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BIOLOGICAL MANIPULATION OF MIGRATION RATE: THE USE OF ADVANCED PHOTOPERIOD TO ACCELERATE SMOLTIFICATION IN YEARLING CHINOOK SALMON, 1990

Annual Report of Research

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CONTENTS

ABSTRACT

Research was conducted during 1990 to assess the feasibility of biologically manipulating physiological development and migratory behavior of yearling spring chinook salmon, *Oncorhynchus tshawytscha*. At Dworshak National Fish Hatchery, one treatment group was exposed to a 3-month advanced photoperiod schedule for 13 weeks preceding release to accelerate smolt development. Another group was exposed to the same advanced photoperiod schedule, but additionally was reared at an elevated water temperature (11.9°C) for 10 days prior to release. At Leavenworth National Fish Hatchery, a treatment group was exposed to a 3-month advanced photoperiod schedule for 17 weeks. Gill Na^+-K^+ ATPase development and migratory performance were described for all groups. The treated fish which were the most physiologically advanced at release were detected in the highest proportions at collector dams and also migrated fastest downstream--similar to results obtained in 1988 and 1989.

INTRODUCTION

Hydroelectric development on the Columbia and Snake Rivers created conditions that adversely affect juvenile salmonids as they migrate seaward (Ebel 1977; Raymond 1979, 1988). The dams cause mortality directly by killing fish passing through turbines and spillways. The impoundments created by dams reduce natural springtime flows and affect smolt survival indirectly by delaying migrations and prolonging exposure of smolts to predators (Poe and Rieman 1988). In drought years, smolts are subjected to an additional risk of mortality because of degraded environmental conditions, particularly for some species, in the form of increased water temperature (Zaugg and Wagner 1973).

The relationship between increasing river flows and faster inriver migration was described by Sims et al. (1984) for both yearling chinook salmon, Oncorhynchus tshawytscha, and steelhead, 0. mykiss. To expedite the migration of smolts through the river system, particularly in low-flow years, the Northwest Power Planning Council established a Water Budget Program in 1984 (NWPPC 1987). This program calls for strategic releases of water from storage reservoirs to flush smolts through the river system. However, juvenile salmonids may not fully respond to such measures if they are not physiologically prepared to migrate.

Giorgi et al. (1988) found that yearling chinook salmon with elevated gill Na^{+}-K^{+} ATPase activity were generally more susceptible to guidance by submersible traveling screens at Lower Granite and Little Goose Dams. Muir et al. (1988) found a positive correlation between inseason increases in fish guidance efficiency (FGE) and degree of smolt development in yearling chinook salmon at the same dams. These data suggest that changes in fish behavior associated with smolt development affect FGE.

It has been demonstrated that smolt development of hatchery stocks of salmonids may be accelerated by altering environmental conditions, especially temperature and photoperiod (Poston 1978, Wedemeyer et al. 1980). Furthermore, there is evidence that changes in migratory behavior of steelhead accompany such physiological changes (Zaugg and Wagner 1973, Wagner 1974). In 1988 and 1989, National Marine Fisheries Service (NMFS) research at Dworshak National Fish Hatchery (NFH) demonstrated that yearling chinook salmon exposed to an advanced photoperiod treatment or photoperiod plus temperature increase near release had accelerated smolt development and altered migratory behavior (Giorgi et al. 1990, 1991).

The purpose of the present research was to determine if yearling chinook salmon behave differently at different stages of smolt development. Our measures of performance included detection proportions of migrants at hydroelectric dams as well as in-river downstream migration rates. Our strategy was to accelerate smolt development in experimental groups in two hatchery populations by subjecting treatment groups to various advanced photoperiod and temperature schedules and compare their physiological development and downstream migratory behavior to corresponding control groups. In addition, at Dworshak NFH, fish from the control and photoperiod treatment groups were coded-wire tagged to evaluate the effect of photoperiod treatment on adult contribution.

METHODS

The research was conducted using yearling chinook salmon at Dworshak NFH on the Clearwater River near Orofmo, Idaho and Leavenworth NFH on Icicle Creek, a tributary of the Wenatchee River near Wenatchee, Washington (Fig. 1). Experimental groups were exposed to 3-month advanced photoperiods for 13 weeks (3m/13w) at Dworshak NFH and for 17 weeks (3m/17w) at Leavenworth NFH. Length of treatment was dependent on hatchery release date. Corresponding control groups (control) were exposed only to ambient light and water temperature conditions during the same periods. Two additional

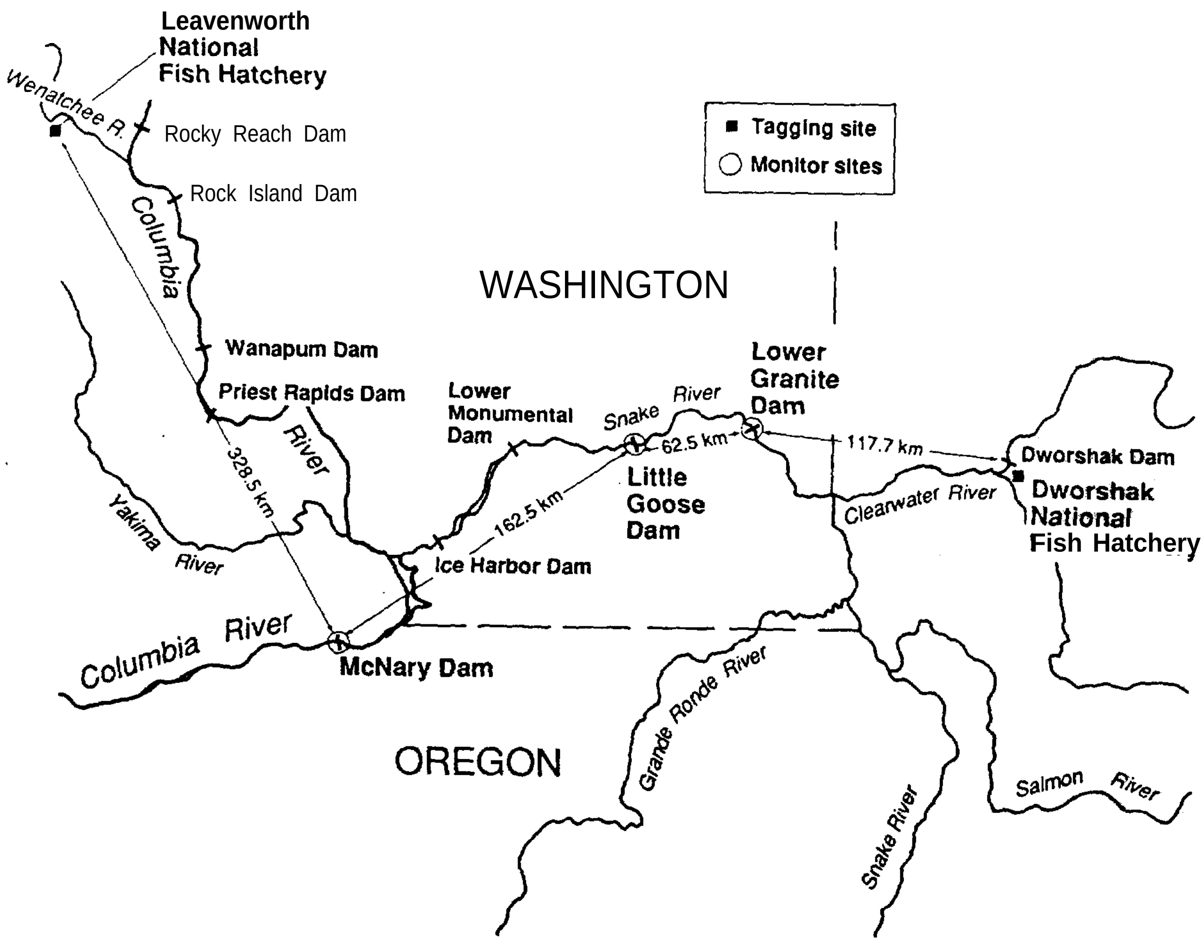

Figure 1.--Location of Dworshak and Leavenworth National Fish Hatcheries and downstream PIT-tag monitoring sites on the Snake and Columbia River. In-river distances (kilometers) between sites are indicated.

test conditions were evaluated at Dworshak NFH. A 3m/13w photoperiod treatment group was reared at increased water temperature for 10 days prior to release and a group of fish from the control population was held for an additional 18 days prior to release (designated as 3m/13w + T and delayed release, respectively).

About 1,000 fish from each group were tagged with passive integrated transponder (PIT) tags (Prentice et al. 1990a,c) (Table 1). At Dworshak NFH, fish were tagged on 28-29 November 1989 for the control and photoperiod test groups and on 26 March 1990 for the group exposed to increased water temperature and the group held for delayed release. At Leavenworth NFH, fish were tagged on 18-19 December 1989. PIT-tagged fish were used to evaluate migrational characteristics. Coded-wire tags (CWT) were implanted in two groups (3m/13w and the control group) at Dworshak NFH to evaluate the effect of photoperiod treatment on adult contribution. A total of 124,185 treatment and 206,695 control fish were coded-wire tagged in November 1989 (Table 1). CWT fish for the US/Canada contribution study were used as controls.

Experimental fish were held in eight separate raceways at Dworshak NFH and in two separate raceways at Leavenworth NFH. Each raceway was 24.4-m long by 2.4-m wide, and water depth was 0.8 m at the end screen. Sidewalls projected 0.4 m above the water surface. Three light fixtures were suspended from walls of each treatment group's raceway 0.8 m and 0.6 m above the water surface at Dworshak and Leavenworth NFHs, respectively. Each fixture was fitted with a 400-watt metal halide bulb. Lights were turned on daily at 2:30 pm and off each night until a 3-month advanced photoperiod treatment was applied. Light operation was controlled by a timer which was reset every 10 days to maintain the advanced photoperiod schedule. Light treatment began on 2 January 1990 for the 3m/13w group at Dworshak NFH and on 20 December 1989 for

Table l.--Marking summary for spring chinook salmon photoperiod study at Dworshak and Leavenworth National Fish Hatcheries. Treatment and control fish were held in separate raceways.

Experimental condition	Marking date	Number marked		Number released	
		PIT tags	CWT	PIT tags	CWT.
		Dworshak NFH			
Control	29 Nov 89	1,020	206,695	1,016	200,572
3m/13w	28 Nov 89	1,023	124,185	1,018	121,611
3m/13w + T	26 Mar 90	1,021		1,020	
Delayed release	26 Mar 90	1,040		984	
		Leavenworth NFH			
Control	19 Dec 89	1,021		1,014	
3m/17w	18 Dec 89	1,020		1,019	

[a] Adjusted-for mortality and tag loss.

the 3m/17w group at Leavenworth NFH. Both the treatment and control raceways were maintained on normal hatchery diets and pond maintenance schedules.

On 26 March, 10 days prior to release, approximately 1,000 fish from the 3m/13w group at Dworshak NFH were removed from their raceway, PIT tagged, and moved into two tanks in the Dworshak NFH nursery room to establish the 3m/13w + T treatment group. Each tank was l-m wide and 5-m long. Water depth was approximately 0.5 m. The 3m/13w photoperiod schedule was maintained by suspending two 100-watt light bulbs above each of the two tanks. Water temperature was raised 1°C per hour from 5.0 to 11.9°C and maintained at this temperature until release on 5 April. All test and control groups were released within a 3-hour time period.

Also on 26 March, a group of about 1,000 fish were taken from the control raceway, PIT-tagged; and moved to a tank in the egg incubation room at Dworshak NFH. They were maintained on ambient water temperature and photoperiod until the delayed release on 23 April.

Dead fish were regularly removed from the raceways, stored frozen, and later interrogated for PIT tags or checked for CWT, to calculate the number of PIT-tagged and CWT fish released in the treatment and control groups (Table 1).

Mark-Recovery Data

Lower Granite, Little Goose, and McNary Dams are equipped with PIT-tag detectors which interrogate 100% of the juveniles in the collection systems (Prentice et al. 1990b). The electronic detectors transmit a radio signal which activates the tag as a tagged fish passes through the detection tunnel. The tag then transmits its unique code which is in turn "read" by the detector. These data, including the time of detection, are automatically stored in a computer file. PIT-tag detection data provided detailed information regarding the migration rate of individual experimental fish as they migrated downriver.

After release from Dworshak NFH, PIT-tagged fish were detected at the three downstream monitoring sites while those released from Leavenworth NFH were detected only at McNary Dam (Fig. 1). During low-flow years, spring chinook salmon (including PIT-tagged fish) collected in the bypass systems at Lower Granite and Little Goose Dams are transported to below Bonneville Dam. Transport occurred during the 1990 outmigration and affected the travel time and detection rate for Dworshak fish collected below Lower Granite Dam. For this reason, travel times to Lower Granite Dam are probably the best indication of treatment effect. Detection rates were reduced at downstream sites by the number of PIT-tagged fish collected and transported from upriver sites. Spill occurred at McNary Dam near the end of the outmigration and reduced the number of detections from the different groups. Fish in the delayed release group were most affected since a few were still migrating during this time; the other experimental groups had mostly migrated past McNary Dam by the time spill commenced.

Coded-wire tags will be recovered in the various fisheries and at Dworshak NFH in subsequent years.

Smolt Physiology

To monitor changes in the physiological status of the experimental groups, gill Na^+-K^+ ATPase activity was measured in a series of samples taken at Dworshak and Leavenworth NFHs from initiation of the treatment until release of the experimental groups. Samples were collected monthly from December through February and then biweekly until release. At Dworshak NFH, samples of 15 fish were dipnetted from two of the treatment and two of the control raceways on each sample occasion. Additional 15-fish samples were collected from the photoperiod treatment plus temperature (one sample) and delayed release (two samples) groups from 26 March to release. At Leavenworth NFH, 15 fish were dipnetted from the control raceway and 15 fish from the treatment raceway on each sample date. Gill filaments from individual fish were trimmed from the gill arch and placed into a 1.5-ml microcentrifuge tube filled with a buffer solution of sucrose, ethylenediamine tetraacetic acid, and imidazole. Samples were stored frozen below -75°C until they were processed. Assays for Na^{+}-K^{+} ATPase activity followed procedures described by Zaugg (1982) with minor modifications. Mean Na^{+}-K^{+} ATPase levels were then calculated for each group for each sample date.

Bacterial Kidney Disease

Concurrent with this study, research at Dworshak NFH evaluated the use of medicated feed (erythromycin) to control bacterial kidney disease (BKD) (Elliot et al. 1989). Two of the three photoperiod treatment raceways and two of the three control raceways containing PIT-tagged fish received medicated feed (raceways B29-B30 and A11-A12, respectively). Fish PIT-tagged for the increased water temperature and delayed release portions of the study did not receive medicated feed.

Statistics

Student's t-test was used to compare travel time and physiological data. When unequal variances were detected with an F-test, Satterthwaite's approximation was used (Snedecor and Cochran 1980). The chi-square test was used to compare recovery proportions and mortality rates.

RESULTS

Smolt Development

During hatchery residence, mean gill Na^+-K^+ ATPase activity in the control group at Dworshak NFH ranged from 4.3 to 10.9 µmol Pi . mg $Prot^{-1}$. h^{-1}, and was at 9.8 units by the production release on 5 April (Fig. 2). The 3m/13w photoperiod treatment group was significantly higher ($P < 0.001$) by 28 February and remained significantly higher until release (13.2 units) (Fig. 2).

Temperature treatment further accelerated gill Na^+-K^+ ATPase development in the 3m/13w + T group to 13.9 units by 5 April, the highest level observed for any group at the hatchery on this date. This was significantly higher ($P < 0.001$) than the control group on this date but not significantly higher than the photoperiod treatment alone.

Gill Na^+-K^+ ATPase levels continued to increase in fish from the delayed release group up to the time of their release on 23 April (Fig. 2). By 11 April, this group was at 14.0 units and by 23 April 16.0 units, both significantly higher ($P < 0.001$) than the 5 April control release. This group also had significantly higher ($P < 0.05$) gill Na^+-K^+ ATPase activity on 23 April than the 3m/13w group did on 5 April.

At Leavenworth NFH, there was only a slight change in the control group's gill Na^+-K^+ ATPase level from December through March, ranging from 5.6 to 7.4 units. When sampled on 10 April, their activity had increased significantly ($P < 0.001$) to 11.8 units and was at 13.0 units when released on 18 April (Fig. 3). The 3m/17w photoperiod treatment group's gill Na^+-K^+ ATPase level was significantly higher ($P < 0.001$) than that of the control group by 26 February, and remained significantly higher until the last sample date on 17 April when there was no significant difference between the two. Detailed gill Na^+-K^+ ATPase data for each sample date at both hatcheries are contained in Appendix Tables 1 and 2.

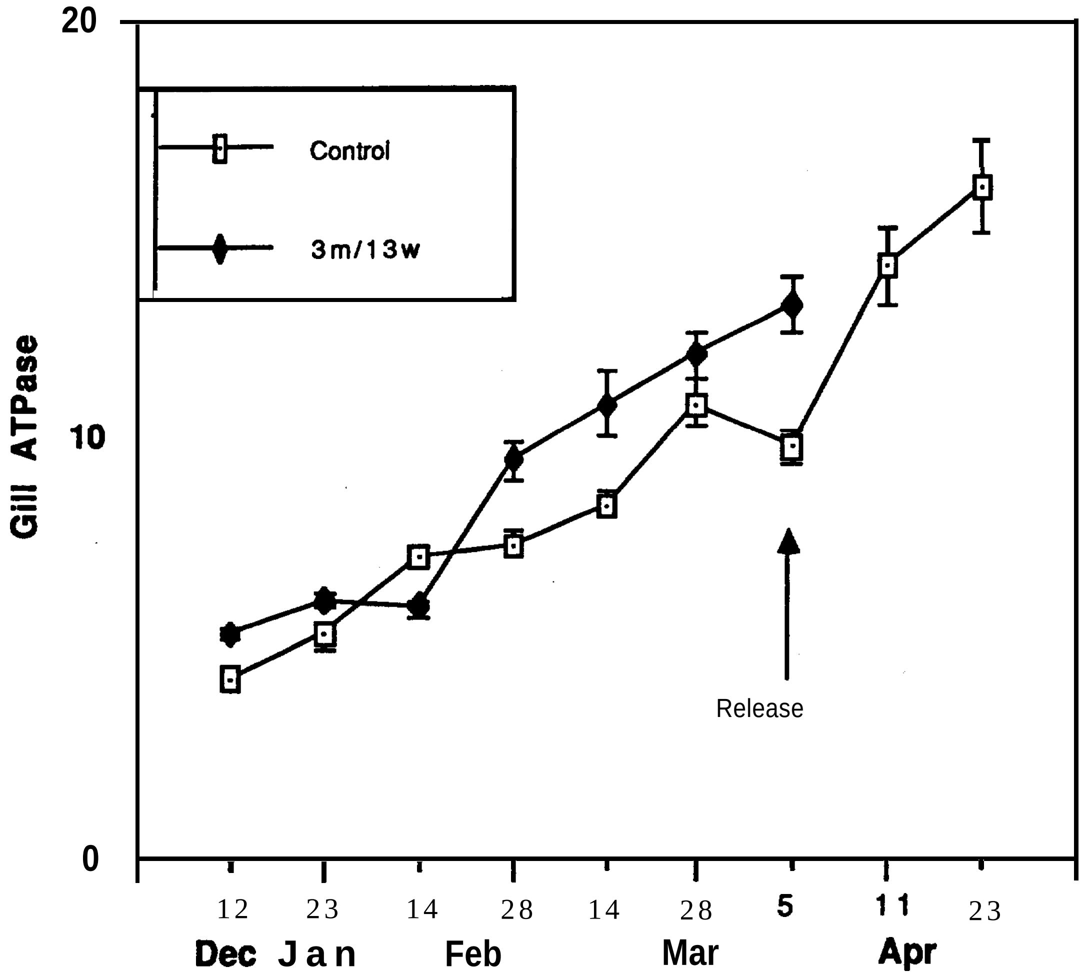

Figure 2.--Mean gill Na^{+}-K^{+} ATPase activities (μmol Pi·mg $Prot^{-1}$·h^{-1}) from spring chinook salmon photoperiod treatment (3m/13w) and control groups collected at Dworshak NFH. Bars represent standard errors; n = 15 to 30. Final two points for the control group were obtained from fish in the delayed release group.

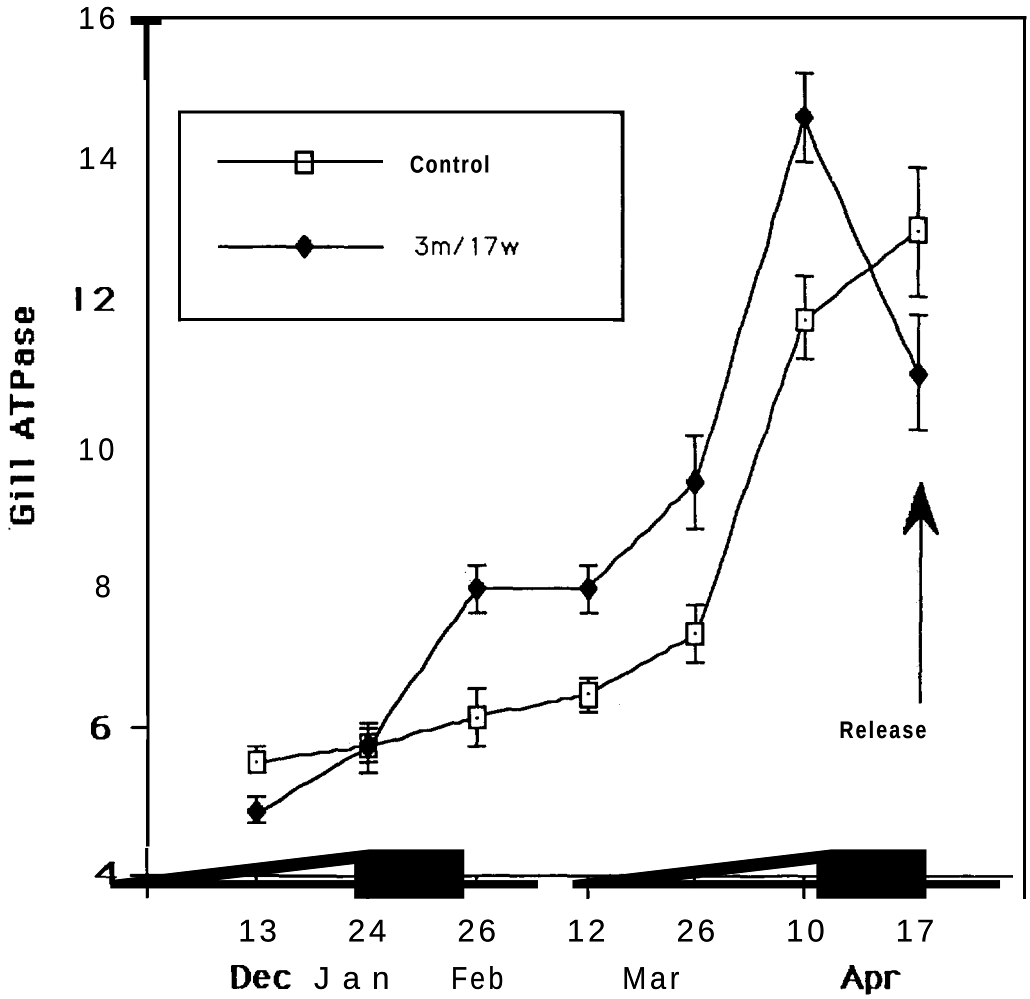

Figure **3.--Mean** gill **Na^+-K^+ ATPase** activities **(µmol Pi·mg $Prot^{-1}$·h^{-1})** from spring chinook salmon photoperiod treatment **(3m/17w)** and control groups collected at Leavenworth NFH. Bars represent standard errors; **n** = 15.

Migratory Behavior

The total percentage of the 3m/13w + T treatment group released from Dworshak NFH and detected at the three downstream collector dams equipped with PIT-tag detectors (Lower Granite, Little Goose, and McNary Dams) was significantly higher (56%, X^2 = 8.04, df = 1, $P < 0.01$) than for the control group (49.7%) (Table 2). The 3m/13w treatment group had a higher overall detection rate (51.8%) than controls, but not significantly so. For the delayed release group from Dworshak NFH, significantly fewer ($P < 0.05$) fish were detected overall (44.3%) than for the production control release group (49.7%). The differences in detection percentages at individual detection sites were not significant.

The 3m/13w, the 3m/13w + T, and the delayed release groups from Dworshak NFH all migrated to Lower Granite Dam significantly faster ($P < 0.001$) than the control group (Table 3). Mean travel times were 23.5 days for the controls, 17.7 days for the 3m/13w photoperiod treatment group, 14.3 days for the 3m/13w + T group, and 17.9 days for the delayed release group (Fig. 4). The 3m/13w + T group had the fastest migration rate at 8.2 km/day from the hatchery to Lower Granite Dam while the control group migrated at 5.0 km/day. Most of the PIT-tagged fish identified at Lower Granite Dam were transported to a release site below Bonneville Dam. Because the more highly smolted fish are generally collected at a higher rate (Giorgi et al. 1988), the observed travel times for fish remaining in the river below Lower Granite Dam were considered biased. However, the travel times and passage patterns of these fish, as observed at Little Goose and McNary Dams, are presented in Appendix Table 3 and Appendix Figures 1 and 2.

The mid-80% of the control group took 24 days to pass Lower Granite Dam while the 3m/13w group and the 3m/13w + T group took only 17 and 13 days, respectively, to pass this site (Table 4).

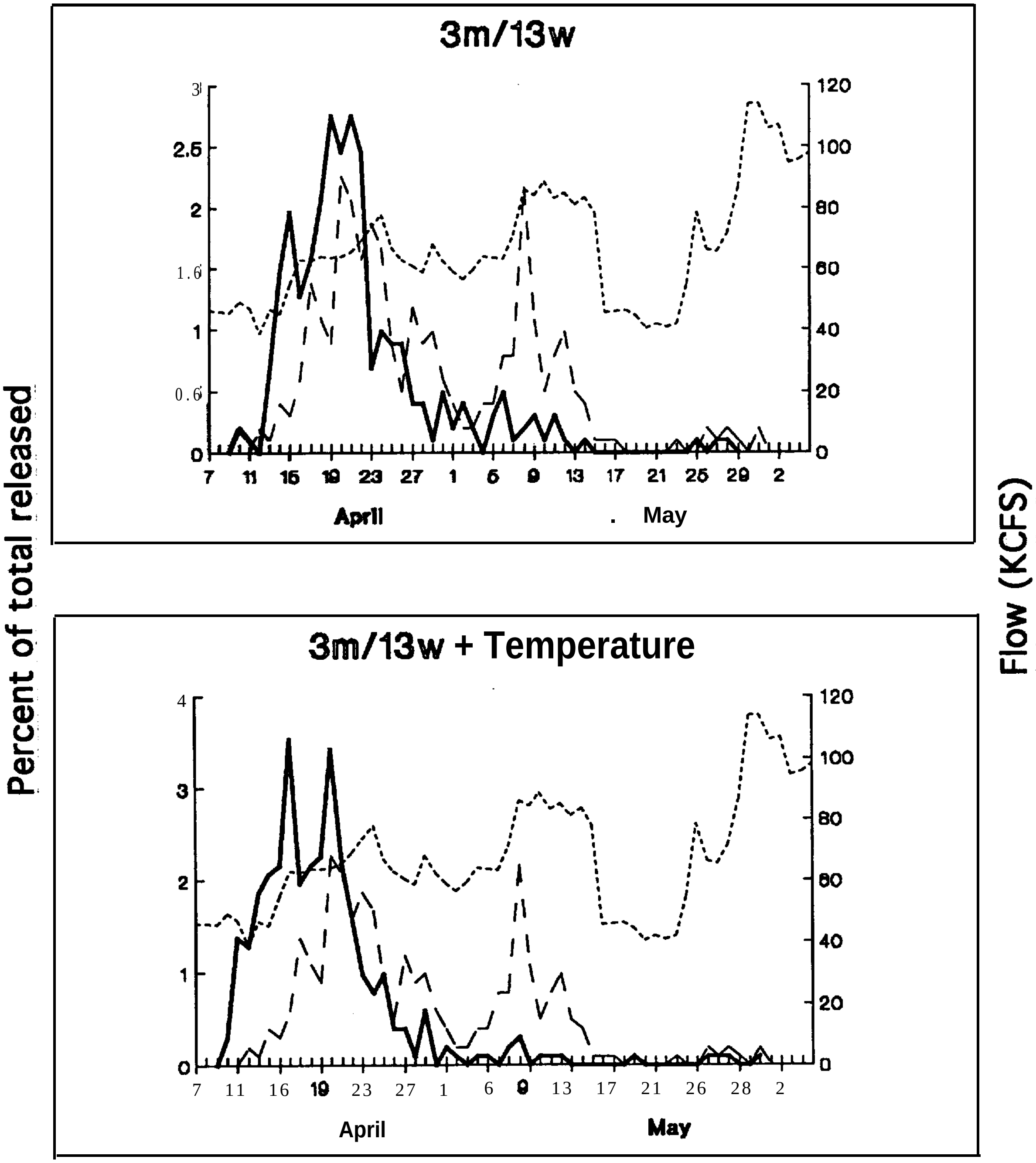

Figure 4.--**Daily** PIT-tag detections (percent of total released) and flow (·····) at Lower Granite Dam for the treatment (——) and control (----) groups from Dworshak National Fish Hatchery, 1990.

Table Z.--Number and percentages of PIT-tagged spring chinook salmon from Dworshak and Leavenworth NFHs detected at Lower Granite (LGR), Little Goose (LGO), and McNary (MCN) Dams, 1990. Asterisks represent chi-square significance level between treatment and control group detection numbers; * = P < 0.05, ** = P < 0.01.

	Detection site							
	LGR		LGO		MCN		Total	
Treatment	No.	%	No.	%	No.	%	No.	%
				Dworshak NFH				
Control	306	30.1	123	12.1	76	7.5	505	49.7
3m/13w	281	27.6	149	14.6	97	9.5	527	51.8
3m/13w + T	327	32.1	153	15.0	91	8.9	571	56.0**
Delayed release	299	30.4	88	8.6*	49	4.8	436	44.3*
				Leavenworth NFH				
Control	---	----	---	----	266	26.2	266	26.2
3m/17w	---	----	---	----	301	29.5	301	29.5

Table 3.--Travel time and migration speed of PIT-tagged spring chinook salmon released from Dworshak NFH on 5 April and 23 April (delayed release) and detected at Lower Granite Dam and released from Leavenworth NFH on 18 April and detected at McNary Dam. T-statistics and probabilities are for comparisons of control and experimental group mean travel times.

Experimental group	Travel time (days) Median	Mean	(SD)	t	P	Mean speed to detection site (km/day)
		Dworshak NFH				
Control	20	23.5	(10.0)			5.0
3m/13w	16	17.7	(7.3)	8.03	<0.001	6.6
3m/13w + T	13	14.3	(7.2)	13.16	<0.001	8.2
Delayed release	18	17.9	(7.4)	7.77	<0.001	6.6
		Leavenworth NFH				
Control	22	26.7	(6.4)			12.3
3m/17w	21	25.3	(6.7)	2.51	0.012	13.0

Table 4.--Passage dates for percentages of PIT-tagged spring chinook salmon arriving at Lower Granite and McNary Dams and the time elapsed between the 10th and 90th passage percentiles following release. Fish were released from Dworshak NFH on 5 April and 23 April (delayed release) and from Leavenworth NFH on 18 April 1990.

Detection site	Experimental group	Percentile of run 10%	50%	90%	10-90% segment (days)
		Dworshak NFH			
Lower Granite					
	Control	4/18	4/25	5/12	24
	3m/13w	4/16	4/21	5/03	17
	3m/13w + T	4/13	4/18	4/26	13
	Delayed release	5/01	5/11	5/24	23
		Leavenworth NFH			
McNary					
	Control	5/06	5/15	5/21	15
	3m/17w	5/04	5/14	5/20	16

The percentages of fish released from Leavenworth NFH detected at McNary Dam (the only site equipped with a PIT-tag detector in this reach) for the 3m/17w group (29.5%) and the control group (26.2%) were not significantly different (Table 2). The photoperiod treatment group released from Leavenworth NFH migrated to McNary Dam in 25.3 days, which was significantly faster ($P < 0.05$) than the control group's 26.7 days (Table 3 and Fig. 5). The treatment group migrated to this site at 13.0 km/day while the control group migrated at 12.3 km/day (Table 3).

Pond Mortality

Pond mortality at Dworshak NFH (from December through release) was higher in the control raceways overall (0.90%) than in the 3m/13w photoperiod treatment raceways (0.53%) (Table 5). There was no significant difference ($X^2 = 0.8$, df = 1, P = 0.3567) in mortality rates between fish in the control and treatment raceways fed medicated feed. However, the percent mortality of fish in the control raceway on unmedicated feed (2.1%) was significantly higher ($X^2 = 171.6$, df = 1, P = <0.001) than for fish in the 3m/13w treatment raceway on unmedicated feed (0.96%). Fish in the 3m/13w photoperiod plus increased water temperature treatment group did not incur additional mortality compared with other groups. At Leavenworth NFH, mortality was low in both treatment (0.12%) and control (0.05%) raceways (Table 5).

Summary 1988 - 1990

The effects of photoperiod and photoperiod/temperature treatment on gill Na^+-K^+ ATPase development, travel time, and downstream detection rates during 1990 were similar to the effects observed in previous years (Table 6). Overall detection rates and gill Na^+-K^+ ATPase levels were highest and travel time to Lower Granite Dam the shortest in the photoperiod/temperature treatment group during the 2 years this treatment was

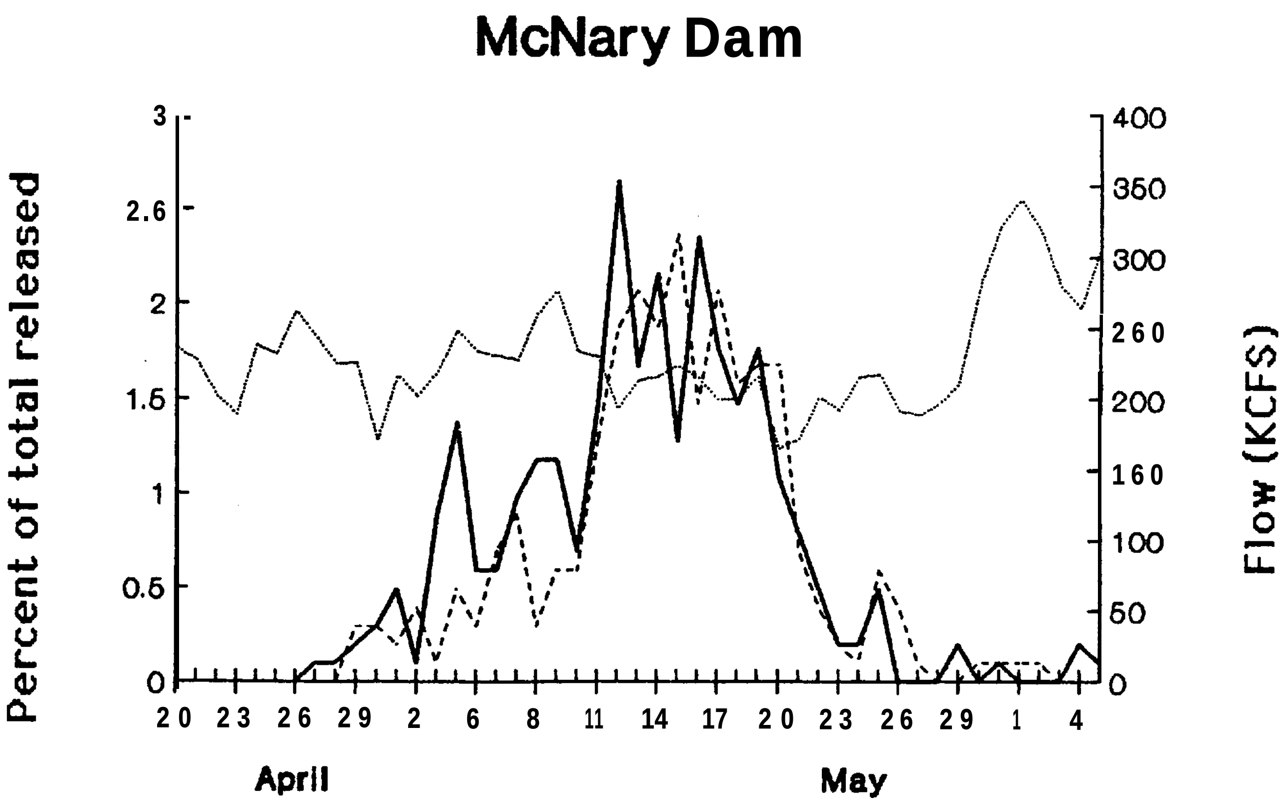

Figure 5.--Daily PIT-tag detections (percent of total released) and flow (····) at McNary Dam for the 3m/17w treatment (—) and control (----) groups from Leavenworth National Fish Hatchery, 1990.

Table 5.--Spring chinook salmon pond mortalities from the photoperiod studies at Dworshak and Leavenworth National Fish Hatcheries from December 1989 to release on 5 April and 18 April 1990, respectively. Numbers in bold are group totals.

Test group	Raceway numbers	No. of mortalities	Percent mortality
		Dworshak NFH	
Control	A 11 *	188	0.40
	A 12 *	141	0.29
	B 22	920	2.10
		1,249	**0.90**
3m/13w	B 28	388	0.96
	B 29 *	156	0.37
	B 30 *	116	0.28
		660	**0.53**
		Leavenworth NFH	
Control	44	14	0.05
3m/17w	47	32	0.12

* Medicated feed treatment.

Table 6.--Results of 3 years of photoperiod research at Dworshak NFH. Travel time (TT) to Lower Granite Dam was determined by PIT-tag detections. Overall detections were from Lower Granite, Little Goose, and McNary Dams combined. ATPase units are in $\mu mol\ Pi \cdot mg\ Prot^{-1} \cdot h^{-1}$. Significance was determined using a Student's t-test for ATPase and mean TT data and a chi-square for overall detection proportions; ** = $P < 0.01$, *** = $P < 0.001$.

Year	Treatment		
	Control	Photoperiod	Photo + Temp
ATPase at release			
1988	13.6	15.0	-
1989	6.9	**9.4****	**15.3****
1990	9.8	**13.2*****	**13.9*****
Median **TT** to Lower Granite (days)			
1988	22	21	
1989	32	25	25
1990	20	16	13
Mean TT to Lower Granite (days)			
1988	24	**22*****	
1989	32	**26*****	**24*****
1990	24	**18*****	**14*****
Overall detection (%)			
1988	44.3	45.3	
1989	47.6	**53.1*****	**58.0*****
1990	49.7	51.8	**56.0*****

applied. Photoperiod treatment alone resulted in increased overall detection rates and gill Na^+-K^+ ATPase levels and shorter travel time to Lower Granite Dam for the 3 years this treatment was applied.

DISCUSSION

The smoltification process in salmonids causes morphological, behavioral, and physiological changes that affect downstream migration as well as the ability to survive in seawater. In a natural environment, this process is regulated primarily by photoperiod and temperature (Folmar and Dickhoff 1980, Wedemeyer et al. 1980). The majority of smolts emigrating from the Snake River are now of hatchery origin and do not become fully smolted while at the hatchery (Rondorf et al. 1985, Muir et al. 1988). They are often exposed to environmental factors that differ from those experienced by wild juveniles. Security lights, constant food supply, and stable water temperatures create unnatural environmental conditions. Furthermore, their release is often dictated by management concerns unrelated to their physiological status (Folmar and Dickhoff 1981). As a result, fish are released that may not be physiologically or behaviorally prepared to migrate. This is evidenced by the lag time between hatchery release and initiation of downstream migration as observed at Lower Granite Dam (FPC 1989). In this study, we demonstrated that developmentally advanced yearlings (those which are more smolted), moved downstream more quickly and were observed in higher proportions than less smolted counterparts.

Over several years, the measurement of gill Na^+-K^+ ATPase as an index of smoltification in spring chinook salmon at Dworshak NFH has shown consistent results. As a consequence, we consider this our most reliable and readily interpretable index of smolt development. We have measured this enzyme at the hatchery for 4 years

(1986-1989). Enzyme activity has been low and stable at the hatchery from December through release with a two- to three-fold increase in fish recaptured downstream at Lower Granite Dam (Swan et al. 1987, Muir et al. 1988, Giorgi et al. 1990). Similar results have been found by others (Rondorf et al. 1985, 1988; Zaugg et al. 1985), indicating that the migrational experience, subsequent to release from the hatchery environment, may be necessary for the full development of this enzyme.

Photoperiod and photoperiod/temperature treatment effects were apparent in downstream migratory behavior. Treatment fish moved downstream significantly faster than the controls as reflected in their travel times through the hydroelectric complex. Zaugg and Wagner (1973) and Wagner (1974) had similar results with steelhead where they found that an advanced photoperiod schedule increased their migration rate. Increased water temperature near the time of release further accelerated migratory behavior when applied to the 3m/13w photoperiod treatment group at Dworshak NFH.

The results of physiological development, migrational timing, and detection rates obtained in 1990 are consistent with the results obtained in 1988 and 1989 with yearling chinook salmon released from Dworshak NFH (Giorgi et al. 1990, 1991). The degree to which photoperiod and photoperiod/temperature treatment affected these results varied between years, but the trends were consistent. Differences between years may have been due to yearly variations in river flow, water temperature, hatchery practices, and/or general fish condition.

A higher percentage of photoperiod/temperature treatment fish than controls were detected at all of the collector dams, although only the overall differences for PIT-tag detections were significant. Possible explanations for this higher percentage for the treatment fish include increased FGE at collector dams or lower reservoir-related mortality. Giorgi et al. (1988) and Muir et al. (1988) presented data which indicated that yearling chinook salmon with elevated gill Na^+-K^+ ATPase activity were generally more susceptible to guidance by submersible traveling screens at Lower Granite and Little Goose Dams. Since fish exposed to the photoperiod and photoperiod/temperature treatments were in the reservoir for a shorter time, they may also have suffered less reservoir-related mortality due to predation. This predation impact may be compounded by the fact that, as seasonal water temperatures increase, predators become more active (Poe and Rieman 1988).

Although photoperiod treatment alone accelerated smolt development, additional exposure to increased water temperature for 10 days prior to release produced the most dramatic response. The same result was achieved when this treatment was applied to a 3m/18w photoperiod group in 1989; however, temperature treatment alone applied to an ambient photoperiod control group in 1989 did not accelerate smolt development. Wedemeyer et al. (1980) identified photoperiod as "the major environmental priming factor and coordinator which brings these endogenous physiological processes together on a temporal basis" and temperature as "the major controlling factor setting the range within which these processes can proceed and within limits, determining their rates of reaction." In laboratory experiments with Atlantic salmon, Salmo salar, Duston et al. (1990) observed that an elevation in water temperature increases the rate of physiological response cued by the increase in day length.

The objective of the bypass and transportation programs is to collect the maximum number of migrating fish. The objective of providing increased flows is to move fish faster to collection dams or downstream through the hydroelectric complex. Clearly, the degree of smolt development in yearling chinook salmon released from hatcheries will influence the success of these programs. In this study, we altered photoperiod cycles, in some cases in conjunction with elevated rearing temperatures, to accelerate smolt development. We were able to significantly increase the migration rates in these treatment groups at a similar flow level. Providing increased flows to move hatchery smolts that are not physiologically ready to migrate may not be effective.

The results obtained at Leavenworth NFH and with the Dworshak NFH delayed release group indicated that the positive benefits of photoperiod treatment may be realized by simply using ambient light and a later release date. At both of these hatcheries, gill Na^{+}-K^{+} ATPase levels in fish under ambient light conditions increased sharply in mid-April, catching up with fish under photoperiod control.

If early release dates are necessary, using advanced photoperiod and temperature treatment on hatchery spring chinook salmon smolts may be a realistic approach to accelerate smoltification and improve downstream migration. For this study, lights and timers sufficient for treating three raceways containing approximately 120,000 smolts were purchased for under $3,000. On a production scale, existing hatchery security lighting systems could be utilized (and expanded if necessary) and regulated with an automatic timer to attain the desired photoperiod effect at very little cost. This would have a negligible impact on normal hatchery operations. There is some concern that the cost of heating water is prohibitive. This may not be the case, however, when heating costs are balanced against the improvements realized in downstream passage. Considering the water temperature in this experiment increased only about 5” to 6°C for 10 days, this may be a relatively small cost in the overall fish production effort.

This study demonstrated that more physiologically advanced smolts traveled faster, and were detected in higher proportions downstream. Greater emphasis should be placed on releasing hatchery smolts at the optimum time of year and physiological condition for rapid migration and enhanced survival. We feel that evaluating additional methods to maximize smolt development in the hatchery will be valuable.

SUMMARY

1) This research indicated that the level of smolt development in yearling chinook salmon, when released from the hatchery, affected their performance as they migrated seaward. These effects were apparent in terms of shorter travel times and increased PIT-tag detection proportions observed at hydroelectric dams.

2) Photoperiod and photoperiod/temperature treatment increased gill Na^{+}-K^{+} ATPase in yearling chinook salmon at Dworshak NFH to levels significantly higher than the control group's level at release.

3) The photoperiod, photoperiod/temperature, and delayed release groups had significantly shorter travel times than the control group to Lower Granite Dam for fish released from Dworshak NFH. Travel times were reduced for treatment groups at equivalent flows.

4) Increased water temperature, when applied to the 3m/13w photoperiod treatment group 10 days prior to release, produced the most accelerated smolt development, shortest travel time, and highest downstream detection proportion.

5) Delayed release (23 April) resulted in significantly increased gill Na^{+}-K^{+} ATPase activity and significantly shorter travel time compared to controls. However, detection proportions were significantly lower than the control group released on 5 April.

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Appendix Table l.--Gill Na^{+}-K^{+} ATPase data (mean, standard deviation, and sample size) from spring chinook salmon from Dworshak NFH photoperiod experiment - 1990. Units are in µmol Pi·mg $Prot^{-1}$. h^{-1}. Asterisks represent t-test significance level between treatment and control, group; * = P < 0.05, ** = P < 0.01, and *** = P < 0.001.

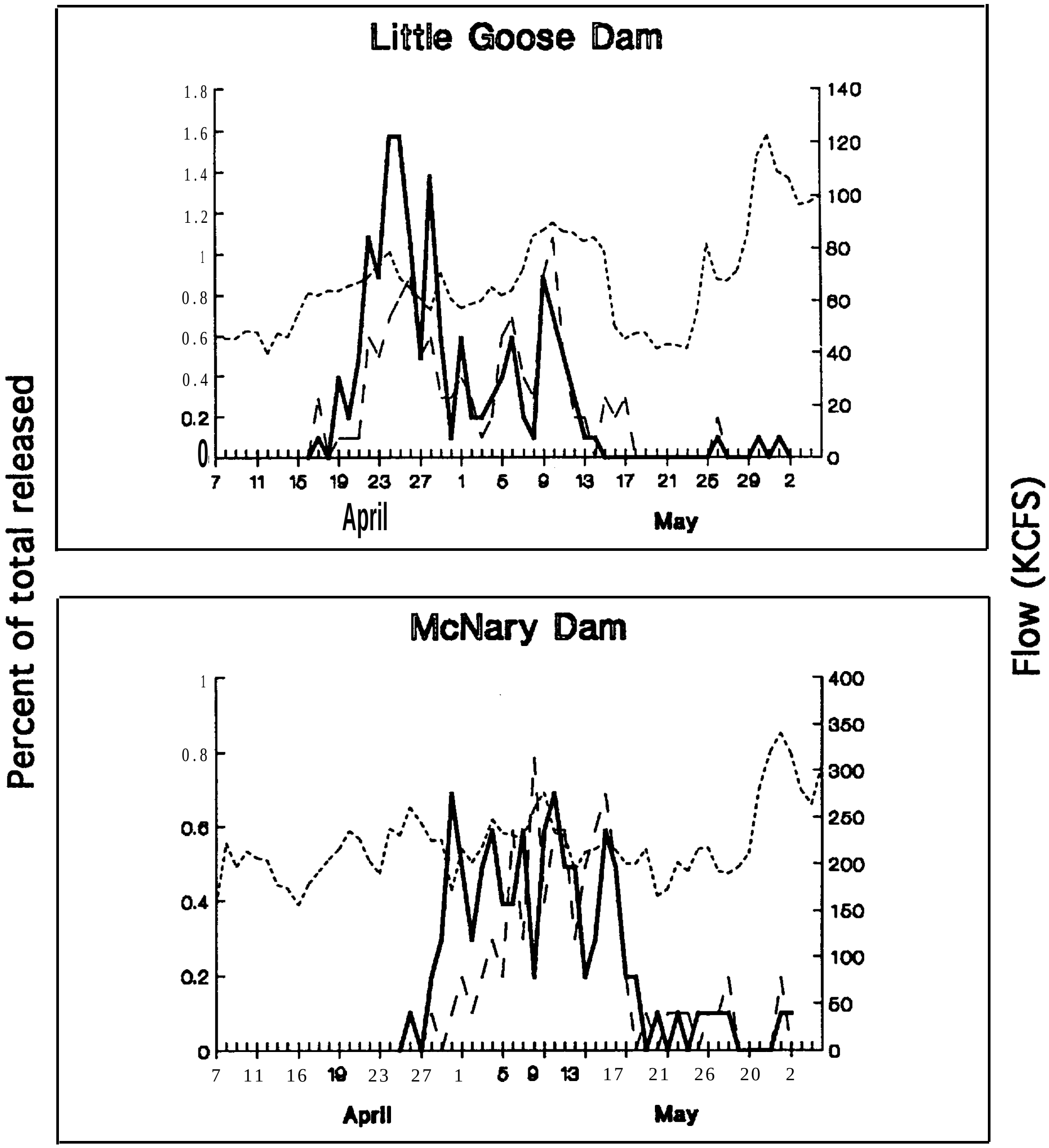
Sample date		Test conditions		
		Control	3m/13w	3m/13w+T
12 Dec	x	4.3	5.4**	----
	SD	1.62	0.75	----
	n	30	30	----
23 Jan	x	5.3	6.1*	
	SD	1.68	0.78	----
	n	30	30	----
14 Feb	x	7.2	6.0***	
	SD	0.95	1.08	
	n	30	30	
28 Feb	x	7.5	9.5***	
	SD	1.51	2.50	
	n	30	30	----
14 Mar	x	8.3	10.8**	----
	SD	1.71	4.34	----
	n	30	30	
28 Mar	x	10.9	12.0	----
	SD	2.94	3.09	----
	n	30	30	----
3 Apr	x	9.8	13.2***	13.9***
	SD	2.05	3.81	3.55
	n	30	30	15
11 Apr	x	14.0		----
	SD	3.56		----
	n	15	----	
23 Apr	x	16.0	----	
	SD	5.16	----	
	n	15		----

Appendix Table 2.--Gill Na^{+}-K^{+} ATPase data (mean, standard deviation, and sample size) from spring chinook salmon from Leavenworth NFH photoperiod experiment - 1990. Units are in µmol Pi·mg $Prot^{-1} \cdot h^{-1}$. Asterisks represent t-test significance level between treatment and control group; * = P < 0.05, ** = P < 0.01, and *** = P < 0.001.

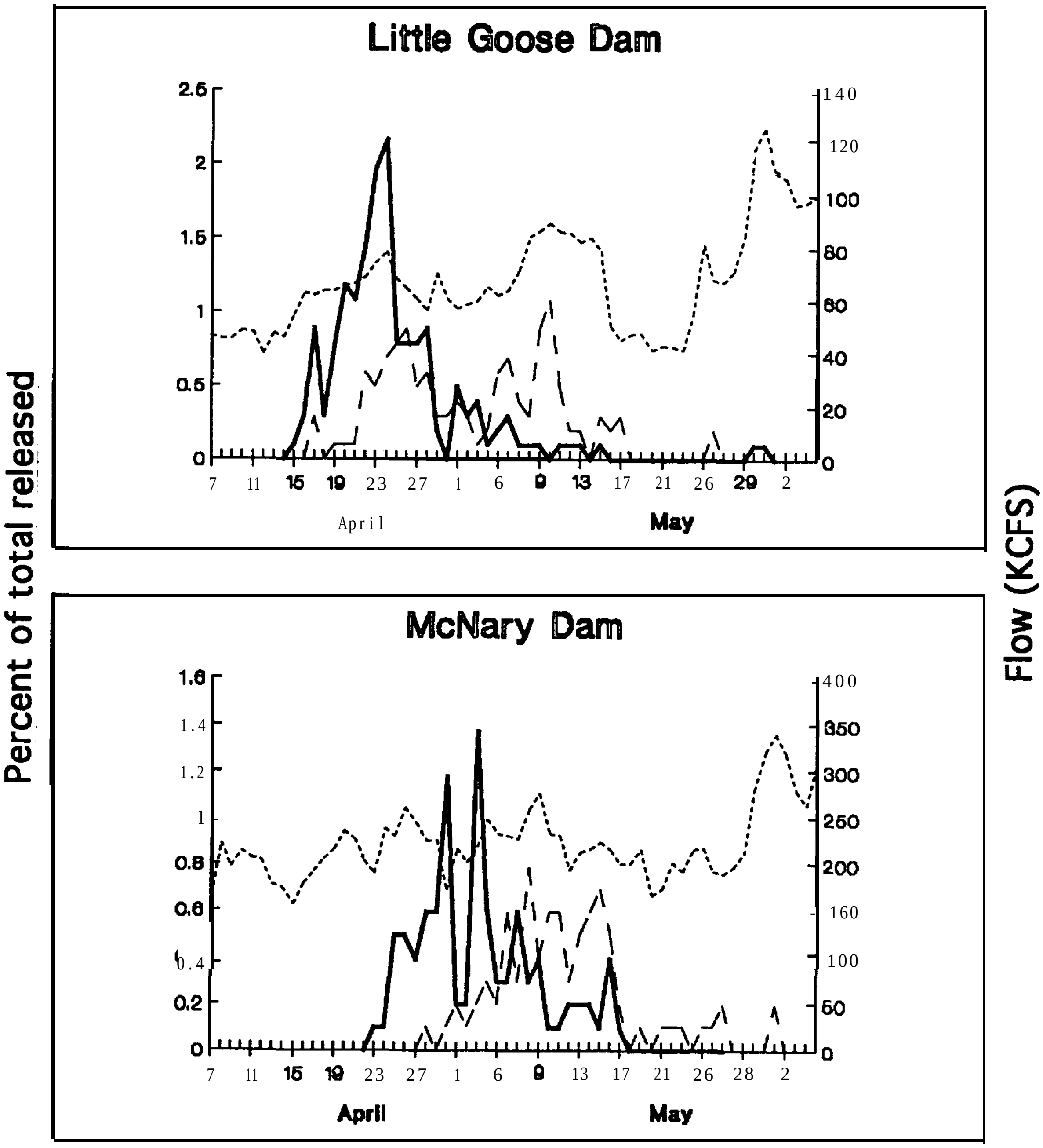
Sample date		Test conditions Control	3m/17w
13 Dec	x	5.6	4.9*
	SD	0.72	0.74
	n	15	15
24 Jan	x	5.8	5.8
	SD	1.35	0.99
	n	15	15
26 Feb	x	6.2	8 0***
	SD	1.38	1.21
	n	15	15
12 Mar	x	6.5	8 0***
	SD	0.86	1.22
	n	15	15
26 Mar	x	7.4	9.5**
	SD	1.56	2.46
	n	15	15
10 Apr	x	11.8	14.5**
	SD	2.39	2.44
	n	15	15
17 Apr	x	13.0	11.0
	SD	3.44	3.12
	n	15	15

Appendix Table 3.--Travel time and migration speed of PIT-tagged spring chinook salmon released from Dworshak NFH on 5 April and 23 April (delayed release) and detected at Little Goose and McNary Dams. T-statistics and probabilities are for comparisons between control and experimental group mean travel times.

Detection site	Experimental group	Travel time (days) Median	Mean	(SD)	t	P	Mean speed to detection site (km/day)
Little Goose	Control	27	27.4	(8.2)			6.6
	3m/13w	22	24.4	(7.8)	3.12	0.0020	7.4
	3m/13w + T	19	19.9	(6.8)	8.27	<0.001	9.0
	Delayed release	28	27.1	(7.4)	0.28	0.7799	6.6
McNary	Control	36	36.6	(6.8)	9.4		
	3m/13w	34	34.0	(7.5)	2.49	0.0137	10.1
	3m/13w + T	28	28.2	(5.9)	8.96	<0.001	12.1
	Delayed release	31	30.8	(6.3)	5.04	<0.001	11.1



Appendix Figure 1.--Daily PIT-tag detections (percent of total released) and flow (····) at two downstream detection sites for the 3m/13w treatment (-) and control (----) groups from Dworshak National Fish Hatchery, 1990.



Appendix Figure Z.--Daily PIT-tag detections (percent of total released) and flow (····) at two downstream detection sites for the 3m/13w + T treatment (—) and control (----) groups from Dworshak National Fish Hatchery, 1990.

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650