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Table of Contents

Seminatural Raceway Habitat Increases Chinook Salmon Post-release Survival

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Abstract — There is growing concern that hatchery-reared salmonids die at higher rates than their wild-reared counterparts. We hypothesize that seminatural raceway habitats (raceways fitted with overhead cover, instream structure, and substrate) will improve the Post-release survival of hatchery-reared salmonids by better acclimating fish to their Post-release environment. Three experiments were conducted to evaluate if seminatural raceway habitats increased the Post-release survival of chinook salmon (*Oncorhynchus tshawytscha*).

In the first experiment, ocean type chinook salmon were reared from swim-up to smoltification (4 months) in 400-L raceways with opaque overhead cover, plastic aquarium plant structure, and sand or gravel substrates. During culture, the seminaturally-reared fish exhibited escalated agonistic behavior compared to conventionally-reared fish. At the end of rearing, the skin hue and chroma of seminaturally-reared fish differed significantly ($P < 0.05$) from conventionally-reared fish. This effectively enhanced their ability to camouflage to their post-release stream background. When released into a small coastal stream (Little Anderson Creek on Hood Canal) the survival to a collection weir 2.2 km downstream was significantly ($P < 0.05$) higher (51%) for seminaturally-reared than conventionally-reared fish.

In the second experiment, an acclimation approach to seminatural raceway habitat rearing was evaluated. Stream type chinook salmon were initially reared in barren circular tanks for 9 months after swimup. These fish were then transferred to either 400-L seminatural or conventional raceway tanks for the final 4 months of experimental rearing. The seminatural habitat in this experiment consisted of opaque overhead covers, ornamental junipers for structure, and gravel substrate. When released as smolts into the Yakima River under clear water conditions, the Post-release survival of seminaturally-reared fish to a collection weir 225 km downstream was significantly higher (24%;$P < 0.05$) than conventionally-reared fish. When released under turbid water conditions, there was no significant difference in the Post-release survival of the two treatment groups.

In the final experiment, culture vessel size was increased to 5,947-L, and ocean type chinook salmon were reared for about 3 months (from swimup to smoltification) in raceways outfitted with camouflage net covers, fir tree structure, gravel substrate, and an underwater feed-delivery system. At the end of rearing, the skin coloration of seminaturally-reared fish again appeared to be better suited for blending into the natural stream background. When released into a tributary of the Satsop River (Bingham Creek), the seminaturally-reared fish averaged significantly higher (26%;$P < 0.05$) Post-release survival to a collection weir 21 km downstream than their conventionally-reared counterparts.

In all three experiments, seminaturally-reared fish developed more natural camouflage coloration than conventionally-reared fish. We hypothesize that the higher Post-release survival of seminaturally-reared fish resulted from their lower predator vulnerability due to their enhanced crypsis in the stream environment. Seminatural raceway habitats provide fish culturists a tool to increase the Post-release survival of salmon released in fisheries enhancement and conservation programs.

Introduction

NATURES (Natural Rearing Enhancement System) studies developed by National Marine Fisheries Service and Washington Department of Fish and Wildlife scientists are aimed at developing salmon culture techniques that rear fish in a more natural environment. Traditionally, salmon are reared in barren concrete raceways that lack natural substrate, instream structure, or overhead cover. The fish are fed in an unnatural manner with artificial feeds that are mechanically or hand broadcast across the water surface. This traditional approach can markedly increase the egg-to-smolt survival of hatchery-reared fish over that of wild-reared salmon. However, once hatchery-reared fish are released into the wild, their smolt-to-adult survival is usually much lower than wild-reared salmon. In the best fall chinook salmon hatchery programs, only 0.1- 5.0 % of the released fish survive (note: Survival = catch + escapement using CWT) (Mahnken et al 1997.

The lower Post-release survival of hatchery-reared fish may stem from how their behavior and morphology differs from wild-reared salmon. After release, hatchery-reared fish are inefficient foragers and are often found with empty stomachs or stomachs that are filled with indigestible debris (Miller 1953, Hochachka 1961, Reimers 1963, Sosiak et al.1979, Myers 1980, O'Grady 1983, Johnsen and Ugedal 1986). Their social behavior also differs, with hatchery-reared fish congregating at higher densities, being more aggressive, and displaying less territory fidelity than wild-reared fish (Fenderson et al. 1968, Bachman 1984, Swain and Riddle 1990). In the natural environment, this results in hatchery-reared fish spending more time in high risk aggressive behavior and less time in beneficial foraging behavior than their wild-reared counterparts. Hatchery-reared fish are also more surface oriented than wild-reared salmonids (Mason et al. 1967, Sosiak 1978). This may increase their risk of being attacked by avian predators, such as kingfishers, that search for fish near the surface. Although some of the differences observed between wild and hatchery-reared fish are innate (Reisenbichler and McIntyre 1977, Swain and Riddle 1990), many are conditioned and can be modified by altering the hatchery rearing environment.

Rearing salmon in a more stream-like environment may be a way to produce fish with more natural behavior and morphology that increases their Post-release survival. NATURES researchers have developed a stream-like rearing habitat concept that can be retrofitted to existing hatchery raceways. In this seminatural rearing habitat, the raceway bottom is covered with sand or gravel substrates matching the substrate color of streams into which the fish will be released. An under-gravel filtration system may be placed beneath the gravel substrate to assist in the biological decomposition of organic particles that become lodged in the substrate. Artificial aquatic plants or heavily branched conifers are placed throughout the raceway to create instream structure. Opaque black covers or military camouflage netting is hung 30 cm or less from the water surface to simulate the overhanging vegetation and undercut banks found along salmon stream margins.

Rearing salmon in these more stream-like habitats should prepare them for life in the natural environment they will be released into as smolts. In addition, seminatural rearing may slow down the genetic divergence (domestication) occurring between hatchery fish and the wild populations from which they were sourced. We have conducted several NATURES experiments to demonstrate that rearing salmon in seminatural raceway habitat can increase salmonid Post-release survival.

1992 Little Anderson Creek Release Experiment

The benefit of rearing chinook salmon in seminatural raceway habitat was first demonstrated in an experiment conducted in 1992 (Maynard et al. 1996 a, b). In this experiment, 12 400-L rectangular tanks with a grey background were each stocked with 40 fall chinook salmon swimup fry. Four of the tanks served as experimental controls. To simulate conventional raceway environments, these control tanks had grey bottoms and sides, clear plexiglass tops that provided no shade, and no instream structure except for the aeration system used to compensate for the air-driven under-gravel filtration system in the seminatural habitat tanks. In addition to the control features, four of the seminatural habitat tanks were fitted with a sand substrate on the bottom, artificial aquatic plants for instream structure, and opaque black covers to shade the fish. The other four seminatural tanks were similar, except that the sand was replaced with a pea gravel substrate spread over an under-gravel filter plate.

The fish in both types of seminaturally-reared tanks exhibited significantly ($P = 0.046$) more aggressive acts (contact nips, threat nips, and chases) to one another than conventionally- reared fish (Fig. 1). This escalated aggressive activity may have been the product of the plastic aquarium plants providing more focal points around which fish could establish territories. The increased number of territorial individuals in the seminatural tanks in turn raised the number of territorial disputes that resulted in aggressive actions. The complex habitat structure of seminatural tanks thus seemed to produce aggressive activity that was more natural than that found in the conventional artificial rearing environment.

Fish in conventional tanks struck at drifting material significantly ($P = 0.004$) more often than fish in seminatural tanks (Fig. 2). As the fish were not fed prior to or during the observation period, it appears this striking activity was directed at decaying food and fecal material drifting in the water column. The plants, substrates, or interstitial microorganisms in seminatural tanks seemed to provide the fish with a more sanitary rearing environment by removing these organic particles from the water column. The reduced level of visible drifting debris in the seminatural tanks seems to be responsible for the decreased striking activity observed in these tanks.

The external body coloration of conventionally- and seminaturally-reared fish strongly differed (Fig. 3). Conventionally-reared fish had a uniform light tan coloration that blended in with the homogenous light grey background of their rearing tanks. In contrast, seminaturally-reared fish had a dark brown skin coloration that matched the sand and gravel substrates they were reared over. The parr marks and dorsal spotting were also more pronounced in seminaturally- than conventionally-reared fish. In a stream or river environment these features would help the fish visually blend into the background, with the parr marks breaking up the overall body outline and dorsal spotting mimicking small dark stones randomly scattered over the bottom. After release, visually hunting predators should have more difficulty detecting seminaturally- than conventionally-reared salmon, because the former has developed camouflage that blends in with the stream background.

After the fish were reared from the swimup fry to smolt stage, they were tagged and released into Little Anderson Creek to determine if seminatural rearing enhanced Post-release survival. In the 2.2 km migration corridor from the release site to the weir, the survival of seminaturally-reared fish was 51% higher than conventionally-reared fish (Fig. 4a). This survival difference was most likely the result of seminaturally-reared fish having better camouflage coloration in the stream environment than conventionally-reared fish.

1994 Yakima River Release Experiment

In 1994 a second experiment was conducted to determine if the benefits of seminatural rearing could be obtained when fish were conditioned only during the last part of the freshwater rearing cycle (Maynard et al. 1996 a, c). In this experiment, each 400-L rearing tank was stocked with 80 spring chinook salmon fry that had been previously reared for more than 8 months in uniform blue colored circular tanks. Twelve of the tanks were conventional raceway habitats with grey backgrounds, clear covers, and no instream structure. The other 12 tanks were seminatural raceway habitats with pea gravel substrates, under-gravel filter plates, opaque overhead cover, and juniper trees for instream structure. After 4 months of experimental rearing, the fish were tagged and released as smolts into the Yakima River to evaluate their Post-release survival.

The fish were released into the Yakima River under two distinctly different water conditions. In the first release, the Yakima River water was running clear, and visually hunting predators would have to detect the fish against the heterogenous background coloration of the river bottom. Under these conditions, fish reared in seminatural tanks would theoretically have the best camouflage coloration. The second release occurred when the water in the Yakima River was very turbid. This condition produced a bright uniform background coloration against which visual hunting predators would have to detect their prey. Theoretically, conventionally-reared fish should have the camouflage advantage, with their light uniform coloration blending in better with the turbid water background. The darker seminaturally-reared fish should be slightly easier to detect against this bright uniform background. Each release was paired, with all the fish from six seminatural and six conventional rearing tanks being released on each day.

When released into the Yakima River, seminaturally- and conventionally-reared fish were observed to maintain their color differences, even after several hours of being held in a common transport tank. As theoretically expected in the clear water release, seminaturally-reared fish had a significantly higher (24%; $P = 0.036$) survival than conventionally-reared fish (Figure 4b). Under turbid water conditions, conventionally-reared fish had a slightly (10%), but statistically insignificant ($P > 0.05$), higher recovery rate than seminaturally-reared fish. Fish from both rearing treatments migrated down river at similar speeds, although the downstream migration of fish was faster under turbid than clear water conditions. These findings indicate that an acclimation approach, in which fish are held in seminatural raceway habitats for only the last few months before release, can be successfully used to increase chinook salmon Post-release survival.

1994 Bingham Creek Release Experiment

Another experiment was initiated in 1994 to determine if the seminatural raceway habitat concept could be scaled up to production size raceways (Maynard et al. 1996 a, 1996,d). This experiment was conducted in six fiberglass raceways that were 6.4-m long by 1.5-m wide by 0.6-m deep at the Washington Department of Fish and Wildlife's (WDFW)

Bingham Creek Hatchery. In February 1994, each raceway was stocked with 6,000 fall chinook salmon swimup fry. The three conventional raceways were again barren grey tanks containing only water and fish. The seminatural raceway habitats had pea gravel substrate that covered under-gravel filter plates and heavily branched conifers for instream structure. The conventional raceways were only covered with a translucent bird net that prevented predation, while a shade-producing military camouflage net covered 80% of the seminatural raceway surface. In this experiment, an underwater feeder was added to the seminatural raceways. The fish in the conventional raceways were hand-fed from the surface as in the previous experiments. The fish were reared in these environments until June 1994. The fish were tagged and three paired releases at a point 21 km above a collection weir were made into Bingham Creek.

As in the previous experiment, seminaturally-reared fish developed camouflage coloration better suited to the clear water stream environment than conventionally-reared fish (Figure 5). Once again, the fish maintained these color differences even after being held in a transport tank for several hours prior to release. During the first week after release all fish intercepted at the weir had either conventionally- or seminaturally-reared color patterns. Fish with intermediate color patterns were not seen until 2 weeks after release. This suggests conventionally-reared fish could not develop proper camouflage coloration suitable for the natural stream environment for at least a week after release.

In the three Bingham Creek releases, seminaturally-reared fish had 13.5 to 66.5% higher Post-release survivals than conventionally-reared fish. On average the survival of seminaturally- reared fish was 26% higher than conventionally-reared fish (Fig. 4c). These findings suggest that the seminatural rearing habitat concept developed in 400-L raceways can be successfully scaled up and still increase Post-release survival.

Conclusion

These three experiments demonstrate that rearing salmonids in seminatural habitat with overhead cover, instream structure, and natural substrate markedly increases hatchery-reared salmonid Post-release survival. This seminatural habitat is slightly harder to maintain than conventional tanks, with overhead covers and instream structure needing to be removed during raceway cleaning and fish handling operations. As in conventional tanks, gravel substrates in seminatural tanks are cleaned by vacuuming, but require somewhat longer to clean as the gravel must be separated from decaying food and feces during this process. The Post-release survival benefits of seminatural rearing far outweigh these increased maintenance requirements.

The Post-release survival advantage offered by seminatural rearing has numerous benefits (Maynard et al. 1995). Increased survival can reduce the number of broodstock that startup and supplementation hatchery programs must remove from the natural spawning population. Operational costs can be reduced by decreasing the number of smolts a facility must produce to yield a given number of recruits to the fishery. Releasing fewer smolts can reduce Post-release competition between wild and hatchery-reared salmon. Finally, the higher Post-release survival of seminaturally-reared fish should produce more recruits to the fishery and spawning population. This increased production can then be used by managers to increase harvest, meet mitigation goals, or speed the rebuilding of endangered and threatened salmon runs.

Acknowledgments

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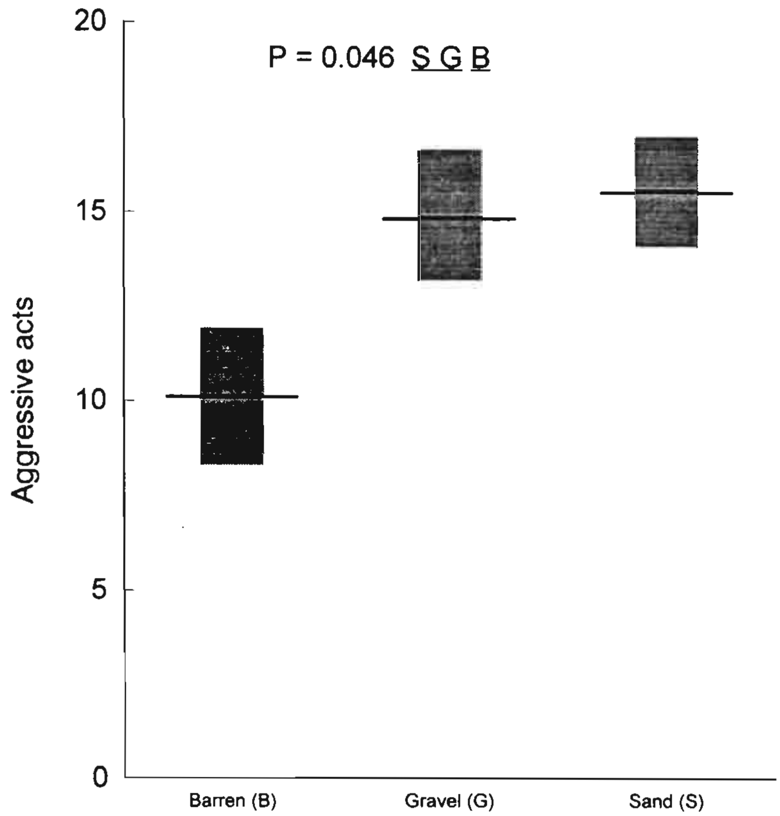

Figure 1. Mean number of aggressive acts per 10 minute scan sample in conventional and seminatural raceway habitat tanks in 1992 Little Anderson Creek release experiment. (Bars are mean values and boxes are standard error.)

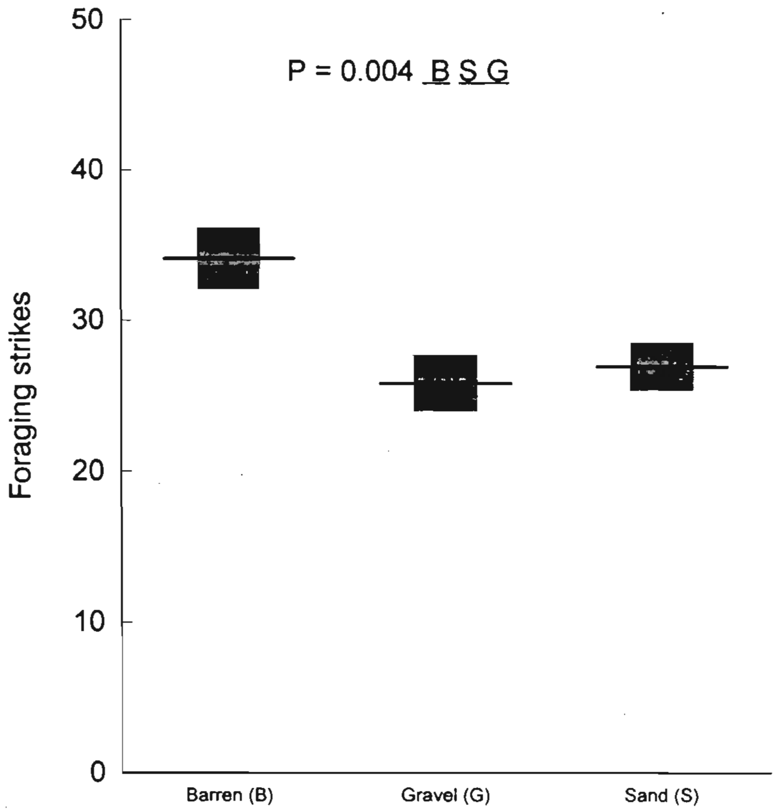

Figure 2. Mean number of particle strikes per 10 minute scan sample in conventional and seminatural raceway habitat tanks in 1992 Little Anderson Creek release experiment. (Bars are mean values and boxes are standard error.)

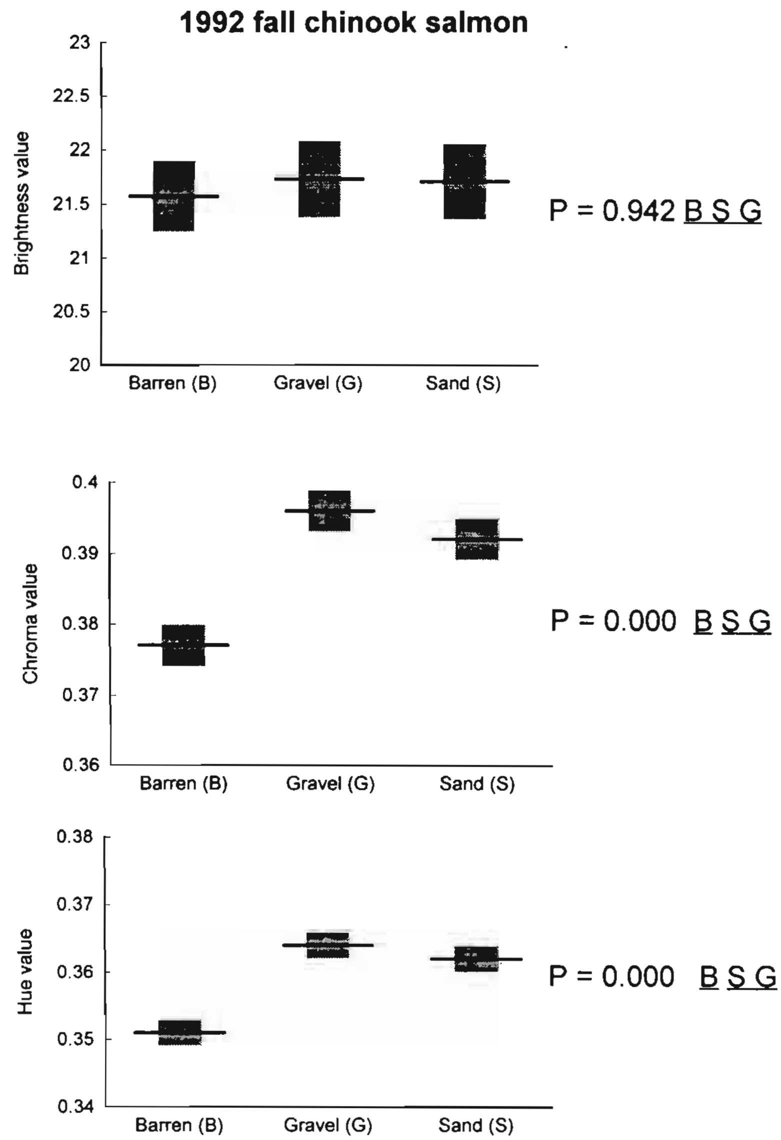

Figure 3. Mean brightness, chroma, and hue value for ocean type chinook salmon reared in conventional and seminatural raceway habitats in 1992 Little Anderson Creek release experiment. (Bars are mean values and boxes are standard error.)

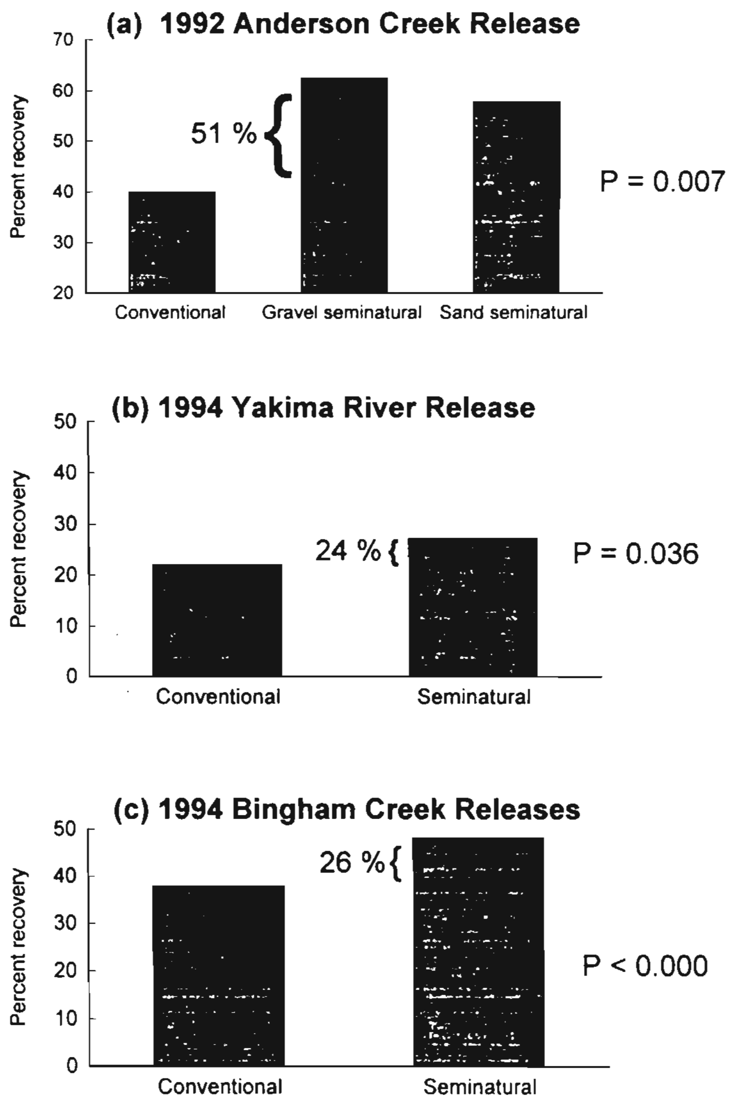

Figure 4. Percent recovery of conventionally- and seminaturally-reared chinook salmon from clearwater releases into: (a) Little Anderson Creek in 1992; (b)the Yakima River in 1994; and (c)Bingham Creek in 1994.

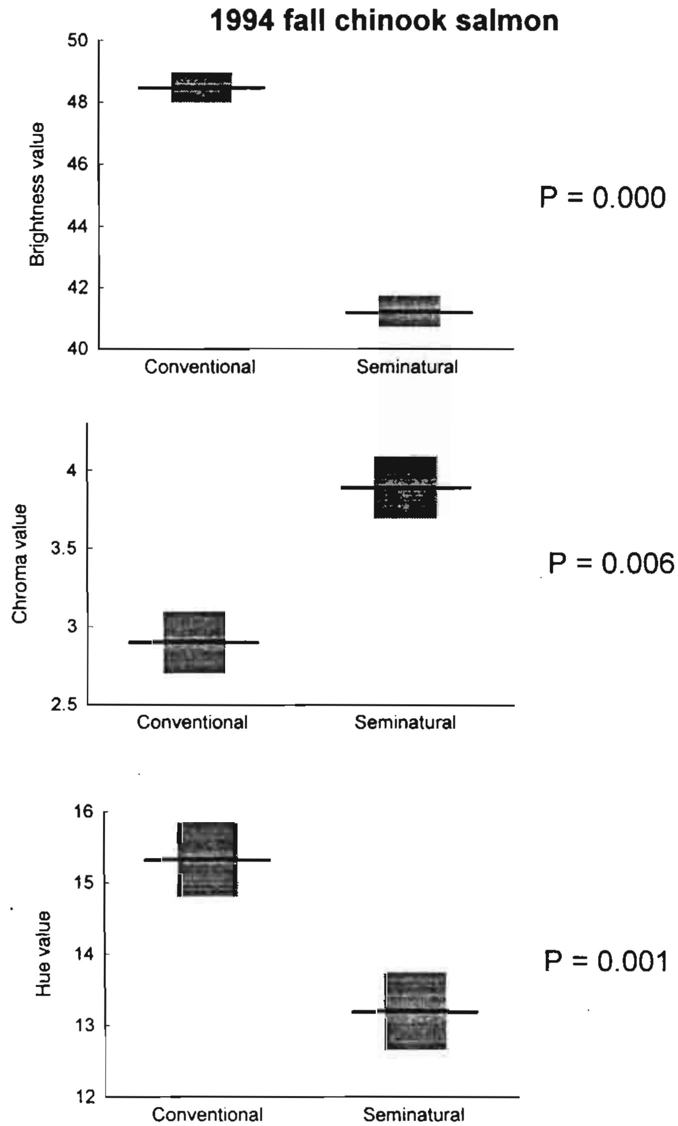

Figure 5. Mean brightness, chroma, and hue value for ocean type chinook salmon reared in conventional and seminatural raceway habitats in 1994 Bingham Creek release experiment. Bars are mean values and boxes are standard error.)