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NATIONAL MARINE FISHERIES SERVICE
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31 January 2001

Mr. Bob Lohn
Northwest Power Planning Council
851 SW 6th Avenue, Suite 1100
Portland, OR 97204

Dear Mr. Lohn, Bob

Enclosed is a revised experimental design for Project 21024 Evaluate Hatchery Reform Principles that the National Marine Fisheries Service (NMFS), Northwest Fisheries Science Center (NWFSC), Resource Enhancement and Utilization Technologies (REUT) Division submitted under the Columbia Gorge Province review process. The ISRP final recommendation for Project 21024 was "Do not fund until an experimental design is adequately presented". The ISRP expressed concerns regarding the need to isolate NATURES main and interaction effects and adequately describe experimental variables and power analyses. Accordingly, the revised experimental design includes a full-factorial assessment of NATURES variables and power analyses for both instream smolt survival and adult survival evaluations.

NMFS feels that a full production-scale evaluation of NATURES concepts is critical to the development of conservation hatchery principles to aid restoration of the Region's anadromous salmonid resources. The proposed experiments at the Carson NFH will complement, but not duplicate, other ongoing or planned NATURES-type tests in the Columbia River Basin (e.g., Nez Perce Tribal Hatchery, Yakima Indian Nation Cle Elum Hatchery test of supplementation). Because of its long propagation history, the Carson NFH spring chinook salmon stock should serve as the best available model for application of NATURES-type Conservation Hatchery strategies to existing hatcheries. We estimate that costs for the project will be about $925K in year one and $875K in year two and remain in this area for the duration of the study.

Thank you for considering this revised proposal. Please feel free to contact me (206-860-3380) or Tom Flagg of my staff (360-871-8306) if you have any questions.

Sincerely,

R. Iwamoto

Dr. Robert N. Iwamoto
Director

cc:F/NWC2 – Dickhoff
F/NWC2 - Flagg
F/NWC2 - Maynard
F/NWC2 – Berejikian
Brian Allee, CBFWA

Bonneville Power Administration
FY 2001 Provincial Project Review

PART 2. Narrative

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Title: Evaluate Hatchery Reform Principles

Section 9 of 10. Project description

a. Abstract

The development of techniques to produce wild-like hatchery fish with improved post-release survival is called for in sections 7.2D.1-3 of the Columbia Basin Fish and Wildlife Program. The need for improving hatchery rearing and release strategies is also supported in the 2000 FCRPS Biological Opinion. A fundamental assumption is that improved rearing technology will reduce environmentally induced physiological and behavioral deficiencies presently associated with cultured salmonids. The proposed production-scale evaluation is based on two significant areas of scientific research, which hold promise for improving hatchery rearing technology. First, enriched (NATURES) rearing environments, including a combination of underwater feed-delivery systems, submerged structure, overhead shade cover, and gravel substrates, have been demonstrated to improve instream survival of chinook salmon (*O. tshawytscha*) smolts during seaward migrations in most studies. Second, salmon reared in hatcheries are typically naïve to naturally occurring predators, but can learn quickly to recognize them. Laboratory studies have demonstrated that anti-predator conditioning can improve predator recognition in chinook salmon. The proposed study will determine whether actual survival can be increased by implementing i) enriched rearing environments and ii) anti-predator conditioning in a production facility (Carson National Fish Hatchery). Demonstrated effectiveness at improving salmon culture technology to improve post-release survival at production-scale facilities would: i) reduce the number of wild broodstock that must be taken into fish culture programs to produce a given number of recruits in the next generation, ii) reduce the time required for supplementation programs to rebuild self-sustaining runs, and iii) enhance the efficiency of mitigation and fishery enhancement hatchery programs.

b. Technical and/or scientific background

The proposed study focuses on development and testing of conservation hatchery strategies to propagate juveniles similar in morphology, physiology, behavior, and postrelease survival to their wild cohorts. Hatcheries, while continuing to meet legally mandated mitigation requirements, must successfully evolve from a strict focus on fish production to one that supports fish recovery and restoration. The strategic role of a conservation hatchery is to promote restoration of wild stocks of fish. This requires fish rearing be conducted in a manner that mimics the natural life history patterns, improves the quality and survival of hatchery-reared juveniles, and lessens the genetic and ecological impacts of hatchery releases on wild stocks.

Conservationists recognize that rearing any living creature in captivity and then releasing it into its natural habitat is a difficult process. It requires application and integration of a number of rearing strategies, all of which are known individually to affect the inherent fitness of the animal to survive and breed in its natural ecosystem. For an aquatic animal, like fish, the process is even more complex, as some strategies must be executed within an invisible ecosystem and not in the controllable confines of captivity.

A conservation hatchery may be defined as a rearing facility to breed and propagate a stock of fish with equivalent genetic resources of the native stock, and with the full ability to return to reproduce naturally in its native habitat (Flagg and Nash 1999). A conservation hatchery is therefore a facility equipped with a full complement of culture strategies to produce very specific stocks of fish in meaningful numbers. It can also permute individual strategies to match the particular requirements and biodiversity of any individual stock to its ecosystem. One combination of strategies may be used to produce fish to restore a depressed stock, and another to reduce the risks of a certain supplementation program. The operation and management of every conservation hatchery is therefore unique in time, specific to an identifiable stock and its native habitat. There are no true conservation hatcheries in existence at the present time. Various production hatcheries are applying some individual conservation strategies in an attempt to improve fitness and increase stock survival, but there is currently no single hatchery capable of applying a full package of strategies to produce a fish with the equivalent genetic resources of a local native stock. One reason for the absence of conservation hatcheries is that the elements of their make-up have never been fully tested at production levels.

A main focus of the National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center (NWFSC) Resource Enhancement and Utilization Technologies (REUT) Division has been conducting research to improve the quality of hatchery fish. Recent efforts have focused on developing culture methods that will maintain the attributes of wild fish. REUT Division's research on natural rearing enhancement systems (NATURES) variables is integral to the development of biological tools and the hatchery reform protocols required for transitioning from traditional production hatcheries to hatcheries dedicated to the conservation and rebuilding of listed species. For example, production hatcheries presently rear fish in barren raceways. Not surprisingly, hatchery fish produced under these conditions lack the behavioral, physiological and morphological development required for high survival in the post-release environment.

Although the protective nature of hatchery rearing increases egg-to-smolt survival, it has been reported for many years (Greene 1952, Miller 1952, Reimers 1963) that post-release survival and reproductive success of cultured salmonids are both considerably lower than that of wild-reared fish. Hatchery practices which induce genetic changes (domestication, etc.) are often considered prime factors in reducing fitness of hatchery fish in natural ecosystems (Reisenbichler and McIntyre 1977, Nickelson et al. 1986, Goodman 1990, Waples 1991, Waples 1999, and Hilborn 1992). Rearing practices which disrupt innate behavioral responses may also play a major role in reduced performance of hatchery fish after release.

Behavioral deficiencies in released animals have been cited as causes of failure to re-establish wild populations by, among others, Gipps (1991), Johnson and Jensen (1991), DeBlieu (1993), and Olney et al. (1994). Current fish culture techniques may be imparting similar behavioral deficiencies in hatchery reared salmon. Social divergence of cultured fish may begin as early as the incubation stage as food availability and rearing densities in hatcheries far exceeded those of natural streams and may contribute to differences in agonistic behavior between hatchery- and wild-reared fish (Symons 1968, Bachman 1984, Maynard et al. 1995). Allee (1974), Dickson and MacCrimmon (1982), Berejikian (1995a), and others, have demonstrated that cultured and naturally-reared salmonids respond differently to habitat. In most cases, for example, wild fish utilized both riffles and pools in streams while newly released hatchery fish primarily used pools. Reisenbichler and Rubin (1998) summarized the current situation by concluding that, "...the only similarities in hatchery and wild environments for salmonids are water and photoperiod." Almost every other component of the hatchery rearing environment, such as food, substrate, density, temperature, flow regime, competitors, and predators, etc., differed from those naturally experienced by wild fish.

Consequently, the National Research Council (NRC 1996) and, more recently, others (SRT 1998, Anders 1998, Flagg and Nash 1999, Waples 1999, Flagg et al. 2000a) have suggested that operational strategies of production hatcheries can be changed to conservation strategies for the protection of wild stocks. It has been recommended (SRT 1998, Flagg and Nash 1999) that conservation hatcheries include among strategies:

- Provide incubation and rearing vessels with options for habitat complexity to produce fish more wild-like in appearance, and with natural behaviors and higher survival
- Provide prerelease training experiences, such as forage conditioning and anti-predator conditioning which, while still somewhat theoretical, are beginning to show improved survival and fitness.

These hatchery strategies specific to the current proposal are discussed below. A complete array of conservation hatchery strategies is fully described in Flagg and Nash (1999). Details of the ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations are described in Flagg et al. (2000b).

Enriched habitats

Research on higher vertebrates has shown that simple and practical (habitat enrichment) changes to the way animals are kept and grown can have beneficial effects on their physiology as well as their behavior (Gipps 1991). Providing animals with more complex rearing habitats which approximate natural conditions is an increasingly popular method for improving the well being of animals in zoos. In many cases, behavioral repertoires may be recovered even after many generations of absence simply by recreating the correct environmental stimuli. These habitat enrichment techniques, according to Johnson and Jensen (1991), DeBlieu (1993), Olney et al. (1994), and others, may also have application to salmonid hatchery populations.

Fish culturists have long recognized that fish reared in earthen-bottom ponds have better coloration than those reared in concrete vessels (Piper et al. 1982). However, only recently has it been understood that rearing salmonids over natural substrates, similar to those over which they will be released, increases survival by enhancing cryptic coloration. Research by Fuji (1993) indicates these morphological color changes can take weeks to complete, as pigments and chromatophore units are developed to match the general background. The cryptic coloration ability generated by these long-term stable color adaptations appears to reduce detection by predators. Donnelly and Whoriskey (1991) found that brook trout reared for 11 weeks over distinct background colors were significantly less vulnerable to predators when challenged over background colors similar to those over which they were reared. Maynard et al. (1996a) and Donnelly and Whoriskey (1993) attributed increased vulnerability of hatchery fish to predators to decreased crypsis (camouflage coloration) for stream environments. This lack of camouflage coloration is caused by the monochrome background of the (concrete) rearing environments of the hatchery raceways.

Extensive work by Maynard et al. (1995, 1996a, 1998a) with salmonids reared in natural rearing enhancement systems, which promote full development of the morphological camouflage pattern needed after release, showed that survival was increased. In these systems (called NATURES) the complexities of the experimental artificial rearing habitats simulate the release habitats. Substrates were configured in several ways, using sand, gravel, rock pavers, or painted patterns. Every effort was made to match the color of the substrate (which produces the cryptic coloration patterns in fish) to that of the receiving-stream environment to produce body camouflage patterns (fish crypcisity) most likely to reduce vulnerability to predators. In these studies, the in-stream post-release survival of fish reared in NATURES was compared with the survival of fish reared in conventional hatchery tanks. The results of the studies are briefly summarized below:

- 1991-1992. Fall chinook salmon were reared from swim-up to smolt in 400-L raceways (3 replicates/treatment) fitted with cover, structure, and substrate. Relative post-release survival to a collection weir about 2 km downstream was about 50% higher (40 versus 60%; $P=0.007$) for NATURES fish.
- 1994. Spring chinook salmon were reared for 3 months in 400-L raceways (6 replicates/treatment) fitted with cover, structure, and substrate. Relative post-release survival to a collection weir about 225 km downstream was about 23% higher (22 versus 27%; $P<0.05$) for NATURES fish under clear water conditions, but not in turbid water conditions (34 versus 31%; $P = 0.285$).
- 1994. Fall chinook salmon were reared from swim-up to smoltification in pilot scale 5,947-L raceways (3 replicates/treatment) fitted with cover, structure, substrate, and an underwater feed delivery system. Relative post-release survival to a collection weir about 20 km downstream was 26% higher (38 versus 48%; $P=0.001$) for NATURES fish.

- 1997. Fall chinook salmon were reared to smolt for about 3 months in 18,000-L production scale raceways (2 replicates/treatment) fitted with cover, structure, and substrate at a WDFW hatchery. Relative post-release survival to a collection weir about 20 km downstream was about 3.5% higher (73 versus 76%; P>0.05) for both groups.
- 1998. Fall chinook salmon were reared to smolt in the 18,000-L raceways (3 replicates/treatment). Relative post-release survival to a collection weir about 20 km downstream was 11% higher (60 versus 67%: P<0.001) for NATURES fish.
- 1999. Fall chinook salmon were reared to smolt in 18,000-L raceways (3replicates/treatment). Relative post-release survival to a collection weir about 20 km downstream was 24% higher (59 versus 73%; P<0.001) for NATURES fish.
- 2000. Fall chinook salmon were reared to smolt in the 18,000-L raceways (3 replicates/treatment). Relative post-release survival to a collection weir about 20 km downstream was 1% higher (80 versus 81%: P>0.604) for NATURES fish.

These results suggest that in-stream post-release survival of fish reared in these special habitats is significantly greater than that of their counterparts reared conventionally. Consequently, although not yet documented, it is assumed that survival to adulthood will be improved. The studies in 1997-2000 included components to evaluate ocean returns. However, complete adult return data will not be available for a number of years.

Natural stream-side cover can be created by suspending camouflage netting over about 75% of each vessel by about 1 m above the water surface along the margins of the raceways (Flagg and Nash 1999). Internal structures can be created by suspending small defoliated fir trees in rearing vessels occupying 30-60% of the surface area (Flagg and Nash 1999). Substrates have been configured in several ways, using sand, gravel, artificial rugose inserts, or painted patterns (Maynard et al. 1996a, Flagg and Nash 1999). Every effort should be made to match the color of the substrate (which produces cryptic coloration patterns in fish) to that of the receiving-stream environment to produce body camouflage patterns most likely to reduce vulnerability to predators. Other potential components of an enriched rearing environment for salmonids, including foraging training, natural like feed delivery systems, and changing flow velocities to exercise the fish, could also offer advantages for increased survival and behavioral fitness (Maynard et al. 1995).

In conclusion, it appears habitat enrichment strategies can aid in the production of 'wild-like' hatchery fish more suited for enhancement programs than fish reared in conventional systems.

Predator conditioning

Studies on salmonids carried out over many years have demonstrated an increase in post-release survival of juveniles following anti-predator conditioning in hatchery vessels. Thompson (1966), working in a natural stream, demonstrated that post-release survival of chinook salmon smolts exposed to electrified predator models was greater than unconditioned smolts, and Kanayama (1968) reported improved post-release survival of chum salmon after similar conditioning.

More recently, juvenile salmonids from wild and hatchery populations were shown to exhibit differences in predator avoidance behavior (Johnsson and Abrahams 1991) and ability (Berejikian 1995a, 1995b). This suggested a genetic basis for these traits. However, the ability of juvenile salmonids to avoid predation improved with experience. Work by Olla et al. (1998) suggested that hatchery rearing environments deprived salmon of the psycho-sensory stimuli necessary to develop anti-predator behaviors fully. Maynard et al. (1995) reviewed information indicating that hatchery strains of salmonids have increased risk-taking behavior and lowered fright responses compared with wild fish. These authors, together with Uchida et al. (1989) suggested that surface feeding conditioned hatchery fish to approach the surface of the water column, thus increasing their susceptibility to avian predation.

Laboratory studies by Patten (1977), Healey and Reinhardt (1995), and others, demonstrated that anti-predator behavior and predator avoidance ability of juveniles of several salmon species improved following exposure to actual predation events. Suboski (1988) and Olla and Davis (1989) suggested that anti-predator conditioning involved various combinations of visual, olfactory, and auditory stimuli, all of which could trigger innate anti-predator responses. Brown and Smith (1997 and 1998) and Berejikian et al. (1999) demonstrated that conditioning by a combination of injured con-specific predator odors in the absence of visual and auditory stimuli improved subsequent predator recognition and avoidance behavior in rainbow trout and chinook salmon, respectively.

The use of predator avoidance training as tool to increase the post-release survival of chinook salmon has been investigated by Maynard et al. (1998b). Fall chinook salmon reared in pilot scale raceways were exposed to limited predation by birds (great blue heron and hooded merganser) and fish (largemouth bass and brown bullhead). The in-stream post-release survival of the conditioned fish was 26% higher than naive controls.

These studies suggest anti-predator training can be used to increase the post-release survival of hatchery-reared fish. There is no evidence that anti-predator conditioning has a detrimental effect on post-release survival.

In conclusion, simple and practical alterations to the way fish are reared (e.g., rearing in structurally enriched habitats and predator avoidance training) can substantially increase post-release survival. However, to date, most research to improve the quality of hatchery fish has been conducted in pilot-scale tanks and raceways. Considerably more in-depth production-scale studies (like those proposed in the current research proposal) are required in all aspects of conservation hatchery strategies to fully develop and validate the concept.

c. Rationale and significance to Regional Programs

The development of (NATURES-type) techniques to produce wild-like hatchery fish with improved post-release survival is called for in sections 7.2D.1-3 of the Columbia Basin Fish and Wildlife Program and in the Northwest Power Planning Councils Review of salmonid artificial production in the Columbia River Basin. The need for development of conservation hatchery strategies is also supported in the 2000 NMFS FCRPS Biological Opinion. The proposed Carson NFH evaluation of NATURES variables should provide rigorous conservation hatchery husbandry criteria applicable to all stocks of salmonids in the Columbia River Basin. Information from on-going and the proposed Carson NFH NATURES research will benefit development and implementation of conservation hatchery strategies for state, Federal and Tribal programs, including those for the Yakama Indian Nation and Nez Perce Indian Nation tribal hatchery projects.

d. Relationships to other projects

The proposed Carson NFH NATURES evaluation focuses on evaluating two NATURES rearing protocols (enriched raceway habitat and anti-predator conditioning). The statistical design (Full Factorial Three Way ANOVA) for the enriched raceway habitat experiment will allow us to partition the effects of each major component of enriched raceway habitat (substrate, structure, and cover) and examine their interactions. This is a fully crossed factoral evaluation of enriched raceway habitat that was called for in a previous ISRP review of the proposal. This in depth approach to evaluating enriched raceway habitat is not being used in any other NATURES evaluations. Other Columbia River Basin NATURES-type studies are evaluating limited sets of variables. For example, the Cle Elum project is limited to an evaluation of the effects of enriched raceway habitats with painted substrate bottoms. A recent Cle Elum Hatchery-related Washington Department of Fish and Wildlife (WDFW) study indicated painted, simulated substrates may produce similar instream post-release juvenile survival as rugose (gravel-type) substrates. Nonetheless, evidence in the literature suggests that rugose substrates may increase fish quality through mechanisms such as reduced fin erosion (e.g., Wagner et al. 1996), and hence, may be a factor in increased post-release fitness. All previous NMFS enriched raceway habitat research studies that have produced increases in juvenile instream survival have utilized rugose forms of substrate raceway (Maynard et al. 1995, 1996a,b, 1998a). Most recently, NMFS research has been focusing on substrates composed of local river gravel imbedded in a resin matrix to form a small (less than 1m x 1m) paver that can be secured in groups to the bottom of raceways. The proposed Carson study will continue to incorporate these (more natural) types of rugose substrates in the evaluation of NATURES variables. Finally, the proposed Carson NFH study will focus on traditional hatchery practices of on-site smolt release, while the Cle Elum project focuses on evaluation of new supplementation techniques such as off-site acclimation.

A major goal of hatchery reform is development of culture methods that can be retrofitted to existing hatcheries with stocks that may be the product of generations of domestication as well as directed selection. An important concern at present is the conservation needs of Columbia River Basin spring chinook stocks in Idaho, Oregon, and Washington headwater areas. Because of its long propagation history, the Carson NFH spring chinook stock should serve as a reasonable model for the majority of Columbia River Basin hatchery spring chinook stocks. Moreover, the proposed Carson NFH NATURES study will complement other NATURES-type studies in the Columbia River Basin such as the WDFW coho salmon project at the Elochoman Hatchery and the Yakima Indian Nation's spring chinook study at the Cle Elum Hatchery.

Because of the complexity of the form and purpose of existing hatchery programs, changes as part of the reformation process will likely involve the development and testing of many different strategies. Diversity in experimental goals and approaches will be essential. Hence, while the above-mentioned programs also endeavor to address Hatchery Reform issues, the proposed Carson NFH evaluation offers several unique perspectives as well as experimental advantages. For example, because the Carson NFH is a lower river facility, the higher smolt-to-adult returns should provide higher statistical ability to test critical hypotheses. Also, the Carson NFH evaluation should serve as a model for retrofitted hatcheries in the basin with established hatchery stocks whereas the Cle Elum project focuses on wild fish during their first generation of culture. Hence, the latter study may be most applicable to design and operation of new facilities.

e. Project history (for ongoing projects)

N/A

f. Proposal objectives, tasks and methods

The proposed research is to conduct production-scale hatchery reform protocol studies that would evaluate the relative effects of i) structurally complex rearing habitats and ii) anti-predator conditioning on the survival of stream-type chinook salmon and steelhead. We propose that these tests be centered at the Carson NFH in the Columbia River Basin. Experimental treatments will be compared to conventional rearing methods to determine their importance in improving smolt-to-adult return (SAR) rates.

Objective 1. Enriched Habitat Rearing

Experimental Designs

The Enriched Habitat experiment would test the following null hypotheses:

> H0,1: The substrate component of enriched raceway habitat has no effect on post-release survival of spring (stream-type) chinook salmon
>
> H0,2: The structure component of enriched raceway habitat has no effect on post-release survival of spring (stream-type) chinook salmon
>
> H0,3: The cover component of enriched raceway habitat has no effect on post-release survival of spring (stream-type) chinook salmon

H0,4: There is no interaction of the effects of substrate and structure on post-release survival of spring chinook salmon.

H0,5: There is no interaction of the effects of substrate and cover on post-release survival of spring chinook salmon.

H0,6: There is no interaction of the effects of structure and cover on post-release survival of spring chinook salmon.

H0,7: There is no interaction of the effects of substrate, structure and cover on postrelease survival of spring chinook salmon

In the enriched habitat experiment, an equal number (e.g., 24,000) of 0-age spring chinook salmon will be stocked into 24 similar sized raceways. The following fish culture protocols (treatments) would be applied:

1) Controls with no substrate, no structure, and no cover (n = 3 raceways)
2) Substrate only (n = 3 raceways)
3) Structure only (n =3 raceways
4) Cover only (n =3 raceways
5) Substrate and structure (3 raceways)
6) Substrate and cover (3 raceways)
7) Structure and cover (3 raceways)
8) Substrate, structure, and cover (3 raceways)

Post-release survival data will be analyzed by Three Factor ANOVA (Fully Crossed Factorial design) with substrate (fixed effect), structure (fixed effect), cover (fixed effect) and their interactions as the main effects. Data will be blocked by release year and the study repeated for 5 years.

A power analysis was conducted to estimate the relative percent differences (d) in survival among the treatments that could be detected with 80% power ($(1 - \beta) * 100$) at $\alpha = 0.05$. Smolt-to-adult survival rates generated from several years of coded-wire-tag data at the Carson Hatchery were used to calculate variance in survival rates. With 15 raceways/treatment (3 raceways/treatment/year), d = 20% if releases were to be conducted over 5 years, assuming the historic SARs.

Objective 2. Antipredator Conditioning

The anti-predator conditioning experiment would test the following null hypothesis

H0,1: Anti-predator conditioning has no effect on the post-release survival of spring chinook salmon

In the antipredator conditioning experiment an equal number (e.g., 24,000) of 0-age spring chinook salmon will be stocked into 12 similar sized raceways. The following fish culture protocols (treatments) would be applied:

1) No antipredator conditioning (6 raceways)
2) Antipredator conditioning (6 raceways)

Post-release survival data will be analyzed with Student t-tests. Data will be blocked by release year and the study repeated for 5 years.

A power analysis was conducted to estimate the relative percent differences (d) in survival among the treatments that could be detected with 80% power ((1 -ß)*100) at $\alpha = 0.05$. Smolt-to-adult survival rates generated from several years of coded-wire-tag data at the Carson Hatchery were used to calculate variance in survival rates. With 30 raceways (6 per treatment/year), d = 20% if releases were to be conducted over 5 years, assuming the historic SARs.

Task 1.1. Fish Rearing

The fish in the conventional rearing treatment would be grown using traditional salmon culture practices in standard concrete raceways. These raceways would not be equipped with any form of natural instream structure or overhead cover. However, they would be covered with a transparent or white bird netting to prevent avian predation on the experimental fish confounding the results. The fish in this treatment would be reared using the facilities' standard fish culture protocols, including rearing densities and growth schedule, with densities not to exceed 1 lb/ft^3.

The enriched environment treatment would be based on the enriched raceway habitat developed in previous NATURES studies, which includes substrate, instream structure, underwater feeders, and overhead cover (Maynard et al. 1995; 1996a,b; 1998a). Raceway bottoms would be lined with exposed aggregate or resin-rock pavers that match the substrate color of the immediate post-release environment (Wind River). Instream structure would be created by suspending two series of weighted fir trees from a pair of cables running the length of each raceway. Overhead covers with a single layer of military specification camouflage net would be used to cover 80% of the surface area of each raceway. The center (20%) of each raceway would be left free of camouflage net covering. Each cover frame will be constructed so that it can easily be lifted out of the way when working the raceway. As with the control raceway, translucent or white bird-netting would be suspended over the entire raceway to eliminate avian predation as a confounding factor. Except for these experimental variables, the fish would be reared in a manner identical to the conventionally-reared fish.

Salmon reared in hatcheries are typically naïve to naturally occurring predators (Olla et al. 1998), but can learn quickly to recognize them (Berejikian 1995b, Healey and

Reinhardt 1995, Olla and Davis 1998). Laboratory studies have demonstrated that anti-predator conditioning can improve predator recognition in chinook salmon (Healey and Reinhardt 1995, Berejikian et al. 1999). The proposed study will determine whether actual survival can be increased by implementing anti-predator conditioning in a production facility.

The anti-predator conditioning program will be implemented within a week prior to release. A combination of live predators (Maynard et al.1998b), and predator odor paired with the odor of injured chinook salmon (Berejikian et al. 1999) will be introduced into half of the conventional and half of the enriched raceways.

The growth of fish in enriched and conventional habitat raceways will be evaluated by weighing and measuring 100 fish from each treatment at monthly intervals. Overall health will be determined by maintaining mortality logs and performing a fish health analysis on a representative sample of 40 fish from each treatment at the end of rearing. The development of cryptic aspects of skin coloration will also be evaluated by a monthly colorimetric analysis on a representative sample of 40 fish from each treatment. Physiological development will be determined by sampling fish 1-2 times per month in January, February, March, and April of their release year. At each sampling 5 fish will be sampled from each raceway for a total of 15 fish/treatment. At this time each fish will be sampled for length, weight, condition factor, plasma thyroxin and insulin-like growth factor-1 (IGF-1) levels, whole body lipid and gill Na^{+}/K^{+}-ATPase activity.

To document the effects of rearing environment on brain development, 20 fish per raceway will be sampled for brain allometry just prior to release. Brains will be fixed in Bouin's fixative, dissected and photographed. Linear dimensions of four brain areas (olfactory bulb, optic tectum, telencephalon, and cerebellum) will be measured from digitized photographs. Brain volumes will be calculated from histological sections. We will use standard statistical methods of MANCOVA and ANCOVA to determine the effects of body size and rearing environment on the width and volume of four brain areas.

Prior to release fish from each treatment will be compared for their ability to survive predation. In these bioassays a representative sample (n = 20 fish/treatment) will be removed from each treatment and placed in a predation test arena. Predators will be allowed to prey on fish in the arena until about one quarter of the salmon are killed. The predators will then be removed and surviving fish from each treatment identified and enumerated. This procedure will be repeated at least 15 times.

Task 1.2. Post-release evaluations

The most crucial study data will come from the juvenile and adult post-release survival evaluations. The post-release survival of juvenile salmon will be determined by PIT tagging 500 fish per treatment, releasing them from the hatchery, and then evaluating their downstream survival to the PIT-tag interrogation sites at Bonneville Dam. It is estimated that at least 14% of the PIT-tagged fish released at the hatchery will be interrogated at Bonneville Dam.

Instream survival data for PIT-tagged spring chinook salmon released from Carson Hatchery and interrogated at Bonneville Dam were obtained from the PTAGIS database. This data was used to estimate instream survival variance over this river reach. Two power analysis were then conducted to estimate the power to detect a 20% relative difference in survival among the treatments (in each study) within any given year. With 3 raceways/treatment in the enriched habitat raceway study and 6 raceways/treatment in the predator avoidance conditioning study, statistical power is better than the standard 80% [(1 -ß)*100) at $\alpha = 0.05$].

PIT-tag recovery data from Bonneville Dam will also be used to compare the migration speed of fish in each rearing treatment. All fish in each raceway will be coded-wire tagged so that their smolt-to-adult post-release survival can be evaluated. Each year after the first release investigators will utilize the coded-wire tag data base to determine the number of fish from each treatment recovered in the fishery, at the hatchery, and on the spawning grounds. This information will then be used to determine each treatment's contribution to the fishery, survival to adulthood, maturation age, and size at maturity.

Fish rearing and release experiments will be repeated annually for 5 years. Instream post-release survival evaluations will begin in year 2. Since spring chinook salmon returning to the hatchery may mature at age 6, the inspection of CWT recovery information as well as the adults at the hatchery will continue for 5 years after the last releases have been made. However, it is anticipated that age-4 returning adult fish will provide the majority of recovery information.

Research Schedule

January (year 1)	Complete refinement, bid specifications, and procurement of enriched raceway habitat components.
March (year 2)	Complete installation of enriched raceway habitat components.
April (year 1)	Begin rearing first year class (BY 2001) in enriched raceway habitat and on appropriate growth modulation profiles.
April (year 3)	Release smolts and begin instream evaluations
April (year 7)	Complete rearing of fifth year class (BY 2005) in experimental conditions.
June (year 10)	Complete CWT database query.
December (year 10)	Complete CWT data analysis and submit final project report.

Expected Results

Sustainable fisheries for salmon and steelhead in the 21st century will depend on the successful integration of natural and hatchery production. Even under optimistic scenarios, natural populations cannot be expected to satisfy commercial, sport, and tribal harvest goals; therefore, hatchery fish will play an important role in supporting salmon abundance into the near future. However, the operation and management of salmonid hatcheries must be reformed not only to maintain at some level the traditional production role, but also complement goals to aid recovery of ESA-listed stocks of Pacific Salmon. The proposed research addresses this need to develop and implement agency related guidelines for Conservation Hatcheries. The high post-release survival characteristic of fish produced under these strategies will: 1) reduce the number of wild broodstock that must be taken into fish culture programs to produce a given number of recruits in the next generation, 2) reduce the time required for supplementation programs to rebuild self-sustaining runs, and 3) enhance the efficiency of mitigation and fishery enhancement hatchery programs.

g. Facilities and equipment

Fish rearing will be conducted at the Carson National Fish Hatchery. The hatchery has appropriate equipment for rearing of fish. Some specialized equipment may be required to allow for sampling and feeding fish reared in the NATURES habitats. NATURES habitats for the treatment raceways at the hatchery will be constructed and installed by NMFS. NMFS has most necessary and appropriate equipment for inculture sampling of fish during rearing. Laboratory analysis of physiological parameters will be conducted at the NWFSC in Seattle. PIT tagging of fish will be conducted by NMFS. PIT tags, injectors, and hand-held interrogators will be required at the hatchery. Two personal computers will be required at the hatchery for logging fish culture data, PIT tag data, other scientific evaluation data, and for data analysis and reporting. Tag recovery information will be collected through query of regional PIT tag and CWT databases.

h. References

Reference (include web address if available online)	Submitted w/form (y/n)
Allee, B.J. 1974. Spatial requirements and behavioral interaction of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Ph.D. Thesis, Univ. Washington, Seattle, 160 p. Anders, P.J. 1998. Conservation aquaculture and endangered species. Fisheries 23(11):28-31. Bachman, R.A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Trans. Am. Fish. Soc. 113:1-32.	No references submitted with form

Reference (include web address if available online)	Submitted w/form (y/n)
Berejikian, B.A. 1995a. The effects of hatchery and wild ancestry and environmental factors on the behavioral development of steelhead trout fry (*Oncorhynchus mykiss*). Ph.D. Thesis, Univ. Washington, Seattle, 111 p.	
Berejikian, B.A. 1995b. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (*Oncorhynchus mykiss*) to avoid a benthic predator. Can. J. Fish. Aquat. Sci. 52:2076-2082.	
Berejikian, B.A., R.J.F. Smith, E.P. Tezak, S.L. Schroder, and C.M. Knudsen. 1999. Chemical alarm signals and complex hatchery rearing habitats affect anti-predator behavior and survival of chinook salmon (*Oncorhynchus tshawytscha*) juveniles. Can. J. Fish. Aquat. Sci. 56: 830-838.	
Brown, G.E., and Smith, R.J.F. 1997. Con-specific skin extracts elicit anti-predator responses in juvenile rainbow trout (*Oncorhynchus mykiss*). Can. J. Zool. 75:1916-1922.	
Brown, G.E., and Smith, R.J.F. 1998. Acquired predator recognition in juvenile rainbow trout (*Oncorhynchus mykiss*): conditioning hatchery reared fish to recognize chemical cues of a predator. Can. J. Fish. Aquat. Sci. 55: 611-617.	
DeBlieu, J. 1993. Meant to be wild: the struggle to save endangered species through captive breeding. Fulcrum Publishing, Golden, 302 p.	
Dickson, T.A., and H.R. MacCrimmon. 1982. Influence of hatchery experience on growth and behavior of juvenile Atlantic salmon (*Salmo salar*) within allopatric and sympatric stream populations. Can. J. Fish. Aquat. Sci. 39:1453-1458.	
Donnelly, W.A., and F.G. Whoriskey Jr. 1991. Background-color acclimation of brook trout for crypsis reduces risk of predation by hooded mergansers (*Lophodytes cucullatus*). N. Am. J. Fish. Manage. 11:206-211.	
Donnelly, W.A., and F.G. Whoriskey Jr. 1993. Transplantation of Atlantic salmon (*Salmo salar*) and crypsis breakdown. *In* R. J. Gibson and R. E.Cutting (editors), Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Can. J. Fish. Aquat. Sci. Special Publications 118:25-34.	
Flagg, T.A. and C.E. Nash (editors). 1999. A conceptual framework for conservation hatchery strategies for Pacific salmonids. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-38, 48 p.	

Reference (include web address if available online)	Submitted w/form (y/n)
Flagg, T. A., D. J. Maynard, and C.V.W. Mahnken. 2000a. Conservation hatcheries. Encyclopedia of Aquaculture, J. Wiley and Sons, p.174-176.	
Flagg, T. A., B. A. Berejikian, J. E. Colt, W. W. Dickhoff, L. W. Harrell, D. J. Maynard, C. E. Nash, M. S. Strom, R. N. Iwamoto, and C. V.W. Mahnken. 2000b. Ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-41, 91 p.	
Fuji, R. 1993. Coloration and chromatophores. *In* D.H. Evans (editor), The physiology of fishes, p. 535-562. Academic Press, New York.	
Gipps, J.H.W. (editor). 1991. Beyond captive breeding: reintroducing endangered species through captive breeding. Zool. Soc. London Symp. 62, London.	
Goodman, M.L. 1990. Preserving the genetic diversity of salmonid stocks: a call for federal regulation of hatchery programs. Environ. Law 20:111-166.	
Greene, C.W. 1952. Results from stocking brook trout of wild and hatchery strains at Stillwater Pond. Trans. Am. Fish. Soc. 81:43-52.	
Healey, M. C., and Reinhardt, U. 1995. Predator avoidance in naïve and experienced juvenile chinook and coho salmon. Can. J. Fish. Aquat. Sci. 52:614-622.	
Hilborn, R. 1992. Hatcheries and the future of salmon in the Northwest. Fisheries 17:5-8.	
Johnson, J.E., and B.L. Jensen. 1991. Hatcheries for endangered freshwater fish. *In* W.L. Minckley and J.E. Deacon (editors), Battle against extinction, p. 199-217. Univ. Arizona Press, Tucson.	
Johnsson, J.I., and M.V. Abrahams. 1991. Domestication increases foraging under threat of predation in juvenile steelhead trout (*Oncorhynchus mykiss*) - an experimental study. Can. J. Fish. Aquat. Sci. 48: 243-247.	
Kanayama, Y. 1968. Studies of the conditioned reflex in lower vertebrates. X. Defensive conditioned reflex of chum salmon fry in a group. Mar. Biol. 2:77-87.	
Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken. 1995. A review of	

Reference (include web address if available online)	Submitted w/form (y/n)
innovative culture strategies for enhancing the post-release survival of anadromous salmonids. Am. Fish. Soc. Symp. 15:307-314.	
Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken (editors). 1996a. Development of a natural rearing system to improve supplemental fish quality, 1991-1995. Report to Bonneville Power Administration, Contract DE-AI79-91BP20651, 231 p.	
Maynard, D. J., T. A. Flagg, C.V.W. Mahnken, and S. L. Schroder. 1996b. Natural rearing technologies for increasing postrelease survival of hatchery-reared salmon. Bull. Natl. Res. Inst. Aquacult., Suppl. 2:71-77.	
Maynard, D. J., E. P. Tezak, M. Crewson, D. A. Frost, T. A. Flagg, S. L. Schroder, C. Johnson, and C. V. W. Mahnken. 1998a. Seminatural raceway habitat increases chinook salmon post-release survival, P. 81-91. In R. Z. Smith (editor), Proceedings of the 48th Annual Pacific Northwest Fish Culture Conference, Gleneden Beach, OR, December 1997.	
Maynard, D. J., A. LaRae, G. C. McDowell, G. A. Snell, T. A. Flagg, and C. V. W. Mahnken. 1998b. Predator avoidance training can increase post-release survival of chinook salmon, P. 59-62. In R. Z. Smith (editor), Proceedings of the 48th Annual Pacific Northwest Fish Culture Conference, Gleneden Beach, OR, December 1997.	
Miller, R.B. 1952. Survival of hatchery-reared cutthroat trout in an Alberta stream. Trans. Am. Fish. Soc. 81:35-42.	
National Research Council (NRC). 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C., 452 p.	
Nickelson, T.E., M.F. Solazzi, and S.L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) pre-smolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 43:2443-2449.	
NORTHWEST POWER PLANNING COUNCIL, Artificial Production Policy Statement, Columbia Basin Hatcheries: A Program in Transition, February 17, 1999, Document 99-2 (http://www.nwppc.org/99-2_pol.htm)	
Olla, B.L., and M.W. Davis. 1989. The role of learning and stress in predator avoidance of hatchery-reared coho salmon (*Oncorhynchus kisutch*) juveniles. Aquaculture 76:209-214.	
Olla, B. L., Davis, M. W., and Ryer, C. H. 1998. Understanding how the	

Reference (include web address if available online)	Submitted w/form (y/n)
hatchery environment represses or promotes the development of behavioral survival skills. Bull. Mar. Sci 62: 531-550.	
Olney, P.J.S., G.M. Mace, and A.T.C. Feistner. 1994. Creative conservation: interactive management of wild and captive animals. Chapman and Hall, London, 571 p.	
Patten, B.G. 1977. Body size and learned avoidance as factors affecting predation on coho salmon fry by torrent sculpin (*Cottus rotheus*). Fish. Bull., U.S. 75:451-459.	
Piper R.G., I.B. McIlwain, L.E. Orme, J.P. McCraren, L.G. Fowler, and J.R. Leonard. 1982. Fish hatchery management. U.S. Dep. Interior, U.S. Printing Office, Washington, D.C., 517p.	
Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery reared trout in Convict Creek, California. Trans. Am. Fish. Soc. 92:39-46.	
Reisenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, *Salmo gairdneri*. J. Fish. Res. Board Can. 34:123-128.	
Reisenbichler, R.R. and S.P. Rubin. 1998. Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplemented populations. ICES J. Mar. Sci.	
SRT (Science Review Team). 1998. Review of salmonid artificial production in the Columbia River Basin. Report 98-33, Northwest Power Planning Council. Portland, OR., 77 p.	
Symons, P.E. 1968. Increase in aggression and strength of the social hierarchy among juvenile Atlantic salmon deprived of food. J. Fish. Res. Board Can. 25:2387-2401.	
Suboski, M.D. 1988. Acquisition and social communication of stimulus recognition by fish. Behav. Processes 16:213-244.	
Thompson, R.B. 1966. Effects of predator avoidance conditioning on the post-release survival rate of artificially propagated salmon. Ph.D. Thesis, Univ. Washington, Seattle, 155 p.	
Uchida, K., K. Tsukamotot, S. Ishii, R. Ishida, and T. Kajihara. 1989. Larval competition for food between wild and hatchery-reared ayu (*Plecoglossus altivelis*) in culture ponds. J. Fish. Biol. 34:399-407.	

Reference (include web address if available online)	Submitted w/form (y/n)
Wagner, E. J., M. D. Routledge, and S. S. Intelmann. 1996. Fin condition and health profiles of albino rainbow trout reared in concrete raceways with and without a cobble substrate. Prog. Fish Culturist 58:38-42.	
Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. Can. J. Fish. Aquat. Sci. 48:124-133.	
Waples, R.S. 1999. Dispelling some myths about hatcheries. Fisheries 24(2):12-21.	

Section 10 of 10. Key personnel

1. Mr. Thomas A. Flagg, Fisheries Research Biologist, Team Leader. Co-principal Investigator. Duties include internal project oversight; research; external project coordination; data analysis and report writing; etc. [See attached resume for qualifications.]

2. Dr. Desmond J. Maynard, Fisheries Research Biologist: Co-principal Investigator. Duties include internal project oversight; research; external project coordination; data analysis and report writing; etc. [See attached resume for qualifications.]

3. Dr. Barry A. Berejikian ,Fisheries Research Biologist, Team Leader: Co-principal Investigator. Duties include internal project oversight; research; external project coordination; data analysis and report writing; etc. [See attached resume for qualifications.]

4. Dr. William T. Fairgrieve. Research Biologist @ 100% FTE. Duties include fish husbandry and program evaluation. [See attached resume for qualifications.]

Curriculum Vitae-- Dr. Barry A. Berejikian

Education:

- Ph.D, Fisheries Science, University of Washington, Seattle, WA, 1995.
- M.S., Fisheries Science, University of Washington, Seattle, WA, 1992.
- B.S., Fisheries Science, California Polytechnic State University, San Luis Obispo, CA., 1990.

Employer: National Marine Fisheries Service, Northwest Fisheries Science Center, Resource Enhancement & Utilization Technology Division.

Position: Fisheries Research Biologist, NMFS employee since 1994.

Present assignment: Principal investigator on the NATURES project. Dr. Berejikian's responsibilities include developing NATURES protocols, designing experiments to evaluate the effect of these protocols on postrelease survival, oversight of daily experimental activities, analyzing data, preparing the study finding for publication in annual reports and journal articles.

Previous research/expertise: Dr. Berejikian's research as a graduate student dealt with salmonid behavior and predator-prey interactions. He has applied that expertise to NATURES experiments in which he evaluated the consequences of predation training for chinook salmon. In addition, in 1996-1997, he has participated in a large cooperative effort with the Washington Department of Fish and Wildlife (WDFW) to evaluate the relative contributions of different NATURES rearing variables (e.g., cover, structure, substrate) to salmonid survival. Most recently, Dr. Berejikian has published research on the chemical (pheromone) basis of predator recognition.

Relevant Publications include:

Flagg, T. A., B. A. Berejikian, J. E. Colt, W. W. Dickhoff, L. W. Harrell, D. J. Maynard, C. E. Nash, M. S. Strom, R. N. Iwamoto, and C. V.W. Mahnken. 2000. Ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-41, 91 p.

Berejikian, B. A., E. P. Tezak, A. LaRae, T. A. Flagg, and E. Kummerow, and C. V. W. Mahnken. 2000. Social dominance, growth and habitat use of age-0 steelhead (*Oncorhynchus mykiss*) grown in enriched and conventional hatchery rearing environments Can. J. Fish. Aquat. Sci. 57: 628-636.

Berejikian, B. A., R. J. F. Smith, E. P. Tezak, S. L. Schroder, and C. M. Knudsen. 1999. Chemical alarm signals and complex hatchery rearing habitats affect anti-predator behavior and survival of chinook salmon (*Oncorhynchus tshawytscha*) juveniles. Can. J. Fish. Aquat. Sci. 56: 830-838.

Berejikian, B. A., E.P. Tezak, S. L. Shroder, T. A. Flagg, and C. M. Knudsen. 1999. Competitive differences between newly emerged offspring of captively reared and wild coho salmon salmon (*Oncorhynchus tshawytscha*). Trans. Am. Fish. Soc. 128: 832-839.

Hard, J. J, B. A. Berejikian, E. P. Tezak, S. L. Schroder, C. M. Knudsen, and L. T. Parker. 2000. Evidence for morphometric differentiation of wild and captively reared adult coho salmon (*Oncorhynchus kisutch* Walbaum): a geometric analysis. Env. Biol. Fish. 58: 61-73.

Scholz, N. L., N. Truelove, B. French, B. Berejikian, T. Quinn, E. Casillas, and T. Collier. In press. Diazinon disrupts antipredator and homing behaviors in chinook salmon. Can. J. Fish. Aquat. Sci.

Curriculum Vitae--Dr. Desmond J. Maynard

Education:
- Ph.D., Fisheries Science, University of Washington, Seattle, WA, 1987.
- M.S., Fisheries Science, University of Washington, Seattle, WA, 1980.
- B.S., Marine Biology, University of Massachusetts, North Dartmouth, MA, 1974.
- A.A., Business management, Cape Cod Community College, Hyannis, MA, 1971.

Employer: National Marine Fisheries Service, Northwest Fisheries Science Center, Resource Enhancement & Utilization Technology Division.

Position: Fisheries Research Biologist, NMFS employee since 1988.

Present assignment: Principal investigator on the NATURES project. Dr. Maynardís responsibilities include developing NATURES protocols, designing experiments to evaluate the effect of these protocols on postrelease survival, oversight of daily experimental activities, analyzing data, preparing the study finding for publication in annual reports and journal articles. The research he has conducted on the project has demonstrated that enriched raceway habitat increases instream survival, live food supplemented diets improve foraging ability, and predator avoidance conditioning improves postrelease survival.

Previous research/expertise: Dr. Maynard's primary expertise is in fish behavior and culture. He has taught graduate level courses on fish sociobiology and behavioral ecology, conducted research on the social behavior of salmon, and investigated the effects of petroleum on salmon homing and migration. Dr. Maynard has been a member of the Animal Behavior Society since 1977, where he has served on the applied animal behavior and film committees. He has taught college level courses on Aquaculture and his research since 1992 has focused on developing culture techniques to increase the postrelease survival of hatchery salmon. Dr. Maynard also has expertise in fish taxonomy and evolution and has been a member of the NMFS Biological Review Teams for several petitioned listings. He also has expertise in fish tagging having led several investigations comparing the effects of tags on fish survival.

Relevant Publications include:

Flagg, T. A., B. A. Berejikian, J. E. Colt, W. W. Dickhoff, L. W. Harrell, D. J. Maynard, C. E. Nash, M. S. Strom, R. N. Iwamoto, and C. V.W. Mahnken. 2000. Ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-41, 91 p.

Flagg, T. A., D. J. Maynard, and C.V.W. Mahnken. 2000. Conservation hatcheries. Encyclopedia of Aquaculture, J. Wiley and Sons, p.174-176.

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken, and S. L. Schroder. 1996. Natural rearing technologies for increasing postrelease survival of hatchery-reared salmon. Bull

Natl. Res. Inst. Aquacult., Suppl. 2:71-77.

Maynard, D. J., G. C. McDowell, E. P. Tezak, and T. A. Flagg. 1996. The effect of diets supplemented with live-food on the foraging behavior of cultured fall chinook salmon. Prog. Fish-Cult. 58:187-191.

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken (editors). 1996. Development of a natural rearing system to improve supplemental fish quality. Report to the Bonneville Power Administration, Contract DE-A179-91BP20651, 216 p. (Available Northwest Fisheries Science Center., 2725 Montlake Blvd. E., Seattle, WA 98112.)

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken. 1995. A review of semi-natural culture strategies for enhancing the postrelease survival of anadromous salmonids. American Fisheries Society Symposium 15:307-314.