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Where, When, and How Does Mortality Occur for Juvenile Chum Salmon *Oncorhynchus keta* in Their First Ocean Year?

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Chum salmon (*Oncorhynchus keta*) migrate seaward as fry, and move from the coast of Hokkaido offshore by the end of their juvenile stage after completing ossification (Fig. 1; Kaeriyama 1986). Migration patterns of juvenile chum salmon can be summarized as (1) prior residence near the spawning area, (2) growth inversion in the river, (3) foraging and initial migration along the coast (Kaeriyama and Ueda 1998). Ishikari River juvenile chum salmon migrate to the Okhotsk Sea at 120 mm length by the end of June (Mayama and Ishida 2003). We investigated the relationship between growth and survival of juvenile chum salmon released from the Ishikari River in the first ocean life year to clarify critical mortality mechanisms affecting the life history strategy of chum salmon.

We analyzed 2,432 scales of female chum salmon collected in the Ishikari River during 1970–2001 except for 1973 and 1985. Scale distances and numbers of circuli from the focus to the inner edges of check (Rcj and Ros) and annuli (r1–r4) were measured by a scale image processor (Ratoc System Engineering Co.). Individual growth in fork length was back-calculated from the scale radius based on Kaeriyama et al. (in press). Data on sea surface temperature (SST) during 1950–2004 were provided by the Meteorological Agency of Japan as a monthly mean of 1° latitude and longitude blocks (25–49°N, 121–180°E) and satellite data from the NVHRR/NOAA (50–56°N, 145–155°E).

Analysis of Ishikari River chum salmon scales showed that younger adults grew faster than older fish in the first ocean life year (Fig. 2; $H = 26.22$, $P < 0.001$). In all age groups of salmon, growth during the first year increased in the 1990s. The number of circuli in the first year also increased in the 1990s despite no change in circulus intervals (Fig. 3). This growth increase occurred in the Okhotsk Sea, but not in the coast of Hokkaido (Fig. 4). In the Okhotsk Sea, the extent of ice cover decreased in the 1990s (Ustinove et al. 2002). The correlation map also showed that the ice cover area was negatively correlated with winter SST in the Okhotsk Sea (Fig. 5). Growth and circuli numbers of Ishikari River chum salmon at the first year was negatively correlated with sea ice concentration in winter (Fig. 6a, b), and positively correlated with SST during summer and fall in the Okhotsk Sea (Fig. 6c, d). The correlation map indicated that the growth anomaly of the Ishikari River chum salmon strongly positive-correlated with summer and fall SST in the Okhotsk Sea (Fig. 7). According to Merzlvakov et al. (2005), zooplankton biomass in the Okhotsk Sea has decreased since the 1980s. These results suggest that the growth of the Ishikari River chum salmon will be affected by SST in summer and fall and not by productivity

Fig. 1. The developmental stage of chum salmon in their early life period (modified from Kaeriyama 1986).

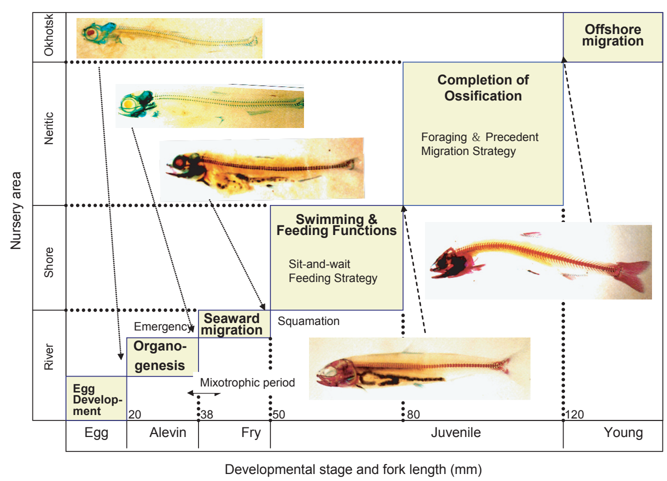


Fig. 2. Mean and standard deviation of growth (fork length, mm) at the first year of chum salmon by the age returning to the Ishikari River in 1970–2001. H, result of the Kruskal-Wallis test.

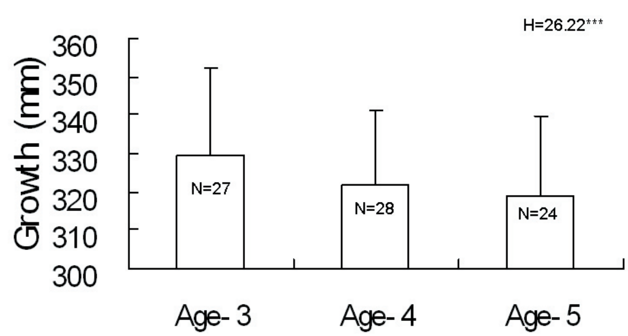


Fig. 3. Changes in mean and standard deviation of body growth (A), number and interval of circuli (B) at the first year of Ishikari River chum salmon in the Okhotsk Sea. A, age 3–5; B, age 4; I, circulus interval (μm); C, number of circuli.

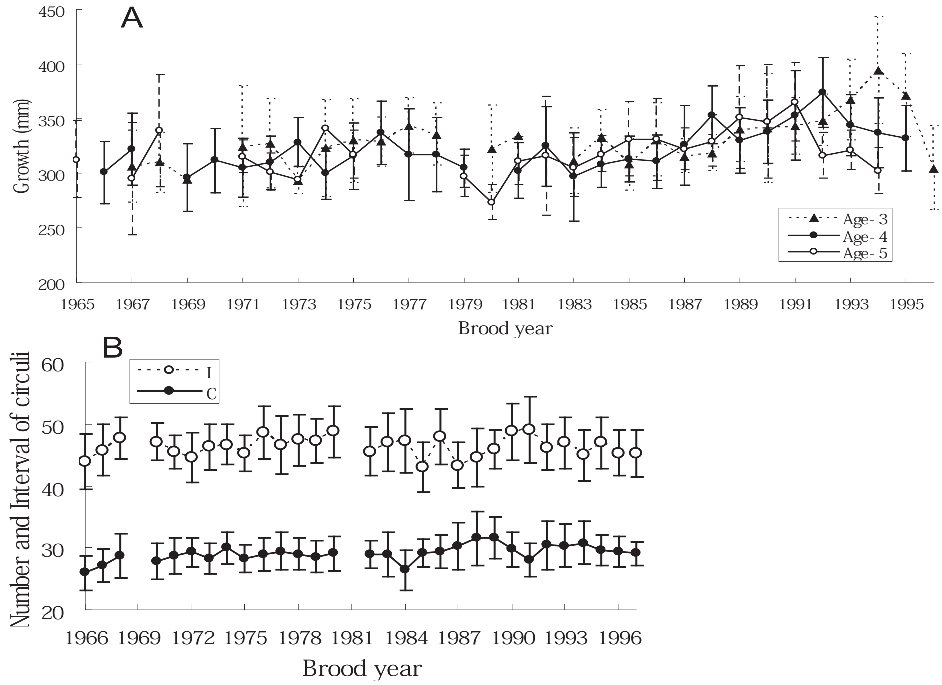


Fig. 4. Changes in mean and standard deviation of body growth at the first year for Ishikari River age-4 chum salmon in the coast of Hokkaido (Lc) and the Okhotsk Sea (Lo).

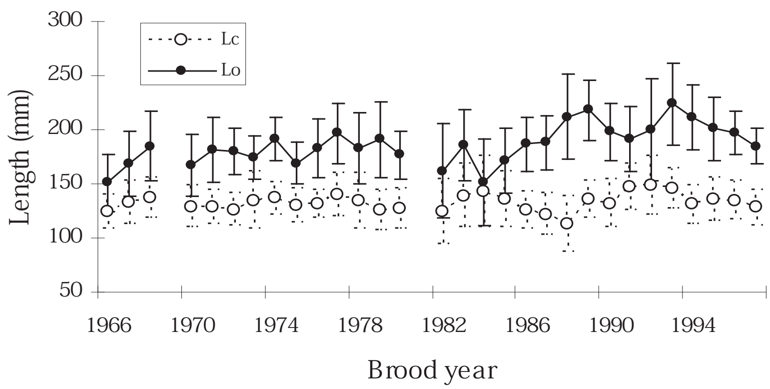


Fig. 5. Correlation map between 1° gridded sea-surface temperature in the winter (January–March) and ice cover area in the Okhotsk Sea during 1957–2004. Grey and white circles indicate positive and negative correlations, respectively.

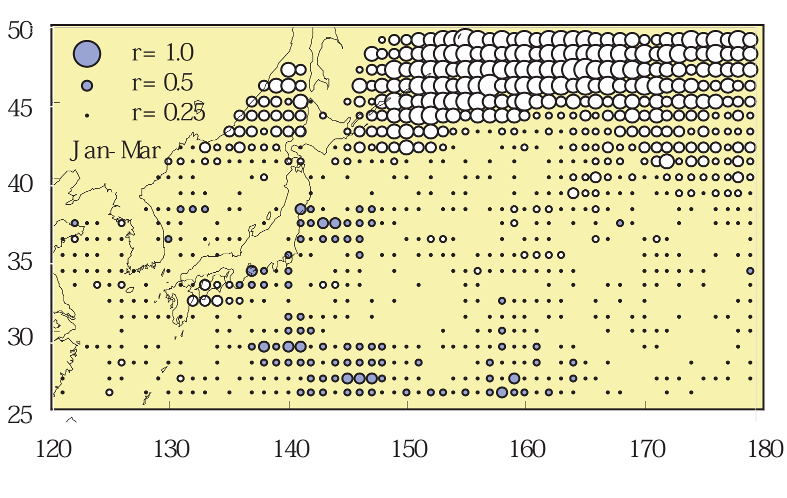


Fig. 6. Annual changes in anomalies of growth (Lo) and circuli number (Co) and sea ice concentration (SI; a and b), and the sea surface temperature (SST) during summer (c) and fall (d) in the Okhotsk Sea for age-4 chum salmon returning to the Ishikari River.

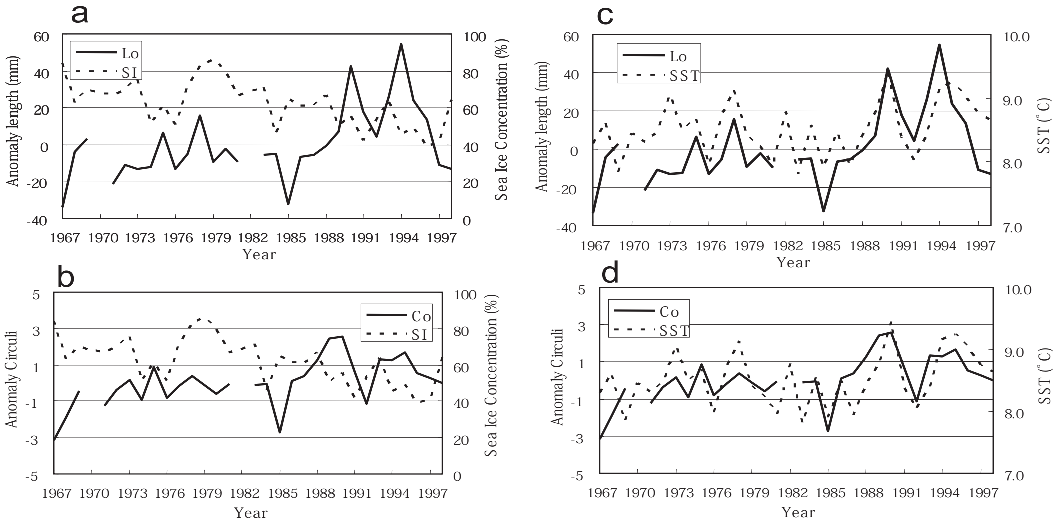


Fig. 7. Correlation map between 1° gridded sea-surface temperature in July–December and growth anomaly of the Ishikari River chum salmon in the Okhotsk Sea during 1957–2004. Grey and white circles indicate positive and negative correlations, respectively.

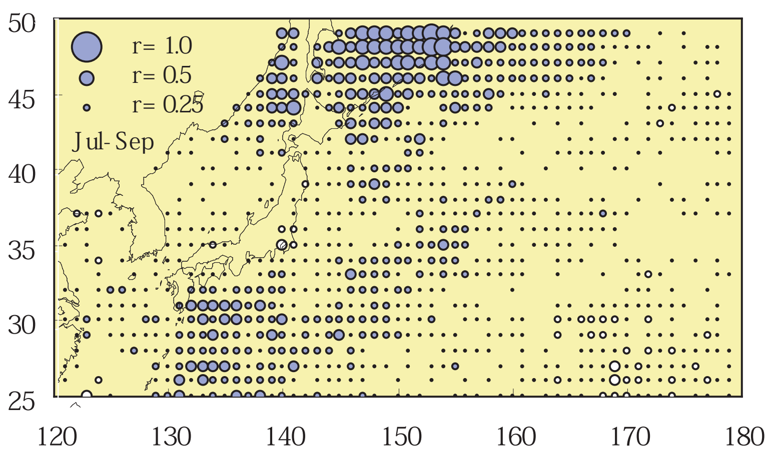


Table 1. Result of stepwise multiple regression analysis in return rate of Hokkaido chum salmon population on body size (g) at the release and growth of the Ishikari River chum salmon in the age 1.

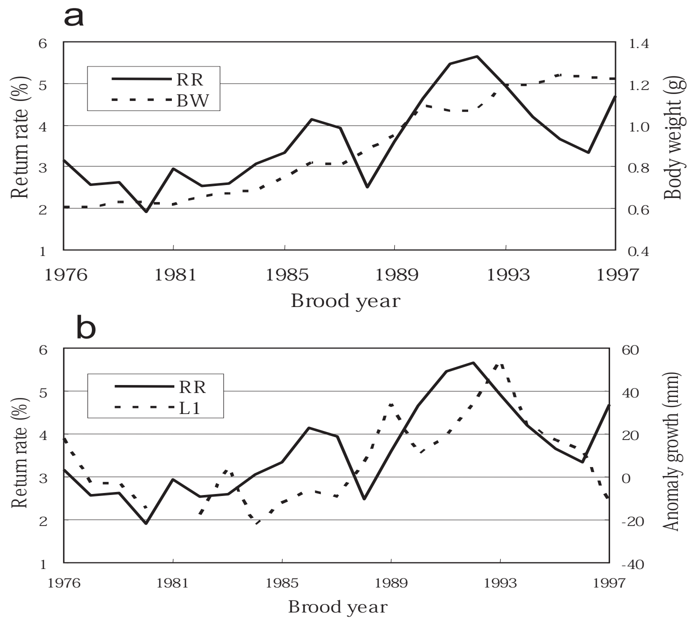
Variable	Slope	Partial Correlation	T	*P*
Body size at release	3.010	0.653	3.339	0.004
Growth in the Okhotsk Sea	0.024	0.434	1.866	0.082
Growth in the coast	-0.010	-0.112	0.437	0.668
Number of circuli in the Okhotsk Sea	-0.391	-0.425	1.817	0.089
Constant	0.965		1.235	0.236

$r^2 = 0.617$, df: n1 = 4, n2 = 20, F = 6.046, P = 0.004, AIC = 50.763

trends, relating to the sea ice concentration in the Okhotsk Sea.

The marine survival from fry to adult for chum salmon ranges from 0.3% to 3.2%, with a mean of ~1.8% (Salo 1991). There are two hypotheses on the period of critical mortality in the Pacific salmon: (1) Size-selective mortality in the early marine life period (Healey 1982) and (2) Size-related mortality over the first marine fall and winter relating to the sufficient growth by the end of the first marine summer (Beamish et al. 2004, Moss et al. 2005). Return rates of hatchery salmon measure the survival from release to return. The return rate of Hokkaido chum salmon is significantly correlated with mean body size at release (Fig. 8a) and the growth of the Ishikari River salmon in the Okhotsk Sea (Fig. 8b). However, the result of step wise multiple regression analysis in return rate on

Fig. 8. Changes in anomaly of growth at the first year (L1) of the Ishikari River chum salmon, mean body weight (BW) at the release, and return rate (RR) of Hokkaido chum salmon.



body size at release and growth in the Okhotsk Sea showed that the mortality of Ishikari River chum salmon would be higher at the seaward migration in the spring than in the first winter (Table 1).

In conclusion, 1) Larger chum salmon, which have the higher growth rate and energy metabolism in the Okhotsk Sea, migrate more rapidly than others. 2) In the Okhotsk Sea, chum growth increased in the 1990s, in association with increased SST during summer and fall, and decreased in areas of dense sea ice. 3) Chum salmon have 2 periods of critical mortality: (a) their early marine life (immediately after seaward migration), and (b) their first winter in the ocean. 4) The critical mortality of chum salmon will be higher in the early marine life than in the first winter. 5) The survival of Ishikari River chum salmon can be accurately predicted by the body size at release from hatchery and the growth in the Okhotsk Sea.

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