Factors that Affect the First Year Growth of Chum Salmon Released from Japanese Hatcheries

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Increased abundance has been related to reduced adult size in a number of studies from the mid-1960s to the mid-1990s (Kaeriyama 1989, 1998, 1999; Ishida et al. 1993; Bigler et al. 1996). The authors suggested that density-dependent processes play important roles in regulating their ocean growth because these reductions in size occurred simultaneously in geographically widespread populations. However, salmon abundance is generally thought to be determined during their coastal residence period (e.g., Mueter et al. 2002). Accordingly, salmon abundance in the Bering Sea would be related to the abundance of survivors in the coastal waters. From this point of view, the density-dependent growth in the Bering Sea would also be related to the coastal events in different regions of the Pacific Rim. Thus, studies of density-dependent processes during the early ocean life of salmon are indispensable. In the present study, year-to-year variations in growth at age 0.1 (hereafter the first year growth) were investigated using age 0.3 chum salmon of 1977–1999 brood years returning to five rivers (Ishikari, Shari, Nishibetu, Tokachi, and Yurappu Rivers) in Hokkaido, Japan.

The first year growth of individual fish was estimated by their scale increments at age 0.1 (i.e., radius at the first annulus). Scale measurements were conducted using a microscope ($\times$ 25) equipped with a scale measurement system (ARP/W, Version 3.20. Ratoc system engineering Co. Ltd., Tokyo, Japan). The measurements were directly used as an indicator for the first year growth of individual fish. Although sample size varied from six to 114 between sexes, as well as among the populations and brood years, 202 (87.8%) of 230 samples (2 sexes $\times$ 5 populations $\times$ 23 brood years) consisted of more than 30 fish. In total, scales from 10,917 fish were measured. Brood-year averages were then obtained for both sexes from the five populations.

Annual variations in the first year growth were compared between male and female within each population as well as among the populations, by using the correlation analysis of Pyper and Peterman (1998). The method adjusts degrees of freedom for significance tests, taking autocorrelation of data into account. I selected it rather than the standard product-moment correlation analysis because some of the time series of the brood-year averages showed significantly autocorrelation. The brood-year averages were significantly correlated within each population (r = 0.70–0.94, $p < 0.01$ for all tests), but not completely synchronous among the populations (r = -0.15–0.79, some tests were not significant). These results indicate that the first year growth varied showing some different patterns among the populations. A factor analysis was applied on the brood-year averages to group populations showing a similar trend in the growth. Three factors were observed. As result of the factor loadings, the factor 1 was associated with the growth of Shari, Nishibetu, and Tokachi populations, and the factor 2 and 3 were linked with that of Ishikari and Yurappu populations, respectively.

Although each factor grouped populations according to similarities in the first year growth, the factor analysis cannot identify mechanisms. To understand possible components of the factors, I examined relationships between the factors and effects of hatchery programs and ocean conditions. As effects of hatchery programs, I considered the following two variables: (1) the number of released chum fry from Hokkaido and (2) the brood-year averages of size at release for each population. Effects of ocean conditions were evaluated by sea surface temperature (SST) in the following five areas: mean March–July SST in (1) Japan Sea coast (JS area; 43–46˚N, 140–142˚E); (2) Okhotsk Sea coast (OH area; 43–46˚N, 142–147˚E); (3) East and (4) West of Erimo Peninsula coasts (EP and WP areas; 41–43˚N, 143–146˚E and 41–43˚N, 140–143˚E, respectively); and (5) mean August–November SST in the Okhotsk Sea (Okhotsk Sea; 46–59˚N, 142–157˚E). The areas where SST were analyzed corresponded approximately to areas that juvenile salmon occupied during their early ocean life. Original SST data, expressed as ten-day mean SSTs for 1˚ $\times$ 1˚ mesh, were provided by the Japan meteorological agency (Near-GOOS Regional real time database). For the hatchery and SST variables, time series that corresponded to 1977–1999 brood years were prepared, and then they were utilized as independent variables for constructing multiple regression models that incorporated each factor as dependent variable. Variable selection for each model was carried out with a stepwise method. As result of multiple regression analyses, the factor 1 was more strongly affected by the mean size at release of Shari, Nishibetu and Tokachi populations, indicating a possibility that release of chum fry with larger size contributed to increasing

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the first year growth of those populations. The factor 2 was positively related to the SST in the JS area, where chum salmon released from Ishikari River are distributed before leaving from Japan. However, since the value of the coefficient of determination (R^2) was extremely low ($R^2 = 0.14$), the model was thought to poorly explain the appropriate components that affected the growth of Ishikari population. The factor 3 was positively linked with the SST in the Okhotsk Sea, and negatively related to the number of released chum fry and the SST in the EP area. Among those variables, the number of released chum fry was the most influential variable. Although the number of released chum fry is not a direct indicator for abundance of juvenile salmon during early ocean life, this result indicates that density-dependent growth may have occurred in Yurappu population.

The present study suggests that the factors affecting the first year growth of chum salmon are probably different among populations. Included in these factors are effects of hatchery programs as well as ocean conditions.

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