An Assessment of the Relationship Between Smolt Development and Fish Guiding Efficiency at Lower Granite Dam, 1989

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COASTAL ZONE AND ESTUARINE STUDIES

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INTRODUCTION

Research conducted by the National Marine Fisheries Service (NMFS) in cooperation with the U.S. Army Corps of Engineers (COE) has demonstrated that fish guiding efficiency (FGE) not only changes from year to year and among dams, but can also change during any year's outmigration. Determining the causes of this variation at Lower Granite and Little Goose Dams--the two collector dams for fish transportation on the Snake River--is of major importance to the success of the transportation program. The submersible traveling screens (STS) that divert migrating juvenile salmonids from the turbine intakes into gatewells are vital components of the collection systems, and high FGEs are desired.

Data acquired at Lower Granite and Little Goose Dams from 1985 to 1987 suggest that intraseasonal changes in FGE are associated with the changing physiological status of the smolt population. NMFS researchers have presented evidence which indicates that yearling chinook salmon, *Oncorhynchus tshawytscha,* that are fully smolted within the population are more likely to be guided by traveling screens (Giorgi et al. 1988; Muir et al. 1988). We hypothesize that over the course of the outmigration the proportion of fully smolted fish in the population increases, which in turn could explain intraseasonal increases in FGE observed at Lower Granite Dam.

Because of atypical flow conditions encountered during 1987, we repeated a portion of the FGE/smoltification studies at Lower

Granite Dam in 1989 with the following objectives: 1) to determine if seasonal changes in the physiological status of the migrant population are evident at Lower Granite Dam and 2) to assess whether those changes are related to prevailing FGE estimates. Results of the FGE portion of this study can be found in Swan et al. (1989).

METHODS AND MATERIALS

Physiological Development

Gill Na^+-K^+ ATPase

To examine the relationship between guidability and smolt development, fish were collected during FGE tests and assayed for gill Na^+-K^+ ATPase activity. Up to 20 yearling chinook salmon were sampled from the gatewell and each net level (excluding the gap nets) and placed on ice until gill samples could be taken. Fish were weighed and measured; gill filaments were trimmed from the gill arch and placed into 1.5-ml microcentrifuge tubes filled with a buffer solution containing sucrose, ethylenediamine, and imidazole (SEI). Samples were immediately placed in a freezer and held at <-20°C until assayed.

To assure that any observed differences in gill Na^+-K^+ ATPase activity between live gatewell and dead fyke-net captured fish were not caused by deterioration of this enzyme in the dead fish, gatewell fish were killed and placed in water at ambient river temperature until the fyke nets were removed from the water. The net catches were then processed in a random order so that the time elapsed between death and gill removal did not consistently favor any net level or the gatewell. Assays for gill Na^+-K^+ ATPase activity were conducted using procedures described by Zaugg (1982), with minor modification.

To test for differences in gill Na^+-K^+ ATPase levels between guided and unguided fish, fyke-net catches were combined and compared to those sampled from the gatewell using a two-sample t-test with $\alpha = 0.05$. To characterize the physiological status of the smolt population on each sample date, the mean gill Na^+-K^+ ATPase level was determined for each net level, weighted for the number of fish captured at that level, and averaged for all of the net levels and gatewell combined. The relationship between this index of smoltification and FGE was then examined.

Samples were collected from Unit 4B on eight test dates from 11 April through 30 April (samples collected on 27 April were lost due to improper storage). Samples were taken during control tests using a standard STS with a 62-ft raised operating gate (Swan et al. 1989).

Morphometrics

We assessed the feasibility of using morphometric measurements as an index of smolt development in FGE studies. The yearling chinook salmon that were collected for gill samples were placed on paper over a flat polystyrene surface and holes were punched through the paper at the appropriate locations for digitizing as described by Winans (1984). This morphometric index describes changes in fish shape associated with the physiological process of smoltification (Winans and Nishioka 1987).

To test for differences in the morphometric index between guided and unguided fish, fyke-net catches were combined and compared to those sampled from the gatewell using a two-sample t-test with $\alpha = 0.05$. To characterize the physiological status of the smolt population on each sample date, the mean morphometric index was determined for each net level, weighted for the number of fish captured at that level, and averaged for all of the net levels and gatewell combined. Morphometric samples were collected on four test dates.

Mark Recoveries

All yearling chinook salmon captured during the FGE (test and control) and vertical distribution tests were examined for brands and PIT tags from the Bonneville Power Administration (BPA) funded Dworshak photoperiod study. It was hoped that a sufficient number of marks could be recovered to provide a measure of the effects of advanced photoperiod on yearling chinook salmon susceptibility to guidance. All yearling chinook salmon were visually examined for brands, then passed through a PIT-tag detector.

RESULTS

FGE and Smoltification

Yearling chinook salmon exhibited a steady increase in gill Na^{+}-K^{+} ATPase activity as the outmigration progressed (Fig. 1). Weighted mean values for the enzyme increased from a low of 16.0 μmol $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$ on 11 April to a high of 29.4 μmol $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$ on 30 April (Fig. 1, Table 1).

Concomitantly, FGE generally increased over the sampling period (Table 1). During the first week of sampling (11-18 April), FGE was relatively low, ranging from 43.4 to 55.1% (mean = 51.5%). During the remainder of the sampling period (20-30 April), FGE was higher, ranging from 49.6 to 66.5% (mean = 61.5%).

The relationship between the FGE measured at the dam and the physiological status of the population, as indexed by gill Na^{+}-K^{+} ATPase, is described by an exponential function (Fig. 2), $FGE = e^{3.44 + 0.025\,(ATPase)}$. This relationship is significant; using ANOVA, we tested and rejected the null hypothesis, H_o:β=0 ($F_{1,6}$ = 6.293, P = 0.0460).

When gill Na^{+}-K^{+} ATPase levels of guided and unguided fish were compared, 88% of the time the guided fish exhibited higher enzyme levels. On two occasions they were significantly so (P <0.05) (Table 2 and Fig. 3). However, on one occasion, 23 April, unguided yearling chinook salmon had significantly higher Na^{+}-K^{+} ATPase levels than those that were guided. Detailed sampling data are presented in Table 3.

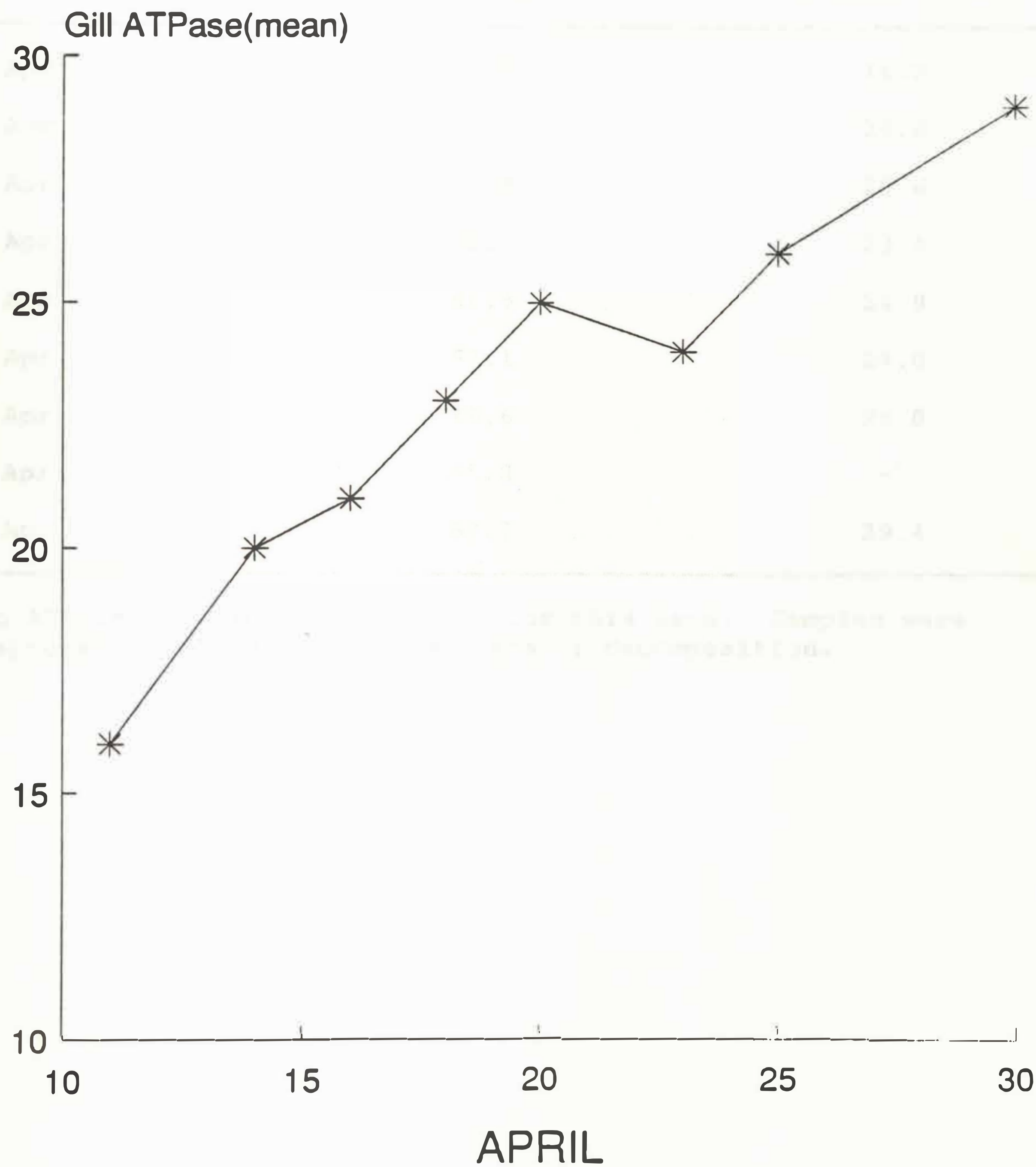

Figure 1.--Weighted mean gill Na^{+}-K^{+} ATPase ($\mu mol\ P_i \cdot mg\ Prot^{-1} \cdot h^{-1}$) in yearling chinook salmon on date of capture at Lower Granite Dam, 1989.

Table 1.--Fish guidance efficiency (FGE) and corresponding gill Na^{+}-K^{+} ATPase ($\mu mol\ P_i \cdot mg\ Prot^{-1} \cdot h^{-1}$) activity level (weighted mean) from Lower Granite Dam, Unit 4B, 1989.

Date	% FGE	ATPase (mean)
11 Apr	43.4	16.0
14 Apr	55.0	20.6
16 Apr	52.3	20.6
18 Apr	55.1	23.4
20 Apr	66.5	24.9
23 Apr	62.1	24.0
25 Apr	49.6	26.0
27 Apr	65.8	-[a]
30 Apr	63.7	29.4

[a] No ATPase estimate is available for this date. Samples were improperly stored and showed signs of decomposition.

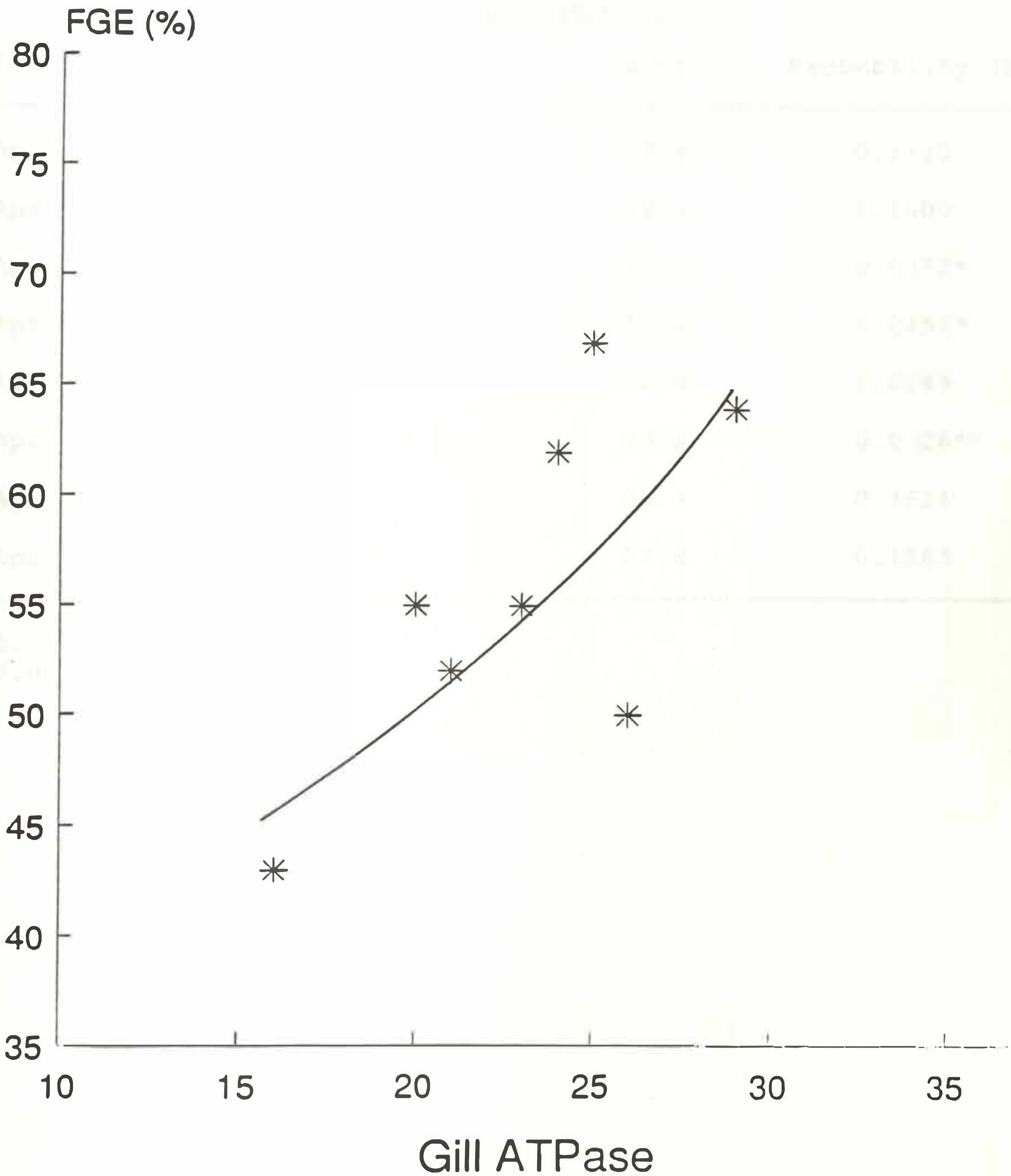

Figure 2.--Weighted mean gill Na^+-K^+ ATPase (μmol $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$) in yearling chinook salmon and corresponding fish guiding efficiency (FGE %) at Lower Granite Dam, 1989. The relationship is described by the function: $FGE = e^{344} + 0.025\ (ATPase)$; ANOVA, F_1, 6 = 6.293, P = 0.046.

Table 2.--Results of two-sample t-tests for guided (gatewell) vs unguided (nets) fish Na^{+}-K^{+} ATPase activity (µmol $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$) at Lower Granite Dam, 1989.

Date	Na^{+}-K^{+} ATPase (mean)		Probability (P)
	Gatewell	Nets	
11 Apr	16.8	15.6	0.1790
14 Apr	21.2	19.4	0.1600
16 Apr	22.0	19.2	0.0352*
18 Apr	24.7	21.5	0.0452*
20 Apr	25.6	23.8	0.2245
23 Apr	22.0	26.6	0.0028**
25 Apr	26.7	25.4	0.4624
30 Apr	30.6	27.8	0.1283

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

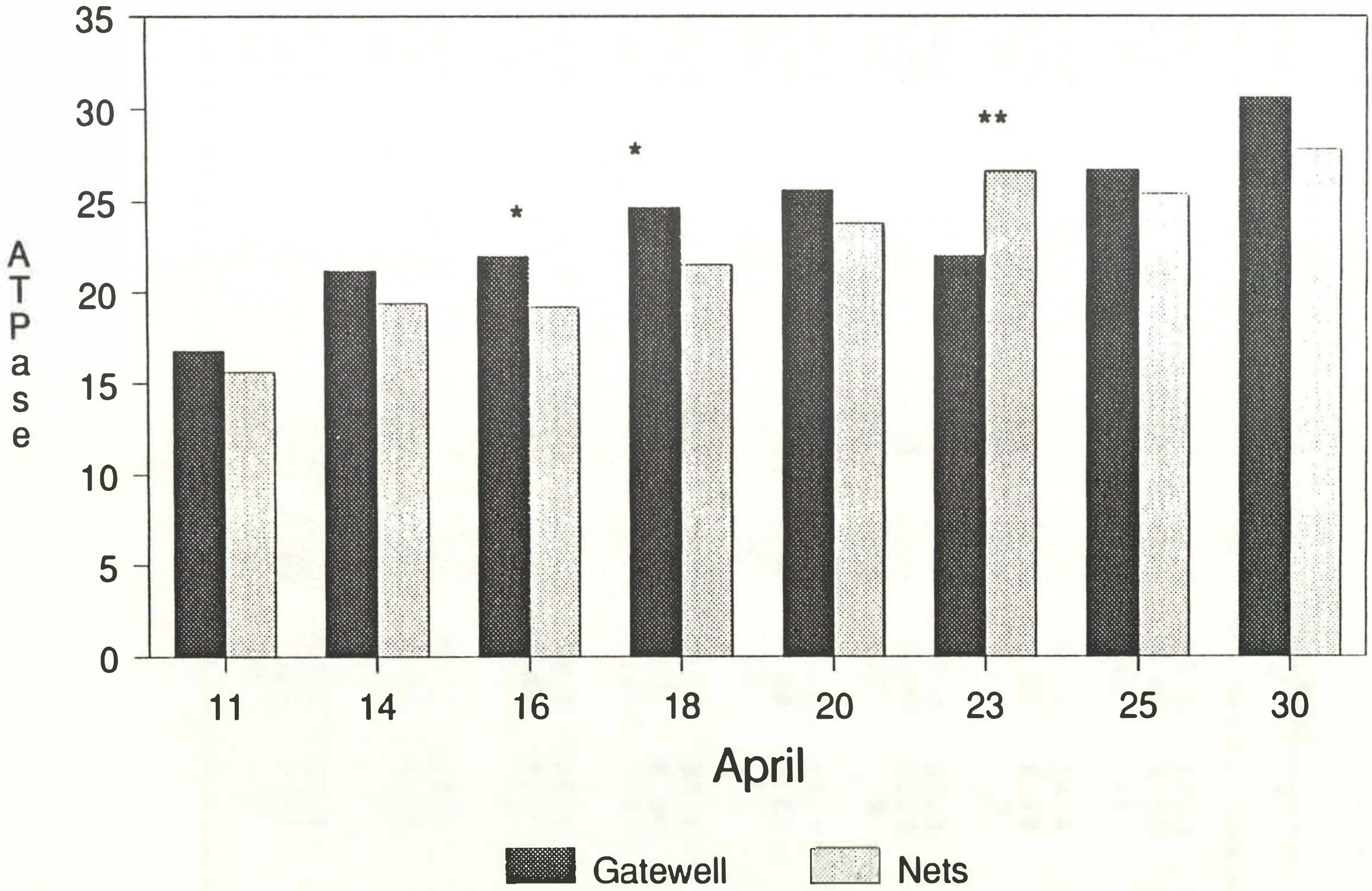

Figure 3.--A comparison of gill Na^+-K^+ ATPase activity (μmol $P_i \cdot$ mg $Prot^{-1} \cdot h^{-1}$) in yearling chinook salmon caught in gatewell (guided) vs those captured in the fyke nets (unguided) at Lower Granite Dam, 1989. Indicated levels of significance are results of t-tests: *, $0.01 < P < 0.05$; **, $0.001 < P < 0.01$.

Table 3.--Gill Na^+-K^+ ATPase ($\mu mol\ P_i \cdot mg\ Prot^{-1} \cdot h^{-1}$) data for yearling chinook salmon from FGE tests at Lower Granite Dam, Unit 4B, 1989.

Date		Gatewell	Closure net	Fyke nets 1	2	3	4	5
11 Apr	x	16.8	16.6	15.3	15.0	15.6	14.8	16.4
	SD	3.51	3.84	3.89	4.44	3.42	4.09	3.84
	n	20	20	10	20	19	16	5
14 Apr	x	21.2	16.6	-	21.0	22.1	14.8	-
	SD	4.81	4.30	-	3.60	6.14	2.58	-
	n	20	20	0	20	17	5	0
16 Apr	x	22.0	21.0	17.8	18.2	20.0	18.3	14.6
	SD	5.59	4.80	4.93	5.26	6.77	3.29	-
	n	20	20	16	20	20	9	1
18 Apr	x	24.7	22.4	20.6	22.2	22.8	17.7	-
	SD	6.37	7.65	3.54	6.42	6.59	6.09	-
	n	20	20	16	20	20	11	0
20 Apr	x	25.6	24.5	26.3	22.7	21.7	23.2	21.0
	SD	6.18	7.03	5.73	5.54	5.33	4.00	-
	n	20	19	20	20	18	6	1
23 Apr	x	22.0	24.9	24.3	29.2	25.4	32.4	33.2
	SD	4.67	4.34	5.81	6.08	7.82	4.17	-
	n	20	18	6	15	9	2	1
25 Apr	x	26.7	26.3	25.6	25.5	24.3	24.5	-
	SD	7.60	5.49	6.96	6.47	8.04	8.08	-
	n	19	19	18	20	19	5	0
30 Apr	x	30.6	28.0	30.8	25.2	28.8	23.9	-
	SD	7.87	5.07	9.27	5.50	7.09	7.21	-
	n	19	20	17	20	11	3	0

Morphometrics

The weighted mean morphometric index (PC II) increased from -0.79 to 0.84 over the sampling period, 14 to 30 April (Table 4). Generally, juvenile salmonids undergoing the parr-smolt transformation are expected to exhibit negative PC II values (Winans and Nishioka 1987). Morphometric indices from guided and unguided fish were compared on four sampling dates, using a two-sample t-test (Table 5). In all cases we failed to reject the null hypothesis, concluding that guided and unguided fish were morphometrically similar. Thus, the utility of this index as a measure of guidance potential is questionable.

Mark Recoveries

A total of 13,533 yearling chinook salmon sampled during the 22 different FGE and vertical distribution tests were examined for brands and passed through a PIT-tag detector. An insufficient number of marks (PIT tags and/or brands) from the Dworshak photoperiod study were recovered during sampling at Lower Granite Dam. A total of only 64 brands, or 0.05% of the 132,246 freeze-branded fish released, and 36 PIT tags or 0.25% of the 14,221 PIT-tagged fish released, were observed.

Table 4.--Morphometric data (PC II) for yearling chinook salmon from FGE tests at Lower Granite Dam, Unit 4B, 1989.

Date		Gatewell	Closure net	Fyke nets 1	2	3	4	5
14 Apr	x	-0.88	-0.74	-	-0.60	-0.79	-0.65	-
	SD	0.64	0.69	-	0.55	0.55	0.78	-
	n	20	20	0	19	17	5	0
23 Apr	x	-0.67	-0.67	-1.19	-0.92	-0.76	-1.22	-0.58
	SD	0.67	0.58	0.40	0.79	0.57	0.53	-
	n	20	18	6	13	9	2	1
27 Apr	x	0.67	0.48	0.12	0.71	-	0.31	-
	SD	0.64	0.59	0.73	0.78	-	0.52	-
	n	20	20	20	20	0	8	0
30 Apr	x	0.80	0.45	0.72	1.33	0.45	0.89	-
	SD	0.65	0.87	0.78	0.72	1.00	0.68	-
	n	20	20	17	20	13	3	0

Table 5.--Results of two-sample t-tests for guided (gatewell) vs unguided (nets) fish morphometric measurements (PC II) and combined weighted mean (guided and unguided) PC II measurements at Lower Granite Dam, 1989.

Date	PC II (mean)		P	Combined PC II
	Gatewell	Nets		(weighted mean)
14 Apr	-0.88	-0.70	0.27	-0.79
23 Apr	-0.67	-0.84	0.34	-0.75
27 Apr	0.67	0.42	0.16	0.61
30 Apr	0.80	0.77	0.88	0.84

DISCUSSION

Data collected at Lower Granite Dam in 1989 provide additional evidence that the physiological status of yearling chinook salmon changes over the tested portion of the outmigration. Weighted mean gill Na^{+}-K^{+} ATPase levels for yearling chinook salmon generally increased over the 3-week sampling period. Concomitantly, FGE also increased over the same period. This is consistent with patterns observed at both Lower Granite and Little Goose Dams during 1987 (Muir et al. 1988).

A possible explanation for this intraseasonal change in yearling chinook salmon guidance behavior could be that fish in the early or transitional stages of the parr/smolt transformation could be more demersally oriented, resulting in lower guidance. Conversely, yearling chinook salmon, farther along in their physiological development, may become more pelagically oriented and more susceptible to interception and guidance by an STS.

Alternatively, fish which are more fully smolted may respond differently to an STS. Smolts are pelagic and surface-oriented, whereas parr tend to be demersal or thigmotropic (Hoar 1976; Schreck 1981). Perhaps, upon sensing a foreign object such as an STS or the trash racks, the more fully smolted, pelagic individuals may respond by swimming upward. In nature such a response would enable them to take advantage of their cryptic countershading when approached or pursued by a predator. The less smolted individuals may be more demersally oriented and darkly pigmented, and may turn toward protective bottom cover in response to a foreign object, thus avoiding interception by the STS.

Studies on gill Na^{+}-K^{+} ATPase activity (Rondorf et al. 1985, 1988, 1989; Zaugg et al. 1985; Swan et al. 1987; Muir et al. 1988) suggest that riverine migration is necessary for enzyme levels to fully develop. The close proximity of several large fish hatcheries to Lower Granite Dam influences the makeup of the population at the dam (Ledgerwood et al. 1987). Rondorf et al. (1989) has shown that mean gill Na^{+}-K^{+} ATPase levels in these local hatchery stocks increase as their outmigration progresses. Early in the outmigration, the yearling chinook salmon population passing Lower Granite Dam is comprised primarily of these local hatchery stocks which have not yet had time to become fully smolted.

The morphometric index (PC II) appeared to be a poor index of guidance potential. Na^{+}-K^{+} ATPase levels, measured in the same samples from which the PC II were calculated, indicated that the migrants were smolting. Yet, the PC II values on two dates suggested otherwise. The reason for this is unclear. It is thought that changes in PC II at the onset of smoltification are a reflection of rapid growth in the caudal peduncle. As smoltification progresses and fish become more streamlined, the anterior portion of the fish "catch up" morphometrically with the elongated tail. Other multivariate morphometric components which summarize overall body slenderness must be developed and used for applications in downstream research such as this. The usefulness of the morphometric index as an indicator of early smolt development is being investigated in hatchery effectiveness studies funded by BPA.

CONCLUSIONS

1. At Lower Granite Dam, gill Na^+-K^+ ATPase activity (a measure of smoltification) in yearling chinook salmon increased steadily over the tested portion of the smolt outmigration.
2. FGE estimates at Lower Granite Dam displayed a significant relationship with the prevailing physiological status of the population as indexed by gill Na^+-K^+ ATPase, suggesting that yearling chinook salmon in advanced stages of smolt development are more susceptible to guidance by STS.
3. Morphometric indices (PC II) observed at Lower Granite Dam during 1989 FGE studies were inconclusive. The index is not recommended for use in studies of this type until the utility of the index can be further demonstrated.

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