Steelhead Migration: Potential Temperature Effects as Indicated by Gill Adenosine Triphosphatase Activities

Abstract. *Yearling steelhead trout held in fresh water at cold temperatures (6.5° or 10°C) showed an increase in gill microsomal Na+, K+-stimulated adenosine triphosphatase activity during parr-smolt transformation, whereas trout held in warm water (15° or 20°C) did not. Adenosine triphosphatase activity increased and other indications of transformation were observed in fish transferred from warm to cold water, whereas the reverse occurred on transfer from cold to warm water.*

Pollution from the discharge of waste heat into river systems is a particular concern in the conservation of anadromous fishes. Proposed nuclear power plants for electric power generation are the largest potential source of waste heat along the Columbia River and its main tributaries. If water from the rivers were used in straight-through cooling systems for the reactors, significant increases in river temperatures would occur. In this study we show that water temperatures higher than 12°C may alter the migratory behavior and physiological condition of steelhead trout (*Salmo gairdneri*).

Steelhead propagate naturally in many tributaries of the Columbia River and are reared in state and federal hatcheries. Just prior to seaward migration, young fish known as parr undergo adaptive biochemical and physiological changes and become migratory smolts (*1, 2*). One biochemical change of special interest in this study is the elevation in the Na+, K+-stimulated adenosine triphosphatase activity of gill microsomes which accompanies the transformation from parr to smolt and has been observed in two species of salmon as well as in steelhead (*3, 4*).

Size appears to be a major determinant in the parr-smolt transformation of steelhead. Yearling parr that fail to reach the necessary size by the migratory season—March to June (peak movement occurs in April and May)—remain in fresh water until the following spring (*5*). On the other hand, smolts ready to migrate seaward, but held in fresh water, revert to "parr" generally by the first of July and lose their ability to adapt to salt water (*6*). Reversion is accompanied by a decrease in the previously elevated adenosine triphosphatase activity.

Six hundred yearling steelhead trout (average weight, 30 g) were divided into four groups of 150 fish each, and these groups were held at constant temperatures of 6.5°, 10°, 15°, and 20°C (44°, 50°, 59°, and 68°F), respectively. Fish were fed a commercially prepared diet twice daily until mid-April when feeding was increased to three times daily, 6 days a week. Adenosine triphosphatase activities were determined in duplicate on microsomal preparations from gill filaments of individual fish (*3*). After Na+, K+-stimulated adenosine triphosphatase had reached peak activity in the 6.5° and 10°C groups, which indicated that parr-smolt transformation had occurred, all groups were further divided so that fish held at each of the four original temperatures were then placed in the other temperature regimens.

The Na+, K+-stimulated adenosine triphosphatase activity in steelhead held at 6.5°C increased during parr-smolt transformation, beginning in March and reaching peak activity in the latter part of May (Fig. 1A). Activity fell rapidly in the latter part of June to a presmolt level, thus indicating reversion to the nonmigratory parr stage. The time during which Na+, K+-stimulated adenosine triphosphatase activity remained elevated coincides with observed seaward migration of juvenile steelhead. Adenosine triphosphatase activity dropped sharply in fish transferred on 20 May from 6.5° to 15°C water (Fig. 1A).

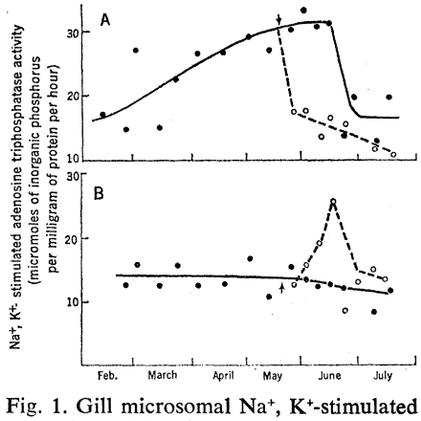

Fig. 1. Gill microsomal Na+, K+-stimulated adenosine triphosphatase activity of yearling steelhead trout as a function of the time of year and temperature: (A) (solid line) fish held at 6.5°C; (dashed line) fish transferred from 6.5° to 15°C water on 20 May; (B) (solid line) fish held at 15°C; (dashed line) fish transferred from 15° to 10°C water on 19 May. The transfer to different temperatures is indicated by arrows. Beginning 29 March, each point represents an average of values obtained from three separate fish [six fish were used on 11 February (A) and two each for the next three points through 15 March (A and B)].

No increase in adenosine triphosphatase activity was observed in fish held at 15°C (Fig. 1B) until they were transferred to cooler water (10°C). Activity rose steadily after transfer on 19 May until the latter part of June when it dropped sharply as fish reverted.

Although we do not present complete data for fish at all temperatures, similar patterns of activity were found in all situations when transfers were made between warmer (15° and 20°C) and cooler (6.5° and 10°C) water. Coefficients of condition [the ratio of the weight to length (*2*)] changed concurrently with changes in adenosine triphosphatase activity; they decreased when adenosine triphosphatase activity rose and increased when adenosine triphosphatase activity fell.

As a preliminary test of adaptability to salt water, four fish were removed from each group on 7 May and placed abruptly in artificial seawater [Instant Ocean Salts (*3, 7*), 30 parts per thousand, 12.5°C]. At the time of transfer to salt water, fish at 6.5° and 10°C had elevated Na+, K+-stimulated adenosine triphosphatase activities whereas those at 15° and 20°C had low activities (see Fig. 1). All four fish from the 20°C group and three from the 15°C group died within 3 days. No mortalities occurred in the groups at 6.5° and 10°C. Abrupt transfer into fresh water involving similar temperature changes caused no mortality. In October when adenosine triphosphatase activities were low, 24 steelhead were tested for saltwater survival with 100 percent mortality occurring in less than 5 days.

We conclude that elevation of the Na+, K+-stimulated adenosine triphosphatase activity in gill microsomes is closely associated with parr-smolt metamorphosis and, therefore, may be used as an index of migration preparedness. The observed decrease in this activity and the change in the coefficient of condition, either because of exposure to warm water or because of normal reversion in late June, reflects a loss of smolt characteristics and saltwater adaptability. Thus, the absence of elevated adenosine triphosphatase activity in fish held in 15°C water suggests that

they would not migrate seaward. Such a conclusion has received support from the results of very recent experiments conducted in cooperation with Dr. Harry Wagner of the Oregon State Game Commission. In these experiments the timing of parr-smolt transformation was regulated by varying photoperiod regimens and the migratory behavior of fish released into a freshwater stream was tested. We found that fish migrated downstream only during periods of elevated adenosine triposphatase activity and ceased to migrate as soon as the activity fell, even if the decrease occurred during what is considered the normal migratory season.

The Federal Water Pollution Control Administration has suggested a provisional maximum temperature of 68°F (20°C) as compatible with the migration of salmonids (*8*). The report recommended that "during any month of the year, heat should not be added to a stream in excess of the amount that will raise the temperature of the water by more than 5°F (based on the minimum expected flow for that month)" (*8*). We propose that a temperature of 68°F is much too high for migrating juvenile steelhead, although adults migrate upstream in waters of this temperature. With respect to using the recommended 5°F elevation limit, we urge caution. The temperature of the Columbia River at Bonneville Dam, for example, reached 54°F on 7 May 1971 (*9*). An increase of 5°F would have resulted in a river temperature of 59°F (15°C). Steelhead smolts entering waters of this temperature from upstream may experience a reduction in adenosine triphospnatase activity and revert to the nonmigratory parr stage.

On the basis of the experiments reported herein we show only that the parr-smolt transformation may not occur or persist at some temperature between 10° and 15°C. We have conducted other experiments, however, which indicate the limiting temperature to be near 13°C. Pending further investigation, we suggest 12°C (about 54°F) as an upper limit for waters used by migrating juvenile steelhead.

Steelhead are now being reared in state and federal hatcheries in warmer waters (up to 15°C) in an effort to produce larger fish for increased survival during seaward migration. On the basis of the results of these studies, we suggest that steelhead reared under these conditions will need to be exposed to cooler environmental temperatures (6° to 10°C) for a period of 1 to 2 months prior to migration in order to allow parr-smolt transformation.

We recognize that laboratory tests such as those reported here are not identical to situations encountered in the natural environment. However, we believe that they can serve as good indices for establishing upper limits for temperatures of waters used by steelhead for seaward migration.

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References and Notes

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Tidal Growth Increments in the Cockle Clinocardium nuttalli

Abstract. *Sets of growth lines in the shell of* Clinocardium nuttalli *are extinguished every 13 or 14 increments only to be replaced by other sets, half an increment out of phase with the first. This can be explained only by assuming that the lines are deposited during periods of exposure at low tide. The average duration of an increment is 24 hours and 50 minutes.*

It has been demonstrated that the skeletal parts of many animals contain a record of their growth pattern. Daily increments have been reported from the epitheca of corals (*1*), mollusk shells (*2, 3*), and fish otoliths (*4*). Pannella and MacClintock (*3*) examined more than 40 species of recent and fossil bivalve shells and conducted detailed experiments on *Mercenaria mercenaria*. They concluded that all the forms they looked at exhibited daily increments. It is the purpose of this report not to question the findings of these workers but to sound a note of caution by pointing out that the basic growth increments of some clams are not daily but tidal in nature.

In bivalves two types of daily increments are recognized, simple and complex (*3*). The former are bounded by two sharp surfaces with a wide, relatively homogeneous layer between. The latter are also bounded by two sharp surfaces but show a pronounced inner surface that divides the increment into two parts. In *M. mercenaria* and other bivalves with a prismatic outer layer the boundaries are thin layers of conchiolin with aragonite between.

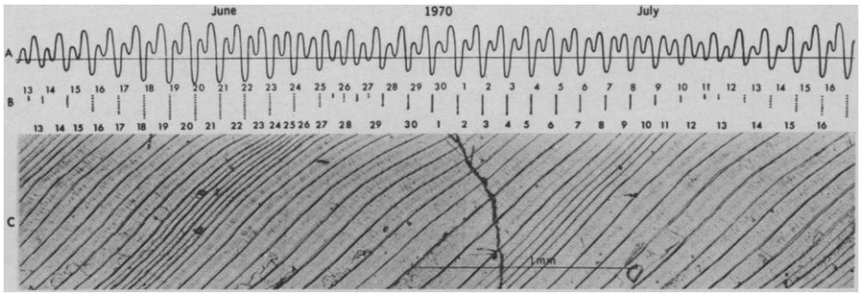

Fig. 1. (A) The fluctuating line shows the predicted tidal movements from 13 June to 16 July at Empire, Oregon. The extremes for the period were experienced on 19 and 20 June (+2.3 to −0.7 m). The straight line passes through the +0.6-m level at which *Clinocardium nuttalli* is thought to live. The dates are located at the noon position for each day. (B) Predicted time and extent of exposure. The dotted and solid lines represent the two alternating sets of low tides, which are half a period out of phase with each other. (C) A portion of the shell deposited during this period. Each equivalent date is placed above the part of the shell thought to be deposited at noon of that day. The time scale is distorted because of the variable rate of growth of the shell.