A Review of Recent Studies Investigating Seminatural Rearing Strategies As A Tool For Increasing Pacific Salmon Postrelease Survival

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Abstract

Traditional hatchery salmonids lack many behavioral and morphological attributes needed to survive after release (Maynard et al.1995). The Seminatural rearing concept hypothesizes that exposing hatchery salmonids to natural habitats, foods, predators, and currents will induce them to develop the wild behavior, physiology, and morphology needed for postrelease survival. The paper reviews recent studies investigating the efficacy of this concept. Rearing salmonids in seminatural rearing habitat, with natural fluvial substrates, structure, and overhead cover usually improves survival. Supplementing hatchery fish diets with live foods often enhances their ability to hunt live prey. However, utilizing automated underwater feeders to feed chinook salmon in a more natural manner did not alter their depth preference, response to novel visual stimuli at surface, or predator vulnerability as predicted. In most, but not all cases, conditioning salmonids to avoid predators improves their postrelease survival. Exercise usually improves growth and health, but does not always increase postrelease survival. Fisheries managers can use the increased survival successful seminatural rearing strategies offer to increase recruitment to the fishery and spawning population, reduce competitive impacts on listed stocks, or simply reduce operational costs.

Introduction

Seminatural rearing strategies that promote the development of natural behavior, physiology, and morphology may provide fish culturists the tools needed to increase the postrelease survival of ocean ranched salmonids. Mitigation, enhancement, and conservation programs all rear juvenile salmonids in protective environments, ensuring high inculture survival (usually greater than 95%). However, hatchery fish typically suffer very high mortality after release, with less than 1% of the chinook (*Oncorhynchus tshawytscha*) and 10% of coho salmon (*O. kisutch*)produced by hatcheries normally surviving to recruit to the fishery or spawning population. This large prerelease-postrelease survival difference dictates that fish culture practices which enhance postrelease survival will have a much greater impact on recruitment than those that increase inculture survival. As an example, a 5% increase in inculture survival (e. g., from 95% to 100%) for a hatchery stock with 2% recruitment will produce only one additional recruit for the fishery or spawning population per 1,000 individuals released (Figure 1). Whereas a 5% boost in postrelease survival (from 2 to 7%) will yield an additional 48 fish for harvest or restoration of the natural spawning population. Even a 1% (2-3%) increase in postrelease survival will generate an order of magnitude more recruits to the fishery and spawning population than a 5% increase in inculture survival. This relationship dictates researchers will make their greatest gains at increasing the number of recruits to the fishery and spawning population by focusing their efforts on developing fish culture practices that increase postrelease survival.

Hatcheries provide fish little experience for the peril-filled natural postrelease environment they must reside in during most of their life cycle. As an example, ocean type chinook salmon are typically cultured in slack water environments lacking natural substrates and structure. In this manmade environment, they are protected from predators and fed pellets for up to nine months before being released to survive on their own for the remaining 24 to 72 months of their life cycle. This artificial environment produces fish that are: 1) unfamiliar with the predators they must evade after release; 2) inexperienced with the natural habitat they must migrate through to reach the sea, 3) unprepared to swim in swift turbulent currents on their downstream migration; and 4) inexperienced hunters that are inept at searching out and capturing elusive prey.

These observations have led many behavioral biologists to hypothesize that exposing hatchery fish to more natural rearing conditions prior to release might help prepare them for life on their own. Seminatural rearing habitats, automated underwater feeders, exercise current velocities, live food diets, predator avoidance training, lower rearing densities, and oxygen supplementation have all been suggested as ways to provide hatchery fish with "heads up" training for life in the natural world (Butler 1981, Wiley et al. 1993, Suboski and Tempelton 1989, Olla et al. 1994, Maynard et al. 1995, Olla et al. 1998, Brown and Laland 2001). These approaches are all based on the central paradigm that rearing fish in a more natural hatchery environment helps promote the expression of traits enhancing the fish's survival in the wild. The behavioral expression of these traits may include learning to recognize and evade predators, becoming skilled at swimming in a turbulent flow, and developing appropriate hunting techniques. The physiological expression of these traits may involve the cardiovascular and skeletal muscle conditioning required to swim in turbulent currents. Morphological expression may produce fish with the appropriate camouflage colorations for the habitat backgrounds found in streams, rivers, lakes, and estuaries. Maynard et al. (1995) reviews the theoretical approaches for seminatural conditioning of fish prior to release. Over the last decade, research evaluating the effectiveness of these theoretical approaches has expanded considerably. The present paper reviews current research examining the efficacy of seminatural rearing strategies as a tool for increasing the postrelease survival of ocean ranched fish.

Seminatural Rearing Habitat

Seminatural rearing habitat incorporates components of natural substrate, structure, and cover into fish culture vessels. This seminatural habitat provides fish the opportunity to experience natural environmental complexity prior to release. It offers fish the opportunity to develop the skills needed to rapidly swim through woody debris type structure, seek shelter, and develop appropriate camouflage coloration before these skills become vital to their postrelease survival. Seminatural raceway habitat is one subset of seminatural rearing habitat that is designed to make raceways resemble the natural fluvial habitat which most salmonids rear in (Maynard and Flagg 2001). This approach incorporates natural substrate (e.g., sand, gravel, epoxy resin rock pavers, or exposed aggregate pavers), structure (e.g., plastic aquarium plants or conifers), and overhead cover (e.g., solid opaque or camouflage net) simulating natural stream and riverine environments.

In the last few years, we have conducted four studies examining the effect of seminatural raceway habitat on chinook salmon behavior, growth, morphology, health, and survival. In addition we have a fifth study examining the effect of seminatural raceway habitat on coho salmon growth, morphology, health, and smolt-to-adult survival currently underway. The experiments ranged in scale from 400-l rectangular tanks to standard production raceways with a rearing volume of more than 28,320-l (Maynard et al. 1996 a, b, d; 2001a; 2003a; 2003c). Over the course of these experiments seminatural raceway habitat has evolved from a somewhat difficult to maintain loose sand or gravel substrate, plastic aquarium plant structure, and opaque overhead cover to an easier to work form consisting of gravel embedded in concrete pavers that can be vacuumed, with conifers suspended from cables that can be easily moved when working the raceways, and self lifting covers fitted with military specification camouflage net that can easily be opened during fish culture operations (Maynard et al. 1996d, Maynard et al. 2003c). Although in most experiments, fish have been reared full term from the swimup fry to smolt stage in seminaturally raceway habitat, an acclimation approach has also been successfully used where fish are placed in the experimental habitat for only the last few months preceding their release.

The general results from these five experiments are surprisingly similar given the wide range of experimental conditions under which they were conducted. In seminatural raceway habitat chinook salmon were observed to engage in natural aggressive activity more often and strike at decaying debris in the water column less often than conventionally reared fish (Maynard et al. 1996d). However, the inculture depth distribution behavior of chinook salmon reared in seminatural raceway habitat appears to be similar to controls (Maynard et al. 2003c). The growth of chinook salmon reared in seminautral raceway habitat usually lagged slightly behind that of fish grown in the conventional raceway environment (Maynard et al. 1996 a, b, c, 2003 a). However, the health of chinook salmon reared in seminatural raceway habitat is equivalent to or better than that of conventionally reared fish (Maynard et al. 1996a, b, d, 2003a). Both the growth and health of coho salmon reared in seminatural raceway habitat is similar to that of controls (Maynard et al. 2003c). The skin color of seminaturally and conventionally reared fish in all five experiments diverged during culture (Maynard et al. 1996 a, b, d, 2003 a, c). These color differences appear to enhance the ability of seminaturally reared fish to blend into stream and river backgrounds. In addition to this coloration advantage, predation bioassays suggest seminatural rearing may improve the ability of chinook salmon to evade predators (Maynard et al. 2003a). Importantly in 16 out of 17 releases, the instream survival of chinook salmon reared in seminatural raceway habitat was higher than that of their respective controls (Figure 2).

Some other studies have also observed that seminatural rearing habitat produces salmonids with more natural behavior and better fin condition. For instance, the addition of natural substrate to the bottom of grey fiberglass tanks has been shown to increase the number of Atlantic salmon (*Salmo salar*) exhibiting territorial behavior (Mork et al. 1999). Several experiments have demonstrated that covering the bottom of concrete ponds with natural cobble substrates usually improves trout fin condition (Bosakowski and Wagner 1994, Bosakowski and Wagner 1995, Wagner 1996, Arndt et al. 2001). However, the addition of cobble substrate tends to reduce trout condition factor, fat levels, and total length (Wagner 1996). The addition of structure to the rearing environment of rainbow trout (*O. mykiss*) has been shown to produce visual isolation that reduces territory size, but does not result in an increase in volitional density (Imre et al. 2002).

Other research has also demonstrated that rearing salmonids in seminatural rearing habitat may also lead to increased postrelease survival. As an example, brown trout (*Salmo trutta*) reared in natural ponds were found to have higher survival than those reared in conventional tanks (Naslund 1992). Similarly, the smolt-to-adult survival of cutthroat trout (*O. clarki*) reared in gavel bottom ponds was observed to be higher (60%) than fish reared in standard concrete raceways (Tipping 1998, 2001). Rearing coho salmon in seminatural ponds with gravel substrate, woody debris structure, and cover was found to produce a slight (but not significant) increase in their smolt-to-adult survival above that observed for fish reared in conventional concrete raceways (Fuss and Byrne 2002). Preliminary data indicate coho salmon reared in ponds with camouflage net covers and plastic crate structure have increased smolt-to-adult survival (Vander Hagen and Appleby 1998, Vander Hagen personal communication). When challenged to survive on their own the growth of age-0 steelhead cultured in tanks enriched with camouflage net cover and conifer structure was greater than that of conventionally grown fish, suggesting the possibility of a survival advantage (Berejikian et al. 2000). Unfortunately, for most of the studies mentioned above, the effects of density and the presence of natural feeds can not be separated out from the effect of seminatural rearing habitat.

In summary, most research conducted over the last two decades indicates seminatural rearing habitat leads to increased postrelease survival. In most studies, this rearing strategy appears to produce salmonids with more natural territorial behavior and skin coloration without any reduction in fish health. Seminatural raceway habitat, has been developed into a form that can be readily retrofitted to existing raceways.

Developing Hunting Skills

Wild salmonids are skilled predators successfully hunting for a variety of elusive invertebrate and vertebrate prey. Coevolution of salmonids and their prey has resulted in prey organisms being well camouflaged, exhibiting cryptic behavior, and possessing a variety of predator evasive behaviors. In sharp contrast, artificial feeds are designed to be highly visible and easy to consume to ensure maximum feed conversion which minimizes economic and environmental waste. Unfortunately, this ease of detection and capture of artificial feeds may result in hatchery salmonids failing to develop vital hunting skills they will need after release. This potential inability of hatchery fish to hunt may explain why they have often been observed to starve for prolonged periods after release (Miller 1953, Hochackka 1961, Reimers 1963, Sosiak et al. 1979, Myers 1980, O'Grady 1983). Behavioral research suggests that pellet-reared fish usually have some difficulty developing successful hunting techniques when they first encounter live prey (Coughlin 1991, Maynard et al. 1996e, Reiriz et al. 1998, Munakata et al. 2000, Sundstrom and Johnson 2001, Ellis et al. 2002, Kahilainen and Lehtonen 2002). Hypothetically, it may be possible to develop natural hunting skills in hatchery fish by supplementing or replacing their artificial diet with live prey. A number of experiments have evaluated the validity of this concept during the last two decades.

We have investigated the use of live food or live food supplemented diets as a tool to improve the hunting ability of hatchery reared chinook salmon. In the first study the diet of ocean type chinook salmon was supplemented with live feeds. When the fish were tested in laboratory aquaria, it was observed that fish whose diet had been supplemented with live food fed on twice the number of familiar and novel prey as fish reared only on commercial fish food (Maynard et al. 1996e). In the second study, when stream type chinook salmon reared on a similar live food supplemented diet were challenged to forage in freshwater and marine enclosures for a week, it was the pellet only fed fish that were most successful (Maynard et al. 1996f). Many fish from both rearing treatments in this second study had empty stomachs and it is possible that both contagious (trained fish teaching naïve fish) and despotic behavior (one fish dominates the food supply) effects may have confounded the results. In a subsequent third study, the behavior of individual fish was again observed in laboratory tanks where it was noted that fish reared on live food diets showed greater interest in live prey, while fish reared on pellets were more interested in nonfood items (Maynard et al. 2001e). Field trials, where individual fish foraged in cages suspended in a large coastal stream for a week, found that the gut contents of fish reared on live food diets were not significantly different by weight than those of fish reared only on a pellet diet (Maynard et al. 2001e).

Live food diets have been used with some success to improve the foraging skills of other species. Providing tiger muskellunge (hybrid *Esox lucius* x *E. masquinongy*) with the opportunity to hunt live prey enhanced their foraging behavior by decreasing the time and number of strikes required to capture natural live prey (Gillen et al. 1981). Similarly, the hunting skill of naïve sockeye salmon (*O. nerka*) tested in the laboratory improved with increasing experience (Vineyard 1982). Laboratory evaluations indicated that the foraging success of pellet-reared brown trout challenged to capture live crickets was lower than that of wild reared trout, but improved with experience (Sundstrom and Johnson 2001). Although the development of hunting skills in Atlantic salmon raised on pellets lags behind that of those raised on live food, the hunting skills of pellet reared fish improved in subsequent encounters (Coughlin 1991, Reiriz et al. 1998, Brown and Laland 2002).

Intriguingly, it has been shown in the laboratory that the image of experienced demonstrators is sufficient to accelerate this learning process in Atlantic salmon (Brown and Laland 2002). This contagious behavior suggests it may be possible to train a small group of hatchery fish to serve as demonstrators that can be used to rapidly train the remainder of the population in successful hunting tactics. Laboratory trials with hatchery reared turbot (*Scophthalmus maximus*) have found they are also less successful hunters than wild-reared fish (Ellis et al. 2002). As with salmonids, providing hatchery-reared turbot experience with live foods improved their hunting skills, although nonfood items, like stones, continued to be attacked for at least six weeks due to their pellet-like visual characteristics. Although these results suggest live food diets may be used to improve hatchery fish hunting skills, further research is needed to refine the techniques before they are ready for implementation at production hatcheries.

Conditioning Appropriate Anitpredator Behavior

Postrelease survival of hatchery fish may be improved by fish culture practices that encourage the proper development of strategies fish use to counter predation. These strategies usually include: 1) stealth (e.g., cryptic coloration); 2) avoiding habitats predators use; 3) adopting appropriate behavior when detecting predators (freezing, hiding, flight, etc.); 4) evolving better swimming and maneuvering ability than their predators, and 5) outgrowing their predators gape. As previously discussed, seminatural rearing habitat is a culture strategy that can be used to encourage fish to develop appropriate cryptic coloration. This section focuses on reviewing techniques to condition fish to recognize predators. The following sections will then discuss fish culture approaches that train fish to avoid habitats where they are most vulnerable to predators and to exercise salmonids to enhance their speed and maneuverability.

In the hatchery, fish are unlikely to experience the various visual, acoustic, and chemical cues emitted by most of the predators they will encounter after release. Hatchery fish may develop some experience with predation from the small suite of avian predators such as kingfishers (*Ceryle alcyon*), crows (*Corvus caurinus*), gulls (*Laurus sp*), and herons (*Ardea herodias*). However, they usually have no prerelease exposure to predacious fish such as trout, pikeminnow (*Ptychocheilus oregonensis*), and sculpins and most of the piscivorous birds such as mergansers (*Mergus merganser, Lophodytes cucullatus*), terns (*Sterna caspia*), and cormorants (*Phalacrocorax species*) that attack them on their postrelease migration. This predator naivety may be alleviated by conditioning hatchery fish to recognize and respond appropriately to the cues given off by the various predators they will encounter after release. Ideally, this conditioning process will result in little or no mortality during the hatchery rearing phase.

The predator recognition behavior of salmonids has both innate and learned components. The innate component produces reactions such as the fright response of artic charr (*Salvelinus alpinus*) to the cues given off by predacious burbot (*Lota lota*) and pike (*Esox lucius*) (Hiroven et al. 2000). The learned component has been demonstrated in the many studies where salmonids have been observed to rapidly associate danger with the specific visual, chemical, and acoustic cues given off by a predator (Thompson 1966, Patten 1977, Olla and Davis 1989, Jarvi and Uglem 1993, Healey and Reinhardt 1995, Brown and Smith 1998, Berejikian et al. 1999, Brown 1999, Yamamoto and Reinhardt

2003, Hiroven et al. 2000). This learned component of predator recognition provides fish culturists the opportunity to train their fish to recognize predators prior to release.

The efficacy of predator avoidance conditioning has been examined in several studies conducted over the last four decades. Thompson (1966) pioneered this concept with a series of laboratory experiments demonstrating that salmonids modify their behavior after being exposed to predation events. He then applied this concept at the hatchery level by exposing chinook salmon to an electrified model of a steelhead trout (*O. mykiss*). As predicted, the instream survival of predator conditioned chinook salmon to a downstream weir was higher than that of predator naïve controls. A similar study was conducted in Japan where an electrified model of a predacious goby was used to condition chum salmon (*O. keta*) to avoid predators (Kanayama 1968). However, the efficacy of this goby model at increasing survival in an enclosed stream section varied with fish size.

Direct exposure to predators usually produces a positive result. Exposing sockeye salmon to predacious rainbow trout increased their survival in predator laden stream channels by more than 16% (Ginetz and Larkin 1976). Similarly the direct exposure of coho salmon to predacious torrent sculpin (*Cottus rhotheus*) increased their relative survival in subsequent encounters by 67% (Patten 1977).

Field trials have shown that exposing chinook salmon to caged predators such as hooded mergansers, largemouth bass (*Micropterus salmoides*), and brown bullhead catfish (*Ictalurus nebulosus*) during raceway rearing increases their instream survival by 26% (Maynard et al. 2001c). Exposure to caged predators (blue crab, *Callinectes* *sapidus*) also increased the survival of hatchery-reared summer flounder (*Paralichtheys dentatus*) by more than 50% in subsequent encounters (Kellison et al. 2000).

Laboratory research has demonstrated that coho salmon may only need exposure to the visual, acoustic, and chemical cues given off by lingcod (*Ophidon longatus*) during a predation event to increase their survival in subsequent encounters (Olla and Davis 1989). The success of predator avoidance conditioning generally seems to improve as the number of cues the learner is exposed to increase. Thus, laboratory studies have found that directly exposing Atlantic salmon to predators generated a better response than exposure to caged predators (Jarvi and Uglem 1993). Nonetheless, because of the ease of application, efforts have even been made to use single cues, like video images or odors alone, as tools to condition hatchery reared salmonids to avoid predators (Berejikian et al. 1999, BBC News 2001). Field trials using stream enclosures have shown that chemosensory predator recognition training can be used to successfully increase the survival of brook trout faced with chain pickerel (*Esox niger*) predation by 5% (Mirza and Chivers 2000).

Unfortunately, not all predator avoidance conditioning research has been able to develop successful training protocols. As an example, one recent experiment determined that coho and chinook salmon both modify their behavior after being exposed to predation (Healey and Reinhardt 1995). However, this behavioral modification only improved the survival of coho salmon during open field trials. Similarly exposing chinook salmon to cutthroat predation did not increase their instream survival (Berejikian 1996), nor did predator avoidance training reduce the poststocking mortality of tiger muskies (Koupal 2000). These studies indicate that individual exposure protocols need to be developed for each species of concern. Properly developed, predator avoidance conditioning should be a very useful tool for enhancing the postrelease survival of hatchery salmonids.

Conditioning Natural Habitat Preference

The types of postrelease habitat fish utilize may markedly affect predator vulnerability. Fish culturists maybe able to improve the postrelease survival of fish by conditioning them use the subset of natural habitats where they are less susceptible to predators. Surface orientation is one of the most notable attributes of hatchery salmonids that may increase their vulnerability to predation (Sosiak 1978, Mason et al. 1967, Uchida et al. 1989, Reinhardt 2001). Although this surface orientation has innate components, it is also known to be partially conditioned. As an example, although farmed and ocean ranched masu salmon (*O. masou*) are innately more surface oriented than wild stocks, they all become increasingly more surface oriented the longer they are fed pellets from the surface (Reinhardt 2001). This surface orientation of hatchery fish can markedly increase vulnerability to surface feeding predators, such as terns (Collis et al. 2001).

In a study conducted during the mid 1990s, we hypothesized that fish could be conditioned to be more benthic oriented by feeding via automated underwater feed delivery systems that do not positively reinforce surface orientation behavior. The concept of using automated underwater feeders as a tool to condition salmon to avoid the surface has been examined. This study incorporated an automated underwater feeder system into one of the previously described seminatural raceway habitat experiments (Maynard et al. 1996b). Subjective observations conducted during this experiment suggested chinook salmon reared with the automated subsurface feed delivery system exhibited more natural territorial behavior and seemed less likely to strike at debris falling on the surface than did hand fed fish. However, during this study the effects of the feeder could not be separated from those of the other seminatural raceway habitat components.

In the follow up experiment, ocean type chinook salmon were reared in raceways where they were either fed by hand or using the automated underwater feed delivery system (Maynard et al. 2001b). As in the first experiment, the hand fed fish rapidly became conditioned to swim towards fish culture personnel and would swarm at the surface when humans approached the raceway. However, testing revealed no depth preference, innate fright response, or predator vulnerability differences had developed between fish in the two feeding treatments. Only the response hand fed fish gave to the visual image of a human standing beside the raceway differed between fish in the two rearing treatments. This suggests hand feeding at the surface may not increase the postrelease predation risk for chinook salmon.

As noted above, for other species the results may be quite different. Research conducted with sea run cutthroat trout indicates elimination of hand feeding can have beneficial postrelease survival effects (Tipping 2001). In this case, the smolt-to-adult survival of fish reared on demand feeders exceeded (but nonsignificantly) that of traditional hand fed fish by 10% (Tipping 2001). Since both feeding methods disperse food at the surface, the survival benefit must be attributed to not deconditioning the fish to fear large moving objects at the surface.

Developing Stamina

Fish culturists may be able to increase the postrelease survival of salmonids by improving their swimming performance. Swimming performance is not only a key factor in bursting away from and outmaneuvering predators, but is also critical in avoiding injuries from turbulent currents during downstream migration. Most hatchery salmonids gain little experience with any form of flow prior to release. This is because raceways and rearing ponds velocities are normally less than 1 cm/sec. This low flow environment fails to challenge the fish to swim as they would in their natural fluvial habitat.

There is ample evidence exercising salmonids provides fish culture benefits. In one study examining exercise as a fish culture tool, brook trout (*Salvelinus fontinalis*) were reared for 10 weeks in circular tanks with or without exercise (Leon 1986). This exercise significantly increased fish growth and swimming stamina over that experienced by unexercised controls. Other investigations have observed exercise routinely improves food conversion (Christiansen et al. 1989, Christiansen and Jobling 1990, Christiansen et al. 1992, Nielsen et al. 2000, Azuma 2001) and swimming performance (Besner and Smith 1983, Schurov et al. 1986, McDonald et al. 1998). Regular exercise also improves the ability of salmonids to adapt to seawater and reduce their ion loss in epinephrine challenge tests (Khovanskiy et al. 1993, McDonald et al. 1998).

Burrows developed the rectangular circular pond as a tool to improve the quality of ocean ranched salmonids. His pioneering work indicates that the exercise velocities these rearing vessels generate improves fall chinook salmon smolt-to-adult survival by 62% (Burrows 1969). Similar results were observed with brown trout with the instream survival of exercised fish being more than 50% higher than that of unexercised trout (Cresswell and Williams 1983). Prerelease exercise also seemed to increase the instream survival of Atlantic salmon (Schurov et al. 1986). However, exercise does not always lead to increased postrelease survival. Coho salmon reared full term in the exercise velocities generated by Burrows ponds did not experience higher smolt-to-adult survival than controls reared in nonexercise standard raceway velocities (Lagasse et al. 1980). Exercise also did not improve the return of adult steelhead to Coles River Hatchery (Evenson and Ewing 1993).

An energetically efficient exercise system that can be retrofitted to standard raceways was recently developed by Maynard et al. (2001d). Exercising ocean type Chinook salmon for 24-h a day for a week in this system did not increase postrelease survival. However, the exercise regime did significantly increase inculture mortality probably because of high rearing water temperatures (to 18° C) encountered during that study (Maynard et al. 2001d). Adopting a 2-h a day exercise protocol and suspending the exercise program at the first sign of a disease outbreak significantly increased growth and decreased inculture mortality of exercised fish relative to that of unexercised controls (Maynard et al. 2003b). While this exercise protocol may have slightly increased resistance to hooded merganser attacks, it did not increase downstream survival. Further refinement and evaluation of exercise protocols are needed before the smolt-to-adult survival advantage observed by Burrows (1969) can be realized on a consistent basis.

Conclusion

A number of seminatural rearing strategies exist for increasing hatchery fish postrelease survival. As previously reviewed, reducing rearing density appears to consistently increase smolt-to-adult survival (Maynard et al. 1995). Seminatural rearing habitat and predator avoidance training are beginning to prove their worth as tools for increasing hatchery fish instream survival. Data from fish now at sea will help determine if these strategies also lead to increased recruitment to the fishery and spawning population. Unfortunately, other seminatural strategies, like subsurface feed delivery systems, live food diets, and exercise protocols have proven to be less useful as tools for increasing postrelease survival. These techniques require further refinement before they can be generally adopted as fish culture tools to enhance recruitment to the fishery and spawning population.

The continued development of fish culture techniques that improve postrelease survival is mandatory if recruitment to the fishery and spawning population is to be improved. Economic and social factors suggest it unlikely that the reduction in both the quantity and quality of freshwater rearing habitat can be totally reversed. Thus, we believe hatcheries will continue to be a necessity for the maintenance of anadromous salmonids stocks. The inculture survival of fish in hatcheries is already so high that further increases will have only minor impacts on the number of fish recruiting to the fishery and spawning population. Only fish culture techniques that increase the postrelease survival of fish released to sea offer any meaningful hope of improving recruitment. Fishery managers may use these new techniques to generate more recruits to the fishery, more returning spawners to listed populations, or simply to improve economic efficiency of hatchery operations. They may also use this increased postrelease survival tool to reduce the impact of mitigation and enhancement hatcheries on wild salmonids. This can be done since increased postrelease survival will enable hatcheries to release fewer smolts that negatively interact with wild fish, while maintaining stable recruitment levels to the fishery.

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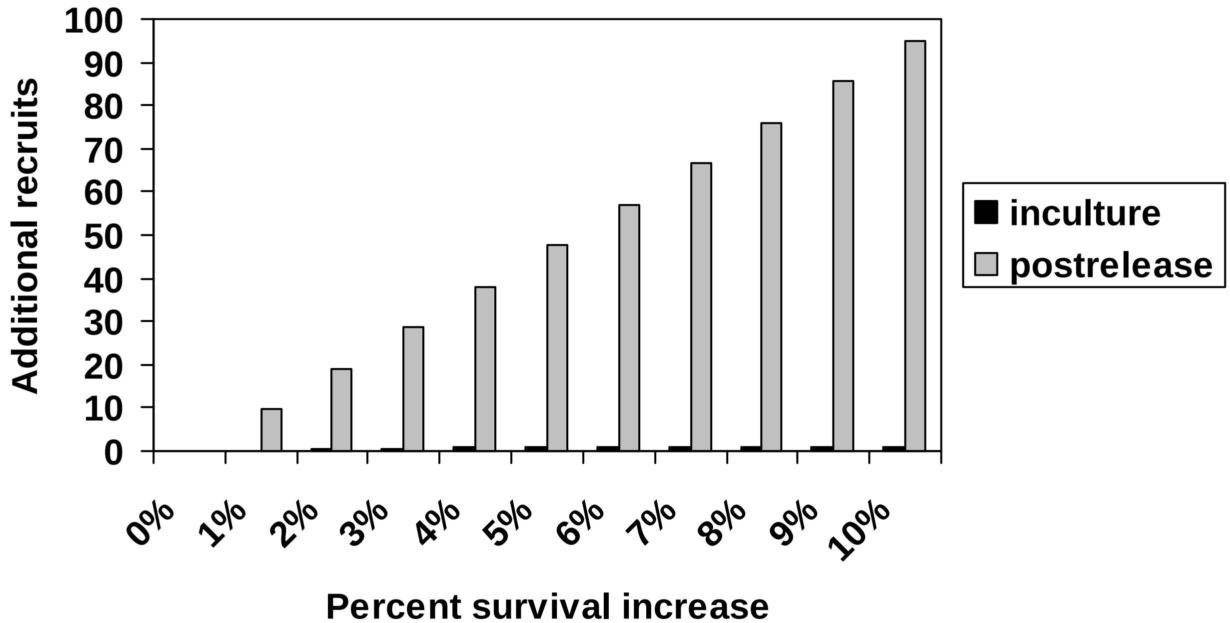
Figure 1. The number of additional recruits generated by equivalent increases in pre- and postrelease survival. (Assumptions: base inculture survival = 95%: base postrelease survival = 2%).

Figure 2. Summarized instream recovery of chinook salmon reared in conventional and seminatural raceway habitats (Combined data from Maynard et al. 1996 a, b, d, 2003 a, c).


100
90
80
70
60
50
40
30
20
10
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Additional recruits
0%
1%
2%
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4%
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7%
8%
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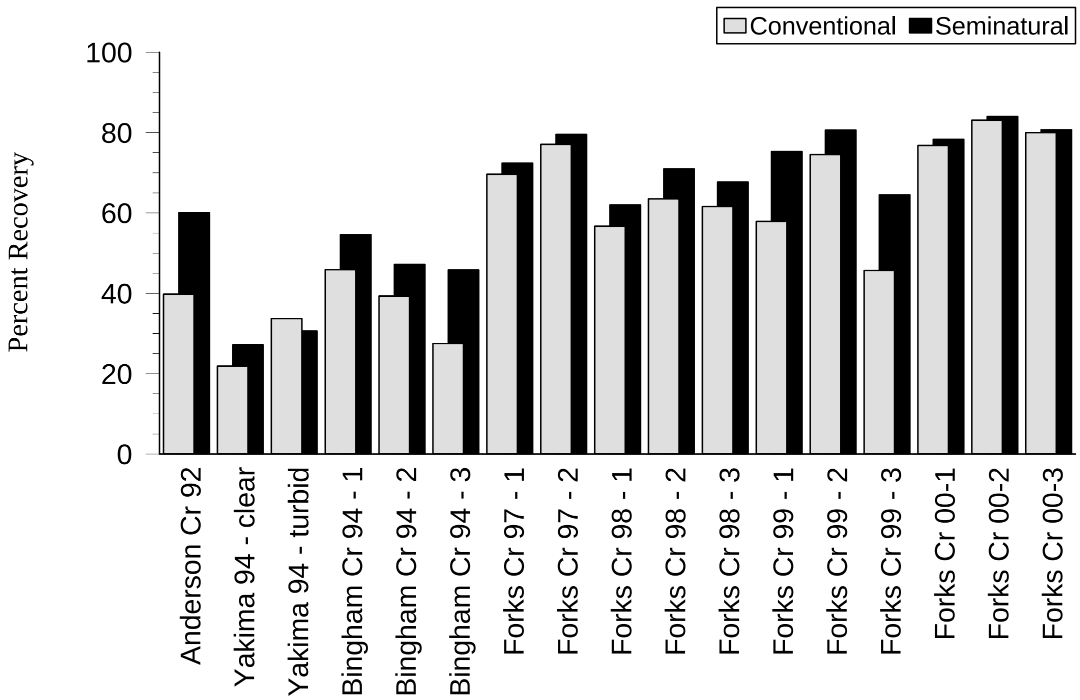
10%
Percent survival increase
inculture
postrelease


Conventional
Seminatural
Percent Recovery
100
80
60
40
20
0
Anderson Cr 92
Yakima 94 - clear
Yakima 94 - turbid
Bingham Cr 94 - 1
Bingham Cr 94 - 2
Bingham Cr 94 - 3
Forks Cr 97 - 1
Forks Cr 97 - 2
Forks Cr 98 - 1
Forks Cr 98 - 2
Forks Cr 98 - 3
Forks Cr 99 - 1
Forks Cr 99 - 2
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