PREDICTION OF SARDINE FISHING GROUND AS DETERMINED BY MULTI-SENSOR REMOTE SENSING AND CIS

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Abslract. Fishing ground predictionc analyzed Ihc fishing ground environment of sardines with ihc complex method combining multi-sensor remote sensing and Geographical Information System (GIS). and examined methods f is now one of the keywords for a planned and efficient use of fishery resources. In this paper, wor prediction. As a result, the study showed the field area of fishing ground formation, the depth of fishing grounds, the favorable environment for fishing grounds by 3-D scaltergram and Ihe short-term trend of oceanic environment through time analysis before and after fishing ground formation. Also the study overlaid these results using GIS and showed prediction fishing grounds map.

Keywords: GIS. Mull i-sensor, Sardine Fishing Ground

I. Introduction

1.1. Background of this Study

As the management of fishery resources emerges as one of Ihc most important topics concerning food issues in the 21st century, fishing ground prediction is now one of the keywords for a planned and efficient use of fishery resources.

In fishery resources and ocean studies, satellite remote sensing is considered a powerful tool effective in diverse situations such as fisheries oceanography research and fisheries management (Laurs and Polobina, 2002). Saitoh (1988, 1999) presented the specific direction in applying remote sensing data to fishery resources and ocean studies, and the importance of the complex use of data. Laurs *el al.* (1984) showed the effectiveness of satellite data in fishery by comparing tuna catch, Satellite Sea Surface Temperature (SST) data, and Satellite Ocean Color data. In the ocean area surrounding Japan, which is the subject of this study, Saitoh *el al.* (1986) and Sugimoto and Tameishi (1992) clarified the relation between fish school and boundaries of water masses, and between fish school and streamer by comparing SST and fishing grounds.

Although past studies mainly performed analysis using SST data, it is now possible to utilize various and diverse satellites and sensors such as satellite chlorophyll-a(Chl-a) images (Saitoh *el al.*, 2001) and night visible images (Kiyofuji *el al*, 1998). The application of multi-sensor remote sensing method that effectively combines various satellite data is now necessary in analyzing fishing ground environment and performing fishingground prediction.

Since multi-sensor remote sensing integrates images with different projection and resolution, sensitivity is necessary to achieve consistency of information regarding ground location. It also handles various types of images and data, whose size often becomes large in total. GIS is effective for the efficient processing and display of diverse and large data, and it should be considered working together with multi-sensor remote sensing.

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1.2. Objectives of this Study

This study uses sardines *(Sardinops melanosticlus)* as its subject species. Sardines arc one of the most popular fish species in the Japanese fishery and one designated species under the resource management plan by the Japan Fisheries Agency. The main fishing method for sardines is by a purse seine. Understanding the mechanism of sardines' fishing ground formation and resource changes will give significant information for fishery. Inagake (1984) compared sardine fishing grounds in the eastern sea of Hokkaido with data from survey vessels, and clarified the vertical structure of water mass in the fishing ground area. Tameishi and Sugimoto (1993) indicated that streamer is important for the formation of fishing grounds. Many of the past studies on sardines compared water temperature and fishing grounds, however not many have clarified the relation between the fishing grounds of sardines and phytoplankton that is the indicator of sardines' food resource.

This study will investigate the environment of purse seine fishing grounds for sardines and the mechanism of fishing ground formation by utilizing multi-sensor remote sensing and GIS. The study will then discuss fishing ground prediction methods.

2. Data and Method

2.1. Data Set

The study area was selected off Sanriku water, so-called Tolioku Area (Figure 1). There are two remarkable thermal fronts at subsurface depths in the Tohoku Area: the southern is called the Kuroshio Front; and the northern the Oyashio Front. The water in the Tohoku Area is hydrographically divided by the two fronts into three areas: the Kuroshio Area, the Perturbed Area and Oyashio Area. The most complicated hydrograpbic conditions are encountered in the Perturbed Area, where numerous eddies and thermal fronts arc irregularly distributed. Relatively large fishing grounds tend to be formed in this perturbed and m ixed water.

We employed thcChI-a image and the SST image derived from version 4 ADEOS/ Ocean Color and Temperature Scanner (OCTS) Real Time Coverage (RTC) data sets which were provided by Japan Aerospace Exploration Agency (JAXA). ADEOS operated only for eight months. However, profitable data was acquired by observing SST and Chl-a simultaneously. Number of scenes and period of data are summarized in Table 1.

The data of water depth used ETOPOS (5-Minute Gridded Elevation Data) by National Geophysical Data Center <NGDC)/NOAA.

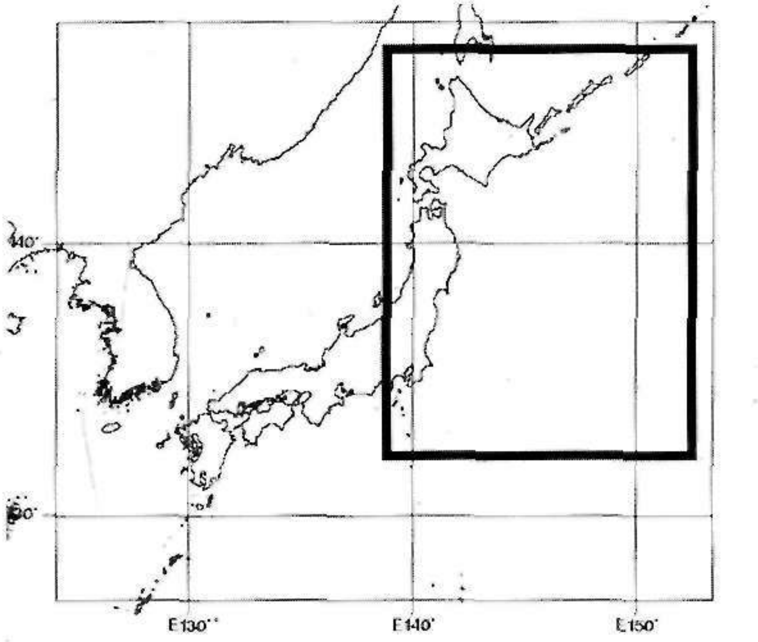

Figure 1. Study area.

Product	Ver.	Satellite	Sensor	Term	Number of Scene
MCSST	RTC ver. 4	ADEOS	OCTS	Nov 2. 1996-Jun 19, 1997	128
Chlorophyll-a	RTC ver. 4	ADEOS	OCTS	Nov 2. 1996-Jun 19. 1997	128

Table 2. Fishing ground data.

Fish	Method	Term	Total Number of Data	Total Number of Match up Data	Match up Ratio
Sardine	Purse seine	Jan 6. 1989-Dec 31.2000	60.515	313 (MCSST) 422 (Chlorophyll-a)	13% (MCSST) 17% (Chlorophyll-a)

The purse seine fishing ground data was collected by Japan Fisheries Information Service Center (JAFIC). In the purse seine fisheries, fishermen exchange operation communication information (so-called QRY information) between fishing boats, and we can obtain the location and catch data sets from QRY information. The sardine fishing ground data sets were selected from all of purse seine fisheries data set. To understand historical fishing ground distribution, data from 1989 to 2000 was analyzed. The number of data to be able to do match-up analysis between the fishing ground data and the satellite data is shown in Table 2. The ratio of satellite data and comparable fishing ground data was about 20% of all the fishing ground data.

2.2. Data Processing

Figure 2 shows **the** flow of data processing. To compose as an output result on GIS, each processing generated data for GIS. Basic data processing is divided into the following three parts.

- Extraction of historical fishing ground region that depends on analysis of fishing ground data.
- Grasp of fishing ground depth by comparison between water depth data and fishing ground data.
- Grasp of ocean environment in the vicinity of fishing ground data by comparison between satellite data and fishing ground data.

To understand results of a historical fishing ground formation, the fishing ground distribution map was made first. The fishing ground data was processed dividing into four in consideration of sardine stock level. The data from 1989 to 1990 is a period of increase, from 1991 to 1995 is a high-level stock period. From 1996 to 1999 is a decrease stock level, 2000 year is a low-level period. The fishing ground region map was made by plotting all the fishing ground data. Next, the GIS data was made by polygon processing of this map (polygon: area extraction processing).

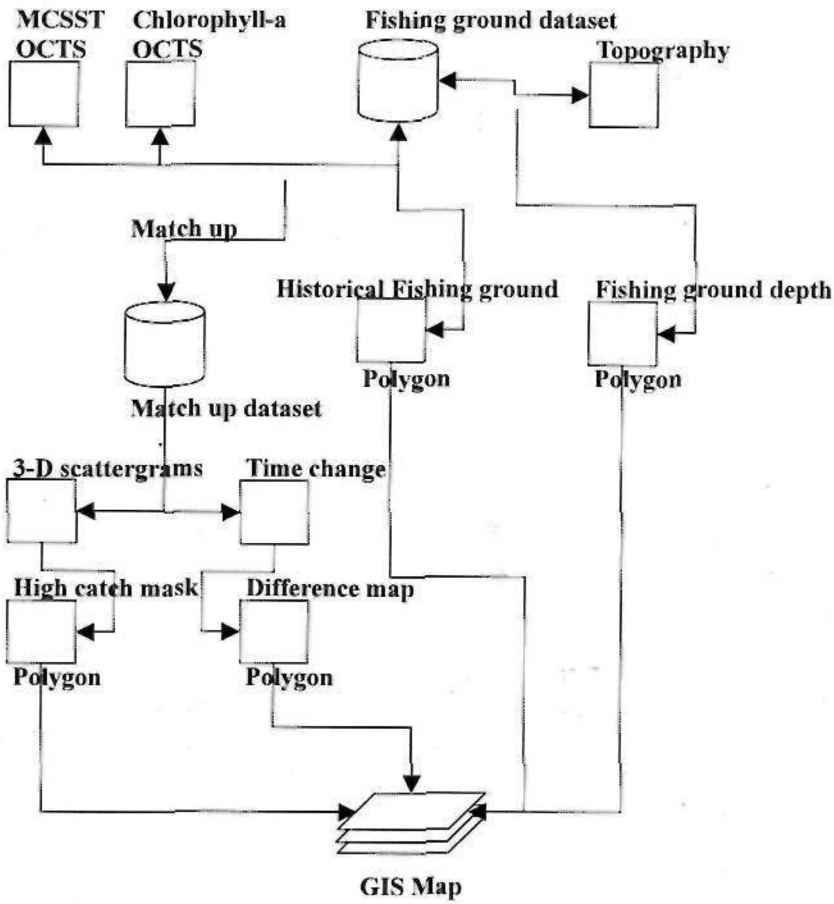

Figure 2. Data processing flow

Average water deplh (fishing ground depth) at the fishing position was obtained by Match-up analysis between ETOPOS and fishing ground data. The fishing ground depth map was made by statistical processing of fishing ground water depth data. Next, the GIS data was made by processing this map in the polygon.

Match-up analysis of the satellite data and the fishery data was executed on the following conditions.

- The statistic of 5x5 pixels that centers on the fishing ground in consideration of positional accuracy of the satellite image is calculated.
- When the cloud influences it depending on screening, it excludes it from processing.

The statistic calculated total value, mean value, maximum value, lowest value, standard deviation of a valid pixel (Excluding a cloud and a defective pixel) and number of effective pixels. The mean value was chiefly used for the analysis in this research. The obtained statistical data was compared with the fishing catch and the relation between SST and Chl-a was made three dimension scatter chart (3-D scattergram). 3-D scattergram was divided according to the season (autumn: October to December, winter: January to March, spring: April to June). The good fishing ground environmental condition area of each image has been extracted based on 3-D scattergram. In 3-D scattergram, the environment that fishing catch becomes a peak was assumed to beagood fishing environment.

The satellite can observe the marine environment of the place before and after the fishing ground formation. To make the best use of this advantage, and to understand a time change of marine environment at fishing ground, match-up analysis was executed in images of three days before and after the fishing ground formation. Because a short-term prediction was assumed in this research. it was assumed three days before and after the fishing ground formation. According to each season, the average short-term time change was calculated from all data of three days before and after the fishing ground formation. In addition, this short-term change tendency was applied to the time series image, and the oceanic short-term environmental trend image was made.

To extract the boundary region, the spacial deviation of the image was calculated. The boundary is a step light and shade change, and in the image data processing, this is called an edge. In this research. The decentralized value operation processing of size 5^X5 of the filter was done in each image.

3. Result

3.1. Historical Feature of Fishing Ground Formation by Analysis of Fishing Data

Figure 3 shows the distribution of a historical sardine fishing ground. The fishing ground is always distributed in a continental shelf on the other hand the range of fishing ground distribution is different depending on the stock level. Since the latter half of the 90's, fishing ground distribution region has reduced when the resource decreases as Mihara (1998) shows. This map is most basic map where the area with the possibility that the fishing ground is formed is shown. The possibility that the fishing ground is formed in the place that comes off from this area is low. A lot of fishing grounds are formed along a continental shelf regardless of the stock level. When the fishing ground is forecast. Fig.3 extracts the range with the possibility that the fishing ground is formed as GIS map first.

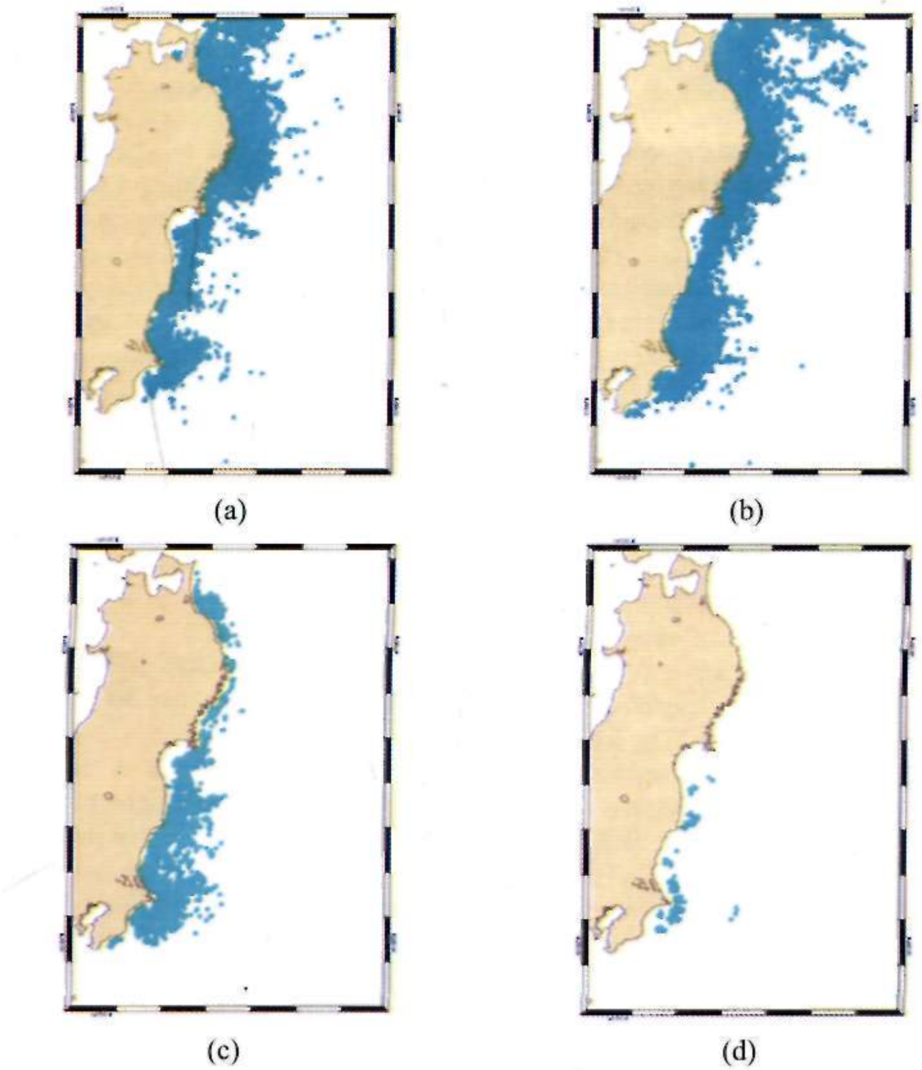

Figure 3. Distribution of all sardine fishing ground: a) 1988-1989; b) 1990-1940; c) 1995-1999; and d) 2000.

3.2. Water Depth of Fishing Ground

Figure 4 is a histogram of water depth at the sardine fishing ground. The average is 327 m, the mode is 91 m, and the fishing ground is often formed to about 100 m. Small numbers of fishing ground were formed also in the place of 1000 m depth. However, the sardine is not the target species of this place. In general, purse seine fisheries are formed in the vicinity of the continental shelf edge. In the result of this research, the entire fishing ground of 60% was formed in a place that was shallower than 200 m. Moreover, the fishing ground of 80% was formed in a place that was shallower than 700 m. Figure 5 is 200-700 m area map for GIS. The possibility that the fishing ground is formed is low excluding this area.

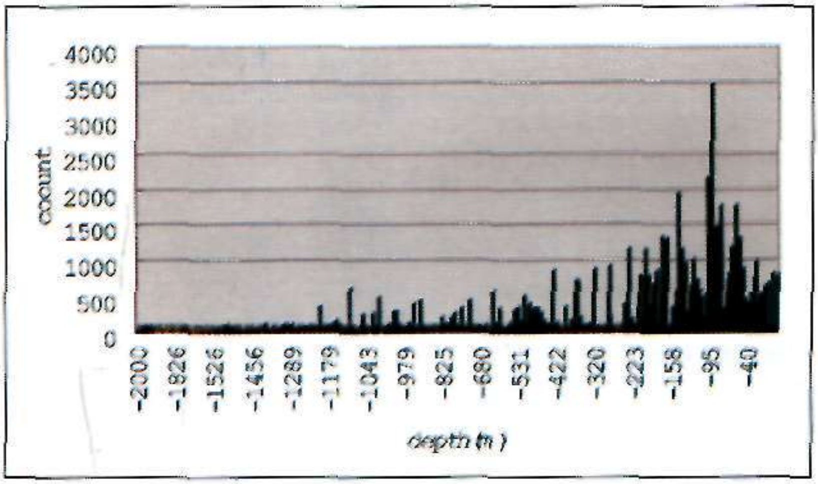

Figure 4. Histogram of sardine fishing ground depth.

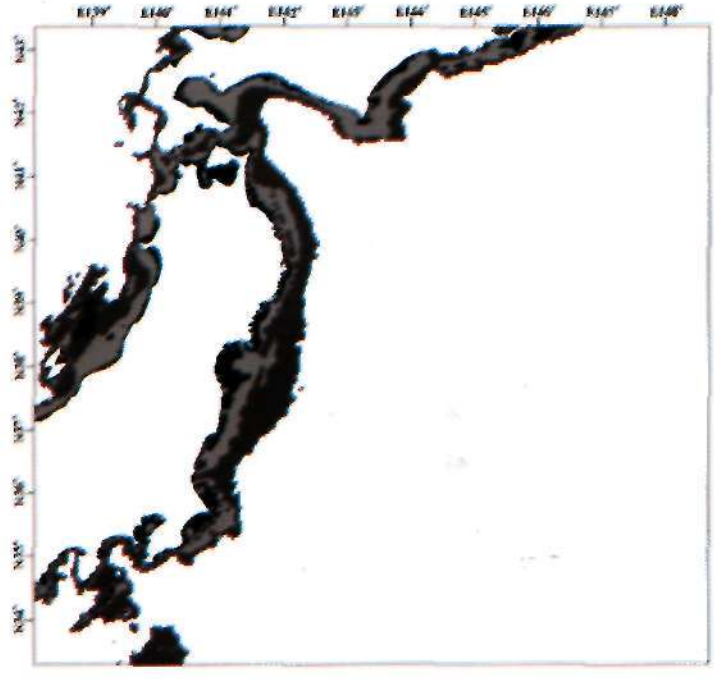

Figure 5. Fishing ground depth mask image.
(Gray: 50-200m depth, Dark gray: 200-700 m depth)

3.2. Feature of Fishing Ground Environment by Comparison with Satellite Data

The statistic of SST and Chl-a about the sardine fishing ground that had been obtained by Match-up analysis was shown in Table 3. Figure 6 shows 3-D scattergram of SST, Chl-a, and the sardine catch. X axis shows SST, and Y axis shows Chl-a and Z axis shows catch. SST changes greatly by the season. On the other hand, the difference was seen about Chl-a at the season. The fishing ground is formed in the high Chl-a region in spring. However, there was no big difference in fishing ground Chl-a in Autumn and winter. In the region of high catch (over 40lons) in autumn, SST was 10-14X, and Chl-a was 0.1-5ug/l. In the region of high catch (over lOOtons) in winter, SST was 13-16X, Chl-a was under 1 ug/1, and three sharp peaks were seen. In the region of high catch (over 50 tons) in spring, SST was 15-17X, Chl-a was under 5 ug/1, and a sharp peak appeared. Figure 7 is a map that overlays the area of the good fishing environment obtained with 3-D scattergram in the Chl-a image April 26, 1997. In the data of this research, it was distributed in the area of the good fishing environment to obtain with 3-D scattergram a fishery actual at the probability of 78% from (Table 4). 78% of an actual fishing ground in the data of this research was distributed in the area of the good environment that had been obtained from 3-D scattergram. Figure 8 shows the boundary image of SST and Chl-a by edge detection processing of April 25, 1997. A blue area is a SST boundary and a red area is a Chl-a boundary. A white area is good fishing region by 3-D scattergram. The boundary of SST and Chl-a was adjacent to a good fishing environmental area or was included.

Table 3. Fishing ground environment by ADEOS/OCTS.

Value	Fish	Method	Season	Average	Max.	Min.	St. Dev.
MCSST	Sardine	Purse sein	Autumn	18.73	20.45	14.00	1.45
			Spring	15.26	16.46	14.22	0.64
	'		Winter	14.26	16.31	12.18	0.83
				X	X	X	
Chlorophyll-a	Sardine	Purse sein	Autumn	0.58	1.76	0.14	0.31
			Spring	4.92	16.17	0.29	4.20
			Winter	0.58	2.88	0.17	0.43
				ug/1	ug/1	ug/1	

Table 4. Match up ratio between ground and GIS area.

Fishing Date	Number of Fishing Ground Area	The Data within the GIS Area	Ratio
Dec 8, 1996	9	7	77.8
Jan 11, 1997	13	13	100.0
Jan 27, 1997	23	17	73.9
Feb 24, 1997	2	1	50.0
Feb 25, 1997	3	3	100.0
Mar 5, 1997	3	1	33.3
Apr 11, 1997	22	17	77.3
Apr 25, 1997	4	3	75.0

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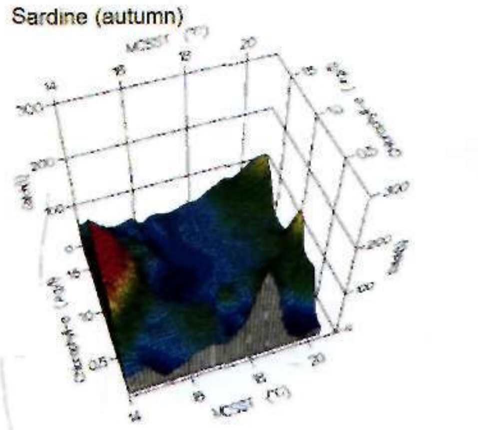
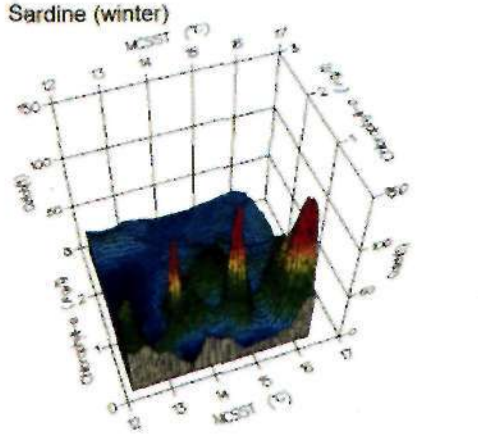


(a)



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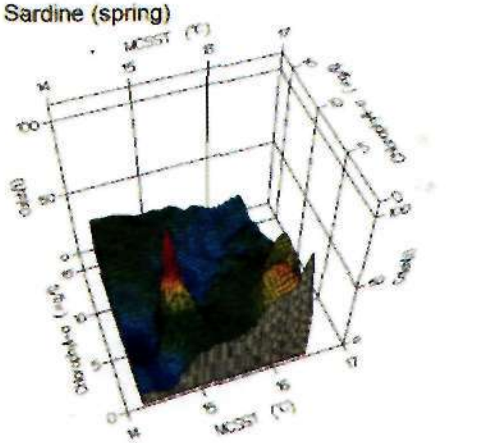


(c)

Figure 6. 3-D scattergram of sardine at autumn - spring (X axis is MCSST(°C), Y axis is chlorophyll-a (ug/C), and Z axis is fishing catch (ton, CPUE)). a) Nov-Dec; b) Jan-Mar; c)Apr-Jun.

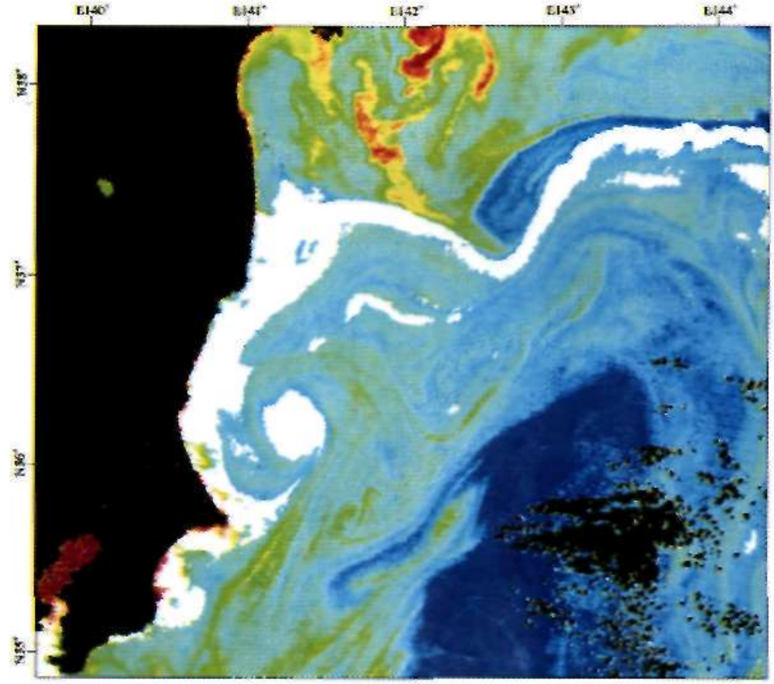


Figure 7. High catches environment area of sardine on April 26, 1997. Base image is Chlorophyll-a. White masking area is high catches environment by 3-D scattergram.

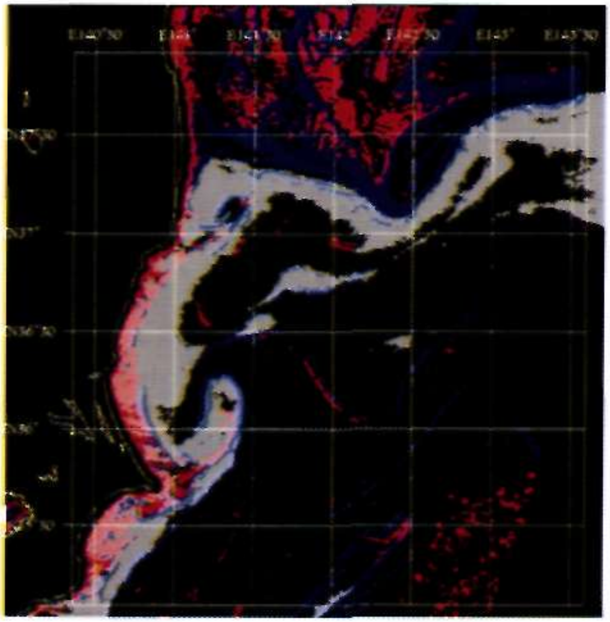


Figure 8. Relationship between high catches ocean environment and boundary area in April 25,1997. White area shows high catches environment by 3-D scattergram. Blue area shows temperature boundary calculated by 5x5 deviation filter. Red area shows Chlorophyll-a boundary calculated by 5x5 deviation filter.

3.3. Time Change of Fishing Ground Environment

Figure 9 shows the result of Match-up analysis that uses the image before and after the fishing ground formation. At all seasons, an upward trend was seen in the time series Chl-a change before the fishing ground was formed. On the other hand, downtrend was seen in SST data at all seasons. The width of the increase and decrease was 8 ug/1 in Chl-a before and after the fishing ground formation. However, the fluctuation width of autumn is 0.4 ug/1 and winter is 0.2 ug/1. The fluctuation width of spring was larger than other seasons. The fluctuation width of SST became as 4°C in spring, 0.5°C in winter, and 2°C in autumn. As for the short-term change ofthe marine environment in a narrow area like this, it is related to the vertical change of water in addition to the horizontal change such as warm streamers that Sugimoto and Tameishi (1992) showed. It is suggested that the change of the marine environment of small scale also give the important effect in the fishing ground formation. It is important information in the fishing ground forecast that SST and the Chl-a environment change on a short scale of within three or seven days. Figure 10 is time series of the sardine catch and number of fishing boats until April, 5^{th} through April, 15^{h}, 1997. The catch increased rapidly on April 11. Figure 11 is a change value image of April 10, 1997 and April 8, 1997. The fishing ground of April 11 is distributed in the area where an increase of Chl-a, and SST are descending.

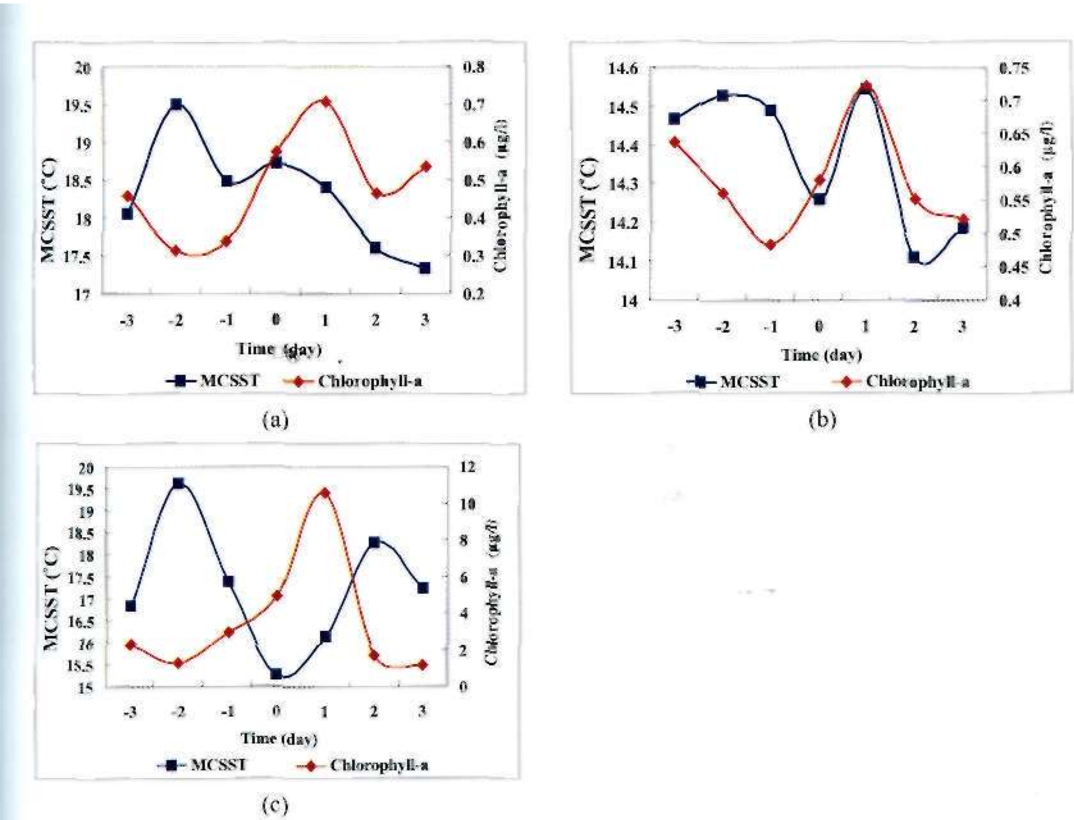


Figure 9. Time change of ocean environment in sardine fishing ground position (before three days and after three days), a) Nov-Dec; b) Jan-Mar; c) Apr-Jun.

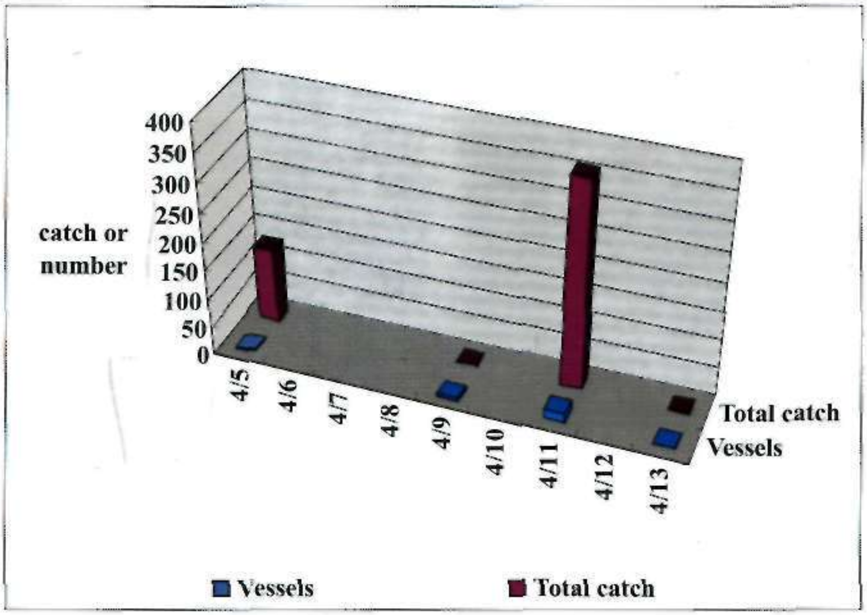
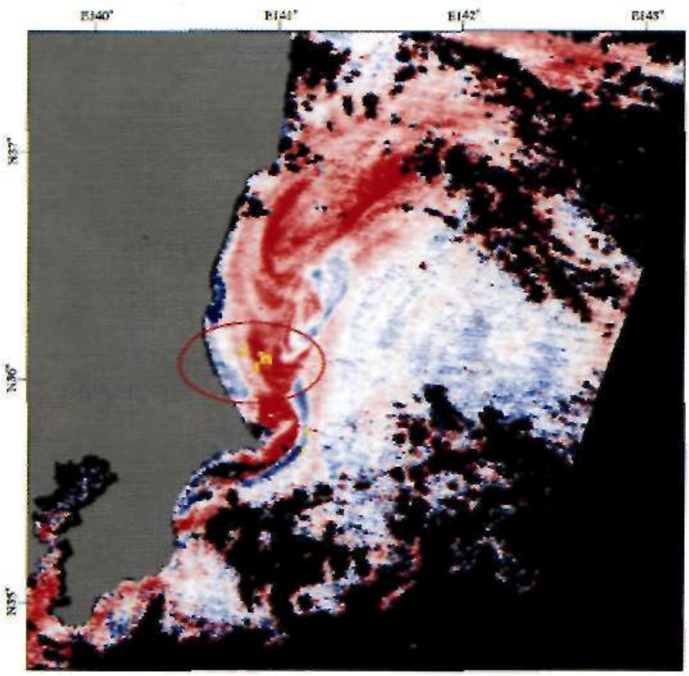
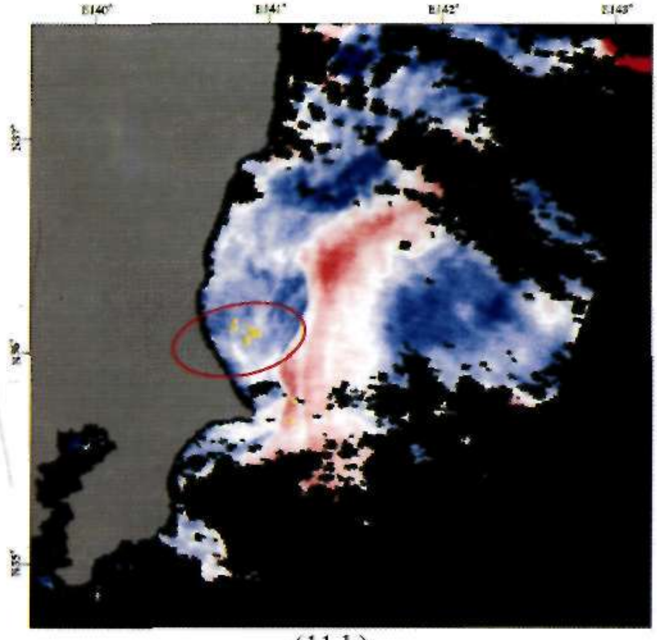


Figure 10. Change of a sardine fishing trend from April 5, 1997 to April 13, 1997 (Total number of fishing vessels and total catch).

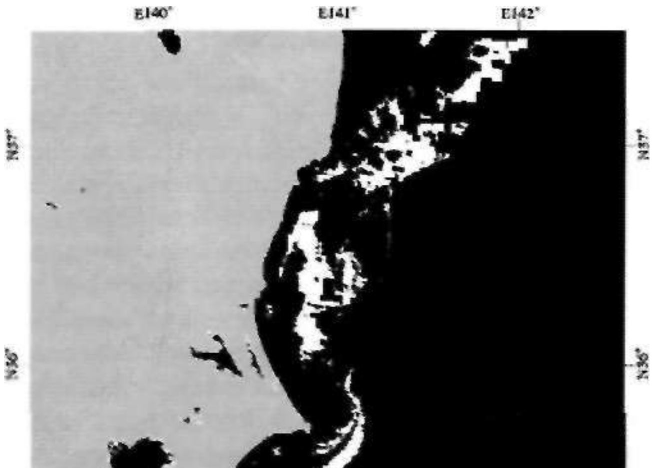


(11.a)



(11.b)

higure 11. Difference image with sardine hshing ground. Red area is an increase area, blue area is a decrease area. Yellow marker: sardine fishing ground at April 11, 1997. a) Chlorophyll-a difference between April 10, 1997 and April 8,1997; b) Temperature difference between April 10,1997 and



Figurel2. Prediction GIS image of this study. Base image is April 11,1997. White area show prediction sardine fishing ground filtering by result of this study.

4. Discussion

4.1. Feature of Sardine Fishing Ground Environment

Based on the results that this research obtained, we categorized the parameters of fishing ground environment as follows:

1. Historical Characteristics
   a) Distribution of the past fishing grounds.
   b) Resource conditions.
2. Spatial Characteristics
   a) Geographical information such as depth and submarine topography.
   b) Information of oceanic environment such as surface temperature and chlorophyll concentration.
   c) Spatial information on a regional scale such as streamer, boundaries and water mass distribution.
   d) Distance from ports.
3. Temporal Characteristics
   a) Short-term trend in surface temperature and chlorophyll concentration.
   b) Trend in meteorological variation.
4. Economic Characteristics
   a) Price and its trend.
   b) Stock amount.

Historical characteristics are obtained by the analysis of the past fishing ground data. Kuroda (1991) noted that the distribution of fishing grounds varies depending on resource levels since groups that migrate in large areas appear when resource is at a high level, while groups that migrate in smaller areas are mainly observed when resource is at a low level. The condition of fishing ground distribution is closely related to the condition of resource for fish. The field map of fishing ground formation, which reflects the condition of resource, indicates the most basic picture of the possible areas for fishing ground formation.

Spatial characteristics are categorized into two groups: First, geographical characteristics such as submarine topography and depth; and second the characteristics of oceanic environment obtained from satellite data. For the first category, the study found that fishing grounds are formed based on the depth of 200 m and 700 m. It is a common factor among fish species that fishing grounds be formed along continental shelves; it derives from the fact that continental shelves have high productivity. Also, continental shelves are located in the close proximity from ports. Coastal operation can reduce fuel consumption, and it is beneficial from the perspective of preserving fish freshness. The field map of fishing ground formation shown in Figure.3 reflects the distance from ports, which suggests that the location of ports was always considered in the past in choosing fishing grounds.

Characteristics of oceanic environment signify SST, Chl-a and boundaries of water masses, all of which change from hour to hour. These data vary due to their large spatiotemporal changes, thus they need to be obtained on an image to image basis. Characteristics of oceanic environment are variables related directly to the movement of fish school and provide basic information for prediction. They are divided into numeric (one-dimensional) variables, such as SST and Chl-a, and vectoral (two-dimensional) variables with space and direction, such as streamer and boundaries. The accuracy of numeric variables can be raised by increasing data size in match-up analysis. Vectoral variables are obtained by match-up analysis of satellite images and spatial analysis. Figure 8, in this study, shows the images of boundaries extracted by edge detection. We used the existing operator for the edge detection, but we believe that it is possible to develop an operator that fits the characteristics of spatial distribution of SST and Chl-a. The extraction of boundaries by edge detection, in this study, revealed three types of results between SST and Chl-a boundaries: Boundaries formed in the same place: in different places; and only one boundary formed. This seems to derive from the difference in vertical structure (Matsumura and Fukushima. 1990). However, further study is necessary to understand the relation between surface information captured by satellites and \ertical structure.

Temporal characteristics are obtained by matching up subject data with satellite data collected around fishing grounds for a few-days before and after their formation. Areas where oceanic environment is rapidly changing should be noted since the changes influence fishing grounds and fish school. This study showed that the temporal trend of SST and Chl-a can become indicators for fishing ground prediction (Figure 9). The temporal trend of ocean ic environment could derive from the changes of water mass structure in a horizontal direction (Tameishi and Sugimolo, 1993), and those in a vertical direction such as up welling, and the influence from weather.

Economic characteristics signify fish price and catch landed, which for fishermen could become more important than catch itself. This study does not discuss this topic, but the analysis of economic characteristics will be necessary. Fish price and catch landed are considered attribute information incidental to information on location of ports. The analysis of attribute information is a basic function of GI.S, and thus it is possible to perform the analysis by using GIS.

4.2 Prediction GIS Map

Figure 12 shows the oceanic environment of favorable fishing grounds obtained from 3-D scattergram, the short-term trend of the areas of fishing ground formation, the field map of fishing ground formation, the bathymetric map of fishing grounds, and GIS-map (hat combines them all. The reference date of Figure. 12 is April II, 1997. First, we extracted the oceanic environment of favorable fishing grounds from SST and Chl-a images on April II by 3-D scattergram. Then we extracted time-series changes from SST and Chl-a images obtain during April 8 Jo 10. Finally we overlaid the field map of fishing ground formation and the bathymetric map of fishing grounds, and masked the areas where all the conditions were overlapped. The pixel percentage that matches the conditions in Figure 12 is as follows:

a) Percentage of the image of the total area extracted by 3-D scattergram: 12.7% of the total.
b) When the conditions of locations where fishing grounds formed in the past were added to a): 5% of the total.
c) When the extraction conditions of depth wasaddedtob): *5%* ofthe total.
d) When the short-term trend of SST and Chl-a was added to c): 3% of the total.

By using the field map of fishing ground formation and the bathymetric map of fishing grounds in addition to 3-D scattergram it was possible to narrow down favorable areas for fishing grounds to 5%. By obtaining the information of short-term trend, the area was narrowed down to 3%.

5. Conclusions

In this study, we analyzed the fishing ground environment of sardines with the complex method combining multi-sensor remote sensing and GIS, and examined methods for prediction. As a result, the study showed the field area of fishing ground formation, the depth of fishing grounds, and the favorable environment for fishing grounds by 3-D scattergram. We also indicted the short-term trend of oceanic environment through time analysis before and after fishing ground formation. Also the study overlaid these results using GIS and showed that it is possible to narrow down the areas of fishing grounds. Oceanic environment of the favorable fishing grounds can be obtained with higher accuracy by increasing the number of comparative data between satellite data and fishing ground data, it is important to accumulate such data. The methods of this study should be applicable to other fish species and fishing methods.

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