ORIGINAL ARTICLE

Interannual Variability of Common Squid Fishing Ground in the East Sea derived from Satellite and *In-situ* Data

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Abstract

In this study, we estimate the interannual spatial and temporal distributions of fishing grounds at night in the East Sea based on satellite and in-situ data. We observe that the 15°C thermal front moves in the north-south direction according to the movement of the warm water (above 18°C) in the Tsushima Warm Current (TWC) area, forcing the cold water area (below 10°C) to either expand or shrink. The interannual variations of sea surface temperature (SST) in winter represented by the indicator SST of 6°C are consistent with the east-west zonal areas in the central East Sea which represented over 1°C standard deviation of SST in February during 1990-2000. Annual SST in the fishing grounds of common squid fishing vessels, observed both by fishing vessels and satellites range from 9-22°C, with the satellite-observed data having a larger range than the fishing vessel-based ones. The interannual distributions of the common squid fishing grounds in the East Sea are mostly concentrated in the TWC area in the southwestern part of the East Sea and in the coast of southern Honshu and Hokkaido in Japan. The interannual distributions of the nighttime fishing vessels are consistent with the catches investigated from the fishing vessel.

Key words : Interannual variability, East Sea, Squid fishing ground, SST, Satellite data

1. Introduction

The East Sea is commonly known as a miniature ocean as it mimics features found in larger oceans. In the middle part of this area, a thermal front is formed when the Tsushima Warm Current (TWC), which originates in the southern part, and transports warm salty water into the basin through the Korean Strait, meets the North Korea Cold Current (NKCC), which transports cold fresh water. The thermal front in the central East Sea highly variable, play an important role in creating a good fishing ground and migratory route for fishes like squid, saury, and mackerel (An et al., 1994; Kim et al., 2000; Kim et al., 2002).

Due to the effects of accelerating climate change, the East Sea has gradually been turning subtropical. Temperature rise, one of the potential effects of climate change, has continuously brought subtropical aquatic organisms like the yellow ray and octopus into the East Sea. An increase in the number of warm jellyfish has caused damages to the fishery industry as well. In addition, temperature rise has caused changes in the stocks at the fisheries. While walleye pollack, a common cold water species in the 1960s and 70s has, mostly vanished, the common squid, a warm water species, is now mainly caught in the East Sea. Due to the limitations of in-situ boat surveys, studies on the long-term temporal and spatial variability

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of sea temperature are mostly based on satellite tools that are able to conduct several observations per day and thus considered as both economic and convenient.

Sea surface temperature (SST) data derived from NOAA AVHRR (Advanced Very High Resolution Radiometer), used for measuring the temporal and spatial variability of the water temperature, have frequently been used to monitor the coastal upwelling, which occurs every year in the southern East Sea (Suh et al., 2001; Lee et al., 2003; Kim et al., 2010), and variability of the Eastern Korean Warm Current (Isoda and Saitoh: 1988, Isoda et al., 1991). Being highly sensitive to temperature, the common squid, one of the major species in the East Sea as well pelagic fishes like saury can provide important physical oceanographic data to analyze the relationship of the SST images to these species.

The common squid is a major commercial species in the East Sea. Though it is being increasingly caught by trawls, it is mostly caught at night by jigging vessels, since this species is attracted to lights (Sakurai et al., 2000; Cho et al., 2004). The Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) sensor can effectively detects light emissions from squid vessels (Elvidge et al., 1999; Cho et al., 1999; Kiyofuji et al., 2001; Kim, 2002). Previous studies on the temporal analysis of

fishing conditions for common squid were mostly based on long-term oceanic conditions and catch data and those on the spatial distributions of the fishing grounds for common squid focused on monthly variabilities of the fishing grounds (Kiyofuji et al., 2001; Kim, 2002; Cho et al., 2004; Choi et al., 2008). However, there are relatively few studies on the interannual variabilities of the fishing grounds.

For this study analysis of interannual oceanographic conditions in the East Sea utilizing SST derived from the NOAA satellite was carried out. Then, a combined analysis of in-situ squid catch data, SST images and DMSP/OLS nighttime visible band images was carried out to analyze the interannual temporal and spatial variabilities of the nighttime fishing grounds for common squid.

2. Materials and methods

In order to analyze the temporal and spatial distributions of nighttime squid fishing boats in the East Sea, we utilized interannual means of daily DMSP/OLS visible band images during 1993-2000 in areas bounded by the 33-45°N latitude and the 126-142°E longitude provided by the National Geophysical Data Center, NOAA (Fig. 1). SST images were obtained from annual means of daily Multi-

Fig. 1. NOAA/MCSST (left) and DMSP/OLS (right) images in the East Sea between 33-45°N in latitude and 126-142°E in longitude. The ellipse area indicates the Yamato Ridge.

Channel Sea Surface Temperature (MCSST) for 11 years (1990-2000) based on NOAA AVHRR band 4 and 5 which were directly received by the National Fisheries Research & Development Institute (NFRDI) of Korea (McClain et al., 1985). Although we analysed the MCSST images for the same years as those for which DMSP/OLS images were obtained, we calculated mean and standard deviation from the MCSST images for the 11 years (1993-2000) to determine average variations of the oceanic conditions in the East Sea. SST anomalies were also calculated by subtracting the mean from the annual SST to identify interannual SST variations.

Coastal and offshore jigging fishery data grids (0.5° latitude×0.5° longitude) were obtained from the Fishing Conditions Survey Periodicals (NFRDI, 1993- 2000), published by the NFRDI, to analyze the caught of common squid.

3. Results and discussion

3.1. Temporal and spatial distributions of SST

The yearly mean and standard deviations of SST in the East Sea during 1990-2000 are illustrated in Fig. 2. The mean SST ranges from 8-20°C with the 15°C thermal front forming in the 38-41°N area. The warm water with temperatures above 18°C and flowing

from the Korean Strait was located south of the front, while the cold water below 10°C was located north of the front. This showed a strong SST slope from north to south. The standard deviation of SST was derived as over 0.5°C for the entire East Sea except for the south of the Korean Strait and north of 42°N. In particular, it was relatively higher over 0.75°C in the central East Sea where the thermal front crossed the east-west direction.

With the movement of the north-south of the 15°C thermal front, the interannual distribution of SST showed a steep slope north of the front (Fig. 3). This can be explained by the fact that the warm water over 18°C from the TWC in the southern East Sea forced the thermal front to move north-south and the thermal front which was now running north caused the cold water below 10°C in the north East Sea to either expand or shrink, causing a steeper slope in the SST as compared to the south East Sea. The movement of the front resulted in large meandering in the east-west direction, which showed an irregular pattern every year with large vertical fluctuations (Isoda et al., 1991; Choi et al., 1993).

In order to obtain a detailed understanding of the spatial variations of the warm and cold water, we drew 6°C and 25°C fronts, representing winter and summer, respectively (Fig. 4). A SST of 6°C has been

Fig. 2. Horizontal distribution of yearly mean and standard deviation of sea surface temperature (SST, °C) from 1990 to 2000.

Fig. 3. Yearly mean SST images in the East Sea from 1990 to 2000.

suggested as an indicator SST for the thermal front in winter by Choi et al.(1993). The interannual variations of SST of 6°C for winter was distributed in a range of 2-3 degrees in latitude near the coasts of Korea and Hokkaido in Japan. The area in between the coast of Korea and Hokkaido had a narrow range of 1 degree of latitude for the SST distribution. Isoda (1994) has

suggested that the decadal variability of the thermal front correlated with the TWC while the 2-4 year long-term variability was influenced by the Asia winter monsoon. Areas showing over 1°C standard deviation of SST as shown in Fig. 5 are quite consistent with those subject to the horizontal and vertical movement of the thermal front. It means that

Fig. 4. Interannual variations of SST derived from satellite data in February (left) and August (right) from 1990 to 2000. Contour lines indicate the isothermal of 6°C in February and 25°C in August.

Fig. 5. Horizontal distributions of standard deviation of SST in February (left) and August (right) from 1990 to 2000.

data on the movement of the front can serve as an important source to estimate the strength of the TWC.

The SST of 25°C for summer showed large interannual variations in the entire East Sea, ranging from 34°N in the south to 40°N in the north. The interannual variations showed the largest latitudinal fluctuation during 1993-1994. The isotherm of the SST of 25°C in 1993 reached Tsushima Island near 34°N, the southernmost of the range while the one in 1994 formed near 40°N, which is the northernmost. The largest spatial variations in SST in summer were

observed during the same period in this study. The result that the variations in summer SST were higher than those in winter is related to the variations in strength of the TWC, and the large distributions of the summer SST's are coincide with the areas having over 1.5°C standard deviation of SST in August as shown in Fig 5.

3.2. Distributions of SST, squid catches and nighttime fishing vessels

SST, squid catches and DMSP OLS nighttime fishing

Fig. 6. Yearly mean distributions of SST(°C, isothermal lines), catch of common squid (M/T), and nighttime fishing boats (white color) from 1993 to 2000.

vessels are shown in Fig. 6. Here, the SST is expressed as contour lines derived from the data in Fig. 3, the squid catches as circles and the nighttime fishing vessels are the white color in the images.

Yearly distributions of SST in the fishing areas where common squid fishing vessels operate derived from in-situ data and satellite images as shown in Fig. 6 are tabulated in Table 1. Our analysis reveals that the SST in the East Sea where the catches were distributed ranged from 11–21°C while those in the area where the nighttime fishing vessels were distributed ranged from 9–22°C, which shows a wider range than the catch area. Among the 8 survey years from 1993 to 2000, the year 1998 had the widest SST range of 9–22°C.

Table 1. Yearly SST observed both by fishing boats and DMSP/OLS images

Years	In-situ fishing boats	Fishing boats derived from DMSP/OLS satellite
1993	14–21°C	11–20°C
1994	14–21°C	11–21°C
1995	13–19°C	10–21°C
1996	11–19°C	9–21°C
1997	12–20°C	10–21°C
1998	15–21°C	9–22°C
1999	13–21°C	9–21°C
2000	13–19°C	10–21°C
Range	11–21°C	9–22°C

The nighttime fishing boat images represent the average distribution of locations with the strongest vessel lights. The yearly nighttime fishing boats were most concentrated in the TWC area in the southwestern part of the East Sea, around Yamato Ridge, the southern coast of Honshu Island and the coast of Hokkaido, and this is consistent with the catch distributions obtained from the fishing vessels. In particular, the data from 1993 and 1994, when significant interannual variabilities of the summer SST occurred, indicates

decreases, both in the number of fishing vessels and catches, around the coast in the central East Sea. The Yamato Ridge located in the central East Sea shows powerful lights from densely situated boats in all years, except in 1997 when the strength of the lights becomes weaker, indicating a lower density of fishing vessels. In the same area, the catches of common squid were relatively high in all the years, except in 1993, 1997 and 2000. The squid fishing vessels catches surveyed along the East Sea coast and around Yamato Ridge show a strong correlation with the nighttime fishing vessel images, although the comparison cannot cover the entire area of the East Sea due to the absence of Japanese catch data.

In general, the nighttime fishing vessel data and catch data correlate with each other in the East Sea. As possible explanation for the area where the interannual data of nighttime images and catches are not consistent, has been given by Kim et al. (2005) who suggest it is caused by the large number of vessels moving northward along the temperature front during the high catch season from September to December and the fact that sampling from these fishing vessels occurred only once. The DMSP/OLS nighttime images represent images taken daily while the catch data are from monthly data. We concur that the satellite nighttime image distributions are the more accurate data for estimating interannual squid fishing ground distributions.

4. Conclusion

In this study we analyzed satellite and in-situ data to estimate the interannual spatial and temporal distributions of fishing grounds for common squid jigging fishery at night in the East Sea during 1990–2000 based on NOAA SST, DMSP/OLS nighttime images and field investigated squid catches.

While analyzing the interannual variability of SST, we observed that the 15°C thermal front moved in the

north-south direction according to the movements of the warm water (above 18°C) in the TWC area, forcing the cold water area (below 10°C) to either expand or shrink. The interannual variations of SST in summer were large, those in winter represented by the indicator SST of 6°C were consistent with the east-west zonal areas in the central East Sea which represented over 1°C standard deviation of SST in February during 1990-2000.

Annual SST in the fishing ground of common squid jigging fishery observed both by the fishing vessels and the satellites ranged from 9-22°C, with the satellite-observed data having a larger range than the fishing vessel-based ones. The interannual distributions of the common squid fishing grounds in the East Sea were mostly concentrated in the TWC area in the southwestern part of the East Sea and also in the coast of southern Honshu and Hokkaido in Japan. The distributions are well consistent with those of the catches obtained from the fishing vessels.

Satellite can observe and provide very useful data for estimating the location of fishing grounds covering a very large area. Satellite derived SST is particularly useful for estimating the location of fishing grounds of major commercial species including pelagic fishes in surface waters.

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