PART I - ADMINISTRATIVE

Section 1. General administrative information

Title of project

Assessment Of Smolt Condition: Biological And Environmental Interactions

BPA project number: 8740100
Contract renewal date (mm/yyyy): 4/1999 ☐ **Multiple actions?**

Business name of agency, institution or organization requesting funding
U.S. Geological Survey, Biological Resources Division, Columbia River Research Laboratory

Business acronym (if appropriate) USGS

Proposal contact person or principal investigator:

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NPPC Program Measure Number(s) which this project addresses
4.2A, 5.0A, 5.7A.4, 5.7B.17, 5.8A.8, 5.9A.1, 7.2D.1, 7.2D.3

FWS/NMFS Biological Opinion Number(s) which this project addresses
NMFS Bio. Op. Section 7: Operations of the Columbia River Power System, Columbia River Management Plan, Smolt Monitoring Program, and Juvenile Fish Transport Program

Other planning document references
Recovery Plan for Snake River Salmon 2.1.d, 2.3.d, 4.1, 4.3, 4.4, 4.5, Columbia River Anadromous Fish Restoration Plan of the Nez Perce, Umatilla, Warm Springs, and Yakama Tribes

Short description
Evaluate the biology of wild and hatchery salmonids by determining the effects of rearing and river conditions on smolt quality; assist hatchery managers in producing fish with wild-like characteristics and thereby increase smolt-to-adult returns.

Target species

salmonids species: Oncorhynchus spp.

Section 2. Sorting and evaluation

Subbasin
Systemwide

Evaluation Process Sort

CBFWA caucus	Special evaluation process	ISRP project type
Mark one or more caucus	If your project fits either of these processes, mark one or both	Mark one or more categories
☒ Anadromous fish ☐ Resident fish ☐ Wildlife	☒ Multi-year (milestone-based evaluation) ☐ Watershed project evaluation	☐ Watershed councils/model watersheds ☒ Information dissemination ☐ Operation & maintenance ☐ New construction ☒ Research & monitoring ☐ Implementation & management ☐ Wildlife habitat acquisitions

Section 3. Relationships to other Bonneville projects

Umbrella / sub-proposal relationships. List umbrella project first.

Project #	Project title/description
20542	Biological Monitoring of Columbia Basin Salmonids
8740100	Assessment of Smolt Condition: Biological and Environmental Interactions.
9082	Evaluate feeding strategies to reduce residualism in steelhead

Other dependent or critically-related projects

Project #	Project title/description	Nature of relationship
9102900	Supplementation and survival of fall chinook in Snake River	smolt assessment technical assistance
9801005	Pittsbugh Landing Creek portable acclimation release facility	smolt assessment technical assistance
	USGS-Performance and stock productivity impacts of hatchery supplementation	smolt assessment technical assistance
	USGS-COE Eval.of Collection, Transport, Passage of Outmigrating	smolt assessment technical assistance

	Salmon	
	WDFW-Cowlitz Falls Anadromous Fish Reintroduction Project	smolt assessment technical assistance
	WDFW-Snake River Lab Acclimation and direct stream release of chinook	smolt assessment technical assistance
	WDFW, Chelan PUD-Temperature, precocity, residualism in steelhead	smolt assessment technical assistance
	WDFW-Survival differences in coho salmon under seminatural rearing	smolt assessment technical assistance

Section 4. Objectives, tasks and schedules

Past accomplishments

Year	Accomplishment	Met biological objectives?
1998	Obj.1 & 2. hatchery evaluation in progress	yes, current analysis of rearing information in progress for release to hatcheries for review in February 1999 and release as annual report
1998	Obj. 3. results of lysozyme research reported	yes, publication of results for coho and chinook salmon is in peer review, for submission for publication in December 1998
1998	Obj 4. provided technical assistance to 2 USFWS, 2 USGS, 1 COE, and 4 WDFW smolt monitoring projects	yes, sampling and analysis complete for 1998 field season, results have been released to cooperating agencies
1998	Assessment of Smolt Condition for Travel Time Analysis: Project Review 1987-1997	yes, review is available on BPA homepage
1998	Developed cooperative project with USFWS, Idaho Fishery Resource Office under Obj 4.	yes, applied research complete, preliminary results presented at NWFCC, Boise, ID 12/1998
1998	Sponsor 20th Smolt Workshop in cooperation with WDFW, scheduled Feb 1-3, 1999 Olympia, Washington	yes
1997	Hatchery rearing conditions survey completed for 10 hatcheries	yes
1997	Smolt condition assessment technical assistance to 15 projects, including to 3 USFWS, 2 USGS, 2 COE, 4 WDFW	yes, results released, found in cooperating agency project reports
1997	Cooperative research with USFWS to determine effects of enhanced feeds on growth and disease resistance in chinook	yes, analysis and report in progress

	salmon	
1996	Cooperative research with USFWS to enhance smolt performance with glucan feeds, continued monitoring for FPC	yes, analysis and report in progress
1995	Conducted cooperative research with USFWS, continued monitoring for FPC	yes
1995	Conducted gas bubble monitoring of juvenile salmon at 6 dams on the Snake and Columbia Rivers, continued monitoring for FPC	yes
1994	Sampling with NMFS Lower Granite Survival Study continued from 1993, continued monitoring for FPC	yes

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Investigate the effects of rearing and river conditions on the physiology and migration success of juvenile salmonids.	a	Analyze hatchery stock rearing data to identify factors contributing to smolt-to-adult survival.
		b	Work cooperatively with reference hatcheries to interpret, summarize, and report findings from individual hatchery analysis.
		c	Develop cooperative sampling with regional managers for non-invasive monitoring of wild salmon populations.
		d	Determine performance indicators for production, based on wild fish physiology monitoring.
2	Maintain a comprehensive database of juvenile salmonid performance and adult survival.	a	Integrate hatchery and wild rearing and migration data, and adult returns with environmental data.
		b	Analyze integrated smolt condition database for effects of rearing on smoltification, migration success, and adult returns.
3	Develop monitoring program to evaluate in-river migration performance of reference stocks comparing wild fish and hatchery fish reared under modifed conditions.	a	Cooperate with basin hatchery managers to promote adaptive modifications at hatcheries and provide evaluations of migration success based on wild salmonid comparisons.

		b	Assist in the determination of reference stocks for in-river biological monitoring.
4	Develop and evaluate indices of smolt condition.	a	Determine use of mucus lysozyme activity as measure of smolt condition in juvenile salmonids.
		b	Validate eye pigment ratio as non-invasive indicator of smolt condition, with correlation to gill ATPase.
5	Provide technical assistance to cooperating agencies and BPA-funded projects.	a	Provide research and sampling design review, and laboratory analysis to cooperating agencies, for determination of the physiological status of salmon and steelhead.
		b	Organize annual regional smolt workshop to facilitate information exchange among Columbia basin salmonid managers and agencies. Distribute smolt workshop proceedings.

Objective schedules and costs

Obj #	Start date mm/yyyy	End date mm/yyyy	Measureable biological objective(s)	Milestone	FY2000 Cost %
1	4/2000	3/2001	correlations of smolt-to-adult returns with rearing, and river and ocean conditions	3/2005	25.00%
2	4/2000	3/2001	systemwide documentation of biological characteristics of smolts under varied conditions	3/2005	20.00%
3	4/2000	3/2001	provide biological evaluation of reference stocks during migration	3/2005	25.00%
4	4/2000	3/2005	allow biological monitoring under ESA restrictions	2/2005	20.00%
5	4/2000	3/2005	biological assessment of smolt condition for regional fish managers, annual exchange of	2/2005	10.00%

			biological information		
				Total	100.00%

Schedule constraints
Coordination of technical assistance activities within cooperative agency project schedules.

Completion date
3/2005

Section 5. Budget

FY99 project budget (BPA obligated): $199,000

FY2000 budget by line item

Item	Note	% of total	FY2000
Personnel	2 FT, 2 1/4T	%54	107,272
Fringe benefits		%13	25,341
Supplies, materials, non-expendable property		%3	5,000
Operations & maintenance		%0	
Capital acquisitions or improvements (e.g. land, buildings, major equip.)	computer upgrade and software for database	%2	3,500
NEPA costs		%0	
Construction-related support		%0	
PIT tags	# of tags:	%0	
Travel	includes vehicle for 6 months	%2	4,500
Indirect costs		%27	53,433
Subcontractor		%0	
Other		%0	
TOTAL BPA FY2000 BUDGET REQUEST			$199,046

Cost sharing

Organization	Item or service provided	% total project cost (incl. BPA)	Amount ($)
	All technical assistance projects cover materials and labor for the assistance	%5	10,000

	activities (figure based on 1997 & 1998).		
		%0	
		%0	
		%0	
		Total project cost (including BPA portion)	$209,046

Outyear costs

	FY2001	**FY02**	**FY03**	**FY04**
Total budget	$206,000	$212,000	$218,000	$225,000

Section 6. References

Watershed?	**Reference**
☐	Adams, C. E., and J. E. Thorpe. 1989. Photoperiod and temperature effects on early development and reproductive investment in Atlantic salmon (Salmo salar L.). Aquaculture 79:403-409.
☐	Alexander, G., R. Sweeting, and B. McKeown. 1994. The shift in visual pigment dominance in the retinae of juvenile coho salmon (Oncorhynchus kisutch): an indicator of smolt status. Journal of Experimental Biology 195:185-197.
☐	Barton, B. A., C. B. Schreck, R. D. Ewing, A. R. Hemmingsen, and R. Patino. 1985. Changes in plasma cortisol during stress and smoltification in coho salmon, Oncorhynchus kisutch. General and Comparative Endocrinology 59:468-471.
☐	Beatty, D. D. 1965. A study of the succession of visual pigments in Pacific salmon (Oncorhynchus). Canadian Journal of Zoology 44:429-455.
☐	Beeman, J. W., D. W. Rondorf, J. C. Faler, M. E. Free, and P. V. Haner. 1990. Assessment of smolt condition for travel time analysis. Annual Report 1989 (Contract DE-AI79-97BP35245) to Bonneville Power Administration, Portland, Oregon.
☐	Beeman, J. W., D. W. Rondorf, J. C. Faler, M. E. Free, P. V. Haner, S. T. Sauter, and D. A. Venditti. 1991. Assessment of smolt condition for travel time analysis. Annual Report 1990 (Contract DE-A179-87BP35245) to Bonneville Power Administration.
☐	Beeman, J. W., D. W. Rondorf, and M. E. Tilson. 1994. Assessing smoltification of juvenile spring chinook salmon (Oncorhynchus tshawytscha) using changes in body morphology. Canadian Journal of Fisheries and Aquatic Sciences 51:836-844.
☐	Beeman, J. W., D. W. Rondorf, M. E. Tilson, and D. A. Venditti. 1995. A nonlethal measure of smolt status of juvenile steelhead based on body morphology. Transactions of the American Fisheries Society 124:764-769.
☐	Borgatti, A. R., A. Pagliari, and V. Ventrella. 1992. Gill (Na+, K+)-ATPase

	involvement and regulation during salmonid adaptation to salt water. Comparative Biochemistry and Physiology 102A:637-643.
☐	Carmichael, R. W. and R. T. Messmer. 1995. Status of supplementing chinook salmon natural production in the Imnaha River basin. In Uses and Effects of Cultured Fishes in Aquatic Ecosystems. American Fisheries Society Symposium 15:284-291.
☐	Dickhoff, W. W., B. R. Beckman, D. A. Larsen, C. V. W. Mahnken, C. B. Schreck, C. Sharpe, and W. S. Zaugg. 1995. Quality assessment of hatchery-reared spring chinook salmon smolts in the Columbia River basin. In Uses and Effects of Cultured Fishes.
☐	Fevolden, S. E., T. Refstie, and K. H. Roed. 1991. Selection for high and low cortisol stress response in Atlantic salmon (Salmo salar) and rainbow trout (Oncorhynchus mykiss). Aquaculture 95:53-65.
☐	Fevolden, S. E., T. Refstie, and K. H. Roed. 1992. Disease resistance in rainbow trout (Oncorhynchus mykiss) selected for stress response. Aquaculture 104:19-29.
☐	Fevolden, S. E., K. H. Roed, and B. Gjerde. 1994. Genetic components of post-stress cortisol and lysozyme activity in Atlantic salmon; correlations to disease resistance. Fish and Shellfish Immunology 4(7):507-519.
☐	Folmar, L. C., and W. W. Dickhoff. 1981. Evaluation of some physiological parameters as predictive indices of smoltification. Aquaculture 23:309-324.
☐	Foote, C. J., W. C. Clarke, and J. Blackburn. 1991. Inhibition of smolting in precocious chinook salmon, (Oncorhynchus tshawytscha). Canadian Journal of Zoology 69:1848-1852.
☐	Grinde, B. 1989. Lysozyme from rainbow trout, Salmo gairdneri Richardson, as an antibacterial agent against fish pathogens. Journal of Fish Diseases 12:95-104.
☐	Grinde, B., J. Jolles, and P. Jolles. 1988. Purification and characterization of two lysozymes from rainbow trout (Salmo gairdneri). European Journal of Biochemistry 173:269-273.
☐	Haner, P. V., J. C. Faler, R. M. Schrock, D. W. Rondorf, and A. G. Maule. 1995. Skin reflectance as a nonlethal measure of smoltification for juvenile salmonids. North American Journal of Fisheries Management 15:814-822.
☐	Heath, D. D., N. J. Bernier, J. W. Heath, and G. K. Iwama. 1993. Genetic, environmental, and interaction effects on growth and stress response of chinook salmon (Oncorhynchus tshawytscha) fry. Canadian Journal of Fisheries and Aquatic Sciences 50(2):43
☐	Hoar, W. S. 1988. The physiology of smolting salmonids. Pages 275-323. In W. S. Hoar and D. J. Randall (eds), Fish Physiology Volume XI, Part B. San Diego: Academic Press, Inc.
☐	Klontz, G. W., M. G. Maskill, and H. Kaiser. 1991. Effects of reduced continuous versus intermittent feeding of steelhead. Progressive Fish-Culturist 53:229-235.
☐	Maule, A. G., J. W. Beeman, R. M. Schrock, and P. V. Haner. 1994. Assessment of smolt condition for travel time analysis. Annual Report 1991-

	1992 (Contract DE-A179-87BP35245) to Bonneville Power Administration, Portland, Oregon.
☐	Maule, A. G., C. B. Schreck, and S. L. Kaattari. 1987. Changes in the immune system of coho salmon (Oncorhynchus kisutch) during the parr-to-smolt transformation and after implantation of cortisol. Canadian Journal of Fisheries and Aquatic Sciences 44:
☐	McCormick, S. D., R. L. Saunders, and A. D. MacIntyre. 1989. Mitochondrial enzyme and Na+, K+-ATPase activity, and ion regulation during parr-smolt transformation of Atlantic salmon (Salmo salar). Fish Physiology and Biochemistry 6(4):231-241.
☐	Miller, W. H. 1990. Analysis of salmon and steelhead supplementation. Part 1, emphasis on unpublished reports and present programs; Part 2, synthesis of published literature; Part 3, concepts for a model to evaluate supplementation. USFWS report.
☐	Muir, W. D., A. E. Giorgi, C. C. Travis. 1994. Behavioral and physiological changes in yearling chinook salmon during hatchery residence and downstream migration. Aquaculture 127(1):69-82.
☐	Muir, W. D., W. S. Zaugg, S. McCutcheon, and J. G. Williams. 1992. Biological manipulation of migration rate: the use of advanced photoperiod to accelerate smoltification in yearling chinook salmon, 1990. Annual report 1990. NMFS/NOAA: 37pp.
☐	Roed, K. H., H. J. S. Larsen, R. D. Linder and T. Refstie. 1993. Genetic variation in lysozyme activity in rainbow trout (Oncorhynchus mykiss). Aquaculture 109:237-244.
☐	Rondorf, D. W., J. W. Beeman, J. C. Faler, M. E. Free, and E. J. Wagner. 1989. Assessment of smolt condition for travel time analysis. Annual Report 1988 (Contract No. DE-AI79-87BP35245) to Bonneville Power Administration, Portland, Oregon.
☐	Schrock, R. M., J. W. Beeman, P. V. Haner, K. M. Hans, J. D. Hotchkiss, S. T. Sauter, S. P. Vanderkooi, W. L. Gale, P. A. Petrusso, and A. G. Maule. 1998. Assessment of smolt condition for travel time analysis, project review 1987-1997. BPA report.
☐	Schrock, R. M., J. W. Beeman, D. W. Rondorf, and P. V. Haner. 1994. A microassay for gill sodium, potassium-activated ATPase in juvenile Pacific salmonids. Transactions of the American Fisheries Society 123:223-229.
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☐	Smith, R. R. 1987. Methods of controlling growth of steelhead. Progressive Fish-Culturist 49:248-252.
☐	Viola, A. E. and M. L. Schuck. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. North American Journal of Fisheries Management 15(2):488-493.
☐	Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Environmental factors affecting smoltification and early marine survival of anadromous

	salmonids. National Marine Fisheries Service Marine Fisheries Review 42:1-14.
☐	Zaugg, W. S. 1981a. Relationships between smolt indices and migration in controlled and natural environments. Pages 173-183. In E. L. Brannon and E. O. Salo (eds), Salmon and Trout Migratory Behavior Symposium.
☐	Zaugg, W. S. 1981b. Advanced photoperiod and water temperature effects on gill Na+, K+ adenosine triphosphatase activity and migration of juvenile steelhead (Salmo gairdneri). Canadian Journal of Fisheries and Aquatic Sciences 38:758-764.
☐	Zaugg, W. S. and B. R. Beckman. 1990. Saltwater-induced decreases in weight and length relative to seasonal gill Na+ -K+ ATPase changes in coho salmon (Oncorhynchus kisutch): a test for seawater adaptability. Aquaculture 86: 19-23.

PART II - NARRATIVE

Section 7. Abstract

The goal of the project is to investigate the interactions of the physiological condition of wild and hatchery salmonids with the environment on survival, from emergence to adult. The project addresses research, monitoring, and salmon goal measures of the FWP by conducting biological evaluations of Columbia basin stocks for production and management purposes. The methods applied have been developed during the eleven year history of the project when real-time physiological data was provided to the Fish Passage Center for Water Budget Management. Non-lethal and non-invasive methods for smolt assessment were developed and are applied in cooperative efforts between production, research, and management projects to evaluate and monitor strategies to improve smolt-to-adult survival even under Endangered Species Act listing restrictions. A decadal comprehensive database provides documentation of the interactions of smolt physiology and the environment under known rearing, river, and hydropower system conditions. As wild stocks are incorporated into hatchery broodstock programs the migration physiology of juvenile salmonids of the Columbia basin will change. Comparisons of growth and migration rates between wild and hatchery fish, the assessment of smolt condition of reintroduced stocks, and evaluations of the effects of new feeding and rearing programs on smolt condition and migration success are major objectives. Cooperative research projects hold the greatest promise of efficient initiation and evaluation of new and innovative programs to increase smolt-to-adult survival, and for information exchange. The broad approach with established monitoring and analysis procedures allows prompt adaptation to innovative cooperative research programs.

Section 8. Project description

a. Technical and/or scientific background

A recent draft report from the Scientific Review Team Independent Scientific Advisory Board regarding the Artificial Production Review to the NWPPC pointed out the need to alter hatchery rearing practices to create hatchery fish that are more like wild fish. It is the primary goal of this project to assist hatchery managers to release fish that are physiologically and behaviorly similar to their wild counterparts. The return of juvenile salmonids as adults is based on complex interactions of genetic heritage and developmental biology (Heath *et al.* 1993), within diverse rearing, migration, estuarine, ocean, and spawning environments. The complex life history of anadromous salmon belies use of a single factor to determine the cause of mortality at any life stage, but management objectives call for quantitative measurements to assist in making informed decisions and developing effective strategies to simultaneously manage both wild and hatchery salmonid stocks that interact during migration, and during estuarine and ocean residence. A large body of literature exists to document quantitative and qualitative measurements of smolt condition and health in both wild and hatchery salmonids (Wedemeyer *et al.* 1980; Folmar and Dickhoff 1981; Hoar 1988). Continuing adaptive management efforts that have altered habitat; hatchery broodstocks; rearing and release strategies; hydrosystem operations; release, transport and passage strategies; and in-river monitoring techniques have occurred at a magnitude that has altered the nature of the migrating stocks as well as the anadromous environment. The decline of Columbia basin salmonid stocks is typified by the increasing number of stocks listed as threatened or endangered under the Endangered Species Act. Smolt monitoring activities such as enumeration of migrants and survival estimates have continued during the decline, but projects that provide the correlative physiological data to determine the effects of the tremendous management changes taking place in the Columbia basin are few.

From the time of spawning through juvenile and adult migration, the physiology of the fish is an indicator of the probability of success under specific environmental conditions. The rearing environment and smolt condition varies in wild fish due to annual climatic changes, and in hatcheries under different rearing programs. Differences between wild and hatchery stocks include travel time and numbers of migrants, stress response, level of smoltification, physiological condition, and fish health (Zaugg 1981a; Miller 1990; Sharpe *et al.* 1994).

Differences in the migration rates and mortality of hatchery stocks have compelled management agencies to develop strategies to produce fish with smolt characteristics similar to wild fish. Natural rearing systems (Howard Fuss, WDFW, unpublished data), acclimation before release (Viola and Schuck 1995), altered temperatures (Adams and Thorpe 1987; Foote *et al.* 1991) and photoperiod (Zaugg 1981b; Muir *et al.* 1992), and modified diets and feeding regimes (Smith 1987; Klontz *et al.* 1991; Jones and Schrock, USFWS and USGS, unpublished data) are methods being applied at Columbia basin hatcheries. The goal of these studies has been to decrease disease incidence, residualism and precocity, and to produce mitigation and supplementation fish with migration behavior and survival similar to their wild counterparts (Carmichael and Messmer 1995). We have received requests from regional fishery professionals identifying rearing practices as an important area of interest, and asking for our assistance. A major requirement for evaluation of rearing programs is the ability to assess physiological condition of fish before release and during migration. Development of laboratory facilities and staff within each agency would be unreasonably

expensive. This project provides this capability to cooperating agencies throughout the region and conducts research to develop analytical methods for field applications.

Gill sodium, potassium-activated ATPase activity remains the physiological measurement most often used to evaluate the potential osmoregulatory capacity of juvenile salmon (McCormick *et al.* 1989; Zaugg and Beckman 1990; Borgatti *et al.* 1992) describing smolt condition. We continue to use gill ATPase activity as the measure against which all other smolt indices are validated, while developing new non-invasive methods to eliminate the necessity of tissue collection for field monitoring of smoltification (Beeman *et al.* 1994, 1995; Schrock *et al.* 1994; Haner *et al.*1995).

Many other factors of juvenile salmonid physiology and behavior change during development (Muir *et al.* 1994, Dickhoff *et al.* 1995), and measurements of these variables provide valuable evaluative and predictive data for further modification of management programs. Lysozyme, an enzyme found in mucus, is bactericidal against fish pathogens (Grinde 1989). The non-specific enzyme, present as two isoenzymes in rainbow trout (Grinde *et al.* 1988), displays genetic heritability in breeding experiments and has been proposed as a possibility for selective breeding programs (Roed *et al.* 1993). The lysozyme response is closely linked to the cortisol stress response and disease resistance in salmon (Fevolden *et al.* 1991, 1992, 1994), a response that needs to be understood during smoltification and migration when stress (Barton *et al.* 1985) and immune responses (Maule *et al.* 1987) may be compromised. A survey of baseline levels of mucus lysozyme has been completed for reference stocks of this project, and the mucus lysozyme profile for juvenile spring chinook salmon and coho salmon during smoltification has been documented. Mucus lysozyme level decrease during smoltification, a decrease that procedes the increase in gill ATPase (Schrock, unpublished data). We will continue to determine annual profiles of mucus lysozyme levels in basin stocks for possible application as a field method not requiring tissue biopsy to assess smolt condition.

Visual pigments change during different life stages in Pacific salmon (Beatty 1965). There is a shift in pigment dominance during smoltification (Alexander *et al.* 1994), and measurement by reflectance spectroscopy may offer a non-invasive, benign method of assessing smoltification. We are developing a method to measure the ratio of rhodopsin to porphyropsin in smolting salmon using reflectance spectroscopy. The ratio will be documented during smoltification, and correlated to levels of gill ATPase in hatchery and wild salmonids for monitoring and evaluation purposes.

The scope of the project provides a central, organized program of response to regional requirements for continued monitoring and evaluation of juvenile salmon and steelhead. Demand for smolt monitoring capabilities is expected to continue in the region as long as Columbia basin agencies manage hatchery and wild salmon stocks. Scheduled activities include assessment of the migration physiology of hatchery fish of wild broodstock origin and of production fish reared under innovative hatchery conditions, and continued monitoring of reintroduced stocks. We are developing the program design based on our experience of providing data to the Fish Passage Center from 1987-1997. Results will be evaluated by analysis and reporting of research data, and the successful application of methods to management requirements.

b. Rationale and significance to Regional Programs

The rationale for the project is found in multiple measures of the FWP. The measures require a systemwide approach to the evaluation of management adaptations because of the anadromous life history of salmon, especially the wide geographic migration range of juveniles and adults. Research and monitoring activities are mandated under measures 5.0F and 5.9A, and performance standards for different salmonid stocks under 5.4 and 5.7. Both mitigation and supplementation are addressed under 7.0B, 7.0D, 7.1F, 7.2A, 7.2D, 7.4A, and 10.2. Sections 6.1D, 6.1E, 7.0B and 7.8G relate to environmental factors affecting the juvenile migration. Basinwide coordination of monitoring of juvenile salmonids under proposed hatchery and hydrosystem modifications would provide managers with the biological information necessary to determine the success of individual adaptive management changes during rearing, release, transport, passage, migration, and estuary and ocean residence. The successful return of juvenile salmon as adults is based on the successful interaction between the physiology of the fish and the environment. The complex life history of anadromous fish requires evaluation and isolation of those factors that promote juvenile survival and adult returns. From the time of spawning through the juvenile and adult migrations, the physiology of the fish is an indicator of the probability of success under specific environmental conditions. Differences are recognized between wild and hatchery salmonids; differences include travel time and numbers of successful migrants, levels of smoltification, physiological condition and health, and subsequently adult returns. Rearing practices vary at the hatcheries and in the wild; a comparison of these differences and differences in juvenile and adult migrants will help identify factors that contribute to higher adult returns.

This project would expand regional knowledge of the biological basis of 1) the influence of life history and environment on juvenile fish condition, migration success, and survival to adult; 2) the incorporation of wild broodstock into production programs and its effect on survival; 3) juvenile condition by expanding the smolt condition database to include rearing, river, and environmental conditions; 4) continued development and field application of innovative methods to non-lethally monitor salmon to allow continued research under ESA restrictions; and 5) the technical assistance program to to coordinate interagency research to avoid duplication of effort and enhance information exchange.

Increasingly, other agencies have requested consultations with us to develop physiological monitoring programs (see Section 8c). We provide these agencies with the analytical capabilities to monitor physiological variables for adaptive management purposes. The research emphasis of these cooperating agencies has been to investigate different production strategies, such as natural rearing systems, acclimation before release, and altered temperature and feeding regimes. The physiological assessment that we provide gives the managers a measure of the potential success of their actions before the three to five years required for adult returns.

The scope of the project provides a central, organized program of response to regional requirements for continued monitoring and evaluation of juvenile salmon and steelhead. Demand for smolt evaluation capabilities is expected to continue in the region as long as Columbia basin agencies manage hatchery and wild salmon stocks. Research and methods will be needed to address specific management needs, including new indices

of smolt condition and health, adapted to Endangered Species Act restrictions. Results from the project will be evaluated by analysis and reporting of research data, and the successful application of methods to management requirements.

c. Relationships to other projects

The eleven year record of the Assessment of Smolt Condition for Travel Time Analysis in the Columbia River basin has resulted in acknowledgment of the Columbia River Research Laboratory as a resource for technical answers, assistance, and cooperation regarding smoltification and migration of juvenile salmon and steelhead. Continued participation in the following projects is anticipated.

Rock Island Evaluation, WDFW **Study of the Influence of Temperature on Precocity and Residualism in Wenatchee River Steelhead Smolts**

Hatcheries Program, WDFW **Survival Differences in Coho Salmon Reared under Semi-natural Conditions and Standard Conditions in a Hatchery**

Fish Management, WDFW **Cowlitz Falls Anadromous Fish Reintroduction Project**

Hatcheries Program, WDFW Snake River Laboratory
Stress in Acclimated versus Direct Stream Released Fish: Tucannon River Spring Chinook and Lyons Ferry Fall Chinook

Abernathy Salmon Culture Technology Center, USFWS
Effectiveness of beta-Glucans as Feed Additives For Increasing Disease Resistance and
Determination of the Seasonality of Mucus Lysozyme During Smoltification

Idaho Fishery Resource Office, USFWS **Evaluation of Fish Cultural Techniques at Dworshak National Fish Hatchery**

USGS-BRD, WFRC **Performance and Stock Productivity Impacts of Hatchery Supplementation**

USGS Oregon Cooperative Fishery Research Unit
Evaluation of Facilities for Collection, Bypass and Transportation of Outmigrating Chinook Salmon. U.S. Army Corp of Engineers funding

d. Project history (for ongoing projects)

Smolt indices provided by this project were used by the Fish Passage Center for real time information about migrating juveniles for management of the Water Budget. An eleven year record now exists of physiological indices for juvenile salmon and steelhead from

hatcheries and during the migration. The project has adapted to changing fish passage and production goals by modifying individual tasks and objectives. Objectives were designed to meet specific management goals or to determine physiological function of juvenile salmon during critical periods in their development. Methods developed by the project are now being used by other agencies and projects for the evaluation of health and condition during rearing, smoltification and migration. The methods have gained acceptance as tools to assess fish status, and many agencies request our help in evaluating their fish management strategies and the physiological condition of fish populations. Four non-lethal indices of smoltification have been developed by the project and two more are in development.

The methods have been applied in technical assistance to other projects to determine the level of smoltification: 1) in radio tagging studies to determine dam passage efficiencies; 2) in relationship to smolt migration patterns; 3) in assessing condition of migrants in a reintroduction project; 4) to determine the effects of rearing in Natures ponds; 5) to determine the effects of rearing temperatures on precocity and residualism; 6) to assess release strategies; and 7) to evaluate the effects of nutritionally enhanced feeds and modified feeding rates. The project has provided an understanding of smoltification and its importance to juvenile survival in an impounded river.

An example of the adaptive management inherent in this project is our ability to respond to changes in water management and the effects of those changes on smolts. In 1994, salmon managers began the spill program to provide an alternative passage route (i.e., non-turbine) for emigrating juvenile salmonids. Spill can cause increased gas supersaturation; it was necessary to monitor fish to ensure that the increased spill did not cause significant mortality. Within a very short time, this project developed, validated and instituted a gas bubble disease (GBD) monitoring program. In 1996, the GBD monitoring and research objectives became a separate BPA-funded project (BPA number 96-201). The monitoring was subsequently turned over to the Smolt Monitoring Program which is administered by the Fish Passage Center.

This project has monitored the biology of Columbia River salmon and steelhead for the past decade (Rondorf *et al.* 1989; Beeman *et al.* 1990, 1991; Maule *et al.* 1994; Schrock *et al.* 1998) as the Assessment of Smolt Condition for Travel Time Analysis (ASCTTA) project. The major goal of the project was to determine the physiological mechanisms of smoltification that contribute to faster migration rates. Rapid migration reduces the exposure time of juvenile fish to predation, disease, and environmental effects of the impounded river, and reduces the interactions of hatchery fish with wild and resident fish populations. The project provided real time information on smolt status to the Fish Passage Center for management of the Water Budget for flow augmentation. As water management has changed, the project emphasis shifted to investigating life history factors, in particular rearing conditions, that promote smoltification. The project objectives have been modified to include evaluation of new rearing methods at hatcheries, and monitoring of wild broodstock releases from hatcheries.

Non-lethal methods developed to determine smolt condition (Beeman *et al.* 1994, 1995; Schrock *et al.* 1994; Haner *et al.* 1995) allow continued research and monitoring under the restrictions of Endangered Species Act listings and decreasing adult returns.

In 1997, we began an evaluation of our 10-year database to determine variables of juvenile salmon life histories that are most predictive of adult returns. During 1997 we

also circulated a survey among our reference hatcheries to gather rearing information to incorporate into the comprehensive database. In 1998, we are expanding our database to include environmental measurements and are conducting multivariate analysis to compare wild and hatchery stocks, and salmonids under different environmental and rearing conditions.

We provide other Columbia basin agencies with the analytical capabilities to monitor physiological variables for adaptive management purposes (see Section 8c). Research emphasis has been to investigate different strategies, such as "Natures" rearing systems, acclimation before release, altered temperature, and modified feeding regimens. The goals of these studies have been to reduce residualism and precocity, and to produce mitigation and supplementation fish similar to their wild counterparts. The physiological assessment that we provide gives the managers a measure of the potential success of their actions before the three to five years required for adult returns. During 2000 we will continue to collaborate with other agencies; however, some tasks associated with developing non-invasive methods are still in progress.

Project reports and technical papers:

Beeman, J.W., D.W. Rondorf, J.C. Faler, M.E. Free, and P.V. Haner. 1990. Assessment of smolt condition for travel time analysis. Annual report 1989 (Contract DE-A179-87BP35245) to Bonneville Power Administration, Portland, Oregon.

Beeman, J.W., D.W. Rondorf, J.C. Faler, P.V. Haner, S.T. Sauter, and D.A. Venditti. 1991. Assessment of smolt condition for travel time analysis. Annual report 1990 (Contract DE-A179-87BP35245) to Bonneville Power Administration, Portland, Oregon.

Beeman, J.W., D.W. Rondorf, and M.E. Tilson. 1994. Assessing smoltification of juvenile spring chinook salmon (*Oncorhynchus tshawytscha*) using changes in body morphology. Canadian Journal of Fisheries and Aquatic Sciences 51:836-844.

Beeman, J.W., D.W. Rondorf, M.E. Tilson, and D.A. Venditti. 1995. A non-lethal measure of smolt status of juvenile steelhead based on body morphology. Transactions of the American Fishery Society 124:764-769.

Haner, P.V., J.C. Faler, R.M. Schrock, D.W. Rondorf, and A.G. Maule. 1995. Skin reflectance as a non-lethal measure of smoltification for juvenile salmonids. North American Journal of Fisheries Management 15:814-822

Maule, A.G., J.W. Beeman, R.M. Schrock, and J.V. Haner. 1994. Assessment of smolt condition for travel time analysis. Annual report 1991-1992. (Contract DE-A179-87BP35245) to Bonneville Power Administration, Portland, Oregon.

Maule, A.G., D.W. Rondorf, J. Beeman, and P. Haner. 1996. Incidence of *Renibacterium salmoninarum* infections in juvenile hatchery spring chinook salmon in the Columbia and Snake Rivers. Journal of Aquatic Animal Health 8:37-46.

Maule, A.G., R.M. Schrock, C. Slater, M.S. Fitzpatrick, and C.B. Schreck. 1996. Immune and endocrine responses of adult chinook salmon during freshwater immigration and sexual maturation. Fish and Shellfish Immunology 6:221-233.

Rondorf, D.W., J.W. Beeman, J.C. Faler, M.E. Free, and E.J. Wagner. 1989. Assessment of smolt condition for travel time analysis. Annual report 1988. (Contract DE-A179-87BP35245) to Bonneville Power Administration, Portland, Oregon.

Schrock, R.M., J.W. Beeman, D.W. Rondorf, and P.V. Haner. 1994. A microassay for gill sodium, potassium-activated ATPase in juvenile Pacific salmon. Transactions of the American Fisheries Society 123:223-229.

Schrock, R.M., J.W. Beeman, P.V. Haner, K.M. Hans, J.D. Hotchkiss, S.T. Sauter, S.P. VanderKooi, W.L. Gale, P.A. Petrusso, and A.G. Maule. 1998. Assessment of Smolt Condition for Travel Time Analysis: Project Review 1987-1997. Bonneville Power Administration Homepage Publication. 68 p.

Years underway: 11
Past costs: $4,085,122

e. Proposal objectives

Objective 1. Investigate effects of rearing and river conditions on physiology and migration success of salmon.

1a. A report with recommendations from individual hatchery reviews from the 15 hatcheries we monitored (1987-1998) during the past 10 years will be prepared and completed in 1998 and 1999.

1b. To evaluate the short term success of current altered hatchery practices the annual smolt evaluation results will be analyzed and reported.

1c. This task will be initiated if the opportunity to monitor wild and hatchery migrants becomes available through our cooperators or technical assistance program. The proposed budget does not allow for establishment of our own monitoring and sampling program.

1d. The success of this task depends on Task 1c being undertaken. A critical assumption is that there is a difference in smolt indices of wild and production fish as measured by the non-invasive methods we employ.

Objective 2. Maintain a comprehensive database of juvenile salmonid performance and adult survival.

2a. An annual update of the database will be completed with integration of environmental and physiological data from cooperative and technical assistance projects.

2b. A program of routine analysis of the updated database will be completed and results released.

Objective 3. Develop a monitoring program to evaluate in-river migration performance comparing wild and hatchery fish reared under modified conditions.

3a. Cooperate on multi-agency hatchery project by monitoring the migration physiology and performance of hatchery fish of wild broodstock origin.

3b. Promote the in-river physiological monitoring of stocks affected by changes in broodstock, rearing, transportation, or passage modifications.

Objective 4. Develop and evaluate indices of smolt condition and health for monitoring of endangered and threatened species.
4a. Determine seasonal mucus lysozyme profiles for wild and hatchery salmonids for direct application as an index of smolt condition and health.
4b. Determine correlation between gill ATPase activities and eye pigment ratios in smolts to validate eye pigment analysis as a replacement for invasive gill tissue sampling.

Objective 5. Provide technical assistance to cooperative agencies and BPA funded projects.
5a. Provide physiological assessment capabilities to basin agencies involved in salmonid management that lack the necessary laboratory facilities and staff.
5b. Provide for information exchange among smolt managers and researchers by providing an annual workshop forum.

f. Methods

Objective 1. The project smolt monitoring database (1987-1998) will be combined with data from hatcheries where we monitored smolt releases during the past 11 years. The comprehensive database will be analyzed using multivariate analyses to determine factors of fish condition (e.g., gill ATPase, condition factor, prevalence and severity of BKD) which contribute to adult survival as determined from coded-wire tag data and adult returns to the hatchery. Data, including information on stocks and adult spawners, facility design, water sources and temperatures, feed, disease management, raceway stocking densities, and release strategies, and river conditions (e.g., temperature, flow, spill) will be combined to identify factors that have influenced physiological measurements. Over fifty variables are included in the hatchery database and include records for all years sampled at each hatchery. The primary critical assumptions are that factors of salmon life history before they enter the ocean influence adult survival, and that the variables for which we have data are critical to salmon survival. We anticipate that most of the work under this task for individual hatcheries will be completed during 1999 and that project activities under Objectives 3 and 5 will be incorporated into the database as described in Objective 2. Anticipated reports are the project annual report, and a summary of participating Idaho hatchery data that has been requested with the accompanying database.

Objective 2. The database will be maintained with current information, and integrated with the database with the Meta-data National Biological Information Infrastructure (NBII) program of the U.S. Geological Survey and StreamNet. As information from technical assistance projects develops, the influence of factors beyond those in the project database on smolt performance will be included.

Objective 3. Specific tasks include review of the rearing data from the new reference hatchery, review of migration data from closely related stocks from the same area, projection of the migration timing and pattern of the stock based on the performance of related stocks, design of the tagging and sampling study with coordination with migration

managers, sampling and analysis, and cooperative interpretation of physiological and environmental data to determine the effect of wild broodstock and controlled growth rearing practices on the migration success of production fish. A critical assumption is that wild fish physiology, behavior, and performance characteristics will be maintained in the hatchery-reared wild stock, and that those attributes will be measurable during the migration as differences in smolt condition, health, and migration patterns and rates, as well as increased survival.

Objective 4. We have considerable data on gill ATPase and condition factor in wild fish; however, we have only preliminary information on mucus lysozyme and no visual pigment ratios in wild fish. We will be adapting accepted methods in fishery laboratory research to field monitoring and evaluation. Critical assumptions are that the patterns of change seen in mucus lysozyme and eye pigment ratios in hatchery and research populations will occur in wild juvenile migrants. Changes in eye pigments are known to occur during smoltification (Alexander *et al.* 1994) and we will be developing a novel application of fiber optic reflectance probe technology to replace the need to sample tissue to determine eye pigment ratios or gill ATPase activities. Results will be analyzed by multivariate analysis, and will be reported as a project report, with results being incorporated into the reference hatchery program report. We do not know the appropriate sample size for these physiological measurements because we do not know the variability to expect. As we gather data, we will conduct power analyses to ensure that sample size is adequate to detect biologically significant differences. Critical assumptions are that smolt condition and health are important to survival, and that changes in ratios of mucus lysozyme types, and in visual pigment ratios are indicative of fish condition and/or health. The proposed budget does not allow for establishment of our own marking program. We will use the expertise and results of local marking programs to determine the number of fish to be marked, and to estimate detection and recapture rates at downstream sample sites. A critical assumption is that there is a difference in smolt indices of wild and production fish as measured by the non-invasive methods we employ, and that the new rearing techniques will effect changes in the smolt physiology of hatchery released fish.

Objective 5. We have every indication that these requests for technical assistance will continue in 2000, and that the activities described in Objectives 1, 2, and 3, and development of non-invasive methods described in Objective 4 will increase our value to similar projects in the region. Critical assumptions are that the smolt indices we develop are applicable to field evaluations of juvenile migrants.

g. Facilities and equipment

The Columbia River Research Laboratory (CRRL) has three state-of-the-technology analytical laboratories totaling 1600 sq. ft. dedicated to enzymology, immunology and cell culture, and general physiology. In addition to standard equipment such as centrifuges, pH meters, and balances, the laboratories are equipped with VIS-UV and reflectance spectrophotometers, enzyme-linked-immunosorbent assay (ELISA) plate

readers, a flame photometer, and -80 C freezers. The lab is staffed with trained technicians and biologists proficient in these techniques with backgrounds in fishery genetics, immunology, physiology, and endocrinology. The 1500 sq. ft. wet lab facilities with 64 tanks are more than adequate to conduct any level of investigation into fish development or behavior, including studies on disease resistance, predator avoidance, thermal preference, osmoregulation, swimming performance and bioenergetics.

All of the laboratory equipment is linked to the CRRL computer network which services 80 users at CRRL and has 8 gigabytes of memory. Computer software available for data analyses includes SAS, Excel, rBase, Statgraphics, and a variety of other word processing and data management software. The CRRL has its own T-1 line for Internet access. The quality of the CRRL laboratory capability is indicated by our publications addressing physiological variables. Moreover, the fact that we have the equipment and expertise available, means that others in the region need not equip additional laboratories to obtain data about the health and development of fish of any species.

Field monitoring capabilities include 25 vessels and gear for electroshocking, radio telemetry, hydro acoustic, and in-river field sampling.

h. Budget

The proposed budget includes two full time fishery biologists, and part time allocations for the project leader and laboratory technician. Both the project leader and laboratory technician are shared with other projects at our facility. The two biologists share field sampling, laboratory analysis associated with method development, data analysis, interpretation and writing duties. The laboratory technician performs routine analysis associated with monitoring and technical assistance activities. Supplies are restricted to materials for field sampling, because technical assistance cooperators cover materials for laboratory activities. All materials estimates are based on project needs from previous years, and we have detailed and exacting records of those expenditures. We require a vehicle for the 6 months of field sampling, and accommodations during activities at hatcheries and in-river sampling sites.

Section 9. Key personnel

Alec G. Maule

Education

B.A., University of California, Riverside (Psychology) 1969
B.S., California Polytechnic University, San Luis Obispo (Natural Resource Management) 1979
M.S., Oregon State University (Fisheries Science) 1982
Ph.D., Oregon State University (Fisheries Science) 1989

Employment

Assistant Professor of Fisheries (Courtesy), OSU (1991-present)
Adjunct Associate Professor of Biology, Portland State University (1992-present)
Research Physiologist, USGS, BRD, Columbia River Res. Lab. (1991-present)

Publications (most recent 5 of 29)

Maule, A.G., and M.G. Mesa. 1994. Efficacy of electrofishing to assess plasma cortisol

concentration in juvenile chinook salmon passing hydroelectric dams on the Columbia River. North American Journal of Fisheries Management 14:334-339.

Maule, A.G., D. Rondorf, J. Beeman, and P. Haner. 1996. Incidence and severity of Renibacterium salmoninarum in spring chinook salmon in the Snake and Columbia rivers. Journal of Aquatic Animal Health 8: 37-46. (Finalist for Best Paper in the journal for 1996).

Haner, P. V., J. C. Faler, R. M. Schrock. D. W. Rondorf, and A. G. Maule. 1996. Skin reflectance as a non-lethal measure of smoltification for juvenile salmonids. North American Journal of Fish Management.

Maule, A.G., R. M. Schrock, C. Slater, M. S. Fitzpatrick, and C. B. Schreck. 1996. Immune and endocrine responses of adult spring chinook salmon during freshwater migration and sexual maturation. Fish and Shellfish Immunology 6:221-233.

Beeman, J.W., P.V. Haner, and A.G. Maule. 1998. A new miniature pressure-sensitive radio transmitter. North American Journal of Fisheries Management.

Professional Service

I am currently an Associate Editor for the Journal of Aquatic Animal Health

American Fisheries Society

Fish Health Section

Snieszko Graduate Award Committee (Chair) 1989-91

Physiology Section (Charter member)

Vice Pres., Pres.-elect, Pres., Past-President 1993-97

Awards Committee (Chair) 1997-98

Oregon Chapter AFS Legislative Committee 1983-84

Annual Meeting, Program Committee 1985-93

Director of Internal Committees 1989-90

Pres.-elect/Pres./Past Pres. 1990-93

Regional Committees Dissolved Gas Team 1995 -present.

Grand Coulee Dam Dissolved Gas Committee (Chair) 1996 -present.

Robin M. Schrock

Education

M.S., University of Wisconsin, Stevens Point, WI (Natural Resource Management - Fisheries) 1986

B.A., Portland State University, Portland, OR (Biology and German) 1982

Diploma, School for Medical Technologists, Bern, Switzerland 1975

Experience

Research Fishery Biologist, USGS-Biological Resources Division, Columbia River Research Laboratory and Marrowstone Marine Station. 1987 to present.

Publications

Schrock, R.M., J.W. Beeman, D.W. Rondorf, and P.V. Haner. 1994. A microassay for gill sodium, potassium-activated ATPase in juvenile Pacific salmonids. Transactions of the American Fisheries Society 123:223-229.

Haner, P.V., J.C. Faler, R.M. Schrock, D.W. Rondorf, and A.G. Maule. 1995.

Skin reflectance as a non-lethal measure of smoltification for juvenile salmonids. North American Journal of Fisheries Management 15:814-822.

Maule, A.G., R.M. Schrock, C. Slater, M.S. Fitzpatrick, and C.B. Schreck. 1996. Immune and endocrine responses of adult spring chinook salmon during freshwater migration and sexual maturation. Fish and Shellfish Immunology 6:221-233.

Beckman, B.R., W.W. Dickhoff, W.S. Zaugg, C. Sharpe, S. Hirtzel, R.M. Schrock, D.A. Larsen, R.D. Ewing, A. Palmisano, C.B. Schreck, and C.V.W. Mahnken. 1999. Growth, smoltification, and smolt-to-adult return of spring chinook salmon (*Oncorhynchus tshawytscha*) from hatcheries on the Deschutes River, Oregon. Transactions of the American Fisheries Society, accepted for publication.

Reports

Schrock, R.M., J.W. Beeman, P.V. Haner, K.M. Hans, J.D. Hotchkiss, S.T. Sauter, S.P. VanderKooi, W.L. Gale, P.A. Petrusso, and A.G. Mauls. 1998. Assessment of Smolt Condition for Travel Time Analysis: Project Review 1987-1997. Bonneville Power Administration Homepage publication, 68 pp.

Schrock, R.M. 1994. Quantifying non-specific disease response in adult and juvenile salmon. Proceedings of International Fish Physiology Symposium, University of British Columbia, Victoria, Canada. July 1994:476-480.

Maule, A.G., J.W. Beeman, R.M. Schrock, and P.V. Haner. 1994. Assessment of smolt condition for travel time analysis. Annual report 1991 - 1992. Prepared for the Bonneville Power Administration.

Schrock, R.M. and J.W. Beeman, 1993. Microassay for sodium, potassium-activated ATPase in juvenile salmon. Research Information Bulletin No. 67. U.S. Fish and Wildlife Service.

Zaugg, W.S., W.W. Dickhoff, B.R. Beckman, C.V.W. Mahnken, G.A. Winans, T.W. Newcomb, C.B. Schreck, A.N. Palmisano, R.M. Schrock, G.A. Wedemeyer, R.D. Ewing, and C.W. Hopley, 1991. Smolt quality assessment of spring chinook salmon. Annual report to Bonneville Power Administration.

Palmisano, A.N., R.M. Schrock, W.T. Yasutake, and G.A. Wedemeyer. 1990. Tolerance of juvenile fall chinook salmon to selenium exposure from water and the food chain: impacts on smoltification and early marine survival. U.S.B.O.R. and U.S.F.W.S. report.

Section 10. Information/technology transfer

Research results will be published in peer-reviewed journals. Annual reports will be prepared, and reports written with cooperating agencies. Sections of the database pertaining to specific reference hatcheries will be released to the cooperating agencies and hatcheries upon request. In the case of participation in production level research projects, we will publish joint annual reports and peer reviewed articles. The database will be available through the Coordinated Information System, the USGS Meta-data archive system, and will be available to StreamNet.

Congratulations!