

ABSTRACT

We observed and sampled wild juvenile salmonids at treatment (downstream of hatchery release) and control (upstream) sites on three streams in order to estimate the effects of hatchery releases on the abundance, behavior, habitat use, growth, and condition of wild juvenile salmonids. The majority of hatchery fish that were released emigrated from stream sites very quickly. We found little evidence that hatchery releases had any significant effects on the ecology of wild salmonid fry, although comparisons had low power in most cases. There were no significant changes in the abundance of trout fry, coho salmon fry, or total salmonid fry caused by hatchery releases, but the statistical power of comparisons was low. Hatchery releases appeared to have no consistent effect on the social behavior or macrohabitat use of coho salmon or trout fry. Coho salmon fry held positions significantly lower in the water column in the presence of hatchery fish in one stream, but not in another; no other microhabitat variables showed consistent changes related to hatchery releases. There were no apparent effects of hatchery releases on the frequency of feeding attempts by coho salmon fry. The frequency of aggressive acts by coho salmon fry was higher in the presence of hatchery fish on two streams, but differences were not significant and comparisons had low power. Coho fry were larger and in better condition at the control site on the Nemah River than at the treatment site, but this may have been confounded by the higher density of coho fry at the treatment site. Estimates of sample sizes and effort required to obtain sufficient power suggest that comparisons of growth and physiological condition may be the most cost-effective means of estimating the effects of hatchery releases on wild salmonids, but wild fish abundance estimates would also be required to examine the effects of fish density on growth and condition.

EXECUTIVE SUMMARY

This study was designed to determine the feasibility of using field methods to estimate the effects of hatchery releases on the abundance, behavior, habitat use, growth, and condition of wild juvenile salmonids. We observed and sampled wild juvenile salmonids at treatment (downstream of hatchery release) and control (upstream) sites in order to estimate the effects of hatchery releases on wild fish. We also estimated the sample sizes and effort required to obtain 80% power for comparisons between treatment and control sites.

The majority of released hatchery smolts left the study sites quickly (within a day) and few were observed interacting with groups of wild fish, suggesting that any effects of hatchery releases on wild salmonid ecology are likely to be ephemeral. The abundance of non-migrant (residual) steelhead smolts varied widely among streams, and most were observed near the hatcheries. Some residual steelhead had been feeding on wild salmonids.

Overall, there was little evidence of a decrease in the abundance of wild salmonid fry following the release of hatchery smolts. There were no significant differences in abundance of coho salmon or trout fry between treatment and control sites after hatchery releases. High temporal variability in abundance estimates, however, resulted in low power of statistical tests. Future work should use both day and night counts, should attempt to validate counts with electrofishing, and should estimate observer variability.

There were few indications of changes in social behavior or macrohabitat use of coho salmon and trout fry due to hatchery releases. The distance that coho salmon fry held off the substrate was the only microhabitat variable for which an effect of hatchery releases was evident; coho salmon fry occupied positions significantly lower in the water column in one stream when hatchery fish were present, but this was not observed in another stream. For all other microhabitat variables, significant differences between treatment and control sites either did not exist on all dates when hatchery fish were present or were also observed when no hatchery fish were present.

We observed individual fish while snorkeling to estimate rates of aggressive interactions and feeding strikes by wild coho salmon fry on two streams. There were no apparent effects of hatchery releases on the rate of feeding attempts by coho salmon fry. The rate of aggressive acts by coho salmon fry was higher in the presence of hatchery fish in both streams, but differences were not significant and comparisons had low power. The observation of individual fish by snorkeling appears to be an impractical method for comparisons of feeding or aggressive behavior of coho salmon fry in streams due to the large number of samples required to obtain adequate power. Other methods (e.g., underwater video) or sampling designs may need to be developed to study the effects of hatchery releases on feeding and aggression of coho salmon fry.

The length, weight, condition factor and body lipid levels of wild coho salmon fry were significantly higher at the control site on the Nemah River than at the treatment site, suggesting that hatchery releases may have an effect on the growth of wild coho salmon fry. Coho salmon fry density was much higher at the treatment site, however, which may be partly responsible for differences in growth and physiological condition. Moreover, coho escaped from the hatchery and moved downstream into this site. Future studies should evaluate the effects of experimental hatchery releases in areas upstream of hatcheries in order to avoid the potential effects of fry that may escape from hatcheries.

Our estimates of the sample sizes and effort required to obtain sufficient power to detect differences ($1-\beta=0.8$, $\alpha=0.05$) suggest that comparisons of growth and physiological condition may be the most cost-effective means of estimating the effects of hatchery releases on wild salmonids. Low sample sizes and effort are needed to obtain sufficient power to detect differences for growth and physiological variables, and some variables (e.g., percent body lipids) have been shown to have a direct link to fitness or survival. Abundance estimates must also be obtained in order to examine the effects of fish density on growth and condition. Any attempts to study the effects of hatchery releases on wild salmonids are likely to be logistically challenging and will involve considerable effort.

PURPOSE

In order to estimate the ecological risks of hatchery releases to ESA-listed wild salmon populations, it is necessary to determine the effects of hatchery fish on the ecology of wild juvenile salmonids. There is currently a great deal of uncertainty regarding the effects of hatchery-reared salmonids on wild juvenile salmonids (Pearsons and Hopley 1999; Waples 1999; Flagg et al. 2000). Although there is some evidence that hatchery-reared salmonids may affect the ecology of wild salmonids (Hillman and Mullan 1989; Nielsen 1994; McMichael et al. 1999), tools for evaluating ecological interactions between the two are poorly developed and have not been standardized.

Developing standard methods to estimate the effects of hatchery releases on wild juvenile salmon will produce results that can be compared among regions. Because of limited resources available for field investigations, it is also important to determine the level of effort necessary to obtain statistically valid results, and to estimate the costs associated with field studies. We used snorkeling to observe hatchery releases on several streams to determine the feasibility of estimating the effects of hatchery releases on the abundance, behavior, habitat use, growth, and condition of wild juvenile salmonids. We estimated the sample sizes required to obtain sufficient statistical power to detect significant differences between treatment and control sites ($\exists-1=0.8$, $\forall=0.05$), and we determined the cost effectiveness of all techniques applied.

Project Objectives

1. Develop a quick, cost-effective method to evaluate the effects of hatchery releases on wild salmonids.
2. Determine how the release of hatchery-reared salmonids affects the abundance, movement, behavior, habitat use, growth, stomach fullness, and condition of wild salmonids.
3. Determine how hatchery practices affect the survival and residualism of released fish.

APPROACH

Study Sites

We chose study sites on four streams in western Washington – the North Nemah River, Forks Creek, Goodman Creek, and Stevens Creek. The fish communities in these streams are composed of coho salmon *Oncorhynchus kisutch* (hereafter coho), chinook salmon *O. tshawytscha* (hereafter chinook), steelhead *O. mykiss*, cutthroat trout *O. clarki*, sculpins *Cottus spp*, and lamprey *Lampetra spp*. The North Nemah River also supports a population of chum salmon *O. keta*. These basins are relatively undeveloped except for forest harvest and agriculture. Study sites ranged in length from 45-102 m, contained a combination of habitat types (riffle, run, pool), and were chosen to be representative of the habitats available in the rivers.

The North Nemah River is a tributary of Willapa Bay located approximately 40 km north of Naselle, Washington. The Nemah Hatchery (WDFW) is located approximately 7 km upstream from the mouth; coho, chinook and steelhead are reared and released on-site as smolts. Four snorkeling sites were chosen on the Nemah River, two upstream of the hatchery (control sites) and two downstream (treatment sites). Treatment sites were located approximately 800 m (Site 1) and 100 m downstream (Site 2) of the hatchery, while control sites were located approximately 300 m (Site 3) and 600 m (Site 4) upstream. We were unable to snorkel each site on each visit to this stream and effort was concentrated on Sites 2 and 3, the closest to the hatchery.

Forks Creek Hatchery (WDFW) is located on Forks Creek, a tributary of the Willapa River located near the town of Lebam, Washington. Coho, chinook and steelhead are reared and released on-site as smolts. We chose two sites for snorkeling on lower Forks Creek. Site 1 (treatment) was located approximately 200 m downstream of the hatchery, near the confluence of Forks Creek with the Willapa River; the control site (Site 4) was located approximately 1800 m upstream of the hatchery. Other sites were initially sampled but logistical constraints prevented us from snorkeling them repeatedly. The treatment site in the lower part of the river (Site 1) is somewhat atypical due to a predominance of bedrock substrate and the effects of a highway bridge and an abandoned railway trestle immediately upstream. We also chose two sites approximately 8 km upstream of the Forks Creek hatchery to evaluate the effects of three experimental releases of approximately 1000 chinook smolts (22 and 29 June 2000 and 6 July 2000). These sites were located approximately 25 m downstream (Site 5, treatment) and 100 m upstream (Site 6, control) of the point of chinook release.

Goodman Creek is a small coastal stream located approximately 19 km west of the town of Forks, Washington. The lower 3 km of the stream flows through Olympic National Park directly into the Pacific Ocean. Approximately 20,000 winter steelhead smolts from the Bogachiel Hatchery are transported and released in Goodman Creek annually in mid-to-late April. We chose six snorkeling sites on Goodman Creek, three treatment sites

located approximately 700 m, 400 m, and 50 m downstream of the point of hatchery releases (Sites 1, 2, and 3, respectively), and two control sites located approximately 30 m, 300 m, and 450 m upstream (Sites 4, 5, and 6, respectively). Results of snorkel surveys for salmonid abundance are not presented for Sites 2 and 6 because too few salmonids were observed at these sites to provide meaningful results.

The Humptulips Hatchery (WDFW) is located approximately 300 m from the mouth of Stevens Creek, a tributary of the Humptulips River located approximately 40 km north of the town of Hoquiam, Washington. The hatchery rears and releases coho, chinook and steelhead. Two snorkeling sites were chosen approximately 25 m downstream and 100 m upstream of the hatchery. 26,000 steelhead smolts were marked with polymer tags to indicate the release method (forced or volitional). Data from this stream were compromised by low visibility, and logistical constraints prevented us from visiting these sites sufficiently often to provide useable data on abundance, habitat use, or social behavior.

Abundance, Social Behavior, and Macrohabitat Use of Wild Salmonids

We estimated the abundance of fish at each site by snorkeling. Two divers entered each site at the downstream end and proceeded upstream; all sites were narrow enough to be effectively surveyed by two divers. Juvenile salmonids often occurred in groups. Upon encountering an individual or group of fish, divers recorded the number of fish of each species in the group and the distance of the center of the group from the nearest bank (≤ 1 m or > 1 m). Data were recorded on slates by the observers while underwater. Daytime snorkel surveys took place between 10:00 and 17:30 and were conducted only when visibility was greater than 3 m. Nighttime snorkel surveys began after the onset of total darkness, the time of which varied over the course of the study. Because underyearling cutthroat trout, rainbow trout, and steelhead are indistinguishable while snorkeling, we refer to these fish as trout fry.

On 25 July, Sites 2 (treatment) and 3 (control) on the Nemah River were sampled by three-pass electrofishing to obtain population estimates for comparison with snorkel counts. The sites were enclosed with small-mesh seines to ensure population closure, and all fish captured were anesthetized (MS-222), measured (nearest mm), weighed (nearest g) and returned to the stream near their point of capture after electrofishing was completed. Maximum-likelihood estimates of population size for coho and trout fry were computed using the program CAPTURE (White et al. 1978).

Microhabitat Use

We examined microhabitat use by wild coho fry (the only salmonid abundant enough to provide adequate data at most sites) on several occasions on the Nemah River and

Goodman Creek. Divers located coho fry, noted the number of fish in the group (as above), noted the length and focal point elevation (distance off the substrate) of the fry, and left a numbered weight at the position occupied by the fish. These methods allowed us to conduct fish counts at the same time as microhabitat use data were collected. As soon as possible after each snorkel survey we measured water column depth, water column velocity, focal point velocity, and the distance to the nearest bank at the locations marked by numbered weights.

Feeding and Aggressive Behavior

We collected data on feeding and aggressive behavior of wild coho fry before and after hatchery chinook releases in the Nemah River (23 May and 6 June) and Forks Creek (25 and 31 May). Divers located groups of wild fish and chose an individual fish for observation. The length of the fish and the group size were estimated, and fish were observed for as long as possible, usually until the observer lost track of the fish or it was displaced by another fish. Observers noted the number of feeding strikes and aggressive acts (i.e., total of nips, butts, chases, and threats) performed by each fish over the duration of the observation period.

Growth and Condition

Wild coho fry were captured using seines at locations upstream and downstream of the Nemah Hatchery on 3 occasions. On 24 May and 19 June, coho fry were captured, anesthetized, measured, weighed, and immediately returned to the river near their point of capture. On 25 July, 257 coho fry were anesthetized, measured, weighed, and all but 48 fish were returned to the river. The 24 wild fish retained at each site were sacrificed for physiological analysis, as were 24 adipose-clipped hatchery coho fry that had escaped into the river and 24 fish from the hatchery ponds. Blood samples were taken from severed caudal vessels, centrifuged, and stored on dry ice. Livers were removed, weighed, and stored on dry ice, and carcasses were individually bagged and stored on ice. Plasma and liver samples were stored at -80°C until analysis. Whole body lipids and plasma insulin-like growth factor (IGF-1) were quantified using standard methods; IGF-1 analyses are based on pooled plasma from two fish per sample because insufficient plasma was obtained from individual fish due to their small size. Hepatosomatic index was estimated as the ratio of liver weight to body weight. Whole-body minerals and liver glycogen analyses have not yet been completed.

Statistical Analyses

All variables that were used in statistical tests were tested for normality using Proc Univariate in SAS (SAS 1989). In most cases, data were not normal and were log-transformed. For comparisons of feeding and aggressive behavior, microhabitat use, growth, and physiological condition, individual fish were the unit of replication. For comparisons of wild fry abundance, the unit of replication was the site.

To test for effects of hatchery releases on wild fry abundance, we performed repeated measures ANOVA on log-transformed fry abundance data from sites on all streams where sufficient data were available. For each analysis, we used abundance data from the sampling occasion that immediately preceded the first hatchery release and the three sampling occasions that followed it. For coho and total salmonid fry, we used data from four sites (two treatment and two control) on Forks Creek, four sites (two treatment and two control) on Goodman Creek, and two sites (one treatment and one control) on the Nemah River. Data from the same sites on Forks Creek and the Nemah River were used for comparisons of trout fry abundance; suitable trout fry abundance data were not available from Goodman Creek.

Sample sizes needed to achieve sufficient statistical power to detect significant differences ($1-\beta = 0.8$, $\alpha = 0.05$) of comparisons made in this study were estimated using the SAS module *UnifyPow* (O'Brien 1998). We performed retrospective power analysis for all variables using the observed variance of the variable in question and two predetermined 'effect sizes' of 0.2 and 0.5 (i.e., differences in the mean between control and treatment sites of 20% and 50%). We used these analyses to predict the number of samples that would be necessary to achieve sufficient power to detect differences, which we defined as power $(1-\beta) = 0.8$, for each comparison.

We recorded the time required to collect data in the field and laboratory, and estimated the amount of time required to obtain data for a given comparison, not including data processing, analysis and reporting. These estimates were then multiplied by the sample sizes required for a given level of power to produce an estimate of the effort (in terms of man-hours) required to achieve sufficient power to detect significant differences for a given comparison.

Project Management

This project was managed by Stephen Riley (NMFS) and Howard Fuss (WDFW). Fieldwork for this project was conducted by Stephen Riley, Howard Fuss, Larry LeClair (WDFW), Brant Boltz (WDFW), Eric Buhle (NMFS), Eric Kroeger (NMFS), Paul Parkins (NMFS), Todd Pearsons (WDFW), and Amy Robinson (NMFS). Fieldwork was conducted between 3 April – 25 July 2000.

FINDINGS

Observations of hatchery fish

Coho and steelhead

Hatchery steelhead and coho were released together into Stevens Creek, Forks Creek, and the Nemah River in late March and early April (Table 1), and were observed in large mixed groups, mostly near the middle of the channel (Table 2). Most fish did not appear to be feeding. The majority of steelhead and coho smolts left the sites very quickly. On the Nemah River, for example, only 31 hatchery steelhead were observed in the site immediately downstream of the hatchery less than four hours after 11,400 smolts were released. Similarly, 709 coho smolts were observed on the same day that 538,000 were released, and 33 were present in the site approximately 5 weeks later.

Few steelhead or coho smolts were observed near the streambanks (where the majority of wild salmonid fry were located) and few were observed interacting with groups of wild fish (Table 2). There was a tendency for steelhead and coho that remained after several weeks to be located closer to the banks and to interact to a greater degree with wild fish than those observed immediately after release.

We conducted extensive snorkel surveys near the hatcheries on Stevens Creek (20 June), Forks Creek (26 June), and the Nemah River (7 July) to estimate the numbers of hatchery steelhead that remained in these streams after their typical outmigration period (i.e., residuals). The abundance of residuals varied widely among streams (Table 3), and most were observed close to the hatcheries. On Forks Creek, a total of 56 hatchery steelhead residuals were sacrificed on three sampling dates (26-27 June and 7 July). Ninety-three percent of the 44 fish sampled on 26 and 27 June were male and 77% of these showed advanced maturity; five stomachs (11%) contained salmonid fry remains and five contained unidentifiable fish remains. Of the 12 fish sampled on 7 July, 75% were males with 43% of these showing advanced maturity; one stomach contained a single unidentified fish. On Stevens Creek, too few residual steelhead were observed to make valid comparisons of the rate of residualism between release groups.

Chinook

We observed production-scale chinook releases on Forks Creek and the Nemah River in late May and early June (Table 1). In both cases, the majority of chinook that were released moved through the study sites quickly (Table 4). For example, although approximately 1.4 million chinook were released from the Forks Creek hatchery between 25 and 31 May, only 97 were observed in Site 1 (ca. 200 m below release site) on 1 June. Similarly, over 700,000 chinook were released from the Nemah hatchery on 5 June but

only 96 were present in Site 2 (less than 100 m downstream of the hatchery) the following day. Approximately two weeks after these releases, only 1 and 7 hatchery chinook remained in treatment sites on the Nemah River and Forks Creek, respectively.

Most of the chinook observed migrating immediately after release in both streams were in deeper water in the middle of the channel. Many hatchery chinook were found in large (>100 fish) groups, and group size seemed to decrease with time as many smaller groups (10-30 fish) of fish migrated downstream. Some fish were observed feeding but few aggressive interactions among hatchery fish were observed. Initially, few (< 15%) hatchery chinook were observed in groups with wild salmonids (Table 4).

Abundance of wild salmonids

Coho fry

The abundance of wild coho fry showed little apparent response to the release of hatchery fish on any of the study streams (Fig. 1). On two occasions, coho fry abundance appeared to decrease at the treatment sites on Forks Creek after releases of chinook (downstream sites, 31 May; upstream sites, 22 June; Fig. 1), but in both cases coho abundance was similar at treatment and control sites at the end of the sampling period. Repeated measures ANOVA suggests that there was no significant overall effect ($P = 0.6761$) of hatchery releases on coho abundance, but the power of this test to detect the observed difference is very low (0.1) due to the high variability in coho abundance within and among sites. Overall mean abundance appeared to decline over the season (Fig. 2), and there did not appear to be a marked difference in mean abundance between treatment and control sites.

Trout fry

Too few trout fry were observed in Goodman Creek to provide sufficient data for analysis. Daytime counts of trout fry on the other study streams were highly variable within and among sites and did not appear to be related to hatchery releases (Fig. 3). In most cases, patterns of trout fry abundance were similar at control and treatment sites. Daytime counts of trout fry at the upper treatment site on Forks Creek increased immediately after two chinook releases and then decreased at the end of the sampling period (Fig. 3). Repeated measures ANOVA indicated that there was no significant overall effect ($P = 0.9915$) of hatchery releases on trout fry abundance in the study sites, but the power of this test to detect the observed difference is quite low (0.37). There did, however, appear to be differences in mean trout fry abundance between treatment and control sites on the first sampling occasion after hatchery releases (Fig. 2).

Chinook fry

Too few chinook fry were observed at the sites on Goodman Creek to provide a meaningful statistical analysis. There did not appear to be any effects of hatchery releases on chinook fry abundance on the other streams (Fig. 4). Chinook abundance at the upper treatment site on Forks Creek appeared to decrease after the final hatchery chinook release, but abundance returned to the pre-release level by the next day.

Total salmonid fry

Patterns of total salmonid fry abundance were similar to those observed for coho fry, which made up the majority of the wild fry in these streams (Fig. 5, cf. Fig. 1). There were few indications of decreased salmonid fry abundance associated with hatchery releases. Repeated measures ANOVA suggested that there was no significant overall effect ($P = 0.4998$) of hatchery releases on salmonid fry abundance in the study sites, but the power of the test to detect the observed difference is very low (0.09).

Electrofishing population estimates for coho and trout fry in the control site of the Nemah River underestimated both day and night snorkeling counts from the previous day (Table 5). The population estimate for coho fry in the treatment site was greater than both day and night counts, while the estimate for trout fry was intermediate between the day and night count. Electrofishing may not have been as effective at the control site because of a very deep pool which was difficult to sample.

Social Behavior

Data on social behavior were examined for coho and trout fry. Daytime observations suggest that the proportion of solitary coho fry was highly variable both within and among sites, and generally did not appear to be affected by hatchery releases (Fig. 6). The single exception is upper Forks Creek, where the proportion of solitary coho decreased in the treatment site immediately after the third chinook release, but returned to the pre-release level by the following day. The proportion of solitary coho appeared to be increasing during the sampling period at this site, a pattern that was not observed at other sites.

There were few indications of changes in social behavior of trout fry caused by hatchery releases (Fig. 7). Daytime observations on all streams suggest that the proportion of trout fry that were solitary tended to increase over the sampling period.

Macrohabitat Use

Data on the proportion of coho fry that were within one meter of the streambank were available for the Nemah River, Forks Creek, and Goodman Creek; similar data for trout fry were available at the Nemah River and Forks Creek. The proportion of coho located within one meter of the bank was extremely variable within and among sites and appeared to show no effects of hatchery releases with the exception of the last chinook release at the upper sites on Forks Creek, where a decrease in the proportion of near-bank coho was noted in the treatment site (Fig. 8).

Microhabitat Use

There were few apparent effects of hatchery releases on the microhabitat use of coho fry at sites on the Nemah River (Table 6). The distance that coho held off the substrate was the only variable for which a clear effect of hatchery releases was evident; coho fry occupied positions significantly lower in the water column at Site 2 (treatment) than at Site 3 (control) during day and night observations on 17 April and 5 June (when hatchery fish were released), but not on other sampling dates. For all other microhabitat variables, significant differences between the treatment and control site either did not exist on both dates when hatchery fish were present or were also observed when no hatchery fish were present. For example, coho fry at the treatment site on the Nemah appeared to generally occupy stations with significantly faster column velocities than those at the control; differences were significant for daytime observations on 10 April (no hatchery fish present), day and night on 17 April (hatchery fish present), and during the day on 19 June (no hatchery fish present). These differences are probably unrelated to the presence of hatchery fish because this appears to be a general pattern and mean column velocities used by coho fry varied little over the season at Site 2 (with the exception of daytime observations on 19 June).

Sample sizes for microhabitat at Goodman Creek were small (3-26 fish) and represent fish from three treatment and three control sites. We observed no consistent significant differences in the microhabitat use of coho fry between treatment and control sites on Goodman Creek. Coho fry appeared to occupy positions lower in the water column, closer to the bank, and in shallower water at treatment sites than at control sites during nighttime observations on 12 April (when hatchery fish were released), although only distance from the bank and column depth were significantly different (distance off bottom was nearly so) between treatment and control (Table 7). Daytime observations, however, suggest the opposite - coho fry at treatment sites on 12 April occupied positions higher in the water column, further from the bank, and in deeper and slower water than those in control sites, although only depth and velocities were significantly different.

Feeding and Aggressive Behavior

The rates of feeding strikes and aggressive acts by coho fry were similar at upstream and downstream sites on Forks Creek on 25 May, before hatchery chinook were released (Table 8). On 31 May, after the chinook release, the rate of feeding strikes was again similar between the two sites. The rate of aggressive acts, however, remained at a similar level at the control site but increased at the treatment site after the release, although not significantly so.

On the Nemah River, the rate of feeding attempts was higher in the treatment site before the chinook release, but not significantly so. After the release, the feeding rate was similar between the two sites. The rate of aggressive acts was higher in the treatment site both before and after the release, but the differences were not significant.

The rate of feeding strikes by coho fry did not appear to be related to fish length or group size (Fig. 9). The rate of aggressive acts did not appear to be related to fish length; there did appear to be a relationship between the rate of aggressive acts and group size (Fig. 9), but there was no significant linear relationship between the two ($p=0.2039$, by linear regression).

Growth and Condition

Wild coho fry at the treatment site (Site 2) on the Nemah River were significantly larger than those at the control site (Site 3) in May (Table 9). In June and July, wild coho fry were larger (significantly so only in July) at Site 3. Wild coho fry were heavier at Site 3 in June and July, but the difference was significant only in July; wild coho fry at Site 3 had a significantly higher mean condition factor than those at Site 2 in both June and July.

Hatchery fry had a significantly higher hepatosomatic index (HI) than the other three groups; wild fry from Site 3 had a slightly higher HI than those at Site 2, but the difference was not significant (Table 10). Hatchery fry had the highest lipid levels, followed by wild fry from Site 3, which had significantly higher lipid levels than fry from Site 2. Escaped hatchery fry had significantly higher plasma levels of Insulin-like growth factor (IGF-1) than all other groups; wild fry from Site 3 had higher IGF-1 levels than fry from Site 2, but the difference was not significant.

Statistical Power and Sampling Effort

We performed several repeated measures ANOVA analyses on salmonid abundance from treatment and control sites on three streams. Retrospective power analysis indicates that

14-68 pairs of sites are required to obtain 80% power depending on the effect size (ES) and species (Table 11). We estimated that habitat variables should be measured on 374-1,106 fish to obtain 80% power at ES = 0.2, and 64-180 fish at ES = 0.5. Comparisons of the rate of feeding strikes require fewer samples (128-158 fish for ES = 0.2, 24-28 fish for ES = 0.5) than comparisons of aggressive interactions (1,072-7,074 for ES = 0.2, 174-1,134 for ES = 0.5) because of the relatively greater variability in aggressive acts among individual fish. Comparisons of the growth and physiological indices of condition between treatment and control sites on the Nemah River generally required lower sample sizes (14-46 for ES = 0.2, 4-16 for ES = 0.5) to achieve sufficient power to detect significant differences, with the exception of the hepatosomatic index (108 for ES = 0.2, 24 for ES = 0.5).

Estimates of the amount of effort required to obtain a data point for the statistical comparisons in this study vary widely (0.05-3 h, Table 11) because data points are measured in different terms for the different types of comparisons. For example, a data point for abundance is an estimate of the abundance of coho at a given site, while a data point for length comparisons is the length of a single coho fry. The level of effort required to obtain sufficient power (0.8 at ES = 0.5) for the comparisons in this study varies widely, from 0.2 hours for weight to 102 hours for total salmonid abundance.

Discussion

Our observations suggest that the majority of the fish released from hatcheries tend to hold positions away from the streambanks and that few interact with wild salmonids. Our observations also suggest that most released fish migrate downstream immediately and very few remain in the stream for more than a few days. These observations suggest that any ecological effects of hatchery releases on wild salmonids are likely to be ephemeral.

We observed residual hatchery steelhead which remained in three of our study streams for more than two months, and we determined that these fish were feeding on salmonid fry in at least one of the streams. Because residual steelhead occur at relatively low densities in these streams (1.25-37.7 per km), the effects that they might have on fry abundance, behavior, habitat use and condition are likely to be very difficult to demonstrate. Predation by residual steelhead on wild salmonids, however, may represent an important impact on wild salmon populations and deserves further study.

Overall, there was little evidence of a decrease in the abundance of wild salmonid fry following the release of hatchery smolts. High temporal variability in abundance estimates, however, resulted in low power of statistical tests. Temporal variability may be due to movement or mortality of individuals, fish concealment, or observer variability. Counts of salmonids obtained by snorkeling are often less than population estimates derived from electrofishing (Thurow and Schill 1996; Mullner et al. 1998; Roni and Fayram 2000), especially at low temperatures (Hillman et al. 1982), but night snorkeling

may provide more accurate counts (Roni and Fayram 2000, but see Thurow and Schill 1996). Because snorkeling counts may be biased, the use of this technique may contribute to the variability in wild salmonid abundance estimates and therefore may compromise our ability to detect trends in abundance related to hatchery releases. The only alternative to snorkeling is repeated multiple-pass electrofishing, which is not suitable for our purposes because it is too time-consuming, may cause fish injury (Kocovsky et al. 1997; Thompson et al. 1997), may affect fish behavior and physiology (Mesa and Schreck 1989), and may affect fish movements (Nordwall 1999). Snorkeling is therefore the only practical method of obtaining multiple estimates of juvenile salmonid abundance at a number of sites.

Snorkeling to obtain abundance estimates of wild salmonids in streams is logistically very difficult. Teams of 2-4 trained divers are required to repeatedly snorkel a number of sites on several streams during both day and night. Precipitation events often reduce visibility in streams for several days and may interfere with sampling schedules, and it is often necessary for snorkeling crews to work irregular days and hours. Moreover, hatchery fish are usually released into a large number of streams in a given area over a short time period, making it difficult for the same team to observe hatchery releases on several streams.

Due to logistical constraints, we were unable to complete sufficient night snorkeling estimates to provide meaningful comparisons with our day counts, and we compared snorkel counts with electrofishing estimates at only two sites. Moreover, we did not conduct sufficient multiple counts (where the same site is counted by multiple observers) to estimate observer variability. Future work should use both day and night counts, should attempt to validate final counts with electrofishing, and should provide estimates of observer variability.

Changes in the behavior and habitat use of juvenile salmonids may result from interspecific competition, but these effects have rarely been rigorously documented (Fausch 1988). For example, there is evidence that the presence of competing species may result in juvenile salmonids moving to less favorable stream positions closer to stream margins (Larson and Moore 1985) or closer to the substrate (Bremset and Berg 1999), but rigorous experimental documentation of these effects is lacking. Coho fry from the Nemah River appeared to hold positions lower in the water column when hatchery fish were present, but similar results were not found at Goodman Creek. The high degree of variability in habitat use and generally low power of the majority of the tests indicate that larger sample sizes are necessary to assess the effects of hatchery releases on juvenile salmonid habitat use.

Frequencies of feeding strikes and aggressive interactions of coho fry on the Nemah River and Forks Creek were not significantly different between treatment and control sites, although comparisons had very low power. Relatively small sample sizes and high variability in rates of feeding and aggression contributed to the low power of these comparisons. Feeding and aggressive behavior in juvenile salmonids is generally quite variable and can be affected by a number of factors, including size, position in a

dominance hierarchy, predation risk (Metcalf et al. 1987, Martel 1996), stream habitat (Healy and Lonzarich 2000) and sex (Johnsson and Akerman 1998).

We attempted to estimate rates of aggressive interactions and feeding strikes by observing individual fish while snorkeling, but the estimated sample sizes required to obtain adequate power for behavioral comparisons are so high as to render the techniques that we used impractical. Juvenile coho may be classified into several foraging phenotypes which may differ in feeding and aggressive behavior (Nielsen 1992, 1994), and feeding behavior may depend on group size (Grand and Dill 1999). It is therefore possible that the high variability in feeding or aggressive behavior might be reduced by focusing on, for example, lone individuals of a single foraging phenotype, and this might reduce the required sample sizes. It might, however, be difficult to locate sufficient fish of a single foraging type within a reasonable amount of time. Future studies may consider using other methods (e.g., underwater video) to study the effects of hatchery releases on feeding and aggression of coho fry.

The overwinter survival rate of juvenile fish may be related to their growth rate or size (Hunt 1969; Meyer and Griffith 1997; Fullerton et al. 2000) or physiological condition (Gardiner and Geddes 1980). If the presence of hatchery fish causes reduced growth (as reflected by length, weight, and condition factor) or compromised physiological condition (as reflected by body fat levels or liver glycogen content) of wild salmonids, wild fish may suffer greater overwinter mortality at sites affected by hatchery releases. The length, weight, condition factor, and lipid levels of coho fry were significantly higher at the control site on the Nemah River than at the treatment site, which suggests that hatchery releases may reduce the growth and condition of wild coho fry.

The slower growth and lower condition factor of wild coho fry at the treatment site on the Nemah may also have been due to higher fish density rather than any specific effects of hatchery fish. Coho fry density at the treatment site on the Nemah River was 2-9 times higher than at the control site throughout the season. Estimates of fish density should be performed at all sites where sampling for growth and physiological condition is undertaken in order to determine the effects of density on growth and condition.

The higher density of coho fry at the treatment site on the Nemah River may have resulted from large numbers of coho spawning directly below the hatchery (H. Fuss, personal observation). If large numbers of hatchery fish tend to spawn naturally immediately downstream of hatcheries, and if unmarked fry escape from hatcheries, then fry in areas immediately downstream of hatcheries may be primarily of hatchery origin. Assuming that relatively fewer hatchery fish spawn upstream, fry populations upstream of hatcheries might be expected to support a higher proportion of wild fish. Large numbers of hatchery-origin fry at our treatment sites might invalidate the comparisons that we have attempted to make because we would essentially be comparing wild vs. hatchery fry. Future studies should assess the effects of experimental hatchery releases on wild salmonids at sites located away from hatcheries to avoid the potentially confounding effects of hatchery-origin fry.

Our estimates of the sample sizes and effort required to obtain 80% power suggest that comparisons of growth and physiological condition may be the most cost-effective means of estimating the effects of hatchery releases on wild salmonids. Low sample sizes and effort are needed to obtain sufficient power to detect differences for growth and physiological variables, and some variables (e.g., lipids) may have a direct link to fitness or survival. Repeated sampling of growth and physiological parameters over the course of a season would be preferable to single 'snapshot' samples, but this would require removing wild individuals from study sites, which would have unknown effects on the ecology of wild fry.

In summary, we observed no consistent changes in abundance, habitat use, or behavior of wild salmonid fry in response to hatchery releases. We did observe a significant difference in growth and physiological condition of wild coho fry between treatment and control sites on the Nemah River, however, but the higher density of coho fry at the treatment site may be partly responsible for reduced growth and condition of wild fry at the treatment site. Estimates of abundance are therefore required at all sites where the growth and condition of wild salmonids are estimated. A combination of abundance estimates and sampling for growth and condition might be the most effective means of examining the effects of hatchery releases on wild juvenile salmonids in streams.

EVALUATION

The results of this investigation will be combined with data obtained in 2001 and submitted to a peer-reviewed journal for publication. Results will also be incorporated into models designed to estimate the effects of hatchery releases on the dynamics of wild salmon populations.

Objective 1. Develop a quick, cost-effective method to evaluate the effects of hatchery releases on wild salmonids.

Progress was made toward the achievement of this goal in 2000. We estimated the sample size and effort required to obtain adequate statistical power for comparisons of the abundance, habitat use, feeding behavior, aggressive behavior and growth and condition of juvenile salmonids at treatment and control sites. Data collection is continuing in 2001 to refine our estimates of sample size and effort. Based on results from 2000, it appears that estimates of growth and physiological condition are the most cost-effective means of determining the effects of hatchery releases on wild juvenile salmonids, although the effects of fish density on growth and condition must be considered. Abundance estimates are required to examine the effects of fish density on growth and condition, and the most effective field program might therefore be a combination of abundance estimates and sampling for growth and condition.

Objective 2. Determine how the release of hatchery-reared salmonids affects the abundance, behavior, habitat use, growth, stomach fullness, and condition of wild salmonids.

We made significant progress toward the achievement of this goal. We found little evidence that hatchery releases had any significant effects on the ecology of wild salmonid fry, although comparisons between treatment and control sites in most cases had low power. We did not estimate stomach fullness due to time constraints; this will be completed in 2001. The time and effort required to conduct the fieldwork for this project was underestimated, which resulted in fewer sites being used than we had originally planned. Rainfall events that decreased visibility in the study streams also prevented us from performing observations on a number of occasions. Work in FY 2001 will address the effects of hatchery releases on wild fry ecology more intensively on fewer streams in order to achieve adequate sample sizes.

Objective 3. Determine how hatchery practices affect the survival and residualism of released fish.

We counted hatchery steelhead released from Humptulips hatchery in lower Stevens Creek and the Humptulips River on 5 and 6 April, 2000, but poor visibility prevented us from identifying fish marked from the different release groups. We conducted snorkel surveys on Stevens Creek on 20 June in order to count residual steelhead from the marked release groups, but too few residuals remained to provide a meaningful comparison between the groups. Marked adults that will return to the hatchery in 2002-2003 will provide data on survival, but no comparison of residualism between the two groups could be made.

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Figure Captions

Figure 1. Abundance of wild coho salmon fry at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (second panels from top), upper Forks Creek (third panels from top), and Goodman Creek (bottom panels). Abundance estimates were made by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 2. Mean abundance of wild fry at treatment (solid lines) and control (dashed lines) sites on the Nemah River, Forks Creek, and Goodman Creek. Mean abundance was calculated for the sampling occasion before (PRE) and the three sampling occasions immediately following (POST1-POST3) the release of hatchery fish. Top panel: coho fry abundance; middle panel: rainbow trout fry abundance; bottom panel: total salmonid fry abundance.

Figure 3. Abundance of wild rainbow trout fry at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (middle panels), and upper Forks Creek (bottom panels). Abundance estimates were made by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 4. Abundance of wild chinook salmon fry at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (middle panels), and upper Forks Creek (bottom panels). Abundance estimates were made by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 5. Abundance of wild salmonid fry (all species) at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (second panels from top), upper Forks Creek (third panels from top), and Goodman Creek (bottom panels). Abundance estimates were made by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 6. The proportion of coho salmon fry that were solitary at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (second panels from top), upper Forks Creek (third panels from top), and Goodman Creek (bottom panels). Data were collected by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 7. The proportion of rainbow trout fry that were solitary at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (second panels from top), upper Forks Creek (third panels from top), and Goodman Creek (bottom panels). Data were collected by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 8. The proportion of coho salmon fry that were within 1 m of the bank at treatment (solid lines) and control (dashed lines) sites on the Nemah River (top panels), lower Forks Creek (second panels from top), upper Forks Creek (third panels from top), and Goodman Creek (bottom panels). Data were collected by snorkeling during daytime (left panels) and nighttime (right panels). Vertical arrows indicate the dates that hatchery fish were released.

Figure 9. The rate of feeding strikes and aggressive acts by coho salmon fry as a function of fish length and group size. Data were collected by snorkeling from the Nemah River and Forks Creek, Washington.

