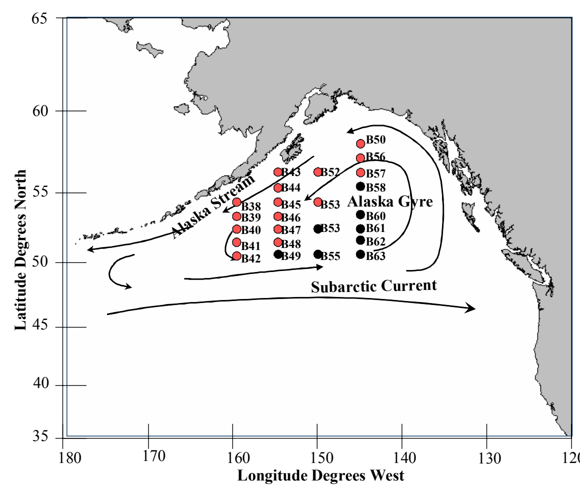
Spatial Comparison of the Feeding Ecology of Sockeye (*Oncorhynchus nerka*) and Pink Salmon (*O. gorbuscha*) in the Ocean during the Summer of 2003

Miwako Kitagawa[1], **Tomonori Azumaya**[2], **Katherine W. Myers**[3], and **Masahide Kaeriyama**[4]
[1]School of Engineering, Hokkaido Tokai University,
5-1-1-1 Minamisawa, Minami-ku, Sapporo, Hokkaido 005-8601, Japan
[2]Hokkaido National Fisheries Research Institute, Fisheries Research Agency,
116 Katsurakoi, Kushiro, Hokkaido 085-0802, Japan
[3]High Seas Salmon Research Program, School of Aquatic and Fishery Sciences, University of Washington,
Box 355020, Seattle, WA 98195-5020, USA
[4]Graduate School of Fisheries Science, Hokkaido University,
3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan

Keywords: Pink salmon, sockeye salmon, feeding ecology, spatial overlap

Research on the feeding ecology of Pacific salmon has been carried out in the North Pacific Ocean and adjacent seas since the late 1950s (e.g., Ito 1964; LeBrasseur 1966; Shimazaki and Mishima 1969; Pearcy et al. 1988, 1999; Aydin et al. 2000; Kaeriyama et al. 2000, 2004; Radchenko and Mathisen 2004). These studies have shown that salmon are extremely adaptable to changes in the ocean environment and their forage base, and prey on a wide diversity of organisms. In summer 2003, the Japan BASIS study area was expanded to adjacent North Pacific waters in order to investigate potential changes in the distribution and feeding ecology of salmon during a year of high abundance of Asian pink salmon (*Oncorhynchus gorbuscha*). In this paper we investigate spatial differences in the feeding ecology of immature sockeye (*O. nerka*) and maturing pink salmon in the western Gulf of Alaska (145–160°W, 50–58°N), examine the effects of oceanographic environment and biological interactions on salmon feeding behavior, and evaluate our methods and results with respect to future BASIS research.

Fig. 1. Locations for collections of Pacific salmon (red circles) and CTD-data (red and black circles) in the Gulf of Alaska in August 2003.



Salmon samples were collected aboard R/V *Kaiyo maru* during daytime (1-hr) tows of a surface trawl at 16 stations in the western Gulf of Alaska (145–160°W, 50–58°N) from 2 August to 14 August 2003. A conductivity, temperature, and depth sensor (CTD) was used at 24 stations in the same area for measuring water temperature and salinity (Fig. 1). The relative abundance or catch per unit effort (CPUE) of each species at each station was calculated as the number of individuals caught per 1-hr tow of the trawl. The whole body mass (BW, g), gonad somatic mass (GSW, g), and fork length (FL, mm) of salmon were measured. Stomachs were collected from up to 10 fish of each salmon species at each trawl station, and preserved in a 10% Formalin-seawater solution. Stomach contents were classified to 12 taxa (Kaeriyama et al. 2000) to the lowest identifiable taxon using a dissecting microscope, and counted and weighed by species. A gonad somatic index (GSI; GSW / BW × 100) was used to evaluate the maturity stage. Stomach contents were analyzed in terms of a stomach index (SCI; prey weight × 100 / BW), as well as a modified index of relative importance (IRI) method (Pinkas et al. 1971; Kaeriyama et al. 2000). The Shannon-Wiener index (H'; Colwell and Futuyma 1971) was used to measure prey diversity. A simplified Morishita's index (C_H; Horn 1966) was used to estimate diversity and similarity of food niche between species by their prey composition. The average linkage clustering method (Krebs 1998) was used to estimate food similarity among sampling stations by prey composition. Student's and Welch's t-tests, and a nonparametric Mann-Whitney

All correspondence should be addressed to M. Kaeriyama.
e-mail: salmon@fish.hokudai.ac.jp

test were used to compare biological characters of sockeye and pink salmon. Significance in all tests was accepted at the P = 0.05 level.

In August 2003, stations in the Alaska Stream (B38, B43, B50, and B56) had warmer water temperatures than stations farther offshore in the Alaska Gyre (Fig. 2). Sockeye salmon were distributed in more southern areas (51–53°N, 155–160°W) than pink salmon (54–56°N, 155–160°W). The CPUE of sockeye salmon (8.79±10.34 fish) was higher than that of pink salmon (5.52±10.18 fish), although the difference was not significant (Mann-Whitney test; P = 0.93). Pink salmon were significantly larger (FL 514±34 mm, BW 1,666±289 g) than sockeye salmon (FL 425±65 mm, BW 905±462 g; Welch's t-test; P < 0.001). The GSI of female pink salmon (8.05±2.25) was significantly higher than that of female sockeye salmon (0.53±0.56; Student's t-test; P < 0.001). Most of female pink salmon were fully mature. Pink salmon distributed in coastal waters (Alaskan Stream) were at the maturing stage during their homing migration, whereas sockeye salmon distributed on the high seas (Alaska Gyre) were at the immature stage.

Sockeye salmon (0.80±1.08, n = 94) had a higher SCI than pink salmon (0.48±0.50, n = 35), although the difference was not significant (Mann-Whitney test; P = 0.98). The offshore sockeye salmon had a higher SCI than coastal fish. Immature sockeye and maturing pink salmon consumed diverse prey, e.g., fishes, squids, amphipods, decapods, and pteropods (Figs. 3 and 4). At low CPUEs of both species, sockeye salmon fed on prey that were larger (fishes and squids) and had higher energy content than at high CPUEs. The cluster analysis results showed that sockeye salmon fed dominantly on pteropods in coastal waters, decapods in middle waters, and hyperiid amphipods and squids in offshore waters (Fig. 3), despite unclear results for pink salmon (Fig. 4). Sockeye salmon had a more diverse food niche (0.744±0.306) than pink salmon (0.417±0.384; Student's t-test; P = 0.02). These differences in feeding ecology of pink and sockeye salmon may be caused by differences in their sexual maturity. The diets of sockeye and pink salmon did not shift from small to large prey with increase in body size (Fig. 5). The feeding niche overlap of sockeye and pink salmon was high (C_H > 0.6), and both species fed on the same dominant prey (i.e., pteropods and decapods), when their distribution was sympatric (Fig. 6).

In conclusion, our results suggest that sockeye and pink salmon are omnivorous and opportunistic feeders, feeding on available and abundant prey species according to intra- and inter-specific competition, food composition, and oceanic environment. However, the sampling period (2–14 August) of our study was too late in the year to investigate the major period of overlap (winter-spring) in the distribution of sockeye salmon and Asian pink salmon in the Gulf of Alaska. More importantly, data from plankton sampling aboard the *Kaiyo maru* in August 2003 were not available at the time of our analysis. For future BASIS research, we recommend seasonal basin-scale process studies to investigate the effects of climate-induced changes in feeding conditions (especially prey composition and availability) and density-dependent interactions among species, size, age, and maturity groups, and stocks of salmon that migrate between the Bering Sea and Gulf of Alaska.

Fig. 2. Vertical profile of temperature (A) and relationship between salinity and temperature (B) in the Gulf of Alaska. Red dots: Sts. B38, B43, B50, and B56; Blue dods: other stations.

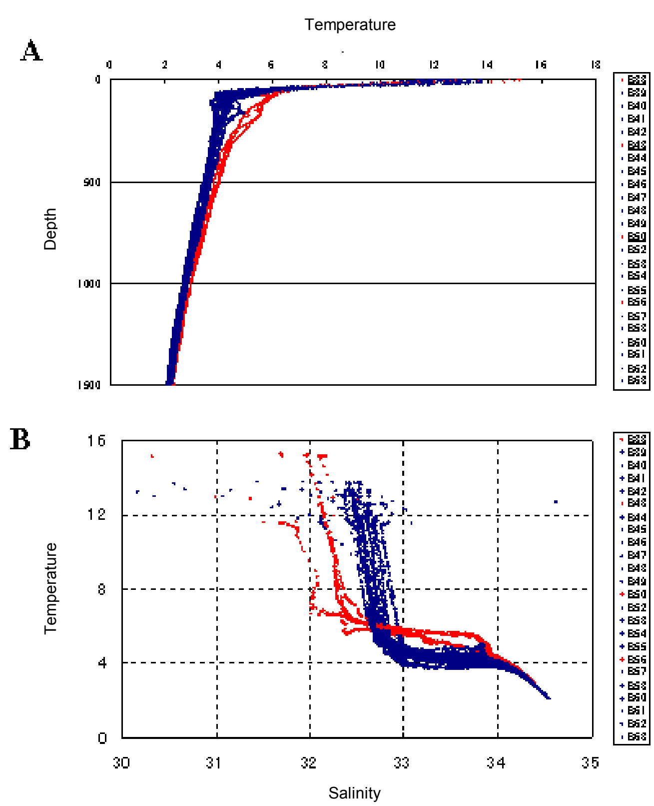


Fig. 3. IRI (A) and result of the cluster analysis (B) on stomach contents of sockeye salmon in the Gulf of Alaska in August 2003 (n: number of samples. EU: euphausiids, CO: copepods, AM: amphipods, DE: decapods, SQ: squids, PT: pteropods, FI: fish, PO: polychaetes, CH: chaetognaths, GE: gelatinous zooplankton, OS: ostracods, OT: other species).

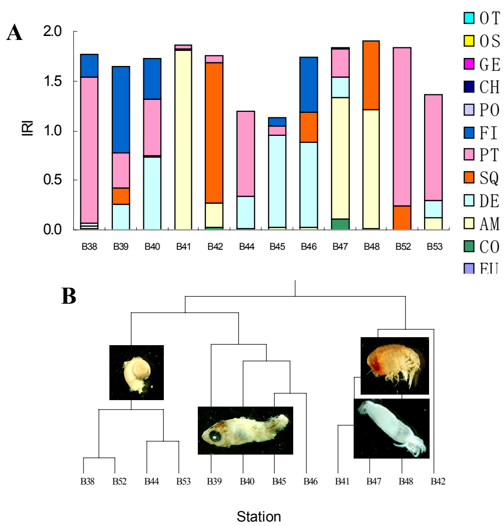


Fig. 4. IRI (A) and result of the cluster analysis (B) on stomach contents of pink salmon in the Gulf of Alaska in August 2003 (n: number of samples. EU: euphausiids, CO: copepods, AM: amphipods, DE: decapods, SQ: squids, PT: pteropods, FI: fish, PO: polychaetes, CH: chaetognaths, GE: gelatinous zooplankton, OS: ostracods, OT: other species).

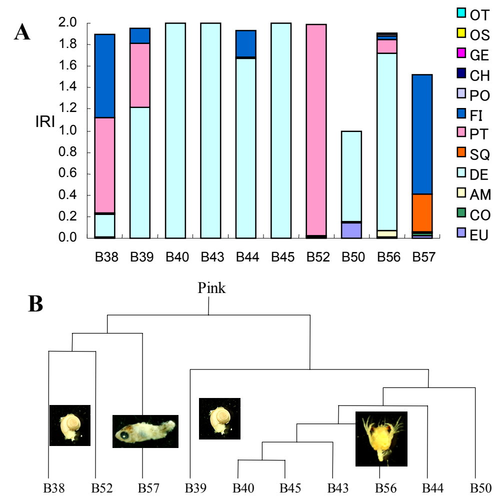


Fig. 5. Changes in rates of squid and nekton (squid and fish) occupied in the stomach of sockeye and pink salmon in the Gulf of Alaska in summer 2003.

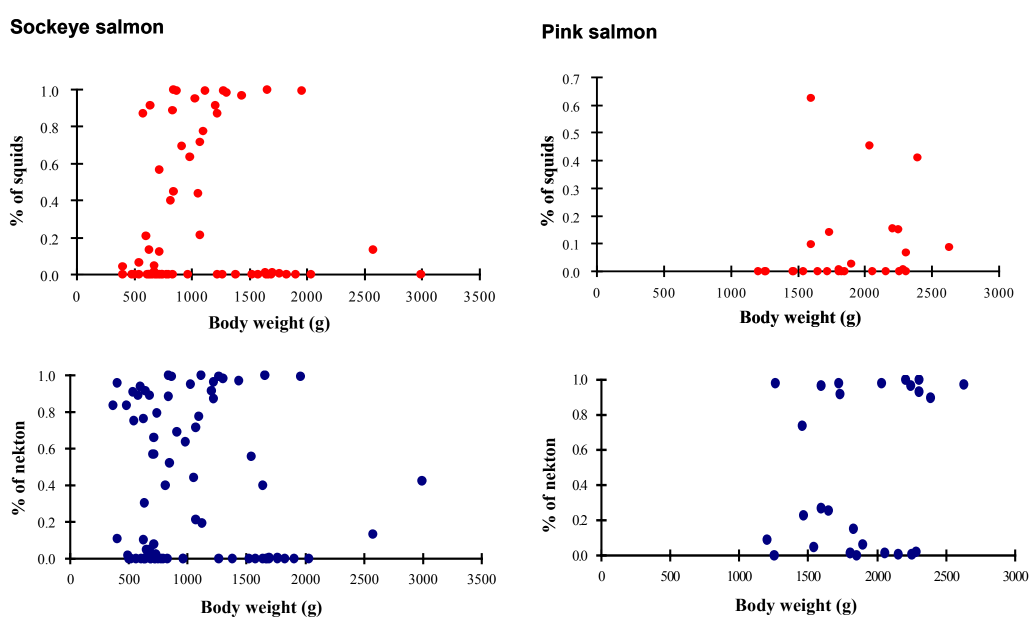
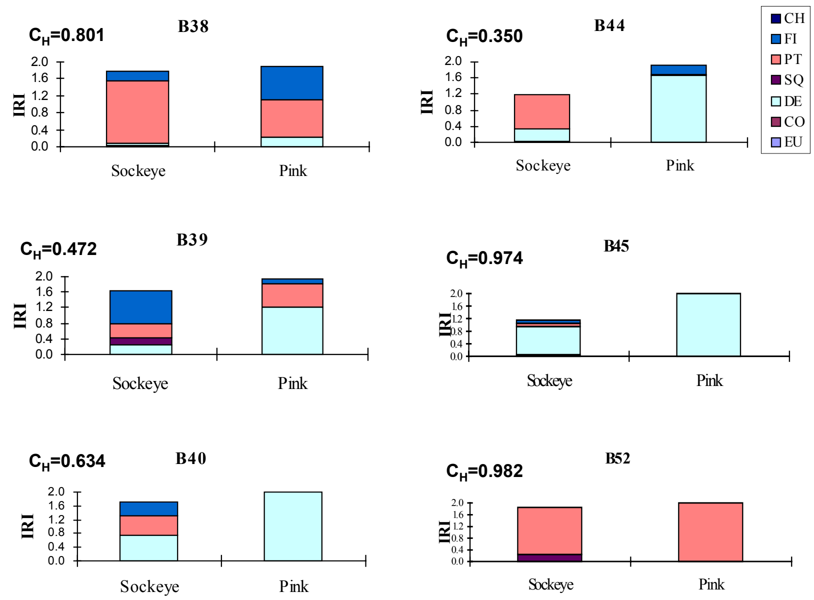


Fig. 6. Diversity and overlap of feeding niche between sockeye and pink salmon in the Gulf of Alaska in summer of 2003.



REFERENCES

Aydin, K.Y., K.W. Myers, and R.V. Walker. 2000. Variation in summer distribution of the prey of Pacific salmon (*Oncorhynchus* spp.) in the offshore Gulf of Alaska in relation to oceanographic conditions, 1994–98. N. Pac. Anadr. Fish Comm. Bull. 2: 43–54.

Colwell, R. K., and D. J. Futuyma. 1971. On the measurement of niche breadth and overlap. Ecology 52: 567–576.

Horn, H.S. 1966. Measurement of "overlap" in comparative ecological studies. Am. Nat. 100: 419–424.

Ito, J. 1964. Food and feeding habit of Pacific salmon (genus *Oncorhynchus*) in their oceanic life. Bull. Hokkaido Reg. Fish. Res. Lab. 29: 85–97.

Kaeriyama, M., M. Nakamura, M. Yamaguchi, H. Ueda, G. Anma, S. Takagi, K.Y. Aydin, R.V. Walker, and K.W. Myers. 2000. Feeding ecology of sockeye and pink salmon in the Gulf of Alaska. N. Pac. Anadr. Fish Comm. Bull. 2: 55–63.

Kaeriyama, M., M. Nakamura, R.R. Edpalina, J.R. Bower, H. Yamaguchi, R.V. Walker, and K.W. Myers. 2004. Change in feeding ecology and trophic dynamics of Pacific salmon (*Oncorhynchus* spp.) in the central Gulf of Alaska in relation to climate events. Fish. Oceanogr. 13: 197–207.

Krebs, C.J. 1998. Ecological Methodology. 2nd ed. Addison-Welsey, Menlo Park, CA.

LeBrasseur, R.J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. J. Fish. Res. Board Can. 23: 85–100.

Pearcy, W.G., R.D. Brodeur, J. Shenker, W. Smoker, and Y. Endo. 1988. Food habits of Pacific salmon and steelhead trout, midwater trawl catches, and oceanographic conditions in the Gulf of Alaska, 1980–1985. Bull. Ocean. Res. Inst., Univ. Tokyo 26: 29–78.

Pearcy, W.G., K.Y. Aydin, and R.D. Brodeur. 1999. What is the carrying capacity of the North Pacific Ocean for salmonids? PICES Press, 7: 17–23.

Pinkas, L., M.S. Oliphant, and I.L.K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. Calif. Fish Game, Fish. Bull. No. 152: 1–105.

Radchenko, V.I., and O.A. Mathisen. 2004. Distribution, growth, and feeding of sockeye salmon in the western Bering Sea. Trans. Am. Fish. Soc. 133: 606–621.

Shimazaki, K., and S. Mishima. 1969. On the diurnal change of the feeding activity of salmon in the Okhotsk Sea. Bull. Fac. Fish., Hokkaido Univ. 20: 82–93.