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DECADAL VARIATION IN EGG ABUNDANCE OF A MESOPELAGIC FISH, *MAUROLICUS JAPONICUS*, IN THE JAPAN SEA DURING 1981-2005

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Key words: regime shift, mesopelagic fish, *Maurolicus japonicus*, Japan Sea.

ABSTRACT

Egg abundance of *Maurolicus japonicus*, a dominant mesopelagic fish in the Japan Sea, was analyzed during 1981-2005 as an index of the spawning-adult abundance. There was a major change in egg abundance around 1988/1989, with negative anomalies occurring during 1981-1988 and positive anomalies occurring from 1989. At about the same time (1986/1987), the Tsushima Current shifted from cold to warm conditions. Environmental indices were found to be positively correlated with egg abundance two years later. Our results suggest that the abundance of *M. japonicus* is affected by climatic regime shifts, and that it could be used as an indicator species.

I. INTRODUCTION

Decadal variability in the climate affects various marine organisms including phytoplankton, zooplankton and fish through changes in environmental conditions, such as water temperature and mixed layer depth [1, 3, 4, 8, 16, 25, 29]. Such decadal variability in marine ecosystems is commonly called a “regime shift” [2, 25], and there have been many documented cases in pelagic waters, but relatively few in the mesopelagic zone [10, 15].

The mesopelagic zone is inhabited by many organisms such as crustaceans, cephalopods and micronektonic fishes,

which form a substantial biomass [6]. Their interaction with the pelagic zone is important and indispensable for understanding marine ecosystems, as many pelagic organisms feed on mesopelagic micronektonic species [20, 30]. Moreover, mesopelagic species play an important role in transporting organic material between the productive pelagic zone and less productive mesopelagic zone through diurnal vertical migration [9, 27].

In the Japan sea *Maurolicus japonicus* (North Pacific lightfish, Family Sternoptychidae) is a dominant mesopelagic micronektonic species with a huge biomass and is recognized as a key species in the marine ecosystem [12, 19]. Egg surveys for Japanese sardine (*Sardinops melanostictus*) have been conducted since 1978, and during these surveys, *M. japonicus* eggs have also been collected. The data were collected in the upper 150 m depth by deep vertical net hauls conducted from the shore to oceanic areas in spring (described in MATERIAL AND METHODS section) [7]. *M. japonicus* occurs along the continental shelf and spawns throughout the year, except during the severe winter season (i.e., February) [11]. Its eggs are negatively buoyant, abundant below 100 m depth and hatch approximately six days after they are spawned [13, 18]. Its egg shell is unique, so it can easily be distinguished from those of other species [17]. Hence, although the surveys were designed for Japanese sardine, they can provide information on the annual egg abundance of *M. japonicus* throughout the Japan Sea.

In this study we examined the long-term variability of *M. japonicus* egg in relation to the marine environment in the Japan Sea, assuming that the egg abundance would reveal the spawning adult abundance. We also discuss how ecosystem regime shifts might affect this species.

II. MATERIAL AND METHODS

Egg abundance data have been collected in April, May and June since 1978 by the Japan Sea National Fisheries Research

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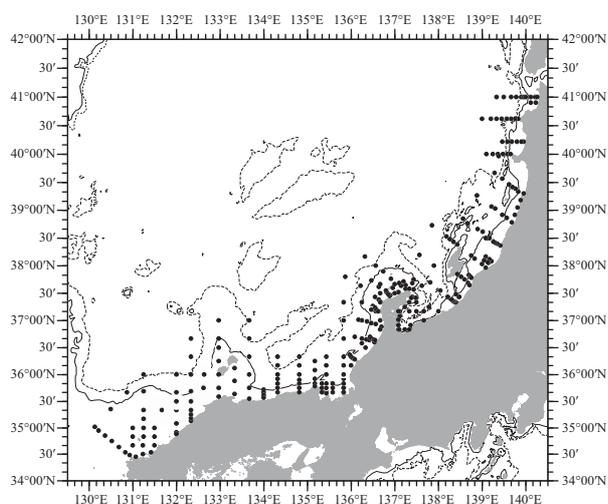


Fig. 1. Location of the survey points in May 2005. Bold line indicates 200 m isobaths, dash line indicates 1000 m isobaths.

Institute and the prefectural experimental stations from the Japan Sea. Fig. 1 shows the locations of the survey stations in May 2005 as an example. The survey stations were located within approximately 185 km from shore at 129°30' E - 140°30' E and 34°27' N - 41°10' N with an approximately consistent effort. The number of tows and area coverage have fluctuated over the years, however a large area has been sampled annually in May throughout the Japan Sea, with more than 224 stations conducted since 1981 (Table 1).

During the survey period, a conical or cylindrical-conical plankton net with a mouth opening ring diameter of 45 cm and a mesh size of 330, 335 or 345 μm was towed from 150 m or just above the seafloor (if the bottom depth was <150 m) to the surface to collect eggs and larvae (Table 1). A calibrated flow meter was mounted on the mouth of the net to measure the filtered volume. We estimated egg density per 1 m^2 sampled for each station during 1981-2005 in May, calculated the average egg density of the whole sampling area, and used the value as an index of the adult *M. japonicus* abundance for each year.

To investigate environmental change, we used two indices of the Tsushima Current, a warm current in the Japan Sea that is affected by climate regime shifts and affects various marine organisms [25, 31]. The first index was area-averaged 50 m depth water temperature, which is commonly used as an indicator of the Tsushima current [14]. Temperature data were collected during monthly oceanographic monitoring observations conducted by Japanese governmental organizations [28]. We used the average temperature along the entire coast of the Japan Sea in spring (April-June). The second index was the Tsushima Current Index (TCI) provided by the Japan Meteorological Agency. The TCI is the monthly anomaly of the area warmer than 10°C at 100 m depth over the whole Japan Sea (the anomaly was calculated using the average of

Table 1. Details of the NORPAC net surveys conducted in the Japan Sea in May, 1981-2005.

Year	Egg abundance (per m^2)		Num. of tows	NORPAC net	
	Average	Max.		Mesh-size	Material
1981	26.1	749	286	330 μm	NGG54
1982	17.6	709	257	330 μm	NGG54
1983	0.8	72	262	330 μm	NGG54
1984	4.1	552	224	330 μm	NGG54
1985	4.1	309	257	330 μm	NGG54
1986	17.1	974	270	330 μm	NGG54
1987	18.7	1307	329	330 μm	NGG54
1988	4.3	539	332	345 μm	NIP60
1989	27.2	903	306	345 μm	NIP60
1990	33.5	798	333	345 μm	NIP60
1991	37.4	1621	310	345 μm	NIP60
1992	24.5	1494	354	345 μm	NIP60
1993	21.8	982	407	345 μm	NIP60
1994	43.6	2228	391	345 μm	NIP60
1995	27.5	1785	300	345 μm	NIP60
1996	24.0	1096	295	345 μm	NIP60
1997	32.8	1825	296	345 μm	NIP60
1998	44.6	2778	305	335 μm	Nytaal52GG
1999	30.6	1729	271	335 μm	Nytaal52GG
2000	43.1	1404	291	335 μm	Nytaal52GG
2001	38.4	2581	289	335 μm	Nytaal52GG
2002	80.9	4017	281	335 μm	Nytaal52GG
2003	41.6	2082	282	335 μm	Nytaal52GG
2004	63.5	2313	297	335 μm	Nytaal52GG
2005	20.0	722	293	335 μm	Nytaal52GG

1971-2000, represented by percentage) and reveals the fluctuation of the warm water area in the Japan Sea. We calculated the average 12-month value centering on May to obtain the annual value of the TCI. Area-averaged 50 m water temperature and TCI data from 1981 to 2005 were compared with the egg abundance data.

To determine if any major shifts occurred in the time series data, we applied a sequential *t*-test analysis of regime shift (STARS) developed by Rodionov [22]. STARS uses a *t*-test analysis to determine whether sequential observations in a time series represent statistically significant departures from mean values observed during the preceding period of a pre-determined duration. Because of the presence of autocorrelation in the time series, we used a "prewhitening" procedure before applying the STARS algorithm (ver.3) [23]. The change in the confidence of a regime shift is reflected in the value of the regime shift index (RSI), which represents the cumulative sum of the normalized anomalies. The STARS results are determined by the cut-off length for proposed regimes (L), and the Huber weight parameters (H), which define the range of departure from the observed mean, beyond which observations are considered outliers. Based on exploratory analyses with STARS, L was set at 5, and H at 1. STARS is written in Visual Basic for Application (VBA) for Microsoft

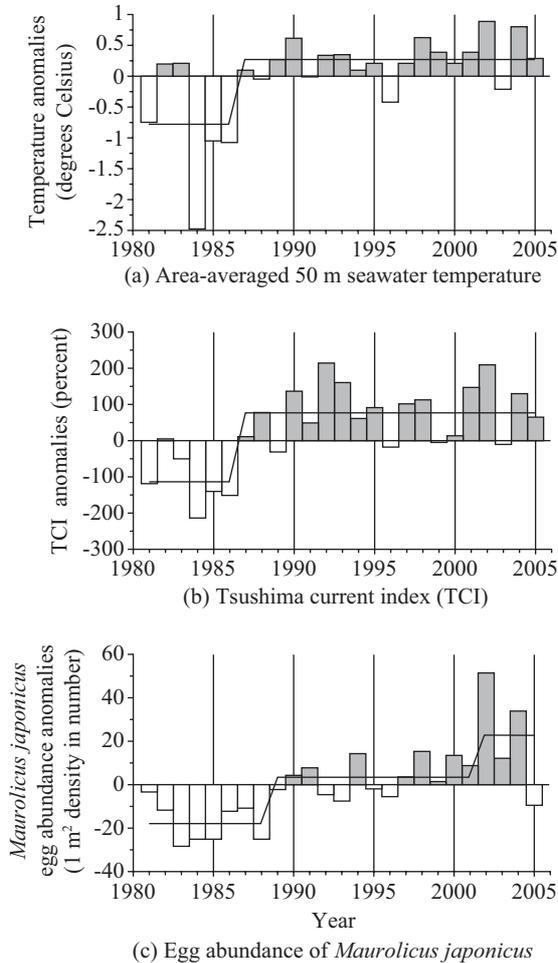


Fig. 2. Annual change of anomalies in area-averaged 50 m seawater temperature (a), Tsushima current index (b), Egg abundance of *Maurolicus japonicus* (c) during 1981-2005. The grey (white) bar represents positive (negative) anomalies. The step changes detected by STARS ($P = 0.1, L = 5, H = 1$) are shown in solid lines.

Excel and is available at www.beringclimate.noaa.gov [22-24].

III. RESULTS

The area-averaged 50-m water temperature showed negative anomalies during 1981-1986 (-0.83°C) and positive anomalies during 1987-2005 (0.26°C) (Fig. 2(a)). The TCI showed a similar fluctuation pattern with negative anomalies during 1981-1986 (-112.0) and positive anomalies during 1987-2005 (78.8) (Fig. 2(b)). There was no evident autocorrelation and no significant linear trend, but the STARS analysis indicated that a shift occurred from negative to positive anomalies for both the area-averaged 50 m water temperature and TCI in 1986/1987 (Fig. 2(a), (b)).

The average egg abundance ranged from 0.8 to 80.9 per m^2 during 1981-2005 (Table 1). There was a large interannual fluctuation, but it seems to show a decadal-scale variation

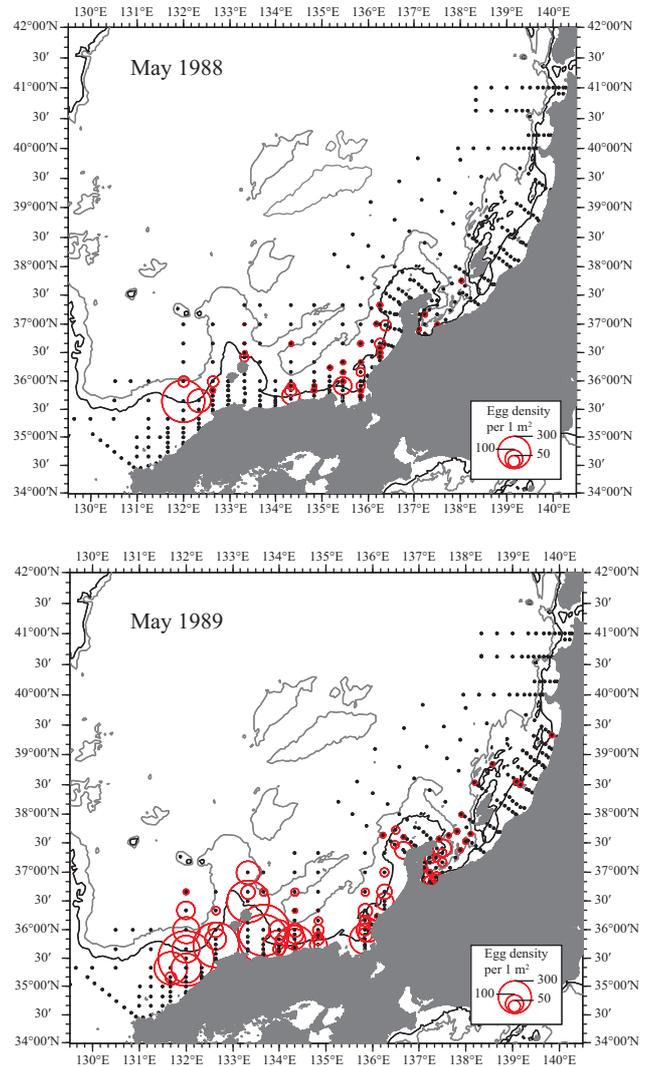


Fig. 3. The egg distribution of 1988 and 1989. Bold line indicates 200 m isobaths, grey line indicates 1000 m isobaths.

pattern. Egg abundance showed negative anomalies during 1981-1988 (-17.5) and positive anomalies during 1989-2005 (1998-2001 = 3.9, 2002-2005 = 22.4) (Fig. 2(c)). Again, there was no evident autocorrelation and no significant linear trend, but the STARS analysis indicated two major shifts: one from negative to positive anomalies in 1988/1989, and another from low positive to high positive anomalies in 2001/2002 (Fig. 2(c)).

Fig. 3 shows the egg distribution before and after the first shift. Before the shift, eggs occurred mainly in the southwest part of the Japan Sea, however after the shift, eggs started to occur in the northern area, and the egg density increased; the maximum egg number was less than 1307 in 1987, but regularly over 1000 after 1989, reaching 4017 in 2002 (Table 1). Area-averaged 50 m water temperature and TCI were both positively correlated with egg abundance two years later (Spearman's rank correlation test, $P \leq 0.01$).

IV. DISCUSSION

In the Japan Sea, temperature and TCI data indicated there was an environmental shift from negative to positive anomalies in 1986/1987 (Fig. 2(a), (b)). Two years following this change, fluctuations in egg abundance showed a clear shift from negative to positive anomalies (Fig. 2(c)). Using the same STARS test, Tian *et al.* [25] reported a similar shift in abundance following environment change that occurred in the late 1980s in the Japan Sea. The authors indicated that commercially important pelagic warm-water species such as yellowtail (*Seriola spp.*), Japanese common squid (*Todarodes pacificus*) and Japanese anchovy (*Engraulis japonicus*) also showed abundance increases in 1988/1989 (for yellowtail) and 1990/1991 (for Japanese common squid and Japanese anchovy) after a shift from cold to warm temperatures. The close agreement between the abundance of *M. japonicus* and changing environmental conditions found in the present study suggest that the regime shift also affected the mesopelagic ecosystem.

The coincidence in the timing of the shift in abundance of *M. japonicus* and the commercially important species suggest that *M. japonicus* might be useful as a biological indicator of the ecosystem. Biological indicators such as the abundance of zooplankton, which have a rapid response to environment change and are unaffected by fishing, would be useful to detect the occurrence of ecosystem regime shifts [29]. *M. japonicus* is also unaffected by fishing as it is not fished commercially or caught as bycatch. Hence it should be useful for detecting ecosystem regime shifts at mid-trophic levels.

It is unclear why *M. japonicus* increased in abundance during a warm regime, however prey conditions may have been a factor. *M. japonicus* occurs near the pelagic zone; 100-250 m during the day and shallower depths at night [5]. In relation to the prey organism, Ikeda *et al.* [12] reported that *M. japonicus* in Toyama Bay, on the central coast of Japan, feeds mainly on epipelagic warm water copepods such as *Calanus sinicus*, *Oncaea media*, *O. mediterranea* and *O. venusta*. Warm water copepods such as *C. sinicus* are sensitive to temperature during their reproduction process [26], and several studies have indicated that some warm water copepods increase in abundance during warm regime through an increase of their habitat area [3, 21]. In the Japan Sea, no species specific zooplankton data are available, however Tian *et al.* [25] reported that the total zooplankton biomass increased in the late 1980s. *M. japonicus* has a 20-22 month life span and is considered to require approximately 12 months to mature [11]. As Tian *et al.* [25] proposed, bottom up processes following an ecosystem regime shift from cold to warm conditions in the Japan Sea may have benefited *M. japonicus* by increasing the abundance of its prey organisms.

In future studies, regional abundance of adults should be investigated together with studies on the feeding ecology of *M. japonicus* related to dominant zooplankton species fluctuations. The present study observed a spread of the distribu-

tion and an increase of egg density mainly in the southwestern area during the shift in the late 1980s (Table 1, Fig. 3). The abundance of adults in the southwestern area is presumably significant, however their density and contribution to the total biomass is unknown. Recently acoustic means have been shown useful in monitoring the adult biomass in the Japan Sea [5]. Comparing the egg abundance with the adult abundance derived from the acoustic results may verify the quantitative interpretation of the egg data and help explain how abundance has shifted in the past.

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