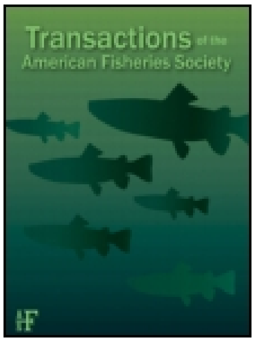

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Returns of Pen-Reared Steelhead from Riverine, Estuarine, and Marine Releases

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Abstract.—Hatchery-reared steelhead (anadromous rainbow trout *Oncorhynchus mykiss*) were released as smolts in 1982 and 1983 at four locations in and near the Keogh River on northern Vancouver Island, British Columbia, to determine the effect of release location on adult return rate. Smolts were released at four sites simultaneously: 10 km upstream from the river mouth (10-km site), 0.4 km upstream from the river mouth above a fish-counting fence (0.4-km site), in the tidal area below the fence (0.3 km upstream), and in the ocean about 1.6 km off the mouth of the river. Return rates were estimated by mark and recapture of adults and kelts at the counting fence 1–3 years later. Based on numbers released, the return rates of the 1982 groups were 7% for the 10-km site, 11% for the 0.4-km site, 10% for the tidal site, and 11% for the ocean site. The respective return rates of the 1983 groups were 3, 5, 7, and 5%. We suggest that failure to migrate, as well as predation, accounted for the lower return rates of fish released at the 10-km site because few of the nonmigrant fish released at this site were collected at the fence as smolts the next year. Smolts that were acclimatized to salt water at the river mouth and then released at the ocean site returned at a rate similar to that of fish released into the lower reach of the river (0.3- and 0.4-km sites). Release of cultured smolts into the lower reaches of small coastal rivers is therefore recommended to maximize adult survival and to minimize competition with wild steelhead.

Return of hatchery-reared salmonids to their approximate site of release has been well documented (Donaldson and Allen 1958; Wagner 1969; Jensen and Duncan 1971; Cramer 1981; Quinn and Fresh 1984). Norwegian researchers have reported substantially higher survivals and returns to the commercial marine fishery from open-sea releases of Atlantic salmon *Salmo salar*, but decreased homing to the natal river (Gunnerød et al. 1988). For steelhead (anadromous rainbow trout *Oncorhynchus mykiss*), it is unknown if smolts released in the open sea would survive at a higher rate than those released in the river and if this higher survival would result in more fish returning to the natal stream, where they would be available to the stream fishery. Similarly, it is unknown if smolts released at the mouth of a river return at a rate different from that of fish released farther upstream.

Success in steelhead culture is ultimately assessed by the number of adults returning to the natal river. To enhance survival, fish culturists have focused on meeting optimal temperature, flow, space, and feeding requirements, and on releasing smolts at optimal size and time (Hallock et al. 1961; Wagner et al. 1963; Wagner 1968; Hager and Noble 1976). A complication with introduction of hatchery smolts to a river is the failure of some to migrate due to inappropriate size (too small or too large) or precocious sexual development (Wagner et al. 1963; Slaney and Harrower 1981; Rempel et al. 1984). Failure of released fish to migrate can represent a cost to natural production when wild trout are displaced by competition with released fish (Vincent 1987) and a cost to fish culture because nonmigrants contribute little to the steelhead fishery (Hooton et al. 1987; Seelbach 1987). Release of fish near the river mouth could be expected to reduce the numbers of fish that fail to migrate. In addition, based on Wood's (1987a, 1987b) examination of predation on salmonid parr and smolts, releases lower in the river may reduce early predation on hatchery fish. Both factors should be reflected in the number of smolts entering the ocean and in subsequent survival to the adult stage. In 1981 and 1982, we reared steelhead smolts at a lake net-pen facility to test the migration success of smolts stocked in the river and the return rates of smolts introduced at four sites in or near the river of origin. We report the results of our work here.

Methods

Our study was conducted at the Keogh River, on the northeast coast of Vancouver Island (Figure 1). The river is 31 km long, drains an area of

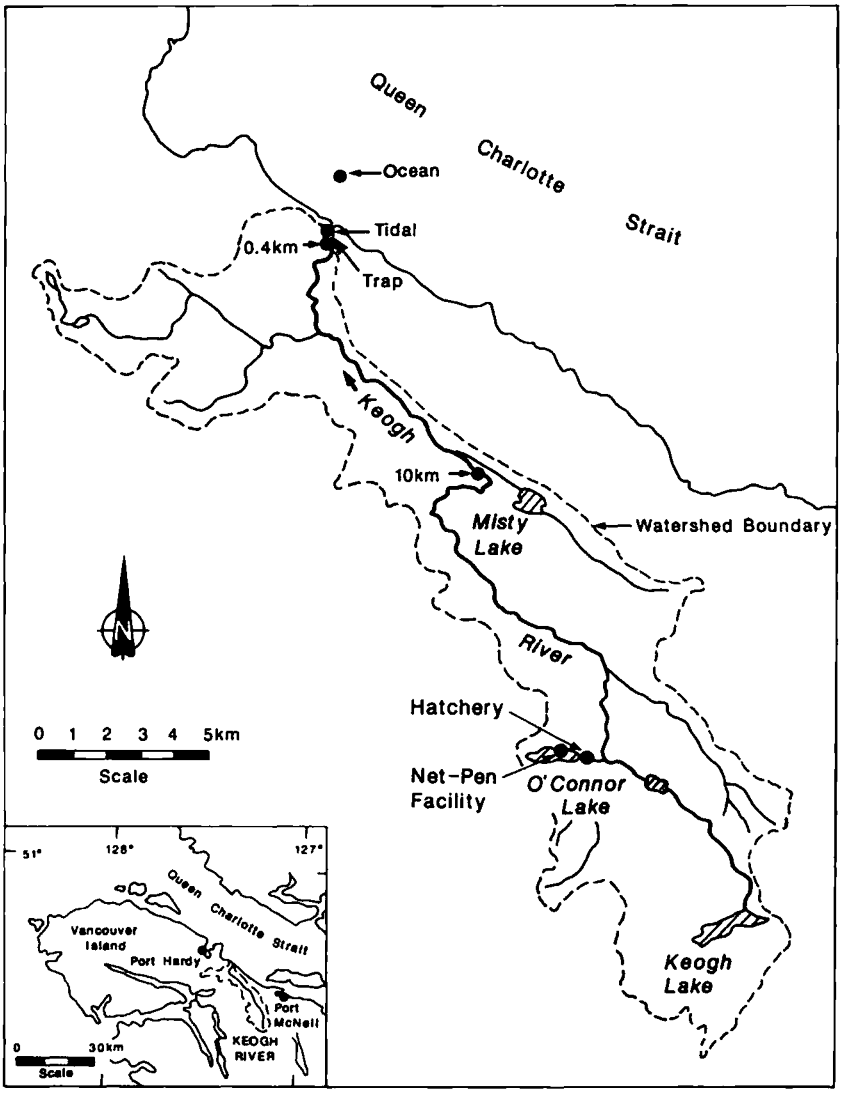

FIGURE 1.—The Keogh River watershed, showing the general location of the drainage basin (dashed line) on Vancouver Island, British Columbia, and the location of the O'Connor Lake net-pens and hatchery, the counting fence, and the smolt-release locations.

129 km^2, and includes four lakes and 19 tributaries (Ward and Slaney 1979). Ward and Slaney (1988) described the study area and fish enumeration facilities.

We collected wild brood stock from February to March 1981 and 1982 at a trapping facility located 0.3 km upstream from the river mouth (Figure 1). We incubated eggs and reared young steelhead at a small hatchery near O'Connor Lake (Figure 1). The fish were transferred to floating net-pens in O'Connor Lake during July, at a mean size of 1.3 g, and were reared in the net-pens until smoltification the following spring (Slaney and Harrower 1981). About 2 weeks before release, fish that weighed less than 15 g (about 10% of all fish) were removed from the experimental group, and the remaining smolts were arbitrarily assigned to four release groups.

We released smolts at the same four locations in 1981 and 1982 (Figure 1). One group was released 10 km upstream from the Keogh River mouth (10-km group). A second, "control," group (0.4-km group) was released 50 m above the fish fence to allow us to detect any effects of handling during smolt enumeration on return rate when we compared the first release group to the third and fourth groups. The third group (tidal group) was released directly below the fish fence in the tidal area, and a fourth group, the ocean group, was loaded into mesh-covered net-pens located 200 m above the river mouth in tidal water and held there for 4 d. The pens were then towed 1.6 km from the river mouth at night on a high tide, and the fish were dipnetted from the pens into salt water (local depth, about 28 m). Samples were taken from each group (N = 51–94), and fish were measured to obtain mean lengths and weights for each group.

We marked each fish with a fin clip before release. In 1982, the 10-km group was marked by a left pelvic fin clip, and the other three groups were marked with a right pelvic fin clip. In 1983, the 10-km group was identified with an adipose fin clip and a small caudal fin clip (upper lobe), whereas the other three groups were given an adipose fin clip only. A coded wire tag (Northwest Marine Technology, Inc.) was placed in the nasal cartilage of each fin-clipped fish, with the exception of those whose left pelvic fins were clipped, to identify groups by year and site of release (Table 1). A sample of fish from each group was tested for tag retention, which averaged 81% (range, 74–86%) for 1982 and 90% (range, 86–94%) for 1983. Smolts (N = 24,297 in 1982; 18,798 in 1983) were transported by tank truck to their assigned release sites on May 18–21, 1982, and May 10, 1983, to coincide with the timing of migration by wild smolts.

Hatchery smolts migrating through the fence were enumerated along with wild salmonids. We tested the ability of the trap to capture all migrants by mark and recapture of large coho salmon smolts *Oncorhynchus kisutch*. We estimated the efficiency of capture to be 90–100% (Ward and Slaney 1988; Irvine and Ward 1989) and adjusted the total number of migrating steelhead accordingly.

We obtained population estimates for adult steelhead by mark and recapture at the fish fence from 1983 to 1986 and determined return rates for each release treatment. Adults moving upstream were captured and given a small mark in the opercular plate; they were then released immediately upstream. Downstream-migrant kelts (spent adults) were inspected for marks to derive a Peterson population estimate stratified by sex (Ward and Slaney 1988; Ward et al. 1989). Previous studies indicated very little bias for age or size in the kelt migration (Ward and Slaney 1988). On average, 46% of the population was marked during the upstream migration. To decode the re-

TABLE 1.—Numbers of pen-reared steelhead smolts released, numbers trapped in a counting fence after release, and sizes at release for fish released at four sites in or near the Keogh River, British Columbia, in 1982 and 1983. Subsequent return rates are expressed as percentages of smolts released and percentages of smolts trapped. Ocean-age frequencies are percentages of fish at each age in the returns from each of the 1982 and 1983 releases. Values in parentheses are SDs.

	Number of smolts		Release measurements			Return rate (%)		Ocean-age frequency (%)	
Release site	Released	Trapped	Mean length (cm)	Mean weight (g)	N	Released	Trapped	2 years	3 years
				1982					
Ocean	6,376		17.1 (1.8)	59.1 (18.8)	64	10.5		91.8	8.2
Tidal	6,361		17.2 (1.6)	58.2 (14.4)	62	9.8		88.9	11.1
0.4 km from river mouth	5,243	5,243	17.9 (2.0)	65.3 (20.5)	51	11.4	11.4	90.8	9.2
10 km from river mouth	6,317	3,664	17.5 (1.4)	62.2 (15.7)	57	7.0	12.1	89.7	10.3
				1983					
Ocean	4,698		17.3 (2.2)	62.2 (17.6)	94	5.3		27.9	72.1
Tidal	4,700		17.4 (1.8)	60.3 (17.2)	84	7.0		29.7	70.3
0.4 km from river mouth	4,700	2,873	17.5 (1.8)	60.4 (17.9)	76	5.0	8.2	18.5	81.6
10 km from river mouth	4,700	2,695	17.3 (1.8)	61.3 (18.9)	81	3.2	5.6	30.7	69.3

lease location of fish with adipose or right pelvic fin clips, we removed their coded wire tags. Adults were sampled systematically at the fence during their ascent (e.g., every second or third fish, depending on expected returns, to obtain about 200 coded-wire-tagged heads from each fin-clipped group), and kelts were similarly sampled during their descent of the river.

Sample sizes obtained from returns of the 1982 and 1983 smolts were 310 adults with right pelvic fin clips, 207 adults with adipose fin clips, 178 kelts with right pelvic fin clips, and 217 kelts with adipose fin clips. These samples were used to estimate the proportions of returns belonging to the eight release groups. The numbers for each tagged group were adjusted for small differences in tag retention determined before release. The number of adults sampled for decoding coded wire tags was added to the Peterson population estimate. Fork lengths and sexes of marked upstream migrants and downstream-migrant kelts were recorded, and scale samples were taken for age analysis (Ward and Slaney 1988; Ward et al. 1989).

We based our estimate of return rate on the number of smolts released within a year from a given release site and the estimated total adult returns for that group, summed over the three years of returns. Where the release site was above the fish fence, we calculated one return rate based on estimated numbers of smolts moving through the fence and another based on the numbers released. We used chi-square analysis for comparison of return rates among sites; the level of significance was set at $P < 0.05$ (Sokal and Rohlf 1981). Observed adult returns were compared with expected values on the assumption of equal survival among released groups. For those fish enumerated during passage through the fish fence, we assumed equal survival after their release downstream from the fish fence.

The chi-square analysis was based on estimates, not counts, of returns within each release group and therefore must be interpreted with caution. However, an analysis based solely on the number of coded wire tags recovered could lead to misinterpretation because it would otherwise be difficult to correct for several sources of error, including differences in representation of tags in the sample relative to the population size and differences in tag retention. Furthermore, a comparison between tagged and untagged groups was possible only by comparing the population estimates. Ages and sex ratios were also compared between the two release years. Differences in lengths and weights of release groups were tested by analysis of variance (level of significance $P < 0.05$) with SPSS software (Nie 1983).

Results

Stream flow and temperature conditions differed between the two release years. Mean flows during May 1982 and 1983 were 2.3 and 0.6 m^3/s, respectively. Stream temperatures in May averaged 10.0°C in 1982 and 11.9°C in 1983. Therefore, the stream was, on average, higher and colder in May 1982 than in May 1983.

Smolts were released in four similar-sized groups at the four release locations. Mean lengths and weights were similar between years: 17.4 cm and 61.0 g in 1982 and 17.4 cm and 61.1 g in 1983 (Table 1). Mean sizes of smolts within years were not significantly different for all release groups, and size-frequency distributions were similar, with a slight skewness to the right (data on file).

On average, the estimated return rate of smolts released in 1982 (9.6%) was almost twice that of the 1983 release (5.1%). Return rates from the four release locations were significantly different within smolt years (Table 1). The 1982 smolts released at the 10-km site returned at a significantly lower rate (7%) than those released at the ocean (10%), tidal (10%), and 0.4-km (11%) sites. There were no statistically significant differences between the expected and the observed return rates of fish released at the 0.4-km, tidal, or ocean sites. In 1983, the smolt group released at the 10-km site again had a significantly lower return rate (3%) than those of the other groups. However, there was a significantly higher return rate (7%) of fish released at the tidal site for 1983 smolts than of those released at the ocean (5%), 0.4-km (5%), and 10-km (3%) sites. Potential mortality effects of smolt handling at the fence were not statistically significant, although an effect in 1983 is suggested in that there was a 5% return from the release above the fence and a 7% return from the release below the fence.

In both release years there were large differences between numbers released above the fish fence and numbers enumerated at the fence as smolts (Table 1). Only 58% of the fish released at the 10-km site in 1982 and 1983 migrated through the fence. In contrast, all smolts released directly upstream from the fence (0.4-km site) passed through the fence in 1982; in 1983, however, only 61% of the fish released from that site passed through the fence. Fish released at the 10-km site that were presumed to have failed to migrate were rare as smolts the following year: 2.5% of the 1982 nonmigrants were enumerated in 1983, and none of the 1983 nonmigrants appeared as smolts in the 1984 enumeration.

A comparison of return rates based on the number of smolts enumerated through the fence versus numbers released above the fence (0.4- and 10-km sites) revealed that the rates were, on average, 53% higher when based on fence counts (Table 1). For 1982 smolts, the return rate at the 10-km site was greatest (12%) and was significantly greater than the returns of fish released at the tidal and ocean sites (each about 10%). However, for 1983 smolts enumerated through the fence, those released at the 0.4-km site had a higher return rate (8%) than those released at the 10-km site (6%).

The predominant age at return of the 1982 and 1983 smolts differed significantly between years (Table 1). On average, 90% (range, 89–92% for the four release groups) of the returning 1982 smolts came back after 2 years in the ocean, whereas 73% of the returning 1983 smolts came back after 3 years in the ocean (range, 69–82%). For all release years and locations, most males spent 2 years in the ocean, whereas most females returned after 3 years. Fish returning after 1 yr in the ocean were rare (less than 1% of the 1982 release, and none from 1983) and all were males. A high proportion (82–87%) of the repeat spawners consisted of females.

Discussion

Our study of steelhead smolts reared in net-pens and released at different test sites demonstrated the importance of release location on the rate of adult returns to a small river. The lowest return rate was from the release site 10 km upstream from the mouth. For the 1982 release, a much higher proportion of smolts from the 10-km group were unaccounted for at the trap site than those from the 0.4-km group. However, in 1983, the proportions of smolts in the 10-km and 0.4-km groups counted through the fence were similar (58 and 61%, respectively), possibly due to the earlier release date. Subsequent survival to the adult stage followed a similar pattern between years as would be expected based on the number of smolts counted as they passed through the fence. There was no improvement in return rates to the river by smolts released at the ocean site versus those released at the lower-river sites.

Different results may be obtained when returns are based on angler catch or when smolt releases are made in larger streams with higher flow rates. Although results were variable, stocking of steelhead smolts in the lower reaches of the Alsea and Wilson rivers, Oregon, provided increased catch rates by anglers (Wagner 1969). Our results are in general agreement with those of Wagner (1969), but we based our findings on adult return estimates derived from recoveries at a counting fence, not on catch statistics, which could be more biased. Additionally, the Keogh River has a much lower mean flow than either the Alsea or the Wilson River. Systems with a high-flow regime, in which smolt passage may be more passively assisted, may not demonstrate the response we observed.

Differences in return rates between 1982 and 1983 releases may have been related to the 10-d difference in release dates between years. Peak migration of wild steelhead smolts occurred on May 25, 1982, and May 29, 1983 (Ward and Slaney 1988; author's unpublished data). Therefore, releases in 1982 coincided with the peak in migration of wild fish. Fish released several days before this date in 1983 would have been exposed to predation for a longer period and, in the case of the estuarine or marine release site, may have been affected by incomplete smolting (i.e., the fish were less prepared physiologically for life in salt water; Farmer et al. 1978). All fish released at the 0.4-km site in 1982 were accounted for, whereas only 61% of the 0.4-km group passed downstream in 1983, perhaps due to a reduced readiness to migrate. Wagner (1968) found that Alsea River steelhead released as smolts in April survived better than those released at a slightly larger size in February or March. Parkinson and Slaney (1975) noted that such studies may be confounded by size and time interactions, and definitive data are not available. The patterns of time and size of smolts passing through the counting fence were different for the 10-km and 0.4-km groups in 1982, whereas similar patterns of time and size were apparent for these two groups in 1983 (data on file). Such patterns may affect the subsequent survival of salmonids (Irvine and Ward 1989).

Predation may account for the difference between the number of smolts released upstream and the number subsequently counted through the fence. Keogh River predators could include mustelids, several predaceous birds (particularly common mergansers *Mergus merganser* with broods; Wood 1987b), and anglers. Larsson (1985), for example, reported that at least 50% of the initial number of wild Atlantic salmon smolts released upstream failed to reach salt water in the Baltic

Sea, and he estimated mortality due to predation on hatchery smolts at about 26%. We are unsure if predation in the Keogh River is that high, but Slaney and Harrower (1981) found a large difference between the number of fish that failed to migrate from the Keogh River and the number that remained instream in 1981, indicating either high mortality of these fish or migration out of the 4-km reach that was sampled.

Many hatchery fish that fail to migrate (predominantly males) become resident in the stocked stream (Slaney and Harrower 1981; Rempel et al. 1984). Hatchery steelhead stocked as yearling smolts probably displace wild fish because the former are about four times larger than wild steelhead parr (Slaney and Harrower 1981). Therefore, hatchery fish that failed to migrate in our study probably competed with wild fish. In two Montana rivers where catchable hatchery rainbow trout were repeatedly introduced among wild rainbow trout, the latter were reduced in abundance (Vincent 1987). We found that few of the fish that remained in the stream migrated as smolts the following spring, and the fate of the nonmigrants is unknown. The apparent low survival may be common for hatchery steelhead (Wagner et al. 1963; Hooton et al. 1987; Seelbach 1987).

Our release groups did not differ in size at release, but in both years fish in the 10-km group averaged 10 mm longer at the counting fence than at release (unpublished data). Similarly, fish in the 0.4-km group were 8 mm longer when trapped than at release in 1983, although there was no such difference in 1982. These findings generally agree with earlier studies in which fish that failed to migrate were 10 g lower in mean weight than were migrants (Slaney and Harrower 1981). This size difference may explain the difference in return rates of the 10-km and 0.4-km groups when estimates based on smolts counted through the fence were compared with those based on numbers released. Size strongly affects the survival of wild steelhead smolts (Ward et al. 1989). Accordingly, differences in return rates were probably also influenced by the pattern of time and fish size in the outmigration, which was indirectly the consequence of stocking location and size-biased failure to migrate.

Higher return rates (compared with those for the 10-km site) were observed from releases at the tidal site located directly below the fence and 0.3 km from the river mouth. The effects of predation in fresh water should have been reduced at this site near the river mouth compared with those at the 10-km site, from which smolts passed a possible gauntlet of predators to reach the river mouth (Larsson 1985). However, when compared with the marine group, the estuarine group would be expected to have additional nearshore mortality (Hvidsten and Møkkelgjerd 1987; Wood 1987a). If there were additional mortality, we could not detect it because we could not separate the effects of predation rate from straying rate. The marine group was held for several days in pens in the tidal area, so we assumed that these smolts were well imprinted on Keogh River water. Consequently, we expected high returns from this group, which was unexposed to riverine or estuarine predation. Instead, return rates of the 0.3-km (tidal), 0.4-km, and ocean release groups were similar for 1982 fish, and the return rate of the ocean group was lower than that of the tidal group for 1983 releases. However, this comparison in 1983 was probably confounded by the differing release dates between years. The 0.4-km group may have been delayed by the counting fence and relatively lower river flow, which may have subsequently affected their survival.

Fish released in the marine habitat may have had a greater propensity to stray to other rivers. Some evidence of adults straying to the Cluxewe River, 20 km east of the Keogh River, was obtained from annual angler questionnaires (e.g., Billings 1987), but the rate appeared to be no greater than in years when smolts were released 2 km upstream from the mouth of the Keogh River. Sample sizes were insufficient to test this statistically.

Different oceanographic conditions might explain differences in overall survival and age at return between years (1982 and 1983) in our study. Average survival of hatchery smolts was about one-third that of wild Keogh River smolts within years. We estimated that survival rates for 1982 and 1983 wild smolts were 26 and 15%, respectively (Ward and Slaney 1988). The higher survival of the 1982 pen-reared smolts corresponded with the higher survival of wild smolts in the same year, suggesting that oceanographic conditions were favorable for both wild and hatchery smolts during 1982–1983 (Mysak 1986; Ward and Slaney 1988; Ward et al. 1989; Ward and Wightman 1989). Thus, the year-to-year variation in survival was probably more related to marine conditions than to stocking location. Although there was a large difference in the age at return between years, there were no within-year differences of age at return among the various release groups. The returning hatchery adults were similar to wild steelhead in the pattern of age at return. Most wild and hatchery fish spent 2 years in the ocean after migrating as smolts in 1982, and 3 years in the ocean after migrating as smolts in 1983 (Ward and Slaney 1988). Ocean conditions appeared to have affected the ages at maturity of wild and hatchery fish similarly each year (Scarnecchia 1984; Martin and Mitchell 1985; Ward et al. 1989).

In summary, stocking location within and near the mouth of the river of origin can affect the returns of hatchery steelhead, at least in smaller rivers. A lower return rate of adults from smolts released in an upstream reach compared with the return rate of fish released in a downstream reach of the Keogh River was an important result of our experiment. Also, release of smolts in the lower reach minimized competitive interactions between nonmigrant hatchery smolts and wild steelhead parr (Slaney and Harrower 1981). Our results provide further evidence that hatchery smolts failing to migrate contribute marginally to the smolt migration in the next year. Furthermore, we could detect no increment in adult return rate from a release at an ocean site, where it was assumed that predation would be reduced. However, releases farther from the coast should also be examined over several years. Steelhead stocking strategies should take into account the effects of release location, as well as effects of smolts size, time of release, and the historical location of the sport fishery.

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