups moved at a slower rate in the river upstream of the Fall Creek receiver array (Figure 4). Most smolts stayed within range of the freshwater river receiver arrays for less than 30 min, although a few smolts remained in the vicinity of a receiver array for 24 h.

The time at which smolts first came in contact with the receiver arrays suggested that all three release groups tended to move more at night while in freshwater. We observed 377, 352, and 337 first contact events at the freshwater receivers for the traditional brood, new brood, and naturally reared release groups, respectively. These data indicated that 71, 75, and 76% of first arrival times at freshwater receivers were between sunset and sunrise for the traditional brood, new brood, and naturally reared groups, respectively. Differences in night movement among groups were not significant (Pearson chi-square test: $P > 0.10$). For all three groups, the downstream movement tended to be more concentrated in the hours immediately after sunset and slowed in the early morning hours before sunrise. We did not observe any relationship between the time fish arrived at an array and the concurrent water temperature and river discharge; we also observed no relationship between the time fish arrived at an array and the changes in stream temperature or streamflow.

There was a significant relationship between fish size (fork length) and the number of days taken to

TABLE 4.—Probability of detection (generated in SURPH; SE in parentheses) at acoustic receiver array locations for three steelhead release groups. Hatchery-reared smolts were tagged and released from the North Fork Alsea Hatchery (river kilometer [rkm] 84.9). Naturally reared smolts were tagged and released in Crooked Creek (2.5 km above the Creek's mouth), which enters the North Fork Alsea River at rkm 84.0.

Array location	rkm	Number of receivers	Release group		
			Traditional brood	New brood	Naturally reared
North Fork Alsea River	83.4	2	—	—	—
Main-stem Alsea River					
Campbell Park	66.8	2	1.00 (0.00)	0.96 (0.02)	1.00 (0.00)
Mouth of Fall Creek	50.4	2	0.98 (0.02)	0.96 (0.02)	1.00 (0.00)
Above Five Rivers	39.8	1	0.98 (0.02)	0.96 (0.02)	1.00 (0.00)
Below Five Rivers	38.7	1	0.98 (0.02)	0.96 (0.02)	1.00 (0.00)
Head of tide	23.7	3	0.98 (0.02)	0.96 (0.03)	1.00 (0.00)
Upper tidewater	13.0	2	0.98 (0.02)	0.98 (0.02)	1.00 (0.00)
Upper estuary	9.0	2	0.97 (0.03)	0.93 (0.04)	0.90 (0.05)
Lower estuary	2.6	3	0.88 (0.06)	0.93 (0.05)	0.86 (0.07)
Estuary mouth	0.2	4	1.00 (0.00)	0.82 (0.12)	0.90 (0.09)
Offshore of river mouth	—	5	—	—	—

TABLE 5.—Mean number of days to acoustic receiver locations at Fall Creek (river kilometer [rkm] 50.4), the head of tide (rkm 23.7), and the Alsea Bay mouth (rkm 0.2), Oregon, for each steelhead smolt release group. Number of days is calculated from the time of arrival at the receiver array immediately below the release location (rkm 83.4) to the time of first detection at each downstream receiver array. Differences between groups were not significant at any location (ANOVA of log-transformed data: $P > 0.05$).

Array location	Release group	Number detected	Days to location	
			Mean	Range
Fall Creek	Traditional brood	62	6.1	1.0–31.3
	New brood	55	7.6	0.4–58.5
Head of tide	Naturally reared	57	6.7	0.8–48.5
	Traditional brood	59	9.7	1.7–33.3
Alsea Bay mouth	New brood	54	11.2	1.2–59.2
	Naturally reared	53	10.4	1.9–54.0
	Traditional brood	36	11.3	2.2–33.8
	New brood	37	11.3	1.7–59.9
	Naturally reared	28	11.1	2.9–54.7

migrate through the river to the head of tide for all three groups (all $P < 0.001$; Figure 5). Fish size alone, however, explained little of the variation for the naturally reared ($R^2 = 0.137$) and traditional brood ($R^2 = 0.252$) groups.

The relationship between fork length and travel time to a given location is described by the following equation:

$$\begin{aligned} \text{Number of days since detection at first array} \\ = \exp[\text{distance past first array} \\ \times (\beta_1 + \beta_2 \times \text{fork length})] - 1. \end{aligned}$$

The regression parameters β_1 and β_2 cannot be given a biological interpretation because a logarithmic trans-

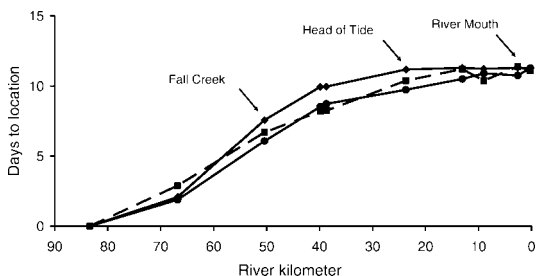


FIGURE 4.—Mean number of days to each acoustic receiver array in the Alsea River and estuary, Oregon, for three steelhead smolt release groups (solid line with circles = traditional brood group; solid line with diamonds = new brood group; dashed line with squares = naturally reared group). Arrival time at the receiver array immediately below the release point was used as the start time. Data reflect initial unidirectional movement downstream. High mortality in the lower 9 km of the estuary resulted in a decline in sample size at the lower estuary arrays, accounting for mean values that were slightly smaller than at the arrays upstream. For all locations, differences among groups were not significant ($P > 0.05$).

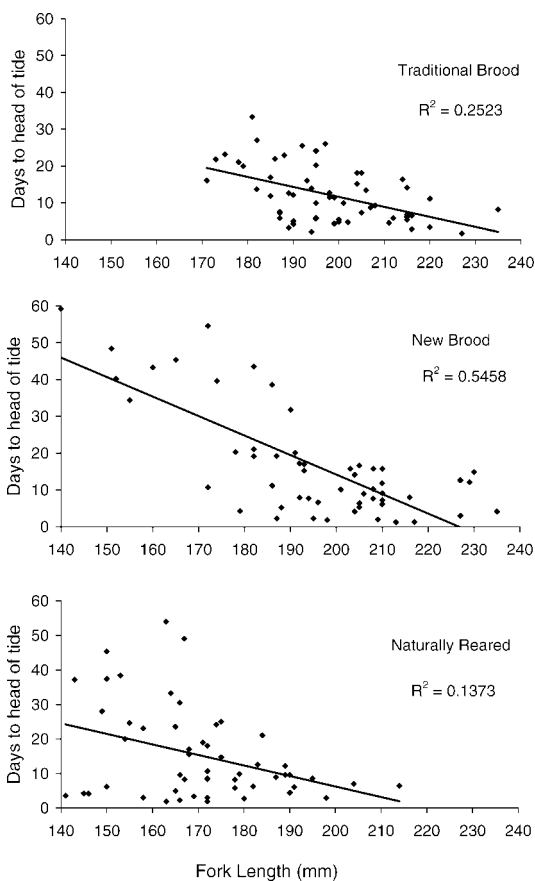


FIGURE 5.—Relationship between steelhead size (fork length) and the number of days from detection at the first acoustic receiver array to detection at the head-of-tide array in the Alsea River, Oregon, for three smolt groups (traditional brood, new brood, and naturally reared). Regressions for all three groups were significant ($P < 0.001$).

formation of the response variable, number of days since detection at the first array + 1, was used in the regression analysis to provide the best descriptive fit to the migration rate data. The β_1 values were 0.114, 0.110, and 0.074 and the β_2 values were -0.00038 , -0.00036 , and -0.00020 for the traditional brood, new brood, and naturally reared groups, respectively. Only distance past the first array and fork length were statistically significant in the model ($P < 0.01$ for both). The terms related to individual release groups were not statistically significant (all other $P > 0.25$). Release group terms were retained in the model, however, to allow comparison of the migration among groups (Figure 6).

We found no significant differences among the three release groups in the number of days it took to initially reach the mouth of the estuary (i.e., Alsea Bay mouth; ANOVA: $P = 0.996$; Table 5). However, upon reaching various locations within the estuary, including the Alsea Bay mouth, some fish from all three groups reversed direction and were detected at a receiver array located upstream of a receiver at which they were previously detected. This was most pronounced for the two hatchery-reared smolt groups: 52% of traditional brood smolts and 53% of new brood smolts showed this movement pattern once they entered the estuary. In contrast, only 32% of the naturally reared smolts exhibited this movement pattern in the estuary. No smolts that were detected at estuarine receiver arrays were observed to move back upstream into freshwater past the head-of-tide receiver array. Fish from the traditional brood and new brood groups tended to move downstream in the estuary during daytime ebb tides and conversely generally moved upstream on nighttime flood tides. In contrast, fish in the naturally reared group appeared to move downstream with a higher probability regardless of diel period and tide stage (Figure 7).

For smolts that successfully migrated through the estuary, we found no significant difference in the mean estuarine residence time (h) between the three release groups (43.7 h for the traditional brood group, 44.1 h for the new brood group, 29.3 h for the naturally reared group; ANOVA: $P = 0.273$). However, some successful migrants from both hatchery-reared groups did reside in the estuary for as long as 18–20 d, while all successful migrants from the naturally reared group moved through the estuary within 3 d. Unsuccessful estuary migrants (smolts that were last detected in the estuary at locations other than the Alsea Bay mouth or offshore) from hatchery-reared groups tended to have a longer estuary residence time than successful migrants, but differences were not significant ($P > 0.05$). We found no significant relationship between estuary

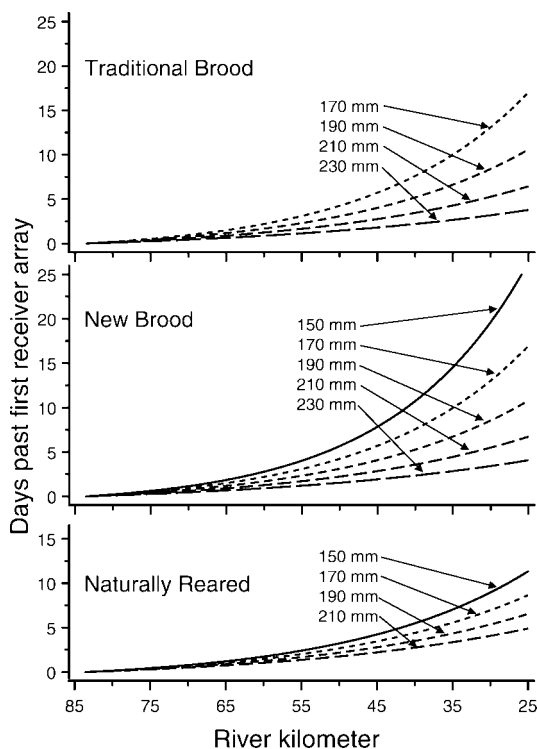


FIGURE 6.—Predicted relationship between steelhead smolt movement downstream in freshwater (number of days after detection at first receiver array) and fish size (fork length) based on the mixed regression model for three release groups in the Alsea River, Oregon.

residence time and fish size (fork length) for the three release groups (traditional brood: $P = 0.384$; new brood: $P = 0.371$; naturally reared: $P = 0.459$). We also found no significant relationship between estuary residency time and arrival date to the head of tide (traditional brood: $P = 0.416$; new brood: $P = 0.685$; naturally reared: $P = 0.177$).

Fish Survival

Survival probabilities in stream reaches between receiver arrays are presented in Table 6. These results indicate that 87% of the tagged smolts in the traditional brood group successfully migrated through the river to the receiver array at the head of tide; 78% of the new brood group and 84% of the naturally reared group successfully migrated to the head-of-tide receiver array (Figure 8). Differences in survival to the head of tide between groups were not significant (likelihood ratio test: $P > 0.25$). While tagged smolts may have moved into tributaries rather than migrate through the river, our results indicate that no tagged smolts entered Five Rivers, the largest tributary on their migratory route.

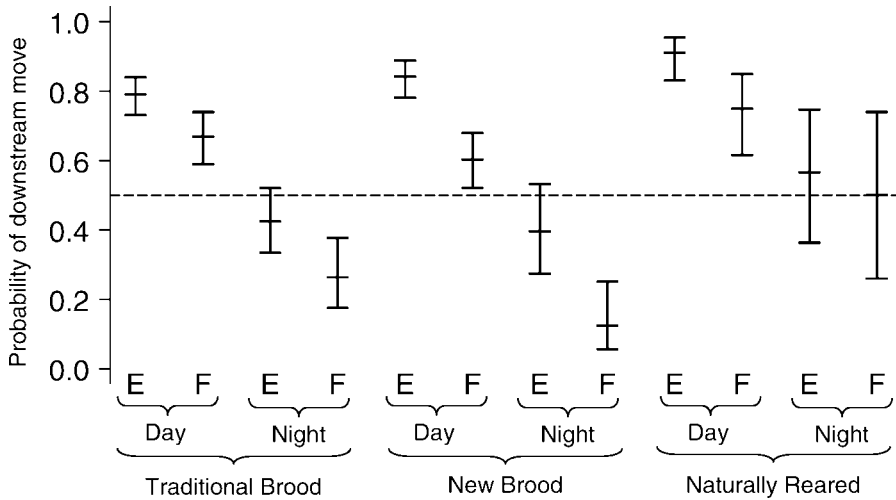


FIGURE 7.—Predicted relationship between the probability of downstream movement (mean ± 95% confidence interval) and diel period (daytime versus nighttime) or tide stage (E = ebb tide; F = flood tide) for three steelhead smolt release groups in the Alsea River estuary, Oregon.

All tagged smolts detected at the receiver array immediately above the mouth of Five Rivers were also detected at the receiver array immediately below Five Rivers (Table 6; Figure 1). Survival probabilities were high for all groups moving through the upper tidewater portion of the estuary, but survival for all three groups dropped substantially as they moved through the lower 9 km of the estuary (Figure 9; Table 6). Estimates of survival of the tagged smolts to the ocean were 37, 45, and 47% for the traditional brood, new brood, and naturally reared groups, respectively (Figure 8). Again, differences in survival to the estuary between groups were not significant (likelihood ratio test: $P > 0.25$). The percent of smolts that survived their migration through the estuary (calculated as [number of fish surviving to the Alsea Bay mouth]/[number of fish surviving to the head of tide]) was

estimated to be 43, 57, and 56% for the traditional brood, new brood, and naturally reared groups, respectively. Differences were not significant (likelihood ratio test: $P > 0.10$).

We found that size tended to be related to the survival probability in the new brood group. Overall, for tagged fish in the new brood group, 50% of 140–169-mm individuals, 74% of 170–199-mm fish, and 89% of 200-mm and larger individuals were detected at the head-of-tide receiver array (Figure 10). This relationship between fish size and survival probability was less apparent once the new brood group reached the Alsea Bay mouth (Figure 10). The traditional brood group had few small fish (140–169 mm) in the population, and thus only two fish from this size category were fitted with transmitters. These two fish were only detected in the upper river shortly after release. The two larger size-

TABLE 6.—Survival probabilities (generated in SURPH; SE in parentheses) for three steelhead release groups in stream reaches of the Alsea River and estuary, Oregon.

Stream reach	rkm	Release group		
		Traditional brood	New brood	Naturally reared
North Fork Alsea River–Campbell Park	83.4–66.8	0.97 (0.02)	0.93 (0.03)	0.93 (0.03)
Campbell Park–Fall Creek	66.8–50.4	0.94 (0.03)	0.86 (0.04)	0.97 (0.02)
Fall Creek–above Five Rivers	50.4–39.8	0.98 (0.02)	0.98 (0.02)	0.98 (0.02)
Above–below Five Rivers	39.8–38.7	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Below Five Rivers–head of tide	38.7–23.7	0.97 (0.02)	1.00 (0.00)	0.95 (0.03)
Head of tide–upper tidewater	23.7–13.0	0.97 (0.02)	0.96 (0.03)	1.00 (0.00)
Upper tidewater–upper estuary	13.0–9.0	0.97 (0.03)	0.95 (0.03)	0.93 (0.04)
Upper estuary–lower estuary	9.0–2.6	0.69 (0.07)	0.90 (0.05)	0.83 (0.07)
Lower estuary–estuary mouth	2.6–0.2	0.66 (0.08)	0.69 (0.11)	0.73 (0.10)
Overall		0.37 (0.06)	0.45 (0.08)	0.47 (0.07)

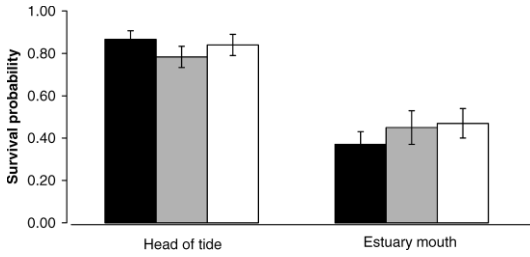


FIGURE 8.—Probability of survival ± SE (generated in SURPH; Lady et al. 2001) at the head-of-tide acoustic receiver array and estuary mouth receiver array in the Alsea River, Oregon, for steelhead smolts from the traditional brood (black bars), new brood (gray bars), and naturally reared (open bars) groups.

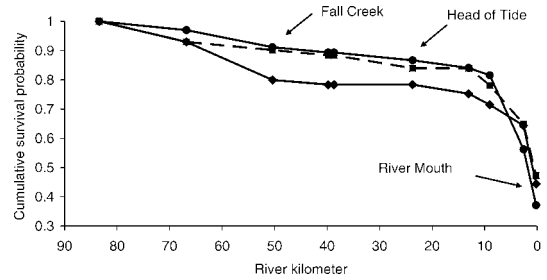


FIGURE 9.—Cumulative survival probabilities (generated in SURPH; Lady et al. 2001) for three steelhead release groups as fish moved downstream in the Alsea River and estuary, Oregon (solid line with circles = traditional brood group; solid line with diamonds = new brood group; dashed line with squares = naturally reared group).

groups of fish in the traditional brood group showed no difference in survival probability at the head of tide (90% for 170–199-mm smolts; 93% for smolts ≥ 200 mm; Figure 10).

In the naturally reared group, survival probability at the head of tide was 84% for the smaller (140–169-mm) tagged fish and 92% for 170–199-mm fish (Figure 10). However, the smaller fish tended to survive at a higher rate by the time the fish reached the Alsea Bay mouth (48% for 140–169-mm fish; 35% for 170–199-mm fish). Only two naturally reared fish in the largest size category (≥200 mm) were tagged, and both were detected at the head of tide and the Alsea Bay mouth.

Discussion

Neither the degree of hatchery domestication nor the juvenile rearing environment (hatchery raceway versus natural stream) appeared to influence the number of steelhead smolts that successfully migrated to the ocean. While smolts from the newly created broodstock did appear to have lower mortality in the estuary compared with smolts from the older domesticated broodstock, these gains were offset because fewer of the smolts from the new brood group successfully migrated down the river. Thus, in the end, the number of smolts entering the ocean was similar between the two hatchery-reared groups. Both groups of hatchery-reared smolts also survived at rates similar to those of naturally reared smolts, contrary to previous laboratory study results suggesting that hatchery-reared fish are more susceptible to predation than are naturally reared fish (Johnsson and Abrahams 1991; Olla et al. 1994; Berejikian 1995).

While most smolts from all three groups were detected at the head of the estuary, all three groups appeared to suffer high mortality in the lower estuary. Thus, estimates of survival to the ocean were only 37%

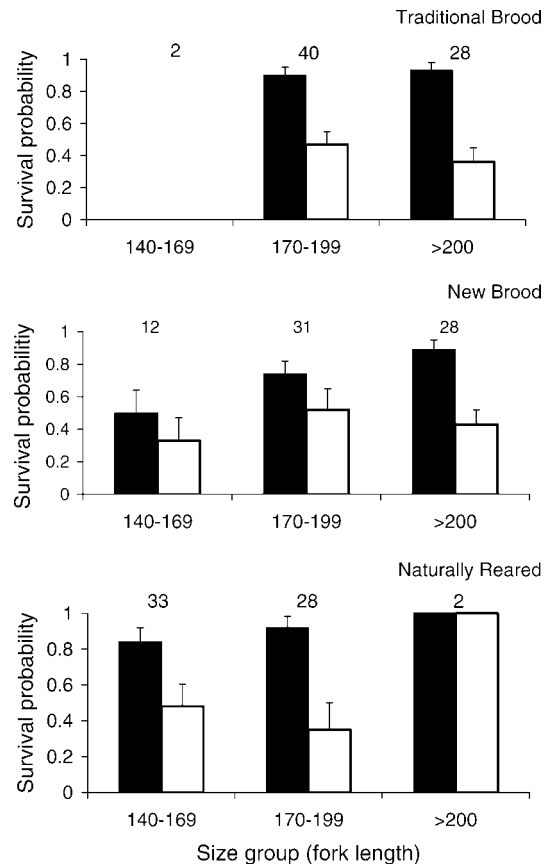


FIGURE 10.—Probability of survival + SE (generated in SURPH; Lady et al. 2001) at the head-of-tide acoustic receiver array (black bars) and the Alsea Bay mouth receiver array (open bars) for steelhead smolts in three fork length categories (140–169, 170–199, and ≥200 mm) and three rearing groups (traditional brood, new brood, and naturally reared groups). Numbers above bars represent the number of fish that were originally tagged in each size category.

for the traditional brood group, 45% for the new brood group, and 47% for the naturally reared group. Clements and Schreck (2003) reported much larger differences in survival between acoustically tagged wild and hatchery-reared steelhead smolts in the Nehalem River estuary, Oregon, where 71% of wild smolts survived compared with only 34% of the tagged hatchery-reared smolts. Chittenden et al. (2008) also reported higher survival for wild smolts of coho salmon *O. kisutch* compared with hatchery-reared smolts in the Campbell River estuary, British Columbia. Thorstad et al. (2006), however, did not observe differences in postrelease survival of wild and hatchery-reared smolts of Atlantic salmon *Salmo salar* in a Norwegian fjord system.

Melnychuk et al. (2007) also estimated survival of acoustic-tagged wild steelhead smolts from the Cheakamus River in British Columbia. Steelhead smolts in their study migrated a much shorter distance in freshwater (16.7 km compared with 61.2 km in our study) and then entered the open ocean through Howe Sound and the Strait of Georgia (approximately 400 km), but their estimates for steelhead smolt survival through freshwater (75% and 86%) and to the open ocean (27% and 27%) for the 2-year study were similar to our results. Both studies suggest that a large portion of the smolt-to-adult mortality occurs before the smolts reach their open-ocean feeding areas.

We made no attempt to quantify predation on steelhead smolts by the various predators in the river and estuary. We observed a major drop in detection rates in the lower 9 km of the estuary, suggesting that this was the primary area of mortality for all three groups. This corresponds to the portion of the estuary where the channel becomes unconstrained, wider, and shallower and is characterized by multiple channels at low tide.

Avian predation has been identified as a primary source of mortality for hatchery-reared smolts in the estuaries of the Columbia River (Collis et al. 2002; Roby et al. 2003) and in the Nehalem River (Clements and Schreck 2003). Avian predators, including cormorants *Phalacrocorax* spp., mergansers *Mergus* spp., great blue herons *Ardea herodias*, and terns *Sterna* spp., are found in the Alsea River and estuary. Mammalian predators include the North American river otter *Lontra canadensis*, which is found throughout the Alsea River and in the upper portions of tidewater. A breeding population of 500–750 adult harbor seals *Phoca vitulina* is located in lower Alsea Bay (Wright et al. 2007). Seals use several haul-out areas in the lower estuary but are commonly observed throughout the estuary. As smolts entered the estuary throughout the spring, mortality rates remained rela-

tively constant. Thus, there was no evidence to indicate that early migrants were more likely to slip through the estuary undetected by predators or that predators increased their feeding on the steelhead smolts over the month when most of the smolts were in the bay.

We may have underestimated smolt survival if the transmitters were expelled from the tagged fish during the out-migration. To minimize the possibility of tags shedding through the initial incision, we used three sutures to close the incision. However, tag loss of acoustic tags via extrusion through the body wall has been noted for various species of salmonids (Chisholm and Hubert 1985; Lacroix et al. 2004) and for steelhead in particular (Welch et al. 2007). Welch et al. (2007) reported that the expulsion of tags in steelhead smolts was related to body size. Smolts that were 130 mm or smaller shed 16–30% of implanted tags, while only 7% of 150-mm and larger smolts expelled their tags. In our study, all tagged smolts were 140 mm or larger and most exceeded 150 mm, so we assume that the tag loss was less than 10% based on fish size. In addition, Welch et al. (2007) reported that instances of tag extrusion occurred primarily 4–12 weeks after implantation. In our study, most smolts reached the mouth of the estuary in less than 3 weeks, well before tags would presumably have time to exit the fish via the body wall. Estimates of smolt survival would also be too low if smolts that were last detected at middle or upper estuary receivers residualized in the estuary for a time and eventually entered the ocean after the batteries in the transmitters had expired. We believe this is an unlikely scenario. Biologists from ODFW sample in the Alsea River estuary (and other coastal estuaries) each spring and summer to obtain juvenile salmonid catch-per-unit-effort data. Steelhead smolts are often captured in the spring (April and May) but are rarely captured in June, July, or August (B. Buckman, ODFW, personal communication). If any of the fish did residualize, they might be more likely to move out of tidewater and back into the freshwater of the lower river. However, we observed no fish returning upstream from the estuary to the head-of-tide receiver array.

While we acknowledge that a small amount of tag loss could have occurred and decreased the survival estimates, it is equally possible that our estimates of survival could be biased high because we defined a smolt as a survivor if it was last detected by the receiver array at the mouth of the estuary. Although we concluded that seven smolts last detected at the mouth of the estuary were mortalities because of abnormally long and consistent transmission histories, it is entirely possible that some other smolts were detected at this array and then immediately became prey for the seals

and avian predators that frequent the mouth of the estuary. If this occurred, then our estimates of survival to the mouth of the estuary are high.

We observed no significant difference in the diel movement patterns between the three release groups based on first contact events at the freshwater receivers. Smolts from all three groups, regardless of rearing history (hatchery versus stream), tended to move more after dark, particularly in the hours after sunset. We recognize that these observations are based on static receiver locations and that active tracking (e.g., using radio transmitters) is a more reliable method for determining diel changes in movement. Still, the large number of first contact observations (>300 per group) provides evidence that there was little difference in the diel movement patterns for the three release groups.

We observed no significant difference in the in-river migration rate between groups (number of days between detection at the North Fork Alsea River receiver array [rkm 84.7] and detection at the head-of-tide receiver array [rkm 23.7]). The mean rate of downstream movement through freshwater was 6.2, 5.3, and 5.7 km/d for the traditional brood, new brood, and naturally reared groups, respectively. Clements and Schreck (2003) reported somewhat slower in-river migration rates for naturally reared steelhead smolts (3.5 km/d) but similar rates for hatchery-reared smolts (6.3 km/d) released in the Nehalem River. Fish size (fork length) was correlated to the rate of migration through the river for all three rearing groups, although it accounted for little of the variation in migration rate for the traditional brood and naturally reared groups. The importance of fish size was more apparent in the new brood group, where fish smaller than 170 mm fork length took an average of 45.1 d to migrate through the river (1.3 km/d) compared with an average of only 13.4 d (9.0 km/d) for 170-mm and larger migrants. Because we also observed fewer in-river tag detections for the smaller smolts in the new brood group, we suspect that many of the new brood group smolts smaller than 170 mm did not migrate but instead took up residence in the upper river. Hulett et al. (2004) and Reisenbichler et al. (2004) reported a lack of downstream movement by small age-1 smolts that were progeny of wild parents. While some smaller smolts in the naturally reared group also showed slower movement through the river, other naturally reared smolts between 140 and 170 mm migrated to the head of tide in less than 10 d, similar to the 170-mm and larger naturally reared smolts (Figure 5). All of the small smolts in the naturally reared group were age 2, which may explain the observed difference in migration rates between these small smolts and the new brood group.

Wagner et al. (1963) noted similar results when

studying and developing the original Alsea River hatchery broodstock program and recommended that age-1 smolts be released at a minimum size of 160 mm to reduce residualism and improve smolt-to-adult survival. Results from our study reinforce those observations. While this size guideline is generally achievable in domesticated hatchery stocks, it is often difficult to accomplish in the hatchery-reared progeny of wild adult spawners because wild adults often spawn several months later than the domesticated stocks and because most wild brood programs specifically collect adults to encompass a wide range in spawn timing. Thus, hatching and rearing programs for juveniles from wild broodstocks typically start later than those for many domesticated broodstocks. In addition, juveniles that originate from wild adults often exhibit more variation in growth rates in hatchery raceways than their domesticated counterparts (Hulett et al. 2004; Reisenbichler et al. 2004). Sharpe et al. (2007) found that if additional facilities and resources are available, sorting juveniles by size and initiating different feeding regimes can alter growth rates and diminish some of these problems for wild brood programs; they do not, however, eliminate the problem. While some of the smaller hatchery-reared smolts may survive in the river and migrate as age-2 smolts the next spring, analysis of scales from returning adult hatchery steelhead in the Alsea River suggests that this is rare (Wagner et al. 1963; L. Borgerson, ODFW, personal communication). However, if large numbers of hatchery juveniles residualize and rear for a period of time in nearby streams, they will certainly compete with other naturally rearing juvenile salmonids for limited habitat and food. In the spring 2007 production release of steelhead smolts from the North Fork Alsea Hatchery, 15% of the new brood smolts (about 9,000 smolts) were smaller than 160 mm. Our results would indicate that about half of these fish never left the upper portion of the Alsea River. Comparatively, less than 0.5% of the traditional brood smolts were smaller than 160 mm at release.

The mean estuary residence time for successful estuary migrants was similar among all three groups and indicated that successful migrants were spending only about 30–40 h in the estuary prior to ocean entry. Smolts from the naturally reared group showed less variability in estuary residence time than hatchery-reared smolts, showed less of a tendency to move back into the middle or upper estuary once they reached the lower estuary, and moved through the estuary primarily during the day regardless of tidal direction. Moving downstream during a flooding tide would require additional energy as the smolts would be forced to swim against the current. However, once these fish

found themselves exposed in a shallow estuary with little cover to escape a substantial predator population, swimming against the current to leave the estuary may have been the best survival strategy. Smolts from both hatchery-reared groups showed a tendency to move back upstream in the estuary on flood tides, particularly at night. This contributed to a larger variation in estuary residence time for the two hatchery-reared groups. Clements and Schreck (2003) observed that wild steelhead smolts spent less than 1 d in the Nehalem River estuary, while hatchery-reared smolts spent up to 4 d in the estuary. However, in our study over 50% of the fish in both hatchery-reared groups and 30% of the naturally reared smolts showed complex movement patterns (i.e., were detected as moving back into the middle or upper estuary after being detected in the lower estuary), whereas Clements and Schreck (2003) reported only unidirectional movement of both wild and hatchery-reared smolts in the Nehalem River estuary.

The use of acoustic transmitters and receiver arrays allowed us to quantify the survival of steelhead smolts as they migrated downstream through the Alsea River and estuary. We recognize that the results from this study represent only 1 year and that changes in flow patterns, turbidity, and water temperature throughout the spring may affect both migration patterns and survival. Still, these results indicate that in this Oregon coastal river, freshwater and estuarine mortality may be as important as open-ocean mortality in determining steelhead smolt-to-adult survival, regardless of the history of broodstock domestication or juvenile rearing. This study also highlights the problem of increased residualism that is often associated with smolt releases of newly developed steelhead broodstocks. We would encourage the use of this technology to repeat this experiment in other coastal rivers or to answer other management questions relating to postrelease behavior and survival of steelhead smolts.

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