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COASTAL ZONE AND ESTUARINE STUDIES

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INTRODUCTION

Lower Granite and Little Goose Dams, near Lewiston, Idaho, are facilities on the Snake River equipped with juvenile salmonid bypass systems. Over the years, a variety of structural modifications and modes of dam operation have been tested at Lower Granite Dam to improve fish guiding efficiency (FGE). It was commonly held that mechanical and structural features of the dam are the primary factors affecting fish guidance, and research to date has focused on these aspects. However, estimates of FGE were variable between and within years and not consistently related to structural configurations tested. In 1984 and 1985, FGE was lowest (about 30 to 35%) when fish began to pass the dam in early April, increased to over 70% about halfway through the migrations, and remained at that level until sampling was terminated in late May (Swan et al. 1985, 1986). Therefore, it was hypothesized that biological factors could be influencing FGE.

The population of yearling chinook salmon, Oncorhynchus tshawytscha, passing Lower Granite Dam is comprised of numerous wild and hatchery stocks which adds complexity when attempting to identify biological factors that might affect FGE. These migrants display significant size disparity, ranging in length from about 100 to over 200 mm. During April and May, the parr/smolt transformation accelerates; however, the timing of smoltification probably is not uniform throughout the population (e.g., while most wild fish may be smolted, some hatchery fish may not be by the time they arrive at Lower Granite Dam). Furthermore, the rate of smoltification can be influenced by the fish's size; Johnston and Eales (1970) observed that large Atlantic salmon parr smolted faster than smaller individuals.

Of the physiological, anatomical, and behavioral changes which occur during the parr/smolt transformation, several have been documented that are of particular concern with respect to assessing FGE:

1) Salmonid parr tend to be demersally oriented whereas smolts are pelagic and often aggregate near the surface (Folmar and Dickhoff 1980).
2) Atlantic salmon smolts (Salmo salar), were more positively buoyant than parr (Pinder and Eales 1969). Presumably, this is a mechanism to facilitate their downstream migration by enabling them to maintain position within the swifter surface waters. Buoyancy is a function of swim-bladder volume (Saunders 1965; Pinder and Eales 1969).
3) Flagg and Smith (1982) demonstrated that coho salmon smolts (O. kisutch) are less proficient swimmers than parr. Glova and McInerney (1977) observed decreased swimming-proficiency through smoltification. Similar observations were made for Atlantic salmon (Thorpe and Morgan 1978).
4) Studies conducted in the mid-Columbia River demonstrated that Na^+-K^+ ATPase activity increases dramatically as yearling chinook salmon migrate downstream through the first few dams and stabilizes by the time fish reach McNary Dam (Rondorf et al. 1985).

Based on this information and the presumption that the cited biological features apply to yearling chinook salmon, the following scenario could be occurring at Lower Granite Dam. During the yearling chinook salmon outmigration, the smoltification profile and/or the size composition of the population changes. Early in the migration, a large proportion of the fish are in parr or transitional stages; later, smolts predominate. Concomitantly, the relative buoyancy of the population may become more positive, the fish more surface-oriented, and swimming stamina may decrease as smolts comprise an increasing proportion of the population. Either separately or in concert, changes in these mechanisms, buoyancy and swimming ability, may directly affect a fish's susceptibility to interception and diversion by a submersible traveling screen (STS).

Data collected in 1985 at Lower Granite Dam and in 1986 at Little Goose Dam suggest that such a scenario is reasonable (Giorgi et al. 1988). Yearling chinook salmon were sampled during FGE tests from the guided and unguided portions of the catch and assayed for Na^{+}-K^{+} ATPase activity (a recognized index of the status of smoltification). The data suggested that fish displaying elevated Na^{+}-K^{+} ATPase activity may be more susceptible to guidance by an STS; however, data on buoyancy and swimming stamina were inconclusive.

In 1987, FGE/smoltification research was scheduled to span most of the outmigration at both Lower Granite and Little Goose Dams and had the following objectives:

1) Define changes in buoyancy and swimming stamina which may influence yearling chinook salmon susceptibility to interception and diversion by the STS.
2) Determine if the smoltification status of yearling chinook salmon passing Lower Granite and Little Goose Dams changes over the course of the outmigration and assess its relation to FGE.

METHODS AND MATERIALS

Swimming Stamina

Changes in swimming stamina through time were documented for Dworshak and Rapid River spring chinook salmon. Twelve fish were randomly selected from the population and held in laboratory tanks for a 24-h period prior to a test. Fish were anesthetized in a 50 ppm MS222 solution, weighed to the nearest 0.1 g, fork length measured to the nearest mm, and placed in numbered test compartments within the swim chamber and allowed a 1-h recovery period (Fig. 1). Initial water velocity was 1.5 body lengths per second (BL/s) and increased 0.5 BL/s every 15 min until the fish reached fatigue (i.e., fish could no longer hold position in the current and remained impinged against the electrified screen). Because the index of swimming stamina, U-critical, was designed for fish that could swim for at least one complete trial period, U-critical data were recorded only for fish that could swim for at least 15 min at 1.5 BL/s.

Swimming stamina (U-critical) for each fish was calculated using the swimming speed at fatigue and the time of fatigue, by the methods described in Beamish (1978): U-critical = $U_i + (t_i/t_{ii} \times U_{ii})$. Where U-critical = critical swimming speed (BL/s), U_i = highest velocity maintained for the prescribed period (BL/s), U_{ii} = velocity increment in each test (BL/s), t_i = time (minutes) that the fish swam at the fatigue velocity, and t_{ii} = prescribed period of swimming (minutes).

Buoyancy

Changes in buoyancy through time were documented. Fish buoyancy as influenced by adjustments in swim-bladder volume were measured indirectly by employing the Cartesian diving principle described by Pinder and Eales (1969). Basically, individual fish were placed in a closed chamber to which a vacuum was applied. The pressure at which the fish just rose off the bottom of the chamber adjusted to the prevailing atmospheric pressure was the indirect measure of swim-bladder volume. This measure, referred to as the pressure of neutral buoyancy (PNB) (Saunders 1965), is defined as: PNB (mm Hg) = PA - PR where PA = atmospheric pressure and PR = vacuum required to achieve flotation. Buoyancy measurements were made in a cylindrical Plexiglas[1] pressure-chamber

1/ Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

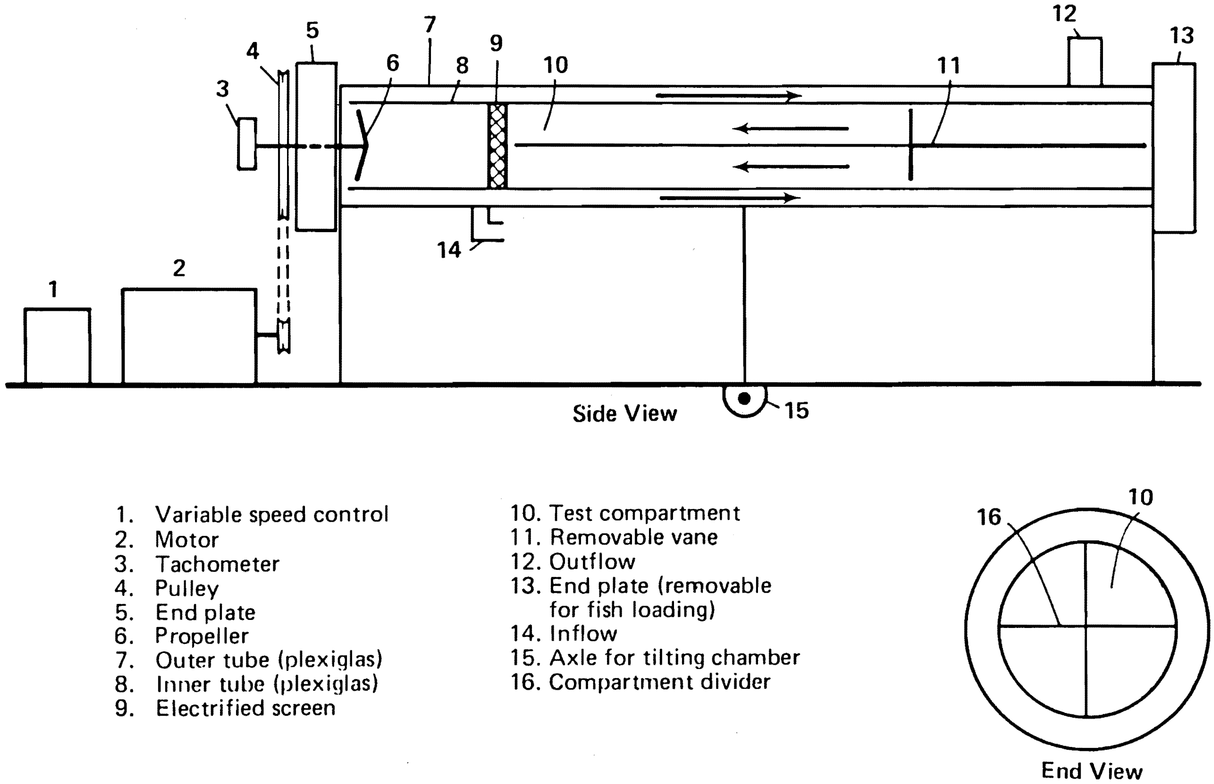


Figure 1.--Schematic diagram of swim chamber used to measure swimming stamina.

30 cm high by 25 cm in diameter 0.8 filled with a 50 ppm MS222 solution. Pressure within the system was controlled with an electric vacuum pump and monitored with a vacuum gauge. Atmospheric pressures were obtained from the National Weather Service in Lewiston, Idaho, and adjusted for the elevation at each sample location.

Twelve fish were randomly selected from the hatchery population and held in laboratory tanks for 24 h prior to the test. A screen was placed just below the surface in the container to restrict the fish's access to air. Sufficient water flow was maintained to ensure suitable water quality. Fish were anesthetized in the screened container to keep them from entraining air before being tested.

Smoltification Indices

Three physiological indices of smoltification were assayed: gill Na^+-K^+ ATPase and the thyroid hormones thyroxine (T_4) and triiodothyronine (T_3). Gill filaments used for the Na^+-K^+ ATPase assay were trimmed from the gill arch and placed into a 1.5-ml microcentrifuge tube filled with a buffer solution containing sucrose, ethylenediamine, and imidazole (SEI) and immediately frozen on dry ice. The Na^+-K^+ ATPase activity was determined according to the method of Zaugg (1982) with minor modification.

Heparinized blood was centrifuged, and the plasma was collected and frozen at $<-20^{o}C$ until assayed for T_3 and T_4. Hormones were assayed using a specific radio-immunoassay (Dickhoff et al. 1978, 1982).

In addition to physiological indices, lengths and weights were recorded for all specimens, and a condition factor (K) (Lagler et al. 1977) was calculated for all fresh-killed specimens.

Sampling

To define changes in swimming stamina and buoyancy associated with the smoltification process (as indicated by assorted smolt indices), we sampled spring chinook salmon from Dworshak and Rapid River hatcheries monthly from January 1987 through release later that spring. Freeze-branded segments of these populations were later intercepted at Lower Granite Dam from their fish monitoring facility where the behavioral and physiological indices were again assessed.

A group of fish was maintained at Dworshak Hatchery to evaluate the effect of time on smolt development and the accompanying behavioral indices. Data from this group were compared with Dworshak fish arriving at Lower Granite Dam.

Additional experiments were conducted with spring chinook salmon from Little White Salmon Hatchery to examine the effects of increasing water temperature on smolt development and the behavioral indices. These studies were conducted at Bonneville Dam in June 1987. Three Living Stream systems were maintained at water temperatures of 5°, 10°, and 13°C to simulate the water temperature range encountered at the Idaho hatcheries and Lower Granite Dam. Each Living Stream was stocked with 30 fish acclimated to the desired temperature over a 2-day period. Fish were fed Oregon Moist Pellets once a day to satiation. Fish were held for 12-13 days, then tested for swimming stamina and buoyancy and assayed for Na^+-K^+ ATPase, T_3, and T_4. Swimming stamina and buoyancy tests were conducted in water at the same temperature in which each group had been held using a recirculating system and a chiller.

To determine whether the smoltification status of the population passing Lower Granite and Little Goose dams changed over the course of the outmigration and assess its relation to FGE, we sampled fish from FGE tests conducted on eight dates at Lower Granite Dam and five dates at Little Goose Dam. Up to 20 fish were sampled from the gatewell and each fyke-net row and assayed for gill Na^{+}-K^{+} ATPase. The first 20 yearling chinook salmon chosen were assayed without regard to size or visual appearance.

To determine if gills collected from fyke net fish (dead) had deteriorated significantly from those from gatewell fish (live), two gill samples were taken from each gatewell fish. The gill samples (one side) were taken from fresh-killed fish and then the fresh-killed fish were placed in water for 2-3 h to simulate what was occurring for fyke-net fish. After the specified time, the fish were removed from water and the second gill samples (remaining side) were taken. To be consistent, we employed the non-parametric Mann-Whitney U Statistical test in our treatment of the data.

RESULTS

Swimming Stamina

At Dworshak and Rapid River Hatcheries, the swimming stamina of spring chinook salmon was relatively stable over the sampling period with U-critical values ranging from 2.37 to 2.96 BL/s (Table 1 and Fig. 2). Both hatchery groups were intercepted at Lower Granite Dam and early arriving fish exhibited stamina levels higher than at the hatchery, but not significantly so (Fig. 2). However, for both groups, fish arriving later at Lower Granite Dam had significantly higher stamina levels ($P < 0.01$) than were measured at release (Fig. 2). Mean swimming stamina for Dworshak fish increased from 2.49 BL/s in the hatchery at the time of release (2 April) to 2.97 and 3.60 BL/s at Lower

Table 1.--Swimming stamina (U-critical) data for Dworshak and Rapid River stocks, 1987. Stocks were intercepted at Lower Granite Dam (LGR).

Stock	Sample site	Sample date	Water temp. (°C)	U - critical (BL/s)		
				Mean	SD	n
Dworshak	Hat	14 Jan	4.9	2.66	0.20	12
	Hat	12 Feb	4.9	2.73	0.23	12
	Hat	10 Mar	5.2	2.37	0.27	12
	Hat	2 Apr[a]/	4.9	2.49	0.26	12
	Hat	18 Apr	5.4	2.53	0.36	12
	LGR	15 Apr	11.0	2.97	0.69	11
	LGR	1 May	11.8	3.60	0.69	12
Rapid River	Hat	16 Jan	3.2	2.46	0.23	12
	Hat	10 Feb	5.0	2.68	0.20	12
	Hat	12 Mar	5.8	2.96	0.28	11
	Hat	23 Mar[a]/	5.2	2.78	0.52	12
	LGR	19 Apr	10.6	3.12	0.63	12
	LGR	1 May	11.8	3.58	0.41	12

a/ Date of release from hatchery.

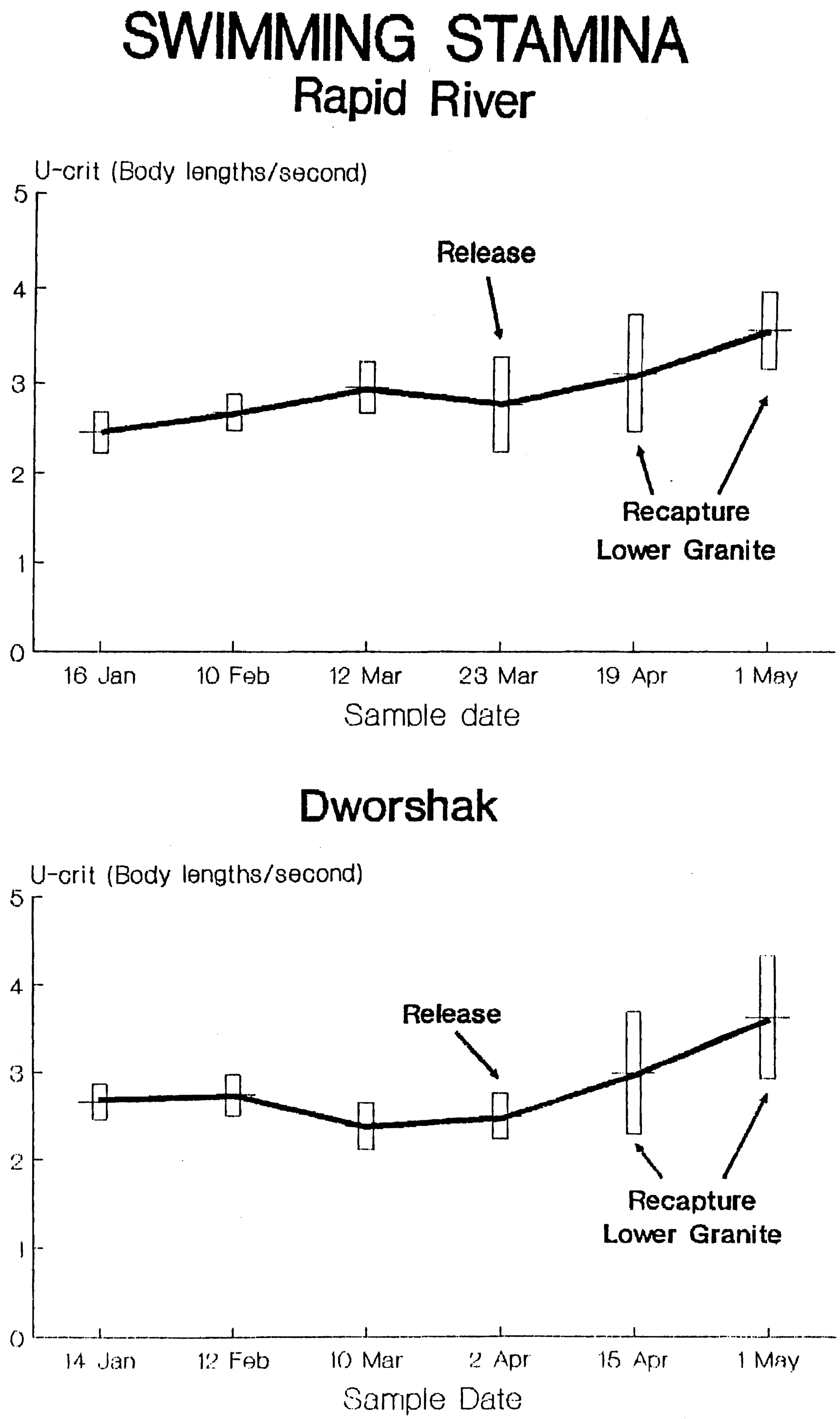


Figure 2.--Swimming stamina data (BL/s) for spring chinook salmon reared at Rapid River and Dworshak sampled at the hatcheries and at Lower Granite Dam, 1987. Bars represent standard deviations.

Granite Dam on 15 April and 1 May, respectively (Table 1). Similarly, stamina levels in Rapid River fish increased from 2.78 BL/s at release to 3.12 and 3.58 BL/s at Lower Granite Dam (early and late arrivals) (Table 1). Fish held until 18 April at Dworshak Hatchery under normal hatchery conditions exhibited little change in swimming stamina compared to release values (Table 1).

Buoyancy

At Rapid River and Dworshak hatcheries, values of PNB were relatively stable over the sampling period (January - March) ranging from 57.3 to 64.8 cm Hg (Table 2 and Fig. 3). At the time of release, fish at both hatcheries exhibited increased buoyancy--significantly so ($P < 0.05$) for the Dworshak fish (Table 2). Yet, those buoyancy levels were not maintained through their migration to Lower Granite Dam (Fig. 3). When the Rapid River fish were intercepted at Lower Granite Dam, buoyancy was the same as at release whereas Dworshak fish exhibited significantly lower buoyancy ($P < 0.05$) at Lower Granite Dam than measured at release (Table 2 and Fig. 3); fish held at Dworshak Hatchery until 18 April displayed no significant change in PNB when compared to values at release (Table 2).

Smoltification Indices

Gill Na^+-K^+ ATPase values observed in spring chinook salmon at Dworshak and Rapid River hatcheries were relatively low and stable prior to being released on 2 April and 23 March 1987, respectively (Table 3 and Fig. 4). At Dworshak Hatchery, gill Na^+-K^+ ATPase values increased significantly ($P < 0.01$) in the fish at release from a mean of 8.4 to a mean of 11.3 μmol Pi·mg $Prot^{-1} \cdot h^{-1}$ (Table 3). Conversely, at Rapid River Hatchery, there was a significant decrease ($P < 0.001$) in gill Na^+-K^+ ATPase activity in fish at the time of

Table 2.--Fish buoyancy data expressed as the pressure of neutral buoyancy (PNB) for Dworshak and Rapid River stocks, 1987. Stocks were intercepted at Lower Granite Dam (LGR).

Stock	Sample site	Sample date	Water temp.(°C)	PNB (cm Hg)		
				Mean	SD	n
Dworshak	Hat	14 Jan	4.9	60.9	6.05	12
	Hat	12 Feb	4.9	62.2	4.47	12
	Hat	10 Mar	5.2	60.3	5.01	12
	Hat	2 Apr[a]	4.9	66.5	3.19	12
	Hat	18 Apr	5.4	67.5	2.28	12
	LGR	15 Apr	11.0	60.0	5.16	12
	LGR	1 May	11.8	62.9	3.70	12
Rapid River	Hat	16 Jan	3.2	61.5	6.91	10
	Hat	10 Feb	5.0	57.3	5.91	12
	Hat	12 Mar	5.8	61.7	3.96	12
	Hat	23 Mar[a]	5.2	64.8	3.23	12
	LGR	19 Apr	10.6	62.7	7.44	12
	LGR	1 May	11.8	65.3	3.17	12

a/ Date of release from hatchery.

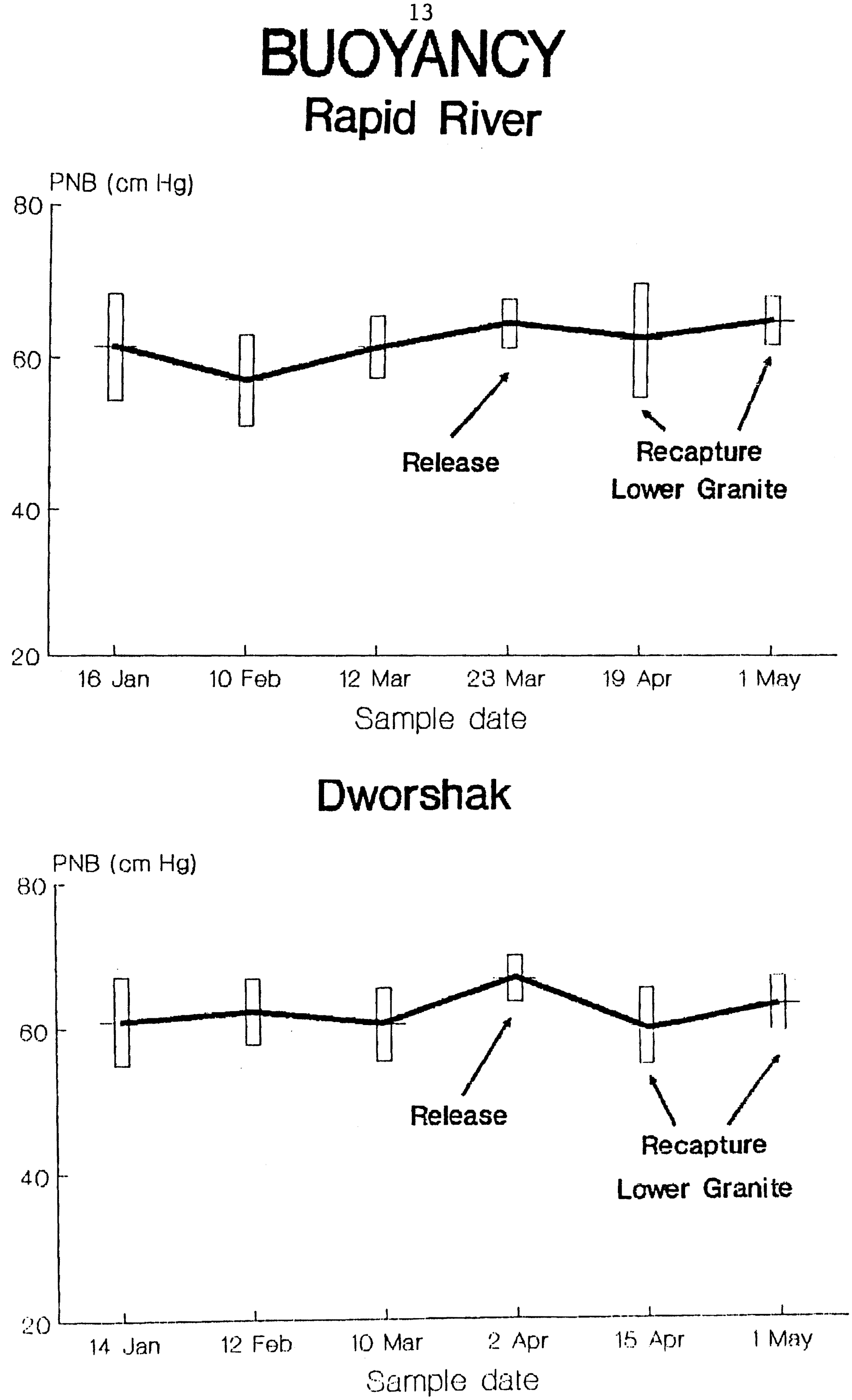


Figure 3.--Pressure of neutral buoyancy (PNB) data (cm Hg) for spring chinook salmon reared at Rapid River and Dworshak sampled at the hatcheries and at Lower Granite Dam, 1987. Bars represent standard deviations.

Table 3.--Gill Na^{+}-K^{+} ATPase data (μmol Pi·mg $Prot^{-1}\cdot h^{-1}$) for Dworshak and Rapid River stocks, 1987. Stocks were intercepted at Lower Granite Dam (LGR).

Stock	Sample site	Sample date	Water temp. (°C)	Gill Na^{+}-K^{+} ATPase Mean	SD	n
Dworshak	Hat	14 Jan	4.9	7.5	1.47	12
	Hat	12 Feb	4.9	8.4	1.39	12
	Hat	10 Mar	5.2	8.4	2.37	12
	Hat	2 Apr[a]	4.9	11.3	2.17	12
	Hat	18 Apr	5.4	9.7	2.70	12
	LGR	15 Apr	11.0	22.1	5.42	12
	LGR	1 May	11.8	17.2	7.27	11
Rapid River	Hat	16 Jan	3.2	8.3	0.71	12
	Hat	10 Feb	5.0	7.8	0.77	12
	Hat	12 Mar	5.8	8.3	0.82	12
	Hat	23 Mar[a]	5.2	5.8	1.12	12
	LGR	15 Apr	11.0	30.3	4.83	12
	LGR	19 Apr	10.6	29.8	4.28	12
	LGR	1 May	11.8	28.3	5.46	12

a/ Date of release from hatchery.

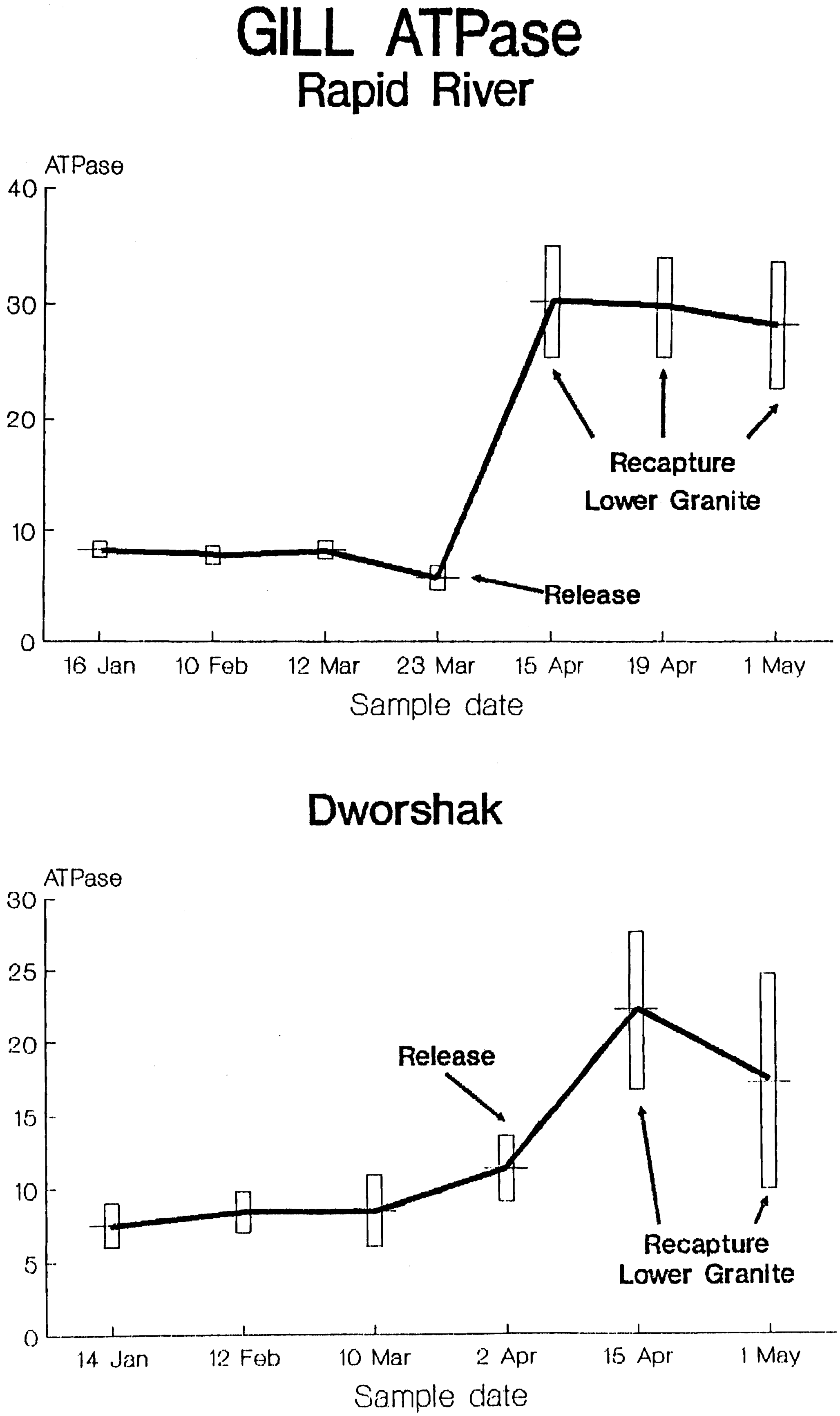


Figure 4.--Gill Na^{+}-K^{+} ATPase data (µmol Pi·mg $Prot^{-1}$·h^{-1}) for spring chinook salmon reared at Rapid River and Dworshak sampled at the hatcheries and at Lower Granite Dam, 1987. Bars represent standard deviations.

release from a mean of 8.3 to a mean of 5.8 μmol Pi·mg $Prot^{-1} \cdot h^{-1}$ on 12 March and 23 March, respectively.

From the date of release to arrival at Lower Granite Dam fish from both hatcheries exhibited marked increases in gill Na^{+}-K^{+} ATPase. Mean gill Na^{+}-K^{+} ATPase values for Rapid River fish increased significantly ($P < 0.001$) from 5.8 μmol Pi·mg $Prot^{-1} \cdot h^{-1}$ at release on 23 March to 30.3 umol Pi·mg $Prot^{-1} \cdot h^{-1}$ at Lower Granite Dam on 15 April. Rapid River fish were sampled on two subsequent dates at Lower Granite Dam (19 April and 1 May), and Na^{+}-K^{+} ATPase values remained stable at this elevated level (Table 3 and Fig. 4). Dworshak fish also exhibited a significant increase ($P < 0.001$) in Na^{+}-K^{+} ATPase values from 11.3 μmol Pi·mg $Prot^{-1} \cdot h^{-1}$ at release on 2 April to 22.1 μmol Pi·mg $Prot^{-1} \cdot h^{-1}$ upon recapture at Lower Granite Dam on 15 April. Later arriving Dworshak fish (1 May) also had elevated Na^{+}-K^{+} ATPase levels, but not significantly so.

Fish held at Dworshak Hatchery past the 2 April release date until 18 April exhibited little change in gill Na^{+}-K^{+} ATPase activity compared to values measured at the time of the release on 2 April (Table 3). However, these fish had significantly lower ($P < 0.001$) Na^{+}-K^{+} ATPase values than those fish recaptured at Lower Granite Dam on about the same date (Table 3).

The physical condition factor, K, was also calculated for both Dworshak and Rapid River fish (Table 4 and Fig. 5). The K-factors for both groups of fish decreased significantly upon arrival at Lower Granite Dam (Table 4 and Fig. 5). For Rapid River fish, the K-factor decreased from 1.07 at release to 0.92 on 15 April at Lower Granite Dam ($P < 0.001$). Dworshak fish had a similar decrease in K-factor--1.09 at release to 1.00 on 15 April and 0.91 on 1 May at Lower Granite Dam ($P < 0.01$ and $P < 0.001$, respectively). For fish held at Dworshak Hatchery after the production release, K-factors decreased significantly ($P < 0.01$) to

Table 4.--Condition factor (K) data for Dworshak and Rapid River stocks, 1987. Stocks were intercepted at Lower Granite Dam (LGR).

Stock	Sample site	Sample date	K - factor		
			Mean	SD	n
Dworshak	Hat	14 Jan	1.14	0.08	12
	Hat	12 Feb	1.14	0.05	12
	Hat	10 Mar	1.12	0.05	12
	Hat	2 Apr[a]	1.09	0.04	12
	Hat	18 Apr	1.02	0.05	12
	LGR	15 Apr	1.00	0.06	12
	LGR	1 May	0.91	0.03	12
Rapid River	Hat	16 Jan	1.04	0.06	12
	Hat	10 Feb	1.13	0.07	12
	Hat	12 Mar	1.07	0.06	12
	Hat	23 Mar[a]	1.07	0.04	12
	LGR	15 Apr	0.92	0.04	12
	LGR	19 Apr	0.94	0.04	12
	LGR	1 May	0.92	0.07	12

a/ Date of release from hatchery.

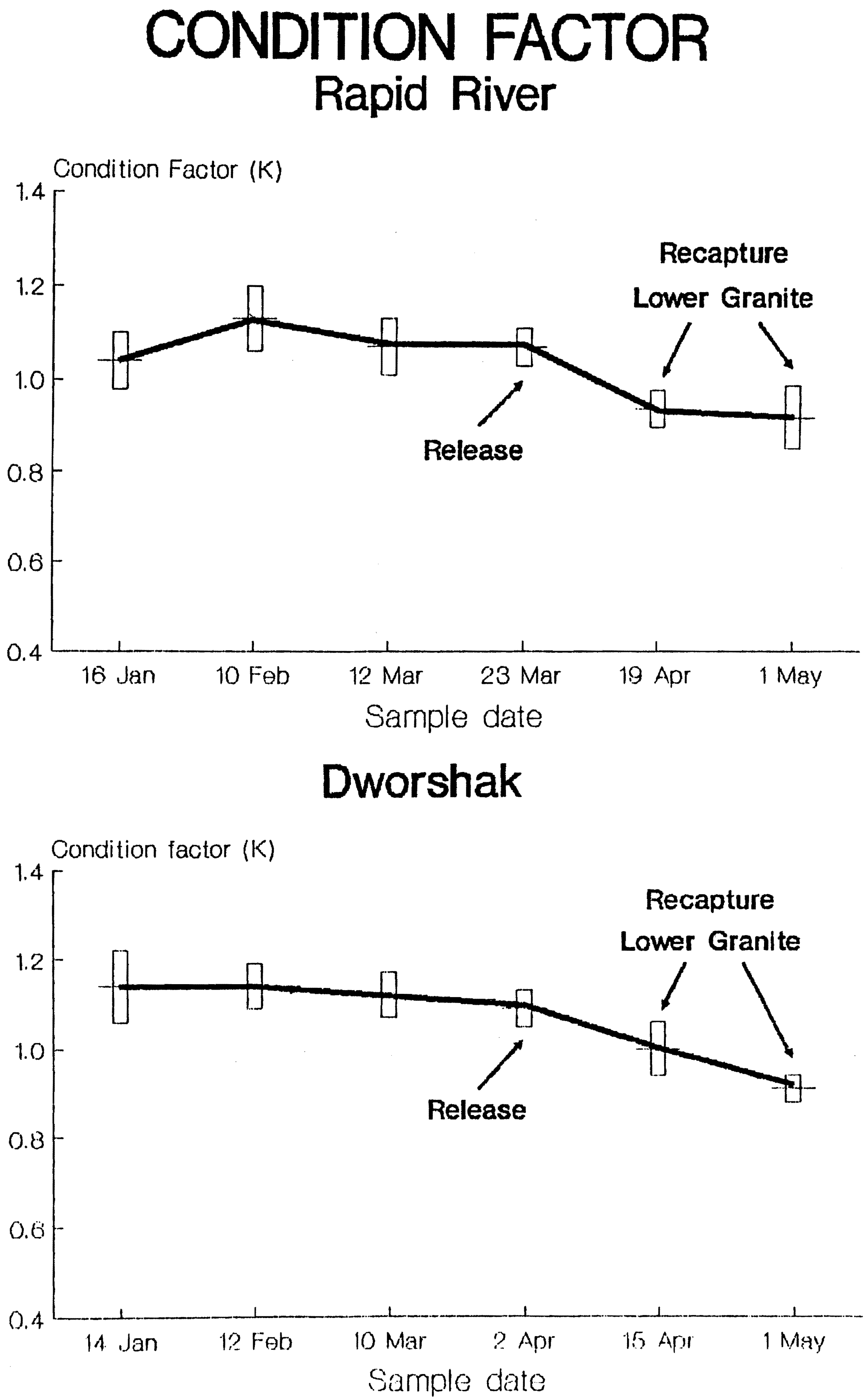


Figure 5.--Condition factor (K) data for spring chinook salmon reared at Rapid River and Dworshak sampled at the hatcheries and at Lower Granite Dam, 1987. Bars represent standard deviations.

($P < 0.01$) to levels similar to those observed at Lower Granite Dam during this same time period (Table 4 and Fig. 5).

Triiodothyronine (T_3) data showed similar patterns for Dworshak and Rapid River fish. The lowest values were observed in January ($0.3\ ng\cdot ml^{-1}$) at both hatcheries followed by monthly increases into March (Table 5 and Fig. 6). At Dworshak Hatchery, T_3 values peaked on 10 March at $2.2\ ng\cdot ml^{-1}$ and dropped slightly to $1.8\ ng\cdot ml^{-1}$ by the production release on 2 April. At Rapid River Hatchery, peak T_3 values were observed the day of the production release on 23 March at $1.9\ ng\cdot ml^{-1}$. For both groups, T_3 values were lower upon recapture at Lower Granite Dam, significantly so ($P < 0.01$) for Rapid River fish (Table 5 and Fig. 6).

For fish held until 18 April at Dworshak Hatchery, T_3 values dropped to $0.4\ ng\cdot ml^{-1}$--significantly less ($P < 0.001$) than at the production release on 2 April ($1.8\ ng\cdot ml^{-1}$) or upon recapture at Lower Granite Dam ($1.7\ ng\cdot ml^{-1}$) on 15 April (Table 5 and Fig. 6).

Thyroxine (T_4) data for Dworshak and Rapid River fish also showed similar patterns in 1987 (Table 6 and Fig. 7). Values at the hatcheries from January through March were relatively low and stable ($4.4 - 6.2\ ng\cdot ml^{-1}$) and increased significantly ($P < 0.001$) by their production release dates. At Dworshak Hatchery, T_4 values increased to $17.7\ ng\cdot ml^{-1}$ at release on 2 April whereas at Rapid River Hatchery, T_4 values increased to $11.6\ ng\cdot ml^{-1}$ at release on 23 March.

Upon recapture at Lower Granite Dam on 15 April, both groups had significantly lower T_4 values--$9.8\ ng\cdot ml^{-1}$ for Dworshak fish ($P < 0.001$) and $9.0\ ng\cdot ml^{-1}$ for Rapid River fish ($P < 0.01$). When sampled at Lower Granite Dam on 1 May, T_4 values continued to decrease for both groups to $3.8\ ng\cdot ml^{-1}$ for

Table 5.--Triiodothyronine (T_3) data for Dworshak and Rapid River stocks, 1987. Stocks were intercepted at Lower Granite Dam (LGR).

Stock	Sample site	Sample date	Water temp.(°C)	T_3 $(ng \cdot ml^{-1})$ Mean	SD	n
Dworshak	Hat	14 Jan	4.9	0.3	0.18	12
	Hat	12 Feb	4.9	0.6	0.39	9
	Hat	10 Mar	5.2	2.2	0.52	12
	Hat	2 Apr[a]	4.9	1.8	0.41	12
	Hat	18 Apr	5.4	0.4	0.26	12
	LGR	15 Apr	11.0	1.7	0.82	12
	LGR	1 May	11.8	1.0	0.50	11
Rapid River	Hat	16 Jan	3.2	0.3	0.29	12
	Hat	10 Feb	5.0	0.8	0.55	12
	Hat	12 Mar	5.8	1.7	0.57	12
	Hat	23 Mar[a]	5.2	1.9	0.59	12
	LGR	15 Apr	11.0	0.9	0.60	12
	LGR	19 Apr	10.6	0.9	0.54	12
	LGR	1 May	11.8	0.9	0.65	12

a/ Date of release from hatchery.

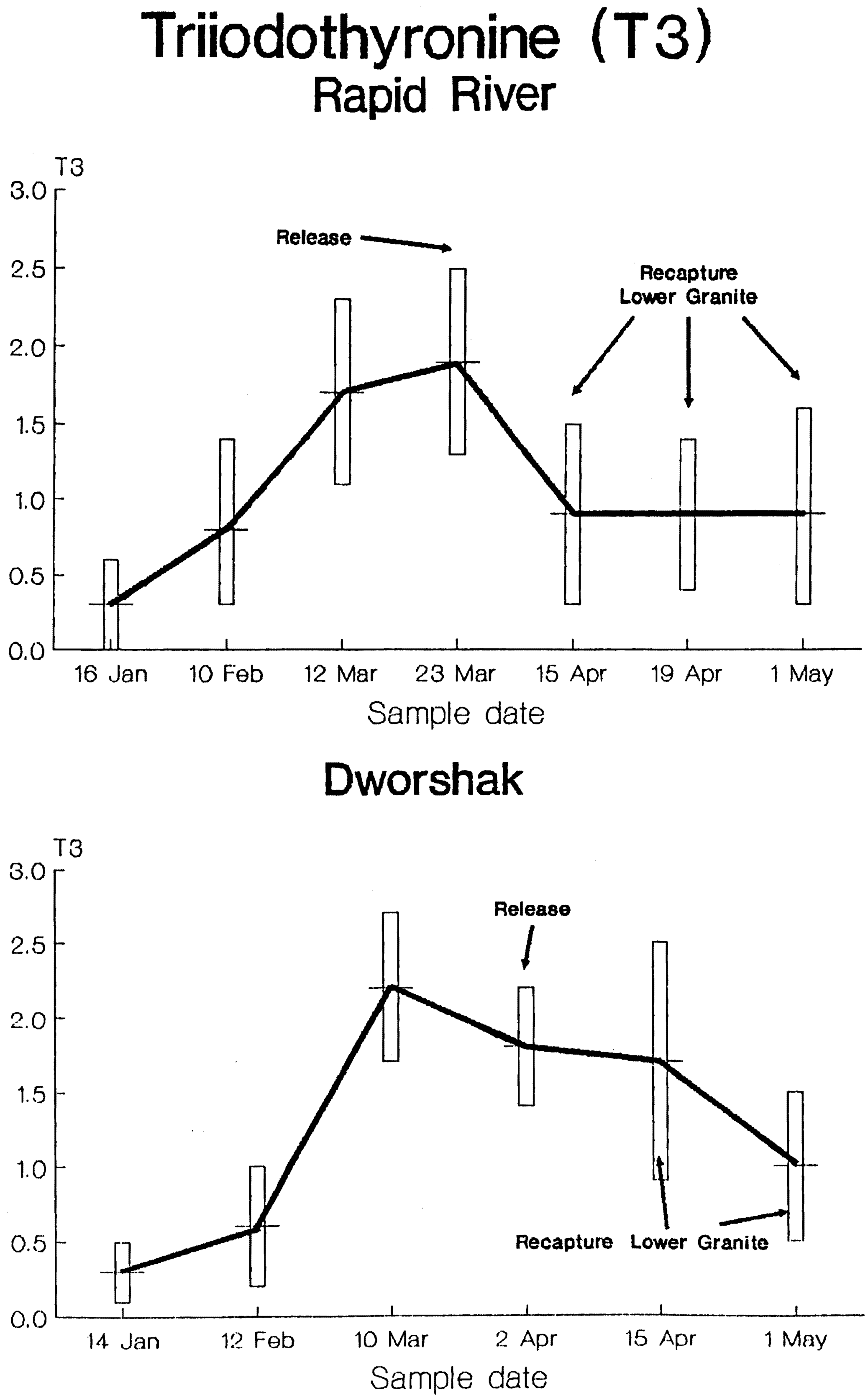


Figure 6.--Triiodothyronine (T_3) data ($ng \cdot ml^{-1}$) for spring chinook salmon reared at Rapid River and Dworshak sampled at the hatcheries and at Lower Granite Dam, 1987. Bars represent standard deviations.

Table 6.--Thyroxine (T_4) data for Dworshak and Rapid River stocks, 1987. Stocks were intercepted at Lower Granite Dam (LGR).

Stock	Sample site	Sample date	Water temp. (°C)	T_4 (ng·ml^{-1}) Mean	SD	n
Dworshak	Hat	14 Jan	4.9	4.4	1.33	12
	Hat	12 Feb	4.9	5.8	0.91	9
	Hat	10 Mar	5.2	6.2	1.25	12
	Hat	2 Apr[a]	4.9	17.7	6.40	12
	Hat	18 Apr	5.4	7.2	2.75	12
	LGR	15 Apr	11.0	9.8	3.02	12
	LGR	1 May	11.8	3.8	2.21	12
Rapid River	Hat	16 Jan	3.2	4.5	1.64	12
	Hat	10 Feb	5.0	6.0	2.68	12
	Hat	12 Mar	5.8	5.6	2.11	12
	Hat	23 Mar[a]	5.2	11.6	3.80	12
	LGR	15 Apr	11.0	9.0	3.09	12
	LGR	19 Apr	10.6	6.3	2.81	12
	LGR	1 May	11.8	4.7	1.85	12

a/ Date of release from hatchery.

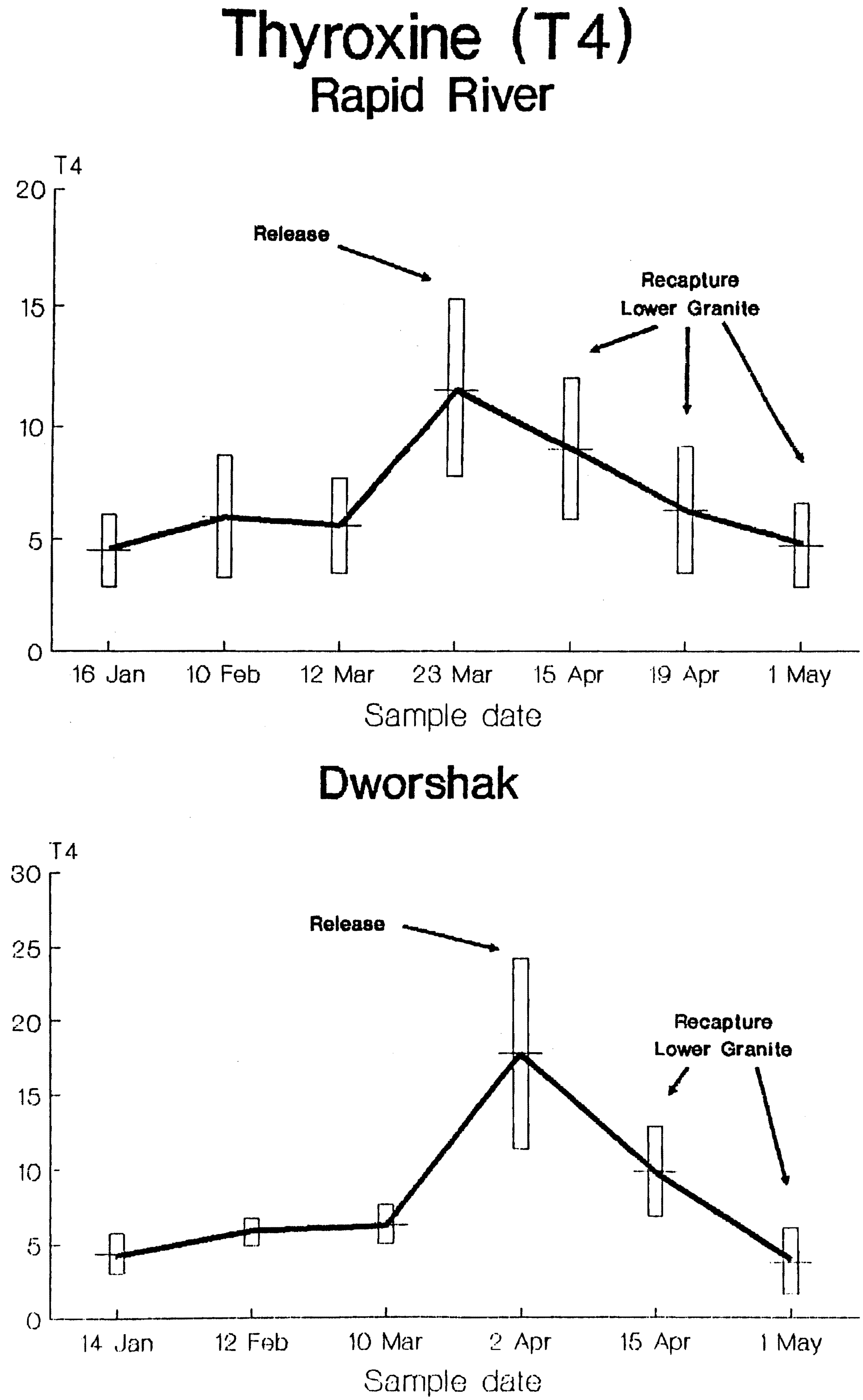


Figure 7.--Thyroxine (T_4) data ($ng \cdot ml^{-1}$) for spring chinook salmon reared at Rapid River and Dworshak sampled at the hatcheries and at Lower Granite Dam, 1987. Bars represent standard deviations.

Dworshak fish and 4.7 ng·ml^{-1} for Rapid River fish. These values were as low or lower than the lowest values observed at the hatcheries prior to release.

For fish held at Dworshak Hatchery until 18 April, T_4 values decreased significantly ($P < 0.001$) from values observed on 2 April, the date of the production release (from 17.7 to 7.2 ng·ml^{-1}). The T_4 values observed at the hatchery on 18 April (7.2 ng·ml^{-1}) were similar to the values recorded at Lower Granite Dam on 15 April (9.8 ng·ml^{-1}).

Temperature Effects

Experiments conducted with Little White Salmon spring chinook salmon indicated that temperature had an important influence on the behavioral and physiological indices. For fish held at 4°, 10°, and 13°C, the mean swimming stamina was 2.77, 3.41, and 4.01 BL/s, respectively (Table 7). For each increase in temperature, swimming stamina increased significantly ($P < 0.01$). These U-critical values are similar to the results obtained with similar temperatures for fish at Rapid River and Dworshak hatcheries and at Lower Granite Dam (Fig. 8).

These experiments with Little White Salmon fish also showed that buoyancy decreased with increasing temperature (Table 7). There was a significant difference ($P < 0.05$) in the buoyancy of fish at the two temperature extremes. Similar results were obtained for Atlantic salmon (Pinder and Eales 1969) and fathead minnows, *Pimephales promelas*, (Gee 1977).

Temperature affected gill Na^+-K^+ ATPase activity in the spring chinook salmon tested (Fig. 9). There was a significant increase ($P < 0.001$) in Na^+-K^+ ATPase values for fish held at 10°C (24.1 μmol Pi·mg Prot^{-1}·h^{-1}) over those held at 4°C (9.5 μmol Pi·mg Prot^{-1}·h^{-1}) (Table 7). Fish held at 13°C also showed elevated Na^+-K^+ ATPase activity (15.4 μmol Pi·mg Prot^{-1}·h^{-1}) over fish held at

Table 7.--Mean values for the behavioral and physiological indices for Little White Salmon spring chinook salmon held for 12-13 days at various temperatures in June. Standard deviations are in parentheses; n=12 for each temperature/index.

	Water temperature (°C)		
	4.0	10.0	13.0
U-critical (BL/s)	2.77 (0.27)	3.41 (0.37)	4.01 (0.27)
PNB (cm Hg)	66.4 (2.75)	64.2 (3.84)	62.8 (3.17)
K-factor	1.05 (0.06)	1.14 (0.06)	1.19 (0.10)
Na^+-K^+ ATPase (μmol Pi·mg $Prot^{-1}\cdot h^{-1}$)	9.5 (1.15)	24.1 (3.28)	15.4 (6.85)
T_3 ($ng\cdot ml^{-1}$)	1.9 (0.62)	1.8 (0.44)	2.3 (0.43)
T_4 ($ng\cdot ml^{-1}$)	11.4 (4.07)	8.1 (2.91)	5.4 (1.24)

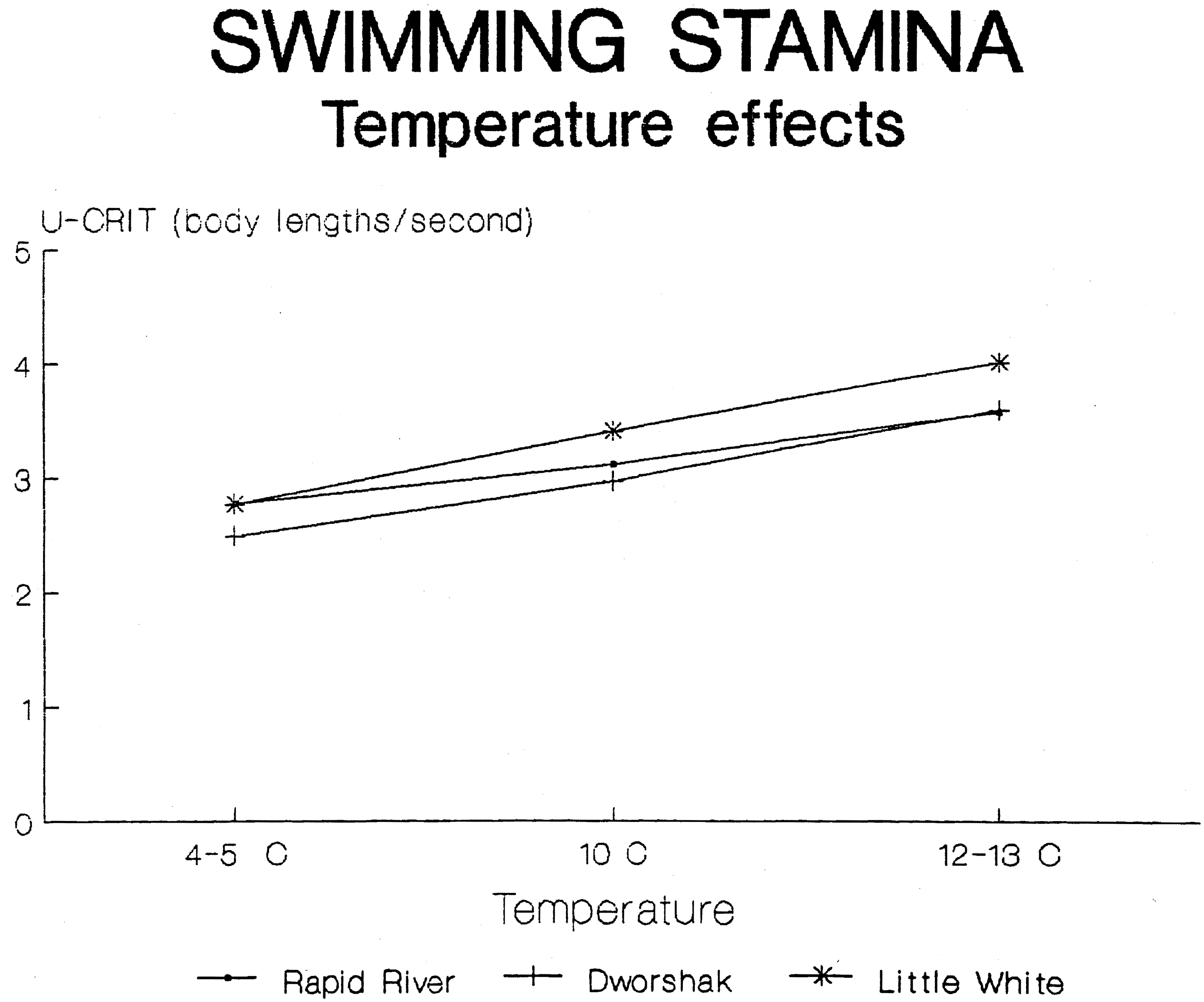


Figure 8.--Results of swimming stamina tests for three hatchery groups of spring chinook salmon at various temperatures, 1987.

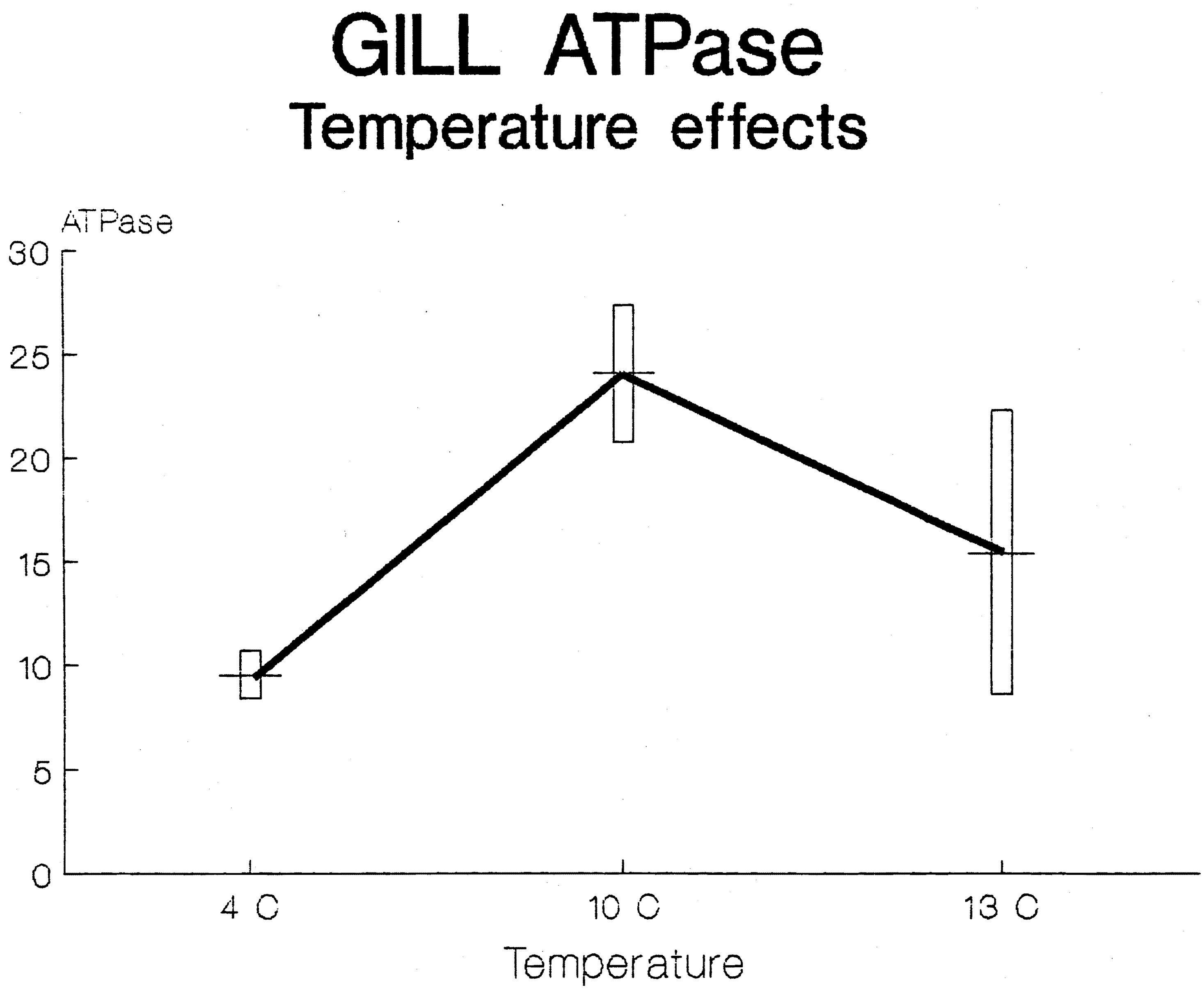


Figure 9.--The effects of temperature on gilll Na^{+}-K^{+} ATPase (µmol Pi·mg $Prot^{-1}\cdot h^{-1}$) for Little White Salmon spring chinook salmon. Fish were acclimiated for 12-13 days. Bars represent standard deviations.

4°C, but not significantly so. There was a significant decrease ($P < 0.01$) in Na^+-K^+ ATPase activity for fish held at 13°C vs those held at 10°C.

Condition factor increased with increasing temperature, significantly so ($P < 0.01$) for fish held at 10°C (1.14) over those held at 4°C (1.05) (Table 7). There was a further increase for fish held at 13°C (1.19), but the increase was not significant.

The effects of increasing temperature on T_3 were less apparent, even though a significant increase ($P < 0.05$) in T_3 values were observed for fish held at 13°C (2.3 $ng \cdot ml^{-1}$) over those held at 10°C (1.8 $ng \cdot ml^{-1}$) (Table 7 and Fig. 10).

Temperature appeared to have a more dominant effect on T_4. There was a significant decrease ($P < 0.05$) in T_4 values for fish held at 10°C (8.1 $ng \cdot ml^{-1}$) from those held at 4°C (11.4 $ng \cdot ml^{-1}$) and a further significant decrease ($P < 0.01$) for those held at 13°C (5.4 $ng \cdot ml^{-1}$) (Table 7 and Fig 10).

FGE and Smoltification

The Na^+-K^+ ATPase patterns observed in yearling chinook salmon at Lower Granite Dam showed a gradient of decreasing activity with increased depth on five of eight sample dates (Table 8). At Little Goose Dam on three of five sampling dates, this vertical gradient was apparent (Table 9). This is less consistent than observations made in 1985 and 1986 when a gradient of decreasing Na^+-K^+ ATPase activity with increasing depth was observed on three of four sample dates.

Partitioning the samples into those obtained from the gatewell (guided) vs. fyke and closure nets combined (unguided), we tested the hypothesis that both groups exhibited the same levels of Na^+-K^+ ATPase activity. At Lower Granite Dam on five of eight occasions ($P < 0.05$) we rejected the null hypothesis concluding that guided fish have significantly higher gill Na^+-K^+ ATPase levels (Table 10 and Fig. 11). For the remaining three dates we accepted the null

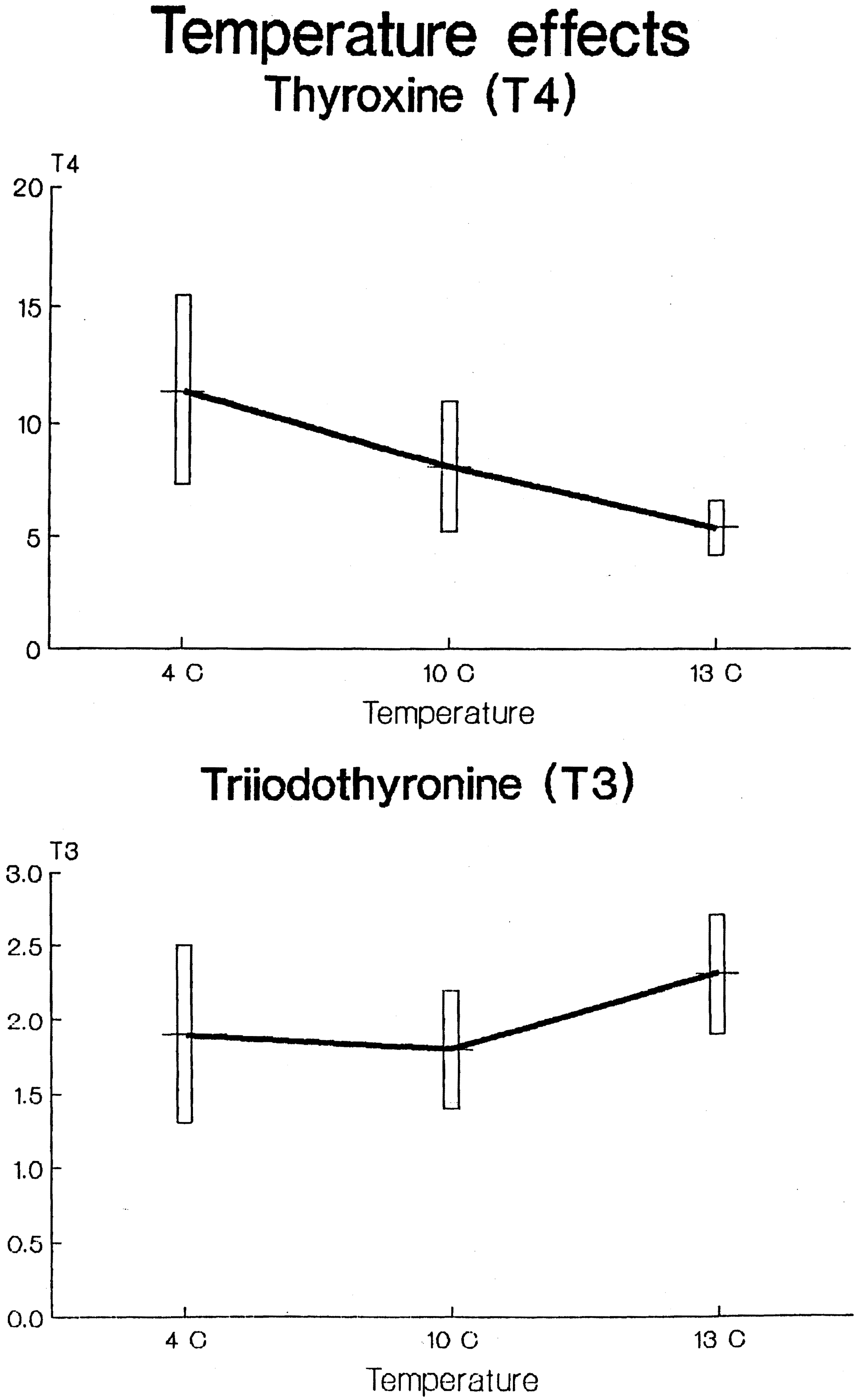


Figure 10.--The effects of temperature on Thyroxine and Triiodothyronine ($ng \cdot ml^{-1}$) for Little White Salmon spring chinook salmon. Fish were acclimated for 12-13 days. Bars represent standard deviations.

Table 8.--Gill Na^{+}-K^{+} ATPase (μmol $P_i \cdot$mg $Prot^{-1} \cdot h^{-1}$) data for yearling chinook salmon from FGE tests at Lower Granite Dam - 1987.

Date		Gatewell	Closure net	Fyke nets 1	2	3	4	5
11 Apr	x	22.3	17.9	15.5	12.9	17.1	16.3	15.9
	SD	3.99	4.86	4.61	3.51	6.78	3.98	5.08
	n	20	20	18	19	20	20	8
14 Apr	x	21.7	20.6	-	17.6	18.2	21.2	15.5
	SD	4.92	5.93	-	4.42	4.37	5.94	-
	n	20	20	0	19	20	6	1
15 Apr	x	25.3	23.3	21.1	22.2	17.3	21.6	23.2
	SD	5.75	4.53	6.08	4.16	4.90	4.31	4.00
	n	20	20	20	19	20	17	9
24 Apr	x	26.6	27.1	33.7	26.6	22.2	36.2	25.4
	SD	5.92	5.34	6.10	6.42	5.82	-	5.46
	n	20	20	19	20	16	1	4
25 Apr	x	26.5	22.6	27.7	25.2	26.7	21.5	27.5
	SD	5.35	5.92	6.33	7.06	7.24	4.60	3.57
	n	20	20	20	20	20	14	4
29 Apr	x	26.5	22.4	26.4	22.3	18.4	12.8	-
	SD	8.28	6.04	6.26	5.64	5.48	4.65	-
	n	20	20	20	20	20	3	0
1 May	x	25.9	25.6	18.7	22.8	12.7	11.9	17.1
	SD	7.24	7.16	6.50	8.47	5.76	-	-
	n	20	20	20	20	20	1	1
3 May	x	21.5	24.0	24.5	24.0	18.3	18.5	23.0
	SD	6.78	9.60	7.36	8.49	6.76	6.37	10.94
	n	20	20	20	20	20	17	4

Table 9.--Gill Na^{+}-K^{+} ATPase (μmol $P_i \cdot$mg $Prot^{-1} \cdot h^{-1}$) data for yearling chinook salmon from FGE tests at Little Goose Dam - 1987.

Date		Gatewell	Closure net	Fyke nets 1	2	3	4	5
20 Apr	x	27.6	25.9	27.4	26.1	32.7	25.6	26.0
	SD	7.22	6.54	11.31	8.59	10.09	7.09	-
	n	20	20	20	20	20	5	1
21 Apr	x	26.9	31.9	28.7	23.5	32.7	23.6	29.5
	SD	8.42	8.89	8.22	7.01	10.38	6.07	8.84
	n	20	20	20	20	20	8	2
5 May	x	35.3	31.7	30.8	30.9	33.5	45.6	32.0
	SD	7.00	5.50	9.57	8.53	9.03	3.25	15.16
	n	20	20	20	20	20	2	5
6 May	x	37.6	37.7	33.4	37.3	24.4	32.9	38.7
	SD	8.26	7.44	7.48	13.38	6.23	12.24	-
	n	20	20	20	20	20	9	1
7 May	x	34.0	32.5	32.1	30.1	31.2	-	-
	SD	7.76	10.29	6.28	8.33	2.47	-	-
	n	20	19	9	17	2	0	0

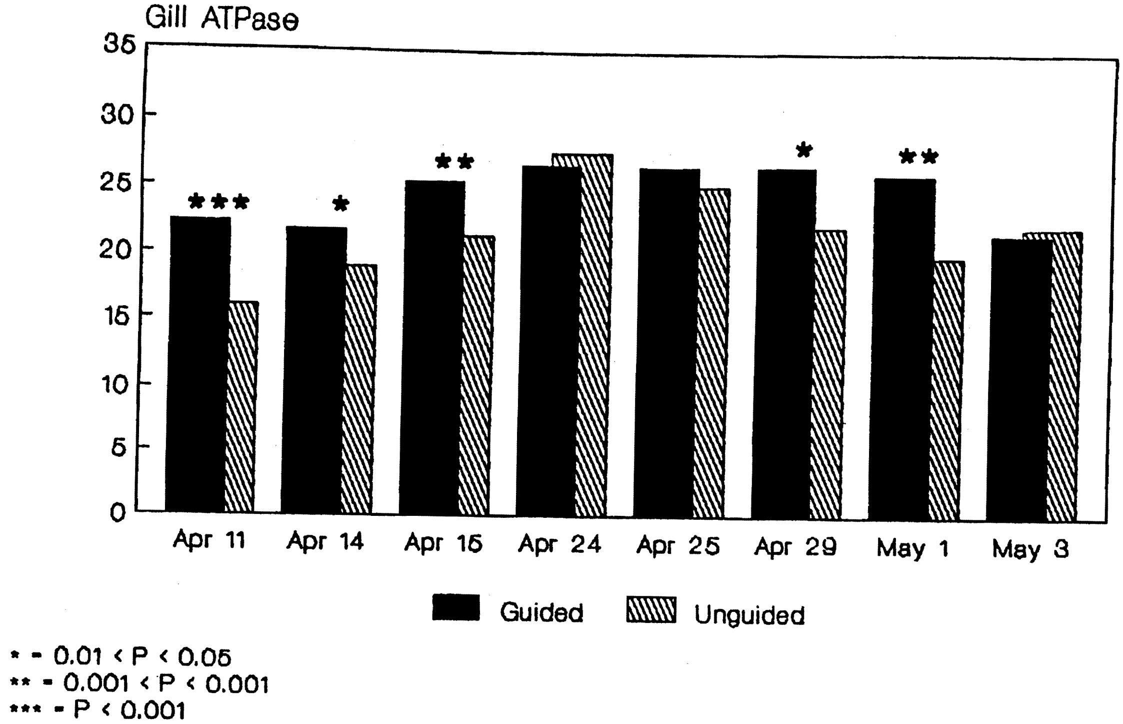
Table 10.--Results of Mann-Whitney tests for guided vs unguided fish Na^{+}-K^{+} ATPase activity (μmol $P_i \cdot$mg $Prot^{-1} \cdot h^{-1}$) at Lower Granite and Little Goose Dams - 1987.

Date	Na^{+}-K^{+} ATPase (mean)		P
	GW	Nets	
	Lower Granite Dam		
11 Apr	22.3	16.0	0.0000***
14 Apr	21.7	19.0	0.0419*
15 Apr	25.3	21.3	0.0031**
24 Apr	26.6	27.6	0.6760
25 Apr	26.5	25.0	0.4135
29 Apr	26.5	22.0	0.0207*
1 May	25.9	19.8	0.0024**
3 May	21.5	22.0	0.8533
	Little Goose Dam		
20 Apr	27.6	27.9	0.9421
21 Apr	26.9	28.7	0.3875
5 May	35.3	32.0	0.0731
6 May	37.6	33.2	0.0686
7 May	34.0	31.5	0.2671

* = $0.01 < P < 0.05$
** = $0.001 < P < 0.01$
*** = $P < 0.001$

FGE - 1987

Lower Granite Dam



Little Goose Dam

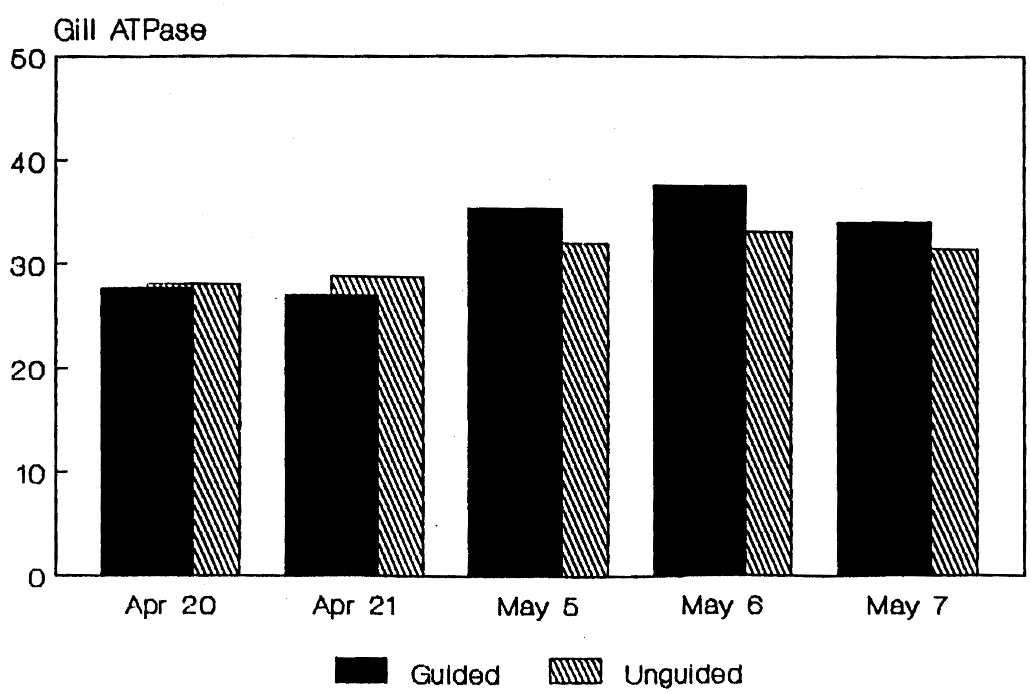


Figure 11.--A comparison of gill Na^{+}-K^{+} ATPase levels (µmol Pi·mg $Prot^{-1}$·h^{-1}) in yearling chinook salmon measured in gatewell caught (guided) vs those captured in the fyke nets (unguided) during 1987. Levels of significance indicated are results of Mann-Whitney U tests: * = 0.01 < P < 0.05, ** = 0.001 < 0.01, *** = P < 0.001.

hypothesis. For samples obtained from Little Goose Dam we accepted the null hypothesis on all five dates (Table 10 and Fig. 11).

In 1986, there was concern that since gatewell fish were freshly killed and fyke net sampled fish could be dead for 2-3 h prior to processing, there might be some enzyme degradation in the fyke net sampled fish. If that degradation were substantial it could account for the vertical gradient patterns we observed. We tested the hypothesis that the two samples had the same Na^+-K^+ ATPase activity. On 4 of 13 dates we rejected the null hypothesis (Table 11). On these four occasions (25 and 29 April and 5 and 6 May) we documented significant ($P < 0.05$) decreases in enzyme activity for samples which were held for up to 3 h. Our methodology coupled with prevailing environmental conditions on these four dates may well account for the decreased enzyme activity we observed. Between samplings, gatewell fish were placed in 2-3 gallons of water and placed outdoors. Unseasonably warm air temperatures resulted in sample fish being exposed to temperatures higher than they would have experienced at ambient river temperature. Since enzymes are sensitive to warm temperature, we suspect this may account for the enzyme degradation observed in some of the samples, and do not feel the results are representative of what fish held at ambient river temperatures (10° to 12°C) would have exhibited. Particularly since significant decreases in enzyme activity were documented on only 4 of 13 sample dates.

Using all fish assayed during each FGE test, a weighted mean Na^+-K^+ ATPase level was calculated for each sample-night's migrant population. The mean was weighted in proportion to the FGE estimate for the number of fish in each net level. In all cases, FGE tests were the standard or control condition tested at each dam (Ledgerwood et al. 1988). To examine the relationship between FGE and the level of smolt development in the migrant population, we plotted the FGE estimate against the weighted mean Na^+-K^+ ATPase level for each date (Table 12

Table 11.--Results of Mann-Whitney tests for differences between gill Na^{+}-K^{+} ATPase samples (μmol $P_i \cdot$mg $Prot^{-1} \cdot h^{-1}$) collected from freshly killed spring chinook salmon (Na^{+}-K^{+} ATPase-A) and from fish allowed to soak in water for 2-3 h (Na^{+}-K^{+} ATPase-B) - 1987.

Date	Site	ATPase-A	ATPase-B	P
11 Apr	LGR	22.3	21.3	0.4989
14 Apr	LGR	21.7	22.6	0.5838
15 Apr	LGR	25.3	23.3	0.0884
24 Apr	LGR	26.6	22.5	0.1231
25 Apr	LGR	26.5	22.2	0.0110 *
29 Apr	LGR	26.5	21.1	0.0275 *
1 May	LGR	25.9	25.2	0.7868
3 May	LGR	21.5	24.5	0.2287
20 Apr	LG	27.6	26.2	0.5979
21 Apr	LG	26.9	27.7	0.6652
5 May	LG	35.3	26.2	0.0007***
6 May	LG	37.6	30.1	0.0207*
7 May	LG	34.0	34.4	0.9353

* = 0.01 < P < 0.05
*** = P < 0.001

Table 12.--Percent FGE and corresponding gill Na^{+}-K^{+} ATPase activity level (weighted mean) from Lower Granite (LGR) and Little Goose (LG) Dams, 1987.

Date	Dam	% FGE	ATPase (mean)
11 April	LGR	38.4	18.1
14 April	LGR	52.7	20.3
15 April	LGR	58.4	23.6
24 April	LGR	64.1	26.9
25 April	LGR	59.4	26.0
29 April	LGR	69.5	25.2
1 May	LGR	58.9	23.9
3 May	LGR	53.0	22.0
20 April	LG	57.3	27.4
21 April	LG	55.4	26.9
5 May	LG	62.3	33.9
6 May	LG	72.8	36.9
7 May	LG	77.7	33.4

and Fig. 12). Results indicated that FGE was positively correlated with the stage of smolt development ($r = 0.8011$, $P < 0.01$). There was no correlation between FGE and water temperature ($r = 0.2471$).

DISCUSSION

Results of swimming stamina tests conducted during 1986 and 1987 for selected hatchery groups were similar (Swan et al. 1987). During both years, swimming stamina was relatively stable during hatchery residence, increased upon arrival at Lower Granite Dam, and further increased at Lower Granite Dam later in the outmigration. There are several possible explanations. Experiments conducted with Little White Salmon fish to examine the effects of temperature on the behavioral and physiological indices indicated that temperature appeared to be an important factor influencing swimming stamina; swimming performance increased at higher water temperatures (Fig. 8). Similar results were obtained by Glova and McInerney (1977) working with coho salmon and by Brett (1964) working with sockeye salmon (O. nerka). Since water temperature in the Snake River increases rapidly during the spring, especially compared to hatchery water temperatures, changes in swimming stamina associated with the parr-smolt transformation are difficult to isolate.

Perhaps yearling chinook salmon increase their stamina in response to the more vigorous physical activity they experience after release from the hatchery; Besner (1980) found that coho salmon had such a response to exercise. Alternatively, once released from the hatchery, the weaker fish, those exhibiting poor stamina, may die leaving only the hardiest, those exhibiting the highest stamina, to survive to Lower Granite Dam. Swimming stamina may be naturally associated with smolt development. In fact, both groups (Rapid River

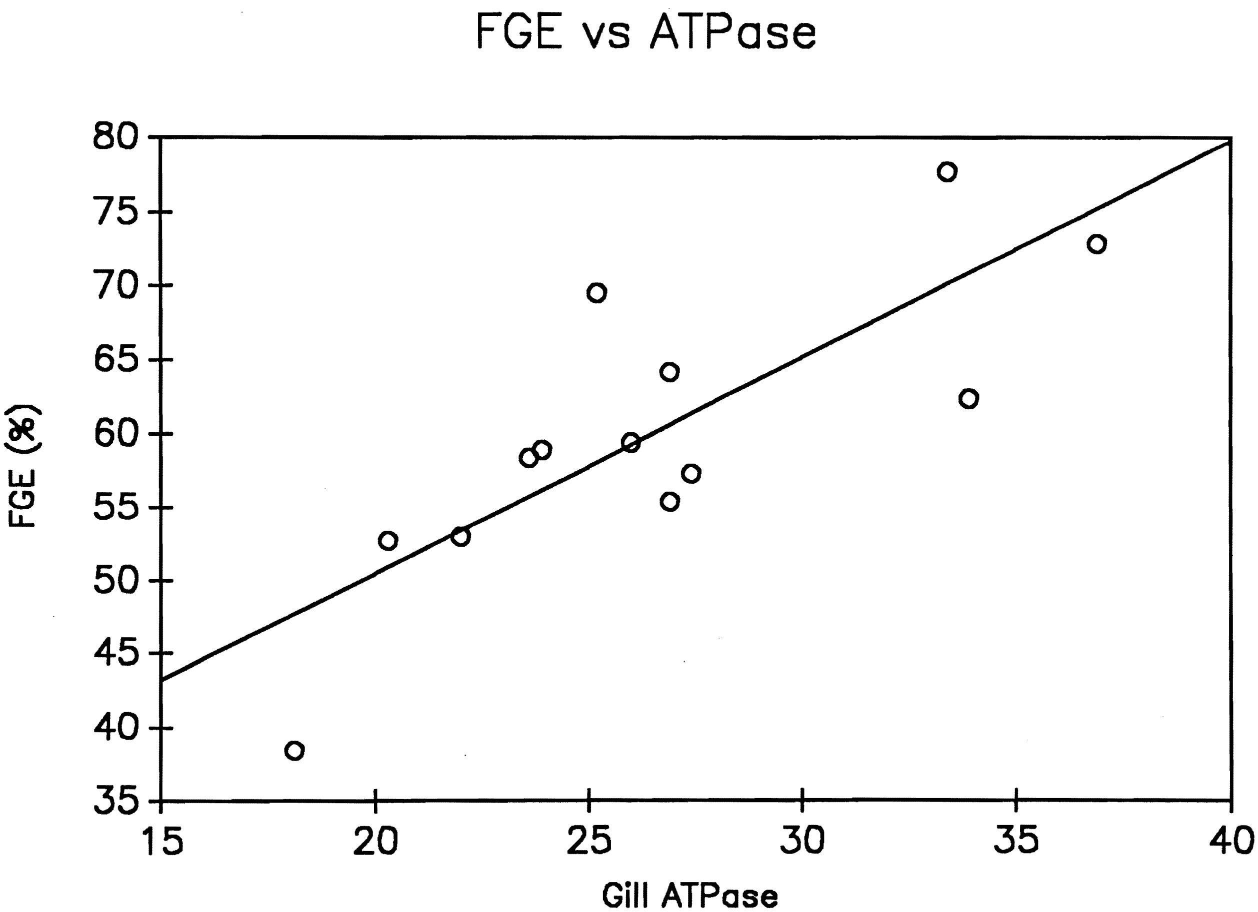


Figure 12.--Yearling chinook salmon Fish Guiding Efficiency (FGE) vs weighted mean gill $Na^{+}-K^{+}$ ATPase (µmol Pi·mg $Prot^{-1}$·h^{-1}) at Little Goose and Lower Granite Dams, 1987.

and Dworshak) showed a significant increase in Na^{+}-K^{+} ATPase at downstream sites (Table 3).

Video taped observations of spring chinook salmon passing through turbine intakes at Little Goose Dam in 1973 indicated that fish were negatively buoyant and assumed a tail-down swimming attitude (Long et al. 1977). Reasonably then, stronger swimmers could be higher in the water column and hence more susceptible to guidance by the STS. Since swimming speed is largely a function of fish size, larger fish could display higher guidance. However, length frequency data collected in 1986 (Swan et al. 1987) and 1987 (Ledgerwood et al. 1988) do not support this, indicating that size-related behavior does not play an apparent role in FGE.

Changes in buoyancy due to the smoltification process are also difficult to isolate. While at the hatchery, fish are subjected to stable temperatures and minimal flows; upon release, they experience increasing temperatures and flows and possibly adjust their buoyancy accordingly. Other researchers working with Atlantic salmon and brown trout (S. trutta) found that hatchery reared fish were more buoyant than wild fish, a result of the hatchery experience and/or hatchery diet, and that buoyancy decreased with increasing water velocity (Neave et al. 1966; Saunders 1965; Sosiak 1982; and Legault and Lalancette 1985). In many of these studies, smoltification effects could not be isolated from environmental effects. As a result, their interpretations are confounded. Examination of our own results reveals the same limitation. Changes in riverine conditions may be confounding changes in fish buoyancy which may be associated with smolt development. Following release from the hatchery, gill Na^{+}-K^{+} ATPase levels in our test groups began rising, which theoretically should have been associated with increased buoyancy. At the same time increasing riverine temperature and water velocity could have been reducing buoyancy resulting in inconclusive observations.

Gill Na^{+}-K^{+} ATPase activity for Dworshak and Rapid River spring chinook salmon during 1987 followed the same patterns as those observed during the 1986 outmigration (Swan et al. 1987); activity levels were relatively low and stable at the hatchery and significantly higher at Lower Granite Dam. This indicates that either these groups were released early in their physiological development or that the migrational experience is needed to stimulate gill Na^{+}-K^{+} ATPase activity. Fish held at Dworshak Hatchery an additional 2 weeks past the general release date did not exhibit elevated gill Na^{+}-K^{+} ATPase activity during 1987. However this may still be relatively early (mid April) in their physiological development (Zaugg, unpublished data). Rondorf et al. (1985) found that Leavenworth Hatchery spring chinook salmon held past the normal release date continued to show an increase in gill Na^{+}-K^{+} ATPase activity until late May. However, the maximum activity level was about one-half of that attained by migrants recaptured downstream. Similar results were obtained by Zaugg et al. (1985) with spring and fall chinook salmon, coho salmon, and steelhead (S. gairdneri). These studies indicate that the migrational experience is necessary to stimulate the full development of gill Na^{+}-K^{+} ATPase activity.

One of the environmental factors associated with riverine migration which may be responsible for stimulating smolt development and the expression of elevated gill Na^{+}-K^{+} ATPase activity appears to be increasing temperature. Holding Little White Salmon spring chinook salmon for 2 weeks at 10°C resulted in gill Na^{+}-K^{+} ATPase activities 2.5 times higher than fish held at 4°C (Fig. 8). This temperature change is about the same as that experienced by Dworshak and Rapid River fish migrating from the hatchery to Lower Granite Dam resulting in a similar increase in gill Na^{+}-K^{+} ATPase activity. Interestingly, holding these fish at 13°C resulted in a significant decrease in gill Na^+-K^+ ATPase activity. Thus, a temperature near 10°C appears to be a temperature beneficial for smolt development in spring chinook salmon. Similar results were reported for other salmonid species (Wedemeyer et al. 1980).

There was a significant correlation between mean gill Na^+-K^+ ATPase and mean condition factor for Dworshak ($r = -0.835$, $P<0.05$) and Rapid River ($r = -0.943$, $P<0.01$) fish, with condition factor decreasing as gill Na^+-K^+ ATPase activity increased. This suggests that condition factor is a viable index of smolt development for spring chinook salmon, and it may be desirable to document it in future investigations.

Analyses of blood thyroid hormone levels suggest that smoltification had begun near the end of March at both hatcheries. In both groups of fish captured at Lower Granite Dam, both T_3 and T_4 had declined from the peak values at release and had returned to baseline levels (January-February) by 1 May. These results indicate that the thyroxine surge associated with smoltification was completed in sampled fish by this time. The relatively low levels of T_3 and T_4 observed in Dworshak fish at the hatchery on 18 April and in Rapid River fish on 19 April suggest that this process may have been completed by these dates.

Although T_4 levels peaked at both hatcheries at the time of release, similar increases in gill Na^+-K^+ ATPase were not observed (although a slight increase was observed at Dworshak). Based on other studies of spring chinook salmon, some increase in Na^+-K^+ ATPase would have been expected shortly after the increases in thyroid hormones (Zaugg and Dickhoff, unpublished data). It's possible that the relatively low and stable water temperatures encountered at the two hatcheries suppressed the observed Na^+-K^+ ATPase activities. The elevated levels of gill Na^+-K^+ ATPase activities associated with declining thyroid hormone levels in fish captured at Lower Granite Dam is a pattern that appears to be common in migrating salmonids (Zaugg and Dickhoff, unpublished observations). These observations support the notion that smoltification is completed during riverine migration after release from the hatchery.

Smoltification is only one of several factors affecting FGE. Other probable factors include changes in flow or dam operation, changing turbidity, and arrival of different stocks of fish. Even so, over the 1987 outmigration, we have accumulated additional evidence that FGE was highest when gill Na^+-K^+ ATPase levels were highest, and a vertical gradient in Na^+-K^+ ATPase activities was apparent some of the time. This would suggest that by manipulating the physiological status of fish, while still in captivity, it may be possible to increase the potential for increased FGE with the fish. In future years, we propose to direct our research toward implementing and evaluating such a strategy.

CONCLUSIONS AND RECOMMENDATIONS

1. Yearling chinook salmon which are farther along in the parr/smolt transformation appear to be more susceptible to guidance by an STS. Levels of gill NA^+-K^+ ATPase (a measure of smoltification) were significantly higher for guided than unguided fish at Lower Granite Dam in 1987 on some occasions. These observations are consistent with those documented previously at these sites.
2. Swimming stamina and gill Na^+-K+ ATPase measured at Lower Granite Dam were significantly higher than measured at time of the fish's release from the hatchery.
3. The buoyancy data were inconclusive. Further examination of this response using this methodology is not recommended.

4. Experiments with Little White Salmon yearling chinook salmon indicate that temperature has an important influence on swimming stamina and the physiological indices. Fish held at higher temperatures exhibit increased swimming stamina and T_3 levels, decreased T_4 levels, and variable Na^+-K^+ ATPase activity. Resolution of the mechanism and relationships require further experimentation.
5. We recommend that future research focus on manipulating smolt development in the hatchery with the intention of increasing FGE for yearling chinook salmon.

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