Section 5

THE BEHAVIOR AND POSTRELEASE SURVIVAL OF FALL CHINOOK SALMON REARED IN CONVENTIONAL AND SEMINATURAL RACEWAYS, 1992[3]

By

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Introduction

In 1992, we constructed a rearing environment (for chinook salmon) comprised of sand and gravel substrates, aquatic plants for instream structure, and overhanging cover. We theorized that salmonids cultured in raceways that simulated their natural environment should develop more natural behavior and cryptic coloration, and should have higher rates of postrelease survival than those reared in conventional raceways. The initial experiment described in this section compared the effect of this seminatural rearing environment vs. a conventional culture environment on the behavior, coloration, disease status, growth, and postrelease survival of fall chinook salmon (*Oncorhynchus tshawytscha*).

Material and Methods

This study was conducted at the National Marine Fisheries Service (NMFS) Freshwater Fish Culture Laboratory at the University of Washington's (UW) Big Beef Creek Research Station near Seabeck, Washington. Fall chinook salmon eggs were obtained from the UW Big Beef Creek Hatchery.

Fish were reared under one of three treatment conditions (Fig. 5- 1). The conventional treatment represented a standard raceway environment (as described by Leitritz and Lewis 1980, Riper et al. 1982), and thus lacked any substrate, structure, or opaque overhead cover. The other two treatments represented seminatural rearing environments, with plastic aquarium plants and live watercress mot wads for instream structure and with opaque covers to simulate overhanging banks. Seminatural rearing treatments were outfitted with either sand or undergravel filter covered with pea gravel on the tank bottom. Four rearing tanks were used per treatment, and fish in all three treatments were fed a standard prepared pellet diet from the surface by hand. No therapeutic treatments were required during the study.

Fish were reared in 12 rectangular 400-L acrylic tanks. Each tank was 46 cm wide, 46 cm deep, 152 cm long, and was maintained at a depth of 43 cm Four liters per minute of 10ºC well water was supplied to each tank through a lo-cm-diameter opening. All 12 tanks were supplied with air via four airstones spread along the bottom rear of each tank. Sheets of grey-black painted polystyrene were fitted to the outside of both ends, the rear, and the bottom of all tanks to simulate the grey concrete background coloration of a standard raceway. The experimental rearing vessels were set up outside in two banks of six tanks each. The area between banks was enclosed in a tent, which darkened the area and thus enabled observers to watch the fish without disturbing them. The tanks were lit from the surface by ambient sunlight. Each week, algae was scrubbed off the sides of the tank and flocculent material siphoned off the bottom.

The rearing experiment was initiated by randomly dividing a population of 480 Big Beef Creek hatchery fall chinook salmon swimup fry among the 12 model raceway tanks (i.e., 40 fry/tank). Each fry was anesthetized with MS-222 and measured to the nearest mm.

Aggression and foraging activity were the only variables measured during the experimental rearing period. Nipping and debris-striking were estimated by observing fish behavior in each tank for a 10-minute period each week The observer scanned each tank until observing either type of activity, and then recorded the behavior and resumed scanning the tank for new activity.

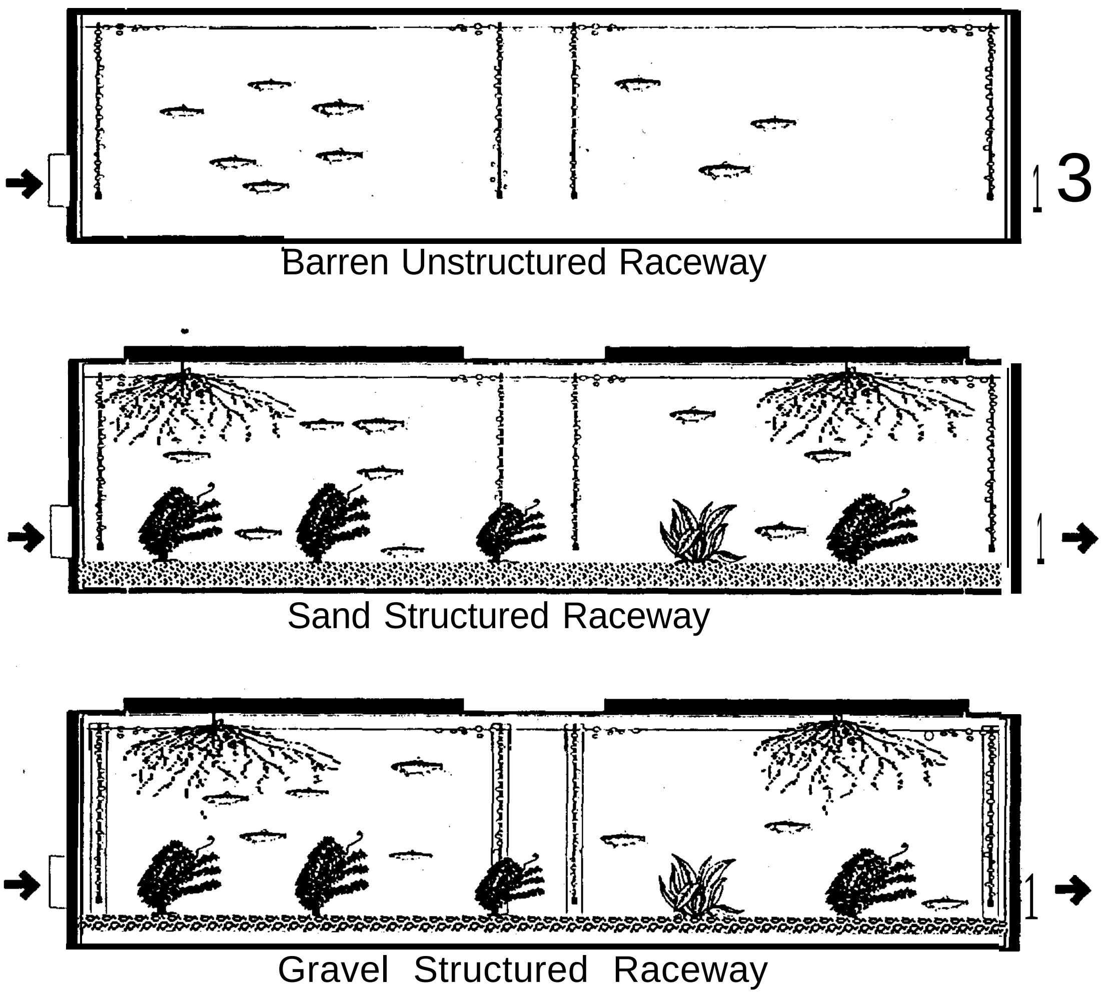

Figure 5-l. Unstructured conventional (Barren) and structured seminatural (Gravel, Sand) raceway habitats that fall chinook salmon were reared in at the Big Beef Creek Facility near Seabeck, Washington, 1992.

Nipping behavior included all contact nips, threat nips, and miss nips as defined by Maynard (1987). Foraging strikes refer to attacks on air bubbles, decaying food, and fecal debris. No food was presented to fish on observation days until after the observation period.

Experimental rearing was terminated on 20 May 1992 after all the fish experienced a transient color change that indicated they had undergone their first smoltification. All the study fish were anesthetized with MS-222, measured, and weighed, and every fourth fish was euthanatized in a lethal concentration of MS-222 for cryptic coloration and pathological analyses. The anesthesia eliminated neural control of chmmatophore units, assuring that the observed color. differences represented cell structure changes rather than behavioral differences. The majority of fish were tagged with passive integrated transponder (PIT) tags, following the method described by Prentice et al. (1991), and used to evaluate the effect of the rearing treatments on postrelease survival.

Each fish in the lethal subsample was submerged on its side in a shallow tray filled with water and was then photographed under standardized lighting conditions. Resulting photographic slides were viewed on a video monitor, and the images were analyzed visually and with the aid of computer software. The base skin color immediately below the dorsal fin and above the lateral line was matched to color chips from Ma&z and Paul (1950). Brightness, chrome, and hue of each color chip was then determined with a colorimeter, and the relative darkness of each parr mark was visually matched to chips on a Kodak gray scale. The length and width of each of the three anterior-most parr marks was measured and used to calculate parr mark area. This number was divided by total body area (fork length multiplied by width) to determine relative parr marked area. The number of observable lesions on the photographed fish were counted. In addition, each of the visible fins of the photographed fish were examined for fraying and evidence of erosion.

Euthanatized fish were dissected and examined for the presence of bacterial disease organisms in the kidney. A sterile inoculation loop was first dipped into the kidney and then streaked across prepared media in a petri dish. Petri dishes were incubated at room temperature and after 24 hours examined for the presence of furunculosis (Aeromonas *salmonicida*) or enteric redmouth (Yersinia *ruckeri*) organisms. After plating, the kidney was removed and homogenized. A clean cotton swab was then used to streak homogenized kidney across glass slides that were then examined for the presence of Renibacterium *salmoninarum*, the causative agent of bacterial kidney disease (BKD), using the florescent antibody technique presented by Bullock and Stockey (1975).

Tagged fish were held in a 2,000-L fish transport tank overnight and then released into Anderson Creek near Seabeck, Washington, where they were challenged to survive at 2.1 km outmigration to an estuarine weir. Anderson Creek is a small coastal stream with a heavily wooded riparian zone that supports a healthy population of cutthroat trout (0. *clarki*), rainbow trout (0. *mykiss*), and coho salmon (0. *kisutch*), but lacks a chinook salmon run. The outmigration was monitored at the weir for more than 30 days. At the end of the study, the majority of the creek was electrofished to ensure that the study fish had not taken up residence within the creek.

Results and Discussion

Growth and Survival during Rearing

There were no significant differences (P > 0.05) in length or weight of fish reared in any of the three treatments (Table 5- 1). The condition factor (ratio of length/weight, as described in Piper et al. 1982) was similar for all three treatments, and prerelease survival was nearly 100% for all replicates in both treatments. However, a few fish died from jumping out of the tanks in conventional treatment groups.

No disease-related mortalities occurred, and no fin fraying or erosion was noted in fish from any of the three treatments. However, fish in both seminatural treatments had more skin lesions (15.4%) than fish in the conventional treatment tanks (5.6%). Kidney tissue cultures indicated neither furunculosis, enteric redmouth, nor BKD was present in any of the treatment groups. However, unidentified diplococcus bacteria and yeast were found significantly more often (P = 0.003) in cultures taken from fish reared in the sand-bottom tanks than from fish in the other two treatments. It is possible that bacteria were introduced into the structured treatment tanks with the watercress or sand. We recommend that in future experiments, all inorganic material be sterilized to reduce the risk of disease contamination from these sources.

Raceway Maintenance

Both the conventional and seminatural tanks used in this study appeared to foul mote quickly than other raceway systems we have worked with. The growth of filamentous algae on plastic aquaria plants was the most difficult to clean. It was also observed that chinook salmon failed to feed on pellets which had fallen over pea-gravel, but did retrieve feed from the floor of sand or acrylic bottom tanks. However, a prototype seminatural raceway containing sand substrate and a sheared 2-m-tall Douglas fir (*Pseudotsuga* menziesii) for structure, presented no unusual cleaning problems (D. Maynard, NMFS, pers. observation). Therefore, we suggest that large-scale seminatural rearing efforts focus on using sand substrates layered over pea-gravel-covered undergravel filters. Sheared live trees should also be used to provide instream structure rather than plastic foliage.

Fish Behavior

Fish in both types of seminatural tanks exhibited significantly greater (P = 0.046) aggressive activity (contact nips, threat nips, and chases) than fish in unstructured tanks. Aggressive activity did not significantly differ (P = 0.096) between the two structured treatments. Subordinate chinook salmon in the seminatural tank often sought refuge from aggression in the watercress root wads. The plastic aquarium plants may have provided territorial focal points for dominant individuals, as has been observed in other studies (D Maynard, NMFS, unpublished data). The greater frequency of aggression in the tanks containing structured habitat may be related to the greater number of territorial focal points afforded by structure:

Fish in conventional rearing habitats exhibited a significantly greater (P = 0.004) number of debris strikes than those reared in either of the seminatural tanks. Since these fish were not fed prior to or during observations, foraging was primarily directed at decaying food and fecal material drifting in the water column. Organic debris (particularly fecal material) is considered a potential source of horizontal disease transmission in cultured fish. Lower levels of debris within the water column of seminatural tanks may have been responsible for the reduced foraging activity recorded in these two treatments. Apparently, either the plants, substrates, or interstitial microorganisms

Table 5-1. Number, length, weight, and condition factor[a] of Big Beef Creek fall chinook salmon reared in three artificial habitats, 1992.

	Habitat type		
	Unstructured	Structured	
Variable	Barren	Gravel	Sand
Length (mm)[b]			
n	138	154	154
Mean	74.5	74.3	74.8
sd	7.6	4.9	5.1
Weight (g)[b]			
n	138	154	154
Mean	4.4	4.1	4.3
sd	1.4	1.0	1.0
Condition factor[b]			
n	138	154	154
Mean	1.01	0.99	1.01
sd	0.05	0.05	0.05

[a] Condition factor = weight (g)* $100/\text{length (cm)}^3$

[b] There were no statistical differences ($P < 0.05$) between treatments based on ANOVA.

present in seminatural tanks removed these organic particles from the water column: this suggests that structured habitats may provide a more sanitary rearing environment than unstructured tanks.

Morphology

No significant difference was detected in the number of dorsal spots developed by fish in any of the three treatments. This supported the hypothesis that spotting pattern is primarily under genetic rather than environmental control. Following the logic of Donnelly and Dill (1984). sahnonid spot patterns may differ between stocks, with each stock evolving a pattern that matches the grain of its native habitat,

The base integument coloration of fish from all three treatments had a similar brightness component, but the chroma and hue of seminaturally reared salmon was significantly different from that of conventionally reared fish (Table 5-2). The grey scale rank of parr marks was similar for fish from all three treatments.

Subjective observations, made over the last 2 months of rearing, indicated that fish reared in both seminatural treatment tanks consistently displayed a more olive-brown coloration, larger and darker parr marks, and darker spots than fish reared in the conventional treatment tanks. Fish in the conventional treatment tanks always appeared light tan and had poorly developed parr marks and few noticeable spots. Even after fish were removed from the tanks and anesthetized in MS-222, these differences in background skin coloration persisted. On average, the parr marks of seminaturally reared fish occupied a greater percentage of body surface than the parr marks of conventionally reared fish (Table 5-3). This percentage appeared to increase in proportion to the grain size used in the rearing environments. Fish reared over course-grained gravel had the largest parr marks, and those reared over fine-grained sand had the next largest parr marks, although their parr marks were similar in size to those of fish reared in extremely fine-grained conventional tanks.

In essence, fish from all three treatments developed cryptic skin coloration that blended with the background they were reared over: Conventionally reared fish developed a homogenous bright grey coloration that enabled them to blend in with the light uniform grey background coloration of their tank. Similarly, fish reared in the seminatural treatment tanks developed the dark, mottled, tan background coloration of their rearing environment. It is generally recognized that the former color pattern is cryptic in the open water environment of lakes and the ocean, while the latter pattern is cryptic in the more structurally complex environments of streams, rivers, and estuaries.

Thus, lighter colored conventionally reared fish were cryptically mismatched to the stream bed background of Anderson Creek, while seminaturally reared fish should have been cryptic in that environment. Fiih can quickly alter melanophore dispersion to make existing parr mark and spot patterns match environmental background. However, other facets of camouflage patterning, such as changes in hue, which require new pigment synthesis, take weeks to complete (Fuji 1993). Until all aspects of background matching were fully developed, the conventionally reared fish in this study should have remained more conspicuous in the stream.

Post release Survival

A significantly greater proportion of fall chinook salmon recovered at the weir were reared under seminatural than conventional conditions (60.1 vs. 39.8%, P = 0.007) (Table 5-4). Most fish were recovered at the weir within 3 days after their release into Anderson Creek As there were no weir failures, and no chinook salmon were captured when the creek was electrofished, recovery presumably represents survival. Predation may have been responsible for the majority of

Table 5-2. Base skin colorimetry values for fall chinook salmon reared in barren, gravel, and sand habitats, 1992.

	Habitat type				
	Unstructured	Structured			
Variable	Barren	Gravel	Sand	P value[a]	Post Hoc grouping[b]
Brightness				0.942	B S G
n	36	37	39		
Mean	21.572	21.730	21.710		
Sd	1.983	2.169	2.195		
Hue				0.000	B S G
n	36	37	39		
Mean	0.35 1	0.364	0.362		
Sd	0.011	0.011	0.013		
Chroma				0.000	B S G
n	36	37	39		
Mean	0.377	0.396	0.392		
Sd	0.017	0.016	0.017		

[a] Probability of difference between treatments; values are based on ANOVA.

[b] Grouping of statistically similar and different treatments; determined by Tukey Test.

Table 5-3. Parr mark characteristics of fall chinook salmon reared in barren, gravel, and sand habitats, 1992.

	Habitat type				
	Unstructured	Structured			
Variable	Barren	Gravel	Sand	P value[a]	Post Hoc grouping[b]
Parr mark (% body area)				0.018	B S G
n	2	34	30		
Mean	5.6	6.3	5.8		
sd	1.0	1.0	0.9		
Dorsal spot count				0.758	G B S
n	27	29	35		
Mean	10.11	9.552	10.086		
sd	3.826	2.720	3.166		

*Probability of difference between treatments; values are based on ANOVA.

[b] Grouping of statistically similar and different treatments; determined by Tukey Test.

Table 5-4. Number of Big Beef Creek fall chinook salmon released from each treatment into Anderson Creek and recovered at the estuary weir by 8 June 1992.

	Habitat type		
	Unstructured	structured	
Variable	Barren	Gravel	Sand
Number released	88	101	102
Number recovered	33	63	59
Number not recovered	50	38	43
Survival to weir (%)	39.8	62.4	57.8

postrelease mortality as 1) outmigration was rapid, 2) no chinook salmon appeared to take up residence within the creek, and 3) no fish were found dead or moribund at the weir.

Healey (199 1) indicated that predation is a major source of mortality for chinook salmon. Based on our personal observation of a single heron that fed on over 80 similar-sized trout within a few hours, and on information from the literature (Elson 1962, Wood 1987). it appears that avian predators are the greatest threat to newly released hatchery fish; however, losses to predatory fish and reptiles may also be significant. The main piscivorous predators observed in the vicinity of Anderson Creek were great blue herons, kingfishers, mergansers, garter snakes, sculpins, cutthroat trout, and rainbow trout. All of these animals are primarily visually hunting predators.

There are three main antipredator strategies available to an animal: 1) avoid areas where predators are found, 2) escape predators when attacked, and 3) be cryptic to avoid detection by predators. There is no reason to believe fish from any rearing treatment would be better able to avoid areas where predators were found. Within a healthy monospecific group, size has been shown to be the most important factor in escaping predators, once a fish has been detected The similarity in size of fish from each treatment suggests their ability to flee from predators would be equal. However, as noted above, the distinctive heterogeneous coloration of seminaturally reared fish probably enhanced their crypticity for the stream bed coloration of Anderson Creek more than the coloration of their homogeneously colored conventionally reared counterparts. Thus, coloration was the strategy that reduced predator vulnerability for fish from the seminaturally reared treatments.

Conclusions

Historically, salmonids have been reared in earthen raceways, similar to the seminatural raceways in this study. Piper et al. (1982) stated that many fish culturists believed that fish produced from these earthen raceways were healthier, more colorful, had better fin condition than those produced by concrete raceways. Our study results supported this view, and in addition, our seminaturally reared fish had better postrelease survival than fish grown in conventional, concrete-bottomed vessels. As we have pointed out, the primary advantage of providing seminatural habitats for rearing hatchery fish appears to be that fish reared under these conditions develop body coloration that is cryptic in postrelease stream environments.

This cryptic background color matching is a crucial component of the camouflage that enables prey to avoid detection by visually hunting predators. It appears that fish reared over naturally colored sand and gravel substrates in this study were less vulnerable to visually hunting predators (birds and fish) than conventionally reared fish. The mechanism promoting increased survival of the seminaturally reared fish appears to be enhanced crypsis in the stream environment.

Although this study does not examine whether seminaturally reared salmonids are exposed to the same selection pressures or exhibit the same behavior as wild fish, it does demonstrate that modification of the culture environment can induce significant positive differences in coloration and postrelease survival of hatchery fish. This is an important first step in developing seminatural culture habitats that can produce wild-like fish for use in genetic conservation and supplementation programs.

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