Inter-decadal fluctuations in length-at-age of Hokkaido-Sakhalin herring and Japanese sardine in the Sea of Japan

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Introduction

The total catch of Hokkaido spring herring (*Clupea pallasii*) in Japan peaked at 972 thousand tons in 1897 and tended to decline thereafter with steep peaks and deep troughs (Fig. 46). Spawning occurred from February to May along the coasts of northern Japan and southern Sakhalin, within the Sea of Japan and partly in the Sea of Okhotsk. With the decline of the population, spawning retreated to the north and finally disappeared from the coasts of Hokkaido in the middle 1950s (Morita 1985). After that the catches were from the local populations distributed in the coastal waters off northern Japan.

The Tsushima Current subpopulation of Japanese sardine (*Sardinops melanostictus*) in the East China Sea and the Sea of Japan experienced a peak in the late 1980s, similar to the Pacific subpopulation of these species (Watanabe *et al*. 1995). Total catch of the subpopulation first exceeded 1 million tons in 1984, maintained at this level until 1992, then rapidly declined to 33 thousand tons in 1998 (Fig. 47).

Size-at-age of these two clupeid fishes varied through the years of the large population fluctuations. In this paper we describe inter-decadal variability in size-at-age of both species and examine correlations between size-at-age and population size.

Materials and methods

Hokkaido spring herring mature at age 3 and start migrating to the spawning grounds along the west coast of Hokkaido (Hanamura 1963). Ages of about 4000 individual fishes per year caught in this area were determined from scales after 1910. Mean total length-at-age (TL) was calculated based on number of fish by ages and by 5 mm TL intervals (Kitahama, 1955). Time series of catch-at-age 3 and older fish from 1910-1960 reported by Hanamura (1963). We used this data for estimating total number of fish at age 3 and older from 1910-1950 by VPA (virtual population analysis).

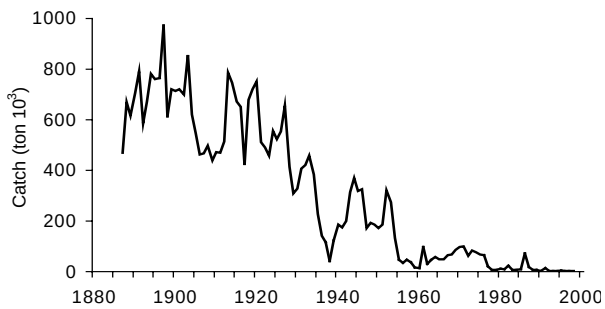

Fig. 46 Total catch of Hokkaido spring herring (*Clupea pallasii*) in Japan. Data for 1887-1911 are from Hanamura (1963); after 1911 - from Catch Statistics.

Fig. 47 Total catch of the Tsushima Current subpopulation of Japanese sardine (*Sardinops melanostictus*) from 1978-1998.

Data on catch-at-age and size-at-age of Japanese sardine caught by the Japanese purse seine fishery in the East China Sea and the Sea of Japan have been compiled since 1978. Total numbers of fish-at-age were estimated each year by VPA.

Results

Clupea pallasii. VPA estimates of spawner abundance (>3 years) of Hokkaido spring herring fluctuated greatly with a maximum of 19.6 billion fishes in 1924 and minimum of 0.4 billion in 1937. Total catch in number ranged from 3.0-0.04 billion fishes. The exploitation rate was estimated to be <30% with exceptions in the middle 1930s and the late 1940-early 1950s. Year-class population at age 4 varied greatly from 1907-1947 (Fig. 48). Dominant year-classes (>5.0 billion in number at age 4) occurred 6 times in 1909, 1911, 1915, 1921, 1926 and 1939. The maximum was 9.9 billion fishes in 1921, and minimum was 0.029 billion in 1933, about a 2.5 order of magnitude difference.

We calculated deviations (%) of the mean TL at age 3 year and older for each year-class from the 40-year mean (Fig. 49). The coefficients of determination (R^2) are summarized in Table 11. The deviations-at-age are positively correlated. The coefficients between age 3 *vs* 5 and 3 *vs* 7 were small compared with those between age 4 *vs* 6 or 4 *vs* 8. Correlations of 4 year and older ages with age 3 were not statistically significant, but those of 5 year and older ages with age 4 were highly significant. This implies that the TL trends of year-classes were fixed by age 4 at the latest. The mean TL at age 3 did not represent TL trend of a year-class. Total catches in number at age 3 accounted for about 60% of those at age 4 in the 40 year-classes. Only a limited proportion of age 3 fish migrated to the coastal spawning grounds.

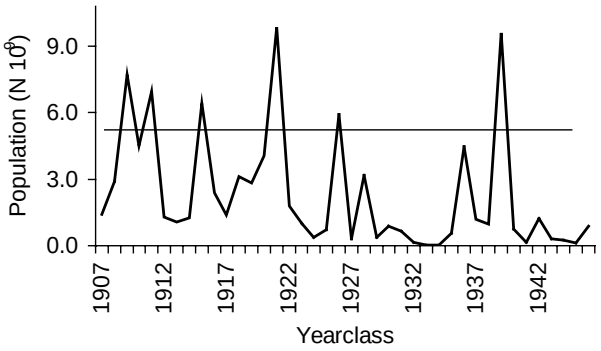

Fig. 48 Variability in year-class population at age 4 of Hokkaido spring herring.

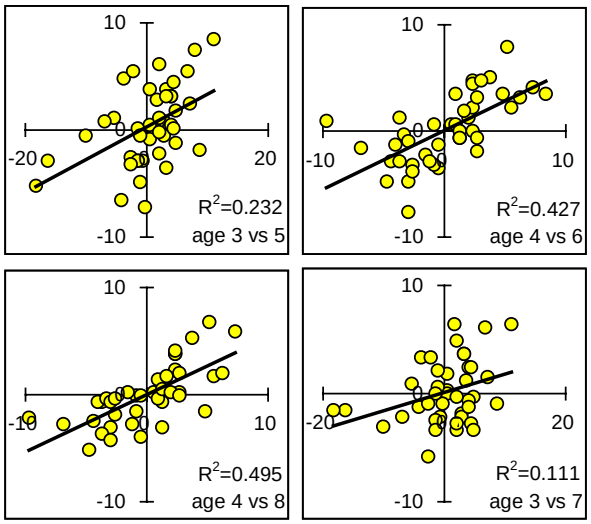

Fig. 49 Correlations of deviations (from the 40-year mean) of the mean TL-at-age in each year-class of Hokkaido spring herring.

Table 11 Coefficients of determination of TL deviations from the 40-year mean across ages (* P<0.01, ** P<0.001).

	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
Age 3	0.323	0.232	0.127	0.111	0.103	0.068
Age 4		**0.747	**0.427	**0.465	**0.495	**0.531
Age 5			**0.573	**0.431	**0.573	**0.533
Age 6				**0.509	**0.559	*0.505
Age 7					**0.601	*0.457

TL-at-age 4 varied from 25.5 in 1925 to 30.3 in 1944 with the average of 28.2±1.0 cm (Fig. 50). TL was not necessarily smaller than the long-term mean for the 6 dominant year-classes. It tended to be larger than the mean in the early 1910s, smaller in the 1920s, and recovered in the early 1930s. A similar TL trend was found at age 5 (40 year mean was 30.0 cm).

TL-at-age 4 was not correlated with the year-class size in number at age 4. The coefficient of determination was 0.068, indicating that only a small amount of the TL variability was explained by year-class strength (Fig. 51).

TL-at-age 4 was correlated significantly ($P < 0.05$) with the mean spawning population in years when a given year-class was at age 1 to 4. About 17% of the inter-annual variability in the mean TL of year-classes at age 4 could be explained by the size of the spawning population (R^2=0.165). The variability in size-at-age of the herring inhabiting the Sea of Japan and Sea of Okhotsk is considered to be determined in a density independent manner.

Sardinops melanostictus. For Japanese sardine, year-class abundance at age 2 varied greatly during the 20 year study from 1976-1996 (Fig. 52). The population was <20 billion fishes in the 1970s. Strong year-classes (>30 billion) occurred consecutively in 1980-82 and 1984-87. Abundance reduced dramatically in 1988 year-class and further declined to 1995. The maximum and minimum year-class strengths were 77.3 and 1.4 billion in number at age 2, about a 1.7 order of magnitude difference. Strong year-classes >50 billion occurred consecutively in the 1980s. Deviations (%) of the mean TL at age 3 of year-classes from the 20-year mean were correlated with those at age 2, but not with age 1 (Fig. 53). The inter-annual trend in TL-at-age of each were fixed by age 2 at the latest in sardine. Age 1 sardines of the Tsushima Current subpopulation are not fully recruited to the Japanese purse seine fishery and do not represent size-at-age or strength of the year-classes.

Body length (BL) at age 2 of the sardine was >180 mm in the 1970s. It remarkably declined to 169 mm in 1980 and remained smaller than 170 mm until 1988. Then BL recovered to the 1970s level of around 180 mm (Fig. 54). Similar BL trend was found in size-at-age 3. The interannual fluctuation in BL corresponded inversely with the fluctuation in year-class size (Fig. 54).

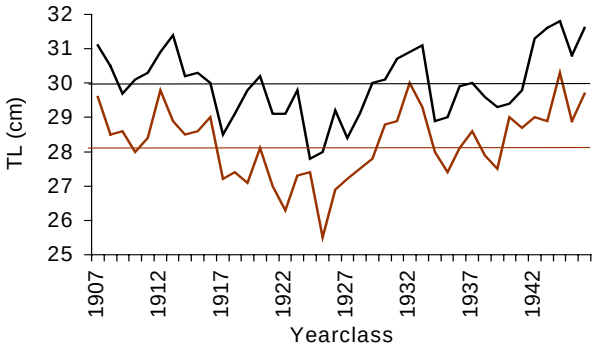

Fig. 50 Inter-decadal variations in TL-at-age 4 and age 5 of Hokkaido spring herring.

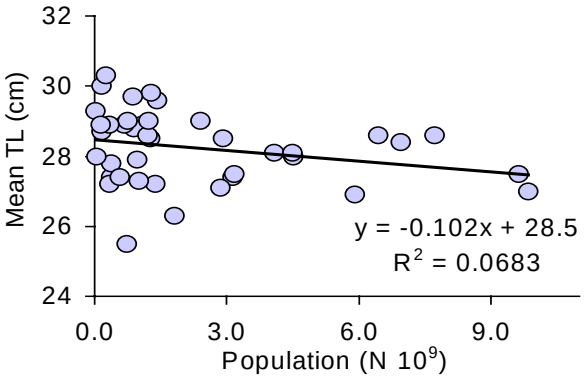

Fig. 51 Relationship between TL and year-classes size at age 4 of Hokkaido spring herring.

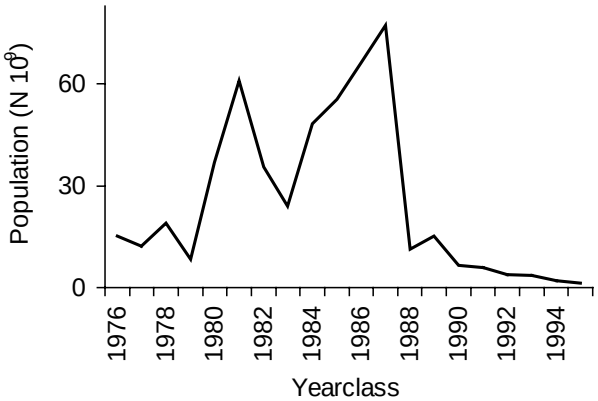

Fig. 52 Variability in year-class population at age 4 of Japanese sardine.

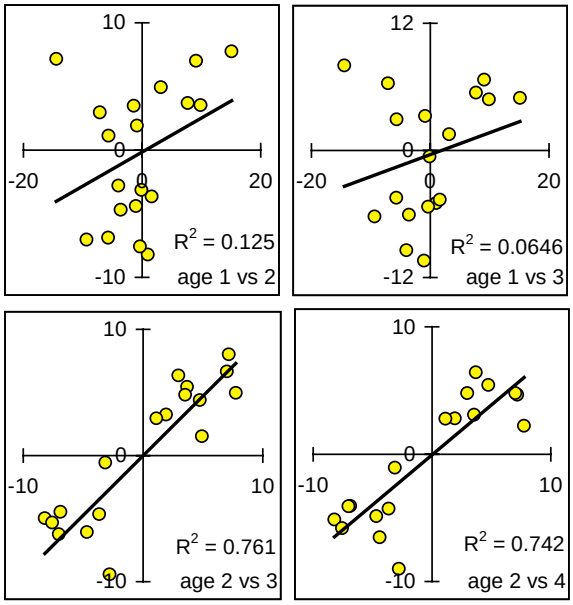

Fig. 53 Correlations of deviations from long term mean TL (20 years) among year-classes of Japanese sardine, by age.

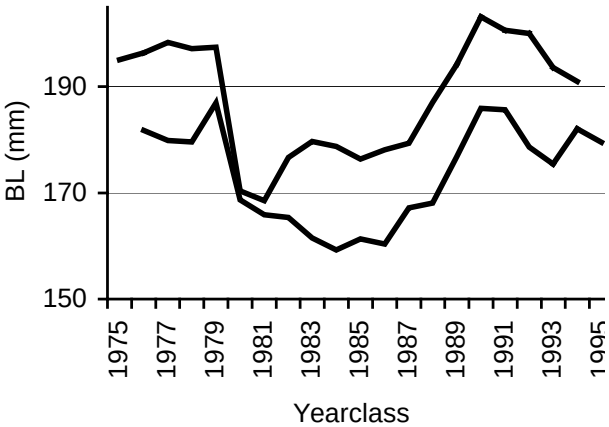

Fig. 54 Inter-decadal variations of BL-at-age 2 and 3 of Japanese sardine.

BL-at-age 2 was significantly ($P<0.001$) correlated with the year-class size in number at age 2 (Fig. 55). The coefficient of determination indicated that 60% of the BL variability can be explained by year-class strength. BL-at-age 2 was significantly ($P<0.001$) correlated with the total population at age 2. The coefficient of determination was 0.587. The variability in BL-at-age of the sardine inhabiting in the temperate Sea of Japan and the East China Sea is considered to be determined in a density-dependent manner.

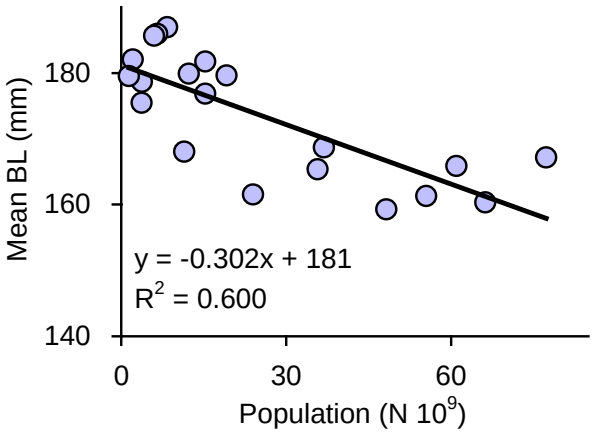

Fig. 55 Correlation of the mean BL with population of year-classes at age 2 of Japanese sardine.

Discussion

The fluctuations in year-class strengths were greater in the herring (2.5 orders) than in the sardine (1.7 orders) during the years studied. This may be related to the differences in the magnitude of inter-annual variability of ocean environment between the subarctic and temperate waters.

Size-at-age of herring and sardine varied about ±4 or 5% in the years studied. Growth of sardine up to 2 years old is considered to be largely determined through density-dependent processes such as competition for food, while that of the herring up to 4 years old was independent from the density of the population. Two factors may be responsible for the difference in the growth determining processes in herring and sardine.

The maximum year-class strength of the Tsushima Current subpopulation of the sardine was as large as 77.3 billion in 1987. The total population reached 370 billion in 1987. In the Hokkaido spring herring, the maximum year-class was 9.8 billion in 1921 and the total spawning population reached 19.6 billion in 1924. The population size of sardine was more than 10 times larger than herring. Comparison in migration ranges of sardine in the East China Sea and the Sea of Japan and of herring in the Sea of Japan and the Sea of Okhotsk are required, but the large population size of sardine seems to be a potential factor of density-dependent determination of size-at-age.

Another potential factor is the difference in biological productivity between the temperate and subarctic waters in the Sea of Japan and the Sea of Okhotsk. The Tsushima Current is derived from the warm Kuroshio Current and its productivity is considered to be lower than subarctic waters inhabited by the herring. Carrying capacity of the subarctic waters in the Sea of Japan and the Sea of Okhotsk may be sufficiently greater than the total food requirement of the herring population and competition for food may not be realized in these waters.

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Long-term variability in length of walleye pollock in the western Bering Sea and east Kamchatka

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The mean body length of walleye pollock yearlings from the western Bering Sea increases when the area of the ice cover is reduced. The average length of 2 to 6-year-old walleye pollock varies in relation to the dynamics of total stock biomass and environment. The biomass of walleye pollock is lower when the area of ice cover in the Bering Sea exceeds 700,000 km^2. When the area of ice cover is reduced, the total stock abundance of walleye pollock increases and the average length of 2 to 6-year-old fish decreases. A reliable relationship has been observed between condition factor and the growth of fish, indicating that the growth of walleye pollock is dependent on the forage base. Currently the biomass of walleye pollock in the western Bering Sea is very poor, therefore the growth in length is not dependent on the environment and total stock biomass.

The average length of 2 to 6-year-old walleye pollock in the Pacific Ocean waters adjacent to Kamchatka has changed in relation to the biomass of total stock and the abundance of generations. When the biomass has been high, the growth has been slow and *vice versa*. The environmental factors do not affect the growth of walleye pollock to the east of Kamchatka.

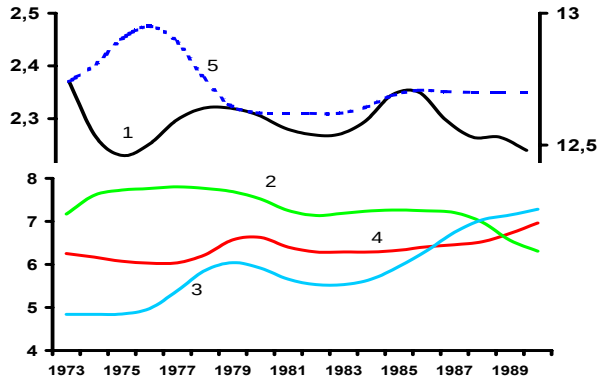

Fig. 56 Variation of natural logarithms of average length of walleye pollock yearlings (1), walleye pollock (2), Pacific herring (3), mesoplankton biomass (4), and area of ice cover (5) in the western Bering Sea.