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Adult Production of Fall Chinook Salmon Reared in Net-Pens in Backwaters of the Columbia River

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Abstract.—Adult production of fall chinook salmon *Oncorhynchus tshawytscha* reared at several densities in net-pens in two backwater areas of the Columbia River are compared with production by means of traditional hatchery methods. Rearing densities in the pens were primarily limited by water flow; densities were below recommended limits based on rearing space, but flow index recommendations were exceeded in three of four treatments. Rearing costs using net-pens were generally lower than costs in the hatchery. Lower adult contribution of fish reared in net-pen treatments compared with adult contribution of hatchery controls resulted in greater cost per adult produced in net-pens than fish reared and released using traditional methods. However, comparisons of adult return rates were confounded by release locations.

In 1967 the completion of John Day Dam, river mile 216 of the Columbia River, created a 76.4-mi-long reservoir that inundated salmon spawning and rearing habitat. To mitigate for this loss, upriver bright fall chinook salmon *Oncorhynchus tshawytscha* have been reared at Bonneville State Fish Hatchery (SFH; Oregon Department of Fish and Wildlife) and Spring Creek and Little White Salmon National Fish Hatcheries (NFH; U.S. Fish and Wildlife Service) for release above John Day Dam. In an effort to increase the return of adult chinook salmon to this area, in 1983 the U.S. Fish and Wildlife Service, with funding from the Bonneville Power Administration, began to evaluate rearing and imprinting of juvenile fall chinook salmon in temporary facilities installed in backwaters and ponds adjacent to John Day Reservoir. The goal of this research was to determine if upriver bright fall chinook salmon could be successfully reared and imprinted using temporary rearing facilities in backwaters along the Columbia River, resulting in adult contribution to various fisheries.

Methods

During 1986 and 1987 fall chinook salmon juveniles were reared in net-pens at up to four different densities as part of a larger study to investigate alternative chinook salmon rearing scenarios in the Columbia River basin. In 1983, 34 potential backwater areas were surveyed and rated according to their suitability for rearing juvenile chinook salmon. Rock Creek (river mile 228) was chosen as a study site at this time based on criteria including depth, area, accessibility, potential for water temperature fluctuations and wave action, entrance to the Columbia River, public use, and water quality (Novotny et al. 1984; Figure 1). Drano Lake (river mile 162) was added as a study site in 1987 (Novotny et al. 1987).

Fish used for this study were from upriver bright fall chinook salmon adults spawned at the Bonneville SFH. Eggs were hatched and initially reared at Spring Creek NFH. The upriver bright fall chinook salmon program was transferred from Spring Creek NFH to Little White Salmon NFH in 1987. Fish reared at Rock Creek in 1986 were from Spring Creek NFH, whereas those reared at Drano Lake in 1987 were from the Little White Salmon NFH.

The net-pens were 20 ft × 20 ft and were fitted with 0.2-in-mesh, knotless-ace nets that extended 7 ft into the water when attached to the pen frame and enclosed an area of 2,800 ft^3. The nets extended 2 ft above the water surface and were fitted with nylon covers to minimize avian predation.

Fish were reared at four densities (regular, double, triple, quadruple), ranging from 0.060 to 0.273 lb/ft^3 at release; or about 18,000 to 74,000 fish per pen. The "regular" rearing density was chosen based on available water flow and quality, maximum rearing temperatures of 61°F, and proposed release weights of 45 fish/lb (Novotny et al. 1984). Water flow was the most important criterion for determining initial densities.

Water flow through the net-pens at Rock Creek was estimated using backwater inflow and volume

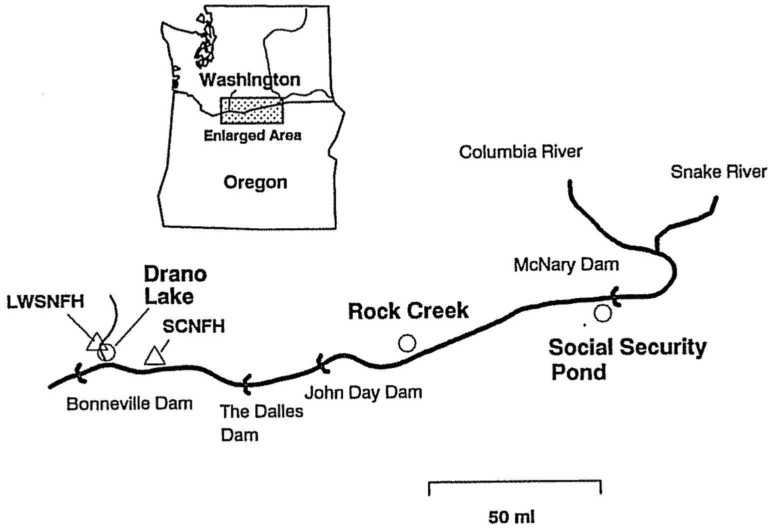

FIGURE 1.—Map of the Columbia River, from its confluence with the Snake River to Bonneville Dam, showing locations of dams as well as study sites (circles) and hatcheries (triangles) used for fish rearing during 1986–1987. Hatcheries are Spring Creek National Fish Hatchery (SCNFH) and Little White Salmon National Fish Hatchery (LWSNFH).

measurements. Flow in Drano Lake was estimated using movement of dye through a net-pen because the morphometry of Drano Lake (small inlet, backwater lake, and small outlet) made laminar flow estimates inappropriate. Water flow through the net-pens at Rock Creek was estimated as 56.5 gal/min. The estimated flow through the pens in Drano Lake ranged from 349.1 to 87.3 gal/min, based on measurements of 1–4 h for the dye to flow through a net-pen; the latter estimate was used to determine fish loading densities in Drano Lake. Carrying capacity estimates based on water flow and temperature were from Leitritz and Lewis (1980).

Each year fish were transferred from the hatcheries between 7 and 18 March and were released from the study sites between 15 and 22 May. Fish were reared until water temperatures reached and remained above 60°F, at which point fish had typically reached a size of about 90 fish/lb; enteric redmouth disease caused by the bacterium *Yersinia ruckeri* had been observed above this temperature during previous rearing trials. Fish in the net-pens were fed a commercial formulated dry feed at a rate of 3–4% body weight/d by means of automatic feeders. Fish in the hatcheries were hand-fed a moist feed at the same rate. Moist feed could not be used at the off-station sites due to the lack of refrigeration. More detailed information pertaining to rearing can be found in Novotny and Macy (1991).

In 1987, prior to the rearing trials, broodstock spawned at the Little White Salmon NFH were diagnosed with infectious hematopoietic necroses (IHN). Eggs from the entire upriver bright stock at the hatchery were subsequently exposed to IHN virus in the rearing water. Therefore, transferring fish off-station was not possible because it was contrary to disease policies of the U.S. Fish and Wildlife Service and other agencies in the Columbia River basin. To continue the study, net-pens from Rock Creek were relocated to Drano Lake, the backwater of the Little White Salmon River adjacent to the hatchery. After the juvenile fish were transferred to the net-pens in Drano Lake, those in the hatchery were diagnosed with IHN and were subsequently destroyed. Fish in the net-pens were examined for the presence of disease on eight occasions over the 9-week rearing period. Results of these examinations were negative, and fish were released from the net-pens on schedule. Fish were not reared at Rock Creek in 1987.

Adult contributions of fish reared off-station was compared with fish reared and released from the Little White Salmon NFH because all upriver bright chinook salmon reared at Spring Creek NFH were released at off-station locations. All fish were tagged with coded wire tags and had their adipose fin clipped for evaluation of adult contribution. Unique tag codes were used for each of the net-pen density treatments and hatchery control groups. Fish reared at the Little White Salmon NFH were released directly from the hatchery into Drano Lake. This site is two dams and 66 river miles downstream from the Rock Creek study area.

A combination of trap nets and weirs was used to capture adults returning to Rock Creek during 1986–1989. A Merwin trap net was the most effective capture method at this site. On-site returns from the hatchery and the 1987 rearing trials in Drano Lake were recovered from the adult collection facility at the Little White Salmon NFH.

Adult recoveries were compiled from coded-wire-tag information in the Regional Mark Information System, Pacific States Marine Fisheries Commission, Portland, Oregon. Recoveries presented in this paper are estimated numbers of adults recovered listed in the database as of June 1993.

To normalize the percent recovery data, a modification of the Freeman and Tukey arcsine transformation was used (Zar 1984). Differences between arcsine-transformed percent adult contribution of the fish reared from net-pen treatments and the hatchery control were tested for significance using analysis of variance followed by Student–Newman–Keuls' multiple-range tests when significant $P \leq 0.05$ differences existed (SAS Institute 1986). Comparisons between net-pen treatments and hatchery control were not possible for the 1987 rearing year.

Rearing costs were compared using present value theory (Senn et al. 1984). This method incorporates capital costs, project life, and operating costs of each rearing method, enabling comparisons of diverse methods on a common scale. In our estimates, hatchery efficiency ratios (HER), in U.S. dollars per pound produced, were calculated based on the costs to produce a net gain of 1,000 lb of fish by means of each rearing method. More detailed information pertaining to HER calculations for the net-pen treatments may be found in Novotny and Macy (1991).

Estimates of rearing cost per adult recovery were made for each treatment based on the HER, size at release (number per pound), number of fish released, and total number of adults recovered. The cost per adult recovery, in 1987 dollars, was calculated as

$$\frac{\text{HER} \times \left(\dfrac{\text{number of juveniles released}}{\text{number per pound at release}}\right)}{\text{number of adults recovered}}.$$

Results

Rearing densities in the net-pens were approximately 3–14 times lower than the recommended maximum densities based on rearing space, and were 5–15 times lower than those in the hatchery raceways (Banks et al. 1979; Table 1). However, based on flow indices, densities in the net-pens were often greater than both the recommended maxima and those in the hatchery raceways (Wedemeyer et al. 1981). Despite the high flow indices, survival during rearing was greater than 98% in all treatments; manifestations of overcrowding were not observed in any of the net-pen or hatchery treatments in 1986, but IHN was diagnosed in control fish from the Little White Salmon NFH in 1987.

The percent adult contribution of fish from the net-pen treatments in 1986 was significantly lower than from fish released from the Little White Salmon NFH (Figure 2A). Percent contribution from the regular density treatment at Rock Creek in 1986 was significantly higher than that from the double density treatment, but the triple density treatment was not significantly different from either of these. There were no significant differences in percent recovery between the four densities tested at Drano Lake in 1987.

There was a direct relation between the number of fish reared in the pens and the total number of adult recoveries per pen. This relation was most evident in the 1987 Drano Lake trials, in which each increase in density produced a significant increase in the total number of adults recovered per pen (Figure 2B). The triple density treatment at Rock Creek in 1986 resulted in significantly more adult recoveries per pen than did the regular and double densities, which were not different from each other.

Based on cost per adult recovered, the hatchery raceway was a more economical rearing method than were the net-pen treatments at Rock Creek in 1986. Rearing cost per adult recovered for the hatchery was US$11.57 in 1986 (Table 2). The cost per adult recovered from the net-pen treatments in 1986 ranged from $25.90 (triple density) to $54.83 (double density). Cost per recovery for the Drano Lake trials in 1987 ranged from $4.06 (quadruple density) to $13.82 (regular density). These costs depended primarily on the number of adults recovered in each year, as the rearing costs (HER) varied little between years. Hatchery estimates are not available for the 1987 trials due to disease.

TABLE 1.—Summary of fall chinook salmon off-station rearing treatments tested at Rock Creek (RC) in 1986 and Drano Lake (DL) in 1987, and hatchery controls at the Little White Salmon NFH (LW) in 1986. The four treatment densities ranged from 0.06 to 0.273 lb/ft^3.

Site and enclosure type	Release information: Treatment	Rearing survival (%)	Number fish/pen	Fish/lb	Spatial index (lb/ft^3)[a]	Flow index[b]	Adult contribution (%)
			1986				
RC, net-pen	Regular	98.4	18,030	78	0.082	1.39	0.180
	Double	99.8	37,794	70	0.193	3.34	0.080
	Triple	99.7	55,055	72	0.273	4.81	0.124
LW, raceway		99.6	201,657	108	1.250	1.22	0.408
			1987				
DL, net-pen	Regular	99.7	17,873	107	0.060	0.17–0.68	0.582
	Double	99.6	36,826	101	0.130	0.36–1.44	0.495
	Triple	99.2	54,380	110	0.176	0.51–2.05	0.471
	Quadruple	99.4	74,358	105	0.253	0.72–2.91	0.523

[a]Recommended maximum 0.890 lb/ft^3 (Banks et al. 1979).
[b]Flow index equals weight fish/(fish length × gal/min); flow indices at Rock Creek based on 56.5 gal/min; those at Drano Lake based on 87.3 to 349.1 gal/min. Recommended maximum is 1.26–1.80 (Wedemeyer et al. 1981).

Discussion

The lack of differences between percent adult contribution from the different density treatments indicates that the densities tested in this study did not exceed a maximum density under the rearing conditions at the off-station sites. It may also be concluded that there was no density effect over the range of densities tested. In this study, fish reared at the highest density produced the greatest number of adults per unit of rearing space. We believe this was not due to a direct relation between increased rearing density and adult production, but to the low densities used in this study. Other investigators have found inverse relations between juvenile salmonid rearing density and adult contribution (Martin and Wertheimer 1989; Banks 1992). However, the densities tested in their studies were higher than ours, possibly due to differences in flow and temperature conditions during rearing.

The maximum practical loading densities for the rearing conditions and methods we employed are difficult to estimate, as water temperatures and flow rates in backwaters of the Columbia River can be unpredictable and are beyond the control of the fish manager. Loading densities in this study were limited not by rearing space but by water flow. We based our densities on measured water flows at the sites; however, the appropriate rearing density may have been underestimated, as it did not account for water movement caused by fish in the pen. Chacon-Torres et al. (1988) reported that water exchange through net cages can be increased by swimming behavior of fish.

The rearing densities in this study were not high enough to determine the density limits in these backwaters. However, our results indicate that a density of at least 0.273 lb/ft^3 at release can be used with success in backwaters of the Columbia River. We chose to be conservative in choosing the densities in this study, and manifestations of overcrowding in the rearing enclosures were not noted. Water temperature was the primary impetus for release, because disease problems were noted during sustained water temperatures above 60°F during prior trials.

Comparisons of adult contribution of fish reared at the off-station sites and those at the Little White Salmon NFH were confounded by differences in release locations. Juveniles reared at Rock Creek were required to migrate past two dams and 66 miles of reservoir before reaching the release site of fish from the Little White Salmon NFH. We believe much of the difference in contribution between hatchery and Rock Creek treatments was due to in-river mortality of juveniles associated with the difference in release locations. Estimates of juvenile mortality associated with dam and reservoir passage vary from 10 to 45% per project (Schoeneman at al. 1961; Sims and Ossiander 1981; McKenzie et al. 1983). This includes mortality from predation by other fish, which has been estimated as 14% in John Day Reservoir alone (Rieman et al. 1991). It is

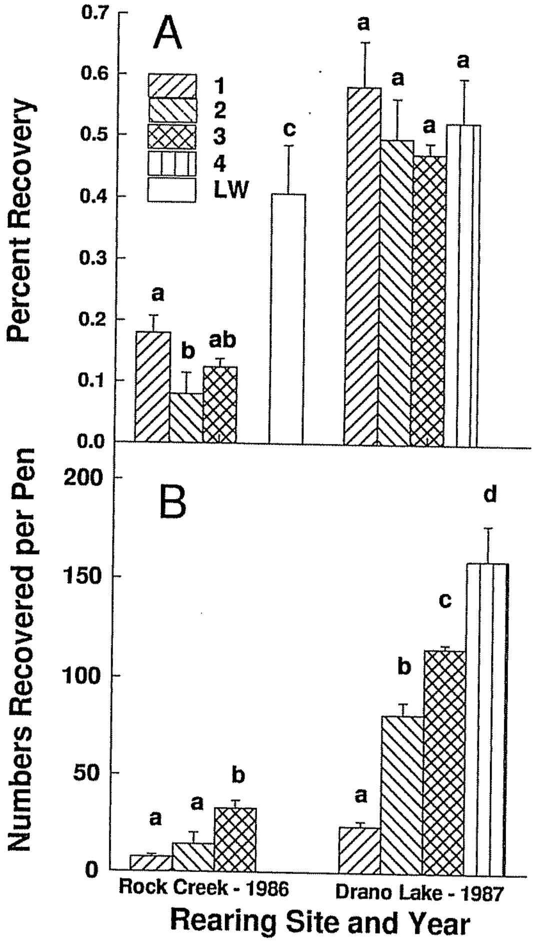

FIGURE 2.—Mean percent (A) and mean numbers (B) of adult upriver bright fall chinook salmon recovered per net-pen for regular (1), double (2), triple (3), and quadruple (4) densities of fish reared in net-pens at Rock Creek in 1986 and Drano Lake in 1987, and those reared at the Little White Salmon NFH (LW) in 1986. Vertical bars represent one standard deviation. In the same years, bars with the same letter are not significantly different from one another ($P \leq 0.05$).

likely that much of the difference in adult recoveries between hatchery and Rock Creek treatments was due to in-river mortality of juveniles; fish were healthy during off-station rearing, grew faster, were at a more advanced stage of smoltification at release, and were larger at release compared with those reared in the hatcheries (Novotny and Beeman 1990; Novotny and Macy 1991). This premise is supported further by data indicating the contribution of fish reared at Rock Creek (mean = 0.128%) was not significantly different than that of fish from

TABLE 2.—Data used to calculate rearing cost per adult fish recovered. Cost per recovery is (efficiency ratio × number released ÷ number/pound) ÷ number recovered. Treatments include four rearing densities in net-pens and fish reared at the Little White Salmon NFH (Hatchery).

Year and treatment	Efficiency ratio[a]	Fish released	Fish/lb	Fish recovered	Cost per adult (US$)
1986					
Regular	7.64	205,930	78	370	54.52
Double	3.09	70,803	70	57	54.83
Triple	2.34	105,839	73	131	25.90
Hatchery	5.10	195,310	108	797	11.57
1987					
Regular	8.61	194,917	107	1,135	13.82
Double	3.96	65,880	101	326	7.92
Triple	3.15	98,005	110	462	6.07
Quadruple	2.23	121,839	105	637	4.06

[a]See Novotny and Macy (1991).

Spring Creek NFH released one reservoir upstream in the Hanford reach of the Columbia River (mean = 0.126%), and was significantly higher than that of fish released in the lower Yakima River (also one reservoir upstream; mean = 0.037%; $P = 0.0029$).

It is unfortunate that the hatchery control fish in 1987 contracted IHN and were subsequently destroyed. The comparison of adult returns from the rearing trials in Drano Lake and controls from the Little White Salmon NFH would have been a comparison of rearing methods without the confounding effects of differences in release sites. The 1987 rearing trials in Drano Lake resulted in higher adult recoveries than previous off-station trials, indicating a possible site effect. However, these differences could have also been due to changes in ocean conditions or other postrelease variables.

Fish reared in the net-pens may have been less susceptible to disease than were fish reared in the hatchery. Disease was not detected in fish transferred to the net-pens in 1987, although they were from the same bank of raceways as the fish in the hatchery that later were destroyed due to IHN. The reduced spatial densities in the net-pens is one possible reason IHN was not detected in these fish. Increased rearing density has been shown to elicit stress in juvenile salmonids, which can increase susceptibility to disease (Wedemeyer 1976; Maule et al. 1989; Salonius and Iwama 1993).

In summary, rearing fish off-station produced mixed results. Fish reared in net-pens performed well during rearing, but yielded a lower adult contribution than did fish reared and released directly at the hatchery two dams downstream. This comparison was confounded by differences in release sites, and disease in the hatchery limited comparisons to only one year. Based on growth and physiology during rearing and adult contribution, fish reared at the highest density (about 74,000 fish per pen) proved to be the most productive off-station method used in this study. Rearing fish in backwaters and ponds along the Columbia River may be useful as a repository for "thinning releases," as a low-cost method to hold increased production when egg take exceeds hatchery rearing capacity, or possibly as an outright addition to traditional hatchery methods.

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