Biological Manipulation of Migration Rate: The Use of Advanced Photoperiod to Accelerate Smoltification in Yearling Chinook Salmon

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

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by

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ABSTRACT

Research was conducted to assess the feasibility of biologically manipulating physiological development and migratory behavior of yearling spring chinook salmon, Oncorhynchus tshawytscha. At Dworshak National Fish Hatchery, treatment groups were exposed to a variety of advanced photoperiod cycles preceding release to accelerate smolt development. Physiological development and migratory performance were described for all groups. The treatments included a 14-week exposure to a 3-month advanced photoperiod cycle, an 18-week exposure to a 3-month advanced photoperiod cycle, and an 18-week exposure to a 4-month advanced photoperiod cycle. Two additional groups, an 18-week exposure to a 3-month advanced photoperiod and a control equivalent, were reared at an elevated water temperature (11°C) for 2 weeks prior to release. Results indicated that the treated fish which were the most physiologically advanced at release were detected in the highest proportion at collector dams and also migrated fastest downstream.

CONTENTS

INTRODUCTION

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

The relationship between increasing river flow volumes and faster inriver migration has been demonstrated for both yearling chinook salmon, Oncorhynchus tshawytscha, and steelhead, O. mykiss (Sims et al. 1984). 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 (NWPPC 1987). This program calls for strategic releases of water from storage reservoirs to flush smolts through the system. However, juvenile salmonids may not fully respond to such measures if they are not physiologically prepared to migrate. Zaugg (1981) presented evidence that subyearling chinook salmon migrated at different rates depending on their level of physiological development within the transformation from parr to smolt. Juveniles in the more advanced stages of smolt development exhibited the highest inriver migration rates.

Giorgi et al. (1988) reported that yearling chinook salmon with elevated gill Na^+-K^+ ATPase activity were generally more susceptible to guidance by submersible traveling screens (STS) 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 (see reviews by 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). However, these data are based largely on laboratory observations or limited numbers of marked fish migrating inriver. In 1988, National Marine Fisheries Service (NMFS) research at Dworshak National Fish Hatchery (NFH) demonstrated that exposing yearling chinook salmon to a 3-month advanced photoperiod treatment for 14 weeks accelerated smolt development and altered migratory behavior (Giorgi et al. 1990).

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 include detection proportions at hydroelectric dams as well as inriver migration rates. Our strategy was to accelerate smolt development in experimental groups in a hatchery population by subjecting treatment groups to various advanced photoperiod and temperature cycles and compare their physiological development and downstream migratory behavior to a corresponding control group.

METHODS

The research was conducted using yearling chinook salmon at Dworshak NFH on the Clearwater River near Orofino, Idaho (Fig. 1). Experimental groups were exposed to three photoperiod treatments: a 3-month advanced photoperiod cycle for 14 weeks (3m/14w), a 3-month advanced photoperiod cycle for 18 weeks (3m/18w), and a 4-month advanced photoperiod cycle for 18 weeks (4m/18w). A corresponding control group (control) was exposed only to ambient light and water temperature conditions during the same periods. In addition, two groups, a 3m/18w and a second photoperiod control group, were reared at increased water temperature for the 2 weeks prior to release (designated as 3m/18w + T, and control + T, respectively) .

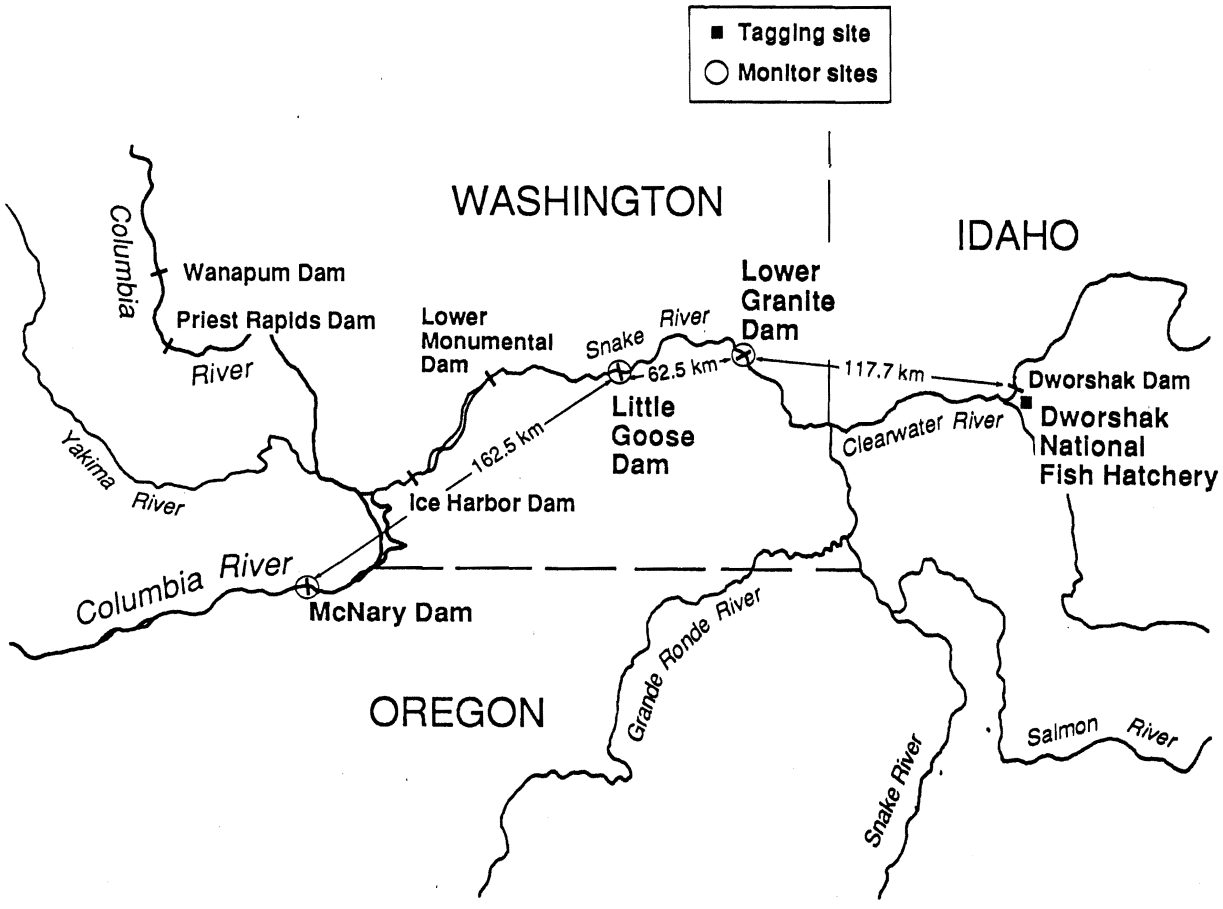


Figure 1.--Location of Dworshak National Fish Hatchery and downstream interception sites in the Snake and Columbia Rivers. River kilometers between sampling sites are indicated.

A portion of each group was implanted with passive integrated transponder (PIT) tags (Prentice et al. in press); approximately 2,350 PIT tags were used in each group (Table 1). Fish were tagged on 8 November for the control and photoperiod test groups and on 15 March for groups reared at the increased water temperature. PIT tags were used to evaluate migrational characteristics. Freeze brands (Mighell 1969) were applied to two groups (4m/18w and the control group) primarily for visual identification at the sampling sites at Lower Granite and McNary Dams where experimental fish were collected for physiological assays. A total of 73,530 treatment and 64,643 control fish were branded on 8 November (Table 1).

Experimental fish were held in four separate, adjacent raceways. Each raceway was 24.4 m long by 2.4 m wide, and water depth was 0.6 m. A partition 1.0-m high ran the length of each raceway, splitting each raceway in half. Sidewalls projected 3.0 m above the water surface. Four light fixtures were suspended from walls of the treatment group raceways 1.8 m above the water surface. This arrangement shielded the control raceway from incidental light. Each fixture was fitted with a 400-watt metal halide bulb. Light operation was controlled by a timing device which was reset every 10 days to maintain the advanced cycle. Light treatment began on 21 November for the 4m/18w group, on 23 November for the 3m/18w group, and on 20 December for the 3m/14w group. Both the treatment and control raceways were maintained on normal hatchery diets and pond maintenance schedules.

Two weeks prior to release, approximately 2,300 fish from the 3m/18w group and 2,300 fish from the control group were removed from their respective raceways, PIT tagged, and moved into four tanks in the Dworshak NFH nursery room. Each tank was 1 m wide and 5 m long. Water depth was approximately 0.5 m. The 3m/18w group was maintained on its photoperiod schedule by suspending two 100-watt light bulbs above each of its two tanks. Water temperature was raised 1°C per hour from 4.5° to 11°C and maintained at this temperature until release.

Table 1.--Marking summary for spring chinook salmon from Dworshak National Fish Hatchery photoperiod study. Treatment and control fish were held in separate raceways. PIT-tagged fish in each raceway were reared with approximately 76,000 unmarked fish.

Experimental condition	Marking date	Number marked		Number released[a]	
		PIT tags	Brands	PIT tags	Brands
Control	8 Nov 88	2,379	64,643	2,377	58,716
3m/14w	8 Nov 88	2,362	-	2,340	-
3m/18w	8 Nov 88	2,342	-	2,322	-
4m/18w	8 Nov 88	2,387	73,530	2,265	65,298
3m/18w + T	15 Mar 89	2,351	-	2,214	-
Control + T	15 Mar 89	2,352	-	2,224	-

[a] Adjusted for mortality, brand legibility, and tag loss.

Dead fish were regularly removed from the raceways; brands were enumerated. Unbranded fish were stored frozen and later interrogated for PIT tags. These data were used to calculate the number of tagged and branded 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 juvenile collection systems. The electronic detectors transmit a radio signal which stimulates the tag as a tagged fish passes through the detection tunnel. The tag then transponds 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. A detailed description of the PIT-tag system is presented in Prentice et al. (in press). PIT-tag data provided detailed information regarding the migration rate of individual experimental fish as they migrated through the Snake River and into the Columbia River.

During low flow years, Lower Granite and Little Goose Dams transport spring chinook salmon collected in their bypass systems including PIT-tagged fish. This occurred during the 1989 outmigration and affected the travel time and detection rate data collected below Lower Granite Dam. For this reason, the mean travel times to Lower Granite Dam are probably the best indication of a treatments' effect on travel time. The detection rates are certainly reduced at downstream sites by the number of PIT-tagged fish collected and transported at upriver sites.

Subsequent to release from the hatchery, marked individuals were recaptured at three downstream interception sites (Fig. 1). At Lower Granite and McNary Dams, branded fish were sampled from the juvenile fish collection systems during routine smolt monitoring activities (FPC 1989). These fish were later assayed for several physiological indices of smolt development.

Smolt Physiology

To monitor changes in the physiological status of the experimental groups, three indices of smolt development were assayed: gill Na^+-K^+ ATPase, and the thyroid hormones, thyroxine (T_4) and triiodothyronine (T_3). A series of samples was taken at the hatchery from initiation of the treatment until release of the experimental groups. On each occasion a sample of 15 fish was dipnetted from each of the treatment and control groups. Samples were collected monthly from December through February and then biweekly until release. 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 followed procedures described by Zaugg (1982) with minor modifications. Heparinized blood was centrifuged, and the plasma was collected and frozen until assayed for T_3 and T_4 hormones. We used assay procedures described by Dickhoff et al. (1978). Following release from the hatchery, branded fish intercepted at Lower Granite and McNary Dams were also assayed for these indices. Mean values were calculated for each test group for each sample date and indice.

Bacterial Kidney Disease

Samples of 60 fish from each treatment group and the control group were checked for the presence of bacterial kidney disease (BKD) using the enzyme-linked immunosorbent assay (ELISA) technique. Samples were taken at the time of tagging on 22 November and again at the time of release on 29 March. ELISAs were conducted at Dworshak NFH by the U.S. Fish and Wildlife Service (USFWS). Some fish from the 22 November sample were combined because of small size. A mean BKD level was then calculated for each test group for each sample date.

Statistics

The paired t-test was used to compare travel time data, for comparisons of physiological data, and for comparisons of BKD levels. The chi-square test was used to compare recovery proportions.

RESULTS

Smolt Development

During hatchery residence, gill Na^+-K^+ ATPase activity in the control group changed very little (Fig. 2). It ranged from 5.8 to 7.5 µmol Pi · mg $Prot^{-1}$ · h^{-1} and was at 6.9 units on release on 29 March. All of the photoperiod treatment groups were significantly higher ($P < 0.001$) by 21 February and remained higher until release (Fig. 2). The 3m/14w group was at 9.4 units at release, the 3m/18w group at 14.4 units, and the 4m/18w group at 10.9 units, all significantly higher ($P < 0.01$, $P < 0.001$, and $P < 0.001$) than the control group on 29 March.

Temperature treatment had a varied effect on gill Na^+-K^+ ATPase activity (Fig. 2). In the 3m/18w group, it increased activity to 15.3 units by 29 March, the highest level observed for any group at the hatchery. This was significantly higher ($P < 0.001$) than the control group on this date. Conversely, temperature treatment had no effect on gill Na^+-K^+ ATPase activity when applied to the control group. This group was at 6.8 units at release.

Subsequent to release from the hatchery on 29 March, a sample of the two freeze-branded groups was intercepted at Lower Granite Dam on 14 April. The control and the 4m/18w treatment groups exhibited enzyme levels which were significantly higher ($P < 0.001$) than observed at release, with means of 17.5 and 25.2 units, respectively (Fig. 2). Furthermore, the enzyme level in the (4m/18w) treatment group was significantly higher ($P < 0.01$) than the control group. By 24 April, both groups had increased significantly ($P < 0.001$) to means of 35.7 and 40.0 units for the control group and treatment group, respectively. When sampled at the same dam 4 days later

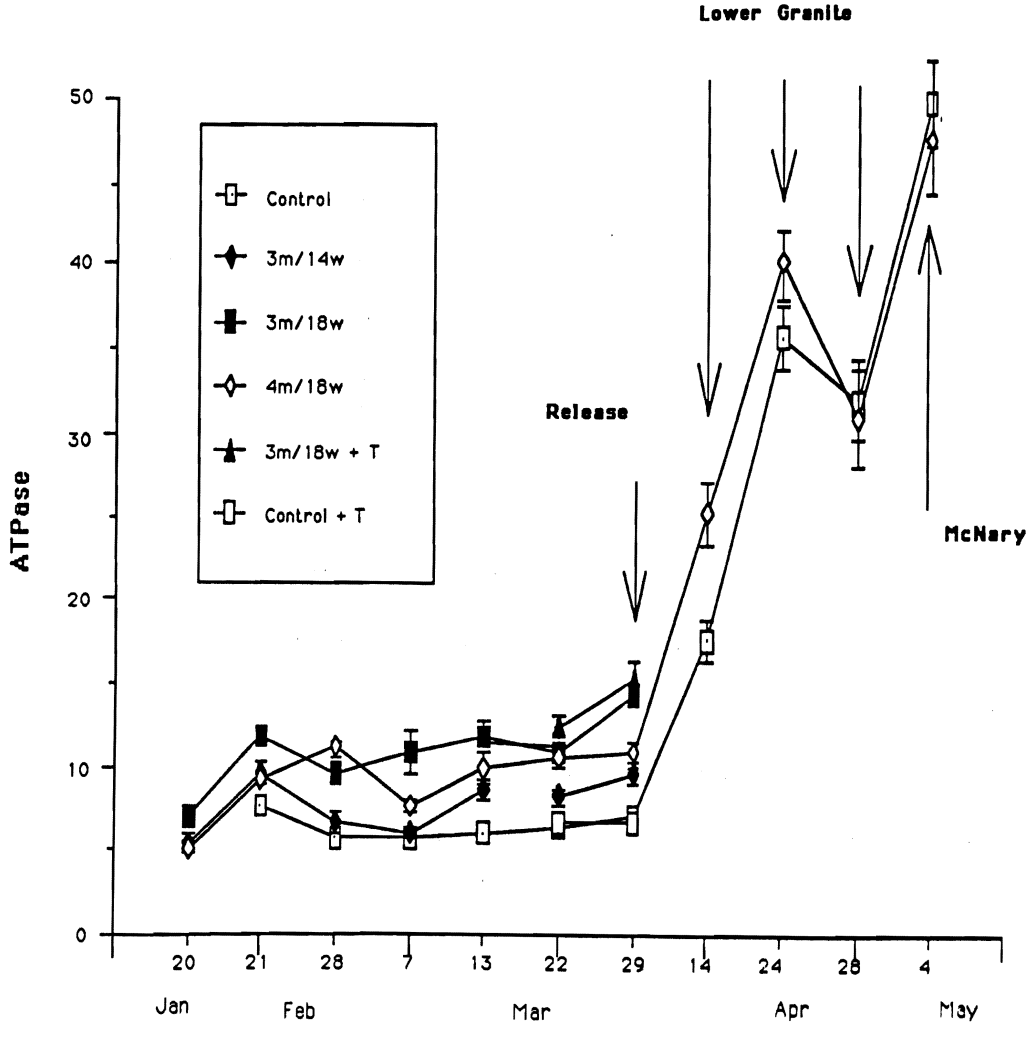


Figure 2.--Mean gill Na^+-K^+ ATPase activities (µmol Pi·mg $Prot^{-1}h^{-1}$)) from spring chinook salmon photoperiod and/or temperature treatment and control groups collected at Dworshak National Fish Hatchery and downstream recovery sites (n = 6 to 15). Bars represent standard errors.

on 28 April, gill Na^+-K^+ ATPase activity was lower in both groups at 32.0 and 30.9 units for the control group and treatment group, respectively. On 4 May at McNary Dam, gill Na^+-K^+ ATPase levels had increased significantly ($P < 0.001$) to 49.6 and 47.3 units for the control group and treatment group. Detailed gill Na^+-K^+ ATPase data for each sample date are contained in Appendix Table 1.

All of the photoperiod treatment groups had significantly lower ($P < 0.01$) thyroxine (T_4) levels than the control group when first measured on 20 December (Fig. 3). The treatment groups ranged from 3.4 to 3.7 $ng \cdot ml^{-1}$ while the control group's T_4 level was at 6.2 $ng \cdot ml^{-1}$ on that date. When measured on 20 January, all three photoperiod treatment groups had increased significantly ($P < 0.001$), and were significantly higher ($P < 0.05$) than the control group on that date. T_4 levels in the three photoperiod treatment groups ranged from 9.7 to 11.0 $ng \cdot ml^{-1}$, while the control group was at 5.4 $ng \cdot ml^{-1}$. All of the treatment groups (both photoperiod and temperature) and the control group reached their peak levels on 22 March, 1 week prior to release. When the freeze-branded groups were sampled downstream at Lower Granite and McNary Dams, their T_4 levels were similar to levels at release. Detailed T_4 data for each sample date are contained in Appendix Table 2.

Triiodothyronine (T_3) levels in the treatment and control groups were generally low throughout the study, both at the hatchery and upon recapture downstream (Fig. 4). Although significant differences were detected between treatment and control groups on various dates, no obvious trends were identified. Detailed T_3 data for each sample date are contained in Appendix Table 3.

Migratory Behavior

The total percent detected at the three downstream collector dams (Lower Granite, Little Goose, and McNary Dams) equipped with PIT-tag detectors was significantly

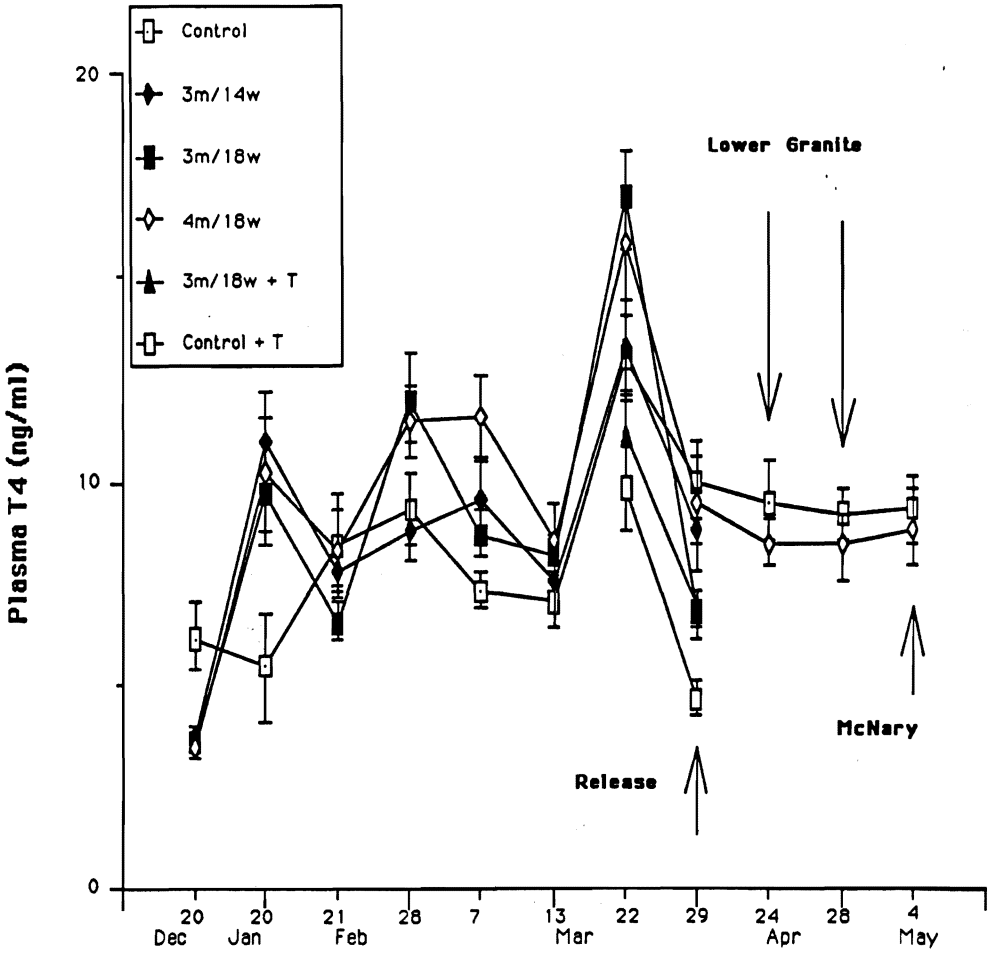


Figure 3.--Mean thyroxine (T_4) levels ($ng \cdot ml^{-1}$) from spring chinook salmon photoperiod and/or temperature treatment and control groups collected at Dworshak National Fish Hatchery and downstream recovery sites (n = 10 to 15). Bars represent standard errors.

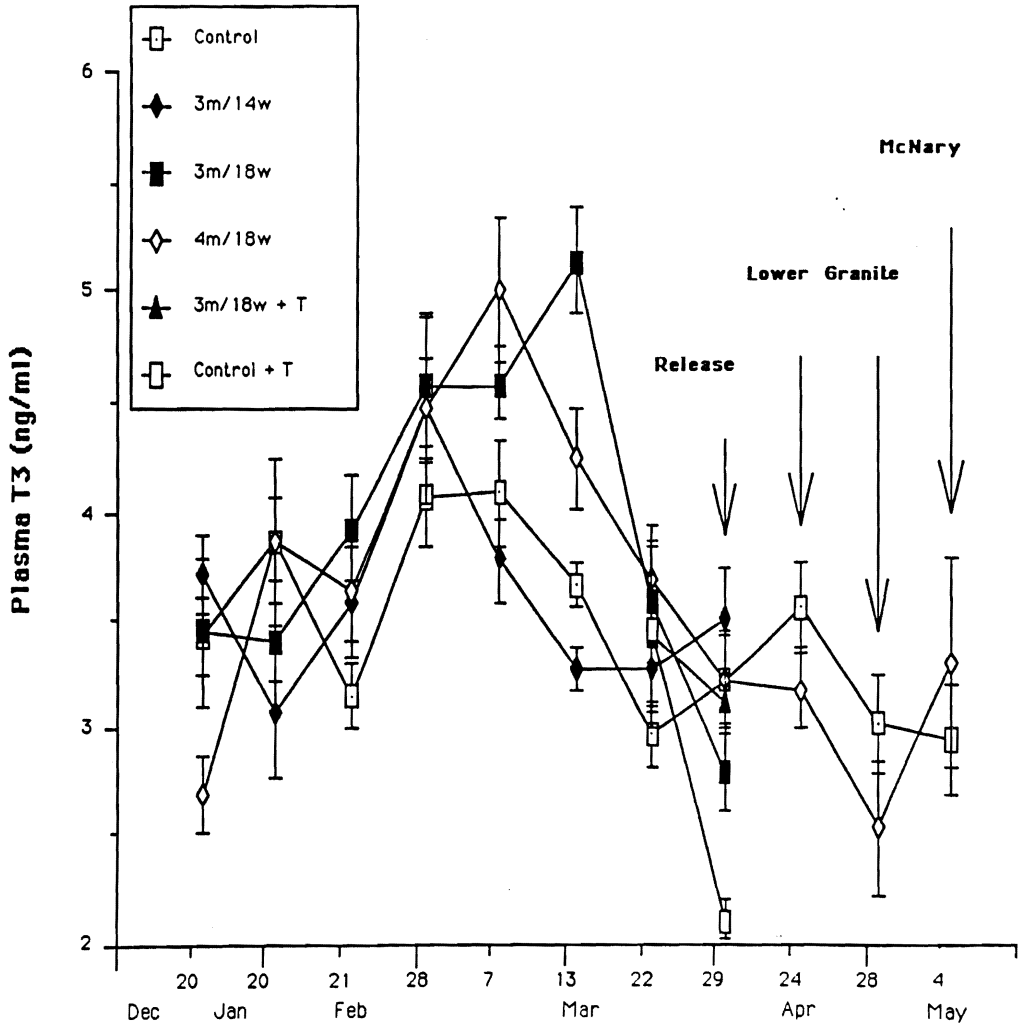


Figure 4.--Mean triiodothyronine (T_3) levels ($ng \cdot ml^{-1}$) from spring chinook salmon photoperiod and/or temperature treatment and control groups collected at Dworshak National Fish Hatchery and downstream recovery sites (n = 10 to 15). Bars represent standard errors.

higher for both the 3m/14w (X^2 = 14.25, df = 1, P < 0.001) and the 3m/18w + T (X^2 = 49.46, df = 1, P < 0.001) treatment groups than for the control group (Table 2). Overall, 47.6% of the control group was detected while 53.1% of the 3m/14w and 58.0% of the 3m/18w + T groups were detected. The other treatment groups, except the control + T group, had higher overall detection rates than the control, but not significantly so. At Lower Granite Dam, only the 3m/18w + T group had a significantly higher (X^2 = 17.34, df = 1, P < 0.001) detection rate than the control group, while at Little Goose Dam, both the 3m/14w (X^2 = 19.60, df = 1, P < 0.001) and 3m/18w + T (X^2 = 15.22, df = 1, P < 0.001) treatment groups had significantly higher detection proportions (Table 2). At McNary Dam, there were no significant differences between any treatment group and the control group detection proportions.

All of the advanced photoperiod treatment groups and the 3m/18w + T group migrated to Lower Granite Dam significantly faster (P < 0.001) than the control group (Table 3). The mean travel time from the hatchery to this site was 31.8 days for the control group while the photoperiod treatment groups' mean travel times ranged from 25.7 days (3m/14w) to 27.9 days (4m/18w). The 3m/18w + T group had the fastest mean travel time to Lower Granite Dam at 24.5 days while the control + T group had the slowest mean travel time at 34.5 days, significantly slower (P < 0.001) than the control group.

This trend continued from the hatchery to recovery at Little Goose Dam with the photoperiod treatment groups and the 3m/18w + T group having significantly shorter (P < 0.001) mean travel times while the control + T group had significantly longer (P < 0.001) mean travel time (Table 3). To Little Goose Dam, the control group's mean travel time was 36.1 days from the hatchery while the photoperiod treatment groups ranged from 30.8 days (3m/14w) to 31.9 days (4m/18w). The 3m/18w + T group had the fastest mean travel time to Little Goose Dam at 29.2 days while the control + T had the slowest at 39.3 days.

Table 2.--Number and percentages of PIT-tagged spring chinook salmon from Dworshak National Fish Hatchery detected at Lower Granite (LGR), Little Goose (LGO), and McNary (MCN) Dams, 1989. Data do not include multiple detections. Asterisks represent chi-square significance level between treatment and control group detection numbers; *** = P < 0.001.

	Recovery site							
	LGR		LGO		MCN		Total	
Treatment	No.	%	No.	%	No.	%	No.	%
Control	666	28.0	338	14.2	128	5.4	1,132	47.6
3m/14w	647	27.6	445	19.0***	151	6.5	1,243	53.1***
3m/18w	621	26.7	374	16.1	149	6.4	1,144	49.3
4m/18w	637	28.1	360	15.9	131	5.8	1,128	49.8
3m/18w + T	746	33.7***	409	18.5***	129	5.8	1,284	58.0***
Control + T	661	29.7	279	12.5	118	5.3	1,058	47.65

Table 3.--Travel time and migration speed of PIT-tagged spring chinook salmon released from Dworshak National Fish Hatchery on 29 March, 1989. Detection sites were at Lower Granite (LGR), Little Goose (LGO), and McNary (MCN) Dams.

Recovery site	Treatment	Travel time (days) Mean (SD)	Median	t-statistic for means	P	Mean speed from hatchery to recovery site (km/day)
LGR	Control	31.8 (8.4)	32.2			3.7
	3m/14w	25.7 (7.9)	25.3	13.64	0.0000	4.6
	3m/18w	26.0 (7.7)	25.9	12.89	0.0000	4.5
	4m/18w	27.9 (8.3)	27.1	8.52	0.0000	4.2
	3m/18w + T	24.5 (6.6)	24.9	18.15	0.0000	4.8
	Control + T	34.5 (9.4)	36.2	-5.51	0.0000	3.4
LGO	Control	36.1 (7.6)	35.4			5.0
	3m/14w	30.8 (6.9)	30.5	10.22	0.0000	5.8
	3m/18w	31.4 (5.6)	31.2	9.36	0.0000	5.7
	4m/18w	31.9 (6.9)	31.6	7.71	0.0000	5.6
	3m/18w + T	29.2 (5.6)	28.1	14.19	0.0000	6.2
	Control + T	39.3 (9.2)	39.6	-4.67	0.0000	4.6
MCN	Control	44.0 (7.7)	42.7			7.8
	3m/14w	38.8 (5.9)	39.2	6.40	0.0000	8.8
	3m/18w	39.2 (7.1)	39.2	5.37	0.0000	8.7
	4m/18w	40.9 (7.7)	40.1	3.30	0.0011	8.4
	3m/18w + T	36.1 (7.8)	35.8	8.13	0.0000	9.5
	Control + T	46.1 (8.9)	46.2	-1.91	0.0576	7.4

The control group's mean travel time from the hatchery to McNary Dam was 44.0 days (Table 3). The photoperiod treatment groups ranged from 38.8 days (3m/14w) to 40.9 days (4m/18w) to this site, all significantly faster ($P = 0.001$ for 4m/18w) than the control group. The 3m/18w + T had the shortest mean travel time to McNary Dam at 36.1 days, also significantly faster ($P < 0.001$) than the control group.

All of the photoperiod treatment groups (including 3m/18w + T) arrived at Lower Granite Dam sooner than did the control group (Table 4 and Figs. 5-9). The tenth percentiles of the photoperiod treatment groups arrived at this site between 11 and 15 April while the control and control + T groups tenth percentile arrived on 19 and 21 April, respectively. The ninetieth percentile of the 3m/18w + T group passed Lower Granite by 29 April, a 10 to 90% duration of 16 days. The other photoperiod treatment groups' ninetieth percentile arrived on 4 and 5 May, for durations ranging from 20 to 23 days. The control and control + T groups' ninetieth percentile arrived on 8 and 11 May, respectively, for durations of 19 and 20 days.

Similar results were obtained at Little Goose and McNary Dams with the photoperiod treatment groups' tenth percentile arriving 2 to 4 days earlier at Little Goose Dam and 2 to 7 days earlier at McNary Dam (Table 4 and Figs. 5-9). The control + T group's tenth percentile arrived 3 days after the control group. The ninetieth percentiles of the photoperiod treatment groups also passed these sites sooner than the control and control + T groups. The 3m/18w + T group continued to be the fastest group with its ninetieth percentile passing Little Goose Dam 8 days and McNary Dam 11 days earlier than the control group did.

All of the treatment and control groups increased their migration rate as they moved downstream (Table 3). All of the photoperiod treatment groups had higher migration rates to all three interception sites than did the control and control + T groups. The 3m/18w + T group had the highest migration rate at 4.8 km/day from the hatchery to Lower Granite Dam, increasing to 6.2 and 9.5 km/day from the release site

Table 4.--Passage dates for percentages of PIT-tagged spring chinook salmon arriving at Lower Granite (LGR), Little Goose (LGO), and McNary (MCN) Dams and the time elapsed between the tenth and ninetieth percentiles following release from Dworshak National Fish Hatchery, 1989.

Recovery site	Treatment	Percentile of run			10-90% segment (days)
		10	50	90	
LGR	Control	4/19	4/29	5/08	19
	3m/14w	4/11	4/23	5/04	23
	3m/18w	4/12	4/23	5/04	22
	4m/18w	4/15	4/24	5/05	20
	3m/18w + T	4/13	4/22	4/29	16
	Control + T	4/21	5/03	5/11	20
LGO	Control	4/24	5/03	5/12	18
	3m/14w	4/20	4/28	5/06	16
	3m/18w	4/22	4/28	5/06	14
	4m/18w	4/22	4/29	5/09	17
	3m/18w + T	4/20	4/25	5/04	14
	Control + T	4/27	5/08	5/19	22
MCN	Control	5/01	5/10	5/21	20
	3m/14w	4/28	5/05	5/14	16
	3m/18w	4/28	5/05	5/16	18
	4m/18w	4/29	5/05	5/18	19
	3m/18w + T	4/24	5/02	5/10	16
	Control + T	5/04	5/14	5/23	19

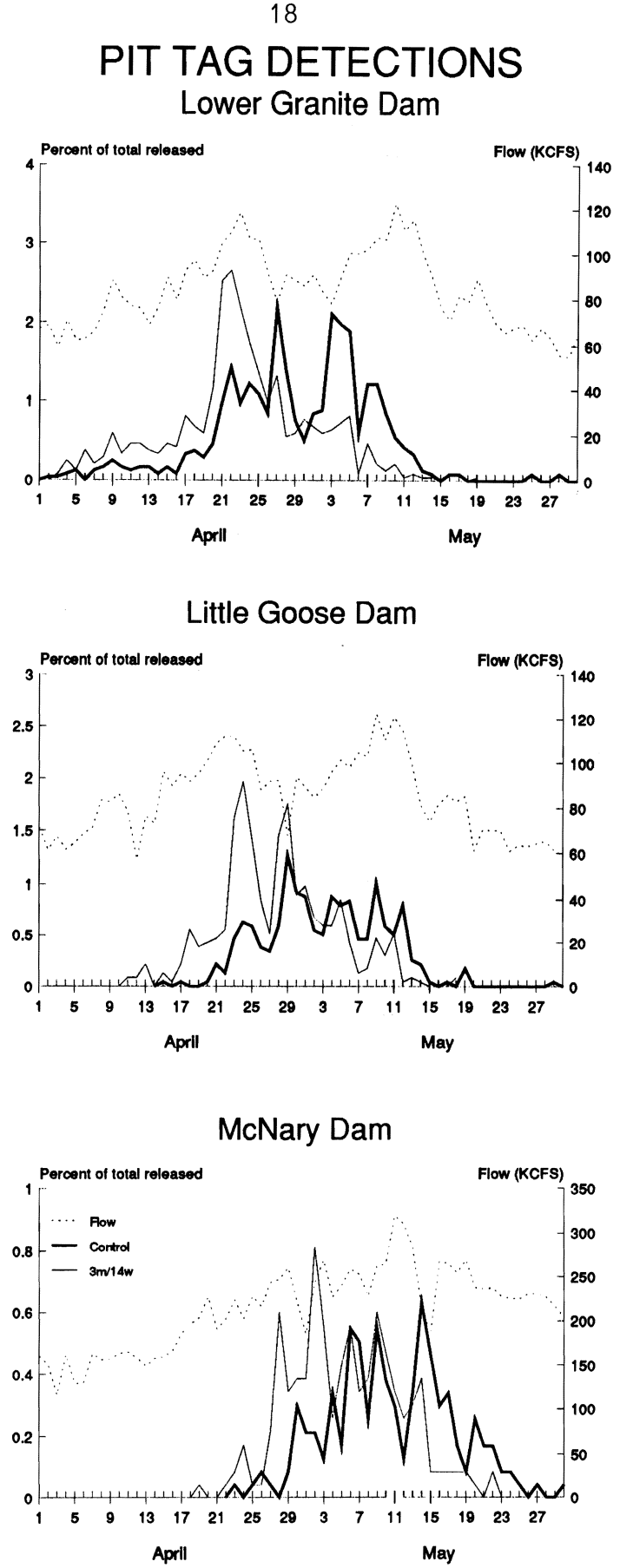
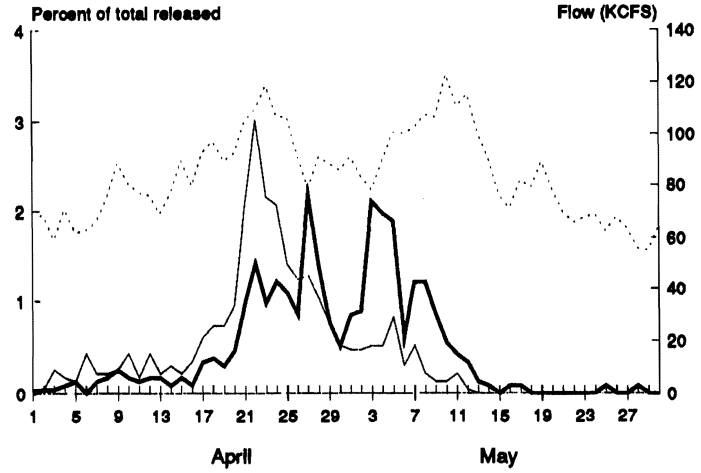


Figure 5.--Daily PIT-tag detections (percent of total released) and flow (kcfs) at three downstream collection sites for the control and 3m/14w photoperiod treatment group from Dworshak National Fish Hatchery.

PIT TAG DETECTIONS

Lower Granite Dam



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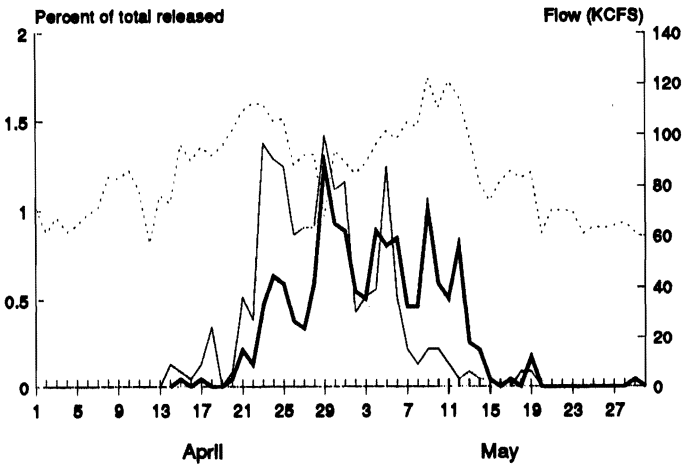


McNary Dam

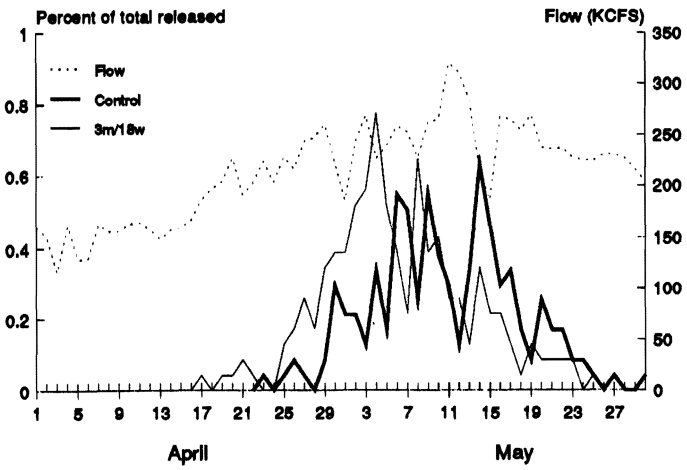


Figure 6.--Daily PIT-tag detections (percent of total released) and flow (kcfs) at three downstream collection sites for the control and 3m/18w photoperiod treatment group from Dworshak National Fish Hatchery.

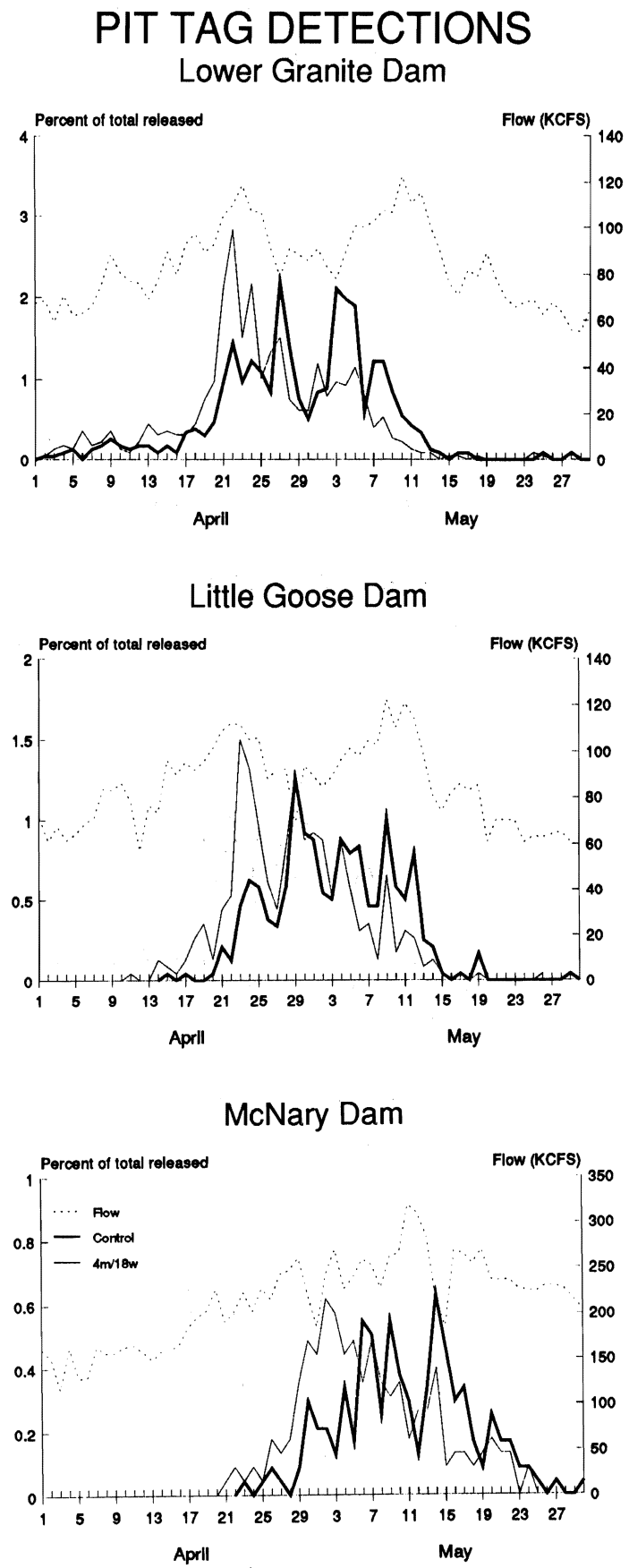
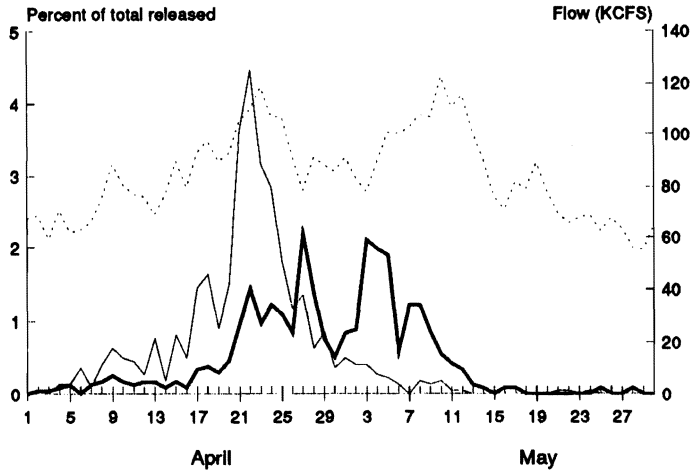


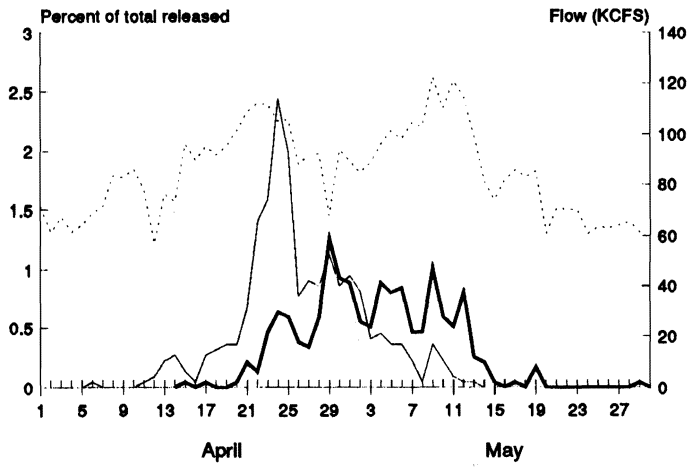
Figure 7.--Daily PIT-tag detections (percent of total released) and flow (kcfs) at three downstream collection sites for the control and 4m/18w photoperiod treatment group from Dworshak National Fish Hatchery.

PIT TAG DETECTIONS

Lower Granite Dam



Little Goose Dam



McNary Dam

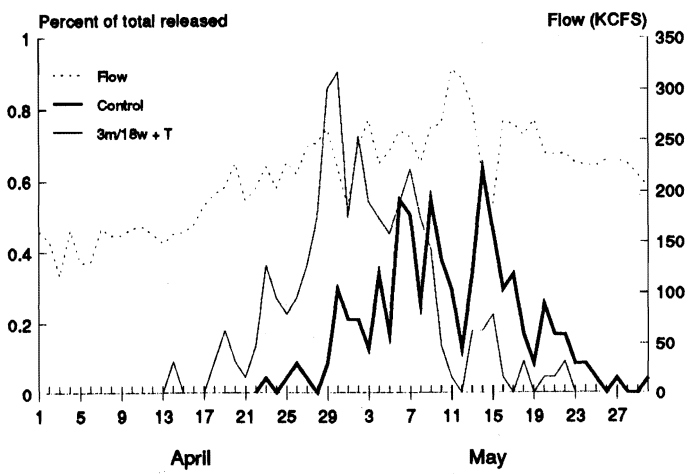


Figure 8.--Daily PIT-tag detections (percent of total released) and flow (kcfs) at three downstream collection sites for the control and 3m/18w + T photoperiod treatment group from Dworshak National Fish Hatchery.

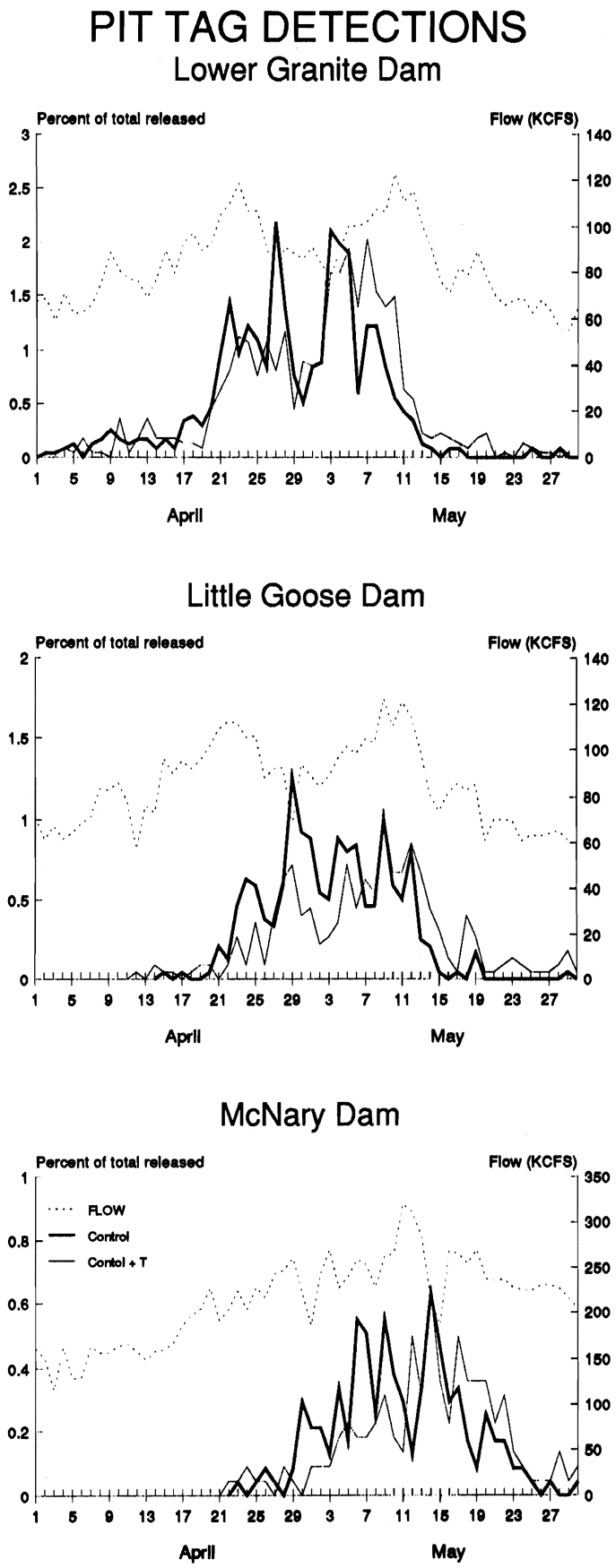


Figure 9.--Daily PIT-tag detections (percent of total released) and flow (kcfs) at three downstream collection sites for the control and control + Temperature treatment group from Dworshak National Fish Hatchery.

to Little Goose and McNary Dams, respectively. The control group migrated at 3.7 km/day to Lower Granite Dam, 5.0 km/day from the hatchery to Little Goose Dam, and 7.8 km/day to McNary Dam. This observed increase in migration rate for all groups is due in part to the initial lag time spring chinook salmon have after entering Lower Granite reservoir. As their outmigration progresses downstream, the effect of this lag time is attenuated.

Bacterial Kidney Disease

Photoperiod and/or increased water temperature treatment did not increase the incidence of BKD. The mean level of BKD detected using the ELISA technique did not differ significantly between the control and test groups when compared on 22 November or at release on 29 March (Fig. 10). Only one group, the 3m/18w photoperiod treatment group, had a significant change ($t = 2.50$, $df = 34$, $P < 0.05$) over this time period with a lower level detected at release.

Pond Mortality

Photoperiod treatment appeared to have no effect on mortality at the hatchery, with mortality rates ranging from 0.43 to 1.35% for the various groups (Table 5). The 4m/18w photoperiod treatment group had the highest mortality (1.35%) while at the hatchery; however, the fact that this was the only treatment group to be freeze branded may have accounted for this increase. There was no additional mortality caused by the water temperature treatment.

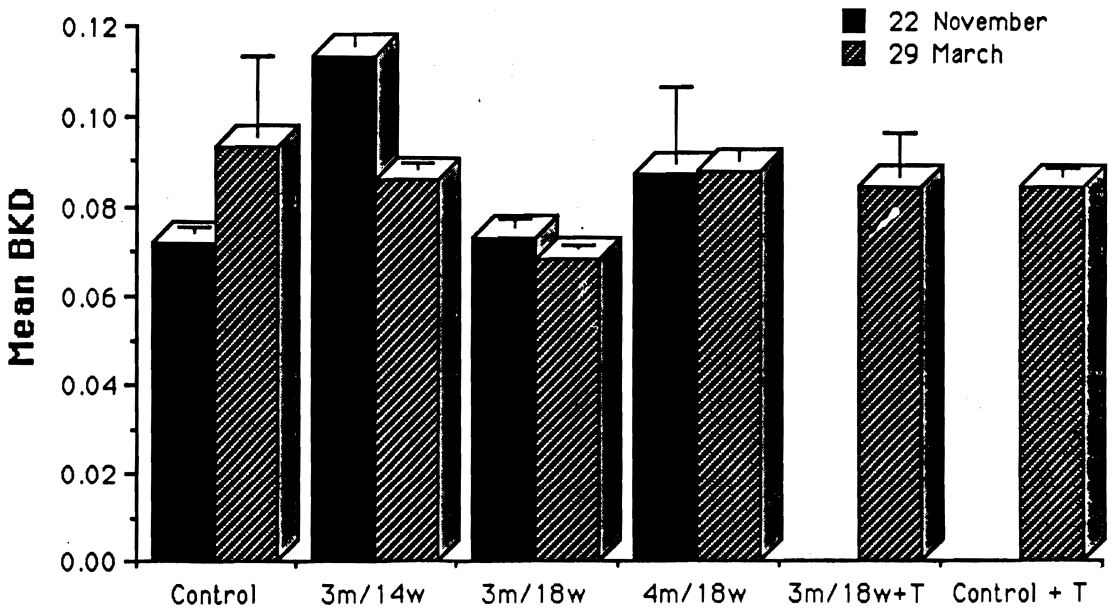


Figure 10.--Mean bacterial kidney disease ELISA (optical density) on 22 November and 29 March for the photoperiod treatment and control groups at Dworshak National Fish Hatchery. Capped lines represent standard errors.

Table 5.--Spring chinook salmon pond mortalities from Dworshak National Fish Hatchery photoperiod study from December 1988 to release on 29 March 1989. Fish in raceways 7 and 8 were nitrogen freeze-branded.

Treatment	Raceway numbers	No. of mortalities	Percent mortality
Control	11 + 12	350	0.43
3m/14w	9 + 10	382	0.56
3m/18w	5 + 6	356	0.43
4m/18w	7 + 8	1,052	1.35

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 (Muir et al. 1988; Rondorf et al. 1985). They are often exposed to environmental factors that differ from those experienced by natural 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). The result is that 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 3 years (1986-1988). 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 (Figs. 5-9). 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 cycle increased their migration rate. Increased water temperature near the time of release further accelerated migratory behavior when applied to the 3m/18w photoperiod treatment group, but did not accelerate development when applied to the control group. This indicated that spring chinook salmon released in early April may not be physiologically ready to respond fully to temperature.

The physiological and migrational timing results obtained in 1989 are consistent with the results obtained in 1988 at this hatchery (Giorgi et al. 1990). During 1988, only one photoperiod treatment was applied (3m/14w) which resulted in advanced physiological development and faster travel time, but not to the extent observed in 1989.

A higher percentage of photoperiod and photoperiod/temperature treatment fish than controls were detected at all of the collector dams, although the differences for PIT-tag recoveries were only significant for some groups (Table 2). The combined photoperiod and increased water temperature treatment had the highest overall detection rate, 10.4% higher than the control group. Possible explanations for this higher percentage include increased FGE at collector dams or lower reservoir-related mortality of the treatment fish. 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 less reservoir-related mortality due to predators. 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, subjecting the 3m/18w photoperiod treatment group to increased water temperature for 2 weeks prior to release produced the most dramatic response. However, temperature treatment alone applied to the control group 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 experients 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 fish. The objective of providing 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. Our analyses and comparisons are at this time limited to experimental groups used in this research. The next step is to evaluate the degree of smolt development in general hatchery production populations and to assess their performance and determine if an accelerated smoltification treatment may be beneficial. In this study we altered photoperiod cycles, in some cases in conjunction with elevated rearing temperatures, to accelerate smolt development. There may be other strategies that would accomplish similar results, such as merely delaying the release of yearlings by several weeks, thus providing ample time for smolt development.

The spring chinook salmon used in this experiment (both treatment and control groups) were reared in the converted adult holding ponds at Dworshak NFH . Fish

reared in the upper A and B bank raceways had gill Na^+-K^+ ATPase levels similar to our treatment groups at release; they also migrated at similar rates as our treatment fish. Apparently, the holding-pond fish did not develop as well physiologically as the A and B bank raceway fish. In 1990, this study was moved to the A and B bank raceways to avoid this problem.

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 240,000 smolts were purchased for under $3,000. On a production-wide basis, existing hatchery security lighting systems could be utilized (and expanded if necessary) and regulated with an automatic timer to attain the desired 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 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 2 weeks, this may be a relatively small cost in the overall fish production effort.

This research continued at Dworshak NFH during 1990.

SUMMARY

1. This research indicates that the level of smolt development in yearling chinook salmon, when released from the hatchery, affects their performance as they migrate seaward. These effects are apparent in terms of shorter travel times and increased proportions observed at hydroelectric dams.

2. Photoperiod and photoperiod/temperature treatments increased gill Na^+-K^+ ATPase in yearling chinook salmon to levels significantly higher than the control group's level at release.
3. The photoperiod and photoperiod/temperature treatment groups had significantly shorter travel times than the control group to downriver sampling sites.
4. The photoperiod and photoperiod/temperature treatment groups had higher detection proportions than the control group; proportions were significantly higher for the 3m/14w and 3m/18w + T groups.
5. Increased water temperature 2 weeks prior to release produced the most accelerated smolt development, shortest travel time, and increased detection rate downstream when applied to the 3m/18w photoperiod treatment group. However, temperature increase had no effect when applied to the control group.

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APPENDIX

Appendix Table 1.--Gill Na^+-K^+ ATPase data (mean, standard deviation, and sample size) from spring chinook salmon from Dworshak photoperiod experiment, 1989. Units are µmol Pi·mg $Prot^{-1}h^{-1}$. Asterisks represent t-test significance level between treatment and control group; * = 0.01 < P < 0.05, ** = 0.001 < P 0.01, and III = P < 0.001. See text for abbreviations.

Sample date	Sample location		Test conditions					
			C	C + T	3m/14w	3m/18w	3m/18w+T	4m/18w
20 Jan	DNFH	x		-	5.5	6.9	-	5.1
		SD		-	1.12	1.37	-	0.82
		n		-	8	12	-	11
21 Feb	DNFH	x	7.5	-	9.7**	11.8***	-	9.1*
		SD	2.08	-	0.95	2.26	-	1.24
		n	15	-	15	15	-	15
28 Feb	DNFH	x	5.8	-	6.6	9.6***	-	11.1***
		SD	0.58	-	2.07	2.07	-	1.81
		n	6	-	13	15	-	15
7 Mar	DNFH	x	5.8	-	6.1	10.8**	-	7.7***
		SD	1.00	-	1.40	4.59	-	1.19
		n	14	-	14	14	-	15
13 Mar	DNFH	x	6.1	-	8.7**	11.8***	-	9.8**
		SD	1.24	-	2.33	3.14	-	3.87
		n	13	-	15	15	-	15
22 Mar	DNFH	x	6.4	6.7	8.2**	10.7***	12.3***	10.4***
		SD	1.31	1.38	1.85	2.78	2.87	2.15
		n	14	15	13	15	15	15
29 Mar	DNFH	x	6.9	6.8	9.4**	14.4***	15.3***	10.9***
		SD	1.89	1.64	2.39	2.42	3.62	2.36
		n	15	15	15	14	15	15
14 Apr	LGR	x	17.5	-	-	-	-	25.2**
		SD	4.48	-	-	-	-	7.42
		n	15	-	-	-	-	15
24 Apr	LGR	x	35.7	-	-	-	-	40.0
		SD	7.31	-	-	-	-	7.81
		n	15	-	-	-	-	15
28 Apr	LGR	x	32.0	-	-	-	-	30.9
		SD	9.55	-	-	-	-	8.81
		n	15	-	-	-	-	10
4 May	MCN	x	49.6	-	-	-	-	47.3
		SD	9.82	-	-	-	-	10.29
		n	15	-	-	-	-	11

Appendix Table 2.--Thyroxine (T_4) data (mean, standard deviation, and sample size) from spring chinook salmon from Dworshak photoperiod experiment, 1989. Units are $ng \cdot ml^{-1}$. Asterisks represent t-test significance level between treatment and control group; * = 0.01 < P < 0.05, II = 0.001 < P 0.01, and *** = P < 0.001. See text for abbreviations.

Sample date	Sample location		Test conditions					
			C	C + T	3m/14w	3m/18w	3m/18w+T	4m/18w
20 Dec	DNFH	x	6.2	-	3.7**	3.5**	-	3.4**
		SD	3.08	-	1.05	0.72	-	0.76
		n	15	-	15	15	-	14
20 Jan	DNFH	x	5.4	-	11.0**	9.7*	-	10.2*
		SD	4.97	-	4.57	4.73	-	5.25
		n	14	-	14	15	-	15
21 Feb	DNFH	x	8.4	-	7.8	6.5	-	8.3
		SD	4.91	-	1.68	1.78	-	3.97
		n	15	-	15	15	-	15
28 Feb	DNFH	x	9.3	-	8.8	12.0	-	11.5
		SD	3.55	-	2.99	4.27	-	3.62
		n	15	-	15	15	-	15
7 Mar	DNFH	x	7.3	-	9.6	8.7	-	11.6**
		SD	1.86	-	4.10	2.07	-	4.15
		n	15	-	15	15	-	15
13 Mar	DNFH	x	7.0	-	7.5	8.1	-	8.6
		SD	2.39	-	2.52	1.93	-	3.17
		n	15	-	15	15	-	15
22 Mar	DNFH	x	13.0	9.8*	13.3	16.9*	11.0	15.8
		SD	4.02	4.01	4.12	4.76	4.16	5.33
		n	15	15	15	15	15	15
29 Mar	DNFH	x	10.0	4.6***	8.8	6.7**	6.8**	9.4
		SD	3.81	1.85	3.89	2.00	1.71	4.18
		n	15	15	15	15	15	15
24 Apr	LGR	x	9.5	-	-	-	-	8.5
		SD	3.45	-	-	-	-	2.27
		n	14	-	-	-	-	15
28 Apr	LGR	x	9.2	-	-	-	-	8.3
		SD	2.46	-	-	-	-	2.75
		n	15	-	-	-	-	10
4 May	MCN	x	9.3	-	-	-	-	8.8
		SD	3.26	-	-	-	-	2.99
		n	15	-	-	-	-	10

Appendix Table 3.--Triiodothyronine (T_3) data (mean, standard deviation, and sample size) from spring chinook salmon from Dworshak photoperiod experiment, 1989. Units are $ng \cdot ml^{-1}$. Asterisks represent t-test significance level between treatment and control group; * = 0.01 < P < 0.05, II = 0.001 < P 0.01, and *** = P < 0.001. See text for abbreviations.

Sample date	Sample location		Test conditions					
			C	C + T	3m/14w	3m/18w	3m/18w+T	4m/18w
20 Dec	DNFH	x	3.3	-	3.6	3.3	-	2.6*
		SD	0.75	-	0.71	1.33	-	0.68
		n	15	-	15	15	-	13
20 Jan	DNFH	x	3.8	-	2.96	3.3	-	3.8
		SD	1.08	-	1.01	0.59	-	0.64
		n	8	-	11	11	-	13
21 Feb	DNFH	x	3.0	-	3.5	3.8*	-	3.5
		SD	0.59	-	0.95	0.92	-	0.88
		n	14	-	14	15	-	15
28 Feb	DNFH	x	4.0	-	4.4	4.5	-	4.4
		SD	0.88	-	1.62	1.23	-	0.92
		n	15	-	15	15	-	15
7 Mar	DNFH	x	4.0	-	3.7	4.5	-	4.9*
		SD	0.92	-	0.73	0.67	-	1.29
		n	15	-	15	15	-	15
13 Mar	DNFH	x	3.6	-	3.2*	5.0***	-	4.1*
		SD	0.40	-	0.39	0.95	-	0.94
		n	15	-	15	15	-	15
22 Mar	DNFH	x	2.9	3.4	3.2	3.5	3.3	3.6*
		SD	0.61	1.54	0.70	1.02	1.60	1.01
		n	14	15	15	14	14	15
29 Mar	DNFH	x	3.1	2.0***	3.4	2.7	3.0	3.1
		SD	0.87	0.35	0.90	0.69	0.55	0.80
		n	15	15	15	14	15	14
24 Apr	LGR	x	3.4	-	-	-	-	3.1
		SD	0.73	-	-	-	-	0.73
		n	13	-	-	-	-	14
28 Apr	LGR	x	2.9	-	-	-	-	2.4
		SD	0.81	-	-	-	-	0.89
		n	14	-	-	-	-	9
4 May	MCN	x	2.8	-	-	-	-	3.2
		SD	0.96	-	-	-	-	1.52
		n	15	-	-	-	-	10