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Behavioral Interactions among Hatchery-Reared Steelhead Smolts and Wild *Oncorhynchus mykiss* in Natural Streams

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Abstract.—The potential for hatchery fish to negatively impact wild fish has been identified as a concern for dwindling stocks of naturally produced anadromous salmonids in the Pacific Northwest. Using a control–treatment approach, we performed a multiscale examination of potential behavioral impacts of releases of hatchery-produced steelhead *Oncorhynchus mykiss* (anadromous rainbow trout) on preexisting wild populations of *O. mykiss* (anadromous and potamodromous) over a 4-year period. We released approximately 33,000 conventionally reared hatchery steelhead smolts (treatment) into an upper Yakima River tributary in 1991, 1992, 1993, and 1994 and investigated behavioral interactions and small-scale displacement (0.2–5.0 m). Snorkelers conducted behavioral observations and observed small-scale displacements in treatment and control streams for approximately 1 month following releases. Hatchery steelhead were generally larger than wild *O. mykiss* and dominated most (68%) contests. The types of behavioral interactions observed differed between control and treatment streams ($P < 0.01$). Behavioral interactions involving physical contact (e.g., nips) were observed more frequently in treatment streams than in control streams, whereas those involving nonphysical contact displays (e.g., threats and chases) were more frequent in control streams. Contrary to our expectations, total behavioral interaction rates were generally higher in control streams than in treatment streams, though the difference was not statistically significant ($P = 0.07$). Hatchery steelhead displaced wild *O. mykiss* in 79% of the contests observed between these groups. Our results indicate that the behavior of hatchery steelhead can pose risks to preexisting wild *O. mykiss* where the two interact. Strategies to minimize undesirable risks associated with behavior of released hatchery steelhead should be addressed if protection and restoration of wild *O. mykiss* stocks is the management goal.

Releases of cultured fish have the potential to ecologically impact wild fish species (Marnell 1986; Steward and Bjornn 1990; Schramm and Piper 1995; White et al. 1995). Cultured fish may interact with wild fish through a variety of ecological mechanisms, such as competition (Nickelson et al. 1986; McMichael et al. 1997), predation (Sholes and Hallock 1979), behavioral anomalies (Hillman and Mullan 1989), and pathogenic interactions (Goede 1986; Coutant 1998; Moffitt et al. 1998). In hatchery-reared anadromous salmonids, these interactions can occur immediately after release (presmolt or smolt stage) or after most hatchery smolts have emigrated. Juvenile wild steelhead *Oncorhynchus mykiss* may rear in freshwater from 1 to 3 years before emigrating as smolts (Busby et al. 1996). This complexity is difficult to mimic under artificial conditions. Most traditional artificial propagation programs for steelhead attempt to produce actively emigrating smolts in 1 year to achieve desired smolt to adult survival rates at an acceptable cost.

Hatchery steelhead released as smolts may impact wild *O. mykiss* (meaning steeelhead, which are anadromous and rainbow trout, which are potamodromous and spend their entire life in freshwater [Gresswell 1997]) through a variety of direct and indirect ecological mechanisms. However, our investigation was restricted to competition and displacement manifested by behavioral interactions. Competition may occur if the presence of hatchery steelhead limits the availability of resources that would ordinarily be used. This may occur when hatchery steelhead and wild *O. mykiss* (which hereafter means either the anadromous or potamodromous forms or both) utilize common resources, the supply of which is limited (e.g., exploitative competition); or if the resources are not in limited supply, competition may occur when hatchery steelhead limit access of wild *O. mykiss* that are seeking a desired resource (e.g., interference competition; Birch 1957). To maximize smolt-to-adult survival, hatchery programs typically produce steelhead that are released at a larger size than sympatric wild *O. mykiss* and therefore have a size advantage in social interactions. Abbott et al.

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(1985) reported that a 5% difference in weight confers an advantage in social dominance among steelhead. In addition, some studies have shown that hatchery fish are extremely aggressive, which may also confer dominance (Ruzzante 1994). Nielsen (1994) observed that agonistic interaction rates among coho salmon *O. kisutch* increased after hatchery coho were introduced, and 83% of wild coho salmon were displaced from foraging habitats by hatchery coho salmon. As a result of agonistic interactions, wild *O. mykiss* may be displaced from preferred feeding and hiding locations (Abbott et al. 1985; McMichael et al. 1997). This displacement from preferred locations may result in increased vulnerability to predators and decreased ability to forage in profitable locations, which may affect growth (Dill and Fraser 1984; Fausch 1984; Abbott and Dill 1989; McMichael et al. 1997).

Proposed supplementation of steelhead in the Yakima basin, Washington, (Clune and Dauble 1991) prompted a series of investigations exploring potential ecological interactions between artificially produced steelhead and wild *O. mykiss*. Supplementation is defined as ''the use of artificial propagation in an attempt to maintain or increase natural production while maintaining the long term fitness of the target population, and keeping the ecological and genetic impacts on non-target populations within specified biological limits'' (RASP 1992; BPA 1996). The extent to which supplementation programs can effectively function within the restrictions of this definition is not yet understood (Bugert 1998). It is possible that nontraditional approaches to hatchery culture associated with supplementation (Cuenco et al. 1993; Maynard et al. 1995; Bugert 1998) might lead to releases of hatchery fish that are more genetically and ecologically like their wild counterparts. In the Yakima River case, however, concerns were raised that releases of cultured steelhead would ecologically impact wild *O. mykiss*. Wild *O. mykiss* are abundant in the upper Yakima basin and are predominantly potamodromous, providing the best wild trout fishery in the state of Washington (Krause 1991; Probasco 1994). In contrast, the abundance of wild steelhead in the Yakima River, a mid-Columbia River tributary, is currently at low levels. The abundances of steelhead in mid-Columbia tributaries have declined to the extent that steelhead in this area have recently been proposed by the National Marine Fisheries Service as ''threatened'' under the Endangered Species Act. Anadromous and potamodromous *O. mykiss* are not visually discernable as juveniles until the anadromous form reaches the smolt stage.

We conducted a multiscale field experiment in the upper Yakima basin to test hypotheses associated with behavioral interactions between hatchery steelhead at the smolt release and emigration period (up to 1 month following release) and wild *O. mykiss*. We tested the following null hypotheses: (1) larger hatchery steelhead would not dominate and displace smaller wild *O. mykiss*; and (2) rates of behavioral interactions would not be different in streams where hatchery steelhead were released than in streams where no hatchery steelhead were present.

Methods

Study area.—This research was conducted within the Teanaway River watershed north of the town of Cle Elum, Washington. The Teanaway River drains a portion of the east slope of the Cascade Mountains and is a tributary to the Yakima River (see McMichael et al. 1997 for more detail). Hatchery-produced steelhead were released into Jungle Creek, a tributary to the North Fork of the Teanaway River (Figure 1).

The hatchery steelhead released into Jungle Creek (at rkm 0.5) migrated downstream into the North Fork of the Teanaway River. Jack Creek flows into the North Fork of the Teanaway River, approximately 1.6 km below the mouth of Jungle Creek. Upstream passage into Jack Creek was blocked by a weir 0.2 km from its mouth. The Middle Fork of the Teanaway River parallels the North Fork of the Teanaway River; no hatchery steelhead were released there. Summer rearing densities of wild salmonids in Jack Creek and the Middle Fork of the Teanaway River were generally about 38% higher than in Jungle Creek and the North Fork of the Teanaway River (Pearsons et al. 1996).

Experimental design.—Our study used a multiscale control–treatment approach. Jungle Creek served as a small treatment stream and the North Fork of the Teanaway River served as a large treatment stream. Jack Creek was a small control stream and the Middle Fork of the Teanaway River served as a large control stream (no hatchery fish were released in control streams). We released 22,500–38,000 hatchery-reared steelhead smolts into Jungle Creek during early May of 1991, 1992, 1993, and 1994. The annual targeted number of fish to be released (33,000) represented the proposed number of hatchery steelhead that would be released from one acclimation pond, and there

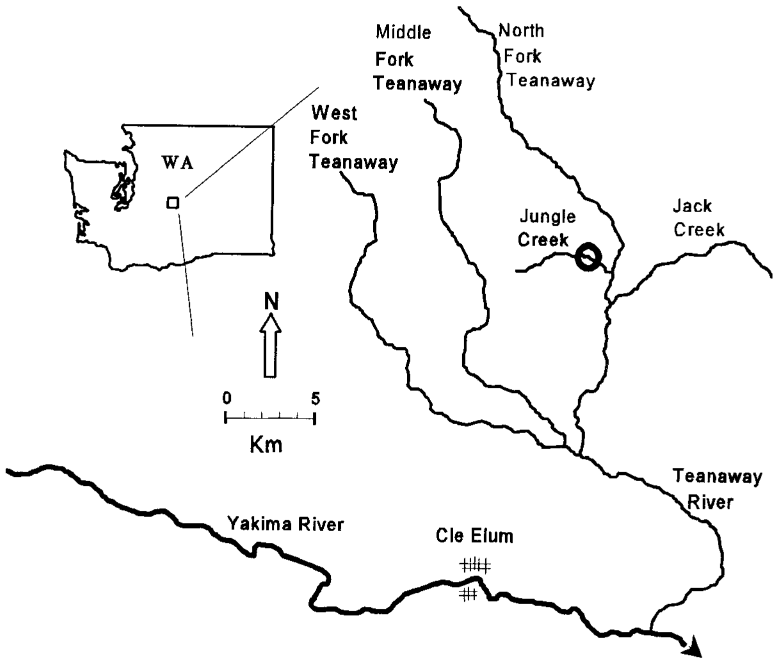

FIGURE 1.—Map of the upper Yakima River basin showing the four study streams in the Teanaway River watershed: Jungle and North Fork (treatment streams) and Jack and Middle Fork (control streams). The hatchery steelhead release location on Jungle Creek is marked by an open circle.

were plans to have three ponds at each release site (total release was to be 99,000 smolts in this area; Clune and Dauble 1991). Smolts were released in a manner intended to roughly mimic the emigration pattern that we expected during a volitional release from an acclimation pond such as the ones proposed for the supplementation program in the Yakima basin. Approximately 45% of the fish were scheduled for release on day 1, 33% on day 3, and the remaining 22% on day 10. During the study duration, no supplementation facilities had been constructed; thus, the hatchery steelhead used were from the Washington Department of Wildlife's Yakima Hatchery, the nearest available source. These fish were reared using conventional protocols and without any supplementation rearing procedures (e.g., Maynard et al. 1995; Bugert 1998).

Smolt attributes were determined for a subsample (N = 100–200) of the hatchery steelhead at the time of release. Fork length and weight measurements, percentage of precocial males (those expressing milt), and percentage of smolts (based on external characteristics; Ewing et al. 1984) were recorded for each fish examined as they exited the hatchery truck. Mean lengths, weights, and condition factors were weighted by the release number to account for different sizes of fish released from different rearing vessels. Condition factor (CF) was calculated using the following standard equation: $CF = (W \times 10^5)/FL^3$, where W = weight (g) and FL = fork length (mm).

To examine behavioral interactions between fishes, direct underwater observations were performed by snorkeling in treatment streams (where hatchery steelhead were released) and control streams (where no hatchery steelhead were released). In 1991, behavioral observations were only made in treatment streams. From 1992–1994, behaviors were observed in control and treatment streams. Three index sites were established in pool-run habitats in each control and treatment stream to observe behavioral interactions. Index sites were two to four channel-widths long (15–50 m per index site) and were sampled two to four times per week from the date of the first hatchery release in early May to the end of the month. All snorkeling was conducted during daylight between 0800 and 1800 hours (Pacific Daylight Time).

To conduct behavioral observations, a snorkeler approached an index site from the downstream margin and moved into the site slowly until a group of salmonids was located. Observation periods were typically 20 min in duration. Snorkelers (one

TABLE 1.—Hatchery steelhead releases into Jungle Creek from 1991 to 1994: number released, number sampled, weighted mean fork length (mm), weight (g), condition factor (CF), percentage classified as smolts, and percent precocial males; 95% confidence intervals are shown in parentheses.

Year	Number released	Number sampled	Mean length	Mean weight	Mean CF	% smolts	% precocial males
1991[a]	31,542	50	194 (190–199)	[a]	[a]	<50	4.0
1992	38,000	200	188 (185–191)	70 (67–73)	1.01 (1.00–1.02)	72–76	0.0 to 2.0
1993	22,500	150	180 (176–183)	61 (57–64)	1.00 (0.99–1.01)	92–100	0.0 to 2.0
1994	32,579	150	180 (177–184)	64 (59–68)	1.05 (1.02–1.07)	74–86	0.0

[a] Only one release group was sampled in 1991, and weights were not measured on all samples in 1991.

per site) recorded the number and type of interactions observed, as well as the species and size of the interacting fish, which fish initiated the interaction, which (if either) fish dominated, and ultimately, whether the subordinate fish was displaced (defined below). Hatchery steelhead were distinguished by an adipose fin clip. When observers faced multiple groups of interacting fish in treatment streams, those including both hatchery steelhead and wild salmonids (as opposed to all hatchery steelhead or all wild salmonids) were selected for observation.

To standardize among observations in different streams with differing fish densities and different observation durations, interaction rates were calculated for each observation period by dividing the total number of interactions observed by the number of fish observed and then by the duration (minutes) of the observation period. Therefore, interaction rates are presented in terms of total interactions per fish per minute.

In 1991 and 1992, all agonistic behavioral interactions were recorded as simply agonistic behavior. In 1993 and 1994, five agonistic interaction classifications were used: threat, crowd, chase, nip, or butt. We defined threats as overt signs of aggression, such as fin-flares and body arching (Taylor and Larkin 1986; Holtby et al. 1993). Crowds occurred when fish moved toward other fish laterally, causing a subordinate fish to move out of the way (Helfrich et al. 1985; Taylor and Larkin 1986; Holtby et al. 1993). Chases occurred when one fish pursued another fish for two or more body lengths without making physical contact (Keenleyside and Yamamoto 1962; Helfrich et al. 1985; Taylor and Larkin 1986). Nips were classified as physical contact in which one fish actively bit another fish (Stringer and Hoar 1955; Helfrich et al. 1985; Taylor and Larkin 1986). Physical contact made between two fish, with the mouth of the attacking fish closed, was classified as a butt. A fish was considered to be dominant if it displaced (defined below) its opponent in a contest or successfully defended a location from an opponent. A contest was a discrete interaction or group of interactions between two specific fish without breaks between interactions of more than 1 min. Many contests included multiple interactions. For example, a hatchery steelhead and a wild rainbow trout could chase and nip each other several times during one contest.

We examined displacement of juvenile hatchery-reared steelhead by snorkeling. Small-scale displacements (0.2–5.0 m) were defined as those that occurred within a stream channel unit, such as a pool. We defined a displacement as one fish causing another fish to move at least two body lengths away from what the observer considered to be a preferred feeding or holding site.

Statistical procedures.—Mean total interaction rates in control and treatment streams were compared using analysis of variance (ANOVA) with treatment as the independent factor. The percentages of interactions that resulted in the displacement of the subordinate fish were compared using *t*-tests. A chi-square test was used to compare the frequency of the different types of agonistic behaviors observed in control and treatment streams.

Results

Total numbers, sizes, and smolt classifications of hatchery steelhead released into Jungle Creek varied among the 4 years of study (Table 1). Mean lengths and weights decreased from year to year, except between 1993 and 1994. Mean condition factor was highest in 1994. In only 1 year (1993) were more than 90% of the juvenile steelhead released classified as smolts. Furthermore, in 3 of the 4 years, from 0.7% to 4.0% of the steelhead

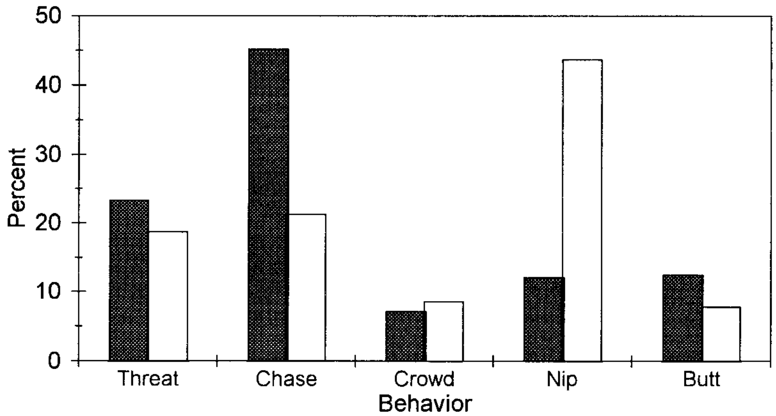

FIGURE 2.—Frequency of five different types of agonistic behaviors observed in control (solid bars) and treatment (open bars) streams in 1993 and 1994.

released were sexually mature precocial males (Table 1).

The frequencies of the different types of agonistic interactions differed between control and treatment streams ($\chi^2 = 98.8$, df = 4, $P < 0.01$). Interactions observed in control streams generally involved less physical contact than those observed in streams where hatchery steelhead were present (Figure 2). Interactions in which physical contact was made (nips) were observed at higher rates in treatment streams than in control streams. Furthermore, higher percentages of threats and chases were observed in the control streams than in the treatment streams.

Hatchery steelhead were larger than wild *O. mykiss* and generally initiated and dominated contests. Hatchery steelhead in Jungle Creek and the North Fork of the Teanaway River initiated 61% of the contests between hatchery steelhead and wild *O. mykiss* and dominated preexisting wild trout in 68% of contests observed. When agonistic interactions among all groups of fish were pooled, larger fish dominated 71% of the contests observed. In treatment streams, larger fish initiated 57% of the agonistic contests observed, and small fish initiated 30% of the contests. Both fish were judged to be the same size in 13% of the contests observed in treatment streams. The fish that initiated an agonistic interaction was judged to be dominant in 84% of the contests in treatment streams and in 89% of the contests in control streams.

Hatchery steelhead displaced wild *O. mykiss* from presumably preferred microhabitats within habitat units (0.2–5 m). The percentage of contests that resulted in the displacement of the subordinate fish was higher in treatment streams (79% of the contests between hatchery steelhead and wild *O. mykiss*) than in control streams (68% of the contests among wild *O. mykiss*), though not significantly ($t = -0.18$, df = 12, $P = 0.86$). In treatment streams, hatchery steelhead displaced wild *O. mykiss* with greater frequency (79% of contests) than wild *O. mykiss* displaced hatchery steelhead (58% of contests), although again, the difference was not significant ($t = 1.07$, df = 4, $P = 0.34$). Nearly all (99.5%) of the displacements observed were judged to be the result of an agonistic interaction. Only one (0.5%) of the displacements was thought to have been the result of social interaction. In that interaction, a small wild *O. mykiss* was seen leaving a holding location to follow a group of hatchery steelhead moving downstream as they passed the holding location of the wild *O. mykiss.*

Interaction rates within years were generally lower in treatment streams than in control streams (Table 2). Even though total fish densities were more than 6 times higher in treatment streams, interaction rates in control streams were higher, although not significantly higher ($F = 3.96$, df = 11, $P = 0.07$), than in treatment streams (in four of five comparisons using rate 2 in Table 2). Interaction rates also generally increased as the study progressed.

Discussion

Hatchery steelhead behaviorally dominated wild *O. mykiss* in most situations. Hatchery steelhead were generally larger and behaved more aggressively and violently than wild fish, which may have contributed to their dominant status. Exceptions to this pattern generally occurred when wild fish were

TABLE 2.—Behavioral interaction data from treatment and control streams between 1991 and 1994: observation time (min), number of contests observed, number interactions observed (Int1), number of interactions observed excluding interactions among only hatchery steelhead (Int2), number of wild trout observed for all species combined (trout), number of hatchery steelhead observed (HSH), number of trout observed per minute (Trout/min), total number of fish observed per minute (Fish/min), interaction rate [number of interactions $\times$ fish^{-1} $\times$ min^{-1} $\times$ 1,000; Rate1], and interaction rate excluding interactions among only hatchery steelhead (Rate2). In control streams, Rate1 = Rate2 and Int1 = Int2, so number not repeated.

Stream[a] and year	Minutes	Contests	Int1	Int2	Trout	HSH	Trout/min	Fish/min	Rate1	Rate2
Treatment										
Jungle										
1991	788	28	117	35	264	1,055	0.33	1.67	0.1127	0.0337
1992	1,497	23	103	80	118	3,233	0.08	2.91	0.0205	0.0159
1993	575	51	411	141	120	524	0.21	1.12	1.1099	0.3808
1994	698	69	831	204	114	5,693	0.16	8.32	0.2052	0.0504
NFT										
1991	948	14	151	32	52	1,719	0.05	1.87	0.0899	0.0191
1992	419	3	20	1	20	217	0.05	0.57	0.2014	0.0101
1993	83	2	28	2	2	80	0.02	0.99	4.1140	0.2939
1994	236	8	79	66	45	82	0.19	0.54	2.6358	2.2020
Total	5,244	198	1,740	561	735	12,603				
Mean							0.14	2.24	1.0612	0.3757
Control										
Jack										
1992	520	12	29	—	232	0	0.45	0.45	0.2404	—
1993	372	17	58	—	185	0	0.49	0.49	0.8428	—
1994	526	67	400	—	300	5	0.57	0.58	2.4933	—
MFT										
1992	467	3	21	—	68	0	0.15	0.15	0.6613	—
1993	5[b]				0	0				
1994	162	5	15	—	26	3	0.16	0.18	3.1928	—
Total	2,052	104	523		811	8				
Mean							0.36	0.37	1.4861	

[a] NFT = North Fork Teanaway River, MFT = Middle Fork Teanaway River.
[b] Poor water visibility precluded observation in the MFT in 1993.

larger than hatchery steelhead. This suggests that dominance may be at least partly a function of fish size, not just origin (hatchery or wild). Regardless, in most cases juvenile hatchery steelhead are likely to be larger than their wild counterparts, whether reared using traditional or supplementation methods.

Dominance of hatchery steelhead for preferred microhabitats may reduce wild *O. mykiss* survival if wild *O. mykiss* have low energy reserves following winter or if they become more susceptible to predators (Dill and Fraser 1984). Furthermore, hatchery steelhead may not benefit from dominating and displacing wild *O. mykiss.* Hatchery fish were often observed roaming and engaging in agonistic encounters with both hatchery and wild fish, with no apparent benefit to the roaming hatchery fish when it succeeded in displacing its opponent. In other words, hatchery fish often did not move into and occupy a vacated microhabitat that would be expected to provide an energetically profitable foraging position (Fausch 1984). These findings are similar to those reported by Bachman (1984) for hatchery brown trout *Salmo trutta.* We consider the threat and chase behaviors exhibited more by wild fish in the absence of hatchery fish to be more energy efficient hierarchy maintenance behaviors than the more violent interactions involving physical contact that were more commonly observed in interactions involving hatchery steelhead.

The displacement that occurred at the microhabitat scale were primarily the result of agonistic interactions. We observed many instances of hatchery fish agonistically displacing wild fish, but we only observed one instance where a wild fish appeared to migrate because hatchery steelhead were moving downstream past the wild fish's position. We also trapped emigrating fish moving out of the small and large control and treatment streams in an attempt to evaluate mid- and large-scale displacement of wild fish due to the movement of the hatchery steelhead. Unfortunately, even though there were significant correlations between hatchery and wild fish movement in some years, the results did not prove causation. In the absence of a wide array of environmental data and control streams that were adequately similar to treatment streams in both biotic and abiotic characteristics, we were unable to conclude that hatchery steelhead emigration caused premature mid- to large-scale movement of wild *O. mykiss.*

We observed that interaction rates were lower in streams where hatchery steelhead were introduced than in streams without hatchery steelhead. This finding may be due to suppressed activity of wild fish in the presence of hatchery fish or to effects of overall high fish densities in treatment streams compared to control streams. The suppressed agonistic behavior of wild fish may be related to the large numbers of potential competitors (territorial behavior switched to schooling behavior), the inappropriate response of hatchery fish to visual cues (e.g., fin-flares or threat postures), or large size and aggressiveness of hatchery fish (described below) intimidating wild fish. Unfortunately, our data do not allow us to distinguish differences in carrying capacity between control and treatment streams; however, densities of wild fish in control streams were about 38% higher than densities of wild fish in treatment streams (summer population estimates; Pearsons et al. 1996). Wild fish were also observed at a higher rate in control streams (mean = 0.36/min) than in treatment streams (mean = 0.14/min) during snorkeling. When hatchery fish were included, total salmonid densities in treatment streams (mean = 2.24/min) were much higher than in control streams (mean = 0.40/min). If interaction rates were purely a function of the number of individuals within an area, then we should have seen a much higher interaction rate in the treatment streams. We favor the hypothesis that differences in interaction rates were due to the suppressed agonistic behaviors that we saw in the presence of hatchery fish. We observed wild fish taking submissive positions or hiding when large numbers of hatchery fish were migrating through the same reach of stream. A typical scenario consisted of a wild fish attempting to defend a location until so many hatchery fish were present that it gave up. At this point the wild fish would either take a submissive position somewhat downstream or would try to stay away from the path of hatchery steelhead, by moving to the stream margin or hiding under a rock. These wild fish would frequently cease feeding when they were not in their original position.

If we look at interaction rate independent of the number of fish observed, the mean interaction rate in control streams was 0.22 interactions/min, while it was 0.38 interactions/min in treatment streams (including interactions among hatchery steelhead). Nielsen (1994) observed that interaction rates (number of interactions/min) were higher in streams with hatchery coho salmon than in streams without them; when our data are similarly analyzed (interactions/min), our results agree with Nielsen's. Finally, interaction rates may not be a good variable to indicate severity of behavioral interactions because different conclusions may be drawn depending on the denominator that is used in the interaction rate calculation; types of interactions (i.e., threats compared to nips) may differ in their resultant biological impacts (i.e., stress compared to injury), and low interaction rates may or may not correspond to low impacts. For example, in the same stream that we found low interaction rates (interactions/fish/min), previous studies indicated that residual hatchery steelhead (fish that do not emigrate in the year they are released) affected growth of wild rainbow trout (McMichael et al. 1997).

Agonistic interactions of hatchery steelhead and wild *O. mykiss* were observed, which resulted in small-scale displacements of the wild form. However, although the temporal distribution of wild *O. mykiss* changed, we did not examine effects on abundance and size structure of the population in this study. Our data associated with cumulative impacts of the 4 years of hatchery steelhead releases (e.g., as spring smolts and, over the longer term, as residuals) to the abundance and size structure of wild *O. mykiss* will be the subject of a future analysis.

Management Implications

Artificial propagation of anadromous fish is used for a wide variety of purposes, including harvest augmentation, stock reintroduction, supplementation, and conservation of naturally spawning wild populations. To achieve efficient use of available fiscal and biological resources while wrestling with implementation and management of sustainable ecosystem or watershed management approaches, it will be increasingly important for managers to simultaneously address potentially competing objectives for multiple species.

Our study confirmed that releases of conventionally reared hatchery steelhead can pose ecological risks to preexisting wild populations. Further research is needed to determined how hatchery fish reared using innovative supplementation techniques might produce different results. In any case, fish managers should carefully evaluate, minimize, and contain such risks where species of concern exist.

Several strategies to minimize undesirable behavioral interactions of hatchery steelhead on wild populations were outlined by McMichael et al. (1999). One of these strategies was to stock steelhead at temperatures less than 8°C when wild fish are relatively inactive during the day. This strategy has the potential to significantly reduce agonistic interactions. Another strategy proposed by McMichael et al. (1999) was to release fish of a size that minimizes interaction potential between hatchery and wild fish (smaller than wild fish). Indeed, we observed that the larger hatchery steelhead generally dominated the smaller wild fish. Furthermore, hatchery steelhead might be released into areas where habitat resources are especially diverse, so that resource partitioning and visual isolation would have the best chance of occurring. Visual isolation of hatchery and wild fish could minimize agonistic interactions. Hillman and Mullan (1989) observed that wild fish that could not see hatchery fish migrating downstream (i.e., visually isolated) were not ''pulled'' or displaced downstream.

Acknowledging that releases of hatchery salmonids may affect preexisting wild salmonid populations is an important step toward protection and recovery of imperiled populations of wild anadromous salmonids. Thorough evaluation of current hatchery programs and implementation of rigorous monitoring programs should be required in watersheds where depressed stocks of wild salmonids occur, even though these precautions will not ensure that wild stocks are protected or restored (Waples 1999).

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