

Relationships Between Smolt Indices and Migration  
in Controlled and Natural Environments

by

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#### INTRODUCTION

Following reports by Utida et al. (1966) and Epstein et al. (1967) many studies have been conducted to determine the role of gill  $\text{Na}^+-\text{K}^+$  stimulated adenosine triphosphatase ( $\text{Na}^+-\text{K}^+$  ATPase) in the saltwater adaptation of a variety of fishes. Generally, a significant increase in the activity of this enzyme is observed when animals are transferred from fresh to salt water, reflecting the need for physiological adjustments to cope with the passive influx and ingestion of greater quantities of salts. Apart from the observed increases associated with saltwater adaptation, elevated levels of gill  $\text{Na}^+-\text{K}^+$  ATPase activities have been shown to occur seasonally in several species of salmonids residing in fresh water (Zaugg and McLain 1970, 1972; Zaugg and Wagner 1973; McCartney 1976; Ewing et al. 1979). These rising levels of enzyme activity occur during parr-smolt transformation and are generally associated with other indicators of this event, such as increased body silvering, thyroid activity, migrating tendency, etc. (see reviews by Wedemeyer et al. 1980; Folmar and Dickoff 1980).

For smolt indicators to be effective tools for fishery management, relationships must be established between the status of smoltification at the time of release, as measured by these indicators, and survival to adults. An understanding of these relationships would then permit sounder decisions regarding hatchery rearing conditions and practices and release timing. This report discusses observed relationships between changes in gill  $\text{Na}^+-\text{K}^+$  ATPase activity and downstream migratory behavior in steelhead and coho and chinook salmon.

## RESULTS AND DISCUSSION

### Steelhead Trout (Salmo gairdneri)

Wagner (1974) showed that phase adjustment of photoperiod had a profound influence on the timing of parr-smolt transformation. Increases in gill  $\text{Na}^+-\text{K}^+$  ATPase activities occurred earlier than normal in winter steelhead that received an advanced photoperiod schedule; whereas activities were delayed under a delayed photoperiod regime (Fig. 1; Zaugg and Wagner 1973). Migration of these groups of steelhead within the first 15 days after release into a natural stream coincided generally with the  $\text{Na}^+-\text{K}^+$  ATPase profile (Fig. 2); greater numbers of fish moved downstream while enzyme activities were elevated.

The same relationship between elevating levels of gill  $\text{Na}^+-\text{K}^+$  ATPase activities and migratory movement has been observed in summer run steelhead held in a closed system (Zaugg 1981). Two dams were placed in a 10-x 80-ft (3-x 25-m) hatchery raceway. The first dam was located 25 ft (7.7 m) from the upper end and the second, lower dam at the midpoint. An 8-ft section of the pond just above the first dam was covered. About 400 juvenile summer steelhead were placed in the upper pond in January. A retaining screen was placed on the dam until February when it was removed, allowing the fish to move at will over the dams to the end of the raceway where they could be retrieved by net. Mass movement over the dams did not begin until the first of May which corresponded to observed increases in gill  $\text{Na}^+-\text{K}^+$  ATPase activity of the migrants (Fig. 3). Migrants were removed and divided equally between two Fiberglass<sup>1/</sup> tanks. When a sufficient number of fish had been collected, water temperature in one of the tanks was raised to 55°F (13°C) while water in the other tank remained at 43°F (6°C).

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

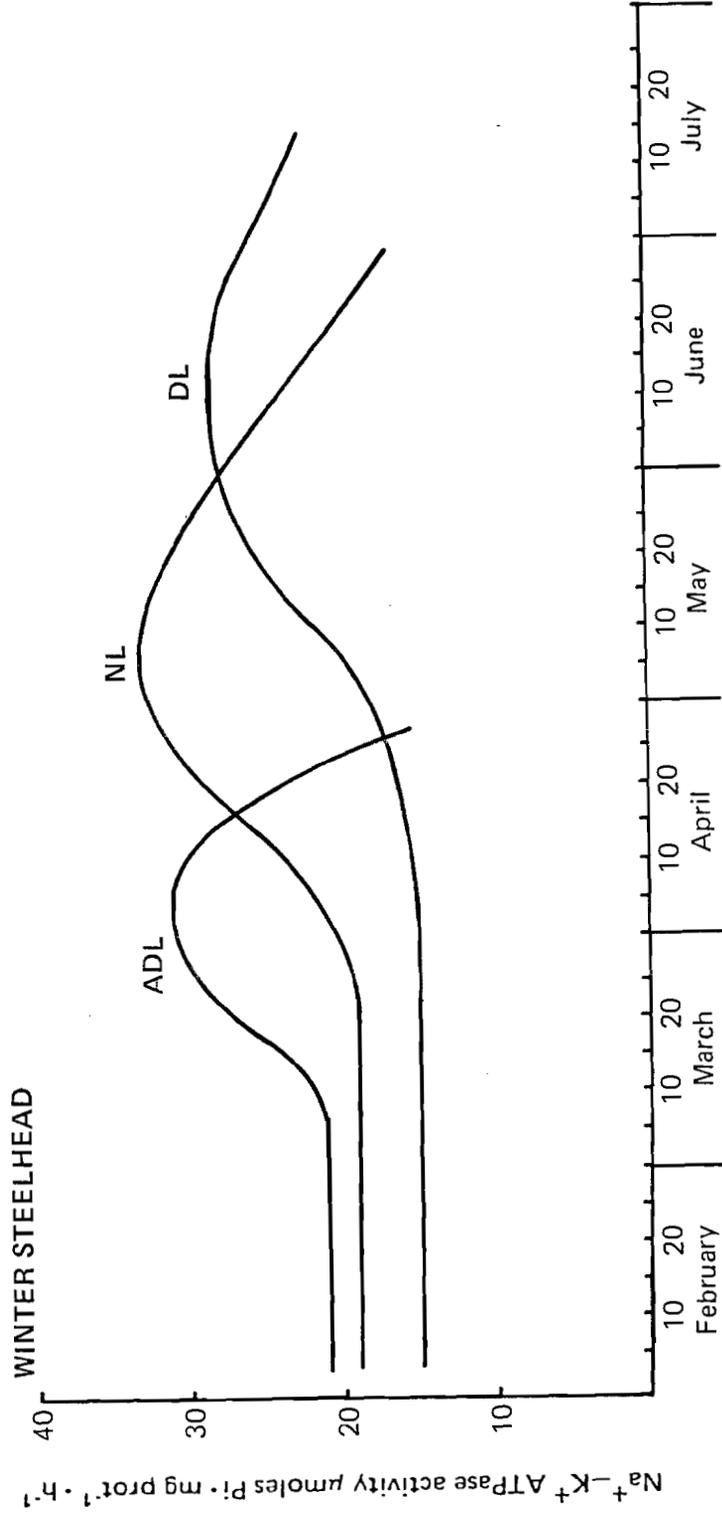


Figure 1. Influence of photoperiod on gill Na<sup>+</sup>-K<sup>+</sup> ATPase of winter run steelhead trout.

Photoperiod schedules: NL = normal, ADL = advanced (3 months),

DL = delayed. See Wagner (1974).

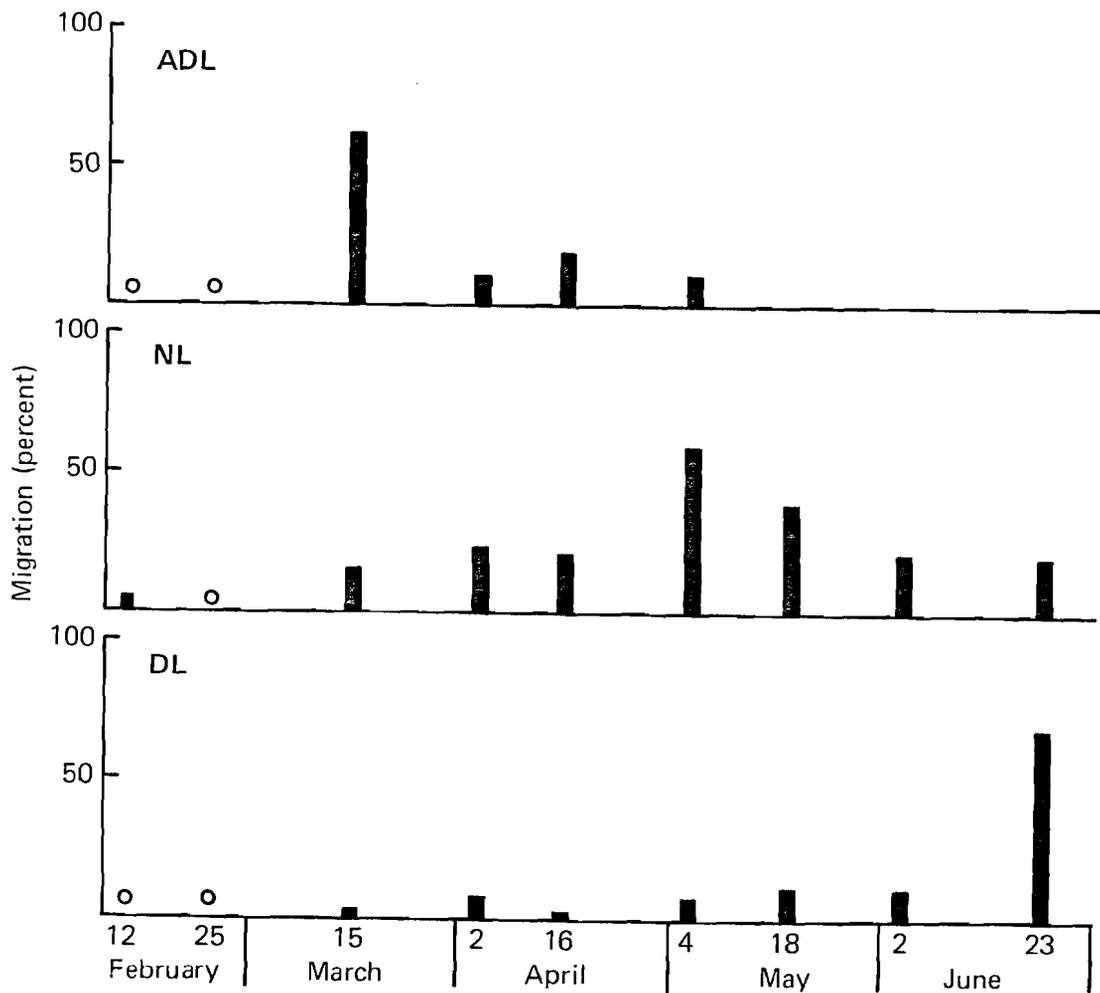


Figure 2. Influence of photoperiod on migration of winter run steelhead.

Photoperiod schedules: NL = normal, ADL = advanced (3 months), DL = delayed. Bars represent percent of fish migrating within 15 days of release (25 - 40 fish per release). See Wagner (1974).

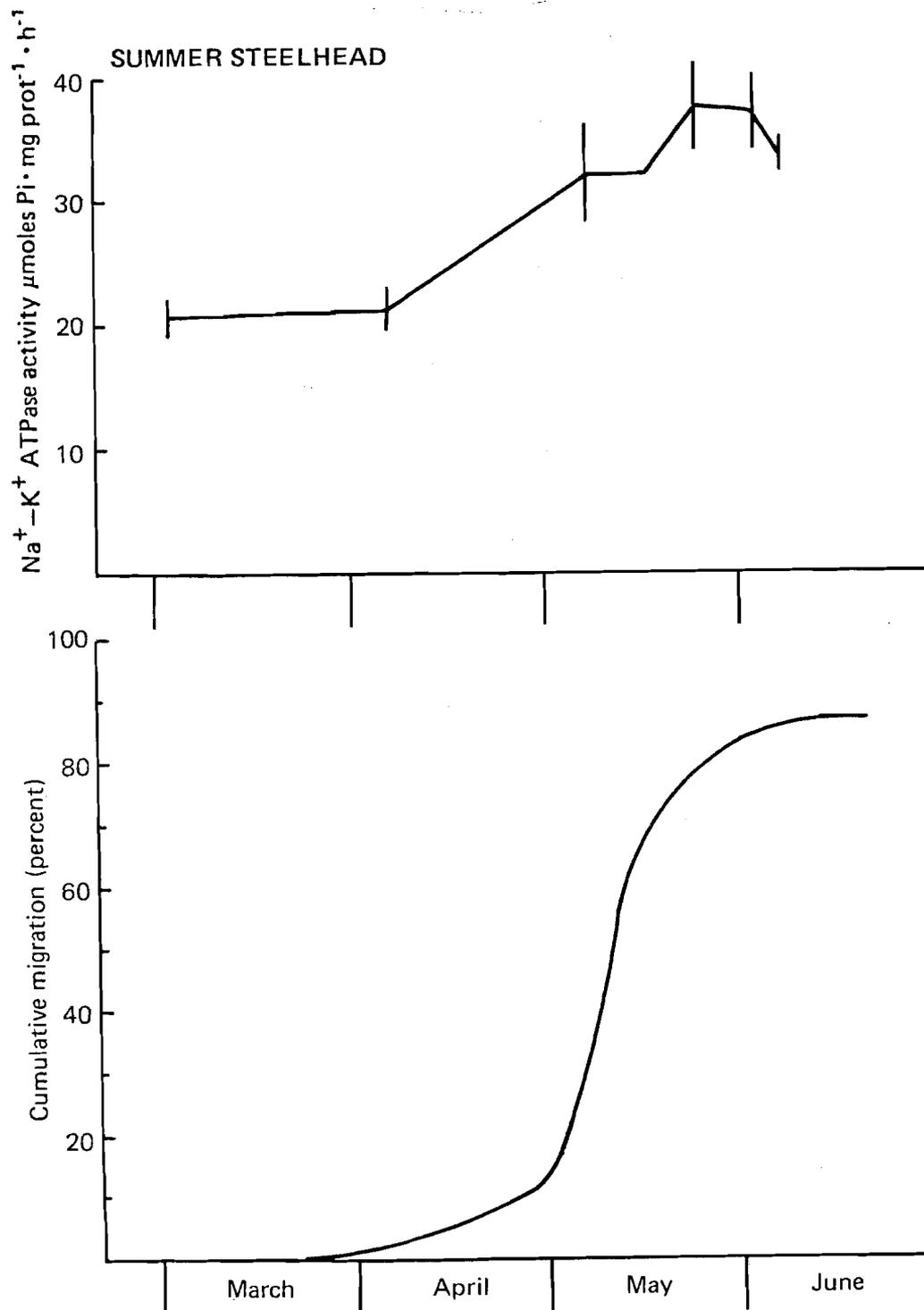


Figure 3. Relationship between gill  $\text{Na}^+ - \text{K}^+$  ATPase (top) and migration (bottom) of summer run steelhead in a modified raceway.

A hatchery raceway was modified for testing migratory behavior (see text). Gill  $\text{Na}^+ - \text{K}^+$  ATPase activities were determined on migrants.

After 20 days, fish from both tanks were combined (identified by fin clips) and placed in a modified raceway. Exposure to 55°F water resulted in delayed movement, in fewer fish migrating, and in lower gill  $\text{Na}^+-\text{K}^+$  ATPase activities (Fig. 4). Other experiments have shown that temperatures of 54°F (12°C) and higher inhibit the development of elevated gill  $\text{Na}^+-\text{K}^+$  ATPase activities usually observed with the onset of smolting and result in low saltwater tolerance (Adams et al. 1975).

How detrimental the influence of river temperatures above 54°F (12°C) might be on actively migrating steelhead smolts is unknown, but the studies reported here suggest adverse effects are likely. For example, the Columbia River normally reaches 54°F by mid-May, but in years of low water flow (e.g. 1977) this may occur much earlier (Fig. 5). In 1977, many steelhead smolts failed to migrate out of Snake and Columbia River reservoirs (Sims et al. 1978). Seaward movement of steelhead through the lower Columbia River usually peaks from mid- to late May (Fig. 5) just as river temperatures reach levels which could cause reversion of fish to a nonmigratory state. When river temperatures elevate earlier than usual, successful migration to the ocean, especially from the upper river, may be difficult to accomplish.

#### Coho Salmon (Oncorhynchus kisutch)

Coho salmon, like steelhead, experience a period of elevated gill  $\text{Na}^+-\text{K}^+$  ATPase activity in the spring. The development of elevated levels of activity in coho salmon, however, is not as sensitive to warm water (Zaugg and McLain 1976).

In a study designed to determine the effect of release time (size held constant) on coho salmon survival, personnel from Washington State Fisheries made three releases (May, June, and July) from the Toutle Hatchery in 1979. Gill  $\text{Na}^+-\text{K}^+$  ATPase activities were measured on all three groups from mid-April to

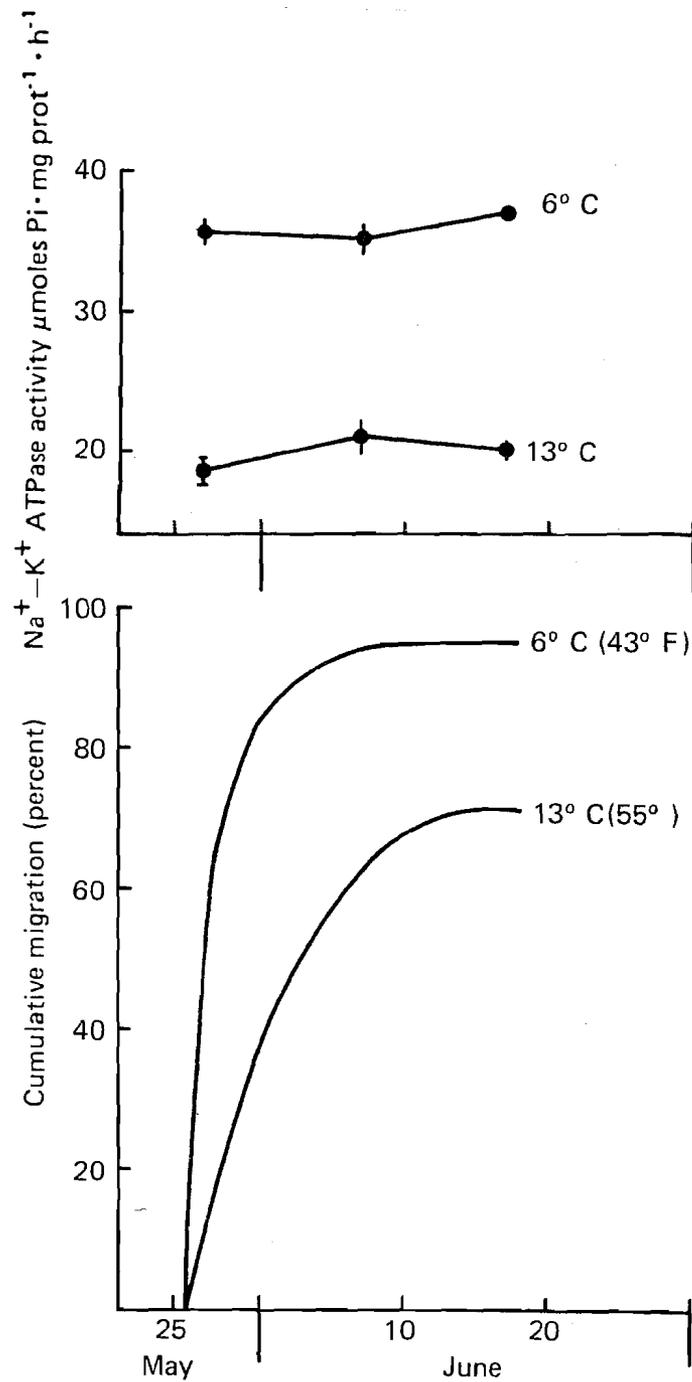


Figure 4. Effect of exposure to 55°F (13°C) water on gill  $\text{Na}^+-\text{K}^+$  ATPase activity (top) and migration behavior (bottom) of summer run steelhead trout.

Following exposure to 55°F (13°C) for 20 days steelhead were tested for migratory behavior and gill  $\text{Na}^+-\text{K}^+$  ATPase activity (see text).

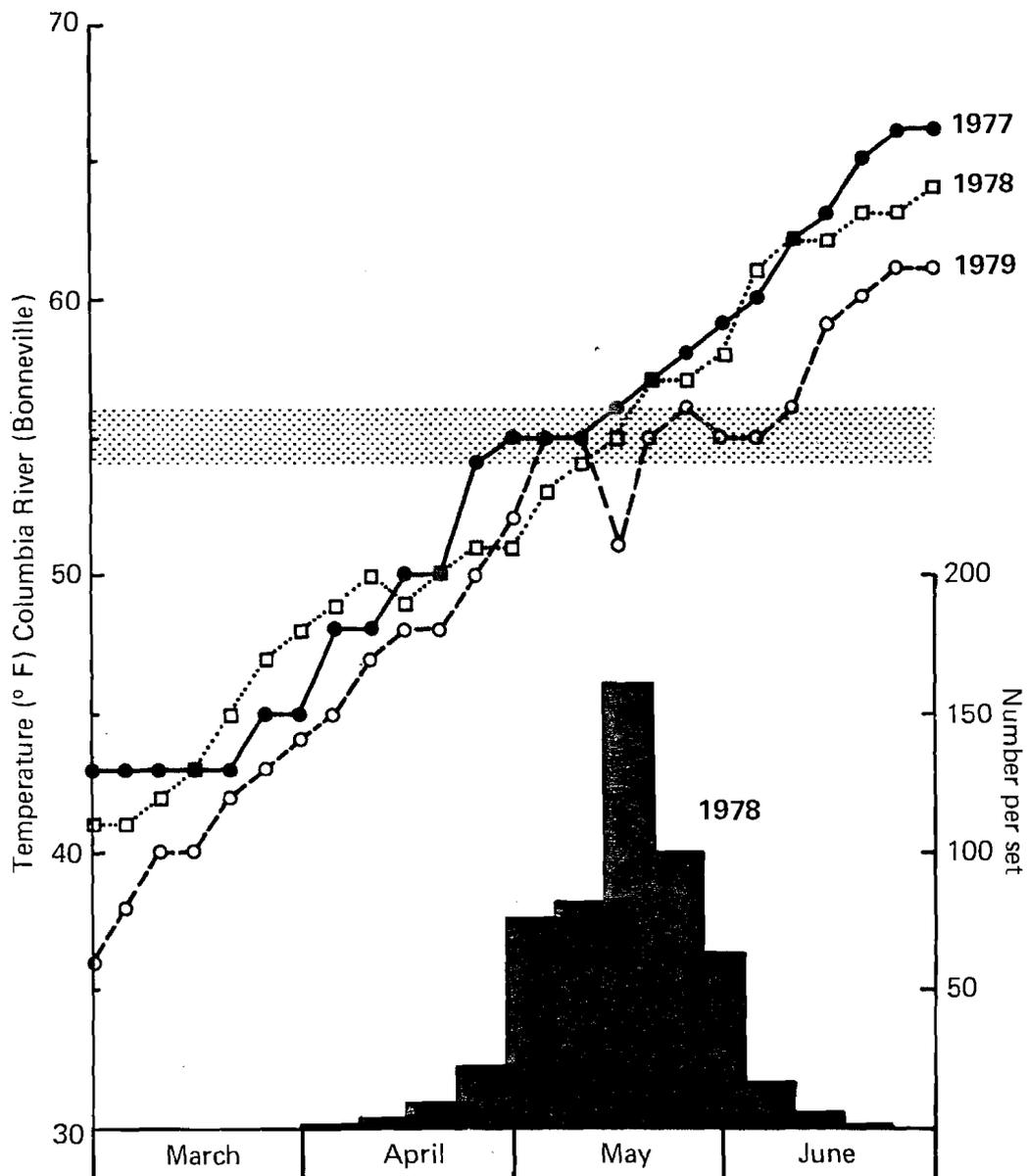


Figure 5. Temperatures of the Columbia River at Bonneville Dam in 1977, 1978, and 1979 and migration pattern of steelhead at Jones Beach (Oregon).

Data on steelhead given as number of migrants captured at Jones Beach per set of purse seine (Dawley et al. 1979).

release. Peak activity occurred at about the time of the first release on 7 May (Fig. 6). When the second group was released on 7 June, gill  $\text{Na}^+-\text{K}^+$  ATPase activities had declined significantly. By 7 July, when the third group was liberated, activities were at pre-smolt levels. Smolt recovery information gathered by the National Marine Fisheries Service station at Jones Beach (Oregon), about 47 miles (75 km) from the mouth of the Columbia River, showed that releases made when gill  $\text{Na}^+-\text{K}^+$  ATPase activities were low (June and July) were characterized by rapid seaward migrations (Fig. 6). In fact, fish in the later releases moved downstream more rapidly than those released in May at peak  $\text{Na}^+-\text{K}^+$  ATPase activity. Median rates of movement were 8 km/day for the May release and 15 and 12 km/day, respectively, for the June and July releases (Dawley et al. 1980). Determination of gill  $\text{Na}^+-\text{K}^+$  ATPase levels in individual migrants revealed that the migrating fish were rapidly regenerating elevated levels of activity in conjunction with downstream movement (Fig. 6). Migrants examined from the May release had much higher levels of enzyme activity than fish retained at the hatchery for later releases. Migrants captured on 16 July from 7 July release had higher enzyme activities than migrants captured on 12 July (Fig. 6), which suggests development of elevated levels with time from release.

These same observations were made with coho salmon from two other hatcheries conducting the same study. The results suggest that retention in the hatchery of coho salmon beyond the time when smolt development has occurred causes loss of at least some characteristics associated with smoltification (silvery coloration and elevated gill  $\text{Na}^+-\text{K}^+$  ATPase), but that these characteristics can be rapidly regained upon liberation into a stream, at least up to July. It is quite possible that releases at some point later in the summer or fall would not result in a resmoltification, but rather a failure to migrate until the following spring.

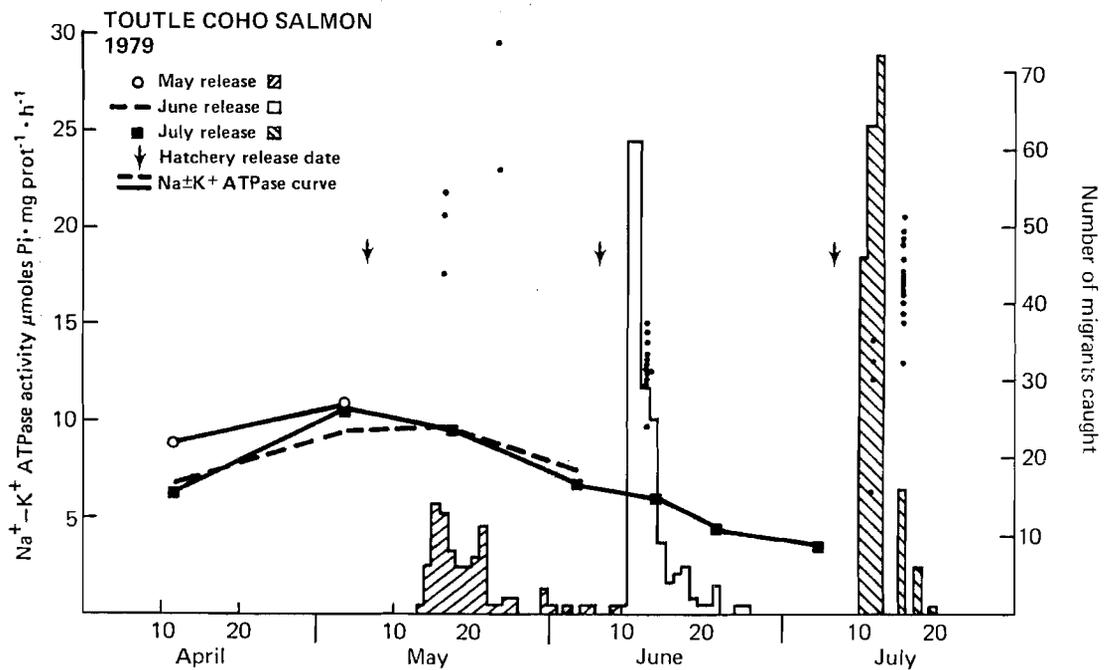


Figure 6. Gill  $\text{Na}^+-\text{K}^+$  ATPase activities in yearling coho salmon from the Toutle Hatchery and numbers of migrants captured at Jones Beach (Oregon).

Arrows indicate releases on 7 May, 7 June, and 7 July 1979.

Single points (.) show gill  $\text{Na}^+-\text{K}^+$  ATPase activities for individual migrants captured at Jones Beach.

### Chinook Salmon (Oncorhynchus tshawytscha)

Changes in gill  $\text{Na}^+-\text{K}^+$  ATPase activity in chinook salmon are much more complex than in steelhead or coho salmon. Size and growth rate are at least two factors that influence when elevations in activity occur (Ewing et al. 1980a) and there are probably other undetermined factors.

Gill  $\text{Na}^+-\text{K}^+$  ATPase activities have been determined in fall chinook salmon at the Spring Creek National Fish Hatchery (NFH) for three successive years (Fig. 7). Activity profiles in 1978 and 1979 were similar with respect to peak timing. However, a much different profile occurred in 1980 (Fig. 7). The reasons for such a difference remain unknown.

Seaward migration of subyearling chinook salmon is also more complex than that of steelhead and yearling coho salmon. Downstream movements have been observed in the absence of elevated levels of gill  $\text{Na}^+-\text{K}^+$  ATPase activities (Ewing et al. 1980b). However, these movements are probably induced by changing environmental conditions and are not associated with transformation from parr to smolt. Numbers of migrants captured at Jones Beach (Oregon) from releases at Spring Creek NFH in 1979 are recorded in Figure 8. Migration from the 20 March release (prior to a major peak in gill  $\text{Na}^+-\text{K}^+$  ATPase activity) was characterized by an extended period of downstream movement, with two periods when greater numbers of migrants were captured--immediately after release in late March and again in early May. Fish released on 20 April migrated much more rapidly than those from the March release, and very rapid migrations characterized fish released on 18 May and 13 August. Of the total number of migrants captured at Jones Beach from the March releases in 1979 and 1980, a greater percentage was caught in the initial movement in 1980 (~60%) than in 1979 (~40%) and, consequently, a lower percentage in the second surge of late April-early May 1980 (Fig. 9). It

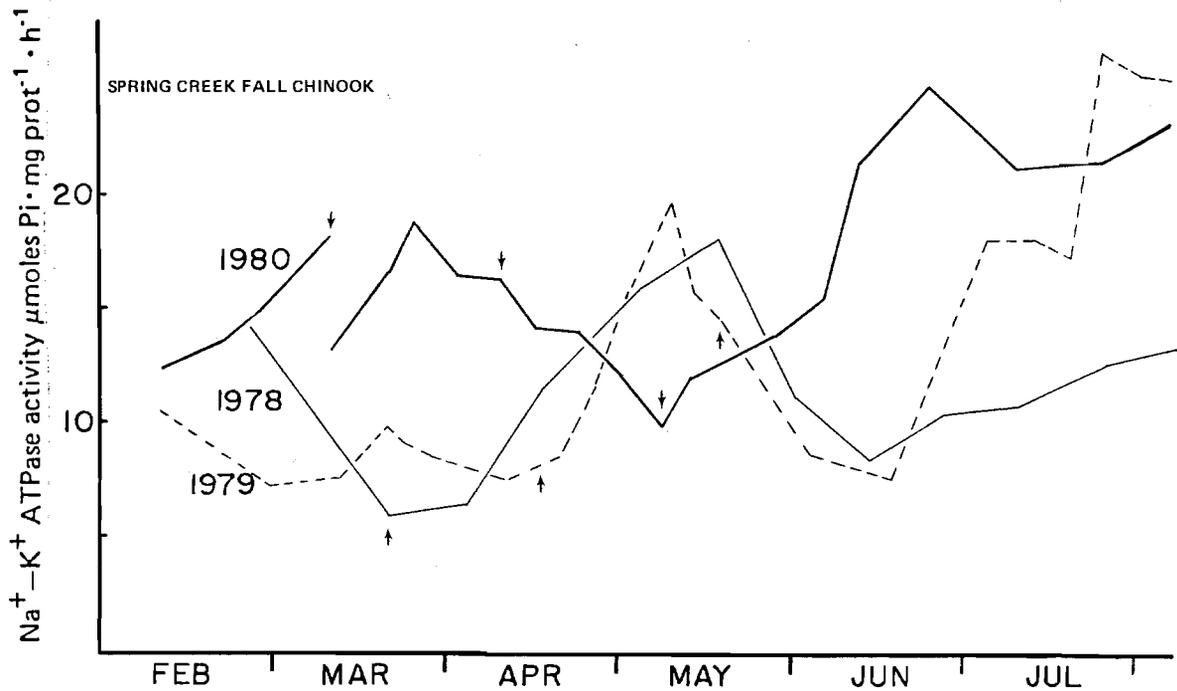


Figure 7. Gill  $\text{Na}^+ - \text{K}^+$  ATPase activities in fall chinook salmon from Spring Creek National Fish Hatchery.

Arrows indicate releases on 10 March, 10 April, and 9 May 1980; 20 March, 20 April, and 18 May 1979; and 21 March, 18 April, and 19 May 1978. In 1980, all fish released on 10 March had been fed a diet containing added 7% NaCl which resulted in salt-induced increases in gill  $\text{Na}^+ - \text{K}^+$  ATPase activity.

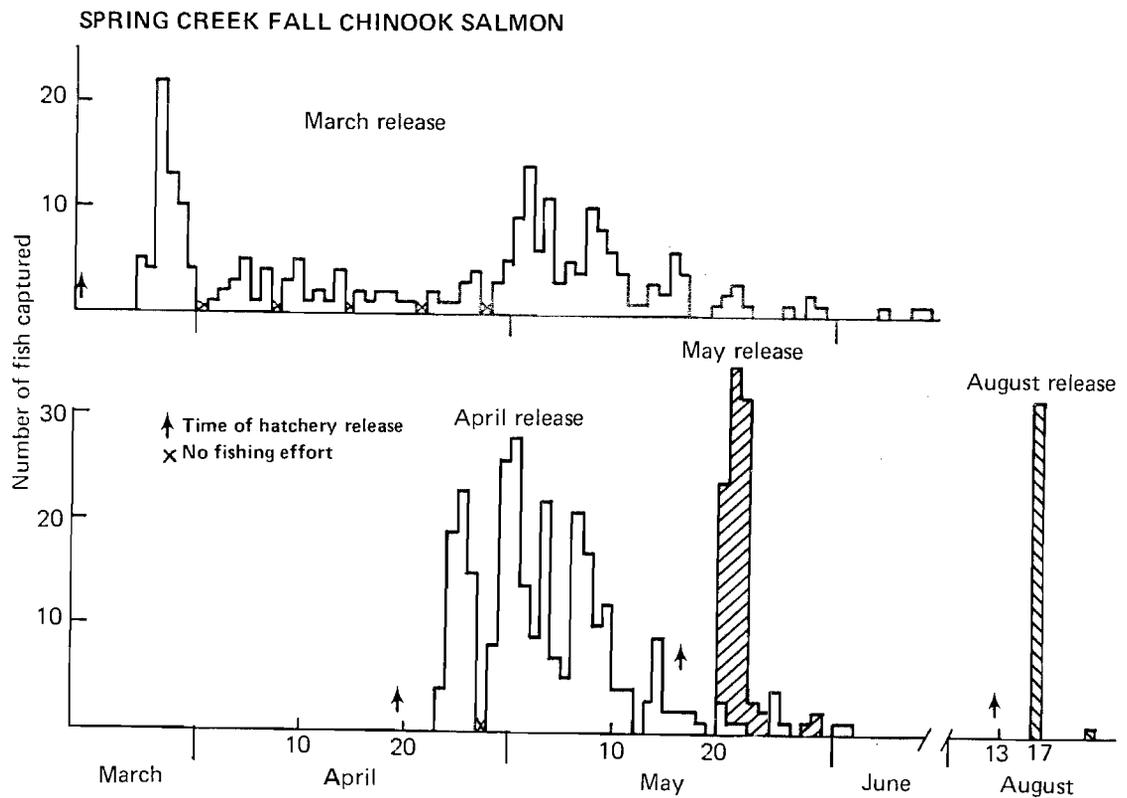


Figure 8. Numbers (actual) of Spring Creek fall chinook salmon captured at Jones Beach (Oregon) 1979.

Releases (arrows) were made on 21 March, 18 April, 19 May, and 13 August.

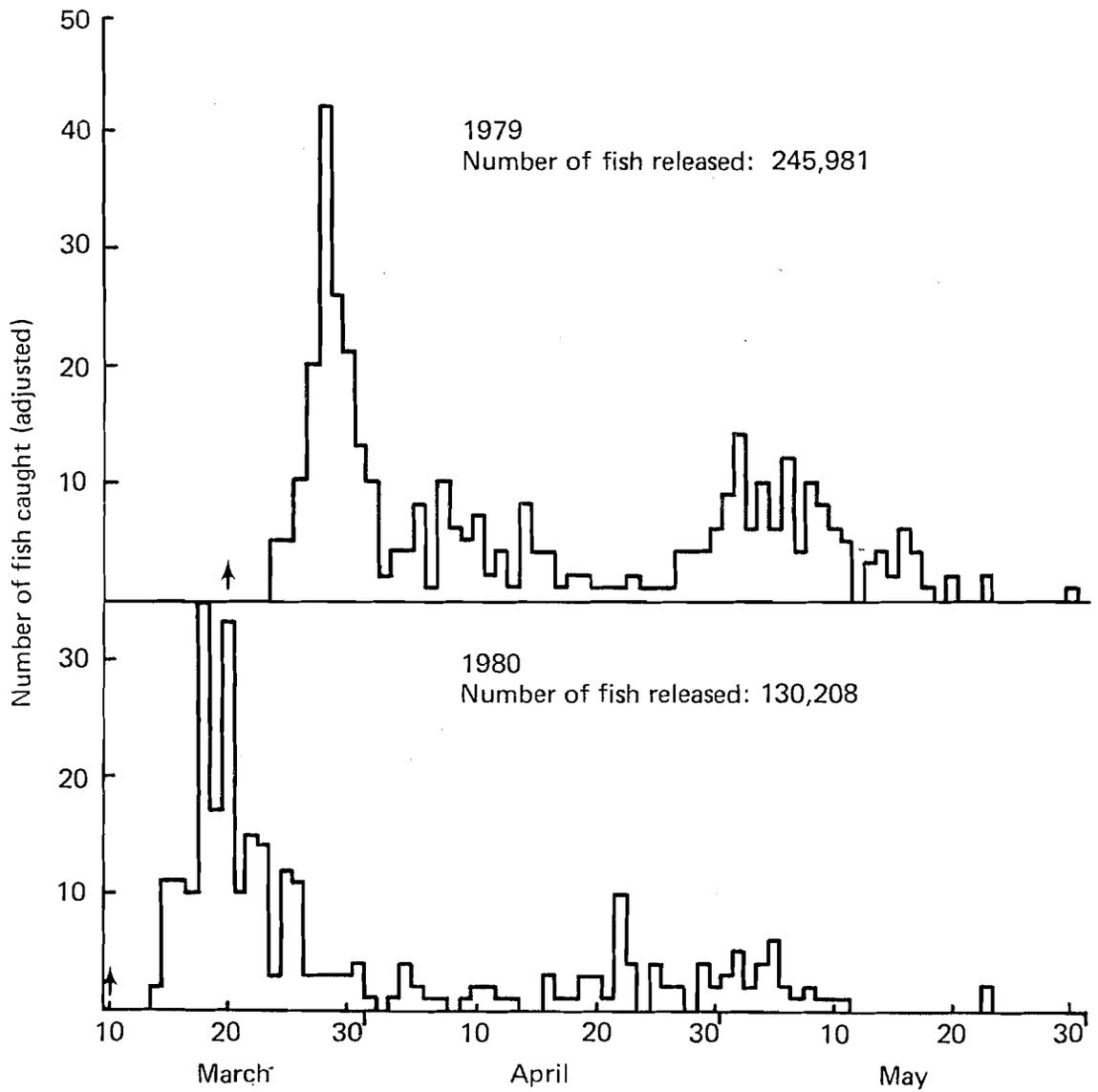


Figure 9. Comparison of numbers of Spring Creek fall chinook salmon captured at Jones Beach (Oregon) from the March releases of 1979 and 1980. Arrows indicate release dates of 21 March 1979 and 10 March 1980. Numbers have been adjusted for fishing effort.

is not known if this difference resulted from a greater proportion of smolted fish in 1980 than in 1979 as suggested by relative levels of gill  $\text{Na}^+-\text{K}^+$  ATPase activity. Migration rates of fish released in April, May, and August 1980 differed little from corresponding releases in 1979. Although the May 1980 release was made with depressed enzyme levels, the possibility of rapid resmoltification, such as was observed with coho salmon, remains likely.

Gill  $\text{Na}^+-\text{K}^+$  ATPase activities in fall chinook salmon from the Kalama Falls Hatchery (Washington Department of Fisheries) did not become elevated prior to release in 1978 or in 1979, yet some individual migrants captured at Jones Beach within 11 days after the 12 July 1979 release had very high enzyme levels (Fig. 10). The same wire tag code was used in fish released on both dates in 1979 (22 June and 12 July), but capture data from Jones Beach indicated that most fish from the earlier release had moved past the capture site before fish from the second release arrived (Fig. 11). Although some fish moved downstream quite rapidly [26 mi (42 km) from hatchery to Jones Beach], many remained in the river for several weeks prior to passing the capture site. Increasing fork lengths of the migrants with time suggests that growth as well as mortality among smaller fish may have occurred during the extended river residence (Fig. 11).

Fall chinook salmon were held at the Willard NFH beyond the normal spring release time and were liberated as three separately tagged groups on 12 July and 14 November in 1978 and on 19 April 1979 (yearlings). Gill  $\text{Na}^+-\text{K}^+$  ATPase activities were rising on the first release, low on the second release, and elevating on the last release (Fig. 12). Migrants from the first and last releases all moved to the estuary within a month or less, but fish from the November release were still being captured the following March (Fig. 12). This

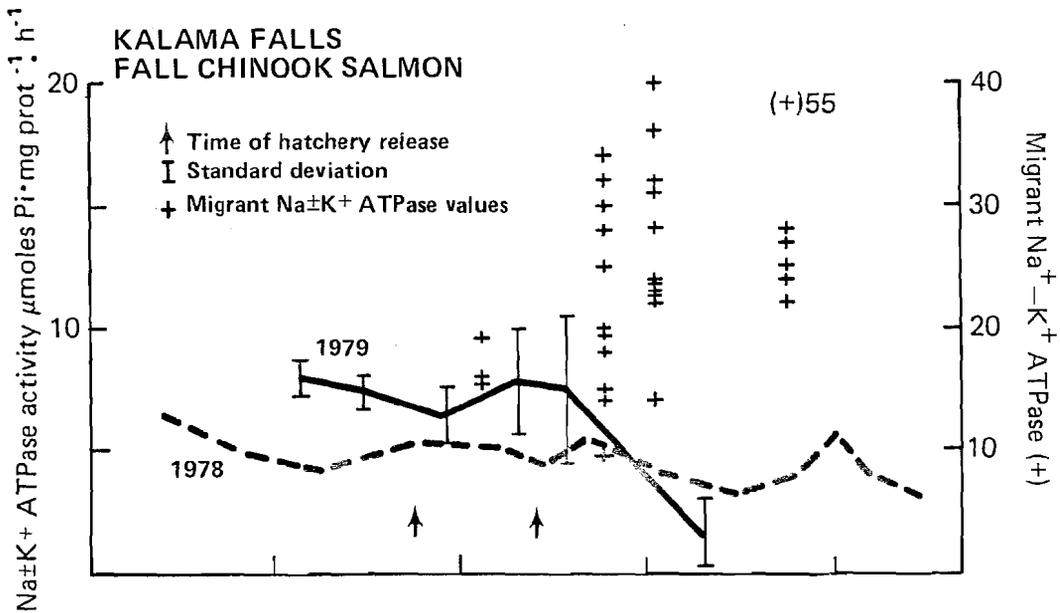


Figure 10. Gill Na<sup>+</sup>-K<sup>+</sup> ATPase activities in fall chinook salmon from Kalama Falls - 1978, 1979.

Arrows indicate release dates (1979) of 22 June and 12 July.

Individual Na<sup>+</sup>-K<sup>+</sup> ATPase activities of migrants (+) are plotted using the right hand ordinate.

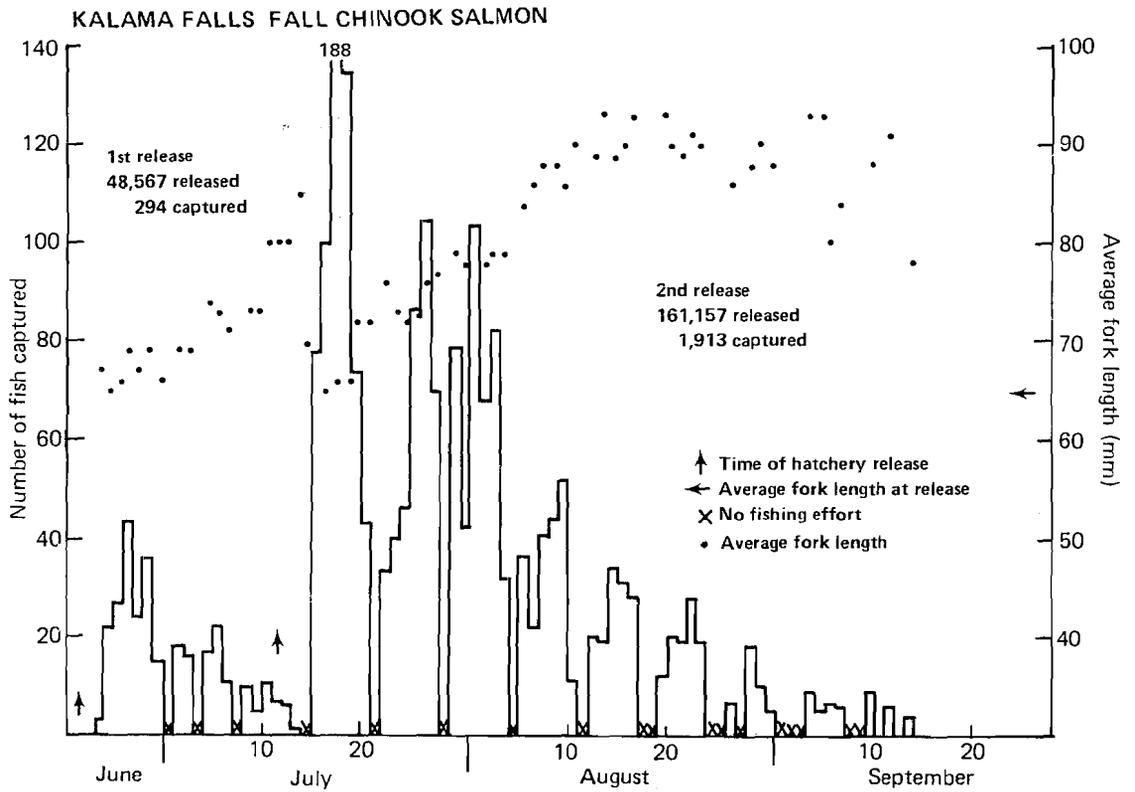


Figure 11. Number (actual) of Kalama Falls fall chinook salmon migrants captured at Jones Beach (Oregon) and average fork lengths (mm) of the total number of fish captured on the indicated day.

Release dates (vertical arrows) were 22 June and 12 July.

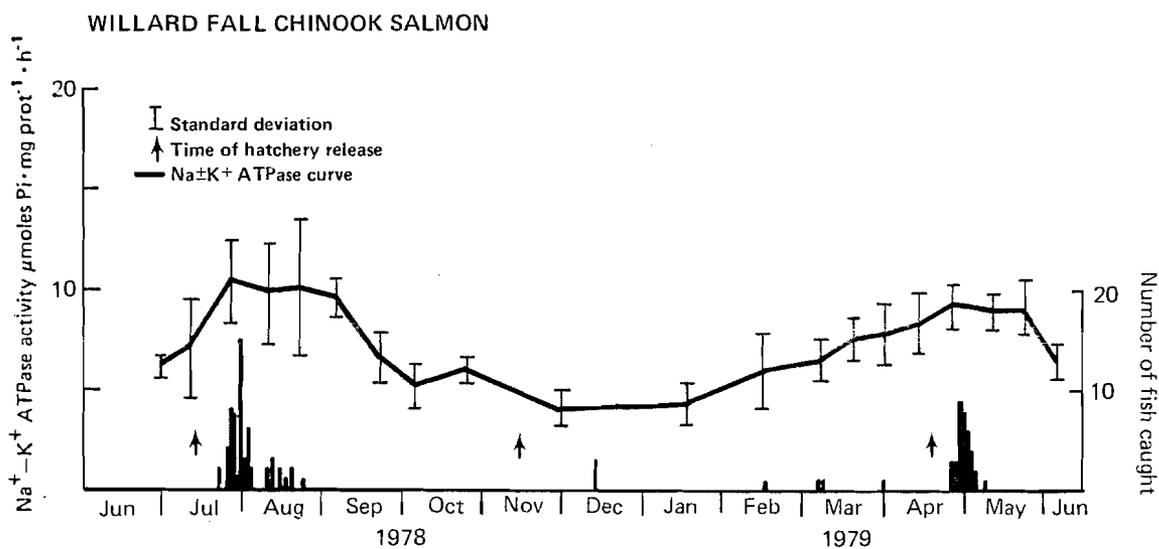


Figure 12. Gill Na<sup>+</sup>-K<sup>+</sup> ATPase activities of fall chinook salmon from Willard National Fish Hatchery and numbers (actual) of migrants captured at Jones Beach (Oregon).

Arrows indicate release dates of 12 July and 14 November 1978 and 19 April 1979.

same phenomenon of delayed migration has also been observed in other groups of fall chinook salmon, especially from releases made in September, October, and November of larger than normal fish (13-75 g) (Dawley et al. 1980).

#### CONCLUSIONS

Water temperatures in excess of 54°F (12°C) adversely affect migratory behavior and gill  $\text{Na}^+-\text{K}^+$  ATPase activity of steelhead trout. Columbia River temperatures normally reach this limit in mid-May, at the peak of steelhead seaward migration. In years of low water flow, river temperatures can rise to 54°F by late April and therefore may present a serious threat to the successful completion of seaward migration. High river temperatures probably contributed to the poor outmigration of steelhead from the upper river in 1977.

Yearling coho salmon held at hatcheries beyond normal May release times showed loss of smolt characteristics and reversion to parr-like fish having low gill  $\text{Na}^+-\text{K}^+$  ATPase levels and losing silver coloration. Nevertheless, upon release into natural streams in June and July, these fish rapidly migrated seaward and regenerated elevated levels of gill  $\text{Na}^+-\text{K}^+$  ATPase activity. It appears that "reversion" to a parr-like state does not involve a complete loss of all of the physiological changes that occurred on transformation to smolts. This is indicated by the very rapid return of smolt-like characteristics upon liberation. The regeneration of elevated levels of gill  $\text{Na}^+-\text{K}^+$  ATPase activity, for example, is much more rapid than the rate of elevation accompanying initial smoltification in April and early May. Also, seaward migration of late released fish is more rapid than the movement of fish released in May. Preliminary data indicate adult returns are better for the June released fish, which suggests that rapid seaward migration may be desirable for increasing overall survival.

Relationships between seaward migration and typical smolt indicators are not so clearly established for subyearling chinook salmon. In part, this is due to the fact that seaward movements occur in the absence of indications of smoltification (Ewing et al. 1980b). Whether such movements terminate at the ocean or stop short of ocean entry has not been determined. It may be important to note that some migrants have very high gill  $\text{Na}^+ - \text{K}^+$  ATPase levels whereas others, though elevated, are only moderately so. This leads to the question of extended estuary rearing of those animals that may have to develop greater osmoregulatory capability (indicated by high gill  $\text{Na}^+ - \text{K}^+$  ATPase activity) before entering the ocean. On the contrary, those animals arriving at the ocean with high enzyme activities should be able to immediately enter the ocean without undue stress. Observations that some chinook salmon decrease their travel rate upon entering the upper estuary whereas coho salmon and steelhead do not (Dawley et al. 1980) suggest that in many instances more time may be required for the development of maximum seawater adaptability. Our observations thus far show that some subyearling fall chinook salmon released from hatcheries prior to development of major peaks in gill  $\text{Na}^+ - \text{K}^+$  ATPase activity migrate rather rapidly to the estuary, but others remain in the river for several weeks or months. On the other hand, releases made after gill  $\text{Na}^+ - \text{K}^+$  ATPase activities have peaked seem to result in more rapid seaward migration.

#### ACKNOWLEDGMENTS

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## FIGURE LEGENDS

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