Low Nutritional Status in the Freshwater Phase and Temperature at Seawater Entry Reduce Swimming Performance of Juvenile Chum Salmon

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Chum salmon (*Oncorhynchus keta*) is an important commercial fish in Hokkaido and northeastern Japan, and its resources are maintained by stock enhancement programs (Nagata et al. 2012; Miyakoshi et al. 2013; Kitada 2014). Japanese chum salmon likely experience substantial mortality when entering the sea and reaching the Sea of Okhotsk; however, little is known about the causes of this early mortality. Following their release, juvenile chum salmon spend days to weeks in the river (Hasegawa and Takahashi 2013; Kasugai et al. 2013), and the nutritional condition of individuals decreases during this time (Shimizu et al. 2016). In the salmon of eastern Hokkaido, the adult return rate tends to be low when coastal water temperatures are low, during the early stages of marine life (Nagata et al. 2016). Thus, sea surface temperature (SST) has been implicated as a key factor in determining the distribution and outmigration of chum salmon along the coast. When juvenile chum salmon experience low water temperatures ($\leq 5^{\circ}\text{C}$) in coastal waters, their movements are restricted and their growth ceases (Miyakoshi et al. 2007; Kasugai et al. 2012). However, it is unclear whether the nutritional conditions of freshwater and SST interact to affect the growth and swimming ability of juvenile chum salmon. The purpose of this study is to elucidate the combined effects of freshwater feeding status and seawater temperature on the swimming ability of juvenile chum salmon under laboratory conditions.

Fig. 1. Design of rearing experiments. The experiment was conducted in April and May 2018. Salmon fry were reared in freshwater at feeding rates of 0, 1, and 3% for five days, followed by seawater rearing with sufficient food at 4, 7, and 10°C, respectively.

Juveniles weighing approximately 1.0 g were categorized into the following three groups and reared in freshwater for five days at different feeding rates (FR): 0% (fasted), 1%, and 3% per body weight. Fish from each group were then acclimated for three days to seawater at low (5°C), medium (7°C), or high (10°C) temperatures, creating nine treatments (Fig.1). Fish were then reared for an additional five days in which they were fed to satiation. Critical swimming speed (U_{crit} , Brett 1964) was evaluated using a stamina tunnel as an indicator of swimming ability.

U_{crit} was affected by both fasting experience in freshwater and seawater temperatures (Fig.2). U_{crit} on the 5th day of seawater rearing was not affected by the feeding rate during freshwater rearing, but the effect of seawater temperature was observed and was significantly lower in the 5°C group. On the 10th day of seawater rearing, there was a significant difference in U_{crit} between the FR 0% group and the FR 3% group. U_{crit} was also significantly lower at lower water temperatures.

The results of this study indicate that low seawater temperatures reduce the swimming ability of juvenile chum salmon, and that relatively short periods of freshwater fasting affect swimming ability. The effect of water temperature on swimming ability is known in many salmonid fishes. However, the possibility that nutritional status during freshwater life affects swimming ability after the transition to seawater is a new finding. The improvement of nutritional status may contribute to the improvement of the survival rate of hatchery juvenile chum salmon after release.

Fig. 2. Effects of feeding rate in freshwater and transfer to a different seawater temperature with feeding on critical swimming speed (U_{crit}) for juvenile chum salmon. Values are expressed as means $\pm$ SE ($n = 10$). The effect of feeding rate during freshwater rearing was tested by the Kruskal-Wallis test. Results of the experiment on days five and ten after seawater transfer were analyzed using a two-way ANOVA (feeding rate $\times$ temperature). A two-way analysis of variance showed no interaction between feeding rate and seawater temperature. Therefore, multiple comparison tests were performed using the Tukey-Kramer method, with the level of statistical significance taken as $p < 0.05$. Groups sharing the same letter are not significantly different.

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