ASSESSMENT OF SMOLT CONDITION FOR TRAVEL TIME ANALYSIS

Annual Report 1989

Prepared by:

John W. Beeman
Dennis W. Rondorf
Joyce C. Faler
Mary E. Free
Philip V. Haner

U.S. Fish and Wildlife Service
National Fishery Research Station

Prepared For:

Patrick H. Poe, Project Manager
U.S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife
P.O. Box 3621
Portland, OR 97208-3621

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

November 1990

ABSTRACT

The Water Budget is a volume of water used to enhance environmental conditions (flows) in the Columbia and Snake rivers for juvenile salmonids during their seaward migration. To manage the Water Budget, the Fish Passage Center estimates travel times of juvenile salmonids in index reaches of the main-stem rivers, using information on river flows and the migrational characteristics of the juvenile salmonids. This study was initiated to provide physiological information on the juvenile salmonids used for these travel time estimates.

The physiological ability to respond to stressors was evaluated by measuring concentrations of plasma cortisol, glucose, and chlorides before and after a 30-s handling-stress challenge test. As in 1988, most groups responded satisfactorily to the challenge. The scope for response was compromised among two groups of juvenile chinook salmon that were trucked to release sites and in steelhead from one hatchery after unusual marking and transportation protocols were used.

The development of smoltification was assessed by measuring gill Na^{+}-K^{+} ATPase activity and plasma thyroxine concentrations. Mean ATPase activities of marked hatchery groups of juvenile chinook salmon and steelhead changed little during the month before release and rose sharply for about the first 20 d of the migration after release. Mean plasma thyroxine was highest during the first 20 d after release. Mean gill ATPase activity of spring chinook salmon from the migration-at-large peaked at about the 90th percentile of passage at Rock Island and Lower Granite dams, and at about the 50th percentile of passage at McNary Dam. Mean gill ATPase activity of wild steelhead was higher than gill ATPase activity of hatchery steelhead at Rock Island Dam, the Snake River Trap, and Lower Granite Dam, but not at McNary Dam. This was attributed to a time-dependent relationship between increases in ATPase activity and the number of days fish migrated before recapture. Correlations of gill ATPase activity and/or plasma thyroxine concentrations with condition factor, morphology, or skin guanine concentration may be useful as non-lethal indicators of smoltification for inclusion in a smoltification index.

Prevalence of bacterial kidney disease in spring chinook salmon was generally higher than in 1988, ranging from 81-100% using an enzyme-linked immunosorbent assay (ELISA) method. Fish from Snake River hatcheries had more severe infections than those from mid-Columbia hatcheries. The percentage of fish with severe infections was lower at two downstream dams than at the Snake River hatcheries of origin, suggesting a bias in dam collection facilities or that these fish ceased to migrate, either of which could lead to biases in travel time estimates.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES **(Cont)**

LIST of FIGURES (cant)

LIST OF TABLES

LIST OF APPENDICES

LIST OF APPENDICES (cont)

LIST OF APPENDICES (Cont)

LIST OF APPENDICES (cont)

LIST OF APPENDICES (cont)

LIST OF APPENDICES (cont)

LIST OF APPENDICES (cont)

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, Magic Valley, McCall, Niagara Springs, Priest Rapids, Rapid River, Sawtooth, 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, and Ron Pascho, National Fisheries Research Center - Seattle, USFWS, for analyses in their laboratories. 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 (Oncorhvnchus sp.) and steelhead (0. mvkiss) in the Columbia River Basin. This information is used primarily to help manage and evaluate the Water Budget, a volume of water used to enhance environmental conditions (flows) for seaward migrating smolts. Implicit in the Water Budget concept is that by augmenting flows, travel time of smolts can be decreased, thereby increasing survival by reductions in delayed migration and exposure to predators. In addition to river flows, biological attributes or smolt condition, such as levels of stress, extent of smoltification, and the prevalence and severity of diseases have been shown to affect the travel time and survival of smolts (Schreck et al. 1989; Zaugg 1989).

To manage the Water Budget, the Fish Passage Center estimates travel times for marked groups of smolts. Travel time is estimated as the number of days between date of release and median passage date at a downstream monitoring station, or as the number of days between median passage dates between two monitoring stations, e.g., Rock Island Dam to McNary Dam on the mid-Columbia River.

In 1989, this study was funded by the Bonneville Power Administration to measure levels of stress, smoltification, bacterial kidney disease (BKD), and to identify useful measures of smoltification suitable as indices for selected marked groups used by the Fish Passage Center to estimate travel time. Part one of this report describes the biological attributes of marked groups of smolts used to estimate travel time. Part two consists of preliminary investigations of physiological and morphological variables that may prove useful in the development of a smolt condition index as an aid for in-season management of the Water Budget.

PART ONE: BIOLOGICAL ATTRIBUTES OF SMOLTS USED TO ESTIMATE TRAVEL TIME

STRESS AT RELEASE

Introduction

The Smolt Monitoring Program uses marked groups of hatchery reared fish to monitor the onset and progress of the smolt migration throughout the Columbia River basin. Individual fish of each marked group are enumerated as they pass smolt monitoring sites at traps and dams in the Basin. These monitoring facilities are sited at the upstream and downstream ends of index reaches of the main-stem river that the juvenile fish migrate through. Information derived from the numbers of marked fish recorded at fish collection facilities, traps, and dams enable the Fish Passage Managers to manage the Water Budget for the maximum benefit of the juvenile migrants.

Some of the marked groups of chinook salmon and steelhead are transported by truck to release sites away from the hatcheries as part of larger production releases. The advantage of using these groups is that the release sites are generally in the upper Columbia and Snake river basins, providing data on fish with long migration distances. The disadvantage is that the number of marked fish recovered is occasionally low prohibiting an acceptable estimate of travel time. In the past, these releases have been of concern because the transportation of juvenile salmonids can induce variable levels of stress. Although the stress response is normal and has adaptive value, elevated stress levels can have deleterious effects on behavior and survival of juvenile salmonids. Some groups of marked fish used for the program were released directly from the hatchery while others were trucked for 0.5 to 7 h to remote release sites. Inasmuch as these procedural differences could affect the subsequent migration behavior and survival, it was deemed necessary to determine if any groups were physiologically compromised by the transportation. Because stress and the accompanied physiological changes are normal responses to stressors, we selected the ability to respond to a standardized stressor, a handling-stress challenge test, to determine if their ability to respond to stressors had been compromised.

Methods

Fish used in this study were from marked groups used by the Fish Passage Center to estimate travel time in the Columbia and Snake rivers (Table 1). These fish included steelhead from Idaho Department of Fish and Game (IDFG), U.S. Fish and Wildlife Service (USFWS), Washington Department of Wildlife (WDW), and the Oregon Department of Fish and Wildlife (ODFW); spring chinook salmon from hatcheries operated by USFWS and IDFG; fall chinook salmon from hatcheries operated by Washington Department of Fisheries (WDF); and summer chinook salmon from an IDFG hatchery.

Table 1. The hatchery, species, Fish Passage Center lot number (FPCLOT#),brands, and release site of fish sampled during 1989.

HATCHERY	SPECIES	FPCLOT#	BRANDS	RELEASE SITE
mid-Columbia River				
Entiat NFH	SPCH	89226	RA-7T-1/3	Hatchery
Leavenworth NFH	SPCH	89227	LA-7C-1/3 RD-7C-1	Hatchery
Winthrop NFH	SPCH	89244	RA-7N-1/3 LD-7N-1	Hatchery
Priest Rapids SFH	FACH[a]	89013-1	LA-T-1	Hatchery
	FACH[a]	89013-5	LA-T-2	Hatchery
Wells SFH	STHD	89361	RD-7F-1/3	Similkameen R.
	STHD	89362	LA-7F-1/3	Methow R.
Snake River				
Dworshak NFH	SPCH	89200	RA-7H-1 RD-7H-1/3	Hatchery
	STHD	89210	-[c]	Hatchery
Lyons Ferry SFH	FACH[a]	89011	LA-U-1/3	Hatchery
	FACH[b]	89010	LA/LD-7U-1/3	Hatchery
	STHD	89353	RA-IJ-1/3	Hatchery
Irrigon SFH	STHD	89118	LA/RA-J-4	Grand Ronde R.
Magic Valley SFH	STHD	89264	[c]	Little Salmon R.
McCall SFH	SUCH	89257	RA-R-1/2/3/4	S. Fork Salmon R.
Niagara Springs SFH	STHD	89259	[c]	Hells Canyon
Rapid River SFH	SPCH	89254	LA/LD-7H-1/3	Hatchery
	SPCH	89255	-[c]	Hells Canyon
Sawtooth SFH	SPCH	89252	LA-R-1/2/3/4	Hatchery

i Sub-yearling
Yearling
[c] PIT tagged

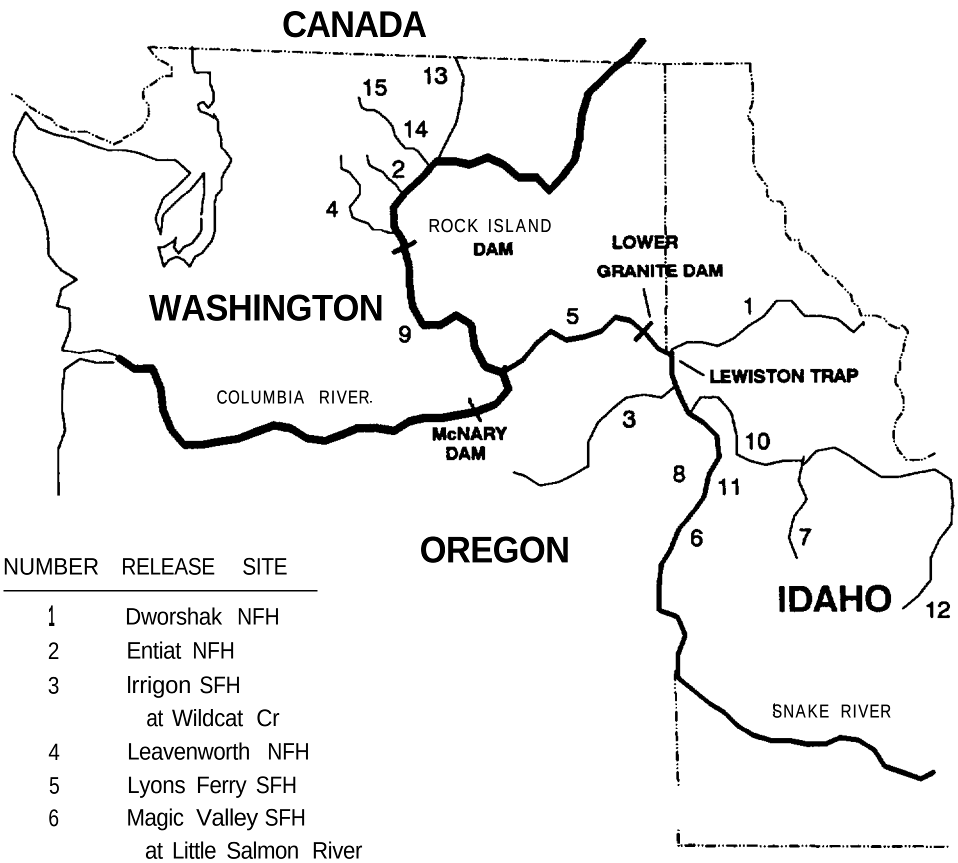
Concentrations of plasma cortisol, glucose, and chlorides were measured to assess baseline levels of these physiological parameters in fish prior to release from each hatchery. In addition to a sample of 20 'undisturbed" fish as a baseline (pre-test), a handling-stress challenge test was used to assess the ability of fish to respond to a standardized stress (Barton et al. 1985). In this challenge, fish were netted, held out of water for 30 s, and **returned** to a container of water with a maximum loading of 30 $g \cdot L^{-1}$ (0.25 $lb \cdot gal^{-1}$). After one hour, the fish were anesthetized and blood samples were collected (post-test). Samples at release were collected before fish were subjected to disturbances related to hatchery release procedures (e.g. raceway drawdown, crowding, etc.) and prior to daily activities such **as** feeding. Additional pre- and post-test samples were collected from groups released off-station by dip-netting fish from truck tanks at the release sites. Release site locations are shown in Figure 1.

Plasma cortisol was analyzed using the radioimmunoassay approach of Redding et al. (1984). Plasma glucose was analyzed using a hexokinase enzymatic method (Sigma Diagnostics, St. Louis, Missouri.); chloride concentrations were determined using a chloridometer. As a quality assurance, samples were analyzed in a random order with standards at regular intervals during the assays. Data were analyzed using paired t-tests. In the text, use of the term significant refers to a statistically significant difference at the probability $P < 0.05$.

Results

The normal response to the stress challenge was an elevation of plasma cortisol and glucose concentrations and a decline in plasma chloride ions. The responses of spring chinook salmon and steelhead were generally similar. For example, after the stress challenge at the hatchery, the plasma cortisol levels increased to levels greater than 50 $ng \cdot mL^{-1}$ usually a 5 to 10 fold increase. The increase in cortisol after ;he challenge was interpreted as a desirable response. Conversely, a negligible increase in cortisol in response to the challenge was considered undesirable as it indicates no further scope for response to stress.

The expected response to stress is an increase in plasma glucose concentration. The results ranged from no significant change to about a 30% increase in plasma glucose; a decline in plasma glucose is considered an undesirable response to the stress challenge. The changes in plasma chloride concentrations is indicative of the ability of juvenile salmon to maintain plasma ion concentrations. Following stress, the degree of osmoregulatory system failure is indicated by the extent of decline in plasma chloride concentration. The average decline in chloride ion levels was 4.6% among spring chinook salmon and 3.9% among steelhead at the hatchery (excluding Wells SFH).



NUMBER	RELEASE SITE
1	Dworshak NFH
2	Entiat NFH
3	Irrigon SFH at Wildcat Cr
4	Leavenworth NFH
5	Lyons Ferry SFH
6	Magic Valley SFH at Little Salmon River
7	McCall SFH
6	Niagara Springs SFH at Hells Canyon
9	Priest Rapids SFH
10	Rapid River SFH
11	Rapid River SFH at Hells Canyon
12	Sawtooth SFH
13	Wells SFH at Similkameen R
14	Wells SFH at Methow R
15	Winthrop NFH

Figure 1. Map of the Columbia River basin showing release locations of marked groups of juvenile salmonids from hatcheries sampled in 1989.

Each of the three measures, plasma cortisol, glucose, and chloride, should be considered in consort with the others as the ability of each group of fish is evaluated. To facilitate this the results for the three measures are presented in each figure by species (yearling chinook salmon or steelhead) and by river basin of release (mid-Columbia or Snake rivers).

Yearling chinook salmon released in the mid-Columbia River exhibited typical plasma cortisol, glucose and chloride responses to the stress challenge, characterized by increases in mean cortisol and glucose and slight decreases in mean chloride values. (Figure 2; Appendices l-3). One exception was that mean glucose of spring chinook salmon from Entiat NFH showed no significant change in response to the stress challenge.

Most yearling spring, summer, and fall chinook salmon from Snake River hatcheries also exhibited typical plasma cortisol, glucose, and chloride responses to the stress challenge (Figure 3; Appendices 4-8). Spring chinook salmon at Sawtooth SFH exhibited the most variable glucose response with a coefficient of variation of the mean of 49% compared to all other groups with an average of 17%. The high variability contributed to no significant change in response to the challenge. Yearling fall chinook salmon at Lyons Ferry SFH had a relatively large cortisol response and small glucose response to the stress challenge at the hatchery.

The two groups of yearling chinook salmon trucked to release sites did not respond to the stress challenge in the desirable manner observed in most groups at the hatchery. These groups were summer chinook salmon from McCall SFH and spring chinook salmon from Rapid River SFH (Hells Canyon release). After being trucked from McCall SFH to the South Fork of the Salmon River, a trip of about 1.5 h, summer chinook salmon had pre-test levels of cortisol at the truck release about 50% higher than the Rapid River spring chinook salmon after they were trucked 5 h. Furthermore, the summer chinook salmon did not respond to the stress challenge with a significant increase in plasma cortisol levels. This response was the most undesirable response observed among all groups of chinook salmon. Both groups had high variability associated with their mean plasma glucose values, with no significant change in mean plasma glucose of either group in response to the challenge. After trucking to Hells Canyon Dam, spring chinook salmon from Rapid River SFH responded to the stress challenge with a 7.3% decrease in plasma chloride levels. This decline is large compared to an average decline in plasma chloride levels of 4.6% for all yearling chinook salmon when the stress challenge was given at the hatchery. After the fish were transported and subjected to the stress challenge, mean chloride levels (120 $mEq \cdot L^{-1}$) were 13% below basal levels of fish (138 $mEq \cdot L^{-1}$) at the Rapid River SFH before the trucking procedure began.

Steelhead from Wells SFH on the mid-Columbia River exhibited higher mean plasma cortisol values and glucose concentrations than any other group examined (Figure 4; Appendix 9). At Wells SFH, mean basal glucose of fish released at the Similkameen and Methow rivers were 240 and 200 $mg \cdot dL^{-1}$, respectively.

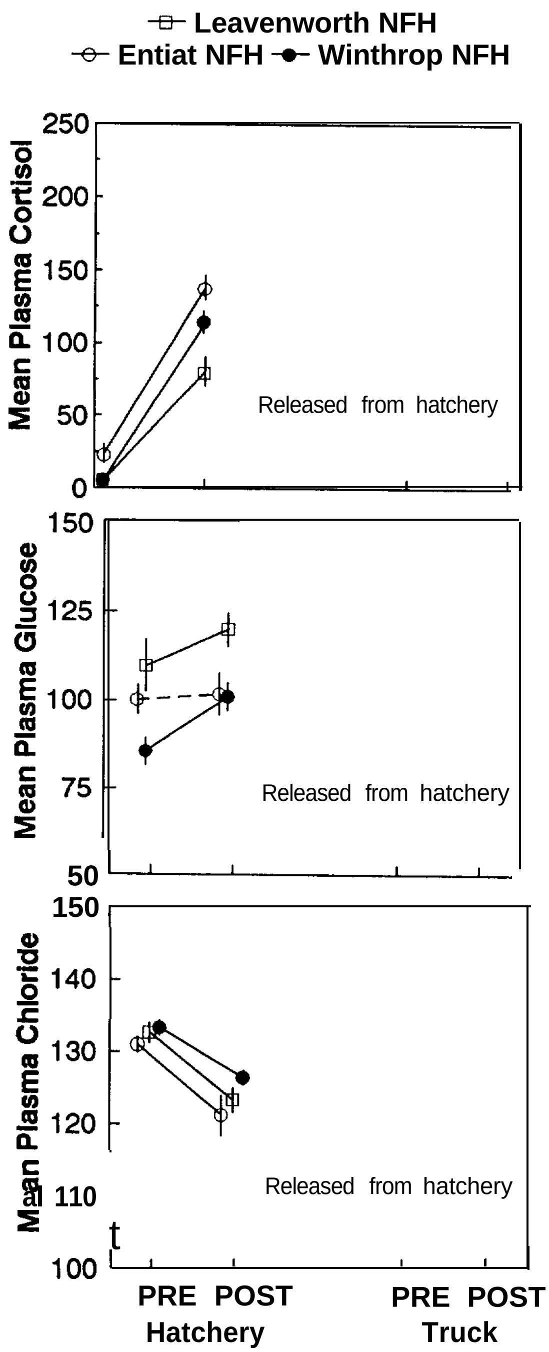


Figure 2. Mean plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) of yearling chinook salmon from mid-Columbia River hatcheries, spring 1989. Samples were collected from fish before (PRE) and after (POST) a 30-s handling-stress challenge. Solid lines between points indicate a significant difference between PRE and POST samples, dashed lines indicate no significant difference ($P > 0.05$). Vertical lines represent ± 1 standard error.

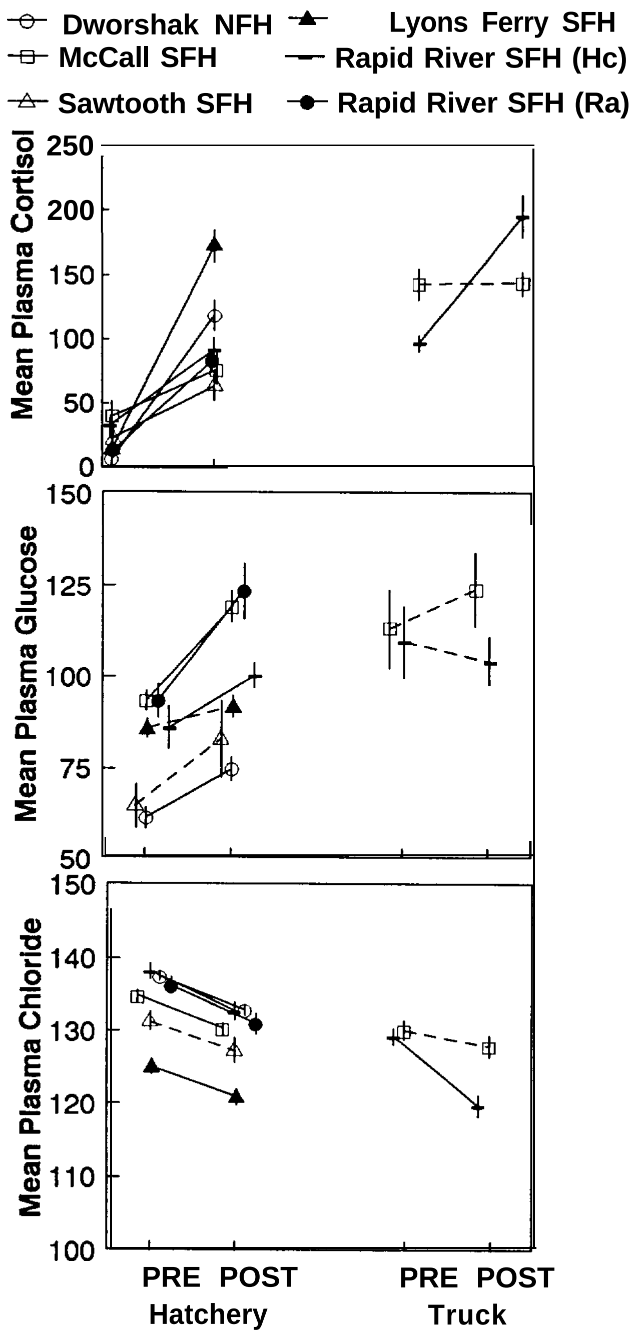


Figure 3. Mean plasma cortisol ($ng \cdot mL^{-1}$) glucose ($mg \cdot dL^{-1}$) and chloride ($mEq \cdot L^{-1}$) of yearling chinooksalmon from Snake River hatcheries, spring 1989. Samples were collected from fish before (PRE) and after (POST) a 30-s handling-stress challenge. Solid lines between points indicate a significant difference between PRE and POST samples, dashed lines indicate no significant difference ($P > 0.05$). Vertical lines represent ± 1 standard error.

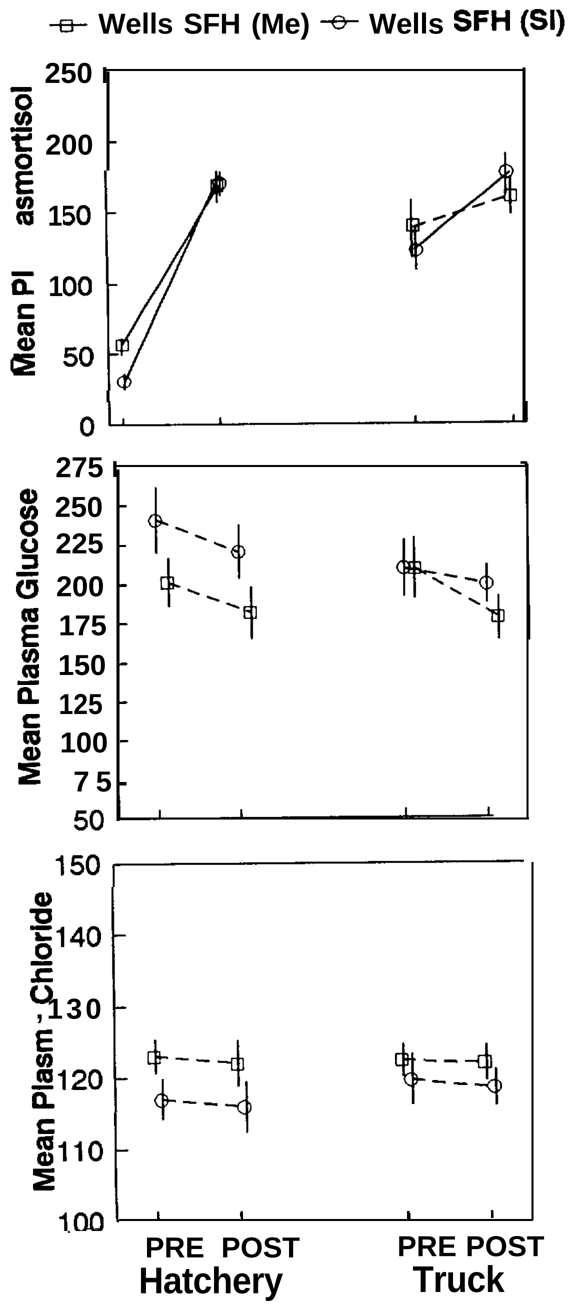


Figure 4. Mean plasma cortisol (ng·mL^{-1}), glucose (mg·dL^{-1}), **and** chloride (mEq·L^{-1}) of steelhead from mid-Columbia River hatcheries, spring 1989. Samples were collected from fish before (PRE) and after (POST) a 30-s handling-stress challenge. Solid lines between points indicate a significant difference between PRE and POST samples, dashed lines indicate no significant difference ($P > 0.05$). Vertical lines represent ± 1 standard error. respectively.

Neither group exhibited an increase in glucose during the stress challenge at the hatchery or after trucking. The plasma chloride values were also the lowest of all groups sampled at a hatchery, but they were able to maintain similar levels after trucking and the stress challenge.

Steelhead from most Snake River hatcheries had typical responses to the stress challenges at the hatchery with two significant exceptions (Figure 5, Appendices 10-13). Steelhead at Dworshak NFH had higher plasma cortisol levels than any other group. The steelhead at Magic Valley SFH were loaded from a raceway with a temperature of 14 C into a truck with a water temperature of 6 C. After being trucked to the Little Salmon River, a 6.5 h trip, steelhead from Magic Valley SFH had relatively high pre-test levels of cortisol and did not change significantly in response to the stress challenge.

Steelhead from Irrigon SFH were transported to release at Wildcat Creek, a tributary of the Grand Ronde River. These fish were transported with two trucks using different routes, one going to Wildcat Creek via Lewiston, ID, the other via La Grande, OR. Transportation via the Lewiston route took about 8 h and it took about 7 h on the La Grande route. The two groups of steelhead from Irrigon responded to the stress challenge with similar changes in plasma cortisol, glucose, and chlorides.

Discussion

Most groups of yearling chinook salmon responded to the stress challenge similarly, exhibiting a significant rise in mean plasma cortisol and glucose and a slight decrease in mean plasma chloride levels. There were, however, several groups whose responses distinguished themselves from the others. Spring chinook salmon at Entiat NFH exhibited little change in mean plasma glucose concentration in response to the stress challenge in comparison with the other mid-Columbia groups, and this response was a departure from the norm. The response was almost identical to that observed in 1988 (Rondorf et al. 1989). One hundred percent of juvenile fish at this hatchery are known to be infected with a myxosporidian parasite, although this is not known to compromise their stress response (J.K. Morrison, Olympia Fish Health Center, USFWS, personal communication).

The large cortisol response of the yearling fall chinook salmon from Lyons Ferry SFH is probably not due to some undesirable attribute, but is likely related to smoltification or race. Juvenile salmonids are known to have larger cortisol responses to stress during smoltification (Barton et al. 1985). The mean gill ATPase activity of these fish was about 30 μmoles $P_i \cdot mg\ Prot^{-1} \cdot hr^{-1}$, while those of the spring and summer chinook salmon from the Snake River hatcheries were less than 10 units (see smoltification section) indicating a more advanced stage of smoltification. The mean plasma thyroxine was also high compared to other groups of yearling chinook salmon, another indication that smoltification was underway. The racial differences may have also been a factor,

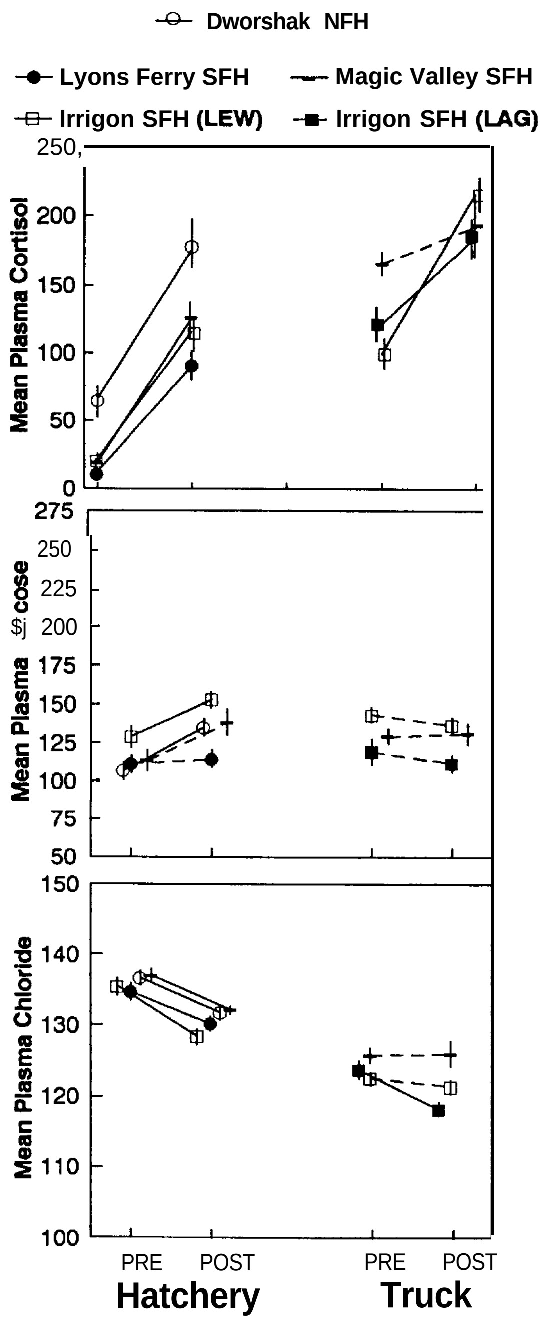


Figure 5. Mean plasma cortisol ($ng \cdot mL^{-1}$) glucose ($mg \cdot dL^{-1}$) and chloride ($mEq \cdot L^{-1}$) of steelhead from Snake River hatcheries, spring 1989. Samples were collected from fish before (PRE) and after (POST) a 30-s handling-stress challenge. Samples from Irrigon SFH were collected from trucks using routes through Lewiston, ID (LEW) and LaGrande, OR (LAG). Solid lines between points indicate a significant difference between PRE and POST samples, dashed lines indicate no significant difference ($P > 0.05$). Vertical lines represent ± 1 standard error.

inasmuch as they were the only group of yearling fall chinook examined. Barton and Schreck (1987) observed similar responses in subyearling juvenile fall chinook salmon exposed to a 30-s stress challenge.

After summer chinook salmon were trucked from McCall SFH to the release site, they exhibited the most undesirable response to the stress challenge of any group. At the truck, they had a high pre-test cortisol level and failed to increase cortisol levels in response to the stress challenge. When the fish were checked at the halfway point of the trip, the driver noticed there were "a lot of dead fish in there". The elevated cortisol level confirms that the fish were highly stressed at the release site. The lack of any change in cortisol after the challenge is very unusual particularly when the glucose response was normal and the chloride response indicated that hemodilution had not yet occurred.

Although spring chinook salmon from Rapid River SFH trucked to Hells Canyon responded with an acceptable increase in plasma cortisol level, they exhibited less desirable glucose and chloride responses. After being transported to Hells Canyon by truck the pre-test levels of plasma glucose and chloride concentrations were still within the range observed after the stress challenge at the hatchery. However, the decline in plasma chloride after the additional stress of a stress challenge at the release site resulted in the lowest mean plasma chloride value observed in any group of yearling chinook salmon and demonstrated little scope for additional stressors. The observed response is disappointing because juvenile salmonids often exhibit recovery during long periods of transportation, such as this 5 h trip, that can result in improved ability to respond to the stress challenge. The stress responses of summer chinook salmon from McCall SFH and spring chinook salmon from Rapid River SFH may, to some extent, be attributed to the sensitivity of yearling chinook salmon to stressors, but this does not make the observations any more desirable.

The two groups of steelhead from Wells SFH exhibited the most unusual stress responses. These fish were characterized by high glucose and low chloride levels before the stress challenges and had reductions in mean plasma glucose in response to the tests. In addition, glucose values were higher and chloride values were lower than Wells steelhead sampled in 1988 (Rondorf et al. 1989). These were signs that the fish collected in 1989 were in a more stressed condition than those from 1988, and were, in fact more stressed than fish sampled at any hatchery in either year: The hatchery manager has long emphasized that the marking procedure is stressful to the fish, but the procedure is limited by the facility. Just prior to marking, about l-3 d before release, steelhead from Wells SFH are either netted from an emigration trap or seined from a large rearing pond and trucked across the hatchery to the freeze-branding trailer. After branding, they are held in raceways for 0.5-l d prior to trucking to the release sites. This protocol, and the stressful conditions it creates, are unlike those of any other marking procedure used by the Fish Passage Center.

The results demonstrate that some groups of fish have one or more compromised stress responses after trucking. However, determining the extent to which these conditions affect post-release recovery was not determined. The numerous variables involved in determining post-release migration behavior and travel time make determining the relation between stress response and travel time difficult without the appropriate test and control groups. Furthermore, the Smolt Monitoring Program for 1990 has dropped most of the steelhead groups that were transported by truck in the upper Snake River basin.

Inasmuch as few of the remaining marked groups of fish used for the Smolt Monitoring Program are trucked to release sites, we recommend that the monitoring of stress responses be reduced or discontinued, although production fish from these hatcheries will continue to be released in this manner. Most of this transportation results in minimal stress expected from the loading and transportation conditions. However, we encourage state and federal agencies to develop procedures of quality control and increased accountability to minimize stress on fish during transport.

SMOLTIFICATION

Introduction

The daily management of the Water Budget is based on past experience and in-season flow and migrational characteristics of juvenile salmon and steelhead. The approach is to maximize the benefit of the Water Budget by taking advantage of the migrational behavior associated with smoltification of juvenile salmon and steelhead. Behavioral changes during smoltification result in a migrational disposition that enables smolts to migrate to the ocean using river flows, probably in a mostly passive manner, with the juvenile salmon being transported by the water velocity.

The behavioral changes and the development of the disposition to migrate are paramount to maximize use of the river flows available. Juvenile salmonids released from hatchery environments seldom resemble actively migrating smolts and have been described as "non-functional" smelts (Wedemeyer et al. 1980). The in-river migration is apparently associated with the completion of the smoltification of non-functional smolts and the development of the disposition to migrate. The in-river migration experience is also associated with certain, measurable, physiological changes characteristic of smoltification (Zaugg et al. 1985). Therefore, Fish Passage Managers want to know the smoltification status of branded groups and the smolt migration as a whole, to assess the extent to which in-river smoltification has taken place. To provide this information, selected measures of smoltification are provided to the Fish Passage Center for in-season management use. This report provides a post-season analysis of the results and presents them in perspective to the migration as it occurred during 1989.

Two physiological parameters were measured on groups of juvenile salmonids as indicators of smoltification, gill $Na^{+}-K^{+}$ adenosine triphosphatase activity ($Na^{+}-K^{+}$ ATPase) and plasma thyroxine concentrations. Elevated gill ATPase activity is associated with the development of the osmoregulatory system necessary for osmoregulation in seawater although elevated levels, indicative of ongoing smoltification, occur in freshwater prior to seawater entry. Elevated plasma thyroxine levels, and perhaps more complicated changes in the dynamics of clearance of thyroxine from the blood, have been implicated with a number of changes associated with smoltification such as migratory behavior, silvering, and shape changes.

Methods

To assess smoltification of juvenile salmonids during the downstream migration, we used two sampling strategies. The first strategy was to sample juvenile chinook salmon and steelhead marked and released from hatcheries as part of the Smelt Monitoring Program. Groups of fish were marked with freeze brands prior to release from the hatcheries enabling us to identify and sample these fish at downstream smolt monitoring sites of index reaches. These fish were considered representative of large hatchery production releases in the Columbia River basin. The second strategy was to sample groups of migrants, marked with passive integrated transponder (PIT) tags or freeze brands, that were released into the index reaches from the smolt monitoring sites. Juvenile fish sub-sampled from migrants were considered representative of the migration at large.

Juvenile chinook salmon and steelhead were marked with freeze brands (Mighell 1969) or with PIT tags (Prentice et al. 1986). Fish from 19 marked groups originating from 13 hatcheries were sampled to assess smoltification prior to release from hatcheries. Four of the groups of steelhead at Idaho state fish hatcheries received only PIT tags, precluding recapture at downstream sites.

Steelhead at Idaho state fish hatcheries were PIT tagged in spring 1989. Steelhead and subyearling fall chinook salmon were f'reeze branded in the spring of 1989; yearling chinook salmon were branded in the fall of 1988, about 6 months before release. Spring chinook salmon and hatchery and wild steelhead from the run at large were PIT tagged at the Snake River Trap and Rock Island Dam during the seaward migration. Migrants at McNary Dam were marked with freeze brands because a PIT tag detector was not available at fish collection facilities downstream. The marking and tagging program is described in more detail by the Fish Passage Center (1990).

To assess the level of smoltification, a sample of 20 fish was removed from hatchery raceways or ponds at about one month, two weeks, and shortly before release. Marked fish recaptured at smolt monitoring sites were sub-sampled to assess the ongoing smelt development. A sample of 20 fish was collected from the early, middle, and late segments of their migration past Rock Island, Lower Granite, and McNary dams. The early, middle, and late samples correspond approximately to the 25th, 50th, **and** 75th percentiles of the migration of each branded group past a location. Fish were sampled bi-weekly from the migration at large at the Snake River Trap (March 29 - May 25), Lower Granite Dam (April 6 - May 24), Rock Island Dam (April 25 - May 23), and McNary Dam (May 2 - June 1, 1989).

Gill ATPase activity and plasma thyroxine levels were used to evaluate the extent of smoltification. Fish were sacrificed by overdose in tricaine (MS-222). Gill filament samples were collected and assayed for $Na^{+}-K^{+}$ ATPase activity using the method of Zaugg (1982) with minor modifications. Samples were analyzed in random order with known phosphate standards at regular intervals during the assay. Plasma samples were assayed for thyroxine using the radioimmunoassay described by Dickhoff et al. (1978) and modified by Specker and Schreck (1982). The data on gill ATPase activity and plasma thyroxine concentrations were analyzed using analysis of variance (ANOVA) and Student-Newman-Keuls multiple range tests (SNK). Statistical differences reported refer to $P <$ 0.05.

The use of PIT tags to mark migrants at smolt monitoring sites enabled us to collect measures of smoltification from fish of various origins that were **tagged** on **the** same **date** and released at the same location. From migrants, biweekly samples of gill tissue were collected and assayed for gill ATPase activity. Median travel time and average flow data for each release at the Snake River trap were from IDFG, Lewiston, ID (Buettner and Nelson 1990) and were from the Fish Passage Center (1990) for releases **at Rock Island** Dam. Data from these sources used in regression analyses were sub-sets of the original data since samples for ATPase activity were not collected on every day. Regression analyses were performed using median travel time (days), mean flow (kcfs), **and** mean gill ATPase activity of fish at the time of tagging. Flow at Lower Granite Dam was computed for each release group as the average flow (kcfs) over the period from the date of release through the median date of recapture. Flow at Priest Rapids Dam was computed as the average flow over the seven day period comprised of the back-calculated median date of detection (based on the observed passage at McNary) ± three days (Fish Passage Center 1990). Median and mean values were transformed using natural logarithms. A stepwise multiple regression procedure was used with a probability $P > F \leq$ 0.15 required for entry into the model.

Results

Juveniles released from hatcheries

Mean gill ATPase activity of yearling spring and summer chinook salmon collected at the mid-Columbia and Snake river hatcheries exhibited similar increasing trends over time, but activities diverged markedly as fish were recaptured at smolt monitoring sites (Figure 6; Appendices 14-22). Fish recaptured from a given segment of the migration (early, middle, or late), particularly at upstream sites such as Rock Island Dam, were at different stages of smolt development because of the time dependent pattern of increases in gill ATPase activity. For example, fish from Entiat NFH recaptured late in the migration at Rock Island Dam, about 15 days after release, had a mean gill ATPase activity of 17 μmoles $P_i \cdot mg\ Prot^{-1} \cdot hr^{-1}$ (Figure 6A). In contrast, **fish from** Winthrop NFH recaptured late in the migration at Rock Island Dam, about 35 days after release, had **a** mean gill ATPase activity of 39 pmoles Pi.mg Prot-.hr-'. The differences between ATPase activities of these groups of spring chinook salmon are typical of the differences in degrees of smolt development of different groups of fish as they **pass** smolt monitoring sites.

Gill ATPase activities of fish recaptured at smolt monitoring

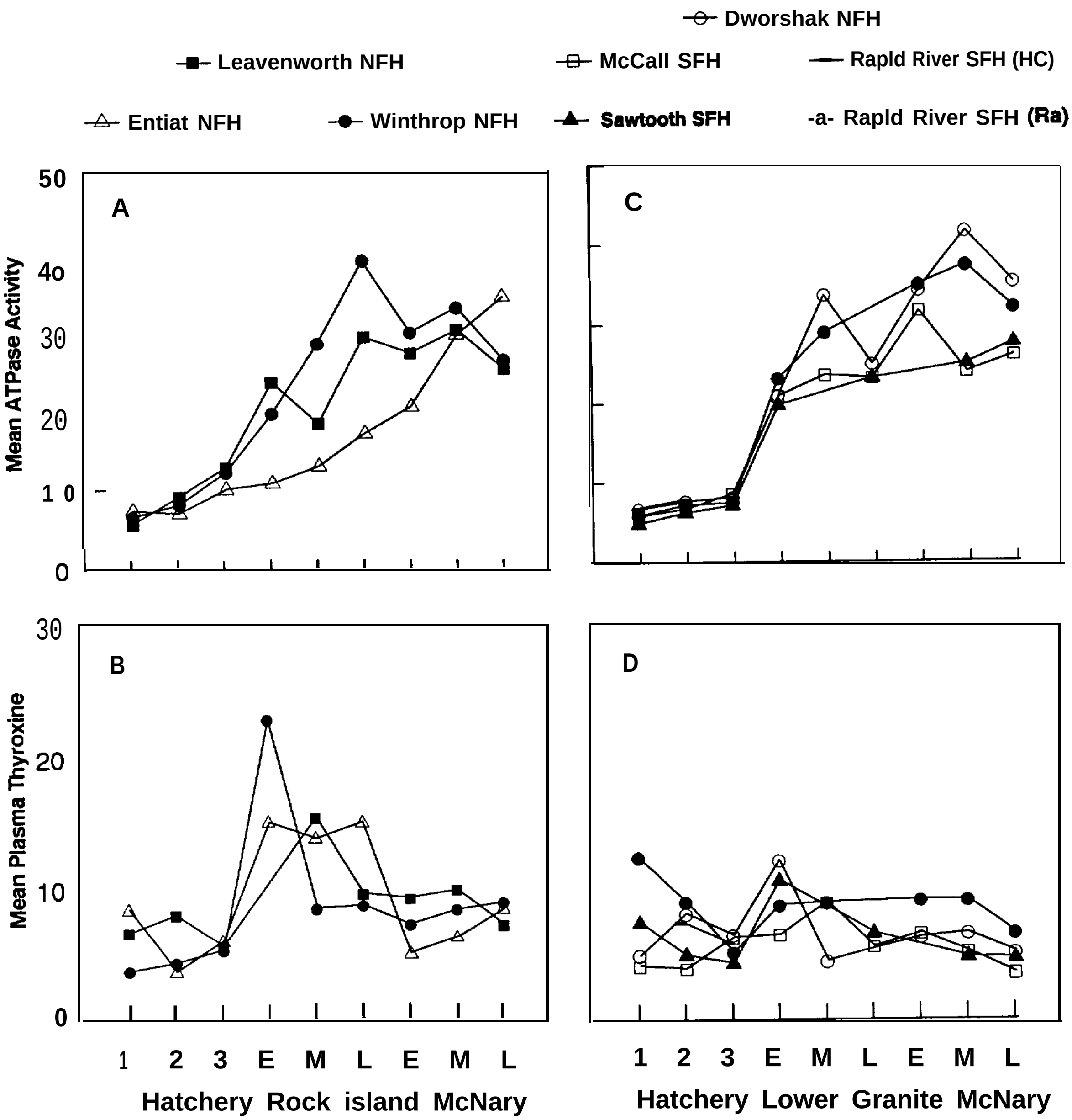


Figure 6. Mean gill ATPase activity (μmoles $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$) and plasma thyroxine ($ng \cdot mL^{-1}$) of spring chinook salmon from mid-Columbia (A, B) and Snake River (C, D) hatcheries, spring 1989. Samples were collected one month (1), two weeks (2), and shortly before (3) release and again at the early (E), middle (M), and late (L) portions of the migration past Rock Island or Lower Granite, and McNary dams.

sites were about two to three fold higher compared to levels at release from the hatchery. Although a complete time series for any one group of fish from release to completion of the migration is not available, a pattern emerges when mean ATPase activity of all groups is plotted against the number of days of in-river migration that fish have experienced prior to collection (Figure 7A). The mean gill ATPase activity of spring chinook salmon released from the mid-Columbia and Snake river hatcheries was 9.6 **μmoles $P_i \cdot$mg Prot$^{-1} \cdot$hr^{-1}.** About 20-,days, after release, values were greater than 20 **μmoles $P_i \cdot$mg** Prot $\cdot$**hr .** After 40 d of migration mean ATPase activities trend lower. Groups collected after this time originated primarily in the upper Snake River basin.

Mean plasma thyroxine levels of many of the groups of spring chinook salmon had relatively high values as they migrated past upstream monitoring sites of Rock Island Dam and Lower Granite Dam (Figure 6; Appendices 14-22). Grau et al. (1981; 1982) presented convincing evidence that lunar phasing of plasma thyroxine in juvenile salmon occurs at about the second new moon following the vernal equinox for Washington and northern Oregon stocks, which corresponds to about May 5 in 1989. Most groups of spring chinook salmon attained their highest post-release mean plasma thyroxine levels in late April and early May. Fish from Winthrop NFH and Leavenworth NFH exhibited maximum thyroxine concentrations at the time of the second new moon, and conversely, fish from Dworshak NFH and Entiat NFH had elevated plasma thyroxine levels at the full moon following the vernal equinox. Recaptured fish exhibited their highest plasma thyroxine concentrations during the first 20 days of migration with no elevated levels among fish that had migrated 40 to 70 days (Figure 7B; Appendices 14-22).

Mean gill ATPase activities of yearling and sub-yearling fall chinook salmon generally increased during the month before release and had increased substantially by the time they reached McNary Dam (Figure 8; Appendices 23-25). Yearling fall chinook salmon released from Lyons Ferry SFH were unlike other groups of yearling and subyearling fish in that they had a relatively high mean gill ATPase activity (28 pmoles P,.mg **Prot$^{-1} \cdot$hr^{-1})** at release and ATPase activities did not increase significantly after release. Two groups of subyearling fall chinook salmon, the first and last of five groups released from Priest Rapids SFH, had markedly different attributes. The first group, released on June 12, 1990, had a mean gill ATPase activity of 29 **μmoles $P_i \cdot$mg Prot$^{-1} \cdot$hr^{-1}** in the early segment of the migration (Figure 8A) were exposed to an average river flow of 140 kcfs, and had a median travel time to McNary Dam pf 9,d. The fifth group had activities of 18 **μmoles $P_i \cdot$mg Prot^{-}** .hr in the early segment of the migration, were exposed to an average river flow of 76 kcfs, and had a median travel time of 12d.

Mean plasma thyroxine levels of the sub-yearling fall chinook salmon from Lyons Ferry SFH and Priest Rapids SFH were similar before and after release (Figure 8; Appendices 23-25). The yearling fall chinook salmon from Lyons Ferry SFH had higher mean plasma thyroxine levels than the sub-yearling groups.

The general pattern of gill ATPase activity of steelhead

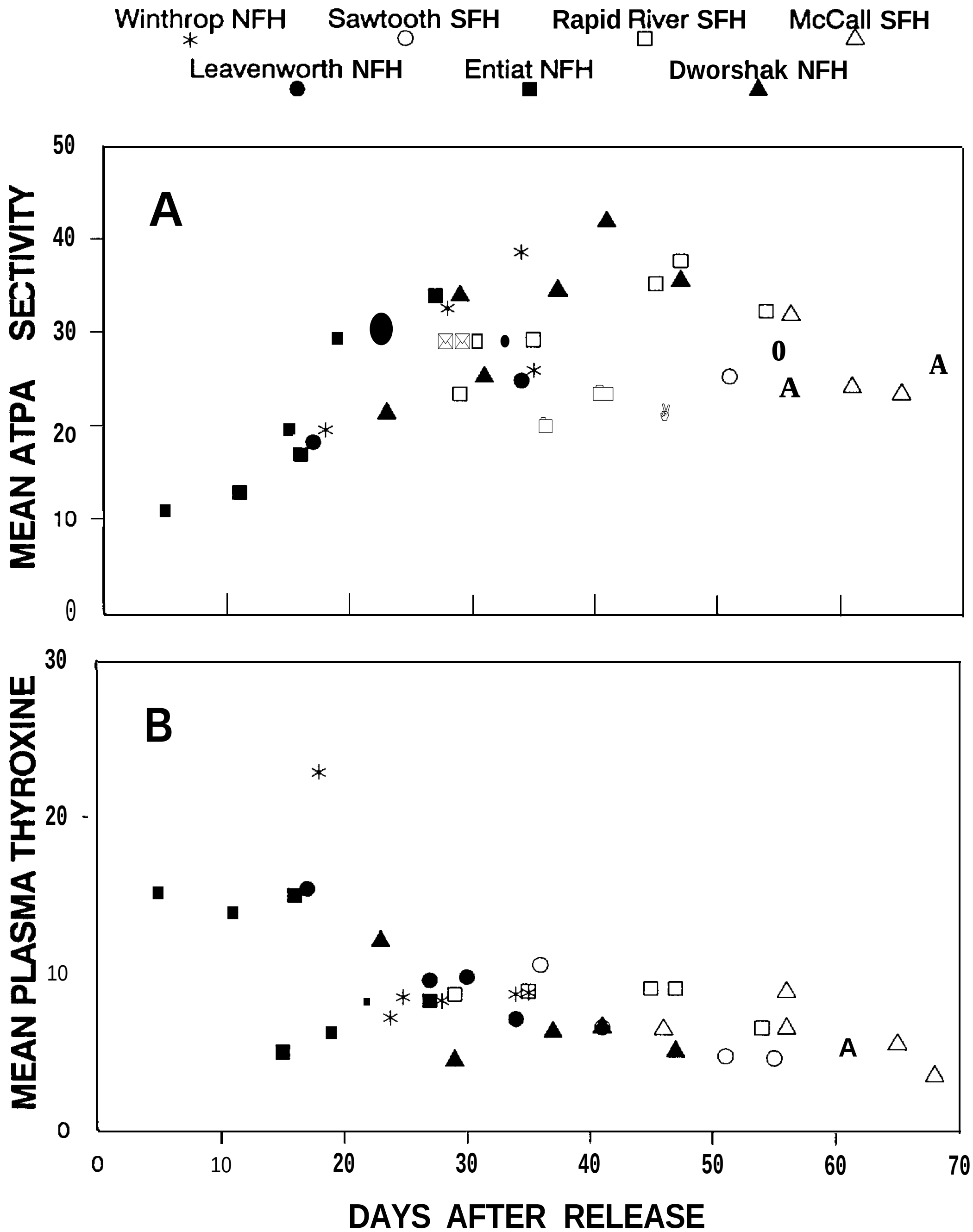


Figure 7. Mean ATPase activity (μmoles $P_i \cdot$mg $Prot^{-1} \cdot h^{-1}$) (A) and plasma thyroxine ($ng \cdot mL^{-1}$) (B) with days after release of spring chinook salmon from mid-Columbia and Snake river hatcheries, spring 1989.

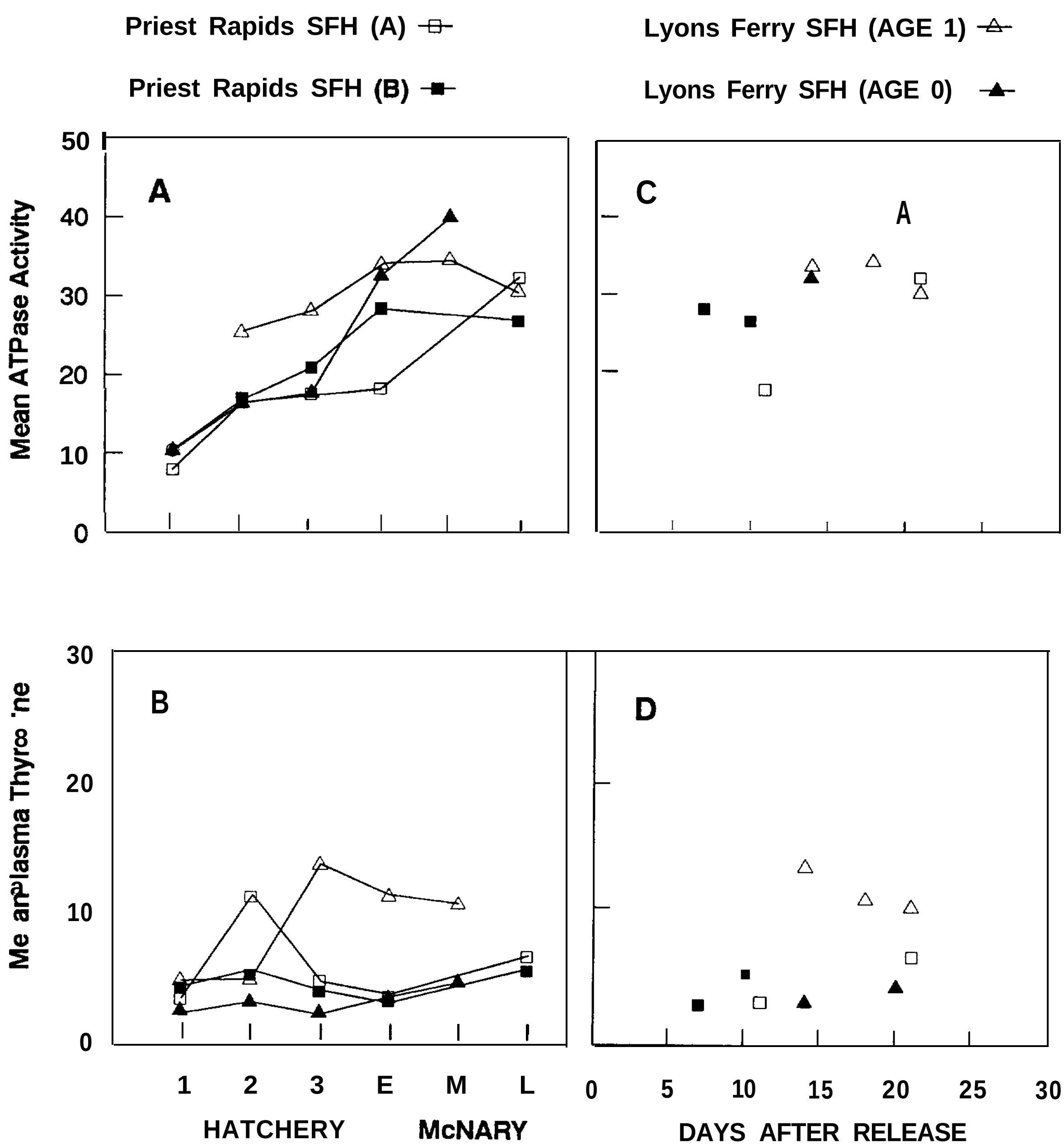


Figure 8. **Mean gill ATPase activity (μmoles $P_i \cdot mg\ Prot^{-1} \cdot h^{-1}$) and** plasma thyroxine ($ng \cdot mL^{-1}$) of fall chinook salmon from mid-**Columbia hatcheries, spring 1989. Samples were collected one** month (l), two weeks (2), and shortly before (3) release and again at the early (E), middle (M), and late (L) portions of the migration past McNary Dam.

released from hatcheries was similar to yearling chinook salmon, inasmuch as activities were low prior to release and activities increased after in-river migration. An exception to this pattern was the steelhead from the Wells SFH, which had little change in mean gill ATPase activities between one month and two weeks prior to release, but increased sharply during the last two weeks before release (Figure 9A; Appendices 26-27). Steelhead reared in Snake River hatcheries had relatively static ATPase activities in the hatchery (Figure 9B; Appendices 28-32). Fish from Irrigon SFH and Lyons Ferry SFH were the only groups from the Snake River recovered after release because the other groups were PIT tagged and could not be identified at the dams.

Three groups of steelhead exhibited relatively high mean plasma thyroxine concentrations, two of which had elevated plasma thyroxine in agreement with lunar phasing as proposed by Grau et al. (1981; 1982) (Figure 9C,D). The highest mean plasma thyroxine concentrations for steelhead from Dworshak NFH and Irrigon occurred at about the time of the new moon of May 5, 1989. Steelhead from Irrigon SFH had high plasma thyroxine at the new moon, but plasma thyroxine concentrations remained high during the first 20 days of migration, even during the next full moon. In contrast, steelhead from Wells SFH had the highest plasma thyroxine concentrations at the hatchery prior to the new moon of April 6, and all plasma thyroxine concentrations during the migration remained relatively low. Since other groups exhibited no significant increase in plasma thyroxine concentrations, no discernable pattern was evident as the migration progressed over time.

<u>Juveniles from the migration at large</u>

Yearling chinook salmon

Mean ATPase activity of spring chinook salmon from the migration at large increased progressively until late in the migration at upstream monitoring sites (Figures 10,ll; Appendix 33). Mean gill ATPase activity of spring chinook salmon at Rock Island Dam had the highest values on May 23, after the 90th percentile of passage on May 19, 1989 (Figure 10). At the Snake River Trap, peak gill ATPase activities of spring chinook salmon occurred on May 2 and the 90th percentile of passage on May 6, while at Lower Granite Dam gill ATPase activities peaked on May 5 and again on May 22 with the 90th percentile of passage on May 25, 1989 (Figure ll),, A relatively high mean ATPase activity of 32 pmoles $P_i \cdot mg$ Prot $\cdot hr^{-1}$ occurred as early as the 50th percentile of migration at McNary Dam suggesting that all migrating yearling chinook salmon were at a more advanced stage of smoltification as they migrated past this site - the furthest downstream monitoring site where yearling chinook salmon were collected.

Travel time of spring chinook salmon was inversely related to mean flow and mean ATPase activity, with travel time being low when river flow and gill ATPase were relatively high. A preliminary analysis of travel time, gill ATPase actlvlty, and flow

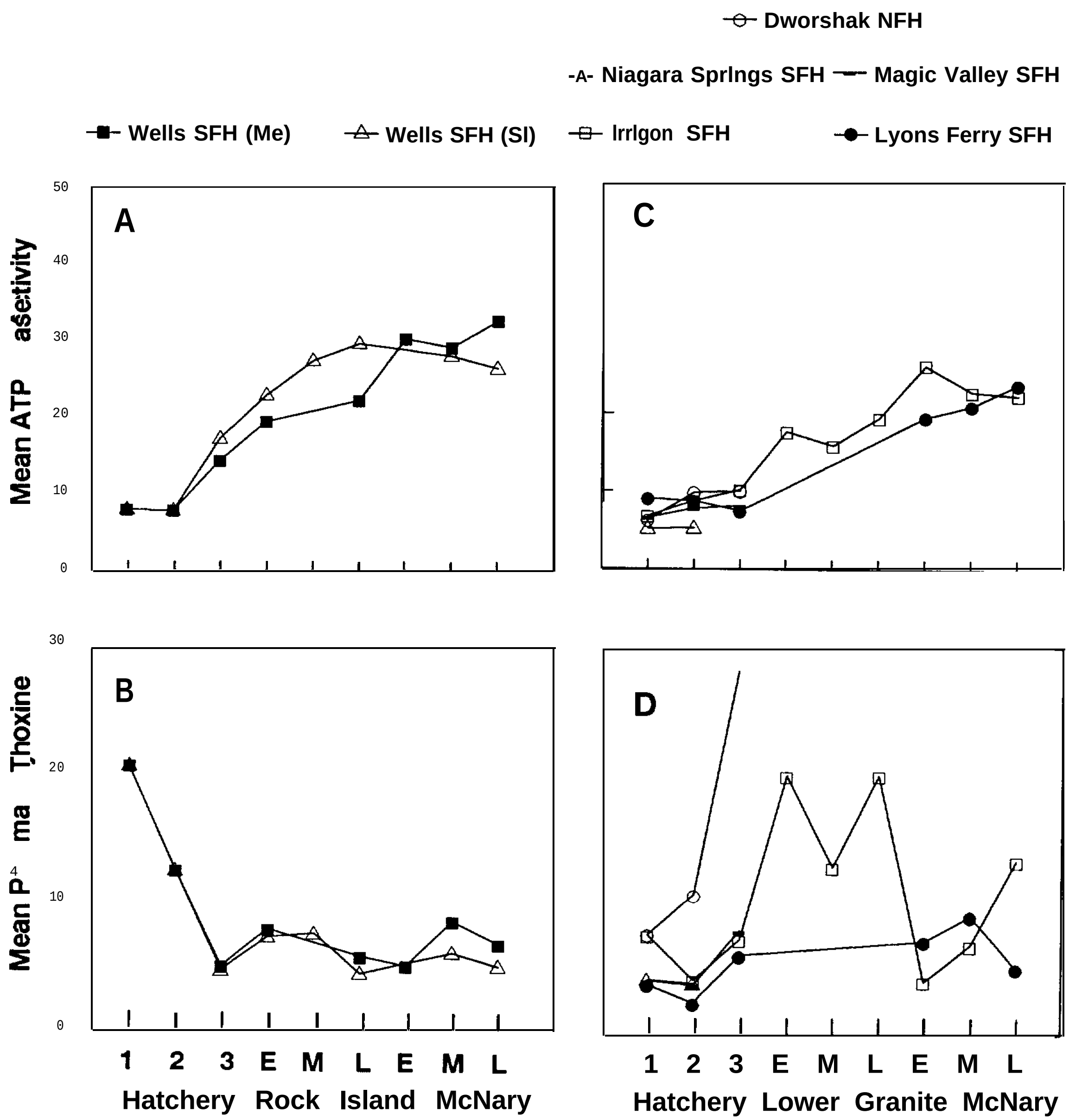


Figure 9. Mean gill ATPase activity (μmoles $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$) and plasma thyroxine ($ng \cdot mL^{-1}$) of steelhead from mid-Columbia (A, B) and Snake River (C, D) hatcheries, Spring 1989. Samples were collected one month (1), two weeks (2), and shortly before (3) release and again at the early (E), middle (M), and late (L) portions of the migration past Rock Island or Lower Granite, and McNary dams.

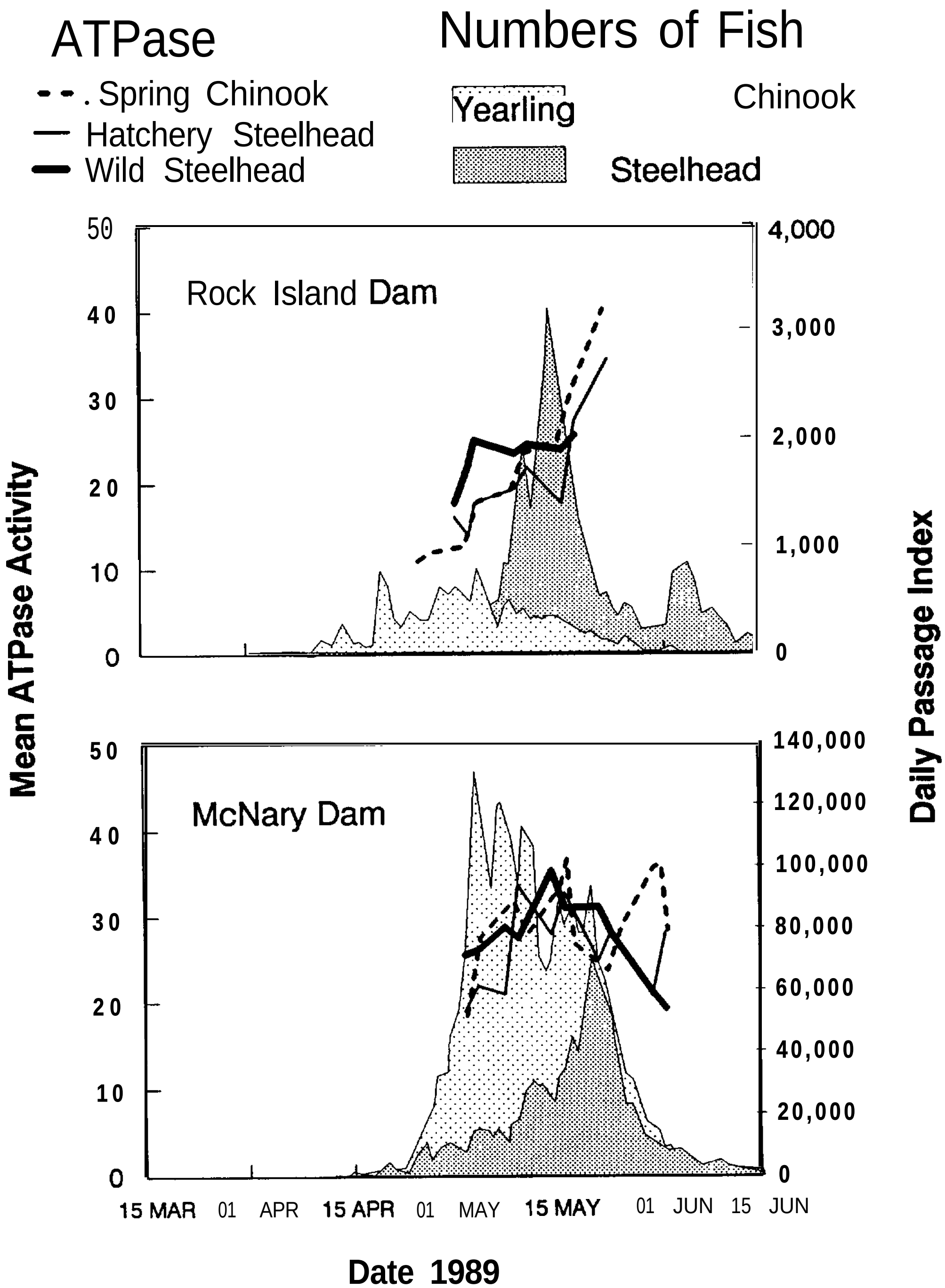


Figure 10. Daily passage index at Rock Island and McNary-,dams overlaid by mean ATPase activities (μmoles P_i · mg Prot · h) of spring chinook salmon and hatchery and wild steelhead from the run at large, spring 1989.

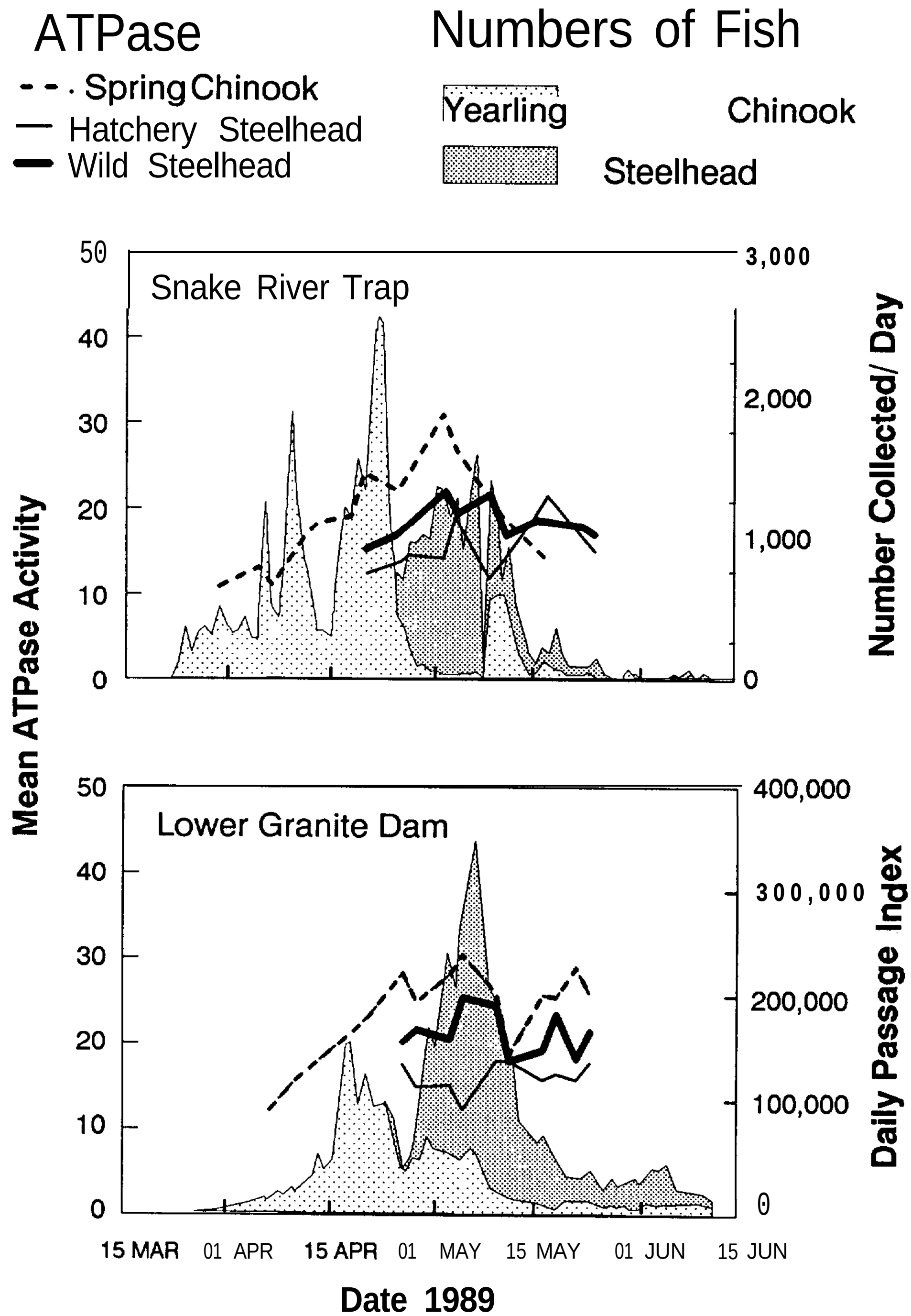


Figure 11. Number collected at the Snake River Trap per day and daily passage index at Lower Granite Dam overlaid by mean ATPase activities (μmoles $P_i \cdot$ mg Prot$^{-1} \cdot h^{-1}$) of spring chinook salmon and hatchery and wild steelhead from the run at large, spring 1989.

indicated both smoltification, as measured by gill ATPase activity,and flow accounted for variability of travel time of spring chinook salmon. It is important to note that data used in these analyses were sub-sets of data obtained from IDFG and FPC since ATPase activity information was not collected on each day. A multiple regression of the natural logarithm of travel time on flow and ATPase variables of spring chinook salmon at Rock Island Dam (Figure 12) resulted in the following equation:

$$LnMTT = 4.1640 - 0.5984\ LnATP$$
$$\text{with } N = 8 \text{ and } R^2 = 0.68,$$

Where LnMTT is the natural logarithm of median travel time from Rock Island Dam to McNary Dam in days, and LnATP is the natural logarithm of mean gill ATPase of fish sub-sampled from spring chinook salmon that were PIT tagged. Neither mean flow (at Priest Rapids Dam) nor the natural logarithm of mean flow entered the model despite the conservative alpha to include variables in the equation of $\alpha = 0.15$. The variables LnFLOW and LnATP of yearling chinook salmon were significantly correlated ($r = 0.90$; $P < 0.01$).

The equation resulting from multiple regression analysis of travel time of spring chinook salmon PIT tagged and released from the Snake River Trap included both gill ATPase activity and flow variables (Figure 12). The equation was:

$$LnMTT = 15.5277 - 2.3673 LnATP - 0.9651 LnFLOW$$
$$\text{with } N = 11 \text{ and } R^2 = 0.87,$$

where LnMTT is the natural logarithm of median travel time from the Trap to Lower Granite Dam, LnATP is the natural logarithm of mean gill ATPase, and LnFLOW is the natural logarithm of mean river flow at Lower Granite Dam. Partial R-squared coefficients indicate the gill ATPase activity variable explained about 75% of the variability and flow about 12%. Simple regressions using LNFLOW and LNATP separately resulted in r^2 values of .73 and .76, respectively. The correlation between LnATP and LnFLOW was $r = 0.70$ ($P < 0.05$). Predicted travel times using this regression are similar to those in Buettner and Nelson (1990) when the ATPase activity variable is changed to match changes occurring during the outmigration.

Steelhead

Mean gill ATPase activity of steelhead fluctuated throughout the period sampled, with wild steelhead having higher ATPase activity and lower travel time compared to steelhead of hatchery origin (Figures 13,14; Appendices 34, 35). The mean gill ATPase activity of wild steelhead sub-sampled from migrants was significantly higher than ATPase activity of hatchery steelhead at the Snake River Trap, Lower Granite Dam, and Rock Island Dam, but not at McNary Dam (ANOVA; $P < 0.05$).

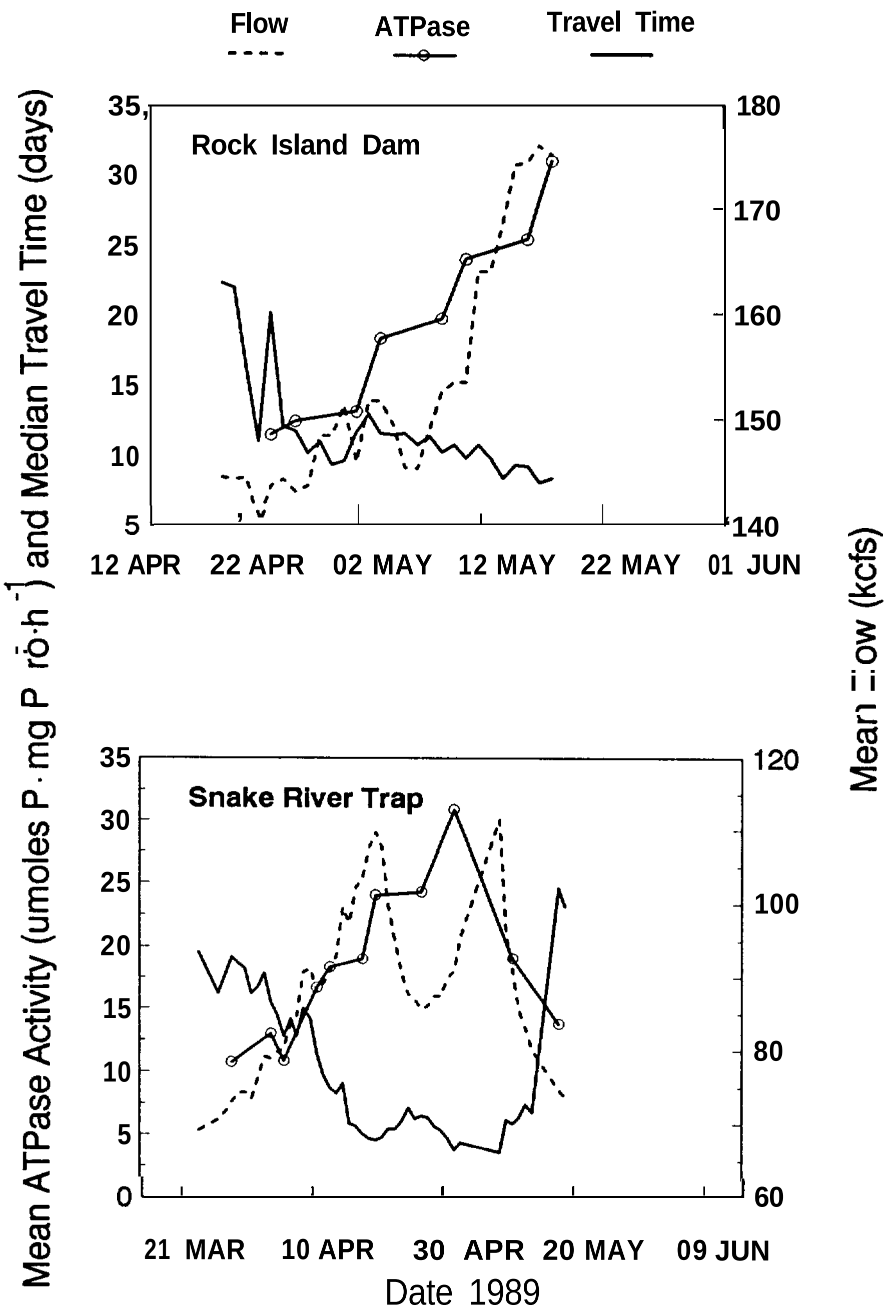


Figure 12. Mean flow, ATPase activity, and travel time of spring chinook salmon from the run at large PIT tagged at Rock Island Dam and Snake River Trap, spring 1989. Flow and travel time data is from Fish Passage Center, 1990.

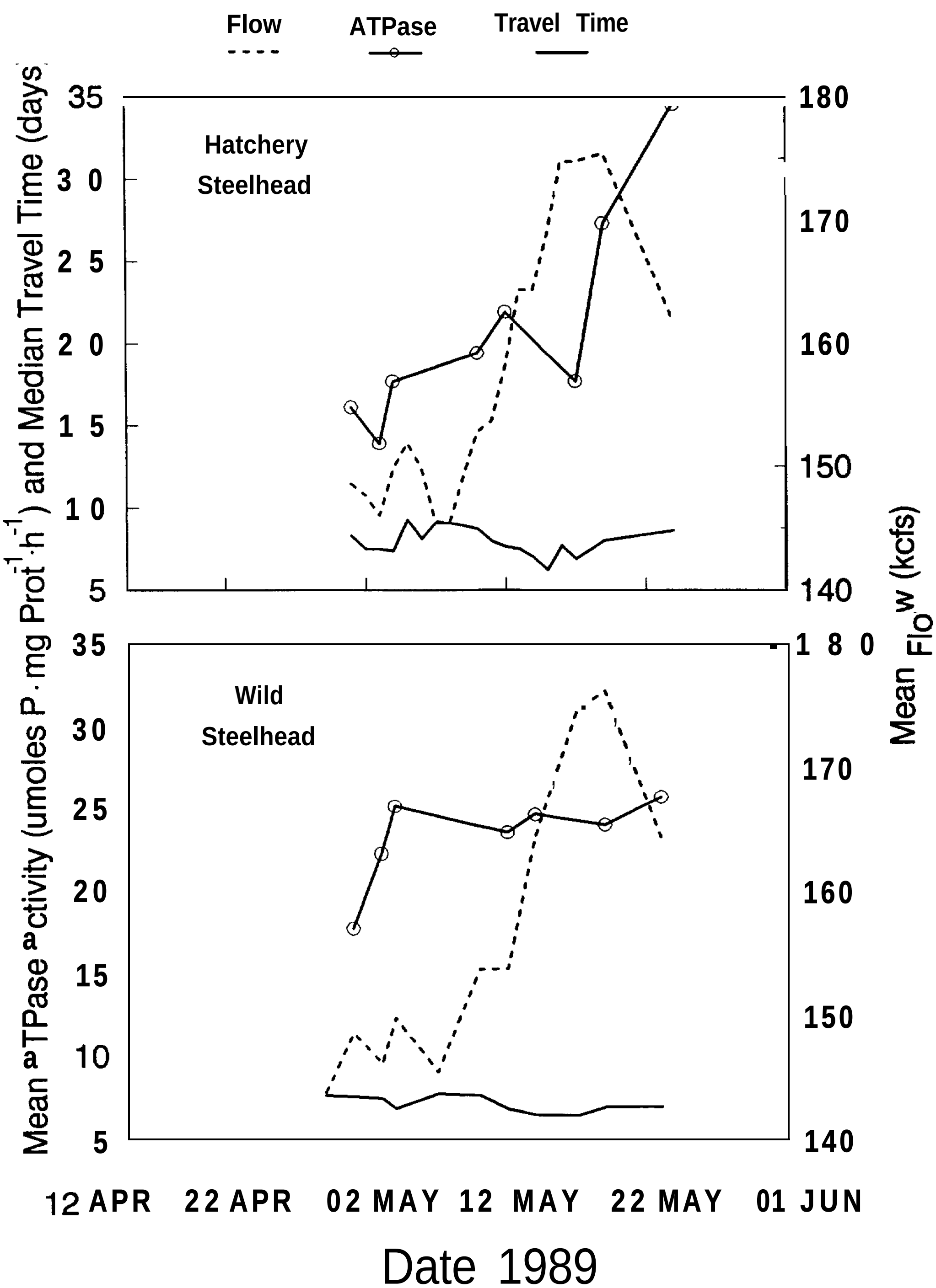


Figure 13. Mean flow, ATPase activity, and travel time of hatchery and wild steelhead from the run at large PIT tagged at Rock Island Dam, spring 1989. Flow and travel time data is from Fish Passage Center, 1990.

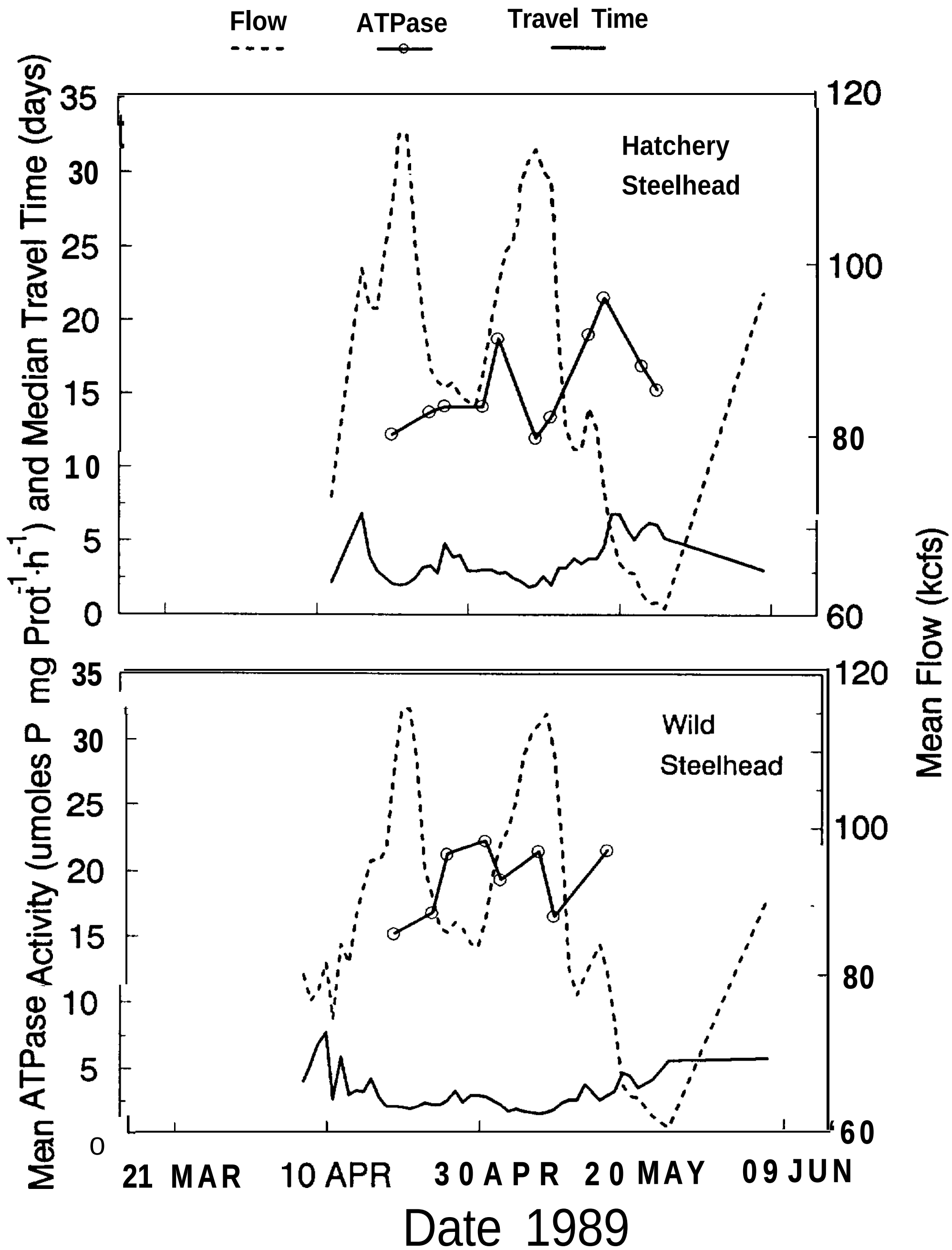


Figure 14. Mean flow, ATPase activity, and travel time of hatchery and wild steelhead from the **run at large PIT tagged at the Snake** River Trap, spring 1989. Flow and travel **time** data is **from Fish Passage Center, 1990.**

Wild steelhead had slightly lower median travel times when compared to hatchery steelhead under similar conditions, indicating a faster migration rate (Figures 13 and 14; Fish Passage Center 1990). Travel times of hatchery steelhead averaged about one day greater than wild steelhead in the upstream index reaches under the observed flows. The median travel time estimates for hatchery steelhead from Rock Island Dam to McNary Dam ranged from 6.2 to 9.3 d and from 6.5 to 7.8 d for wild steelhead (Fish Passage Center 1990). The median travel time estimates from the Snake River Trap to Lower Granite Dam ranged from 1.9 to 5.8 d for hatchery steelhead and from 1.7 to 3.4 d for wild steelhead during the period between April 16 and May 12, 1989.

The gill ATPase activity variables of PIT tagged steelhead did not explain the variability of travel time of steelhead. Flow and gill ATPase activity were not significant in the regressions when hatchery and wild steelhead released at Rock Island Dam were analyzed separately or when they were pooled (hatchery and wild steelhead; $N = 15$; $P > 0.05$). Analysis of the hatchery and wild steelhead data together is appropriate because, for the purpose of this analysis, the apparent difference between these fish is the degree of smoltification, reflected in ATPase activity, and we wanted to determine if smoltification influenced travel time through some causal mechanism.

The multiple regression analysis of travel times of hatchery and wild steelhead released from the Snake River Trap and detected at Lower Granite Dam revealed that the flow variable, LnFLOW, alone resulted in $R^2 = 0.91$ for hatchery steelhead ($N = 11$) and $R^2 = 0.84$ for wild steelhead ($N = 8$). Gill ATPase did enter models using the pooled data of hatchery and wild steelhead. In the regression model using un-transformed data mean gill ATPase was significant, but it explained only about 4% of the overall variability after the flow variable entered the equation ($R^2 = 0.87$, $P = 0.030$). The regression model using natural logarithm transformed data resulted in entry of the LnATP variable, but the variable explained only about 2% of the variability ($P = 0.110$). The variable LnFLOW alone proved to be equally useful in explaining the variability and the resulting equation was:

$$\text{LnMTT} = 9.72 - 1.9931\,\text{LnFLOW}$$
with $N = 19$ and $R^2 = 0.87$

Predicted travel times were closest to those in Buettner and Nelson (1990) using separate regressions for hatchery and wild steelhead. **We chose to used** regressions from Buettner and Nelson (1990) using raw flow rather than stratified flow, although predicted values of these equations are similar. For a flow of 70 kcfs, mean travel times **of** hatchery steelhead were 4.93 d and 5.1 d using Buettner and Nelson (1990) and our formulas, respectively. At 100 kcfs, predicted travel times were 2.76 and 2.62 d, respectively. For wild steelhead predicted travel times were 3.97 d and 3.86 d at 70 kcfs, and at 100 kcfs were 2.36 d and 2.27 d using Buettner and

Nelson (1990) and our formulas, respectively.

Discussion

Thyroxine

Plasma thyroxine is of particular interest because other investigators have found it to be related to migratory behavior of juvenile salmonids (Youngson and Simpson 1984; Birks et al. 1985). Hoar (1988) concluded that there is ample evidence that thyroid activity is usually elevated at the time of the typical Parr-smolt transformation. Furthermore, Folmar and Dickhoff (1981) in a review of predictive indices of smoltification described the relation between the proportion of the plasma thyroxine cycle that juvenile coho salmon had completed and the percent of surviving fish after six months of seawater rearing. These relations prompted us to include plasma thyroxine as a measure of smoltification.

In this study, the plasma thyroxine concentrations of marked hatchery fish recaptured at downstream sites may reflect the influence of lunar phase and the exposure to new or "novel water" sources. The plasma thyroxine concentrations of three groups of spring chinook salmon and two groups of steelhead increased during late April to early May, about the same time as the new moon of May 5, 1989. Several authors have studied the relationship between thyroxine dynamics and lunar cycles, and it is generally agreed that many other environmental factors may affect thyroxine dynamics as well (Mason 1975; Grau et al. 1982; Barron 1986). Recently, investigators have found that plasma thyroxine levels of chinook salmon were increased to a maximum about 10 days after experimental exposure to novel water chemistry such as would be experienced by exposure to the waters of various tributaries (Hoffnagle and Fivizzani 1990). The highest levels of plasma thyroxine we observed were during the first 20 d of the downstream migration, prior to maximum observed gill ATPase activities (Figure 7). This observation is in agreement with typical patterns of plasma thyroxine and gill ATPase activity described for yearling coho salmon, in which plasma thyroxine peaked prior to gill ATPase activity (Dickhoff et al. 1985). Birks et al. (1985) argues that high levels of plasma thyroxine are antagonistic to migration behavior and that increased disposition to migrate occurs as the plasma thyroxine concentrations decrease.

If high levels of thyroxine must occur prior to full development of the disposition to migrate, then the patterns of plasma thyroxine concentrations may be of interest to managers, particularly for the fish of hatchery origin. However, since there are many factors influencing thyroxine dynamics and changes in plasma thyroxine can occur in a matter of hours to days (Grau et al. 1982), the monitoring design may limit the use of plasma thyroxine as a variable. For example, if the increases are prerequisite to full development of migratory behavior during the first 10 to 20 d of migration, an increase in plasma thyroxine and subsequent decrease may be missed because many of the groups are not recaptured during the first 10 d of the migration. Restricting recaptures to smolt monitoring sites places limitations on any use of plasma thyroxine as a predictive variable.

Gill ATPase

Increased levels of gill ATPase activity among juvenile salmonids has been interpreted as indicating a more advanced degree of smoltification. Smoltification, as measured by gill ATPase activity during 1989, was similar to that observed in 1988 (Rondorf et al. 1989). This pattern was characterized by relatively low levels of ATPase activity in fish at release from the hatcheries. The spring chinook salmon from the mid-Columbia River basin had increasing ATPase activities during the month prior to release, while in 1988 activities declined during the two week period prior to release. Considering the relatively low levels of gill ATPase activities observed at the hatcheries, an increase was considered desirable, but we were unable to identify a cause for the difference between 1988 and 1989.

The large increase in mean ATPase activity of steelhead prior to release from Wells SFH may have been due to differences in the fish collection methods. Prior to marking at release, the fish were collected with an umbrella net from a large rearing pond, whereas the fish sampled at release were collected directly from raceways holding marked fish. These fish were collected from an emigrant trap at the outflow of the pond (personal communication, Steve Miller, Hatchery Manager, Wells SFH, Washington Department of Wildlife), and as emigrants, may have had higher ATPase activities than fish seined from the general population of the pond. The procedure should be examined closely to assure that fish marked are representative of the fish transported to the release sites.

The current strategy of monitoring physiological measures of smoltification three times prior to hatchery release and at the early, middle, and late portions of each brand groups migration past two dams is not necessarily the most efficient strategy for using this information along with travel time estimates. This strategy was designed to provide a broad base of information with which to evaluate smoltification and stress of branded groups. Other strategies may prove more efficient once data from several years are evaluated.

Seaward migratory behavior of smolts is currently believed to be passive rather than active, with fish using flow to transport them downstream. In this scenario, smoltification results in a change of behavior from one of actively resisting flow, as in natal streams, to one of passive migration. It is in this capacity that we believe smoltification, as measured by changes in gill ATPase activity, affects rates of travel during the seaward migration of salmonids.

Release of PIT tagged migrants at Rock Island Dam and the Snake River Trap enabled the Smelt Monitoring Program to estimate travel time of spring chinook salmon and steelhead for each day of release or over a period of several days. This data allowed the analysis of travel time, river flow, and gill ATPase as a measure of smoltification. The analysis is made possible because of the larger sample size resulting from travel times estimated from PIT tagged fish, whereas sample size for data from freeze branded fish is limited because it is collected from two sub-basins, 12 different hatcheries, two species, and three races of chinook salmon.

The travel time data from PIT tagged spring chinook salmon illustrates the relation of gill ATPase activity and river flow to travel time. The independent variables, gill ATPase activity and river flow, were intercorrelated, and therefore can carry redundant or misleading information (Snedecor and Cochran 1967). In simple regressions both parameters had similar r-squared values, however, because the ATPase variable was entered first by the stepwise regression procedure, the contribution of the flow variable was underestimated. Biologically, flow is probably a more important determinant of travel time than smoltification as measured by gill ATPase activity. Gill ATPase activity probably acts as a determinant within the constraints of flow.

The lack of a significant predictive relationship between ATPase activity and median travel time of hatchery and wild steelhead when a relationship was evident for spring chinook salmon may be expected. The ATPase activities of the steelhead changed little compared to those of the spring chinook salmon during the study period (Figures 12, 13, and 14). Regression analysis using data from sources such as the Smolt Monitoring Program, sometimes referred to as "unplanned data", can have independent variables with small ranges causing the corresponding regression coefficients to be found nonsignificant (Draper and Smith 1981), i.e., if an effective predictor variable does not vary, it will show little or no effect. The relatively small differences in median travel time of steelhead compared to the chinook salmon may further preclude a definitive relationship that would include any measure of smoltification. Data from steelhead will have to be collected over a wider range of ATPase activities, and perhaps travel times, to discern the relationship between ATPase activities and median travel time. Ideally, both travel time and ATPase activity would be measured from individual fish.

BKD IN SPRING CHINOOK SALMON

Introduction

In 1985, the Fish Passage Center (known then as the Water Budget Center) began using estimates of travel time to manage and evaluate the Water Budget. Estimates from groups of fish assumed to be similar varied widely, leading to the onset of monitoring biological attributes of fish groups. It was thought that physiological differences between groups may exist, and that these differences may help explain more of the variability in the travel time estimates than flow alone. One biological parameter examined was the prevalence and severity of bacterial kidney disease in spring chinook salmon caused by the bacterium Renibacterium salmoninarum. The effects bacterial kidney disease (BKD) could have on travel time estimates were unknown, but it was considered a parameter of interest since prevalences were known to be high in other groups of spring chinook salmon. Bacterial kidney disease could affect travel time estimates directly, by changing migration rates, indirectly, by causing mortality which could skew median dates of passage by altering the distribution of fish past index sites, or by a combination of these or other means.

Methods

The incidence of BKD in spring chinook salmon from Sawtooth SFH, Dworshak NFH, Leavenworth NFH, and Winthrop NFH was estimated. Kidney and spleen samples were collected at the hatcheries and at Rock Island Dam (Leavenworth NFH, Winthrop NFH), Lower Granite Dam (Dworshak NFH, Sawtooth SFH), and McNary Dam (all groups). Samples were stored in vials in liquid nitrogen until they reached the laboratory, where they were stored in a freezer **at - 80 C.**

Tissue samples were mashed and smears were analyzed using the fluorescent antibody test (FAT) with **a** loo-field count (McDaniel 1979). Samples were arbitrarily divided into one of four categories depending on the number of BKD conjugates as follows: negative, none found; low, 1-15; medium, 16-90; and high, greater than 90.

The same material was analyzed for antigen levels with an enzyme-linked immunosorbent assay (ELISA) using the method of Pascho et al. (1987). ELISA results were considered positive for BKD when optical densities were greater than or equal to 0.074. Samples were arbitrarily divided, based upon the optical density COD), into four categories: negative, less than 0.074; low, 0.074 to 0.120; medium, 0.121 to 0.280; and high, greater than 0.280. The FAT method was used to provide information consistent with methods used by the Augmented Fish Health Monitoring Program, however, we relied primarily on the results of the ELISA method because of its higher sensitivity. Few fish from Winthrop NFH and

Leavenworth NFH were collected at Rock Island Dam, so ELISA tests were not run on these samples. Similarly, few fish from Sawtooth SFH were recaptured at McNary Dam and ELISA tests were not run on these samples.

Results

The prevalence of BKD at the hatcheries, as determined with the ELISA method, ranged from 92% at Dworshak NFH to 100% at Leavenworth NFH. Prevalence of BKD as determined with the FAT and ELISA methods are summarized in Tables 2, 3, and 4. The BKD infections in fish from Sawtooth SFH and Dworshak NFH were much more severe than those at Leavenworth NFH or Winthrop NFH. Positive fish at Dworshak NFH and Sawtooth SFH had 46% and 47% with high optical densities, respectively, whereas those from Winthrop NFH had 12% and samples from Leavenworth NFH had no fish in this category (Table 3). In fact, most fish from Leavenworth NFH and Winthrop NFH had low optical densities at the hatcheries (84% and 67%, respectively).

Prevalence of BKD at Dworshak NFH (92%), as determined using the ELISA method, was about twice the level observed in 1988 (53%) and the percentage of fish with high antigen levels (46%) was 46 times higher (Rondorf et al. 1989). The prevalence of BKD at Sawtooth SFH (99%) was about the same as in 1988 (91%), and the percentage with high antigen levels (47%) was about 7 times higher than in 1988. Prevalence of BKD at Winthrop NFH (96%) was higher than in 1988 (79%), but the percent with high antigen levels remained about the same (13% and 12% in 1988 and 1989, respectively). Fish from Leavenworth NFH were not tested for BKD in 1988.

When recaptured at downstream dams, prevalence of BKD of each hatchery group, as determined with ELISA, was similar or slightly lower than that prior to release, but the percentage with high antigen levels was much lower in the group from Sawtooth SFH sampled at Lower Granite Dam (22%) and Dworshak NFH group sampled at McNary Dam (17%) (Table 3; Figure 15). The percent of fish with high antigen levels in Winthrop NFH and Leavenworth NFH groups changed little between the hatchery release and recapture at McNary Dam (Figure 16). The mean percent of fish from Winthrop NFH showing visual signs of BKD at McNary Dam was 2, 3, and 23% at the early, middle, and late parts of their passage, respectively. This difference is highly significant (chi-square = 20.5, N = 184, df = 2, p = 0.000). No other group examined showed this pattern when recaptured at any dam.

The Dworshak NFH group was the only group from which numbers sufficient for adequate BKD analysis were collected at two dams. The prevalence of BKD of this group was slightly lower at Lower Granite (83%) and McNary (80%) dams than at the hatchery (92%) but the distribution of low, medium, and high antigen levels at McNary the fraction with high optical densities was about half (17%) that

Table 2. Prevalence of BKD (%) in spring chinook salmon from four Columbia and Snake river hatcheries as determined by Enzyme Linked Immnunosorbent Assay (ELISA) and Fluorescent Antibody Test (FAT). Fish were collected at the hatchery and at downstream dams after release.

	SAMPLING SITE							
Stock	Hatchery		Lower Granite		Rock Island		McNary Dam	
	ELISA	FAT	ELISA	FAT	ELISA	FAT	ELISA	FAT
Dworshak NFH	92	33	82	48			80	21
Sawtooth SFH	99	54	100	29			(a)	30
Leavenworth NFH	100	8			(a)	2	97	8
Winthrop NFH	96	17			(a)	8	96	30

(a) ELISA not performed due to low numbers collected.

Table 3. Results of the Enzyme Linked Immunosorbent Assay (ELISA) for bacterial kidney disease in spring chinook salmon from four Columbia and Snake river hatcheries. Positive samples are divided into three categories based upon the optical density (LOW, 0.074-0.120; MEDIUM, 0.121-0.280; HIGH, greater than 0.280). 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 %
Dworshak NFH	92	38	8	46	98	3
Lower Granite Dam	82	30	10	42	176	10
McNary Dam	80	51	12	17	136	5
Sawtooth SFH	99	38	14	47	86	24
Lower Granite Dam	100	46	32	22	100	6
McNary Dam [a]						
Leavenworth NFH	100	84	16	0	99	0
Rock Island Dam [a]	-	-				
McNary Dam	97	86	9	2	173	0
Winthrop NFH	96	67	17	12	100	9
Rock Island Dam [a]	-	-				
McNary Dam	93	59	16	18	182	9

[a] ELISA not performed due to low numbers collected.

Table 4. Results of the Fluorescent Antibody Test (FAT) for bacterial kidney disease in spring chinook salmon from four Columbia and Snake river hatcheries. Positive samples are divided into three categories based upon the number of conjugates found in 100 fields (low, 1-15; medium, 16-90; high, greater than 90) 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 %
Dworshak NFH	33	16	8	9	99	3
Lower Granite Dam	48	11	2	35	175	10
McNary Dam	21	8	4	9	138	5
Sawtooth SFH	54	5	5	44	100	24
Lower Granite Dam	29	17	3	9	99	6
McNary Dam	30	15	3	12	34	12
Leavenworth NFH	8	7	0	1	99	0
Rock Island Dam	2	2	0	0	42	0
McNary Dam	8	8	0	0	194	0
Winthrop NFH	17	9	2	6	99	9
Rock Island Dam	8	4	4	0	28	0
McNary Dam	30	13	1	16	184	9

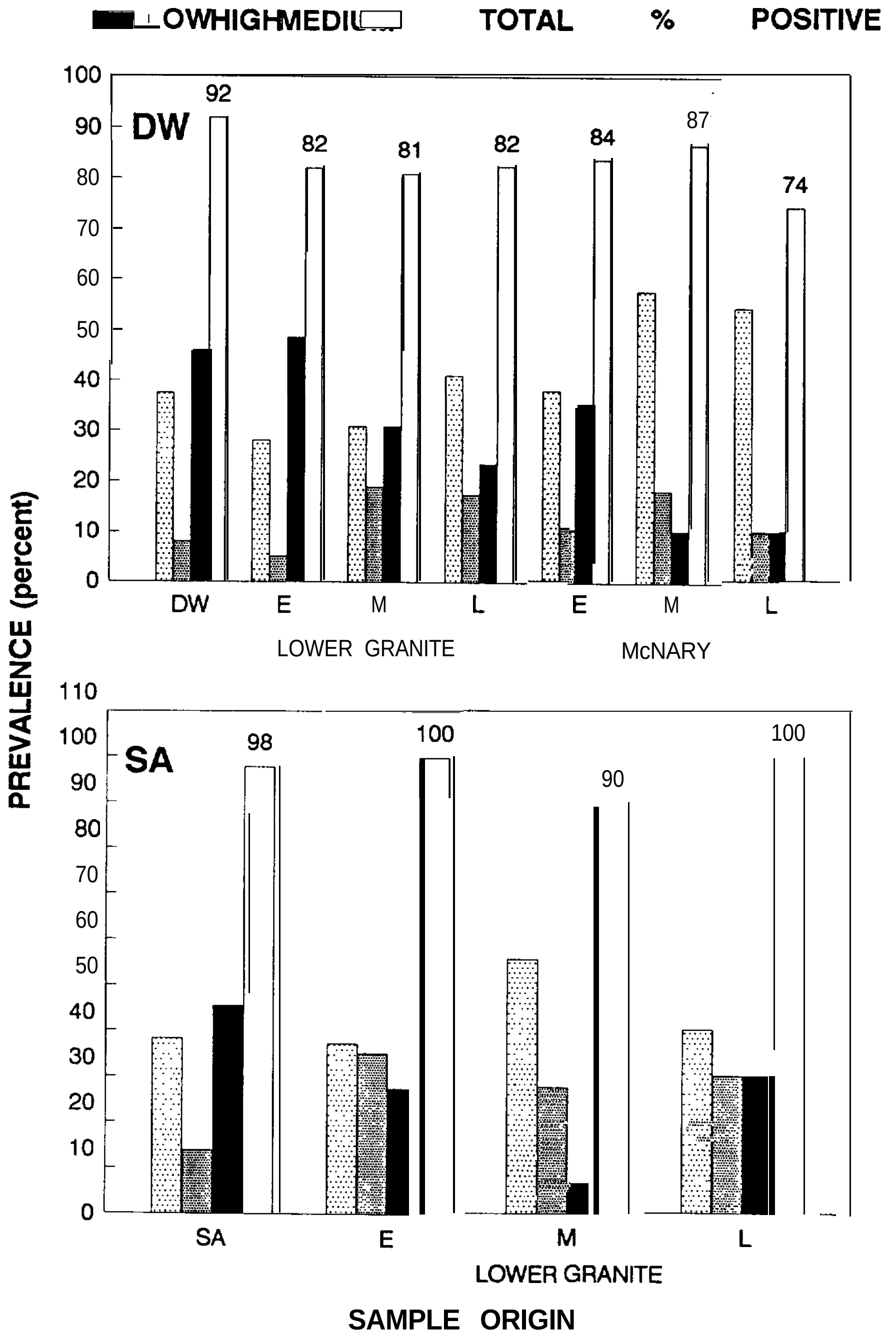


Figure 15. Prevalence of bacterial kidney disease in spring chinook salmon from Dworshak NFH (DW) and Sawtooth SFH (SA) determined using the enzyme-linked immunosorbent assay. Samples were collected from the hatchery (DW, SA) and at the early (E), middle (M), and Late (L) portions of their migrations past McNary and or Lower Granite dams, spring 1989.

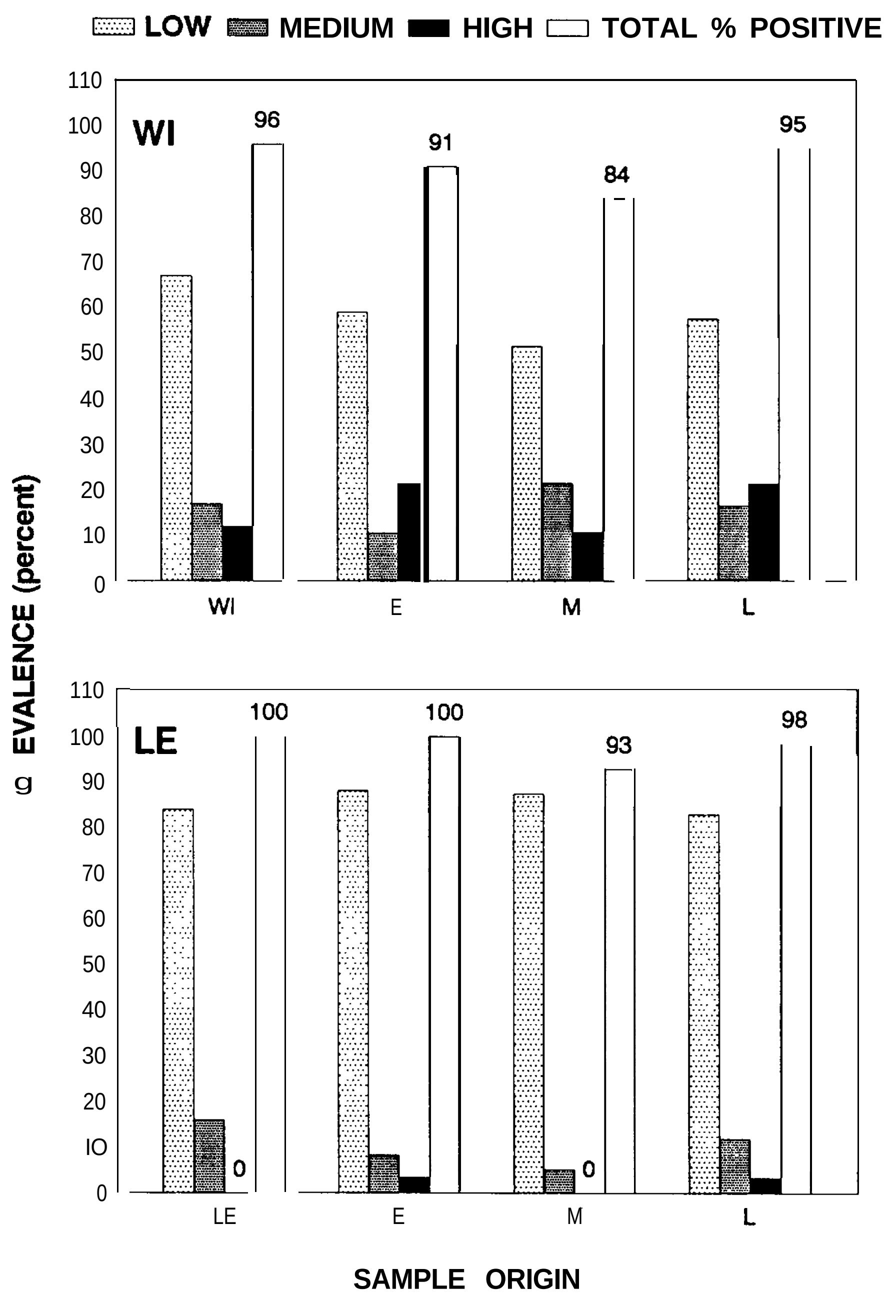


Figure 16. Prevalence of bacterial kidney disease in spring chinook salmon from Winthrop NFH (WI) and Leavenworth **NFH (LE)** determined using the enzyme-linked immunosorbent assay. **Samples were collected** from the hatchery (WI, LE) and at the early (E), middle (M), and Late (L) portions of their migrations past McNary Dam, spring 1989.

Dam was markedly different than at the other sites. At McNary Dam at either Lower Granite Dam (42%) or the hatchery (46%), indicating the fish with the most severe infections had disappeared from the sample population by the time it reached McNary Dam. Also at McNary Dam, the fractions with high antigen levels were lower in the middle and late portions of the passage than they were during the early part.

Discussion

The results of ELISA tests for BKD can be initially misleading, since prevalences near 100% are not uncommon. A positive result with the ELISA method means that, in the tissue examined, the optical density, an indicator of soluble antigen produced by the bacterium Renibacterium salmoninarum, is higher than the optical density of samples from fish known to be "BKD free", or "unexposed" to R. salmoninarum. In any closed population containing individuals with infections of BKD, such as a raceway or pond, there is a high probability that all other fish in that population will be exposed to the bacterium and will therefore be diagnosed as positive using the ELISA method. It is important to note that a positive result does not imply impending death - only that the fish has been exposed. Unfortunately, there appears to be nothing in the literature to answer the question "At what antigen level are fish going to die?".

The advantage of ELISA over other methods of BKD detection is the sensitivity and specificity - not because of the total prevalence that can be determined, but because of the increased power with which it can be used to examine the distribution of antigen levels within the population. Thus, a population with a prevalence of 100% containing 84% with low antigen levels (Leavenworth NFH, 1989) is in a more desirable condition than one with a prevalence of 92% and 46% with high antigen levels (Dworshak NFH, 1989). Such analysis can be performed with other methods of BKD detection, but none have the sensitivity and specificity of the ELISA method.

The prevalence of BKD in most groups tested in 1989 was higher than when fish from the same hatcheries were tested in 1988, and more importantly, the percentage of the samples with high antigen levels from the two Snake River hatcheries were many times higher than they were in 1988 and they were also much higher than those of the two mid-Columbia hatcheries. As in 1988, fish from Winthrop NFH had a much higher percentage of fish with visible signs of BKD in the late part of the migration past McNary Dam than those of the early and middle parts. We do not observe this phenomenon in fish from other hatcheries and at this time have have no explanation for it.

Since the percentage of fish from Dworshak NFH with high antigen levels was lower at McNary Dam than at the hatchery or Lower Granite Dam, it appears that fish in this category either died or ceased to migrate during the migration between Lower Granite Dam and McNary Dam, or between a median sample date of 28 d and 48 d after release. The data from Sawtooth SFH also indicates this trend, although data was not available from sites closer to the hatchery than Lower Granite Dam, a median sample date of 35 days after release. Other possible explanations for the disappearance of these fish from the sample population include: 1) fish with high antigen levels cease to migrate; 2) there was a difference and/or bias in sampling efficiency of BKD infected fish at these dams; and 3) fish with high antigen levels recover.

Pascho and Elliott (1989), in a study of impacts of BKD on survival of fish used in the transportation program, present data indicating mean ELISA OD (antigen level) increases during the late part of the spring and summer chinook out-migration past Lower Granite and Little Goose and dams. This may lend support to the hypothesis that fish with the highest antigen levels migrate slower than other fish, but it does not support our findings of fewer of these fish with time. One difference between their study and ours that should be noted is that we were sampling specific marked hatchery releases with known times of in-river migration, whereas Pascho and Elliott (1989) were sampling the migration at large, comprised of hatchery and wild groups with varying and unknown in-river migration times.

Matthews et al. (1988) collected fish at Lower Granite Dam on three dates and found a bias in that system. They found the prevalence of BKD was higher in guided than in unguided smolts. This type of bias would overestimate the percent of the population with high antigen levels, not underestimate them. Therefore, it seems unlikely that the difference was due to a sampling bias, unless there were multiple biases occurring at different rates at each dam. Although there is some evidence that infected fish can recover (Cvitanich 1987), recovery would seem least likely for individuals with high antigen levels.

Losses of fish due to BKD could have detrimental effects on travel time estimates. For example, at Dworshak NFH 46% of the sample population had high antigen levels and 17% had them at McNary Dam. Extrapolating these numbers to the branded release of 58,716 fish, a total of 27,009 fish had high antigen levels at the hatchery and 9,982 at McNary Dam, leaving a 29% difference, or 17,027 fish with high antigen levels which presumably never migrated past McNary Dam. The prevalence of BKD among fish from Dworshak NFH collected at Lower Granite and McNary dams indicate the proportion of fish with high antigen levels decreases as fish pass each project, so that the early migrants have the highest and the late migrants have the lowest numbers of fish in this category. The loss of fish with high antigen levels from the population would then be analogous to removal of fish for the smolt transportation program, the effect of which is to change the distribution of fish, resulting in biased travel time estimates (Skalski 1988). In addition to the effects on travel time estimates, the effects of losses of this magnitude on overall spring chinook salmon production could be grave.

PART TWO: DEVELOPMENT OF AN INDEX OF BMOLTIFICATION

Introduction

An index of fish condition would be a useful tool in summarizing the many attributes of smolt condition for in-season management of the Water Budget and for comparison of years with varied flow regimes. Ideally, such an index would account for a large percentage of the variation observed in fish condition, be non-lethal to allow repeated examination of individual fish, and be readily measured so that it could be available for in-season management decisions on a daily basis.

Other indices are currently applied to fisheries and used in the Smolt Monitoring Program. The fish passage indices are used as indicators of the relative abundance of smolts migrating past monitoring sites and are used to assist with the in-season management of the Water Budget. At selected hatcheries throughout the Columbia River basin an organosomatic analysis is applied by state and federal agencies to assess health and condition of smolts prior to release. The organosomatic analysis approach continues to be developed as the fish health condition profile by Ronald W. Goede, Utah Division of Wildlife and Joseph B. Hunn, National Fisheries Contaminant Research Center, USFWS.

Three attributes of smoltification, changes in the length-weight relation, body morphology, and purine content of the skin are considered here as potential measures for an index of smoltification. Changes in the length-weight relation during smoltification are reflected in the streamline body shape of smolts compared to Parr. The purine content is being investigated as a quantitative measure to determine the validity of using a measure of silvering as a component of a smoltification index. Silvering is due to the deposition of purines, mainly guanine and hypoxanthine, in the skin and scales of salmonids during the smolt transformation (Markert and Vanstone 1966; Lee et al. 1969).

Methods

Fork length and body weight of each fish were recorded to estimate the condition factor of fish at the hatcheries and dams. Spring chinook salmon from Leavenworth NFH, Winthrop NFH, and Dworshak NFH and steelhead from Wells SFH (Methow River release group) were measured to the nearest millimeter. Weights of these fish were measured to the nearest 0.1 gram. Condition factor was calculated as $K = (\text{weight}/(\text{fork length} \cdot 10^3)) \cdot 10^5$.

Photographs of each fish were used to record the body shape during collection at the hatchery and at the dams using methods adapted from Winans (1984). Photographs of spring chinook salmon from Winthrop NFH and Dworshak NFH and steelhead from Wells SFH were collected at the hatchery and at McNary Dam for later analysis. A digitizer was used to record X and Y coordinates of specific points on the photographs, forming a truss network (Bookstein et al. 1985). The actual length of each line segment was calculated from the X and Y coordinates and a scale on each photograph. Principal components analysis was applied to data of marked fish collected at the hatcheries and at McNary Dam (SAS 1988). The second principal component was sheared to remove size effects based on a program from Bookstein et al. (1985). The individual eigenvector scores of the first principal component, describing mostly size, and the second principal component sheared for size, describing body shape (Pimentel 1979; Bookstein et al. 1985), were further analyzed using the Kruskal-Wallis test (SAS 1988). The shape of fish was considered different when the Kruskal-Wallis test for sheared second principal component eigenvector scores of fish collected at the hatchery and dam were significantly different ($P < 0.05$).

The degree of silvering of spring chinook salmon from Winthrop NFH, Leavenworth NFH, and Dworshak NFH were quantitatively measured by determining the amount of guanine in skin using the guanase and xanthine oxidase enzyme assay described by Staley (1984) with minor modification. The mean guanine content of skin samples was examined for correlation with mean plasma thyroxine, mean gill ATPase, and date of sample using Pearson product-moment correlation. In the text, use of the term significant refers to statistically significant relation at the probability $P < 0.05$ unless reported differently.

Results

Mean condition factor (K) of spring chinook salmon and steelhead groups sampled was characterized by little change at the hatchery and declines after release (Figure 17; Appendices 36 and 37). When marked smolts reached McNary Dam, mean K had declined by about 40%. The decline in K values indicated that for a given fork length, fish weighed less when collected at the dam than when collected at the hatchery. Values from spring chinook salmon and steelhead were similar, although steelhead had slightly lower mean **K** values than spring chinook salmon at Rock Island Dam. Mean K was significantly correlated with mean gill ATPase activity in spring chinook salmon ($r = -0.78$; $N = 30$; $P < 0.0001$) and steelhead ($r = -0.87$; $N = 11$; $P < 0.0005$).

Principal components analysis indicated changes in size and body shape of fish as they migrated from the hatchery to McNary Dam. A plot of the principal component scores for each fish illustrates a shift to the right in the coordinates along the first principal component, or x-axis, for fish collected at McNary Dam (Figure 18). The increase in scores of the first principal

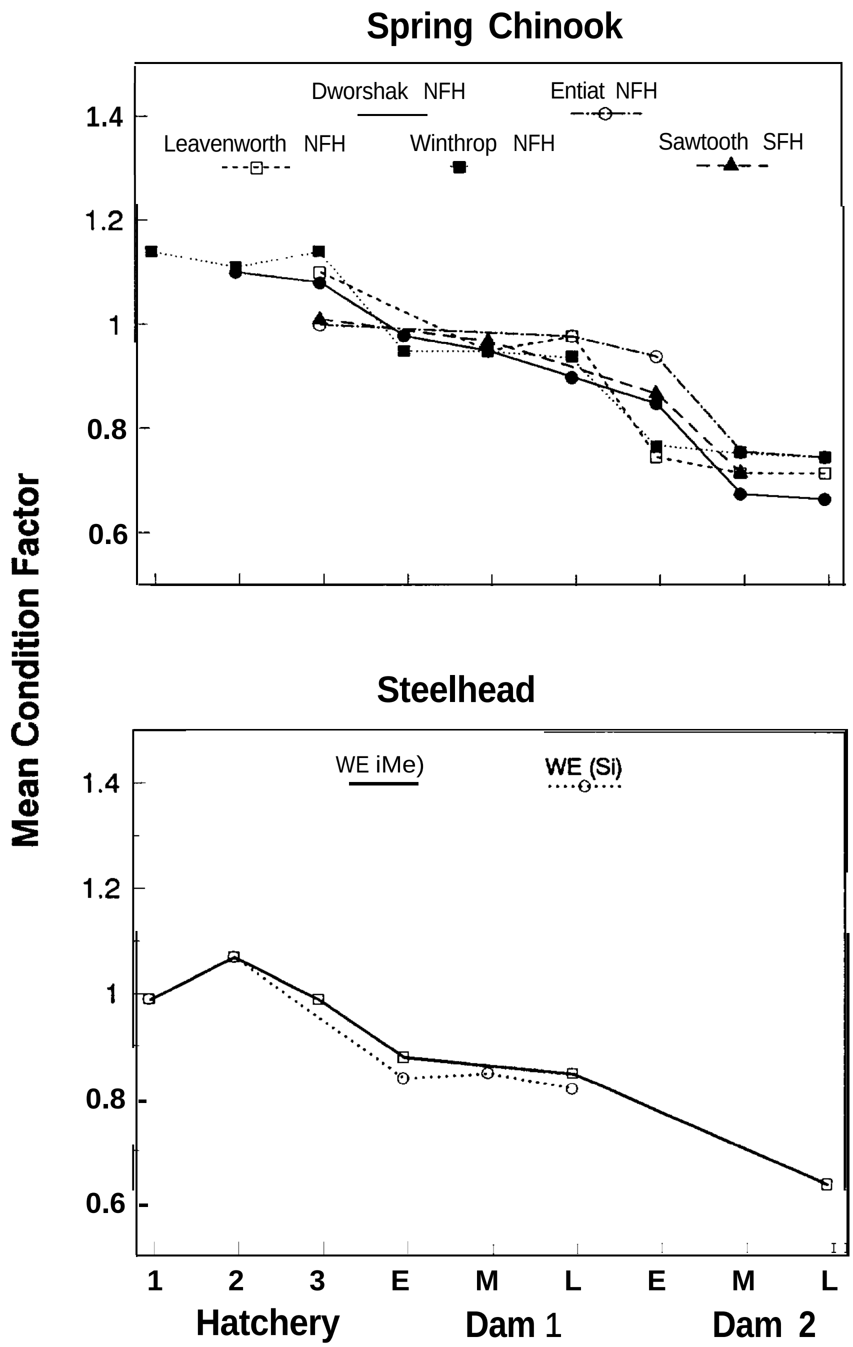


Figure 17. Mean condition factor of spring chinook salmon and steelhead, spring 1989. Samples were collected one month (l), two weeks (2), and shortly before release (3) and again at the early (E), middle (M), and late (L) portions of the migration past Rock Island or Lower Granite dams (DAM1) and McNary Dam (DAM2).

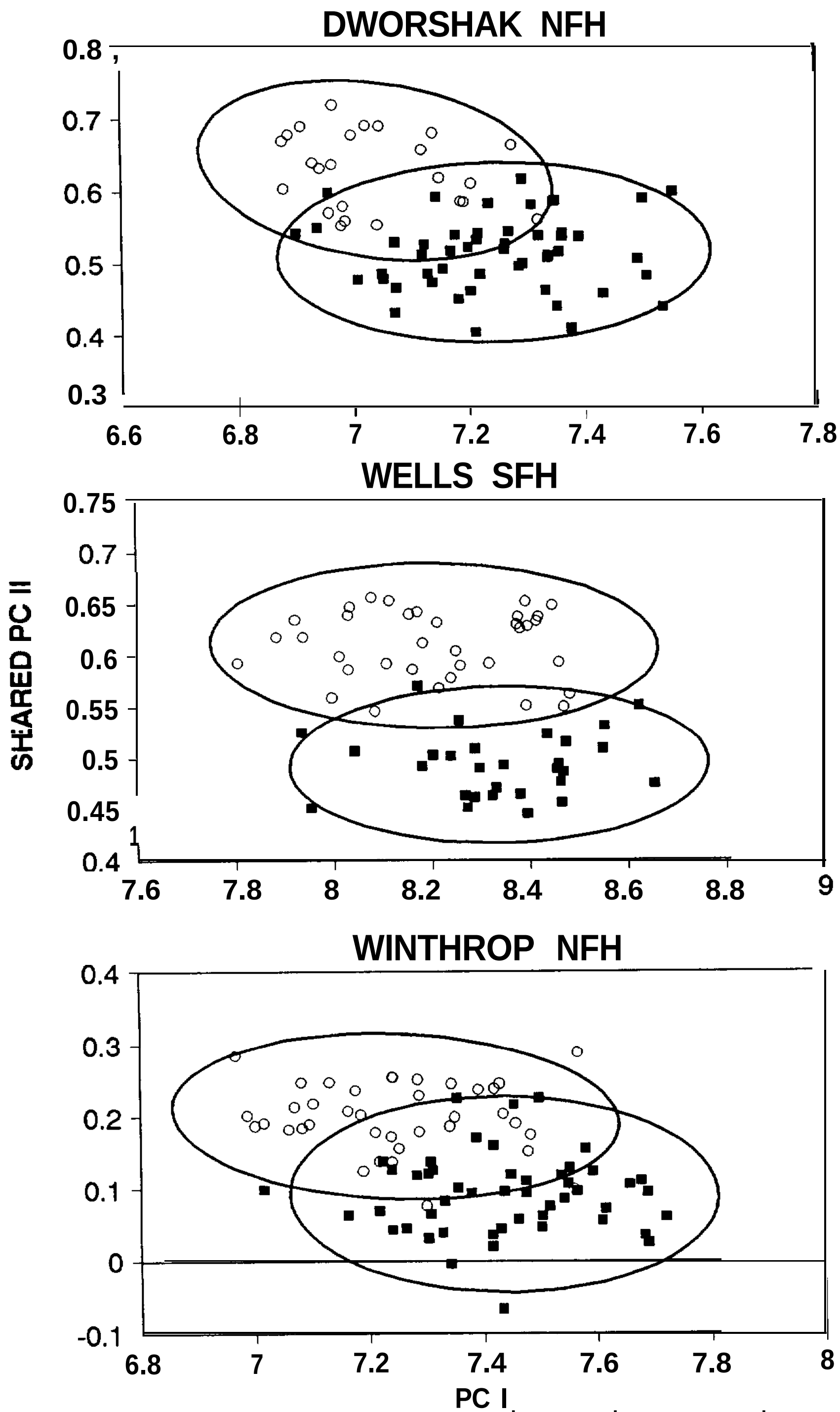


Figure 18. First (PCI) and sheared second components from principal components analysis of 34 morphometric variables of spring chinook salmon from Dworshak NFH and Winthrop NFHs and steelhead from Wells SFH, spring 1989. Samples were collected shortly before release from the hatcheries (0) and at the early, middle, and late portions of the migration past McNary Dam (m)

component (PCl) are indicative of a significant increase in size of the fish at McNary Dam compared to fish at the hatcheries (Kruskal-Wallis test; $P < 0.05$). The increase in size is also evidenced by the shift to the right of the 95% confidence ellipsoids illustrated in Figure 18. The mean fork length of spring chinook salmon released from Dworshak NFH increased from 128 mm at the hatchery to 138 mm at McNary Dam. Fish from Winthrop NFH increased from 132 mm at the hatchery to 141 mm at McNary Dam. The mean fork length of steelhead from Wells SFH increased from 198 mm to 210 mm.

The shearing process removes size effects from the second principal component and permits a comparison of shape free of the effects of size. Fish recaptured at McNary Dam had lower scores of the second principal component and a resultant downward shift of the 95% confidence ellipsoids along the y-axis. Significant decreases in the second principal component scores were evident within spring chinook salmon and steelhead groups when fish from the hatchery were compared to fish recaptured at McNary Dam (Kruskal-Wallis test: $P < 0.001$).

Mean guanine concentration in skin of spring chinook salmon tested increased after release from the hatchery and peaked in late April-early May (Figure 19; Appendices 38-40). This peak was similar in timing to the peak of mean plasma thyroxine of these groups (Figures 7 and 9; Appendices 15-17). A significant correlation exists between mean guanine levels and mean plasma thyroxine concentrations of spring chinook salmon ($r = 0.52$; $N = 21$; $P < 0.05$), but mean gill ATPase was not correlated with mean guanine ($P > 0.05$).

Mean guanine concentrations in the skin of steelhead from Wells SFH (Methow River release) were about half the levels observed in the spring chinook salmon (Figure 19; Appendix 41). Mean guanine of steelhead increased slightly with time and was correlated with gill ATPase activity after release from the hatchery ($r = 0.90$; $N = 7$; $P < 0.01$) and with sample date ($r = 0.87$; $N = 7$; $P < 0.05$), but not with plasma thyroxine concentrations ($P > 0.05$).

Discussion

The condition factor, K, was considered a potential component of an index of smoltification and was examined for correlations with gill ATPase activity levels because ATPase activity has been widely applied as a measure of smoltification for research activities and management purposes. The correlations with ATPase activity support the use of K as a non-lethal component of an index of smoltification. Inasmuch as K is likely related to the well known shape changes and gill ATPase activity is related to the osmoregulatory development of the smolt, there is no functional relation that dictates the two measures should be closely correlated, although changes in both occur during smoltification.

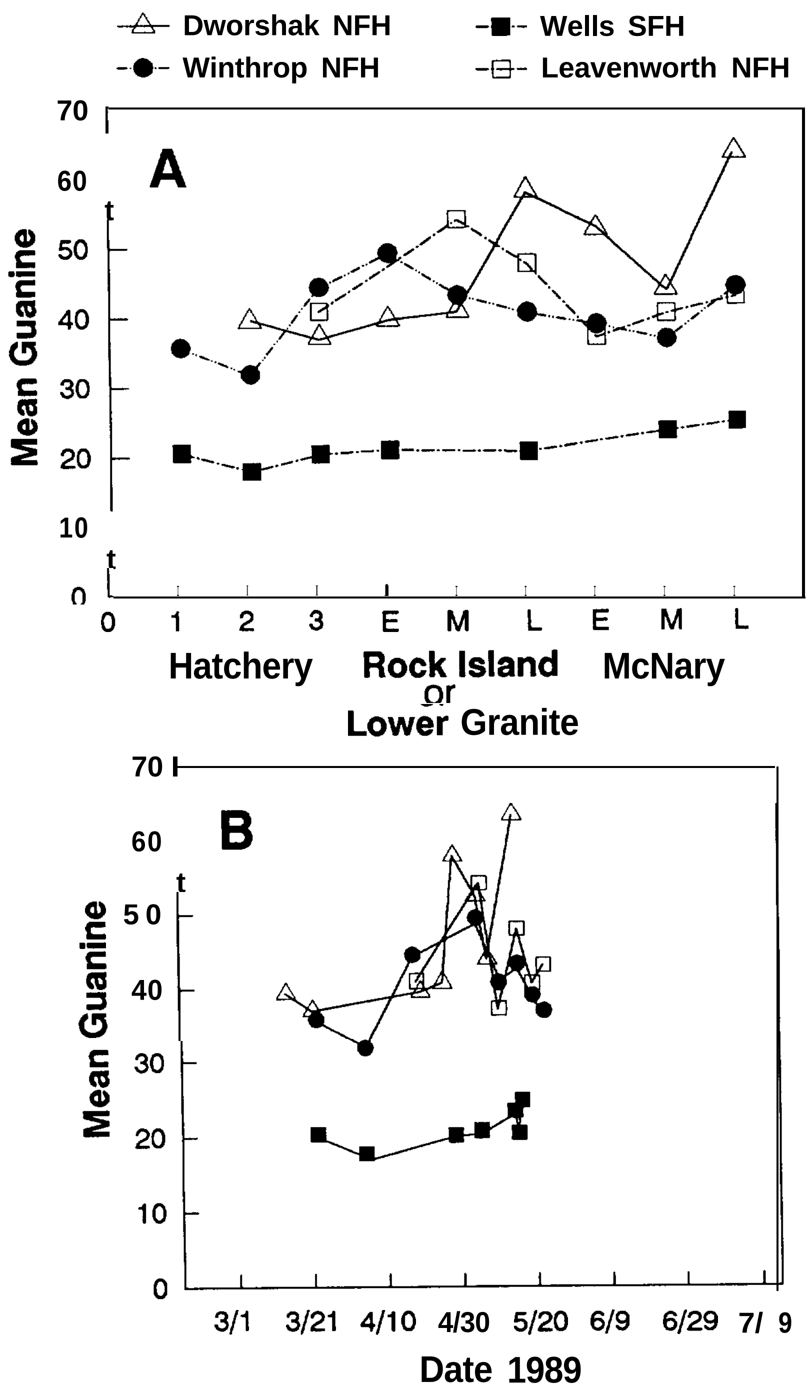


Figure 19. Mean guanine $(mg \cdot g\ tissue^{-1})$ in skin and scales of spring chinook salmon and steelhead (Wells SFH only) from mid-Columbia and Snake river hatcheries, spring 1989. Samples were collected one month (1), two weeks (2), and shortly before release (3) and again at the early (E), middle (M), and late (L) portions of the migration past Rock Island or Lower Granite dams and McNary Dam.

However, condition factor can be affected by variables other than smoltification, for example, fish health and food ration level, which may place limitations on its use in an index. The relative importance of the health and feeding ration must be placed in perspective of the 40% decline in K values between values at the hatcheries and at McNary Dam. However, caution should be used because the effects of limited food consumption by smolts of hatchery origin after release may play a role in our observations.

Analysis of morphological variables of smolts can be used to illustrate changes in shape and size as fish migrate seaward. However, ATPase activity of fish at release and at McNary Dam is usually significantly different while some overlap is evident in the 95% confidence ellipsoids of the second principal component sheared for size (Figure 18). On the other hand, morphometric data does have the advantage of collection with minimal or no effect on the fish and may lend itself to video analysis. In an index, an average of the eigenvector of the second principal component for each fish (values plotted in Figures 18) could be used, or they could be used in a discriminant function or regression predicting smoltification. We will continue to investigate the use of morphology in a smoltification index due to its non-lethal nature and promise for automation.

The guanine levels in the skin of spring chinook salmon were correlated with plasma thyroxine, itself an indicator of smoltification. However, the mechanism of guanine deposition in skin and scales results in a much more stable parameter than plasma thyroxine, the dynamics of which can vary dramatically from day to day. Deposition of guanine in the skin may be an adaptation for the silvery appearance common to pelagic marine fishes, but the deposition also reflects physiological adaptation for the marine environment as an efficient way of disposing of guanine. Guanine is an insoluble by-product of nitrogen metabolism which is presumably more efficient to deposit in the skin than to further metabolize and excrete in a soluble form in a saline environment (Hoar 1988). Since smoltification is characterized by numerous changes in metabolism, the increased levels of guanine may reflect the metabolic changes. Chua and Eales (1971) induced increases in guanine and hypoxanthine of brook trout (*Salvelinus fontinalis*) by increasing thyroxine levels using thyroid powder and thyroid stimulating hormone. Since other investigators have indicated plasma thyroxine has a role in metabolism and is characteristic of smoltification, the correlation of guanine and thyroxine may be useful. The high correlation coefficient between gill ATPase and guanine of the Wells SFH steelhead group is similar to that found by other investigators (Rodgers et al. 1987), but more data is needed to confirm this relation. Results thus far indicate that guanine, specifically some type of non-lethal measure of silvering, may be of use in a smoltification index.

SUMMARY

1) As in 1988, most groups performed satisfactorily in the 30-s handling-stress challenges. Unsatisfactory responses to the stress challenge occurred when yearling chinook salmon were transported from McCall SFH and Rapid River SFH. Marking and transportation protocols for steelhead from Wells SFH resulted in stressed fish at the time of release. We recommend that monitoring stress at release of groups that are not transported be reduced or discontinued in this program.

2) We encourage agencies to develop procedures of quality control and increased accountability to minimize stress on fish during transport.

3) Mean gill ATPase activities of spring chinook salmon from mid-Columbia hatcheries were rising during the 2-week period prior to release, whereas they declined prior to release in 1988. Gill ATPase activities of branded hatchery releases of chinook salmon and steelhead rose for about the first 20 days after release, changing little afterward. We believe this is due to a partially time-dependent relation between days of migration and post-release increases in gill ATPase activity.

4) Mean plasma thyroxine concentrations of juvenile chinook salmon released from hatcheries was highest during the first 20 days after release, subsequently returning to low levels.

5) This was the first year of sampling the juvenile salmonid migration-at-large. At the upstream sites of Rock Island Dam, Lower Granite Dam, and the Snake River Trap, gill ATPase activity of wild steelhead was significantly higher than hatchery-reared steelhead, but not downstream at McNary Dam. Maximum gill ATPase activity of spring chinook salmon occurred late in the migration past upstream sites, at about the 90th percentile of passage, and at about the 50th percentile of passage at McNary Dam.

6) Preliminary regression analyses indicate that gill ATPase activity and flow variables can be used as predictors of travel time of spring chinook salmon, describing 68-87% of the variation in travel times, depending on the site.

7) A flow variable alone was the best predictor of travel time of steelhead (hatchery and wild combined), describing 87% of the variation in travel time. Travel times and gill ATPase activity of steelhead varied little compared to spring chinook salmon.

8) Prevalence of bacterial kidney disease in spring chinook salmon from four hatcheries was generally higher than in 1988, ranging from 92-100% in samples at the hatcheries and 81-100% in samples from fish collected at dams. Although overall prevalences

were similar in mid-Columbia and Snake river hatcheries, the samples from the Snake River hatcheries had a much larger percentage of fish with high antigen levels as indicated by ELISA. Data suggests that fish with the most severe infections disappear from populations of migrants collected at Lower Granite and McNary dams, which could bias travel time estimates.

9) Correlations with gill ATPase activity and/or plasma thyroxine concentrations indicate condition factor, morphology, and skin guanine concentrations may all be useful indicators of smoltification. We will continue to collect data on these parameters to further evaluate their use as non-lethal measures of smoltification.

LITERATURE CITED

Barron, M.G. 1986. Endocrine control of smoltification in anadromous salmonids. Journal of Endocrinology 108:313-319.

Barton, B.A., C.B. Schreck, R.D. Ewing, A.R. Hemmingsen, and R. Patino. 1985. Changes in plasma cortisol during stress and smoltification in coho salmon, Oncorhynchus kisutch. General and Comparative Endocrinology 59:468-471.

Barton, B.A., and C.B. Schreck. 1987. Influence of acclimation temperature on interrenal and carbohydrate stress responses in juvenile chinook salmon (Oncorhynchus tshawytscha). Aquaculture 62:299-310.

Birks, E.K., R.D. Ewing, and A.R. Hemmingsen. 1985. Migration tendency in juvenile steelhead trout, Salmo grairdneri Richardson, injected with thyroxine and thiourea. Journal of Fish Biology 26:291-300.

Bookstein, F.L., B. Chernoff, R.L. Elder, J.M. Humphries, G.R. Smith, and R.E. Strauss. 1985. Morphometrics in Evolutionary Biology. Special Publication 15, The Academy of Natural Sciences of Philadelphia.

Buettner, E.W. and V.L. Nelson. 1990. Smolt condition and timing of arrival at Lower Granite Reservoir. 1989 annual report. Prepared by Idaho Department of Fish and Game, Lewiston, Idaho, for Bonneville Power Administration, Portland, Oregon.

Chua, D., and J.G. Eales. 1971. Thyroid function and dermal purines in the brook trout, Salvelinus fontinalis (Mitchill). Canadian Journal of Zoology. 49:1557-1561.

Cvitanich, J. 1987. Renibacterium salmoninarum "bar forms": Evidence of a host response to bacterial kidney disease infection. Pages 55-57 *in* B.D. Hicks and W. Pennell, editors. Bacterial kidney disease research planning meeting (October 16, 1987). B.C. Ministry of Agriculture and Food, Abbotsford, and B.C. Salmon Farmers Association, West Vancouver.

Dickhoff, W.W., L.C. Folmar, and A. Gorbman. 1978. Changes in plasma thyroxine during smoltification of coho salmon, Oncorhvnchus kisutch. General and Comparative Endocrinology 36:229-232.

Dickhoff, W.W., G. Sullivan, and C.V.W. Mahnken, 1985. Methods of measuring and controlling the parr to smolt transformation (smoltification) of juvenile salmon. Pages 5-9 *in* C.J. Sniderman, editor. Proceedings of the eleventh U.S.-Japan meeting on aquaculture, salmon enhancement, Tokyo, Japan, October 19-20, 1982. NOAA technical report NMFS-27. National Marine Fisheries Service, U.S. Department of Commerce, Washington D.C.

Draper, N.R., and H. Smith. 1981. Applied regression analysis. John Wiley and Sons, New York.

Fish Passage Center. 1990. Fish Passage Managers 1989 annual report. Prepared by the Fish Passage Center of the Columbia Basin Fish and Wildlife Authority for Bonneville Power Administration, Portland, Oregon.

Folmar L.C., and W.W. Dickhoff. 1981. Evaluation of some physiological parameters as predictive indices of smoltification. Aquaculture 23:309-324.

Grau, E.G., W.W. Dickhoff, R.S. Nishioka, H.A. Bern, and L.C. Folmar. 1981. Lunar phasing of the thyroxine surge preparatory to seaward migration of salmonid fish. Science 211:607-609.

Grau, E.G., J.L. Specker, R.S. Nishioka, and H.A. Bern. 1982. Factors determining the occurrence of the surge in thyroid activity in salmon during smoltification. Aquaculture 28:49-57.

Hoar, W.S. 1988. The physiology of smolting salmonids. Pages 275-343 *in* W.S.Hoar and D.J. Randall, editors. Fish Physiology, volume 11. Academic Press, New York.

Hoffnagle, T.L., and A. J. Fivizzani. 1990. Stimulation of plasma thyroxine levels by novel water chemistry during smoltification in chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 47:1513-1517.

Lee, A.S.K., W.E. Vanstone, J.R. Markert, and N.J. Antia. 1969. UV-absorbing and UV-fluorescing substances in the belly skin of fry of coho salmon (Oncorhynchus kisutch). Journal of the Fisheries Research Board of Canada 26:1185-1198.

Markert, J.R. and W.E. Vanstone. 1966. Pigments in the belly skin of coho salmon Oncorhynchus kisutch. Journal of the Fisheries Research Board of Canada 23:1095-1098.

Mason, J.C. 1975. Seaward movement of juvenile fishes, including lunar periodicity in the movement of coho salmon (Oncorhynchus kisutch) fry. Journal of the Fisheries Research Board of Canada 32:2542-2547.

Matthews, G.M., D.L. Park, J.R. Harmon, and T.E. Ruehle. 1988. Evaluation of transportation of juvenile salmonids and related research on the Columbia and Snake rivers, 1987. Annual report, National Marine Fisheries Service, Seattle, Washington.

McDaniel, D., editor. 1979. Procedures for the detection and identification of certain fish pathogens. American Fisheries Society Fish Health Section, Bethesda, Maryland.

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

LITERATURE CITED (cont)

Pascho, R.J., D.G. Elliott, R.W. Mallet, and D. Mulcahy. 1987. Comparison of five techniques for the detection of Renibacterium salmoninarum in adult coho salmon. Transactions of the American Fisheries Society 116:882-890.

Pascho, R.J., and D.G. Elliott. 1989. Juvenile fish transportation: Impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual report 1988. Prepared by the U.S. Fish and Wildlife Service for Bonneville Power Administration, Portland, Oregon.

Pimentel, Richard, A. 1979. Morphometrics: The multivariate analysis of biological data. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Prentice, E.F., D.L. Park, T.A. Flagg, and S. McCutcheon. 1986. A study to determine the biological feasibility of a new fish tagging system, 1985-1986. Report 83-319, National Marine Fisheries Service, to Bonneville Power Administration, Portland, Oregon.

Redding, J.M., C.B. Schreck, E.K. Birks, and R.D. Ewing. 1984. Cortisol and its effects on plasma thyroid hormone and electrolyte concentrations in fresh water and during seawater acclimation in yearling coho salmon, Oncorhynchus kisutch. General and Comparative Endocrinology 56:146-155.

Rodgers, J.D., R.D. Ewing, and J.D. Hall. 1987. Physiological changes during seaward migration of wild coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Science 44:452-457.

Rondorf, D.W., J.W. Beeman, J.C. Faler, M.E. Free, and Eric J. Wagner. 1989. Assessment of smolt condition for travel time analysis. Annual report 1988. Prepared by U.S. Fish and Wildlife Service for Bonneville Power Administration, Portland, Oregon.

SAS (Statistical Analysis System). 1988. SAS/STAT guide for personal computers. Version 6.03. SAS Institute, Cary, North Carolina.

Schreck, C.B., M.F. Solazzi, S.L. Johnson, and T.E. Nickelson. 1989. Transportation stress affects performance of coho salmon, Oncorhynchus kisutch. Aquaculture 82:15-20.

Skalski, J.R. 1988. Statistical evaluation of the smolt monitoring program at McNary and John Day dams. Prepared by Center for Quantitative Science, School of Fisheries, University of Washington Seattle, for the Pacific Northwest Utilities Conference Committee, Portland, Oregon.

Snedecor, G.W., and W.G. Cochran. **1967.** Statistical methods. Iowa State University Press, Ames.

Specker, J.L. and C.B. Schreck. 1982. Changes in plasma corticosteroids during smoltification of coho salmon Oncorhynchus kisutch. General and Comparative Endocrinology 46:53-58.

Staley, K.B. 1984. Purine deposition in the skin of juvenile coho salmon, Oncorhynchus kisutch. Masters thesis, Oregon State University, Corvallis.

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

Winans, G.A. 1984. Multivariate morphometric variability in Pacific salmon: technical demonstration. Canadian Journal of Fisheries and Aquatic Sciences 41:1150-1159.

Youngson, A.F. and T.H. Simpson. 1984. Changes in serum thyroxine levels during smolting in captive and wild Atlantic salmon, Salmo salar L.. Journal of Fish Biology 24:29-39.

Zaugg, W.S. 1982. A simplified preparation for adenosine triphosphatase determination in gill tissue. Canadian Journal of Fisheries and Aquatic Sciences 39:215-217.

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

Zaugg, W.S. 1989. Migratory behavior of underyearling Oncorhynchus tshawytscha and survival to adulthood as related to prerelease gill (Na^+-K^+)-ATPase development. Aquaculture 82:339-353.

APPENDICES

Appendix 1. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon frpm Entiat NFH (RA-7T-1/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	23.3	21.5	88	5.95	13	137.8	32.5	24	8.67	14
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	99.6	14.7	15	4.09	13	101.o	13.3	13	5.94	5
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	131.1	4.4	3	1.01	19	121.4	12.3	10	2.75	20
TRUCK	(released at hatchery)									

Appendix 2. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Leavenworth NFH (LA/RD-7C-1/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	5.9	3.0	51	0.91	11	80.0	40.1	50	10.03	16
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	109.2	26.1	24	7.23	13	119.6	16.5	14	4.77	12
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	132.5	6.4	5	1.42	20	123.3	7.5	6	1.69	20
TRUCK	(released at hatchery)									

Appendix 3. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Winthrop NFH (RA/LD-7N-1/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	6.4	6.4	101	1.56	17	113.9	36.2	32	7.23	25
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	84.8	17.6	21	3.92	20	100.5	19.9	20	3.99	25
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	133.2	5.4	4	1.01	28	126.4	5.2	4	0.97	29
TRUCK	(released at hatchery)									

Appendix 4. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Dworshak NFH (RA/RD-7H-1/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	6.1	5.7	93	1.18	23	119.4	63.5	53	12.45	26
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	60.8	15.1	25	2.97	26	74.2	16.9	23	3.20	28
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	137.1	3.1	2	0.60	27	132.8	3.5	3	0.67	28
TRUCK	(released at hatchery)									

Appendix 5. Summary of 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 (LA/LD-7U-1/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	13.7	10.9	79	3.02	13	173.0	45.1	26	12.06	14
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	86.9	10.8	12	2.47	19	92.9	12.5	13	2.80	20
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	125.2	4.8	4	1.07	20	121.1	4.6	4	1.03	20
TRUCK	(released at hatchery)									

Appendix 6. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of yearling summer chinook salmon from McCall SFH (RA-R-1/2/3/4 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	40.4	49.9	123	12.10	17	77.6	48.2	62	12.06	16
TRUCK	142.5	46.8	33	11.70	16	142.8	34.3	24	8.86	15
GLUCOSE										
HATCHERY	92.8	12.4	13	2.77	20	118.9	18.2	15	4.17	19
TRUCK	112.4	45.0	40	10.60	18	122.8	43.8	36	10.05	19
CHLORIDE										
HATCHERY	134.8	3.8	3	0.85	20	130.3	3.5	3	0.80	19
TRUCK	130.0	5.6	4	1.32	18	127.8	6.5	5	1.50	19

Appendix 7. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Rapid River SFH released at the hatchery (LA/LD-7H-1/3 brand group) and below Hells Canyon Dam (pit tag group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
Hatchery release										
CORTISOL										
HATCHERY	12.3	8.7	71	2.34	14	84.7	29.2	34	7.81	14
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	93.0	20.3	22	4.54	20	123.4	29.2	24	7.54	15
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	136.2	5.0	4	1.12	20	131.0	5.8	4	1.40	17
TRUCK	(released at hatchery)									
Hells Canyon Dam release										
CORTISOL										
HATCHERY	32.6	36.2	111	8.52	18	92.2	37.6	41	8.87	18
TRUCK	96.0	25.3	26	6.14	17	194.5	67.9	35	16.00	18
GLUCOSE										
HATCHERY	85.6	24.9	29	5.72	19	100.1	14.8	15	3.31	20
TRUCK	108.7	39.0	36	9.75	16	103.0	30.1	29	6.88	19
CHLORIDE										
HATCHERY	138.1	4.5	3	1.02	19	132.6	5.8	4	1.29	20
TRUCK	129.3	4.6	4	1.06	19	119.8	6.4	5	1.43	20

Appendix 8. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Sawtooth SFH (LA-R-1/2/3(4 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	22.4	32.8	147	8.76	14	63.6	40.0	63	10.70	14
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	64.2	22.0	34	5.88	14	82.5	40.2	49	10.39	15
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	133.2	5.6	4	1.25	20	127.2	7.3	6	1.68	19
TRUCK	(released at hatchery)									

Appendix 9. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Wells SFH released at the Similkameen River (RD-7F-1/3 brand group) and at the Methow River (LD-7F-1/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
Similkameen River release										
CORTISOL										
HATCHERY	30.4	24.8	82	5.69	19	170.8	32.5	19	8.11	16
TRUCK	124.6	59.5	48	14.87	16	177.0	56.9	32	14.22	16
GLUCOSE										
HATCHERY	240.4	90.2	37	20.18	20	220.6	73.0	33	16.32	20
TRUCK	209.8	79.7	38	17.82	20	199.6	53.3	26	11.92	20
CHLORIDE										
HATCHERY	117.4	12.3	10	2.74	20	116.4	15.4	13	3.44	20
TRUCK	119.8	15.6	13	3.50	20	118.8	11.3	10	2.52	20
Methow River release										
CORTISOL										
HATCHERY	55.6	26.2	47	6.17	18	168.6	37.6	22 35	10.86	12
TRUCK	139.2	78.0	56	20.15	15	161.6	56.0		12.84	19
GLUCOSE										
HATCHERY	200.7	67.8	34	15.16	20	181.4	71.0	39	16.26	19
TRUCK	208.8	80.2	38	18.88	18	177.7	60.7	34	13.58	20
CHLORIDE										
HATCHERY	123.3	10.1	8	2.27	20	122.3	13.5	11	3.10	19
TRUCK	122.8	9.5	8	2.17	19	122.5	10.9	9	2.44	20

Appendix 10. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Dworshak NFH (pit tag group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
---CORTISOL---										
HATCHERY	65.8	39.7	60	10.24	15	176.4	49.8	28	12.07	17
TRUCK	(released at hatchery)									
---GLUCOSE---										
HATCHERY	104.6	24.6	23	5.96	17	132.4	24.1	18	5.38	20
TRUCK	(released at hatchery)									
---CHLORIDE---										
HATCHERY	136.5	4.2	3	1.03	17	131.6	4.6	3	1.02	20
TRUCK	(released at hatchery)									

Appendix 11. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Irrigon SFH (LA/RA-J-4 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport trucks (HATCHERY) and during release from the truck. Two routes were monitored: one via Lewiston, ID (TRUCK 1), the other via La Grande, OR (TRUCK 2). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	23.6	14.2	60	3.34	18	115.4	40.5	35	11.25	13
TRUCK 1	99.9	45.5	46	10.72	18	215.1	53.3	25	12.56	18
TRUCK 2	121.2	54.0	45	12.72	18	187.0	73.7	39	17.37	18
GLUCOSE										
HATCHERY	126.5	26.1	21	6.83	20	150.4	21.0	14	4.95	18
TRUCK 1	138.8	20.3	15	4.66	20	132.1	23.2	18	5.47	18
TRUCK 2	115.2	37.1	32	8.29	20	107.4	24.3	23	5.43	20
CHLORIDE										
HATCHERY	135.3	5.7	4	1.28	20	128.3	4.4	3	1.04	18
TRUCK 1	122.5	5.5	4	1.27	19	121.3	4.2	4	0.99	20
TRUCK 2	123.8	4.1	3	0.91	20	118.3		4	0.94	20

Appendix 12. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Lyons Ferry SFH (RA-IJ-l/3 brand group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	11.8	7.8	66	1.85	18	91.7	46.0	50	10.28	20
TRUCK	(released at hatchery)									
GLUCOSE										
HATCHERY	109.2	25.2	23	5.63	20	112.2	25.0	22	5.58	20
TRUCK	(released at hatchery)									
CHLORIDE										
HATCHERY	134.6	5.5	4	1.23	20	130.1	4.8	4	1.08	20
TRUCK	(released at hatchery)									

Appendix 13. Summary of mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Magic Valley SFH (pit tag group) sampled for plasma cortisol ($ng \cdot mL^{-1}$), glucose ($mg \cdot dL^{-1}$), and chloride ($mEq \cdot L^{-1}$) during spring 1989. Samples were collected prior to loading on the transport truck (HATCHERY) and during release from the truck (TRUCK). Fish were sampled before (PRE-TEST) and one hour after a stress challenge (POST-TEST).

	PRE-TEST					POST-TEST				
SAMPLE	X	SD	CV	SE	N	X	SD	CV	SE	N
CORTISOL										
HATCHERY	20.4	12.8	63	2.94	19	124.9	48.9	39	13.09	14
TRUCK	166.0	30.9	19	8.27	14	192.9	81.6	42	21.80	14
GLUCOSE										
HATCHERY	112.0	28.1	25	6.28	20	135.7	35.9	26	8.24	19
TRUCK	125.8	20.2	16	4.77	18	127.2	28.2	22	6.64	18
CHLORIDE										
HATCHERY	137.1	4.4	3	0.99	20	132.2	2.6	2	0.58	19
TRUCK	125.7	4.5	4	1.07	18	125.9	7.1	6	1.68	18

Appendix 14. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Entiat NFH (RA-7T-1/3 brand group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg$ prot$^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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, 1989.

SAMPLE TIME	Na^{+}-K^{+} ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N
----------sample site = Hatchery----------										
3/23	7.5	3.5	47	0.89	16	8.5	3.4	40	1.08	10
4/5	7.1	1.8	25	0.41	19	3.8	2.0	53	0.70	8
4/19	10.1	2.1	21	0.47	19	6.1	1.9	32	0.65	9
----------sample site = Rock Island Dam----------										
EARLY	10.8	2.4	23	0.70	12	15.1	5.5	37	2.10	7
MIDDLE	12.9	4.2	32	1.71	6	13.8	3.0	22	1.74	3
LATE	17.0	2.5	15	1.27	4	15.0	9.2	61	4.09	5
----------sample site = McNary Dam----------										
EARLY	20.3	4.4	22	0.98	20	5.0	3.2	53	1.02	10
MIDDLE	29.3	6.2	21	1.38	20	6.2	2.6	42	0.83	10
LATE	34.0	8.7	26	1.89	21	8.3	3.6	43	1.19	9

Appendix 15. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Leavenworth NFH (LA/RD-7C-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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, 1989. ND = no data.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----------------------sample site=Hatchery----------------------------										
3/23	5.8	1.2	20	0.28	17	6.8	2.7	39	0.84	10
4/5	9.2	2.1	23	0.48	19	8.1	4.8	59	1.69	8
4/18	12.8	2.8	22	0.63	19	5.7	4.3	76	1.35	10
------------------sample site=Rock Island Dam-------------------------										
EARLY	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIDDLE	18.3	6.2	34	1.86	11	15.4	5.9	38	1.98	9
LATE	29.1	8.2	28	2.72	9	9.6	5.7	60	2.03	8
------------------- -sample site = McNary Dam--------------------------										
EARLY	27.0	7.6	28	1.85	17	9.2	3.9	42	1.22	10
MIDDLE	29.9	8.9	30	2.03	19	9.8	3.6	37	1.15	10
LATE	24.9	8.9	36	2.00	20	7.1	2.8	40	0.89	10

Appendix 16. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Winthrop NFH (RA/LD-7N-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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, 1989.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----sample site = Hatchery----										
3/22	6.7	2.3	34	0.44	28	3.9	2.4	63	0.48	26
4/4	8.2	2.3	28	0.43	28	4.5	2.9	64	0.61	22
4/17	12.2	3.7	30	0.67	30	5.4	2.2	40	0.47	21
----sample site = Rock Island Dam----										
EARLY	19.6	6.4	33	2.26	8	22.9	19.7	86	6.98	8
MIDDLE	28.3	8.3	29	2.76	9	8.5	4.2	49	1.49	8
LATE	38.7	13.3	34	4.71	8	8.7	5.8	66	2.05	8
----sample site = McNary Dam----										
EARLY	29.6	7.2	24	1.53	22	7.2	3.6	50	0.76	22
MIDDLE	32.7	5.4	16	1.08	25	8.3	6.8	83	1.40	24
LATE	26.0	6.6	26	1.39	23	8.8	6.1	69	1.31	22

Appendix 17. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Dworshak NFH (RA/RD-7H-1/3 brand, group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg prot $\cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 28, 1989. ND = no data.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery										
3/l	7.1	2.4	33	0.45	28	5.0	2.7	54	0.51	28
3/14	8.0	1.9	23	0.34	30	8.1	4.9	60	0.91	29
3/28	8.5	2.0	23	0.41	22	6.5	3.0	45	0.55	29
sample site = Lower Granite Dam										
EARLY	21.4	5.5	26	1.30	18	12.1	5.7	47	1.90	9
MIDDLE	34.0	7.8	23	1.90	17	4.5	3.6	80	1.48	6
LATE	25.3	5.0	20	1.91	7	ND	ND	ND	ND	ND
sample site = McNary Dam										
EARLY	34.6	8.1	23	1.97	17	6.3	4.6	73	1.72	7
MIDDLE	42.0	9.2	22	2.10	19	6.6	2.8	43	0.76	14
LATE	35.6	9.3	26	2.27	17	5.1	2.3	45	0.81	8

Appendix 18. 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 (LA/LD-7U-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg$ prot$^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). Samples were collected from the hatchery 2 weeks before 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 14, 1989.

SAMPLE TIME	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N
sample site = Hatchery										
3/29	25.4	7.3	29	1.63	20	4.7	1.2	27	0.42	9
4/13	28.3	6.8	24	1.51	20	4.8	1.7	36	0.57	9
sample site = McNary Dam										
EARLY	34.1	9.2	27	2.06	20	13.8	9.1	66	2.89	10
MIDDLE	34.8	7.1	20	1.63	19	11.4	8.6	76	2.73	10
LATE	30.8	11.1	36	2.48	20	10.8	5.3	49	1.29	17

Appendix 19. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of summer chinook salmon from McCall SFH (RA-R-1/2/3!? brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg prot $\cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 at the South Fork of the Salmon River on March 21, 1989.

SAMPLE TIME	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N
sample site = Hatchery										
2/23	6.1	1.3	21	0.29	20	4.2	3.2	76	1.06	9
3/8	7.1	1.4	20	0.34	17	4.0	0.9	22	0.37	6
3/20	9.0	2.0	22	0.45	20	6.3	3.7	59	1.18	10
sample site = Lower Granite Dam										
EARLY	21.3	8.0	37	2.21	13	6.5	4.6	71	1.53	9
MIDDLE	23.9	3.9	16	1.12	12	8.9	3.8	42	1.33	8
LATE	23.6	6.5	27	2.05	10	5.6	3.5	63	1.17	9
sample site = McNary Dam										
EARLY	32.0	6.5	20	1.57	17	6.6	3.6	55	1.21	9
MIDDLE	24.3	5.7	23	1.43	16	5.2	2.3	45	0.82	8
LATE	26.4	7.8	30	1.96	16	3.6	1.9	52	0.67	8

Appendix 20. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Rapid River SFH (LA/LD-7H-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 volitionally released from the hatchery between March 15 and March 25, 1989. ND = no data.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----sample site = Hatchery----										
2/23	6.2	0.7	11	0.16	19	12.4	5.4	43	1.71	10
3/8	7.6	1.6	22	0.36	20	9.0	7.0	78	2.49	8
3/20	7.9	2.6	33	0.58	20	5.2	3.6	70	1.21	9
----sample site = Lower Granite Dam----										
EARLY	23.5	5.5	23	1.20	21	8.7	3.3	38	1.17	8
MIDDLE	29.3	8.3	28	1.86	20	8.9	4.3	48	1.35	10
LATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
----sample site = McNary Dam----										
EARLY	35.3	8.7	25	2.11	17	9.1	5.2	57	1.72	9
MIDDLE	37.7	7.4	20	2.06	13	9.1	5.8	63	2.04	8
LATE	32.4	7.7	24	2.00	15	6.6	2.3	34	0.81	8

Appendix 21. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Rapid River SFH (pit tag group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release. Fish were released from below Hells Canyon Dam on March 21, 1989. ND = no data.

SAMPLE TIME	Na^+-K^+ ATPase X	SD	CV	SE	N	Thvroxine X	SD	CV	SE	N
----------sample site = Hatchery----------										
	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/8	7.2	1.7	24	0.39	20	7.5	4.4	58	1.38	10
3/20	8.3	1.9	23	0.43	20	6.0	3.6	61	1.15	10

Appendix 22. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Sawtooth SFH (LA-R-1/2/3/4 brand, group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg prot $\cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 15, 1989. ND = no data.

SAMPLE TIME	Na^+-K^+ ATPase					Thyroxine				
	X	SD	CV	SE	N	X	SD	CV	SE	N
----sample site=Hatchery----										
2/22	5.2	0.9	17	0.20	19	7.5	6.0	80	2.26	7
3/7	6.6	0.9	13	0.19	20	5.0	4.0	79	1.77	5
3/15	7.5	1.3	17	0.28	20	4.4	1.7	39	0.69	6
----sample site=Lower Granite Dam----										
EARLY	20.2	2.8	14	0.72	15	10.6	4.1	39	1.38	9
MIDDLE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
LATE	23.6	7.6	32	2.69	8	6.6	3.6	55	2.11	3
----sample site=McNary Dam----										
EARLY	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIDDLE	25.4	7.1	28	1.59	20	4.8	1.9	39	0.50	14
LATE	28.0	4.9	18	1.63	9	4.7	3.4	73	1.22	8

Appendix 23. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of subyearling fall chinook salmon from Lyons Ferry SFH (LA-U-1/3 brand group) and sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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, 1989. ND = no data.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----------sample site = Hatchery----------										
5/10	10.4	5.7	54	1.37	17	2.4	0.9	36	0.36	6
5/25	16.4	7.6	46	1.74	19	3.1	1.2	39	0.40	9
6/6	17.8	4.0	23	0.90	20	2.3	0.3	13	0.11	7
----------sample site = McNary Dam----------										
EARLY	32.7	10.2	31	2.28	20	3.5	1.9	54	0.55	12
MIDDLE	40.2	6.6	16	1.47	20	4.6	2.5	54	0.87	8
LATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix 24. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of subyearling fall chinook salmon from Priest Rapids SFH (LA-T-1 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg prot$^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 12, 1989. ND = no data.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery										
5/11	10.5	2.5	24	0.79	10	4.1	0.4	11	0.20	5
5/24	17.0	3.8	23	1.22	10	5.3	1.4	26	0.62	5
6/6	20.9	3.4	16	0.76	20	4.0	1.6	38	0.49	10
sample site = McNary Dam										
EARLY	28.6	4.5	16	1.04	19	3.3	1.5	47	0.55	8
MIDDLE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
LATE	27.1	6.7	25	1.53	19	5.6	3.1	56	1.10	8

Appendix 25. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of subyearling fall chinook salmon from Priest Rapids SFH (LA-T-2 brtyd group) sampled for gill Na^{+}-K^{+} ATPase activity (μmoles $P_i \cdot mg$ prot $\cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 28, 1989. ND = no data.

	Na^{+}-K^{+} ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----------sample site=Hatchery----------										
5/11	8.0	1.7	22	0.55	10	3.3	1.0	30	0.44	5
5/24	16.5	3.6	22	1.15	10	11.2	11.0	98	4.92	5
6/26	17.7	4.8	27	1.08	20	4.7	3.1	67	0.99	10
----------sample site=McNary Dam----------										
EARLY	18.4	4.0	22	0.92	19	3.5	2.3	66	0.74	10
MIDDLE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
LATE	32.8	5.6	17	2.11	7	6.8	2.4	42	1.73	2

Appendix 26. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of summer steelhead from Wells SFH (LA-7F-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 at the Methow River on April 28, 1989. ND = no data.

	Na^+-K^+ ATPase					Thvroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----------sample site = Hatchery----------										
3/22	6.5	1.7	26	0.37	20	19.9	5.9	30	2.69	8
4/4	6.4	2.2	34	0.49	20	11.7	7.3	63	2.31	10
4/28	12.9	3.6	28	0.81	20	4.3	2.5	57	0.94	7
----------sample site = Rock Island Dam----------										
EARLY	18.0	4.0	22	0.98	17	7.2	3.7	51	1.16	10
MIDDLE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
LATE	20.8	4.9	23	1.41	12	5.1	2.2	44	0.65	12
----------sample site = McNary Dam----------										
EARLY	29.0	7.3	25	1.67	19	4.4	2.4	54	0.85	8
MIDDLE	27.9	7.1	25	1.58	20	7.9	5.0	64	1.19	18
LATE	31.4	6.9	22	1.58	19	6.1	6.6	107	1.59	17

Appendix 27. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Wells SFH (RD-7F-l/3 brand-,group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg$ prot $\cdot hr^-$) and thyroxine ($ng \cdot mL^{-1}$). 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 at the Similkameen River on May 3, 1989. ND = no data.

SAMPLE TIME	Na^+-K^+ ATPase					Thvroxine				
	X	SD	CV	SE	N	X	SD	CV	SE	N
sample site = Hatchery										
3/22	6.5	1.7	26	0.37	20	19.9	5.9	30	2.69	8
4/4	6.4	2.2	34	0.49	20	11.7	7.3	63	2.31	10
5/3	15.7	5.0	32	1.11	20	4.0	3.1	77	1.37	5
sample site = Rock Island Dam										
EARLY	21.4	3.6	17	1.14	10	6.6	5.3	81	1.68	10
MIDDLE	26.0	7.5	29	1.68	20	6.9	3.8	55	1.35	8
LATE	28.3	5.1	18	1.20	18	3.8	1.6	42	0.65	6
sample site = McNary Dam										
EARLY	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIDDLE	26.8	6.9	26	1.50	21	5.4	4.4	81	1.67	8
LATE	25.2	7.1	28	1.60	20	4.4	3.7	83	1.30	8

Appendix 28. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Dworshak NFH (pit tag group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release. Fish were released from the hatchery on May 1, 1989.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----------sample site = Hatchery----------										
4/5	6.4	1.8	28	0.40	20	7.8	3.1	39	0.97	10
4/19	10.0	3.4	34	0.79	19	10.9	5.0	45	1.75	8
5/1	10.2	2.4	24	0.68	13	29.2	31.1	107	10.37	9

Appendix 29. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Irrigon SFH (LA/RA-J-4 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). 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 at Wildcat Creek on April 25, 1989.

SAMPLE TIME	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N
----sample site = Hatchery----										
3/30	6.9	2.2	32	0.50	20	7.7	6.1	79	2.03	9
4/11	8.9	3.2	36	0.73	19	4.3	1.8	41	0.67	7
4/25	10.3	3.7	36	0.83	20	7.4	4.6	62	1.53	9
----sample site = Lower Granite Dam----										
EARLY	17.8	5.8	32	1.29	20	20.2	12.5	62	4.17	9
MIDDLE	16.0	4.8	30	1.08	20	13.1	10.8	82	3.41	10
LATE	19.6	5.9	30	1.33	20	20.3	15.1	74	4.77	10
----sample site = McNary Dam----										
EARLY	26.5	4.5	17	1.17	15	4.3	1.7	39	0.57	9
MIDDLE	23.0	7.8	34	1.84	18	7.1	3.2	46	1.08	9
LATE	22.6	6.5	29	1.54	18	13.7	14.4	105	4.81	9

Appendix 30. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Lyons Ferry SFH (RA-IJ-1/3 brand group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot$mg prot$^{-1} \cdot$hr^{-1}) and thyroxine (ng$\cdot$mL^{-1}). 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 30, 1989.

SAMPLE TIME	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N
----------sample site=Hatchery----------										
3/29	9.2	5.2	56	1.18	19	3.9	2.4	63	0.81	9
4/12	8.9	3.3	37	0.76	19	2.5	0.8	33	0.28	9
4/30	7.6	2.2	29	0.50	20	6.2	5.6	91	1.50	14
----------sample site=McNary Dam----------										
EARLY	19.7	5.0	26	1.13	20	7.4	3.0	41	1.08	8
MIDDLE	21.2	3.9	19	0.88	20	9.4	10.9	116	3.43	10
LATE	24.0	10.2	42	2.33	19	5.4	4.3	81	1.37	10

Appendix 31. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Magic Valley SFH (pit tag group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). Samples were collected from the hatchery 4 weeks, 2 weeks, and immediately prior to release. Fish were released at the Little Salmon River on April 20,1989.

	Na^+-K^+ ATPase					Thyroxine				
SAMPLE TIME	X	SD	CV	SE	N	X	SD	CV	SE	N
----------------------sample site = Hatchery----------------------------										
3/30	6.7	1.7	26	0.39	20	4.2	2.0	47	0.63	10
4/11	7.9	2.1	27	0.48	19	3.9	2.1	55	0.68	10
4/20	8.3	2.4	28	0.53	20	8.1	4.1	51	1.37	9

Appendix 32. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Niagara Springs SFH (pit tag-group) sampled for gill Na^+-K^+ ATPase activity (μmoles $P_i \cdot mg\ prot^{-1} \cdot hr^{-1}$) and thyroxine ($ng \cdot mL^{-1}$). Samples were collected from the hatchery 4 weeks and 2 weeks prior to release. Fish were released from the hatchery on April 25, 1989.

SAMPLE TIME	Na^+-K^+ ATPase X	SD	CV	SE	N	Thyroxine X	SD	CV	SE	N
sample site = Hatchery										
3/30	5.3	0.8	15	0.18	18	4.3	2.3	54	0.87	7
4/11	5.4	0.9	17	0.21	19	4.0	3.4	85	0.13	9

Appendix 33. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from the run at large and sampled for gill Na^+-K^+ ATPase activity (μmoles Pi·mg prot^{-1}·hr^{-1}). 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.

	Na^+-K^+ ATPase				
SAMPLE TIME	X	SD	CV	SE	N
sample site = Rock Island Dam					
4/25	11.5	2.5	22	0.80	10
4/27	12.5	2.9	24	0.93	10
5/2	13.2	3.0	23	1.22	6
5/4	18.4	6.9	38	2.18	10
5/9	19.8	4.0	20	1.27	10
5/11	24.1	8.8	37	2.79	10
5/16	25.5	11.0	43	3.48	10
5/18	31.1	7.7	25	2.33	11
5/23	40.9	10.5	26	3.31	10
sample site = McNary Dam					
5/2	19.0	6.4	34	1.85	12
5/4	28.1	7.6	27	1.53	9
5/9	32.4	6.5	20	2.04	10
5/11	28.4	8.0	28	2.54	10
5/16	34.1	4.7	14	2.10	5
5/17	37.2	9.3	25	4.17	5
5/18	27.3	6.3	23	1.99	10
5/23	24.2	7.3	30	2.32	10

Appendix 33. (continued)

SAMPLE TIME	X	SD	CV	SE	N
------------------------sample site = McNary Dam----------------------					
5/25	29.2	12.2	42	3.85	10
5/30	36.2	7.2	20	3.22	5
5/31	36.7	6.4	17	3.19	4
6/1	28.9	9.8	34	3.09	10
-------------------sample site = Snake River Trap-------------------------					
3/29	10.7	2.3	21	0.51	20
4/4	13.0	4.3	33	1.35	10
4/6	10.8	2.4	22	0.77	10
4/11	16.7	4.0	24	1.25	10
4/13	18.3	3.8	21	1.27	9
4/18	19.0	6.2	33	1.96	10
4/20	24.1	6.1	26	1.94	10
4/25	22.0	6.7	30	2.12	10
4/27	24.3	5.1	21	1.62	10
5/2	30.9	6.5	21	2.06	10
5/4	26.6	3.8	14	1.25	9
5/11	19.0	5.1	27	1.62	10
5/18	13.8	6.7	49	2.13	10
---------------------sample site = Lower Granite Dam------------------					
w	12.6	3.3	26	0.78	18
4/10	16.2	2.7	17	0.86	10
4/13	18.2	4.4	24	1.40	10
4/19	22.2	6.8	30	2.14	10

Appendix 33. (continued)

SAMPLE TIME	X	SD	CV	SE	N
---------------------sample site = Lower Granite Dam----------------------					
4/23	23.7	7.1	30	2.25	10
4/26	28.7	9.0	31	2.85	10
4/28	25.3	8.9	35	2.96	9
5/3	28.6	7.6	26	2.39	10
5/5	30.8	10.6	34	3.34	10
5/10	26.4	6.5	25	2.07	10
5/12	19.1	5.3	28	1.69	10
5/17	26.1	7.8	30	2.45	10
5/19	25.9	8.4	32	2.66	10
5/22	29.3	6.9	24	2.20	10
5/24	26.3	5.6	21	1.76	10

Appendix 34. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of hatchery steelhead from the run at large and sampled for gill Na^+-K^+ ATPase activity (μmoles Pi·mg prot^{-1}·hr^{-1}). 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 TIME	Na^+-K^+ ATPase X	SD	CV	SE	N
---sample site = Rock Island Dam---					
5/1	16.1	4.9	30	2.19	5
5/3	13.9	2.3	17	0.95	6
5/4	17.7	6.1	34	2.72	5
5/10	19.4	6.2	32	1.95	10
5/12	21.9	7.1	32	2.26	10
5/17	17.7	5.1	29	1.55	11
5/19	27.3	7.2	26	2.41	9
5/24	34.5	11.0	32	3.49	10
---sample site = McNary Dam---					
512	19.0	3.6	19	1.15	10
5/4	22.0	7.9	36	2.50	10
5/8	21.0	4.6	22	1.44	10
5/10	33.8	8.0	23	2.51	10
5/15	28.0	7.4	26	2.33	10
5/17	32.9	12.3	37	3.89	10
5/22	24.8	5.6	22	1.77	10
5/24	28.5	12.6	44	3.97	10
5/30	20.8	8.7	42	3.06	8
6/l	28.2	4.5	16	1.42	10

Appendix 34. (continued)

SAMPLE TIME	X	SD	CV	SE	N
------------------sample site = Snake River Trap------------------------					
4/20	12.3	3.4	27	1.06	10
4/25	13.8	4.5	32	1.42	10
4/27	14.2	4.9	34	1.55	10
5/2	14.2	4.5	31	1.41	10
5/4	18.8	5.1	27	1.60	10
5/9	12.0	4.1	34	1.30	10
5/11	13.5	5.5	41	1.75	10
5/16	19.1	5.6	29	1.76	10
5/18	21.6	5.8	27	1.83	10
5/23	17.0	5.4	32	1.70	10
5/25	15.3	4.4	29	1.40	10
------------------sample site = Lower Granite Dam--------------------					
4/26	17.5	5.1	29	1.60	10
4/28	14.8	6.1,	41	1.92	10
5/3	15.0	5.0	33	1.57	10
5/5	12.2	3.6	29	1.13	10
5/10	17.9	5.2	29	1.64	10
5/12	17.9	6.3	35	1.98	10
5/17	15.7	5.0	32	1.57	10
5/19	16.4	6.0	37	1.90	10
5/22	15.7	8.8	56	2.92	9
5/24	17.6	6.3	36	1.98	10

Appendix 35. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of wild steelhead from the run at large and sampled for gill Na^+-K^+ ATPase activity (μmoles $Pi \cdot mg\ prot^{-1} \cdot hr^{-1}$). 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 TIME	Na^+-K^+ ATPase X	SD	CV	SE	N
---sample site = Rock Island Dam---					
5/1	17.7	9.9	56	4.44	5
5/3	22.2	4.8	22	2.40	4
5/4	25.1	8.4	34	3.77	5
5/10	23.5	8.1	34	2.55	10
5/12	24.6	8.7	36	2.76	10
5/17	24.0	4.1	17	1.36	9
5/19	25.7	10.2	40	3.08	11
---sample site = McNary Dam---					
512	25.6	6.5	25	2.06	10
5/4	26.1	5.6	22	1.79	10
5/8	28.8	10.1	35	3.20	10
5/10	27.6	6.3	23	2.00	10
5/15	35.3	11.0	31	3.68	9
5/17	31.1	7.3	23	2.30	10
5/22	31.2	6.9	22	2.20	10
5/24	27.9	11.4	41	3.61	10
5/30	21.3	6.1	29	1.92	10
6/l	19.4	4.7	24	1.56	9

Appendix 35. (continued)

SAMPLE TIME	X	SD	CV	SE	N
------------------sample site = Snake River Trap-------------------------					
4/20	15.3	4.3	28	1.37	10
4/25	16.9	5.5	32	1.82	9
4/27	21.3	7.0	33	2.20	10
5/2	22.3	8.4	38	2.65	10
5/4	19.4	4.5	23	1.44	10
5/9	21.5	8.9	41	2.82	10
5/11	16.6	4.6	28	1.45	10
5/16	18.8	3.9	20	1.29	9
5/18	21.6	4.5	21	1.41	10
5/23	18.1	3.9	22	1.95	4
5/25	17.1	4.1	24	1.29	10
--------------------sample site = Lower Granite Dam--------------------					
4/26	20.1	4.6	23	1.44	10
4/28	21.5	7.6	35	2.41	10
5/3	20.5	6.3	31	2.00	10
5/5	25.4	9.1	36	2.88	10
5/10	24.4	8.1	33	2.57	10
5/12	17.9	7.3	41	2.31	10
5/17	19.1	6.5	34	2.05	10
5/19	23.4	3.0	13	0.94	10
5/22	18.2	4.6	25	1.44	10
5/24	21.3	7.2	34	2.41	9

Appendix 36. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon sampled for condition factor (K = weight / (fork $length \cdot 10^3) \cdot 10^5$). Samples were collected prior to release from the hatcheries and at the early, middle, and late parts of their migration past Rock Island Dam (mid-Columbia River groups), Lower Granite Dam (Snake River groups), and McNary Dam (all groups). ND = no data.

	Condition Factor (K)				
SAMPLE TIME	X	SD	CV	SE	N
Dworshak NFH					
Hatchery					
3/14	1.10	0.04	4	0.01	30
3/28	1.08	0.07	7	0.01	30
Lower Granite Dam					
Early	0.98	0.04	4	0.01	17
Middle	0.95	0.06	6	0.01	17
Late	0.90	0.05	5	0.02	8
McNary Dam					
Early	0.85	0.13	15	0.03	15
Middle	0.68	0.03	5	0.01	19
Late	0.67	0.05	8	0.01	17

Appendix 36. (continued)

SAMPLE TIME	Condition Factor (K)				
	X	SD	CV	SE	N
Entiat NFH					
Hatchery					
4/19	1.10	0.05	4	0.01	60
Rock Island Dam					
Early	ND	ND	ND	ND	ND
Middle	ND	ND	ND	ND	ND
Late	0.98	0.10	10	0.04	5
McNary Dam					
Early	0.94	0.06	7	0.02	14
Middle	0.76	0.04	6	0.01	19
Late	0.75	0.04	5	0.01	21
Leavenworth NFH					
Hatchery					
4/18	1.10	0.05	5	0.01	60
Rock Island Dam					
Early	ND	ND	ND	ND	ND
Middle	0.95	0.04	5	0.01	11
Late	0.98	0.03	4	0.01	9
McNary Dam					
Early	0.75	0.04	5	0.01	17
Middle	0.72	0.03	4	0.01	18
Late	0.72	0.03	5	0.01	20

Appendix 36. (continued)

SAMPLE TIME	Condition Factor (K) X	SD	CV	SE	N
-----Winthrop NFH-----					
Hatchery					
3/22	1.14	0.05	5	0.01	30
4/04	1.11	0.06	5	0.01	30
4/17	1.14	0.06	5	0.01	99
Rock Island Dam					
Early	0.95	0.05	5	0.02	8
Middle	0.95	0.04	4	0.01	9
Late	0.94	0.05	5	0.02	8
McNary Dam					
Early	0.77	0.04	5	0.01	21
Middle	0.76	0.06	8	0.01	25
Late	0.75	0.04	5	0.01	22
-----Sawtooth SFH-----					
Hatchery					
----	ND	ND	ND	ND	ND
Lower Granite Dam					
Early	1.01	0.07	7	0.02	15
Middle	ND	ND	ND	ND	ND
Late	0.98	0.04	4	0.01	8

Appendix 36. (continued)

SAMPLE TIME	Condition Factor (K)				
	X	SD	CV	SE	N
----Sawtooth SFH----					
McNary Dam					
Early	ND	ND	ND	ND	ND
Middle	0.87	0.04	5	0.02	4
Late	0.72	0.04	6	0.02	6

Appendix 37. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of steelhead from Wells SFH sampled for condition factor (K = weight / (fork length·10^3)·10^5). Samples were collected prior to release from the hatchery and at the early, middle, and late parts of their migration past Rock Island Dam and McNary Dam. ND = no data.

	Condition Factor (K)				
SAMPLE TIME	X	SD	CV	SE	N
Methow River Release					
Hatchery					
3/22	0.99	0.06	6	0.01	20
4/04	1.07	0.05	5	0.01	20
4/28	0.99	0.06	6	0.01	20
Rock Island Dam					
Early	0.88	0.05	5	0.01	17
Middle	ND	ND	ND	ND	ND
Late	0.85	0.05	6	0.01	12
McNary Dam					
Early	ND	ND	ND	ND	ND
Middle	ND	ND	ND	ND	ND
Late	0.64	0.03	5	0.01	17

Appendix 37. (continued)

SAMPLE TIME	Condition Factor (K)				
	X	SD	CV	SE	N
---Similkameen River Release---					
	Hatchery				
3/22	0.99	0.06	6	o.oi	20
4/04	1.07	0.05	5	0.01	20
	Rock Island Dam				
Early	0.84	0.06	7	0.02	10
Middle	0.85	0.05	6	0.01	20
Late	0.82	0.04	5	0.01	18
	McNary Dam				
Early	ND	ND	ND	ND	ND
Middle	ND	ND	ND	ND	ND
Late	ND	ND	ND	ND	ND

Appendix 38. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Leavenworth NFH (LA/RD-7C-1/3 brand group) sampled for skin guanine ($mg \cdot g$ tissue^{-1}). 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, 1989. ND = no data.

SAMPLE TIME		Guanine				
	FL	X	SD	CV	SE	N
---sample site = hatchery---						
3/23	ND	ND	ND	ND	ND	ND
4/5	ND	ND	ND	ND	ND	ND
4/18	128.5	40.8	11.7	29	2.77	18
---sample site = Rock Island Dam---						
EARLY	ND	ND	ND	ND	ND	ND
MIDDLE	122.6	53.9	13.7	25	4.58	9
LATE	129.8	47.7	11.8	25	4.18	8
---sample site = McNary Dam---						
EARLY	140.2	37.1	10.1	27	2.38	18
MIDDLE	133.9	40.5	11.8	29	2.70	19
LATE	137.9	42.9	13.0	30	2.92	20

Appendix 39. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size. (N) of spring chinook salmon from Winthrop NFH branded (RA/LD-7N-1/3 brand group) sampled for skin guanine (mg.g tissue-'). 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,.1989.

		Guanine				
SAMPLE TIME	FL	X	SD	cv	SE	N
------------------------sample site = hatchery----------------------						
3/22	132.0	35.7	6.1	17	1.45	18
4/4	135.7	31.8	8.1	25	1.86	19
4/17	135.3	44.3	13.2	30	2.96	20
------------------------sample site = Rock Island Dam----------------						
EARLY	132.9	49.2	10.1	21	3.57	8
MIDDLE	141.5	43.1	10.3	24	3.66	8
LATE	153.0	40.6	11.8	29	4.44	7
------------------------sample site = McNary Dam--------------------						
EARLY	138.9	38.9	11.1	29	2.37	22
MIDDLE	145.4	36.8	11.1	30	2.22	25
LATE	147.7	44.3	18.9	43	3.94	23

Appendix 40. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE), and sample size (N) of spring chinook salmon from Dworshak NFH (RA/RD-7H-1/3 brand group) sampled for skin guanine (mg.g tissue"). Samples were collected from the hatchery 2 weeks before 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 28, 1989.

		Guanine				
SAMPLE TIME	FL	X	SD	cv	SE	N
------------------------sample site = hatchery------------------------						
3/14	123.6	39.2	7.6	19	1.39	30
3/28	124.8	36.9	6.3	17	1.19	28
--------------------sample site = Lower Granite Dam------------------						
EARLY	135.0	39.4	7.0	18	1.44	24
MIDDLE	128.2	40.6	7.8	19	1.60	24
LATE	123.8	57.7	10.8	19	3.26	11
------------------------sample site = McNary Dam--------------------						
EARLY	135.9	52.2	14.8	28	4.09	13
MIDDLE	134.1	43.7	11.3	26	2.59	19
LATE	139.0	63.1	6.9	11	3.98	3

Appendix 41. Mean (X), standard deviation (SD), coefficient of variation (CV), standard error (SE) and sample size (N) of steelhead from Wells SFH (LA-7F-l/3 brand group) sampled for skin guanine (mg.g tissue-'). 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 at the Similkameen River on May 3, 1989. ND = no data.

		Guanine				
SAMPLE TIME	FL	X	SD	cv	SE	N
----sample site = hatchery----						
3/22	191.4	20.3	3.4	17	0.77	20
4/4	195.5	17.7	3.5	20	0.78	20
4/28	198.7	20.1	3.8	19	0.85	20
----sample site = Rock Island Dam----						
EARLY	211.9	20.7	3.4	16	0.85	16
MIDDLE	ND	ND	ND	ND	ND	ND
LATE	208.0	20.4	2.4	12	0.75	10
----sample site = McNary Dam----						
EARLY	ND	ND	ND	ND	ND	ND
MIDDLE	ND	23.3	5.7	24	1.27	20
LATE	210.7	24.7	6.4	26	1.43	20