PART I - ADMINISTRATIVE

Section 1. General administrative information

Title of project

Effects Of Supersaturated Water On Reproductive Success Of Adult Salmonids

BPA project number: 20067
Contract renewal date (mm/yyyy): ☐ **Multiple actions?**

Business name of agency, institution or organization requesting funding
U.S. Geological Survey, Western Fisheries Research Center, 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
5.6.E.1

FWS/NMFS Biological Opinion Number(s) which this project addresses
BIOP RPE# 2, 6

Other planning document references
Independent Scientific Advisory Board (ISAB Page 2, 1998), Dissolved Gas Team (DGT page 17, 1998)

Short description
This study will determine in-situ exposures of adult salmonids to total dissolved gas supersaturation (TDGS) and conduct laboratory assays to determine the effects of TDGS exposure on their reproductive performance.

Target species
Spring/summer chinook salmon, steelhead and sockeye salmon

Section 2. Sorting and evaluation

Subbasin
Mainstem

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

Other dependent or critically-related projects

Project #	Project title/description	Nature of relationship
9300802	Symptoms of gas bubble trauma induced in salmon (Oncorhynchus spp.) by ...	We will determine TDGS exposure and reproductive effects, they monitor adults for gbt signs
	Migration of adult chinook salmon and steelhead past dams and through ...	Cooperative use of equipment and study fish
	The above project is funded by USACE, conducted by Ted Bjornn of U of Idaho	See Section 8c for details.

Section 4. Objectives, tasks and schedules

Past accomplishments

Year	Accomplishment	Met biological objectives?
	new study	

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Determine in-situ exposure of adult salmonids to total dissolved gas supersaturation (TDGS).	a	Determine in-situ migration depths of adult salmonids in a Columbia River reservoir.
		b	Determine in-situ migration depths of adult salmonids in the near-dam areas of

			Columbia/Snake river dams.
2	Determine if exposure to TDGS affects reproductive performance.	a	Conduct laboratory experiments to determine the effects of TDGS exposure on reproductive performance of adult salmonids.

Objective schedules and costs

Obj #	Start date mm/yyyy	End date mm/yyyy	Measureable biological objective(s)	Milestone	FY2000 Cost %
1	1/2000	4/2003	In-situ exposure histories of adult salmonids		90.00%
2	2/2000	4/2003	Quantitative assessment of TDGS effect on reproductive performance		10.00%
				Total	100.00%

Schedule constraints
Costs may be reduced substantially by reducing species examined

Completion date
4/2003

Section 5. Budget

FY99 project budget (BPA obligated):

FY2000 budget by line item

Item	Note	% of total	FY2000
Personnel	base salaries plus overtime	%40	341,643
Fringe benefits		%7	64,247
Supplies, materials, non-expendable property		%2	17,500
Operations & maintenance		%8	68,380
Capital acquisitions or improvements (e.g. land, buildings, major equip.)	telemetry receiver upgrades	%0	4,500
NEPA costs			0
Construction-related support			0
PIT tags	# of tags: 200 RADIO TAGS	%14	120,000
Travel		%0	8,000
Indirect costs		%25	215,623
Subcontractor			0
Other			0
TOTAL BPA FY2000 BUDGET REQUEST			$839,893

Cost sharing

Organization	Item or service provided	% total project cost (incl. BPA)	Amount ($)
None			
		Total project cost (including BPA portion)	$839,893

Outyear costs

	FY2001	FY02	FY03	FY04
Total budget	$848,533	$872,697		

Section 6. References

Watershed?	Reference
☐	Beeman, J. W., P. V. Haner, and A. G. Maule. 1998. Evaluation of a new miniature pressure-sensitive radio transmitter. North American Journal of Fisheries Management 18:458-464.
☐	Beiningen, K. T. and W. J Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1986. Transactions of the American Fisheries Society 99:664-671.
☐	Campbell, P.M., T.G. Pottinger, and J.P. Sumpter. 1992. Stress reduces the quality of gametes produced by rainbow trout. Biology of Reproduction 47:1140-1150.
☐	Carragher, J.A., and J.P. Sumpter. 1990. The effect of cortisol on the secretion of sex steroids from cultured ovarian follicles of rainbow trout. General and Comparative Endocrinology 77:403-407
☐	Carragher, J.A., and N.W. Pankhurst. 1991. Stress and reproduction in a commercially important marine fish, Pagrus auratus (Sparidae). Pages 253-255 in A.P. Scott, J.P. Sumpter, D.E. Kime, and M. Rolfe, editors. Reproductive physiology of fish 1991.
☐	Carragher, J.A., J.P. Sumpter, T.G. Pottinger, and A.D. Pickering. 1989. The deleterious effects of cortisol implantation on reproductive function in two species of trout, Salmo trutta L. and Salmo gairdneri Richardson. General and Comparative Endocrin
☐	Colt, J. 1984. Computation of dissolved gas concentrations in water as functions of temperature, salinity, and pressure. American Fisheries Society Special Publication 14.
☐	Contreras-Sánchez, W. M. 1995. Effects of stress on the reproductive performance and physiology of rainbow trout (Oncorhynchus mykiss). Master's thesis. Oregon State University, Corvallis, Oregon.
☐	CRITFC (Columbia River Intertribal Fish Commission). 1995. Tribal Restoration Plan: Wy-Kan-Ush-Mi Wa-Kish-Wit: The Columbia River anadromous fish restoration plan of the Nez Perce, Umatilla, Warm Springs, and Yakama tribes. Columbia Riv
☐	DGT (Dissolved Gas Team). 1998. Draft Columbia Basin Fish and Wildlife Authority dissolved gas research plan. Unpublished.
☐	Ebel. W. J. 1971. Dissolved nitrogen concentrations in the Columbia and Snake rivers in 1970 and their effect on chinook salmon and steelhead trout. NOAA Technical Report NMFS SSRF-646.
☐	Ebel, W. J., H. L. Raymond, G. E. Monan, W. E. Farr, and G. K. Tanonaka. 1975. Effect of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia rivers. Report of the National Marine Fisheries Service, Se

☐	Gorham, F. P. 1901. The gas bubble disease of fish and its causes. Bulletin of the United States Fish Commission (1899) 19:33-37.
☐	ISAB (Independent Scientific Advisory Board). 1998. Review of the U.S. Army Corps of Engineers' Capital Construction Program. Part II: Dissolved Gas Abatement Program. ISAB Report 98-8 for the Northwest Power Planning Council and the National Marine F
☐	Melotti, P., A. Roncarati, E. Garella, O. Carnevali, G. Mosconi and A. Polzonetti-Magni. 1992. Effects of handling and capture stress on plasma glucose, cortisol and androgen levels in brown trout, Salmo trutta morpha fario. Journal of Applied Ichthyol
☐	Mesa, M. M. and J. J. Warren. 1997. Predator avoidance ability of juvenile chinook salmon (Oncorhynchus tshawytscha) subjected to sublethal exposures of gas-supersaturated water. Canadian Journal of Fisheries and Aquatic Sciences 54:757-764.
☐	Montgomery, J. C. and C. D. Becker. 1980. Gas bubble disease in smallmouth bass and northern squawfish form the Snake and Columbia rivers. Transactions of the American Fisheries Society 109:734-736.
☐	Muir, W. D., S. G. Smith, K. W. McIntyre, and B. P. Sanford. 1998. Project survival of juvenile salmonids passing through the bypass system, turbines, and spillways with and without flow deflectors at Little Goose Dam, 1997. Prepared by National Marine
☐	Nebeker, A. V., D. G. Stevens, and R. K. Stroud. 1976. Effects of air-supersaturated water on adult sockeye salmon (Oncorhynchus nerka). Journal of the Fisheries Research Board of Canada 33:2629-2633.
☐	NMFS (National Marine Fisheries Service). 1995. Endangered Species Act – Section 7 Consultation. Biological Opinion. Reinitiation of Consultation on 1994 – 1998 Operation of the Federal Columbia River Power System and Juvenile Transportation Program in
☐	NPPC (Northwest Power Planning Council). 1995. 1994 Columbia River Basin fish and wildlife program. Prepared by the Northwest Power Planning Council, Portland, Oregon, document 94-55.
☐	Pankhurst, N. W., and M. Dedual. 1994. Effects of capture and recovery on plasma levels of cortisol, lactate and gonadal steroids in a natural population of rainbow trout. Journal of Fish Biology 45:1013-1025.
☐	Pickering, A.D., T.G. Pottinger, J. Carragher, and J.P. Sumpter. 1987. The effects of acute and chronic stress on the levels of reproductive hormones in the plasma of mature male brown trout, Salmo trutta L. General and Comparative Endocrinology 68:249
☐	Sumpter, J.P., J.F. Carragher, T.G. Pottinger, and A.D. Pickering. 1987. Interaction of stress and reproduction in trout. Pages 299-302 in D.R. Idler, L.W. Crim, and J.M. Walsh, editors. Reproductive Physiology of Fish 1987. St. Johns: Memorial Unive
☐	Weitkamp, D. E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.
☐	Wendelaar-Bonga, S. E. 1997. The stress response in fish. Physiological Reviews 77:591-625.
☐	Westgard, R. L. 1976. Physical and biological aspects of gas-bubble disease in impounded adult chinook salmon at McNary spawning channel. Transactions of the American Fisheries Society 93:306-309.
☐	

PART II - NARRATIVE

Section 7. Abstract

This project has two goals. They are to determine the *in-situ* exposure of adult salmon to total dissolved gas supersaturation (TDGS) and determine if exposure to TDGS affects their reproductive performance. Exposure to TDGS has been shown to cause direct and sub-lethal mortality in salmonids (see Section 7a, below). These goals are associated with the Columbia Basin Fish and Wildlife Program and NMFS

Biological Opinion through sections addressing improvements in juvenile salmonid survival through increased use of spill to pass fish over dams and the impacts of increased TDGS due to this action (refer to page 1 for specific measures). We propose to investigate the possibility that increases in survival achieved by passing juvenile salmonids via increased spill are accompanied by deleterious effects on adults.

The first goal benefits fish by determining the extent of hydrostatic compensation during adult migration. Hydrostatic compensation reduces the exposure aquatic animals receive in waters with TDGS. This can compensate for about 10% of TDGS per meter of depth. The vertical and horizontal distributions of adult salmon are needed to assess their exposure to TDGS and risk of gas bubble disease, a potentially-lethal condition analogous to "the bends" of human divers. We will collect this information via telemetry using depth-reporting transmitters. The second goal will determine if exposures to TDGS impair reproduction of salmon. Together, the goals will enable us to determine what, if any, exposure is deleterious to reproduction and determine if adult salmon receive such exposures in the Columbia River.

Section 8. Project description

a. Technical and/or scientific background

Information about the effects of exposure to total dissolved gas supersaturation (TDGS) on the reproductive success of fish in the Columbia and Snake rivers is needed. The main source of TDGS in the Columbia and Snake rivers is spill at dams. Exposure to TDGS can cause gas bubble trauma (GBT) in aquatic animals. This trauma is analogous to "the bends" of human divers. Gas bubble trauma has been shown to affect animals via direct impairment or death due to gas emboli in the tissues and vasculature, and through sub-lethal effects such as increased susceptibility to predators (Westgard 1976, Weitkamp and Katz 1980, Mesa et al. 1997).

Total dissolved gas concentrations in the Columbia and Snake rivers have recently been elevated due to involuntary spill from high spring runoff and voluntary spill used as a method to pass juvenile salmonids over dams. The voluntary spill program is based on data indicating passage survival is greatest in juvenile salmonids passing via spill than via turbine or bypass routes (Muir et al. 1998). The goal of the voluntary spill program is to reap the benefits of increased fish passage survival without losing those benefits via mortality due to exposure to TDGS.

Many studies have been conducted to assess the direct and sub-lethal effects of TDGS exposure on fish. Descriptions of significant acute effects of GBT in fish have been reported, but little is known about the sub-lethal effects in adult salmonids. Studies describing signs and direct mortality of adult salmonids exposed to TDGS are common in the literature (Gorham 1901, Beiningen and Ebel 1970, Ebel 1971, Nebeker et al. 1976). Westgard (1964) found a nearly 15-fold increase in pre-spawning mortality in adult chinook salmon exposed to TDGS in a spawning channel near McNary Dam. He also reported sub-lethal effects in fish blinded from exposure to TDGS including females that did not dig redds and males that were unable to successfully cover eggs with milt.

There is evidence that sub-lethal effects of exposure to TDGS could affect the reproductive performance of adult salmonids. Montgomery and Becker (1980) reported intra-vascular bubbles in ovarian arteries of adult smallmouth bass exposed to TDGS in the Columbia River; these bubbles could reduce or eliminate the blood supply to developing eggs and affect reproductive success. It has been shown that changes in water quality, such as temperature, water hardness, and dissolved oxygen, can cause a stress response in fish (see review: Wendelaar-Bonga, 1997), so it is reasonable to assume that exposure to TDGS will result in stress responses in adult salmon.

Studies have also demonstrated that stress can alter levels of reproductive hormones in fish (Picketing et al. 1987; Craggier et al. 1989; Craggier and Pankhurst 1991; Melotti et al. 1992; Pankhurst and Dedual 1994). Cortisol, the corticosteroid hormone secreted by fish in response to a variety of environmental stressors, has been shown to inhibit production of estradiol and testosterone by ovarian follicles of rainbow and brown trout (Sumpter et al. 1987; Craggier and Sumpter 1990). Campbell et al. (1992) reported that exposure of female hatchery rainbow trout to acute stress resulted in smaller egg size, delayed ovulation, and lower survival of larvae compared to unstressed fish. Thus, there are a variety of ways TDGS may affect reproductive performance of adult salmon, yet nothing is known about what, if any, effects may be at work in fish exposed to TDGS in the Columbia River.

We propose to conduct a study to 1) determine the *in-situ* exposure of adult salmonids to TDGS and 2) determine if TDGS exposure affects reproductive performance of salmon. Results from this study will broaden the understanding of the effects of TDGS exposure on adult salmonids, provide a quantitative description of the *in-situ* TDGS exposure of adult salmonids, and determine if TDGS exposure affects their reproductive performance.

b. Rationale and significance to Regional Programs

The NMFS Biological Opinion (NMFS 1995), the Columbia River Basin Fish and Wildlife Program (NPPC 1995), and the Tribal Restoration Plan (CRITFC 1995) have recommended the implementation of a spill program at the federal hydroelectric projects designed to achieve an >80% fish passage efficiency (FPE) objective. To achieve the FPE, fish must pass through a bypass system or over the spillway. As noted in the NMFS Biological Opinion in section IV.A.2.d (NMFS 1995) dissolved gas levels increase during spill as water passes over the spillway and plunges to the tailrace. Although numerous studies have been initiated to investigate the effects of TDGS on juvenile fish, information pertaining to adult salmonids is limited (ISAB 1998). Thus, to insure that benefits of spill for juvenile fish are not compromised by negatively impacting adult migrants, further research is necessary to investigate the potentially lethal and sub-lethal effects of TDGS on adult salmonids.

Fishery agencies, research groups and recovery plans have recognized the need for additional GBT studies that specifically address adult salmonids. Section 5.6E.1 of the Columbia River Basin Fish and Wildlife Program request that studies focus on the relationship between "supersaturation and its effects on salmon and steelhead passing…adult ladders, reservoirs, and other mechanisms" (NPPC 1995). More recently, the Independent Scientific Advisory Board noted that critical studies were needed to investigate the "depth distribution of…adult salmonids" and to study "gas bubble trauma and its critical physiological, behavioral, and reproductive effects in migrating adult salmonids" (ISAB, page 2, 1998). In concurrence with the ISAB, the Dissolved Gas Team (DGT) also recognized the need for additional adult GBT research in the Columbia Basin (DGT, page 15, 1998).

c. Relationships to other projects

This project is related to three on-going projects. The first is BPA project number 9602100, "Gas bubble disease and monitoring of juvenile salmonids", which we began in 1996. The nature of this relationship is one of common methodology and researchers, as we will use similar methods to collect data from radio-tagged fish and examine fish in laboratory studies for signs of GBT. The second relationship is with two US Army Corps of Engineers projects entitled "Migration of adult chinook salmon and steelhead past dams and through reservoirs in the Lower Snake River and into tributaries" and "Evaluation of adult salmon , steelhead, and lamprey migrations past dams and through reservoirs in the lower Columbia River and into tributaries", conducted by Dr. Ted Bjornn at the University of Idaho. There is a good opportunity for cooperation between our studies. The cooperation could range from their fixed telemetry equipment detecting our tagged fish passing dams, to that plus their personnel substituting our depth-sensitive radio tags for some of their standard radio tags, thereby reducing the combined need for study fish. The cooperation between our studies is not paramount to completion of our study, as the main thrust of our use of telemetry will be collecting data from fish in reservoirs rather than in fish ladders. However, cooperation between the studies is required for the completion of Objective 1, Task b.

d. Project history (for ongoing projects)

This is a new study.

e. Proposal objectives

1. Determine *in-situ* exposure of adult salmonids to total dissolved gas supersaturation (TDGS) in a the Columbia River.

This objective is a field study of fish distribution based on radio telemetry. The outcome of this objective will be a database of repeated measures from individuals including date, time, fish depth, TDG, water temperature, water depth, and spatial location. Results will be used to determine the extent of hydrostatic compensation and the reduction in TDGS exposure it affords adult salmonids. These data can be used to determine if exposures used in Objective 2 reflect exposures encountered in the river. *The cost of Objective 1 can be reduced substantially by reducing the number of species studied.*

Hypothesis A: Immigrating adult salmonids do not adjust their migration depth to compensate for high TDGS.

Assumption A1: Tag and tracking procedures do not affect fish behavior.
Assumption A2: Data from radio tags can be received at depths of adult fish.
Assumption A3: Fish will encounter water with TDGS in at least one year of study.
Assumption A4: Data from tagged fish can be collected with equipment used by Ted Bjornn's study.
Assumption A5: Life of depth tags will be sufficient so they may be substituted for standard radio tags used by Ted Bjornn's study.

2. Determine the effects of TDGS exposure on the reproductive performance of adult salmonids.

Hypothesis B: Exposure to TDGS does not affect reproductive performance of salmon.

Assumption B1: Changes in reproductive performance occur and can be measured.
Assumption B2: Groups of adult salmon can be exposed to TDGS until the LT20 and subsequently survive to time of spawning.

f. Methods

Objective 1. Determine *in-situ* exposure of adult salmonids to total dissolved gas supersaturation (TDGS). *The cost of Objective 1 can be reduced substantially by reducing the number of species studied.*

Task A will be to determine the *in-situ* exposures of adult salmonids to TDGS during their spring migration. Methods similar to those used in BPA project 9602100,"Gas bubble disease research and monitoring of juvenile salmonids", will be used to collect data from radio-tagged adult fish. We have successfully developed and used these methods on juvenile chinook salmon and steelhead since 1996. Several modifications will be required to adapt these methods to use with adult fish. These include the use of a larger depth-reporting radio transmitter, use of a transmitter compatible with existing telemetry equipment at mainstem dams as part of US Army Corps of Engineers project "Evaluation of adult salmon, steelhead, lamprey migration past dams and through reservoirs in the lower Columbia River and into tributaries" (University of Idaho, Ted Bjornn), and the possibility of alternative tag attachment methods (i.e., gastric or external rather than surgical implantation). These modifications are generally minor changes to established protocols.

We believe we can meet the assumptions required for completion of this Objective (Hypothesis A, Section 8e). We have successfully completed this type of research on juvenile salmonids, which presented unique problems due to the small size of the radio transmitter. Larger transmitters used in adult salmonids will have improved range, resulting in larger detection distances and greater reception at depth; the technical assumptions (Assumptions A1 and A2) are achievable. Assumption A3, dependence on water with TDGS, is also achievable, either through high runoff and involuntary spill, or via the current use of voluntary spill to pass juvenile salmonids. Assumptions A4 and A5 are technically feasible, assuming cooperation with the COE study. There are tag life considerations that may need to be overcome if depth tags are to be substituted for some of the standard radio tags they are currently using (Ken Tolotti, University of Idaho, personal communication). However, this is not insurmountable in a tag of this size.

We will use a tracking protocol designed to maximize the number of repeated contacts of individuals, as this is the strength of this technology. Data will be collected from tagged fish via boat-mounted gear. We will collect data from as many fish as possible at one-hour intervals; each of two vessels should be able to track 1-3 fish per release in this manner. A total of about 200 fish will be tagged in each year, including about 50 spring/summer chinook salmon, 50 sockeye, and 100 steelhead, depending on passage timing at Bonneville Dam. Fish will be tagged and released from mid-April until late September. This procedure will result in a depth and TDGS exposure history from each fish consisting of data once each hour from release to passage at Bonneville Dam, or the dam upstream of the release site, depending on specific study design. Data collected from each fish will be maximized by restricting collection to the river pool immediately upstream of the release site. For example, if fish were released at Bonneville Dam, we would collect data under this Objective from the release site up to the boat restricted zone in the tailrace of The Dalles Dam. We will collect data on fish location based on GPS, fish depth, TDGS and water temperature at each hourly contact.

We will also record fish depths once per minute during several 15-minute time periods each day. This data will be collected from one fish located from each boat near the times of sunrise, sunset, noon, and midnight. The boats will remain about 50-200 m from the fish while collecting this data to avoid affecting fish behavior. Fish depths and water temperature will be the only data collected during these periods. This will provide fine-scale information about the variability in fish depths.

The probability of detecting each individual will be partially dependent on their depth due to the attenuation of radio signals in water. This limitation is due to the physical properties of radio waves. Tracking protocols were designed in 1996 such that the distances between boat tracks while searching for tagged fish were near enough to permit detection of fish at depths near the lower limit of detection based on Beeman et al. (1998). We will determine detection distances at various water depths prior to releasing fish so that appropriate tracking protocols can be developed with the larger tag. All data will be added to a geographical information system (GIS) database.

Task B will serve to collect detailed information about the vertical and horizontal distribution of tagged fish as they approach and pass dams on the Columbia and Snake rivers as well as an exit station to indicate when the fish have left the mobile-tracking study area. This system of automated receivers is part of the COE study by Ted Bjornn of the University of Idaho. Their cooperation will be required to gather this data.

The equipment mounted at the dams by The University of Idaho generally consists of data-logging telemetry receivers and antennas. They are placed to collect data from yagi (aerial) antennas 1-3 kilometers (km) below the dam and several aerial and underwater antennas along the fish ladder. Their configuration is designed to detect tagged fish entering the area near the dam tailrace, approaching the fish ladder, and passing the dam. They have equipment at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams.

Data collected will be tested for normality prior to statistical analysis to determine whether parametric or non-parametric analyses are appropriate. Previous study indicates most depth data is non-parametric. The depths of individuals will be used to determine the percent of time each individual and all fish combined spent above and below the compensation depth in the reservoir and in the near-dam areas. The compensation depth will be determined from TDGS data collected at each fish contact. The effects of hydrostatic compensation will be calculated as 9.6% of ambient TDG per meter of depth, according to Colt (1984). Measures of central tendency and associated confidence limits will be calculated from the depths of each fish. Correlations between fish depth, TDGS, and other factors will be examined for statistical significance. Statistical comparisons of the depths and exposures between species will be made.

Depth histories and TDGS exposures will be compiled for each individual and for all individuals combined by species with reference to the time from their release. The uncompensated TDG, which is the effective TDG exposure after consideration of depth, will be determined. This will enable researchers determine if the laboratory treatments reflect exposures fish receive under field conditions and to assess the relative risk of adult salmon to any reproductive effects found during laboratory studies of Objective 2.

Objective 2. Conduct laboratory experiments to determine the effects of TDGS exposure on the reproductive performance of adult salmonids.

We believe our assumptions (Hypothesis B, section 8c) can be met. Assumption B1, that changes in reproductive performance can be measured, has been validated by Contreras-Sanchez (1995) working with rainbow trout. He was able to show changes in reproductive performance after exposures to stress. Therefore, the work we propose under Objective 2 is based upon methods described by Contreras-Sanchez (1995). We believe we can satisfy Assumption B2, adult survival from treatment to spawning, by avoiding water temperatures above 15C and by using low-density rearing in the laboratory. Ebel et al. (1975) described work of Bouck et al. (1970), who noted a direct relationship between post-capture mortality of adult sockeye salmon and water temperature. They reported 19% mortality at 10C in 44 d, 32% mortality at 16C (ambient) in 44 d, and 100% mortality at 20C and 22.5C in 31 d and 12 d, respectively. We will attempt to reduce holding mortality by conducting our experiments with spring chinook salmon (Year 1) at 12C and experiments with sockeye at no more than 15C. Water temperatures in experiments with steelhead will be higher than 15C (e.g., 20C) as their migration occurs later and in warmer water than the other species.

Adult salmon from a lower-Columbia River fish hatchery (e.g., Little White Salmon, Spring Creek, or Abernathy) will be used for this Objective. Early-run fish will be transported to our laboratory for exposure to TDGS. Fish will be stocked into large, circular tanks that will receive water of ambient temperature near 100% TDGS for recovery from transport. There will be two basic treatments, TDGS exposed at three TDGS levels and controls, with two replicate tanks for each treatment.

Treatments will be TDGS exposures at 110%, 120%, and 130% until the time needed to result in a 20% mortality (i.e., LT20). Water temperatures will be chosen depending on general river temperatures encountered by the study species during their migration. For example, experiments with spring chinook salmon would be carried out at 12C, whereas temperatures above 15C may be more appropriate for steelhead. A maximum of 15C will be used with sockeye to limit holding mortality as described above.

The experiments at each TDGS level will be conducted with 10 fish in each of two TDGS treatment tanks and each of two control tanks. Treatments will begin when the fish are approximately half way between the date of arrival and the estimated date of spawning (as indicated by hatchery records). One species will be tested in each year. We will begin with chinook salmon in year 2000. This Objective will require 40 adult salmon for each treatment for a total requirement of 120 fish per year.

When fish are sexually mature, we will spawn all treatment and control fish at our laboratory using standard aquaculture procedures. Fertilized, water-hardened eggs will be transferred to the a hatchery for incubation and hatching. We will use a single, pooled sperm sample from several males to fertilize the eggs. We will record female weight, total length, weight of the eggs, and ovarian fluid weight. Eggs from each female will be incubated in separate chambers. Using sub-samples of eggs from each female, we will weigh and measure the diameter of each egg in the sub-sample (ca. 50-100 eggs per female). The gonadosomatic index, absolute and relative fecundity, percent of fertilized eggs, and the percent of eggs hatched from each female will be determined. We will cease monitoring the fish when they are moved from the incubation trays shortly after hatching.

We will use analysis of variance (ANOVA) as a check on randomization for a similar distribution of fish size throughout all tanks. Data from within each tank will be pooled for analysis, and we will check for tank effects between replicates using t-tests, or, if data distribution warrants it, their non-parametric equivalents. For all pairwise comparisons between treatments, we will use t-tests or non-parametric equivalents. We will use correlation and regression analyses to assess the relation between egg and fry size, and egg size and mortality and compare the relations between treatments. The level of significance for all tests will be 0.05.

g. Facilities and equipment

The Columbia River Research Laboratory has facilities and equipment adequate for completion of this project. Incubating and hatching eggs will be performed at an established fish hatchery. Most special equipment required for this project is owned by the USGS, or was purchased by BPA during previous years of other studies. The laboratory has wetlab, drylab, office, boat, vehicle, and computer facilities available for this project.

h. Budget

The budget for this project is dominated by costs associated with Objective 1. This is due to monitoring in-situ TDGS exposures of three species of salmon each year and the associated long period of monitoring fish. The cost of Objective 1 can be reduced substantially by reducing the number of species studied each year. For example, limiting research to one species per year would reduce radio tags required from 200 to about 50, saving $90,000 per year on tags alone. Further cost reductions would also be realized through a shorter field season. Data could still be collected from the three species, but it would then be done with a different species each year. The advantage of this is cost reduction. The disadvantage is collecting data from each species under different environmental conditions.

Section 9. Key personnel

Key personnel in this project include Dr. Alec Maule (project leader, 0.5 FTE), John Beeman (principal investigator of field studies, 0.5 FTE), and Matt Mesa (principal investigator of laboratory studies, 0.5 FTE). Dr. Maule oversees research under each project objective, while Mr. Beeman and Mr. Mesa participate in and direct field and laboratory research. Brief resumes are attached.

Resume of 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. 1995. Skin reflectance as a non-lethal measure of smoltification for juvenile salmonids. North American Journal of Fish 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.

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-Pres. 1993-97

Awards Committee (Chair) 1997-98

Oregon Chapter

AFS Legislative Committee 1983-84

AFS Oregon 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.

Resume of John W. Beeman

Present Position: Research Fishery Biologist
U. S. Geological Survey
Northwest Biological Science Center, Columbia River Research Laboratory
Cook-Underwood Road
Cook, Washington 98605

Current assignment: Team leader of research project addressing the effects of dissolved gas supersaturation on juvenile salmonids.

Education:

Degree/Course	Date	School
Bachelor of Science	1981	Saint John's University
Master of Arts	1984	University of South Dakota

Experience:

Research Fishery Biologist, Columbia River Research Laboratory, Cook, WA.

Laboratory Technician, heavy metals analysis, University of South Dakota/US Army Corps of Engineers

Laboratory Technician, zooplankton analysis, University of South Dakota/South Dakota Department of Game, Fish and Parks

Expertise:

Pen-rearing of juvenile salmonids

Juvenile salmonid seaward-migration and smoltification

Non-lethal measures of smoltification assessment; radio-telemetry of juvenile salmonids

Five most recent 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.

Beeman, J. W. and J. F. Novotny. 1995. Adult production of fall chinook salmon reared in net-pens in backwaters of the Columbia River. American Fisheries Society Symposium 15:261-266.

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 Fisheries Society 124:764-769.

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.

Beeman, J. W., P. V. Haner, and A. G. Maule. 1998. Evaluation of a new miniature pressure-sensitive radio transmitter. North American Journal of Fisheries Management 18:458-464.

Resume of Matthew G. Mesa

Experience

1991-Present	Research Fishery Biologist, US Geological Survey, Biological Resources Division, Columbia River Research Lab, Cook, WA Current responsibilities: Team leader on research projects addressing the effects of dissolved gas supersaturation on juvenile salmonids and evaluating predator-prey relations in Columbia River fishes
1989-1991	Fishery Biologist, US Fish and Wildlife Service, Seattle-NFRC, Columbia River Field Station, Cook, WA
1986-1989	Fishery Biologist/CEA Appointee, Seattle-NFRC, Oregon Cooperative Fisheries Research Unit, Oregon State University, Corvallis, OR
1984-1986	Fishery Biologist, US Fish and Wildlife Service, Seattle-NFRC, Columbia River Field Station, Cook, WA

Education:	School	Degree and Date Received
	California Polytechnic State University at San Luis Obispo	B.S., Res. Mgt. 1984
	Oregon State University	M.S., Fisheries, 1989
	Oregon State University	Ph.D, 1999 (anticipated)

Expertise: My areas of expertise include predator-prey interactions in fishes, fish behavior and performance, and general and stress physiology of fishes

Publications and Reports (five most relevant)

Mesa, M.G. and C.B. Schreck. 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Transactions of the American Fisheries Society 118:644-658.

Mesa, M.G. 1991. Variation in feeding, aggression, and position choice between hatchery and wild cutthroat trout in an artificial stream. Transactions of the American Fisheries Society 120:723-727.

Mesa, M.G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123:786-793.

Mesa, M.G., T.P. Poe, D.M. Gadomski, and J.H. Petersen. 1994. Are all prey created equal? A review and synthesis of differential predation on prey in substandard condition. Journal of Fish Biology 45 (Supplement A):81-96.

Mesa, M.G., T.P. Poe, A.G. Maule, and C.B. Schreck. *In press*. Vulnerability to predation and physiological stress responses in juvenile chinook salmon experimentally infected with *Renibacterium salmoninarum*. Canadian Journal of Fisheries and Aquatic Sciences.

Section 10. Information/technology transfer

Results will be disseminated in oral and written formats. Written results will include quarterly and annual reports to BPA and publications in peer-reviewed journals. Information will be presented orally at local, regional, and national meetings.

Congratulations!