INTERCEPTION OF YEARLING CHINOOK SALMON IN TURBINE INTAKES OF HYDROELECTRIC DAMS BY SUBMERSIBLE TRAVELING SCREENS: EVIDENCE FOR SMOLTIFICATION EFFECTS

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June 1986

ABSTRACT

A number of hydroelectric dams in the Columbia-Snake River System are equipped with submersible traveling screens which project into the turbine intakes. The screens are designed to divert juvenile migrant Pacific salmon (*Oncorhynchus* spp.) and steelhead (*Salmo gairdneri*) from the intake upward into gatewells and the adjoining central bypass system. At Lower Granite Dam, the fish guidance efficiency (FGE) of the screens for yearling chinook salmon (*O. tshawytscha*) has been variable, typically increasing over the course of the outmigration. The observed change in FGE has not been attributable to hydraulic or structural changes associated with the dam. Assays of gill Na^{+}-K^{+} ATPase from yearling chinook salmon collected during a routine FGE test revealed that Na^{+}-K^{+} ATPase levels were significantly higher in fish which were guided into the gatewell than those not guided. A model is proposed to explain the observation and guide future research efforts.

Turbine-related mortality of juvenile Pacific salmon (Oncorhynchus spp.) and steelhead (Salmo gairdneri) at hydroelectric dams in the Snake-Columbia River System has an adverse impact on these valuable stocks of salmonids. It has been estimated that up to 33% of the migrants passing through a powerhouse die from direct and indirect effects (Long et al. 1968). One effort to alleviate some of this dam-related mortality is the installation of fingerling bypass systems within the structure of dams. Since the late 1970s, the National Marine Fisheries Service (NMFS) has been conducting research to evaluate the effectiveness of submersible traveling screens (STS) in diverting emigrating juvenile salmonids, including yearling chinook salmon (Oncorhynchus tshawytscha), from the turbine intakes of hydroelectric dams and guiding them upward into gatewells and associated fingerling bypass systems (Swan et al. 1985).

Lower Granite Dam, near Lewiston, Idaho, is one of two facilities on the Snake River with such a bypass system (Matthews et al. 1977). Over the years, a variety of structural modifications and modes of dam operations have been tested at this site with the intention of improving fish guiding efficiency (FGE). However, estimates of FGE were variable between and within years, and not consistently related to structural configurations tested. In 1984, and again in 1985, FGE was lowest (approximately 30 to 35%) when fish first 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). It is commonly held that mechanical and structural features of the dam are the primary factors affecting fish guidance, and research to date has focussed on these aspects.

The implied assumption of such a position is that all fish migrating past the dam are equally susceptible to interception and guidance by an STS. However, the temporal patterns witnessed at Lower Granite Dam in 1984 and again in 1985 suggest this may not be the case, but rather the susceptibility and guidability of the population changes through time. One variable being examined is the degree of smoltification of the population through time.

The transformation from parr to fully smolted fish is not an instantaneous process; physiological and behavioral changes associated with the process occur over weeks or months. Certainly behavioral mechanisms that change during smoltification, such as thigmotropic and rheotropic responses and swimming proficiency and buoyancy, can potentially effect the position and performance of fish in the water column and hence the susceptibility of yearling chinook salmon to interception and guidance by the STS. Thus susceptibility may be a function of the degree of smoltification exhibited by members of the population.

The purpose of this investigation was to determine whether there was any evidence to indicate an association between a recognized index of smoltification, such as gill Na^{+}-K^{+} ATPase enzyme activity (Zaugg and McLain 1972; Zaugg 1982), and the susceptibility of yearling chinook salmon to interception and guidance by submersible traveling screens.

MATERIALS AND METHODS

Fish used in these analyses were collected on the evening of 16 May 1985 during routine FGE testing at Lower Granite Dam. The testing procedure involved deploying a framework of fyke nets behind an STS in a deactivated turbine intake (Fig. 1). Once the nets were in place, the turbine was activated from 2100 to 2300 hours while fish accumulated in the assorted nets and gatewell. The closure net and fyke nets captured fish that traveled under the STS as they passed through the intake. The gap net collected fish that were intercepted by the STS but reentered the turbine intake via an opening situated between the STS and the dam structure. The net frame was removed from the water immediately following the 2-hour collection period, and samples of yearling chinook salmon to be assayed for gill Na^{+}-K^{+} ATPase activity were removed from the assorted nets. Fish collected in the gatewell were sampled using a dip net (Swan et al. 1979). Sampled fish were placed on ice and dispatched to the NMFS Laboratory at Cook, Washington, where gill filaments were removed and stored frozen until processing. Assays for gill Na^{+}-K^{+} ATPase activity followed procedures described by Zaugg (1982) with minor modifications. Fork lengths of fish were recorded for all samples assayed.

In the treatment of these data, fish that entered the gatewell as well as those collected in the gap net were considered to be intercepted and guided by the STS. Samples from the closure net and fyke nets were classified as unguided.

RESULTS

A total of 61 yearling chinook salmon were assayed for gill Na^{+}-K^{+} ATPase. The number of fish processed from each sample location are detailed in Table 1. Observed gill Na^{+}-K^{+} ATPase activity ranged from 16.4 to 66.3 μ moles $P_i \cdot$ mg $prot^{-1} \cdot hr^{-1}$, but mean values for the different net and gatewell samples ranged from 33.0 to 43.4 units. When the mean values of enzyme activity from each sample location were compared, the highest activity was observed in the gatewell catch. The lowest mean enzyme activity was observed in row 4 of the fyke net. Inspection of the data suggests that a vertical gradient of gill Na^{+}-K^{+} ATPase activity exists (Fig. 1). Except for the closure net, mean values of gill Na^{+}-K^{+} ATPase activity generally decreased with increasing depth. Overall, fish with the highest Na^{+}-K^{+} ATPase activity were captured higher in the water column.

Partitioning the samples into those obtained from gatewell versus fyke and closure nets combined, we tested the hypothesis that guided fish possessed higher gill Na^{+}-K^{+} ATPase levels than unguided fish using a one-tailed t-test modified for unequal variances (Brownlee 1965). We rejected the null hypothesis ($0.025 < P < 0.05$), concluding that guided fish have significantly higher gill Na^{+}-K^{+} ATPase levels.

Yearling chinook salmon ranged in size from 90 to 163 mm in fork length. Fish length was significantly correlated with Na^{+}-K^{+} ATPase activity ($r = 0.384$, 59 df, $P < 0.01$; Fig. 2). There was no evidence, however, that the size composition of guided and unguided fish was different. Using a two-sample t-test, we failed to detect any difference in the mean length between guided and unguided fish ($0.25 < P < 0.50$). Employing a two-sample Kolmogorov-Smirnov test (Hollander and Wolfe 1973), we also failed to detect any difference in the overall size distribution of guided and unguided fish ($P > 0.10$).

DISCUSSION

This study suggests that more intensely smolted yearling chinook salmon are more susceptible to guidance by STS. Guided fish displayed significantly higher levels of gill Na^{+}-K^{+} ATPase than unguided individuals. Furthermore, the data indicate a propensity for the least smolted individuals to reside deeper in the water column as they pass through the turbine intake, thus avoiding interception by the STS. Within the fyke net rows, mean values of the enzyme activity steadily decreased with increasing depth (Table 1, Fig. 1).

Independent from structural features of the dam, behavioral changes associated with the parr/smolt transformation may affect a fingerling's susceptibility to guidance by an STS. Changes in buoyancy during the transformation from parr to smolt have been observed in Atlantic salmon (Salmo salar). Smolts were more positively buoyant than parr, and buoyancy was regulated by adjusting swim bladder volume (Saunders 1965; Neave et al. 1966; Pinder and Eales 1969). This change in buoyancy is concomitant with the transition from a bottom dwelling to a pelagic mode of life and, it is hypothesized, may expedite downstream migration by providing a mechanism which assists smolts to reside in swifter surface waters (Saunders 1965). Reasonably, such buoyancy changes could effect vertical distribution in the water column. There is also evidence that the swimming performance of coho salmon (O. kisutch) changes during smoltification. Smolts displayed depressed swimming proficiency and stamina relative to parr (Flagg and Smith 1982; Glova and McInerney 1977). Furthermore, the degree of both buoyancy and swimming performance changed throughout the parr/smolt transformation, suggesting that the further along an individual is in the transformation process, the poorer the realized swimming performance and the greater the buoyancy it would exhibit. If such changes in behavioral and locomotory mechanisms are similarly manifested in yearling chinook salmon, then the most positively buoyant and/or poorest swimmers may be the most susceptible to guidance by virtue of their vertical position in the water column or decreased ability to avoid an STS. Assuming that these or other associated mechanisms affect susceptibility, an overall increase in smoltification within the population through time could explain the increase in FGE observed over the course of the outmigration.

The population of yearling chinook salmon arriving at Lower Granite Dam is heterogeneous in several respects. First, it is comprised of several stocks, both wild and hatchery. For example, in 1983 five hatcheries made 11 releases at as many sites in the upper Snake and Salmon River drainages (Scully et al. 1984). Second, hatchery fish may not be synchronized with wild fish with respect to the parr/smolt transformation. Zaugg and McLain (1972) observed that certain hatchery stocks of spring chinook salmon smolted 2 to 3 weeks earlier than wild fish. Third, asynchrony of smolt status in the population could also result from hatchery releases being made on different dates according to no apparent standard criteria. Finally, the size composition of the entire river-run population is disparate ranging from 80 to over 190 mm in length (Scully et al. 1984). Both size and growth rate of chinook salmon can modify the timing of the seasonal elevation in gill Na^{+}-K^{+} ATPase activity (Ewing et al. 1980). Separately or in concert, these factors can affect the rate and intensity of smoltification.

We theorize that the heterogeneous population arriving at Lower Granite Dam in early April is not synchronized with respect to smoltification. Certain segments of the population may be fully smolted, whereas others are at earlier stages within the parr/smolt transformation. Early in the migration the overall status of smoltification for the population is relatively low. Through time, as more individuals pass through the transitional stages, the population becomes more homogeneous, and fully smolted individuals predominate. If fully smolted fish are more susceptible to interception and guidance by an STS than earlier developmental stages, then our proposed model (Fig. 3) can explain the intramigrational increases in FGE observed at Lower Granite Dam.

Typically, by mid-May (the time of our sampling) in excess of 75% of the population has passed Lower Granite Dam (Sims et al. 1983, 1984). According to our hypothetical scenario, we would expect that most fish would be fully smolted by that point in the outmigration. In fact, the observed gill Na^{+}-K^{+} ATPase levels corroborate that position, with sample means ranging from 33.0 to 43.4 Na^{+}-K^{+} ATPase units. Such values correspond to maximal levels observed for chinook salmon during their seaward migration (Rondorf et al. 1985).

Even though at the time of our sampling the population was comprised primarily of fully smolted individuals, there was a definite tendency for the less smolted individuals to travel under the STS. In fact, during the FGE test on 16 May, 23% of the yearling chinook salmon entering the turbine intake sounded under the STS and were captured in the fyke net array (Swan et al. 1986). Research is scheduled in 1986 to define the relation between FGE and the status of smoltification within the population over the course of the entire outmigration.

ACKNOWLEDGMENTS

The majority of the funding for this research was provided by the U.S. Army Corps of Engineers.

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Table 1. Gill Na^+-K^+ ATPase (μ moles $P_i \cdot$ mg $prot^{-1} \cdot hr^{-1}$) data acquired from sampling conducted at Lower Granite Dam on 16 May 1985. The sample size (n) indicates the number of fish assayed from each location.

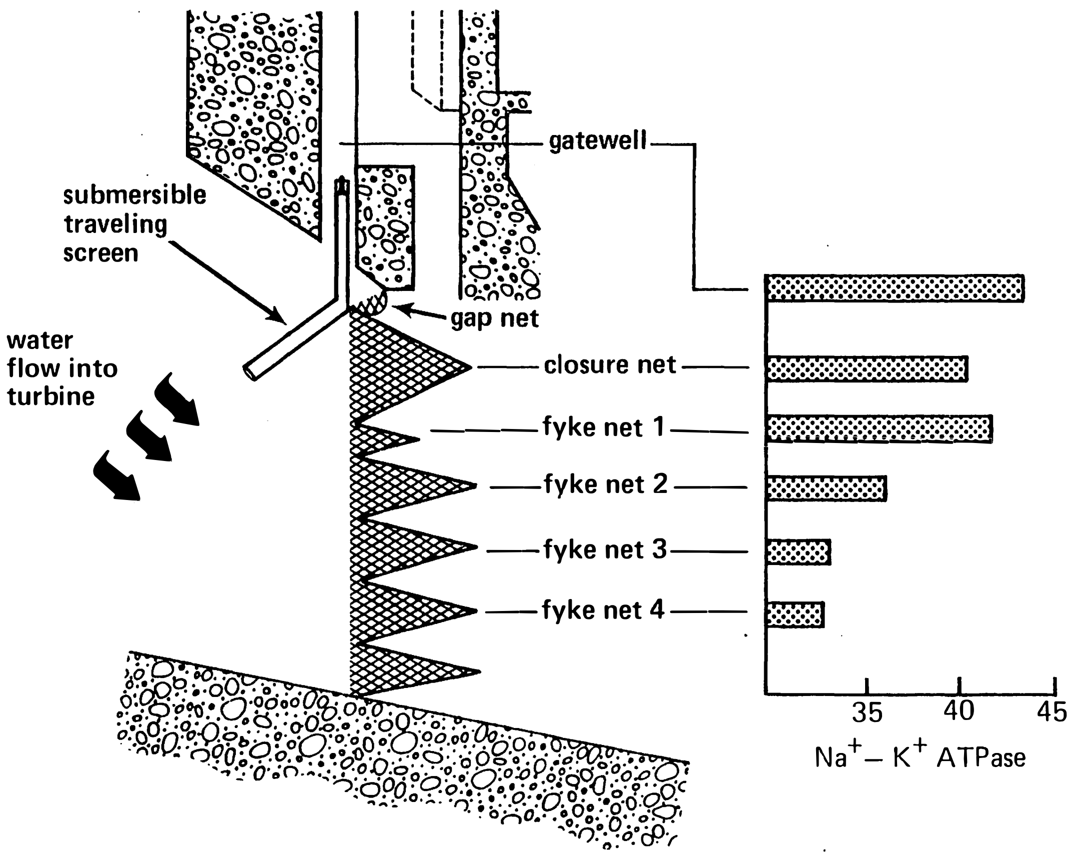
	Gatewell	Closure net	Fyke net			
			1	2	3	4
n	14	12	11	11	11	2
$\bar{X}$ ATPase	43.4	41.3	42.3	36.4	33.6	33.0
St.error of $\bar{X}$	2.2	3.8	4.3	2.7	2.9	8.0

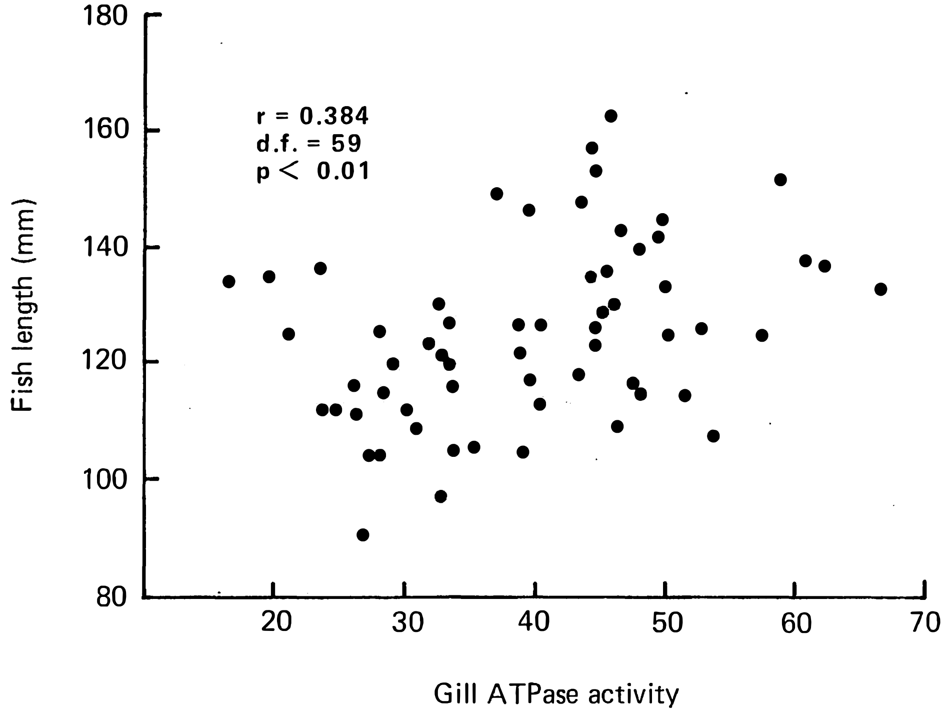
FIGURE CAPTIONS

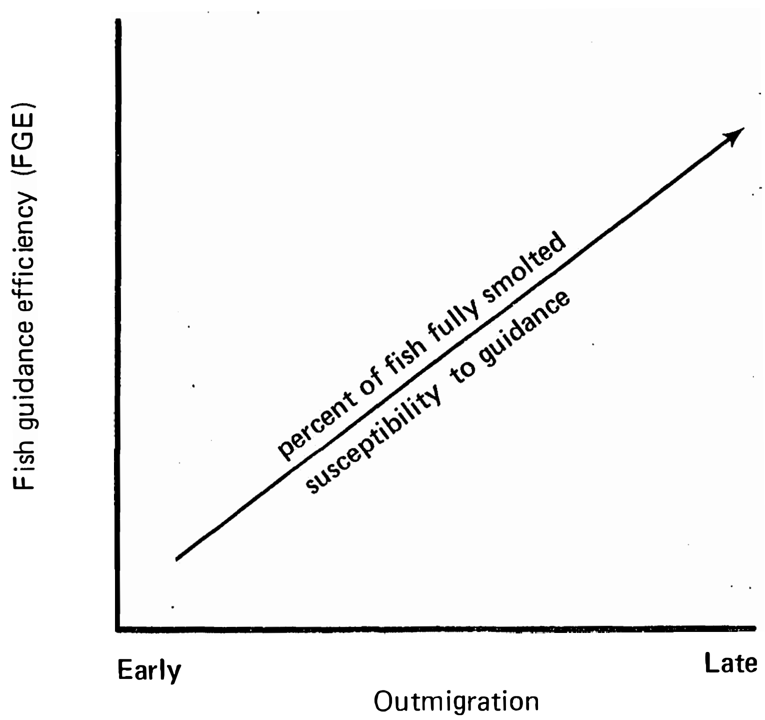
Figure 1. Cross section of turbine intake at Lower Granite Dam. Net frame used for sampling is situated behind the submersible traveling screen and projects downward to the floor of the intake. Histogram presents the mean value of gill Na^{+}-K^{+} ATPase.

Figure 2. Correlation between fork length and gill Na^{+}-K^{+} ATPase activity (μ moles Pi • mg $prot^{-1}$ • hr^{-1}) in yearling chinook salmon.

Figure 3. Proposed model to explain the observed increases in fish guiding efficiency observed over the course of the yearling chinook salmon outmigration at Lower Granite Dam.


gatewell
submersible traveling screen
gap net
water flow into turbine
closure net
fyke net 1
fyke net 2
fyke net 3
fyke net 4
35
40
45
Na+– K+ ATPase


r = 0.384
d.f. = 59
p < 0.01
Fish length (mm)
180
160
140
120
100
80
20
30
40
50
60
70
Gill ATPase activity



Fish guidance efficiency (FGE)
percent of fish fully smolted
susceptibility to guidance
Early
Late
Outmigration