

Effects of Residual Hatchery-Reared Steelhead on Growth of Wild Rainbow Trout and Spring Chinook Salmon

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Abstract.—We investigated the effects of nonmigrant (residual) juvenile hatchery steelhead (anadromous rainbow trout *Oncorhynchus mykiss*) on growth of wild rainbow trout and juvenile spring chinook salmon *O. tshawytscha* to examine how increased densities of residual hatchery steelhead might affect the growth of preexisting wild rainbow trout and chinook salmon. We used screened enclosures in a natural stream to examine food utilization and physiological stress, factors that might affect fish growth. The presence of residual hatchery steelhead led to reduced growth of wild rainbow trout (1993: $P = 0.019$; 1994: $P = 0.020$) but not of spring chinook salmon ($P = 0.360$). Enclosures did not reduce the total number of food items available but did influence the species composition of aquatic and terrestrial invertebrates. The food habits of paired and unpaired fish differed; however, the power of those tests was low. Cortisol level, a measure of physiological stress, did not differ between paired and unpaired fish held in enclosures. Cortisol levels were significantly lower in fish confined for 42 d than in wild fish outside the enclosures at the end of the experiment. Our results suggest that adverse effects on wild rainbow trout growth resulting from high densities (a doubling) of residual juvenile steelhead from hatchery releases may be significant.

During the past decade, concerns over the effects that fish released from hatcheries may have on naturalized and indigenous fish populations have increased (Bachman 1984; Vincent 1987; Goodman 1990; Waples 1991; Schramm and Piper 1995). Hatchery-reared salmonids may compete with wild fish (Bachman 1984; Nickelson et al. 1986; Vincent 1987). Large releases of hatchery-reared fish increase the total density of fish in certain areas for various lengths of time, and competition for limited resources increases when fish density increases (Li and Brocksen 1977; Kennedy and Strange 1986; Heggenes 1988; Christiansen et al. 1992). Social interactions between hatchery and wild fish may increase stress levels in wild fish (Noakes and Leatherland 1977; Ejike and Schreck 1980) and reduce their feeding opportunities (Abbott and Dill 1989).

Knowledge of competition between wild salmonids is more fully developed than understanding

of competition between hatchery-reared and wild salmonids. Many studies have focused on the mechanisms of competition among salmonids, such as agonistic interactions (Abbott et al. 1985; Huntingford et al. 1990; Hughes 1992) and niche separation (Griffith 1972; Hearn and Kynard 1986). For example, Everest and Chapman (1972) found that juvenile steelhead *Oncorhynchus mykiss* and chinook salmon *O. tshawytscha* used different habitats in streams and showed little evidence of competition.

Juveniles of the anadromous (steelhead) and resident (rainbow trout) forms of *O. mykiss* have similar ecological requirements in freshwater and would be expected to be interact strongly if a common resource were limiting. Kennedy and Strange (1986) showed that fish of the same species compete strongly. Releases of hatchery-reared steelhead juveniles often result in relatively prolonged increases in salmonid density and biomass when a portion of the released fish fail to migrate seaward and become residuals (Viola and Schuck 1995). Residual hatchery steelhead are defined as those not emigrating from the release area prior to June 1.

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Four years of underwater observations showed that residual hatchery steelhead and rainbow trout occupied similar habitat types and engaged in agonistic interactions throughout the summer (McMichael et al. 1992, 1994; Pearsons et al. 1993). To better understand the impacts of residual hatchery steelhead on wild juvenile rainbow trout and spring chinook salmon, we conducted a series of experiments in small enclosures in a natural stream in the upper Yakima River basin, Washington. Our objectives were to learn whether residual hatchery steelhead induced slower growth in wild juveniles and, if they did, to learn the mechanisms by which this effect was exerted. Our results have implications for current as well as future artificial propagation programs where fish are released into areas that have populations of wild salmonids.

Methods

Study area.—We conducted growth experiments in the North Fork of the Teanaway River, a tributary that enters the Yakima River, Washington, 282 km upstream from the confluence of the Yakima and Columbia rivers. The North Fork of the Teanaway River is 29 km long and drains a portion of the eastern slope of the Cascade Mountains covering a basin area of 246 km². Our 2.5-km study reach ranged in elevation from 750 to 780 m above sea level. Streamside vegetation was composed of conifers and deciduous trees and shrubs. Substrate composition was dominated by cobbles and areas of sandstone bedrock. Water temperatures measured during the study periods ranged from 7 to 20.5°C.

Both wild rainbow trout and residual hatchery steelhead were present in the study reach. Hatchery fish were identified by an excised adipose fin. Natural production of steelhead in the study area was extremely low during the study (McMichael et al. 1992). Wild resident rainbow trout are not visually distinguishable from juvenile steelhead prior to the smolt stage; thus all naturally produced *O. mykiss* were classified as resident rainbow trout. Other fish species observed in the study reach during the study period included, in order of decreasing abundance, shorthead sculpin *Cottus confusus*, torrent sculpin *C. rhotheus*, longnose dace *Rhinichthys cataractae*, mountain whitefish *Prosopium williamsoni*, bridgelip sucker *Catostomus columbianus*, and brook trout *Salvelinus fontinalis*. Our study reach overlapped the area of previous study of interactive behavior between wild rainbow trout and hatchery steelhead (McMichael et al. 1992, 1994; Pearsons et al. 1993).

Experimental design.—Our experiment used a control-treatment design that focused on differences in growth of paired and unpaired fish. Growth experiments pairing residual hatchery steelhead with (1) wild rainbow trout and (2) wild spring chinook salmon were performed from July 7 to August 19, 1993. Test 1 with wild rainbow trout was repeated from July 5 to August 17, 1994.

A solitary fish (control) was placed in one chamber of an enclosure (described below) and a treatment fish (steelhead) and a response fish (rainbow trout or chinook salmon) were placed in the other. The control and response fish were of the same species for a given test. The combinations used in this experimental design were intended to ascertain effects on response fish. The terms control, response, and treatment fish distinguish the different groups of fish in each test; "control" and "unpaired" are used interchangeably, as are "response" and "paired." Each of the tests was replicated 10 times in 1993 and test 1 (with rainbow trout) was replicated 20 times in 1994.

In the area where we conducted these tests, residual hatchery steelhead are typically about 40% longer than wild rainbow trout and nearly twice the length of wild age-0 spring chinook salmon during the summer rearing season. This experiment was not designed to determine which species were most dominant when fish sizes were equal. It was instead designed to determine if the presence of a treatment fish influenced the growth of the response fish. We designed the experiment in this manner in an attempt to determine what effect a doubling in the density of salmonids (due to presence of residual steelhead from hatchery releases) would have on the growth of preexisting wild salmonids.

Twenty enclosures were constructed with 5-cm × 5-cm wood frame members enclosed with galvanized wire (0.95 cm mesh) on all sides and the bottom. The inside dimensions of each enclosure were 91 cm high by 91 cm long and 99 cm wide. Each enclosure was divided into two equal-sized (0.46 m²) chambers by a plywood barrier. Four large cobbles (20–30 cm in diameter) were collected from the wetted stream channel and positioned in each chamber of each enclosure to coarsely simulate natural conditions and to provide substrate for benthic organisms. A plywood lid was attached to the top of each enclosure to increase fish security.

The 20 enclosure sites used in 1993 were selected on June 29. Each site was assigned randomly to either a pool or run habitat type with depths

TABLE 1.—Beginning mean lengths and weights (SDs and ranges in parentheses) of test fish used in enclosure growth experiments with wild juvenile rainbow trout, wild juvenile spring chinook salmon, and residual hatchery-reared steelhead. Control fish were isolated singly in half an enclosure; paired response fish and treatment fish grew in the other half; all treatment fish were steelhead. Sample sizes (number of replicates) were 10 fish per group in 1993 and 20 fish per group in 1994.

Test	Year	Group	Species	Fork length (mm)	Weight (g)
1	1993	Control	Rainbow trout	114.4 (14.6, 101–143)	18.0 (8.5, 11.5–36.0)
		Response	Rainbow trout	117.0 (13.5, 102–140)	18.9 (6.0, 12.8–29.6)
		Treatment	Steelhead	169.4 (25.1, 140–204)	51.0 (23.2, 26.9–88.7)
	1994	Control	Rainbow trout	115.9 (9.2, 108–136)	18.8 (6.0, 14.4–32.6)
		Response	Rainbow trout	118.4 (15.0, 102–138)	21.1 (5.9, 13.3–28.9)
		Treatment	Steelhead	168.5 (10.1, 156–183)	47.2 (9.4, 37.0–61.4)
2	1993	Control	Chinook salmon	76.1 (10.6, 64–92)	5.7 (2.4, 2.9–9.7)
		Response	Chinook salmon	70.1 (3.9, 64–76)	4.0 (0.9, 2.5–5.2)
		Treatment	Steelhead	155.9 (38.4, 117–213)	43.5 (29.8, 15.1–90.6)

of 0.35–0.70 m and water velocities of 0.12–0.42 m/s. These criteria were developed from fish–habitat relationships previously studied (McMichael et al. 1992). Enclosures were distributed randomly among the selected sites on July 6. In 1994, site selection criteria were the same as in 1993, and enclosures were placed in pool and run habitats ranging in depth from 0.35 to 0.66 m and in velocity from 0.20 to 0.43 m/s.

Rainbow trout used in 1993 and 1994 were collected within 50 m of the enclosure in which each was placed. They were collected on July 7, 1993, and on July 5, 1994, with battery-powered backpack electrofishers set for pulsed direct current, 300 V, and either 30 or 60 Hz. We targeted fish of 100–150 mm in fork length (FL), which bracketed the modal length of trout (125 mm) previously observed in the study reach at that time of year (McMichael et al. 1992). The relative sizes of the groups of fish used in this experiment (Table 1) were those typically found during the summer rearing period in streams in the upper Yakima River basin. We did not age the trout used in this experiment, but available age and size information from the North Fork of the Teanaway River suggest that trout between 100 and 150 mm FL are predominantly of ages 1 and 2 (Martin and Pearsons 1994). On the day of collection, rainbow trout were anesthetized in a 0.1-g/L solution of tricaine (MS-222), measured to the nearest mm FL, and weighed to the nearest 0.1 g; the external appearance of each fish (e.g., fin condition) was recorded.

Age-0 spring chinook salmon were not present near the study area when this experiment began, and they were collected by electrofishing from the main stem of the Yakima River near the town of Cle Elum, Washington, on July 7, 1993. These fish were immediately transported in aerated vessels

approximately 30 km to the study area, where they were distributed into the appropriate enclosures (for test 2) in the same manner described for rainbow trout. Control and response rainbow trout and spring chinook salmon were allowed to acclimate to, or establish “prior residence” in, the enclosures for 2 d before a residual hatchery steelhead (treatment fish) was placed into one of the chambers in each enclosure. Wild fish normally have established prior residence before hatchery fish are released into streams. For a variety of reasons, prior residence affords an advantage to stream salmonids in competitive situations (Allée 1982; Heggenes 1988; Metcalfe and Thorpe 1992).

Treatment fish (steelhead) were placed in the enclosures on July 9, 1993, and on July 7, 1994. In both years, residual hatchery steelhead were electrofished from Jungle Creek, a tributary to the study stream, placed into a holding vessel for transportation, and measured and examined like the other fish. A steelhead was then placed in one of the chambers (assigned randomly) in each of the enclosures containing rainbow trout (test 1) or spring chinook salmon (test 2).

Enclosures in which one or more deaths occurred before the end of the study period were discarded from the final analyses. Death occurred in three of the replicates of both tests 1 and 2 in 1993. Ten of the 20 replicates in 1994 were not used because one or more fish were missing at the end of the experiment. We assumed that most missing fish had died, although some may have escaped.

On August 19, 1993, 42 d after the control and response fish were placed in the enclosures, all fish were collected from the enclosures, euthanitized in a lethal concentration (>200 mg/L) of MS-222, measured to the nearest mm FL, weighed to the

nearest 0.1 g, and bled for physiological analyses (described later).

Capture protocol consisted of approaching an enclosure from the downstream side, quickly removing the plywood top and cobbles, and electrofishing within the enclosure with the same equipment and settings used in the initial collections. The amount of time to capture all fish within each enclosure averaged 1 min, 54 s (range, 1–3 min). The reason fish were collected by electrofishing, instead of by simply netting them, was to provide samples collected from inside and outside enclosures by like means for physiological testing at the conclusion of the experiment. In 1994, all fish were netted from the enclosures on August 17 (after 43 d in the enclosures), anesthetized in MS-222, and measured and weighed.

In 1993, we compared food habits of control and response rainbow trout and spring chinook salmon by examining stomach contents from a subsample of all fish. Stomachs were extracted and preserved in 10% buffered formalin at the end of the experiment. The contents of a subset of the rainbow trout stomachs (six control and six response) and spring chinook salmon stomachs (five control and five response) were examined with binocular dissecting microscopes. Food items were counted and identified to order from their head capsules.

Between August 26 and 28, 1993, a test was conducted to determine whether the presence of the mesh screen influenced food availability within the enclosures. In run habitat downstream of a riffle in the middle of the study reach, six screens (0.95-cm-square galvanized wire mesh) were attached along a transect to 13-mm-diameter metal rebar that had been pounded into the substrate perpendicular to the water surface. These screens were left 48 h to accumulate the debris load typically found on our experimental enclosures. Drift nets (46 cm × 31 cm, 363- μ m mesh) were then attached to the downstream side of the screens, and six additional unscreened nets were placed along the same transect, alternating with the screens. Drift nets were deployed for 22–24 h. Samples were preserved in 70% isopropyl alcohol. Using a binocular dissecting microscope, we identified and counted insects in each order observed.

In 1993, we examined potential enclosure effects on stress physiology (plasma cortisol levels) and condition factor ($10^5 \cdot \text{weight}/\text{length}^3$) of test fish. Fish were collected inside enclosures on August 19 and outside enclosures on August 20. The caudal peduncle of anesthetized fish was severed

and blood was collected in ammonium-heparinized capillary tubes. After centrifugation, the plasma was frozen for later analysis. Plasma cortisol levels were obtained by radioimmunoassay according to the protocol developed by Foster and Dunn (1974) as modified by Redding and Schreck (1983).

Data analyses.—Specific growth rate (SGR) was calculated by the following equation (Fausch 1984):

$$\text{SGR} = (\log_e W_t - \log_e W_0)/t;$$

W_t = weight (g) at the end of the period, W_0 = weight (g) at the beginning of the period, and t = time (days).

One-tailed paired t -tests were performed to test for differences in SGR among control and response fishes. For stress physiology samples, paired t -tests were used to evaluate differences in mean plasma cortisol concentrations. Sample distributions of cortisol levels were normalized by log transformation. Two-tailed paired t -tests were used to compare screened with unscreened drift samples and control with response fish diets. Statistical significance was set at $\alpha = 0.05$. Statistical power analyses (Snedecor and Cochran 1981; Peterman 1990) for t -tests involving control and response fish growth, food habits, and physiological stress were performed to aid in the interpretation of these results.

Results

Residual hatchery steelhead reduced the specific growth rate of wild rainbow trout juveniles but not of age-0 spring chinook salmon. In both 1993 and 1994, control (unpaired) rainbow trout had higher mean SGRs than response trout paired with residual hatchery steelhead ($P \leq 0.002$; Table 2). Fish of all groups lost weight during the tests, on average, but the magnitudes of SGR decline were similar between years for response trout and treatment steelhead.

Spring chinook salmon paired with hatchery steelhead residuals in test 2 did not exhibit significantly different SGRs from their unpaired counterparts ($P = 0.360$; Table 2). The statistical power of the SGR comparison for test 2, however, was low (0.109). The average decrease in SGR for steelhead in test 2 was similar to those in test 1.

In 1993, control and response fish did not ingest significantly different numbers of food items. In test 1 that year, control rainbow trout contained an average of 27.5 items while response fish averaged 6.0 items (Table 3). The difference was not significant ($P = 0.129$) but, the power of that test

TABLE 2.—Mean specific growth rates (SDs and ranges in parentheses) of wild juvenile rainbow trout, wild juvenile spring chinook salmon, and residual hatchery-reared steelhead in stream enclosures. Sample sizes (number of replicates) were 7 fish per group in 1993 and 10 fish per group in 1994.

Test	Year	Group	Species	Specific growth rate (d ⁻¹)
1	1993	Control	Rainbow trout	-0.0016 (0.0029, -0.0053 to +0.0016)
		Response	Rainbow trout	-0.0060 (0.0020, -0.0094 to -0.0032)
		Treatment	Steelhead	-0.0020 (0.0015, -0.0042 to -0.0002)
	1994	Control	Rainbow trout	-0.0039 (0.0020, -0.0071 to -0.0017)
		Response	Rainbow trout	-0.0061 (0.0021, -0.0109 to -0.0034)
		Treatment	Steelhead	-0.0023 (0.0021, -0.0064 to -0.0003)
2	1993	Control	Chinook salmon	-0.0004 (0.0040, -0.0049 to +0.0071)
		Response	Chinook salmon	-0.0006 (0.0048, -0.0051 to +0.0087)
		Treatment	Steelhead	-0.0018 (0.0013, -0.0036 to 0.0000)

was low (0.357). Prey eaten by control fish, however, represented significantly more taxonomic orders of insects than the prey eaten by their paired counterparts ($P = 0.006$). Paired and unpaired spring chinook salmon did not contain significantly different numbers of food items ($P = 0.109$) or prey orders ($P = 0.115$; Table 3).

Insects of the orders Diptera, Ephemeroptera, Hymenoptera, Trichoptera, and Hydracarina were numerous in the stomachs of rainbow trout and chinook salmon in 1993 (Table 4). Hymenopterans and trichopterans were proportionally more important to trout than to salmon; dipterans were relatively more important to salmon. Adult hymenopterans (terrestrials) appeared with greater frequency in stomach than in drift samples.

Mesh screen similar to that used to delimit the experimental enclosures did not affect the total number of food items passing through but did appear to affect the relative occurrence of two orders (Table 4). Numbers of food items in unscreened drift samples (mean, 204.8; range, 117–387) were similar to those in screened samples (mean, 244.5; range, 31–416; $P = 0.64$). Furthermore, the diversity of insect orders in unscreened samples (mean, 7.3; range, 6–9) and screened samples

(mean, 7.2; range, 4–10) was similar ($P = 0.88$). But unscreened samples contained a higher percentage of Trichoptera larvae, and screened samples contained a higher percentage of Ephemeroptera nymphs. Dipterans were most abundant in drift samples as they were in stomach samples, but whereas fish ate large numbers of adults, nearly all (98%) of dipterans in the drift samples were larvae.

Enclosures appeared to have no effect on mean condition of rainbow trout. Condition factors of trout inside the enclosures (mean, 1.20) were not significantly different from those of trout captured outside the enclosures (mean, 1.18) at the end of the 1993 experiment ($P = 0.320$).

Titers of circulating cortisol did not differ significantly between control and response rainbow trout ($P = 0.740$) or chinook salmon ($P = 0.510$; Figure 1). However, rainbow trout that were confined for 42 d had significantly lower circulating levels of cortisol than rainbow trout captured outside the enclosures at that time ($P = 0.010$; Figure 1).

Discussion

Our results indicate that residual hatchery steelhead reduced the growth of wild resident rainbow trout during summer under controlled conditions. We infer that when hatchery steelhead become residuals, thus increasing local densities of salmonids for extended periods, the growth of sympatric wild rainbow trout growth is likely to decrease. A reduction in size, due to slower growth during the summer, could decrease overwinter survival (Hunt 1969; Toneys and Coble 1979, 1980; Oliver and Holeyton 1979), resulting in decreased population size (Cunjak et al. 1987).

In the competitive relationships we tested, fish species was more important than fish size. Age-0

TABLE 3.—Mean number of food items and prey orders identified in stomachs of control and response fish from enclosures at the end of experiments, August 19, 1993. Ranges are shown in parentheses. Sample sizes were six rainbow trout stomachs per group and five spring chinook salmon stomachs per group.

Test	Species	Group	Mean number of:	
			Food items	Orders
1	Rainbow trout	Control	27.5 (6–107)	4.2 (3–5)
		Response	6.0 (1–15)	2.3 (1–4)
2	Chinook salmon	Control	53.0 (19–68)	4.2 (3–5)
		Response	42.2 (1–76)	3.2 (1–6)

TABLE 4.—Total numbers of food items (column percentages in parentheses), by prey order, found in screened and unscreened drift samples and in stomachs of rainbow trout and spring chinook salmon, 1993; *N* is number of drift samples or stomachs.

Order	Drift		Stomachs (%)	
	Screened (<i>N</i> = 6)	Unscreened (<i>N</i> = 6)	Rainbow trout (<i>N</i> = 12)	Chinook salmon (<i>N</i> = 10)
Ephemeroptera	492 (33.5)	100 (8.1)	46 (12.4)	60 (12.6)
Plecoptera	10 (0.7)	10 (0.8)	1 (0.3)	2 (0.4)
Diptera	752 (51.3)	781 (63.5)	259 (69.6)	384 (80.5)
Trichoptera	136 (9.3)	233 (19.0)	11 (3.0)	3 (0.6)
Coleoptera	8 (0.5)	7 (0.6)	13 (3.5)	1 (0.2)
Hemiptera	7 (0.5)	5 (0.4)	4 (1.1)	5 (1.0)
Hymenoptera	6 (0.4)	10 (0.8)	30 (8.1)	13 (2.7)
Neuroptera	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)
Odonata	0 (0.0)	1 (0.1)	2 (0.5)	0 (0.0)
Collembola	3 (0.2)	3 (0.2)	0 (0.0)	0 (0.0)
Hydracarina	50 (3.4)	77 (6.3)	6 (1.6)	8 (1.7)
Lepidoptera	2 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)
Araneae	1 (0.1)	1 (0.1)	0 (0.0)	1 (0.2)
Total	1,467	1,229	372	477

spring chinook salmon showed no diminuation of growth upon the introduction of steelhead twice their length, whereas growth of rainbow trout faced with a conspecific half again as large grew significantly less well than isolated fish. The existing literature on competition among salmonids suggests that larger fish generally dominate smaller fish in both inter- and intraspecific interactions (Griffith 1972; Abbott et al. 1985; Hearn 1987; Chandler and Bjornn 1988; Huntingford et al.

1990; Hughes 1992). A dominant fish might increase its feeding success (Helfrich et al. 1985) at the expense of smaller subordinate fish (Li and Brocksen 1977). Abbott et al. (1985) showed that within a species (steelhead in their study), a weight advantage of only 5% can assure dominance. Socially dominant fish exhibit greater mobility and feeding success than smaller subordinates (Helfrich et al. 1985). Subordinate fish in our study were not allowed to emigrate from the test encl-

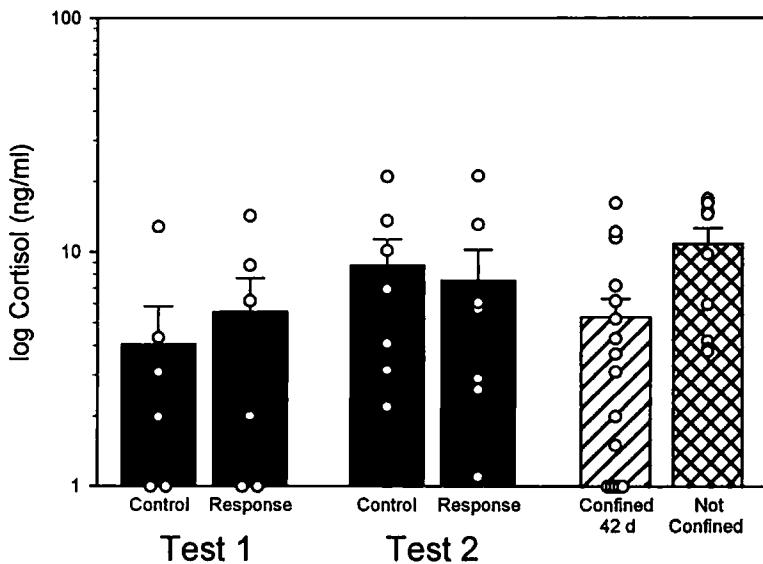


FIGURE 1.—Mean plasma cortisol concentrations (\log_{10} scale) in control and response fish—rainbow trout in test 1, spring chinook salmon in test 2—and mean cortisol levels in unconfined and confined rainbow trout at the end of the 1993 experiment. Confined fish were in enclosures; unconfined fish were captured from the stream outside enclosures. Error bars indicate 1 SE; open circles are individual data points.

tures. Under natural conditions, subordinate fish may emigrate and find environments that are below carrying capacity and thus support better growth. Nevertheless, fish of the same species might be expected to compete more than fish of different species due to the commonality in their ecological requirements at similar life stages (Allee 1982; Kennedy and Strange 1986).

Why might chinook salmon have been unaffected by introductions of steelhead in our experiment? First, competition may not have occurred because spring chinook occupied different niches than the residual hatchery steelhead. When fish species differ and the difference in fish size is very large, competitive effects may be reduced by niche partitioning (Lister and Genoe 1970; Everest and Chapman 1972; Dolloff and Reeves 1990). The spring chinook salmon we observed were generally higher in the water column than steelhead (G.A.M., unpublished data). Second, the sample sizes we used were smaller than would have been preferable for statistical considerations given the actual variation in our results. The resulting power of the chinook salmon test was relatively low (0.109), thereby increasing our chances of making type II errors. Given the observed differences in mean SGRs between control and response spring chinook salmon, and the relatively high standard deviation in this test, we would have had to deploy 8,241 enclosures to achieve a statistical power of 0.9. This number of trials would obviously be impractical, but it does illustrate that this method may not be well suited for examination of growth impacts for some species combinations. We think, however, that standard deviation would decrease as sample size increased, thereby reducing the number of required trials. In any case, interspecific effects on growth were much smaller than intraspecific effects.

Mean SGR for all groups of fish in our experiments was negative. Some individuals did gain weight, but most (81%) lost weight during the 6-week study periods. Therefore, we had to compare negative SGRs. Weight loss by stream salmonids has been reported for fish placed in enclosures. For example, Miller (1952) found that hatchery cutthroat trout *Oncorhynchus clarki* lost weight during the first 40 d after they were placed in enclosed stream sections with wild trout. Fausch and White (1986) reported negative SGRs for individual brown trout *Salmo trutta* and brook trout in competition experiments with coho salmon *O. kisutch* in an artificial stream. Our enclosures prevented fish inside enclosures from foraging on nat-

ural substrates (with the exception of the four cobbles in each chamber). This feeding restriction may have contributed to the negative SGRs.

Our enclosures may have affected fish behavior and movement. Stream salmonids move in response to fluctuating environmental factors such as daylight, invertebrate drift, and water temperature. For example, Edmundson et al. (1968) observed juvenile steelhead occupying inshore, low-velocity areas during darkness and in areas with moderate current during daylight hours. The fish inside our enclosures were unable to move naturally. Fish outside our enclosures were able to adjust their positions in response to water temperature fluctuations, changes in the intensity of sunlight, periodicity of insect emergence, drift, flow, and density of other fishes and potential predators. Nonetheless, all fish in our tests were subjected to a standardized confinement protocol, making comparisons between control and response fish inside the enclosures meaningful.

The uniformly low cortisol levels among confined fish suggest that the fish may have completely acclimated to their new environment (enclosures). The significantly lower cortisol levels in confined than in unconfined fish at the end of the experiment may, in part, be explained if conditions were less stressful inside the enclosures than outside with respect to the availability of overhead cover (plywood top) and protection from predation. However, the experiment was not designed to characterize the physiological changes associated with the capture and handling of the fish immediately before their confinement, nor was the statistical power of the statistical test sufficiently high to detect low levels of variation. We did detect some negative results from imposition of residual steelhead, suggesting that a more powerful experimental design incorporating larger sample sizes or shorter time intervals between sampling might better reveal the physiological basis of competitive interactions.

Our enclosures did not affect the amount of food available to fish inside them, though the composition of invertebrate orders in the diet was somewhat affected. The mesh size we used (0.95 cm) was considerably larger than the sizes that Cooper et al. (1990) found to significantly influence the immigration and emigration of invertebrates in enclosures in trout streams. In our study, the screen's should have had little effect on invertebrate movement into enclosures even when they went uncleaned for 24–48 h. Some invertebrate orders, such as Ephemeroptera, may have been more common

in screened samples due to their affinity for the vegetative matter that accumulated on the screens. The effect on SGR of the shift in relative proportions of invertebrate orders available to fish inside our enclosures is unclear, though it probably was small.

Our results may be useful in the evaluation of risks associated with behavioral interactions resulting from high residual densities of steelhead after hatchery releases into areas containing wild populations. The application of these results to hatchery programs falls into two general categories; (1) assessment of the potential impacts of hatchery residuals on wild fish populations, and (2) alternative hatchery operations that affect the incidence and density of residuals.

If hatchery-reared salmonids compete with wild fish to the detriment of the latter, decreased productivity of the wild population could result. In areas such as the northwestern United States, where many wild stocks of salmonids are at critically low levels (Nehlsen et al. 1991; WDF et al. 1993), the impact of hatchery-produced fish may be serious enough to warrant program review and modification. Our study suggests that the species and size of the hatchery fish influences the potential for impacts on the growth of wild salmonids. In cases where hatchery residuals are larger than their wild conspecifics, the impacts would be expected to be greatest. Very large size differences at release, however, could reduce competition through differential habitat segregation (Pearsons et al. 1994). However, if very large hatchery steelhead (over 250 mm long) become residuals, the potential for predation on wild salmonid fry might increase (Cannamela 1992). However, research in Washington state has shown that predation by hatchery steelhead residuals on wild salmonids is low (Martin et al. 1993; Pearsons et al. 1993).

Hatchery release strategies that minimize the occurrence of nonmigrating residual steelhead and that minimize the spatial and temporal overlap of residual steelhead with wild rainbow trout are likely to have the least impact. Where many hatchery steelhead smolts become residuals, the impacts of these fish on wild rainbow trout could be acute. Where most hatchery fish emigrate quickly, their short-term impacts should be relatively minor. As an indication of the potential seriousness of this issue, the National Marine Fisheries Service (NMFS 1995) has drafted hatchery steelhead smolt size criteria for releases to be made in the area encompassed by the draft Snake River Chinook Recovery Plan. Research on methods to achieve

hatchery program objectives while maintaining wild stocks (e.g., Viola and Schuck 1995; McMichael et al., in press) is urgently needed.

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