Bonneville Power Administration
Fish and Wildlife Program FY99 Proposal

Section 1. General administrative information

Supplementation Fish Quality (Yakima)

Bonneville project number, if an ongoing project 9105500

Business name of agency, institution or organization requesting funding
National Marine Fisheries Service

Business acronym (if appropriate) NMFS

Proposal contact person or principal investigator:

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Subcontractors.

Organization	Mailing Address	City, ST Zip	Contact Name
N.A.			

NPPC Program Measure Number(s) which this project addresses.
7.2D.1, 7.2D.3 7.4K.1

NMFS Biological Opinion Number(s) which this project addresses.
ESA Snake River Salmon Recovery Plan Section 4.4.c and 4.4.d

Other planning document references.
Snake River Salmon Recovery Plan Section 4.4.c and 4.4.d

Subbasin.
Yakima, Snake River

Short description.
Develop and evaluate fish culture techniques (seminatural raceway habitat, predator avoidance training, exercise, live food diets, etc.) for a natural rearing enhancement system that increases the postrelease survival of artificially propogated salmon.

Section 2. Key words

Mark	Programmatic Categories	Mark	Activities	Mark	Project Types
X	Anadromous fish		Construction	+	Watershed
+	Resident fish	+	O & M	+	Biodiversity/genetics
	Wildlife	+	Production	+	Population dynamics
+	Oceans/estuaries	X	Research	+	Ecosystems
	Climate	+	Monitoring/eval.	+	Flow/survival
	Other	+	Resource mgmt	+	Fish disease
			Planning/admin.	X	Supplementation
			Enforcement		Wildlife habitat en-
			Acquisitions		hancement/restoration

Other keywords.
Postrelease survival, seminatural culture techniques, hatchery-wild interactions

Section 3. Relationships to other Bonneville projects

Project #	Project title/description	Nature of relationship
9701300	Yakima Cle Elum Hatchery O & M	Strategies being developed under NATURES are implemented in YKFP test of supplementation.
8335000	Nez Perce Tribal Hatchery O & M	Strategies being developed under NATURES are planned to be used in the Nez Perce Hatchery.

Section 4. Objectives, tasks and schedules

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Determine if rearing salmon in seminatural raceway habitat increases postrelease survival.	a	Develop raceway habitats composed of natural substrate, instream structure, and overhead

			cover.
		b	Use pilot-scale evaluations to determine how these seminatural raceway components affect salmon behavior, coloration, growth, disease status, predator vulnerability, and instream postrelease survival.
		c	Based on these pilot-scale evaluations, select a workable seminatural raceway habitat with the greatest promise of producing wild-like fish with increased smolt-to-adult postrelease survival.
		d	Conduct production-scale evaluations at salmon enhancement hatcheries to verify the selected seminatural raceway habitat increases smolt-to-adult survival.
2	Determine if rearing salmon in raceways where food is presented in a natural manner by underwater feeders increases postrelease survival.	a	Develop underwater feeding systems.
		b	Use pilot-scale evaluations to determine how underwater feed delivery systems affect salmon behavior, growth, disease status, predator vulnerability, and instream postrelease survival.
		c	Based on these pilot-scale evaluations, select a workable underwater feed delivery system with the greatest promise of producing wild-like fish with increased smolt-to-adult postrelease survival.
		d	Conduct production-scale evaluations at salmon enhancement hatcheries to verify the selected underwater feed delivery system increases smolt-to-adult survival.
3	Determine if predator avoidance	a	Develop predator avoidance

	training increases postrelease survival.		training protocols.
		b	Use pilot-scale evaluations to determine how these predator avoidance training protocols affect salmon behavior, growth, disease status, predator vulnerability, and instream postrelease survival.
		c	Based on these pilot-scale evaluations, select a predator avoidance training protocol with the greatest promise of producing wild-like fish with increased smolt-to-adult postrelease survival.
		d	Conduct production-scale evaluations at salmon enhancement hatcheries to verify the selected predator avoidance training protocol increases smolt-to-adult survival.
4	Determine if rearing salmon in raceways with natural current velocities that exercise fish increases postrelease survival.	a	Develop technology to increase the water velocity in raceways to at least one body length per second.
		b	Using this technology, develop exercise protocols.
		c	Use pilot-scale evaluations to determine how these exercise protocols affect salmon behavior, morphology, growth, pathology, predator vulnerability, and instream postrelease survival.
		d	Based on these pilot-scale evaluations, select a workable exercise protocol with the greatest promise of producing wild-like fish with increased smolt-to-adult postrelease survival.
		e	Conduct production-scale evaluations at salmon enhancement hatcheries to verify the selected exercise protocol increases smolt-to-adult survival.
5	Determine if rearing salmon on diets supplemented with natural	a	Develop live food diets.

	live feeds increases postrelease survival.		
		b	Use pilot-scale evaluations to determine how live food diets affect salmon behavior, foraging ability, coloration, growth, disease status, predator vulnerability, and instream postrelease survival.
		c	Based on these pilot-scale evaluations, select the live food diet with the greatest promise of producing wild-like fish with increased smolt-to-adult postrelease survival.
		d	Conduct production-scale evaluations at salmon enhancement hatcheries to verify the selected live food diet increases smolt-adult survival.

Objective schedules and costs

Objective #	Start Date mm/yyyy	End Date mm/yyyy	Cost %
1	8/1991	12/2005	45.00%
2	3/1994	10/1996	10.00%
3	8/1991	8/2005	10.00%
4	3/1997	12/2005	20.00%
5	8/1991	10/1998	15.00%
			TOTAL 100.00%

Schedule constraints.
The schedule may be modified when new ideas offering solutions to problems arise. The main constraints that may cause schedule changes are the level of funding and the accessibility of production-scale facilities to evaluate smolt-to-adult survival.

Completion date.
2006

Section 5. Budget

FY99 budget by line item

Item	Note	FY99
Personnel		$154,000
Fringe benefits		$28,000
Supplies, materials, non-expendable property		$60,600
Operations & maintenance		$28,000
Capital acquisitions or improvements (e.g. land, buildings, major equip.)		$57,000
PIT tags	# of tags: 6000	$17,400
Travel		$18,000
Indirect costs		$54,000
Subcontracts	contractual services	$83,000
Other		$ 0
TOTAL		$500,000

Outyear costs

Outyear costs	FY2000	FY01	FY02	FY03
Total budget	$500,000	$500,000	$500,000	$600,000
O&M as % of total	5.60%	5.60%	5.60%	5.60%

Section 6. Abstract

The overall goal of the project is to develop a Natural Rearing Enhancement System (NATURES) that allows hatcheries to produce fish that can be used to maintain the biological diversity and genetic integrity of Pacific salmon. The project's primary objectives are to determine if seminatural raceway habitats, exercise current velocities, automated underwater feeders, live food supplemented diets, and predator avoidance training can be used by fish culturists to produce wild-like fish with increased postrelease survival.

The project's methodology includes the following steps: 1) develop fish rearing protocols, 2) evaluate each protocol on a pilot scale to determine if it produces wild-like salmon with increased instream survival, 3) refine the protocols and reevaluate them, 4) select the best protocol, and 5) evaluate its effect on smolt-adult survival with production-scale releases. The evaluation process generally takes less than 3 years to prove that a protocol increases instream survival and an additional 4 or more years to determine if the technique also increases smolt-to-adult survival.

The project has already developed several fish culture practices that produce wild-like fish with a 25-50% higher instream survival than conventionally reared salmon. The natural rearing enhancement system will enable supplementation and conservation hatcheries to produce wild-like salmon with high postrelease survival that can be used to rapidly rebuild naturally spawning runs. This project will both help return a productive fishery to the river and conserve the salmonid resources of the Columbia River Basin.

Section 7. Project description

a. Technical and/or scientific background.

The Resource Enhancement and Utilization Technologies Division, National Marine Fisheries Service, in collaboration with the Washington Department of Fish and Wildlife and US Fish and Wildlife Service has been conducting research to develop a natural rearing enhancement system (NATURES) suitable for producing "wild-like" fish with high postrelease survival from hatcheries. NATURES research is currently directed at providing guidelines for the Yakima Fisheries Project test of supplementation. However, NATURES has application to restoration of many depleted stocks of fish in the Snake River Basin (e.g., those listed under the U.S. Endangered Species Act). Development of natural rearing systems that minimize behavioral changes in hatchery-reared fish is identified as a priority [4.4.c and 4.4.d] in the proposed Recovery Plan for Snake River salmon. The development of fish culture techniques to increase the survival of Columbia River hatchery salmonids is called for in sections 7.2D.1, 7.2D.3, and 7.4K.1 of the Columbia Basin Fish and Wildlife Program.

We have reviewed the literature to determine how fish culture practices alter salmonid behavior. This literature review has been published in detail in an annual report to BPA (Maynard et al. 1996a) and in several journal articles (Maynard et al. 1995, Maynard et al. 1996b and c). The literature indicates that conventional hatchery-reared salmonids are less adept at foraging, less cryptic, more aggressive, and more vulnerable to predators than their wild counterparts (Maynard et al. 1996d). These differences are the product of hatchery practices that through domestication and conditioning reduce the fitness of hatchery fish for survival in natural ecosystems. Present hatchery practices are geared toward mass-production under unnatural conditions (e.g., the fish are reared in the open, over uniform concrete substrate; provided no structures behind or under which to seek refuge from predators or dominant conspecifics; held at high stress-producing densities; surface fed; conditioned to approach large moving objects at the surface, and reared in unnaturally low current velocities). The physiological, behavioral, and morphological modifications resulting from this unnatural rearing environment are probably major factors in the poor postrelease survival of hatchery-reared salmon.

The literature suggested several ways that conventional salmon culture practices can be changed to produce more wild-like fish with higher postrelease survival (Maynard et al 1995). The suggested practices included: 1) rearing salmonids in seminatural raceway habitat so that they developed proper camouflage coloration (Donnelly and Whoriskey

1991, Maynard et al. 1995, Maynard et al. 1996b), 2) supplementing the diet of salmonids with live foods to increase their postrelease foraging ability, 3) feeding salmonids with automated subsurface feeders so as not to condition them to approach large moving objects at the surface, 4) training salmon in the hatchery to avoid the predators they will encounter after release (Thompson 1966, Olla and Davis 1989), 5) exercising salmonids to increase their growth, stamina and postrelease survival 6) reducing rearing densities to maximize postrelease survival, and 7) utilizing oxygen supplementation technology to improve fish health and postrelease survival (see Maynard et al. 1995 for review).

The information from this literature review was incorporated into the design of a NATURES rearing system with the potential to produce "wild-quality" fish with higher postrelease survival than conventional hatchery-reared salmon. These NATURES strategies included: 1) rearing salmon in raceways equipped with cover, structure, and natural substrates that promote the development of natural camouflage coloration; 2) automated underwater feed delivery systems that condition fish to orient to the bottom rather than the surface; 3) training fish to avoid predators; 4) exercising fish to enhance their ability to escape predators; 5) feeding salmon live foods diets to improve their foraging ability; 6) reducing rearing densities; and 7) utilizing oxygen supplementation technology to improve fish health and physiology. These NATURES strategies should enable hatcheries to produce “wild-like” fish that are better suited for use in supplementation programs than conventionally-reared fish. These NATURES strategies should also help minimize the potential genetic divergence between wild and hatchery-reared salmon.

Evaluations of the effect of NATURES rearing strategies on hatchery salmon postrelease survival have been underway since 1992. These evaluations begin with laboratory scale studies where the proposed concepts are tested and refined until they are proven to produce fish with the desired morphological, physiological, or behavioral attributes. Successful concepts are then run through pilot scale evaluations to verify that they increase instream postrelease survival and can be operated at production facilities. Those concepts that can be adapted to production scale facilities and produce large increases in instream survival are then evaluated with production releases from state and federal hatcheries to determine their effect on smolt-adult survival.

The NATURES project has successfully tested the seminatural raceway habitat and predator avoidance training concepts through the pilot scale stage. These concepts have increased chinook salmon (*Oncorhynchus tshawytscha*) instream survival by 20-50% (Maynard et al. 1996c, Maynard et al. unpublished). Production scale research is now underway to determine the effect of seminatural raceway habitat on the smolt-adult survival of chinook salmon. NATURES laboratory studies have also demonstrated that live food diets can be used to improve the foraging success of chinook salmon (Maynard et al 1996b). However, further investigation of this concept is on hold until it can be shown that the foraging benefits generated by these diets outweigh the economic costs of their implementation at production hatcheries. Pilot scale evaluations indicate that subsurface feed delivery systems do not induce more benthic orientation or reduce the

predator vulnerability of chinook salmon (Maynard et al. unpublished). This research has been set aside until new ideas on how feed delivery systems may be used to increase postrelease survival can be generated. Laboratory scale research is now being conducted to determine if exercise increases the instream survival of chinook salmon.

At the project's conclusion, a complete Natural Rearing Enhancement System will have been developed that produces salmon which are behaviorally, physiologically, and morphologically similar to their wild-reared counterparts. These NATURES salmon will have a high postrelease survival and should be genetically similar to the wild stocks from which they were derived. NATURES rearing protocols will provide supplementation and conservation programs with the type of hatchery-reared salmon needed to rapidly rebuild endangered and threatened runs of Pacific Northwest salmon.

b. Proposal objectives.

All the null hypothesis generated by the objectives can be directly tested and do not require that any assumptions be made. The objectives and their associated testable hypotheses are as follows:

1. Determine if rearing salmon in seminatural raceway habitat increases postrelease survival. Ho: Rearing salmon in seminatural raceway habitat does not increase postrelease survival. Ha: Rearing salmon in seminatural raceway habitat increases postrelease survival.

2. Determine if rearing salmon in raceways where food is presented in a natural manner by underwater feeders increases postrelease survival. Ho: Rearing salmon in raceways where food is presented in a natural manner by underwater feeders does not increase postrelease survival. Ha: Rearing salmon in raceways where food is presented in a natural manner by underwater feeders increases postrelease survival.

3. Determine if predator avoidance training increases salmon postrelease survival. Ho: Predator avoidance training does not increase salmon postrelease survival. Ha: Predator avoidance training increase salmon postrelease survival.

4. Determine if rearing salmon in raceways with natural current velocities that exercise fish increases postrelease survival. Ho: Rearing salmon in raceways with natural current velocities that exercise fish does not increase postrelease survival. Ha: Rearing salmon in raceways with natural current velocities that exercise fish does increase postrelease survival.

5. Determine if rearing salmon on diets supplemented with natural live feeds increases postrelease survival. Ho: Rearing salmon on diets supplemented with natural live feeds does not increase postrelease survival. Ha: Rearing salmon on diets supplemented with natural live feeds increases postrelease survival.

The project's primary products are experimental findings that are published in annual reports and peer-reviewed scientific publications. These finding are also presented at workshops and scientific meetings. In conducting the research, chinook salmon that are produced for experimental purposes are also released into the Columbia River Basin. The project's most valuable products are the new fish culture practices it has developed to increase salmon instream survival by 20-50%.

c. Rationale and significance to Regional Programs.

In the National Research Council (NRC) report "Upstream - salmon and society in the Pacific Northwest" the authors noted that "physical and biological conditions in hatchery facilities have differed greatly from those in natural environments and in general have lacked diversity in habitat structure, cover, and exposure to natural predators". Furthermore, they stated that "the hatchery rearing environment has the potential to alter selection pressures in a single generation, decreasing fitness in the natural environment". The successful use of hatcheries in the recovery process for endangered populations depends on developing new NATURES-like rearing technologies that help hatchery fish retain innate wild attributes.

Development of this NATURES conservation hatchery strategy is a high priority project identified as critical in the NMFS Proposed Endangered Species Act (ESA) Recovery Plan for Snake River sockeye and chinook salmon (Sections 4.4c and 4.4d). Development of strategies to increase postrelease survival of hatchery fish are also called for in the Northwest Power Planning Council's Columbia Basin Fish and Wildlife Program (Section 700e). The development of NATURES fish rearing strategies supports the planned BPA Yakima Fisheries Project test of supplementation as described in the Environmental Impact Statement for the Yakima Fisheries Project (DOE/EIS-0169).

The greatly reduced postrelease survival of hatchery reared salmon compared to their wild reared counterparts demonstrates that new fish culture techniques must be developed to produce hatchery fish with higher postrelease survival. The pre-release conditioning strategies being developed by the NATURES program will enable hatcheries to produce salmonids that are less vulnerable to predators due to their wild-like behavior, physiology, and morphology. Hatchery programs will be able to use high survival NATURES fish to rapidly rebuild endangered and threatened runs of Pacific salmon. The high postrelease survival of NATURES reared fish 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.

The NATURES Program scientists have developed the New Innovative, Limited New Innovative, and Optimal Conventional Treatments as well as the experimental variables to be measured in the Yakima Fisheries Project test of supplementation. The results of past and continuing experimentation are being coordinated with YFP to ensure the experimental variables incorporated into the New Innovative Treatment have the greatest

possibility for increasing smolt-adult survival. In addition, NATURES staff scientists frequently advise Federal, tribal, state, Public Utility District, and regional fisheries enhancement groups on how NATURES fish culture techniques can best be incorporated into their fish culture programs. As a result of these coordination efforts, NATURES fish rearing protocols are beginning to be adopted at various fish culture facilities to increase salmon postrelease survival.

d. Project history

Project reports and technical papers:

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

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. Progressive Fish-Culturist, 58:187-191.

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. Bulletin National Research Institute of Aquaculture, Supplement. 2:71-77.

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken. 1996. Development of a natural rearing system to improve supplemental fish quality. Annual Report 1991-1995. DE-A179-91BP20651, Bonneville Power Administration, Portland, Oregon.

Summary of Major Results Achieved:

The NATURES Program scientists have developed the New Innovative, Limited New Innovative, and Optimal Conventional Treatments as well as the experimental variables to be measured in the Yakima Fisheries Project test of supplementation. The results of past and continuing experimentation are being coordinated with YFP to ensure the experimental variables incorporated into the New Innovative Treatment have the greatest possibility for increasing smolt-adult survival. In addition, NATURES staff scientists frequently advise Federal, tribal, state, Public Utility District, and regional fisheries enhancement groups on how NATURES fish culture techniques can best be incorporated into their fish culture programs. As a result of these coordination efforts, NATURES fish rearing protocols are beginning to be adopted at various fish culture facilities to increase salmon postrelease survival.

The program has evaluated the effectiveness of the seminatural habitat component of the NATURES concept in three postrelease survival experiments conducted on chinook salmon (*Oncorhynchus tshawytscha*). In 1991-1992, fall chinook salmon were reared

from swim-up to smoltification in 400-l raceways outfitted with cover, structure, and substrate. These fish experienced a 50% increase in in-stream survival to a collection weir 2.2 km downstream compared to conventionally reared salmon. In 1994, spring chinook salmon were reared for 3 months in 400-l raceways outfitted with cover, structure, and substrate. These fish exhibited 24% greater postrelease survival to a collection weir 225 km downstream than controls when the fish were released in a clear-water situation. However, when fish were released in turbid water conditions, there was no significant difference in postrelease survival. In 1994, fall chinook salmon were reared from swim-up to smoltification in pilot-scale 5,947-l raceways outfitted with cover, structure, substrate, and an underwater feed delivery system. These fish averaged 27% higher postrelease survival to a collection weir 21 km downstream than their conventionally-reared counterparts.

The use of live-food supplementation to increase the postrelease foraging ability of hatchery-reared fall chinook salmon has also been investigated. Replicate groups of fry were reared in six 2.4-m-diameter circular tanks and fed on two different diets. Fish in three tanks received a standard, commercially available, pelletized diet, while those in the other tanks were given the opportunity to forage on natural live prey (mysids, mosquito larvae, chironomid larvae, and daphnia) prior to their daily ration of pellets. When foraging ability of individual fish was examined in 200-l observation tanks, the trained salmon were found to feed on twice the number of familiar prey (chironomids) and novel prey (mayfly larvae) as untrained fish. This suggests that live-food supplementation can be used to increase the postrelease foraging ability of hatchery-reared salmon.

The use of predator avoidance training as a tool to increase the postrelease survival of chinook salmon has been investigated. Fall chinook salmon reared in pilot scale raceways were exposed to limited great blue heron (*Ardea herodias*), hooded merganser(*Lophodytes cucullatus*), largemouth bass (*Micropterus salmoides*), and brown bullhead (*Ictalurus nebulosus*) predation. The instream postrelease survival of these predator conditioned fish was 26% higher than naïve controls that never experienced predation prior to release.

In 1998-1999, NATURES research will develop exercise protocols and refine predator avoidance training as tools for increasing the postrelease survival of salmonid. Also, a 4-year evaluation program has been initiated at production hatcheries to verify that seminatural raceway habitat increase smolt-adult survival.

Adaptive Management implications:

The goal of supplementation and conservation programs for threatened and endangered stocks is to develop methods to enhance populations by supplementing wild stocks with hatchery fish. The use of hatchery fish to supplement native populations holds good potential for recovery of natural populations, but existing techniques are controversial. NATURES research is a critical step in determining how live food diets, automated subsurface feeders, and seminatural rearing habitat may increase the postrelease survival

of hatchery salmonids. Predation experiments will also help to demonstrate whether predation is a significant factor in the postrelease survival of test fish. These studies will help to define rearing environment factors critical to improving postrelease survival of fish released for supplementation.

The knowledge gained from our past activities has allowed us to focus on and refine those experimental variables that contribute most to enhancing the postrelease survival of hatchery-reared salmonids. Based on our research findings, we recommend that hatchery-reared fish used to supplement, restore, or enhance natural populations be reared in seminatural environments with substrate, instream structure, and overhead cover. Based on these findings, we conclude that future research should focus on: 1) determining the best form of each seminatural habitat component (e.g. pea gravel vs resin encased rock substrate), 2) determining if the increased instream survival benefits of seminatural habitat rearing translate into increased fishery and spawner returns and, 3) developing and evaluating other prerelease conditioning techniques (predator avoidance training, exercise, etc.) for further enhancing hatchery reared salmon postrelease survival.

Years Underway: Six years (1991-1998)

Past Costs: FY 1993 - $472,000; FY 1994 -$0; FY 1995 - $400,000; FY 1996 -$372,000, FY 1997 - $399,200.

e. Methods.

Research in FY 1999 will continue to evaluate and refine NATURES components (seminatural raceway habitat, subsurface automated feeders, predator avoidance training, exercise current velocities, and live food supplemented diets) described under objective 1-5. The work will focus on: 1) verifying that seminatural raceway habitat increases smolt-to-adult survival (task 1.d); 2) refining predator avoidance training protocols with predation bioassays, instream releases, and if the protocol is sufficiently refined in 1998, initiate a smolt-to-adult survival evaluation in FY 1999 (tasks 3 a-d); 3) refining exercise protocols with predation bioassays and instream survival releases(tasks 4 a-d); 4) refining live food supplemented diets and evaluating their effect on postrelease survival (tasks 5a-b); and 5) examining the ecological interactions between conventionally, NATURES-, and wild-reared fish. The general methodology used in these studies has been fully described in Maynard et al. (1996a). This methodology is modified as appropriate to fit the specific location and stock of fish being studied.

The research associated with all five objectives follows the same overall plan. First, the literature is reviewed to develop new fish culture techniques that can be used to increase postrelease survival. Laboratory and pilot scale evaluations are then used to determine how the experimental techniques effect growth, inculture survival, behavior, fish health, predator vulnerability and instream survival. These evaluations are continued until the proposed rearing technique is either fully refined or is recommended for elimination from the program. Fully refined techniques are then evaluated on a production scale at salmon

hatcheries to determine how they affect smolt-adult survival. Those techniques that increase smolt-to-adult survival are recommended for incorporation into the natural rearing enhancement system.

In all experiments, the fish are reared in replicated groups with no less than three groups per treatment. Both control and experimental treatment fish are reared following standard fish culture methods. The only difference in how the control and experimental treatment fish are reared is the specific NATURES protocol being tested. The experimental treatment in these studies has and may include overhead cover, natural substrate, instream structure, subsurface feed delivery systems, exercise current velocities, predator avoidance training protocols, and live food diets. Fish rearing is usually conducted in rectangular raceway-like vessels that are about 400 liters in size in laboratory-scale evaluations, 6,000 liters in size in pilot-scale evaluations, and more than 200,000 l in size in production-scale hatchery evaluations of smolt-adult survival. Most studies will use a full-term rearing approach with the fish reared in the experimental treatments from swimup until they smolt. However, some experiments will use an acclimation approach with the experimental rearing treatments applied only during the last few months of experimental rearing.

Inculture evaluations include comparing the growth performance of fish in the control and experimental treatments by measuring their fork length and weight at 4-week intervals. Fish health is evaluated by maintaining mortality logs and removing a representative sample (n = 30 fish/treatment) and performing a fish health profile at the end of rearing. In studies evaluating seminatural raceway habitat, a representative sample of fish (n = 30) is removed from both treatments for colormetric determination. Where appropriate, the social, aggressive, foraging, and depth distribution patterns of the fish in the control and experimental treatments are compared with appropriate parametric and nonparametric statistics.

In some evaluations, predation and postrelease foraging bioassays are performed prior to the fish being released. In predation bioassays, a representative sample (n = 20 fish/treatment) is removed from each treatment and placed in the predation test arena. Predators are allowed to fish in the arena until half the salmon have been eaten. This procedure is repeated at least 15 times and then the ratio of fish surviving/preyed for the two treatments is compared with contingency table analysis. Foraging bioassays involve placing a single predatory fish in a laboratory test arena cage and challenging it to forage on available prey. This procedure is repeated at least 40 times using 20 fish from each treatment. The foraging behavior data collected during these bioassays is analyzed with nonparametric Mann-Whitney U tests. Stomach weight data are compared with t-tests.

In all NATURES studies, because of the relatively fast turn around time between fish release and data recovery, juvenile instream survival tests constitute the best measure to refine the rearing treatments. In these evaluations, a representative sample of 1,500 fish from each treatment is tagged. The fish are then allowed to recover from the effects of tagging before they are trucked to an upstream release site, where they are released and challenged to successfully survive migration to a downstream weir. The ratio of fish

recovered/unrecovered from the treatments is compared with a contingency table analysis. Depending on the number of treatments, the travel time to the weir is compared by t-test or ANOVA. NATURES instream survival evaluations have been conducted at a number of sites including the Yakima River, Little Anderson Creek, Big Beef Creek, Bingham Creek and Curley Creek.

When a rearing protocol has been fully refined and shown to be workable, smolt-adult survival evaluations are initiated. In these evaluations the control and experimental treatment fish are grown in side-by-side vessels at a production-scale hatchery. At least a month before release, the fish are coded wire tagged so that their smolt-to-adult survival can be compared using tag recoveries from the fishery, spawning ground surveys, and hatchery returns. The number of fish tagged per treatment, number of rearing vessels per treatment, and number of years fish are released depends on the expected tag return rate, hatchery, and stock of fish. The smolt-to-adult survival and size of fish from the rearing treatments will be compared with a contingency table analysis, t-test, or ANOVA depending on the number of treatments and release years. NATURES smolt-to-adult survival evaluations are currently being conducted with chinook salmon in the Willapa and the Snake River Basins.

The goal of supplementation and conservation programs for threatened and endangered stocks is to develop methods to enhance populations by supplementing wild stocks with hatchery fish. The use of hatchery fish to supplement native populations holds good potential for recovery of natural populations, but existing techniques are controversial. NATURES research is a critical step in determining how live food diets, automated subsurface feeders, and seminatural raceway habitat, predator avoidance training, and exercise can be used to increase the postrelease survival of hatchery salmonids. NATURES research to date has developed fish culture strategies allowing hatchery programs to increase the instream survival of their fish by 25-50%. Future research should provide equivalent benefits. These NATURES fish culture techniques will allow supplementation and conservation hatcheries to rapidly restore self-sustaining natural runs in areas where salmon are now threatened, endangered, or extinct.

NATURES studies also provide precision for fish rearing strategies to be used in the planned BPA Yakima Fisheries Project test of supplementation as described in the Environmental Impact Statement for the Yakima Fisheries Project (DOE/EIS-0169). The results of this research should significantly increase the performance of target populations by greatly enhancing postrelease survival.

The NATURES project will provide conservation, supplementation, and enhancement hatcheries with fish culture techniques that enable them to produce wild-like salmon with high postrelease survival. This actions will help return a productive fishery to the river and conserve the Columbia Basin's salmonid resources. Implementation of NATURES strategies will allow Columbia River salmon populations to recover to self sustaining and harvestable levels. NATURES rearing strategies may also result in the genetics of hatchery reared fish being similar to the wild populations from which they were sourced. The guidelines developed by the project will enable the Cle Elum Hatchery to optimize

the production of anadromous fish in the Yakima River Basin.

There are no special animal care or environmental protection requirements. There are also no special risks to habitats, other organisms, or humans.

f. Facilities and equipment.

The research is conducted at the NMFS Manchester Marine Experimental Station freshwater rearing facilities, state hatcheries, and USFWS hatcheries. Experimental rearing at Manchester is conducted in six 6,000 l rectangular raceways and twelve 1,152 l rectangular troughs. The facility is supplied with 330 gpm of pumped surface water from Beaver Creek. Alarms and backup generators are used to ensure an uninterrupted flow of life support water to experimental fish. Emergency oxygen is also available to sustain fish in an emergency. Project fish that are reared at state and federal production facilities are supported with all the standard equipment and backup systems required to ensure fish safety and quality.

The Manchester Station is equipped with predator bioassay test arenas, a fish behavior building containing two 12-m long simulated streams and a 40-m long simulated river channel. The station has all professional grade balances, microscopes, hoods, and reagents required to monitor in culture fish performance and health. Two portable video systems and portable computers equipped with event recording software are available for studying fish behavior. Insulated transport tanks and two one-ton four wheel drive trucks are available for fish transport. Each year the laboratory places a weir on Curley Creek so that it can be used to conduct instream survival evaluations. The laboratory has the skilled personnel and equipment to tag and mark fish with most standard methods (freeze brand, PIT tags, photonic tags, coded wire tags, etc.).

The Manchester station is equipped with computers and software to statistically analyze data, write reports, and produce journal publications. A machine shop and specialized construction equipment including cranes, tractors, backhoes, welding equipment, plumbing equipment, and electrician tools are available on site. This equipment is used in fabricating NATURES environments, predator training cages, insitu foraging cages, weirs, and other specialized research equipment as needed.

g. References.

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 cucculatus*. North. American Journal of Fisheries. Management. 11:206-211.

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

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken. 1996a. Development of a natural rearing system to improve supplemental fish quality. Annual Report 1991-1995. DE-A179-91BP20651, Bonneville Power Administration, Portland, Oregon.

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

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken, and S. L. Schroder. 1996c. Natural rearing technologies for increasing postrelease survival of hatchery-reared salmon. Bulletin of the National Research Institute of Aquaculture, Supplement 2:71-77.

National Research Council. 1996. Upstream: Salmon and society in the Pacific Northwest. National Academy Press, Washington. 452 p.

Olla, B.L. and M.W. Davis. 1989. The of learning and stress in predator avoidance of hatchery-reared coho salmon (*Oncorhynchus kisutch*) juveniles. Aquaculture 76:209-214.

Thompson, R.B. 1966. Effects of predator avoidance conditioning on the postrelease survival rate of artificially propagated salmon. Ph. D. Thesis, University of Washington, Seattle, 155 p.

Section 8. Relationships to other projects

NATURES Program scientists have developed the New Innovative, Limited New Innovative, and Optimal Conventional Treatments as well as the experimental variables to be measured in the Yakima Fisheries Project test of supplementation. The results of past and continuing experimentation are being coordinated with YFP to ensure the experimental variables incorporated into the New Innovative Treatment have the greatest possibility for increasing smolt-to-adult survival. In addition, NATURES staff scientists frequently advise Federal, tribal, state, Public Utility District, and regional fisheries enhancement groups on how NATURES fish culture techniques can best be incorporated into their fish culture programs. As a result of these coordination efforts, NATURES fish rearing protocols are beginning to be adopted at various fish culture facilities to increase salmon postrelease survival.

Section 9. Key personnel

1. Mr. Thomas A. Flagg, Fisheries Research Biologist. Co-principal Investigator @ 25% FTE. 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 @ 100% FTE. 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: Co-principal Investigator @ 50% FTE. Duties include internal project oversight; research; external project coordination; data analysis and report writing; etc. [See attached resume for qualifications.]

CURRICULUM VITAE--**Thomas A. Flagg**

Education: B.S. (Fisheries Biology), University of Washington, Seattle, WA; 1976.
M.S. (Fisheries Biology), University of Washington, Seattle, WA; 1981.

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

Position: Fisheries Research Biologist, NMFS employee since 1978.

Present assignment: Team Leader, Salmon Enhancement Projects. Responsibilities include: development of fish husbandry technology to produce wild-type juvenile salmon for release from hatcheries; development of supplementation techniques for restoration of depleted stocks of salmonids to their native habitats; and development of captive broodstock programs to conserve depleted gene pools of salmonids.

Previous research/expertise: Includes research associated with: determination of status of depleted stocks of fish including those proposed for listing as threatened or endangered under the Endangered Species Act; development of the passive integrated transponder (PIT) tagging system for salmonids; development of freshwater and seawater net-pen aquaculture husbandry and captive broodstock techniques for Atlantic and Pacific salmon (including research in the areas of aquaculture systems design and development, stock rearing strategies, nutrition, disease investigations, maturation and spawning, hormonal sex reversal, smoltification, and stock performance); investigation of fish-collection and transportation related mortalities in juvenile salmonids in the Columbia River system; evaluation of the impact of the 1980 Mt. St. Helens eruption on juvenile salmonids in the Columbia River system; and investigation of the relationship between swimming behavior, smoltification status, and seawater survival for coho salmon.

Relevant Publications include:

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.

CURRICULUM VITAE--**Dr**. **Desmond J. Maynard**

Education:

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

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

Position: Fisheries Research Biologist, NMFS employee since 1988.

Present assignment: Principal investigator on the NATURES project. Dr. Maynard'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. The research he has conducted on the project has demonstrated that seminatural 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:

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.

CURRICULUM VITAE-- **Dr. Barry A. Berejikian**

Education:

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

Employer: National Marine Fisheries Service, Northwest Fisheries Science Center, Resource Enhancement & Utilization Technologies 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 initiated experiments into the chemical (pheromone) basis of predator recognition.

Relevant Publications include:

Berejikian, B. A. 1995. 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. 52:2476-2482.

Berejikian, B. A. 1996. Instream postrelease growth and survival of chinook salmon smolts subjected to predator training and alternate feeding strategies. *In* D. J. Maynard, T. A. Flagg, and C. V. W. Mahnken (editors), Development of a natural rearing system to improve supplemental fish quality, 1991 1995, pages 113-127. Report to Bonneville Power Administration, Contract DE-A179-91BP20651. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112.).

Berejikian, B. A., S. B. Mathews, and T. P. Quinn. 1996. Effects of hatchery and wild ancestry and rearing environments on the development of agonisitic behavior in steelhead trout fry (*Oncorhynchus mykiss*) fry. Can. J. Fish. Aquat. Sci. 53: 2004-2014.

Berejikian, B. A., E. P. Tezak, S. L. Schroder, C. M. Knudsen, and J. J. Hard. In press. Reproductive behavioral interactions between spawning wild and captively reared coho salmon (Oncorhynchus kisutch). ICES Journal of Marine Science, 00: 000-000.

Section 10. Information/technology transfer

Information feedback to management decisions will be through annual reports, scientific journal articles, presentations before professional society meeting, presentations at workshops, and frequent discussions with federal, tribal, state, and PUD fish culture staffs and local fisheries enhancement groups.