

## Comparisons of Run Timing, Spatial Distribution, and Length of Wild and Newly Established Hatchery Populations of Steelhead in Forks Creek, Washington

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**Abstract.**—In Washington State, the approach to management of wild and hatchery steelhead trout *Oncorhynchus mykiss* has been to separate the timing of return and spawning by the two groups through selective breeding for early timing in hatchery fish. However, overlap in timing and spatial distribution could permit genetic and ecological interactions. To evaluate this management approach, we compared the timing, spatial distribution, and size of adult steelhead in the wild and newly established hatchery populations of Forks Creek, Washington. Hatchery fish tended to return and spawn about 3 months before wild fish but there was some temporal overlap. Radio-tracking indicated that the spatial distributions of the populations overlapped considerably, permitting interbreeding and ecological interactions. However, the hatchery fish tended to stay closer to the hatchery, consistent with olfactory imprinting on the hatchery's water supply. Wild females were larger than hatchery females (median fork lengths were 670 and 644 mm, respectively), and wild males and females varied more in length than did hatchery fish of the same sex. In the first year in which naturally spawned offspring of hatchery fish might have returned, we observed a marked increase in early-returning unmarked (i.e., naturally spawned) adults, suggesting that some hatchery fish spawned successfully in the creek.

Wild salmonid populations are largely isolated from one another by the homing of adults to their natal streams to reproduce (Quinn 1993). Local adaptations evolve through differential reproductive success, a function of an individual's ability to survive to maturity and produce viable offspring. Survival and reproduction are influenced by numerous traits, many of which are directly or indirectly related to body size and the timing of spawning (e.g., Hendry et al. 1999). The timing of migration seems to reflect natural selection imposed by conditions affecting passage and survival of adults (e.g., temperature and river discharge; Quinn and Adams 1996). The timing of reproduction is primarily determined by conditions affecting incubation and growth of juveniles, such as temperature (Brannon 1987; Webb and McLay 1996) and gravel movement (Montgomery et al. 1999). Large body size confers competitive advantages to males and females on the spawning grounds (Fleming and Gross 1994; Quinn and Foote 1994). In females, large size is also positively correlated with fecundity and egg size (Beacham and Murray 1993) and with egg burial depth

(Steen and Quinn 1999). All these traits are likely to affect the number of surviving offspring.

Salmonids have been produced in hatcheries for more than a century, but recently concerns have been voiced in North America (Waples 1991; National Research Council 1996; Utter 1998) and Europe (Ryman 1991) that such propagation may have had deleterious genetic or ecological effects on wild populations. The regimes of natural and sexual selection in hatcheries differ greatly from those in rivers; consequently, hatchery salmonids may differ from their wild counterparts at juvenile (Reisenbichler and McIntyre 1977; Berejikian 1995; Berejikian et al. 1996) and adult stages (Fleming et al. 1996). Experiences with Atlantic salmon *Salmo salar* indicate that wild populations can be influenced or even displaced by fish produced in hatcheries or escaped from farms (e.g., Crozier 1993; McGinnity et al. 1997; Sægrov et al. 1997). Chilcote et al. (1986) and Leider et al. (1990) found that naturally spawning hatchery steelhead *Oncorhynchus mykiss* (originating from outside the basin) had substantially less reproductive success than wild fish did but were nevertheless numerically dominant.

Hatcheries producing the semelparous species of Pacific salmon have seldom segregated wild and hatchery populations. Fish produced in the hatchery might spawn in the river, and naturally spawned fish might be used in the hatchery for the

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next generation. In Washington State, steelhead have been managed differently (Crawford 1979): Hatchery stocks are selected for early spawning date, produced in a few locations, and transplanted outside their native basins. Initially, early timing was selected to allow hatcheries to raise steelhead from egg to smolt in 1 year instead of the 2 years typical of local wild populations (Ayerst 1977). Later, this timing pattern was implemented as a management tool to facilitate different fishing rates and to minimize interbreeding between hatchery and wild fish through temporal separation (Leider et al. 1984).

The effectiveness of temporal segregation for managing wild and hatchery steelhead is unclear because many genetic and ecological processes, depending on the temporal and spatial distributions of spawning adults, are not fully known. Early spawning hatchery fish could expose their offspring to unfavorably low temperatures and high flows during incubation in coastal streams or to predation after they emerge. On the other hand, if the progeny of early spawning hatchery fish survive to emerge, then they may secure territories and grow before their wild counterparts emerge; both size and territorial possession would confer advantages to the hatchery fish (Abbott et al. 1985; Chandler and Bjornn 1988; Rhodes and Quinn 1998; Einum and Fleming 2000). Hatchery fish might also interbreed with wild fish if the runs overlap in space as well as time. Such spatial overlap would depend on the specificity of homing to the hatchery and to natal sites in the stream system (Quinn 1993). Finally, hatchery and wild adults may differ in body size, which affects competitive ability, redd depth, fecundity, and egg size.

As the beginning of a long-term study of steelhead in this system, we initiated the present study when the first marked population of hatchery steelhead returned to Forks Creek, a river containing a wild population. We present data on wild and hatchery-origin adults from the first 5 years of these two groups' return, to assess the prospects for genetic and ecological interactions. Using a combination of trapping and radio-tracking, we tested the null hypotheses that the wild and hatchery populations were similar in timing of migration and spawning, spatial distribution, and body size. We also estimated the emergence timing of wild and hatchery-origin fry in the river to help assess possible ecological interactions.

### Methods

Forks Creek Hatchery, operated by the Washington Department of Fish and Wildlife (WDFW),

is located about 200 m upstream of the confluence with the Willapa River in southwestern Washington (Figure 1). Hatchery steelhead had been stocked elsewhere in the basin already but were first introduced to Forks Creek in spring 1994, when 25,000 smolts (as estimated by weight) were brought from the Bogachiel River Hatchery. This hatchery began producing steelhead in 1967 with a combination of native fish and steelhead from the Chambers Creek Hatchery in Puget Sound; currently, it uses returnees for hatchery propagation. The Chambers Creek Hatchery steelhead stock originated in 1921 (Crawford 1979). By the 1940s the hatchery was spawning early-returning adults and propagating 1-year-old smolts (unlike the wild fish, which are predominately 2 years old). Smolts were transferred to (and sometimes back from) hatcheries and streams in Washington, resulting in a generalized hatchery stock that returns and spawns in early winter.

The smolts released in 1994 at Forks Creek were marked by removal of the adipose fin, as were the releases in the following years. In winter 1995 through spring 1996, 217 marked adults, and many unmarked wild adults, were trapped at the hatchery's weir and a smolt fence located at the hatchery. High water and logistical constraints prevented us from sampling as efficiently in March and early April as in the other months in this and subsequent years. Although neither the weir nor smolt trap was completely effective, catches at a given time were assumed to be unbiased with respect to origin.

In the first 2 years when hatchery fish returned (1995–1996 and 1996–1997), 354 adults were allowed upriver and 116 were spawned at the hatchery. In subsequent years, hatchery fish were not deliberately released upriver but some may have circumvented the trap during periods of high water. We report data collected over the first four seasons (1995–1996 through 1998–1999) separately from those for the 1999–2000 season because in the latter season the unmarked (i.e., wild) fish might include naturally produced fish of hatchery origin,—which could have spent 2 years in the creek before leaving as smolts and another 2 years at sea (Busby et al. 1996; Mackey 1999).

Wild and hatchery-origin fish were counted and measured (fork length) on the day they were passed over the weir or smolt fence or on the date of spawning at the hatchery (performed once a week). The spawning date at the hatchery was presumably close to the date on which they would have spawned in the river. Some wild fish were

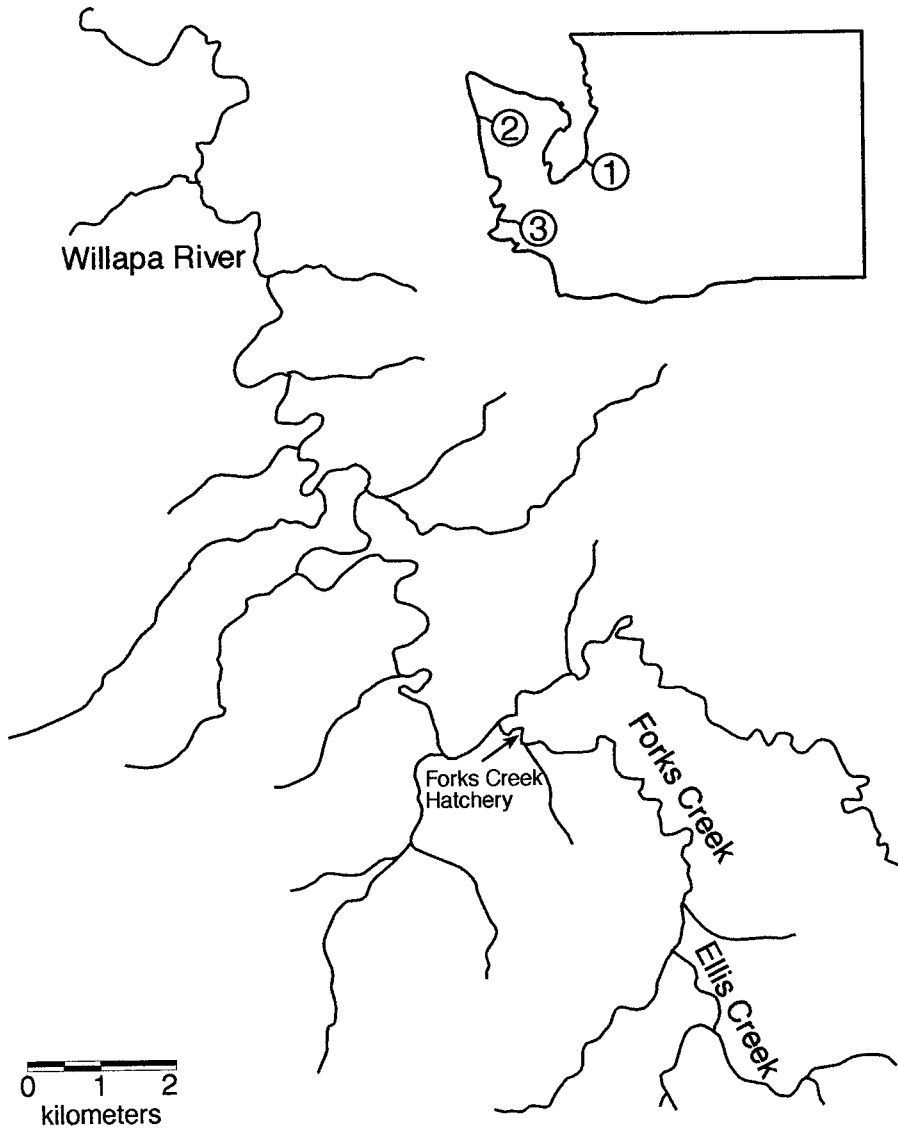


FIGURE 1.—Map of Washington State showing the location of (1) the Chambers Creek Hatchery, (2) the Bogachiel River Hatchery, and (3) the Willapa River, including Forks Creek, and its hatchery. A star indicates the location of the hatchery's water intake structure.

trapped going upstream, before they would have spawned, and some on the way down, after they would have spawned. The error introduced by this was probably slight because the median duration in the stream for radio-tracked wild fish was only 7.5 d (see Results). To be conservative, we conducted statistical analyses on monthly totals rather than the specific dates of capture. Additional information on the timing of spawning by wild steelhead was provided by redd surveys conducted by the WDFW (Richard Brix, WDFW, Montesano,

unpublished data) in March through May 1993 and the same months in 1995–1999. To estimate the potential for interactions between wild and hatchery-origin juveniles in the river, we estimated time to maximum alevin wet weight (when juveniles would be expected to emerge from the gravel and begin exogenous feeding), using the Salmonid Incubation and Rearing Program (Jensen et al. 1992) based on water temperatures recorded at the hatchery.

We estimated the potential for spatial overlap

TABLE 1.—Numbers of wild and hatchery-produced steelhead trapped at Forks Creek, Washington from the 1995–1996 to 1998–1999 seasons and the 1999–2000 season. For summary purposes, winter includes November through March and spring includes April through July.

Month	1995–1996 to 1998–1999		1999–2000	
	Hatchery	Wild	Hatchery	Wild
Nov	15	2	0	0
Dec	125	7	0	0
Jan	472	2	108	54
Feb	67	2	3	0
Mar	8	0	0	0
Apr	2	23	2	8
May	6	92	0	16
Jun	0	18	1	24
Jul	0	1	0	1

between populations in the river by tracking hatchery and wild steelhead with stomach-implanted radio transmitters during the 1995–1996 and 1996–1997 seasons. The fish were captured at the weir or smolt fence, anesthetized, and measured, after which the transmitter was inserted, and each fish was released as soon as it had recovered. An automatic data logger and receiver were mounted to detect fish moving past the hatchery. We also scanned the Forks Creek watershed and the Willapa River for radio-tagged fish at least twice a week with a mobile receiver by driving and walking along the river. Positions of the fish were recorded with a GPS unit, and coordinates were plotted and river distances estimated in ArcView (3.0).

Data from a U.S. Geological Survey flow gauge on the Willapa River were used to estimate flow in Forks Creek. From 1953 to 1970 gauges were used on Forks Creek and (one still operating) on the Willapa River. Using the data obtained by those gauges, we developed a relationship to estimate flow in Forks Creek during this study ( $r^2 = 0.92$ ). Water temperature was recorded by a Hobo (Onset Corporation) data logger or daily maximum–minimum thermometer readings at Forks Creek Hatchery from the 1995–1996 through 1997–1998 seasons.

### Results

From the 1995–1996 through 1998–1999 seasons, the return and spawning of hatchery fish was

much earlier than that of the wild fish ( $\chi^2 = 704.63$ ; 7 df;  $P << 0.001$ , based on monthly totals). The modal month for spawning in the hatchery was January, whereas most wild fish were trapped in May (Table 1). However, some wild fish arrived during the hatchery run, and a few hatchery fish (mostly males) arrived during the wild run. The timing patterns were consistently different each year: Median capture dates for hatchery fish were January 15, 24, 20, and 4 in the 1995–1996 through 1998–1999 seasons, respectively, compared with May 11, 20, 2, and June 2 for the wild fish. Redd counts indicated that fish spawned in Forks Creek from March through May with a peak in April (Table 2)—somewhat earlier than indicated by the fence counts but still much later than the hatchery fish.

The hatchery fish spawned during the period of greatest river discharge and coldest temperatures. Most wild fish entered in late winter and spring, when the river's mean discharge was declining and temperatures were rising (Figure 2). The estimated temporal distributions of emergence of hatchery and wild progeny were widely separated. Steelhead spawning on January 15 (the median date for hatchery fish) would produce progeny emerging about 97 d later, on April 21. Progeny of adults spawning on April 15 (typical of wild fish, based on the redd counts) would require about 63 d to develop and would emerge on June 16 (Figure 2). The data from the trap indicated an even later timing for wild fish (median = May 13); the progeny of fish spawning on that date would emerge 55 d later, on July 6.

The 4 years of data before naturally produced steelhead of hatchery origin could have returned showed a clear pattern of return in winter (99% of the 695 fish were spawned or put upriver from November to March), whereas 91% of the wild fish were trapped in spring (April to July). In the 1999–2000 season, the distribution of hatchery fish did not differ from that in previous years (97% in winter;  $n = 114$ ;  $\chi^2 = 1.60$ ; 1 df;  $P > 0.20$ ). However, the unclipped (naturally spawned) fish differed markedly from the pattern for the first 4 years: Only 48% were trapped in spring ( $n = 103$ ;  $\chi^2 = 58.64$ ; 1 df;  $P << 0.001$ ). Fifty-four un-

TABLE 2.—Counts of new steelhead redds in an index reach of Forks Creek summed over the 1993 and 1995–1999 seasons (Washington Department of Fish and Wildlife, unpublished data).

	Early March	Late March	Early April	Late April	Early May	Late May	Total
Redd count	9	52	77	81	18	12	249

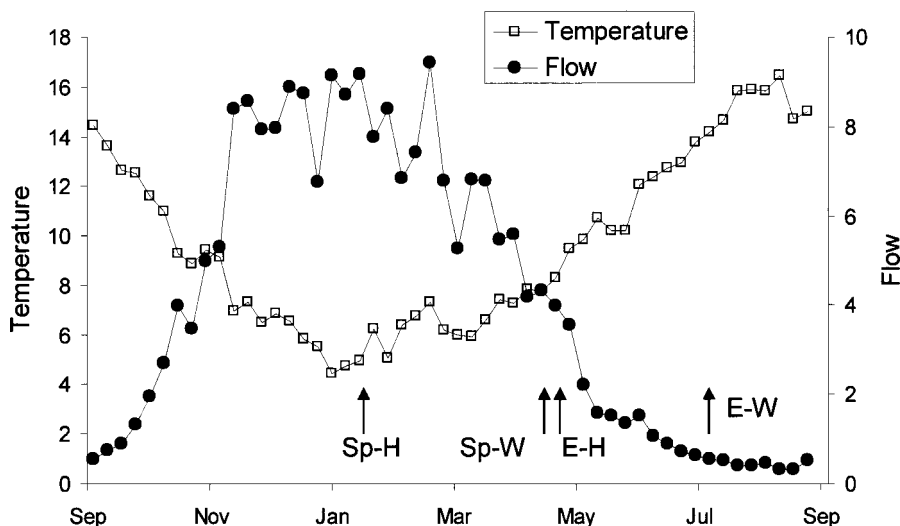


FIGURE 2.—Mean flow ( $\text{m}^3/\text{s}$ ) and temperature ( $^{\circ}\text{C}$ ) in Forks Creek (1995–1998) and the dates of typical spawning by hatchery (Sp-H) and wild (Sp-W) steelhead. Using those spawning dates (January 15 and April 15, respectively), we estimated the dates of emergence by juvenile hatchery and wild fish (E-H and E-W, respectively) based on the observed thermal regime.

clipped fish were sampled at the hatchery in January 2000, more than four times the total from the previous four winters combined (Table 1).

The movements of individual radio-tracked steelhead varied considerably, and the spatial distributions of wild fish and hatchery fish overlapped. However, the wild fish moved farther upstream (median = 3.77 km; 25–75% of the records were between 1.42 and 7.07 km) than hatchery fish (median = 0.59 km, 25–75% range = 0.24–1.47 km; Mann–Whitney rank-sum test on combined data:  $T = 322.0$ ;  $P = 0.004$ ). We also examined the proportions of fish that moved beyond the hatchery's water intake diversion structure (1.8 km upstream from the hatchery) because the wild fish might have imprinted on water from farther upstream (including tributaries of Forks Creek), whereas hatchery fish would have experienced only this source. Only 7 of 33 hatchery fish but 6 of 10 wild fish went above the diversion structure ( $\chi^2 = 5.48$ , 1 df;  $P < 0.02$ ). Despite the shorter distance, hatchery fish took more days to reach their maximum upriver distance (median = 11 vs. 5 d for wild fish, with 25–75% of the records showing between 5 and 16 d for hatchery fish versus 3–7 d for wild fish;  $T = 142.5$ ;  $P = 0.027$ ) and spent longer in the stream (median = 15 versus 7.5 d, 25–75% range = 9–26 versus 5–14 d for hatchery fish versus wild fish;  $T = 149.5$ ;  $P = 0.044$ ).

We compared lengths of steelhead, pooled over

the 4 years, by sex and origin. Wild males and females varied more in length than did hatchery fish of the same sex (males:  $F = 3.02$ ;  $P < 0.001$ ; females:  $F = 1.52$ ;  $P = 0.015$ ). The Mann–Whitney rank-sum test (used because the data were not normally distributed) indicated that wild females were larger than hatchery females ( $P < 0.001$ ). This difference arose from a greater number of larger fish (Figure 3). The wild and hatchery males did not differ in median length ( $P = 0.92$ ), but the wild fish included greater proportions of small (<500 mm) and large (>800 mm) fish than did the hatchery males (Figure 3).

### Discussion

As predicted, the wild and hatchery fish returned at distinctly different times to Forks Creek, indicating strong genetic control over this trait, consistent with other work with this species (Ayerst 1977; Leider et al. 1984; Siitonen and Gall 1989) and other salmonids (Hansen and Jonsson 1991; Smoker et al. 1998; Quinn et al. 2000). However, a few wild fish returned early enough to have been spawned in the hatchery (had they not been distinguished by the presence of an adipose fin), and some hatchery fish returned late enough to spawn with wild fish. The redd counts indicated somewhat earlier spawning by wild fish than did the trap data, a disparity that might have resulted from counting some redds made by hatchery fish or from reduced trapping efficiency during high water pe-

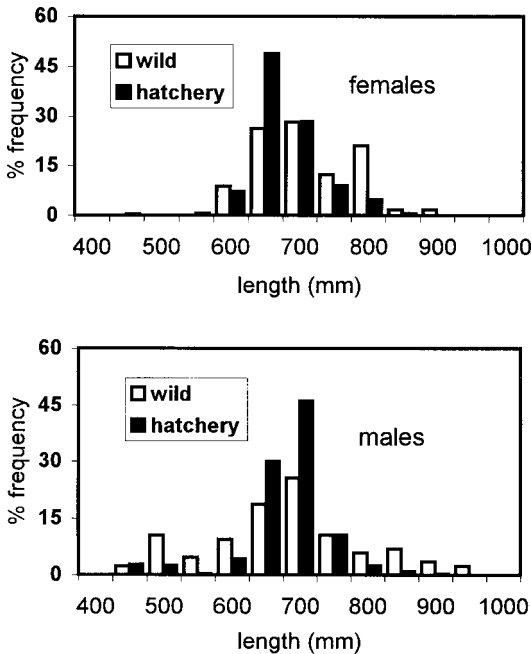


FIGURE 3.—Frequency distribution of the lengths of wild and hatchery-origin male and female adult steelhead trapped in Forks Creek, 1995–1996 through 1998–1999.

riods. In any case, both data sets revealed a marked separation in the timing of wild and hatchery fish. The timing of spawning by the wild fish may be an adaptation to avoid the tendency of the river to flood during the winter (Montgomery et al. 1999) or to optimize conditions (temperature, food, and predation) for fry after emergence. Similar concerns about the relative survival of earlier-emerging progeny of hatchery fish have been expressed for brown trout *S. trutta* (Stefanik and Sandheinrich 1999) and Atlantic salmon (Lura and Sægrov 1993).

Although environmental conditions may generally favor survival of wild fish, during some winters hatchery fish may experience relatively benign conditions and a high rate of survival to emergence. If so, the progeny of naturally spawned hatchery fish would emerge about 2 months before those of wild fish, giving them distinct competitive advantages in size and territorial possession (Abbott et al. 1985; Chandler and Bjornn 1988; Rhodes and Quinn 1998; Einum and Fleming 2000). If their size advantage increases survival in freshwater (Quinn and Peterson 1996) and at sea (Ward and Slaney 1988), then the hatchery fish may be overrepresented among the returning fish.

In addition to temporal distribution, spatial distribution also affects the potential for genetic and ecological interactions in streams. Steelhead reared in hatcheries tend to return to the section of river where they were stocked (e.g., Slaney et al. 1993; reviewed by Quinn 1993). Our radiotelemetry results showed considerable overlap in the distributions of both types, especially in the 1.8 km between the hatchery and its water intake diversion structure, where we have observed high densities of juvenile steelhead (Mackey, McLean, and Quinn, unpublished data). Thus the potential exists for ecological interactions and interbreeding (given the slight overlap in timing of spawning) between populations in the river. Nevertheless, the wild fish tended to go farther upstream, as predicted on the basis of the hypothesis that spawning site is influenced by imprinting as juveniles, so there may be some measure of spatial isolation. The wild fish also took less time to reach their maximum upstream distance and spent less time in the river before leaving than did the hatchery fish, contrary to studies showing that wild Atlantic salmon spent more time in the river than hatchery fish (Jonsson et al. 1990).

The size distributions of hatchery and wild fish also differed. The wild fish included a greater proportion of large females and both large and small males, whereas the hatchery population was dominated by fish of intermediate size. Larger females produce more eggs and should enjoy greater per capita reproductive success than do smaller females (Fleming and Gross 1994; Steen and Quinn 1999), which suggests an advantage for the wild fish. The broad size distribution of males may affect competition and variation in reproductive success but the consequences for the populations are unclear.

In the 1999–2000 season we anticipated the return of the first naturally spawned steelhead of hatchery origin. The number of unclipped fish arriving that winter was unprecedented in the previous 4 years (more than 16 times the annual average), and many of those may have been hatchery-type fish whose parents spawned in the river. The presence of early, unmarked fish of ambiguous origin will complicate efforts to manage these populations. If such fish are allowed upriver and they are genetically of hatchery origin, then they may interbreed with wild fish, altering that gene pool. If they are spawned at the hatchery but are actually wild fish, then the wild population will also be compromised by introgression in the hatchery. If early wild fish are killed at the hatchery, then their

population is compromised by selection on timing and numerical depletion.

In conclusion, management of natural salmonid populations supplemented with hatchery fish is complex. Washington State's approach to steelhead management, attempting to temporally isolate hatchery and wild steelhead, may only be partly successful in Forks Creek because of the overlap of run timing and habitat use and because not all hatchery fish are captured at the weir. Natural reproduction by hatchery fish or interbreeding with wild fish may have taken place, and such steelhead are no longer readily distinguishable as hatchery fish. Continued sampling is planned to determine the long-term fates of these populations.

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