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Winter Distribution of Chum Salmon Related to Environmental Variables in the North Pacific

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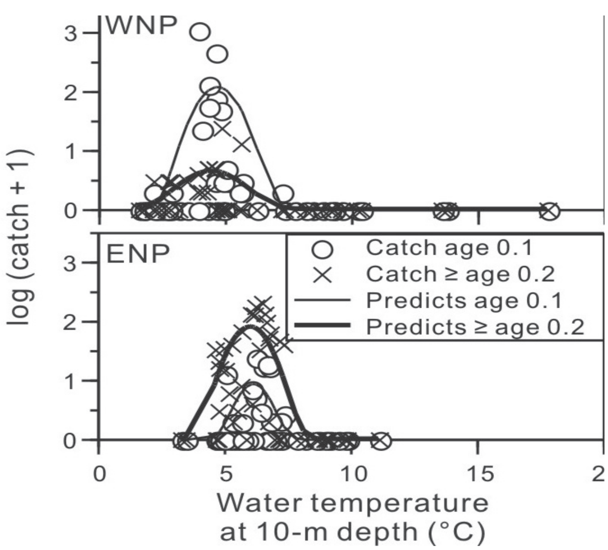
For many years, researchers have hypothesized that environmental factors are related to wintertime ocean distribution of chum salmon (e.g. Shimazaki and Nakayama 1975). In this paper, we analyzed relationships between latitude, temperature, and sea surface salinity, and the number of chum salmon caught during one-hour surface trawl operations. Data were collected during winter salmon research cruises by Japanese research scientists onboard the RV *Kaiyo maru* in the North Pacific (1992, 1996, 1998, and 2006) and Bering Sea (1998).

Fig. 1. Relationship between log-transformed catch of chum salmon caught in one-hour trawls and water temperature at 10-m depth. Fishing operations were conducted during winter in the western North Pacific (WNP; upper) and the eastern North Pacific (ENP; lower). Lines indicate the mean catch of young and older age chum salmon at temperatures predicted by a distribution model.



We constructed a chum salmon distribution model in which the number of salmon caught was a bell-shaped function of each environmental factor (latitude, temperature, or salinity), and trawl catches followed a negative binomial distribution with the mean predicted using a distribution model (i.e. we assumed an aggregate fish distribution). It was assumed that environmental factors did not affect trawl catch efficiency. We fit models to the catch data using the maximum likelihood method, and the best model fit was determined using the Akaike Information Criterion.

Results showed water temperatures in the surface layer in the western North Pacific (west of 180°; WNP) were cooler than in the eastern North Pacific (east of 180°; ENP) in winter. Young chum salmon experiencing their first winter at sea (age 0.1) were abundant in the WNP, and older-aged fish (≥ age 0.2) were abundant in ENP. Both groups of fish were distributed in a narrow latitudinal range, i.e. north-to-south, in the WNP, and in a wide latitudinal range in the ENP. In both areas, young and older-aged chum salmon were distributed in a narrow range of temperatures and in a wide range of salinities.

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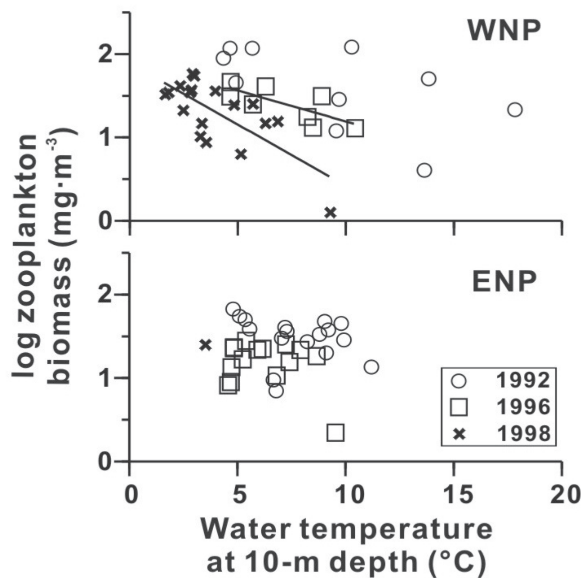
The best fitting model of observed catches of age 0.1 and older-aged chum salmon was a function of water temperature at the 10-m depth by area. The estimated temperature at the center of salmon distribution in the WNP was 4.67°C ± 0.70 SD for age 0.1 fish and 4.48°C ± 1.03 SD for older-aged fish. In the ENP the estimated temperature at the center of salmon distribution was 6.13°C ± 0.55 SD for age 0.1 fish and 6.05°C ± 0.64 SD for older-aged fish (Fig. 1). The estimated temperature ranges were similar for both age groups, although estimated ranges in the WNP were lower than in the ENP.

The estimated temperature range of chum salmon distribution in winter was lower than in summer (6–11°C). This was consistent with a qualitative prediction of the growth-maximization hypothesis (GMH), which states that salmon select thermal habitats and have foraging behaviors that maximize growth rate (Rand 2002). The optimum temperature for salmon growth is lower at a lower ration level (Brett 1979). Therefore, we conclude the optimum temperature for growth of chum salmon should be lower in winter because zooplankton biomass collected at survey sites was about 10% lower in winter than in summer (Nagasawa 2000).

Fig. 2. Relationship between log-transformed zooplankton biomass and water temperature at 10-m depth in winter in the western North Pacific (WNP; upper) and the eastern North Pacific (ENP; lower). Lines indicate regression equations: log zooplankton biomass = 1.94 – 0.0744 temp (R2 = 0.558, p = 0.033) in 1996 WNP, and log zooplankton biomass = 1.89 – 0.147 temp (R2 = 0.529, p < 0.001) in 1998 WNP. Regressions were not significant (p > 0.05) in 1992 WNP, or during any year in the ENP.



The GMH could explain the difference in temperature ranges of chum salmon distribution between the WNP and ENP. We reanalyzed zooplankton biomass from the 1992, 1996, and 1998 *Kaiyo maru* winter surveys (Nagasawa 2000). Although the mean zooplankton biomass was similar between the WNP and ENP (ANCOVA, $p = 0.160$), there was a significant increase in zooplankton abundance with decreasing temperature in the WNP in 1996 and 1998 (Fig. 2). In contrast, there was no relationship between zooplankton abundance and water temperature in the ENP. Therefore, chum salmon may be distributed in cooler waters in the WNP than the ENP in order to avail themselves to greater foraging opportunities in areas of higher zooplankton abundance.

REFERENCES

Brett, J.R. 1979. Environmental factors and growth. *In* Fish physiology, Vol. 8. Bioenergetics and growth. *Edited by* W.S. Hoar, D.J. Randall, and J.R. Brett. Academic Press, New York. pp. 599–675.

Nagasawa, K. 2000. Winter zooplankton biomass in the subarctic North Pacific, with a discussion on the overwintering survival strategy of Pacific salmon (*Oncorhynchus* spp.). N. Pac. Anadr. Fish Comm. Bull. 2: 21–32.

Rand, P.S. 2002. Modeling feeding and growth in Gulf of Alaska sockeye salmon: implications for high-seas distribution and migration. Mar. Ecol. Prog. Ser. 234: 265–280.

Shimazaki, K., and N. Nakayama. 1975. Distribution of the three salmonid fishes (*Oncorhynchus*) in the Northwestern North Pacific in winter. Bull. Fac. Fish., Hokkaido Univ. 26: 87–98. (In Japanese with English abstract).