PART I - ADMINISTRATIVE

Section 1. General administrative information

Title of project

Evaluate Predator Removal: Large-Scale Patterns

BPA project number: 9007800
Contract renewal date (mm/yyyy): 2/1999 ☐ **Multiple actions?**

Business name of agency, institution or organization requesting funding
U.S. Geological Survey

Business acronym (if appropriate) USGS

Proposal contact person or principal investigator:

Name	James H. Petersen
Mailing Address	5501A Cook-Underwood Road
City, ST Zip	Cook, WA 98605
Phone	509 538-2299 x236
Fax	509 538-2843
Email address	jim_petersen@usgs.gov

NPPC Program Measure Number(s) which this project addresses
4.2A (Systemwide analysis of uncertainties), 5.7, 5.7A, 5.7B (Predation), 7.5B.3 (Snake River fall chinook limiting factors)

FWS/NMFS Biological Opinion Number(s) which this project addresses
NMFS Biological Opinion (1995), Section IV Project Effects, Part 5 Northern Pikeminnow Removal Program (p. 64)

Other planning document references
NMFS Proposed Recovery Plan for Snake River Salmon (1995). Task No. 2.8b. "Conduct research to determine the extent of predation problems and evaluate predation control measures".

Short description
Evaluate causes of large-scale geographic patterns in predation on juvenile salmon by northern pikeminnow. Examine complex interactions of temperature, juvenile salmon, and juvenile American shad on predation patterns in mainstem rivers.

Target species

Northern pikeminnow, juvenile salmonids, juvenile American shad

Section 2. Sorting and evaluation

Subbasin

Mainstem Columbia River, Lower Snake 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
20515	Mainstem Columbia River Umbrella

Other dependent or critically-related projects

Project #	Project title/description	Nature of relationship
9007700	Northern Pikeminnow Management Program	Provide supporting analyses to cooperating agencies
9600600	PATH - (also other PATH-related projects)	Provides supporting analyses for PATH analyses of system-wide salmonid mortality
9702400	Predation by Fish-Eating Birds on Juvenile Salmonids in the Columbia River	Provides analyses of fish predation in the lower Columbia River that can be compared to bird predation estimates.

Section 4. Objectives, tasks and schedules

Past accomplishments

Year	Accomplishment	Met biological objectives?
1991	Published results of early predation studies in John Day Reservoir	Yes
1994	Published results of studies on light intensity, predator physiology, and salmonid loss estimates	Yes
1995	Published results of system-wide indexing of predation	Yes
1997	Conducted workshops to train regional biologists in bioenergetic modeling techniques	Yes
1998	Manuscript accepted on northern pikeminnow bioenergetics modeling	Yes

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Document large-scale spatial patterns of predation on juvenile salmonids in major reaches of the Columbia and Snake Rivers.	a	Review existing literature and datasets; compute and perform statistical tests on differences in predation rates and predator growth
2	Test the hypothesis that temperature differences between upriver and downriver locations could produce variations in predation rates and predator growth	a	Document large-scale temperature differences in major reaches of the Columbia and Snake Rivers.
		b	Conduct bioenergetic simulations testing effects of temperature on predation rates and predator growth
3	Test the hypothesis that differences in diet between upriver and downriver locations could produce variations in predation rates and predator growth.	a	Conduct field sampling of northern pikeminnow to document diet differences during September and October
		b	Conduct bioenergetic simulations testing the effects of diet variation on predation rate and predator growth

Objective schedules and costs

Obj #	Start date mm/yyyy	End date mm/yyyy	Measureable biological objective(s)	Milestone	FY2000 Cost %
1	1/2000	12/2000		Report and publication	30.00%
2	1/2000	12/2000		Report and publication	70.00%
				Total	100.00%

Schedule constraints
Field study will require collecting permits.

Completion date
12/31/2000

Section 5. Budget

FY99 project budget (BPA obligated): $40,842

FY2000 budget by line item

Item	Note	% of total	FY2000
Personnel		%45	54,108
Fringe benefits		%12	14,812
Supplies, materials, non-expendable property		%0	500
Operations & maintenance		%0	500
Capital acquisitions or improvements (e.g. land, buildings, major equip.)			0
NEPA costs			0
Construction-related support			0
PIT tags	# of tags: 0		0
Travel		%13	15,500
Indirect costs		%27	32,460
Subcontractor			0
Other			0

TOTAL BPA FY2000 BUDGET REQUEST	$117,880

Cost sharing

Organization	Item or service provided	% total project cost (incl. BPA)	Amount ($)
USGS	Use of agency boats	%4	5,000
ODFW	Miscellaneous personnel	%1	2,000
Total project cost (including BPA portion)			$124,880

Outyear costs

	FY2001	FY02	FY03	FY04
Total budget	$ 0	$ 0	$ 0	$ 0

Section 6. References

Watershed?	Reference
☐	Beamesderfer, R. C., B. E. Rieman, L. J. Bledsoe, and S. Vigg. 1990. Management implications of a model of predation by resident fish on juvenile salmonids migrating through a Columbia River reservoir. N. Am. J. Fish. Manage. 10:290-304.
☐	Beamesderfer, R. C., D. L. Ward, A. A. Nigro. 1996. Evaluation of the biological basis for a predator control program on northern squawfish (Ptychocheilus oregonensis) in the Columbia and Snake rivers. Can. J. Fish. Aquat. Sci. 53:2898-2908.
☐	Beyer, J. M., G. Lucchetti, and G. Gray. 1988. Digestive tract evacuation in northern squawfish . Can. J. Fish. Aquat. Sci. 45:548-553.
☐	Brandt, S. B., and J. Kirsch. 1993. Spatially explicit models of striped bass growth potential in Chesapeake Bay. Trans. Am. Fish. Soc. 122:845-869.
☐	Buchanan, D. V., R. M. Hooten, and J. R. Moring. 1981. Northern squawfish (Ptychocheilus oregonensis) predation on juvenile salmonids in sections of the Willamette River basin, Oregon. Can. J. Fish. Aquat. Sci. 38:360-364.
☐	Cech, J. J. Jr., D. T. Castleberry, T. E. Hopkins, and J. H. Petersen. 1994. Northern squawfish, Ptychocheilus oregonensis, O2 consumption rate and respiration model: Effects of temperature and body size. Can. J. Fish. Aquat. Sci. 51:8-12.
☐	Ebel, W.J., D. C. Becker, J. W. Mullan, and H. L. Raymond. 1989. The Columbia River: Towards a holistic understanding. In: D. P. Dodge, Proc.

	Internat. Large Riv. Symp., Can. Spec. Publ. Fish. Aquat. Sci. 205-219.
☐	Faler, M. P., L. M. Miller, and K. I. Welke. 1988. Effects of variation in flow on distribution of northern squawfish in the Columbia River below McNary Dam. N. Am. J. Fish. Manage. 8:30-35.
☐	Gadomski, D. M., M. G. Mesa, and T. M. Olson. 1994. Vulnerability to predation and physiological stress responses of experimentally descaled juvenile chinook salmon, Oncorhyncus tshawytscha. Environ. Biol. Fish. 39:191-199.
☐	Hanson, P. C., T. B. Johnson, D. E. Schindler, and J. F. Kitchell. 1997. Bioenergetics Model 3.0 for Windows. University of Wisconsin Seagrant Institute, Technical Report WISCU-T-97-001, Madison, WI.
☐	ISG, 1996. Return to the River: Restoration of salmonid fishes in the Columbia River Esosystem. Report to the Northwest Power Planning Council, Portland, Oregon.
☐	Gadomski, D. M., and C. A. Barfoot. In press. Diel and distributional abundance patterns of fish embryos and larvae in the lower Columbia and Deschutes Rivers. Environ. Biol. Fish.
☐	Gray, G. A., G. M. Sonnevil, H. C. Hansel, C. W. Huntington, and D. E. Palmer. 1984. Feeding activity, rate of consumption, daily ration and prey selection of major predators in the John Day pool. Bonneville Power Administration, Portland, Or.
☐	Kitchell, J. F., and L. B. Crowder. 1986. Predator-prey interactions in Lake Michigan: model predictions and recent dynamics. Environ. Biol. Fish. 16:205-211.
☐	Kitchell, J. 1997. Bioenergetics modeling workshops for evaluating predator control programs on the Columbia River. Unpublished report to the U.S. Geological Survey, Cook, Washington.
☐	Marmorek, D. R., and C. N. Peters. 1998. Plan for Analyzing and Testing Hypotheses (PATH): Weight of evidence report. August 1998. ESSA Technologies, LTD., Vancouver, B. C., Canada. 116 p. + appendices.
☐	McKenzie, S. W., and A. Laenen. 1998. Assemby and data-quality review of available continuous water temperatures for the mainstems of the lower- and mid-Columbia and lower-Snake Rivers. Unpublished report and data to the NWPPC and EPA, Portland, Oregon
☐	National Research Council (NRC). 1996. Upstream: Salmon and society in the Pacific Northwest. National Academy Press, Washington D. C.
☐	Parker, R. M., M. P. Zimmerman, and D. L. Ward. 1995. Variability in biological characteristics of northern squawfish in the lower Columbia and Snake rivers. Trans. Am. Fish. Soc. 124:335-346.
☐	Petersen, J. H., M. G. Mesa, J. Hall-Griswold, W. C. Shrader, G. W. Short, and T. P. Poe. 1990. Magnitude and dynamics of predation on juvenile salmonids. Bonneville Power Administration, Portland, Oregon.
☐	Petersen, J. H., and D. L. DeAngelis. 1992. Functional response and capture timing in an individual-based model: predation by northern squawfish

	(Ptychocheilus oregonensis) on juvenile salmonids in the Columbia River. Can. J. Fish. Aquat. Sci. 49:2551
☐	Petersen, J. H. 1994. Importance of spatial pattern in estimating predation on juvenile salmonids in the Columbia River. Trans. Am. Fish. Soc. 123:924-930.
☐	Petersen, J. H., D. M. Gadomski, and T. P. Poe. 1994. Differential predation by northern squawfish (Ptychocheilus oregonensis) on live and dead juvenile salmonids in the Bonneville Dam tailrace (Columbia River). Can. J. Fish. Aquat. Sci. 51:1197-1204.
☐	Petersen, J. H., and D. L. Ward. In press. Development and corroboration of a bioenergetics model for northern pikeminnow (Ptychocheilus oregonensis) feeding on juvenile salmonids in the Columbia River. Trans. Am. Fish. Soc.
☐	Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:405-420.
☐	Poe, T. P., R. S. Shively, and R. A. Tabor. 1994. Pages 347-360 in D.J. Stouder, K. L. Fresh, and R. J. Feller, editors. Ecological consequences of introduced piscivorous fishes in the lower Columbia and Snake rivers. Theory and Application in Fish F
☐	Quinn, T. P., and D. J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology 77:1151-1162.
☐	Rice, J. A., J. E. Breck, S. M. Bartell, and J. F. Kitchell. 1983. Evaluating the constraints of temperature, activity, and consumption on growth of largemouth bass. Environmental Biology of Fishes 9:263-275.
☐	Ricker, W. E. 1941. The consumption of young sockeye salmon by predaceous fish. Journal of the Fisheries Research Board of Canada 5:293-313.
☐	Rieman, B. E., and R. C. Beamesderfer. 1990. Dynamics of a northern squawfish population and the potential to reduce predation on juvenile salmonids in a Columbia River reservoir. N. Am. J. Fish. Manage. 10:228-241.
☐	Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes and smallmouth bass in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:448-458.
☐	Roby, D. D., D. P. Craig, K. Collis, S. L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. 1997 Annual Report. Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.
☐	Rondorf, D. W., M. S. Dutchuk, A. S. Kolok, and M. L. Gross. 1985. Bioenergetics of juvenile salmon during the spring outmigration. Bonneville Power Administration, Portland, Oregon.
☐	Shively, R. S., T. P. Poe, and S. T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho. Trans. Am. Fish. Soc. 125:230-236.

☐	Shuter, B.J., and J. R. Post. 1990. Climate, population viability, and the zoogeography of temperate fishes. Trans. Am. Fish. Soc. 119:314-336.
☐	Somerton, D. A. 1990. Detecting differenes in fish diets. Fishery Bull., U.S. 89:167-169.
☐	Stanford, J. A., and J. V. Ward. 1992. Management of aquatic resources in large catchments: Recognizing interactions between ecosystem connectivity and environmental disturbance. Pages 91-126 In: R. J. Naiman (ed.), Watershed Management. Springer-
☐	Stewart, D. J., J. F. Kitchell, and L. B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. Trans. Am. Fish. Soc. 110:751-763.
☐	Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. N. Am. J. Fish. Manage. 13:831-838.
☐	Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish . Trans. Am. Fish. Soc. 120:421-438.
☐	Vigg, S., and C. C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (Ptychocheilus oregonensis) from the Columbia River. Can. J. Fish. Aquat. Sci. 48:2491-2498.
☐	Ward, D. L., J. H. Petersen, J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Trans. Am. Fish. Soc. 124:321-334.
☐	Welander, A. D. 1940. Notes on the dissemination of shad, Alosa sapidissima (Wilson), along the Pacifc coast of North America. Copeia 1940:221-223.
☐	

PART II - NARRATIVE

Section 7. Abstract

Many recent forums on salmon recovery in the Columbia River Basin have emphasized the importance of a system-wide approach that considers complex ecological processes. A review of predation upon juvenile salmon by northern pikeminnow suggests that there are large, system-wide (upriver versus downriver) patterns in predation processes that have not been appreciated, and which may have consequences for salmonid survival and management. These large-scale patterns include higher rates of predation on salmonids and higher growth and reproductive rates for predators in the Columbia River below Bonneville Dam compared to Columbia River or lower Snake River reservoirs. The goal of this study is to further document these large-scale patterns and examine the potential causes of the patterns through limited field studies and bioenergetic modeling.

Two hypotheses in particular will be examined: 1) Temperature differences in the mainstem rivers can explain predation patterns, and, 2) the abundance of alternative prey, especially juvenile American shad, can explain predation patterns. Both temperature and the abundance of American shad have changed considerably during the last 50 years. The project is planned as a preliminary investigation, and would be completed during FY2000. Results of these analyses might have implications for the predator management program, passage of adult shad, fisheries for shad, or temperature management alternatives.

Section 8. Project description

a. Technical and/or scientific background

Many recent forums on salmon recovery in the Columbia River Basin have emphasized the importance of a system-wide approach that considers complex ecological processes. The Independent Scientific Group (ISG 1996), the National Research Council (NRC 1996), the new Multi-Species Framework, and other groups have emphasized how salmonid problems must be considered in the context of processes and conditions throughout the river system. Others have also shown how growth and survival of fish in lotic systems are linked between upriver and downriver processes (e.g., Stanford and Ward 1992). Recent studies and analyses, described below, suggest there may be large-scale geographic patterns in predation on juvenile salmon by northern pikeminnow *Ptychocheilus oregonensis*, which have not been appreciated. Large-scale patterns occur through the mainstem Columbia and Snake rivers, and these variations could have a considerable effect on the survival of juvenile salmon as they migrate through the mainstem. In this section, we describe the large-scale patterns and present two likely hypotheses that could explain the patterns.

Northern pikeminnow consume juvenile salmonids in rivers, lakes, and reservoirs in Washington, Oregon, Idaho, California, and British Columbia (Ricker 1941; Buchanan et al. 1981; Ward et al. 1995). Northern pikeminnow were identified as the major source of mortality away from dams in the mainstem Columbia and Snake Rivers by BPA-funded studies during the last 16 years (Poe et al. 1991; Vigg et al. 1991; Rieman et al. 1991; Ward et al. 1995; and many others). Passage models used in the PATH decision-making process consider predation to be the primary mechanism of mortality for juvenile salmonids, along with mortality caused by dam passage.

Based on data collected during a 4-year, system-wide study, predation rates on juvenile salmon and predator densities in non-dam areas (= mid-reservoir areas; see Petersen 1994) were highest below Bonneville Dam and decreased with distance upriver (Ward et al. 1995; USGS unpublished analyses). Predation rates, for example, were nearly an order of magnitude greater in the free-flowing river below Bonneville Dam compared to mid-reservoir areas in the lower Snake River. The rates of individual growth and egg production for northern pikeminnow shows a similar pattern, with the highest rates being downriver and the lowest rates occurring in the lower Snake River. Von Bertallanfy growth models fit to large samples of predators suggested that the growth rate of northern pikeminnow is about 18% greater for downriver fish compared to upriver fish

(Parker et al. 1995). These higher rates of growth would cause female predators at age 5, for example, to be 52% larger than comparably aged fish in the lower Snake River. Relative fecundity was 20% higher below Bonneville Dam (38.8 eggs per gram of female mass) than in the lower Snake River reservoirs (32.2 eggs per gram of female mass; Parker et al. 1995). Thus, northern pikeminnows grow faster, are larger at the same age, have a higher predation rate on juvenile salmonids, and have a higher reproductive output in the lower Columbia River compared to reaches further upriver.

The consequences of these large-scale spatial variations could be considerable. First, higher predation rates and larger predators in the lower river would consume more juvenile salmon per individual predator than upriver fish of the same age. Higher per capita predation and the large size of the lower river population (Ward et al. 1995) would cause higher reach mortality for salmonids. Second, higher rates of egg production in the lower river combined with larger individual predators would likely lead to production of more eggs in this reach, and potentially higher rates of recruitment to the predator population. Finally, these patterns of predation and salmonid mortality could suggest adjustments to ongoing programs or new management alternatives in the system, such as predator removal.

Various hypotheses might be developed to explain the observed patterns in predation, but two hypotheses appear to be most probable:

Hypothesis 1: Geographic variation in temperature causes large-scale patterns in predation.. For the period 1980-1995, historical temperatures at Bonneville Dam were slightly higher (+0.5 ^{o}C) during spring-fall than temperatures measured at lower Snake River dams (USGS unpublished analyses). Winter temperatures were several degrees higher on average in the lower Columbia River compared to the lower Snake River, possibly caused by releases from large storage reservoirs in the upper Columbia River. Other studies have also shown that water temperature is higher in the lower Columbia River than further upriver (e.g., Ebel et al. 1989).

Higher water temperature has been shown to cause higher predation rates, higher respiration rates, faster digestion, and faster growth in many fishes, including northern pikeminnow (Beyer et al. 1988; Vigg and Burley 1991; Cech et al. 1994; Petersen and Ward *In press*). Northern pikeminnow predation on salmonids was highest at about 21 ^{o}C in the laboratory (Vigg and Burley 1991). Bioenergetic modeling of northern pikeminnow suggests that growth rate is highest at about 17 ^{o}C, which occurs during both spring and fall periods (Petersen and Ward *In press*).

Hypothesis 2: Geographic variation in prey density or prey quality causes large-scale patterns in predation. Northern pikeminnow consume a variety of prey throughout the river system, including salmonids, other fishes, crustaceans, molluscs, plants, and other material (Poe et al. 1991; Ward et al. 1995; and others). Of these prey categories, anadromous juvenile fishes often form a large part of the diet of northern pikeminnows during spring to fall, and variations in this diet component could contribute to the observed differences in growth and predation. The contribution of juvenile salmon to northern pikeminnow diet has been well documented (Poe et al. 1990; Ward et al. 1995; Zimmerman et al. *In press*). However, anadromous American shad *Alosa* *sapidissima* are also present in the hydrosystem and they may be contributing an important source of energy for growth of northern pikeminnow. This supplemented growth could produce larger predators and higher losses for juvenile salmon in subsequent years.

American shad were introduced into the Sacramento River in 1871, migrated north along the Pacific coast, and were well established in the Columbia River by 1885 (Welander 1940). The number of American shad passing Bonneville Dam has increased dramatically in the last 50 years, from an average of 16,700 adults between 1938-1957 to over 2,000,000 adults between 1988-1992 (Quinn and Adams 1996). In 1997, 2.1 million adult shad were counted at Bonneville Dam, 0.3 million at McNary Dam, while only 106 shad crossed Lower Granite Dam on the Snake River (U.S. Army Corps of Engineers). Mature shad migrate up the Columbia River from May through July, spawn in the reservoirs, and juvenile shad are present in the mainstem Columbia and Snake river during August through at least early November.

The numbers of juvenile shad passing Columbia and Snake River dams are available for 1997-98 from the Fish Passage Center. During 1997 for example, juvenile shad counts increased in late August at Bonneville Dam and remained high through October. Counts at McNary Dam were similar to those at Bonneville Dam, while the counts at Lower Monumental Dam were 2-3 orders of magnitude lower (Fish Passage Center, unpublished data). During 1998, the pattern was similar although counts at McNary Dam were relatively low until mid-October. These counts have not been adjusted for different flows and guidance efficiencies, but they strongly suggest that juvenile shad are much more abundant in the lower Columbia River than in upriver reaches.

Little information is available on shad in the diet of northern pikeminnow since most studies of these predators were conducted during April-July, when juvenile shad are not present in the system. Petersen et al. (1994) collected northern pikeminnow in the tailrace of Bonneville Dam in late August 1990 and 1991 when shad were available. During 1990, juvenile shad were 78% by weight of the diet of northern pikeminnow, while during 1990 sampling, shad were only 5% of the predator's diet. The high diet of shad during 1990 coincided with high passage counts of juveniles shad at Bonneville Dam (NMFS, unpublished data), while the low percentage of shad observed during 1991 coincided with low shad passage indices (Petersen et al. 1994). Studies in John Day Reservoir during August 1982 also found shad were common in the diet of northern pikeminnow (Gray et al. 1984).

Aside from being available in high densities during late summer and fall, American shad appear to have a higher energy density than many other prey eaten by northern pikeminnow. Juvenile American shad contain more energy than juvenile steelhead (+23%), chinook salmon (+32 to +42%), coho salmon (+13%), sockeye salmon (+12%), and crustaceans (+26%; Rondorf et al. 1985; Roby et al. 1998; USGS unpublished analyses).

A high proportion of juvenile shad in the diet of northern pikeminnow during fall could have an indirect effect on predation losses of juvenile salmon. As a relatively high-energy package, shad may be supplementing the diet of predators in the fall when they are doing much of their growth for the year (Petersen and Ward *In press*). Enhanced growth in the fall, stimulated by shad in the diet, may cause the predators to be larger and contain higher stores of lipids as they enter the winter period. These larger predators would likely have a higher overwinter survival rate and be in a better condition the following spring. Thus, enhanced growth in the fall caused by juvenile shad might increase the losses of juvenile salmon the following spring and summer since predators may be larger and have survived the winter better.

b. Rationale and significance to Regional Programs

Predation by northern pikeminnow and smallmouth bass has been identified as the most important cause of mortality for juvenile salmon aside from dam passage mortality (e.g. Rieman et al. 1991). The Fish and Wildlife Program, *Return to the River,* the Snake River Recovery Plan, and other regional documents acknowledge the important role of predators in the system. Model predictions, and other studies, led to the development of a northern pikeminnow management program in the mainstem rivers, supported by regional planning groups (NWPPC Fish & Wildlife Program 5.7; Biological Opinion Section IV, Part 5). The largest component of the predator management program has been focused on removing northern pikeminnow from throughout the system (Beamesderfer et al. 1996). Over 1 million predators have been removed from the system and the program has cost over $25 million. The NWPPC supported continuing the program in 1998, although they recognized its "high cost" and that predation losses may be largely related to "stresses caused by the hydrosystem itself" (unpublished recommendations of the NWPPC, NWPPC Website).

Although predation has been recognized as a problem and is being managed, the large-scale patterns in predation described above have not been taken into consideration. Large losses of juvenile salmon may be occurring in the free-flowing Columbia River below Bonneville Dam, perhaps due to the patterns described here – larger predators, faster growth rates, and higher consumption rates on juvenile salmon. The larger size of predators at the end of the fall period could also produce larger individuals the following year, with higher rates of egg production and thus high recruitment rates for predators.

Recent PATH analyses (e.g., Marmorek and Peters 1998) suggest there is a source of "extra mortality" occurring outside of the juvenile migration corridor, which has been modeled to end just below Bonneville Dam. Especially high rates of predation in the lower Columbia River could be contributing to this extra mortality factor, and could help explain some of the results of PATH life-cycle modeling.

Better understanding of the variations in predation loss through the system may suggest alternative management options for reducing salmonid losses. For example, high losses of juvenile salmonids in the lower river might suggest a directed predator removal program in this reach. If juvenile American shad are supplementing the growth of predators, managers may want to consider directed fisheries for that species, or limiting passage of adults at specific dams.

c. Relationships to other projects

The proposed study would contribute to a regional understanding of salmonid mortality in the mainstem Columbia and Snake rivers. These results should be especially useful to evaluation and possible modification of the Northern Pikeminnow Management Program (Project 9007700), which is conducted throughout the mainstem rivers from Astoria through the lower Snake River. Results of this work could, for example, suggest that the Management Program should adjust removal efforts to concentrate on those areas where the greatest predation mortality is occurring.

Results of this work may also be useful to projects being conducted as part of the PATH analyses (Projects 9600600, 9601700, 9600800, etc.). PATH analyses of spring/summer chinook salmon, for example, have concentrated on testing hypotheses about upriver versus downriver stock production (Marmorek and Peters 1998). Patterns of predation that vary along the river corridor could help explain some results of the PATH studies.

A recent study on predation by birds in the lower Columbia River (Project 9702400) may also benefit from this analysis. Salmonid losses due to fish predators could be compared to losses due to birds in the lower Columbia River.

d. Project history (for ongoing projects)

This project (9007800) originated as a joint research project with the Oregon Department of Fish & Wildlife (ODFW) in the early 1980's and has produced significant products during five phases:

1. During 1983-88, the projects examined several aspects of predation by piscivores in the John Day Reservoir (population size, distribution, predation rates, diets, salmonid mortality). Several reports and over 15 peer-reviewed publications resulted from this work. These studies led to development of the predator removal program and further consideration of predation at dams.

2. During 1990-93, a joint project with USGS, ODFW and Washington Department of Fish & Wildlife was conducted to index the magnitude of predation throughout the Snake and Columbia river reservoirs. This work produced annual reports and several peer-reviewed publications that further described predation (Tabor et al. 1993; Poe et al. 1994; Ward et al. 1995; Shively et al. 1996). Methods and results developed during these studies by USGS have been used in ongoing predation evaluations (e.g. Ward et al. 1995; Beamesderfer et al. 1996).

3. During 1993-98, we examined the mechanisms that may be regulating reproductive success of northern pikeminnow in the Columbia River. Four annual reports were produced, 1 peer-reviewed journal article is in press (Gadomski and Barfoot *In press*), 2 manuscripts are in review at journals, and several manuscripts are in preparation.

4. Thoughout the duration of the project, studies have been conducted to better understand the mechanisms regulating predation on juvenile salmon, such as light intensity, prey density, predator size, and other factors (e.g., Faler et al. 1988; Petersen and DeAngelis 1992; Petersen and Gadomski 1994; Cech et al. 1994).

5. The most recent (1997-Present) work has been in developing tools and evaluating the predator management program. A bioenergetic model for northern pikeminnow (Petersen and Ward *In press*) was developed, a bioenergetics workshop was conducted to train regional biologists in using this tool (Kitchell 1997), and the potential for comensatory feeding by predators following removal of northern pikeminnow is being evaluated (J. H. Petersen, *In preparation).*

e. Proposal objectives

Objective 1. Document, from existing literature and data, the large-scale spatial patterns of predation on juvenile salmonids in major reaches of the Columbia and Snake Rivers.

Objective 2. Test the hypothesis that temperature differences between upriver and downriver reaches could produce variations in predation rates and predator growth.

Objective 3. Test the hypothesis that differences in diet between upriver and downriver locations could produce variations in predation rates and predator growth.

f. Methods

Objective 1.

The data summarized above on large-scale patterns strongly suggests that predation processes vary longitudinally in the mainstem Columbia and Snake rivers. For this Objective, efforts will be made to better document these patterns using existing publications and datasets. Statitisical tests will be conducted on predation rates, growth rates, predator density, juvenile shad counts, temperature, and other parameters that may vary among the different river reaches. Tests will be parametric (e.g. ANOVA) if possible, or nonparametric if data distributions are non-normal. Data for testing hypotheses about spatial variation are available from the collaborating agencies (USGS and ODFW), published documents (e.g. Parker et al. 1995), or regional sources (e.g., shad passage counts are available from the Fish Passage Center).

Objective 2.

Differences in temperature between several locations in the mainstem rivers will first be documented using data from federal dams, USGS gauges, and other appropriate sources. The NWPPC and EPA recently completed an inventory and collation of temperature data in the mainstem rivers and these reviewed datasets will be used in the analysis (McKenzie and Laenen 1998; data available via Streamnet at <*http://www.streamnet.org/subbasin/Crbtdata.html*>).

Bioenergetic modeling will be used to simulate the effects of temperature differences on growth and consumption by northern pikeminnow. Bioenergetic modeling has been used extensively to explore questions about temperature (e.g., Rice et al. 1983; Shuter and Post 1990). Species-specific parameters for northern pikeminnow have been developed (Vigg and Burley 1991; Cech et al. 1994) and we have recently developed and corroborated a model for northern pikeminnow (Petersen and Ward *In press*). We will use this corroborated bioenergetics model to estimate the growth rate potential (Brandt and Kirsch 1993) for different river reaches based on documented temperature regimes. We will explore questions such as "*Are the observed temperature differences between the lower Columbia River and the lower Snake River adequate to explain the differences in predator growth rates?*"

Objective 3.

Little information is available on the diet of northern pikeminnow during the fall period when much of their growth may be occurring. In Task a, we will collect northern pikeminnows from three river reaches during September and October to document diets. Predators will be collected from the below Bonneville Dam, John Day Reservoir, and one or two reservoirs of the lower Snake River during both September and October, 2000. Sampling will be conducted in tailrace areas and in mid-reservoir areas if predators are available. A minimum sample of 30 predators per location will be collected (Petersen et al. 1990; Ward et al. 1995). Collected predators will be processed according to the methods of Ward et al. (1995) and diet analyses will include American shad, other fish, crustaceans, and other prey. Results will be diets (w/w) by area, and diets will be compared for statistical differences using the method of Somerton (1990). Diet studies will be a collaborative effort with the Oregon Department of Fish and Wildlife.

Bioenergetic modeling will be used to examine the effects of diet difference on the growth and consumption by northern pikeminnow. Simulations will be conducted to explore how changes in the composition of the diet and in the energy density of one diet component could influence growth rate or consumption. Similar modeling studies have been conducted on other clupeid prey in large systems (e.g., Stewart et al. 1981; Kitchell and Crowder 1986). Simulations will test such questions as "*Could the presence of high-energy American shad in the diet of northern pikeminnow explain differences in predator growth rates between the lower Columbia River and the lower Snake River?*"

g. Facilities and equipment

Analytical tasks will be performed at the Columbia River Research Laboratory (USGS) and the Oregon Department of Fish and Wildlife Clackamas office, which have state-of-the-art computers, appropriate statistical software (e.g., SAS), and adequate fisheries libraries. Journal articles not available at these facilities can be easily obtained from the University of Washington, Oregon State University, or through USGS libraries. Bioenergetic modeling software has been developed by the University of Wisconsin Seagrant Institute (Hanson et al. 1997), and this software has been implemented for northern pikeminnow (Petersen and Ward *In press*).

Field collection of predators will be conducted via boat electroshockers, which are available from the collaborating agencies. Diet analyses will be conducted by ODFW, which conducts similar analyses each year in relation to evaluation of the predator management program. No special or high-cost equipment is needed.

h. Budget

The budget costs are primarily personnel (analytical tasks and collection of field data), travel costs (per diem, vehicle rentals, boat costs), and indirect costs. A complete breakdown of the costs is available from the Principal Investigator. Indirect rates have been established by the agencies involved (USGS and ODFW).

Section 9. Key personnel

James H. Petersen, Principal Investigator, U. S. Geological Survey

Participation on this project: 0.33 FTE.

Responsible for project oversight, bioenergetic modeling, planning and scheduling field work, and report preparation.

Specific qualifications include 10 years experience with predator-prey dynamics in the Columbia River Basin, development and application of bioenergetic and individual-based models of predation, participation on PATH subgroups, publication of peer-reviewed papers and reports on predation, past and current administration of BPA contracts.

David Ward, Oregon Department of Fish and Wildlife

Participation on this project: 0.1 FTE.

Responsible for analysis of age and diet information, laboratory analysis of field samples, and report preparation.

Specific qualifications include 8 years experience with predation programs in the Columbia River Basin, development and application of bioenergetic models of predation, publication of peer-reviewed papers and reports on predation, past and current administration of BPA contracts.

Resume for: James H. Petersen

Experience

1995-Present	Research Fishery Biologist, U.S. Geological Survey, Biological Resources Division, Columbia River Research Laboratory, Cook, WA. Current responsibilities: Project leader on research project to determine survival of summer steelhead over their first winter in the Wind River Basin (WA). Co-leader on various mainstem Columbia and Snake River projects concerning juvenile salmon passage, predation, and reservoir drawdown.
1994	Acting Director, Columbia River Research Laboratory, USGS, Cook, WA.
1988-93	Research Fishery Biologist, Columbia River Research Laboratory, U.S. Fish and Wildlife Service.
1984-88	Associate Research Curator, Section of Fishes, Natural History Museum of Los Angeles County, Los Angeles, CA.
1983-84	Environmental Scientist, Section of Fishes, Natural History Museum of Los Angeles County.
1977-83	Graduate Teaching Assistant, University of Oregon, Eugene, OR.

Education:	School		Degree and Date Received
	University of Oregon, Eugene	Ph.D.	Marine Ecology, 1983
	University of Queensland, Australia		Rotary Fellowship, 1976
	Boise State University, Boise		B.S. Biology, 1975

Expertise: The primary areas of my expertise include predator-prey dynamics, population dynamics, and application of various modeling techniques to fisheries.

Publications and Reports (five most relevant)

Petersen, J. H. and D. L. DeAngelis. 1992. Functional response and capture timing in an individual-based model: predation by northern squawfish (*Ptychocheilus oregonensis*) on juvenile salmonids in the Columbia River. Can. J. Fish. Aquat. Sci. 49:2551-2565.

Petersen, J. H. 1994. The importance of spatial pattern in estimating predation on juvenile salmonids in the Columbia River. Trans. Am. Fish. Soc. 123:924-930.

Petersen, J.H. and D.M. Gadomski. 1994. Light-mediated predation by northern squawfish on juvenile salmon. J. Fish Biol. 45: 227-242.

Ward, D. L., J. H. Petersen, and J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Trans. Am. Fish. Soc. 124:321-334.

Petersen, J. H., and D. L. Ward. *In press.* Development and corroboration of a bioenergetics model for northern squawfish feeding on juvenile salmonids in the Columbia River. Trans. Am. Fish. Soc.

Resume for : David Ward

Education

Humboldt State University (Arcata, CA)	M.S. Fisheries, 1985
Humboldt State University (Arcata, CA)	B.A. Zoology, 1978

Experience

1984-Present: Oregon Department of Fish and Wildlife, 17330 S.E. Evelyn St., Clackamas, OR. (1) Program Leader for Northwest Region Research Program (1998-Present): Coordinate activities of ongoing departmental and interagency projects, identify needs for and develop future projects, provide technical oversight to project leaders, and supervise project leaders and other program staff. (2) Project Leader: Evaluation of the Northern Pikeminnow Management Program (1991-98). (3) Project Leader: Portland Harbor Study (1988-91). (4) Project Biologist and Technician on various studies (1984-87).

Expertise

Coordinated and integrated activities of cooperating agencies, hired and supervised staff of project leaders, project biologists, and seasonal workers, designed field and laboratory sampling plans, analyzed wide variety of biological data, authored, edited, and reviewed scientific reports and peer-review articles. Organized personnel from cooperating agencies to give symposia at fisheries conferences. Developed and submitted proposals for numerous research projects to various funding sources. Direct experience with methods and gears associated with habitat and fish surveys in streams, rivers, lakes, and reservoirs.

Publications and Reports

Ward, D.L., and M.P. Zimmerman. In Press. Response of smallmouth bass to sustained removals of northern pikeminnow in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society.

Friesen, T.A., and D.L. Ward. In Press(a). Management of northern pikeminnow and implications for juvenile salmonid survival in the lower Columbia and Snake rivers. North American Journal of Fisheries Management.

Zimmerman, M.P., and D.L. Ward. In Press. Index of predation on juvenile salmonids by northern pikeminnow in the lower Columbia river basin from 1994-96. Transactions of the American Fisheries Society.

Beamesderfer, R.C., D.L. Ward, and A.A. Nigro. 1996. Evaluation of the biological basis for a predator control program on northern squawfish in the Columbia and Snake rivers. Canadian Journal of Fisheries and Aquatic Sciences 53:2898-2908.

Ward, D.L., J.H. Petersen, and J.J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Transactions of the American Fisheries Society 124:321-334.

Section 10. Information/technology transfer

1. A final report will be submitted for publication on the BPA webpage.
2. Results will be prepared as one or two manuscripts for publication in a peer-reviewed journal(s).
3. Results will be presented at a national meeting, such as a meeting of the American Fisheries Society or the Ecological Society of America.

Congratulations!