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The Dispersal Pattern of Juvenile Chum Salmon in the Pacific Ocean Off the Coast of Hokkaido, Japan

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Coastal residency of juvenile chum salmon, *Oncorhynchus keta*, is thought to be the period when mass mortality takes place, which often influences their brood year strength (Saito et al. 2011). Predation and/or oceanic conditions may be the main factors causing mortality, but detailed mortality processes are still unclear (Nagasawa 1998; Saito and Nagasawa 2009). Widespread dispersion of juveniles after sea entry and unknown origin of fish after mixing with other stocks after sea entry have impeded further understanding of mortality processes during the early marine period. Otolith thermal marking is a useful tool for determining the origin of juvenile salmon after they leave freshwater. In eastern Hokkaido, otolith-marked juvenile chum salmon have been released into two rivers, the Kushiro River and the Tokachi River, since 2003 and 2005, respectively. Every year, these fish are recaptured in juvenile salmon surveys carried out in coastal waters near the Shiraoi and Konbumori coasts, which are more than 300 km apart. The recapture of marked fish revealed that some juvenile salmon out-migrating from rivers in eastern Hokkaido extend their coastal distribution westward to the vicinity of Shiraoi, which was opposite to the expected eastward direction of migration (Irie 1990; Ohkuma 2007). Comparison of the movement of juveniles originating from the same river (i.e., either Kushiro or Tokachi rivers), but recaptured at either of two distant coastal areas (i.e., Shiraoi[westward] or Konbumori [eastward]) would provide new insights on the early ocean dispersal pattern of juvenile salmon and its consequences. In this study, we examined recapture data of otolith-marked juvenile chum salmon collected in coastal waters of the Shiraoi and Konbumori coasts in April-July, 2005-2010.

At both Shiraoi and Konbumori, a transect line was set and four sampling stations were located along the line from 0.4 km to 8.0 km offshore for capture of juvenile chum salmon. Juvenile salmon were collected with a two-boat surface trawl net. The net used at Konbumori was 20 m in length, 2 m in depth, and a 3-m bag in the middle section. The net used at Shiraoi was 24.3 m in length, 2.25 m in depth, and a 13.3-m bag in the middle section. Both nets were constructed using 4–38 mm mesh sizes. The protocol for net-hauling operations included a 30 min tow at each station at a speed of 2 kts. However, this procedure was not always completed for every operation because of the existence of commercial fishing boats and other fishing gear in the vicinity that had to be avoided. To adjust for the difference in sampling effort among operations, the net-hauling distance was monitored at every operation. Juvenile salmon were collected at both transects four to eight times each year. Consequently, a total of 230 net-hauls, 143 hauls at Shiraoi and 87 hauls at Konbumori, was conducted in 2005–2010. Juvenile salmon samples were stored at -18ºC or less until further analyses could be conducted.

In the laboratory, naturally thawed juveniles were measured for fork length and body weight, and otoliths were collected to check for thermal marks. If a Tokachi River or Kushiro River chum salmon was identified based on the thermal mark on an otolith, the second of the paired otoliths from that fish was utilized for microstructure analysis. In the microstructure analysis, the otolith check formed at the time of sea entry (SEC) was detected under a microscope, then (i) the radius from the otolith core to the SEC, (ii) the number of growth increments from the SEC to the otolith edge, and (iii) the spacing of each growth increment from the SEC to the edge were measured using an otolith measurement system (ARP/W+RI version 5.30, Ratoc System Engineering Co. Ltd, Tokyo). From these measurements, the back-calculated fork length at sea entry (mm), date of sea entry, and average daily growth (mm) within the first week after sea entry were estimated for each marked juvenile salmon. The details of the otolith microstructure analysis were reported by Saito et al. (2007, 2009).

The recapture location (Shiraoi or Konbumori) was analyzed using the binominal GLM. The dependent variable was absence-presence data at Shiraoi, in which fish recaptured at Shiraoi and Konbumori were assigned to “1” and “0”, respectively. Possible explanatory variables included year, river of release, number of released fish, date of sea entry, fork length at sea entry, and average daily growth (mm) within the first week after sea entry. To adjust for the difference in sampling effort among years and between locations, the net-hauling distance was used as an offset variable. Model selection was made using the Akaike Information Criteria.

A total of 351 juvenile chum salmon released from the Tokachi or Kushiro rivers was recaptured during 2005–2010. During the study period, 96 fish from the Tokachi River and six fish from the Kushiro River were collected at Shiraoi, and 185 fish from the Tokachi River and 64 fish from the Kushiro River were caught at Konbumori. Year, date of sea entry, and fork length at sea entry were selected as the explanatory variables of the final GLM model. When the fork length at

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sea entry was set to 59.5 mm, which was the average value for all juveniles estimated in this study, the model predicted that out-migrants with an earlier date of sea entry have a higher probability of movement to Shiraoi. In addition, year-to-year variability in the probability of arrival at Shiraoi was also evident. When the 50% probability point of the model was compared among the years, the timing of sea entry varied from late April in 2008 and 2009 to mid-May in 2005 and 2010. The average date of sea entry of fish going to Shiraoi with a 50% probability was estimated to be 6 May. When the date of sea entry was fixed at 6 May, the fork length at sea entry showed remarkable annual variability. For instance, at a 50% probability of fish moving to Shiraoi, the model predicted that in 2005 and 2010 fish would need to be 45 mm fork length at sea entry. In 2008 and 2009, the fish would need to be 80 mm fork length at sea entry to be found at Shiraoi at the same level of probability. When the date of sea entry was assumed to be 6 May across years, results indicated the larger a fish was at the time of sea entry, the higher the probability of it going to Shiraoi. The year effect of the model, based on the condition that the date of sea entry was 6 May and the fork length at sea entry was 59.5 mm, predicted probabilities from 12% to 86% of fish moving to Shiraoi. These probabilities correlated with the number of adult returns (sum of age-0.1 and -0.2 adults) of the corresponding brood years in the Tokachi River (Spearman's rank correlation: $rs = 0.89$, $n = 6$, $p < 0.05$). A similar correlation was observed for returns to the Kushiro River, but the coefficient was not statistically significant (Spearman's rank correlation: $rs = 0.71$, $n = 6$, $p > 0.05$). These findings indicated that a chum salmon brood year having a higher probability of going to the Shiraoi coast showed relatively higher ocean survival.

In this study, we demonstrated that out-migrants with an earlier date of sea entry, or fish having a larger fork length at sea entry, had a higher probability of westward dispersion after sea entry, which was a direction of movement opposite to what was previously thought. In addition, a brood year having a higher probability of westward dispersion showed higher adult returns to their natal rivers. This implies that wide dispersion during early ocean life may give juvenile salmon opportunities to exploit various habitats and plays an important role in reducing mass mortality of salmon during early marine life.

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