Section 7

THE POSTRELEASE SURVIVAL OF SATSOP RIVER FALL CHINOOK SALMON REARED IN CONVENTIONAL AND SEMINATURAL RACEWAY HABITATS, 1994[5]

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Introduction

The goal of this final experiment was to test on a larger scale the seminatural rearing methods that had been shown to be effective in pilot-scale experiments (Sections 5-6). This experiment was conducted in 1994 as a cooperative project between the National Marine Fisheries Service (NMFS) and the Washington Department of Fish and Wildlife (WDFW). The study was conducted with fall chinook salmon (*Oncorhynchus tshawytscha*) reared in 6,000-L vessels (400-L vessels were used in our previous studies).

Material and Methods

This experiment was conducted at the Washington Department of Fish and Wildlife (WDFW) Simpson Fish Hatchery in the Satsop River Basin in western Washington. Experimental fish rearing was conducted in six rectangular 5,947-L portable fiberglass raceways. The concrete, grey-colored raceways were 6.4 m long by 1.5 m wide by 0.6 m deep.

The three conventional treatment raceways represented a conventional culture environment (Leitritz and Lewis 1980, Piper et al. 1982), lacking any substrate, structure, or overhead cover. However, they were covered with translucent bird netting on PVC pipe frame to prevent entry of avian predators. Conventional treatment fish were fed a standard pellet diet at the surface by hand.

The three seminatural treatment raceways (Fig. 7-l) were semi-production-level versions of the 400-L tanks used in the previous studies described in Sections 5 and 6. Overhead cover, which simulated stream-bank vegetation, was provided in each seminatural raceway by running military camouflage netting along the top of each side so that 80% of the tank surface was covered. The open area down the center of the raceway was covered with bird netting. This cover configuration simulated the canopy produced by riparian vegetation along streams.

The bottom of each seminatural raceway was covered with a 10-cm layer of pea gravel over undergravel filters constructed from perforated aluminum plate on a 5- by 5-cm aluminum box frame. Instream structure was created by placing five heavily branched, small (1- 1.5 m) sheared Douglas fir (*Pseudotsuga* menziesii) trees in each seminatural raceway. The needles were removed from all trees before they were added to the raceways. An automatic vibrating-type hopper feeder dispersed a standard pellet diet into a water current traveling through a 2.5-cm diameter pipe that encircled the perimeter of the raceway (Fig. 7-2). The feed-delivery pipe was laid over the substrate and delivered food through thirteen 7-cm-diameter holes drilled at 0.5-m intervals in the topside of the pipe.

In fall 1993, chinook salmon eggs were randomly divided among five Heath-type incubator trays and thermally marked, following the method of Volk et al. (1990). Eggs placed in these 5 trays were all from a pooled population taken from 5-10 females on a single day. A sixth tray of fish was established from a group of eggs taken from another pooled population of 5- 10 females spawned the following day. At swimup on 21 March 1994, the fry were individually counted, and each experimental raceway was stocked with 6,000 fry.

Fish in both treatments were maintained following standard culture practices (Leitritz and Lewis 1980, Piper et al. 1982). Throughout most of the rearing period, fish from both treatments were fed equivalent rations of commercially prepared dry and semi-moist diets. All mortalities during culture were removed and counted. Fish that died by jumping from the tanks or by injuries from cleaning siphons were counted separately from fish dying from undetermined causes.

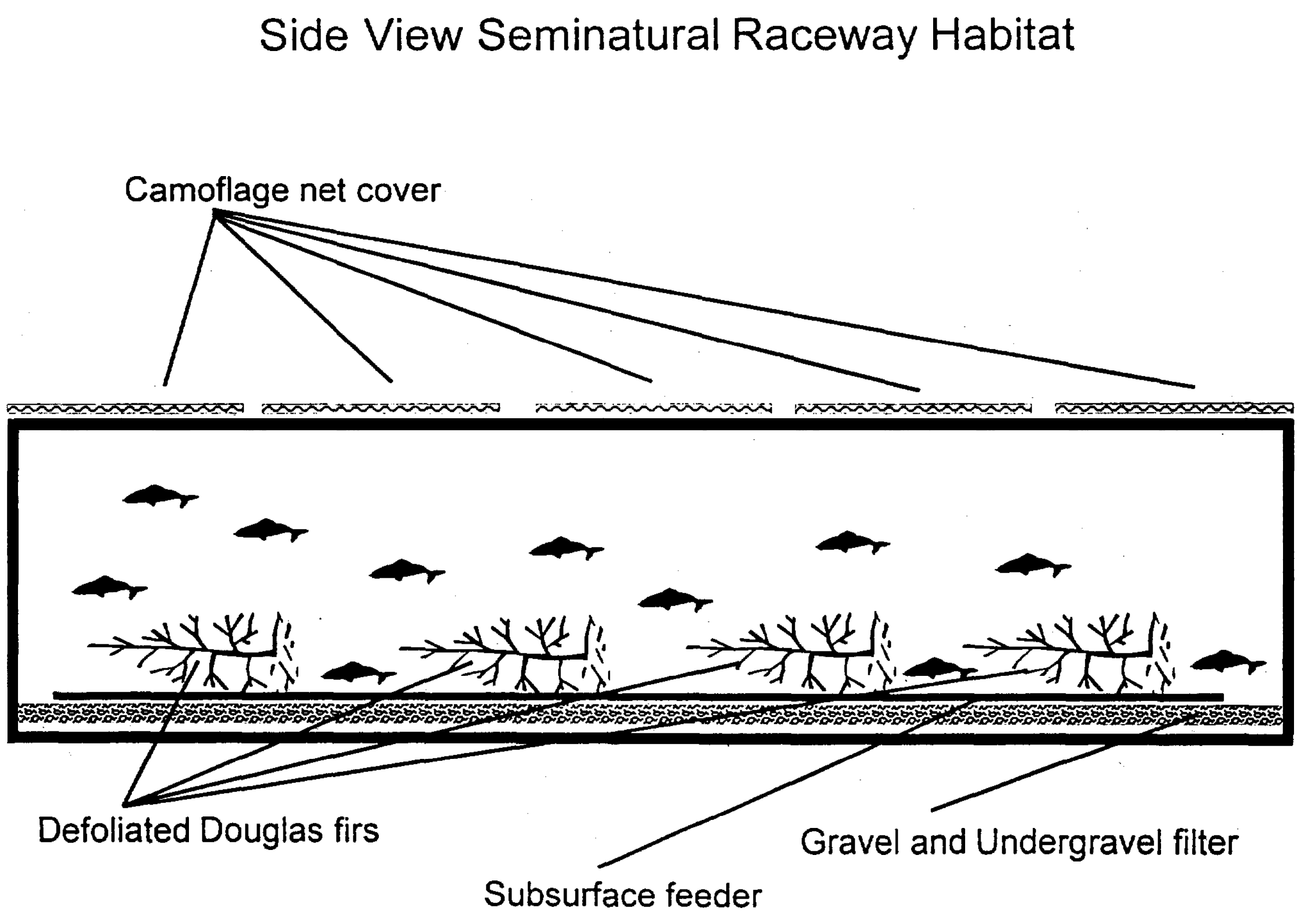
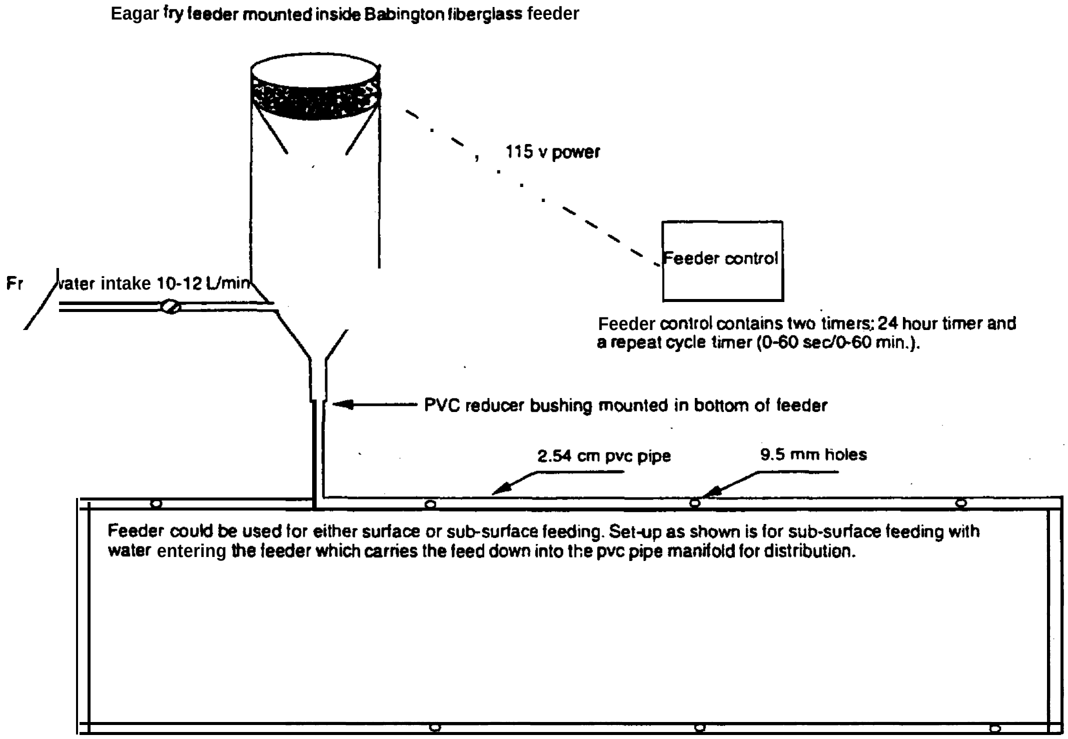
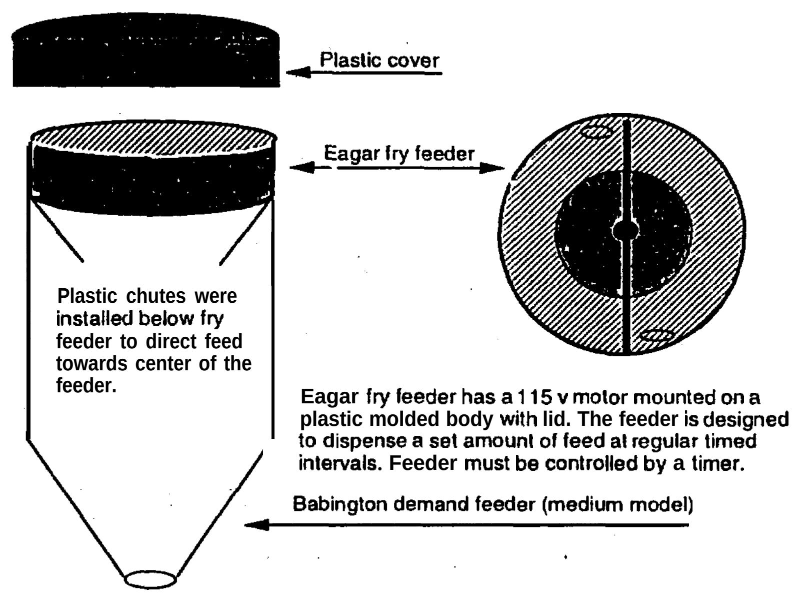


Figure 7-1. Seminatural raceway habitat that Satsop River fall chinook salmon were reared in at WDFW Simpson Hatchery.



Automatic feed system utilizing a Babington fiberglass feeder with a lop-mounted Eagar fry feeder.



Fry feeder has a 1.2 cm lip around the top perimeter of the feeder. Clearance between the inside wall of the fiberglass feeder and the outside wall of the fry feeder is less than 6 mm allowing the fry feeder to be inserted into the top of the fiberglass feeder. The lip of the fry feeder secures it inside and on top of the fiberglass feeder.

Feeder will hold a maximum 3 kg.

Figure 7-2. Subsurface feeding systems incorporated in seminatural raceway habitat that Satsop River fall chinook salmon were reared in at WDFW Simpson Hatchery.

Ten to 50 fish were anesthetized in MS-222 and sampled for growth (length) at the beginning of the experiment and at days 33 and 59. Just prior to release, a representative subsarnple of approximately 530 fish was taken from each raceway. Most of these fish were anesthetized in MS-222, measured for fork length, and PIT tagged following the methods of Prentice et al. (1990). Every twelfth fish in this sample was euthanatized in a lethal concentration of MS-222, measured, and photographed for cryptic coloration analysis. Each fish in the lethal subsample was submerged on its side in a shallow tray filled with water and photographed under standardized lighting conditions. The resulting photographic slides were then viewed on a video monitor, and the image was analyzed visually. The base skin color immediately below the dorsal fin and above the lateral line was matched up with a color chip according to the methods of **Maerz** and Paul (1950). The brightness, chrome, and hue of each color chip was then determined with a **colorimeter.** In addition, gill covers of photographed fish were examined for erosion.

The euthanatized fish were then dissected and examined for the presence of bacterial disease organisms in the kidney. A sterile inoculation loop was dipped into the kidney and streaked across a prepared media in a petri dish. Petri dishes were incubated at room **temperature** for 24 hours and then 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 tissue across glass slides, which were then examined for the presence of ***Renibacterium salmoninarum*,** the causative agent of bacterial kidney disease **(BKD),** using the **florescent** antibody technique (FAT) described by Bullock and **Stockey** (1975).

During the last prerelease sampling period, an additional 500 fish were elastomer tagged for a WDFW comparative tagging study. Also, approximately 2,500 additional fish excess to experimental needs were removed from each raceway and liberated into the **Satsop** River. The remainder of fish, including both PIT- and elastomer-tagged fish, were returned to their raceways and held until release in postrelease survival studies.

Beginning in June 1994, fish were released to Bingham Creek in three paired groups (each including fish from a conventional and seminatural raceway) at l-week intervals. All groups were challenged to survive outmigration to a WDFW weir approximately 21 km downstream. The first release was made on 13 June 1994, during a period of rainfall. The second release was made on 20 June 1994, during a period with no rainfall and stable creek conditions. The third paired release was made on 27 June 1994, with a period of rainfall following several days later.

On each release day, fish from a pair of raceways were crowded, netted, and loaded for transport into an insulated **2,000-L** tank with oxygenated water. Five hundred fish from each raceway were retained for in-culture behavioral observation and other studies. The fish in each release were liberated into Bingham Creek just before dusk (at approximately 2200 h).

Bingham Creek is a medium-size coastal stream with both logged and unlogged riparian habitat. Spawner access to the stream is controlled such that the stream supports a population of cutthroat trout **(*O. clarki*),** rainbow trout (0. ***mykiss*),** and **coho** salmon (0. ***kisutch*),** but lacks a chinook salmon run. Juvenile **salmonid** predators observed in the stream during the challenge included river otter **(*Lutra canadensis*),** great blue heron **(*Ardea*** herodius), belted kingfishers **(*Ceryle alcyon*),** and steelhead trout (0. ***mykiss*).**

The chinook salmon smolt outmigration was monitored at the trap for more than 90 days. The trap was designed to sample 100% of the downstream migrants. Just prior to end of weir operations, several sections of the creek were **electrofished** for residual study fish.

A PIT-tag detector system was used to interrogate all fish for their PIT-tag code as they entered the trap at the weir. This **PIT-tag** information provided an accurate measure of travel time to the weir. The reading efficiency of the PIT-tag detector installed at the **Bingham** Creek weir averaged about 82%. All fish entering the trap were manually sampled at the weir at 0700 h, 1500 h, and **2100** h for fork length (mm) and PIT-tag code.

Results and Discussion

Growth and Survival During Rearing

Total in-culture survival was high; mortality did not exceed 1.33% for either treatment prior to tagging (Table 7-l). Mortality due to known mechanical damage, jumping out of raceways, and sampling were similar for both rearing treatments (Table **7-** 1). However, mortality from other undefined causes was significantly (**P** < 0.001) higher for fish from seminatural than conventional raceways (about 1.2 vs. 0.6%). This increased mortality for seminaturally reared fish may have. arisen from disease or unobserved mechanical damage that occurred during cleaning.

When **ponded,** conventionally and seminaturally reared fish did not significantly differ in size (Table 7-2). However, by day 59 the conventionally reared fish were significantly longer (P = 0.051) and heavier (P = 0.007) than the seminaturally reared fish (Table 7-2). The subsurface feeders on the seminatural raceways failed to deliver an estimated 10% of daily ration. We estimate that the initial growth advantage for conventional fish approximately matched what the subsurface feeder failed to deliver. This suggested that if fish from the seminatural treatment had been presented with an equivalent food ration, their growth would have been similar.

Conventional fish were taken off feed for several days to allow seminaturally reared fish to attain equal size. At release, **seminaturally** reared fish were similar in length and only slightly lower in weight than conventionally reared fish (Table 7-2).

As in the previous two studies (Sections 5 and **6),** no differences in health status were observed between fish **from** the conventional and seminatural rearing treatments. Bacterial colonies produced from kidney streaks on agar culture plates occurred in nearly equal proportions from fish subsampled from both treatments (**P** = 0.7 12) (Table 7-3). Similarly, only slightly more fish from the conventional raceways were positive for BKD, and this difference was not significant (P = 0.217).

In photographs of the lethal subsamples, only 2% of conventionally reared fish had eroded gill covers, while 22.9% of those of the seminaturally reared fish were eroded. A 2 x 2 contingency table analysis indicated difference was highly significant (**P** < 0.001)~ The actual cause of gill cover damage in unknown. However, if disease-related, then prolonged rearing under seminatural conditions may affect survival.

Raceway Maintenance

Both conventional and seminatural raceways required weekly siphoning to vacuum fungus, fecal material, decaying food, and sediment from the tank bottoms. Structure had to be removed from the seminatural raceways to allow thorough cleaning. When the conifers were removed during the cleaning process, an effort was made not to disturb the epiphyte growth on them Complete cleaning required about 1 hour for each conventional raceway and 2 hours for each seminatural raceway. Gravel beds above the undergravel filters also collected sediment and usually

Table 7-l. Number, percentage, and cause of fall chinook salmon mortalities in conventional and seminatural raceways during rearing at WDFW Simpson Hatchery, 1994.

Source	Conventional	Seminatural
Mechanicaldamage	10 (0.06%)	9 (0.05%)
Jumpers	19 (0.11%)	15 (0.08%)
sampling	7 (0.04%)	6 (0.03%)
Unknown causes	101 (0.56%)	209 (1.16%)
TOTAL	137 (0.76%)	239 (1.33%)

Table 7-2. Fork length of fall chinook salmon reared in conventional and seminatural raceways at WDFW Simpson Hatchery, 1994.

	Conventional			Seminatural		
	Raceway			Raceway		
Response variable	1	2	3	1	2	3
Ponding						
n sampled	50	50	50	50	50	50
mean length (mm)	39.5	39.8	39.8	39.8	40.0	39.9
sd	1.3	1.0	1.1	1.2	1.3	1.0
Day 33						
n sampled	10	10	10	10	10	10
mean length (mm)	51.9	49.7	48.6	51.3	48.8	49.3
sd	3.0	3.0	3.0	3.0	3.0	3.0
Day 59						
n sampled	10	10	10	10	10	10
mean length (rum)	64.9	65.1	62.1	63.7	61.6	60.4
sd	4.0	4.0	4.0	4.0	4.0	4.0
Release*						
n sampled	108	98	104	106	100	106
mean length (mm)	70.4	76.0	81.3	69.7	76.1	80.3
sd	4.5	4.6	4.9	3.9	4.1	3.8

[a] Release dates were 13 June 1994 for paired conventional and seminatural raceways 1, 20 June 1994 for paired conventional and seminatural raceways 2, and 27 June 1994 for paired conventional and seminatural raceways 3.

Table 7-3. Health status at PIT tagging for fall chinook salmon reared in conventional and seminatural raceways at WDFW Simpson Hatchery, 1994.

Variable	Conventional	Seminatural	Probability[a]
Number of plates			
Negative	109	112	0.712
Target positive[b]	0	0	
Nontarget positive[c]	3	8	
Number of fish tested for BKD			
Negative	109	114	0.217
Positive	8	3	

[a] Probability of difference between treatments; values are based on student t-tests.

[b] Target organisms were Aeromonas sp., Pseudomonas sp., and Yersinia *ruckeri*.

[c] Nontarget organisms were colonies not attributable to *Aeromonas* sp., *Pseudomonas* sp., or Yersinia *ruckeri*.

required over twice as much time to clean as the conventional raceway bottoms. The sidewalls of conventional raceways required scrubbing to remove algal growth. In an effort to maintain a natural rearing environment, sidewalls of seminatural raceways were not scrubbed, reducing overall labor by about 30%.

As noted above, the subsurface feed system in the seminatural tanks often partially clogged and failed to deliver the total feed ration. In addition, this feed system required 5- 10 minutes to disassemble and flush once or more each week. Nevertheless, the automated feeding system reduced labor compared to hand feeding in the conventional treatment. In future experiments, the subsurface feeder will be modified with clean-out ports to the outside of the raceway. This will allow easy daily flushing to ensure delivery of total ration.

Fish Behavior

The behavior of fall chinook salmon reared in conventional versus seminatural raceways differed markedly. Fish in seminatural raceways were oriented lower in the water column than conventionally reared fish. This benthic-to-midwater orientation appeared to be a result of subsurface presentation of food by the automated feed system in the seminatural treatments. Conversely, the midwater-to-surface orientation of conventionally reared fish appeared to result from the surface presentation of food.

Fish in conventional raceways scrambled in their competition for food. The introduction of pellets at the surface in conventional raceways seemed to induce fish to rush to the surface, where they formed dense clusters.

In seminatural raceways, dominant fish defended feeding territories (despotic competition) around holes in the subsurface feeder. However, when pellets were introduced, subordinate fish formed feeding groups that overwhelmed the dominant fish. The habitat structure in seminatural raceways, coupled with the despotic competition for feeding sites resulted in seminaturally reared fish being more dispersed throughout the raceway than conventionally reared salmon.

Even when not fed, salmon in conventional raceways swarmed to the surface every 15 minutes or so. This swarming behavior was catalyzed by a single insect or dust particle landing on the water surface. When a similar object broke the surface in seminaturalraceways, only a single fish pursued it.

Salmon in seminatural raceways were more polarized (better aligned to one another) than those in conventional raceways. It is unknown whether the structure, cover, feeding methodology, or substrate in seminatural raceways induced salmon to form more polarized groups than in conventional raceways.

Preference for decreased water column depth can increase vulnerability to aerial piscivores (Kramer 1983, 1987). Theoretically, the benthic-to-midwater orientation of seminaturally reared fish should decrease their susceptibility to avian predation. In contrast, the surface-feeding behavior of conventionally reared fish should attract fish-eating birds.

Morphology

As in the previous studies (Sections 5 and 6), the body color of seminaturally reared fish was noticeably more vivid than that of conventionally reared fish. Results from a nested ANOVA of subsamples at tagging indicated that integument brightness, hue, and chroma were significantly different for fish between raceways within treatments (P = 0.008, P = 0.003, P = 0.001, respectively, Table 7-4). However, significant differences between treatments could only be detected for integument brightness (P = 0.006).

Nevertheless, our subjective observations suggested that to the human eye the coloration of fish within treatments was similar, while that of fish from different treatments strongly contrasted. The integument color of seminaturally reared fish visually matched the brown substrate they were reared over, while that of conventional fish visually matched the light grey of the raceway bottom

In addition, the seminaturally reared fish appeared to have more extensive melanophore development in the caudal fin, anal fm, abdominal area, and gill cover margin than conventionally reared fish. The parr marks of seminaturally reared fish were visually more pronounced both in culture and during photography. In the first few days after release, personnel examining fish trapped at the weir felt they could distinguish conventional treatment from seminatural treatment fish based on their coloration. These color differences appeared to begin to diminish within a few days after release, with conventionally reared fish seeming to develop coloration similar to that of seminaturally reared fish.

Postrelease Survival

Average travel time for the fish to cover the 21 km distance from the release site to the weir ranged from 11.0 to 14.4 days for seminaturally reared fish and 13.9 to 19.3 days for the conventionally reared fish (Table 7-5). Average travel time was shortest for fish in the last release group and longest for fish in the second release group (Table 7-5). In a two-way ANOVA, the most important factor affecting travel time was release date (P < 0.001), not treatment type (P = 0.102). The interaction between treatment type and release date was marginally significant (P = 0.054), and there was no significant difference (P = 0.102) in travel time between treatments. These-findings were similarto those of the spring chinook salmon study (Section 6), where seminatural rearing with substrate, cover, and structure also did not have any apparent effect on migratory speed.

Travel rates of 15 to 30 km/day have often been observed for fish in Columbia River system streams (T. Flagg, NMFS, unpublished data). In the present study, travel rates ranged from 1.5 to 1.9 km/day for seminaturally reared fish and 1.1 to 1.5 km/day for the conventionally reared fish. Therefore, we believe that the average travel time observed in this study reflected the length of time it took fish to initiate migration rather than the time of active migration through the reach.

Fish in the last release group probably migrated most rapidly because they were undergoing smoltification and were released close to the stock's natural outmigration time period (July 1). In addition, rainfall occurred immediately after their release. Fish in the second release probably took longer to initiate their migration because they were released earlier than the natural outrnigration time period and were not stimulated to migrate due to a lack of rainfall during the week after their release. Even though they were the smallest, and were released at the date farthest from their natural migration time, the travel time of fish in the first release was intermediate to the other two, probably because of the heavy rainfall immediately after their release.

Table 7-4. Base skin **colorimetry** values at PIT tagging for fall chinook **salmon** reared in conventional and seminatural raceways at **WDFW** Simpson Hatchery, 1994.

	Conventional			Seminatural		
	Raceway			Raceway		
Response variable	1	2	3	1	2	3
Brightness[a]						
n sampled	**40**	**29**	**37**	**28**	**41**	**30**
mean	50.2	**49..1**	**46..1**	**40.9**	**41.9**	**40.5**
sd	1.5	**1.5**	**5.2**	**6.9**	**6.1**	**6.8**
Hue[b]						
n sampled	40	**29** / **17**	37	28	41	30
mean	14.9	..2	14.3	12.7	15.2	10.9
sd	3.1	**2.3**	**5.8**	6.4	6.4	6.1
Chroma[c]						
n sampled	40	29	37	28	41	30
mean	2.4	3.3	3.2	3.4	3.3	3.2
sd	2.1	1.9	1.9	1.7	2.1	1.9

[a] Treatment P = 0.006, Raceway within treatment P = 0.008; values are based on nested **ANOVA.**

[b] Treatment P = 0.193, Raceway within treatment P = 0.003; values are based on **ANOVA.**

[c] Treatment P = 0.238, Raceway within treatment P = 0.001; values are based on **ANOVA.**

Table 7-5. Average time (days) required for fall chinook salmon reared in conventional and seminatural raceways at WDFW Simpson Hatchery to migrate the 21 km from the release site to recapture weir on Bingharn Creek, 1994.

	Conventional[a]			Seminatural[a]		
	Raceway			Raceway		
Response variable	1	2	3	1	2	3
Travel time (days)[b]						
n sampled	171	129	86	187	168	177
mean days	17.8	19.3	13.9	14.4	21.8	11.0
sd	17.6	15.8	14.5	18.3	16.6	13.3

[a] Conventionally and seminaturally reared fish released in paired groups 21 km above Bingham Creek weir. Raceways pairs number 1 were released on 13 June 1994, raceways pairs number 2 were released on 20 June 1994, and raceways pairs number 3 were released on 27 June 1994.

[b] Release $P < 0.001$, Treatment $P = 0.102$, Interaction $P = 0.054$; values are based on **ANOVA.**

Overall, significantly more seminaturally than conventionally reared fall chinook salmon were recovered at the weir (48 vs. 38%, $P < 0.001$) (Table 7-6 and Figs. 7-3, 7-4, and 7-5). Thus, seminatural rearing appears to have increased relative recovery by 26% in this study. No chinook salmon were recovered by electrofishing in Bingham Creek, even though numerous juvenile trout and coho salmon were caught: this suggests that the chinook salmon had probably migrated from the stream reach. Thus, although this survey covered less than 2 km, the weir recovery data should be a reasonable estimate of postrelease survival differences that occurred between fish from the two treatments.

For the first and last releases, the difference observed in daily recovery of fish at the weir between treatments was greatest immediately after release and diminished with time (Figs. 7-3, and 7-5). As noted in Sections 2-3, conventionally reared fish may not begin to develop proper camouflage coloration for the stream environment until several days to weeks after release. Theoretically, conventionally reared fish should be less vulnerable to visual predators if they seek cover and hold position until they have developed proper cryptic coloration for their new environment. Therefore, the proportionally lower recovery of conventionally reared fish during the early postrelease recovery period for the first and third releases may have been due to greater vulnerability to predators during this transition period for cryptic coloration for the stream environment.

The daily recovery of fish from the second release was initially similar for both treatments, but began to diverge with time (Fig. 7-4). The protracted nature of recoveries from the second release was probably due to the fishes' incomplete smoltification and the low stream discharge immediately after release (as described above). We have no explanation why the recovery of seminatural vs. conventionally reared fish from the second release diverged with time (Fig. 7-4). However, other aspects of NATURES rearing (e.g., benthic orientation to structure) may have helped increase fish survival.

Conclusions

This research demonstrated that seminatural rearing techniques developed in pilot-scale studies (Sections 5-6 of this report) can be implemented in production fish rearing scenarios. These seminatural rearing techniques increase postrelease survival of fish in streams. As our previous studies demonstrated, 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 crypticity helps camouflage fish from visually hunting bird and fish predators and probably provides the strongest survival advantage derived from the seminatural rearing techniques we tested. However, it was apparent from the results of this study that automated underwater feeding systems can also reduce predator vulnerability by inducing benthic orientation in hatchery fish.

This research also demonstrated that modification of the culture environment can induce significant positive differences in behavior and postrelease survival of hatchery fish. This is an important step in developing seminatural culture habitats to produce wild-like hatchery fish for genetic conservation and supplementation programs. We believe the approaches described here and in other work (e.g., Thompson 1966, Olla and Davis 1989) can provide solutions for stock restoration programs seeking to produce fish with high survival rates that are similar to their naturally reared cohorts.

Table 7-6. Number of WDFW Simpson Hatchery fall chinook salmon released into Bingham Creek and recovered at the weir, 1994.

	Conventional[a]			S e --		
	Raceway			Raceway		
Response variable	1	2	3	123		
Number released	455	392	396	423	467	454
Number recovered	209	154	109	231	208	208
Numbernotnxovered	246	238	287	192	259	246
Survival to weir **(%)**	45.9	39.3	27.5	54.6	44.5	45.8

[a] Conventionally and seminaturally reared fish released in **paired** groups 21 km above Bingham Creek weir. Raceways pairs number 1 were released on 13 June 1994, raceways pairs number 2 were released on June **20, 1994,** and raceways pairs number 3 were released on 27 June 1994.

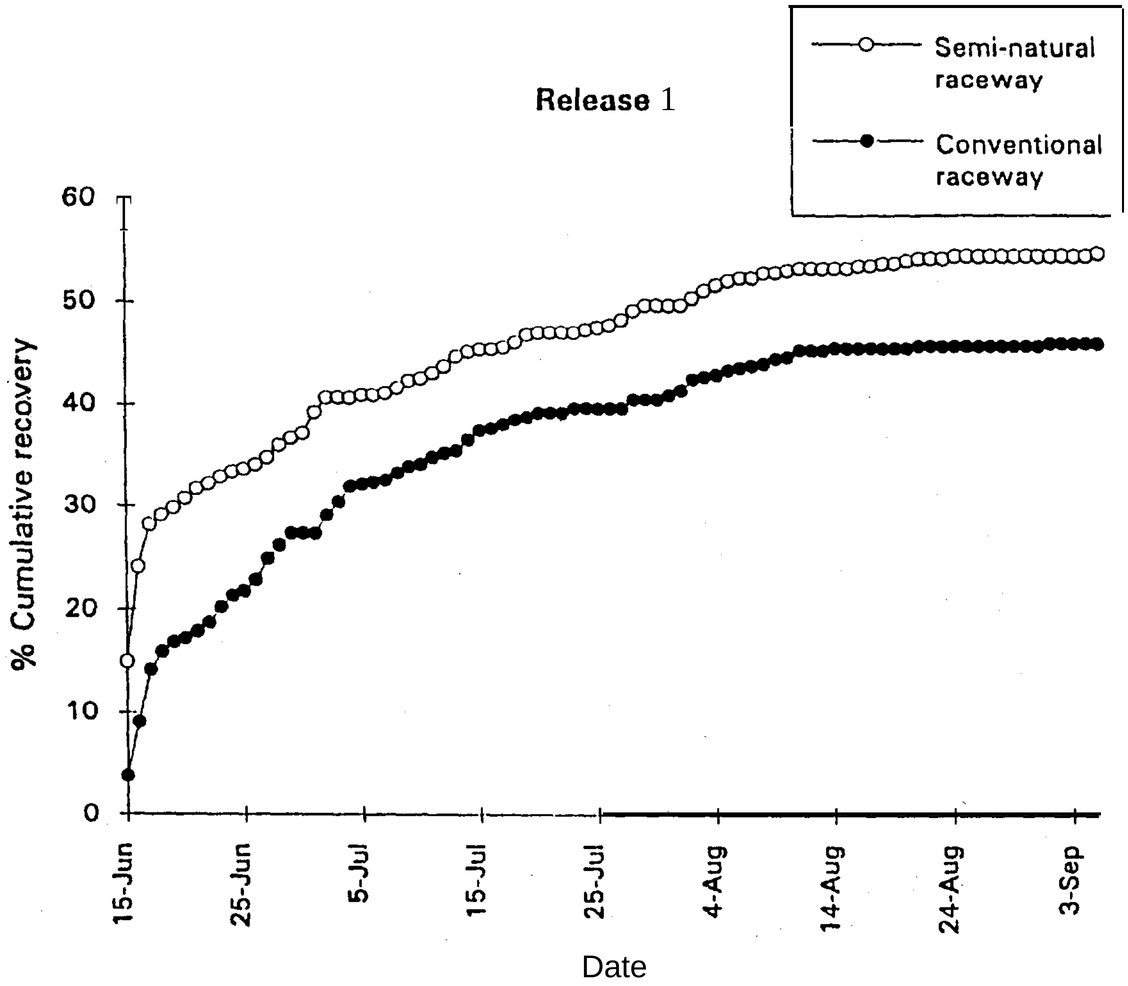


Figure 7-3. Cumulative recovery at Bingham Creek weir for conventionally and seminaturally reared fall chinook salmon from the first paired release, 1994.

Release 2

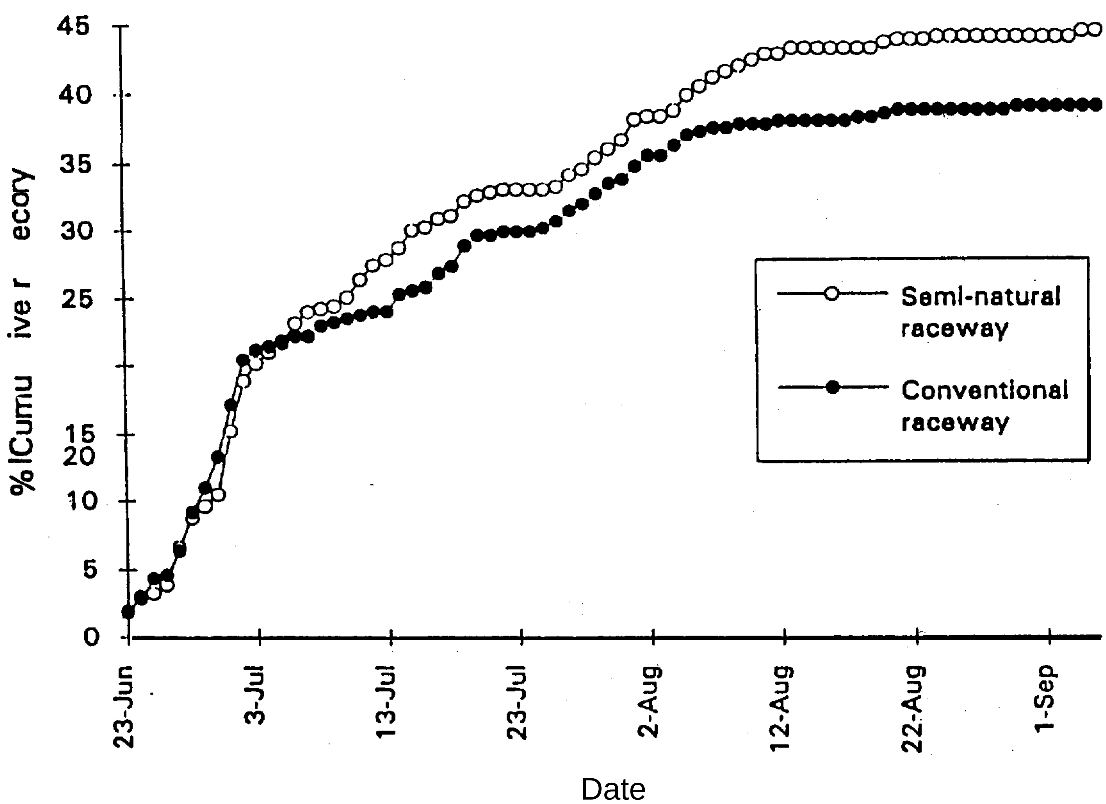


Figure 7-4. Cumulative recovery at Bingham Creek weir for conventionally and seminaturally reared fall chinook salmon from the second paired release, 1994.

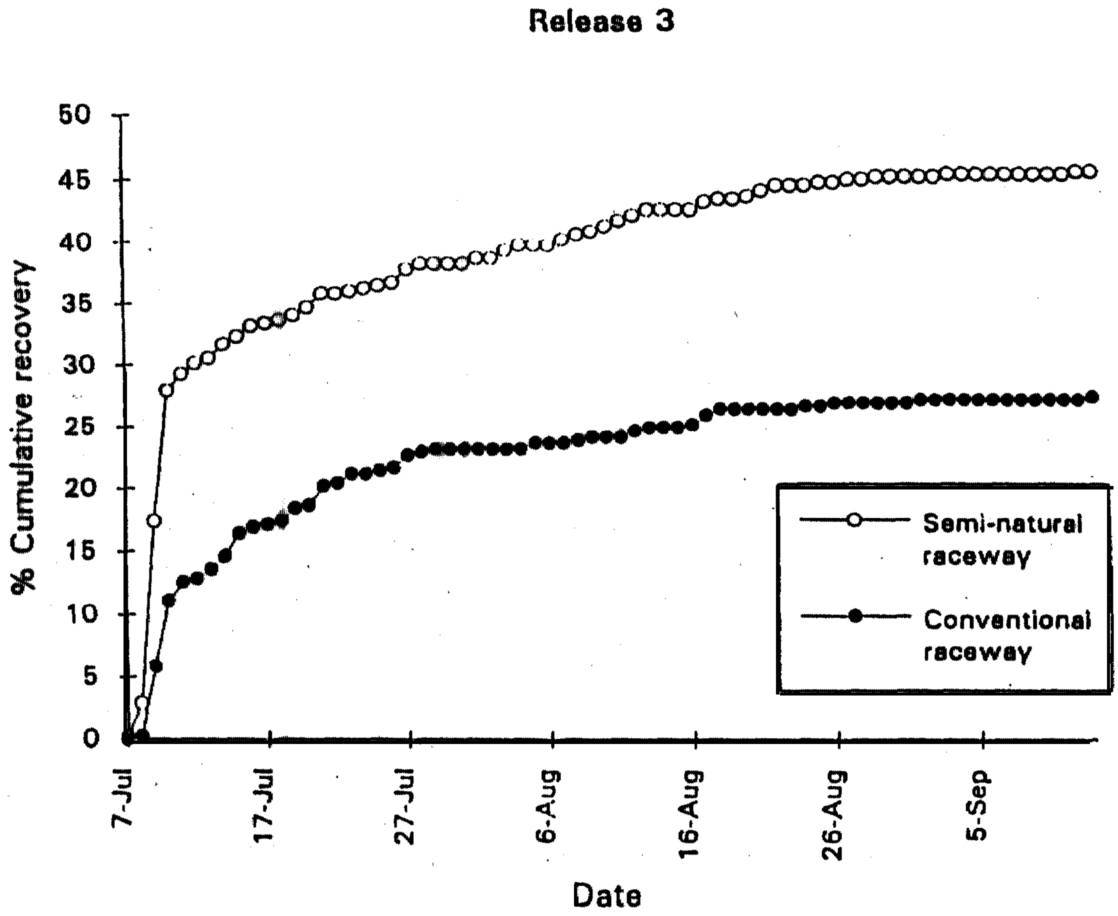


Figure 7-5. Cumulative recovery at Bingham Creek weir for conventionally and seminaturally reared fall chinook salmon from the third paired release, 1994.

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