Current Status of Chum and Pink Salmon: What is Reducing Adult Returns in Japan?

Toshihiko Saito[1] and **Yasuyuki Miyakoshi**[2]

[1]*Hokkaido National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 2-2 Nakanoshima, Toyohira-ku, Sapporo, Hokkaido 062-0922, Japan*

[2]*Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373, Kitakashiwagi, Eniwa, Hokkaido 061-1433, Japan*

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In Japan, the annual catch of chum salmon (*Oncorhynchus keta*) has decreased remarkably since 2010, and by 2016 and 2017 the catches of adults had returned to the low levels seen in the early 1980s, when the annual number of released chum fry was approximately the same as the present level of 1.8–2 billion. The decline in catches is especially evident in the region of the southern part of the Okhotsk coast to the Pacific coasts of Hokkaido and Honshu islands. By comparison, pink salmon (*O. gorbuscha*) are mainly captured along the Okhotsk coast of Hokkaido. Catches of pink salmon have declined sharply since 2011; except for improved returns in 2016, and recent catch levels are comparable to those in the early 1980s and pre-1980s. Thus, the main purpose of this study was to clarify the reasons for the recent declines in adult salmon catches in Japan.

Massive mortalities of salmon often occur during the early life stages in the marine environment, and juvenile salmon survival often affects the brood-year strength or overall adult returns (Pearcy 1992; Beamish and Mahnken 2001). To examine the effects of the coastal environment during the early life history on the brood-year strength of chum salmon, we conducted correlation analyses between data on coastal sea surface temperatures (SSTs) and brood-year strength among the brood years 1989–2013 in four regionally aggregated chum stocks (i.e., Nemuro region, NE; East Erimo Peninsula region, EP; West Erimo Peninsula region, WP; and Honshu Pacific region, HP), wherein poor adult returns were recognized in recent years. In this analysis, the numbers of returning adult chum salmon (i.e., the coastal catch + in-river catch) up to age 0.3 were indexed as denoting the brood-year strength for each region. The original SST data were 10-day mean SSTs analyzed for 0.25-degree mesh grids, as provided by the Japan Meteorological Agency (NEAR-GOOS RRTB: http://ds.data.jma.go.jp/gmd/goos/data/database.html). SST data was selected for the period from early March to late July for the years 1990–2014, for the following areas: Area I: 43.25ºN–46.25ºN, 142.00ºE–146.25ºE for the NE chum; Area II: 41.00ºN–43.25ºN, 143.25ºE–146.25ºE for the EP chum; Area III: 41.00ºN–42.50ºN, 142.25ºE–143.25ºE for the WP chum; and Area IV: 35.75ºN–41.00ºN, 142.50ºE–143.25ºE for the HP chum. Since many correlation analyses were conducted over each of the four areas (at 10-day intervals during early March to late July), we summarized the results as the percentages of mesh grids showing statistically significant positive (negative) correlation to the total number of mesh grids in which the correlation analyses were conducted.

The correlation analyses revealed that statistically significant positive correlations were dominant mainly for March to May for all the areas, meaning that the brood-year strength of each regional chum stock positively correlated with SSTs within each corresponding area. Since the period when the positive correlations were dominant corresponded to the time when juvenile chum salmon start their marine life, conditions of warmer SSTs tended to be associated with better survival of the chum broods from these four regions. However, SST anomalies in March to May tended to be frequently negative after the 2000s in Areas II, III and IV. Although such lower SST anomalies were not evident in Area I, the SSTs in late May—when the positive correlations were the most dominant in the correlation analyses—showed frequent negative anomalies after the 2000s, suggesting that the NE chum had been regularly exposed to lower SSTs during their early marine life. Furthermore, since 2010, an abrupt change from a negative SST anomaly during March to May, to a positive SST anomaly during June to July was frequently observed. Such an abrupt change in the SST anomaly was evident in 2013 and 2014, which likely determined the poor returns of adult chum salmon in 2016 and 2017. Abrupt changes in the SSTs from negative to positive anomalies were also observed for the coastal waters along the Okhotsk coast of Hokkaido during the spring and summer of 2010 and onward; a situation likely linked to the poor returns of adult Japanese pink salmon in recent years (Saito et al. 2016).

A statistically significant correlation was found between the chum salmon catch in Japan and that in Russia during 2003 and 2016 ($r = -0.81$, $p < 0.0001$), based on NPAFC statistics. To understand the opposite trends in

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All correspondence should be addressed to T. Saito.
email: brochet@affrc.go.jp

chum catches between Japan and Russia, we analyzed a Beverton–Holt (BH) model for Amur River chum, using catch data for 1989–2016. Since the Amur River chum stocks are mainly sustained by wild salmon, variability in the catch is probably affected by the extent of natural spawning (i.e., escapements). To estimate escapements for 1989–2012, we assumed an exploitation rate of the stock set at 0.39, which was calculated as a trimmed mean value from estimations of Russian escapements and the catch data for 1993–2013, but excluding the years of 2003 and 2008. The relationship between numbers of escapements in year t and the numbers in the catch plus escapements in year $t + 4$ (t = 1989–2012) revealed that greater adult catches of Amur chum occurred after 2005 (t = 2005). The residuals of the BH model were positively correlated with the 0.25-degree-mesh gridded SSTs, during early May to late July for the period 1990–2013, for a wide range of ocean areas in the vicinity of the Amur River mouth (53ºN–55ºN, 140ºE–142ºE); this result suggests that warmer SSTs were associated with better survival of the Amur River chum stock. In particular, a higher correlation coefficient was observed between the residuals and averaged SST anomalies in mid-June for the ocean areas ($r = 0.75$, $p < 0.001$), and the 2005–2012 broods that showed greater adult returns in recent years had experienced warmer SSTs during the juvenile life stage. Accordingly, the recent higher returns of Amur chum were possibly supported by warmer ocean conditions during their early marine life.

Warmer SSTs during their period of coastal residency are probably associated with better survival of Japanese chum originating from the southern part of the Okhotsk coast and the Pacific coast of Japan, as well as Japanese pink and Amur chum salmon. However, SSTs in the Pacific coastal waters off Japan tended to be lower since the 2000s, with an abrupt shift from low to high anomalies of SSTs often evident since the 2010s. Unlike Japanese coastal waters, SSTs in the Sea of Okhotsk near the Amur River mouth became warmer after the mid-2000s. Such an opposite trend in the SSTs during the early marine life of the salmon probably generated a difference in the productivity of salmon between Japan and Russia in recent years. Elucidating the mechanisms responsible for the opposite trends in the chum catches between Japan and Russia may assist us with understanding regional shifts in salmon production as a consequence of climate change.

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