Effects of Ocean Currents on Juvenile Chum Salmon Migration

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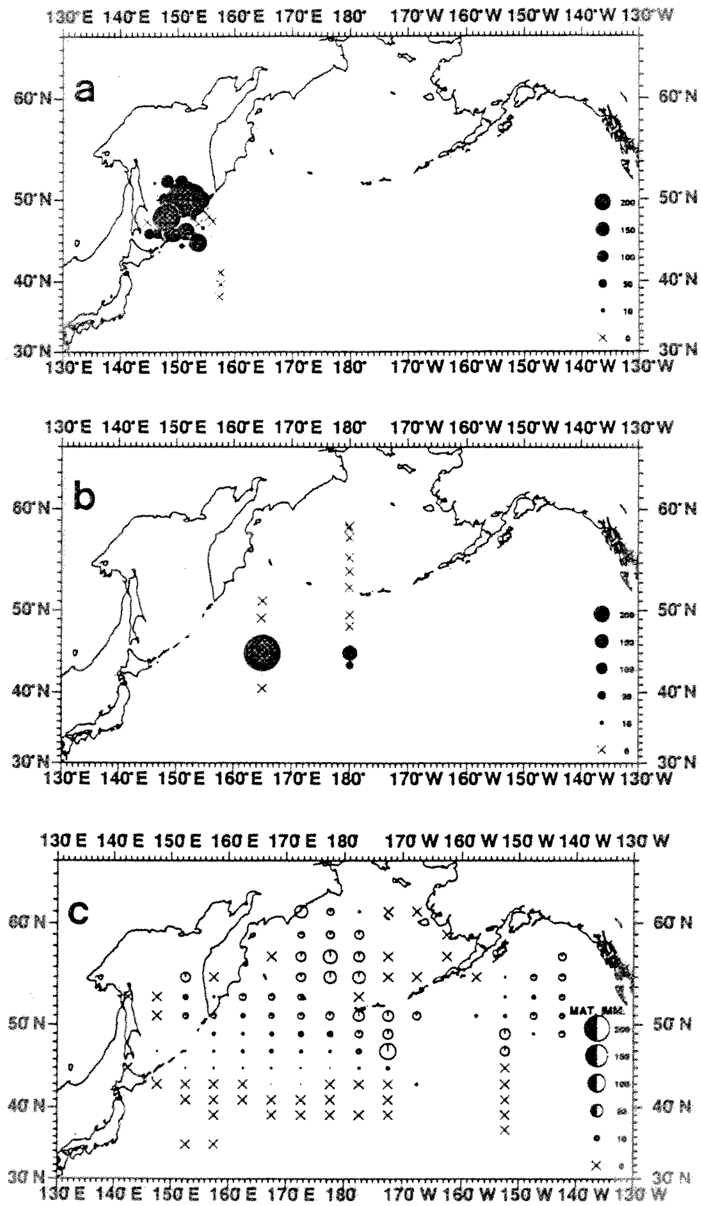
Fig. 1. Observed distributions of juvenile and immature chum salmon. (a) November. (b) February. (c) July.



Recent juvenile salmon research indicates that juvenile chum salmon at age .0 migrate from the central part to the southern part of the Sea of Okhotsk in mid autumn (Ueno and Sakai 1998) (Fig. 1 (a)). Juvenile chum salmon at age .0 were not found in the north part of the central North Pacific Ocean in the early winter, but they were distributed in the western North Pacific in mid and late winter. But juvenile chum salmon at age .1 were not found in the Bering Sea in mid winter (Fig. 1 (b)). In June, immature chum salmon at age .1 were distributed from 40°N to 50°N. In July, they were widely distributed from 45°N to 60°N (Fig. 1 (c)). Immature chum salmon at age .1 were most abundant in the Bering Sea in July and August, compared to the number in the central North Pacific Ocean. Urawa (personal communication) reported that Japanese and Russian chum salmon were distributed in the central North Pacific Ocean and the Bering Sea in the summer. Thus, juvenile chum salmon might migrate eastward from the western North Pacific Ocean to the central North Pacific Ocean during winter and spring, and enter the Bering Sea in summer of their second marine year. Ueno et al. (1999) hypothesized that salmon juveniles were carried eastward by the strong eastward ocean currents from the western to the eastern North Pacific Ocean. However, it is still unclear how the ocean currents contribute to the migration of chum salmon and why juvenile Japanese chum salmon enter the Bering Sea in summer of their second marine year. We examined this problem by studying the temporal effect of ocean currents and salmon distribution using a salmon migration model.

The data were collected from Japanese salmon research vessels in offshore waters of the North Pacific Ocean from 1972 to 1999. Sea surface temperatures (SST) were monthly mean sea surface temperature from 1991 to 1997 provided by Japan Meteorological Agency. Wind driven currents were calculated from climatological wind stress data by Hellerman and Rosenstein (1983). Geostrophic currents were computed from satellite altimetry data of TOPEX/Poseidon in 1991 to 1997 with 5-day and 1 degree of latitude and longitude resolution provided by the Japan Meteorological Agency.

The salmon migration model was essentially a particle-tracking model coupling the passive particle-tracking component and the active salmon swimming component. The passive particle-tracking component was driven by the surface currents, geostrophic currents, and wind driven currents. The active swimming speed of chum salmon was assumed to be 1 body length/second as suggested by Ware (1978). Direction of the salmon swimming depended on the salmon's preferred SST. This water temperature in which salmon were distributed was estimated by weighted average with CPUE of salmon. Ocean migration was simulated for the period of 17 months from 15 September of the first simulation year to 28 February of its third year. The starting date of the simulation coincided with the date when juveniles at age .0 were found in the Sea of Okhotsk (Ueno and Sakai 1998). The starting positions of migration for Japanese, Russian, and Alaskan chum salmon were located in the Sea of Okhotsk, along the east coast of the Kamchatka, and the Alaska coast, respectively.

Calculated Japanese and Russian chum salmon at age .0 started from the Sea of Okhotsk in September and gradually moved into the western North Pacific Ocean by 30 November (after 75 days) (Fig. 2 (a)). In February (after 165 days), calculated distributions of Japanese and Russian chum salmon at age .1 were from 40°N to 50°N (Fig. 2 (b)). In 30 July (after 315 days), calculated Japanese and Russian chum salmon at age .1 were shown to enter the Bering Sea as they were observed (Fig. 2 (c)). The salmon migration model therefore reproduced the observed migration patterns of chum salmon.

We examined the following three velocity components affecting the migration of Japanese chum salmon: geostrophic currents, wind driven currents, and swimming speed of chum salmon (Fig. 3). Wind driven currents affected the migration as well as the active swimming speed of chum salmon in winter. While in summer, mainly the active swimming speed of the salmon affected the migration. These results suggested that Japanese chum salmon were transported eastward by the ocean currents, and they migrated northward from the North Pacific Ocean to the Bering Sea mainly by their own swimming activity in summer.

Fig. 2. Simulated distributions of juvenile and immature chum salmon. Solid circles represent Japanese and Russian chum salmon. Crosses represent Russian chum salmon. Open circles represent Alaskan chum salmon. (a) November. (b) February. (c) July.

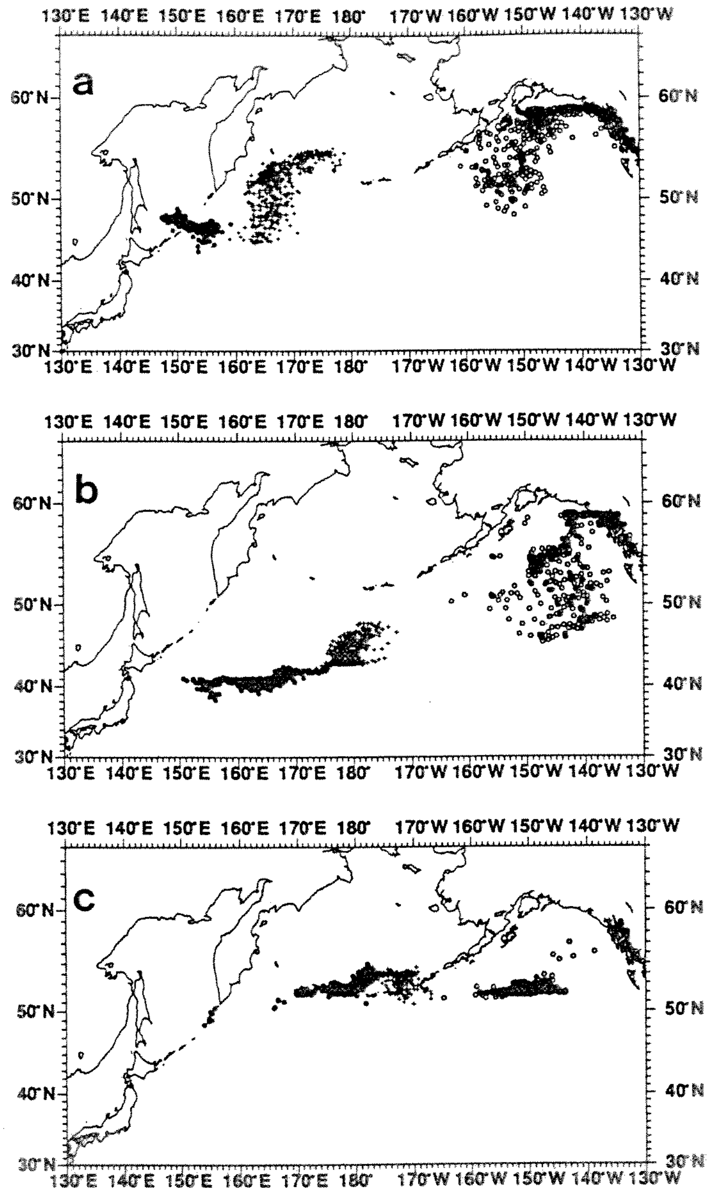
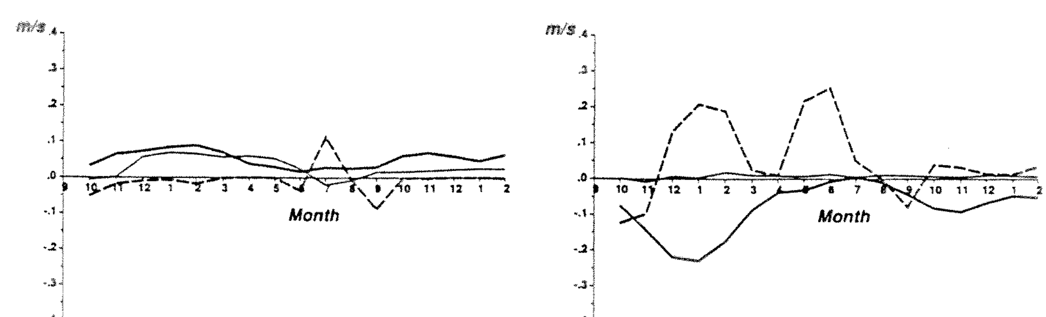


Fig. 3. Seasonal change of longitudinal component of velocity (left panel) and latitudinal component of velocity (right panel). Thick solid lines are velocity of wind driven current. Thin solid lines are velocity of geostrophic current. Broken lines are velocity of salmon actively swimming.



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