KARIN IMMERGUT, OSB #96314
United States Attorney
STEVE ODELL, OSB #90353
Assistant United States Attorney
District of Oregon
600 United States Courthouse
1000 S.W. Third Avenue
Portland, OR 97204-2902
(503) 727-1000

KELLY A. JOHNSON
Acting Assistant Attorney General

SETH M. BARSKY, Assistant Section Chief
ROBERT L. GULLEY, Senior Trial Attorney
RUTH ANN LOWERY, Trial Attorney
ruth.lowery@usdoj.gov
Wildlife & Marine Resources Section
Benjamin Franklin Station, P.O. Box 7369
Washington, D.C. 20044-7369
(202) 305-0217 (ph)
(202) 305-0275 (fax)

FRED R. DISHEROON, Special Litigation Counsel
fred.disheroon@usdoj.gov
U.S. Department of Justice
Environment & Natural Resources Division
Benjamin Franklin Station, P.O. Box 7397
Washington, D.C. 20044-7397
(202) 616-9649 (ph)
(202) 616-9667 (fax)

Attorneys for Defendant

UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

NATIONAL WILDLIFE FEDERATION, et al.,

Plaintiffs,

and

STATE OF OREGON,

Intervenor-Plaintiff

Civ. No. 01-0640-RE (Lead Case)
Civ. No. 05-0023-RE
(Consolidated Cases)

Declaration of
PAUL A. OCKER

v.

NATIONAL MARINE FISHERIES SERVICE,
U.S. ARMY CORPS OF ENGINEERS and
U.S. BUREAU OF RECLAMATION,

Defendants,

and

NORTHWEST IRRIGATION UTILITIES, PUBLIC POWER COUNCIL, WASHINGTON STATE FARM BUREAU FEDERATION, FRANKLIN COUNTY FARM BUREAU FEDERATION, GRANT COUNTY FARM BUREAU FEDERATION, AND STATE OF IDAHO,

Intervenor-Defendants.

COLUMBIA SNAKE RIVER IRRIGATORS ASSOCIATION, AND EASTERN OREGON IRRIGATORS ASSOCIATION,

Plaintiffs

v.

DONALD L. EVANS, in his official capacity as Secretary of Commerce, NOAA FISHERIES, and D. ROBERT LOHN, in his official capacity as Regional Director of NOAA Fisheries,

Defendants.

I, Paul A. Ocker, hereby state and declare as follows:

1. I am a Fishery Biologist in the Northwestern Division Office of the U.S. Army Corps of Engineers (Corps), employed in my present position since April 2004. My primary responsibilities include supporting the Portland and Walla Walla Districts' execution of the

Anadromous Fish Evaluation Program (AFEP) and budgeting the Operations and Maintenance Fish and Wildlife Program for the Portland, Seattle and Walla Walla districts.

2. I earned a Bachelor of Science degree in Biological Sciences, with an emphasis in marine science, from the California Polytechnic State University in San Luis Obispo, CA. in March of 1991, and have attended additional marine science related classes at the University of Oregon.

3. I have worked for the U.S. Forest Service performing habitat work for Chinook and coho salmon and cutthroat trout in the Siuslaw National Forest and was employed by the National Park Service in Homestead, Florida from 1991-1992, where my duties included surveying recreational fishermen and performing water quality analysis for the waters of the park. From 1993-1995, I worked for the National Marine Fisheries Service (NMFS), performing radiotelemetry and PIT tag research of both juvenile and adult salmon and steelhead in the Snake River Basin. From 1995-1999, I worked for the Columbia Basin Fish and Wildlife Authority and the U.S. Fish and Wildlife Service performing fish and wildlife habitat research in the Columbia River Basin. From 1999-2000, I was employed by the Pacific States Marine Fisheries Commission to research and assess the migratory success of adult Pacific Lamprey in relation to the Federal Columbia River Power System (FCRPS).

4. From 2000 to 2004, I worked with the Corps' Walla Walla District, planning and overseeing research under the AFEP (including assessment of the Juvenile Fish Transportation program) and performing the duties of Project Manager for ecosystem restoration projects. As a lead technical fishery biologist, I participated in writing biological assessments, reviewing reports for scientific credibility, and performing ESA consultations.

5. In this declaration, I am providing relevant information in response to the declarations of Stephen W. Pettit and Fredrick E. Olney, regarding Plaintiffs' Motion for Preliminary Injunction.

6. In his declaration, Mr. Pettit indicates that spill has been an important management tool at FCRPS dams, adequate flow and water velocity are critical for salmon and steelhead survival, and that the Plaintiffs' request for injunctive relief will reduce harm to salmon.

7. Mr. Olney's declaration discusses the potential drawing down of reservoirs, spreading the risk with respect to transporting juvenile fish, estimates of inriver survival for fall Chinook, increasing flows for juvenile fall Chinook, and fish research and regional collaboration.

8. In my opinion, many of the statements contained in these declarations are misinterpretations of the data and are taken out of context and have other failings such as they attempt to make correlations concerning fish survival between species that are not appropriate, obfuscate what is meant by spread the risk, and base their opinions on outdated information that ignores more recent analyses.

9. <u>Misinterpretation of Flow survival information</u> – The request for preliminary injunction seeks to decrease water particle travel time by 10% in the Snake River between June 20 and August 31, 2005 from Lower Granite to Ice Harbor dams "in an effort to establish the most favorable conditions for listed species." (Olney Declaration, paragraph 12)

10. However, the relationship of increased flow to the survival of listed Snake River (SR) fall Chinook salmon is poorly understood. While numerous studies have attempted to examine these relationships for Columbia River Basin salmonids overall, recent information has demonstrated that there may be little correlation. (A.R. 209, NOAA AR B.48). Smith et al 2002 indicated that flow survival relationships in the lower Snake River were weak for spring

migrants. In addition, research conducted by NOAA Fisheries indicated that for SR fall Chinook, while a correlation between flows and survival existed, this correlation was not any different than the correlations that occurred with temperature and turbidity changes. (NOAA A.R. B.227)

11. At a flow symposium conducted by NOAA Fisheries and the Northwest Power and Conservation Council on November 9-10, 2004, the Independent Scientific Advisory Board (ISAB) concluded that the state of relevant science on flow survival relationships for fall Chinook salmon was in flux, "providing no unambiguous answers at this time." (A.R. 80) They also indicated that, "[w]ith the recent findings of the large adult contribution from migrants exhibiting the reservoir life history… the strategy of using flow augmentation to speed migration should be reassessed."(A.R. 80)

12. While I agree with Mr. Pettit that salmon need good water and flow conditions to survive and thrive, I believe that the science does not necessarily support his assessment that the operations requested would benefit fall Chinook over current operations. His continual references to research with spring migrants only confuse the issue because spring and summer migrating fish have different behaviors, requirements and life history characteristics.

13. Therefore there is no universal flow survival relationship, and to the extent declarants Pettit and Olney, suggest there is such a relationship, their suggestions are not appropriate. Mr. Pettit repeatedly refers to flow survival relationships and migratory behaviors for spring Chinook (e.g. Ossiander and Sims, Congleton, etc.), and obfuscates the information by applying it to fall Chinook, which exhibit different life history traits, requirements, and behavior (Pettit declaration, paragraphs 12, 15, 16, 20, 21, 48).

14. In the Pettit declaration, paragraph 14, he indicates that the relationship between water particle travel time and survival is supported by the science, however this is incomplete information. Connor et al 2002 (Attachment 1) demonstrated that temperature is another important variable concerning fall Chinook survival. In addition, for fall Chinook released in Hells Canyon, NMFS reported:

> [e]stimated survival to Lower Granite Dam and release date were also significantly correlated with three environmental variables: flow, water temperature, and turbidity. Survival decreased as flow volume and turbidity decreased (water clarity increased) and water temperature increased. Because of strong correlations among the environmental variables, it is not possible to determine unequivocally which variable had greatest influence on survival. (NOAA A.R. B. 227)

15. Relating travel time of actively migrating subyearling fall Chinook salmon to environmental variables through reservoir reaches has proved difficult for researchers and has produced conflicting results. Giorgi et al. (1997) (Attachment 2) found that PIT-tagged subyearling Chinook salmon in the mid-Columbia River showed no response to flow or temperature, although there was a significant positive correlation between fish length and migration rate; whereas, Berggren and Filardo (1993) (Attachment 3) found faster migration with higher flow and lower water temperature. Smith reported that "[r]esults are likely affected by the time and location of tagging and release of subyearling fall Chinook salmon, as they rear and develop physiologically during the migration period and their migration rate generally increases with migration distance and increased size." (NOAA A.R. B. 227)

16. The ISAB has concluded that Connor's flow survival formula showed that increased summertime flows in the lower Snake River may have increased temperatures, which may cause greater mortality rather than survival benefits. (A.R. 80) Therefore, considering flow augmentation without considering the impacts of temperature is a flaw in the plaintiffs'

assertion that increasing flows is necessary for improving fall Chinook survival as indicated in Mr. Olney's declaration (paragraph 17).

17. In Mr. Pettit's declaration, paragraph 16, he refers to "the positive impact increased flows have on moving juvenile salmon and steelhead through the hydrosystem and on decreasing river temperatures…," in an attempt to link flow augmentation to lowering river temperature. This oversimplification fails to acknowledge that the plaintiffs' recommendation to increase water velocities could include increasing releases from Idaho Power Company's Brownlee Reservoir during the summer. These releases would likely increase the water temperatures between Hells Canyon Dam and Lower Granite Reservoir. The benefits to migrating fish with flow augmentation under spring water conditions cannot be construed to be the same with summer water conditions, in part because of the likelihood of increased water temperatures. While temperatures and flow are often correlated, this is not always the case. For example, in Smith et al 2002 (NOAA A.R. B. 227), survival was measured between McNary and John Day Dams in 1998 and 2001. Flow in 2001 was substantially lower than in 1998; however, temperature was substantially lower as well. Survival in that stretch of the river was higher in 2001 than in 1998 when lower flow conditions existed, yet temperatures were lower as well, suggesting that temperature plays a larger role in survival than the plaintiffs' address.

18. The fall Chinook population has been expanding in recent years. Counts of adults (not including jacks, precocious males) have increased between 1995 and 2004, from 1,063 to 14,963 at Lower Granite and from 2,739 to 21,104 at Ice Harbor Dam (including Lyon's Ferry Hatchery fish) (Attachment 4). While this increase is attributed in part to different hatchery practices, ocean conditions, and ocean harvest reductions, it is counterintuitive to

believe that changes to the operation and configuration of the hydrosystem since the listing of the species have not also contributed to this population increase.

19. Misinterpretation of Spread the Risk - The spread the risk approach for juvenile migration is used when there is inadequate scientific information to determine the management strategy that would most benefit either a population or sub-population of anadromous fish (e.g. transport or inriver migration). In this instance, the best management option may be to implement more than one management option in an attempt to maintain stock viability and genetic diversity. (NOAA A.R. B. 157).

20. The spread-the-risk approach for spring/summer juvenile Chinook salmon and steelhead has resulted from decades of applied research. This approach continues to be modified, as was proposed by the Action Agencies in the Updated Proposed Action (UPA), to delay initiation of transport and provide additional spill in the early spring under certain flow conditions as outlined in the UPA.

21. Comprehensive studies to better understand the requirements of fall Chinook, including a spread the risk strategy, are presently being planned. It would be premature to depart from NOAA's recommended strategies without understanding how to most appropriately spread the risk. The recommended summer operation, to maximize transportation of juvenile fall Chinook has been consistently implemented over the last several years, including in the 2000 RPA, the Action Agencies' UPA and the 2004 BiOp. This means that most migrating juveniles are collected and transported at Lower Granite, Little Goose, Lower Monumental, and McNary dams; those that aren't collected either migrate inriver through the turbines or hold over in the reservoirs to migrate to the ocean at a later time.

22. Plaintiffs are advocating a spread the risk approach for Snake River fall Chinook by assuming that the research results for inriver and transported spring migrating fish can be transferred to the transportation of summer migrating fall Chinook. They are asking the court to require that the Action Agencies either provide or increase spill at the four lower Snake River projects and at McNary in the Columbia, except for the amount of water necessary for "station service" at the Snake River dams (Pettit, paragraph 46). Mr. Pettit states that "without spill, there is no spread-the-risk alternative. In order to balance the risks and uncertainties of the benefits of the transportation alternative, spill must be maximized as part of the improvement of inriver migration conditions." (Pettit, paragraph 30). In essence, plaintiffs' suggestion to provide spill is not a spread the risk approach because the consequence is that most fish would likely go through the spillway and turbines leaving very few fish to be collected for transport. This is further confirmed in Mr. Olney's declaration where he states, "the number of juveniles left to migrate in–river would be increased significantly by reducing the number of fish transported." (Olney paragraph 13).

23. Mr. Olney also cites Williams et al 2004 (NOAA A.R. B. 266) stating, "no empirical evidence exists to suggest that transportation either harms or helps fall Chinook salmon. Thus, it is uncertain whether transport provides a benefit or a detriment for SR fall Chinook." However Mr. Olney failed to include the preceding point from Dr. Williams' report in which Williams notes "a severe lack of data on transported fish hindered our ability to provide good comparisons between transported and inriver fish." Williams et al also reported that "strategies such as 'spread the risk' and promotion of diversity suggest we should allow more fish to migrate in the river whenever it appears migration might lead to reasonable return rates compared to the alternatives. At times, transportation may provide the best alternative."

24. A NOAA Fisheries' analysis for fall Chinook (NOAA A.R. C.108) has indicated that system survival for fall Chinook for the 5-year period of 1995-1999 was increased with the use of transport. In addition, while the years 2000 and 2003 showed a modest benefit for inriver migrants over transport, 2001 migrants experienced roughly 280% higher system survival with transport; this is believed to be related to the very low water conditions of that particular year having a deleterious impact to fall Chinook inriver migrants. While recent information has cast some doubts on the actual survival estimates, the comparative nature of this analysis indicates that transport may be the optimum option during a low flow year.

25. However, other analyses regarding the transportation of juvenile fall Chinook salmon raise uncertainties regarding the effectiveness of transport for these fish. Although there was no research conducted to answer these questions, a data analysis was performed by the Fish Passage Center (Attachment 5). This recent analysis suggests that the benefit of the transportation program to fall Chinook may need to be reevaluated and consideration given to using the spread the risk approach, similar to the approach used during the spring migration.

26. The Corps has some reservations about this recent Fish Passage Center analysis for the following reasons: it was unclear which stocks of fish were used (e.g. hatchery fish, wild fish); the comparative ratios of transport to inriver relied on very small numbers and therefore may not be suitable for appropriate statistical precision; and, the groups of fish that were used were handled differently and may not have been representative of the transport process.

27. Recent reports have indicated that estimates of inriver survival for fall Chinook (see paragraph 24), as reported by Mr. Olney, are not calculable due to the numbers of juvenile

fall Chinook holding over in the reservoirs. (A.R. 58, A.R. 80, NOAA A.R. B. 79). Unknown percentages of juvenile fall Chinook hold over in various reservoirs each year and are assumed to be mortalities when performing analyses of downstream survival. There is an inconsistency in the current information, which indicates that some fall Chinook hold over and rear in the lower Snake River reservoirs (holdovers), whereas the basic assumptions in the Cormack-Jolly-Seber Survival Model assume that all fish have an equal probability of detection during that migration year. However, the holdover fall Chinook go undetected and thus may be erroneously assumed to represent additional mortalities. Therefore any calculations of inriver survival that Mr. Olney has used do not accurately represent what is actually occurring.

28. While the plaintiffs want to use information on inriver and transported spring fish to support their contention that there should be a spread the risk approach for juvenile fall Chinook, they fail to use all of the information that would support maximized transportation in low water years. Recent reports have indicated that in low flow years, such as those expected in 2005 (particularly 2001), that benefits of transporting hatchery spring Chinook exceeded 25:1 versus migrating inriver (i.e. transported fish returned as adults at a rate 25 times higher than that for fish that migrated in the river). For wild spring Chinook this value exceeded 9:1, and transporting hatchery summer Chinook exceeded 32:1 (A.R. 73). While I do not believe that this data is fully applicable to fall Chinook, this data does demonstrate that during low flow conditions, transportation has great potential as a management tool for protecting endangered fish.

29. An August 24, 2004 memo from Williams to Ruff (A.R. 133), indicates that while survival downstream for subyearling migrants may be increased by a summer spill operation, the

returning adult population could be decreased due to a reduction of the potential holdover population. The fall Chinook that hold over in reservoirs come back at much higher rates than those fish that migrated out as subyearlings. For example, holdover fish, believed to make up a very small part of the brood year population, have comprised upwards of 25-86% of the adult returns depending on the outmigration year (NOAA A.R. B. 47). Maximizing spill in the lower Snake River would likely flush most of those fish downriver, depriving them of the opportunity to hold over in the Snake River reservoirs.

30. Further, leaving fish to migrate inriver during low flow conditions has substantial risk. Existing information indicates that inriver survival through the free flowing Hells Canyon section of the Snake River and the Lower Granite Reservoir can cause a high level of mortality prior to the fish reaching the first collector project. Smith et al 2002 reported, "[f]rom 1995 through 2000, estimated survival probabilities typically ranged from a high of 45 to 65% for the earliest releases down to a low of 5 to 10% for the latest. In the extremely low-flow conditions of 2001, the greatest survival probability estimates for Billy Creek and Pittsburg Landing release groups were 41% and 11%, respectively. For the latest release groups in 2001, estimated survival was less than 1%."(NOAA A.R. B. 227) While this information should be viewed with caution considering the holdover potential for these fish and the accuracy of the survival estimates, these survival estimates elicit concern for allowing these stocks of fish to migrate inriver.

31. The Corps believes that maximizing transportation during this low water year is the best management strategy with the least risk for 2005 as supported in part by information from the ISAB 2003 review of flow augmentation (Attachment 6), NOAA-Fisheries (NOAA A.R. C. 108) and as addressed by the FCRPS 2000 BiOp, which states on page 9-76, "[t]he Corps

and BPA shall operate the collector projects to maximize transportation during the Summer migration (i.e., no voluntary spill except as NMFS deems necessary for approved research)," "The summer transport strategy is to maximize collection and transportation due to concerns about low inriver survival rates," "fish spill is curtailed, and all collected fish are transported during the summer to improve overall juvenile fish survival," and "NMFS has chosen to maximize transportation of fall migrants because of the adverse conditions that exist for inriver migrants during the summer season."

32. The Corps agrees with NOAA Fisheries that there is a lack of scientific information for spreading the risk for fall Chinook, and believes that to implement a spread the risk transportation operation for 2005 poses unnecessary risks to juvenile fall Chinook salmon in this low flow year. The Corps is planning research towards obtaining better information using a scientific approach (see Peters' Declaration, paragraph 22), and until additional data is obtained, the Corps supports the current transportation strategy for juvenile fall Chinook as addressed by the 2004 BiOp.

Operation of Lower Granite Reservoir at Elevation 723 msl

33. The plaintiffs believe the Corps should operate Lower Granite Reservoir ten feet below the authorized minimum operating pool (MOP) of elevation 733 mean sea level (msl) from June 21, 2005 through August 31, 2005. The plaintiffs claim that this operation will improve subyearling fall Chinook salmon survival through the lower Snake River based on a posited increase in the water travel time from Lewiston, Idaho to the mouth of the Snake River. But such an operation may have adverse affects on the survival of subyearling fall Chinook salmon and other species in the lower Snake River and adverse affects on the Lower Granite Reservoir environment by:

a) Eliminating operation of the juvenile bypass system at Lower Granite Dam and the Juvenile Fish Transportation Program,

b) Impacting adult fish passage at Lower Granite Dam,

c) Negatively affecting shallow water and shoreline aquatic areas in the reservoir and,

d) Negatively affecting riparian habitat and Habitat Management Units along the reservoir.

Juvenile Fish Passage at Elevation 723

34. Operation of the Lower Granite project with a reservoir elevation of 723 msl would negatively impact juvenile fish passage. The lowered reservoir would require the Corps to remove the fish screens from the turbine units with a majority of the river flow spilled, forcing nearly all migrating juvenile fish to pass either through the turbine units or spill. Although some fish would still enter the gatewells, lowering the reservoir to elevation 723 msl would take the juvenile bypass system out of operation. The gatewell orifices for the juvenile bypass system are designed to operate with a reservoir elevation of at least 733 msl. Lowering the reservoir 10 feet to elevation 723 from June 21 to August 31 would lower the water surface of the turbine gatewells to below the level of the orifices, thereby dewatering and eliminating the juvenile bypass system from operation. Turbulent gatewell conditions would ensue and without an orifice for the fish to exit through, high mortality to fish would likely result in just a few hours. Under normal reservoir operations, the Fish Passage Plan (A.R. 77) limits the operation of a turbine unit with a fish screen in place and a closed gatewell to a period of less than 5 hours for emergency purposes only. Lowering the reservoir elevation to 723 msl would also eliminate the juvenile fish transportation program at Lower

Granite Dam (see paragraph 23), thereby reducing the spread the risk management option as discussed by NOAA.

35. Operating the turbine units for fish passage under the lowered reservoir as requested by the plaintiffs would increase turbine mortality above what it is for normal operations. Turbine units would be operating at a lower head (forebay level) outside of the normal designed operating conditions. This turbine operation may cause increased turbulent flow and subject fish to greater risk. This is recognized in the Fish Passage Plan (A.R. 77) with the requirement to operate the more efficient turbine units at Lower Granite during the night, the period of greater turbine passage by juvenile fish, and the requirement to operate all turbine units within one percent of their best efficiency.

36. Operating the reservoir at a lower elevation, however, would eliminate the use of the Removable Spillway Weir (RSW), which has been found to be a beneficial method for passing spring migrating juvenile salmonids. The RSW is a structure installed in spillbay one at Lower Granite Dam and is an extension of the spillway crest to better attract surface oriented fish. The crest of the RSW is at elevation 722 msl and holding the reservoir at elevation 723 msl would essentially take the RSW out of operation.

37. The Corps has observed that when a high percentage of the total river flow is spilled, a large eddy develops in the tailrace of the dam (A.R. 227). A predator study (Attachment 7) showed that during spill operations, predators in the tailrace of Lower Granite Dam tended to seek out the lower velocity areas. If an eddy were set up, it has the potential to continually cycle juvenile fish through it and increase their exposure to predators.

Lower Granite Reservoir Drawdown and Adult Fish Passage.

38. During normal reservoir operations, all water for the Lower Granite adult fish ladder is provided by gravity flow from the reservoir. Adult fish passing the dam swim up the fish ladder and through the ladder exit into the forebay. During lowered reservoir operations for emergency operations or such as the 723 foot elevation suggested by plaintiffs,' the adult fish ladder would be above the water surface. The ladder at Lower Granite Dam was constructed with an auxiliary water supply system and emergency exit to provide for those unusual instances when the reservoir elevation is lowered to prevent flooding at the Snake River-Clearwater River confluence. An alternate overflow weir and slide exit could be re-installed to provide a way for the fish to exit the ladder to the lowered reservoir level. As designed and constructed, the alternate fish ladder was meant for an emergency operation only and provides only a marginal adult fish passage condition.

39. Lower Granite project has operated the alternate fish ladder exit only once since it was constructed. This occurred during 1992 Lower Granite reservoir drawdown test (A.R. 227) Only a few fish were observed passing down the slide on the backside of the overflow weir, indicating only a few fish were able to pass the ladder. It is not known how many fish successfully passed through the exit during this operation, nor is information available on the amount of time fish took to successfully pass that route.

40. Operation of the fish ladder for two months with a lowered reservoir, as requested by the plaintiffs, would require passing nearly all of the adult summer Chinook migration and nearly all of the Snake River sockeye population through the ladder under marginal exit conditions. The 2000-2004 average passage numbers of adult salmon and steelhead during the June 21 through August 31 time period were over 13,000 Chinook, 102 sockeye and over 12,000

steelhead (Attachment 8). Forcing large numbers of adult fish to pass over one overflow weir and down an 18-inch diameter slide would likely cause a delay in fish passage exceeding that of the normal ladder operations.

41. In addition, this system would require a maximum operation of the auxiliary water pumping system to properly operate. Any pump or equipment failures during this long operation would severely impact flows in the ladder preventing operation of the ladder exit. If this were to happen, adult passage would be severely impacted or blocked completely, depending on the severity of the problem.

Impacts on Lower Granite Reservoir Aquatic Ecosystem

42. Operating Lower Granite Reservoir at elevation 723 msl would adversely affect all shoreline aquatic habitats. The 30-day reservoir drawdown test conducted in March, 1992 impacted invertebrates, crustaceans, and mollusks in the exposed shallow water areas (A.R. 227). As the reservoir receded during this test, benthic organisms and crustaceans were able to bury themselves in the mud or ponded areas and survived until these areas dried up. Mussels have limited mobility and were not able to follow reservoir water level as it receded and many perished. A two-month drawdown during the summer would likely result in complete drying out of the drawdown area, resulting in a large loss of aquatic invertebrate species. Loss of organisms in the drawdown area would also cause predatory fish that rely heavily on invertebrates as a food source, to shift towards preying more on salmonids as their food source due to the drawdown.

Impacts on Lower Granite Reservoir Riparian Habitat and Habitat Management Units

43. The Corps operates and maintains eleven intensively managed irrigated Habitat Management Units (HMU's) along the lower Snake River as mitigation for losses of wildlife and riparian

habitat due to the construction of the four projects. Two of these HMU's are located on Lower Granite Reservoir, Chief Timothy and Hellsgate HMU's, and rely on irrigation using water intakes in the reservoir for the establishment and maintenance of vegetation. Lowering the reservoir to elevation 723 msl during the summer would make the irrigation systems inoperable during the peak of the irrigation season. This would lead to the loss of small trees and shrubs during the heat of the summer, impact the growth of grasses used for hiding and nesting cover for upland birds, and retard the growth of food plots designed for additional food supply for wildlife during the fall and winter. Operating the lower Snake River reservoirs at MOP since 1992 has provided a stable reservoir elevation that has enabled riparian vegetation to grow in many areas where it was lacking prior to the initiation of MOP operations. Operating the reservoir ten feet below MOP for two months during 2005 may negatively impact this habitat. This habitat would most likely recover or reestablish itself over time, however, if this operation was not repeated.

Summary

44. In summary, I believe that maximizing transportation for Snake River fall Chinook in 2005 poses less risk to the population than attempting experimental reservoir draw downs, flow augmentation, and experimental spill. This is based in part on the greater number of unknowns that the population is subject to during inriver migration through downstream dams and reservoirs. I also believe that there is no conclusive data to support the argument that there are absolute benefits of transport versus inriver migration. I also believe that drawing down the reservoir to elevation 723 would have serious negative consequences to Snake River fall Chinook, sockeye and steelhead, and the ecology of the Lower Granite Reservoir and adjoining areas.

45. Pursuant to 28 U.S.C. § 1746, I declare under the penalty of perjury that the foregoing is true and correct to the best of my knowledge, based on my education, experience and professional judgment. Executed April 20, 2005, at Portland, Oregon.

Paul A. Ocker
Fishery Biologist
U.S. Army Corps of Engineers

ATTACHMENT 1

Connor et al 2002

DECLARATION OF PAUL A. OCKER

North American Journal of Fisheries Management 23:362–375, 2003
American Fisheries Society 2003

Influence of Flow and Temperature on Survival of Wild Subyearling Fall Chinook Salmon in the Snake River

WILLIAM P. CONNOR* AND HOWARD L. BURGE

U.S. Fish and Wildlife Service, Post Office Box 18, Ahsahka, Idaho 83520, USA

JOHN R. YEARSLEY

U.S. Environmental Protection Agency, 1200 Sixth Avenue, Seattle, Washington 98101-9797, USA

THEODORE C. BJORNN[1]

U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho 83843, USA

Abstract.—Summer flow augmentation to increase the survival of wild subyearling fall chinook salmon *Oncorhynchus tshawytscha* is implemented annually to mitigate for the development of the hydropower system in the Snake River basin, but the efficacy of this practice has been disputed. We studied some of the factors affecting survival of wild subyearling fall chinook salmon from capture, tagging, and release in the free-flowing Snake River to the tailrace of the first dam encountered by smolts en route to the sea. We then assessed the effects of summer flow augmentation on survival to the tailrace of this dam. We tagged and released 5,030 wild juvenile fall chinook salmon in the free-flowing Snake River from 1998 to 2000. We separated these tagged fish into four sequential within-year release groups termed cohorts ($N = 12$). Survival probability estimates (mean ± SE) to the tailrace of the dam for the 12 cohorts when summer flow augmentation was implemented ranged from 36% ± 4% to 88% ± 5%. We fit an ordinary least-squares multiple regression model from indices of flow and temperature that explained 92% ($N = 12$; $P < 0.0001$) of the observed variability in cohort survival. Survival generally increased with increasing flow and decreased with increasing temperature. We used the regression model to predict cohort survival for flow and temperature conditions observed when summer flow augmentation was implemented and for approximated flow and temperature conditions had the summer flow augmentation not been implemented. Survival of all cohorts was predicted to be higher when flow was augmented than when flow was not augmented because summer flow augmentation increased the flow levels and decreased the temperatures fish were exposed to as they moved seaward. We conclude that summer flow augmentation increases the survival of young fall chinook salmon.

Survival of chinook salmon *Oncorhynchus tshawytscha* smolts during seaward migration is affected by biotic factors, some of which are controlled by the physical environment. Researchers have proposed that streamflow and temperature act together to influence survival of chinook salmon smolts (Kjelson et al. 1982; Kjelson and Brandes 1989; Connor et al. 1998). Dams have altered the flow and water temperature regimes of rivers in the western United States, thereby contributing to declines in abundance of many stocks of chinook salmon by reducing smolt survival (e.g., Raymond 1988; Yoshiyama et al. 1988).

Raymond (1979) was the first to estimate survival for yearling Snake River spring and summer chinook salmon smolts, and to relate a decline in survival over years to dam construction. From 1966 to 1968, Raymond (1979) estimated that survival from the Salmon River to Ice Harbor Dam (Figure 1) for yearling spring and summer chinook salmon smolts was 85–95%. Between 1970 and 1975, Lower Monumental and Little Goose dams (Figure 1) were completed, and smolt survival estimates to Ice Harbor Dam decreased to 10–50% (Raymond 1979). Raymond (1979) concluded that during high flow years, lethal levels of dissolved gases killed yearling spring and summer chinook

* Corresponding author: william_connor@fws.gov
[1] Deceased

Received December 14, 2001; accepted July 22, 2002

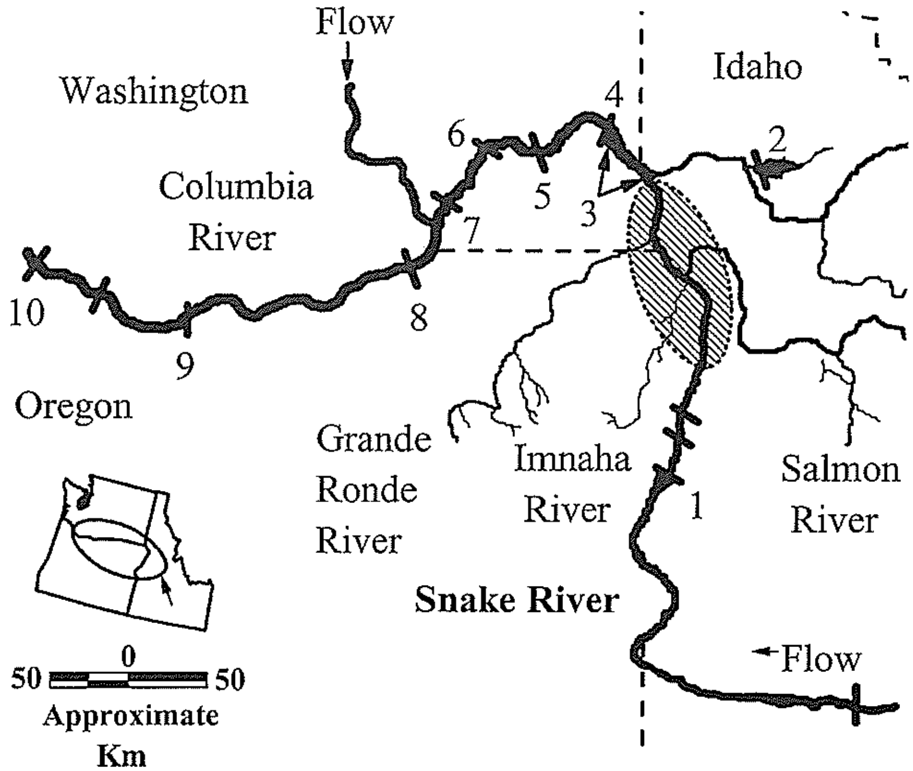


FIGURE 1.—Locations of the free-flowing Snake River where adult fall chinook salmon spawn and their offspring were captured by beach seine (cross-hatched ellipse; river kilometer [rkm] 224 to rkm 361), and other landmarks mentioned in the text. The locations are as follows: (1) Brownlee Reservoir and Brownlee (upstream most), Oxbow, and Hells Canyon dams; (2) Dworshak Dam and Reservoir; (3) Lower Granite Reservoir; (4) Lower Granite Dam (passive integrated transponder [PIT]-tag monitoring); (5) Little Goose Dam (PIT-tag monitoring); (6) Lower Monumental Dam (PIT-tag monitoring); (7) Ice Harbor Dam; (8) McNary Dam (PIT-tag monitoring); (9) John Day Dam (PIT-tag monitoring); and (10) Bonneville Dam (PIT-tag monitoring).

salmon smolts, whereas in low flow years, mortality resulted from low reservoir water velocities, delayed reservoir passage, predation, and passage via dam powerhouses.

Wild subyearling chinook salmon that pass downstream in the lower Snake River reservoirs from May to August include spring, summer, and fall-run juveniles that are listed under the Endangered Species Act (NMFS 1992). Wild fall chinook salmon typically compose the majority of the subyearling smolts that pass downstream during summer in the lower Snake River (Connor et al. 2001a). The minority is composed of wild spring and summer chinook salmon that disperse long distances from natal streams into the Snake River, where they adopt an ocean-type life history similar to that of fall chinook salmon (Connor et al. 2001a, 2001b). For simplicity, we refer to all of the wild subyearling chinook salmon that inhabit the shorelines of the Snake River as fall chinook salmon.

Dam construction changed juvenile fall chinook salmon life history in the Snake River basin by eliminating production in the relatively warmer water of the historical spawning area, thereby restricting spawning to less-productive, cooler reaches of river (Connor et al. 2002). This helps explain why present-day smolts migrate seaward during summer in contrast to their pre-dam counterparts that migrated seaward in late spring (Connor et al. 2002). Summer flow augmentation is intended to help recover the Snake River stock of fall chinook salmon by mitigating dam-caused changes in life history timing (NMFS 1995).

Summer flow augmentation is made up of releases of water from Dworshak Reservoir and reservoirs upstream of Brownlee Dam (NMFS 1995; Connor et al. 1998; Figure 1). These releases increase flow and decrease water temperature in Lower Granite Reservoir (Connor et al. 1998; Figure 1). Summer flow augmentation increases the rate of seaward movement of fall chinook salmon passing downstream in Lower Granite Reservoir, and reduces the time smolts take to pass Lower Granite Dam (Figure 1) by an average of 1–5 d (Connor et al. 2003).

Connor et al. (1998) concluded that summer flow augmentation also increased fall chinook salmon survival to Lower Granite Dam, and recommended that future studies should include sequential within-year releases of tagged fish and survival estimation based on a mark–recapture approach. In this paper, we estimate survival from release in the free-flowing Snake River to the tailrace of Lower Granite Dam with a mark–recapture approach. We test the effects of flow and water temperature on survival and then assess the effect of summer flow augmentation on survival.

Methods

Data collection.—We analyzed data collected on fall chinook salmon from 1998 to 2000. Data for these years were selected because sample sizes of tagged fall chinook salmon were large, and tagged fish were not handled as they passed Lower Granite Dam. Field personnel captured fall chinook salmon with a beach seine (Connor et al. 1998). Sampling typically started in April, soon after fry began emerging from the gravel, and was conducted 3 d/week at permanent stations. Once a majority of fish were at least 60 mm fork length, additional stations were sampled 1–2 d/week for three consecutive weeks. Sampling was discontinued in June or July, when the majority of fish had moved into Lower Granite Reservoir or points downstream.

Passive integrated transponder (PIT) tags (Prentice et al. 1990a) were inserted into parr that were 60 mm in fork length and longer (Connor et al. 1998). Tagged parr were released at the collection site after a 15-min recovery period. Some of the PIT-tagged fish were detected as smolts as they passed downstream in the juvenile bypass system of Lower Granite Dam (Matthews et al. 1977), which is equipped with PIT tag monitors (Prentice et al. 1990b).

After detection at Lower Granite Dam, the PIT-tagged smolts were routed through flumes back to the river. Smolts then had to pass seven more dams (Figure 1) to reach the Pacific Ocean. Little Goose, Lower Monumental, McNary, John Day, and Bonneville dams (Figure 1) were also equipped with monitoring systems that recorded the passage of PIT-tagged smolts in the bypass systems and then routed the bypassed fish back to the river.

Cohort survival.—The first step in the analysis was to divide the annual samples of PIT-tagged fall chinook salmon into four sequential within-year release groups referred to as cohorts. We divided the annual samples into cohorts based on estimated fry emergence dates. We estimated fry emergence date for each fish in two steps. First, the number of days since each PIT-tagged fish emerged from the gravel was calculated by subtracting 36 mm from its fork length measured at initial capture, and then dividing by the daily growth rate observed for recaptured PIT-tagged fish (range 0.9–1.3 mm/d; Connor and Burge, this issue). The 36-mm fork length for newly emergent fry was the mean of the observed minimum fork lengths. Second, emergence date was estimated for each fish by subtracting the estimated number of days since emergence from its date of initial capture, tagging, and release. We sorted the data in ascending order by estimated fry emergence date, and then divided it into four cohorts of approximately equal numbers of fish.

The single release–recapture model (Cormack 1964; Skalski et al. 1998) was used to estimate survival probability (±SE) to the tailrace of Lower Granite Dam for each cohort. We insured that the single release–recapture model fit the data by use of three assumption tests described by Burnham et al. (1987) and Skalski et al. (1998).

Variables.—Cohort survival was the dependent variable for the analysis. The predictor variables were: (1) tagging date, or the median day of year (day 1 = 1 January) fish from each cohort were captured, tagged, and released; (2) mean fork length (mm) at capture, tagging, and release for the fish of each cohort; (3) flow exposure index, calculated as the mean flow (m^3/s) measured at Lower Granite Dam by U.S. Army Corps of Engineers personnel during the period when the majority of smolts from each cohort passed the dam; and (4) water temperature exposure index, calculated as the mean temperature (°C) measured in the tailrace of Lower Granite Dam by U.S. Army Corps of Engineers personnel during the period when the majority of smolts from each cohort passed the dam.

To determine when the majority of smolts passed Lower Granite Dam, the PIT tag detection data were used to calculate a passage date distribution for each cohort including the 25th percentile, median, 75th percentile, range of non-outliers, and mild outliers (Figure 2). The date cutoffs for mild outliers were calculated as the 25th percentile minus the interquartile range multiplied by 1.5

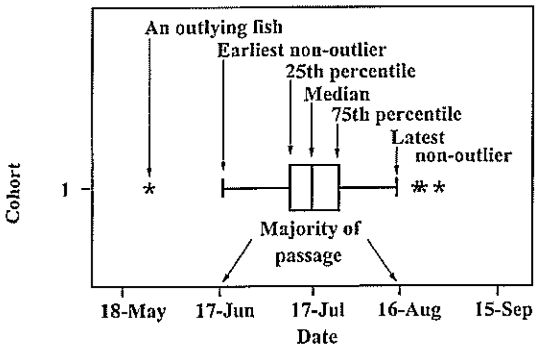


FIGURE 2.—An example of a passage date distribution for PIT-tagged wild subyearling fall chinook salmon at Lower Granite Dam, including the time period that was used to represent the majority of passage for calculating flow and water temperature exposure indices. The left whisker on the box plot extends back to the earliest detection date (17 June) that was later than or equal to the lower fence (25th percentile minus the interquartile range, multiplied by 1.5), and the right whisker extends forward to the detection date (16 August) that was earlier than or equal to the upper fence (75th percentile plus the interquartile range, multiplied by 1.5). The asterisks signify mild outliers (one asterisk represents one fish) that were earlier than the lower fence or later than the upper fence.

(i.e., the lower fence; Ott 1993), and the 75th percentile plus the interquartile range multiplied by 1.5 (i.e., the upper fence; Ott 1993). The left whisker on the box plot in Figure 2 extends back to the earliest detection date (17 June) that was later than or equal to the lower fence, and the right whisker extends forward to the detection date (16 August) that was earlier than or equal to the upper fence. The asterisks in Figure 2 signify mild outliers that were earlier than the lower fence or later than the upper fence (Ott 1993). All but the mild outliers were considered to be in the majority. The mean flow exposure index calculated based on the passage date distribution in Figure 2 would be the average of the mean daily flows measured in the tailrace of Lower Granite Dam between 17 June and 16 August.

Model selection.—We calculated Pearson's product-moment correlation coefficient (r) to test for colinearity among the predictor variables. Predictor variables that were correlated ($r \geq 0.6$; $P \leq 0.05$) were not entered into the same model.

We fit multiple regression models from every combination of non-collinear predictor variables. We compared fit among models based on Mallow's C_p scores (Dielman 1996), Akaike's information criteria (AIC; Akaike 1973), and the coefficient of determination (R^2). The final (i.e., best) regression model had a Mallow's Cp score similar to the number of parameters, the lowest AIC value, the high-

TABLE 1.—Median emergence dates, predictor variables, and estimates of survival probability (%; ±SE in parentheses) to the tailrace of Lower Granite Dam for each cohort of wild subyearling fall chinook salmon, 1998–2000. Predictor variables include: tagging date, defined as the median day of year of tagging; mean fork length (FL; mm) at tagging; flow (m^3/s), a flow exposure index calculated as the mean flow measured at Lower Granite Dam during the period when the majority of smolts passed the dam; and temperature (°C), a water temperature exposure index calculated as the mean temperature measured in the tailrace of Lower Granite Dam during the period when the majority of smolts passed the dam.

Cohort	N	Emergence date	Tagging date	FL	Flow	Temperature	Survival
1998							
1	515	7 Apr	140	80	2,344	17.6	70.8 (2.9)
2	515	15 Apr	141	75	2,021	18.7	66.1 (3.3)
3	515	23 Apr	153	73	1,898	19.0	52.8 (3.1)
4	515	7 May	167	70	1,299	19.8	35.6 (2.9)
1999							
1	441	20 Apr	147	80	2,378	16.3	87.7 (4.6)
2	440	30 Apr	153[a]	77	1,963	17.1	77.0 (3.8)
3	440	5 May	152[a]	70	2,116	16.7	81.2 (5.8)
4	440	13 May	167	68	1,353	18.3	36.4 (3.5)
2000							
1	303	6 Apr	130	77	1,510	16.7	57.1 (4.1)
2	302	15 Apr	144	77	1,296	17.6	53.4 (4.2)
3	302	22 Apr	146	77	1,274	17.8	44.4 (3.6)
4	302	29 Apr	158	71	859	18.5	35.7 (4.3)

[a] Fish from cohort 2 emerged earlier than the fish of cohort 3, but they were initially captured, tagged, and released later than cohort 3.

TABLE 2.—Mallow's C_p scores, Akaike's information criteria (AIC), and coefficients of determination (R^2) used to compare the fit of multiple regression models describing the survival of cohorts of wild subyearling fall chinook salmon from tagging in the Snake River to the tailrace of Lower Granite Dam, 1998–2000. Predictor variables are defined in Table 1.

C_p	AIC	R^2	Variables in model
2	44	0.92	Flow, temperature
4	46	0.92	FL, flow, temperature
4	46	0.92	Tagging date, flow, temperature

est R^2 value, and predictor variables with slope coefficients that differed significantly ($t \geq 2.0$; $P \leq 0.05$) from zero. Only the top three models are reported.

We made residual plots for each predictor variable in the final regression model, as described for flow in the following example. Estimated survival was regressed against temperature. The residuals from this regression were then plotted against flow. A line was then fit to the residuals by regressing them against flow. The resulting residual plots provided a better graphical representation of the relation between survival and flow because the variability in survival attributable to temperature had been removed.

Assessment of summer flow augmentation.—We assessed the effect of summer flow augmentation on cohort survival to the tailrace of Lower Granite Dam by comparing two predictions. First, we predicted cohort survival to the tailrace of Lower Granite Dam by entering the observed mean flow and water temperature exposure indices for each cohort into the final regression model. Cohort survival was then predicted a second time by entering mean flow and water temperature exposure indices, recalculated to remove effects of summer flow augmentation, into the final regression model.

The flow exposure index was recalculated after reducing Lower Granite Reservoir daily outflow by an approximation of the daily volume of water released for summer flow augmentation during 1 July–31 August from Dworshak Reservoir and reservoirs upstream of Brownlee Dam. The daily volume released from Dworshak Reservoir was calculated as the largest of two numbers: (1) the observed outflow at Dworshak Dam (Figure 1) minus observed inflow to Dworshak Reservoir, or (2) a minimum operational outflow of 28 m^3/s. For reservoirs upstream of Brownlee Dam, the daily volume was calculated in two steps: (1) 82 m^3/s (estimated flow released for augmentation from reservoirs upstream of Brownlee Reservoir) was sub-

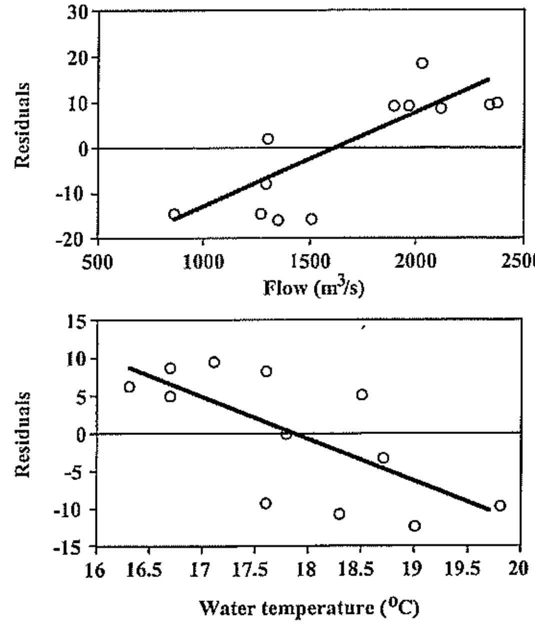


FIGURE 3.—Residual plots for flow (top) and temperature (bottom). Residuals are from ordinary least-squares multiple regression models fit to predict cohort survival from the predictor variables that are not on the x-axis. The line in each plot was predicted by regression of the residuals against the predictor variable on the x-axis.

tracted from daily inflow to Brownlee Reservoir, and (2) the resulting flow was subtracted from observed outflow at Hells Canyon Dam (Figure 1). Finally, the daily sum of the flow approximations for Dworshak Reservoir and reservoirs upstream of Brownlee Dam was subtracted from daily outflow observed at Lower Granite Dam. The Appendix gives the daily flow values for 1 July–31 August that were used to approximate the Lower Granite Reservoir flow that would have occurred if the summer flow augmentation had not been implemented.

The water temperature exposure index was recalculated with temperatures that were simulated for the tailrace of Lower Granite Dam under the approximated flow conditions that would have occurred without summer flow augmentation (Appendix). Water temperatures were simulated with a one-dimensional heat budget model developed for the Snake River by the U.S. Environmental Protection Agency (Yearsley et al. 2001). Past model validation showed that daily mean water temperatures simulated for July and August were within an average of 0.7°C of those observed (Yearsley et al. 2001).

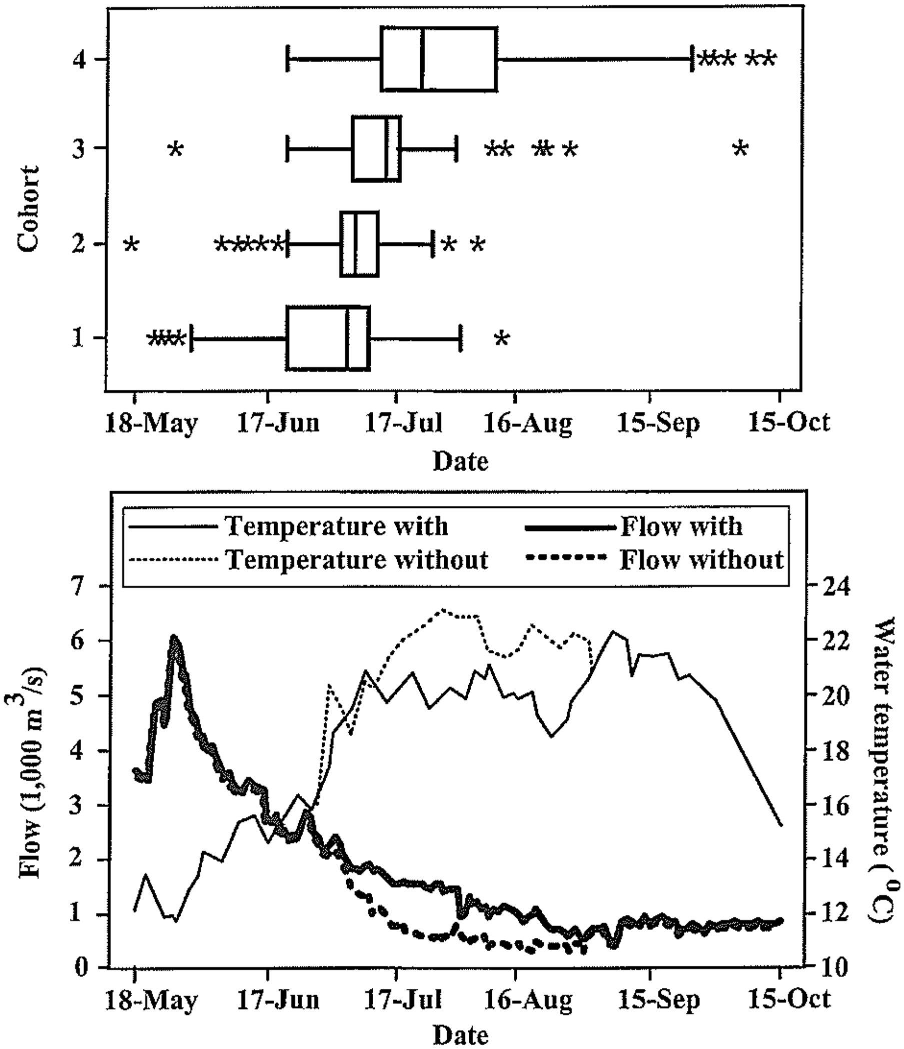


FIGURE 4.—Box plots showing passage timing at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon from each of four cohorts in 1998 (top), and a comparison of the mean daily flows and water temperatures in Lower Granite Reservoir with (observed) and without (estimated) summer flow augmentation (bottom). See Figure 2 for a description of box plots.

Results

During the 3 years of the study, 5,030 fall chinook salmon were captured, PIT tagged, and released along the free-flowing Snake River. Annual sample sizes of PIT-tagged fall chinook salmon were 2,060 in 1998, 1,761 in 1999, and 1,209 in 2000. The number of fall chinook salmon in each of the resulting 12 cohorts was 302–515 (Table 1). Emergence dates, tagging dates, and water temperature exposure indices generally increased from cohort 1 to cohort 4 (Table 1). Flow exposure indices, fork lengths, and survival estimates generally decreased from cohort 1 to cohort 4 (Table 1).

Survival Modeling

Tagging date and fork length were negatively correlated ($N = 12$; $r = -0.76$; $P = 0.004$). Therefore, tagging date and fork length were not entered into the same multiple regression model. Fork length and flow ($N = 12$; $r = 0.47$; $P = 0.12$), fork length and temperature ($N = 12$; $r = -0.54$; $P = 0.07$), and flow and temperature ($N = 12$; $r = -0.45$; $P = 0.15$) were non-collinear.

The model that predicted cohort survival from flow and temperature had a Mallow's C_p score one less than the number of parameters, the lowest AIC value, and an R^2 of 0.92 (Table 2). The models

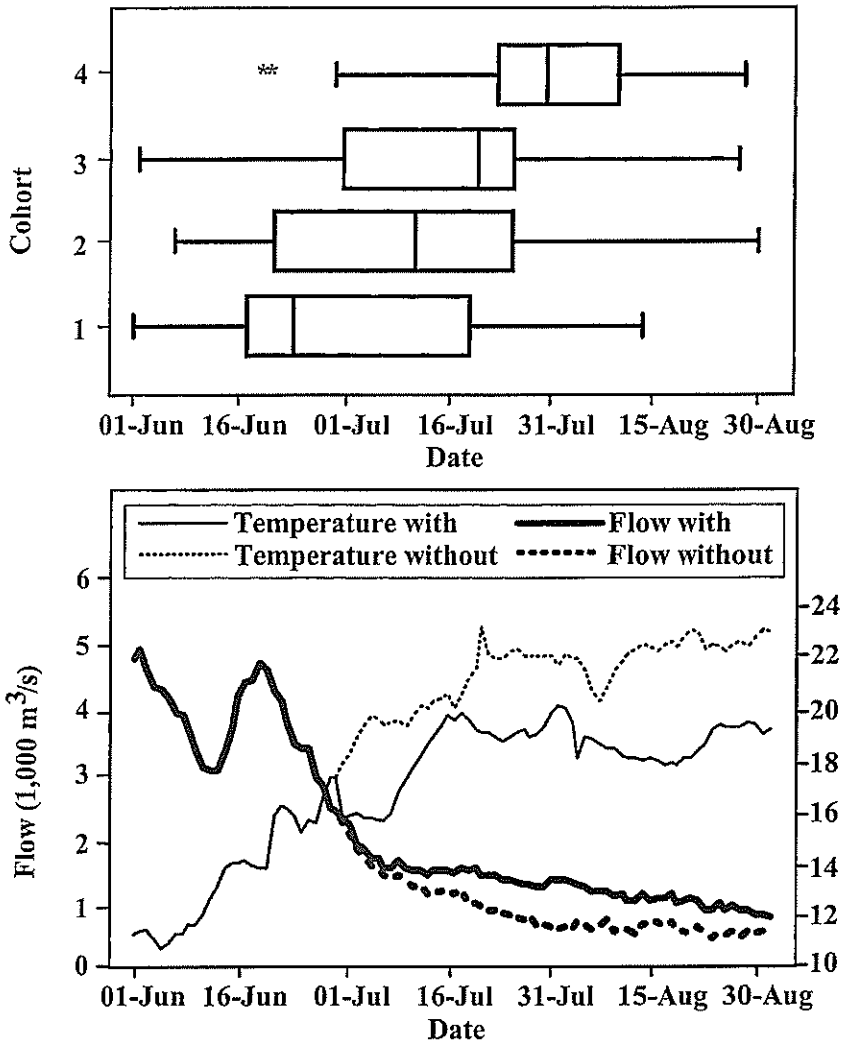


FIGURE 5.—Box plots showing passage timing at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon from each of four cohorts in 1999 (top), and a comparison of the mean daily flows and water temperatures in Lower Granite Reservoir with (observed) and without (estimated) summer flow augmentation (bottom). See Figure 2 for a description of box plots.

that included fork length or tagging date had Mallow's C_p scores that equaled the number of parameters, relatively low AIC values, and R^2 values of 0.92 (Table 2), but the slope coefficients for fork length (t = 0.05; P = 0.96) and tagging date (t = 0.07; P = 0.94) did not differ significantly from zero.

The final multiple regression model was: cohort survival = 140.82753 + 0.02648(flow) − 7.14437(temperature). The final model was significant (N = 12; $P \leq 0.0001$), as were the slope coefficients for flow (t = 6.81; $P \leq 0.0001$) and temperature (t = −3.96; P = 0.003). Flow and temperature explained 92% of the observed variability in cohort survival to the tailrace of Lower Granite Dam. Cohort survival generally increased as flow increased, and decreased as temperature increased (Figure 3).

Assessment of Summer Flow Augmentation

Water releases for summer flow augmentation in 1998, 1999, and 2000 were generally timed to coincide with the passage of later migrating smolts at Lower Granite Dam (Figures 4–6). Therefore, later cohorts were usually predicted to accrue greater survival benefits than earlier cohorts (Table

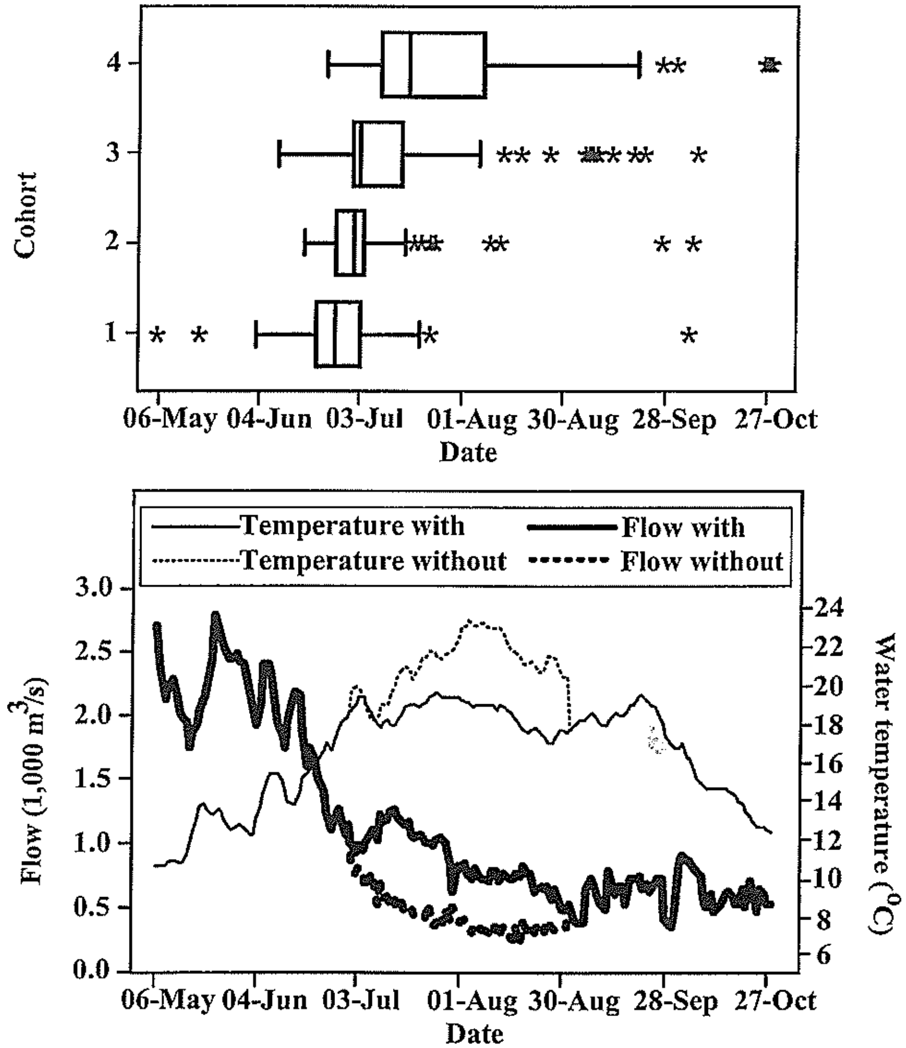


FIGURE 6.—Box plots showing passage timing at Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon from each of four cohorts in 2000 (top), and a comparison of the mean daily flows and water temperatures in Lower Granite Reservoir with (observed) and without (estimated) summer flow augmentation (bottom). See Figure 2 for a description of box plots.

3). For all cohorts, estimated survival to the tailrace of Lower Granite Dam was predicted to be higher when summer flow augmentation was implemented than when it was not implemented (Table 3; Figure 7).

Discussion

Survival of wild subyearling fall chinook salmon from release in the Snake River to the tailrace of Lower Granite Dam generally increased as flow increased, and decreased as temperature increased. Based on the regression model we developed, survival is predicted to change by approximately 3% with each change of 100 m^3/s in flow when temperature is held constant. The change in survival is approximately 7% for each 1°C increase or decrease in temperature when flow is held constant. Kjelson et al. (1982), Kjelson and Brandes (1989), and Connor et al. (1998) also reported that survival of subyearling chinook salmon during seaward migration is directly proportional to flow and inversely proportional to temperature.

Flow and temperature were closely correlated in the above three studies (e.g., $r = -0.999$; Connor et al. 1998), thus the researchers could not determine whether the high correlation between sur-

TABLE 3.—Predicted survival (%; ± 95% confidence interval in parentheses) to the tailrace of Lower Granite Dam for cohorts of wild subyearling fall chinook salmon tagged in the Snake River from 1995 to 1998. Predictions were made with the observed flow and water temperature indices in Table 1 (survival with), and with flow (m^3/s) and water temperature (°C) exposure indices recalculated to approximate conditions that would have occurred without flow augmentation (survival without).

Cohort	Survival with	Recalculated Flow	Recalculated Temperature	Survival without	Difference in survival
1998					
1	77.2 (6.5)	2,066	18.3	64.8 (5.8)	12.4
2	60.7 (6.6)	1,689	19.3	47.7 (7.0)	13.0
3	55.3 (6.8)	1,468	20.1	36.1 (9.3)	19.2
4	33.8 (8.0)	988	21.3	14.8 (13.1)	19.0
1999					
1	87.3 (7.5)	2,128	17.1	75.0 (5.2)	12.3
2	70.6 (4.7)	1,667	18.4	53.5 (4.3)	17.1
3	77.5 (5.8)	1,837	18.0	60.9 (4.0)	16.6
4	45.9 (4.6)	943	20.1	22.2 (9.4)	23.7
2000					
1	61.5 (6.7)	1,314	17.0	54.2 (6.8)	7.3
2	49.4 (5.5)	1,078	17.9	41.5 (6.5)	7.9
3	47.4 (5.3)	978	18.6	33.8 (6.7)	13.6
4	31.4 (7.5)	587	20.1	12.8 (10.6)	18.6

vival and one variable was caused by the other variable. Flows and temperatures were atypically uncorrelated ($r = -0.45$) from 1998 to 2000, therefore we were able to enter both of these predictor variables into the same multiple regression equation without biasing the regression coefficients. Both regression coefficients differed significantly from zero (flow $P \leq 0.0001$; temperature $P = 0.003$). We conclude that flow and temperature act together to influence fall chinook salmon survival.

Correlation does not imply causation unless the causal mechanisms can be identified with certainty. Flow and water temperature, however, are the two most plausible factors affecting survival, since fall chinook salmon are aquatic poikilotherms. We suggest that the two variables simultaneously assert their influence on survival. For example, flow influences rate of seaward movement (Berggren and Filardo 1993; Connor et al. 2003) and water turbidity at the same time temperature is regulating predation (Vigg and Burley 1991; Curet 1994; Anglea 1997). Fall chinook salmon that migrate downstream when flow is low and temperatures are warm might suffer high mortality because they are exposed for longer durations to actively feeding predators in clear water.

Slow downstream movement and late-summer passage associated with low flow levels (Connor et al. 2003) can also result in exposure to temperatures above 20°C. Prolonged exposure to temperatures above 20°C might disrupt fall chinook salmon growth, smoltification, and downstream movement, thereby exacerbating predation (Marine 1997). Temperatures above 20°C have also been associated with disease and stress-induced mortality (Connor, unpublished).

Management Implications

A discussion of the management implications of the results in this paper requires an understanding of the limitations on our study. Post-tagging mortality of cohorts released later in the summer would bias our analyses. Though Prentice et al. (1990a) found that delayed mortality of subyearling fall chinook salmon was low (range, 1–5%) 135–139 d after PIT tagging, their tests were not conducted at temperatures above 14.4°C. Research should be conducted on delayed mortality of PIT-tagged fall chinook salmon at temperatures above 14.4°C. We could not ascertain where PIT-tagged fall chinook salmon died en route to Lower Granite Dam. Our assessment of summer flow augmentation would be weakened if the majority of tagged fish died in the free-flowing Snake River before flow was augmented. We relied on simple approximations of the flow volumes released for summer flow augmentation to simulate temperatures in Lower Granite Reservoir, and to predict fall chinook salmon survival without summer flow augmentation. Advanced hydrological and temperature modeling and more accurate flow and temperature data will be required to accurately describe the flow and temperature effects of summer flow augmentation in Lower Granite Reservoir.

In spite of these limitations, we believe the results in this paper support summer flow augmentation as a beneficial interim recovery measure for Snake River fall chinook salmon. Survival for all cohorts was predicted to be higher with summer flow augmentation than without augmentation. We conclude that increases in flow and decreases in water temperature resulting from summer flow augmentation increase survival of young fall chinook salmon.

Although summer flow augmentation likely increased survival of fall chinook salmon passing downstream in Lower Granite Reservoir, mortality is probably still higher than before dams were constructed. When the lower Snake River was still free-flowing, the latest emigrating juvenile chinook salmon were exposed to mean June flows of approximately 2,800 m^3/s in 1954 and 3,800 m^3/s in

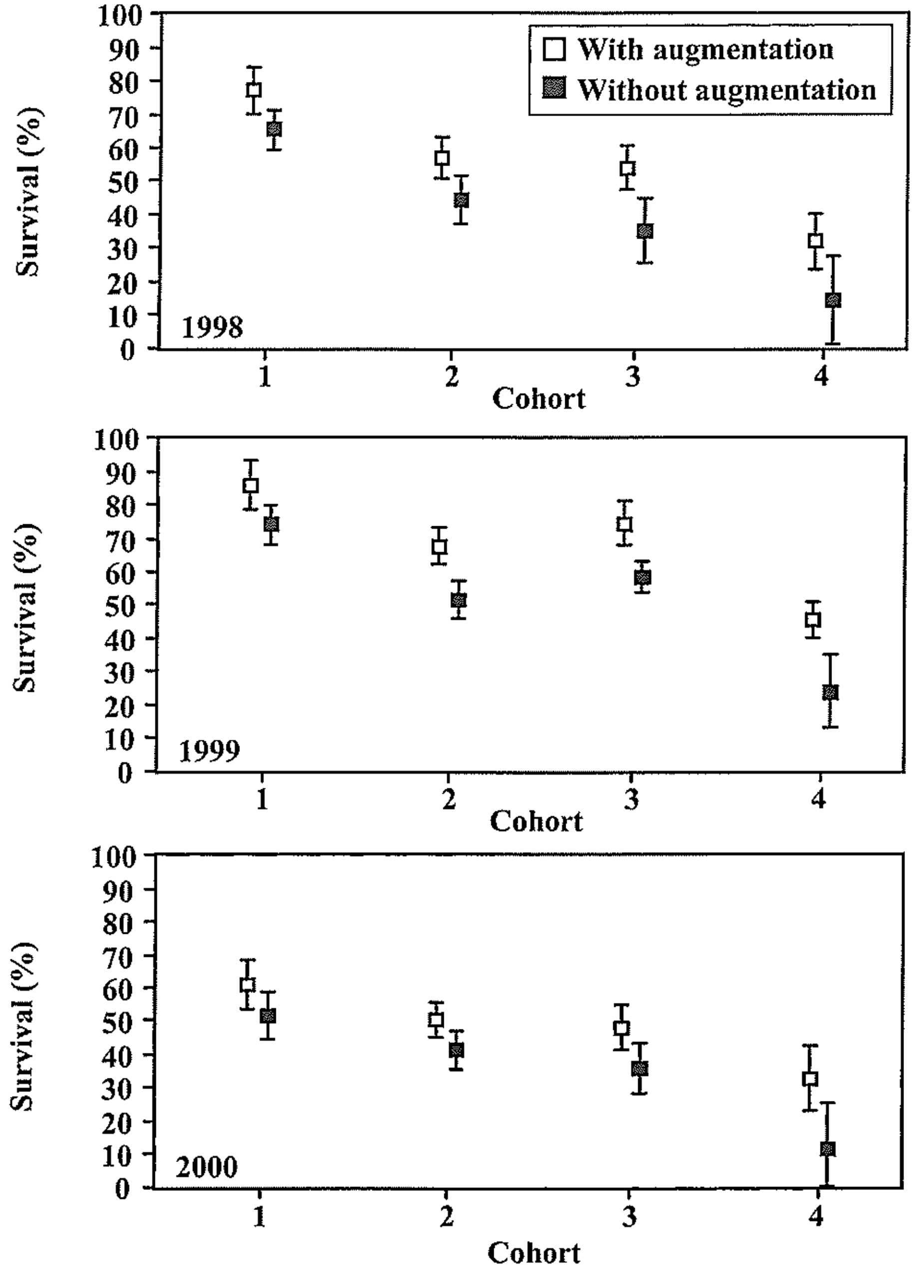


FIGURE 7.—Survival (±95% confidence interval) to the tailrace of Lower Granite Dam for PIT-tagged wild subyearling fall chinook salmon in 1998 (top), 1999 (center), and 2000 (bottom), predicted from mean flows and water temperatures with (observed; from Table 1) and without (estimated; from Table 3) summer flow augmentation. The equation cohort survival = 140.82753 + 0.02648(flow) − 7.14437(temperature) was used to make both sets of predictions.

1955 (estimated from Figure 8 in Mains and Smith [1964]). Mean June temperatures for 1954 and 1955 were approximately 9°C and 11°C, respectively (estimated from Figure 8 in Mains and Smith [1964]). In contrast, the latest emigrating cohorts of fall chinook salmon during 1998–2000 were exposed to mean flows of 859–1,299 m^3/s and mean temperatures of 18.3–19.8°C.

The release of larger volumes of cooler reservoir water during the summer would provide present-day fall chinook salmon with velocity and temperature conditions more similar to their pre-dam counterparts that emigrated primarily in the late spring (Connor et al. 2002). Dworshak Reservoir and reservoirs upstream of Brownlee Dam, however, are the only two sources of additional water. The ability of fishery managers to obtain more cool water for summer flow augmentation from Dworshak Reservoir is limited by supply and competing demands. Dworshak Reservoir is routinely drafted to near-minimum operation levels, so releasing more water would reduce the probability of refill the next year. Release of larger volumes of water from Dworshak Reservoir earlier in the year to cover a larger percentage of the smolt migration would be difficult because of conflicts with summer recreation.

The release of the coldest water available from Dworshak Reservoir by use of the multilevel selector gates of Dworshak Dam would likely disrupt growth and seaward movement of fall chinook salmon that are still rearing in the lower Clearwater River when smolts from the Snake River are passing downstream in Lower Granite Reservoir (Connor et al. 2002). For example, the release of 6°C water in July 1994 decreased temperature in Lower Granite Reservoir from approximately 23°C to 17°C (Connor et al. 1998), thereby improving conditions for survival of smolts from the Snake River. However, the 6°C release also caused water temperature in the lower Clearwater River to decrease from approximately 19°C to 8°C (U.S. Geological Survey data collected at Spalding, Idaho) at a time when young fall chinook salmon were still rearing along the shoreline.

Increasing the supply of water available from reservoirs upstream of Brownlee Dam for summer flow augmentation would be difficult because of supply and competing demands. Cooler water cannot be released from Brownlee Reservoir because Brownlee Dam does not have multilevel selector gates. Consequently, the water released from Brownlee Reservoir for summer flow augmentation is relatively warm (e.g., 17.5–20.3°C; Connor et al. 1998). Development of the ability to selectively release cooler water from Brownlee Reservoir might be the most practical option for improving the effectiveness of summer flow augmentation, provided that cool, oxygenated water is available and impacts on native resident fishes would be acceptable to fishery managers. Cool water could be released from Brownlee Reservoir during summer, when fall chinook salmon smolts from the Snake River are passing downstream in Lower Granite Reservoir, without affecting water temperatures in the lower Clearwater River when fry and parr are still rearing.

Acknowledgments

D. Steele, C. Eaton, R. Nelle, R. Waitt, C. Larsen, J. Bretz, S. Bradbury, C. Piston, and many other employees of the U.S. Fish and Wildlife Service's Idaho Fishery Resource Office collected data. The staff at the Fish Passage Center of the Columbia River Basin Fish and Wildlife Authority provided flow data. C. Stein, D. Marvin, and the staff at the Pacific States Marine Fisheries Commission managed the PIT tag database. S. Smith provided statistical assistance. D. Bennett, P. Bigelow, J. Congleton, A. Graves, M. Scott, and K. Steinhorst reviewed drafts of the manuscript. The editor, an associate editor, David Fast, and one anonymous reviewer improved the manuscript. Funding was provided by the rate payers of the Bonneville Power Administration through contract number DE-AI79-91BP21708, administered by D. Docherty, M. Galloway, D. Praest, M. Beeman, and K. Tiffan.

References

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267–281 *in* V. N. Petrov and F. Csaki, editors. Proceedings of the second international symposium on information theory. Akailseoniai-Kiudo, Budapest.

Anglea, S. M. 1997. Abundance, food habits, and salmonid fish consumption of smallmouth bass and distribution of crayfish in Lower Granite Reservoir, Idaho-Washington. Master's thesis. University of Idaho, Moscow.

Berggren, T. J., and M. J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River basin. North American Journal of Fisheries Management 13:48–63.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society, Monograph 5, Bethesda, Maryland.

Connor, W. P., T. C. Bjornn, H. L. Burge, A. R. Marshall, H. L. Blankenship, R. K. Steinhorst, and K. F. Tiffan. 2001a. Early life history attributes and run composition and of wild subyearling chinook salmon recaptured after migrating downstream past Lower Granite Dam. Northwest Science 75:254–261.

Connor, W. P., and H. L. Burge. 2003. Growth of wild subyearling chinook salmon in the Snake River. North American Journal of Fisheries Management 23:595–600.

Connor, W. P., H. L. Burge, and D. H. Bennett. 1998. Detection of subyearling chinook salmon at a Snake

River dam: implications for summer flow augmentation. North American Journal of Fisheries Management 18:530–536.

Connor, W. P., H. L. Burge, R. Waitt, and T. C. Bjornn. 2002. Juvenile life history of wild fall chinook salmon in the Snake and Clearwater rivers. North American Journal of Fisheries Management 22: 703–712.

Connor, W. P., A. R. Marshall, T. C. Bjornn, and H. L. Burge. 2001b. Growth and long-range dispersal by wild subyearling spring and summer chinook salmon in the Snake River basin. Transactions of the American Fisheries Society 130:1070–1076.

Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2003. Migrational behavior and seaward movement of wild subyearling fall chinook salmon in the Snake River. North American Journal of Fisheries Management 23:414–430.

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

Curet, T. S. 1994. Habitat use, food habits and the influence of predation on subyearling chinook salmon in Lower Granite and Little Goose reservoirs, Washington. Master's thesis. University of Idaho, Moscow.

Dielman, T. E. 1996. Applied regression analysis for business and economics. Wadsworth, Belmont, California.

Kjelson, M. A., and P. L. Brandes. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. Canadian Special Publication of Fisheries and Aquatic Sciences 105:100–115.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1982. Life history of fall-run chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin estuary, California. Pages 393–411 *in* V. S. Kennedy, editor. Estuarine comparisons. Academic Press, New York.

Mains, E. M., and J. M. Smith. 1964. The distribution, size, time, and current preferences of seaward migrant chinook salmon in the Columbia and Snake rivers. Washington Department of Fisheries, Fisheries Research Papers 2(3):5–43.

Marine, K. R. 1997. Effects of elevated water temperature on some aspects of the physiological and ecological performance of juvenile chinook salmon (*Oncorhynchus tshawytscha*): implications for management of California's Central Valley salmon stocks. Master's thesis. University of California, Davis.

Matthews, G. M., G. A. Swann, and J. Ross Smith. 1977. Improved bypass and collection system for protection of juvenile salmon and steelhead trout at Lower Granite Dam. U.S. National Marine Fisheries Service Marine Fisheries Review 39(7):10–14.

NMFS (National Marine Fisheries Service). 1992. Threatened status for Snake River spring/summer chinook salmon, threatened status for Snake River fall chinook salmon. Federal Register 57:78(22 April 1992):14653–14663.

NMFS (National Marine Fisheries Service). 1995. Proposed recovery plan for Snake River salmon. NMFS, Portland, Oregon.

Ott, R. L. 1993. An introduction to statistical methods and data analysis, 4th edition. Wadsworth, Belmont, California.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Pages 317–322 *in* N. C. Parker, A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish-marking techniques. American Fisheries Society, Symposium 7, Bethesda, Maryland.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. Pages 323–334 *in* N. C. Parker, A. E. Giorgi, R. C. Heidinger, D. B. Jester, Jr., E. D. Prince, and G. A. Winans, editors. Fish-marking techniques. American Fisheries Society, Symposium 7, Bethesda, Maryland.

Raymond, H. L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Transactions of the American Fisheries Society 98: 513–514.

Raymond, H. L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River basin. North American Journal of Fisheries Management 8:1–24.

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffman. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:1484–1493.

Vigg, S., and C. C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 48:2491–2498.

Yearsley, J., D. Karna, S. Peene, and B. Watson. 2001. Application of a 1-D heat budget model to the Columbia River system. U.S. Environmental Protection Agency, Region 10, Final Report 901-R-01-001, Seattle.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1988. Historical abundance and decline of chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18: 487–521.

Appendix: Flows and Temperatures in Lower Granite Reservoir

TABLE A.1.—Mean daily flows (m^3/s) in Lower Granite Reservoir with (observed) and without (approximated) summer flow augmentation, 1998 to 2000.

	1998		1999		2000	
Date	With	Without	With	Without	With	Without
Jul						
1	2,195	2,138	2,336	2,243	1,020	892
2	2,212	2,127	2,212	2,050	952	790
3	2,251	2,130	1,931	1,863	1,014	835
4	2,419	2,283	1,832	1,702	977	816
5	2,274	2,116	1,699	1,594	1,020	677
6	2,065	1,957	1,685	1,546	1,090	773
7	1,960	1,844	1,563	1,427	1,121	793
8	1,827	1,592	1,546	1,385	1,059	552
9	1,801	1,515	1,648	1,458	1,246	753
10	1,778	1,436	1,563	1,357	1,198	583
11	1,866	1,385	1,509	1,269	1,204	612
12	1,892	1,504	1,532	1,294	1,274	572
13	1,745	1,087	1,447	1,136	1,280	600
14	1,812	1,198	1,529	1,184	1,229	513
15	1,759	1,164	1,507	1,172	1,184	561
16	1,651	1,073	1,507	1,212	1,161	501
17	1,583	971	1,475	1,136	1,187	507
18	1,555	830	1,541	1,238	1,087	524
19	1,549	844	1,501	991	1,073	470
20	1,577	881	1,546	988	1,099	504
21	1,521	739	1,456	954	1,096	490
22	1,535	719	1,453	912	1,028	450
23	1,549	714	1,456	895	1,028	541
24	1,512	688	1,376	847	1,005	382
25	1,481	685	1,354	824	1,051	399
26	1,444	646	1,345	787	1,076	467
27	1,521	657	1,314	762	1,042	416
28	1,529	762	1,308	824	1,031	515
29	1,410	615	1,257	685	860	436
30	1,453	666	1,263	671	643	530
31	1,439	649	1,368	634	855	453
Aug						
1	1,450	830	1,357	617	833	408
2	954	765	1,382	632	864	428
3	963	612	1,323	615	784	402
4	1,283	705	1,303	702	748	337
5	1,167	586	1,266	660	833	413
6	1,201	634	1,175	615	776	360
7	1,065	592	1,181	640	759	351
8	1,107	671	1,198	753	745	354
9	943	436	1,116	555	733	326
10	1,065	510	1,141	671	813	362
11	1,045	484	1,054	600	813	377
12	1,104	524	1,028	547	733	280
13	1,136	552	1,164	694	787	368
14	1,087	496	1,028	697	773	362
15	1,028	496	1,090	702	750	297
16	960	524	1,073	657	753	261
17	827	396	1,170	711	799	365
18	954	445	1,022	595	767	252
19	974	413	1,025	578	858	408
20	1,065	566	1,070	544	787	354
21	932	521	1,051	637	787	391
22	787	487	906	538	649	329
23	716	498	898	462	677	365
24	719	490	997	569	691	354
25	688	487	892	487	671	331
26	683	552	960	569	685	428
27	575	462	901	467	583	360
28	617	402	912	583	677	354
29	697	544	827	527	566	362
30	592	541	810	552	513	346
31	507	334	782	476	518	368

TABLE A.2.—Mean water temperatures (°C) in Lower Granite Reservoir with (observed) and without (simulated) summer flow augmentation, 1998 to 2000.

	1998		1999		2000	
Date	With	Without	With	Without	With	Without
Jul						
1	16.6	19.0	15.8	16.2	18.8	17.8
2	17.5	19.8	15.9	16.6	19.1	18.2
3	18.1	20.1	16.0	16.9	19.4	18.7
4	18.7	20.1	15.8	16.8	19.4	18.9
5	19.0	20.3	15.8	17.0	19.0	19.2
6	19.0	20.1	15.7	17.0	18.7	19.3
7	19.3	19.7	15.7	16.8	18.4	20.0
8	19.7	19.7	16.0	17.0	18.0	20.1
9	20.1	19.5	16.8	16.7	17.9	20.3
10	20.6	19.7	17.3	17.1	18.1	19.7
11	20.7	19.5	17.7	17.3	18.3	19.2
12	20.8	20.0	18.2	18.1	18.0	19.3
13	20.5	20.4	18.6	18.5	18.0	19.3
14	20.2	20.6	18.9	18.7	18.2	19.1
15	20.0	20.7	19.3	19.0	18.6	19.0
16	19.7	20.7	19.7	19.3	18.9	18.8
17	19.9	20.7	19.6	19.8	19.1	19.3
18	19.9	20.8	19.8	20.1	19.0	19.6
19	20.4	20.9	19.6	20.3	19.0	19.7
20	20.4	21.3	19.2	20.2	18.9	19.9
21	20.9	21.8	19.1	19.9	19.1	20.3
22	20.7	22.0	19.1	19.9	19.2	20.3
23	20.1	22.2	18.9	19.7	19.4	20.2
24	19.7	22.4	18.7	19.8	19.6	20.6
25	19.5	22.6	18.9	19.5	19.7	20.8
26	19.7	22.7	19.1	19.3	19.5	21.0
27	19.7	23.0	19.2	19.4	19.4	21.2
28	19.7	22.9	18.9	19.9	19.5	21.2
29	20.2	23.1	19.0	21.0	19.5	21.6
30	20.1	23.3	19.3	21.2	19.4	21.7
31	20.2	23.7	19.8	20.8	19.4	21.8
Aug						
1	20.0	23.8	20.1	21.0	19.3	22.0
2	19.9	23.9	20.0	21.2	19.2	21.9
3	20.0	24.0	19.5	21.2	19.2	22.0
4	20.2	24.3	18.1	21.3	18.9	22.3
5	21.0	24.4	18.9	21.2	19.0	22.6
6	20.9	24.1	18.8	21.8	19.1	22.4
7	20.7	23.9	18.6	22.4	19.0	22.6
8	21.0	23.5	18.5	22.6	19.0	22.8
9	21.2	23.5	18.5	22.6	19.0	22.5
10	20.8	23.4	18.2	23.2	19.0	22.5
11	20.1	23.2	18.1	22.8	18.8	22.6
12	19.9	23.3	18.1	22.9	19.0	22.4
13	20.0	23.3	18.0	22.8	18.9	22.6
14	20.2	23.4	18.1	22.8	18.8	23.0
15	20.0	23.6	18.0	22.7	18.6	23.1
16	19.9	23.4	17.8	22.3	18.4	23.2
17	20.0	23.1	17.9	22.2	18.3	23.4
18	19.9	22.6	17.8	22.1	17.8	23.3
19	19.8	22.3	18.1	21.9	17.7	23.2
20	19.3	22.2	18.1	21.9	17.6	23.0
21	18.9	22.4	18.4	21.9	17.7	23.0
22	18.7	22.4	18.6	22.1	17.8	23.0
23	18.5	22.5	19.2	21.5	17.7	22.6
24	18.6	22.3	19.4	21.1	17.5	22.9
25	18.6	22.0	19.3	20.9	17.4	22.7
26	18.8	22.2	19.3	20.9	17.1	22.5
27	18.9	21.8	19.3	20.6	17.0	22.2
28	19.5	21.9	19.5	20.6	17.4	22.0
29	19.9	21.5	19.4	21.4	17.7	22.0
30	20.0	21.7	19.0	21.9	17.7	21.7
31	20.4	21.5	19.2	21.9	17.6	21.5

ATTACHMENT 2

Giorgi et al 1997

DECLARATION OF PAUL A. OCKER

North American Journal of Fisheries Management 17:268–282, 1997

Factors That Influence the Downstream Migration Rates of Juvenile Salmon and Steelhead through the Hydroelectric System in the Mid-Columbia River Basin

A. E. GIORGI, T. W. HILLMAN, AND J. R. STEVENSON

BioAnalysts, Inc.
3653 Rickenbacker, Suite 200, Boise, Idaho 83705, USA

S. G. HAYS AND C. M. PEVEN

Chelan County Public Utility District
327 North Wenatchee Avenue, Wenatchee, Washington 98801, USA

Abstract.—We investigated the extent to which key factors influenced the migration rate of the smolts of Pacific salmon *Oncorhynchus* spp. through impounded portions of the mid-Columbia River, during the years 1989–1995. Actively migrating chinook salmon *O. tshawytscha* (ocean-type and stream-type forms), sockeye salmon *O. nerka*, and steelhead *O. mykiss* were analyzed by bivariate and multiple-regression methods. The dependent variable was the rate (km/d) at which uniquely coded PIT-tagged (passive integrated transponder tags) smolts migrated between Rock Island Dam and McNary Dam. Predictor variables consisted of indices of river discharge volume (flow), water temperature, release date of tagged fish, and fish size. The variable of key interest was flow because water management strategies are in place to increase water velocity through flow augmentation, with the intention of increasing smolt migration rate to decrease smolt mortality. For spring-migrating sockeye salmon, hatchery steelhead, and wild steelhead, flow was the primary predictor variable entering the models, and the bivariate models explained 42, 36 and 31% of the observed variation in migration rate for those species, respectively. Yearling chinook salmon migration rate was not correlated with any variable. Summer-migrating ocean-type chinook salmon showed no response to flow over a broad range of discharge (1,500–5,000 m^3/s). However, there was a positive relationship between migration rate and fish length at the time of tagging for ocean-type chinook salmon; r^2 in the bivariate model = 0.59. Implications of these findings to water management strategies are discussed.

Hydroelectric development has been identified as an important factor that has contributed to decreased populations of chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* in the Columbia River basin (Raymond 1979, 1988; Williams 1989). Smolts migrating seaward die as they pass through turbines, bypasses, and spillways at dams. In addition, smolts incur mortality within the reservoirs. The creation of impoundments has increased the cross-sectional area of the river, which has resulted in decreased water velocity. Altered river discharge patterns associated with electric power demand and irrigation water storage and withdrawal as a result of dam construction have also decreased water velocity. Various researchers have attributed the protracted seaward migration of smolts to lower water velocities within the Columbia River system (Ebel and Raymond 1976; Raymond 1979, 1988). For example, Raymond (1968, 1969, 1979) estimated that juveniles moved through reservoirs at 33–50% the rate that they did though free-flowing river stretches of the same length. Slower migration exposes smolts to predatory fish for longer periods, potentially increasing smolt mortality (Berggren and Filardo 1993). Additionally, it has been hypothesized that slower migrations may impair seawater adaptation if migrational delay is too long (Berggren and Filardo 1993). However, the change in survival specifically associated with different migration rates has not been estimated.

In an effort to lessen negative effects associated with delayed migration, regional fisheries managers have developed water management strategies to increase water velocity, principally through flow augmentation. The intent is to increase water velocity and smolt migration rate sufficiently to provide appreciable gains in smolt survival through reservoirs or at ocean entry. In fact, flow augmentation is a principal tool currently employed in the recovery of Snake River salmon populations listed as threatened or endangered under the Endangered Species Act (USNMFS 1995). The effectiveness of this water management program is of interest in the Pacific Northwest because water is reallocated from other uses.

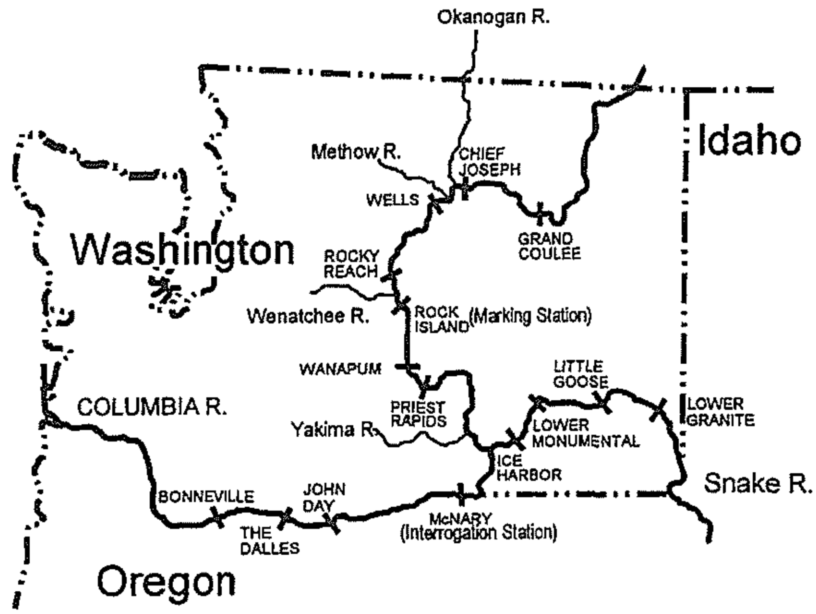


FIGURE 1.—Map of a portion of the Columbia River drainage showing the 259.7-km reach between Rock Island Dam (marking station) and McNary Dam (interrogation station).

There is evidence for some species that the migration rate of smolts through impoundments is positively related to water velocity. This relationship is most obvious for spring-migrating stream-type chinook salmon and steelhead in the lower Snake River and steelhead in the Columbia River (Raymond 1968; Berggren and Filardo 1993). Berggren and Filardo (1993) also identified other influential variables, including the date of release and water temperature. It is assumed that day length triggers the onset of smoltification and water temperature regulates the rate and duration of smoltification. In addition, the degree of smoltification can influence the migration rate of juvenile salmonids. Maule et al. (1994) observed that juvenile salmon with higher levels of gill ATPase activity migrated faster than those with lower levels. Similarly, Muir et al. (1994) experimentally demonstrated that the developmental status of the population with respect to the level of smoltification, as influenced by photoperiod and water temperature, had pronounced effects on migration rate.

The evidence that summer-migrating subyearling ocean-type chinook salmon respond to changes in flow is equivocal. Giorgi et al. (1994) found that none of three predictor variables (flow, temperature, or release date) appeared to influence the migration rate through John Day Reservoir on the Columbia River. Whereas Berggren and Filardo (1993), using a different but similar data set, identified flow as the only significant predictor variable, although the correlation was weak.

The migratory characteristics of Pacific salmon and steelhead smolts through the middle segment of the Columbia River upstream of McNary Dam have not been well described. In recent years, some particularly useful data have been acquired through a regional smolt monitoring program. Since 1989, under that program, actively migrating smolts have been intercepted at Rock Island Dam (Figure 1), tagged with passive integrated transponder (PIT) tags, and released in the tailrace for subsequent detection at McNary Dam (Figure 1). The purpose of our study was to use those data to describe the migratory characteristics of the smolts of chinook salmon, sockeye salmon *O. nerka*, and steelhead between Rock Island and McNary dams. Our objective was to identify those variables that influence migration rate and assess the strength and implications of those relationships.

Methods

We estimated downstream migration rates of juvenile chinook salmon, sockeye salmon, and steelhead in the 259.7-km reach of the Columbia River between Rock Island Dam (RI) and McNary Dam (McN) (Figure 1). Juvenile migrants were intercepted at RI, which is equipped with a smolt bypass system that permits access to smolts for monitoring. Chelan County Public Utility District (PUD) staff collected, anesthetized, and tagged migrants with PIT tags as part of the Columbia Basin Smolt Monitoring Program. Following procedures in Prentice et al. (1990a), PUD staff injected tags into the peritoneal cavity with hypodermic needles. Each tag carried a unique preprogrammed code that permitted identification of individual fish. After fish were tagged and had recovered from the anesthetic, they were released into the RI tailrace.

Between 1992 and 1995, PIT tags were applied to 14,723 age-0 chinook salmon and 12,062 juvenile sockeye salmon. In addition, 23,217 age-1 chinook salmon and 19,281 juvenile steelhead were PIT-tagged between the years of 1989 and 1995 (Table 1). The chinook and sockeye salmon consisted of unknown mixtures of wild and hatchery stocks. Because hatchery personnel removed the adipose fin of all hatchery steelhead, we could analyze hatchery and wild steelhead both separately and combined.

Tag detectors in the smolt bypass system at McN interrogated PIT-tagged fish. This interrogation process required only that PIT-tagged fish be scanned electronically as they passed through the detection equipment. Physical handling of fish was unnecessary. Prentice et al. (1990b) described the interrogation system at McN.

We accessed PIT tag data from the regional database at the Pacific States Marine Fisheries Commission in Portland, Oregon. We downloaded PIT tag release and recovery files for RI and McN, respectively, for the years spanning our study. These files consisted of identification codes, dates of release and subsequent interrogation, fish species, run type (e.g., spring or summer chinook salmon), rearing type (wild, hatchery, unknown), fork lengths (FL, mm) at time of release, and travel times from RI to McN. We converted calendar dates to days of the year (1–365) and travel times (d) into migration rates (km/d). Chelan PUD provided mean daily flow (m^3/s) and water temperature (°C) data at RI for periods of downstream migration of each species. Most annual temperature files were missing a few daily values. For each year in which values were missing, we developed a polynomial equation that estimated missing scores. Polynomials developed from transformed ($\log_e$) temperature data had $r^2 > 0.98$.

We evaluated the effects of river flow, water temperature, fish length, and release date (independent or predictor variables) on the migration rates (dependent variable) of juvenile salmonids in the mid-Columbia River. To index flow conditions encountered by migrating smolts, we selected the Columbia River discharge (m^3/s) as measured at RI, based on the following considerations. Smolts traverse a distance of 260.7 km in route from RI to McN. They reside exclusively within the Columbia River arm for 206.0 km, after which point Snake River discharge enters McNary Reservoir. The only tributary of any size discharging into the Columbia between RI and the confluence with the Snake River is the Yakima River, which enters well below Priest Rapids Dam (Figure 1). The Yakima River is relatively small and does not contribute appreciably to the overall Columbia River discharge. For example, in 1989, the average discharge of the Yakima River during May was 62 m^3/s (as calculated from data presented by Fast et al. 1989), whereas the Columbia River discharge (as indexed at RI) ranged from 2,858 to 4,868 m^3/s that spring (Table 1).

We considered water temperature, fish length, and release date as surrogates for overall smoltification status or readiness to migrate. Initially, we examined the influence of four temperature and four flow indices (1-, 5-, 10-, and 15-d means) on the migration rates of salmonids. However, because 5-d mean scores nearly always correlated more strongly with migration rate (higher r^2) than did the other mean scores, we included only 5-d mean scores in bivariate and multivariate analyses. All mean scores included the day of fish release. For example, 5-d mean flow included flows measured during the day of fish release, plus flows recorded the following 4 d. Both temperature and flow were measured at RI.

Before we examined bivariate and multivariate models, we screened all data for variance patterns and linearity. We used bivariate plots to examine the linearity of untransformed and $\log_e$-transformed variables. In all cases, $\log_e$ transformation improved linearity and variance patterns of both independent and dependent variables. We also used bivariate plots to identify apparent outliers. The Dixon test (Taylor 1990) assessed if apparent outliers could be rejected statistically. Before we rejected a score, however, we considered its biological validity. For example, we found one age-0 chinook salmon that traveled an average of 0.84 km/d between RI and McN (i.e., 259.7 km in 310 d). Although this rate was indeed an outlier statistically, it is biologically possible because some age-0 chinook salmon rear in the Columbia River

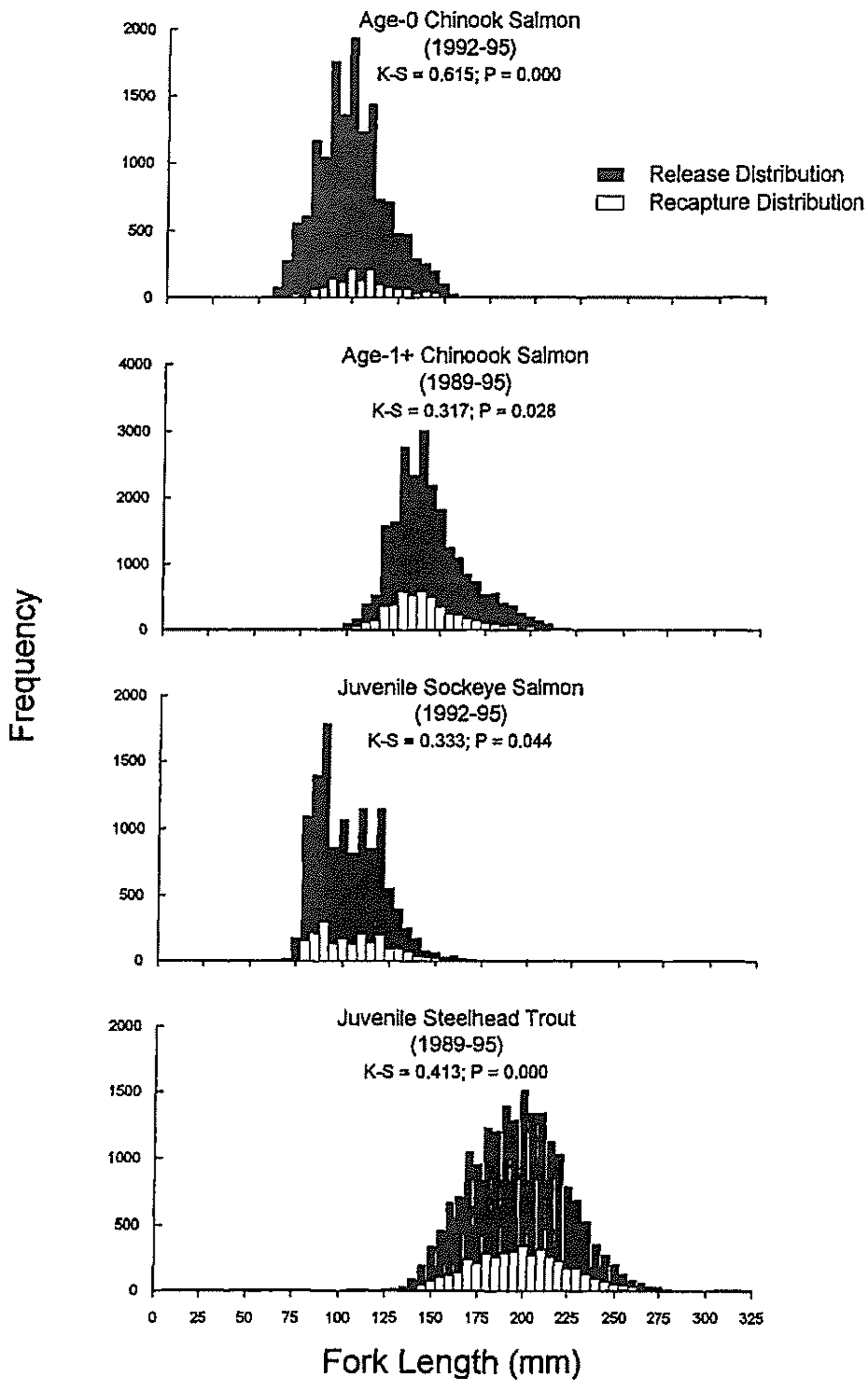


FIGURE 2.—Distributions of fork lengths (mm) of chinook salmon, sockeye salmon, and steelhead marked and released at Rock Island Dam and detected at McNary Dam. Size distributions at detection do not represent the actual size of the fish when they passed McNary Dam but rather the size of the fish when released at Rock Island Dam; K-S = Kolmogorov–Smirnov test.

TABLE 1.—Numbers of PIT-tagged juvenile salmonids released at Rock Island Dam (RI) and later detected at McNary Dam (McN) and range of indices (temperature, flow, and fish length) measured at RI.

Year	PIT-tagged smolts: Number released at RI	PIT-tagged smolts: Number detected at McN	Tagging period (day of the year)	Range of indices for detected fish: Temperature (°C)	Range of indices for detected fish: Flow (m^3/s)	Range of indices for detected fish: Fork length (mm)
			Age-0 chinook salmon			
1992	1,559	82	167–224	14.9–18.9	1,504–4,715	70–145
1993	4,221	260	172–224	15.4–19.4	2,023–3,609	62–167
1994	5,338	352	166–239	14.0–20.0	1,851–4,357	68–152
1995	3,605	638	175–225	14.9–18.6	2,517–4,972	64–144
All	14,723	1,332	166–239	14.0–20.0	1,504–4,972	62–167
			Age-1 chinook salmon			
1989	2,778	855	111–138	7.2–11.4	2,858–4,868	60–204
1990	2,835	660	111–145	7.8–11.4	3,204–4,579	106–202
1991	3,180	633	109–143	7.0–10.6	3,911–5,864	110–215
1992	3,643	764	112–151	8.1–13.3	2,853–4,607	95–222
1993	2,891	271	116–149	6.1–12.1	1,961–5,380	87–216
1994	3,393	870	111–148	8.3–12.0	2,068–3,939	89–208
1995	4,497	625	107–146	6.1–11.7	2,435–4,411	88–179
All	23,217	4,678	107–151	6.1–13.3	1,961–5,864	60–222
			Sockeye salmon			
1992	1,330	288	109–151	7.8–13.4	2,612–4,607	87–215
1993	3,699	536	111–149	5.3–12.0	1,485–5,380	71–139
1994	3,116	571	109–180	8.2–15.7	2,062–4,118	80–204
1995	3,917	548	107–146	6.1–11.6	2,435–4,411	69–164
All	12,062	1,943	107–180	5.3–15.7	1,485–5,380	69–215
			Steelhead			
1989	2,220	742	118–144	8.4–13.4	3,911–4,868	131–278
1990	2,982	730	111–145	7.8–11.4	3,204–4,579	132–295
1991	2,735	674	109–143	7.0–10.6	3,911–5,864	138–282
1992	3,163	905	113–152	8.1–13.4	2,853–4,607	119–279
1993	2,320	226	113–149	5.5–12.0	1,495–5,380	114–271
1994	2,893	606	111–140	8.3–11.2	2,068–3,741	140–303
1995	2,968	303	117–146	7.4–11.6	2,947–4,411	137–250
All	19,281	4,186	109–152	5.5–13.4	1,495–5,864	114–303

for extended periods (Giorgi et al. 1994). Thus, we retained some scores even though they were statistical outliers. On the other hand, we considered fish that traveled unrealistically fast (≥87 km/d, which is several times faster than any previously reported fish migrating through the impounded Columbia River) as outliers statistically and biologically, based on historical observations (Raymond 1968, 1969; Berggren and Filardo 1993). Consequently, we rejected 14 age-0 and 2 age-1 chinook salmon because they supposedly migrated faster than 87 km/d. In addition, we removed 4 age-0 chinook salmon because 2 were unrealistically large (>250 mm FL), 1 was too small to accommodate a PIT tag (27 mm), and 1 traveled 259.7 km in 1,122 d.

Robust bivariate regression (Hamilton 1991) described the relations between migration rates and each independent variable separately. We used robust regression because we retained several outliers in our data files. Robust regression is less sensitive to outliers than is least-squares regression. To increase the range of scores of independent and dependent variables in the analyses, we pooled across years. We analyzed each species, rearing type, and run type separately.

Before conducting multivariate analyses, we calculated Pearson correlation matrices to test for multicollinearity among the independent variables. If two independent variables correlated ($P < 0.05$ and $r^2 > 0.70$), we removed the one that had the poorest relationship (lowest r^2) with migration rate. McHenry's variable selection algorithm (McHenry 1978) selected the final array of independent variables that we used in multiple regression. This stepping procedure selected a subset of variables that provided a minimum Wilk's lambda. Robust multiple regression then described the relationships between migration rates and the final array of independent variables for each species,

TABLE 2.—Multivariate and bivariate robust regression results of migration rates (dependent variable) of age-0 chinook salmon marked at Rock Island Dam and detected at McNary Dam during 1992–1995. All analyses included $\log_e$-transformed dependent and independent variables; N = 1,314.

Independent variable	Regression coefficients	SE	T-value (β = 0)	Probability (β = 0)	Power	R^2 or r^2
			Multivariate models			
Constant	−16.750	0.497	−33.691	0.000	1.000	0.629
Length	2.496	0.059	41.815	0.000	1.000	
Flow	0.963	0.054	17.880	0.000	1.000	
Constant	−4.852	0.477	−10.176	0.000	1.000	0.596
Length	2.531	0.062	40.579	0.000	1.000	
Temperature	−1.511	0.125	−12.103	0.000	1.000	
Constant	−2.510	0.824	−3.046	0.002	0.861	0.585
Length	2.569	0.063	40.840	0.000	1.000	
Date	−1.286	0.141	−9.087	0.000	1.000	
			Bivariate models			
Constant	15.683	0.966	16.237	0.000	1.000	0.122
Date	−2.481	0.184	−13.508	0.000	1.000	
Constant	−9.632	0.285	−33.769	0.000	1.000	0.587
Length	2.648	0.062	42.976	0.000	1.000	
Constant	−8.968	0.575	−15.588	0.000	1.000	0.236
Flow	1.426	0.071	20.125	0.000	1.000	
Constant	10.578	0.477	22.157	0.000	1.000	0.175
Temperature	−2.824	0.169	−16.656	0.000	1.000	

rearing type, and run type. Again, we pooled across years to cover the greatest range of scores possible.

Lastly, the Kolmogorov–Smirnov test assessed if the size distribution of juvenile salmonids interrogated at McN differed significantly from those released at RI. This analysis did not assess growth because fish were not remeasured at McN. Thus, length at interrogation was not the actual size of the fish when they passed McN but rather their size when released at RI. We used this analysis to assess if different size fish were more likely to survive the migration between RI and McN.

Results

Age-0 Chinook Salmon

Approximately 9% of the PIT-tagged age-0 chinook salmon released at RI were detected at McN during the period 1992–1995 (Table 1). Mean migration rates of chinook salmon during the 4 years averaged 15.6 km/d (SD = ±9.5 km/d; range = 0.8–50.9 km/d) between RI and McN. During the migration period in 1992–1995, 5-d mean temperatures and flows ranged from 14.0 to 20.0°C and from 1,504 to 4,972 m^3/s, respectively (Table 1). The size distribution of the subset of tagged chinook salmon detected at McN was significantly different from those released at RI (Figure 2). Larger chinook salmon released at RI were more likely to be detected at McN. Age-0 chinook salmon released at RI ranged from 47 to 171 mm FL, and the subset detected at McN ranged from 62 to 167 mm.

Three different multivariate models explained a significant portion of the variation in downstream migration rates of age-0 chinook salmon (Table 2). The combination of fish length and mean flow explained more of the variation in migration rate than did any other combination of variables. Length, which correlated positively with migration rate (Figure 3), entered all three models and explained the greatest amount of variation in migration rates in both the multivariate and bivariate analyses (Table 2). Although mean flow, mean temperature (negative relationship), and date of release (negative relationship) were also significant in bivariate models, they explained little of the variation in downstream migration rates of age-0 chinook salmon (Figure 3; Table 2). We did not include flow, temperature, and release date in the same multivariate model because they correlated strongly with each other ($r^2 > 0.80$).

Age-1 Chinook Salmon

During the migration period 1989–1995, 20.2% of the age-1 chinook salmon released at RI were detected at McN (Table 1). Across all years, migration rate averaged 21.5 km/d (SD = ±8.4 km/d; range = 0.8–129.8 km/d) between RI and McN. Mean flows and temperatures during the migration

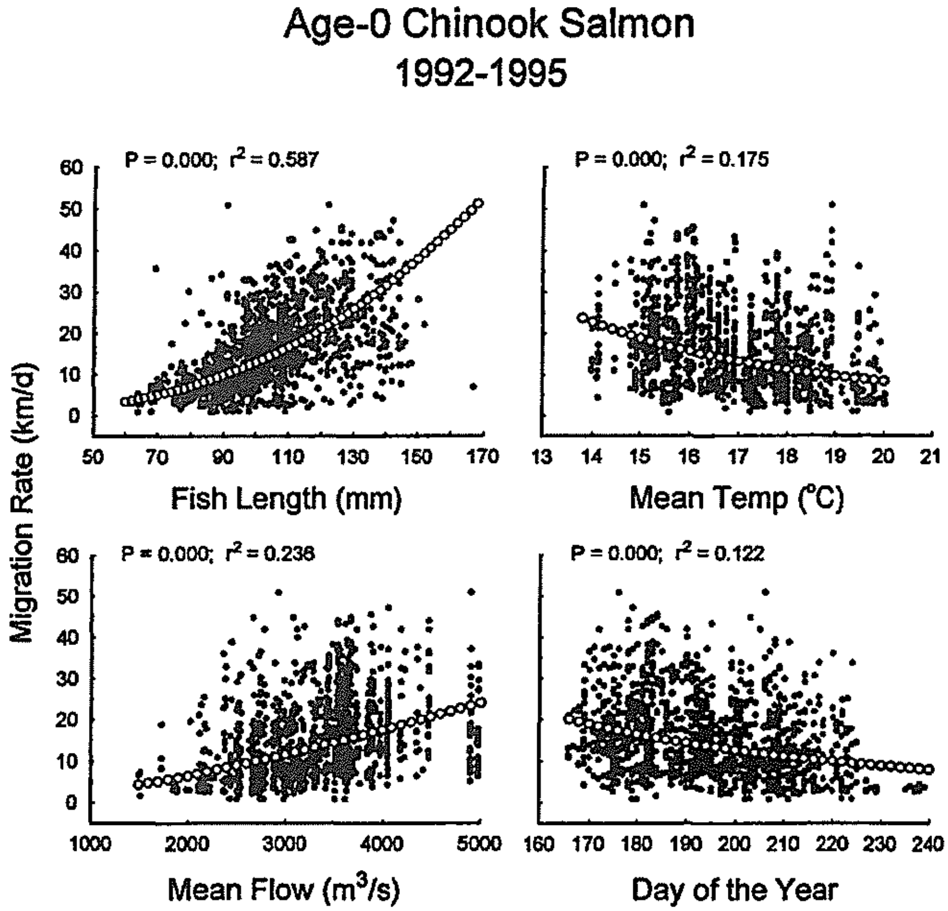


FIGURE 3.—Relationships between migration rates of age-0 chinook salmon and independent variables during the chinook salmon migration period in 1992–1995 between Rock Island Dam and McNary Dam. Open circles represent predicted migration rates from bivariate robust regression analysis; solid circles represent observed migration rates.

period of age-1 chinook salmon ranged from 1,961 to 5,864 m^3/s and from 6.1 to 13.3°C, respectively (Table 1). The size distribution of the subset of chinook salmon detected at McN differed significantly from the size distribution at release. However, visual inspection of the distributions indicates that no particular subset of tagged fish was detected in consistently higher or lower proportions at McN (Figure 2). Age-1 chinook salmon detected at McN ranged from 60 to 222 mm FL, and chinook salmon released at RI ranged from 60 to 298 mm.

Two multivariate models explained a small portion of the variation in migration rates of age-1 chinook salmon between RI and McN (Table 3). The combination of release date and mean flow (positive relationships) explained more variation in migration rates than did the combination of mean temperature and flow (Figure 4). However, no multivariate model explained more than 22% of the variation in migration rates of age-1 chinook salmon. Release date was the most important variable in the bivariate analysis, and it explained 21% of the variation in migration rates (Table 3). Both flow and temperature correlated significantly with migration rate but explained less than 20% of the variation in migration rates.

Juvenile Sockeye Salmon

During the migration period in 1992–1995, 16.1% of the juvenile sockeye salmon tagged and released at RI were subsequently detected at McN (Table 1). Migration rate averaged 26.3 km/d (SD = ±11.3 km/d; range = 2.6–72.1 km/d) between

TABLE 3.—Multivariate and bivariate robust regression results of migration rates (dependent variable) of age-1 chinook salmon marked at Rock Island Dam and detected at McNary Dam during 1989–1995. All analyses included $\log_e$-transformed dependent and independent variables; N = 4,676.

Independent variable	Regression coefficients	SE	T-value (β = 0)	Probability (β = 0)	Power	R^2 or r^2
			Multivariate models			
Constant	−6.947	0.275	−25.267	0.000	1.000	0.221
Date	1.725	0.060	28.587	0.000	1.000	
Flow	0.203	0.021	9.497	0.000	1.000	
Constant	−1.067	0.164	−6.526	0.000	0.999	0.211
Temperature	0.766	0.028	26.919	0.000	1.000	
Flow	0.294	0.021	14.199	0.000	1.000	
			Bivariate models			
Constant	−6.471	0.268	−24.161	0.000	1.000	0.213
Date	1.973	0.055	35.554	0.000	1.000	
Constant	2.870	0.155	18.562	0.000	1.000	0.000
Length	0.038	0.031	1.199	0.231	0.224	
Constant	−0.572	0.168	−3.404	0.001	0.926	0.091
Flow	0.442	0.020	21.610	0.000	1.000	
Constant	1.058	6.112	17.302	0.000	1.000	0.186
Temperature	0.896	0.027	32.619	0.000	1.000	

RI and McN. During the migration period, mean flow and temperature indices ranged from 1,485 to 5,380 m^3/s and from 5.3 to 15.7°C, respectively (Table 1). As with chinook salmon, the subset of sizes of sockeye salmon detected at McN differed significantly from those released at RI, but we found no evidence that any size segment was detected in consistently higher proportions at McN (Figure 2). Detected sockeye salmon ranged from 69 to 215 mm FL, and released sockeye salmon ranged from 57 to 219 mm.

In the multivariate model, both length and release date correlated positively with juvenile sockeye salmon migration rate and together explained 37% of the variation in migration rate (Table 4; Figure 5). Among the bivariate models, flow was the most important single factor and accounted for more variation (r^2 = 0.42) in migration rate than did the multivariate model. Temperature explained slightly more variation in migration rate than did length (Table 4). We could not develop a multivariate model that included flow because flow correlated strongly (r^2 > 0.70) with release date and temperature and did not reduce Wilk's lambda when combined with fish length.

Juvenile Steelhead

During the migration period in 1989–1995, 21.7% of the wild and hatchery-reared steelhead released at RI were detected at McN (Table 1). Steelhead migration rate averaged 30.4 km/d (SD = ±10.9 km/d; range = 0.7–74.2 km/d) between RI and McN. During the migration period, mean flow and temperature indices ranged from 1,495 to 5,864 m^3/s and from 5.5 to 13.4°C, respectively (Table 1). The size distribution of the subset of steelhead detected at McN differed significantly from the tagged population (Figure 2). As with age-0 chinook salmon, visual inspection of the distributions indicates that larger steelhead were more likely to be interrogated at McN. Steelhead released at RI ranged in length from 78 to 305 mm FL, and interrogated steelhead ranged from 114 to 303 mm.

One multivariate model explained 35% of the variation in migration rates of juvenile wild and hatchery steelhead between RI and McN (Table 5). Both mean flow and fish length entered the model and had respective positive and negative relationships with migration rate. In the bivariate analysis, flow was the most important variable and explained 32% of the variation in migration rate. Each of the other variables explained less than 11% of the variation in migration rate (Table 5). Although significant, temperature explained less than 1% of the variation in steelhead migration rates.

Wild steelhead.—We were unable to develop a multivariate model that explained the relationship between independent variables and migration rates of wild steelhead between RI and McN. However, bivariate models indicate that flow, fish length, and release date correlated significantly with migration rate; temperature did not (Table 5). Flow correlated positively with migration rate (Figure 6), and it explained more of the variation in migration rate

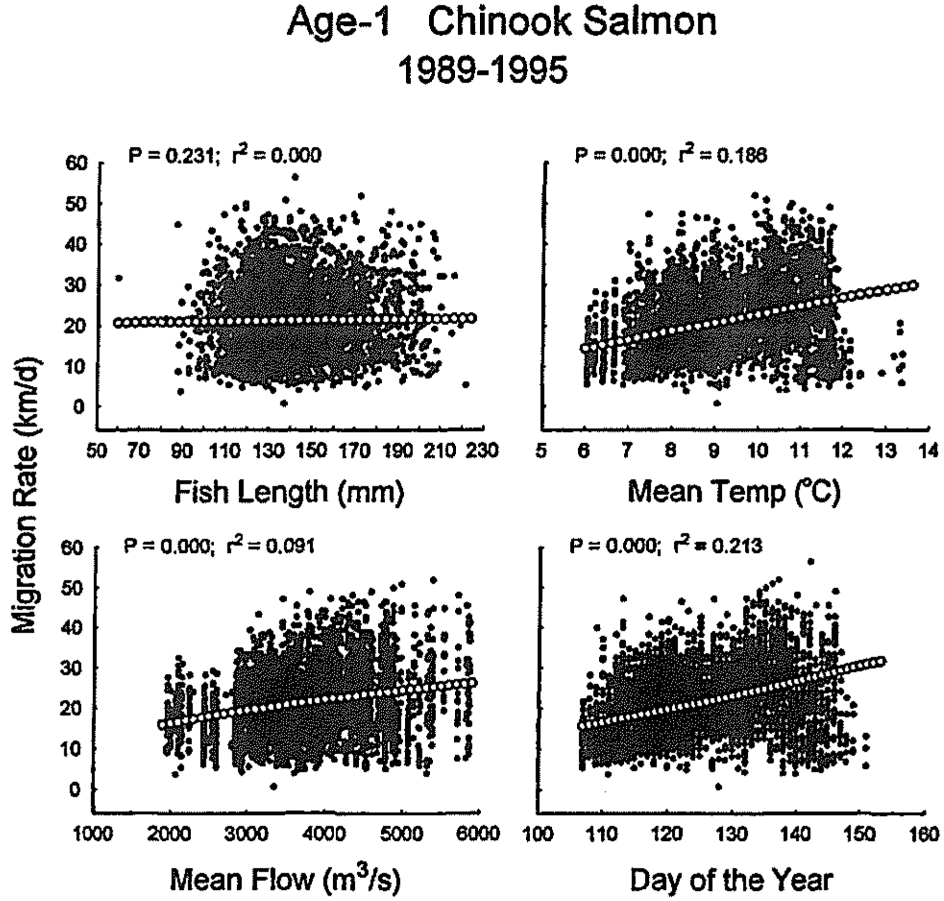


FIGURE 4.—Relationships between migration rates of age-1 chinook salmon and independent variables during the chinook salmon migration period in 1989–1995 between Rock Island Dam and McNary Dam. Open circles represent predicted migration rates from bivariate robust regression analysis; solid circles represent observed migration rates.

TABLE 4.—Multivariate and bivariate robust regression results of migration rates (dependent variable) of juvenile sockeye salmon marked at Rock Island Dam and detected at McNary Dam during 1992–1995. All analyses included $\log_e$-transformed dependent and independent variables; N = 1,943.

Independent variable	Regression coefficients	SE	T-value ($\beta = 0$)	Probability ($\beta = 0$)	Power	R^2 or r^2
			Multivariate models			
Constant	−7.098	0.304	−23.343	0.000	1.000	0.374
Date	1.928	0.067	28.741	0.000	1.000	
Length	0.223	0.037	5.965	0.000	0.999	
			Bivariate models			
Constant	−6.765	0.304	−22.243	0.000	1.000	0.358
Date	2.072	0.063	32.832	0.000	1.000	
Constant	0.403	0.183	2.199	0.028	0.595	0.107
Length	0.604	0.039	15.244	0.000	1.000	
Constant	−2.217	0.147	−15.055	0.000	1.000	0.423
Flow	0.679	0.018	36.981	0.000	1.000	
Constant	1.784	0.058	31.023	0.000	1.000	0.248
Temperature	0.662	0.027	24.846	0.000	1.000	

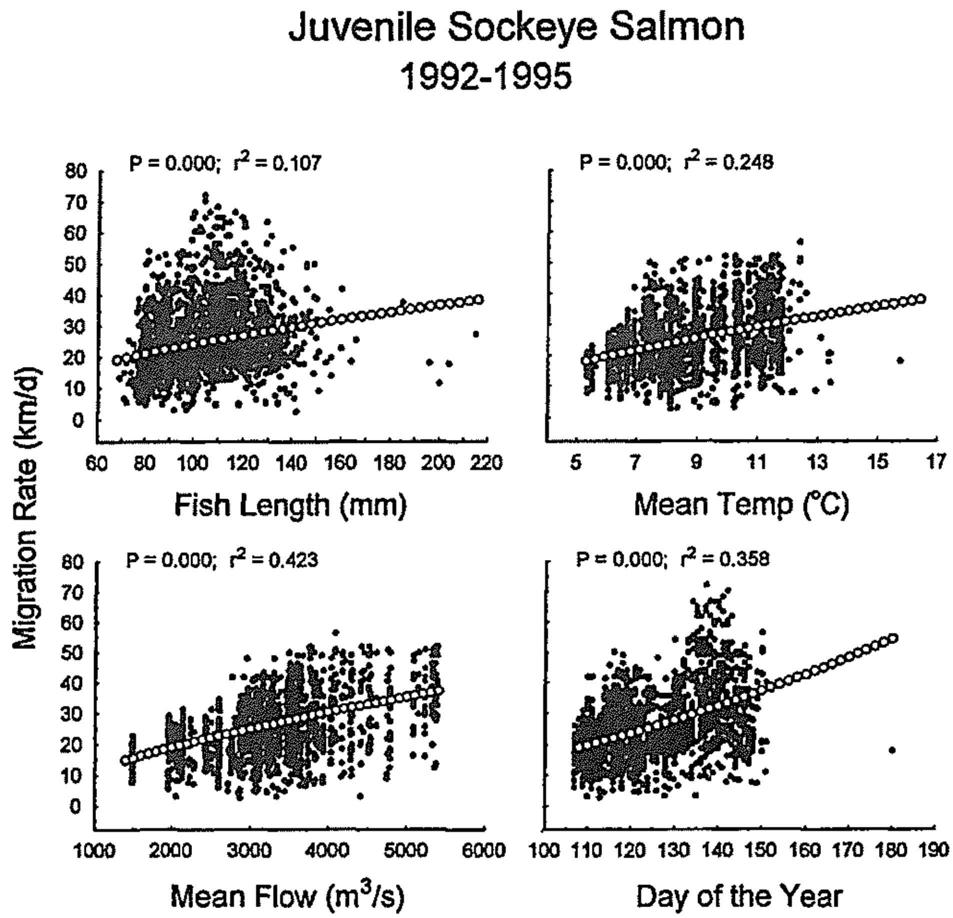


FIGURE 5.—Relationships between migration rates of juvenile sockeye salmon and independent variables during the sockeye salmon migration period in 1992–1995 between Rock Island Dam and McNary Dam. Open circles represent predicted migration rates from bivariate robust regression analysis; solid circles represent observed migration rates.

(r^2 = 0.36) than did other variables. Release date (positive relationship) and length (negative relationship) each explained less than 10% of the variation in migration rates.

Hatchery-reared steelhead.—The combination of flow and length accounted for 35% of the variation in migration rates of hatchery-reared steelhead between RI and McN (Table 5). In the bivariate analysis, flow was the most important variable and explained 31% of the variation in migration rates. Fish length correlated negatively with migration rate, and flow correlated positively with migration rate (Figure 7). As with wild steelhead, temperature had virtually no effect on migration rates of hatchery-reared steelhead.

Discussion

Age-I chinook salmon, sockeye salmon, and steelhead migrate through the Columbia River during the spring. The middle 80% of the migration of all these species typically passes RI from about the last week of April through the end of May (Truscott 1994). On average across all years, the species that migrated fastest was steelhead, with a median rate of 30.4 km/d, followed by sockeye salmon and age-I chinook salmon, at 26.3 and 21.5 km/d, respectively. Age-0 chinook salmon, which migrate past RI primarily during the summer (from the beginning of June through July and into August; Truscott 1994) were the slowest-moving fish, migrating at a median rate of 15.6 km/d. Since

TABLE 5.—Multivariate and bivariate robust regression results of migration rates (dependent variable) of wild and hatchery juvenile steelhead combined (including fish of unknown heritage; $N = 4{,}186$), wild steelhead ($N = 1{,}689$), and hatchery steelhead ($N = 2{,}490$) marked at Rock Island Dam and detected at McNary Dam during 1989–1995. All analyses included $\log_e$-transformed dependent and independent variables.

Independent variable	Regression coefficients	SE	T-value ($\beta = 0$)	Probability ($\beta = 0$)	Power	R^2 or r^2
Wild and hatchery steelhead, multivariate models						
Constant	−0.828	0.212	−3.910	0.000	0.974	0.350
Date	0.765	0.018	42.336	0.000	1.000	
Length	−0.390	0.026	−14.983	0.000	1.000	
Wild and hatchery steelhead, bivariate models						
Constant	−3.044	0.291	−10.461	0.000	1.000	0.106
Date	1.334	0.060	22.225	0.000	1.000	
Constant	6.276	0.161	38.995	0.000	1.000	0.070
Length	−0.542	0.031	−17.761	0.000	1.000	
Constant	−3.058	0.149	−20.595	0.000	1.000	0.323
Flow	0.786	0.018	43.705	0.000	1.000	
Constant	2.931	0.074	39.506	0.000	1.000	0.010
Temperature	0.213	0.033	6.519	0.000	0.999	
Wild steelhead, bivariate models						
Constant	−1.809	0.404	−4.474	0.000	0.994	0.093
Date	1.085	0.083	13.028	0.000	1.000	
Constant	4.858	0.251	19.374	0.000	1.000	
Length	−0.269	0.048	−5.577	0.000	0.999	0.018
Constant	−2.767	0.206	−13.403	0.000	1.000	
Flow	0.757	0.025	30.214	0.000	1.000	0.363
Constant	3.308	0.109	30.216	0.000	1.000	0.001
Temperature	0.065	0.048	1.352	0.176	0.272	
Hatchery steelhead, multivariate model						
Constant	−0.019	0.356	−0.053	0.957	0.050	0.347
Flow	0.779	0.026	30.235	0.000	1.000	
Length	−0.569	0.046	−12.321	0.000	1.000	
Hatchery steelhead, bivariate models						
Constant	−4.293	0.414	−10.371	0.000	1.000	0.122
Date	1.585	0.085	18.557	0.000	1.000	
Constant	8.614	0.277	31.096	0.000	1.000	0.126
Length	−0.981	0.052	−18.879	0.000	1.000	
Constant	−3.469	0.209	−16.557	0.000	1.000	0.310
Flow	0.831	0.025	32.777	0.000	1.000	
Constant	2.766	0.099	27.823	0.000	1.000	0.016
Temperature	0.272	0.044	6.187	0.000	0.999	

age-0 chinook salmon rear and actively forage throughout Columbia River reservoirs (Rondorf et al. 1990), their slower seaward migration is expected. This plausibly explains why they do not exhibit the more directed migrational pattern characteristic of spring-migrating salmonids.

Variables that influence migration rate differ among species. For ocean-type age-0 chinook salmon, only fish size explained a substantive amount of the observed variation in migration rate as evidenced by the moderately large r^2 and R^2 values for bivariate ($r^2 = 0.59$) and multiple-regression ($R^2 = 0.63$) models. The migratory characteristics of this life history form has been studied in John Day Reservoir on the Columbia River. Giorgi et al. (1994) found that over 3 years of study, none of three predictor variables (flow, temperature, or release date) consistently explained the migration rate through John Day Reservoir on the Columbia River. However, Berggren and Filardo (1993), using a similar but expanded data set, did find flow to be an influential variable that explained 28% of the observed variation in travel time through the same reservoir. In our data set, there is no evidence that subyearling chinook salmon respond to changes in river discharge, as observed over a broad range of flow levels (1,500–5,000 m^3/s).

For age-1 chinook salmon, none of the variables we examined explained a substantive amount of

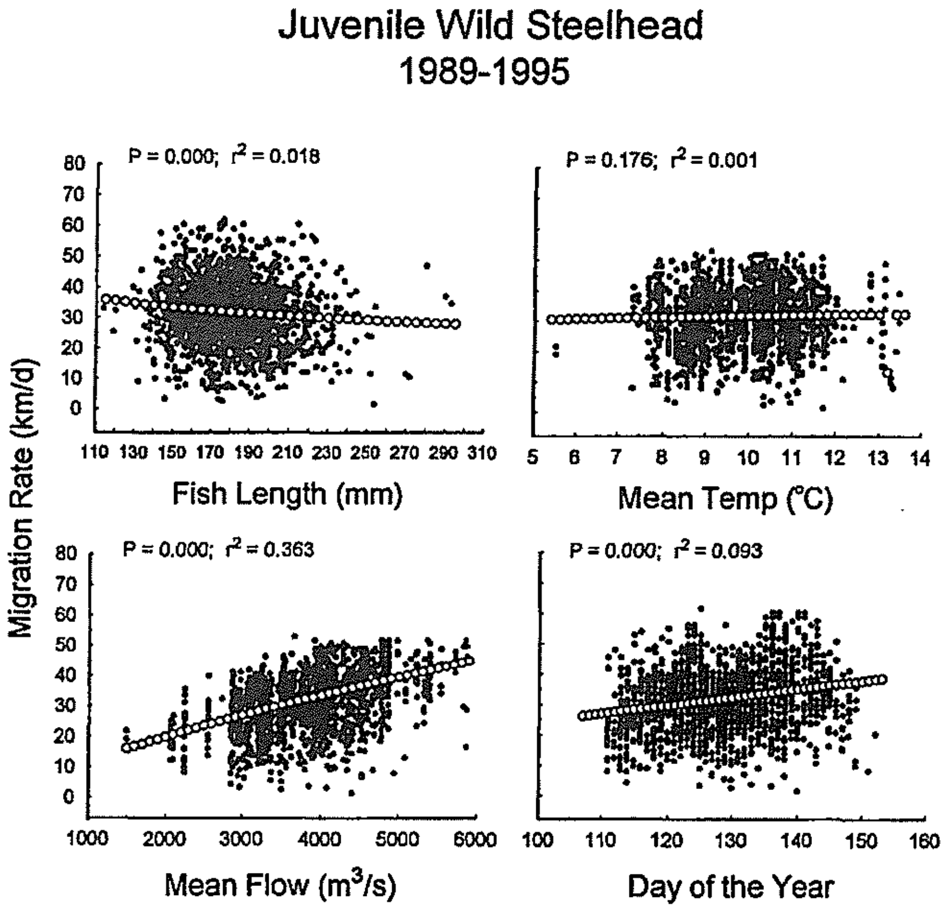


FIGURE 6.—Relationships between migration rates of juvenile wild steelhead and independent variables during the steelhead migration period in 1989–1995 between Rock Island Dam and McNary Dam. Open circles represent predicted migration rates from bivariate robust regression analysis; solid circles represent observed migration rates.

the observed variation in migration rate, as evidenced by the uniformly low R^2 and r^2 values (all <0.23) associated with all models. Evidence for flow effects were not apparent in models for age-1 chinook salmon. This is consistent with results reported by Berggren and Filardo (1993) for age-1 chinook salmon, in the mid-Columbia River. Discharge volume did not enter any model. However, migration rate was positively related to the level of smolt development attributed to the population. In contrast, those same authors found that in the Snake River, the migration rate of stream-type yearling chinook salmon was positively related to flow, which was an important predictor variable (r^2 = 0.46 in their bivariate model). Similarly, Raymond (1968), studying Snake River yearling chinook salmon, identified a positive relationship between migration rate and flow volume. During that era, wild smolts dominated the migrating smolt population (Raymond 1979). Today, hatchery stocks dominate the smolt population, reflecting the depressed status of both Snake River and Columbia River wild stocks and the extensive hatchery program. Behavioral differences between wild and hatchery fish may account for some of the differences observed between this study and that of Raymond (1968).

There is no compelling evidence in these data and analyses that any spring-migrating salmonid species show a substantive response to prevailing river discharge levels through this segment of the Columbia River. Even though for both steelhead and sockeye salmon, flow (as indexed at RI) appeared to be the most influential of the variables, the coefficients of determination were not particularly large. For sockeye salmon, the largest co-

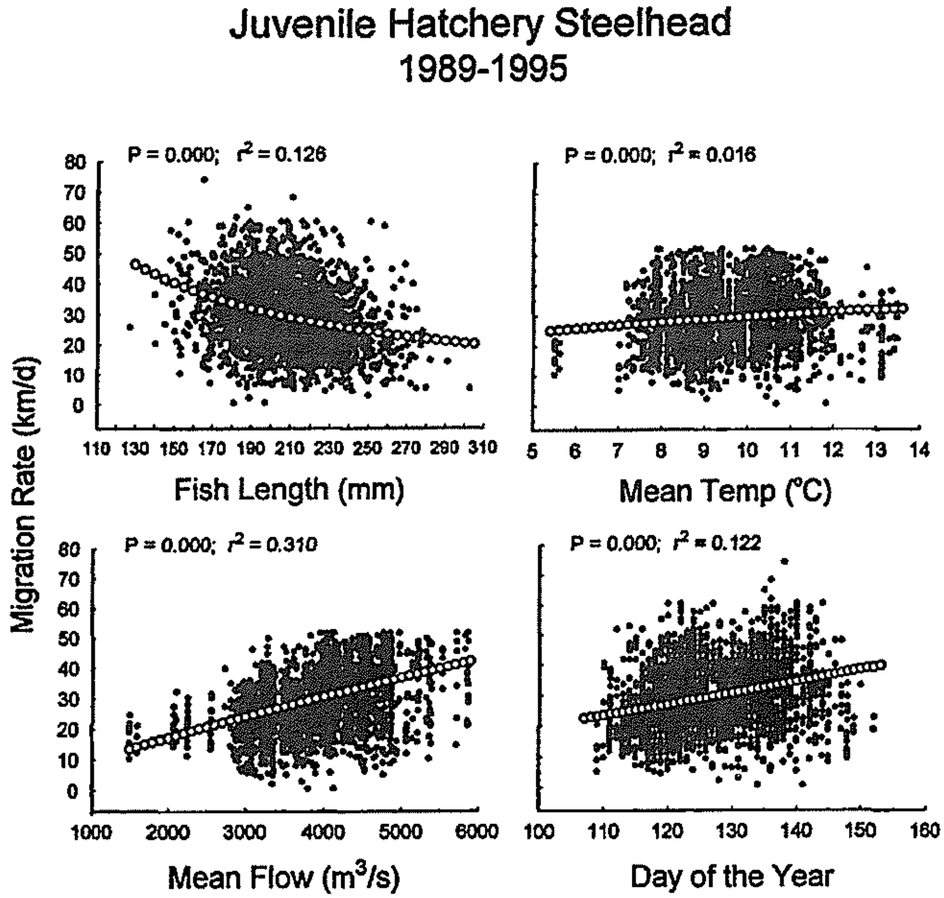


FIGURE 7.—Relationships between migration rates of juvenile hatchery-reared steelhead and independent variables during the steelhead migration period in 1989–1995 between Rock Island Dam and McNary Dam. Open circles represent predicted migration rates from bivariate robust regression analysis; solid circles represent observed migration rates.

efficient of determination was calculated in the bivariate flow model at 0.42, whereas for steelhead, the strongest correlation was evident in the bivariate model for the wild population at 0.36. The steelhead results comport with findings of Berggren and Filardo (1993). They also examined the migratory characteristics of salmonid smolts in the impounded sections of the Snake and Columbia rivers. Using multiple-regression techniques, they examined the relationship between smolt travel time or migration rate and a set of predictor variables similar to those we considered, including indices of river discharge volume, water temperature, and level of smolt development. Within the Columbia River, they reported that the steelhead migration rate was positively related to flow but that the coefficient of determination was low (0.28, similar to what we estimated). In contrast, those same authors reported that in the Snake River their bivariate model yielded an r^2 value of 0.90.

Merely identifying a significant relationship in a regression model does not ensure that the model has reliable or even useful predictive capability. All of the models presented in Table 2 are statistically significant, but the value of the coefficient of determination provides a measure of the strength, or predictive power, of the model. Are the values noted above sufficiently large to ensure that the models provide instructive predictive capability? Prairie (1996) contends that when regression models yield r^2 values less than 0.65, they have poor predictive power, or utility. Under this criterion, both our bivariate and multivariate models may be of questionable value with regard to their predictive capability. However, for age-0 chinook salmon, the r^2 and R^2 values for both bivariate and multivariate models approach the 0.65 value and may provide limited predictive capabilities.

The Biological Opinion Issued by the National Marine Fisheries Service (USNMFS 1995) also calls for flow augmentation in the Columbia River during the summer months to increase the migration rate of subyearling ocean-type chinook salmon. These actions are meant to assist Snake River fall chinook salmon, which are listed under the Endangered Species Act, in traversing the lower Columbia River. However, benefits are presumed to accrue for mid-Columbia River stocks as well. Based on the data acquired in the mid-Columbia River, as analyzed in this investigation, there is no evidence that these chinook salmon respond to broad-scale changes in river discharge during the summer. Their response downstream from McNary Dam has not, and can not, be properly evaluated until adequate PIT tag detection systems are emplaced at dams on the lower river (e.g., John Day or Bonneville dams).

Some of the differences in results reported among the studies cited herein and our investigation may be in part attributable to the type of mark–recovery data used to characterize the migration rate of a freeze-branded, batched-marked groups. Thus, in the models reported by Giorgi et al. (1994) and Berggren and Filardo (1993), median migration rates, or travel times, were used as dependent variables. In our analyses, the specific migration rate of each uniquely identifiable PIT-tagged fish was used as the dependent variable, yielding thousands of observations for model construction. Furthermore, PIT-tagged smolts are recovered in much higher proportions than branded counterparts. This is because every smolt entrained in the bypass system at McNary Dam is interrogated for the presence of a tag. In contrast, only a fraction, typically 3–10%, of the bypassed population was physically sampled and visually inspected for brands in the earlier cited studies. Third, smolts used in these analyses were actively migrating fish, intercepted and tagged at RI, whereas the spring-migrating species used in the Berggren and Filardo (1993) analysis were released directly from the hatchery and may have differed in their level of smolt development.

With regard to the last point, the level of smoltification expressed by yearling chinook salmon has been identified as an important factor influencing migration rate through the Snake River (Berggren and Filardo 1993; Muir et al. 1994). Berggren and Filardo (1993) observed this using regression methods similar to ours. Muir et al. (1994) experimentally demonstrated that well-smolted yearling chinook salmon migrated more readily and quickly than less-smolted counterparts. They found that smolt development was sensitive to both photoperiod and water temperature and that the progress of smolt development increased with increasing day length and water temperature. Because direct physiological indices of smolt development were not available for fish used in this evaluation, we relied on water temperature and date of release to serve as surrogates to reflect smoltification dynamics. However, we observed no evidence for smoltification effects in our analyses.

Acknowledgments

Chelan, Douglas, and Grant County Public Utility Districts, Washington, funded this study. We thank M. Miller for generating figures and N. Mikkelsen for assisting with data compilation. We appreciate the helpful discussions of D. Chapman, M. Miller, D. Nason and the critical reviews of Dennis Rondorf, Howard Raymond, and an anonymous reviewer.

References

Berggren, T. J., and M. J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River basin. North American Journal of Fisheries Management 13: 48–63.

Ebel, W. J., and H. L. Raymond. 1976. Effects of atmospheric gas saturation on salmon and steelhead trout of the Snake and Columbia rivers. U.S. National Marine Fisheries Service Marine Fisheries Review. 38(7):1–14.

Fast, D. E., M. S. Kohn, and B. D. Watson. 1989. Yakima River spring chinook enhancement study. Annual Report, Fiscal Year 1989, to Bonneville Power Administration, Portland, Oregon.

Giorgi, A. E., D. R. Miller, and B. P. Sandford. 1994. Migratory characteristics of juvenile ocean-type chinook salmon, *Oncorhynchus tshawytscha*, in John Day Reservoir on the Columbia River. U.S. National Marine Fisheries Service Fishery Bulletin 92:872–879.

Hamilton, L. 1991. Regression with graphics: a second course in applied statistics. Brooks-Cole, Pacific Grove, California.

Maule, A. G., J. W. Beeman, R. M. Schrock, and P. V. Harner. 1994. Assessment of smolt condition for travel time analysis. Annual Report (Contract DE-A179-87BP35245, Project 87-401) to Bonneville Power Administration, Portland, Oregon.

McHenry, C. 1978. Multivariate subset selection. Journal of the Royal Statistical Society, C 27:291–296.

Muir, W., W. Zaugg, A. Giorgi, and S. McCutcheon. 1994. Accelerating smolt development and downstream movement in yearling chinook salmon with advanced photoperiod and increased temperature. Aquaculture 123:387–399.

Prairie, Y. T. 1996. Evaluating the predictive power of regression models. Canadian Journal of Fisheries and Aquatic Sciences 53:490–492.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990a. Equipment, methods, and an automated data-entry station for PIT tagging. Pages 335–340 *in* N. C. Parker and five coeditors. Fish-marking techniques. American Fisheries Society, Symposium 7, Bethesda, Maryland.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. G. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. Pages 323–334 *in* N. C. Packer and five coeditors, Fish-marking, techniques. American Fisheries Society, symposium 7, Bethesda, Maryland.

Raymond, H. L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake rivers. Transactions of the American Fisheries Society 97:356–359.

Raymond, H. L. 1969. Effect of John Day Reservoir on the migration rate of juvenile chinook salmon in the Columbia River. Transactions of the American Fisheries Society 98:513–514.

Raymond, H. L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Transactions of the American Fisheries Society 108: 505–529.

Raymond, H. L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River Basin. North American Journal of Fisheries Management 8:1–24.

Rondorf, D. W., G. A. Gray, and R. B. Fairley. 1990. Feeding ecology of subyearling chinook salmon in riverine and reservoir habitats of the Columbia River. Transactions of the American Fisheries Society 119:16–24.

Taylor, J. K. 1990. Statistical techniques for data analysis. Lewis Publishers, Boca Raton, Florida.

Truscott, K. B. 1994. Rock Island Dam smolt monitoring, 1994. Report of Chelan County Public Utility District to Pacific States Marine Fisheries Commission, Portland Oregon.

USNMFS (U.S. 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 1995 and future years. USNMFS, Northwest Region, Seattle.

Williams, J. G. 1989. Snake River spring and summer chinook salmon: can they be saved? Regulated Rivers: Research and Management 4:17–26.

ATTACHMENT 3

Berggren and Filardo 1993

DECLARATION OF PAUL A. OCKER

North American Journal of Fisheries Management 13:48–63, 1993

An Analysis of Variables Influencing the Migration of Juvenile Salmonids in the Columbia River Basin

THOMAS J. BERGGREN AND MARGARET J. FILARDO

Fish Passage Center
2501 Southwest First Avenue, Suite 230, Portland, Oregon 97201-4752, USA

Abstract.—The amount of time that it takes juvenile chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* to migrate (travel time) at different river flows through index reaches in the Snake and Columbia rivers was analyzed with bivariate- and multiple-regression models. Smolt travel time estimates for yearling chinook salmon and steelhead in the Snake River, steelhead in the middle Columbia River, and subyearling chinook salmon in the lower Columbia River were inversely related to average river flows. In the multiple-regression analyses, additional predictor variables that were related either to flow or to smoltification were used. These predictor variables were calculated over the same time period as the travel time estimates. Flow-related variables were referenced at a key hydroelectric site within each index reach, and included average river flow, minimum river flow, and absolute change in river flow. The smoltification-related variables provided indirect indices of smoltification. They included water temperature, date of entry into an index reach, chinook salmon race, and travel time prior to entry into an index reach. The final models included those predictor variables explaining significant variation in smolt travel time. The variables in the final multiple-regression models explained 74% and 39% of the variation in the travel time for yearling chinook salmon within the Snake and middle Columbia river index reaches, respectively; 90% and 62% for steelhead within the Snake and middle Columbia reaches; and 65% for subyearling chinook salmon in the lower Columbia reach. Average river flow made the largest contribution to explaining variation in smolt travel time in the majority of the multiple-regression models. Additional variation in smolt travel time could be explained by including other flow- and smoltification-related variables in the models.

The development of hydroelectric dams on the Snake and Columbia rivers has drastically altered the water flows that juvenile anadromous salmonids encounter as they migrate from fresh water to the ocean. Before construction of the dams, the highest flows had occurred in the spring and early summer, and the migration of juvenile salmonids coincided with those high flows (Park 1969). The development and operation of a basin-wide coordinated hydrosystem, along with water withdrawal for irrigation, changed the historical flow pattern and resulted in regulated flows that are lower in the spring and summer and higher in the fall and winter than they were. Increases in cross-sectional area of the river associated with impoundments further reduced water velocities in spring and summer. Raymond (1968, 1969, 1979) estimated that smolts move through the impoundments from one-half to one-third as fast as they do through free-flowing river stretches of the same length. Smith (1982) postulated that smolts swim upstream at a velocity less than that of the water, and thereby move downstream tail-first more slowly than water. The link between smolt migration speed and water speed pointed to river flow as a key factor in determining how quickly smolts will migrate (travel time) through the reservoirs. Juvenile salmonids must arrive at the estuary within a certain time window while they are still physiologically adapted to make the transition from fresh to salt water (Hoar 1976). If they do not enter seawater as smolts, their salinity tolerance regresses (Hoar 1976) and so does their probability of contributing to adult production. Therefore, mitigation was needed to offset the smolt migration delays caused by the dams and impoundments.

When the Northwest Power Planning Council's Columbia River basin fish and wildlife program, authorized by the Pacific Northwest Power Act (Public Law 96-501), was completed in 1982 (NPPC 1987), it addressed this mitigation need by developing the concept of a water budget. The water budget was a volume of water to be used from April 15 to June 15 to augment river flows and thereby reduce delays in the spring smolt migration caused by the hydrosystem. The purpose of the water budget was to improve smolt survival in spring by reducing the travel time of smolts through the reservoirs. This, it was hoped, would reduce the exposure of smolts to riverine predators and allow smolts to reach the estuary while they were still physiologically able to adapt to seawater. Beginning in 1983, the water budget has been applied annually; flows have increased for part of the spring in the middle Columbia River and for a shorter time during spring in the Snake River. Failures of the water budget to provide adequate mitigation for operation of the hydroelectric system have been documented by the Columbia Basin Fish and Wildlife Authority (1991), and are not further addressed in this paper. Instead, the first objective of our study was to document, with recent smolt migration data, whether or not the increased flows decrease the amount of time needed by smolts to travel through the reservoirs.

At the time the water budget was developed, the summer flows necessary for power generation were expected to be sufficient for the summer smolt migration. Since implementation of the water budget, however, summer flows have been below the historic average, due partly to several years of low natural runoff and partly to the practice of refilling the storage reservoirs following the water budget period. For example, average July flow at The Dalles Dam for the 50-year historic record (1929–1978) was 268,700 ft^3/s, whereas the average July flow over the 8 water budget years, 1983–1990, was 144,600 ft^3/s (range, 204,700 ft^3/s in 1983 to 104,000 ft^3s in 1988). Since the inception of a spring water budget, subyearling chinook salmon *Oncorhynchus tshawytscha* have been migrating through the reservoirs in July and August under even lower summer flow conditions than in earlier years. Earlier studies on the migratory behavior of subyearling chinook salmon from 1981 and 1983 (Miller and Sims 1984; Giorgi et al. 1990) had failed to show a significant relation between river flow and either the rate of movement or residence time of summer migrants in John Day reservoir, in contrast to the inverse relations that had been documented for spring migrants (Sims and Ossiander 1981). More recent migration data for subyearling chinook salmon are available for 1986–1988. Because lower summer flows such as those of 1986–1988 appear to be the more likely flow scenario for the future, there was a need to reevaluate the relation (if any) between summer flow and travel time for subyearling fish. Therefore, the second objective of this study was to determine if the travel time of summer migrants is affected by flow.

In addition to flow, other factors can influence how quickly smolts migrate through the reservoirs to the estuary. Zaugg et al. (1985) documented for hatchery chinook salmon, coho salmon *Oncorhynchus kisutch*, and steelhead *O. mykiss* from the Columbia River basin that a period of river migration increases the level of smoltification (as measured by adenosine triphosphotase [ATPase] activity) above the level resulting if the fish are held in net pens for the same time. In another study with Columbia River steelhead, coho salmon, and yearling chinook salmon, Zaugg (1981) noted that migratory behavior and ability to tolerate seawater appear to develop concurrently and that both activities increase over the migration period. Folmar and Dickhoff (1980) associated smoltification with many morphological, behavioral, and physiological changes that allow salmonids to migrate rapidly and adapt readily to seawater. Hoar (1976, 1988) and Wedemeyer et al. (1980) concluded that day length triggers the onset of smoltification, that water temperature regulates the rate and duration of the process and, once the fish are ready to migrate, that a proximal stimulus such as a sudden increase in river discharge actually provokes the migration. Because the stage of smoltification may influence a smolt's migration rate and environmental factors can influence the rate of smoltification, the third objective of our study was to determine if variation in smolt travel time can be explained by variables in addition to flow.

Methods

Study Areas and Monitoring Procedures

Smolt travel time was estimated along key index reaches within the Columbia River basin (Figure 1) for marked subyearling and yearling chinook salmon and steelhead. The key index reaches for spring-migrating yearling chinook salmon and steelhead were from Lower Granite Dam to McNary Dam (140 miles) in the Snake River and from the mouth of the Methow River to McNary Dam (232 miles) in the middle Columbia River. The key index reach for summer-migrating subyearling chinook salmon was from McNary Dam to John Day Dam (76 miles) in the lower Columbia River. The data used to estimate travel time in these index reaches were from the recapture of marked smolts in the fish-sampling facilities at the hydroelectric projects pertinent to each index reach.

Marked spring-migrating yearling chinook salmon came from Rapid River, Sawtooth, and Dworshak hatcheries in the Snake River drainage and Winthrop Hatchery in the middle Columbia River drainage. Marked summer yearling chinook salmon came from McCall Hatchery in the Snake system. Steelhead came from Dworshak Hatchery in the Snake River drainage and Wells Hatchery in the middle Columbia River drainage. Each of these hatcheries is a major contributor of fish to

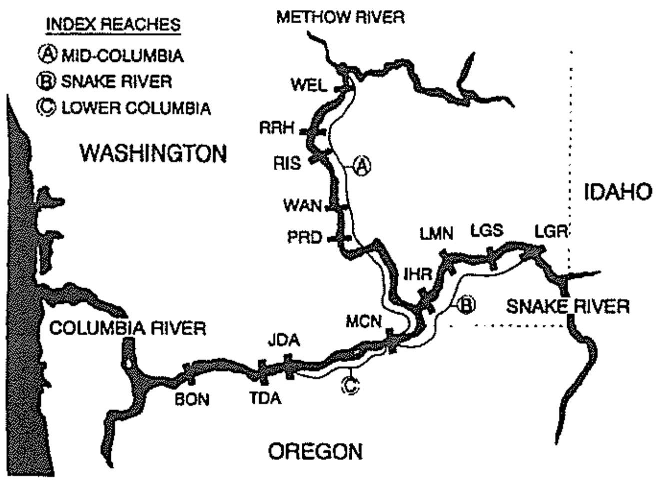


FIGURE 1.—Map of Columbia and Snake river drainages showing the locations of dams and the index reaches used in the travel time analyses. The dams are denoted as follows: LGR = Lower Granite, LGS = Little Goose, LMN = Lower Monumental, IHR = Ice Harbor, MCN = McNary, JDA = John Day, TDA = The Dalles, BON = Bonneville, WEL = Wells, RRH = Rocky Reach, RIS = Rock Island, WAN = Wanapum, and PRD = Priest Rapids.

its respective drainage, and each had a consistent marking program from 1982 or 1983 through 1990. Subyearling chinook salmon were collected at McNary Dam, marked, and released below the dam during two 3-year periods, 1981–1983 and 1986–1988. No marking of subyearling chinook salmon occurred in 1984 and 1985. Each marked subyearling group consisted of an unknown mixture of wild and hatchery stocks of summer and fall chinook salmon. All fish were freeze-branded with silver-tipped brass branding rods cooled in a canister containing liquid nitrogen (Mighell 1969).

The sampling facilities at Lower Granite and McNary dams were similar. At these sites, a proportion of the fish entering the powerhouse were diverted from the turbines by a submersible traveling screen, which directed the fish upward to the gatewell and into a central bypass system (Figure 2). This bypass system was sampled several times per hour and sampled fish were diverted to a holding tank. The sample in the holding tank was counted once every 24 h, and fish were checked for freeze brands. The number of branded fish recovered each day was expanded to a passage index count based on the sampling rate and the proportion of fish estimated to pass the project via the spillway. The proportion of fish passing the project via the spillway was assumed to be equal to the proportion of daily average flow being spilled. A distribution of daily passage indices over time was generated for each marked group.

At John Day Dam, fish were recovered with an airlift sampler (Brege et al. 1990) in one gatewell slot of a turbine unit. In contrast to the continuous collection of fish across all the turbine units at the other dams, this sample came from a single gatewell slot. Hourly collections and brand counts were summed over the 24-h sample period to provide a daily collection as at the other monitoring sites. Daily sample counts were expanded to passage indices by the proportion of daily average river flow going through the sample unit to account for variations in spill and turbine unit loading levels. Again, a distribution of daily passage indices over time was generated for each marked group. Since 1985, fish have been diverted into the gatewell by a submersible traveling screen; however, before that year entry into the gatewell was volitional.

Median Travel Time

Groups of marked smolts with unexpanded mark recoveries of at least 40 were used to estimate median travel time through each index reach (Lower Granite Dam to McNary Dam, Methow River to McNary Dam, and McNary Dam to John Day Dam; Figure 1). The minimum unexpanded sample size of 40 fish was chosen to assure the reliable computation of the travel time estimate. A sample size of 40 recoveries yields a coefficient of variation less than 25% for the relative error associated with recovery of marked fish (deLibero 1986). In addition, the entire data set of all marked groups recovered, regardless of recovery numbers,

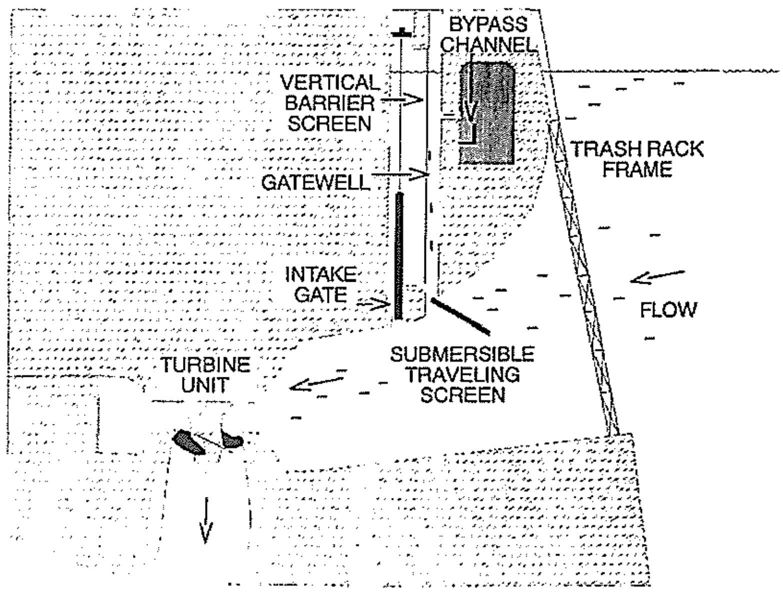


FIGURE 2.—Schematic diagram of the system used to bypass juvenile migrants around turbines and to divert fish to the collection system.

was evaluated for the confidence interval width around the estimated median date of passage. The confidence interval width began to stabilize at 40 unexpanded recoveries.

Most of the brand groups used for this analysis provided unexpanded sample recoveries well in excess of 40 (see Appendix Tables A.1–A.3). The sample size criterion eliminated many of the marked subyearling chinook salmon groups recovered at John Day Dam from 1981 to 1983, when the absence of submersible traveling screens there resulted in very low recoveries of marked fish. Four groups of marked steelhead released from Dworshak Hatchery were eliminated because few marked fish were recovered at McNary Dam as a result of the transportation program at Snake River dams (described later).

The in-river marking of subyearling chinook salmon occurred as part of the transportation study, and could extend over several days until an adequate number of fish were identically marked. Therefore, a criterion of 8 d for the maximum release duration was applied to subyearling chinook salmon releases from McNary Dam to reduce the bias in travel time estimates associated with extended mark–release schedules. Subyearling chinook salmon groups released within the middle 80% of the migration (based on the fish passage timing at McNary Dam for each year) were used in the travel time estimation.

The median travel time for a marked group was estimated as the duration between the group's median date of hatchery release, or dam passage at the upstream end of the index reach, and the median date of dam passage at the downstream end. Median, rather than mean, travel times were computed because passage distributions tended to be skewed. Estimates of median travel time were only as reliable as the estimated dates of median passage at dams, so factors that could affect the distribution of daily passage indices were considered. Two factors to be considered were the transportation program and, of lesser importance, the changes that had occurred in the daily sampling period at recovery sites.

For the Snake River index reach, the distribution of daily passage indices at Lower Granite Dam had to be adjusted to reflect the proportion of the fish that would continue their migration to McNary Dam. Many yearling chinook salmon and most steelhead in the Snake River were collected at Lower Granite and Little Goose dams and transported via barge or truck to release sites in the lower Columbia River. More yearling chinook salmon were transported in years of low flow than in years of high flow, but all steelhead collected were transported regardless of flow. Some chinook salmon were left in the river in all years and some steelhead passed in the spill during high-flow years, and the proportion of fish removed for transportation varied daily in all years. Adjustments for these variables were particularly important for marked summer chinook salmon and steelhead groups that passed Lower Granite and Little Goose dams during periods of transition from a limited to a maximum transportation program. The adjustment factor encompassed the probability of a fish remaining in the river below Lower Granite Dam, conditioned on arriving at Lower Granite Dam, and the probability of that fish remaining in the river below Little Goose Dam, conditioned on arriving at Little Goose Dam. The conditional probabilities were based on deterministic proportions of fish passing with the spill or moving into the powerhouse (passage was assumed proportionally to spill), proportions of fish in the powerhouse going through the turbines or moving through the bypass channel into the collection facility (guidance efficiency research indicated that the traveling screens guided 50% of yearling chinook salmon and 70% of steelhead, on average, into the bypass channel), and the proportion of collected fish actually transported. The daily passage index for each brand group arriving at Lower Granite Dam was multiplied by that day's adjustment factor, and a new distribution of adjusted daily passage indices was obtained for use in subsequent travel time estimation.

The hours defining a 24-h sampling period have differed among monitoring sites and have changed over the years at some sites, so the computation of median travel time had to be standardized. For example, the sampling period had changed from a cycle of noon to noon to one of 0700 to 0700 hours over the years at both Lower Granite and McNary dams. Since each recovery day represented the accumulation of fish collected over the past 24 h, the approach was to interpolate where the median had occurred within that sample period relative to a midnight reference point. This interpolation was made for both release (when applicable) and recovery data. The difference between the two interpolated medians, referenced to midnight, provided the estimate of median travel time in the index reach.

For the middle Columbia River index reach, the date of entry into the Columbia main stem was estimated by allowing a fixed number of days for fish to travel down the Methow River from the hatchery or release site. Marked yearling chinook salmon were assumed to reach the Columbia River at midnight 2 d after release. Marked steelhead also were assumed to reach the main stem at midnight, but on the day of release in 1984–1989 and 1 d after in 1982, 1983, and 1990—differences reflecting changes in release locations over these years.

Sampling occurred 7 d/week in all years at McNary Dam, since 1984 at Lower Granite Dam, and since 1983 at John Day Dam. Prior to this consistent sampling effort, various sampling schedules occurred. In 1982 and 1983, sampling was conducted 6 d/week at Lower Granite Dam. In order to account for noncontinuous sampling, nonsampling days were assigned the average of fish collected on adjacent sampling days for each marked group before estimates of dates of median passage were made. Sampling at John Day Dam was conducted only 5 d/week in 1981 and 1982. Nonsampling days received no average allocation in these cases because few fish were being recovered anyway. Instead, when the computed median date of recovery fell between days of no sampling or between days of sampling with no recoveries at John Day Dam, the date of median recovery was obtained by simple interpolation between those days. Freeze-branded subyearling chinook salmon groups were consistently released below McNary Dam near 2200 hours each year.

To summarize, median travel time through the Snake River index reach was estimated as the difference between the interpolated median date of the adjusted Lower Granite Dam passage distribution and the interpolated median date of McNary Dam passage. Median travel time through the middle Columbia River index reach was estimated as the difference between the adjusted date of entry into the main-stem Columbia River and the interpolated median date of McNary Dam passage. For the lower Columbia River index reach, median travel time was estimated as the difference between the single release dates (1981–1983) or interpolated median release dates (1986–1988) at McNary Dam and the interpolated median date of recovery at John Day Dam.

Predictor Variables

Four variables were considered as surrogates of a marked group's overall smoltification status, or its readiness to migrate. These surrogates were used because no direct measures of the smolts' physiological condition were available for these groups before 1988. The variables considered were river temperature in degrees Fahrenheit (TEMP), prior in-river travel time to Lower Granite Dam in days (TTLGR) for the Snake River migrants, a race indicator variable (RACE) to separate spring and summer chinook salmon in the Snake River, and the day of the year (1–365) that fish entered an index reach (DATE). River temperature stimulates the rate of smoltification (Wedemeyer et al. 1980; Hoar 1988). Yearling chinook salmon and steelhead from the hatcheries used in this analysis have shown substantial increase in ATPase levels during the first 20–30 d of river migration in recent studies (Beeman et al. 1990). Given the different distances hatchery fish travel from release to Lower Granite Dam, 73–465 mi, the TTLGR variable (number of days from release through median recovery date at Lower Granite Dam) was considered an important surrogate for different levels of smoltification among the stocks involved. Date of entry to the index reach (January 1 = day 1) was considered a variable that encompasses the joint effects of all time-related factors (including day length). The RACE variable was 0 for summer chinook salmon and 1 for spring chinook salmon.

Three flow-related variables that might influence smolt migration speed were considered: average flow (FLOW), minimum flow (MINFLOW), and delta-flow (DFLOW). Average flow and minimum flow were considered important variables, given Smith's (1982) findings that smolts tend to orient themselves upstream in the current and to drift downstream at a speed slightly less than that of the water. Delta-flow (maximum minus minimum flow) measured the maximum range of flow encountered by the smolts. To ensure that the conditions experienced by the leading half of a marked group (up to arrival of the median fish) were fully taken into account, average, minimum, and delta-flows, as well as the river temperature, were estimated at a key hydroelectric site in each reach during the time that the first 50% of a group was migrating through that reach. The temperature and flow variables were averages of their daily averages over the estimated median travel times. The key hydroelectric sites chosen to represent conditions in the index reaches were Ice Harbor Dam in the Snake River, Rock Island Dam in the middle Columbia River and John Day Dam in the lower Columbia River.

Bivariate-Regression Analyses

The first two objectives addressed in this paper were whether increased flows decrease smolt travel time through the index reaches, and whether the travel time of subyearling chinook salmon is affected by flow. Bivariate-regression analysis was conducted to address these objectives. The premise was that travel time of fish should follow a similar relation to water passing through a reservoir or series of reservoirs. This would support the findings of Smith (1982) linking smolt travel time to water velocities.

The transit time (in days) of water, or reservoir flow-through time, was estimated by dividing the volume of the reservoir or series of reservoirs by the flow (storage replacement method developed by the U.S. Army Corps of Engineers). Volumes of the reservoirs in each index reach were estimated for capacities designated as full. The flows were referenced at the previously identified sites in each index reach. The Snake River index reach included McNary reservoir, which receives both middle Columbia and Snake river flows. Therefore, the McNary reservoir component of the index reach, a constant adjustment of 140×10^3 ft^3/s (the average spring flow contribution from the middle Columbia River) was added to the flow at Ice Harbor Dam, the lowest dam on the Snake River.

Observed smolt travel time was modeled with a reciprocal flow structure, which is the basis for water transit time through reservoirs. Water transit time is simply a function of flow and the cross-sectional area of the waterway. The similarity of fish travel time to water travel time and what is known about the biology of fish migration suggest that this is the most biologically intuitive model structure.

Multiple-Regression Analyses

The third objective was to determine the importance of other variables for smolt travel time and the relative importance of average flow when other variables were in the model. To address this objective, multiple regression was used on the flow-related and smoltification-related variables.

The goal was to create multiple-regression models having minimal multicollinearity among predictor variables, high R^2 values, and meaningful importance of the variables retained in terms of explaining variation in smolt travel time. All statistical analyses were performed with the SYSTAT statistical package for personal computers (Wilkinson 1990). Visual inspection of bivariate plots and Pearson correlation coefficients provided early indications of the shape and strength of relations between each predictor variable and the dependent variable, and between pairs of predictor variables. In the multiple-regression analysis, a step-flow increased. As a result of the limited range of flows observed in the middle Columbia River, the relation between smolt travel time and flow was not established ($P = 0.95$) for Winthrop Hatchery spring chinook salmon and only marginally established ($P = 0.04$) for Wells Hatchery steelhead (Table 1). The bivariate relations between travel time estimates and average flow are depicted in Figure 3 along with theoretical water transit times for each index reach.

Regression diagnostics indicated the presence of an outlier observation in the bivariate regressions that needed further consideration. This observation was the 1986 yearling chinook salmon group from Dworshak Hatchery. The studentized residual was 4.6, which is within the range that Draper and Smith (1981) defined as an outlier. Because this observation was not a high-leverage point, it did not affect the estimated regression slope or the significance of the regression (Fox 1991). It did, however, substantially increase the variance around the regression. Therefore, this observation was omitted when the bivariate regression model for Snake River yearling chinook salmon was determined (Table 1).

Multiple-Regression Analyses

Snake River index reach.—The predictive model for yearling chinook salmon groups in the Snake River index reach included the reciprocal of average flow ($FLOW^{-1}$), prior travel time to Lower Granite Dam (TTLGR), and delta-flow (DFLOW). The inclusion of the additional variables caused the outlier observation observed in the bivariate analysis to be even more severe (studentized residual, 5.4). The coefficients of the multiple regression did not change significantly with this observation, but the variance about the regression again substantially increased. Therefore, the outlier was excluded, and the resulting model with the remaining 29 observations explained 74% of the variation in smolt travel time (Table 2). The stepwise regression routine selected the variable $FLOW^{-1}$ first ($R^2 = 0.46$), followed by the variables TTLGR ($R^2 = 0.57$) and DFLOW ($R^2 = 0.74$). A 48% reduction in residual error about the

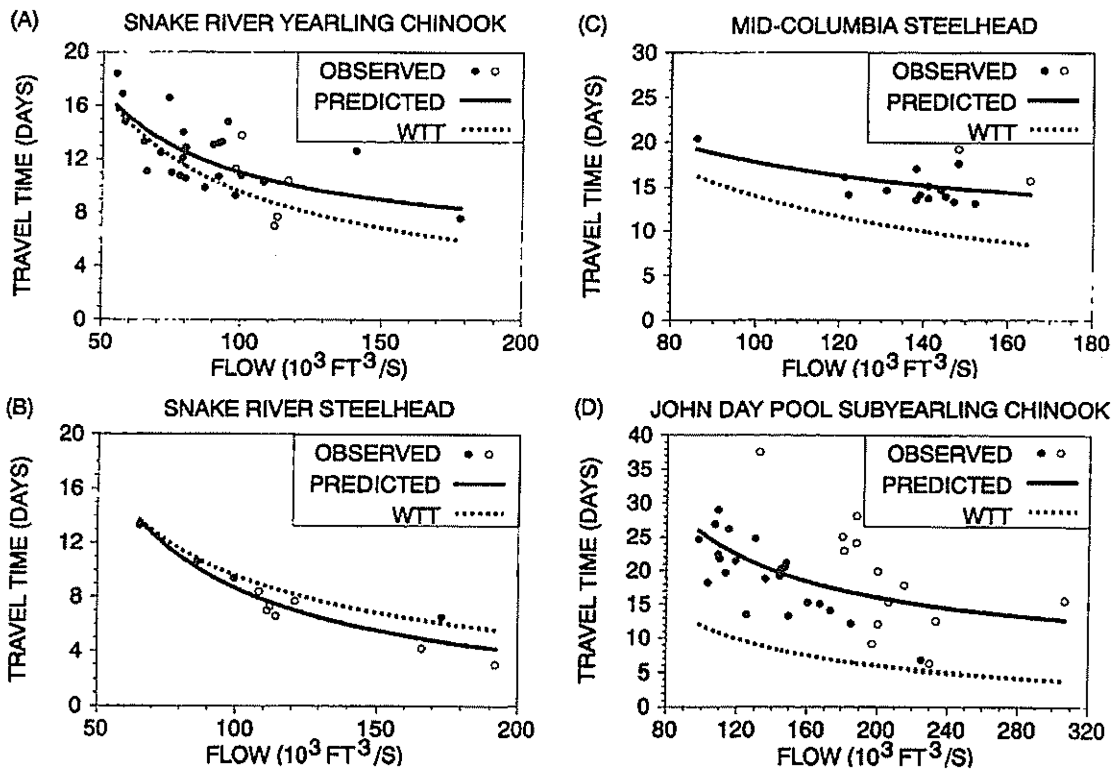


FIGURE 3.—Observed and predicted fish travel time estimates, and estimated water transit time (WTT), versus flow for (**A**) Snake River yearling chinook salmon, (**B**) Snake River steelhead, (**C**) middle Columbia River steelhead, and (**D**) lower Columbia River (John Day pool) subyearling chinook salmon. Open circles (o) denote pre-water budget years 1981–1983; solid circles (•) denote post-water budget years 1984 and beyond.

TABLE 2.—Multiple-regression models for predicting travel time[a] of yearling and subyearling chinook salmon and steelhead in key index reaches of the Columbia River basin.

Group	N	Variable[b]	Coefficient	SE	P[c]	MSE[d]	R^2
		Snake River index reach					
Yearling chinook salmon	29	Constant	6.401	1.541	<0.01	2.13	0.74
		$FLOW^{-1}$	574.072	92.208	<0.01		
		TTLGR	−0.120	0.029	<0.01		
		DFLOW	0.057	0.014	<0.01		
Steelhead	11	Constant	−0.730	0.967	0.47	0.89	0.90
		$FLOW^{-1}$	935.650	103.347	<0.01		
		Middle Columbia River index reach					
Yearling chinook salmon	14	Constant	69.709	16.140	<0.01	5.39	0.39
		DATE	−0.387	0.141	0.02		
Steelhead	16	Constant	42.883	10.108	<0.01	2.05	0.62
		$FLOW^{-1}$	1,040.739	296.388	<0.01		
		TEMP	−0.724	0.209	<0.01		
		Lower Columbia River index reach					
Subyearling chinook salmon	35	Constant	−42.364	9.598	<0.01	16.95	0.65
		$FLOW^{-1}$	3,016.061	445.452	<0.01		
		DFLOW	0.133	0.031	<0.01		
		DATE	0.165	0.042	<0.01		

[a] Median smolt travel time estimate (days) in index reach.
[b] Predictor variables: TTLGR = travel time from hatchery release to Lower Granite Dam (days); $FLOW^{-1}$ = reciprocal of flow (10^3 ft^3/s) averaged over the travel time days; DFLOW = absolute change in daily average flow (10^3 ft^3/s) over travel time days; TEMP = daily river temperature averaged over travel time (°F); DATE = day of entry into the index reach (day 1 = January 1).
[c] Probability (2-tail) that the coefficient is no different from zero; significant when $P \leq 0.05$.
[d] Residual mean-square error.

regression was observed relative to the bivariate model. Because of the high level of independence among the predictor variables (tolerances > 0.94), the beta coefficients were used and showed that $FLOW^{-1}$ explained the highest proportion of the variation in estimated travel time (Table 3). With other variables held fixed, the effect of the TTLGR variable was to shorten travel time in the index reach for yearling chinook salmon groups that migrated a longer time before entering the index reach. The effect of the DFLOW variable was to increase smolt travel time as the difference between minimum and maximum flow increased. This is a function of the curvilinear shape of the relation between average flow and smolt travel time. With the $FLOW^{-1}$ variable in the model, an increasing DFLOW reflected the effect of the time spent migrating at the lower flows.

The bivariate model with $FLOW^{-1}$ for steelhead in the Snake River index reach explained over 90% of the variation in smolt travel time (Table 1). The stepwise multiple-regression routine selected $FLOW^{-1}$ first ($R^2 = 0.90$), and then added TTLGR ($R^2 = 0.97$). However, the positive sign of TTLGR was opposite of what theory would predict and may simply reflect a higher level of smoltification for the later releases in 1982 and 1983. Because $FLOW^{-1}$ alone explained such a high proportion of the variation in smolt travel time, it was retained as the most parsimonious and biologically relevant model (Table 2).

Middle Columbia index reach.—The predictive model for yearling chinook salmon in the middle Columbia River index reach included the day of entry variable DATE. This predictor variable explained 39% of the variation in smolt travel time (Table 2). Smolt travel time decreased for later-migrating groups. The variation in flow experienced by yearling chinook salmon was limited and, therefore, the lack of a significant correlation with $FLOW^{-1}$ was not unexpected. The stepwise regression routine selected the variable DATE first ($R^2 = 0.39$), and then added DFLOW ($R^2 = 0.63$). However, the DFLOW must occur with $FLOW^{-1}$ in the model to retain its biological interpretation. Here, DFLOW may simply reflect that in 1987–1989, flow increased from low levels early in the migration of Winthrop Hatchery spring chinook salmon to levels more similar to the early-May flows of other years. Apparently, the higher flows that occurred later in the migration period, when these hatchery chinook salmon were at a higher smoltification level (Beeman et al. 1990), increased the migration rate and resulted in a shorter

TABLE 3.—Measures of importance of individual predictor variables in the multiple-regression models for smolt travel time.[a]

Group	Variable[b]	Partial coefficient	Tolerance[c]	Beta coefficient[d]
		Snake River index reach		
Yearling chinook salmon	$FLOW^{-1}$	574.072	0.993	0.637
	TTLGR	−0.120	0.942	−0.439
	DFLOW	0.057	0.947	0.418
		Middle Columbia River index reach		
Steelhead	$FLOW^{-1}$	1,040.739	0.983	0.603
	TEMP	−0.724	0.983	−0.595
		Lower Columbia River index reach		
Subyearling chinook salmon	$FLOW^{-1}$	3,016.061	0.738	0.836
	DFLOW	0.133	0.745	0.522
	DATE	0.165	0.988	0.416

[a] Median smolt travel time estimate (days) in index reach.
[b] Predictor variables: TTLGR = travel time from hatchery release to Lower Granite Dam (days); $FLOW^{-1}$ = reciprocal of flow (10^3 ft^3/s) averaged over the travel time days; DFLOW = absolute change in daily average flow (10^3 ft^3/s) over travel time days; TEMP = daily river temperature averaged over travel time (°F); DATE = day of entry into the index reach (day 1 = January 1).
[c] One minus the multiple correlation between a predictor variable and all other predictor variables in the model.
[d] Indicates the relative contribution of each predictor variable in explaining the variation in the dependent variable.

travel time than anticipated, given the low computed average flow. Because the DFLOW variable appears to reflect a more complex flow–smoltification response, which cannot be quantified with available data, the more parsimonious model with only the DATE variable was retained.

The predictive model for steelhead in the middle Columbia River index reach included the reciprocal of average flow ($FLOW^{-1}$) and river temperature (TEMP). These two predictor variables explained 62.3% of the variation in smolt travel time (Table 2). The stepwise regression routine selected DATE first (R^2 = 0.35), then $FLOW^{-1}$ (R^2 = 0.56) and TEMP (R^2 = 0.65). With TEMP in the model, DATE became a nonsignificant contributor (P = 0.36) and was removed in the next step. A 44% reduction in residual error about the regression was observed relative to the bivariate model for these steelhead. Because of the high level of independence between the predictor variables (tolerances > 0.98), the beta coefficients were used and showed that $FLOW^{-1}$ and TEMP explained about equal proportions of the variation in estimated travel time (Table 3). With flow fixed, the effect of increasing river temperatures was to decrease smolt travel time.

Lower Columbia River index reach.—The predictive model for travel time of subyearling chinook salmon through John Day reservoir included the reciprocal of average flow ($FLOW^{-1}$), deltaflow (DFLOW), and day of entry to the reach (DATE). These three variables explained 65% of the variation in smolt travel time (Table 2). The stepwise regression routine selected the reciprocal of minimum flow ($MINFLOW^{-1}$) first (R^2 = 0.35), then DATE (R^2 = 0.52), DFLOW (R^2 = 0.61), and $FLOW^{-1}$ (R^2 = 0.66). With $FLOW^{-1}$ in the model, $MINFLOW^{-1}$ became a nonsignificant contributor (P = 0.58) and was removed in the next step. A 49% reduction in residual error about the regression was observed relative to the bivariate model for subyearlings. A high level of independence occurred between DATE and the other two variables (tolerance = 0.99). A low level of multicollinearity occurred between $FLOW^{-1}$ and DFLOW (tolerance > 0.7), but it was too low to cause any concern about the coefficient estimates (Lewis-Beck 1980). Therefore, the beta coefficients were used and showed that $FLOW^{-1}$ explained the highest proportion of the variation in estimated travel time (Table 3). With the other variables fixed, the effect of DATE was to increase smolt travel time as the summer season progressed. The DATE variable appears to encompass a compounded effect of flow and smoltification. Because flow decreases through the summer migration period each year, the DATE variable includes the effect of this temporal trend. In addition, this variable will encompass smoltification differences in the mixed-stock population. Physiological monitoring of subyearling chinook salmon, begun at McNary Dam in 1990, has shown a lower level of smoltification (as measured by gill ATPase activity) among the later migrants in this mixed population (D. Rondorf, U.S. Fish and Wildlife Service, personal communication).

Discussion

The bivariate- and multiple-regression analyses documented that flows were important during both the spring and summer months when marked groups of salmonid smolts were migrating. With one exception, the relation between smolt travel time and average flow was statistically significant. The marked groups of subyearling and yearling chinook salmon and steelhead, released over 6–9 years during the past decade, showed that the time it takes smolts to migrate through key index reaches in the Columbia River drainage was inversely related to the average flow in the system. The exception was marked groups of yearling chinook salmon migrating in the middle Columbia River index reach, and it may be attributable to the narrow range of higher average flows these groups experienced between 1983 and 1990. When additional variables were considered, average flow was still the most important variable in the model for yearling chinook salmon and steelhead in the Snake River and in the model for subyearling chinook salmon in John Day reservoir. Average flow and temperature (a smoltification-related variable) had about equal importance for steelhead in the middle Columbia River.

Bivariate relations between smolt travel time and average flow and between theoretical water transit time and average flow had similar forms (Figure 3). As stated in the introduction, the link between smolt migration speed and water velocity (Smith 1982) had pointed to river flow as a key factor in determining smolt travel time through reservoirs. The rationale used by the Northwest Power Planning Council (NPPC) when it adopted flow augmentation as a mitigation measure in 1982 for the fish and wildlife program was further substantiated by these analyses.

The NPPC's fish and wildlife program did not provide flow mitigation for summer-migrating subyearling chinook salmon. Studies conducted between 1981 and 1983 had not produced evidence of a relation between average flow and travel time for subyearling migrants (Miller and Sims 1984). Further analysis of these data by Giorgi et al. (1990) again provided no evidence of a significant relation between flow and smolt travel time. In part, the reliability of the travel time estimated used may have been affected by the small sample recoveries. Marked releases of subyearling chinook salmon from McNary Dam between 1986 and 1988 provided additional travel time information (based on samples with higher recovery numbers) under a broader range of flows. With 6 years of data over a broader range of flow and a minimum sample size criterion for all mark groups, both the bivariate- and multiple-regression analyses presented here documented that average flow does have a statistically significant effect on travel time of subyearling chinook salmon during the summer.

The multiple-regression analyses documented the importance of adding a variable to account for the maximum change in flow during migrations. Marked smolts migrate under conditions of changing flow. For yearling chinook salmon in the Snake River and subyearling chinook salmon in the lower Columbia River, increases in delta-flow increased smolt travel time. Because of the curvilinear relation between smolt travel time and average flow, flows below the average have a greater effect on smolt travel time than flows above the average. Therefore, having a large delta-flow about an average level, rather than a relatively constant average flow, would tend to increase smolt travel time. Since yearling chinook salmon migrated during a period of rapidly increasing flows in the spring, and subyearling chinook migrated during a period of rapidly decreasing flows in the summer, the effects of delta-flow were significant. Steelhead tended to migrate closer to the peak of the spring freshet and experienced a longer period when flow fluctuations were lower than those experienced by yearling chinook salmon, so delta-flow was not a significant variable.

The multiple-regression analysis also documented that smoltification, as defined by surrogate variables, played a role in predicting how quickly smolts migrated through the index reaches. Variables including migration time from release at the hatchery to the start of an index reach (at Lower Granite Dam), chinook salmon race, river temperature, and date of entry into the index reach were considered. Other factors that influence smoltification, such as fish size, diet, and disease, were not considered in the modeling because consistent data were not available for all years. The variables used in the analysis were easily obtainable and had a biological link to some stage of smoltification. Travel time to Lower Granite Dam successfully accounted for smoltification differences among the four hatchery stocks of Snake River chinook salmon yearlings that had migrated different distances to the start of the index reach. In-river migration time has been shown to directly increase smoltification (Zaugg et al. 1985). The indicator variable for chinook salmon race was not significant in the model, apparently because potential race differences were already accounted for by the variable of migration time from hatchery to Lower Granite Dam. The summer race of chinook salmon tended to migrate for a longer period of time to the start of the index reach than did the spring race. The day of entry to the index reach captured the effect of the temporal changes (e.g., change in day length; Hoar 1988) on smoltification for middle Columbia River yearling chinook salmon and lower Columbia River subyearling chinook salmon. This variable also included the effect of the decreasing temporal trend in flow that occurs each year for subyearlings. Because day length is so highly correlated ($r > 0.95$) with the day of entry into an index reach, either variable may effectively relate to the level of smoltification attained. Since temperature generally controls the rate of smoltification (Hoar 1988), the presence of river temperature in the middle Columbia River steelhead model may reflect changes in smoltification. Whether day of entry to index reach or river temperature was selected for a particular predictive model may simply have reflected which variable was less correlated with other variables already in the model. Nevertheless, by including a surrogate for smoltification in the models, additional variation in smolt travel time was explained over that possible with flow-related variables alone.

In conclusion, increased flows reduce the travel time of both yearling chinook salmon in the Snake River and steelhead smolts in the middle Columbia and Snake rivers in spring and of subyearling chinook smolts in summer. This means that increased flows can mitigate both the spring and summer outmigration delays that smolts experience as a result of operation of the hydroelectric system in the Columbia River basin. Including variables that account for changes in smoltification during outmigration helps explain additional variation in estimated travel time. Therefore, predicting smolt travel time through key index reaches in the Columbia River basin is best accomplished with multiple-regression models containing both flow-related and smoltification-related variables.

Acknowledgments

Many people have been instrumental in generating the data analyzed in this study, and a special thanks is extended to all these individuals. This includes the hatchery managers and staff who made the fish available for marking, the crews that conducted the marking, and the field crews at each of the monitoring sites who collected the recovery data. We also thank the computer staff of the Fish Passage Center, who compiled and processed the data that went into the anlaysis, created graphics, and prepared the manuscript. We appreciate the time of those individuals who critically reviewed the manuscript and made helpful suggestions for improvements. The Fish Passage Center is funded by the Bonneville Power Administration as directed by the Northwest Power Planning Council's Fish and Wildlife Program.

References

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

Brege, D. A., W. E. Farr, and R. C. Johnsen. 1990. An air-lift pump for sampling juvenile salmonids at John Day Dam. North American Journal of Fisheries Management 10:481–483.

Columbia Basin Fish and Wildlife Authority. 1991. The biological and technical justification for the flow proposal of the Columbia Basin Fish and Wildlife Authority. CBFWA, Portland, Oregon.

deLibero, F. 1986. A statistical assessment of the use of the coded wire tag for chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) studies. Doctoral thesis. University of Washington, Seattle.

Draper, N. R., and H. Smith. 1981. Applied regression analysis, 2nd edition. Wiley, New York.

Folmar, L. C., and W. W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids. A review of selected literature. Aquaculture 21:1–37.

Fox, J. 1991. Regression diagnostics. Sage Publications, Series 7-79, Newbury Park, California.

Giorgi, A. E., D. R. Miller, and B. P. Sanford. 1990. Migrating behavior and adult contribution of summer outmigrating subyearling chinook salmon in John Day reservoir, 1981–1983. Final Report to Bonneville Power Administration, Contract DE-AI79-83BP39645, Portland, Oregon.

Hoar, W. S. 1976. Smolt transformation: evolution, behavior, and physiology. Journal of the Fisheries Research Board of Canada 33:1233–1252.

Hoar, W. S. 1988. The physiology of smolting salmonids. Pages 257–343 *in* W. S. Hoar and D. J. Randall, editors. Fish physiology, volume II, part B. Academic Press, New York.

Lewis-Beck, M. S. 1980. Applied regression, an introduction. Sage Publications, Series 7-22, Newbury Park, California.

Mighell, J. L. 1969. Rapid cold-branding of salmon and trout with liquid nitrogen. Journal of the Fisheries Research Board of Canada 26:2765–2769.

Miller, D. R., and C. W. Sims. 1984. Effects of flow on the migratory behavior and survival of juvenile fall and summer chinook salmon in John Day Reservoir. Annual report to Bonneville Power Administration, Contract DE-AI79-83BP39645, Portland, Oregon.

NPPC (Northwest Power Planning Council). 1987. Columbia River basin fish and wildlife program. NPPC, Portland, Oregon.

Park, D. L. 1969. Seasonal changes in downstream migration of age-group 0 chinook salmon in the upper Columbia River. Transactions of the American Fisheries Society 98:315–317.

Raymond, H. L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake rivers. Transactions of the American Fisheries Society 97:356–359.

Raymond, H. L. 1969. Effect of John Day Reservoir on the migration rate of juvenile chinook salmon in the

Columbia River. Transactions of the American Fisheries Society 98:513–514.

Raymond, H. L. 1979. Effects of dams and impoundments on migrations of juvneile chinook salmon and steelhead from the Snake River, 1966 to 1975. Transactions of the American Fisheries Society 108: 505–529.

Sims, C. W., and F. J. Ossiander. 1981. Migrations of juvenile chinook salmon and steelhead in the Snake River, from 1973 to 1979, a research summary. Report to the U.S. Army Corps of Engineers, Contract DACW68-78-C-0038, Portland, Oregon.

Smith, L. S. 1982. Decreased swimming performance as a necessary component of the smolt migration in salmon in the Columbia River. Aquaculture 28:153–161.

Snedecor, G. W., and W. G. Cochran. 1989. Statistical methods, 8th edition. Iowa State University Press, Ames.

Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. U.S. National Marine Fisheries Service, Marine Fisheries Review 42(6):1–14.

Wilkinson, L. 1990. SYSTAT: the system for statistics. SYSTAT, Evanston, Illinois.

Zaugg, W. S. 1981. Relationships between smolt indices and migration in controlled and natural environments. Pages 173–183 *in* E. L. Brannon and E. O. Salo, editors. Salmon and trout migratory behavior symposium. University of Washington, Seattle.

Zaugg, W. S., E. F. Prentice, and F. W. Waknitz. 1985. Importance of river migration to the development of seawater tolerance in Columbia River anadromous salmonids. Aquaculture 51:33–47.

Appendix: Passage Data for Study Reaches

TABLE A.1.—Snake River index reach data. The reach extends from Lower Granite Dam (LGR) to McNary Dam (MCN).

Year	Median release date[a]	Sample number[b] LGR	Sample number[b] MCN	Travel time (d)[c]	Flow (10^3 ft^3/s)[d] Average	Flow Minimum	Flow Delta[e]	Days to LGR[f]	Average river temperature (°F)[d]	Entry day of the year[g]
				Dworshak Hatchery spring chinook salmon yearlings						
1983	Apr 1	335	142	13.8	100	41	79	21	53	112
1985	Apr 4	384	378	12.1	79	53	55	23	51	117
1986	Apr 2	479	370	20.8	97	78	42	19	52	111
1987	Apr 2	659	358	12.5	71	42	51	22	55	114
1988	Mar 30	502	555	18.4	55	35	55	21	52	110
1989	Mar 30	1,506	211	13.2	92	57	53	26	53	115
1990	Apr 5	372	254	16.6	74	57	33	24	54	119
				McCall Hatchery summer chinook salmon yearlings						
1983	Apr 6	444	289	7.7	113	108	12	29	55	125
1984	Apr 10	196	153	7.6	178	160	37	37	53	137
1985	Apr 3	185	86	13.1	90	59	59	40	54	133
1986	Mar 27	508	170	10.8	100	90	27	37	53	124
1987	Mar 31	98	114	10.6	80	61	32	32	56	122
1989	Mar 21	194	116	9.9	87	56	64	51	55	131
1990	Mar 22	54	91	10.8	78	41	83	61	55	142
				Rapid River Hatchery spring chinook salmon yearlings						
1982	Mar 27	159	144	10.4	117	101	25	26	49	112
1983	Mar 22	617	536	11.3	98	41	79	31	53	112
1984	Mar 27	302	262	10.3	108	88	40	31	49	117
1985	Apr 5	593	362	14.0	79	53	55	20	51	115
1986	Apr 5	1,073	295	14.8	95	78	42	15	52	110
1987	Apr 2	194	98	11.0	75	50	44	24	55	116
1988	Mar 23	116	189	16.9	57	35	55	32	53	114
1989	Mar 30	1,407	165	13.3	93	57	53	24	52	113
1990	Mar 24	297	309	13.3	65	53	23	30	54	113
				Sawtooth Hatchery spring chinook salmon yearlings						
1983	Mar 29	181	113	7.0	112	98	22	35	54	123
1984	Mar 28	230	156	12.6	141	105	92	39	52	126
1985	Mar 27	216	124	12.9	80	59	49	38	53	124
1986	Mar 17	226	65	9.3	98	85	35	38	52	114
1988	Mar 15	47	88	14.8	58	35	55	42	53	116
1989	Mar 15	304	86	10.7	92	57	53	39	52	113
1990	Mar 17	76	96	11.1	66	53	23	37	54	113
				Dworshak Hatchery summer steelhead yearlings						
1982	Apr 19	1,011	268	7.7	121	115	15	8	50	117
1982	Apr 30	512	191	6.6	114	105	21	6	51	126
1982	May 3	508	247	7.3	112	105	17	4	52	127
1982	May 19	613	63	4.2	166	153	43	5	55	144
1983	Apr 20	852	294	8.4	108	96	24	10	54	120
1983	May 3	1,762	301	7.0	111	99	20	5	55	128
1983	May 25	429	140	3.0	192	90	6	5	59	150
1984	May 4	117	67	6.5	173	156	41	10	53	134
1988	May 2	1,000	104	13.3	65	43	39	8	55	130
1989	May 1	714	46	9.4	99	70	51	8	54	129
1989	May 3	623	47	10.6	86	56	64	8	55	131

[a] Release from the hatchery of origin.
[b] Number of marked fish counted at the dam.
[c] Median time to travel the length of the reach.
[d] Measured at Ice Harbor Dam during travel of the leading 50% of the group.
[e] Difference between maximum and minimum flows.
[f] Median time from hatchery release.
[g] Median day of entry into the reach (day 1 = January 1).

TABLE A.2.—Middle Columbia index reach data. The reach extends from the mouth of the Methow River to McNary Dam (MCN). Variables are defined in Table A.1.

Year	Median release date	Sample number, MCN	Travel time (d)	Flow (10^3 ft^3/s)[a]			Average river temperature (°F)[a]	Entry day of the year
				Average	Minimum	Delta		
				Winthrop Hatchery spring chinook salmon yearlings				
1983	Apr 13	480	27.1	159	125	58	48	106
1984	Apr 23	158	23.2	143	101	63	47	116
1985	Apr 16	823	31.1	130	90	68	47	109
1985	Apr 20	457	29.3	133	104	53	48	113
1985	Apr 24	458	28.0	134	104	53	49	117
1986	Apr 21	792	25.8	143	107	63	47	114
1986	Apr 25	546	25.1	140	107	52	48	118
1986	Apr 29	624	22.0	137	107	50	48	122
1987	Apr 20	864	23.2	133	43	134	50	113
1987	Apr 24	658	22.3	145	93	84	51	117
1987	Apr 28	906	22.5	150	108	69	51	121
1988	Apr 19	2,288	24.3	96	55	96	49	112
1989	Apr 18	666	24.7	135	71	97	48	111
1990	Apr 17	425	28.0	143	102	78	48	110
				Wells Hatchery summer steelhead yearlings				
1982	Apr 21	438	19.2	148	114	70	46	113
1983	Apr 23	495	15.7	165	146	38	48	115
1984	Apr 23	454	17.6	148	113	51	46	114
1984	Apr 27	589	13.9	145	113	51	46	118
1985	May 6	611	13.5	138	104	53	49	127
1985	May 10	685	14.6	131	103	54	51	131
1985	May 14	504	14.1	122	90	58	52	135
1986	May 1	645	17.0	138	107	50	48	122
1986	May 5	497	15.1	141	122	35	48	126
1986	May 9	262	14.1	139	114	43	49	130
1987	Apr 23	485	16.1	121	43	119	49	114
1987	Apr 27	449	13.7	141	108	65	50	118
1987	May 1	585	13.1	152	108	66	51	122
1988	Apr 20	559	20.4	86	55	94	48	111
1989	Apr 29	444	14.6	144	102	67	49	120
1990	Apr 26	320	13.3	147	106	74	48	118

[a] Measured at Rock Island Dam.

TABLE A.3.—Lower Columbia index reach data for subyearling summer chinook salmon. The reach extends from McNary Dam to John Day Dam (JDA). Variables are defined in Table A.1.

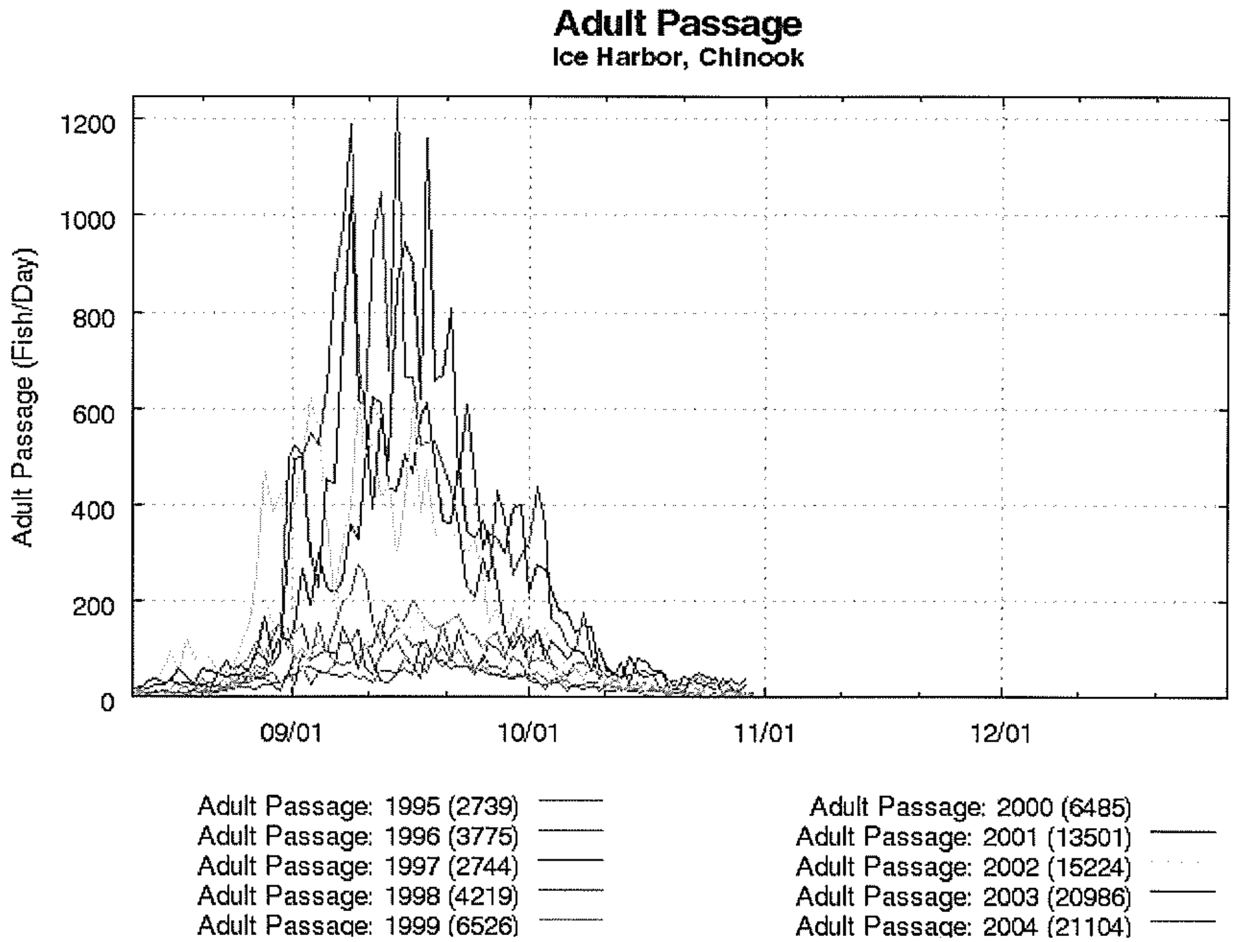
Year	Median release date	Sample number, JDA	Travel time (d)	Flow (10^3 ft^3/s)[a]			Average river temperature (°F)[a]	Entry day of the year
				Average	Minimum	Delta		
1981	Jun 18	44	15.6	306	221	151	57	170
1981	Jul 10	79	17.9	215	149	116	61	192
1981	Jul 16	65	19.9	200	149	96	63	198
1981	Jul 22	50	12.1	200	162	62	64	204
1981	Jul 29	64	9.2	197	164	78	65	211
1982	Jul 29	44	23.0	181	114	122	66	211
1982	Aug 17	46	37.6	132	91	114	66	230
1983	Jun 16	41	12.6	233	192	91	59	168
1983	Jul 15	42	6.3	230	220	38	63	197
1983	Jul 20	60	15.4	206	171	67	64	202
1983	Jul 23	62	28.1	188	149	90	66	205
1983	Jul 27	41	24.1	188	149	90	66	209
1983	Jul 29	71	25.1	180	130	80	66	211
1986	Jun 15	61	6.8	225	173	77	62	167
1986	Jun 18	104	12.2	185	150	100	63	170
1986	Jun 23	124	21.2	148	88	105	65	175
1986	Jul 13	99	14.1	173	152	55	65	195
1986	Jul 15	123	15.1	167	142	64	66	197
1986	Jul 19	113	15.3	160	141	47	66	201
1986	Jul 21	90	20.5	147	122	66	67	203
1986	Jul 22	110	20.3	145	122	57	67	204
1986	Jul 23	117	19.2	144	122	47	67	205
1986	Jul 30	92	18.8	136	87	73	68	212
1986	Aug 1	46	24.8	130	87	73	69	214
1987	Jun 18	114	26.2	115	86	48	65	170
1987	Jun 23	123	19.7	113	86	46	66	175
1987	Jun 26	84	21.8	110	86	46	66	178
1987	Jul 2	87	26.9	107	78	54	67	185
1987	Jul 9	81	29.0	109	78	56	67	191
1988	Jun 15	104	13.3	149	123	45	62	167
1988	Jun 21	82	13.5	125	85	83	64	173
1988	Jun 23	75	21.5	119	85	79	64	175
1988	Jun 29	69	22.4	109	78	56	65	181
1988	Jul 6	89	24.7	98	77	55	66	188
1988	Jul 13	43	18.2	103	77	55	67	195

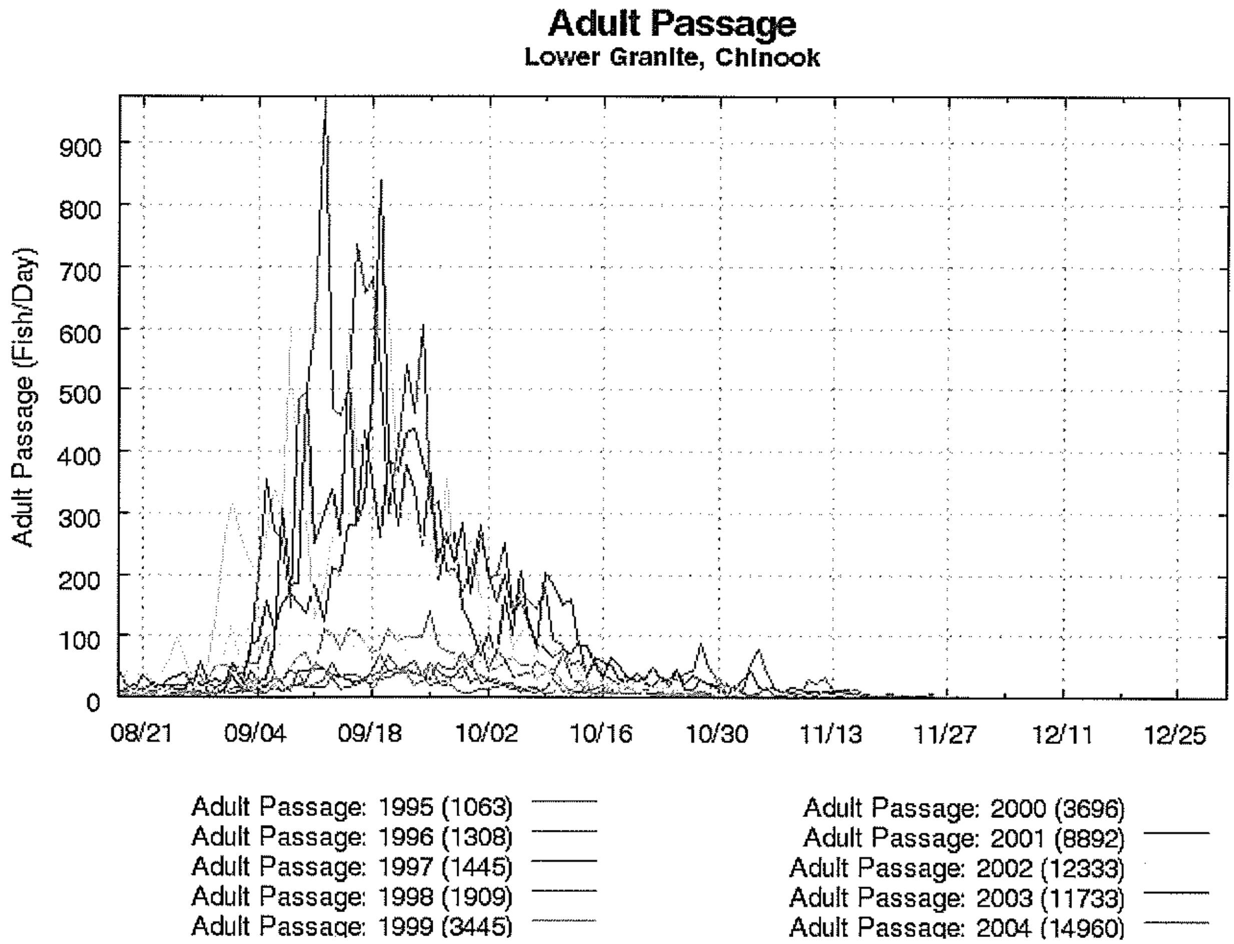
[a] Measured at John Day Dam.

ATTACHMENT 4

Graphs of Adult Fall Chinook Passage at Ice Harbor and Lower Granite 2000-2004

Data Courtesy of Columbia Basin Research, University of Washington


Adult Passage
Ice Harbor, Chinook
Adult Passage (Fish/Day)
1200
1000
800
600
400
200
0
09/01
10/01
11/01
12/01
Adult Passage: 1995 (2739)
Adult Passage: 1996 (3775)
Adult Passage: 1997 (2744)
Adult Passage: 1998 (4219)
Adult Passage: 1999 (6526)
Adult Passage: 2000 (6485)
Adult Passage: 2001 (13501)
Adult Passage: 2002 (15224)
Adult Passage: 2003 (20986)
Adult Passage: 2004 (21104)


Adult Passage
Lower Granite, Chinook
Adult Passage (Fish/Day)
0
100
200
300
400
500
600
700
800
900
08/21
09/04
09/18
10/02
10/16
10/30
11/13
11/27
12/11
12/25
Adult Passage: 1995 (1063)
Adult Passage: 1996 (1308)
Adult Passage: 1997 (1445)
Adult Passage: 1998 (1909)
Adult Passage: 1999 (3445)
Adult Passage: 2000 (3696)
Adult Passage: 2001 (8892)
Adult Passage: 2002 (12333)
Adult Passage: 2003 (11733)
Adult Passage: 2004 (14960)

ATTACHMENT 5

Fish Passage Center Memo April 6, 2004

FISH PASSAGE CENTER

2501 SW First Avenue, Suite 230, Portland, OR 97201-4752
Phone: (503) 230-4099 Fax: (503) 230-7559
http://www.fpc.org
e-mail us at fpcstaff@fpc.org

MEMORANDUM

TO: Rob Lothrop, CRITFC
Bill Tweit, WDFW

FROM: Michele DeHart

DATE: April 6, 2004

RE: Transportation of fall chinook smolts and related fall chinook migration and tag data concerning summer spill for fish passage

In response to your request for smolt to adult return rates on transported fall chinook the Fish Passage Center staff reviewed and analyzed the available PIT tag data. We calculated smolt-to-adult returns for transported and non-transported fall chinook from the Snake and Columbia rivers. This analysis of transported versus in-river migrating smolt-to-adult returns is preliminary; NOAA Fisheries staff will conduct the official analysis.

Our review resulted in several observations about fall chinook migrations, in addition to the smolt-to-adult returns, that relate directly to the present discussions regarding summer spill for fish passage. Thus far all of the discussions surrounding summer spill have centered on the BPA SIMPAS model analysis of average conditions with point estimates of juvenile passage data. The data we reviewed, such as actual adult return PIT tag data was not recognized or considered.

We have summarized our conclusions below, followed by a detailed discussion of each point. These data suggest that the benefits of summer spill for fish passage have been underestimated in deliberations thus far and that a decision to eliminate summer spill carries a significant risk of being in error, particularly in regard to impact on returning adults and assumptions regarding the benefits of the transportation. In accord with our normal FPC procedures, copies of this memorandum responding to your data request have been circulated to other CBFWA members and posted on the FPC web site.

- Smolt-to-adult return rates for transported fall chinook indicate that a spread the risk policy such as that implemented for spring chinook should be considered for fall chinook. The adult return data indicates that the best returns occurred when spill occurred at McNary throughout the summer period. The fall chinook SARs on transported fish are disappointing and may not achieve the recovery goals assumed in the 2000 BIOP. This will affect the analysis of impacts of the summer spill program modifications because a spread the risk policy will result in a larger proportion of Snake River fall chinook migrating in-river. The SIMPAS analysis conducted to date did not examine the impacts of discontinuing summer spill with the implementation of a spread the risk policy for transportation.

- PIT tagged adult fall chinook actual returns from 1994 through 2001, that were detected as juveniles, indicate that a large proportion of the fall chinook that survived to return as adults migrated, as juveniles, past Ice Harbor in late July and August and past McNary in August. This indicates that the SIMPAS predictions of impact on adult returns should be regarded with caution because the juvenile passage distribution assumed in BPA's analysis does not reflect actual adult return data and does not provide a robust basis for decisions. Spill may be much more important to adult returns than inferred from juvenile modeling data.
- Review of the data and research results indicates that there is a flow survival and flow travel time relationship for fall chinook. Analysis of alternative management scenarios and mitigation offsets have not considered or utilized this information. Low flow conditions will shift the passage distribution to later in the migration. SIMPAS analysis of average conditions does not capture this effect because it does not vary flow nor does it relate flow to passage distribution. Elimination of spill in August as discussed by BPA will affect a larger proportion of the migration in low flow years than estimated with their model.
- Our review of the data shows that a comprehensive system wide life cycle monitoring program is needed for fall chinook. We have developed an outline of a PIT tagging monitoring program that would assist the agencies and tribes in deliberations of mitigation and protection hydrosystem actions needed for fall chinook.

Fall chinook smolt-to-adult returns

Smolt-to-Adult return rates (SARs) of subyearling fall chinook for comparing in-river versus transportation migration routes based on available regional PIT tag data.

The PIT tag data available for subyearling fall chinook originating in the Snake River basin above Lower Granite Dam consists of wild fall chinook PIT tagged in the mainstem Snake and Clearwater river above Lewiston and hatchery fall chinook PIT tagged for the supplementation releases made at and near the Pittsburg Landing, Captain Johns Rapids, and Big Canyon Creek acclimation ponds over the years 1995 to 2001. Typically, over 95% of the PIT tagged subyearling fall chinook are hatchery fish. Because the goals of these PIT tag studies required keeping the fish in-river, there were low numbers of PIT tagged subyearling chinook routed to transportation until 2001 when NMFS began a multi-year transport evaluation.

Until the NMFS transportation study, most PIT tagged subyearling fall chinook in the Snake River basin have been purposely returned-to-river for in-river survival estimation. Only PIT tagged fish arriving the transportation sites during the standard timed subsamples were being transported. Consequently, prior to 2001 the sample size for this group was very small. Therefore, for this analysis all PIT tagged smolt detected in the raceways or sample rooms, regardless of prior detection at an upstream dam, were combined to create the transportation category. Fish first-time detected at Little Goose Dam and either transported at Little Goose or returned to river and then transported at Lower Monumental Dam were converted to Lower Granite Dam equivalents by dividing by the CJS survival estimate (derived from the Cormack Jolly Seber Model) between Lower Granite tailrace and Little Goose tailrace. Likewise for first-time detected fish at Lower Monumental Dam, the smolt numbers transported were expressed in Lower Granite Dam equivalents. The sum of all PIT tagged smolts from the four transportation sites expressed in Lower Granite Dam equivalents determined the initial juvenile sample size used in the development of smolt to adult return rates.

The in-river PIT tagged subyearling fall chinook with first-time detections at Lower Granite, Little Goose, Lower Monumental, or McNary dams were each divided by the reach survival component to create the total smolts in Lower Granite Dam equivalents. Because the number of PIT tagged smolts with a detection at a transportation site is a known count, and the number of PIT tagged smolts transported or returned-to-river at each sites is a known count, the only estimation required is the expansion to Lower Granite equivalent and this is done similarly for both in-river and transported fish. This make the comparison of the transported category termed T in Figure 1 and the in-river category termed C1 in Figure 1 the most direct comparison between the two modes of migration through the hydro system. With the exception of one year (1998) the SARs for the in-river fish exceeded the survival of transported fish. While this trend was consistent among years, the low sample sizes for transported fish prior to 2001 must be considered. The most conservative conclusion from the present data is that there appears little difference between PIT tagged subyearling chinook transported or bypassed at collector dams.

The in-river PIT tagged subyearling fall chinook that most closely relates to the untagged population is termed C0 in Table 1. This group must be estimated by first determining the population at Lower Granite Dam and then subtracting off all first-time detected fish at Lower Granite, Little Goose, Lower Monumental, and McNary dams, with numbers from each site divided by the appropriate survival component to create a result in Lower Granite Dam equivalents. The highest SAR for the C0 category occurred for migration year 1999 which had no PIT tagged fish overwintering until the following year. The very high flows of 1999 that extended into the mid-July of that year, and associated spill, may have allowed many subyearling chinook to pass undetected that year under good in-river conditions. The SAR of C0 category subyearling fall chinook appears to be higher than the SAR of either transported or bypassed subyearling migrants for the seven years of samples. A caveat to the above conclusion is a methodological issue with the C0 inriver group, which may require additional resolution. We found a possible discrepancy between CJS estimates of collection efficiency, and FGEs reported in the 2000 FCRPS BiOp, which may affect numbers of smolts in the C0 group. The bypass FGE in Table D-2 of the 2000 FCRPS BiOp is 53% at Lower Granite Dam. With any spill at Lower Granite Dam during the last month of the spring spill program, ending June 20, the effective collection efficiency for subyearling chinook for the season would tend to be somewhat lower than the 53% FGE level. However, the CJS model for the aggregate subyearling chinook was greater than 53% in 4 of the 7 years investigated (0.66 in 1995; 0.63 in 1996; 0.41 in 1997; 0.47 in 1998; 0.43 in 1999; 0.56 in 2000; and 0.68 in 2001). This may lead to a bias in C0 estimated numbers of smolts being too low, and therefore, the SARs being too high. However, even if one were to double the C0 smolt, the SAR of C0 category subyearling fall chinook would still appear to be higher than the SARs of the other two categories in each year.

PIT tag detections systems in the Snake River end operation on October 31, and begin again the next spring. Consequently, fish passing during this period are not detected. However, for fall chinook smolts that overwintered and were detected only during the following year at one or more dams as a yearling, the SARs were over 1% in all cases where large enough smolt numbers were present to provide some adult returns (Table 2). Although these SARs are higher than that of their subyearling chinook counterpart, it is difficult to make a direct comparison because the number of smolts overwintering cannot be expanded to Lower Granite equivalents due to the lack of an overwintering estimate of survival. It appears that even after consideration of these holdover migrants little difference may still exist between transport and in-river survival during the following year since the raw SARs shown in Table 2 are fairly similar between categories.

NMFS began a transportation study at McNary Dam in 2001, but also had large numbers of PIT tagged subyearling fall chinook released in 1999 and 2000 for facility survival studies (Table 3). These latter PIT tagged fish were released in the gatewell for the test group and in the tailrace for the control group. Since most gatewell fish were return-to-river, there were only limited numbers of smolts transported. The SARs of the transported smolts were less than that of the in-river migrants, but these results may simply imply that no real difference occurs between the two categories. The partial returns of the full transportation study began in 2001, show that the SARs of the transported and in-river smolts, based on returning jacks and 2-salt adults, are the same. However, 3 and 4-year ocean fish from the 2001 outmigration are yet to return so complete SARs are not possible. But these trends are suggesting that transportation is likely not showing any benefit over in-river migration routes.

So in summary our preliminary review of fall chinook PIT tag data is not showing a benefit from transportation over in-river migration. Given this information it may prove more advantageous to the migrating fall chinook to adopt a spread the risk policy for fall chinook (similar to spring chinook) and adopt improved in-river migration strategies.

Table 1. Smolt-to-adult survival rates (SARs) from LGR-to-LGR for PIT tagged hatchery and wild subyearling fall chinook released in the mainstem Snake and Clearwater rivers above Lewiston, Idaho, within three categories of outmigration status.

Subyearling fall chinook migration year 1995
(includes 90 smolts partially outmigrating in 1996)

category	smolts	adults	SAR
C0	296	24	8.11%
C1	5,021	45	0.90%
T	1,338	10	0.75%
LGR pop.	**category#**	**%categories in pop.**	
7,049	6,655	94.4%	

Subyearling fall chinook migration year 1999
(no smolts outmigrated in 2000)

category	smolts	adults	SAR
C0	2,479	210	8.47%
C1	19,155	254	1.33%
T	2,428	21	0.86%
LGR pop.	**category#**	**%categories in pop.**	
24,280	24,062	99.1%	

Subyearling fall chinook migration year 1996
(includes 217 smolts partially outmigrating in 1997)

category	smolts	adults	SAR
C0	794	23	2.90%
C1	9,060	46	0.51%
T	1,105	4	0.36%
LGR pop.	**category#**	**%categories in pop.**	
11,232	10,959	97.6%	

Subyearling fall chinook migration year 2000
(includes 223 smolts partially outmigrating in 2001)

category	smolts	adults	SAR
C0	423	10	2.36%
C1	5,391	35	0.65%
T	919	6	0.65%
LGR pop.	**category#**	**%categories in pop.**	
6,832	6,733	98.6%	

Subyearling fall chinook migration year 1997
(includes 607 smolts partially outmigrating in 1998)

category	smolts	adults	SAR
C0	4,453	21	0.47%
C1	37,754	55	0.15%
T	2,831	4	0.14%
LGR pop.	**category#**	**%categories in pop.**	
45,803	45,038	98.3%	

Subyearling fall chinook migration year 2001
(only jacks and 2-salt available, approx 50% of return)
(includes 247 smolts partially outmigrating in 2002)

category	smolts	adults	SAR
C0	2,737	59	2.16%
C1	11,992	40	0.33%
T	30,596	57	0.19%
LGR pop.	**category#**	**%categories in pop.**	
45,621	45,325	99.4%	

Subyearling fall chinook migration year 1998
(includes 490 smolts partially outmigrating in 1999)

category	smolts	adults	SAR
C0	3,270	31	0.95%
C1	44,801	83	0.19%
T	2,174	9	0.41%
LGR pop.	**category#**	**%categories in pop.**	
50,400	50,245	99.7%	

Legend for categories (CJS survival estimates are used to convert smolt numbers to LGR equivalents)

C0	Undetected at 4 transport sites, but surviving to MCN tailrace
C1	Detected at one or more of 4 transport sites
T	Transported at one of 4 transport sites regardless of prior detection upstream

Table 2. Smolt-to-adult survival rates (SARs) for fall chinook completely holding over to migrate as yearlings for PIT tagged hatchery and wild subyearling fall chinook released in the mainstem Snake and Clearwater rivers above Lewiston, Idaho, within two categories of outmigration status.

Migration year 1995 fall chinook completely outmigrating in 1996 (66 smolts detected)

category	smolts	adults	SAR
C	54	0	0.0%
T	12	0	0.0%

Migration year 1996 fall chinook completely outmigrating in 1997 (436 smolts detected)

category	smolts	adults	SAR
C	375	5	1.3%
T	61	1	1.6%

Migration year 1997 fall chinook completely outmigrating in 1998 (814 smolts detected)

category	smolts	adults	SAR
C	733	9	1.2%
T	81	0	0.0%

Migration year 1998 fall chinook completely outmigrating in 1999 (862 smolts detected)

category	smolts	adults	SAR
C	817	27	3.3%
T	45	2	4.4%

Migration year 1999 fall chinook had no outmigrants detected in 2000 due to detection of old 400 kHz PIT tags.

Migration year 2000 fall chinook completely outmigrating in 2001 (504 smolts detected)

category	smolts	adults	SAR
C	467	8	1.7%
T	37	0	0.0%

Migration year 2001 fall chinook completely outmigrating in 2002 (1,049 smolts detected) (only jacks and 2-salt available, approx 50% of return)

category	smolts	adults	SAR
C	1,017	48	4.7%
T	32	2	6.3%

Legend for categories (no survival estimates available to convert smolt numbers of fish totally outmigrating as yearlings to LGR equivalents as subyearlings)

C	Detected at any of 7 dams with PIT tag detection capability totally in the year following the migration year
T	Transported at one of 4 transport sites regardless of prior detection upstream in the year following the migration year

Table 3. Smolt-to-adult survival rates (SARs) from McNary-to-Bonneville Dam for subyearling fall chinook PIT tagged and released from McNary Dam within two categories of outmigration status.

Subyearling fall chinook migration year 1999
(tagged fish released for gatewell or tailrace location)

Category	smolts	adults	SAR
C	45,880	83	0.18%
T	2,224	2	0.09%

Subyearling fall chinook migration year 2000
(tagged fish released for gatewell or tailrace location)

category	smolts	adults	SAR
C	48,862	257	0.53%
T	608	0	0.00%

Subyearling fall chinook migration year 2001
(tagged fish released for barge or river location)
(only jacks and 2-salt available, approx 50% of return)

category	smolts	adults	SAR
C	38,594	29	0.08%
T	23,196	18	0.08%

Legend for categories

C	McNary tailrace or river routed PIT tagged smolts
T	Gatewell fish detected on raceway/sample room routes on transportation days or fish routed to barge routed and not subsequently detected at a downstream dam

The importance of spill for fish passage in August
Fall chinook adult returns, migration timing as juveniles

Most of the analyses that have been conducted to date exploring the impact of eliminating spill in July and August have been based on a single set of conditions in the SIMPAS model using point estimates of juvenile data and average juvenile passage distribution data. We considered the available empirical data. We reviewed all of the adult PIT tagged fall chinook that were detected in the hydrosystem as juveniles and determined when they were observed in the hydrosystem as juveniles. This was done in order to understand the importance of spill for fish passage in August at Ice Harbor and in the Lower Columbia River.

The following tables show the proportion of adult PIT tagged fall chinook returns, which passed McNary and Lower Granite Dam in August versus July as juveniles. These tables show that a significant proportion of returning adults may pass the projects in August. In addition, with an average 15-day travel time from Lower Granite to Ice Harbor, the returning adult, juvenile data indicates that a large proportion of Snake River juvenile fall chinook that survive to adult pass through the lower Columbia River in August.

The adult data raises serious questions about the reliance upon the SIMPAS juvenile model analysis to predict impacts of changing summer spill for fish passage from the BiOp operations when the empirical data seems to suggest a more dramatic potential effect of terminating spill.

Table 4. Juvenile Passage Timing, at Lower Granite Dam of PIT tagged fall chinook, which survived to return as adults (see separately attached plots)

Year Juvenile Migration	Transported 6/20-7/31	Transported 8/1-8/31	In-River 6/20-7/31	In-River 8/1-8/31
1995	16.67%	16.67%	16.67%	36.67%
1996	0.00%	50.00%	12.20%	43.90%
1997	50.00%	0.00%	45.95%	21.62%
1998	80.00%	0.00%	38.00%	28.00%
1999	26.32%	68.42%	30.98%	26.63%
2000	0.00%	33.33%	39.13%	21.74%
2001	33.33%	17.95%	44.83%	31.03%

Table 5. Juvenile Passage Timing, at McNary Dam of PIT tagged fall chinook, which survived to return as adults (see separately attached plots)

Year Juvenile Migration	Transported 7/1-7/31	Transported 8/1-8/31	In-River 7/1-7/31	In-River 8/1-8/31
1995	0.00%	0.00%	10.53%	10.53%
1996	0.00%	0.00%	0.00%	50.00%
1997	0.00%	0.00%	38.46%	46.15%
1998	0.00%	50.00%	53.85%	46.15%
1999	0.00%	100.00%	17.07%	70.73%
2000	0.00%	0.00%	37.50%	37.50%
2001	50.00%	0.00%	16.67%	16.67%

The above data indicates that a significant proportion of returning adults may pass projects in August as juveniles. From the Table below, it is interesting to note that during years when a high percentage of returning adults passed McNary Dam as juveniles during August, spill and flow levels during August were also high in the Lower Columbia River. For example, in 1999, 70.73% of returning PIT tagged adults passed McNary dam in August as juveniles. Spill during August of 1999 was high across all Lower Columbia Projects (see table below), and McNary spilled throughout all of August. August flows were the highest (on average) between the years of 1995 and 2001 at McNary Dam.

	Bonneville August Spill Volume (Kaf)	The Dalles August Spill Volume (Kaf)	John Day August Spill Volume (Kaf)	McNary August Spill Volume (Kaf)	McNary August Average Flow (Kcfs)
1995	5059	4670	253	0	138.2
1996	5594	6143	2350	2072	183.3
1997	6563	7621	2533	2862	198.4
1998	5276	4096	2659	317	142.1
1999	5403	7876	3678	3382	208.5
2000	5464	3351	3067	320	140.4
2001	2396	2025	0	0	96.8

Flow and passage distribution and predicted impacts

Elimination of summer spill could be especially detrimental to fall chinook during low flow years, when the subyearling migration is shifted later into the summer. Because BPA did not analyze this scenario, their estimated adult impacts would be underestimated. Juvenile fall chinook passage data shows that passage distribution is affected by flow. The agencies and tribes recent comments on the BPA summer spill analysis (State, Federal and Tribal Fishery Agencies Joint Technical Staff Memorandum, 2/20/04) illustrated the shift in passage timing relative to migration flow level. The BPA summer spill analysis using SIMPAS was done only for average flow conditions. However, the SIMPAS predicted impacts of eliminating summer spill will be highly influenced by the passage timing distribution utilized in the analysis. The following analysis utilizing the SIMPAS model incorporates a passage distribution that could be expected based upon historical data under low flow conditions. This illustrates the range of potential adult impacts that could be expected.

1) Reach Survival Estimates Using SIMPAS

Reach	BiOp Operation	No Spill Operation	Difference
IHR to Bon	26.4%	15.9%	**12.0%**
MCN to Bon	30.0%	19.8%	**11.6%**
JDA to Bon	44.6%	32.0%	**13.0%**
Tda to Bon	69.4%	56.2%	**14.0%**
Bon to Tailrace	82.4%	74.6%	**8.2%**

In our analysis a 4% increase in pool mortality is assumed. The 2000 BiOp assumed a 5% percent increase in pool survival if the RSW and other aggressive non-breach options were implemented. Therefore if spill, a primary route of passage, is removed it should result in a 4% increase especially under low flow conditions that occur in August. BPA in their SIMPAS analysis assumed 1% at JDA and IHR and 0.5% at Bonn and TDA, and no change at McNary. Other differences are sluiceway guidance at Bonneville Powerhouse II; we used 33% based on radio tag data, while 46% was used by BPA based on hydro acoustic, research results; we decreased survival through the sluiceway when no spill was present from 98% to 96.5%; nighttime spill at Bonneville was set at 125 kcfs in the BPA analysis where as we set it at closer to 145 kcfs; also we used NMFS information of 89% survival fro McNary bypass, BPA used 97%. We also included the assumption that transported fish survival is a constant through both operations. There are small changes in numbers throughout the model depending on which recent reports were used to update parameters.

2) Population Estimates for ESA Listed Fish Only

For estimating impacts to ESA listed fish, we assumed that 1.1 million fish collected at LWG and 50.9% are wild and that the FGE is .534. This results in a starting population at LWG of 1.05 million juveniles.

Using SIMPAS, fish were routed through the collection systems and removed for transportation, resulting in an estimated 8% of the juveniles survival to IHR with a spill operation and 7.0% under a no spill operation. This results in an estimated population between 83,535 and 80,713 would be the extreme difference on population respectively, depending on run timing of those fish.

3) Juvenile Run Time Estimate for Snake River Fish

Using migration timing data from the FPC, the range of SARs is 8% to 43%. (Attachment 1) With the assistance of FPC an estimate of between 8% and 25% of fish would still be above Bonneville after August 1. (Also Attachment 1)

4) Overall Impact to ESA Listed Fish

Using the above numbers and assuming an SAR of .1 (Bowes, 2004) the potential range of adult equivalent mortalities is **46 - 192 adults**. A portion of this number are fish that are passed McNary but have not passed Bonneville dam before August 1. BPA did not account for these fish, nor did they account for extra mortality for transported fish. For additional information on SAR assumptions refer to Bowes, 2004. Adult impacts due to fallback through turbines and bypass systems versus fallbacking through spillways have also not been incorporated into this analysis. Assuming that BPA correctly estimated that adult return for listed Snake River Species to be 2396 then a range of 46 to 192 listed adults would equate to a percent of 1.2% to 8% of this population.

Lastly Option C, which is now the federal proposal, includes a spill evaluation at Bonneville Dam of testing 50 kcfs spill 24 hours versus the BiOp operation. This equates to roughly a 1.8% survival reduction for Bonneville passage. No analysis on this impact to inriver migrants has been completed.

Recommended system wide fall chinook life cycle smolt-to-adult return monitoring program.

Our review shows that there is inadequate fall chinook smolt to adult return and life cycle data available to assess recovery and assessment of hydrosystem measures. We have proposed a marking program that encompasses stocks throughout the Columbia Basin. The rationale is to monitor survival rates to assess, protection, recovery, restoration measures.

Our review of the available PIT tag data on fall chinook surviving to adult and review of the juvenile data which was utilized to model predicted impact on adult returns of fall chinook clearly show that a systemwide smolt to adult return life-cycle evaluation program needs to be put into place in 2004. The following is an outline for a proposed fall chinook evaluation.

The evaluation is proposed over a six year time period, evaluating the Biological opinion flow and spill measures against the Bonneville Power Administration no spill measures including no summer spill in the Snake River and no spill for fish passage in August in the lower Columbia River. PIT tagging efforts need to be in place in 2004 to evaluate and monitor the action agencies no summer spill operation for 2004 through 2006. Then, when transmission issues are resolved, implementation of BiOp summer spill and flow measures and, in addition, spill at the Snake River Projects, and at McNary will be evaluated in 2007 through 2009.

Objectives:

- Estimates of smolt-to-adult return rates for transported versus in river migrating fall chinook during the action agencies no spill option.
- Estimates of smolt-to-adult return rates for transported versus in-river migrating fall chinook during the BiOp summer flow, spill, with spill at the Snake River projects and McNary Dam, evaluation period.
- Juvenile fall chinook reach survival estimates throughout both periods.
- Juvenile fall chinook passage distribution and passage timing at Snake River and Lower Columbia River projects for both evaluation periods.

Approximate numbers of PIT tagged Chinook Salmon Required to Estimate Juvenile to Adult Survival in the Snake/Columbia River Basin.

PIT tag quotas vary depending on where fishes are released or captured tagged and released in the basin. Normally, the further upstream or distance traveled in the river system will relate to greater mortality by the time it reaches the sampling site. In addition, subyearling chinook are more vulnerable to predation and other factors that tend to reduce juvenile survival through the hydrosystem. Tables are listed below for the different reaches that have hatcheries or wild salmon groups where representative groups of fish could be PIT tagged in the Columbia River basin.

From McNary Dam to Bonneville Dam, marking subyearling fall chinook (URBs) would require that an estimate could be completed at Bonneville Dam where possible. The key elements would be survival as juvenile fish to Bonneville and return as adult fish back to Bonneville Dam. Survival to adult fish would vary by year, but numbers normally be considered from 0.5% to 2% as a base return. Since there is no transportation involved, there is no requirement to achieve a minimum/maximum number of fish going the different routes of passage at a dam. The Bonneville and John Day Dam estimate for detection at the respective sampling site is set at 28% and 32%. The collection efficiency of the bypass system is simply the (1-spill proportion) times FGE, given the assumption of a 1:1 spill effectiveness.

Marking sites tentatively considered in this section of river are: Umatilla River hatchery and acclimation ponds, Klickitat Hatchery and Little White Salmon Hatchery. For wild subyearling fall chinook, the Deschutes River and John Day River would provide groups to assess survival from the upper end of this Reach to the Bonneville pool release groups.

Table. Estimated Number of PIT tagged fall chinook required to complete SARs for the Individual River basins (McNary Dam to Bonneville Dam Reach)

Hatchery	# Juvenile chin PIT tagged	# Juvenile Chin at Bonneville Dam
Umatilla	35,000	10,500
Thornhollow Pond (Umat)	35,000	10,500
Total Umatilla	**70,000**	**21,000**
Klickitat	50,000	20,000
Little White Salmon	40,000	20,000
Wild Fall Chinook		
Deschutes R	50,000	20,000
John Day R	Potential mark group	20,300

Note that SARs for the individual groups should equal about 200 adult fish per release area spread among 1 to 4 adult return years. In initial years the Wild fall chinook would be marked to assess migration timing to assure that they arrive at the dams when spill and best passage conditions exist in the hydro-system.

PIT tag quota for two major release groups of subyearling fall chinook from the Mid-Columbia or Hanford Reach have been calculated in past years to achieve detection rates at McNary Dam to achieve transportation/inriver groups of test fish. The hatchery of choice would be Priest Rapids Hatchery with the wild component from Hanford Reach. These groups will provide transport and inriver survival through the hydrosystem.

Table. Estimated number of subyearling fall chinook required to calculate SARS for the individual release groups of hatchery and wild fall chinook in the Mid-Columbia River. [Priest Rapids and Hanford Reach]

	# of Chin-PIT tagged	# Inriver below McNary Dam	# of Trans. Required
Hatchery Chinook			
Priest Rapids	150,000	43,000	43,000
Wild Chinook			
Hanford Reach	185,000	33,700	52,000

With no transportation required for these two groups, i.e., fish were placed directly back to the river at McNary Dam, about 80,000 fish from each release group (Priest Rapids and Hanford) could be PIT tagged to achieve SARs for the inriver migrants.

Table. Estimated number of subyearling fall chinook required to calculate SARS for the individual release groups of hatchery fall chinook in the Snake River Basin Recommended offset for elimination of spill

Hatchery	# of Chin-PIT tagged	# Inriver below LGR Dam	# of Trans. Required
Snake/Clearwater Acclim Ponds	350,000	80,000	32,000

These groups of subyearling fall chinook would be used to evaluate smolt-to-adult survival rates (SARs) for transported and inriver migrants. In addition, this will provide information on inriver survival and timing through the hydrosystem.

CC: FPAC
Brian Brown& Jim Ruff, NOAA
Rod Sando, DBFWA
Fred Olney & Howard Schaller, USFWS
Sharon Kiefer & Pete Hassemer, IDFG
Ed Bowles & Tony Nigro, ODFW

Attachment 1

McNary Percent passage data is presented in Table 1. Also included is the proportion of fish in transit between McNary and Bonneville dams if spill were shut off either July 15 or August 1. We calculated wild origin subyearling chinook timing based on PIT-tag detections at McNary. Then used an average of 8 days travel time McNary to Bonneville Dam. Looking back at McNary to those fish that passed 8 days prior to the proposed shut off date provided the begin percent passage. Subtracting the begin percent from the end percent (the percent passage on the shutoff date) yielded the percent in transit. To calculate percent in transit between McNary and John Day and John Day and Bonneville I would recommend apportioning half of the in transit percentage to each reach.

Using passage timing of Wild Origin subyearling chinook in the Snake River basin we used Lower Monumental detections to develop passage timing expressed as a percent of all annual detections (excluding holdover fish). We then moved back 3 d at Lower Monumental to extrapolate the data for IHR (Table 2). In other words, a passage percentage of 11% at Ice Harbor on 7/15 would have passed Lower Monumental on 7/12 or 3 days earlier based on assumed 3 day travel time.

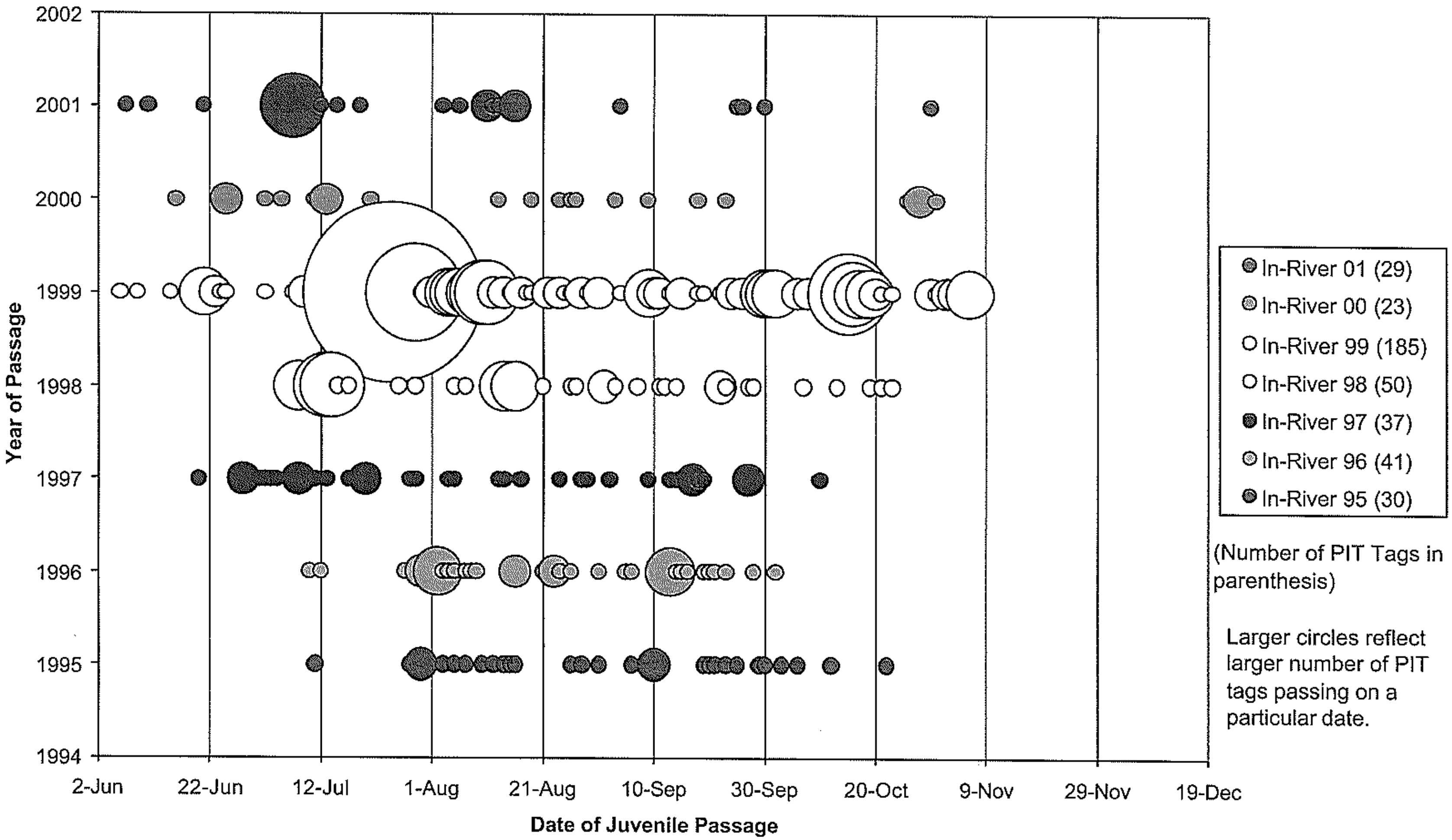
Table 1. Percent of Snake Origin Wild Subyearling chinook affected by End of Spill Operations in Lower Columbia.

	McNary Passage Percent		Percent Pop In Transit (between MCN and BON) at End of Spill	
Date	**7/15**	**8/1**	**If 7/15**	**If 8/1**
1998	41%	87%	13	25
1999	41%	60%	7	8
2000	79%	92%	13	8
2001	10%	57%	1	23
2002	52%	94%	22	16
2003	56%	85%	10	11

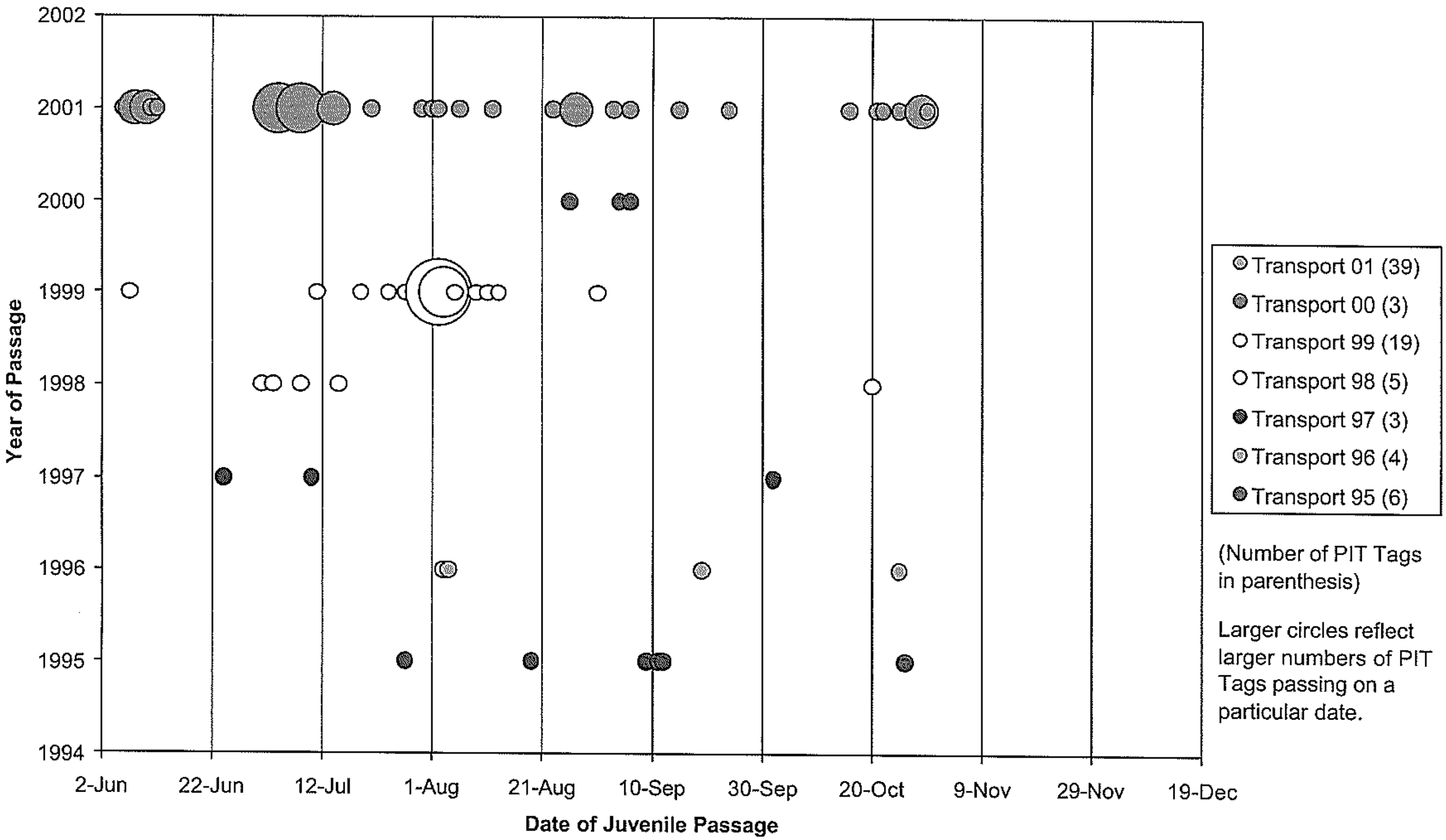
Table 2. Passage Timing at Ice Harbor dams for Wild Subyearling chinook based on 3-day Travel Time from LMN to IHR.

Date	**7/15**	**8/1**
1994	11%	41%
1995	5%	36%
1996	16%	53%
1997	44%	56%
1998	17%	82%
1999	47%	69%
2000	64%	76%
2001	7%	64%
2002	30%	89%
2003	55%	80%

Juvenile Passage Timing at Lower Granite Dam for In-River Fall Chinook that Survived to Adulthood (1995-2001)



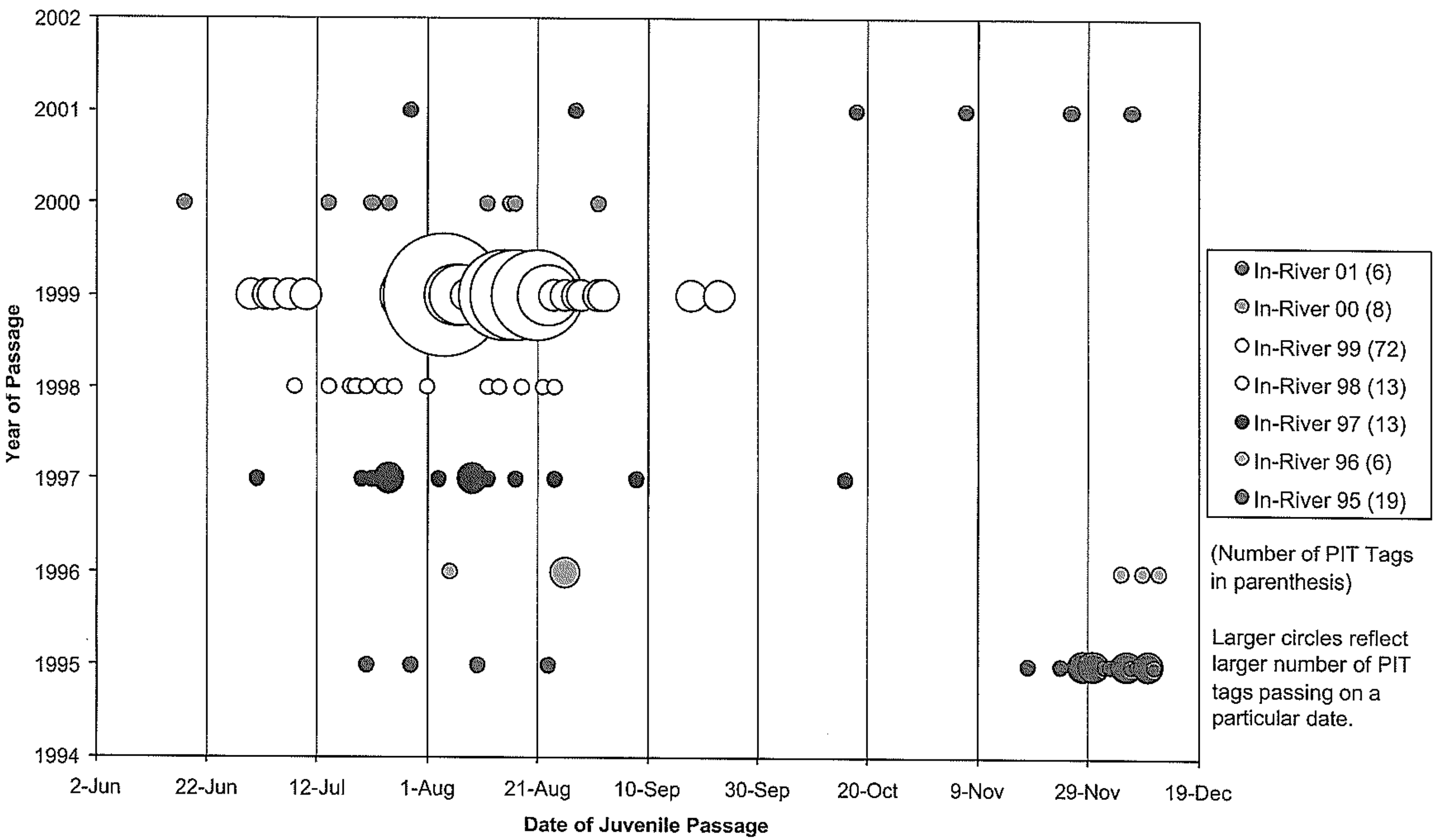
Juvenile Passage Timing at Lower Granite Dam for Transported Fall Chinook that Survived to Adulthood (1995-2001)



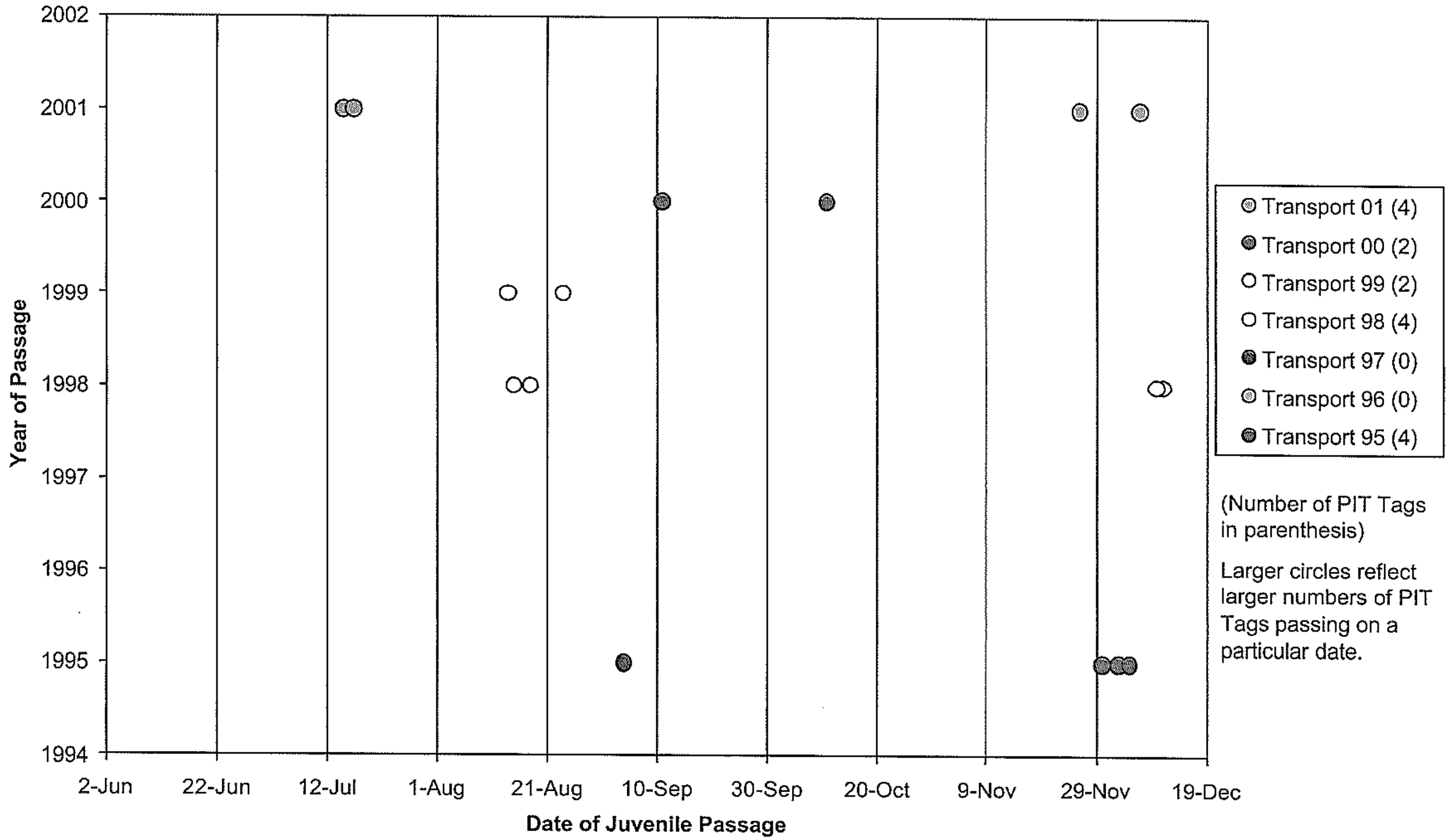
(Number of PIT Tags in parenthesis)

Larger circles reflect larger numbers of PIT Tags passing on a particular date.

Juvenile Passage Timing at McNary Dam for In-River Fall Chinook that Survived to Adulthood (1995-2001)



Juvenile Passage Timing at McNary Dam for Transported Fall Chinook that Survived to Adulthood (1995-2001)



ATTACHMENT 6

ISAB Synopsis on 2003 Flow Augmentation Review

Review of Flow Augmentation: Update and Clarification

February 10, 2003 | document ISAB 2003-1

Read comments from:

- American Rivers, Friends of the Earth, Idaho Rivers United, Institute for Fisheries Resources, National Wildlife Federation, Northwest Sportfishing Industry Association, NW Energy Coalition, Pacific Coast Federation Of Fishermen's Associations, Save Our Wild Salmon, Sierra Club, Trout Unlimited (30k PDF)
- Chelan PUD, Chuck Peven (10k PDF)
- Columbia Basin Research, James Anderson (140k PDF)
- Committee of Nine and Idaho Water Users Association (60k PDF)
- Halter, Michael, Project Fisheries Biologist, Lower Granite Dam (10k PDF)
- Hastings, Terry (5k PDF)
- Nuzum, Robert C, Certified Fisheries Scientist (5k PDF)
- State, Federal and Tribal Fishery Agencies Joint Technical Staff (240k PDF)
- State of Idaho, Governor Dirk Kempthorne (30k PDF)
- Windom, Rita (5k PDF)

read full document > (1.6mb PDF)

Invitation for public comment

The ISAB has prepared this report in response to questions posed by the Council and others about the relationship of fish survival to river flows, flow augmentation, and storage reservoir operations.

[The comment period ended February 25, 2003.] The ISAB's report has obvious relevance for the draft amendments to the mainstem portion of the Council's Fish and Wildlife Program that are now before the Council for consideration. The comment period on the draft amendments has closed, but the Council is re-opening the comment period on the draft mainstem amendments for the very limited purpose of allowing people to respond to this report.

You are invited to submit comments to the Council about this report and the implications of for the Council's deliberations on the mainstem amendments. Comments will be accepted until **5:00 pm, Tuesday, February 25, 2003**. Please direct your comments to:

Mark Walker
Director, Public Affairs Division
Northwest Power Council
851 SW Sixth Avenue, Suite 1100
Portland, OR 97204
fax 503-820-2370 or email comments@nwcouncil.org

Comments about the draft mainstem amendments that are not directly related to the ISAB's report will not be accepted.

Summary of report

At its November 14, 2002 meeting, the Council asked the ISAB to update and clarify its review of flow augmentation by the end of January 2003. The Council and the Columbia River Inter-Tribal Fish Commission submitted questions on the subject to the ISAB. The issue is timely for the Council as it proposes amendments to the mainstem portion of the Fish and Wildlife Program. The issue is important in a broader context, because flow commitments are part of the legal agreements under ESA for some listed stocks. The relationship between river flows and salmon production has been reviewed before by the ISAB, but many questions remain. The ISAB considered the Council's questions and deadline, and suggested (by memo of December 19) that it could make a short response to the questions within that timeframe, and, if requested, follow this response with more detailed information. This report contains our initial response.

Stimulated by the specific questions posed by Council and others, the ISAB has taken a fresh look at the whole matter of river flow and fish survival with special emphasis on the Lower Snake River reaches. There have been improvements in study designs over the years, particularly in the PIT-tag and radiotelemetry studies. Also, the quantity and quality of accumulated data have improved, and the range of factors potentially related to survival of anadromous fish has been extended. This has allowed more patterns to be resolved in analyses. To focus only on the specifics of the questions posed to the ISAB would be to miss the point: the whole issue of flow and fish survival requires reevaluation. Management alternatives for improving survival of migrating juvenile anadromous fish include many dimensions beyond the current procedures for "flow augmentation." The ISAB answered the specific questions in the text of this report, but considers them to be a subset of the broader issue.

A different perspective emerged from this latest review. We realize that the prevailing rationale for flow augmentation is inadequate. It is neither complete nor comprehensive. There is room for alternative explanations of available data that have both scientific justification and practical value for managing the hydrosystem for multiple uses including salmon recovery. We identified several alternative explanations (hypotheses) for the correspondence of observed flow-survival data and radio-telemetry data, which are not necessarily mutually exclusive. These alternatives do, indeed, lead logically to management opportunities that extend beyond flow augmentation as presently defined. This report outlines several of them. We assembled enough information about them to suggest that they need serious further study and evaluation.

The ISAB believes that, with improved knowledge and subsequent management actions, it may be possible to achieve improved survival of juvenile salmonids through the lower Snake River reaches and their dams, even at lower flows. With an expanded perspective, this might occur at lower costs for operation of the hydrosystem and more effective use of stored water for other purposes than is possible with the prevailing flow-augmentation paradigm.

ATTACHMENT 7

Abstract of Bjornn and Piaskowski 1999

Technical Report 99-2

DISTRIBUTION AND MOVEMENTS OF NORTHERN PIKEMINNOW AND SMALLMOUTH BASS DURING OPERATION OF A SURFACE-BYPASS AND COLLECTION SYSTEM FOR JUVENILE SALMONIDS AT LOWER GRANITE DAM, 1996-1997

Prepared by:

T.C. Bjornn and R.M. Piaskowski

U.S. Geological Survey
Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, ID 83844-1141

for

U.S. Army Corps of Engineers
Walla Walla District

1999

Table of Contents

Abstract

Radio telemetry was used to monitor the distribution and movements of 67 adult northern pikeminnows *Ptychocheilus oregonensis* and 13 adult smallmouth bass *Micropterus dolomieui* near Lower Granite Dam to evaluate the potential for increased predation on juvenile salmonids during operation of a prototype surface bypass and collector (SBC) from April to September 1996 and 1997. Four northern pikeminnow monitored in the forebay in 1996, and 7 northern pikeminnow and 6 smallmouth bass monitored in 1997 consistently inhabited nearshore areas. In early June 1996, all four radio-tagged northern pikeminnow released in the forebay left the survey area; two were caught by anglers 49 km and 94 km upstream from Lower Granite Dam in late June and July. Upstream movement from the forebay and downstream from the tailrace was also observed in some smallmouth bass (maximum upstream movement 97 km, downstream 39 km). The reasons for the movement were not determined.

In the tailrace, the distribution of northern pikeminnow was limited to shorelines and protected low velocity areas during the spring runoff when there was continuous spill. Some individuals temporarily moved downstream of the tailrace during periods of peak river discharge and spill. Northern pikeminnow moved into the spillway stilling basin and downstream from the turbines when river flows decreased and there was no spill. The shift in distribution may have been related to spawning behavior or changes in metabolism and foraging opportunity. Northern pikeminnow numbers decreased in the tailrace in late summer as fish migrated into the reservoir, perhaps to overwintering areas.

Activity of northern pikeminnow peaked after dawn and again during the evening, based on hourly monitoring of individuals during consecutive 24-h periods. Light levels during crepuscular and nighttime periods may be advantageous for foraging northern pikeminnow and daily peaks in salmon smolt numbers occur from about 1800 to 0500 hours.

Losses of juvenile salmonids to predation by northern pikeminnow and smallmouth bass vary seasonally and depend on river conditions. The potential for predation on

juvenile salmonids by northern pikeminnow in close proximity to the SBC in the forebay, or by smallmouth bass in either the forebay or tailrace, is not very high because of small numbers of predators and they did not congregate near the SBC. Predation would most likely occur when juvenile salmonids move close to shorelines of Little Goose and Lower Granite reservoirs. In the tailrace, predation by northern pikeminnow on juvenile salmonids could be significant if river flows are low and there is little or no spill when juvenile salmonids are passing through the SBC and over spillbay 1.

ATTACHMENT 8

Adult Salmon Passage at Lower Granite Dam, June 21-Aug 31, 2000-2004

Compiled by Paul Ocker from Columbia Basin Research, University of Washington

	Chinook	Jack Chinook	Total Chinook	Sockeye	Steelhead
2000	3546	3364	6910	299	8166
2001	11233	3647	14880	35	19287
2002	17965	1796	19761	55	21006
2003	11765	3558	15323	10	8634
2004	7248	2298	9546	113	5983
Average	10351.4	2932.6	13284	102.4	12615.2

Data Courtesy of : Columbia River DART
Columbia Basin Research,
School of Aquatic & Fishery Sciences,
University of Washington

Data Query by Paul Ocker on April 19, 2004
Parameters included: Species, Lower Granite Dam, June 21-Aug 31, for 2000-2004