

Long-term variability in the fish populations in the Japan Sea with special reference to the impact of the mid-1970s regime shift

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Abstract

It is reported that a regime shift, characterized by an abrupt change from a cool to warm conditions, occurred in the Tsushima Warm Current (TWC) region in the Japan Sea in the late 1980s, and associated large changes in the TWC ecosystem. However, the impacts of the well-documented 1976/77 regime shift on fish populations were not well understood yet in the Japan Sea. Variation patterns in the fish community in the Japan Sea and its relations with environmental factors were examined using long-term fisheries and environmental data. Detailed analysis including PCA (Principal component analysis) showed that fish populations from demersal to pelagic species changed abruptly during the early-1970s with increase (decrease) in cold- (warm-) water species such as walleye Pollack and sardine (anchovy and horse mackerel), but no evident changes occurred in the mid-1970s. The variation pattern in the fish populations corresponded well with the winter and summer water temperature in the TWC. These results indicate the change in the early-1970s associated largely with the change in the summer water temperature, and the impact of the 1976/77 regime is not evident. It suggests that the response pattern to the 1976/77 regime shift is different between the Japan Sea and central-eastern North Pacific.

Keywords: fish population, community, water temperature, regime shift, Tsushima Warm Current, Japan Sea

1. Introduction

Increasing evidence shows that regime shifts can occur not only in the atmospheric and oceanic fields, but also in small pelagic species such as anchovy and sardine, fish communities and marine ecosystems (e.g. Chavez et al., 2003; Alheit and Bakun, 2010). The late 1980s, and particularly the mid-1970s regime shifts were well documented and identified in various Pacific and Atlantic, including the northeast Pacific (Hare and Mantua, 2000), northwestern Pacific (Wooster and Zhang, 2004), Peruvian upwelling ecosystem in the South Pacific (Alheit and Bakun, 2010).

The Japan Sea is one of the marginal seas in the western North Pacific with characteristics of an ocean despite its small size and semi-enclosed geographical feature (Naganuma, 2000). The oceanographic structures are largely associated with the Tsushima Warm Current (TWC) and Liman Cold Current (Fig. 1). The fish community in

the Japan Sea is diverse from pelagic fishes such as Japanese sardine (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonicus*), yellowtail (*Seriola quinqueradiata*) and tunas (*Thunnus* spp.) to

demersal species such as Pacific cod (*Gadus macrocephalus*), flathead flounder (*Hippoglossoides dubius*) and snow crab (*Chionoecetes opilio*) (Naganuma, 2000; Tian et al., 2006; 2008).

In our previous analysis of Japanese long-term fish catch statistics, we concluded that a regime shift occurred around the late 1980s and affected the ecosystem of TWC including changes in the fish community structure from species composition to habitat distribution of species (Tian et al., 2006, 2008, 2010). However, variability in the fish populations in the 1970s in the Japan Sea and impact of the well-known mid-1970s regime shift in the North Pacific were not well understood. In this paper, we reviewed the variation patterns in the fish populations

from small pelagic to demersal fishes in the Japan Sea in the 1970s and its linkages with environmental factors. We identified that a change in the fish populations occurred around the early 1970s in the Japan Sea, and associated largely with the variability in the summer water temperature in the TWC.

2. The late 1980s regime shift in the Japan Sea

The Japan Sea is one of the most rapidly warming large marine ecosystems in the world ocean, the

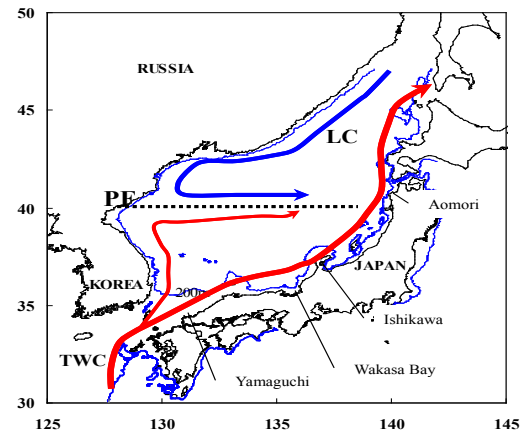


Fig. 1. Schematic diagram showing the oceanographic structures in the Japan/East Sea. Solid arrows indicate the Tsushima warm current (TWC) and Liman cold current (LC). The dotted line indicates the Polar front (PF). Locations of some geographic names mentioned in the text are shown with stars.

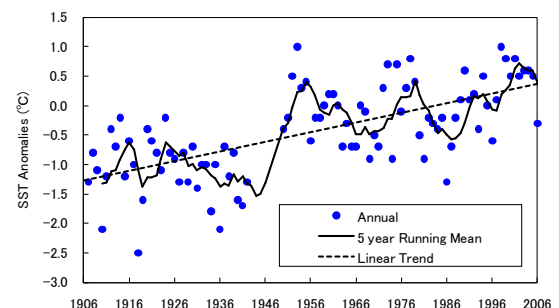


Fig. 2. SST anomalies in the Japan Sea during 1906-2006 (Data source: JMA).

SST increased by 1.09°C between 1982 and 2006 (Belkin, 2009). Based on data from Japan Meteorological Agency (Fig. 2), the average SST in the northern part of the Japan Sea increased by 1.6°C over the last 100 years, which was the highest rate of increase in the waters around Japan, and largely exceeded the average of global warming ($0.50^{\circ}\text{C}/100\text{years}$) of world oceans (Inoue and Hibino, 2007). However, if we focused on the period after the 1950, in which the data was assumed to be with high precision, it showed evident decadal variability rather than increasing linear trend (Tian et al., 2010).

Oceanographic conditions in the Japan, particularly in Japanese coastal waters, are greatly influenced by TWC. Figure 3 showed changed in coastal water temperature (WT) at the 50 m depth in the Japan Sea, which is assumed to be an indicator of TWC. The winter WT showed negative anomalies during 1966-1986 (-0.56°C) and positive anomalies during 1987-2004 ($+0.62^{\circ}\text{C}$) indicating an abrupt change from a cold regime to a warm regime occurred around 1986/1987 in the TWC region. The pattern in summer (Jul.-Sep.) WT differed from that in winter; the WT was generally lower during the late 1970s to early 1990s but higher after the late 1990s. STARS analysis indicated regime shifts occurred in the winter temperature in 1986/87 and in the summer water temperature in 1996/1997. Four distinct regimes in the surface water were observed: 1964-1973 with cold winter and warm summer (CWWS), 1974-1986 with cold winter and cold summer (CWCS), 1987-1996 with warm winter and cold summer (WWCS), and 1987-2004 with warm winter and warm summer (WWWS). The periods for 1974-1987 and 1997-2004 can be defined as cold and warm years for all seasons, respectively.

It seemed that the variability in the oceanographic conditions in the TWC are linked with climate change. Among four typical climate

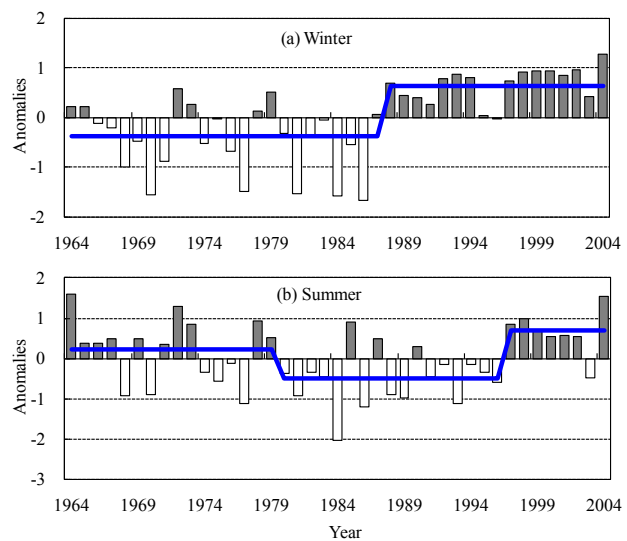


Fig. 3. Changes in water temperature at 50 m depth in the Tsushima Warm Current in the Japan Sea in winter (a) and summer (b). Bold solid lines and dotted arrows indicate STARS-defined trends in water temperature and the year of shift, respectively. CWWS, CWCS, WWCS and WWWS represent the periods of Cold-Winter and Warm-Summer, Cold-Winter and Cold-Summer, Warm-Winter and Cold-Summer, and Warm-Winter and Warm-Summer, respectively.

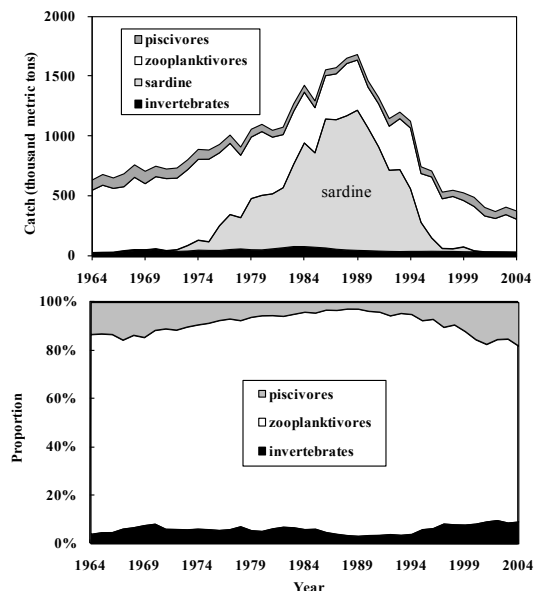


Fig. 4. Annual changes in the catch by species group and their proportions in Japan Sea for the period of 1964-2004.

indices (AO, PDO, MOI, SOI), STARS results indicated that a regime shift in SOI and PDO occurred in 1976/77, with a strong El Niño trend (negative SOI) and intensification of Aleutian Low (positive PDO). On the other hand, AOI and MOI showed a regime shift during 1987–1989 with large interannual variations, indicating a weakening Asian monsoon and intensified AO after 1989, but no distinct changes occurred in the mid-1970s. These results suggest a distinct regime shift in the oceanographic conditions, primarily in winter, in the Japan Sea particularly in the TWC region occurred in the late 1980s, was identified by water temperatures from cool to warm waters and linked with MOI and AOI (Tian et al., 2006, 2008). On the other hand, the 1976/1977 regime shift in global climatic indices such as PDO and SOI, seemed not to be notable in the oceanographic indices of the TWC.

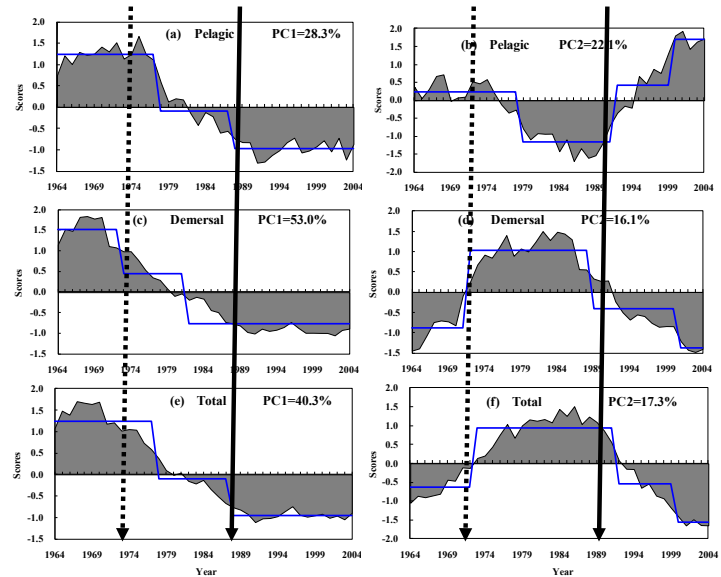


Fig. 5. The first two principal component (PC1-2) scores (shaded area) from the principal component analysis for the pelagic (top panels) and demersal (middle panels), and total (bottom panels) groups during 1964–2004. The solid bold lines represent the step changes estimated by STARS.

3. Response of fish populations to the late 1980s regime shift in the TWC

Japanese catch for 54 taxa (26 pelagic and 28 demersal species) in the Japan Sea has increased greatly since 1970 to a peak of 1.76

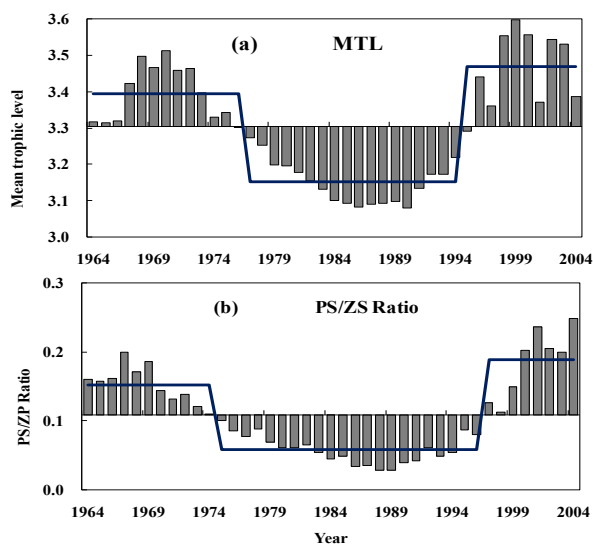


Fig. 7. The change in MTL (mean trophic level) and PS/ZS (piscivore/zooplanktivores) ratio estimated from 54 taxa in the Japan Sea.

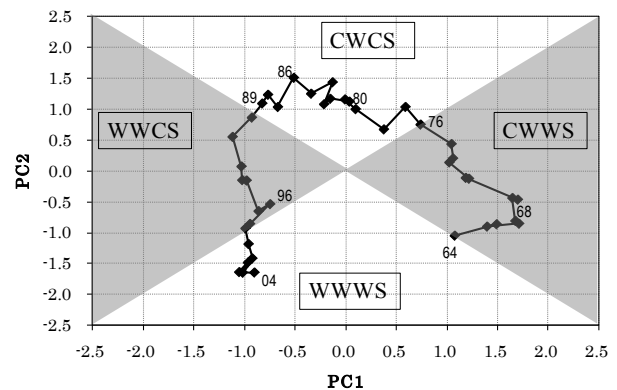


Fig. 6. The trajectory between PC1 and PC2 from PCA for 54 taxa catch in the Japan Sea.

million t in 1989, and then decreased abruptly with the collapse of the Japanese sardine stock (Fig. 4, Tian et al., 2008). The trend in total catch in the Japan Sea has depended largely on pelagic species, and the trend is different between pelagic and demersal species. The catch of

demersal species (15 fishes and 13 invertebrates) has fluctuated with a range of 80,000 to 220,000 tons during 1964-2004. It increased slightly to the early 1970s and has tended to decrease gradually since the 1970s. It is relatively stable compared with the large interannual fluctuations in the pelagic species. Proportion of demersal species to the total varied largely from over 30% during the late 1960s to about 7% in 1989, indicating that the fish community structure changed largely around the late 1980s.

Figure 5 showed the PCA (Principal Component Analysis) results for pelagic, demersal groups and the total. The first two components (PC1-2) of PCA for the fisheries catches, which accounted for 50% and 69% of the total variance for the pelagic and demersal groups, respectively, showed decadal

variation patterns (Fig. 5). The PC1 for the two groups showed similar patterns with a positive score before the 1970s and a negative value after the 1980s, indicated the most important change particularly in the demersal group (PC1 alone accounted for 53% of the total variance) that occurred during the late 1970s to early 1980s. The PC2 pattern seems to be the opposite between the pelagic and demersal groups, despite their synchronous changes around the late 1980s to early 1990s. The PC1-2 for the entire group of 54 taxa were similar to PC1 in the pelagic group and PC2 in the demersal group, respectively. STARS analyses for these PCs indicated that step changes occurred in the pelagic group in 1977/1978 (both PC1 and PC2) and in 1987/1988 (PC1), and in the demersal group in 1972/1973 (both PC1 and PC2), 1981/1982 (PC1) and 1988/1989 (PC2).

PCA shows that both the pelagic and demersal fish assemblages show decadal variability with a step change in 1988 but different response patterns. The PC1 from the bottom trawl data also indicated a step change in 1987.

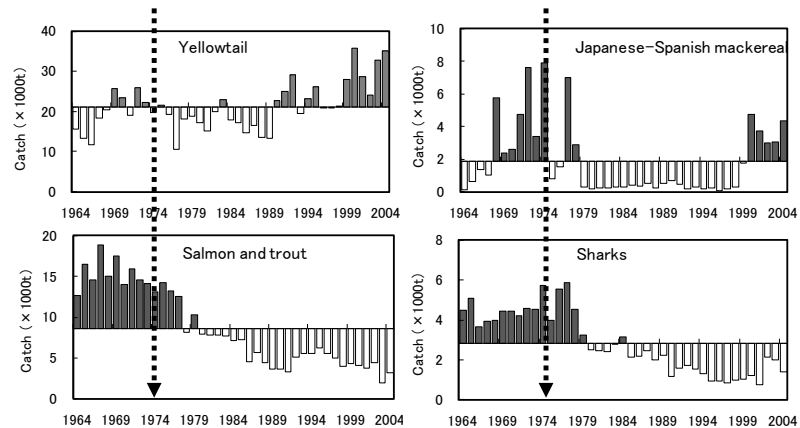


Fig. 8. Changes in the catches for four large fishes. The dotted arrows indicate the changes in the early 1970s.

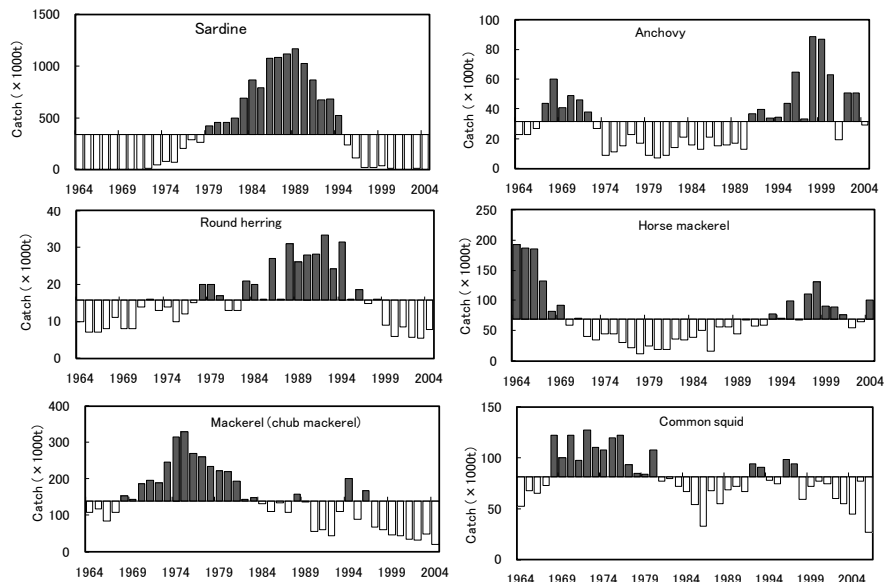


Fig. 9. Changes in the catches for six small pelagic fishes. The dotted arrows indicate the changes in the early 1970s.

Figure 6 showed that trajectory of PC1 and PC2 for 54 taxa. The trajectory of points showed that PC1 dominated during 1964-1976 and 1990-98 (shaded areas) and PC2 dominated during 1977-1989 and 1999-2004 (white areas). The phase change between ordination dimension in PC1 and PC2 indicated three distinct regimes: 1964-1976 cluster with positive PC1, 1977-1986 cluster with positive PC2 and 1990-2004 cluster with negative PC1, which approximated the changing regimes in the 50m depth water temperature between summer and winter (Fig. 3). This suggested that variability in the fish assemblages in the Japan Sea was forced by the variation pattern in water temperature between summer and winter.

4. Variation pattern in the fish populations during 1970s

To indentify the changes in the 1970s, we also examined the biological indices such as MTL and PS/ZS ratio (Tian et al., 2006) addition to the above indices from PCA. Both the MTL and PS/ZS ratio showed similar patterns (Fig. 7): it changed from positive to negative anomalies around the early 1970s, but changed from negative to positive around mid-1990s. PCA for 18 high trophic level fishes also indicated a change occurred around the early 1970s (Tian et al., in prep.).

Figure 8 showed changes in the catches of four large predatory fishes as an example (yellowtail, Japanese-Spanish mackerel, salmon and trout, and sharks); the catches decreased during the early 1970s. On the other hand, small pelagic fishes showed different variation pattern: the Japanese sardine, round herring and chub mackerel increased around the early 1970s, while the anchovy, horse mackerel and common squid decreased (Fig. 9). Most demersal species also changed around the early 1970s with different trends (Fig. 10).

Cold-water species such as Pacific cod, arabesque greenling and crabs (mainly snow

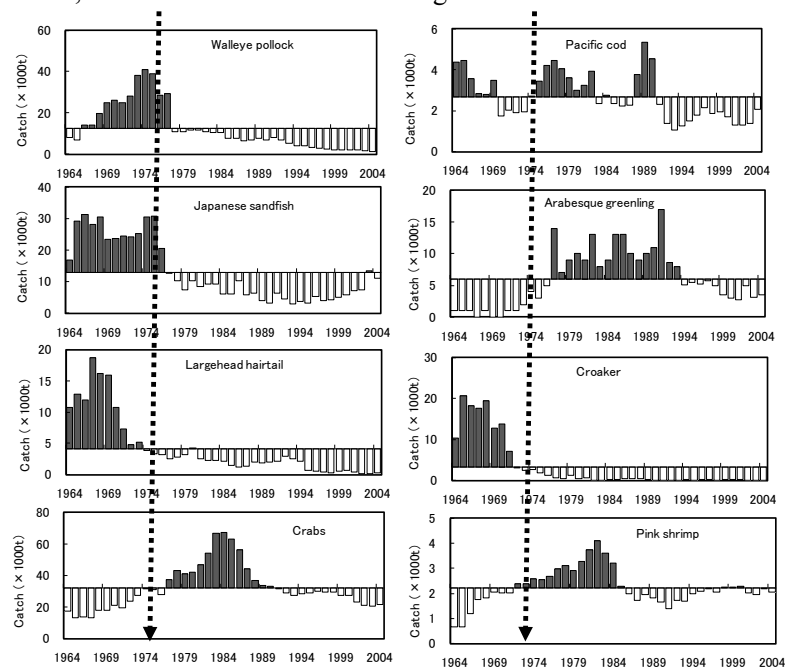


Fig. 10. Changes in the catches for eight demersal fishes. The dotted arrows indicate the changes in the early 1970s.

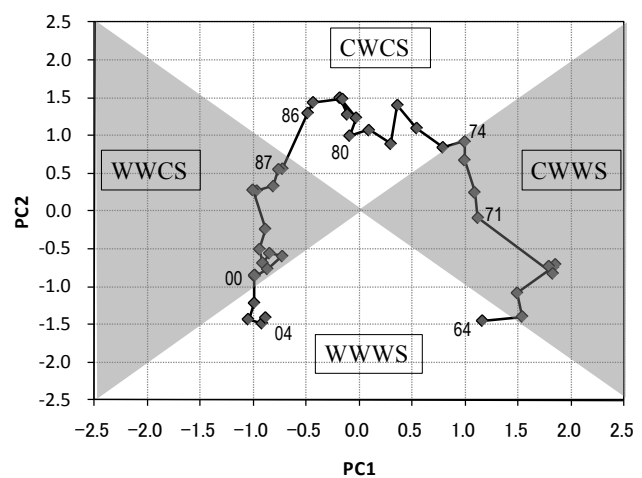


Fig. 11. The trajectory between PC1 and PC2 from PCA for 28 demersal taxa catch in the Japan Sea.

crab and red snow crab) increased, while walleye Pollock and sandfish decreased. Most demersal fishes, which have main distribution in East China Sea

such as largehead hairtail and croakers, decreased in the early 1970s. These results indicated that a change occurred not only in individual species but also in community level in the Japan Sea in the early 1970s.

Correlation analysis between

the biological and oceanic/climatic indices showed the PC1 and PC2 significantly correlated with winter and summer WT respectively (Table 1),

indicating that variation patterns in fish populations in the Japan Sea were largely forced by the WT. Figure 11 showed the trajectory of PC1 and PC2 for 28 demersal species as an example. There were three distinct regimes: 1965 ~ 74, 1975 ~ 86 and 1987 ~ 2000. The phase change was well correspondent with the variation pattern in winter and summer WT as showed in Figure 3. These indicate that variability in fish population in the Japan Sea was forced by both summer and winter WT, the change in the early 1970s was associated largely with summer WT; however, different variation pattern in summer and winter resulted in the complexity of the variability in the fish populations and community structure.

Table 1. Correlation coefficients between climatic/oceanographic indices, and biological/community indices

	SOI	PDO	AOI	MOI	WTwin	WTspr	WTsum	WTaut
MTL	0.29	-0.28	-0.12	0.09	0.13	0.17	0.37*	0.21
PS/ZS ratio	0.11	-0.24	-0.17	0.09	0.21	0.24	0.52**	0.19
DI	0.18	-0.28	-0.27	0.20	0.04	0.13	0.41**	0.11
PC1_pela	0.25	-0.38*	-0.33*	0.41**	-0.50**	-0.34*	0.03	-0.34*
PC2_pela	0.13	-0.24	0.02	-0.01	0.36*	0.37*	0.48**	0.35*
PC1_deme	0.21	-0.36*	-0.36*	0.40*	-0.47**	-0.34	0.06	-0.40**
PC2_deme	-0.03	0.14	-0.03	0.18	-0.43**	-0.38*	-0.48**	-0.22
PC1_ps	0.20	-0.35*	-0.33*	0.38*	-0.50**	-0.27	-0.06	-0.44**
PC2_ps	0.16	-0.23	-0.09	0.13	0.28	0.34*	0.42**	0.45**

SOI: Southern Oscillation Index. PDO: Pacific Decadal Oscillation index. MOI: Winter Asian Monsoon Index. AOI: Arctic Oscillation Index. WTwin, WTspr, WTsum and WTaut represent the 50 m depth water temperature in the Japan Sea, in winter, spring, summer and autumn, respectively. MTL, PS/ZS ratio and DI represent the mean trophic level, the ratio of piscivores to zooplanktivores and diversity index, respectively. PC1_pela, PC2_pela, PC1_deme, PC2_deme, PC1_ps and PC2_ps represent the first two principal components (PC1-2) for the pelagic, demersal and piscivorous groups, respectively. Single and double asterisks represent significance at $P < 0.05$ and $P < 0.01$, respectively. (Tian *et al.* (2008))

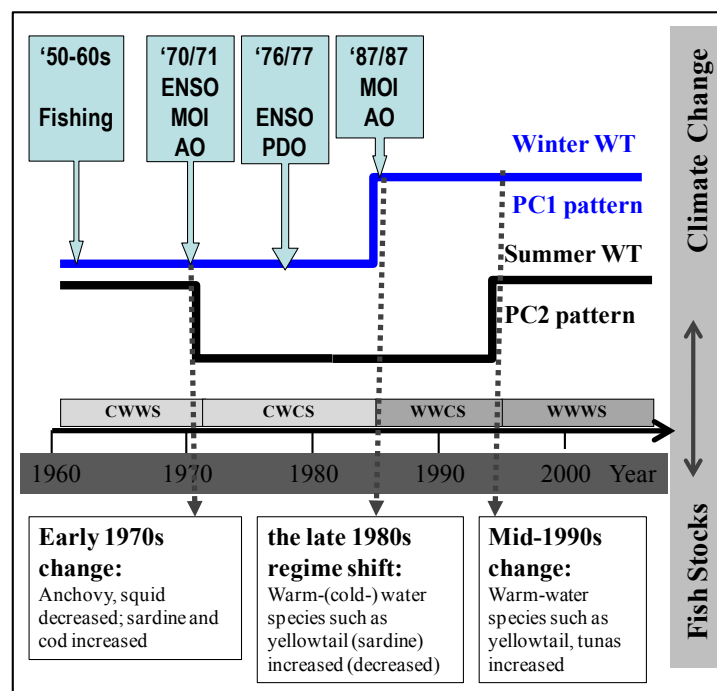


Fig. 12. Illustration showing the response of fish stocks in the Japan Sea to the climate changes.

5. Discussion and conclusions

Figure 12 illustrated the impacts of environmental changes on the long-term variability in the fish populations. The most evident change occurred around the late 1980s was resulted from the late

1980s climate regime shift indicated as changes from cooling to warming in winter WT in the TWC. Detail of the ecological responding process to the late 1980s regime shift was stated in Tian et al. (2008, 2010). For the change occurred in the early 1970s, it was clearly affected by summer WT as indicated as changes from warming to cooling around 1970/71, but it seemed to be not resulted from the well-known mid-1970 climate regime shift as indicated in PDO and SOI.

With the late 1980s regime shift, warm-water species such as yellowtail, tunas, anchovy, horse mackerel and common squid increased their abundances with northward extension in distributions; while cold-water species such as sardine, Pacific cod, walleye Pollack and spear squid reduced both the abundances and distributions (Tian et al., 2008; Tian, 2009). The changes in the early 1970s were opposite with that in the late 1980s: cold-water species such as sardine and Pacific cod increased, while warm-water species such as yellowtail, horse mackerel and anchovy decreased. Climate indices such as MOI, AOI and SOI changed around early 1970s with several years scale, but no regime shift was detected around early 1970s in these climate indices. These indicated that changes in the Japan Sea in the early 1970s seemed different with that occurred in the North Pacific in the mid-1970s.

As summaries, decadal variability in the WT in the Japan Sea was identified with , However, different variation patterns in summer and winter WT. This difference seemed to be important to the fish stocks in the Japan Sea. Climate regime shift occurred in the Japan Sea in the late 1980s, but no regime shift was identified in the mid-1970s. This indicated the regime shift in the Japan Sea was different with that in the central and northeastern North Pacific, where the 1976/77 regime shift was most evident. Change in summer WT in the Japan Sea was identified during the early 1970s, which seemed associated with the 1970/71 minor regime shift in the North Pacific. Inter-annual changes in climate indices (MOI, SOI and AO) were also identified in the early 1970s. These suggest a change in the environment occurred in the early 1970s in the Japan Sea.

A regime shift in the fish community occurred in the late 1980 in the Japan Sea (same as that in the North Sea, Humboldt ecosystem), but the mid-1970s (global) regime shift is not evident in the Japan Sea. Variation patterns in fish populations seemed to be forced by winter and summer WT. An evident change in the early 1970s (71-73) were identified in the fish stocks from small pelagic, demersal to large predatory fishes, and associated with the summer WT indicated as change from warm to cold regime. The fishing (increasing fishing effort in 1950s and 1960s) maybe associated with decreasing in the fish stocks, particular in demersal species.

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