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Seasonal Changes in Seawater Adaptability of the Hatchery Reared Juvenile Sockeye Salmon, *Oncorhynchus nerka*

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Abstract

Seawater (33‰) challenge test was performed to assess the development of seawater adaptability in the underyearling and yearling sockeye salmon, *Oncorhynchus nerka*, from July, 1989 to July, 1990. The body silvering were observed throughout the experimental period, whereas the pigmentation of both dorsal and tail fin margins appeared during from July to October, 1989, and from May to June, 1990. A survival rate of 100% was observed on the 7th day after transfer into seawater in August and September 1989, and in May and June, 1990. Serum sodium contents after the 7th day of transfer into seawater were low in August and September, 1989 and June, 1990. High gill Na^+, K^+-ATPase activities were observed in August, 1989 and June, 1990. These results suggest that the underyearling and yearling sockeye salmon develop seawater adaptability in August and in June, respectively.

Introduction

Smoltification (parr-smolt transformation) in salmonids is a very complex phenomenon composed of morphological, physiological and behavioral changes (Hoar 1976, 1988). In general, almost the salmonids smoltify in the river after hatching out, followed by migration to the sea. During smoltification, seawater adaptability developes simultaneously with the occurrence of both body silvering and pigmentation of dorsal and caudal fin margins (Kubo 1980 ; Gorbman et al. 1982 ; Yamauchi et al. 1984).

Sockeye salmon, *Oncorhynchus nerka*, display the most varied and complex life histories within genus *Oncorhynchus* ; their life patterns are classified into three categories : sea-, river- and lake-types (Wood et al. 1985). However, only the lake-type among them has been reported in Japan. Recently, trials for the release of lake-type sockeye salmon has been performed in order to produce a new resource of the fish. To improve the survival rate of the fish, informations on the physiological characteristics including the development of seawater adaptability are important. This paper describes the seasonal changes accompanying the development of seawater adaptability in hatchery-reared sockeye salmon.

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Materials and Methods

Fish : Eggs were obtained from adult sockeye salmon, *Oncorhynchus nerka*, caught in October, 1988 from the Abira River, Hokkaido. They were transferred to Chitose Branch, Hokkaido Salmon Hatchery and reared in well water indoor ponds (7–8°C). After hatching out in January of 1989, they were raised in outdoor well water ponds (7–8°C) under natural photoperiod until July of the same year. The fish were transported to another outdoor pond, and were samples monthly until July, 1990. Rearing water temperature and photoperiod during the period sampled the fish were shown in Fig. 1. Food (dry pellet : Taiyo Jiryo) were supplied twice a day during the experimental period.

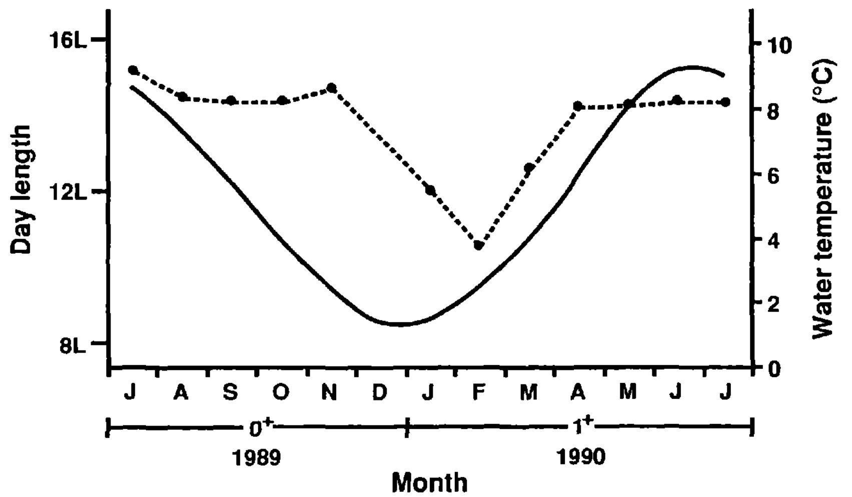

Fig. 1. Seasonal changes in day length (———) and water temperature (···········) from July, 1989 to July, 1990. Water temperature was expressed as mean values of each ten days.

Seawater challenge : To determine seawater adaptability, seawater challenge test were performed (Clarke and Blackburn 1977). 50–100 fish samples collected randomly were transferred into artificial seawater (33‰, 11.0±1.0°C). On the 1st and 7th day after the transfer, after anesthetizing using tricaine methanesulfonate (MS222), their fork lengths were measured (Fig. 2). Blood samples were obtained from the caudal vein using a capillary. Gill fillaments were immediately rinsed in ice-cold homogenizing solution (250 mM Sucrose, 6 mM EDTA-2Na; 20 mM imidazole, pH 6.8) and frozen immersed in the solution (20 times volume) until Na^+, K^+ –ATPase assay. Serum obtained by centrifugation at 10,000 g for 5 min were stored at –40°C until sodium content assay.

Serum sodium concentrations : Serum sodium concentrations in freshwater and seawater were measured using an Atomic Absorption and Flame Emission Spectrometer (Shimadzu, AA-640-13).

Na^+, K^+ –ATPase activity : Gill fillaments were homogenated in 1mℓ of the above solution,

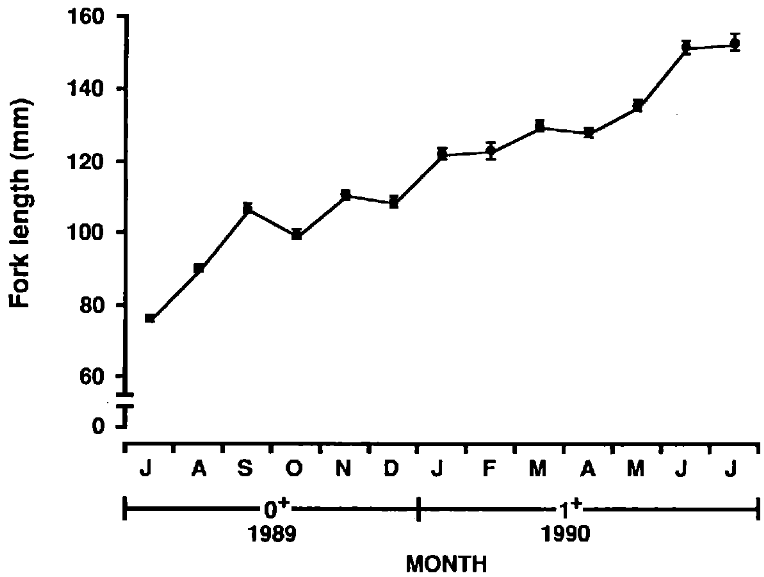

Fig. 2. Seasonal changes in fork length of hatchery-reared sockeye salmon from July, 1989 to July, 1990. The vertical bars represent the mean±SE.

and 40 $\mu\ell$ of the homogenated was incubated either in 160 $\mu\ell$ of reaction mixture A (250 mM imidazole, 12.5 mM ATP2Na, 337.5 mM NaCl, 162.5 mM KCl, 50 mM $MgCl_2$) or 160 $\mu\ell$ of reaction mixture B (reaction mixture A + 2.5 mM ouabain) for 20 min at 37°C in a shaking incubator. The reaction was stopped by adding 4mℓ of iron TCA solution (100 g TCA, 10 g thiourea, 30 g ferrous anmonium sulfate in 1 liter). Free Pi was measured according to the method of Goldenberg and Fernandez (1966) and protein concentrations were determined by the method of Lowry et al. (1966).

Statistical analysis : The data presented are expressed as means±SEM. One-way analysis of variance followed by the Student-Newman-Keul's multiple range test were conducted.

Results

External appearrance : Throughout the experimental period from June, 1988 to June, 1990, body silvering was observed. In contrast, pigmentation on the dorsal fin margins of underyearling and yearling fish was observed from July to October (1989) and from May to June (1990), respectively.

Survival rate in seawater : Survival rate of fish on the 7th day after transfer to seawater was determined (Fig. 3). The survival rates in underyearling fish were 100% in August and October (1989). Thereafter the rate dropped to 33%, in November, followed by low survival rates until February, 1990. In March, the survival rate of the yearling fish increased, and attained 100% in May and June, 1990, followed by dropping to 51% in July.

Serum sodium contents : Serum sodium contents in underyearling freshwater fish showed gradually increasing levels : from 127.6±5.9 mEq/ℓ in July to 154.9±1.3 mEq/ℓ in October

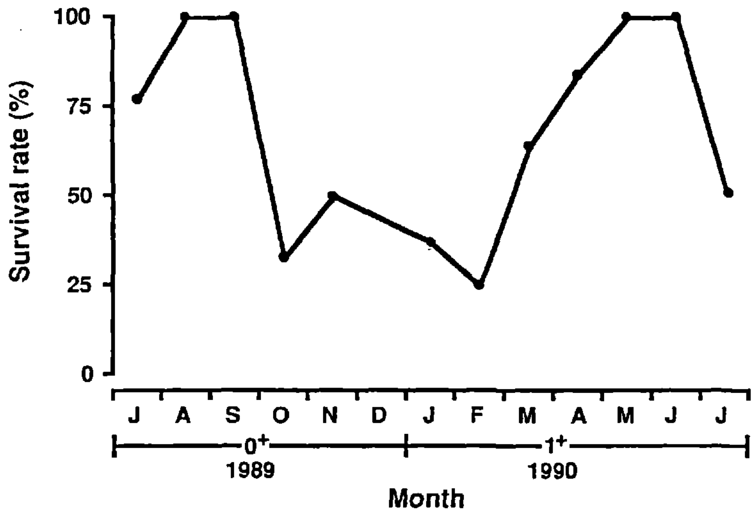

Fig. 3. Seasonal changes in the survival rate on the 7th day after transfer to seawater (33‰) from July, 1989 to July, 1990.

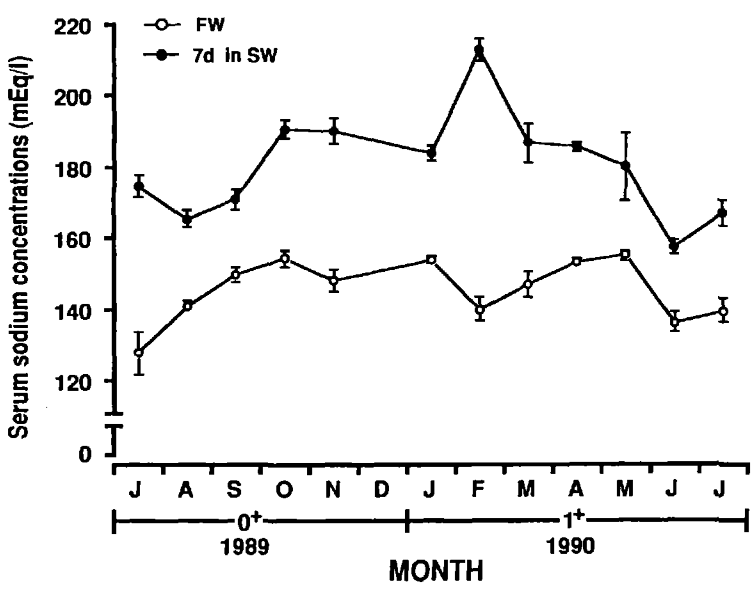

Fig. 4. Seasonal changes in serum sodium concentrations of freshwater fish (○—○) and seawater fish (●—●) on the 7th day after transfer to seawater (33‰) from July, 1989 to July, 1990. The vertical bars represent the mean±SE.

(1989), followed by fluctuating values between 140.0±3.4 mEq/ℓ and 155.2±1.1 mEq/ℓ until May (Fig. 4). In June and July, 1990, the levels dropped again to 136.4±2.7 and 139.3 ±3.4 mEq/ℓ, respectively. In contrast, the concentrations of serum sodium in seawater underyearling fish were low in August (165.5±2.2 mEq/ℓ) and September (169.5±3.1 mEq/ℓ), showing good seawater adaptability, followed by a gradual decrease in adaptability. After the peaked levels in February (1990), the sodium levels began to decrease, and attained lower value (157.5±1.9 mEq/ℓ) in June (1990).

In underyearling fish in August, 1989 and yearling fish in June, 1990, time course changes in serum sodium concentrations were investigated on the 1st and 7th day after transfer to seawater (Fig. 5). Serum sodium levels of August underyearling fish in freshwater was 140.9 ±1.9 mEq/ℓ. The sodium concentrations increased to 184.0±3.9 mEq/ℓ on the 1st day after transfer to seawater, which decreased to 165.5±2.2 mEq/ℓ on the 7th day after transfer to seawater. In contrast, serum sodium concentrations in June yearling fish in freshwater showed 136.4±2.7 mEq/ℓ. The levels on the 1st day after transfer to seawater increased to 164.6± 6.3 mEq/ℓ which were lower in comparison with that in August underyearling fish. The sodium levels on the 7th day after transfer to seawater showed low levels, 157.5±1.9 mEq/ℓ.

Na^+, K^+-ATPase activity : In the freshwater fish, gill Na^+, K^+-ATPase activity peaked in August, 1989 (16.6±2.0 μmoles Pi/mg pro./hr.) (Fig. 6). Thereafter, the activity decreased to 5.5±0.6 μmoles Pi/mg pro./hr., and maintained the same levels (5–6 μmoles Pi/mg pro./hr.) until April (1990). In June, the activity peaked again (16.3±0.7 μmoles Pi/mg pro./hr.). On the other hand, the Na^+, K^+-ATPase activity in seawater fish showed similar patterns to

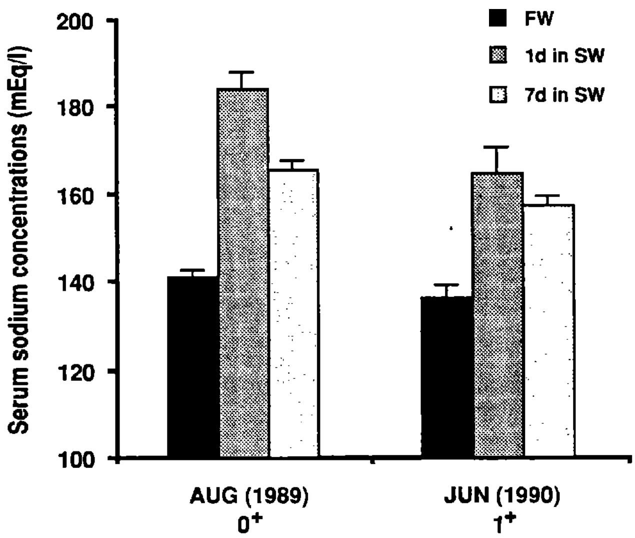

Fig. 5. Time course changes in serum sodium concentrations on the 1st and 7th day after transfer to seawater (33‰) in underyearling (August, 1989) and yearling fish (June, 1990). The vertical bars represent the mean ±SE.

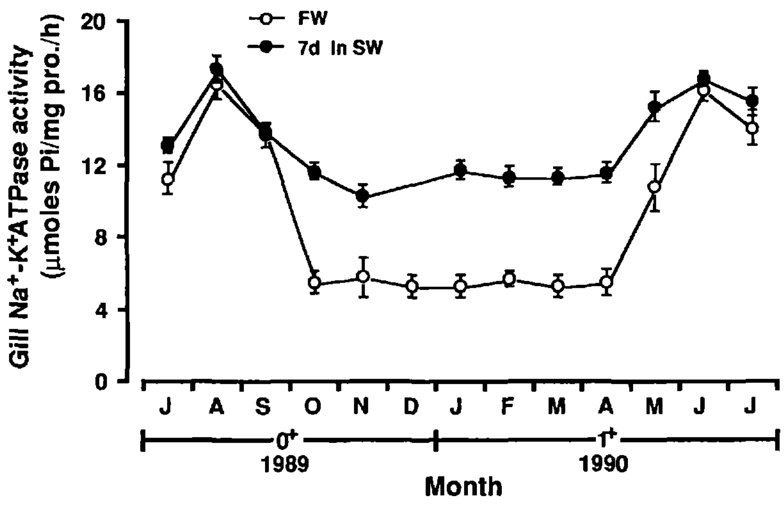

Fig. 6. Seasonal changes in gill Na^+, K^+–ATPase activities in freshwater fish (○—○) and seawater fish (●—●) on the 7th day after transfer to seawater (33‰). The vertical bars represent the mean±SE.

those of freshwater fish. However, the activity in seawater fish between October (1989) and April (1990) were relatively higher (10.8±0.6–11.7±0.5 μmoles Pi/mg pro./hr.) than those of freshwater fish.

Discussion

In general, salmonids are known to change in external appearrance, such as body silvering and pigmentation of the dorsal and caudal fin margins during smoltification (Hoar 1976, 1988). In the present study, sockeye salmon showed body silvering throughout the experimental period during between July (1989) and July (1990), whereas pigmentation of the dorsal and caudal fin margins was observed from July to October, 1989, and from May to June, 1990. The occurrence of the pigmentation coincided with the development of seawater adaptability which will be described in the following discussion. Hence, the pigmentation of dorsal and caudal fin margins seems to be a good criteria to determine the development of seawater adaptability in sockeye salmon.

Aside from changes in the external appearrance, salmonids undergo physiological changes during smoltification. Among them, seawater adaptability developes during smoltification (Hoar 1988). It is reported that gill Na^+, K^+–ATPase activity increases during smoltification in coho salmon (Zaugg and Wagner 1973 ; Folmar and Dickhoff 1980), steelhead trout (Zaugg and McLain 1971), Atlantic salmon (Boeuf et al. 1985) and masu salmon (Ban et al. 1987a, b). Therefore, gill Na^+, K^+–ATPase activity is known to be one of indicators of the development of seawater adaptability in salmonids (Hoar 1976, 1988). In the present study, high gill Na^+, K^+–ATPase activities were observed in underyearling and yearling fish, coincided with the high survival rate in seawater. Furthermore, serum sodium concentration on the 7th after transfer to seawater decreased with a concomitant increase in the gill Na^+, K^+ –ATPase activities.

Furthermore, seawater challenge test is useful to assess the development of seawater adaptability in salmonids (Clarke and Blackburn 1977). In the present study, serum sodium concentrations which were investigated 7th day after transfer to seawater decreased in accord with the increase in gill Na^+, K^+ –ATPase activities. Therefore, gill Na^+, K^+ –ATPase activities, and serum sodium concentrations after transfer to seawater seem to be good indicators to determine the development of seawater adaptability in sockeye salmon as well as in other salmonids.

The results on the survival rate after transfer to seawater, seawater challenge test and gill Na^+, K^+ –ATPase activity suggest that the seawater adaptability develop in both underyearling fish and in yearling fish in August, 1989, and June, 1990, although adaptation to seawater in the underyearling fish was slightly poorer, compared with that of the yearling fish. Baggerman (1960) and McInerney (1964) described that seawater preference observed in the sockeye salmon fry after hatching out was maintained until June, followed by a decrease, which developed again in May-July of the following year. Similarly, in hatchery reared sockeye salmon, Kaeriyama et al. (1987) described that yearling fish showed seasonal changes in seawater adaptability. These findings may indicate that the development of seawater adaptability occur seasonaly in both the underyearling and yearling fish.

Occurrence of smoltification in salmonids including sockeye salmon is judged from the development of seawater adaptability and changes in external appearance (Hoar 1976). In general, almost all of the sockeye salmon smoltify as yearling fish (McInerney 1964 ; Kaeriyama et al. 1987 ; Wood et al. 1987). As described earlier, August underyearling fish as well as June yearling fish developed seawater adaptability concomitant with the pigmentation of dorsal and caudal fin margins. Since environmental factors affect smoltification (Wedemeyer et al. 1980), it seems likely that hatchery-reared sockeye salmon as underyearling fish smoltify under rearing condition adopted. To ascertain this, further investigations are required.

In conclusion, under artificial rearing condition used in the present study, underyearling sockeye salmon may smoltify as well as yearling fish. This finding may explain the occurrence of the varied and complex life histories in the sockeye salmon.

Acknowledgements

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ベニザケ幼魚における海水適応能の季節変化

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ベニザケの0年魚から1年魚にかけての海水適応能を生理学的に調べるために，1989年7月から1990年7月までの間，月1回の海水移行試験を行なった．海水移行7日目まで全個体が生残できたのは，1989年8月および9月と1990年5月および6月のみだった．冬季間の生残率は，30%前後まで下がった．また，海水移行後の魚の血中ナトリウム量が淡水レベル（約150 mEq/ℓ）まで下がったのは，1989年8月および9月と1990年6月だった．冬季間は，海水移行7日目まで生残した個体でも，血中ナトリウム量が200 mEq/ℓを越えた．さらに，血中ナトリウムの排泄に関与する鰓のNa^+, K^+－ATPaseは，1989年8月および1990年6月に最高値に達した．

これらの結果から，池中で飼育したベニザケの幼魚は，0年魚の8月および1年魚の6月に海水適応能が高まることがわかった．