Identification of Stocks and Environmental Characteristics of North Pacific Chum Salmon, *Oncorhynchus keta*, by Chemical Analysis of Otolith

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Since Reibisch's observations in 1899, otoliths have been used to identify the age and/or daily rings of fish. However, the relatively sudden development of otolith elemental analyses appeared in the 1980s (Campana and Thorrold 2001). The advent of otolith chemistry expanded the applications of otoliths to environmental recorders. Elemental composition analyses, called elemental tags or fingerprints, of the fish otoliths have been applied to study age, growth, stock identification, temperature and salinity histories, migration pathways, anadromy, pollution of habitat, and chemical mass marking (Edmonds et al. 1999; Gillanders and Kingsford 1996).

To investigate the stock identification and habitat characteristics of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean, the stable isotopes $\delta^{18}O$, $\delta^{13}C$ and trace elements in otoliths were measured. Otoliths were collected from four sites (Canada, Japan, Korea and USA) during 1997–1999 spawning seasons except Japanese salmon in 1999. Otoliths of fry and immature salmon were collected from the Korean hatchery and off the Aleutian Islands, respectively. The $\delta^{18}O$ and $\delta^{13}C$ values from whole ground otoliths were measured using a mass spectrometer. The $\delta^{18}O$ and $\delta^{13}C$ values increased with age, showing especially high correlation with salmon size (Fig. 1). The mean $\delta^{18}O$ and $\delta^{13}C$ isotope ratios of fry showed –6.97‰ and –12.18‰, where the values of adult salmon were 0.62‰ and –4.86‰, respectively. The isotopic values for immature salmon collected off the Gulf of Alaska appeared in between those of the fry and adult salmon.

The values of the two isotopes of adult salmon separated largely into two groups: Asian and North American chum salmon (Fig. 2). The $\delta^{18}O$ isotope appeared in order of Japan, Korea, US, and Canada with mean differences of ca. 0.81‰ between Japan and Canada in three consecutive years. When assuming $\delta^{18}O$ values are indicative of ocean temperature of the salmon habitat, Asian salmon seemed to reside in lower temperature than North American stocks. Carbon stable isotopes showed the opposite pattern; higher values from North American salmon, and lower from Asian salmon.

Fig.1. Comparison of isotopic composition with respect to life history difference.

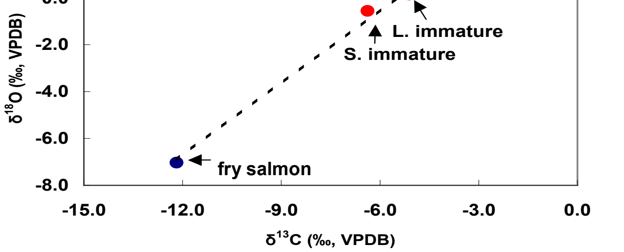
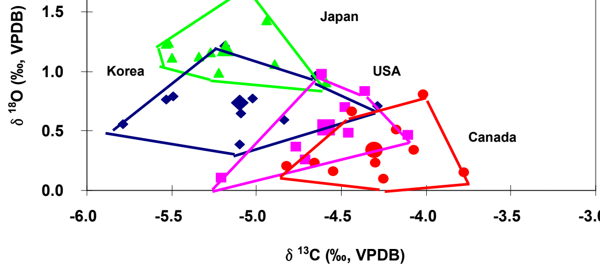


Fig.2. Envelopes of scatter plots of $\delta^{13}C$ and $\delta^{18}O$ in otoliths of adult chum salmon, which were collected in 1997.



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For the trace element analysis, two methods were used: line scanning and spot analysis methods. Concentrations of Ca and Sr in otoliths were measured using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) for the line scanning method. Sr/Ca ratios, known as an indicator of salinity, were elevated in the core of the otoliths, decreased during the freshwater stage, increased suddenly at a certain point and oscillated periodically to the margin corresponding to year-ring (Fig. 3). Peaks of Sr/Ca at nucleus may indicate marine-origin Sr contributed to the egg. During the marine life stages, the Sr peaks of otolith correspond to the translucent (winter) part of the annuli. We speculate that chum salmon might move onshore/offshore or north/south. On the spot analysis of core part of otolith, the result of discriminant analysis with 23 elements (^{7}Li, ^{55}Mn, ^{65}Cu, ^{66}Zn, ^{86}Sr, ^{89}Y, ^{135}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{146}Nd, ^{147}Sm, ^{151}Eu, ^{157}Gd, ^{159}Tb, ^{162}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{174}Yb, ^{175}Lu, ^{208}Pb, and ^{238}U) represents distinct separation in accordance with natal areas of stocks (Fig. 4). Therefore, otolith chemistry is a very effective technique for stock separation and for revealing the effects of environment of salmon populations.

Fig. 3. Combined photographic view of annual rings in otolith with line scan image from Japanese chum salmon. Small box contains the profile of strontium concentration scanned from nucleus to edge across a chum salmon otolith. Four yearly oscillations in strontium concentration matched with annuli in otolith photo.

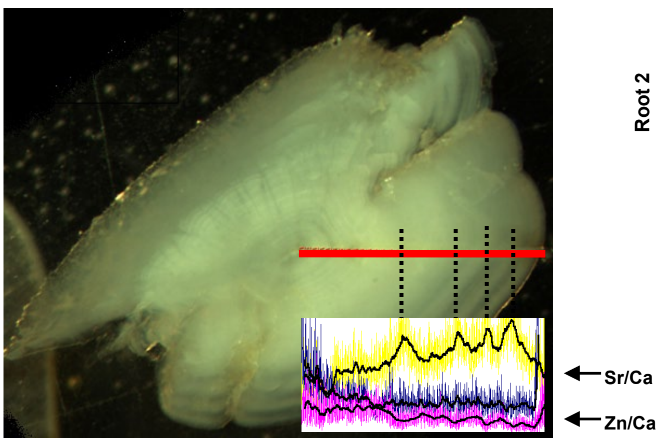
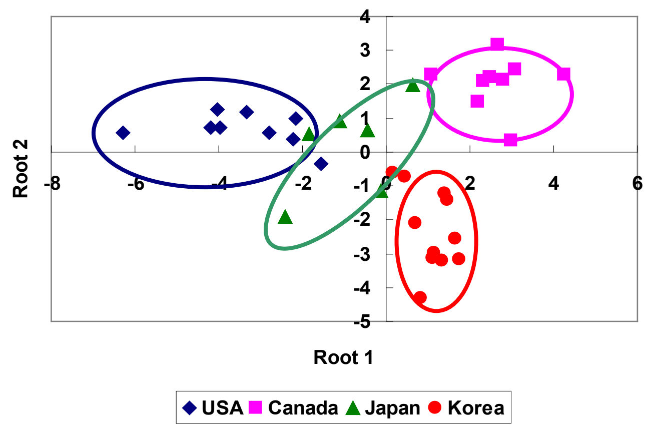


Fig. 4. Discriminant analysis with 23 elements analyzed from nuclei of chum salmon otolith.



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