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RESEARCH NOTE

Effects of Photoperiod and Water Temperature on Smoltification of Yearling Sockeye Salmon (*Oncorhynchus nerka*)

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Abstract.— The effects of photoperiod and water temperature on smoltification of yearling sockeye salmon (*Oncorhynchus nerka*) were investigated. Yearling sockeye salmon separated into six groups (A to F) were reared under artificial photoperiod conditions from January to April. The photoperiods of groups A and D simulated natural day length. Groups B and E and groups C and F were kept at 13 h and 15 h of daylight, respectively. Throughout the experiment, groups A, B and C were supplied with river water (3-5℃) and groups D, E and F were supplied with well water (7-8℃). The serum sodium concentration 24 h after transfer to seawater in groups C and F decreased from 196 mEq/l in January to nearly 160 mEq/l in April. The gill Na^+,K^+-ATPase activity of groups E and F showed a much higher increase from nearly 3 μmols Pi/mg protein/h in January to 15 and 21 μmols Pi/mg protein/h in April. Fin margin blackening was observed in 6% of fish in group E and 45% of fish in group F in April. These results indicate that smoltification of yearling sockeye salmon may be affected by increases in photoperiod and higher water temperature accelerates the parr-smolt transformation.

Key words: sockeye salmon, smoltification, photoperiod, water temperature

Introduction

The early life history of anadromous sockeye salmon (*Oncorhynchus nerka*) is characterized by smoltification preceding seaward migration. Under natural conditions, this phenomenon usually occurs in spring and thus environmental factors such as photoperiod and/or water temperature may affect the developmental process of smoltification. For example, underyearling masu salmon (*O. masou*) exposed to longer day lengths than their natural photoperiod developed their seawater tolerance unseasonably in autumn (Ikuta et al. 1987). Juvenile chinook salmon (*O. tshawytscha*) reared at 17℃ reached maximum seawater tolerance two months earlier than those reared at 9℃ (Clarke and Shelbourn 1985). Duncan and Bromage (1998) reported that the timing of the changes from long to short and short to long day lengths in different photoperiod regimes induced differences in seasonal profile of the various parr-smolt changes in Atlantic salmon (*Salmo salar*). In this study, the effects of photoperiod and water temperature on seawater tolerance of yearling sockeye salmon were investigated.

Materials and Methods

On January 12, 1994, 600 yearling sockeye salmon, which were fertilized at the Chitose Hatchery, National Salmon Resources Center, were separated equally into six groups (A to F-group) and moved to 100 l tanks. They were reared under a uniform feeding ration of 3% body weight per day until April 8, 1994. Throughout the experiment, groups A, B and C were supplied with river water (3-5℃) and groups D, E and F were supplied with well water (7-8℃). All tanks were shielded with vinyl cloth and daylight was controlled using two 20 w fluorescent lamps. The photoperiods of groups A and D were gradually increased from 9.5 h in mid-January to 12.5 h in early-April, which simulated the natural photoperiod (Fig. 1). The photoperiods of groups B and E, and groups C and F were fixed at 11 h and 13 h from mid-January to mid-February, and 13 h and 15 h from mid-February to early-April, respectively. Natural day length at the beginning of the experiment was 9.5 h in

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mid-January.

During the experimental period, these groups were used for monthly seawater challenge tests. For each seawater challenge test, 10 individuals were randomly collected from each tank and transferred directly into artificial seawater at 33 salinity for 24 h. Blood samples were drawn from fish in order to measure serum sodium concentration using an Atomic Absorption and Flame Emission Spectrometer (Shimadzu, AA-640-13). At the same time, the gills for the assay of Na^+,K^+-ATPase activity were taken from other 10 individuals in each freshwater groups. The ATPase activity was measured according to the method of Ban and Yamauchi (1991). This was done after measuring fork lengths and confirming fin margin blackening. Seawater tolerance was assessed by gill Na^+,K^+-ATPase activity and serum sodium concentration 24 h after the transfer of fish to seawater.

The data were subjected to one-way analysis of variance (ANOVA) followed by Student *t*-test to determine significant differences of monthly changes in the gill Na^+,K^+-ATPase activity and serum sodium concentration. A probability level of less than 0.01 was considered significant.

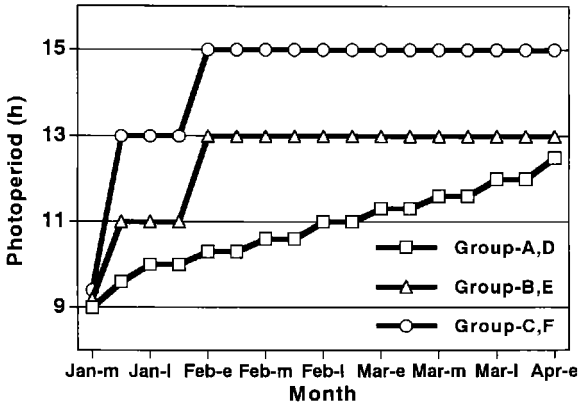

Fig. 1. Experimental designs for changing photoperiod. Groups A, B and C were kept at 3-5°C and groups D, E and F were kept at 7-8°C. The photoperiod of groups A and D simulated the natural day length. The e, m and l in month show early, middle and late, respectively.

Results and Discussion

The mean fork length of fish in each six groups increased from 106-110 mm in mid-January to 112-131 mm in early-April. All fish transferred to seawater at each challenge test survived for 24 h. The serum sodium concentration of fish in groups C and F decreased

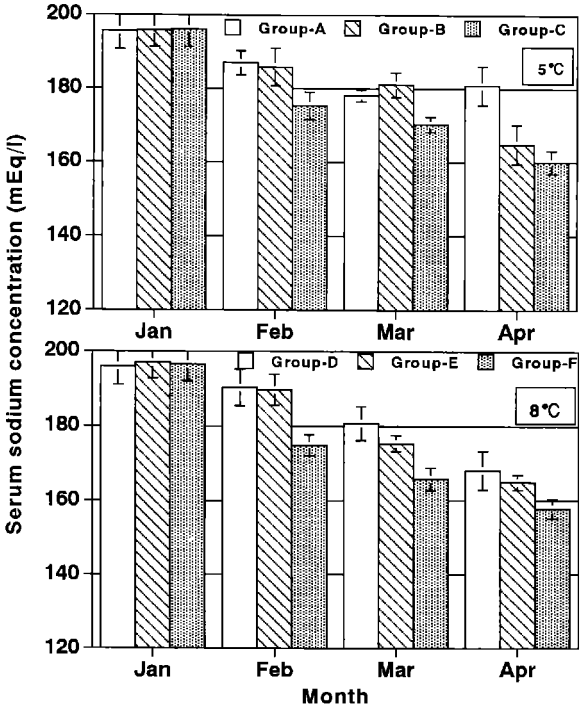

Fig. 2. Changes in serum sodium concentration in groups A-F of sockeye salmon transferred in seawater for 24 h monthly from January to April. The groups A, B and C were kept at 3-5 °C (upper), and groups D, E and F were kept at 7-8°C (lower). Bars indicate SE.

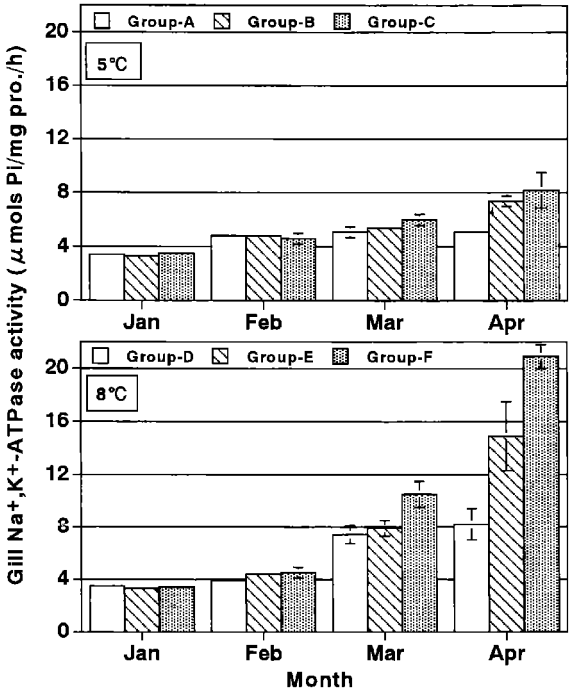

Fig. 3. Changes in gill Na^+,K^+-ATPase activity in groups A-F of sockeye salmon reared in fresh water from January to April. Groups A, B and C were kept at 3-5°C (upper) and groups D, E and F were kept at 7-8°C (lower). Bars indicate SE.

from 195.5 and 196.7 mEq/l in mid-January to 160.0 and 157.8 mEq/l in early-April, respectively. Groups B, D and E and group A had serum sodium concentrations of 164.9-168.0 mEq/l and 180.9 mEq/l, respectively (Fig. 2). These reductions without group A were significant ($p<0.01$). While seawater-challenged fish in all groups showed a reduction in the serum sodium concentration during the experimental period, fish in the groups C and F showed much lower levels than other groups. These data suggest that increases in photoperiod are involved in the development of hypo-osmoregulatory ability in yearling sockeye salmon. This result supports previous findings in Atlantic salmon (Duston and Knox 1992; Sigholt et al. 1998). Furthermore, present data suggest that longer daylight had an enhanced effect on development of seawater tolerance.

The gill Na^+,K^+-ATPase activity of fish in all groups increased continuously and showed significant differences ($p<0.01$) between mid-January and early-April (Fig. 3). However, groups E and F showed a much greater increase in enzyme activity from 3.4 and 3.5 μmols Pi/mg protein/h in mid-January to 14.9 and 20.9 μmols Pi/mg protein/h in early-April. The enzyme activity of groups B, C and D and group A were 7.4-8.2 μmols Pi/mg protein/h and 5.1 μmols Pi/mg protein/h in early-April, respectively (Fig. 3). Fin margin blackening was observed in 6% of fish in group E and 45% of fish in group F. Fish in other groups did not show any change in fin color. These results show that increases in photoperiod together with higher water temperature acted to induce development of the gill Na^+,K^+-ATPase activity and fin margin blackening. Solbakken et al. (1994) also suggested that elevated temperature advanced the development of gill Na^+,K^+-ATPase activity in Atlantic salmon. However, development of hypo-osmoregulatory ability and elevation of the Na^+,K^+-ATPase activity were not synchronized completely in this study. To investigate the seawater tolerance of sockeye salmon, examination of not only the gills, but also other osmoregulatory organs such as the urinary bladder (Richman III et al. 1987) or branchial mantle (Talbot et al. 1982) may be necessary.

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日長と水温がベニザケ1年魚のスモルト化に与える影響

伴　真俊

ベニザケ1年魚を100個体ずつ6群（A-F群）に分け，1月から4月まで人工的にコントロールした異なる日長と水温条件で飼育した．日長は，A群とD群を自然日長と同じに設定し，B群とE群を13時間明期11時間暗期，C群とF群を15時間明期9時間暗期に設定した．水温は，A，B，C群を3-5℃，D，E，F群を7-8℃に設定した．実験終了時の4月に，スモルトの特長であるつま黒を発現し，最も顕著な鰓のNa^+,K^+-ATPase活性の上昇を示したのはE群とF群だった．また，海水移行

24時間後の血中ナトリウム濃度は，C群とF群が最も低い値を示した．この結果から，日長の増加がスモルト化の引き金となること，水温が高いほどスモルト化が加速されることが示唆された．