Relationship Between Environmental Variability and Chum Salmon Production at the Southern Limit of Distribution in Asia

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Chum salmon (*Oncorhynchus keta*) are distributed mostly in the Okhotsk Sea, the Bering Sea, and North Pacific Subpolar Gyre System, and the larger portion of the total production is from the western side of Pacific Ocean. Catches from Japan, Russia, and Korea increased since the late 1970s and amounted to 250~300 thousand metric tones (MT) annually in the 2000s. Since the climate regime shift in 1976/77, ocean environments seem to be favorable for salmon stocks in the North Pacific Ocean (Beamish and Bouillon 1993). In addition, extensive chum salmon enhancement activities by NPAFC members have caused increases in chum salmon production in the 20th century (Kaeriyama 1998). Recently, chum salmon production in the North Pacific is at a record high, although the causes for the high abundance of chum salmon have not been clearly explained. Areas off the Korean Peninsula and the Japanese islands are considered the southernmost limit of chum salmon distribution in the northwestern Pacific Ocean (Kim et al. 2007). This study aims to investigate the relationship between chum salmon production in this region and environmental conditions, such as climate indices and SST in salmon habitats in the North Pacific, and to provide a basis for discussion of fishery management under conditions of changing environment.

Sea surface temperatures (SSTs) were obtained from SODA V2.2.4 during winter 1970-2008, and climate indices including Pacific Decadal Oscillation Index (PDOI), Arctic Oscillation Index (AOI), Southern Oscillation Index (SOI), and Aleutian Low Pressure Index (ALPI) were correlated with chum salmon catch. Fisheries information was collected from statistical books of NPAFC, Japan, and Korea. Some specific statistics data were obstained from hatcheries in Hokkaido (Japan) and Namdae (Korea). The cumulative sum (CuSum) and cross-correlation function (CCF) methods were used for statistical analysis of data sets.

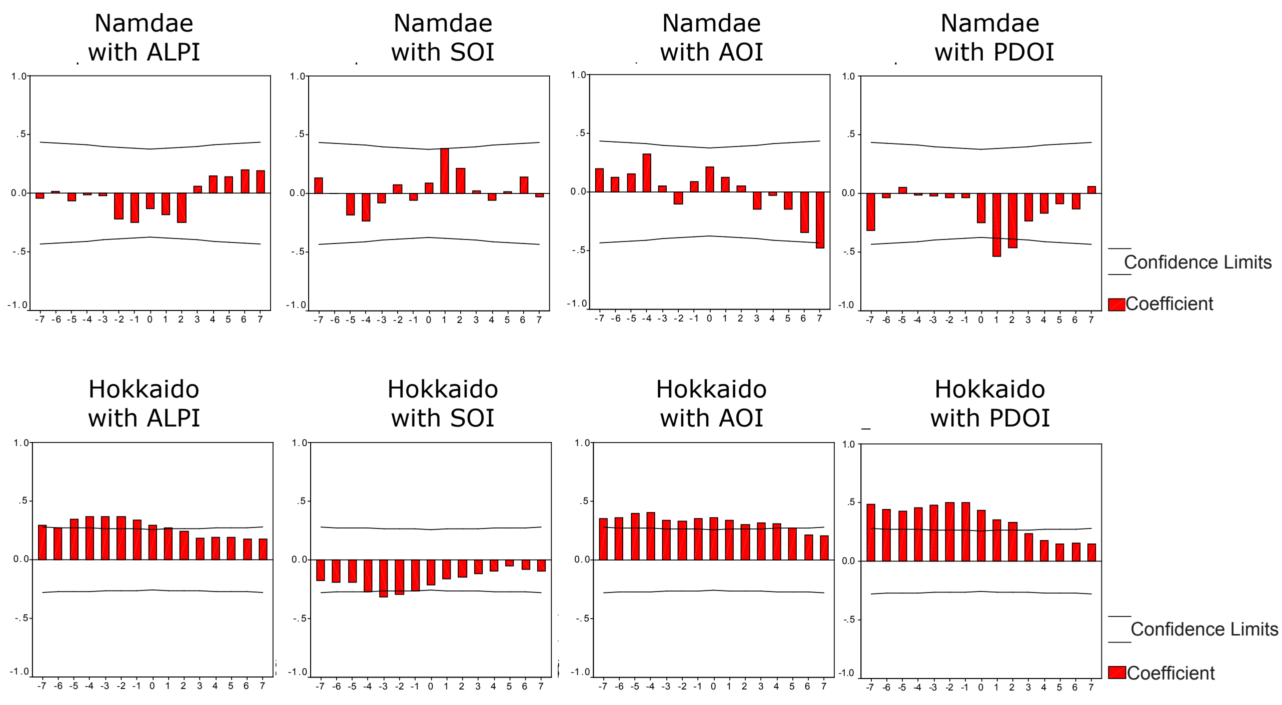

Fig. 1. Results of cross-correlation function (CCF) analysis of chum salmon catches and climate indices.

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Chum salmon might be vulnerable to global warming at the southern limit of their distribution in Asia because the warming rate of winter SSTs has been conspicuously high, showing a 0.21 ºC increase per decade in the northwestern Pacific during the last four decades (Kim et al. 2012). In contrast, the warming rate at the southern limit of chum salmon distribution in the eastern Pacific (i.e., off the coasts of British Columbia, Washington, and Oregon) has not been evident. The CuSum graph of climate indices showed a turning point in the mid 1970s and less conspicuous changes in the late 1980s and 1990s. Annual mean PDOI, SOI, and ALPI were strongly correlated, but AOI was not correlated with the other indices. Retrospective analysis was conducted using a time-series of climate indices with chum salmon catch. The results of CCF and CuSum analyses indicated that there was a major change in climate during the mid 1970s, and that chum salmon populations responded to this climate event with a time-lag. Hokkaido chum salmon catch and all the climate indices had the highest significant correlations with about a 2~4 year time-lag and that Namdae chum salmon catch did not show any significant correlations, possibly due small sample sizes (Fig. 1).

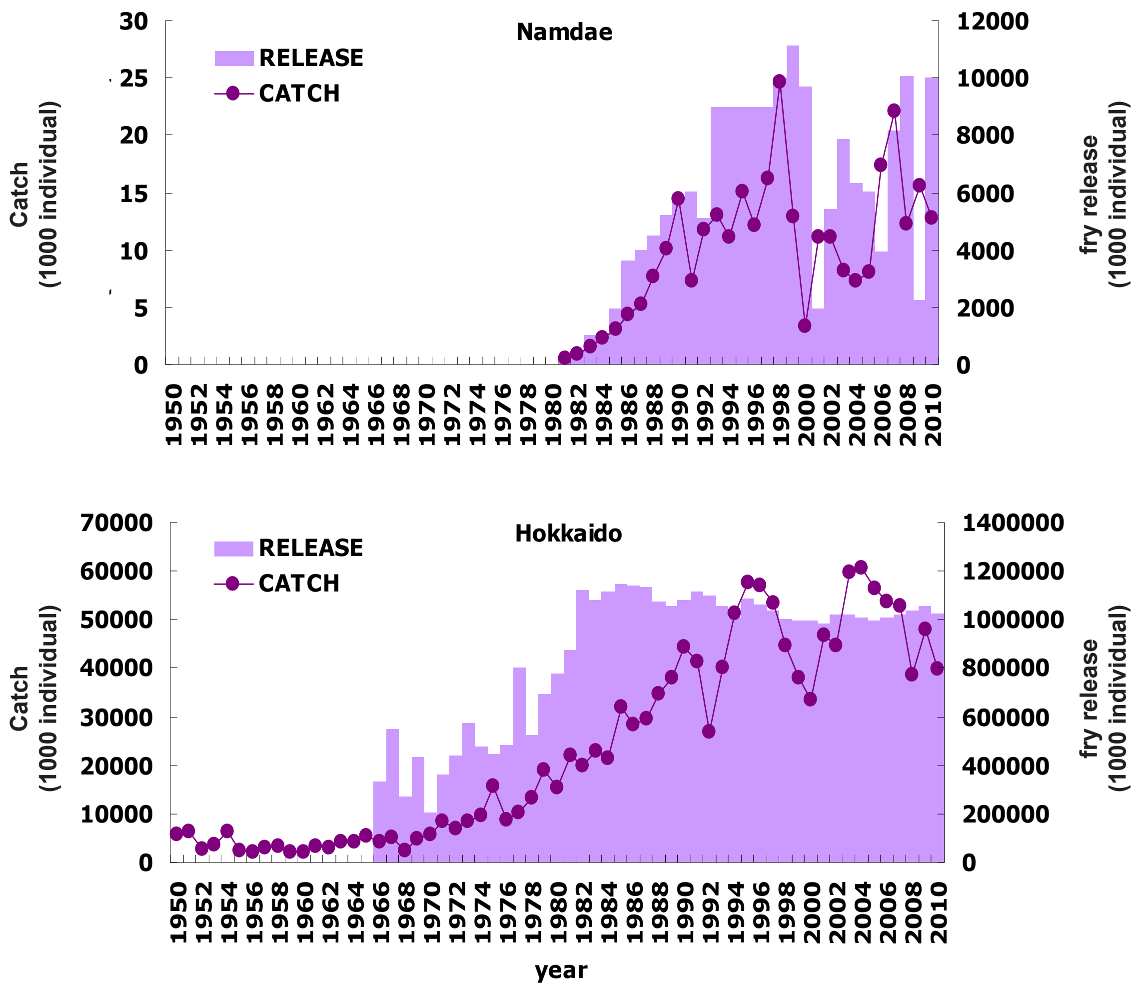

Fig. 2. Number of fry released and catch of returning adult chum salmon to Namdae (Korea) and Hokkaido (Japan).

Returns of chum salmon to Korea and Japan were significantly correlated (r = 0.618, $p < 0.01$), although Japanese catches were much higher than Korean catches. In the beginning of enhancement activities in Korea and Japan, catches of returning salmon were proportional to the number of fry released, but this was not always true due to high environmental variability, such as the 1997/98 El Nino (Fig. 2). We speculated that favorable environmental conditions during early ocean life seemed to be related to better growth and survival of young salmon in coastal areas. However, higher growth in Korean waters during early stages did not seem to relate to improved return rates of spawning adults. Rather, the growth in the Okhotsk Sea or the Bering Sea during the immature stage was significantly correlated with return rate.

Fish size-at-age varied inter-annually, but populations in Japan and Korea trended in similar ways. The body length of Korean female chum salmon decreased prior to the regime shift in 1988/89 and then stabilized at a lower level. The body length of age-2 male chum salmon at spawning increased from 1984 to 1988, but the trend was negative in older males. The fork length of the Hokkaido population showed a decreasing trend from the late 1970s to the mid 1980s, and has leveled off to a smaller size since then.

In the coming years of the 21st century, it is anticipated that the warming trend in the northwestern Pacific (0.6 ºC/decade) will be about 1.5 times higher than the trend in the northeastern Pacific (0.4 ºC/decade; McFarlane et al. 2009). Future chum salmon production in Asia might be more seriously threatened by this warming rate than production in North America. Therefore, it is appropriate that fisheries management plans consider changes in climate and that policymakers and scientists begin discussion of strategies and policies by which to utilize and manage chum salmon resources under changing economic and environmental conditions in Asia.

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