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Effects of Density and Loading on Coho Salmon during Hatchery Rearing and after Release

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Abstract.—Two broods of coho salmon fingerlings (*Oncorhynchus kisutch*) were reared at three densities (25,000, 50,000, and 75,000 fish/raceway) and at three levels of water inflow (757, 1,514, and 2,271 L/min per raceway) at a year-round coldwater hatchery. All nine density–inflow combinations were tested (2 raceways/treatment). During the rearing phase of the study, various physiological and disease status indicators were tested for differences from rearing density (kg of fish/m^3 of rearing space) and loading (kg of fish/[L of water flow·min]). After release from the hatchery, survival, adult contribution, and fishery catch data were also examined for treatment effects. Fingerlings reared at the lowest density were smaller at release than fish reared at the two higher densities. Gill ATPase at release was reduced in fish reared at the highest density and also in fish reared at the lowest water inflow rate. Increased rearing density produced small but significant reductions in percent survival of smolts after release but did not significantly depress total adult contributions per raceway. A direct linear relationship was found between increased rearing density and adult contribution per raceway. Of the adults returning to the hatchery, those that had been reared at the lowest density were longer (based on fork length) than those that had been reared at higher densities. Raceway loadings produced no measurable effects on fish growth, survival, or adult contribution after release.

Historically, salmon have been important to the economy of the Pacific Northwest. Various stocks have been harvested by recreational, commercial, and tribal fishermen in high seas and in coastal and freshwater fisheries for many years. As a result of the steady increase in fishing pressure, conflicts have arisen among the various user groups over a limited and valuable resource. Because of the rising public demand for salmon, production of as many harvestable fish as possible by hatcheries has become increasingly important.

If adult salmon contributions are to be maximized, hatcheries must operate at maximum efficiency by effectively allocating and managing basic resources such as rearing space, water flow, and fingerling production. Previous studies of the effects of rearing density on survival of smolts after release from hatcheries—published studies (Fagerlund et al. 1987; Denton 1988; Martin and Wertheimer 1989) and several unpublished studies (T. Downey, Oregon Department of Fisheries and Wildlife; C. Hopley, Washington Department of Fisheries; A. Hemingsen, Oregon Department of Fisheries and Wildlife; and K. Sandercock, Canada Department of Fisheries and Oceans)—have produced widely variable and sometimes conflicting results. Many factors such as species or stock, water quality, pond type, or disease are likely to interact with different levels of production intensity to give results that are often useful only at individual hatcheries.

The goal of this study was to determine the effects of different levels of both rearing density (kg of fish/m^3 of rearing space) and raceway loading (kg of fish/[L of water flow·min]) on coho salmon (*Oncorhynchus kisutch*) reared in linear-flow raceways in a year-round coldwater environment at the Willard (Washington) National Fish Hatchery. Treatment effects on physiological and disease status of the fingerlings and smolts were evaluated during rearing. Postrelease survival rates, adult contribution levels, lengths of adult hatchery returns, fishery catch : hatchery escapement ratios, and fishery catch distributions were also statistically tested for treatment effects. Additional in-hatchery effects on physiological development have been reported by Patiño et al. (1986).

Methods

Willard National Fish Hatchery is above Bonneville Dam, about 270 km above the mouth of the Columbia River. Rearing was done initially with fish of the 1981 brood and repeated with fish of the 1982 brood. In a three-way factorial design, coho salmon fingerlings were reared for approximately 1 year at densities of 25,000, 50,000, and 75,000 fish/raceway and at constant water inflow rates of 757, 1,514, and 2,271 L/min. Paired raceways were set up for each rearing density–water inflow combination (experimental cell). A total of 18 raceways was used to rear fish of each brood. All fish were released at the hatchery site into the Little White Salmon River, a tributary of the Columbia River.

Fingerlings from each brood in the study were reared from the initial feeding in 2.9-m^3 troughs (0.8 m wide by 4.6 m long by 0.8 m deep) in the hatchery building. Before the test raceways were stocked, fish in all troughs were pooled and overall mean weights were determined from randomly netted subsamples. Mean weights were then used to calculate and randomly establish initial stocking weights in each raceway.

All fish were reared in 35.1-m^3 linear-flow raceways (2.4 m wide by 24.4 m long by 0.6 m deep) in second-use river water from an upper bank of raceways. Inflow into each raceway was monitored with staff gauges mounted on raceway walls. Staff gauge heights were calibrated to elevations of V-notch weirs in the tailrace boards of each raceway.

Fingerlings of the 1981 brood, which averaged 3.8 ± 0.06 g each, were stocked into raceways on June 15, 1982, and released on June 7, 1983. Coho salmon of the 1982 brood, which averaged 4.0 ± 0.03 g each, were stocked on June 14, 1983, and released on June 8, 1984. Raceway populations were not thinned during the study. From initial stocking through final release, all fish were fed the Oregon moist pellet diet. Fish in each raceway were sampled monthly to determine growth rates, and feeding levels were adjusted accordingly. Feeding levels for the 1982 brood were reduced by about 10% beginning in September to maintain growth rates and raceway weights at levels comparable to those of the 1981 brood. Because of an outbreak of bacterial kidney disease (pathogen, *Renibacterium salmoninarum*), fish of the 1981 brood were fed oxytetracycline (TM-50) in the diet (3.5 g active ingredient/45 kg of fish) for 14 d in July 1982. In addition, a 1-h flowing treatment of benzalkonium chloride (Roccal®, 2 mg/L) was used every other day for 3 d during July 1982 to treat 1981 brood fish for cold-water disease (pathogen, *Cytophaga psychrophila*). Oxytetracycline was also fed to the 1982 brood fish for 10 d, as a treatment for bacterial kidney disease, after initial stocking in June 1983. Deaths within each raceway were counted throughout rearing of both broods.

Characteristics of the influent water from the Little White Salmon River were monitored during 1983 with methods outlined in APHA et al. (1975) and EPA (1979). Before fish were released, dissolved oxygen, ammonia, and pH were measured in the effluent of each raceway. Dissolved oxygen was measured with a model 54RC oxygen meter (Yellow Springs Instruments Corp., Yellow Springs, Ohio). A model 407A ion meter (Orion Research, Inc., Cambridge, Massachusetts) was used to measure pH. Ammonia levels were determined with the method of Solorzano (1969). Unionized ammonia concentrations were calculated with the method of Emerson et al. (1975).

The method described by Zaugg (1982) was used to monitor ATPase activity. The test used to measure response to saltwater challenge is outlined in Clarke and Blackburn (1977). The fluorescent antibody technique used to determine bacterial kidney disease carrier rate is described by Bullock et al. (1980).

To evaluate treatment effects on survival after release, about 25,000 fish within each raceway received raceway-discrete coded wire tags (Northwest Marine Technology, Inc., Shaw Island, Washington) and adipose fin clips. All groups were tagged and fin-clipped in June, shortly after initial stocking.

After release, coded-wire-tagged fish were recovered throughout the fisheries through the coastwide sampling efforts of various government agencies. Observed recoveries and catch sampling effort within each fishery were used to expand estimates of fishery catch for each coded-wire-tagged group. All coded-wire-tagged adults returning to the hatchery were recovered at the upstream trap and holding pond at Little White Salmon National Fish Hatchery, Cook, Washington. Hatchery escapements of coded-wire-tagged fish were combined with estimated fishery recoveries to obtain estimates of total recoveries for each tagged group. Tagged release:untagged release ratios were used to further expand total recoveries by tag-group to obtain estimates of total adult contribution from each raceway.

Methods of statistical testing are outlined in Snedecor and Cochran (1967). Regression techniques for three-way analysis of variance (rearing density × loading × brood year) were used to test for treatment effects on fingerlings during rearing, and for treatment effects on survival rates and fishery catch after release from the hatchery. A two-way analysis (rearing density × loading) was used when data were available from only a single brood year or when significant main-factor interactions involving brood year were found. Orthogonal contrasts were used to determine significance of differences among means of levels within treatments. Because of the different expansion factors used to estimate adult yield at each density level, analysis of variance of regression slopes (adult contribution on density level) and orthogonal contrast from a linear trend were used to examine rearing density effects on total adult contribution. Differences were considered significant at the 95% confidence level ($P < 0.05$). The data were analyzed with BMDP (Biomedical Programs) statistical software (1988 release, BMDP Statistical Software, Inc., Los Angeles, California).

Results

In-Hatchery Performance

Influent water, collected from the headbox of the raceways, showed low ion concentrations, low total hardness, and little seasonal variation in any of the measured constituents (Table 1). Water temperatures were low throughout rearing of both broods (Figure 1): mean monthly temperatures ranged from 4.6°C (December 1982) to 7.1°C (August 1982) during rearing of the 1981 brood, and from 3.5°C (December 1983) to 7.2°C (June 1983) during rearing of the 1982 brood.

Over the 1-year period of hatchery residence, fish of each brood increased in size from about 4 g at stocking to 24 g at release. Raceway loadings

TABLE 1.—Seasonal characteristics of influent water from the Little White Salmon River during test rearing of coho salmon of the 1981 brood at Willard National Fish Hatchery in 1983. Values shown are dissolved concentrations (mg/L), except the values for conductivity and pH.

Characteristic	Sampling day: Feb 2	May 10	Aug 10	Nov 30
Alkalinity, as $CaCO_3$	19	17	20	22
Conductivity at 25°C (μS)	44	37	37	51
Total hardness, as $CaCO_3$	15	14	14	20
pH	7.5	7.4	7.1	6.7
Orthophosphate, as PO_4	0.040	0.056	0.039	0.048
Total dissolved residue, as filtrate at 105°C	33	33	26	46
Total suspended residue, nonfilterable at 105°C	2.0	<1.0	2.0	2.0
Chloride	<1.0	<1.0	<1.0	<1.0
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005
Calcium	4.0	3.6	3.7	5.4
Cobalt	<0.03	<0.03	<0.03	<0.03
Copper	0.0014	0.0016	0.0010	0.0007
Iron	<0.03	<0.03	<0.03	<0.03
Lead	0.0036	0.0064	0.0092	0.0092
Magnesium	1.2	1.2	1.2	1.7
Manganese	0.0008	0.0012	0.0053	0.0016
Molybdenum	<0.2	<0.2	<0.2	<0.2
Potassium	0.30	0.46	0.49	0.52
Sodium	2.6	2.1	2.0	2.3
Sulfate, as SO_4	<1.0	<1.0	<1.0	<1.0
Zinc	<0.01	<0.01	<0.01	<0.01

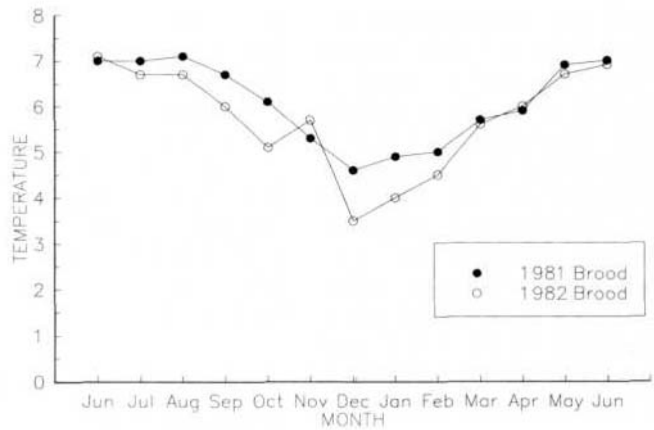

FIGURE 1.—Mean monthly temperatures (°C) of Little White Salmon River water during rearing of coho salmon from the 1981 brood (June 1982–June 1983) and from the 1982 brood (June 1983–June 1984).

(biomass per unit of water flow) had no effect on growth or weight at release of the 1981 or 1982 brood fish (Table 2). Although fish of the 1982 brood received reduced rations, they were larger in mean weight at release than 1981 brood fish. When brood-year data were combined, fish reared at the lowest density weighed less than did fish reared at either of the higher densities (Table 2; $P < 0.001$). Within broods, however, mean weight at release between fish reared at any density was not significantly different.

Fingerling growth produced a sixfold increase in total raceway weight loads by the end of test rearing. Biomass per unit of rearing space varied

TABLE 2.—Mean weights (g/fish) of coho salmon smolts of the 1981 and 1982 broods at their release. Fish were reared in 35.1-m^3 raceways at three densities and at three water inflow rates. Values are means of paired raceways. Standard errors are given in parentheses.

Water inflow (L/min per raceway)	Rearing density (per raceway)			Mean for all densities[a]
	25,000 fish	50,000 fish	75,000 fish	
		1981 brood year[b]		
757	22.9 (0.1)	24.2 (0.4)	23.2 (0.2)	23.4 (0.3)
1,514	22.2 (0.2)	23.9 (0.6)	23.0 (0.0)	23.0 (0.3)
2,271	23.0 (1.3)	22.9 (0.2)	23.9 (0.5)	23.3 (0.4)
Mean for all flows	22.7 (0.4)	23.6 (0.3)	23.4 (0.2)	
		1982 brood year[b]		
757	23.7 (0.9)	24.6 (0.2)	24.0 (0.1)	24.1 (0.3)
1,514	23.8 (0.1)	24.9 (0.1)	24.5 (0.4)	24.3 (0.3)
2,271	22.3 (0.8)	25.1 (0.4)	24.1 (0.1)	23.9 (0.5)
Mean for all flows	23.2 (0.4)	24.9 (0.2)	24.2 (0.1)	
		Combined brood years		
757	23.3 (0.4)	24.4 (0.2)	23.6 (0.2)	23.7 (0.2)
1,514	23.0 (0.1)	24.4 (0.4)	23.7 (0.4)	23.6 (0.3)
2,271	22.7 (0.6)	24.0 (0.7)	24.0 (0.2)	23.7 (0.3)
Mean for all flows[c]	23.0 (0.3) y	24.2 (0.2) z	23.8 (0.2) z	

[a] Mean flows for combined broods did not differ significantly.

[b] Mean weights were 23.0 ± 0.2 g for fish of the 1981 brood and 24.1 ± 0.2 g for fish of the 1982 brood, and these values are significantly different ($P = 0.002$).

[c] Within this row, means followed by different letters are significantly different ($P < 0.001$).

TABLE 3.—Biomass per unit of rearing space and per unit of water inflow at release of coho salmon of the 1981 and 1982 broods. Fish were reared in 35.1-m^3 raceways at three densities and at three water inflow rates. Values are mans of paired raceways.

Brood year	Water inflow (L/min per raceway)	Rearing density (per raceway) 25,000 fish	50,000 fish	75,000 fish
		Density (kg of fish/m^3 of rearing space)		
1981	757	14.8	32.0	44.3
	1,514	14.3	30.8	44.8
	2,271	14.7	29.9	46.1
1982	757	13.4	28.6	37.2
	1,514	13.8	29.8	37.9
	2,271	13.5	27.0	40.0
		Loading (kg of fish/[L of water flow·min])		
1981	757	0.71	1.53	2.12
	1,514	0.35	0.74	1.07
	2,271	0.24	0.48	0.74
1982	757	0.64	1.37	1.78
	1,514	0.33	0.71	0.91
	2,271	0.22	0.43	0.64

proportionately with rearing density (number of fish/raceway). Biomass per unit of water flow varied with both rearing density and rate of water flow (Table 3). Differences in density level resulted in about a threefold increase in biomass produced per unit of rearing space (14.3–46.1 kg/m^3 at release of the 1981 brood and 13.4–40.0 kg/m^3 at release of the 1982 brood). Smolt biomass per unit of water flow varied by a factor of 8.8 at release of the 1981 brood of fish (0.24–2.12 kg/[L·min]) and by a factor of 8.1 (0.22–1.78 kg/[L·min]) at release of the 1982 brood.

Dissolved oxygen, total ammonia, and pH in raceway effluents reflected biomass per unit of water inflow on the day before release (Table 4). The lowest dissolved oxygen and highest total ammonia levels were recorded in the effluents of raceways with the highest rearing density and lowest rate of water inflow. Hydrogen ion concentration did not vary greatly between raceways. Calculated un-ionized ammonia concentrations in the effluents ranged from 0.00033 mg/L in raceways with 25,000 fish and 2,271 L inflow/min to 0.00069 mg/L in raceways with 75,000 fish and 757 L inflow/min at release of the 1981 brood.

Fingerling and smolt losses during rearing were almost entirely due to infections of bacterial kidney disease and cold-water disease. Three-way analysis of variance of percent loss data revealed significant interactions between all possible combinations of factors (rearing density × loading,

TABLE 4.—Dissolved oxygen, total ammonia, and pH in raceway effluents on the day before release of coho salmon of the 1981 and 1982 broods. Fish were reared in 35.1-m^3 raceways at three densities and at three water inflow rates. Values are means of paired raceways. Influent wtaer temperatures at the time of raceway effluent measurements were 7.8°C for the 1981 brood and 8.0°C for the 1982 brood.

Brood year	Water inflow (L/min per raceway)	Rearing density (per raceway) 25,000 fish	50,000 fish	75,000 fish
		Dissolved oxygen (mg/L)[a]		
1981	757	10.2	9.0	8.4
	1,514	11.1	10.8	9.8
	2,271	11.0	10.8	10.1
1982	757	9.6	8.1	8.4
	1,514	9.9	9.4	9.8
	2,271	10.2	9.8	10.1
		Total ammonia (mg/L)[b]		
1981	757	0.23	0.28	0.35
	1,514	0.20	0.21	0.26
	2,271	0.17	0.19	0.23
1982	757	0.24	0.39	0.44
	1,514	0.21	0.25	0.32
	2,271	0.19	0.21	0.26
		pH values[c]		
1981	757	7.1	7.0	7.1
	1,514	7.1	7.1	7.0
	2,271	7.1	7.0	7.0
1982	757	7.1	7.0	6.8
	1,514	7.1	7.1	7.0
	2,271	7.0	7.0	7.1

[a] Influent dissolved oxygen concentrations at the time of raceway effluent measurements were 11.5 mg/L for the 1981 brood and 11.0 mg/L for the 1982 brood.
[b] Influent total ammonia concentrations at the time of raceway effluent measurements were 0.12 mg/L for the 1981 brood and 0.14 mg/L for the 1982 brood.
[c] Influent pH levels at the time of raceway effluent measurements were 7.2 for the 1981 brood and 7.1 for the 1982 brood.

rearing density × brood year, loading × brood year, and rearing density × loading × brood year). Significant interactions were again found when a two-way analysis was done on data within each brood year. Treatment effects on in-hatchery mortality, therefore, were not conclusive. Even though significant differences could not be demonstrated, overall losses for the 1982 brood were nearly four times higher than for the 1981 brood.

Rates of bacterial kidney disease carriers in fish samples collected at release reflected observed differences in fingerling rearing mortality between broods. Carrier rates averaged 2.8% in the 1981 brood and 26.8% in the 1982 brood, and these values differed significantly ($P < 0.001$). Effects of rearing density were not significant. Raceway loadings also had no significant effect on carrier rate.

When samples of fish from the 1982 brood were placed in 26‰ artificial seawater for 24 h just before release, their plasma sodium levels were not significantly affected by either rearing density or water inflow. Plasma sodium concentrations, a reflection of osmoregulatory ability of fish in seawater (Clarke and Blackburn 1977), ranged from 174.8 to 186.4 meq/L. The highest level, however, was observed in fish samples from raceways with the highest rearing density and lowest water inflow.

Gill ATPase activity levels in fish from raceways with the lowest rearing density followed a normal pattern of development (Zaugg and McLain 1972) during the final 2 months of rearing (Figure 2). In contrast, activity levels were suppressed in fish from raceways with the highest rearing density. In the case of both broods, just before release, ATPase levels in fish from raceways with the highest rearing density and lowest water flow showed signs of reversion from the upward trend of activity. On the final sampling date, significant treatment effects from rearing density were found ($P = 0.002$). Marginally significant effects ($P = 0.049$) from loading were also found.

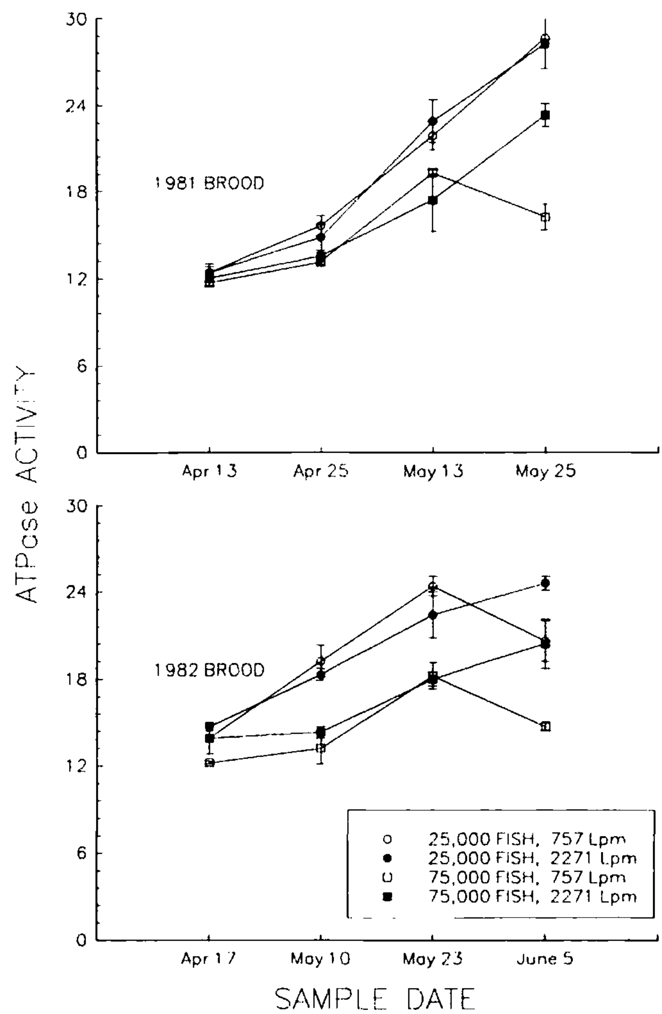

FIGURE 2.—Mean changes in gill Na^+, K^+ ATPase activity (μmol P_i/[h·mg protein]) in coho salmon (1981 and 1982 broods) reared at density of 25,000 or 75,000 fish/raceway and at a water inflow rate of 757 or 2,271 L/min. Vertical bars represent standard errors of the means.

Postrelease Survival and Adult Contribution

After release from the hatchery, coded-wire-tagged fish were caught in 33 sport and commercial fisheries from California to Canada. About 95% of the total catch were from the Oregon, Washington, and Columbia River fisheries. Nearly 60% of all recoveries were adults that returned to the hatchery; only two of these returning fish were 2-year-old fish (jacks).

Increased rearing densities caused reductions in survival rate of smolts after release (Table 5). Percent survival was significantly higher ($P < 0.001$) in fish reared at the lowest density level than in fish reared at either of the two higher densities. The difference in survival between groups of fish reared at the two highest densities was not significant. Raceway loading (biomass per unit of water flow) also had no apparent effect on survival of smolts after release. Survival was greater in the 1982 brood than in the 1981 brood ($P < 0.001$).

Although raceway loading had little effect on adult contribution per raceway, increased rearing densities produced greater numbers of adults (Table 6). Regression slopes of adult yield on rearing density at each level of water inflow were statistically greater than zero (analysis of variance, $P < 0.001$), which indicates that the increased numbers of fish reared at the high densities produced significant increases in adult contribution. An orthogonal-trend analysis of adult yield on rearing density indicated a close relationship to linearity ($P < 0.000$); the least-squares regression estimation was as follows: $y = 44.3 + 0.0034x$, where y = adult yield and x = rearing density level (Figure 3).

Of the fish that returned to the hatchery as adults, those reared at the lowest density were significantly longer ($P < 0.001$) in mean fork length than were those reared at densities of 50,000 or 75,000 fish/raceway (Table 7). Lengths were not different between returning adults from raceways with 50,000 or 75,000 fish, or from raceways with different water inflow. Returns to the hatchery from the 1982 brood were about 9 cm longer than those from the 1981 brood.

Rearing density and raceway loading had no effect on either fishery catch:hatchery escapement ratios or sex ratios in adults returned to the hatchery. Recovery of coded-wire-tagged groups within individual fisheries was too small for evaluations

TABLE 5.—Estimated percentage of coho salmon of the 1981 and 1982 broods that were recovered as adults after release. Fish were reared in 35.1-m^3 raceways at three densities and at three water inflow rates. Recoveries include hatchery returns and fishery catch. Values are means of paired raceways. Standard errors are given in parentheses.

Water inflow (L/min per raceway)	Rearing density (per raceway)			Mean for all densities[a]
	25,000 fish	50,000 fish	75,000 fish	
		1981 brood year[b]		
757	0.43 (0.01)	0.41 (0.02)	0.40 (0.08)	0.41 (0.02)
1,514	0.42 (0.09)	0.40 (0.02)	0.30 (0.00)	0.37 (0.03)
2,271	0.56 (0.13)	0.43 (0.00)	0.41 (0.04)	0.47 (0.05)
Mean for all flows	0.47 (0.05)	0.41 (0.01)	0.37 (0.03)	
		1982 brood year[b]		
757	0.84 (0.08)	0.65 (0.08)	0.62 (0.09)	0.70 (0.06)
1,514	0.59 (0.13)	0.59 (0.11)	0.53 (0.01)	0.57 (0.04)
2,271	0.71 (0.01)	0.46 (0.01)	0.65 (0.00)	0.61 (0.05)
Mean for all flows	0.71 (0.06)	0.57 (0.05)	0.60 (0.03)	
		Combined brood years		
757	0.64 (0.12)	0.53 (0.08)	0.51 (0.08)	0.56 (0.05)
1,514	0.51 (0.08)	0.49 (0.07)	0.42 (0.07)	0.47 (0.04)
2,271	0.64 (0.07)	0.44 (0.01)	0.53 (0.07)	0.54 (0.04)
Mean for all flows[c]	0.59 (0.05) y	0.49 (0.03) z	0.48 (0.04) z	

[a] Mean flows for combined broods did not differ significantly.

[b] Recovery of adults averaged 0.42 ± 0.02% for the 1981 brood and 0.63 ± 0.03% for the 1982 brood, and these values are significantly different ($P < 0.001$).

[c] Within this row, means followed by different letters are significantly different ($P < 0.001$).

TABLE 6.—Estimated number of adult coho salmon recoveries contributed by each raceway for the 1981 and 1982 broods. Fish were reared in 35.1-m^3 raceways at three densities and at three water inflow rates. Recoveries include hatchery returns and fishery catch. Values are means of paired raceways. Standard errors are given in parentheses.

Water inflow (L/min per raceway)	Rearing density (per raceway)			Mean for all densities
	25,000 fish	50,000 fish	75,000 fish	
		1981 brood year[a]		
757	101 (4)	194 (11)	277 (59)	191 (36)
1,514	98 (22)	186 (7)	214 (4)	166 (23)
2,271	131 (32)	201 (1)	286 (30)	206 (31)
Mean for all flows	110 (12)	194 (4)	259 (22)	
		1982 brood year[a]		
757	173 (12)	273 (31)	346 (49)	264 (35)
1,514	135 (32)	255 (45)	297 (5)	229 (34)
2,271	146 (4)	180 (4)	391 (1)	239 (48)
Mean for all flows	151 (11)	236 (23)	345 (21)	
		Combined brood years		
757	137 (21)	233 (26)	312 (37)	227 (26)
1,514	116 (19)	221 (27)	256 (24)	197 (22)
2,271	138 (14)	191 (6)	338 (33)	222 (28)
Mean for all flows	130 (10)	215 (13)	302 (20)	

[a] Mean number of adult coho salmon recoveries per raceway was 187 ± 17 for the 1981 brood and 244 ± 22 for the 1982 brood.

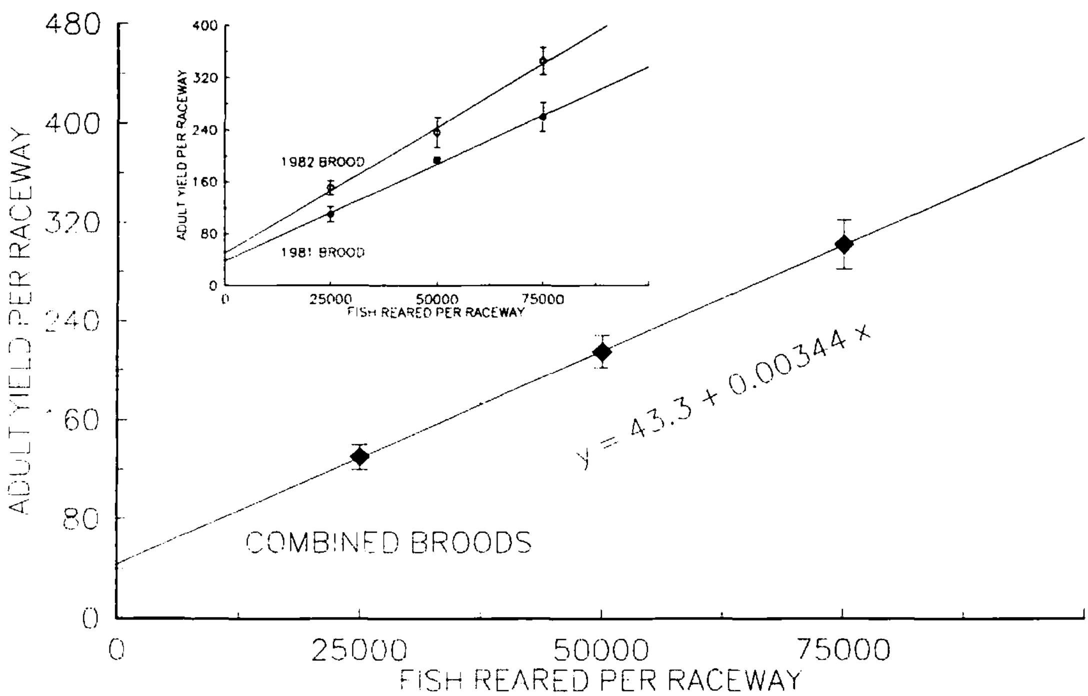

FIGURE 3.—Separate and combined means for adult yield of the 1981 and 1982 broods of coho salmon reared at three levels of rearing density. Vertical bars represent standard errors of the means.

TABLE 7.—Mean fork lengths (cm) of adult coho salmon of the 1981 and 1982 broods that returned to the hatchery. Fish were reared in 35.1-m^3 raceways at three densities and at three water inflow rates. Values are means of paired raceways. Standard errors are given in parentheses.

Water inflow (L/min per raceway)	Rearing density (per raceway)			Mean for all densities[a]
	25,000 fish	50,000 fish	75,000 fish	
		1981 brood year[b]		
757	57.7 (0.5)	56.7 (0.7)	56.7 (0.1)	57.0 (0.3)
1,514	57.0 (0.2)	55.5 (0.1)	56.9 (0.2)	56.5 (0.3)
2,271	57.6 (0.3)	57.3 (0.4)	55.8 (1.0)	56.9 (0.4)
Mean for all flows	57.4 (0.2)	56.5 (0.4)	56.5 (0.3)	
		1982 brood year[b]		
757	66.8 (1.0)	65.4 (0.7)	65.1 (0.6)	65.8 (0.5)
1,514	67.3 (0.3)	65.2 (0.9)	66.0 (0.6)	66.2 (0.5)
2,271	67.5 (0.1)	65.5 (0.3)	66.1 (0.7)	66.4 (0.4)
Mean for all flows	67.2 (0.3)	65.4 (0.3)	65.7 (0.3)	
		Combined brood years		
757	62.2 (2.7)	61.1 (2.5)	60.9 (2.4)	61.4 (1.3)
1,514	62.2 (3.0)	60.4 (2.8)	61.4 (2.6)	61.3 (1.5)
2,271	62.5 (2.9)	61.4 (2.4)	60.9 (3.0)	61.6 (1.5)
Mean for all flows[c]	62.3 (1.4) y	60.9 (1.4) z	61.1 (1.4) z	

[a] Mean flows for combined broods did not differ significantly.
[b] Mean fork lengths were 56.8 ± 0.2 cm for adult returns of the 1981 brood and 66.1 ± 0.3 cm for adult returns of the 1982 brood, and these values are significantly different ($P < 0.001$).
[c] Within this row, means followed by different letters are significantly different ($P < 0.001$).

of treatment effects on catch distribution. When catch data were grouped into larger geographic areas consisting of California and Oregon, the Columbia River, and Washington and Canada, significant treatment effects were not found.

Discussion

Raceway loadings had no effect on survival of smolts after release; and, with the exception of plasma cortisol (Patino et al. 1986) and gill ATPase levels, loadings had no effect on fingerlings or smolts during rearing. These results are not too surprising in view of the year-round cold temperatures of Little White Salmon River water. Although raceway loadings varied by a factor of 8 or 9 between treatment extremes at release, dissolved oxygen levels in raceway effluents were well above levels suggested as minimal for salmonid culture by Burrows and Combs (1968) and Westers and Pratt (1977). Calculated un-ionized ammonia concentrations in raceway effluents were also much lower than levels found to produce pathological changes in trout after prolonged exposure (Smith and Piper 1975).

Although increased rearing densities resulted in significantly reduced survival of fish after release, the strength of this effect was not sufficient to depress adult contributions. In a nearly linear relationship across all rearing densities, adult yield increased by 3.4 fish for each increase of 1,000 fingerlings stocked (Figure 3). Therefore, in terms of maximum adult contribution, the optimum fingerling production level at Willard Hatchery is at least equal to or in excess of 75,000 fish/raceway. At some rearing density in excess of 75,000 fish/raceway, however, adult contribution would be expected to decline. Some indication of practical upper limitations to this production capability were obtained during the rearing phase of the experiment. Fish reared at the highest density with the lowest rate of water inflow appeared lethargic and did not recover quickly during raceway cleaning, when water levels were drawn down. This response was not observed in fish in other raceways, including those with the same densities but higher water inflows.

Even though smolts reared at the lowest density were smaller in mean weight at release than fish reared at the other densities, returning adults from the lowest-density raceways were significantly longer than adults from raceways where either 50,000 or 75,000 smolts were reared. Greater numbers of large smolts from the low density raceways may have survived to return to the hatchery as adults, or smolts from these raceways may have grown faster after release. In rearing density studies with coho salmon, Fagerlund et al. (1981, 1983) reported that length-frequency distribution changed from larger to smaller fish (shift from positive to negative skewness) when fingerlings were reared at increased densities. The observed differences in fingerling length at release in their studies were not reflected in length or weight differences in adult returns, however.

Measurements of fingerling response to density and raceway loading during hatchery rearing included growth rate, mortality, and bacterial kidney disease carrier rate. Tests of smoltification status before release included gill ATPase activity and response to saltwater challenge. In addition, Patiño et al. (1986) monitored treatment effects on the pattern of physiological development during smoltification of the 1981 brood. In this study, significant treatment effects on percent mortality, bacterial kidney disease carrier rate, and response to saltwater challenge were not found. Raceway loading and rearing density both affected gill ATPase activity, however. Patiño et al. (1986) found that high rearing density resulted in reduced plasma thyroid hormones during smoltification. In their study, rearing density and loading were also associated with changes in plasma cortisol levels during the final 2 months of rearing. Although in both studies treatment-related differences were observed in fingerlings and smolts before release, these differences did not reflect the adult production capability of the various treatments. There is evidence that greater adult yields were attained at somewhat reduced levels of smolt quality, and that the adverse effects of crowding were overshadowed by the greater numbers of fish released from the higher rearing densities. In-hatchery fingerling performance or smolt quality, therefore, may not provide adequate information for making production management decisions aimed at obtaining maximum adult yields of coho salmon.

Caution is also warranted when results from rearing density studies at one hatchery are used to establish fingerling production guidelines at other hatcheries. Although effects from raceway inflow were limited in this study, tests of similar raceway loadings in warmer water may produce different results. Warmer temperatures increase fish metabolism and reduce the oxygen carrying capacity of water. At some undefined temperature, these concurrent factors are certain to produce stress-related differences in fish during rearing and differences in survival after release. Many other site-specific factors—such as tolerance of different races or species to crowding, variation in carrying capacity of different types of rearing units, and the presence of disease organisms—can affect survival of hatchery smolts.

Production levels as high as 75,000 fish/raceway seem economically attractive at Willard Hatchery. The increased cost of rearing fish at this level is small in comparison to annual expenditures for operation, maintenance, and administration, which are not related to levels of production intensity. Because of the value of today's salmon runs and the need to operate fish cultural facilities efficiently, studies of the smolt production–adult contribution relationship seem warranted at many other hatcheries.

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