ASSESSMENT OF SMOLT CONDITION FOR TRAVEL TIME ANALYSIS

Annual Report 1990

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Project No. 87-401
Contract No. DE-A179-87BP35245

December 1991

ABSTRACT

The Water Budget is a volume of water used to enhance flows in the Columbia and Snake rivers during the downstream migration of salmonids. To manage the Water Budget, the Fish Passage Center estimates travel times of juvenile salmonids through index reaches of the main-stem rivers using information on river flow and the migrational characteristics of the fish. This study was initiated to (1) provide physiological information about the juvenile salmonids used for these travel time estimates, (2) to analyze the physiological data, and (3) to determine if an "index" of smolt condition could be developed to aid in management of the Water Budget.

The development of smoltification was assessed by measuring gill Na^{+}-K^{+} ATPase (ATPase) activity, plasma thyroxine, and condition factor. Mean ATPase activities of marked groups of juvenile chinook salmon and steelhead were low while in the hatchery environment. After release from the hatcheries, mean ATPase activities rose sharply. Mean plasma thyroxine in 10 out of 18 groups examined peaked shortly after fish were released from the hatcheries, returning to low pre-release levels thereafter. Mean condition factor (K) decreased somewhat in the hatchery environment and dropped dramatically after release.

Analysis of the effects of flow and smoltification (ATPase activity) on travel time using data collected thus far indicated flow was the best predictor of travel time of hatchery and wild steelhead in the reaches tested. Mean ATPase activity was important in explaining travel times of spring chinook salmon in 2 of 3 reaches studied.

The non-lethal methods of condition factor and reflectance of the skin (measured with a video camera) explained 80% of the variability in ATPase activity of spring chinook salmon and hatchery steelhead, indicating these measures could be used in a non-lethal index of smoltification of these species.

Survival in seawater was used to evaluate smolt condition in several experiments using juvenile spring chinook salmon. Migrants taken at McNary Dam had significantly higher mortality than fish taken directly from Leavenworth NFH, possibly due to the sensitivity of smolted fish to stressors. There were no significant differences in mortality of migrants based on FTOT descaling criteria or hemorrhages of the thymus gland compared to control fish. Mortalities in all groups were high and were attributed primarily to bacterial kidney disease.

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ACKNOWLEDGEMENTS

We thank the individuals in the Idaho Department of Fish and Game (IDFG), Idaho Power Company, Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), Washington Department of Fisheries, and Washington Department of Wildlife (WDW) who assisted us in sampling at Columbia Basin hatcheries. We also thank the managers and staff of Entiat, Dworshak, Irrigon, Leavenworth, Lyons Ferry, McCall, Priest Rapids, Rapid River, Ringold, Sawtooth, Wells, and Winthrop hatcheries. This study was facilitated by the cooperation of personnel working on the Smolt Monitoring Program from the Chelan County Public Utility District, Fish Passage Center, IDFG, National Marine Fisheries Service, and WDW. We appreciate the assistance of the Fishery Biologists and staff of the U.S. Army Corps of Engineers. We thank Dr. Dick Ewing, ODFW, for analyses in his laboratory. We extend special thanks to our colleagues at the Columbia River Field Station, USFWS, for their assistance. This project was funded by the Bonneville Power Administration, Department of Energy, under the Northwest Power Planning Council Fish and Wildlife Program, Project No. 87-401.

INTRODUCTION

As a part of the Northwest Power Planning Council's Fish and Wildlife Program, the Fish Passage Center collects information on the migrational characteristics of juvenile salmon and steelhead (Oncorhynchus sp.) in the Columbia River basin. This information is collected through the Smolt Monitoring Program, and is used as a tool in the management and evaluation of the Water Budget. The Water Budget is a volume of water used to enhance environmental conditions (flows) to aid in the seaward migration of juvenile salmon and steelhead. Implicit in the Water Budget concept is that by augmenting flows, travel time of juvenile salmonids will be decreased, thereby increasing survival via reductions in delayed migration and exposure to predators.

Work under this project was initiated in 1987, and consisted of collecting physiological information from test and control groups of hatchery spring chinook salmon and steelhead juveniles used to estimate survival in the Snake and Columbia rivers. Survival estimates were used by the Fish Passage Center to manage and evaluate the Water Budget. Comparisons of smoltification, stress associated with release, descaling rates, and disease (bacterial kidney disease) of test and control groups were made. Results of that work indicated violations of assumptions were present and survival estimates were discontinued.

Since 1987, the Fish Passage Center has relied on estimates of travel times of juvenile salmonids through selected index reaches of the Snake and Columbia rivers to evaluate the Water Budget. This study continues to collect physiological information on the fish used for this purpose although the emphasis has changed somewhat since 1987, reflecting the adaptive management nature of the Smolt Monitoring Program. Measures of stress were discontinued after 1989 since most groups were characterized by "normal" stress responses after release, and most groups trucked to remote release sites had been dropped from the Smolt Monitoring Program for various reasons. The emphasis also shifted from relying solely on data from releases of branded fish from hatcheries with the addition of information collected from PIT-tagged releases of fish from the migration-at-large. These migrating fish are collected, tagged, and released daily at monitoring sites located at the upstream-end of index reaches. Using PIT-tagged groups in this manner allows collection of more information than from releases of branded hatchery groups, since many releases can be made from each site. In addition, fewer fish are handled in this process due to the high rate of downstream detection possible with PIT-tagged fish. Collections from the juvenile fall chinook salmon migrating during summer (June-August) were also added in 1989, as little was known about their physiological status during migration.

Presently, this study is collecting physiological information from releases of branded fish from hatcheries and PIT-tagged groups from the migration-at-large releases from in-river monitoring sites. The emphasis on the migration-at-large is increasing as data can be collected more efficiently from these groups. Efforts are being made to describe smoltification and disease (bacterial kidney disease) of branded hatchery fish used to estimate travel time; model the relationships between smoltification, flow, and travel time through selected index reaches: and develop a non-lethal index of smoltification which could be applied to juvenile salmonids throughout the Snake and Columbia rivers.

PHYSIOLOGY OF HATCHERY GROUPS USED TO ESTIMATE TRAVEL TIME

Introduction

Smoltification status and the prevalence and severity of bacterial kidney disease (BKD) were monitored before and after fish were released from selected fish hatcheries in the Columbia and Snake river drainages. This information was collected to develop a consistent database of these parameters over years when travel time estimates were made. This data was gathered to aid Fish Passage Managers in managing the Water Budget both during the salmonid out-migration, by reporting selected information on a real-time basis, and after the migration, through post-season analysis to help explain variability in the travel time estimates. The following is a post-season summary of information collected in 1990.

Methods

Groups of hatchery fish sampled for this study were also used by the Fish Passage Center to estimate travel time in index reaches of the Columbia and Snake rivers. These groups included yearling spring chinook salmon, yearling summer chinook salmon, yearling and sub-yearling fall chinook salmon, and yearling steelhead. In 1990 this included 18 marked groups from 12 hatcheries (Table 1; Figure 1).

Smoltification development was assessed using three methods. In the first, gill tissues were collected and assayed for $Na^{+}-K^{+}$ ATPase (ATPase) activity using the method of Zaugg (1982). In the second, blood plasma was collected and assayed for thyroxine (T_4) using a radioimmunoassay described by Dickhoff et al. (1978) and modified by Specker and Schreck (1982). The third method was to measure condition factor (K), where $K = (weight/length^3) \cdot 10^5$. This measure is not routinely used for assessment of smoltification, but was collected as part of an investigation into non-lethal methods of smoltification assessment.

Prevalence and severity of BKD was determined from pooled kidney and spleen samples from each fish using an enzyme linked immunosorbent assay (ELISA) technique (Pascho et al. 1987). ELISA results were divided into negative, low, medium, and high categories based on optical densities using criteria similar to those in previous reports from this project (Beeman et al. 1990, Rondorf et al. 1989). Samples for BKD were collected from yearling spring chinook salmon from Entiat National Fish Hatchery (NFH), Leavenworth NFH, Ringold State Fish Hatchery (SFH), Winthrop NFH, Dworshak NFH, McCall SFH, Rapid River SFH, and Sawtooth SFH.

Samples were taken at about one month prior, two weeks prior, and within several days prior to release and again at the early, middle, and late portions of each group past Rock Island Dam (mid-Columbia groups only), Lower Granite Dam (Snake River groups only), and McNary Dam (all groups). Samples taken at the dams corresponded approximately to the 25th, 50th, and 75th percentile of passage of each group. A sample of 20 fish was used to assess

Table 1. The hatchery, agency, species, Fish Passage Center lot number (FPCLOT#), brands, and release site of fish sampled from hatcheries during 1990.

HATCHERY	AGENCY[a]	SPECIES[b]	FPCLOT#		RELEASE SITE
Dworshak NFH	USFWS	SPCH	90203	RA-7U-1/3 LD-7U-1	Hatchery
		STHD	90204	RA-Z-1	Hatchery
Entiat NFH	USFWS	SPCH	90205	RA-7N-1/3	Hatchery
Irrigon SFH	ODFW	STHD	90120	LD/RD-A-4	Wildcat Creek
Leavenworth NFH	USFWS	SPCH	90325	LA-7T-1/3 RD-7T-1	Hatchery
Lyons Ferry Salmon	WDF	FACH1	90014	RA-UL-1/3	Hatchery
McCall SFH	IDFG	SUCH	90309	LD-T-1/2 LD-T-3/4	South Fork Salmon R.
Priest Rapids SFH	WDF	FACHO	90041-1	RA-H-1	Hatchery[c]
			90041-2	RA-H-2	Hatchery
			90041-3	RA-UP-3	Hatchery
			90041-4	RA-UP-1	Hatchery
			90041-5	RD-H-1	Hatchery
Rapid River SFH	IDFG	SPCH	90306	RA-T-1/2/3	Hatchery
Ringold SFH	WDF	SPCH	90040	LA-7S-1/3	Hatchery
Sawtooth SFH	IDFG	SPCH	90308	LA-T-1/2 LA-T-3/4	Hatchery
Wells SFH	WDW	STHD	90402	LD-7H-1/3	Similkameen R.
			90403	RA-7H-1/3	Methow R.
Winthrop NFH	USFWS	SPCH	90219	RA-7C-1/3 LD-7C-1	Hatchery

[a] IDFG-Idaho Department of Fish and Game; ODFW-Oregon Department of Fish and Wildlife; USFWS-U.S. Fish and Wildlife Service; WDF-Washington Department of Fisheries; WDW-Washington Department of Wildlife

[b] FACHO-subyearling fall chinook salmon; FACH1-yearling fall chinook salmon; SPCH-yearling spring chinook salmon; STHD-yearling steelhead

[c] Release site is below Ice Harbor Dam

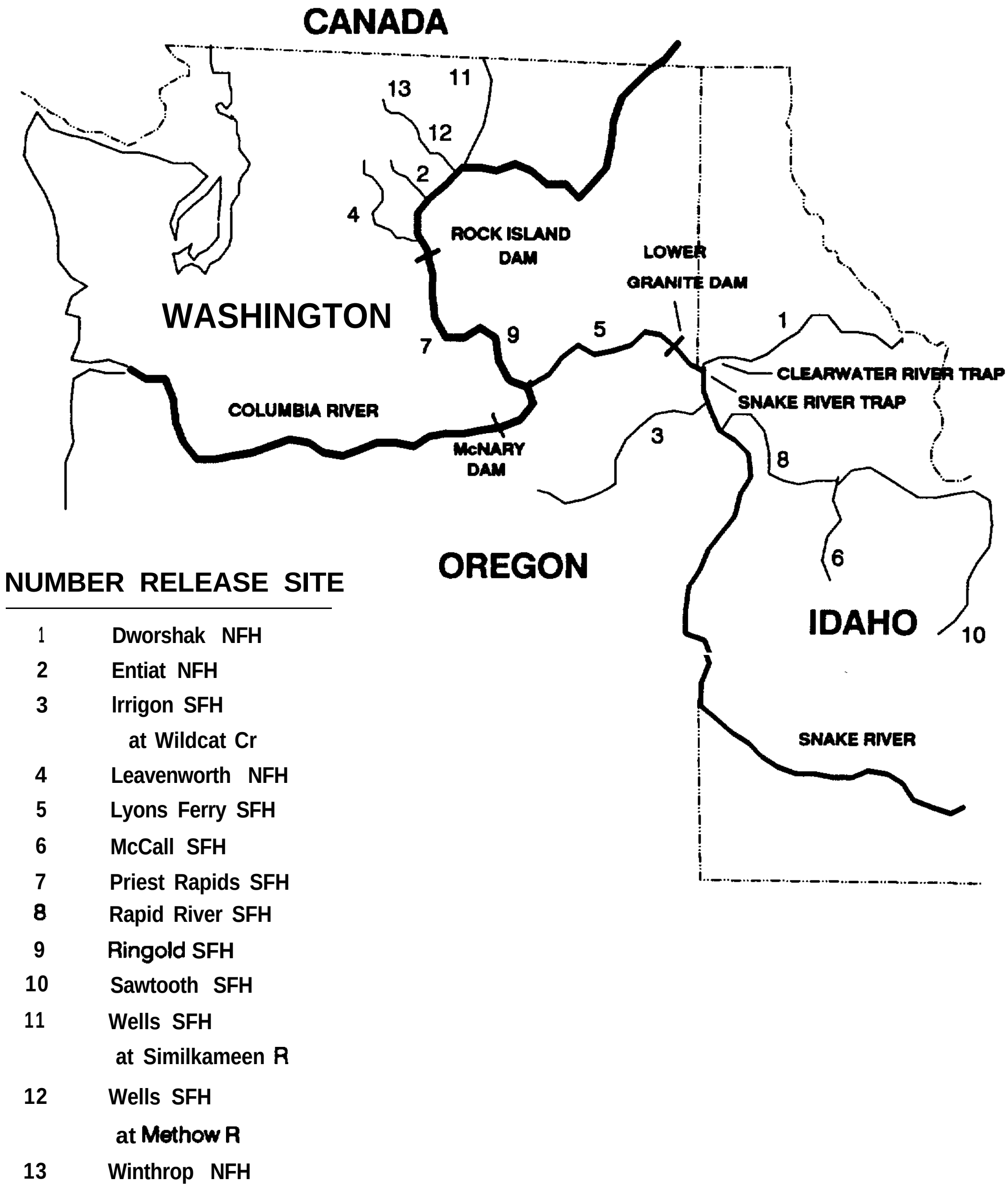

Figure 1. Map of the Columbia River basin showing release locations of marked groups of juvenile salmonids from hatcheries sampled in 1990.

smoltification, whereas a sample of 60 fish was used to evaluate BKD whenever possible. BKD data from groups with less than N = 30 were not included in figures, but can be found in tabular form.

Results

Smoltification

Mean ATPase activity of yearling spring and summer chinook salmon was low and changed little prior to release from the hatcheries (Figure 2; Appendix A). As in prior years, dramatic increases in ATPase activity were noted immediately after release from the hatcheries, with increases slowing as the fish passed McNary Dam. Results from steelhead were similar, although groups from Dworshak NFH and Irrigon SFH were not sampled at McNary Dam, since most juvenile steelhead migrants in the Snake River were transported through the Transportation Program. (Figure 3). Yearling fall chinook salmon from Lyons Ferry SFH had mean ATPase activities higher than sub-yearling fall chinook salmon from Priest Rapids SFH both prior to release and when recaptured downstream at McNary Dam (Figure 3).

Mean plasma T_4 levels of groups of all species were low and changed little prior to release from the hatcheries. Peaks in T_4 after release were observed in 10 of the 18 groups sampled. These peaks did not appear to be correlated with lunar phase and were interpreted as a "novel water" effect caused by entering the new environment of the rivers after release from the hatchery (Hoffnagle and Fivizzani 1990). Mean condition factor of most groups declined somewhat prior to release and then sharply thereafter. Mean condition factor of most groups was still declining as they passed McNary Dam. Detailed data on thyroxine and condition factor of juvenile chinook salmon and steelhead are included in Appendix A.

Bacterial Kidnev Disease

All groups sampled had high prevalences of BKD, indicating the fish had been exposed to the pathogen Renibacterium salmoninarum and had detectable levels of antigen (Figures 4-7; Table 2). The prevalence in most hatcheries was between 80 and 100% of the fish sampled, although that of the Rapid River SFH was 61%. Bacterial kidney disease at most hatcheries was characterized to a large extent by fish with low antigen levels; but more than 50% of the fish sampled at Entiat NFH and Sawtooth SFH had medium and/or high antigen levels, indicating that BKD infections were more severe at these locations. In general, antigen levels increased with migration distance, as shown by increasing prevalences of fish in the medium and high antigen categories as fish migrated from the hatchery to McNary Dam.

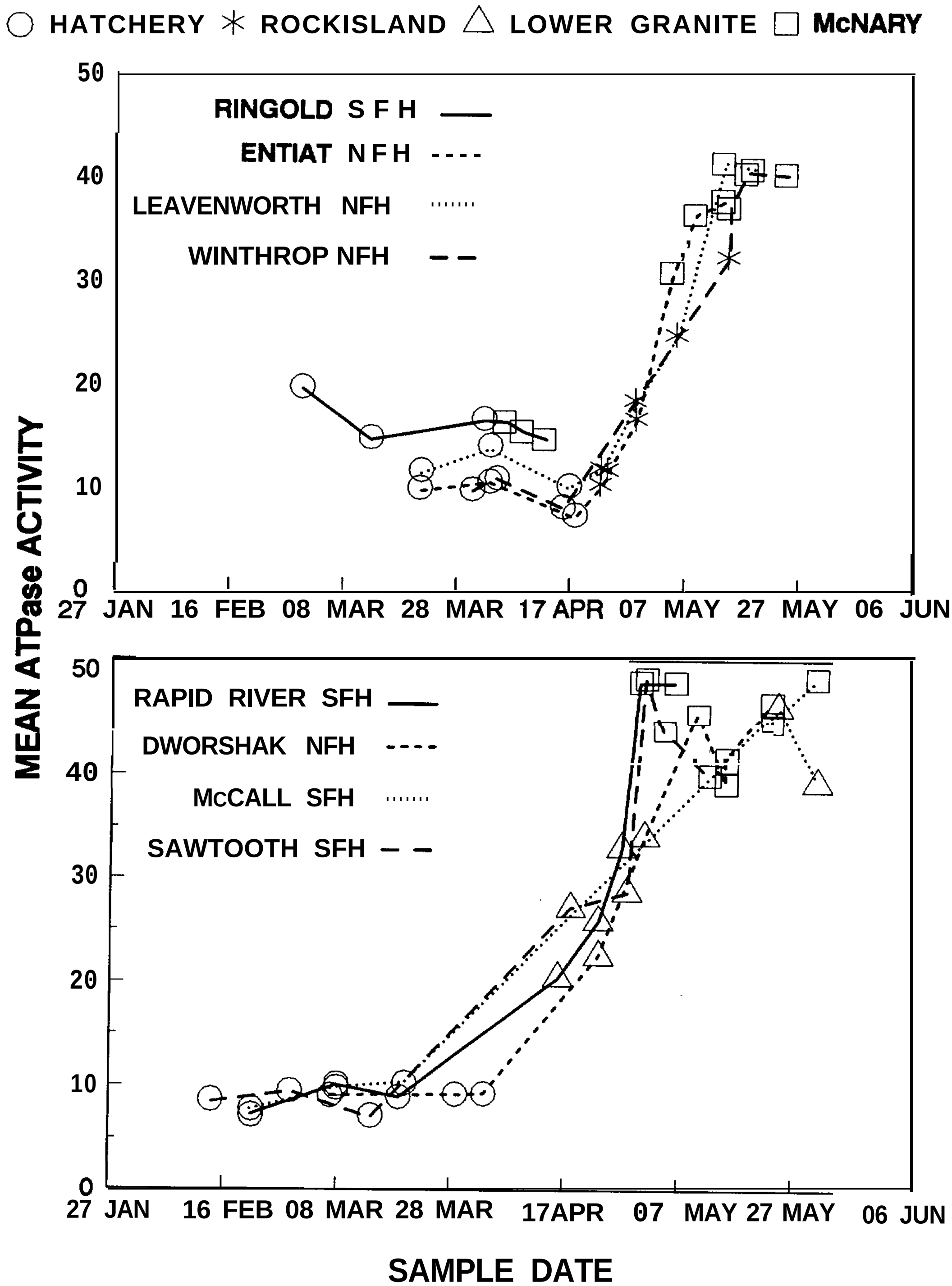

Figure 2. Mean Na^{+}-K^{+} ATPase activity (μmoles P·mg $prot^{-1}$·h^{-1}) and sample dates of juvenile spring chinook salmon collected in spring 1990. Lines indicate hatchery group: symbols indicate sample site.

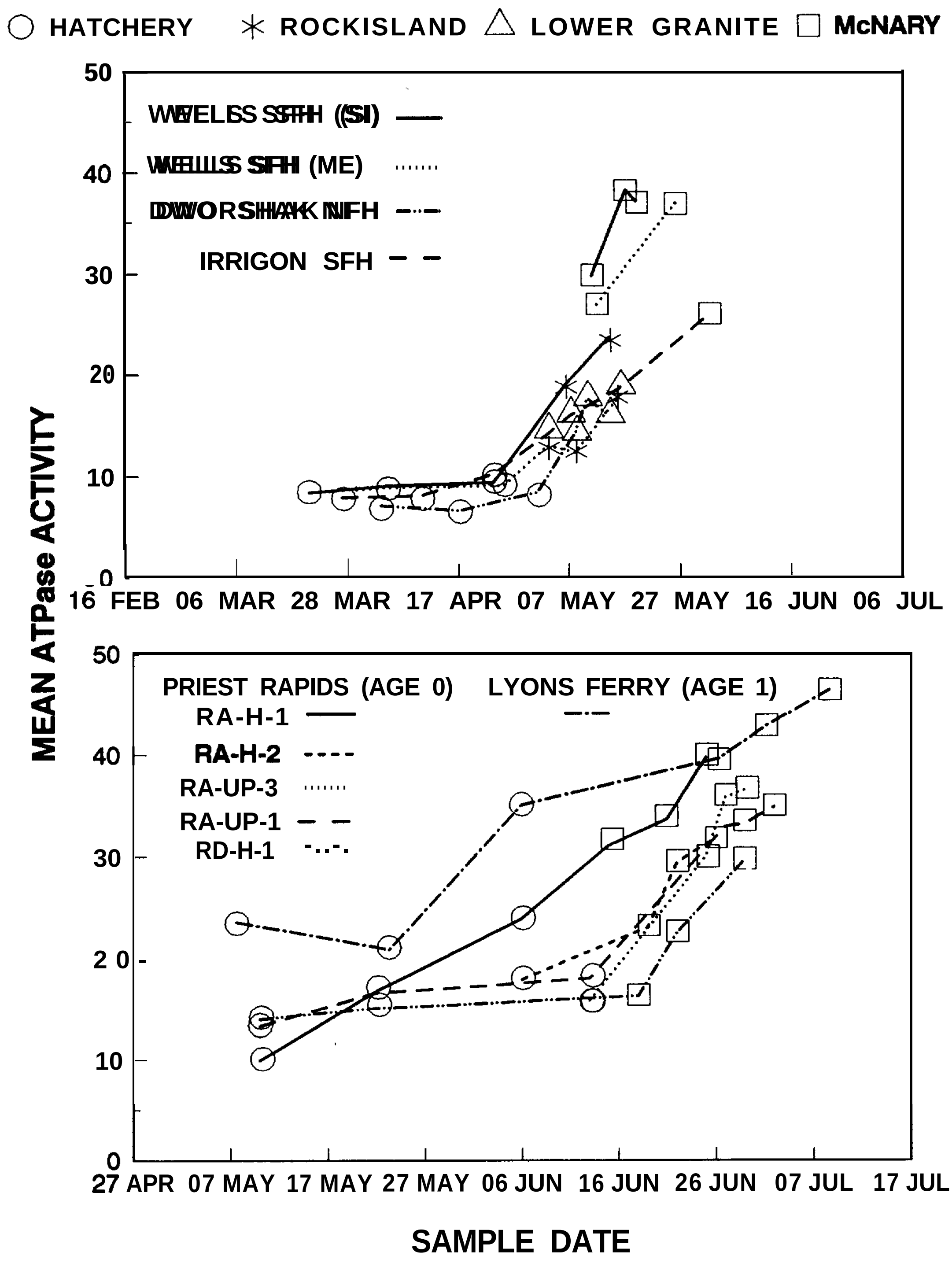

Figure 3. Mean Na^+-K^+ ATPase activity (μmoles P·mg $prot^{-1}\cdot h^{-1}$) and sample dates of juvenile steelhead (upper plate) and juvenile fall chinook salmon (lower plate) collected in spring 1990. Lines indicate hatchery group; symbols indicate sample site.

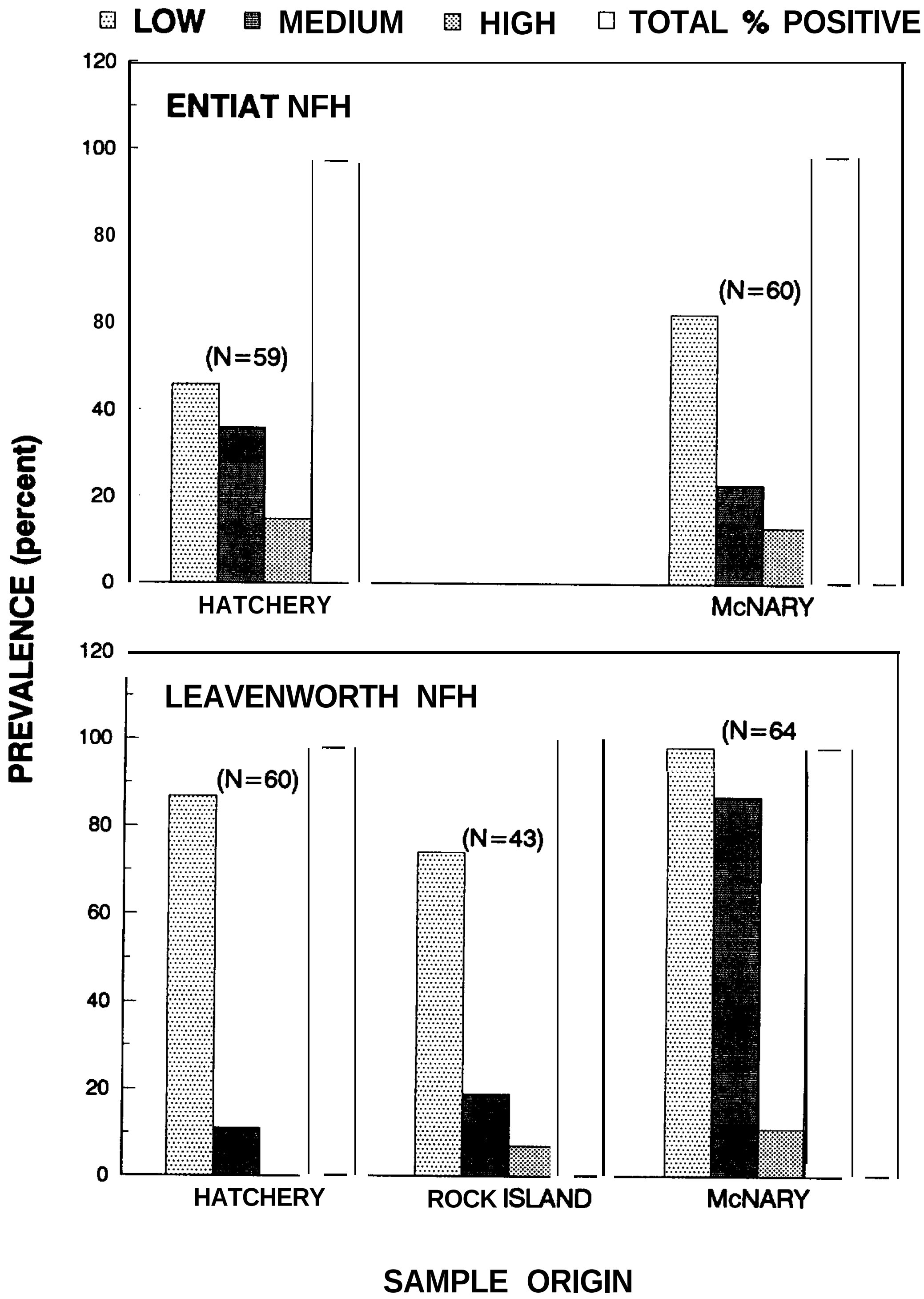

Figure 4. Prevalence of bacterial kidney disease in juvenile spring chinook salmon from Entiat NFH and Leavenworth NFH collected in spring 1990, determined using an enzyme-linked immunosorbent assay (ELISA) technique. Sample sizes are in parentheses.

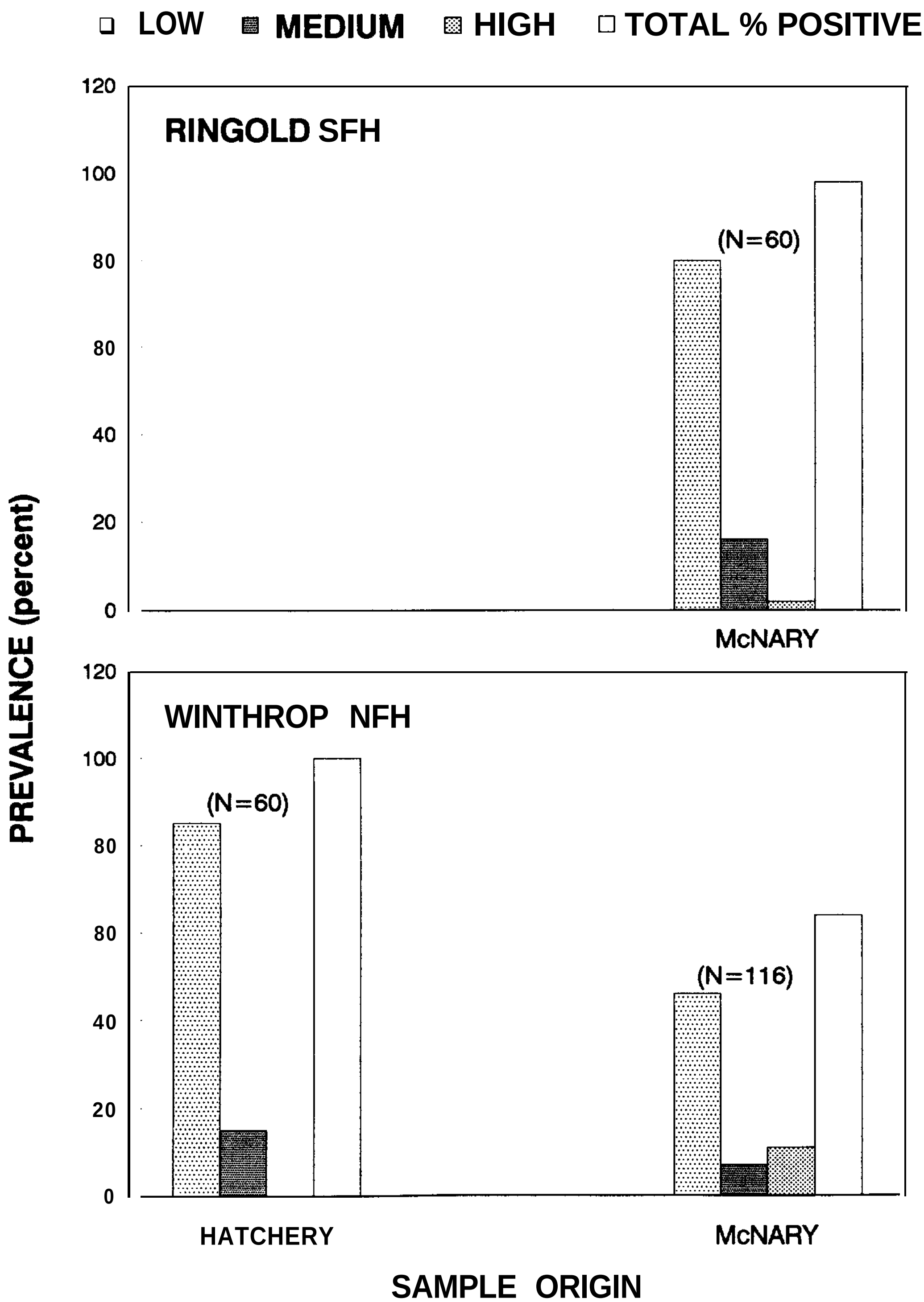

Figure 5. Prevalence of bacterial kidney disease in juvenile spring chinook salmon from Ringold NFH and Winthrop NFH collected in spring 1990, determined using an enzyme-linked immunosorbent assay (ELISA) technique. Sample sizes are in parentheses.

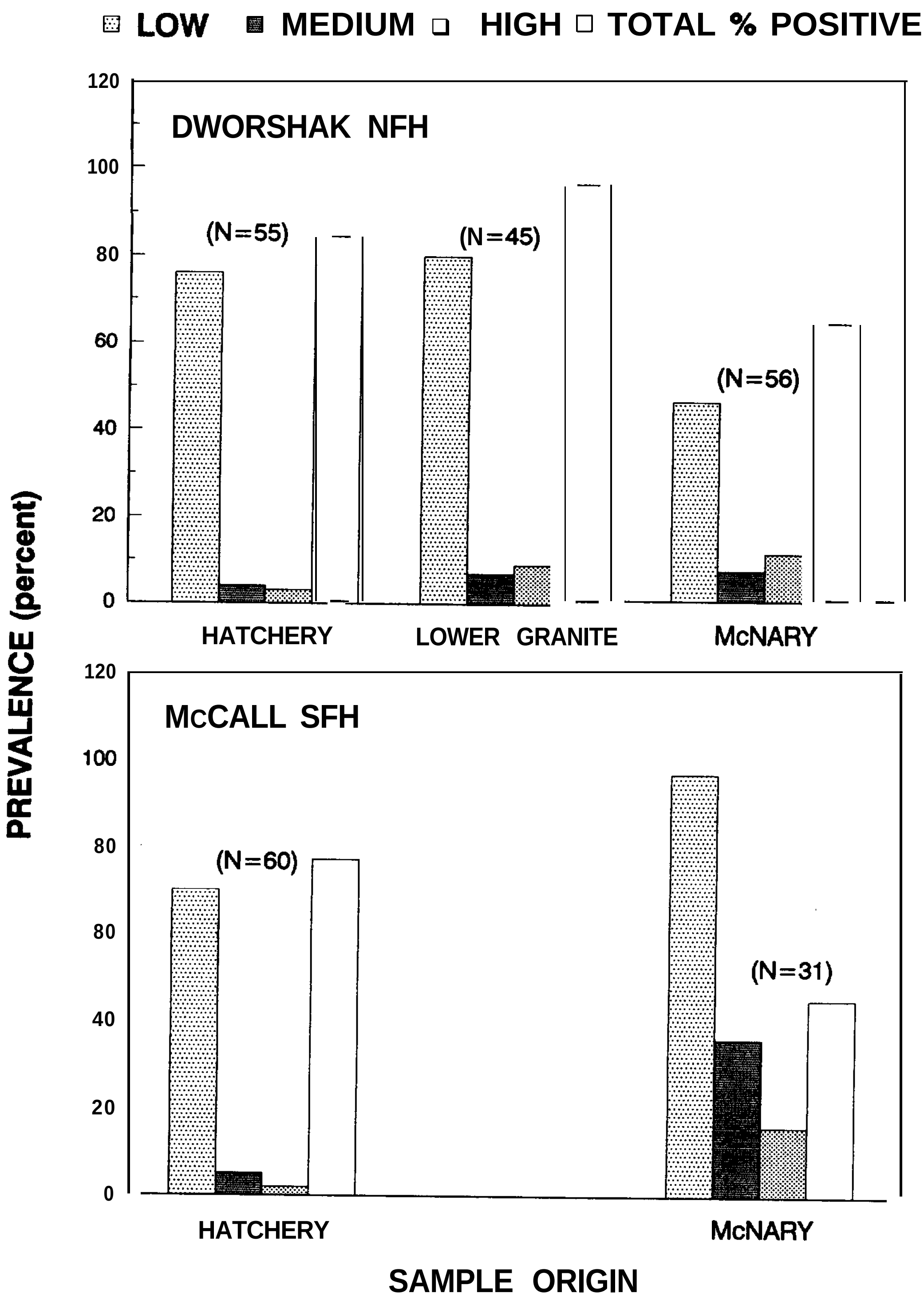

Figure 6. Prevalence of bacterial kidney disease in juvenile spring chinook salmon from Dworshak NFH and McCall SFH collected in spring 1990, determined using an enzyme-linked immunosorbent assay (ELISA) technique. Sample sizes are in parentheses.

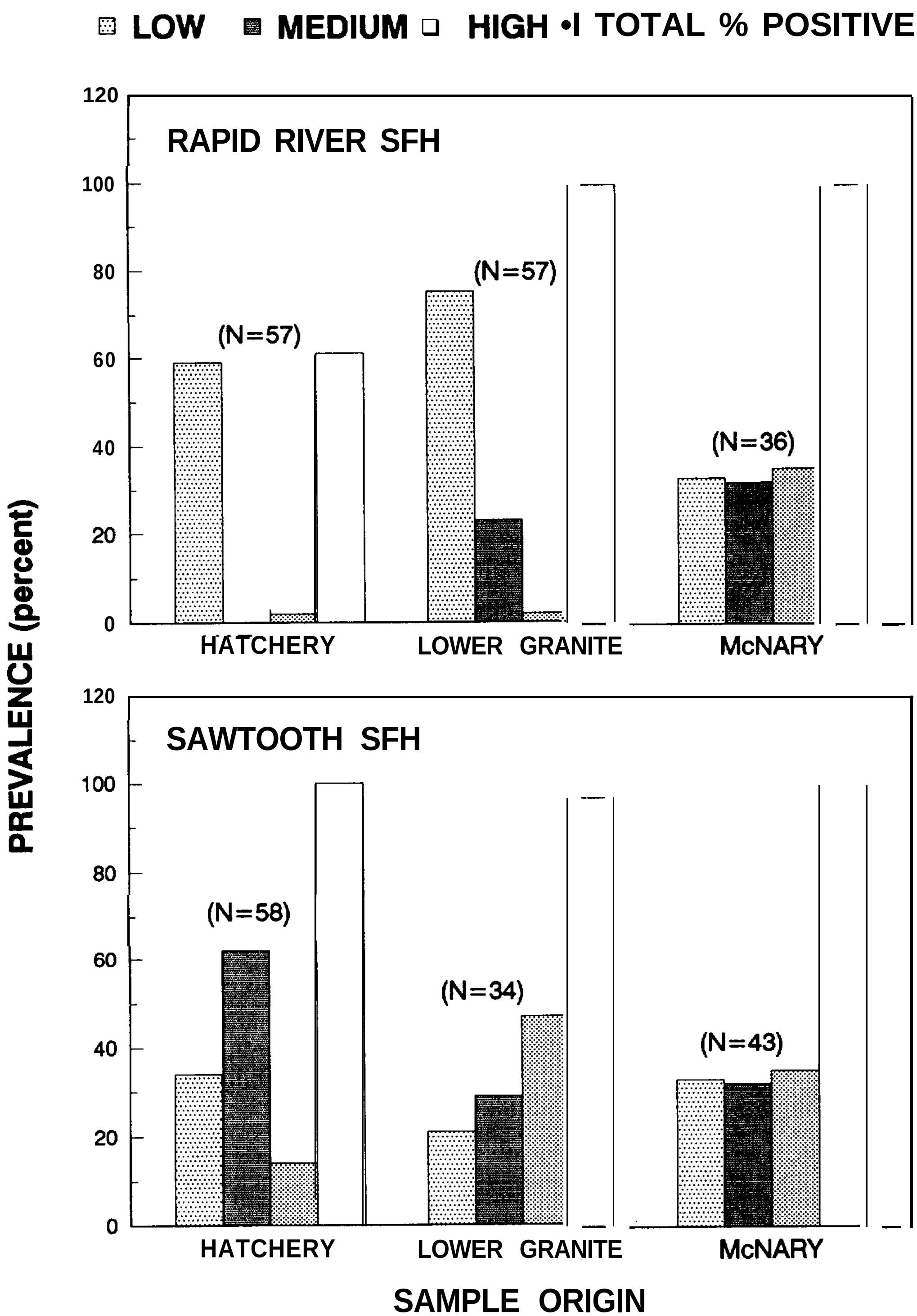

Figure 7. Prevalence of bacterial kidney disease in juvenile spring chinook salmon from Rapid River SFH and Sawtooth SFH collected in spring 1990, determined using an enzyme-linked immunosorbent assay (ELISA) technique. Sample sizes are in parentheses.

Table 2. Results of the enzyme-linked immunosorbent assay (ELISA) for bacterial kidney disease in juvenile spring chinook salmon from Columbia and Snake river hatcheries. Positive samples are divided into low, medium, and high categories based on ELISA optical densities. Also presented are the sample sizes (N) and the percent of fish diagnosed as positive during a visual examination (VISUAL).

SAMPLE SITE	POS %	LOW %	MEDIUM %	HIGH %	N	VISUAL %
Entiat NFH	97	46	36	15	59	3
Rock Island Dam	100	25	50	75	24	4
McNary Dam	98	62	23	13	60	5
Leavenworth NFH	98	87	11	0	60	0
Rock Island Dam	100	74	19	7	43	0
McNary Dam	98	87	11	0	64	0
Ringold SFH	100	58	42	0	19	0
McNary Dam	98	80	16	2	60	0
Winthrop NFH	100	85	15	0	60	0
Rock Island Dam	83	50	33	0	6	0
McNary Dam	85	69	14	2	116	0
Dworshak NFH	84	76	4	3	55	18
Lower Granite Dam	96	80	7	9	45	4
McNary Dam	64	46	7	11	56	5
McCall SFH	77	70	5	2	60	2
Lower Granite Dam	100	18	35	47	17	12
McNary Dam	97	36	16	45	31	10
Rapid River SFH	61	59	0	2	57	4
Lower Granite Dam	100	75	23	2	57	7
McNary Dam	92	67	22	3	36	3
Sawtooth SFH	100	24	62	14	58	5
Lower Granite Dam	97	21	29	47	34	26
McNary Dam	100	33	32	35	43	14

Discussion

Smoltification (ATPase activity) of all groups studied was low and static in the hatchery environments and increased sharply after release. This was the pattern observed in samples collected in 1988 and 1989 as well (Beeman et al. 1990, Rondorf et al. 1989). There were few differences between groups of the same species. The overall prevalence of BKD was high in most hatcheries, but some exhibited more severe infections than others, notably Entiat NFH and Sawtooth SFH. This is the second year in which fish from Sawtooth SFH had more severe BKD than other groups sampled, although fewer groups were sampled in 1989 than in 1990. Data from 1989 suggested that fish with high antigen levels disappeared from the sample population during migration, but this phenomenon was not apparent in data from 1990. Samples from 1990 indicated the proportion of fish in the high antigen category increased with migration. This may be due to differences in the severity of BKD in the groups sampled in each year, as samples from 1989 indicated more severe infections than those from 1990. The differences could also be reflecting differences in migration years or some other factor such as antibiotic treatments prior to release from hatcheries. Firm conclusions should not be drawn based on only two years of data. As in any program compiling a database over time, sampling more than two years will make analyses more meaningful.

ESTIMATING THE EFFECTS OF FLOW AND SMOLTIFICATION ON TRAVEL TIME

Introduction

Understanding the relationships between fish physiology, river flow, and migration rates are paramount to the effective management of the salmonid out-migration through the Columbia and Snake rivers. With such an understanding, managers can best utilize limited available flows for the greatest benefit to the fishery resource. To this end, data has been collected from the salmonid migration-at-large to assess smoltification of juvenile fish used to estimate travel time through index reaches of the Columbia and Snake rivers. Gill Na^{+}-K^{+} ATPase (ATPase) activity was selected as a measure of smoltification based on previous investigations. ATPase activity is considered indicative of smoltification development, a complex process that includes physiological and behavioral changes that accompany downstream migration. This is a summary of analyses of smoltification development, river flow, and travel time conducted using data collected in 1989 and 1990.

Methods

Analyses of river flow, travel time, and smoltification of juvenile fish were conducted using three fish stocks migrating through four index reaches. Juvenile spring chinook salmon, hatchery steelhead, and wild steelhead from the migration-at-large were sampled at the upstream ends of each index reach. Biweekly groups of 10 fish were sacrificed in a lethal dose of MS-222 and gill filaments were removed for determination of ATPase activity. ATPase activity was assessed using the method of Zaugg (1982). Other fish were injected with passive integrated transponder (PIT) tags or were freeze branded (McNary Dam to John Day Dam reach only). Sacrificed fish were assumed to be representative of those marked with PIT tags or freeze brands, from which travel time information was collected through the Smolt Monitoring Program (Fish Passage Center 1990, 1991). Data were collected from fish migrating through the index reaches of Rock Island Dam to McNary Dam (RIS-MCN) and McNary Dam to John Day Dam (MCN-JDA) on the Columbia River, and the Snake River Trap to Lower Granite Dam (SNK-LGR) and Clearwater River Trap to Lower Granite Dam (CLW-LGR) reaches on the Snake River. Data collected in 1989 and 1990 were included in the analysis.

Stepwise multiple regression was used to analyze the pooled data from 1989 and 1990 (SAS 1988). The criterion for entry or exit from the models was set conservatively at $p \leq 0.15$. In all regressions travel time was the dependent variable and flow and ATPase activity were used as independent variables. Regressions were run by index reach and species. Analyses were performed using raw and natural-log transformed data.

All travel time and flow data were from the Fish Passage

Center (FPC) Fish Passage Managers annual reports (Fish Passage Center 1990,1991). In our 1989 annual report we used flow and travel time from Idaho Fish and Game (IDFG) for the Snake River reaches (Buettner and Nelson 1990a). The main difference between IDFG data and FPC data was in the calculation of the flow variable. Buettner and Nelson (1990a) used flow measured at two United States Geological Survey gauges near the Clearwater River (CLW) and Snake River (SNK) traps, whereas the FPC uses flow at Lower Granite Dam (LGR-). In this report we used the FPC information for these reaches because it makes the data more consistent with that used for other reaches. Data from releases of PIT-tagged spring chinook salmon made on 18 May 1989 at the Snake River Trap were omitted from the analyses since these fish were predominantly subyearlings (Buettner and Nelson 1990a).

Results

The following results were based on a limited data set from two years of data collection. Flow and travel time data used in these analyses was a subset of that available to the Fish Passage Center since gill samples for determination of ATPase activities were taken only two days per week, whereas releases of PIT-tagged fish were made each day. Therefore, results from these analyses should be evaluated with caution, since trends evident in the larger Fish Passage Center data set (Fish Passage Center 1990, 1991) may not be discernable with small sample sizes from our collections thus far. A detailed summary of ATPase activity and condition factor of fish collected from the migration-at-large in 1990 is in Appendix B. Data collected in 1989 and 1990 used in regression analyses of flow, ATPase activity and travel time are in Appendix C.

Rock Island Dam to McNary Dam Reach

No significant correlations existed between travel time and either flow or ATPase activity of hatchery or wild steelhead collected in the Rock Island Dam to McNary Dam reach. None of the variables met the criterion for entry into the models describing travel time of steelhead when 1989 and 1990 data were pooled. This was also true in 1989. The pooled 1989 and 1990 spring chinook salmon results were also similar to 1989 in that travel time was negatively correlated with ATPase activity ($r = -0.71$, $p > r = 0.0041$), but no correlation between travel time and flow was present. The most useful model explaining travel time of spring chinook salmon was achieved using the natural-logarithm transformed variables of travel time and ATPase activity ($r^2 = 0.64$, $N = 14$, Table 3). Flow did not explain variation in travel time of spring chinook salmon in the Rock Island Dam to McNary Dam reach. The range of mean flows for all species was relatively narrow, ranging from 136 to 176 kcfs.

Table 3. Summary of linear regressions to predict travel times of juvenile spring chinook salmon (SPCH), hatchery steelhead (STHD) and wild steelhead (WSTH) in index reaches of the Columbia and Snake rivers. Data used were natural log (ln) transformed measurements of travel time in days (lnTRAV), gill Na^{+}-K^{+} ATPase activity (moles $P \cdot mg\ Prot^{-1} \cdot h^{-1}$) (lnATPase) and river flow in kcfs (lnFLOW) from 1989 and 1990 collections.

SPECIES	YEAR	N	R^2	EQUATION (lnTRAV=)
------------------------- REACH = RIS-MCN -------------------------------				
SPCH	89 89&90	84	.64	4.06 - 0.598(lnATPase) 0.523(lnATPase)
STHD	------ NO VARIABLES MEET P ≤ 0.15 --------			
WSTH	------ NO VARIABLES MEET P ≤ 0.15 --------			
------------------------- REACH = MCN-JDA -------------------------------				
SPCH	------ NO VARIABLES MEET P ≤ 0.15 ---------			
STHD	89&90	8	.37	7.59 - 1.14(lnFLOW)
WSTH	------ NO VARIABLES MEET P ≤ 0.15 ---------			
------------------------- REACH = SNK-LGR ------------------------------				
SPCH	89	12	.86	14.96-2.204(lnFLOW)-1.015(lnATPase)
SPCH	89&90	18	.69	8.22-0.678(lnFLOW)-1.085(lnATPase)
STHD	89	11	.88	10.24 - 2.008(lnFLOW)
STHD	89&90	25	.76	8.28 - 1.580(lnFLOW)
WSTH	89 89&90	89	.83	7.01 - 1.336(lnFLOW) 5.25 0.946(lnFLOW)
------------------------- REACH = CLW-LGR ------------------------------				
SPCH	90	9	.71	16.36 - 3.350(lnFLOW)

McNary Dam to John Day Dam Reach

Flow and travel time of pooled 1989 and 1990 hatchery steelhead data were significantly correlated ($r = -0.63$, $p > r = 0.097$). The regression resulting in the highest r^2 included natural-logarithm transformed flow and travel time data from hatchery steelhead ($r^2 = 0.37$, $N = 9$; Table 3). Travel time of wild steelhead was the same (3 d) for each of the three samples from which we collected ATPase activity information, so no predictive relationship was possible. No variables from spring chinook salmon ($N = 8$) or wild steelhead ($N = 3$) met model entry criterion using our data sets. The range of mean flows was small, ranging from 193 to 279 kcfs for species in this reach.

Snake River Trap to Lower Granite Dam Reach

In the Snake River Trap to Lower Granite Dam reach, several significant correlations were present in migration data for which we have ATPase activity levels. Models using natural-logarithm transformed data were significant for all species in this reach (Table 3). The relationship between travel time and flow was similar in 1989 and 1990 for hatchery and wild steelhead, but not for spring chinook salmon (Figure 8). In individual years, the travel time-flow relationship of data from spring chinook salmon was relatively linear, but when both years were pooled, large between-year differences made flow a poor predictor of travel time. These differences could be described by the use of an interaction term, such as a variable including year in the regression equation. However, data in Buettner and Nelson (1990b) indicates the relation between flow and travel time in 1989 was not typical of those from other years during 1987-1990. Therefore, additional data will be needed to determine if an interaction term is justified.

As in 1989, flow alone explained travel time of hatchery and wild steelhead when 1989 and 1990 data were pooled. However, both flow and ATPase activity were significant variables in the model of spring chinook salmon travel time ($R^2 = 0.69$, $N = 18$). Using this regression a family of curves was plotted to represent predicted travel times for various flows and ATPase activities (Figure 9).

Three conclusions can be drawn from Figure 9. First, as flow and/or ATPase activity increased, travel time decreased. Second, the effect of ATPase activity was greatest at low flow. Third, the effects of increased ATPase activity were greater as ATPase increased from 10 to 20, than from 20 to 30, or 30 to 40 units. This indicated that the greatest effects of changes in ATPase activity were early in the smoltification process, an observation which was partly dependent upon the log-log model specification.

Two methods were used to determine the relative influence of the ATPase activity and flow variables in the multiple regression explaining travel time of spring chinook salmon. In the first, simple regressions using flow or ATPase activity to explain travel time were created and r^2 values were compared. In the second, the multiple regression was used. In this method, each independent variable was varied by one standard deviation from the mean while the other was held constant at its mean. The influence of each

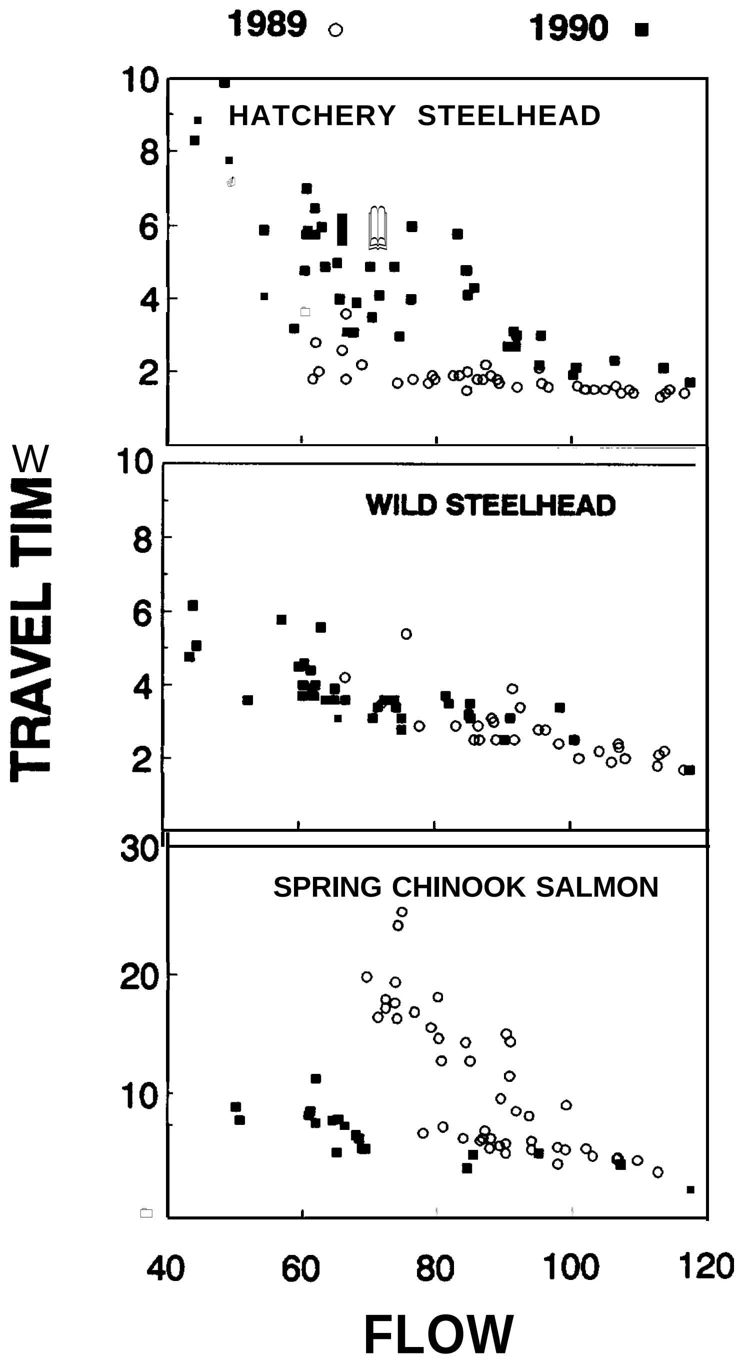

Figure 8. Travel time (days) from the Snake River Trap to Lower Granite Dam and flow (kcfs) at Lower Granite Dam for hatchery steelhead, wild steelhead, and spring chinook salmon juveniles PIT-tagged at the Snake River Trap in 1989 and 1990. Data are from Fish Passage Center Annual Reports (Fish Passage Center 1990,1991).

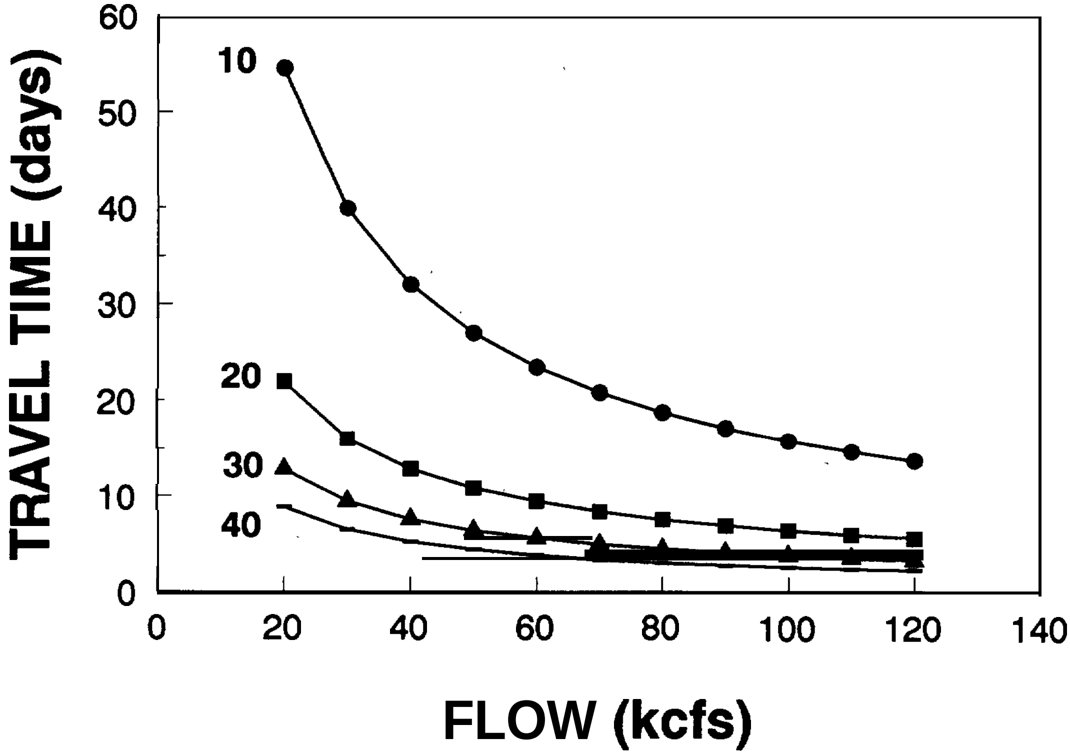

Figure 9. Predicted travel time and flow relationships of juvenile spring chinook salmon migrating through the Snake River Trap to Lower Granite Dam reach at four ATPase activities (10, 20, 30, 40 µmoles $P \cdot mg\ prot^{-1} \cdot h^{-1}$. Data points were generated using a multiple regression.

independent variable was then measured by comparing the changes in travel time due to changes of one standard deviation of each independent variable.

In simple regressions using natural-logtransformedvariables the flow model explained 17% of the variability in travel time: whereas ATPase activity accounted for 65%. Using the multiple regression, when flow was held constant at the mean (mean= 83.3 kcfs, SD = 14.8) and ATPase activity was increased by one standard deviation above its mean (mean = 20.3, SD = 5.8), predicted travel time decreased by 26%. When flow was increased by one standard deviation while ATPase activity was at its mean, predicted travel time decreased by 11%. Decreases in ATPase activity and flow using similar methods increased predicted travel time by 52 and 16% respectively. Thus, each method of comparison indicated that both flow and ATPase activity played important roles in the travel time of spring chinook salmon from the Snake River Trap to Lower Granite Dam. It should be noted that data collected in 1989 and 1990 had a narrow range of river flows, resulting in a smaller standard deviation for flow than would be expected if the data included numerous years and a wider range of flows. With a wider range of flows, the influence of the flow variable would increase in the above comparison.

Clearwater River Trap to Lower Granite Dam Reach

Nineteen-ninety was the first year of physiological data collection in this index reach. Only spring chinook salmon were sampled at the Clearwater River Trap. Significant correlations exist between travel time and both flow and ATPase activity. The coefficients were $r = -0.84$ ($p > r = 0.0050$) with flow and $r = -0.58$ ($p > r = 0.0994$) with ATPase activity. The highest R^2 was achieved with natural-log transformed data. Flow was the only variable meeting the entry requirements in the regression for spring chinook salmon ($r^2 = .71$, $N = 9$; Table 3).

Discussion

Research under this project was initiated based on the theory that both river flow and degree of smoltification development play roles in fish migration behavior. Since river flows in any one year tend to be less variable than flow regimes between years, a multi-year database will be needed for a thorough analysis of this relation. Data collected thus far have come from only two years, and should be viewed with caution.

Results from pooled 1989 and 1990 data were similar to those from 1989 (Beeman et al. 1990). The R^2 values were generally lower than with 1989 data alone, but this is to be expected since small sample sizes (1989 data alone) can often be associated with inflated R^2 values. Data collected in 1989 and 1990 indicate that travel times of hatchery and wild steelhead were best explained by flow alone, as ATPase activity was not a significant contributor in any regressions using steelhead. Smoltification, as measured with

ATPase activity, has been shown to be important in explaining travel time of spring chinook salmon in the RIS-MCN reach, and combined with flow, in the SNK-LGR reach. At this time, it appears that travel time of spring chinook salmon can be explained solely by ATPase activity in the RIS-MCN reach, solely by flow in the CLW-LGR reach, and by both variables in the SNK-LGR reach: however, this is probably a result of the limited database collected thus far. Flow did not explain the travel times of any of the species tested in the RIS-MCN reach, but, again, this may be due to the small range of flows observed during the study periods. Data collected in most index reaches in 1989 and 1990 were typified by narrow ranges of flows, and in the case of the CLW-LGR reach, sporadic trap operation during periods of high flows.

The spring chinook salmon data collected in the SNK-LGR reach is the only data set in which both flow and ATPase activity entered models describing travel time. The model of spring chinook salmon travel time in this reach suggests that both flow and ATPase activity are important variables in explaining variation in spring chinook travel time. Moreover, the effects of ATPase activity are greatest as ATPase activity increases during the early stages of smoltification, with effects diminishing at higher flows. These conclusions are, at least in part, a product of the log-log model specification, and may be different under other types of models.

Data collected thus far suggest that ATPase activity influences travel time of spring chinook salmon but not travel time of hatchery or wild steelhead. Even though the seasonal patterns of development of gill ATPase activity in spring chinook salmon and steelhead were similar, this variable did not contribute to models describing steelhead travel times. This may be due to differences in the migration timing of these species. The steelhead migration in the Snake River is normally later than that of the spring chinook salmon and usually occurs at higher flows, at which the spring chinook salmon model depicted in Figure 9 indicates the effects of ATPase activity are diminished.. It is possible that the relationship between river flow, gill ATPase activity and travel time of steelhead may be similar to that of spring chinook salmon, but the influence of ATPase activity was diminished at the flows available in the current steelhead data sets.

There may also be a behavioral cause for the apparent lack of influence of smoltification on travel time of steelhead. Zaugg (1989) noted that more completely smolted underyearling fall chinook salmon migrating in the Columbia River were more prevalent in faster flowing water offshore than less smolted fish, that tended to be found in nearshore areas. This difference in habitat utilization resulted in faster migration rates for the more smolted fish. Our data may suggest that a similar process occurs in yearling spring chinook salmon, but not in hatchery or wild steelhead. It is possible that steelhead, perhaps because of their relatively large size (150-220 mm FL) compared to spring chinook salmon (120-150 mm FL), migrated in the off-shore, fast-flowing water regardless of ATPase activity development, whereas spring chinook salmon moved into these areas as smoltification development progressed. In addition to possible differences in the horizontal distribution, there may have been differences in the vertical distribution of steelhead and spring chinook salmon during migration. Giorgi et al. (1988), in a study of spring chinook salmon passing Lower Granite Dam, found that fish guided into the gatewell (higher in the water column) had higher ATPase activities than unguided fish on 3 of 4 dates.

In an analysis of variables influencing the migration rates of juvenile salmonids in the Snake and Columbia rivers, Berggren and Filardo (1991) identified surrogate variables related to smoltification development which were useful predictors of migration rates. Inasmuch as our analysis, which included actual measures of smoltification, was a small subset of the travel time and flow data currently available, more data are needed before in-depth analyses of the effects of flow and smoltification on travel time are conducted. Data from 1989 and 1990 were collected under a narrow range of flows, making it difficult to determine the actual influences of flow and ATPase activity on fish travel time in the index reaches. As data are collected over the next several years, the ranges of flows, ATPase activities, and travel times will hopefully increase, making it possible to gain an understanding of the processes involved. More effective management of the salmonid out-migration would be possible with a thorough understanding of salmonid migratory processes.

DEVELOPMENT *OF* AN INDEX *OF* SMOLT CONDITION

NON-LETHAL INDEX *OF* SMOLTIFICATION

Introduction

As a part of on-going efforts to develop a non-lethal index of smoltification, several parameters were measured to identify correlates with gill ATPase activity. Gill ATPase activity is a reliable and widely-used method of assessing smoltification of salmonids, and predicting it using non-lethal methods would be advantageous. In addition to an index that would be non-lethal, a simple test requiring little or no laboratory expertise was sought. The relations between gill ATPase activity, condition factor (K), and skin reflectance, a measure of silvering, were examined. Since skin reflectance is itself a non-lethal measure of guanine in skin and scales, guanine was measured to check the validity of the reflectance measurements.

Methods

Fish used in this investigation were juvenile spring chinook salmon from Dworshak NFH and Winthrop NFH and juvenile steelhead from Lyons Ferry SFH. Fish from Dworshak NFH were collected at the hatchery, Lower Granite Dam, and McNary Dam, whereas those from Winthrop NFH were collected at the hatchery and at Rock Island and McNary dams. Fish from Lyons Ferry SFH were collected at the hatchery, Curl Lake conditioning pond (Tucannon River, WA.), and McNary Dam.

Methods used to collect gill samples for gill ATPase analyses as well as assay methods can be found in earlier reports (Beeman et al. 1990, Rondorf et al. 1989). Fork length to the nearest millimeter and weight to the nearest 0.1 gram were measured and condition factor (K) was calculated as (weight / length^3) . 10^5.

Skin reflectance was measured from video images using JAVA software (Jandel Scientific, Corte Madera, CA) and an IBM-compatible computer. White and black pieces of paper were used to calibrate the readings on a zero (black) to ten (white) scale of light intensity. An opaque box was placed over the samples during measurement to avoid bright spots. Reflectance was measured from skin samples taken using a 16 mm (5/8 in) cork borer for steelhead and a 13 mm (1/2 in) borer for spring chinook salmon. Samples were taken from the left side by freezing the fish and centering the borer on a vertical line extending ventrally from the anterior insertion of the dorsal fin, with the top of the corer just under the lateral line. The circular skin sample was then peeled 'from the fish using a forceps, placed in a vial and frozen in liquid nitrogen. After measurement of reflectance skin samples were assayed for guanine using methods modified from Staley (1984).

In previous work (Beeman et al. 1990) we expressed guanine (GN) concentrations in mg GN • g skin-'. Results from steelhead expressed in this manner exhibited little or no pattern, even though the fish became visually more silvered during the sample period. Further investigation into the guanine assay revealed a negative bias in guanine concentration with increasing skin weight. As fish grow the skin becomes heavier per unit area. This change occurs at a faster rate than guanine deposition, causing a bias in guanine results expressed in a weight of guanine to weight of skin basis. We found that by expressing guanine results on a weight of guanine per area of skin basis this bias did not affect the results. Therefore, guanine results are expressed as mg GN • cm^2 skin-'.

Results

Reflectance and condition factor exhibited linear relationships and were highly correlated with gill ATPase activity of steelhead, indicating each could be useful in predicting gill ATPase activity of this species (Figure 10). Reflectance and condition factor of steelhead were negatively correlated ($r = -0.78$, $p > r = 0.0001$, $N = 69$). Reflectance and guanine were highly correlated ($r = 0.82$, $N = 69$, $p > r = 0.0001$), indicating a strong relationship between the reflectance measures and guanine in the skin and scales. In simple regressions, reflectance and condition factor explained 73% and 66% of the variability in gill ATPase activities of steelhead, respectively ($N = 69$). Using multiple regression, 78% of the variability in gill ATPase activity of steelhead was explained with these variables.

The relationships between condition factor and reflectance with ATPase activity of spring chinook salmon were not linear, so ATPase activity was transformed to natural logarithms (Figure 11). Unlike data from steelhead, which was characterized by a high guanine-reflectance correlation, the relationship between guanine and reflectance of spring chinook salmon was low ($r = 0.41$, $N = 67$, $p > r = 0.0006$). As with steelhead, reflectance and condition factor of spring chinook salmon were negatively correlated ($r = -0.72$, $p > r = 0.0001$, $N = 66$). In simple regressions, reflectance and condition factor explained 55% and 78% of the variability in the natural logarithm of gill ATPase (lnATPase) activities of spring chinook salmon, respectively ($N = 66$). Using multiple regression, reflectance and condition factor explained 80% of the variability in lnATPase ($r^2 = 0.80$, $N = 67$).

Discussion

Data collected to date indicates condition factor and skin reflectance may be useful in the development of a non-lethal index

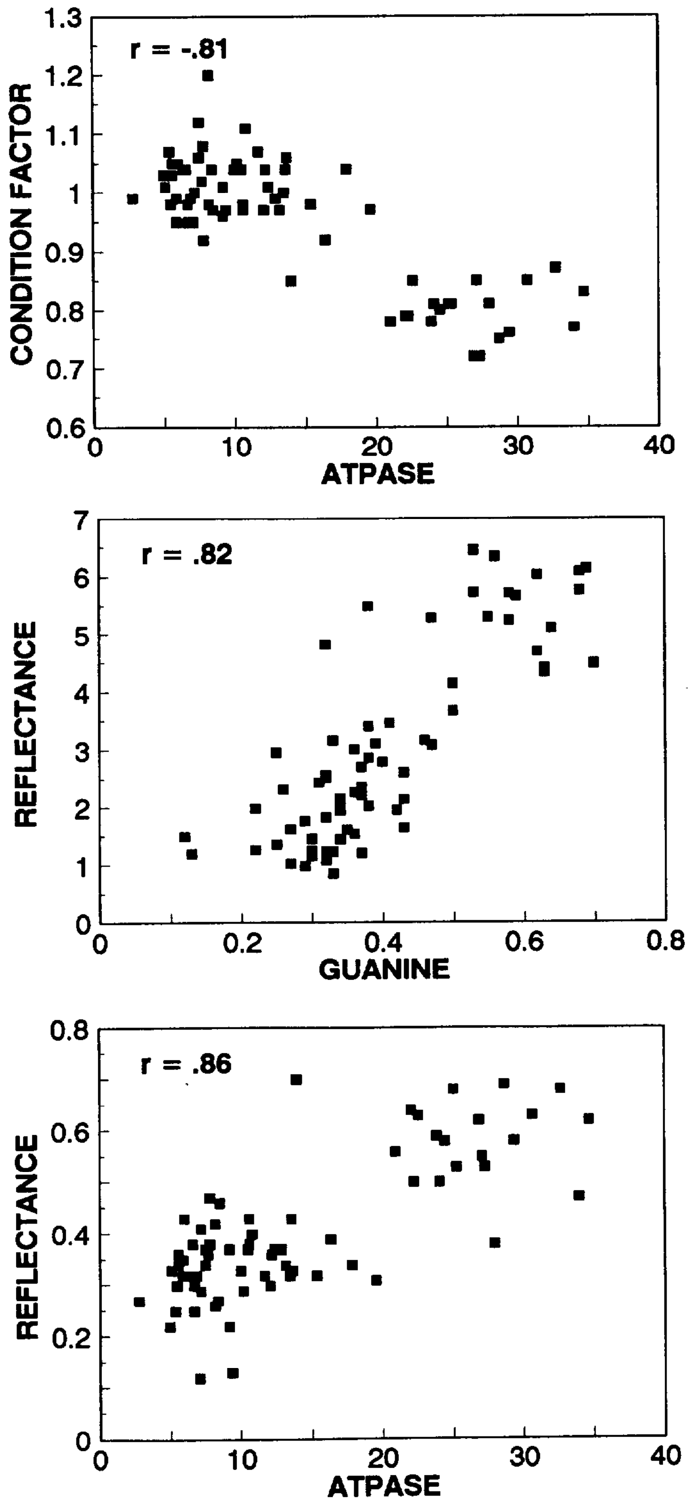

Figure 10. Gill ATPase activity (μmoles P·mg prot^{-1}·hr^{-1}), condition factor, and skin reflectance from juvenile steelhead collected in spring 1990. Correlation coefficients (r) are significant (p>r=0.0001).

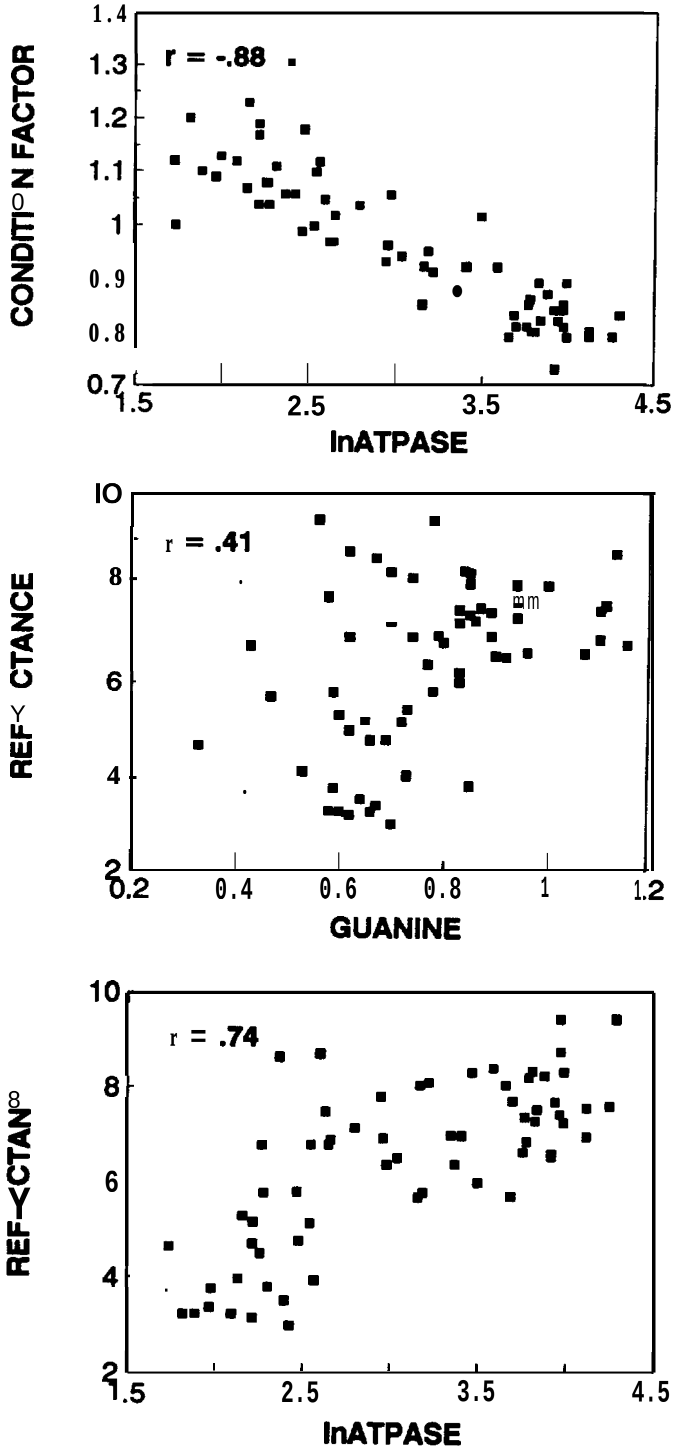

Figure 11. Natural-log transformed gill ATPase activity (μmoles $P \cdot mg\ prot^{-1} \cdot hr^{-1}$), condition factor, and skin reflectance from juvenile spring chinook salmon collected in spring 1990. Correlation coefficients (r) are significant ($p > r \leq 0.001$).

of smoltification of spring chinook salmon and steelhead. Although lnATPase and skin reflectance of spring chinook salmon appear to be highly correlated, the data are suspect since a high correlation between GN and skin reflectance is lacking. The cause of the low correlation ($r = 0.41$) is not known, but differences were noted between steelhead and spring chinook salmon skin thickness and opaqueness, as well as in the deciduous nature of the scales. Continued development, testing, and preliminary application will examine these factors.

We believe condition factor and skin reflectance could be used together in a non-lethal index of smoltification of steelhead and spring chinook salmon. Although these variables are correlated, changes in each parameter, while a part of the smoltification process, are due to separate physiological phenomena occurring during smoltification, and not due to a cause-and-effect relationship. Using both variables will make a more reliable index than if only one parameter were used. It should be noted that condition factor is also related to processes other than smoltification such as feeding and aspects of fish health. However, the changes in condition factor due to smoltification are quite large and should not be overly affected by these processes if samples are obtained from individuals from the migration-at-large rather than a single hatchery group. This is not to say that it could not be used for individual hatchery groups as long as they are in good health and do not have obvious departures from normal.

Summary

1) Both condition factor and skin reflectance were highly correlated with gill ATPase activity of steelhead, indicating they may be useful components of a' non-lethal index of smoltification.

2) Condition factor and reflectance were highly correlated with the natural logarithm of ATPase activity of spring chinook salmon. However, the correlation between reflectance and guanine of spring chinook salmon was low, suggesting the reflectance measures may be in error. Further data collection and analysis are needed in this area.

SEAWATER SURVIVAL TRIALS

Introduction

Three seawater survival experiments were conducted as a part of ongoing efforts to develop a non-lethal index of smolt condition. Survival in seawater was chosen as the method of comparison between groups since it was an easily measured component of smolt condition. This was based on the premise that fish in better overall condition would have higher survival in seawater. Comparisons were made between (1) three hatchery rearing treatments, 2) fish taken directly from the hatchery vs. those collected as migrants, and (3) migrant fish classified into one of several groups based on visual characters.

Methods

Comparison of hatchery rearing treatments and migrants

Seawater survival of juvenile spring chinook salmon from three rearing treatments at Leavenworth NFH were compared. The treatments were (1) branded fish in raceways (branded), (2) unbranded fish in adult holding ponds (pond), and (3) unbranded fish in raceways (control). On April 17, 1990 two groups of 25 fish from each of the branded and pond treatments and three groups of 25 fish from the control treatment were transported to Marrowstone Field Station (MFS). Between May 16 and May 19, 1990 four replicates of 25 Leavenworth NFH fish (migrants from the branded treatment) were collected at McNary Dam. This corresponded to between the 58th and 78th percentile of their passage past McNary Dam. These fish were transported to MFS on May 19, 1990.

During transportation fish were kept in oxygenated water in covered plastic garbage cans at a loading density of less than 10 $g \cdot L^{-1}$ (0.08 lb-gal-'). Temperature was controlled with block ice sealed in plastic bags. Fish were placed in circulartanks at MFS containing 281 L (75 gal) of freshwater, corresponding to a loading density of not more than 2.4 $g \cdot L^{-1}$ (0.02 $lb \cdot gal^{-1}$) with a flow of 7.5 $L \cdot min^{-1}$ (2.0 $gal \cdot min^{-1}$). After a two to five day acclimation period in freshwater fish were transferred to seawater by acclimating for two days in 1/3 and two days in 2/3 strength seawater before changing to full-strength seawater at 28 ppt. Mortalities were recorded during the 180-day rearing period after which remaining fish were sacrificed for determination of the prevalence of bacterial kidney disease (BKD). Samples for BKD were also taken from mortalities from the branded and migrant treatments. Samples for BKD analysis were not taken from mortalities from the pond or control treatments. BKD samples were analyzed using an enzyme-linked immunosorbent assay (ELISA) using the method in Pascho et al. (1987).

Comparisons were made between the percent mortality in each treatment and between the mean ELISA optical density (OD) between the control and migrant treatments. Mortality data in percent was arcsin transformed to allow the use of parametric analysis of variance (ANOVA) procedures. Kruskal-Wallis and Friedman's non-parametric ANOVAs were used to compare mean ELISA OD values, since ELISA ODs were not normally distributed. Statistical analyses were performed using SAS for personal computers (SAS 1988).

<u>Comparison of fish from the migration-at-large</u>

Juvenile spring chinook salmon from the migration-at-large collected at McNary and Bonneville dams were assigned to one of three groups based on visual characters of smolt condition. These characters were (1) descaled, according to criteria established by the Fish Transportation and Oversight Team (FTOT) (Koski et al. 1990) (descaled) (2) hemorrhaged thymus gland (thymus), and (3) no visually observable maladies (control). Three replicates were collected at Bonneville Dam and one group was collected at McNary Dam. Fish from Bonneville Dam collected on May 23 (replicate 1) and 24 (replicate 2) were transported to MFS on May 25, and those collected between May 26-28 (replicate 3) were transported on May 29. Fish collected from McNary Dam between May 20-24 were transported to MFS on May 25, 1990. The second replicate of the descaled treatment from Bonneville Dam contained only 10 fish and was omitted from the analyses. All fish were collected at about the 90th percentile of spring chinook salmon passage at each site. Fish were acclimated in freshwater for five days prior to seawater conversion. The protocol for transportation, seawater conversion and statistical analyses were identical to those described above. Fish in these groups were placed into 637 L (170 gal) circular tanks at MFS corresponding to a loading density of not more than 1.2 $g \cdot L^{-1}$ (0.01 $lb \cdot gal^{-1}$) with a flow of 11.25 $L \cdot min^{-1}$ (3.0 $gal \cdot min^{-1}$).

Results

<u>Comparison of hatchery rearing treatments and migrants</u>

Mean percent mortality of fish taken directly from Leavenworth NFH was 57.1%, 42.0%, 56.0% in the branded, pond, and control treatments, respectively. No significant differences were detected in the mortality rates between these treatments (one-way nested general linear models (GLM) test, df = 6, $P > F = 0.5437$) (Figure 12A). However, the mean percent mortality of migrants (mean = 90.4%) was significantly higher than that of the pooled hatchery treatments (mean = 52%) (one-way GLM, df = 10, $P > F = 0.0061$). Mortalities over time were similar for all treatment groups. Few mortalities occurred during the first two weeks after seawater entry, indicating transportation had no immediate effect on mortality.

The prevalence of BKD (mean ELISA OD) of the migrants was significantly higher than that of the hatchery brand treatment (Kruskal-Wallis Test, df = 1, $P > X^2 = 0.0001$). In the branded

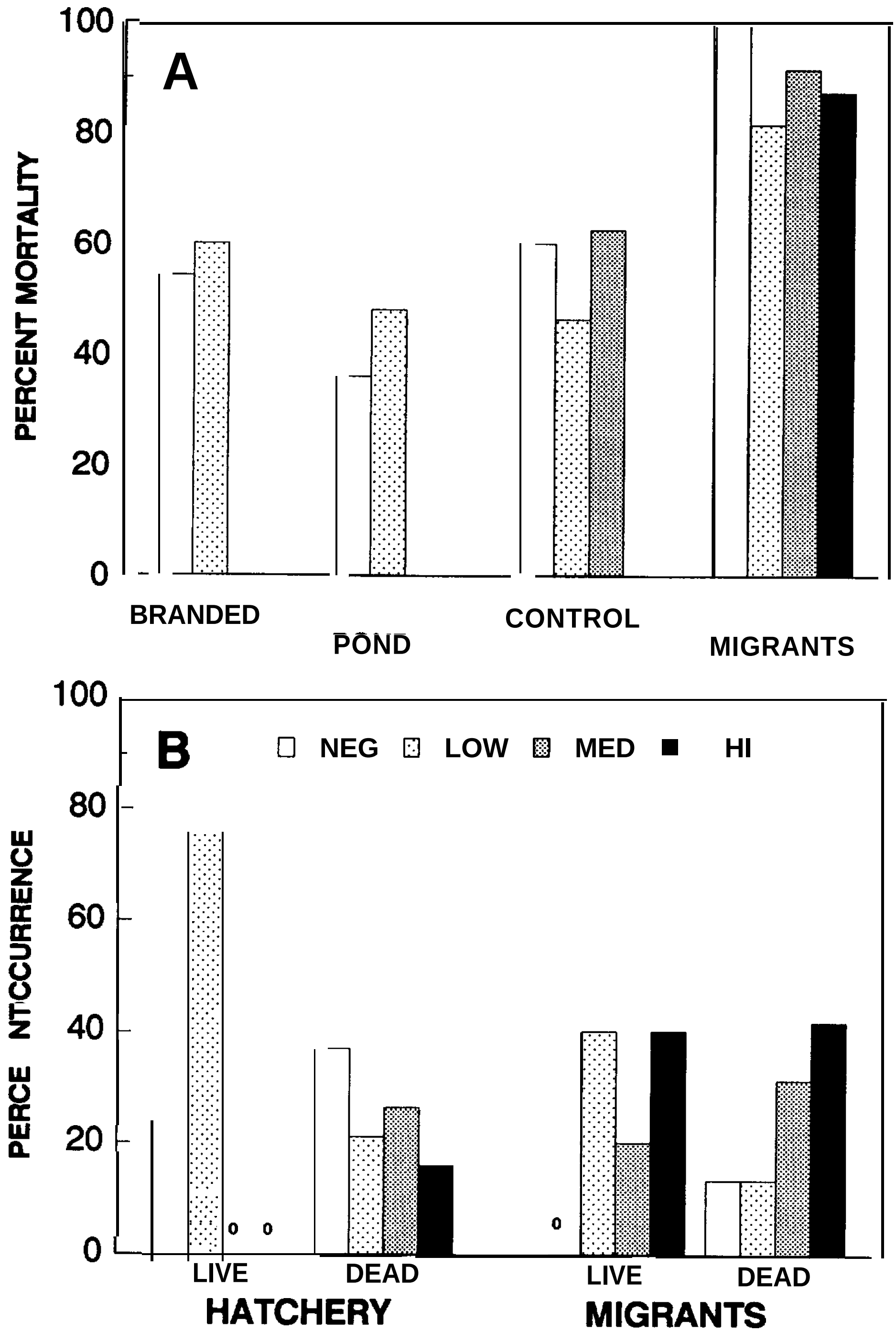

Figure 12. Percent mortality of juvenile spring chinook salmon from branded, pond, and control groups taken from Leavenworth NFH and one migrant group after a 6-month seawater rearing period (A), and percent occurrence of live and dead fish divided into four categories of BKD infection based on ELISA results (B). Samples were collected from fish in 1990.

treatment the BKD infections of fish that died were more severe than the survivors, whereas BKD infections of live and dead migrants were similar (Figure 12B). Survivors from the branded treatment had no fish with ELISA ODs in the medium or high categories, whereas 42% of the mortalities were in these groups. In contrast, the percentage of fish in medium and high ELISA OD groups was high in both live (60%) and dead (73%) migrant fish.

Miaration-at-larse trials

There were no significant differences in mortality rates between any of the treatment groups from either site (Figure 13). However, mortality of fish from McNary was significantly less than fish from Bonneville. Bacterial kidney disease infections of survivors from both sites consisted of fish with low antigen levels, whereas mortalities were characterized by mostly medium and high antigen levels (Figure 14).

Discussion

It was hypothesized that the mortality of the Leavenworth migrants would be less than the hatchery treatments since the advanced smoltification of the migrants would better prepare them for seawater survival. However, mortality of the migrants was significantly higher than in the hatchery treatments. BKD was an important factor contributing to the mortalities in all treatments.

It appears that the hatchery and migrant treatments had similar BKD profiles prior to the experiment, and that the high antigen levels present in fish from the migrant treatment were developed during seawater rearing. Data from Leavenworth migrants sampled under our regular monitoring (collected during the same time period as those in this experiment) indicated the migrants were dominated by fish in the low ELISA OD category (2% negative, 87% low, 11% medium) prior to the transportation for this experiment. This is very similar to BKD of the branded treatment survivors (24% negative, 76% low) and the fish collected from the hatchery during our regular monitoring (2% negative, 86% low, 12% medium). If we assume BKD of the migrant treatment group was similar to that of the regular monitoring group at McNary Dam, it appears that the high antigen levels seen in the migrant group after the seawater rearing were developed while in the seawater environment.

This could be caused by increased sensitivity to stress due to smoltification. It has been shown that smoltification occurs at a rapid rate shortly after release from the hatchery environment (Rondorf et al. 1989, Beeman et al. 1990) and that the stress response of salmonids is heightened during the Parr-smolt transformation (Barton et al. 1985). Moreover, Maule et al. (1987) found that the immune system of coho salmon was impaired during smoltification. Therefore, we postulate that the effects of stress due to osmoregulation in the saltwater environment may have

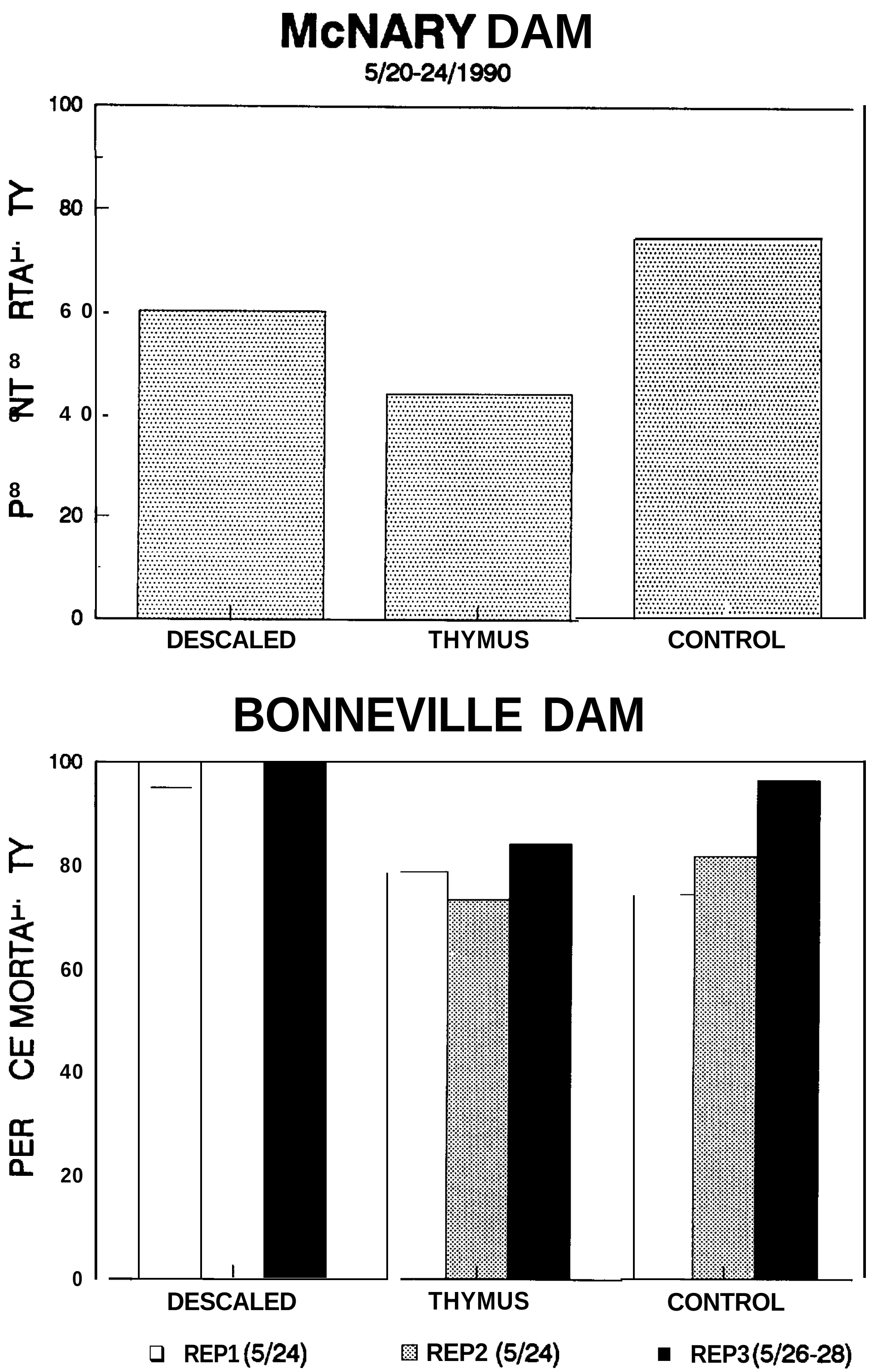

Figure 13. Percent mortality of two treatment (descaled, thymus) and one control group of juvenile spring chinook salmon after 6 months of seawater rearing.

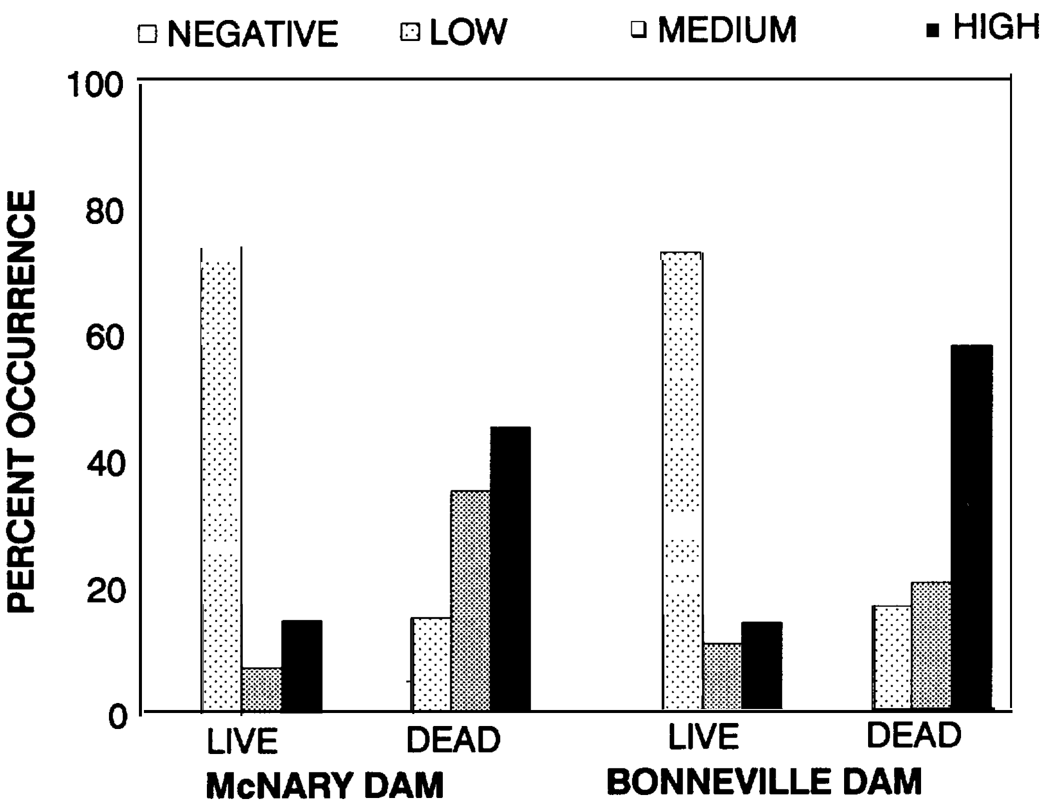

Figure 14. Percent occurrence of live and dead juvenile spring chinook salmon in one of four categories of BKD infection based on ELISA results after 6 months of seawater rearing, 1990.

adversely affected the ability of the more smolted migrant fish to fight infection. In addition, there may have been latent effects from the stresses incurred during transportation. Since most fish had BKD prior to the experiment, albeit low levels, the cumulative stresses endured by' these fish may have overcome their immune systems, allowing BKD to proliferate in the migrants.

The migration-at-large trials indicate that the factors we used to discriminate between groups have no affect on seawater survival. Analyses of kidney and spleen samples suggest mortality was from BKD.

Descaling was thought to be a good criterion of smolt survival in seawater since scale loss should affect ion balance. Preliminary lab experiments conducted with artificially descaled fish indicated that descaling would affect seawater survival but mortalities of groups descaled less than 50% of the body area'were similar to controls (Rondorf et al., unpublished data). Results of the 1990 seawater trials support this finding in that fish with scale loss satisfying FTOT descaling criteria ("If cumulative scale loss equals or exceeds 40% of two body sections...") had mortality similar to control fish with little or no scale loss. It should be noted, however, that a small number of highly descaled fish died prior to transportation to MFS.

Hemorrhage of the thymus gland has been interpreted as a result of exposure to some type of stressor, and is sometimes more prevalent during smoltification (Novotny and Beeman 1990). Hemorrhages of the thymus gland are thought to be the result of stress, although the exact meaning of a hemorrhaged thymus gland is not known. It was chosen as a criterion because it appeared to be common in migrants and can be examined with little or no harm to the fish. Our results indicate no affect on seawater survival based on hemorrhages of the thymus gland.

Summary

1) There was no difference in seawater survival based on rearing treatments at Leavenworth NFH.

2) Migrants had significantly higher seawater mortality than non-migrants. This may be due to increased sensitivity to stressors during smoltification.

3) There was no difference in seawater mortality due to descaling or hemorrhage of the thymus gland. However, seawater mortality appeared to be affected by site, as fish collected at McNary Dam had lower mortality than those collected at Bonneville Dam.

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APPENDIX A

SMOLTIFICATION DATA FROM MARKED HATCHERY GROUPS

Appendix Al. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Dworshak NFH (RA-7U-1/3 and LD-7U-1 brand groups) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Granite and McNary dams. Fish were released from the hatchery on April 5, 1990.

	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/07	9.08	1.81	19.90	0.34	29	5.77	4.27	74.00	1.10	15	1.10	0.06	5.56	0.01	30
3/29	9.19	2.15	23.42	0.42	26	7.09	5.14	72.51	1.33	15	1.06	0.06	5.88	0.01	30
4/03	9.31	2.96	31.77	0.54	30	10.70	8.65	80.84	2.23	15	1.12	0.07	6.12	0.01	60
sample site = Lower Granite Dam															
4/23	22.56	7.31	32.84	1.72	18	12.54	15.08	120.31	5.33	8	0.94	0.64	6.82	0.01	18
5/01	34.14	11.13	32.62	2.62	18	12.30	11.88	96.56	4.20	8	0.91	0.06	6.37	0.01	18
5/15	39.28	5.35	13.63	1.78	9	14.95	21.15	141.52	8.64	6	0.89	0.05	5.33	0.01	11
sample site = McNary Dam															
5/10	45.85	12.09	26.37	2.64	21	4.83	1.54	31.90	0.44	12	0.85	0.05	5.75	0.01	22
5/15	41.44	12.86	31.04	2.95	19	4.78	5.03	105.19	1.59	10	0.84	0.07	8.80	0.02	20
5/23	47.04	10.22	21.73	2.18	22	5.30	3.26	61.46	0.94	12	0.84	0.05	5.99	0.01	22

Appendix A2. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery steelhead from Dworshak NFH (HA-Z-l brand group) sampled for gill $Na^{+}-K^{+}$ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Granite dam. Fish were released from the hatchery on May 4, 1990.

	$Na^{+}-K^{+}$ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
4/03	7.09	2.13	30.00	0.53	16	5.45	3.18	58.31	1.06	9	1.04	0.06	6.10	0.01	20
4/17	6.67	3.12	46.86	0.74	18	8.59	5.80	67.53	1.83	10	0.97	0.23	24.14	0.05	20
5/01	8.21	3.58	43.54	0.65	30	6.20	2.98	48.15	0.77	15	0.98	0.06	6.13	0.01	30
sample site = Lower Granite Dam															
5/08	14.31	4.64	32.43	1.04	20	35.07	21.25	60.57	7.08	9	0.91	0.04	5.00	0.01	20
5/10	17.47	5.19	29.70	1.16	20	16.67	20.56	123.36	6.50	10	0.90	0.06	6.66	0.01	20
5/14	15.97	4.72	29.55	1.05	20	20.63	20.85	101.05	6.95	9	0.86	0.05	6.02	0.01	20

Appendix A3. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Entiat NFH (RA-7N-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg $prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork $length^3$)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Rock Island and McNary dams. Fish were released from the hatchery on April 19, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/22	9.75	1.69	17.35	0.39	19	7.67	3.05	39.74	0.96	10	1.08	0.06	5.58	0.01	20
4/03	10.58	1.85	17.50	0.41	20	3.72	2.87	77.00	1.01	8	1.03	0.09	8.69	0.02	20
4/18	7.22	2.44	33.84	0.63	15	4.76	4.02	84.40	1.21	11	1.04	0.07	6.78	0.01	70
sample site = Rock Island Dam															
4/23	10.46	4.12	39.42	1.46	8	6.10	4.74	77.71	1.94	6	1.00	0.05	5.21	0.02	9
4/24	11.75	5.42	46.15	1.81	9	6.04	3.27	54.17	1.34	6	0.99	0.06	6.17	0.02	10
4/29	16.79	3.46	20.61	1.31	7	22.82	17.82	78.10	8.91	4	0.98	0.05	5.30	0.02	7
sample site = McNary Dam															
5/05	30.94	4.13	13.36	0.95	19	5.01	2.36	47.01	0.74	10	0.94	0.05	4.92	0.01	20
5/09	36.50	10.14	27.79	2.33	19	6.15	4.35	70.74	1.38	10	0.92	0.04	3.90	0.01	20
5/14	37.74	8.61	22.82	2.15	16	3.70	4.40	118.92	1.80	6	0.92	0.04	4.09	0.01	30

Appendix A4. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery steelhead from Irrigon SFH (LD/RD-A-4 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Granite and McNary dams. Fish were released into Wildcat Creek on April 26, 1990.

SAMPLE DATE	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/27	8.03	1.99	24.82	0.51	15	4.04	1.63	40.27	0.54	9	1.10	0.67	6.01	0.01	20
4/10	8.00	2.45	30.67	0.56	19	6.86	3.72	54.28	1.24	9	1.09	0.07	6.13	0.01	20
4/23	10.24	5.98	58.44	1.45	17	7.54	6.42	85.13	1.93	11	1.03	0.06	5.71	0.01	20
sample site = Lower Granite Dam															
5/03	14.40	3.52	24.44	0.79	20	33.43	12.44	37.21	3.93	10	0.96	0.06	6.36	0.01	20
5/07	15.98	4.24	26.54	0.95	20	28.92	15.25	52.73	5.39	8	0.95	0.07	7.11	0.02	20
5/16	18.67	6.62	35.43	1.52	19	21.01	13.46	64.07	3.88	12	0.88	0.05	5.32	0.01	20
sample site = McNary Dam															
6/01	25.96	16.41	63.22	6.70	6	6.66	2.88	43.28	1.18	6	0.79	0.04	5.65	0.02	8

Appendix A5. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample'size (N) of hatchery spring chinook salmon from Leavenworth NFH (LA-7T-1/3 and RD-7T-1 brand groups) sampled for gill Na^+-K^+ ATPase activity (μmoles P_i·mg prot^{-1}·hr^{-1}), thyroxine (ng·ml^{-1}), and condition factor (K = weight / (fork length^3)·10^5). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Rock Island and McNary dams. Fish were released from the hatchery on April 18, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/22	11.43	3.14	27.49	0.70	20	9.83	5.02	51.13	1.59	10	1.08	0.07	6.75	0.02	20
4/03	13.81	2.68	19.44	0.60	20	5.19	3.21	61.82	1.07	9	1.06	0.08	7.45	0.02	20
4/17	10.06	2.73	27.19	0.64	18	7.35	6.52	88.72	2.06	10	1.08	0.06	5.13	0.01	60
sample site = Rock Island Dam															
4/23	12.02	5.27	43.85	1.67	10	12.02	6.59	54.85	3.81	3	1.01	0.06	6.28	0.02	10
4/29	18.58	5.70	30.67	1.31	19	27.37	27.93	102.05	9.87	8	0.97	0.06	6.56	0.01	20
5/06	24.81	5.44	21.95	1.41	15	14.13	5.25	37.13	1.98	7	0.95	0.04	4.31	0.01	15
sample site = McNary Dam															
5/14	41.35	6.37	15.40	1.54	17	6.78	5.00	73.78	1.51	11	0.90	0.04	4.22	0.01	30
5/19	40.80	11.28	27.65	2.59	19	7.06	2.82	39.96	0.85	11	0.88	0.04	4.52	0.01	43

Appendix A6. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of yearling fall chinook salmon from Lyons Ferry SFH (RA-UL-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^{-3}) $\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Monumental and McNary dams. Fish were released from the hatchery on July 10, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
5/08	23.43	10.61	45.29	2.43	19	3.90	2.17	55.66	0.72	9	1.05	0.07	6.80	0.02	20
5/23	21.04	9.70	46.08	2.28	18	3.84	1.24	32.41	0.42	9	1.02	0.05	4.54	0.01	20
6/06	35.06	11.54	32.92	2.58	20	2.50	1.27	50.73	0.40	10	1.02	0.04	3.91	0.01	20
sample site = Lower Monumental Dam															
6/08	38.20	12.60	33.00	3.64	12	10.67	7.04	65.98	2.87	6	1.00	0.05	5.20	0.01	12
sample site = McNary Dam															
6/27	39.47	7.14	18.09	2.15	11	2.53	0.84	33.03	0.32	7	0.97	0.04	4.70	0.01	13
7/02	42.90	6.99	16.30	1.34	27	3.29	1.81	54.92	0.50	13	0.95	0.05	5.70	0.01	27
7/09	46.41	8.22	17.72	2.12	15	3.66	1.84	50.36	0.65	8	1.00	0.05	5.30	0.01	16

Appendix A7. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of summer chinook salmon from McCall SFH (LD-T-1/2/3/4 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^{3})$\cdot 10^{5}$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Granite and McNary dams. Fish were released into the South Fork of the Salmon River on March 23, 1990.

SAMPLE DATE	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
2/21	7.70	2.13	27.67	0.48	20	3.52	1.39	39.57	0.44	10	-	-	-	-	--
3/08	9.76	2.72	27.86	0.61	20	10.94	22.51	205.66	7.12	10	-	-	-	-	--
3/20	10.23	8.71	85.14	2.00	19	11.79	9.56	81.05	3.02	10	1.08	0.06	5.24	0.01	60
sample site = Lower Granite Dam															
5/24	46.60	8.90	19.10	2.97	9	13.25	5.90	44.50	3.40	3	0.91	0.05	5.56	0.01	14
5/31	38.31	3.16	8.26	1.42	5	13.90	6.61	47.58	4.68	2	0.92	0.04	4.16	0.02	5
sample site = McNary Dam															
5/23	45.19	8.84	19.58	2.14	17	4.04	1.62	40.05	0.61	7	0.87	0.04	4.82	0.01	18
5/31	50.36	10.33	20.51	2.50	17	8.11	5.82	71.70	2.06	8	0.88	0.04	4.56	0.01	17

Appendix A8. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of fall chinook salmon from Priest Rapids SFH (RA-H-1 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg$ $prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork $length^{3}$) $\cdot 10^{5}$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past McNary Dam. Fish were released from the hatchery on June 7, 1990.

	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
5/10	9.91	3.34	33.74	0.81	17	1.54	0.65	42.01	0.22	9	1.05	0.06	6.20	0.01	20
5/22	16.76	5.94	35.45	1.33	20	4.70	1.58	33.62	0.50	10	1.08	0.08	7.28	0.02	20
6/06	23.95	8.70	36.33	2.00	19	4.73	3.73	78.86	1.18	10	1.00	0.04	4.49	0.01	20
sample site = McNary Dam															
6/15	31.10	6.36	20.44	1.42	20	5.09	2.88	56.46	0.91	10	0.92	0.05	5.85	0.01	20
6/21	33.63	7.25	21.57	1.71	18	6.78	2.82	41.57	0.89	10	0.89	0.03	3.59	0.01	20
6/25	39.74	6.91	17.40	1.51	21	4.81	2.82	58.62	0.89	10	0.91	0.05	5.25	0.01	21

Appendix A9. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of fall chinook salmon from Priest Rapids SFH (RA-H-2 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^3) $\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past McNary Dam. Fish were released from the hatchery on June 10, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
6/06	17.95	7.09	39.52	1.63	19	3.47	1.29	37.17	0.41	10	1.02	0.06	6.02	0.01	20
sample site = McNary Dam															
6/19	23.09	5.62	24.34	1.32	18	6.33	3.15	49.78	0.95	11	0.93	0.04	4.43	0.01	20
6/22	29.43	6.38	21.68	1.65	15	4.27	1.63	38.24	0.54	9	0.92	0.06	6.54	0.01	18
6/26	31.81	9.52	29.91	2.54	14	2.58	1.01	39.12	0.38	7	0.90	0.04	4.56	0.01	14

Appendix A10. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of fall chinook salmon from Priest Rapids SFH (RD-H-1 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past McNary Dam. Fish were released from the hatchery on June 13, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
5/10	13.98	3.48	24.95	0.87	16	1.26	0.25	20.08	0.08	9	0.99	0.05	5.25	0.01	20
5/22	15.15	5.24	34.59	1.17	20	4.35	2.06	47.26	0.65	10	1.01	0.09	9.35	0.02	20
6/18	16.26	6.43	39.54	1.56	17	3.47	1.45	41.82	0.48	9	0.98	0.06	6.42	0.01	20
sample site = McNary Dam															
6/22	22.61	6.04	26.74	1.91	10	3.94	1.58	40.13	0.64	6	0.89	0.04	4.58	0.01	12
6/26	29.72	4.57	15.38	1.11	17	2.44	0.67	27.46	0.24	8	0.89	0.03	3.92	0.01	17

Appendix A11. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of fall chinook salmon from Priest Rapids SFH (RA-UP-3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^{3})$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past McNary Dam. Fish were released from the hatchery on June 16, 1990.

SAMPLE DATE	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N	Condition Factor (K) X	SD	CV	SE	N
sample site = Hatchery															
6/13	15.86	5.13	32.36	1.18	19	3.68	1.69	45.89	0.53	10	0.93	0.06	6.16	0.01	20
sample site = McNary Dam															
6/25	30.02	5.43	18.11	1.22	20	2.52	1.48	54.75	0.44	10	0.94	0.04	3.77	0.01	20
6/27	35.78	7.33	20.48	1.73	18	2.66	0.65	24.52	0.21	10	0.92	0.05	5.60	0.01	20
6/29	36.56	7.02	19.20	1.61	19	2.43	0.84	34.34	0.26	10	0.90	0.04	4.59	0.01	20

Appendix A12. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of fall chinook salmon from Priest Rapids SFH (RA-UP-1 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg $prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork $length^{-3}$)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past McNary Dam. Fish were released from the hatchery on June 19, 1990.

SAMPLE DATE	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N	Condition Factor (K) X	SD	CV	SE	N
sample site = Hatchery															
5/10	13.33	4.31	32.33	1.02	18	1.61	0.53	32.67	0.17	9	1.03	0.08	7.85	0.02	20
5/22	16.64	3.87	23.28	0.91	18	6.80	2.11	31.06	0.70	9	0.99	0.36	36.38	0.08	19
6/13	18.06	5.05	27.96	1.13	20	2.89	0.84	28.96	0.28	9	1.01	0.07	6.61	0.01	20
sample site = McNary Dam															
6/27	32.92	7.84	23.82	1.75	20	3.28	1.57	47.86	0.52	9	0.92	0.03	3.68	0.01	20
6/29	33.23	7.25	21.83	1.62	20	3.26	1.24	37.94	0.39	10	0.93	0.04	4.11	0.01	20
7/02	34.84	6.98	20.05	1.56	20	2.29	1.37	59.84	0.46	9	0.93	0.04	4.63	0.01	20

Appendix A13. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Rapid River SFH (RA-T-1/2/3 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles P_i ■ mg $prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork $length^{-3}$)$\cdot 10^{5}$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Granite and McNary dams. Fish were released from the hatchery on March 26, 1990.

	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
2/21	7.22	1.26	17.48	0.28	20	4.30	3.74	86.95	1.18	10	1.09	0.06	5.38	0.01	20
3/08	10.08	4.21	41.80	0.94	20	12.08	11.94	98.85	3.77	10	-	-	-	-	--
3/19	8.96	3.57	39.79	0.82	19	8.64	7.84	90.78	2.77	8	1.06	0.04	4.11	0.00	60
sample site = Lower Granite Dam															
4/16	20.42	7.36	36.04	1.73	18	23.83	22.06	92.58	6.37	12	0.95	0.04	4.21	0.01	20
4/23	25.90	9.76	37.70	2.18	20	15.03	12.32	81.93	3.71	11	0.92	0.05	5.41	0.01	20
4/27	33.02	6.03	18.25	1.35	20	9.18	5.31	57.90	1.68	10	0.93	0.05	4.98	0.01	20
sample site = McNary Dam															
4/30	48.98	7.11	14.52	1.59	20	5.54	5.07	91.51	1.60	10	0.85	0.04	4.27	0.01	20
5/06	48.96	9.88	20.17	2.40	17	5.68	3.83	67.56	1.45	7	0.83	0.04	4.67	0.01	17

Appendix A14. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Ringold SFH (LA-7S-1/3 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past McNary dam. Fish were released from the hatchery on April 4, 1990.

	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/01	19.54	6.65	34.02	1.49	20	8.07	5.70	70.70	1.90	9	-	-	-	-	--
3/13	14.68	6.86	46.77	1.57	19	6.88	5.39	78.37	1.80	9	1.06	0.26	24.42	0.06	20
4/02	16.51	7.66	46.43	1.71	20	3.83	4.22	109.97	1.33	10	1.08	0.05	4.39	0.01	20
sample site = McNary Dam															
4/06	16.40	5.30	32.32	1.18	20	9.28	4.40	47.45	1.39	10	1.02	0.04	3.84	0.01	20
4/09	15.50	6.64	42.86	1.45	21	14.60	8.66	59.31	3.06	8	0.99	0.04	4.34	0.01	21
4/13	14.76	5.69	38.57	1.31	19	10.95	7.83	71.52	2.48	10	0.97	0.06	5.80	0.01	20

Appendix A15. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery spring chinook salmon from Sawtooth SFH (LA-T-1/2/3/4 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork $length^3$)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Lower Granite and McNary dams. Fish were released from the hatchery on March 21, 1990.

	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
2/14	8.47	1.32	15.65	0.30	20	3.20	1.83	57.30	0.58	10	1.07	0.06	5.91	0.01	20
2/28	9.44	2.58	27.30	0.61	18	6.29	5.90	93.82	1.87	10	1.06	0.08	7.94	0.02	20
3/14	7.05	1.80	25.53	0.46	15	5.89	5.14	95.42	1.62	10	1.09	0.05	4.80	0.01	60
sample site = Lower Granite Dam															
4/18	27.11	7.21	26.59	1.86	15	16.92	15.51	91.66	6.33	6	0.96	0.06	6.55	0.02	17
4/28	28.68	8.55	29.81	2.07	17	26.45	28.49	107.70	10.77	7	0.94	0.05	5.65	0.01	17
sample site = McNary Dam															
5/01	49.30	6.73	13.66	1.63	17	4.31	3.13	72.63	1.11	8	0.86	0.08	9.64	0.02	18
5/04	44.22	11.62	26.28	3.22	13	5.38	5.33	99.20	1.89	8	0.84	0.04	4.42	0.01	15
5/12	40.02	10.59	26.46	3.19	11	2.01	1.85	92.37	0.93	4	0.81	0.06	8.06	0.02	11

Appendix A16. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery steelhead from Wells SFH (LD-7H-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg $prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor (K = weight / (fork $length^3$)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Rock Island and McNary dams. Fish were released into the Similkameen River on April 26, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/21	8.38	2.97	35.43	0.68	19	7.20	7.91	109.75	2.50	10	1.04	0.06	5.31	0.01	19
4/04	9.01	1.31	14.52	0.29	20	3.90	2.07	53.24	0.78	7	1.05	0.06	5.89	0.01	20
4/23	9.52	3.35	35.18	0.79	19	5.97	4.15	69.57	1.31	10	0.94	0.06	5.87	0.01	20
sample site = Rock Island Dam															
5/06	19.07	4.24	22.24	0.95	20	6.27	3.22	51.43	1.22	7	0.86	0.05	5.91	0.01	20
5/14	23.58	5.95	25.25	1.33	20	3.70	2.55	68.92	0.80	10	0.81	0.04	5.09	0.01	20
sample site = McNary Dam															
5/11	29.77	6.76	22.72	1.59	18	3.99	1.91	47.85	0.55	12	0.79	0.07	8.80	0.02	20
5/17	38.22	8.71	22.79	2.11	17	2.26	1.15	51.12	0.38	9	0.77	0.05	6.44	0.01	20
5/19	37.02	11.72	31.68	2.84	17	2.72	1.46	53.75	0.49	9	0.77	0.03	4.48	0.01	20

Appendix A17. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery steelhead from Wells SFH (RA-7H-1/3 brand group) sampled for gill Na+-K+ ATPase activity (μmoles $P_i \cdot$mg prot$^{-1} \cdot$hr^{-1}), thyroxine (ng$\cdot$ml^{-1}), and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Rock Island and McNary dams. Fish were released into the Methow River on April 28, 1990.

	Na^+-K^+ ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/21	8.38	2.97	35.43	0.68	19	7.20	7.91	109.75	2.50	10	1.04	0.06	5.31	0.01	19
4/04	9.01	1.31	14.52	0.29	20	3.90	2.07	53.24	0.78	7	1.05	0.06	5.89	0.01	20
4/25	9.20	3.65	39.65	0.82	20	4.43	2.00	45.13	0.63	10	0.92	0.04	4.36	0.01	20
sample site = Rock Island Dam															
5/03	12.95	4.86	37.56	1.26	15	25.64	27.25	106.31	9.08	9	0.87	0.05	5.42	0.01	15
5/08	12.57	2.13	16.94	0.67	10	12.72	8.77	69.00	3.92	5	0.85	0.04	4.28	0.01	10
5/15	17.48	7.72	44.17	1.72	20	3.67	1.52	41.47	0.46	11	0.82	0.08	9.59	0.02	20
sample site = McNary Dam															
5/12	27.02	5.11	18.90	1.36	14	4.60	4.32	94.01	1.53	8	0.82	0.05	5.83	0.01	16
5/26	36.88	10.73	29.08	2.89	22	2.79	1.11	39.83	0.39	a	0.77	0.04	5.63	0.01	24

Appendix A18. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Winthrop NFH (RA-7C-1/3 and LD-7C-1 brand groups) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$), thyroxine ($ng \cdot ml^{-1}$), and condition factor ($K = weight / (fork\ length^3) \cdot 10^5$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release, and again at the early, middle, and late portions of the migrations past Rock Island and McNary dams. Fish were released from the hatchery on April 17, 1990.

	Na^{+}-K^{+} ATPase					Thyroxine					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery															
3/21	9.74	2.60	26.74	0.48	29	4.78	2.04	42.62	0.54	14	1.13	0.05	4.45	0.01	30
4/04	10.98	3.30	30.11	0.61	29	4.66	4.53	97.09	1.31	12	1.09	0.05	4.81	0.01	30
4/16	8.11	3.20	39.42	0.67	23	7.52	5.15	68.48	1.33	15	1.09	0.05	4.68	0.01	60
sample site = Rock Island Dam															
5/15	32.31	4.92	15.23	2.01	6	6.74	1.90	28.24	1.34	2	0.92	0.03	3.43	0.01	6
sample site = McNary Dam															
5/15	37.18	8.02	21.56	1.79	20	6.36	2.84	44.60	0.94	9	0.90	0.05	5.91	0.01	21
5/18	40.47	6.70	16.55	1.24	29	4.87	2.05	42.08	0.57	13	0.87	0.06	6.56	0.01	56
5/25	40.23	8.69	21.60	1.64	28	7.31	3.22	44.03	0.80	16	0.88	0.04	4.16	0.00	42

APPENDIX B

SMOLTIFICATION DATA FROM MIGRATION-AT-LARGE GROUPS

Appendix B1. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from the migration-at-large sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg prot$^{-1} \cdot hr^{-1}$) and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected bi-weekly throughout the migrations past Rock Island and McNary dams in the Columbia River and the Clearwater and Snake river traps and Lower Granite Dam in the Snake River.

SAMPLE DATE	Na^+-K^+ ATPase					Condition Factor (K)				
	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Rock Island Dam										
4/22	12.8	4.1	32	1.67	6	0.99	0.08	8	0.02	10
4/23	14.6	2.3	16	0.88	7	1.00	0.09	9	0.03	11
4/29	18.8	6.5	35	2.06	10	0.98	0.08	9	0.03	10
4/30	17.5	7.7	44	2.33	11	0.99	0.10	10	0.03	11
5/6	25.5	6.1	24	1.84	11	0.95	0.06	6	0.02	11
5/7	27.2	9.1	33	3.03	9	0.97	0.06	6	0.02	9
5/13	32.0	7.1	22	2.38	9	0.94	0.04	4	0.01	10
5/14	34.4	9.6	28	3.04	10	0.93	0.03	3	0.01	10
5/20	40.0	14.8	37	4.69	10	0.94	0.05	6	0.02	10
5/21	38.9	10.0	26	3.16	10	0.93	0.05	5	0.01	10
sample site = McNary Dam										
4/9	17.8	8.1	45	2.55	10	1.00	0.06	6	0.02	10
4/10	15.9	5.1	32	1.55	11	1.00	0.04	4	0.01	11
4/16	16.6	4.9	29	1.47	11	1.01	0.03	3	0.01	11
4/17	24.0	9.7	40	2.92	11	0.99	0.05	5	0.01	11
4/23	33.8	7.2	21	2.95	6	0.97	0.04	4	0.01	11
4/24	24.6	12.7	52	4.01	10	0.94	0.04	4	0.01	10
4/30	28.1	10.7	38	3.38	10	0.88	0.07	8	0.02	10
5/1	41.1	13.3	32	4.20	10	0.86	0.05	6	0.02	10
5/7	31.1	5.2	17	1.66	10	0.92	0.09	10	0.03	10
5/8	32.6	10.9	33	3.45	10	0.90	0.06	7	0.02	10
5/14	42.8	10.0	23	3.18	10	0.92	0.05	6	0.02	10
5/15	43.3	12.0	28	3.79	10	0.82	0.06	8	0.02	10
5/21	47.1	12.8	27	4.04	10	0.85	0.07	8	0.02	10
5/22	40.7	6.4	16	2.02	10	0.92	0.05	5	0.02	10
5/29	38.3	11.0	29	3.48	10	0.87	0.06	8	0.02	10
5/30	42.6	4.6	11	1.47	10	0.93	0.07	8	0.02	10
6/4	37.7	12.6	34	4.47	8	0.91	0.05	6	0.02	10
6/5	50.0	14.4	29	4.57	10	0.86	0.05	6	0.02	10
6/11	36.5	16.9	46	5.36	10	0.98	0.07	7	0.02	10
6/12	45.6	12.1	26	3.82	10	0.98	0.06	6	0.02	10
sample site = Clearwater Trap										
3/30	10.9	3.8	35	0.80	23	1.05	0.05	4	0.01	23
4/5	7.9	4.0	51	1.35	9	1.11	0.05	4	0.01	11
4/6	8.5	2.9	34	0.80	13	1.07	0.06	6	0.02	16
4/12	7.7	2.4	31	0.67	13	1.01	0.03	3	0.01	14

Appendix B1. (continued)

DATE	X	SD	CV	SE	N	X	SD	CV	SE	N
------------------sample site = Clearwater Trap----------------										
4/13	13.2	4.6	34	1.32	12	1.08	0.05	4	0.01	12
4/19	6.8	2.3	34	0.93	6	1.04	0.07	6	0.02	10
4/20	9.1	3.1	35	1.19	7	0.97	0.11	12	0.04	10
4/27	16.9	5.7	34	1.65	12	1.04	0.06	6	0.02	12
5/24	17.2	4.0	23	1.27	10	1.06	0.10	10	0.03	10
5/25	21.1	4.2	20	1.33	10	1.15	0.16	14	0.05	10
-----------------sample site = Snake River Trap----------------										
4/13	13.1	4.4	34	0.99	20	1.04	0.07	7	0.02	21
4/19	16.3	8.3	51	2.78	9	1.00	0.06	6	0.02	12
4/20	17.1	7.7	45	2.56	9	1.04	0.07	7	0.02	10
4/26	24.7	6.5	26	2.06	10	1.02	0.05	5	0.02	10
4/27	25.2	8.3	33	2.63	10	1.02	0.06	6	0.02	10
5/3	23.9	8.2	34	2.60	10	0.99	0.06	6	0.02	10
5/4	22.5	8.2	36	3.08	7	1.08	0.07	6	0.02	8
5/10	27.5	8.2	30	2.59	10	1.04	0.06	6	0.02	10
5/11	21.6	7.4	34	2.12	12	1.03	0.05	5	0.02	12
5/17	31.3	7.0	22	3.48	4	1.01	0.05	5	0.03	4
6/1	29.5	6.2	21	1.48	18	1.10	0.05	4	0.01	21
6/14	22.1	8.0	36	3.28	6	1.14	0.03	3	0.01	6
-----------------sample site = Lower Granite Dam----------------										
4/12	18.9	9.0	48	2.84	10	0.98	0.05	6	0.02	10
4/13	17.1	3.8	22	1.27	9	0.93	0.16	17	0.05	10
4/19	28.6	6.6	23	2.10	10	0.94	0.04	4	0.01	10
4/20	25.8	10.0	39	3.18	10	0.93	0.04	4	0.01	10
4/26	28.2	11.8	42	3.75	10	0.98	0.08	8	0.02	10
4/27	29.6	11.4	38	3.61	10	0.91	0.05	6	0.02	10
5/3	37.2	6.8	18	2.06	11	0.92	0.06	6	0.02	11
5/4	36.1	7.6	21	2.42	10	0.90	0.04	5	0.01	10
5/10	38.4	7.4	19	2.32	10	0.94	0.04	5	0.01	10
5/11	41.6	8.9	22	2.83	10	0.92	0.07	8	0.02	10
5/17	39.0	8.2	21	2.59	10	0.90	0.06	6	0.02	10
5/18	39.0	12.0	31	3.20	14	0.92	0.07	8	0.02	14
5/24	39.4	9.6	24	3.04	10	0.94	0.04	5	0.01	10
5/25	45.4	9.8	22	3.10	10	0.92	0.06	7	0.02	10
5/31	46.1	15.9	34	5.02	10	1.00	0.05	5	0.01	10
6/1	40.8	14.8	36	4.68	10	1.00	0.05	5	0.01	10
6/7	26.7	6.7	25	2.11	10	1.01	0.08	8	0.02	10
6/8	31.1	8.6	28	2.88	9	1.03	0.06	6	0.02	9
6/14	39.2	5.4	14	1.70	10	1.04	0.04	3	0.01	10
6/15	42.8	9.2	22	2.91	10	1.04	0.05	5	0.02	10
6/21	33.5	6.9	21	2.20	10	1.05	0.03	3	0.01	10
6/22	32.3	8.1	25	2.56	10	1.04	0.04	4	0.01	9
6/28	33.3	7.0	21	2.20	10	1.04	0.03	3	0.01	10
6/29	30.8	7.2	23	2.29	10	1.05	0.07	7	0.02	10
7/6	25.4	8.6	34	2.72	10	1.06	0.05	5	0.02	10
7/7	26.7	11.7	44	3.70	10	1.06	0.08	8	0.02	10
7/12	23.2	12.8	55	4.04	10	1.10	0.04	4	0.01	10
7/13	19.9	6.5	32	2.05	10	1.08	0.10	10	0.03	10

Appendix B2. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of subyearling fall chinook salmon from the migration-at-large sampled for gill Na^+-K^+ ATPase activity (μmoles P_i·mg prot^{-1} hr^{-1}) and condition factor (K = weight / (fork length^3)·10). Samples were collected weekly throughout the migrations past Lower Monumental Dam in the Snake River and McNary, John Day, and Bonneville dams in the Columbia River.

	Na^+-K^+ ATPase					Condition Factor (K)				
SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Lower Monumental Dam										
6/10	41.2	10.3	25	2.30	20	1.01	0.06	6	0.01	20
6/17	41.8	7.6	18	1.70	20	1.00	0.07	7	0.02	20
6/24	34.6	8.5	25	1.91	20	1.00	0.06	6	0.01	20
7/1	43.1	9.1	21	2.04	20	1.02	0.06	5	0.01	20
7/22	38.6	9.0	23	2.06	19	1.18	0.07	6	0.02	20
sample site = McNary Dam										
6/11	43.8	7.2	21	2.29	10	0.94	0.04	4	0.01	10
6/12	41.4	13.5	32	4.26	10	0.99	0.04	4	0.01	10
6/18	30.8	10.2	33	2.28	20	0.94	0.07	8	0.02	20
6/25	30.6	10.6	34	2.37	20	0.93	0.05	5	0.01	20
7/2	41.8	9.8	24	2.20	20	0.92	0.06	7	0.01	20
7/9	50.1	7.5	15	1.67	20	0.95	0.04	4	0.01	20
7/16	38.5	8.1	21	1.80	20	1.06	0.06	6	0.01	20
7/23	28.0	7.8	28	1.96	16	1.08	0.05	4	0.01	20
8/1	39.1	8.9	23	1.99	20	1.06	0.04	3	0.01	20
8/8	34.4	8.7	25	1.94	20	1.13	0.08	7	0.02	20
8/15	34.2	8.2	24	1.75	22	1.15	0.06	5	0.01	22
8/22	37.8	11.8	31	2.65	20	1.05	0.05	5	0.01	20
8/29	43.0	12.4	29	2.77	20	1.08	0.07	6	0.01	20
9/12	30.8	9.6	31	2.15	20	1.08	0.05	5	0.01	20
sample site = John Day Dam										
6/11	44.7	11.3	25	2.47	21	1.02	0.08	7	0.02	21
6/18	41.5	12.0	29	2.69	20	1.01	0.05	5	0.01	20
6/25	34.7	9.6	28	2.15	20	0.99	0.06	6	0.01	20
7/2	42.0	10.3	24	2.37	19	0.99	0.05	5	0.01	20
7/9	44.6	11.8	26	2.70	19	1.07	0.06	6	0.01	20
7/16	37.4	7.5	20	1.88	16	1.07	0.09	8	0.02	17
7/23	29.1	10.9	37	2.50	19	1.09	0.06	5	0.01	20
7/30	34.5	11.6	34	2.52	21	1.13	0.07	6	0.02	21
8/6	35.1	9.9	28	2.22	20	1.15	0.05	4	0.01	20
8/12	29.3	9.4	32	2.11	20	1.09	0.08	7	0.02	20
8/20	28.2	8.2	29	1.84	20	1.13	0.08	7	0.02	20
8/27	36.0	12.3	34	2.76	20	1.13	0.11	10	0.02	20
9/10	20.3	5.1	25	2.07	6	1.15	0.11	9	0.04	6

Appendix B2. (continued)

SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N
----------sample site = Bonneville Dam----------										
7/15	41.2	12.4	30	2.86	19	1.10	0.08	7	0.02	20
7/29	37.4	8.8	24	1.97	20	1.07	0.07	6	0.01	20
8/5	38.9	10.1	26	2.31	19	1.09	0.06	5	0.01	20
8/13	31.2	9.7	31	2.18	20	1.11	0.06	5	0.01	20
8/19	32.8	12.3	37	2.75	20	1.05	0.07	7	0.02	20
8/26	22.1	12.5	57	2.80	20	1.16	0.06	5	0.01	20
9/9	20.1	9.1	45	2.14	18	1.04	0.10	9	0.02	18
9/24	18.8	9.3	50	2.69	12	1.03	0.10	9	0.03	13

Appendix B3. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery steelhead from the migration-at-large sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected bi-weekly throughout the migrations past Rock Island and McNary dams in the Columbia River and the Snake River Trap and Lower Granite Dam in the Snake River.

SAMPLE DATE	Na^+-K^+ ATPase X	SD	CV	SE	N	Condition Factor (K) X	SD	CV	SE	N
sample site = Rock Island Dam										
4/29	16.8	7.4	44	2.15	12	0.88	0.08	9	0.02	12
4/30	18.4	9.6	52	2.89	11	0.86	0.06	7	0.02	11
5/6	16.7	4.5	27	1.84	6	0.87	0.04	5	0.02	6
5/7	18.2	6.6	36	1.77	14	0.86	0.04	5	0.01	14
5/13	19.4	8.6	45	2.88	9	0.81	0.04	5	0.01	9
5/14	22.9	10.5	46	3.17	11	0.84	0.05	6	0.02	11
5/20	20.7	6.4	31	2.01	10	0.80	0.04	5	0.01	10
5/21	23.8	7.2	30	2.28	10	0.83	0.07	9	0.02	10
sample site = McNary Dam										
4/30	27.6	5.5	20	2.24	6	0.83	0.05	6	0.02	6
5/1	21.7	7.3	34	1.88	15	0.83	0.06	7	0.01	15
5/7	24.5	6.5	26	2.05	10	0.84	0.05	6	0.02	10
5/8	31.4	7.9	25	2.49	10	0.80	0.04	5	0.01	10
5/14	28.5	6.2	22	1.88	11	0.82	0.03	4	0.01	11
5/15	30.5	7.2	24	2.27	10	0.77	0.03	4	0.01	10
5/21	34.5	13.7	40	4.32	10	0.79	0.04	5	0.01	10
5/22	28.5	6.8	24	3.05	5	0.79	0.06	8	0.03	5
5/23	27.5	6.5	24	2.92	5	0.81	0.03	4	0.01	5
5/29	35.5	12.6	36	4.00	10	0.76	0.04	5	0.01	9
5/30	32.9	9.1	28	2.88	10	0.78	0.07	8	0.02	10
6/4	22.9	5.5	24	1.84	9	0.76	0.09	12	0.03	10
6/5	33.0	9.2	28	2.91	10	0.77	0.04	5	0.01	10
6/11	38.8	15.9	41	5.04	10	0.83	0.10	12	0.03	10
6/12	28.4	8.5	30	2.82	9	0.79	0.04	6	0.02	9
6/18	31.7	10.9	34	3.29	11	0.84	0.04	5	0.01	11
6/19	31.7	7.7	24	2.57	9	0.82	0.08	9	0.02	9
sample site = Snake River Trap										
4/19	10.7	5.1	47	1.69	9	0.96	0.09	9	0.03	10
4/20	12.5	7.1	57	2.24	10	0.95	0.05	5	0.02	10
4/26	13.7	3.9	28	1.22	10	0.94	0.04	4	0.01	10
4/27	12.3	4.5	37	1.52	9	0.93	0.05	5	0.02	9
5/2	14.2	7.3	51	1.20	37	0.90	0.05	6	0.01	40
5/3	12.6	8.3	66	2.63	10	0.97	0.07	7	0.02	10
5/4	13.5	3.7	28	1.18	10	0.95	0.06	6	0.02	10
5/9	20.3	7.1	35	1.15	38	0.86	0.05	6	0.01	40

Appendix B3. (continued)

SAMPLE DATE	X	SD	CV	SE	N	X	SD	CV	SE	N
-----sample site = Snake River Trap-----										
5/10	17.8	5.0	28	1.59	10	0.91	0.04	5	0.01	10
5/11	15.8	7.2	46	2.28	10	0.90	0.06	7	0.02	10
5/17	19.4	8.1	41	2.55	10	0.92	0.06	7	0.02	10
5/18	20.4	4.5	22	1.51	9	0.89	0.05	6	0.02	10
5/24	20.7	8.5	41	3.81	5	0.87	0.06	6	0.02	5
5/25	22.8	8.7	38	2.33	14	0.85	0.04	5	0.01	14
6/1	19.9	4.6	23	1.13	17	0.82	0.05	6	0.01	18
6/7	24.6	5.3	22	1.67	10	0.86	0.05	6	0.02	10
6/8	25.5	10.0	39	3.15	10	0.82	0.08	9	0.02	10
6/14	21.5	9.2	43	3.77	6	0.86	0.07	8	0.03	6
6/15	22.0	5.1	23	1.81	8	0.86	0.06	7	0.02	8
-----sample site = Lower Granite Dam-----										
4/19	12.6	4.4	34	1.38	10	0.96	0.05	5	0.01	10
4/20	12.9	4.7	36	1.48	10	0.93	0.04	4	0.01	10
4/26	18.8	8.8	47	2.66	11	0.84	0.12	14	0.04	11
4/27	17.4	6.3	36	1.90	11	0.90	0.07	8	0.02	11
5/3	18.4	5.2	28	1.66	10	0.88	0.05	6	0.02	10
5/4	17.6	7.3	42	2.31	10	0.90	0.06	7	0.02	10
5/10	19.2	3.6	19	1.14	10	0.87	0.05	6	0.02	10
5/11	19.8	7.4	38	2.35	10	0.83	0.05	7	0.02	10
5/17	20.9	8.1	39	2.45	11	0.85	0.02	3	0.01	11
5/18	23.1	8.3	36	2.63	10	0.84	0.05	6	0.02	10
5/24	23.5	10.7	45	3.37	10	0.74	0.09	12	0.03	10
5/25	22.2	3.0	14	1.37	5	0.78	0.06	8	0.02	11
5/31	23.8	8.8	37	2.77	10	0.81	0.06	7	0.02	10
6/1	22.1	3.9	18	1.24	10	0.78	0.06	7	0.02	10
6/7	27.0	6.5	24	2.05	10	0.83	0.05	6	0.01	11
6/8	24.6	4.5	18	1.43	10	0.84	0.04	5	0.01	10
6/14	26.8	11.0	41	3.49	10	0.82	0.04	5	0.01	10
6/15	26.4	6.0	22	1.88	10	0.85	0.06	7	0.02	10
6/21	24.5	10.3	42	3.24	10	0.87	0.09	11	0.03	10
6/22	26.4	5.4	20	1.71	10	0.82	0.05	6	0.02	10
6/28	20.4	6.8	33	2.14	10	0.81	0.04	5	0.01	10
6/29	20.5	4.1	20	1.31	10	0.84	0.07	8	0.02	10
7/6	10.0	4.6	46	1.46	10	0.79	0.05	6	0.02	10
7/7	12.4	7.4	60	2.63	8	0.81	0.05	6	0.02	9
7/12	8.5	2.5	29	0.78	10	0.82	0.06	8	0.02	10
7/13	9.0	4.2	47	1.42	9	0.81	0.04	5	0.01	10

Appendix B4. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of wild steelhead from the migration-at-large sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and condition factor (K = weight / (fork length^3)$\cdot 10^5$). Samples were collected bi-weekly throughout the migrations past Rock Island and McNary dams in the Columbia River and the Snake River Trap and Lower Granite Dam in the Snake River.

SAMPLE	Na^{+}-K^{+} ATPase					Condition Factor (K)				
DATE	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Rock Island Dam										
4/30	20.0	11.2	56	3.96	8	0.83	0.03	4	0.01	8
5/1	20.8	7.2	35	1.99	13	0.86	0.10	12	0.03	13
5/6	28.5	5.3	19	1.69	10	0.85	0.06	8	0.02	10
5/7	24.8	9.0	36	2.71	11	0.85	0.04	5	0.01	11
5/13	26.5	8.4	32	2.52	11	0.86	0.08	9	0.02	11
5/14	26.8	9.3	35	3.11	9	0.85	0.06	7	0.02	10
5/20	33.9	10.9	32	2.37	21	0.88	0.06	7	0.01	21
sample site = McNary Dam										
4/30	28.7	20.1	70	7.11	8	0.92	0.12	13	0.04	8
5/1	27.0	9.4	35	2.71	12	0.84	0.09	11	0.03	12
5/7	34.6	8.4	24	2.54	11	0.85	0.09	10	0.03	11
5/8	28.3	8.8	31	2.79	10	0.82	0.06	8	0.02	10
5/14	38.5	8.6	22	2.73	10	0.81	0.09	11	0.03	10
5/15	45.5	8.8	19	2.79	10	0.77	0.05	7	0.02	10
5/21	42.2	15.6	37	5.52	8	0.84	0.05	6	0.02	8
5/22	34.3	9.0	26	2.60	12	0.85	0.05	6	0.01	12
5/29	36.9	11.6	32	3.68	10	0.84	0.08	9	0.02	10
5/30	36.5	10.5	29	3.31	10	0.84	0.04	5	0.01	10
6/4	31.1	10.2	33	3.23	10	0.80	0.08	10	0.02	10
6/5	40.6	9.7	24	3.06	10	0.86	0.07	8	0.02	10
6/11	34.2	15.4	45	6.29	6	0.91	0.06	7	0.02	6
6/12	37.9	13.5	36	3.89	12	0.87	0.06	7	0.02	12
sample site = Snake River Trap										
4/19	21.4	15.4	72	5.44	8	0.90	0.04	5	0.01	10
4/20	20.8	6.6	32	1.98	11	0.90	0.06	6	0.02	11
4/26	23.0	5.3	23	1.69	10	0.90	0.09	10	0.03	10
4/27	23.8	5.2	22	1.55	11	0.89	0.09	10	0.03	11
5/3	17.1	6.3	37	1.81	12	0.95	0.05	6	0.02	12
5/4	23.6	6.3	27	2.39	7	1.00	0.07	7	0.02	8
5/10	19.0	3.5	18	1.12	10	0.91	0.08	9	0.02	10
5/11	23.2	7.8	34	2.59	9	0.93	0.08	8	0.02	9
5/17	21.9	3.9	18	1.22	10	0.98	0.07	7	0.02	10
5/18	23.7	5.4	23	1.80	9	0.96	0.06	6	0.02	10
5/24	23.8	5.2	22	1.64	10	0.92	0.08	9	0.03	10
5/25	21.2	5.6	26	1.78	10	0.92	0.07	8	0.02	10
6/1	24.8	10.6	42	2.36	20	0.95	0.08	8	0.02	21

Appendix B4. (continued)

SAMPLE DATE	X̄	SD	CV	SE	N	X	SD	CV	SE	N
------------------sample site = Lower Granite Dam------------------										
4/19	16.7	5.7	34	1.64	12	0.86	0.05	6	0.02	12
4/20	16.0	6.9	43	2.08	11	0.86	0.04	4	0.01	11
4/26	19.1	7.8	41	2.47	10	0.87	0.07	8	0.02	10
4/27	22.2	10.3	46	3.26	10	0.87	0.04	4	0.01	10
5/3	22.6	8.2	36	2.58	10	0.87	0.05	6	0.02	10
5/4	25.0	5.7	23	1.81	10	0.89	0.05	6	0.02	10
5/10	28.1	4.5	16	1.41	10	0.85	0.03	4	0.01	10
5/11	22.0	4.1	19	1.30	10	0.88	0.04	5	0.01	10
5/17	28.3	8.9	32	2.23	16	0.85	0.06	6	0.01	16
5/18	28.1	8.0	28	2.52	10	0.84	0.04	5	0.01	10
5/24	31.8	10.6	33	3.35	10	0.86	0.07	8	0.02	10
5/25	33.9	7.4	22	2.45	9	0.84	0.06	7	0.02	10
5/31	28.1	7.2	26	2.28	10	0.87	0.06	7	0.02	10
6/1	28.5	7.4	26	2.34	10	0.88	0.06	7	0.02	10
6/7	28.4	9.2	32	3.06	9	0.90	0.04	5	0.02	9
6/8	32.9	10.1	31	3.20	10	0.88	0.04	4	0.01	10
6/14	32.6	11.7	36	3.71	10	0.94	0.07	7	0.02	10
6/15	34.9	7.3	21	2.31	10	0.92	0.10	11	0.03	10
6/21	34.8	14.2	41	4.49	10	0.93	0.06	6	0.02	10
6/22	38.0	5.8	15	1.83	10	0.93	0.08	9	0.02	10
6/28	20.4	6.8	33	2.13	10	0.92	0.08	8	0.02	10
6/29	20.2	6.3	31	3.16	4	0.94	0.09	10	0.05	4

APPENDIX c

DATA USED IN REGRESSIONS *OF* FLOW, ATPASE, AND TRAVEL TIME

Appendix Cl. Data collected in 1989 and 1990 used in regression analyses of flow, ATPase activity, and travel time. Data listed includes index reach, species (SPCH - yearling spring chinook salmon; STHD - yearling hatchery steelhead; WSTH - wild steelhead), date of collection (DATE), mean flow in kcfs (FLOW), mean ATPase activity in µmoles P·mg prot^{-1}·h^{-1} (ATPase), and travel time in days (TRAV).

DATE	ATPase	FLOW	TRAV
REACH = RIS-MCN SPECIES = SPCH			
04/25/89	11.5	143.8	20.2
04/27/89	12.5	143.2	11.8
05/02/89	13.2	146.1	11.7
05/04/89	18.4	151.9	11.6
05/09/89	19.8	152.8	10.3
05/11/89	24.1	153.7	9.9
05/16/89	25.5	174.7	9.3
			8.4
04/22/90	[illegible]	[illegible]	15.6
04/23/90	14.5	154.6	15:o
04/29/90	18.8	166.2	13.2
04/30/90	16.4	166.2	11.0
05/07/90	27.2	136.4	10.8
05/14/90	34.4	153.1	9.5
REACH = RIS-MCN SPECIES = STHD			
05/03/89	13.9	146.1	7.5
			7.4
05/10/89	[illegible]	[illegible]	8.7
05/12/89	21.9	158.3	7.6
			6.9
05/19/89	[illegible]	[illegible]	8.0
05/24/89	34.5	161.8	8.6
04/29/90	15.5	152.1	7.5
			7.9
05/07/90	[illegible]	[illegible]	9.8
05/14/90	22.9	153.1	8.9
05/20/90	20.7	143.7	7.6
REACH = RIS-MCN SPECIES = WSTH			
05/01/89	17.7	148.6	7.6
05/03/89	22.2	146.1	7.5
05/04/89	25.1	149.8	6.9
05/10/89	23.5	153.7	7.7
05/12/89	24.6	153.7	6.8
05/17/89	24.0	174.7	6.5
05/19/89	25.7	176.2	7.0
04/29/90	20.0	155.8	8.0
05/07/90	21.4	136.4	7.8
05/14/90	26.8	152.3	10.5

Appendix Cl. (continued)

DATE	ATPase	FLOW	TRAV
-------------------- REACH = MCN-JDA SPECIES = SPCH --------------			
5/1-6/89'	22.9	264.1	5.0
5/8-12/89	30.4	279.1	4.0
5/15-19/89			3.0
5/22-26/89	[illegible]	[illegible]	4.0
5/29-6/3/89	32.5	232.9	3:o
4/30-5/4/90	33.8	234.4	5.3
5/7-11/90	31.8	231.8	5.3
5/14-18/90	43.0	195.6	5.2

DATE	ATPase	FLOW	TRAV
-------------------- REACH = MCN-JDA SPECIES = STHD --------------			
5/1-6/89	20.5	263.9	4.0
5/8-12/89	27.4	277.4	3.0
5/15-19/89	30.4	260.5	3.0
5/22-27/89	26.6	231.2	3.0
5/29-6/3/89	24.9	229.0	5.0
4/30-5/5/90	22.9	234.5	4.0
5/6-11/89	31.4	230.1	4.5
5/14-18/90	29.6	193.0	4.6

DATE	ATPase	FLOW	TRAV
-------------------- REACH = MCN-JDA SPECIES = WSTH --------------			
5/1-6/89	25.8	266.4	3.0
5/8-12/89	28.2	276.5	3.0
5/15-19/89	33.1	260.5	3.0

DATE	ATPase	FLOW	TRAV
-------------------- REACH = CLW-LGR SPECIES = SPCH --------------			
03/30/90	11.3	48.6	21.5
04/05/90	7.7	57.7	25.0
04/06/90	7.7	55.3	18.2
04/12/90	7.9	61.1	15.9
04/13/90	12.6	62.7	16.6
04/19/90	6.8	66.8	10.0
04/20/90	9.1	67.0	8.8
05/24/90	17.2	67.3	5.4
05/25/90	21.1	80.3	5.6

[a] Fish Passage Center brand releases in the MCN-JDA reach were summarized by week (Fish Passage Center 1990, 1991).

Appendix C1. (continued)

DATE	ATPase	FLOW	TRAV
-------------------- REACH = SNK-LGR SPECIES = SPCH -------------			
03/29/89	10.7	73.8	19.1
04/04/89	13.0	79.1	15.5
04/06/89	10.8	80.7	12.8
04/11/89	16.7	90.8	11.5
04/13/89	18.3	91.7	8.7
04/18/89	19.0	103.0	5.1
04/20/89	24.1	109.6	4.7
04/25/89	22.0	87.1	7.1
04/27/89	24.3	86.8	6.5
05/02/89	30.9	97.9	4.4
05/11/89	19.0	89.3	5.9
04/19/90	19.7	68.9	5.6
04/20/90	17.1	69.4	5.6
04/26/90	24.7	61.2	8.8
04/27/90	25.2	61.0	8.4
05/01/90	22.6	65.3	8.1
05/10/90	25.0	84.5	4.0
05/31/90	29.5	107.2	4.4
-------------------- REACH = SNK-LGR SPECIES = STHD -------------			
04/20/89	12.3	107.4	2.2
04/25/89	13.8	86.9	3.3
04/27/89	14.2	88.1	4.8
05/02/89	14.2	89.0	3.2
05/04/89	18.8	100.9	2.9
05/09/89	12.0	116.8	2.0
05/11/89	13.5	108.6	2.0
05/16/89	19.1	82.5	3.9
05/18/89	21.6	74.2	4.6
05/23/89	17.0	75.0	5.9
05/25/89	15.3	62.0	6.2
04/19/90	10.7	65.5	4.0
04/20/90	12.5	68.0	3.9
04/26/90	13.7	61.9	5.8
04/27/90	12.3	60.6	7.0
05/03/90	12.7	67.9	5.5
05/04/90	13.5	72.0	5.5
05/10/90	17.8	84.5	4.1
05/11/90	15.8	76.3	6.0
05/17/90	19.4	48.7	8.9
05/18/90	20.4	49.0	8.4
05/24/90	20.7	66.6	3.1
05/25/90	22.8	70.3	3.5
06/01/90	19.9	106.4	2.3
06/07/90	25.0	91.9	3.0

Appendix Cl. (continued)

DATE	ATPase	FLOW	TRAV
--------------------- REACH = SNK-LGR SPECIES = WSTH --------------			
04/20/89	15.3	107.4	2.3
04/25/89	16.9	86.9	2.5
04/27/89	21.3	88.7	3.1
05/02/89	22.3	89.0	3:o
05/04/89	19.4	100.9	2.5
05/09/89	21.5	116.8	1.7
05/11/89	16.6	108.6	2.0
05/18/89	21.6	70.6	3.5
04/19/90	21.4	65.5	3.6
04/20/90	20.8	66.1	3.1
04/26/90	23.0	62.6	4.0
04/27/90	23.8	62.4	3.7
05/03/90	19.1	62.5	3.7
05/04/90	23.6	65.5	3.9
05/10/90	19.0	85.6	3.1
05/12/90	23.2	81.9	3.7
05/17/90	22.7	44.1	4.8
05/25/90	22.5	70.0	3.4
06/01/90	24.8	100.8	2.5