Bonneville Power Administration

Fish and Wildlife Program FY99 Proposal Section 1. General administrative information

Statistical Support For Salmonid Survival Studies

Bonneville project number, if an ongoing project 8910700

Business name of agency, institution or organization requesting funding
University of Washington

Business acronym (if appropriate) UW

Proposal contact person or principal investigator:

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Subcontractors.

Organization	Mailing Address	City, ST Zip	Contact Name
None			

NPPC Program Measure Number(s) which this project addresses.
NPPC Doc 94-55: 3.2, 3.2F, 4.3B, 4.3C.1, 5.0F, 5.2A.7

NMFS Biological Opinion Number(s) which this project addresses.
NMFS 1995 Hydrosystem Operations BO: RPA 13, Develop comprehensive monitoring, evaluation and research program; RPA 13f, Evaluate juvenile survival during downstream migration; RPA 17, Test hypotheses underlying life cycle models.

Other planning document references.
NMFS 1995 Proposed Recovery Plan for Snake River Salmon: 0.3.b, Regional capabilities for biological analysis and modeling; 1.5.a, Determine effects of water withdrawals on salmon survival; 2.1.d.3, Evaluate juvenile survival during downstream migration; 2.1.d.5, Comprehensive monitoring, evaluation and research program; 2.1.d.1,

Test the effects of increased spill on juvenile salmon survival; 2.6.c.3, Investigate survival rates for adult salmonids migrating upriver.

Subbasin.

Short description.
Improve monitoring and evaluation capabilities by developing better measurement tools and study designs to estimate juvenile and adult survival. Develop statistical methods to determine smolt survival rates and survival relationships.

Section 2. Key words

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

Other keywords.
Survival studies, survival relationships, juvenile survival, adult survival, reach survival, system survival, season-wide survival, ocean survival, PIT-tag, radio-tag, statistical methods and design, statistical software, statistical assistance.

Section 3. Relationships to other Bonneville projects

Project #	Project title/description	Nature of relationship
9008000	Columbia Basin PIT-Tag Information System [PSMFC]	This UW project requires high quality PIT-tag data made available through PTAGIS (Project 9008000). Project produces data queries tailored to PTAGIS to extract PIT-tag information to analyze survival data in various formats.
9102900	Supplementation and Survival of Fall Chinook in Snake River [BRD/USGS]	BRD uses the statistical models and computer software (e.g., SURPH) for survival estimation developed, enhanced, and maintained by this

		UW project.
9302900	Survival Estimation for Dam/Reservoir Passage [NMFS-CZES]	Provides direct technical and analytical support to NMFS field studies. Specifically, responds to NMFS requests to enhance survival estimation capabilities incorporated in Program SURPH. Responds to requests to NMFS to investigate alternative analyses.
8712700	Smolt Monitoring by Non-Federal Entities [PSMFC]	Technical assistance and technology transfer of statistical software to Nez Perce Tribe to assist their survival analyses.
9503400	EW Program Support [BPA]	Technical assistance to BPA EW staff related to performance of internal assessment requirements; subject area conduct and analysis of Columbia River Basin survival studies.

Section 4. Objectives, tasks and schedules

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Maintenance of SURPH.1 Software	a	Maintain upkeep of both workstation and PC versions of SURPH software.
		b	Maintain Internet access for both workstation and PC versions of SURPH software.
		c	Alter SURPH software as required to work on changing computer systems and platforms.
		d	Respond to user questions and provide users with manuals and individual instruction.
2	Improve SURPH statistical software	a	Implement new time-varying covariate analyses.
		b	Implement new, more flexible modeling algorithm.
2		c	Develop unified UNIX and PC software.

3	Investigate use of radiotelemetry in survival studies	a	Complete analyses of existing radiotelemetry data for the development of statistical methods and software to extract survival information from radiotagged smolt telemetry studies.
		b	Provide guidelines on conducting radiotelemetry studies, required release sizes, and their proper analysis.

Objective schedules and costs

Objective #	Start Date mm/yyyy	End Date mm/yyyy	Cost %
1	1/1999	12/1999	41.00%
2	1/1999	12/1999	43.00%
3	1/1999	12/1999	16.00%
			TOTAL 200.00%

Schedule constraints.
Changes in the marking programs could impact survival research and scheduled analyses of these tagging studies to determine survival relationships.

Completion date.
Open. The completion dates are for tasks in FY99 not the project. Ongoing indefinitely to support Columbia River Basin survival studies.

Section 5. Budget

FY99 budget by line item

Item	Note	FY99
Personnel		$97,100
Fringe benefits		$20,500
Supplies, materials, non-expendable property	Includes computer upgrades, software, licenses, services, etc.	$12,600
Operations & maintenance	O&M occur across a number of budget items. For FY99, 41% of total budget = $75,153.	
Capital acquisitions or improvements (e.g. land, buildings, major equip.)		$0
PIT tags	# of tags:	$0

Travel		$1,800
Indirect costs	26% of total direct costs less costs for equipment, graduate operating fee, and office lease	$36,000
Subcontracts		0
Other	Graduate operating fee, office lease	15,300
TOTAL		$183,300

Outyear costs

Outyear costs	**FY2000**	**FY01**	**FY02**	**FY03**
Total budget	$187,000	$192,000	$199,000	$205,000
O&M as % of total	41.00%	45.00%	44.00%	47.00%

Section 6. Abstract

Project 8910700 was initiated in 1989 to improve monitoring and evaluation capabilities of the Columbia River Fish and Wildlife Program (FWP) by developing better measurement tools and study designs to evaluate relationships between ambient environmental conditions and the survival of juvenile and adult salmonids. The 1994 FWP states that the relationship between spring and summer flow, velocity, and fish survival should receive highest priority in the region's research efforts. Throughout its history, this project has provided statistical support and guidance on the design and analysis of PIT-tag survival studies to the Northwest fisheries community.

Estimators of smolt and adult salmon survival rates are developed using maximum likelihood methods and generalized least-squares regression models based on release-recapture theory. Tests of survival hypotheses and estimation of survival relationships are based on state-of-the-art statistical analyses devised specifically to assess relationships within capture data. Statistical software (e.g., SURPH.1) is developed and distributed to support ongoing survival investigations.

The ultimate outcome of increased passage survival through the FCRPS depends upon the effectiveness of these survival measures to monitor migration success, investigate river management decisions, and to provide baseline information to evaluate future mitigation options. This project is anticipated to continue in some form beyond 2002 as part of the adaptive management monitoring and evaluation framework of the FWP.

Monitoring and evaluation of products comes from annual post-season evaluations performed by the contractor, direct users of the products, e.g., NMFS, PATH and other regional entities, and independent scientific peer reviews.

Section 7. Project description

a. Technical and/or scientific background.

The Columbia River Basin Fish and Wildlife Program states that the relationship between spring and summer flow, velocity and fish survival should receive highest priority in the region's research efforts. This project was initiated in 1989 to develop the statistical theory and methods needed to analyze smolt and adult PIT-tag survival studies. This study conducted the initial feasibility studies to determine the applicability of using release-recapture theory (Cormack 1964) in conjunction with proposed PIT-tag detection and diversion systems to estimate smolt survival (Dauble et al. 1993). The feasibility studies resulted in sampling protocol used in the initial study designs for the National Marine Fisheries Service/University of Washington (NMFS/UW) Snake River survival studies of 1993-present (Project 9302900).

Because the Fish and Wildlife Program (4.3C.1), the Biological Opinion (13f), and the Recovery Plan for the Snake River (2.1.d.2, 2.1.d.3, 2.2.d.1, 2.6.c.3) call for the need to investigate juvenile and adult survival relationships to river operations and conditions, this project proceeded to develop statistical methods to assess survival effects based on first principle. Until recently (Clobert et al. 1985, 1987), only inefficient two-stage analyses that ignore the distribution nature of tagging data were available to investigators. This project developed statistically valid tests of survival effects (Skalski et al. 1993) using both group-wise and individual-based covariates. This theory led to the development of the software program SURPH.1 available on UNIX and PC platforms. The resulting statistical methods provided valid and more powerful means of assessing survival relationships from tag data. This software and its subsequent developments have been used by NMFS since 1993 to analyze Columbia/Snake River survival studies (Skalski et al. 1998).

As the capabilities to conduct PIT-tag survival studies have expanded, so have the research questions and the subsequent need for statistical methods tailored to the investigations. This project has developed methods to validly analyze fall chinook smolt outmigration over two spring seasons (Lowther and Skalski 1998a), provide season-wide survival estimates (Skalski 1998), provide profile interval estimates of survival (Lowther and Skalski 1998b), and analyze time-varying covariates resulting from the capture-measure-recapture-remeasure of smolt during outmigration. This project continues to respond to user needs for software and statistical assistance in analyzing tagging studies. The software is now used nationally and internationally to assess survival relationships and natural selection.

As more stocks have become listed as threatened or endangered, the ability to tag thousands of smolt has declined. To this end, the project is also looking at the statistical ability of radiotelemetry studies to provide accurate and reliable survival information to fisheries managers.

b. Proposal objectives.

The overall goal of the project is to improve analytical capabilities to conduct research on survival processes of wild and hatchery chinook and steelhead during smolt outmigration. Further, this project stands ready to provide analytical support to estimate

ocean survival and in-river survival of returning adults when adult detection facilities are in place. The resulting improved monitoring and evaluation capabilities will assist in-season river management by optimizing operational and fish passage strategies.

Specific objectives for the 1999 project year are as follows.

Objective 1. Maintain the SURPH.1 statistical software and provide user support.

Objective 2. Provide improvements in statistical theory and software as requested by user groups.

Objective 3. Develop valid statistical models to extract survival information from radiotelemetry fish tagging studies.

The statistical software program SURPH.1 developed at the UW to analyze PIT-tag survival studies is also maintained, debugged, and enhanced at the UW. Maintenance now includes upkeep of both UNIX and PC versions of the software and Internet access. As computer systems routinely upgrade, the software must be altered to work on the newer systems and computer platforms. The other maintenance issues under Objective 1 include responding to user questions and providing users with software, manuals, and individual instruction.

During 1999, a new version of statistical software will be released (i.e., SURPH.2). The new version will have subtle as well as substantive changes in analytical capabilities. First, PC and UNIX versions of Program SURPH.1 will be merged into a single Java-based program capable of running on both platforms. The advances in programming language will permit a single version of SURPH which will simplify maintenance and allow quicker enhancements of statistical software in the future. Significant statistical enhancement in the new version of SURPH.2 will include a more flexible modeling capability, allowing more detailed investigations of survival relationships and the incorporation of analyses to investigate the effects of repeated time-varying measurements as survival. Currently, analyses do not exist to validly incorporate updated information on morphologic changes in release-recapture survival studies.

Finally, statistical methods and software will be developed to extract detailed survival information from radiotagged smolt telemetry studies. With proper design, these radiotelemetry studies have the capability to estimate pool, spillway, bypass, and turbine survival rates along with fish guidance efficiency (FGE) and spill effectiveness (SE). The project will provide guidelines on conducting radiotelemetry studies, required release sizes, and their proper analysis.

Results for 1999 will be presented in technical reports, peer-reviewed scientific publications, and free statistical shareware available through the Internet.

c. Rationale and significance to Regional Programs.

The Northwest's ability to conduct effective and meaningful PIT-tag studies from the onset was a consequence of integrating the programmatic and biological needs with electronics, logistics of PIT-tag facility placement, and statistical design and analyses. The capabilities and limitations of performing PIT-tag studies was known prior to implementation of large tag releases. As a consequence, efficient and worthwhile studies

were prepared from the onset in a cost-effective and scientifically deliberate manner. This history contrasts sharply with the implementation of the coded-wire tag (CWT) methodology in the Northwest where expectations were high but study performance was nearly always below expectations. The statistical community (see literature for the Statistical Support Group, International Pacific Salmon Commission) has strived for a decade to find proper ways to analyze CWT studies.

The project serves as a vanguard in the development of regional capabilities to perform efficient and cost-effective tagging studies providing timely information to resource managers. Studies such as the Snake River survival studies (Project 9302900) performed by NMFS is a direct consequence of this original program.

Today, the project continues to serve its mission by tailoring the statistical methods of survival estimation and regression analyses to evolving regional research issues. The project is providing guidance on the design and analysis of the complex capture histories of fall chinook salmon smolt studies, the implementation of adult detection facilities, taking advantage of the recapture-remeasurement of smolt at downriver detection facilities and the broader issues of multiple-release analyses to estimate season-wide survival and the evaluation of survival effects. Current analyses are analyzing up to 100-200 separate release simultaneously to extract survival and capture effects (Skalski and Perez-Comas1998).

d. Project history

Project 8910700 was initiated in 1989 to develop the statistical theory and methods needed to analyze smolt and adult PIT-tag survival studies. The project developed the initial study designs for the National Marie Fisheries Service (NMFS/University of Washington (UW) Snake river survival studies of 1993-present (e.g. NMFS Project 302900) . These ongoing efforts have produced statistical software (i.e., SURPH) for UNIX- and PC-based computers which are accessible to the Columbia Basin community via Internet and the World Wide Web (WWW). Additional products include a comprehensive users manual for SURPH and software for sample size calculations. As the Snake River survival studies have evolved, the numerical needs for new and more descriptive data analyses have also increased. This project continues to maintain existing analysis capabilities as well as add new data analysis features at program users' (e.g., NMFS) request. As the new 134.2 kHz frequency PIT tag decoder systems come on-line, the survival studies will be extended to the joint analysis of survival of both downriver smolts and returning adults. The project has already developed some of the key statistical software to analyze this data. This projects stands ready to address new issues and questions the fisheries community wants to ask from PIT-tagging investigations.

Specific accomplishments by year include:

1989: Developed theory to assess survival effects that result from ambient river conditions.

1990: Began software development for statistical analyses, and began statistical theory to assess individual covariate effects on survival.

1991: Demonstrated ability to simultaneously assess ambient effects and individual covariate effects.

1992: Extended computer software to include analysis of group and individual covariate effects. Proposed "strawman" design for development of PIT-tag facilities on Snake/Columbia River. Developed study plan for a Snake River survival study evaluation.

1993: Completed statistical software development of analysis package--final debugging of computer program, helped facilitate Snake River survival study, and conducted analysis of hatchery survival studies.

1994: Completed SURPH statistical software and dissemination of a users manual for statistical analysis of data. Continued to support NMFS survival studies.

1995: Produced a PC version of SURPH software and sample size program to design tag-release studies. Continued to support NMFS survival studies.

1996: Produced report on a comparison of procedures for estimating confidence intervals and a report demonstrating applications of SURPH.1 in release-recapture survival studies. Developed proper statistical model to estimate survival rates of fall chinook smolt taking into account residualization. Developed statistical methods for estimating season-wide survival. Continued to support NMFS survival studies.

1997: Improve statistical models and software for expanded survival experiments. Continue to support Columbia River survival studies. Investigate alternative approaches to estimate ocean survival rates. Develop software that appropriately incorporates migratory behavior traits of fall chinook in survival estimation. Continued research on repeated measures of smolt traits and survival; developed model for time-varying (updated) covariates; extracted effects of smolt condition on in-river survival. Assisted Nez Perce tribe in performing survival analyses.

In conjunction with the National Marine Fisheries Service (NMFS), this study has helped to generate new biological understandings of the dynamics of smolt outmigration. These findings include:

1. Information on smolt travel time - survival relationships.
2. Information on river flow/temperature - survival relationships.
3. Comparisons of hatchery and wild chinook and steelhead smolt survival.
4. Comparison of smolt survival across 5 years and 2-4 river reaches.
5. Survival rates of upper Snake River hatchery releases.

6. Baseline survival data for comparison with potential mitigation practices in years to come.

BPA Contract Reports:

DOE/BP-02341-1: Skalski, J. R., A. Hoffmann, and S. G. Smith. 1993. Development of Survival Relationships Using Concomitant Variables Measured from Individual Smolt Implanted with PIT-tags. 1990-1992 Annual Report prepared for Bonneville Power Administration, Portland, Oregon.

DOE/BP-02341-2: Smith, S. G., and J. R. Skalski. 1994. SURPH.1 Manual: Statistical Survival Analysis of Fish and Wildlife Tagging Studies. Computer Software Manual prepared for Bonneville Power Administration, Portland, Oregon.

DOE/BP-02341-3: Center for Quantitative Science, School of Fisheries, University of Washington. 1996. Introduction to SURPH.1 Analysis of Release-Recapture Data for Survival Studies. Technical Report prepared for Bonneville Power Administration, Portland, Oregon.

DOE/BP (in press): Newman, K. Estimating Salmonid Survival with Combined PIT-CWT Tagging. 1998. Volume II in the BPA Technical Report Series, the Design and Analysis of Salmonid Tagging Studies in the Columbia Basin. Bonneville Power Administration, Portland, Oregon.

DOE/BP (in press): Newman, K. Experiment Designs and Statistical Models to Estimate the Effect of Transportation on Survival of Columbia River System Salmonids. 1998. Volume III in the BPA Technical Report Series, the Design and Analysis of Salmonid Tagging Studies in the Columbia Basin. Bonneville Power Administration, Portland, Oregon.

DOE/BP (in press): Lowther, A. B., and J. R. Skalski. 1998. Monte-Carlo comparison of confidence interval procedures for estimating survival in a release-recapture study, with applications to Snake River salmonids. Volume VII in the BPA Technical Report Series, the Design and Analysis of Salmonid Tagging Studies in the Columbia Basin Bonneville Power Administration, Portland, Oregon.

DOE/BP (in press): Lowther, A. B., and J. R. Skalski. 1998. Improved survival and residualization estimates for fall chinook using release-recapture methods. Volume VIII in the BPA Technical Report Series, the Design and Analysis of Salmonid Tagging Studies in the Columbia Basin Bonneville Power Administration, Portland, Oregon.

Dissertations:

Smith, S. G. 1991. Assessing hazards in wild populations using auxiliary variables in tag-release models. Ph.D. dissertation. Univ. of Washington. Seattle, WA.

Hoffmann, A. 1993. Quantifying selection in wild populations using known-fate and mark-recapture designs. Ph.D. dissertation. Univ. of Washington. Seattle, WA.

Other Scientific Reports Produced for Publication:

Skalski, J. R., A. Hoffmann, and S. G. Smith. 1993. Testing the significance of Individual-and cohort-level covariates in animal survival studies. EURING 92. In: Marked Individuals in the study of bird populations, edited by S.D. Lebreton and P.M. North, pp.9-28. Birkhauser Verlag. Boston, MA.

Skalski, J. R., and S. G. Smith. 1994. Risk assessment in avian toxicology using experimental and epidemiological approaches. In: Wildlife toxicology and population modelling: Integrated studies of agroecosystems, pp.467-488. Lewis Publishers. Boca Raton, FL.

Hoffmann, A., and J. R. Skalski. 1995. Inferential properties of an individual-based survival model using release-recapture data: Sample size, validity and power. J. Appl. Stat. 22:579-595.

Skalski, J. R. 1996. Regression of abundance estimates from mark-recapture surveys against environmental covariates. Can. J. Fish. Aquat. Sci. 53:196-204.

Skalski, J. R. 1996. Estimating season-wide survival rates of outmigrating salmon smolt in the Snake River, Washington. Can. J. Fish Aquat. Sci. (in press).

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1996. Use of PIT-tags to Estimate Survival of Migrant Juvenile Salmonids in the Snake and Columbia Rivers. Can. J. Fish. Aquat. Sci. (in press).

Lady, J., and J. R. Skalski. 1997. Estimators of stream residence time of Pacific salmon (spp. *Oncorhynchus*) based on release recapture data. Can. J. Fish. Aquat. Sci. (submitted).

Lowther, A. B., and J. R. Skalski. 1998. A multinomial likelihood model for estimating survival probabilities and residualization for fall chinook salmon (*Oncorhynchus tschawytscha*) smolt using release-recapture methods. J. Agri. Biol. And Envir. Stat. (submitted).

Other Related Joint Contributions:

Skalski, J. R., P. R. Mundy, and W. E. McConnaha. 1989. Suggested work plan for flow/water budget smolt survival evaluation. Submitted to the ad hoc committee on Mainstem Passage Research, Northwest Power Planning Council, June 1, 1989.

Dauble, D. D., J. Skalski, A. Hoffmann, and A. E. Giorgi. 1993. Evaluation and application of statistical methods for estimating smolt survival. Pacific Northwest Laboratory, University of Washington and Don Chapman Consultants, Inc. Technical Report (DOE/BP-62611-1) to Bonneville Power Administration.

Adaptive Management Implications

Both the Northwest Power Planning Council's Fish and Wildlife Program and the National Marine Fisheries Service (NMFS) 1995 Hydrosystem Operations Biological Opinion call for implementation of reliable monitoring and evaluation of mitigation actions within the Columbia River Basin in support of an adopted adaptive management framework. With respect to evaluating actions associated with hydropower operations, three performance measures have been repeatedly identified as being instruction; smolt mitigation speed, smolt survival through the hydroelectric complex, and subsequent survival to adulthood. Activities of this project strive to address these performance measures in an adaptive management framework by:

1. Assessing the accuracy and precision of such performance measures.
2. Identifying any deficiencies in estimation procedures.
3. Identification and/or development of analytical approaches to improve the statistical integrity of such estimates.
4. Examining the relationships between these performance measures and a variety of predictor variables that can affect salmon survival, particularly as associated with conditions encountered during their seaward migration.

This project promotes adaptive management by providing the statistical underpinnings to ongoing smolt survival studies being conducted by NMFS on the Snake/Columbia Rivers. Data generated by these studies are being used to monitor outmigration success, provide baseline information to evaluate future mitigation measures, update Columbia River models (i.e., CRiSP) and investigate river management decisions such as flow augmentation and spill programs.

Budget History

Project Initiated	Year	Annual Budget Obligated
	1989	$99,999
	1990	0,000
	1991	127,871
	1992	130,656
	1993	197,060
	1994	168,011
	1995	164,725
	1996	169,952
	1997	150,888

e. Methods.

State–of-the-art statistical methods for the analysis of PIT-tag release-recapture methods are being developed using first principles (Smith 1991, Hoffmann 1993, Lowther and Skalski 1998, Skalski et al. 1993, Skalski 1998). The research began with standard estimation methods found in Cormack (1964), Jolly (1965), Seber (1965), and Burnham et al. (1987). These point-estimation techniques were then developed in a hypotheses testing framework to assess the effects of treatment effects and group-covariates on survival relationships (Smith 1991). The theory was then generalized to allow quantifying how characterizations of individual fish influence survival and capture probabilities to more realistically characterize survival processes of wild populations (Hoffmann 1993, Hoffmann and Skalski 1995). Valid testing procedures were developed (Skalski et al. 1993) to assure survival effects would be reliably and dependably assessed, using both cohort-based and individual-based covariates. Generalized regression procedures and maximum likelihood methods are currently being investigated to find the most appropriate approach to analyzing longitudinal studies (Diggle et al. 1996) in order to validly assess the effects of updated covariates as smolt migrate downstream. These factors include changing morphology, conditions of the smolt, and their upstream passage history. The focus on valid statistical methods is to assure defensible analytical methods are used in order that the fisheries community and fisheries managers can concern themselves with the biological and resource management issues and not the uncertainties of the analyses.

f. Facilities and equipment.

This project is supported by 8 SUN UNIX workstations, 2 X-terminals, and 3 personal computers. The computer system is also supported by 20 gigabytes of storage memory and a T1 communications line for ethernet access to the Internet. This equipment has proved to be suitable to meet both project and personnel needs as well as those of other Internet users requesting access to the survival analysis software (i.e., SURPH.1).

g. References.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. Amer. Fish. Soc. Monograph No. 5.

Clobert, J., J. D. Lebreton and D. Allaine. 1987. A general approach to survival rate estimation by captures or resightings of marked birds. Ardea 75: 133-142.

Clobert, J., J. D. Lebreton, M. Clobert-Gillet, and H. Coquillart. 1985. The estimation of survival in bird populations by recapture or resighting of marked individuals. Statistics in

Ornithology, edited by B. J. T. Morgan and P. M. North, pp. 197-213, Springer-Verlag, New York.

Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51: 429-438.

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Diggle, P. J., K. Liang, and S. L. Zeger. 1996. Analysis of longitudinal data. Oxford Univ. Press. Oxford, UK. 253 pp.

Jolly, G. M., 1965. Explicit estimates from capture-recapture data with both death and immigration—stochastic model. Biometrika 52: 225-247.

Hoffmann, A. 1993. Quantifying selection in wild populations using known-fate and mark-recapture designs. Ph.D. dissertation. Univ. of Washington, Seattle, WA.

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Lowther, A. B., and J. R. Skalski. 1998a. A multinomial likelihood model for estimating survival probabilities and residualization for fall chinook salmon (*Oncorhynchus tschawytscha*) smolt using release-recapture methods. J. Agri. Biol. And Envir. Stat. (submitted).

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Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52: 249-259.

Skalski, J. R. 1998. Estimating season-wide survival rates of outmigrating smolt in the Snake River, Washington. Can. J. Fish. Aquat. Sci. (in press).

Skalski, J. R., A. Hoffmann, and S. G. Smith. 1993. Testing the significance of individual- and cohort-level covariates in animal survival studies. In: Marked Individuals in the Study of Bird Populations, edited by J. D. Lebreton and P. M. North, pp. 9-28, Birkhauser Verlag, Basel.

Skalski, J. R., and J. A. Perez-Comas. 1997. Using PIT-tag recapture probabilities to estimate project-wide fish guidance efficiency and spill effectiveness at Lower Granite Dam. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.

Smith, S. G. 1991. Assessing hazards in wild populations using auxiliary variables in tag-release models. Ph.D. dissertation. University of Washington, Seattle, WA.

Section 8. Relationships to other projects

This project provides direct support to the NMFS/UW Snake River survival studies (Project 9302900). This project assures the statistical methods and computational capabilities will be available to meet all of the NMFS analytical needs now and into the future. Statistical methods are expanded and tailored to meet the changing requirements for the design and analysis of the studies as the community needs for information grow and evolve. These same capabilities for the design and analysis of tagging studies are also made available to other Northwest agencies and tribes needing assistance in conducting survival investigations.

In 1997, these statistical capabilities were transferred to the Army Corps of Engineers (ACOE) AFEP research program to analyze PIT-tag data to provide information on spill effectiveness (SE), fish guidance efficiency (FGE), and other operational effects. In 1998, these technologies will be transferred to the Mid-Columbia where reach survival studies will be initiated for the first time since the early 1980s. In addition, these estimation capabilities are being investigated by ACOE for sluiceway PIT-tag installations to estimate sluiceway efficiencies.

Section 9. Key personnel

John R. Skalski
Professor of Biological Statistics
School of Fisheries
University of Washington
FTE = 0.17

Dr. Skalski directs the project, guides staff and graduate student progress on research, provides statistical theory underlying the research developments, sets and monitors project milestones, and monitors budget. He also provides public presentation of results, authors peer-reviewed scientific publications, and consults with interested parties on the design and analysis of tagging studies. Dr. Skalski is the author of over 50 papers and books on fish and wildlife studies.

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EDUCATION

B.S.	Wildlife Management/Biology, University of Wisconsin, Stevens Point	1974
M.S.	Wildlife Science, Oregon State University	1976
M.S.	Biometry, Cornell University	1978
Ph.D.	Biometry, Cornell University	1985

EMPLOYMENT HISTORY

1978-1985	Research Scientist, Battelle Pacific Northwest Laboratory, Richland, WA
1985-1987	Senior Research Scientist, Battelle Marine Research Laboratory, Sequim, WA
1987-1995	Associate Professor, University of Washington, Center for Quantitative Science, School of Fisheries, Seattle, WA
1992-1995	Interim Director, Center for Quantitative Science in Forestry, Fisheries, and Wildlife, University of Washington
1994-1995	Chair, Interdisciplinary Graduate Program in Quantitative Ecology and Resource Management, University of Washington
1995-Present	Professor, University of Washington, School of Fisheries, Seattle, WA

CERTIFICATION

Certified Wildlife Biologist, 1982, The Wildlife Society.

EXPERIENCE

Dr. Skalski has 20 years of experience as a research scientist and professor of biological statistics. His expertise is in the statistical methods of parameter estimation, sampling theory, impact assessment, population dynamics, and mark-recapture theory. Of particular relevance is his experience and expertise in effects assessment on mobile species and the design and analysis of animal tagging studies. He has been chief statistician on accident assessments of major oil spills, design and analysis of impact

assessment studies of major energy production facilities, hydroacoustic fish surveys, and fish tagging studies. He has worked on the design and analysis of Columbia River salmonid tagging studies for nine years.

SELECTED PUBLICATIONS

Skalski, J. R. 1998. Estimating season-wide survival rates of outmigrating smolt in the Snake River, Washington. Can. J. Fish. Aquat. Sci. (in press).

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1998. Use of PIT-tags to estimate survival of migrating juvenile salmonids in the Snake and Columbia Rivers. Can. J. Fish. Aquat. Sci. (in press).

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Hoffmann, A., and J. R. Skalski. 1995. Inferential population of an individual-based survival model using release-recapture data: Sample size, validity, and power. J. Appl. Stat. 22: 579-595.

Skalski, J. R., A. Hoffmann, and S. G. Smith. 1993. Testing the significance of individual-and cohort-level covariates in animal survival studies. EURING 92. In: Marked Individuals in the study of bird populations, pp. 9-28. S. D. Lebreton and P. M. North (Eds.). Birkhauser Verlag. Boston, MA.

Skalski, J. R., and D. S. Robson. 1992. Techniques for Wildlife Investigations: Design and analysis of capture data. Academic Press. 237 pp.

Section 10. Information/technology transfer

The primary product of this project is a technology transfer of information on the most appropriate, sensitive, and valid means of analyzing tagging data to extract survival information useful in management decision. The project also conveys information on the most effective and cost-efficient study designs for analyzing smolt and adult survival studies.

Information is disseminated by BPA technical reports, University dissertations, and scientific peer-reviewed literature. SURPH.1 software and user manuals are distributed upon request to all users, and the software and instructions can be downloaded through the Internet (*http://www.cqs.washington.edu/surph)*. In addition, users can perform their analysis through the Internet site. Project personnel are also available to provide statistical support to any individual in the Northwest fisheries community upon request. Personnel respond to requests by telephone, mail, Internet e-mail, and site visits, depending on user needs and preferences.