A Visualization of the Variability of Spawning Ground Distribution of Japanese Common Squid (*Todarades pacificus*) using Marine-GIS and Satellite Data Sets

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ABSTRACT

Geographical Information System (GIS) has been developed in terrestrial fields, however it is not common for oceanography and fisheries science. Our objective of this study is to estimate the spatial and temporal variability of Japanese common squid(*Todarades pacificus*) spawning ground using this GIS technique and satellite data sets for demonstration of applicability of this method to fisheries research. According to recent report, standing stock of Japanese common squid has been increasing from the late 1980's. We assume that there is relationships between standing stock and extension of spawning ground. On the other hand, we made a laboratory experiment of spawning condition and we obtained that the preferable temperature range of spawning is from 15°C to 23°C. Based on the result of past ecological studies and the laboratory work, we constructed assumption about the Japanese common squid spawning ground, which will be formed in the warm surface layers of temperature range from 15°C to 23°C near continental shelf around Japan. To estimate Japanese common squid spawning ground, we collected three data sets, which are monthly global MCSST (multi - channel sea surface temperature) data, climatological oceanographic data set and topography data set. First of all, we adjusted each grid size to 10.54' as same as GMCSST data. We set up a linear equation from climatological oceanographic 0m temperature data and 50m depth temperature data for each grid. We calculate 50m depth temperature for each month from 1984 to 1995 using the linear equation and GMCSST data. Finally, we extract the area that 50m temperature is range from 15°C to 23°C and the sea bottom is with the depth from 100m to 300m. We visualized possible Japanese common squid spawning ground using GIS technique. As a result, we recognized that spatial extension of spawning grounds in 1989, 1990, 1991 related to the increase of standing stock of Japanese common squid from late 1980's. This study demonstrate an usefulness of combination GIS technique with long term Satellite data sets.

1. Introduction

Japanese common squid, *Todarades pacificus* ,distribute around Japan from East China sea to the Maritime Province of Siberia. *T.pacificus* are generally classified three spawning groups with the season. They are autumn–spawning group (Sep. Oct. Nov.), winter–spawning group(Dec. Jan. Feb.) and spring and summer –spawning group(other months). It has been considered that their spawning ground is based on the distribution of paralarvae sampled by research ships, because there has been no observation of *T.pacificus* egg masses in the sea. The spawning ground is formed mainly around Tsushima Strait(Araya, 1981) and near continental shelf. Moreover it has been demonstrated that the preferable temperature range of spawning is from 15℃ to 23℃(Bower et al, 1996).

Catch of *T.pacificus* has been taking the most part of total catch of squid, therefore *T.pacificus* is one of the most important fishery resources. According to previous study, standing stock of *T.pacificus* has been decreasing from 1970 's , and then increasing from the late 1980's(Figure 1). It has been reported that the variability of *T.pacificus* Catch indicates the variability of *T.pacificus* population. Sakurai(1997) suggested that this is due to the spatial and temporal variability of spawning ground and its spatial extension depends on increasing or decreasing of sea surface temperature.

On the other hand, Geographical Information Systems(GIS) has been developed in terrestrial fields, and this technique is powerful tool of management, analysis, display, search environment elements in relation to the living life. However, it is not common for oceanography and fisheries science because of the oceanic changes from hour to hour and the ocean system has different dimension from the land system, which means that we have to consider the direction of depth in the sea.

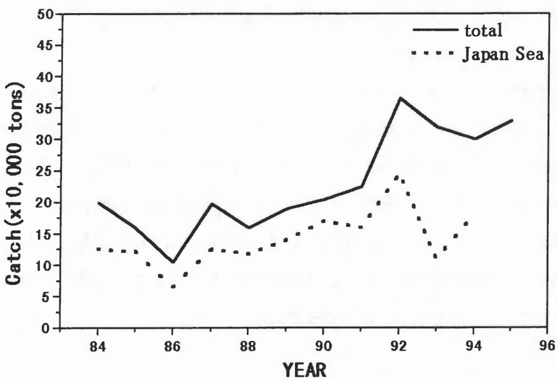

Figure 1 Annual fluctuation in catches of *T. pacificus* from 1984 to 1995

Our objective of this study is to estimate spatial and temporal variability of *T.pacificus* spawning ground using this GIS technique and satellite data sets for demonstration of applicability of this method to fisheries research.

2. Marine-GIS and input data set

2.1 Construction of Marine-GIS

First of all, we should well focus on the objective phenomena, in case of fisheries research, most part of interests are when, where, what kind of spices, why they distribute in the limited area.

In order to apply GIS to fisheries research, we constructed the Marine-GIS which are illustrated in Figure 2. This Marine-GIS is referred to the GIS-RS system that was constructed for land application by AL-GARNI(1996). There are input module, data processing module, feedback module and output module.

After employing data sets, we extract the study area and if the pixel size of each data set are different, we have to make them same pixel size by either interpolation or extrapolation in input module.

After carrying out this process, we will obtain the data sets which overlaid and applied to GIS analysis. In data proceeding module, we carry out overlaying, statistic analysis, simulation and forecasting by using both analysis software package such as ArcView or ERDAS Imagine and software developed by oneself.

Data can be represented as satellite imagery, table, graph and maps in output module. After that, in feedback module, we must validate about the results that we get in output module. When it is necessary to go back to accumulate the data, process and analysis, we should process again with same procedure.

Through these process, we believe that the complex interaction of ocean biological, chemical and physical processes will be analyzed at the same time.

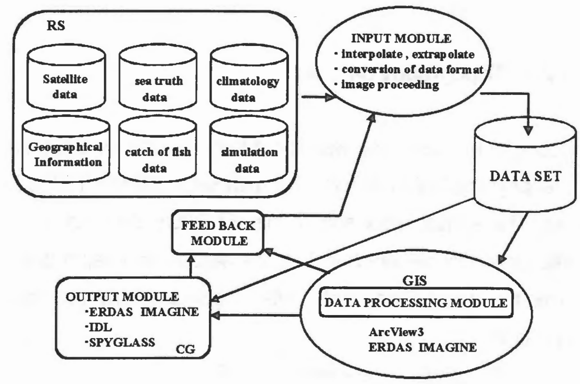

Figure 2 Marine-GIS applied to this study

2.2 Data set

We employed mainly satellite data set because the satellite data has advanced characteristics with repeatability and synoptic scale. We collected climatological data set which is called Levitus data set(Levitus and Gelgeld, 1992) and topography data set.

2.2.1 Global MCSST data set

Global MCSST(GMCSST) data set were proceeded by NOAA / NESDIS (National Environmental Satellite Data and Information). This is on equal-angle grid with dimension 2048 pixels(longitude) x 1024 pixels(latitude), therefore, the spatial resolution is approximately 18 km data. Each data file contains three data sets ; valid data, interpolated data and flag data. In this study, we use the monthly averaged MCSST interpolated Sea Surface Temperature(°C) data which can be derived from Digital Number(DN) and described the following equation,

$$SST(°C) = DN*0.15 - 2.1$$

2.2.2 Levitus data set

Levitus data set is produced by the NODC(National Oceanographic Data Center). This data set includes in situ temperature, salinity, oxygen, phosphate, nitrate, and silicate data and the spatial resolution of these parameters is one degree latitude-longitude mean fields using objective analysis techniques. In the present study, we use the monthly mean temperature data. The spatial resolution with one degree latitude-longitude of this data set differ from monthly global MCSST data, therefore we fitted the spatial resolution of Levitus data set linearly to monthly global MCSST data.

2.2.3 Topography data set

Topography data set was produced by the NGDC(National Geophysical Data Center). This data set is called ETOPO5 data set. The spatial resolution of this ETOPO5 data set is 5' x 5' latitude-longitude, which include the altitude and depth data in all over the world. The depth data is calculated by the following equation.

$$DN = elevation / 15 + 254$$

DN : digital number

elevation : altitude data

We extracted the altitude data from 15m to -3815m.

3.2 Data analysis

3.2.1 Presumption for extraction of possible spawning ground

To estimate the possible *T.pacificus* spawning ground, we constructed three assumptions from previous and latest studies and will be explained in the following.

(1) Presumption about sea bottom topography

T.pacificus stay on the sea bottom just before spawning(Bower et al., 1996; Sakurai・Bower、1997). There were many dead bodies of *T.pacificus* which had spawned already above the continental shelf (Hamabe, 1966), and the paralarvae were collected near and above the continental shelf(Yamamoto, 1996). Therefore these suggest that spawning grounds of *T.pacificus* are formed near and above the continental shelf. So we determine the depth of possible spawning ground of *T.pacificus* is above the continental shelf with the depth from 100m to 300m.

(2) Presumption about hatching temperature

Based on the result of past ecological studies and the laboratory work (Sakurai *et al.*, 1996), we constructed assumption about the Japanese common squid spawning ground, which will be formed in the warm surface layers of temperature range from 15°C to 23°C near continental shelf around Japan.

(3) Presumption about the depth of hatching temperature

Spawned egg masses of *T.pacificus* will be maintained near the warm surface layer(Bower et al., 1996), and distribution density of paralarvae is high at the depth of 20m to 50m(Hayashi, 1991; Kasahara, 1978). Furthermore temperature indicator of paralarvae distribution is 50m depth temperature (Goto, 1989). Following these observations, we select the depth of 50m as the dominant hatching layer of *T.pacificus*.

When we combine (1), (2) and (3) described above, the possible *T.pacificus* spawning ground is near and above the continental shelf with the depth from 100m and 300m, and temperature at the 50m depth is range from 15°C to 23°C.

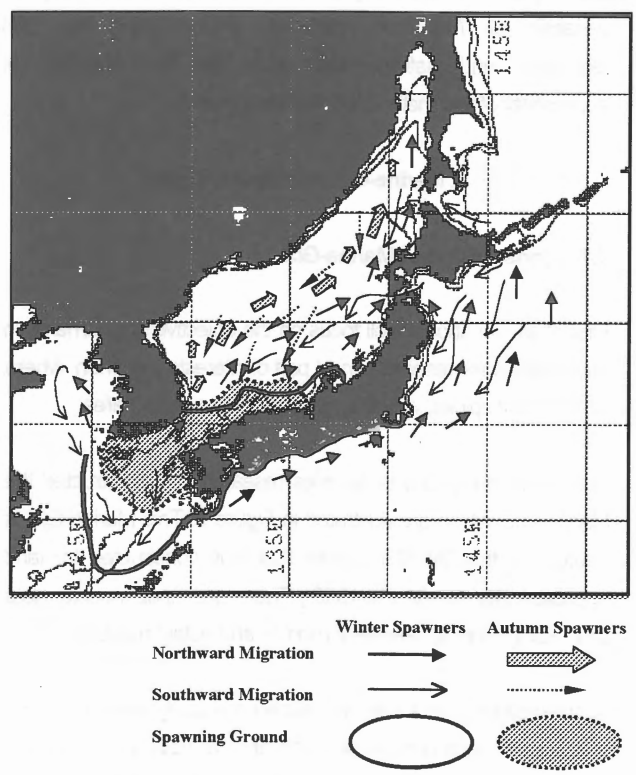

Figure 3 Study area and typical migration pattern of Japanese common squid (modified by Araya, 1981)

3.2.2 Data processing

Study area (26° N, 121° E ~53° N, 153° E) is illustrated in Figure 3 and this area is concerned the migration and spawning ground of *T.pacificus* that indicated by Araya(1981).

Flow chart of data processing and method of calculating the temperature at the 50m depth (°C) is illustrated in Figure 4. Each data set has different pixel size so that make them same pixel size to GMCSST data linearly which is 10.54'.

Linear equation was estimated using relationship between 0m temperature and 50m temperature of Levitus data, and then 50m depth temperature for each month from 1984 to 1995 was calculated using the linear equation and GMCSST data. So we can have maps of 50m depth temperature. Finally, by overlaying the topography data and map of 50m depth temperature(Figure 5), we can have possible spawning ground of *T.pacificus*.

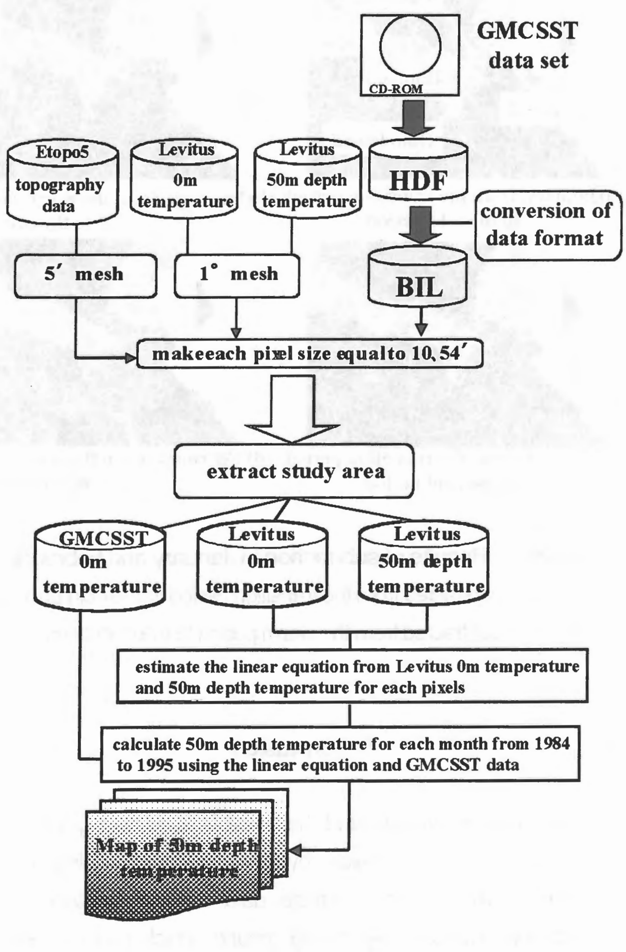

Figure 4 Flow Chart of data processing and method of calculating the temperature at the 50m depth

3.2.3 Estimation the inter-annual variability of possible spawning ground of *T.pacificus*

1. To investigate the area of possible spawning grounds always existing through a year, overlaid the data set from January to December for each year.
2. Kawamura et al. (1997) pointed out that climatological jump occurred in late 1980's. This is as said "a regime shift" with warmer temperature around Japan. We defined the period before climatological jump as the cold period and the period after climatological jump as the warm period. This period of climatological jump is defined as the transition period. To evaluate the difference and the change of spatial variability of spawning ground among each periods, we generate the overlaid images for each period, (1) the cold period image contains the data from 1984 to 1987, (2) the transition period image contains the data from 1988 to 1991, (3) the warm period image contains the data from 1992 to 1995. We operate of subtraction among these overlaid images, we extract the area of possible spawning ground not seen in the cold period.

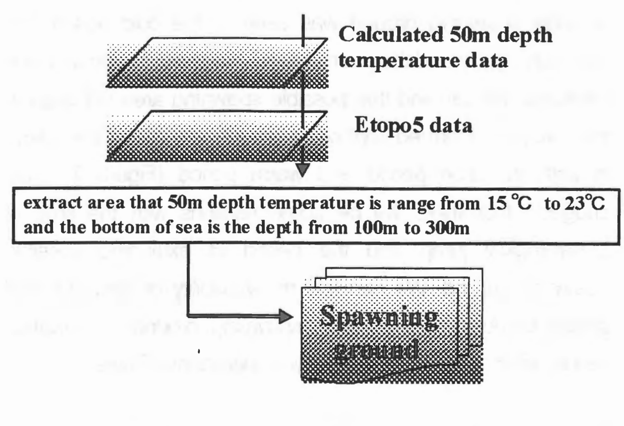

Figure 5 Method of extracting the possible spawning area of Japanese common squid

4. Results and discussions

Spatial distribution of extracted possible spawning ground of autumn-spawning group is almost similar to the area reported by Araya(1981). About winter-spawning group, spring and summer-spawning group, their spawning ground are more extended to south east China sea compare with Araya(1981). We can find the area of possible spawning ground always existing though a year in 1989, 1990, 1991, which were formed around Tsushima Strait and Goto Island (Figure 6). These year are correspond to the same period of increasing the catch of *T.pacificus* (Figure 1).

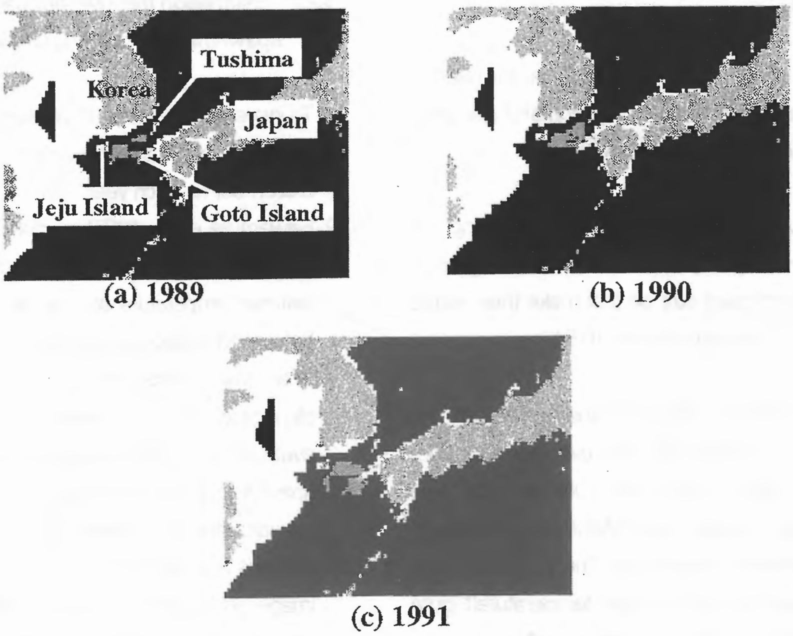

Figure 6 Spawning ground existing through a year

From September to December, no geographical variability of possible spawning ground was seen in the cold period, the transition period and the warm period. However, in January and February, we can find that possible spawning area not seen in the cold period formed from off Hamada to around Goto Island in both transition period and warm period (Figure 7). This suggests that there will be some relations with the time of climatological jump and the period of extending possible spawning ground. We can find the variability of temporal and spatial distribution of possible spawning ground in transition period, when catch of *T.pacificus* was increasing (Figure 1).

Figure8 shows the interannual variability of possible spawning ground in February. The possible spawning grounds are expanding in 1990's (Figure 8 (a)~(d)) and are not formed in 1980's (Figure 8 (e)~(g)), in and around the Tsushima Strait. The spatial extension of the possible spawning ground in 1992(Figure 8(h)) is similar to one in 1980's when the possible spawning grounds are distributing in narrow area. The catch of *T.pacificus* decreased sharply from 1992 to 1993 (Figure 1). This suggests that there was not preferable environment for spawning and the abundance of hatching decreased in 1992, as same as in 1980's, after that recruitment of next year decreased in 1993. There might be a possibility to make forecast the abundance of hatching and recruitment using the distribution of possible spawning grounds extracted by Marine-GIS system.

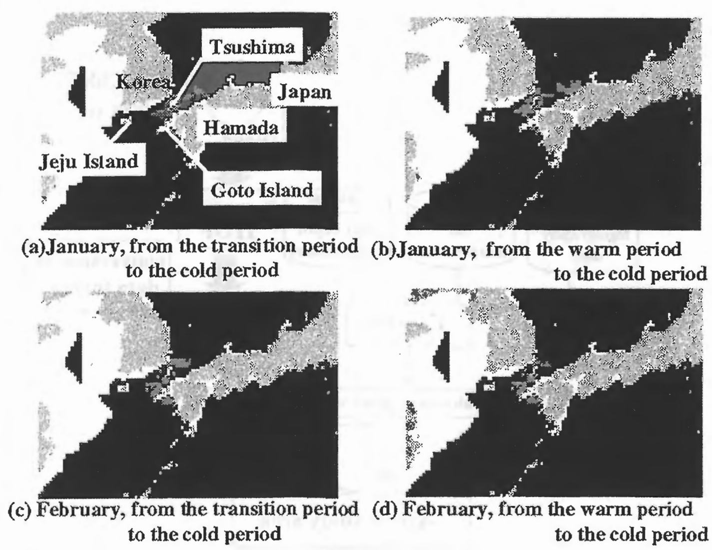

Figure 7 Results of subtraction in January and February

(a), (c) subtracted from the transition period to the cold period

(b), (d) subtracted from the warm period to the cold period

5. Conclusion

In this study, we investigated the possible spawning ground of Japanese common squids by a visualization using GIS technique with long-term satellite data set. We grasped the distribution of possible spawning ground, which had not been recognized so far. In the future, a visualization GIS technique with remotely sensed data will be important tool and give an advancement in fisheries sciences.

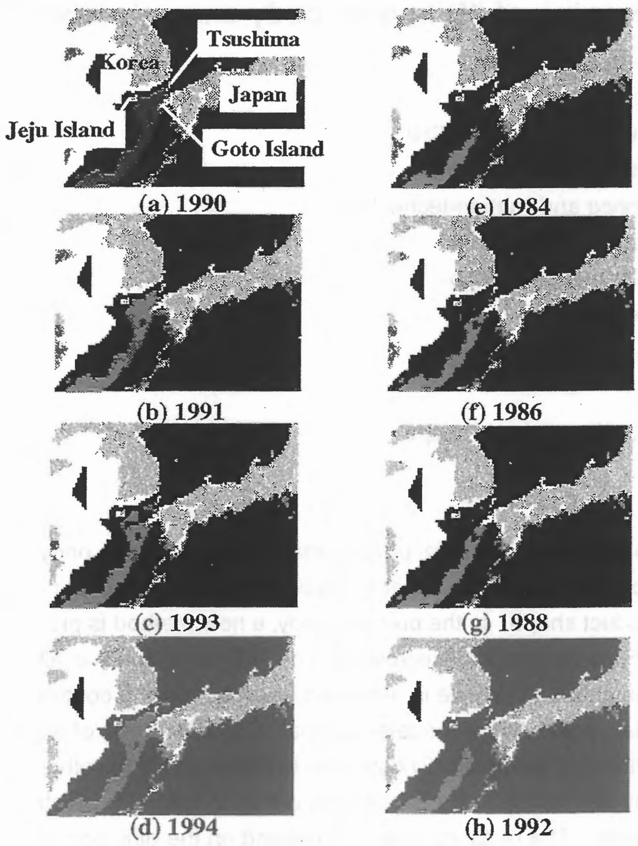

Figure 8 Spawning ground in February, 1984, 1986, 1988, 1990, 1991, 1992, 1993 and 1994
(a)~(d) : spatial extension in wide
(e)~(h) : spatial extension in narrow

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