THE SPATIAL RELATIONSHIP BETWEEN THE DISTRIBUTUION OF OMMASTREPHES BARTRAMI AND MARINE ENVIRONMENT IN THE WESTERN NORTH PACIFIC OCEAN

Wen-yu Wang [a, *], Quan-qin Shao [b]

[a]Beijing Institute of Civil Engineering and Architecture, Beijing 100044
[b]LREIS, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101

KEYWORD：Ommastrephes Bartrami, SST, Chlorophyll-a, Spatial Relationship, Western North Pacific Ocean

ABSTRACT：

In this study, we consider the effects of marine environmental factors on the spatial distribution of Ommastrephes bartrami in the western North Pacific Ocean during the period in which the commercial squid fishery operates. Spatial referenced fishery data and satellite-derived advanced very high resolution radiometry (AVHRR) sea surface temperature (SST) data, Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Chlorophyll a data and the yield data collected from fishery companies were examined using geographic information system (GIS) techniques. The distribution and relative abundance of O. bartrami were examined for the period 1995-2001. The results indicate that the O. bartrami fishery distributed west-eastwards extensively within the Kuroshio Extension and Kuroshio-Oyashio transition regions and two consistent areas of high abundance of O. bartrami were observed to the north-east of Hokkaido and close to the boundary of Japan and Russia. To understand spatial-temporal change of fisheries, the migration route of jig fleets is also mapped. Further, composed maps of SST range and averaged Chlorophyll-a concentration show the sea conditions around fishery. Sea gradients (SST gradients, chlo-a gradients) were used as indicators of mesoscale oceanographic activity and compared with the location of the fishery. It appears that O. bartrami fishery was associated with areas of thermal gradients and Chlorophyll-a concentration gradients, commonly seen at the interface of Kuroshio and Oyashio water. Finally, these results illustrate the insights which can be achieved by combining yield data of O. bartrami with concurrent remotely sensed environmental data.

1. INTRODUCTION

Ommastrephes bartrami is an oceanic squid occurring worldwide in subtropical and temperate oceanic waters (Akihiko Yatsu and Junta Mori, 2000). With the sharp decline in abundance of Japanese common squid (Todarodes pacificus) in the early 1970s, O.bartrameii became the target of fishery in the North Pacific in 1974. This species has a one-year life span and performs an extensive seasonal north-south migration. Extensive Kuroshio-Oyashio transition zone is formed in the western North Pacific Ocean as the result of widely mixing of the two water masses and it becomes one of the most high-yield oceanic fisheries in the world (Pravakar Mishra et al., 2001).

An understanding of the influence of physical oceanographic process on species distribution is integral to the further understanding and possible forecasting of many pelagic fisheries. The use of remote sensing methods to examine physical oceanography is becoming increasingly important within marine fisheries oceanography, and a number of studies have examined the use of satellite data as an aid to locate more productive fishing areas (C.Silva, et al., 2000; Pravakar MISHRA, et al., 2001; H.U.Solanki. et al., 2001; C.M.WALUDA et al., 2001) . Pelagic/oceanic species such as tuna and green turtles may be targeted on the basis of their presumed association with water of a particular temperature and/or colour (e.g. G.C.Hays et al., 2001), or with thermal frontal regions (David S. Kirby et al., 2000; Jeffrey J.Polovina

et al., 2000,2001). In this study, we also take the temperature, ocean colour, and sea fronts into account for the squid fishery.

Geographic information systems (GIS) technology allows the display and overlay of real-time and historical data from many sources. The processing of remotely sensed satellite sea surface temperature (SST) images within GIS can reveal the information such as the location of oceanic fronts and thermal gradients by using edge detection techniques (see Jean-Francois Cayula et al., 1991; 1995). Such associations between remotely sensed data and high resolution fishery data can provide a practical solution for analyzing and forecasting of marine fisheries. The aim of the study was to map the distribution of commercial catches of O. bartrami and to examine the influence of: (1) SST; (2) Chlorophyll-a concentration; (3) surface thermal gradients derived from SST images; (4) Chlorophyll-a concentration gradients derived from SeaWiFs images. Data were examined to test the hypothesis that squid is associated with mesoscale oceanographic processes.

2. DATA

2.1 Study Area

The area of study was chosen to coincide with spatial distribution range of O. bartrami in the Kuroshio Extension and Kuroshio-Oyashio transition regions, western North Pacific

---

* Correspondense. E-mail: wangwenyu@bicea.edu.cn.

Ocean. The separation point for the Kuroshio is reached 35˚N. It defines the transition from the Kuroshio proper to the Kuroshio Extension. Flow in the Extension is basically eastward, but the injection of a strong jet into the relatively quiescent open Pacific environment causes strong instability. The surface oceanography of the western North Pacific Ocean is characterised by two western boundary current systems (the Kuroshio warm current and the Oyashio cold current). Along the east coast off Japan the warm and nutrient depleted current Kuroshio, from the South Pacific and the cold and nutrient rich current Oyashio flowing along the Kuril Islands meet with each other and the confluence region is known as "Kuroshio-Oyashio transitional region".

2.2 Squid Yield Data

In this study, the data of fishery catches were used to analyse the spatial distribution of O. bartrami resources. The dataset has 21565 records containing items of fishing absolute location, fishing grid number, yield, amounts of jig boats, fishing companies. The yield data were collected daily in 0.5°×0.5° grid according to Food and Agriculture Organization (FAO) statistical conventions. The dataset covered the period of 1995 to 2001. The original yielding data set was gathered by the jig working group of Shanghai Aquatic University.

To compare the production, Average square-root production (F) is used to normalize the jig dataset. F is computerized as in equation 1.

$$F = \sqrt{\sum_{i=1}^{N}(m_i * \frac{m_i}{b_i})\bigg/N} \qquad (1)$$

where m_i = the toll production of per fishery per day

b_i = the number of boats working in the fishery

N = the sequential fishing days
F = average double production

2.3 Environmental Data

Remotely sensed infrared SST images were obtained from NOAA/AVHRR global level 3 products. Images were at a spatial resolution of 9 km×9 km, and a temporal resolution of one day . The images used in this study covered the period 1995 to 2001. In this paper, we take out the SST data in the research area from the overall data. The range of the SST (R) was used as the measure of variations .

Satellite ocean colour remote sensing has improved our capability of pigment concentrations over wide areas. SeaWiFS has been collecting high-quality data on ocean colour since September, 1997. Here we use level 3 standard mapped images of 8 days composition, which are projections of the GAC data onto a global, equal-angle grid (2π/2048) with a nominal 9 km×9 km resolution.

Programs were written in C++ language to extract, analysis and display image data within the region defined above. Cloud cover is the primary limitation of these data, temporal averaging can provide increased spatial coverage at the expense of temporal resolution. We composed the images by 8 days to reduce the none data in the images. The 8 days time span is temporal resolution of the ocean colour data we had gathered. SST image data was composed to new datasets of 8 days and yield data was also gathered together in 8 sequential days .

3. MRETHODS

3.1 Object Representations

Object representations describe geometric characteristics of spatial features and provide association with attributes. There are many choices of geometric representations for modelling objects in marine and coastal GIS. A grid or raster is the most popular numerical description of object (including terrain) surfaces in GIS and digital mapping (Dawn J. Wright and Darius J. Bartlett, 2000). Both the squid yield data and the image data are represented by grids. So we choose grid model to describe, analyze and map of yield and environmental data. At the same time, the spatial-temporal analytic frame based on grid model is also discussed in this paper.

3.2 Spatial distribution

The relationship between O. bartrami resources and the ocean environment is represented by the regularly dynamic movement of different O. bartrami species in different times and environments (Cairistiona I.H. Anderson, 2001). So it is our fist work to map out the spatial distribution of squid fishery and the dynamic route of fishing fleets to show the spatial-temporal distribution of squid fishery in a straight way. The migration dynamics of squid fishery was expected to be revealed by calculating the central position of 8 sequential days fishery according to chlo-a images temporal resolution. In this study, the central position of fishery was formulated as:

$$xc = \frac{\sum_d x\rho(x,y)}{\sum_d \rho(x,y)} \qquad (2)$$

where   x, y =the central coordinates of one fishery grid
d = the number of fishery grids taken into account
$\rho(x,y)$ =the resource density of one fishery grid
xc, yc = the central location of the fishery

3.3 Spatial Relationship

The key characteristic of this relationship is the special space distribution strictures that can be analysed spatially by spatial comparability matching. Because the attribute of one grid point and the relationship among these attributes may relate not only the grid point itself but also the attributes of neighbouring grids , the rule of spatial relationship consists of local association rule and neighbour association rule. Local association rule is defined as the relationship among the attributes of the same place and neighbour association rule is defined as the relationship among the attributes of the neighbouring place. In this paper, we applied the local association rule to the research on the relationship among O. bartrami fishery, SST and Chlo-a. Also, we apply the

neighbour association rule to study the relationship between the squid fishery and ocean gradients

To compute the gradients, we modify the traditional arithmetic extraction method of front features from images. (1)We constructed 8 days mean or monthly mean images, there are still many pixels with none value. And also the noise of the image, traditional extraction of front feature is not good here. We only calculated the gradients around the fishery. (2)To calculate the gradient, traditional average front is done, but here we only calculate those pixels of different values and consider the same values as the close water.

The sea gradient is calculated as following. First,the central location of working fishery was calculated. A Moving two-dimensional 6×6 pixel matrix (equivalent to about 54×54 km scale at the equator or roughly 0.5°×0.5°) covered the central pixsel. Direction of gradients was generalized by eight eigenvector from 1 to 8 which represents the direction of North, North-East, East, East-South, South, South-West, West, North-West, respectively. The range of temperature/chlo-a values in each direction were averged and the top 5 biggest value were put into calculation. A power of 1.1 was used when slope is taken into aacount. The center pixel of each matrix returned the most range data of temperature/chlo-a values in 8 directions (gradient value). Pixels within processed matrices with thermal gradient value larger than 0.7°C were defined. The definition of strong front here is the temperature change bigger than 1°C per 9km, weak front ranges from 0.7° to 1°C per 9km. The definition of strong chlo-a front is the chlo-a concentration change bigger than $0.12mg/m^3$ per 9km, weak chlo-a front ranges from 0.06 to $0.12mg/m^3$ per 9km.

4. RUSULTS AND DISCUSSION

4.1 Squid Fishery Spatial Distribution

The fishery began as a jig fishery, with driftnet fishing introduced in 1978. Large-scale driftnet fishing in the high seas, including the squid driftnet fisheries, was stopped at the end of 1992. O. bartrami is presently harvested by commercial jig fleets in western North Pacific Ocean (Akihiko Yatsu, Satoshio Midorikawa, 1997). Since the O. Bartrami resource was developed and utilized in 1993 in China, the production has been expanding very fast. There were about 300 Chinese Squid Jig Ships working in this region in 1993, while the number became 400 in 2000. Furthermore, the fishery has been expanding to the eastern region.

The Spatial distributing of fishing ground of O. Bartrami is mapped using yield data from 1995-2001. Fig.1 shows the O. bartrami fishery distributed west-eastwards extensively, and agglomerated in the long and narrow sea area of 35 - 45°N。 Two consistent areas of high abundance (F>60) of O. Bartrami were observed to the north-east of Hokkaido and close to the boundary of Japan and Russia. The high production fishery to the north-east of Hokkaido agglomerated around 146°E、41°N, and extended outside 3-4 fishery radius. Another vice good fishery extended 3-4 fishery grids along the boundary of Japan and Russia. The fishy shape ellipse, the long axis is north-east, centering about 155°E、43°N. The fishery extended to the east of 160°E，the bigger frequency is around 41°N。 We consider that the production of O. Bartrami is higher in the coastal waters than in the frontal and offshore waters of the Kuroshio. Ocean

environmental differences between the coastal and offshore waters may cause regional variability in the growth of O. bartrami. This conclusion was also taken by M. Takahashi et al. (2001) on the research of copepods species in the Kuroshio-Oyashio transition region. In order to understand the ecology of squid throughout its distribution range, investigations are needed not only in the Japanese coastal waters, but also in the Kuroshio-Oyashio transition region.
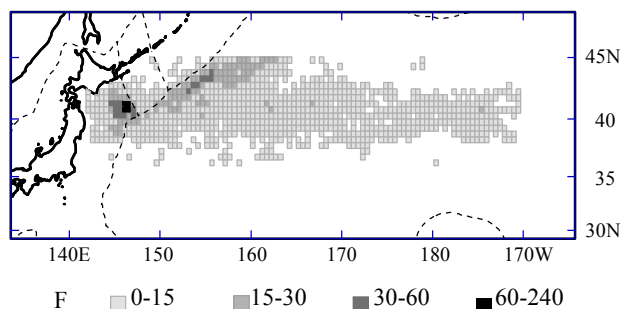

Figure1. The spatial distribution of squid average square-root production from 1995 to 2001. Broken lines indicate the borderline of economic exclusion region.

4.2 The Migration Route of Fishing Fleets

To understand the spatial-temporal variation of fishery, the migration route of jig fleets is also mapped for the period 1998-2001 when economic exclusion region was applied. The migration route map of fishing fleets was drew by the following steps: (1) we ordered the dataset records of fishery catches by date; (2) 8 sequential days span was calculated according to 8 days composed chlo-a images during the period in which the commercial squid fishery operates; (3) the same time spans were used to group the daily fishery catches records into 8 sequential days one; (4)the central positions of 8 sequential days fisheries were computed by equation 2; (5) the central location points were lined sequentially by date on the map.

Fig. 2 shows the migration rout of fishing fleets. It appeared that the extension of squid fishery changed a lot from 1998 to 2001. In 1998, the eastern limit of the fishery is around 175°E, and extended eastward to 180°E in 1999. Till 2001, the eastern limit of the fishery is around 170°W. After the international moratorium on the use of large-scale commercial driftnets, fishing ground extended from the offshore waters of northern Japan and the southern Kuril Islands to the central North Pacific. Fig.2 shows the jig fleets converged offshore when commercial fishing season began in May. The fishery during this fishing season extended horizontally along the longitude of 39°N and developed northward around 42°N within a month. The east sea area was developed newly, and fishery catches were small. When the next fishing season begins at the end of July and the early of August, the fisheries migrated to the sea area around 150-160°E，40-44°N where is mainly in the high sea, and is the main jig fishery of our country. The jig fleet goes north-eastward along the 200 economic excluded line of Russia. The good fishing season started in August and ended in October with each month's yield accounted for 20% higher of one year's yield。 It is assumed that the abundance of prey in the transition waters between the Kuroshio and Oyashio fronts might be responsible for the slow migration rates. At the end of September and the early of October, the jig fleet began to withdraw along the east part of the same way. Till the end of October and the early of November, the jig fleet locates within

the Japanese 200 mile economic region. With the Japanese 200 mile economic excluded region came into actualize, the western fishy base (140 -150˚E) where many medium and small jig boats worked will be lost by our country。So, we should develop the area where the large-scale driftnet fishing sea. The fishing area extends eastward quickly, till 1999 the fishing area extends to the east of 180˚E。
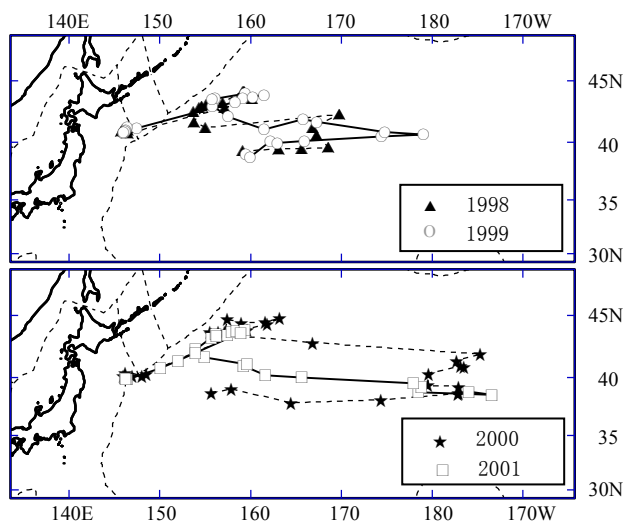

Figure2. The migration route of squid fishing fleets from 1998 to 2001

The migration route of jig fleets reflects the locations where fishers attempted to catch shoals of squid. Fishers attempt to locate shoals of squid using acoustic sounders and oceanographic patterns, primarily sea surface temperature. Fishing occurs primarily at night, when a powerful array of lights are used to attract squid to the fishing vessels. In recent years, continuous fishing resetting the gear at great depths during the day was attempted (DFO, 1999). The migration of O.bartrami is not fully understood. Hypotheses regarding migrations of O.bartrami in western North Pacific Ocean assume that the stock was consisted of an autumn cohort and a winter-spring cohort (Akihiko Yatsu, Junta Mori, 2000). The autumn cohort is main target of driftnet fishing, and locates in the east of 170˚E; the winter-spring cohort distributes in the sea offshore. O. bartrami undertaken extensive seasonal migrations between subarctic and subtropical waters, where they spawn (Akihiko Yatsu, 1997). To understand the ocean environment in the far east sea is very important for oceanic fishing. So images are the best data to help use understand the sea conditions.

4.3 SST and Chlo-a Condition of Squid Fishry

High resolution satellite Sea Surface Temperature (SST) maps were one of the first external ocean products fishermen are often willing to use. SST maps provide useful information on mesoscale ocean flow field (fronts, eddies) , position of the main current systems and regions of upwellings. More recently satellite ocean colour maps (e.g. SEAWIFS) became routinely available. Ocean colour provides in an indirect way a measurement of phytoplankton concentration. As phytoplankton is the primary food and energy source for the ocean ecosystem, fishermen find good fishing spots in areas rich in phytoplankton (H.U.Solanki et al., 2001).

Fig.3 shows the spatial distribution of SST range. It is observed that the sea with the most SST range of 16-20˚C located west to 155˚E，between 40 to 45 ˚N. The SST range in the transition zone is higher than in Kuroshio and Oyashio currents for the reason of mixture of the two currents. An apparent SST range tongue can be found on Fig. 4 along Japanese and Russian boundary (Russian 200 mile line). The front of Oyashio occurs at this place near 41˚N, where the surface temperature tongue shows. Highest population densities of O. bartrami was found along the subarctic frontal zone during July-December (Roper et al.,1984; Murata and Hayse,1993).
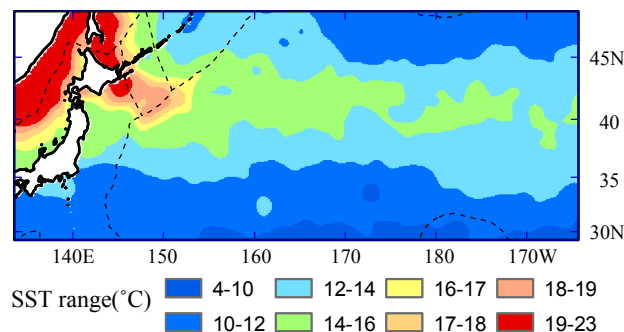

Figure3. The spatial distribution of SST range(1995-2001)

Fig. 4 shows the spatial distribution of chlo-a concentration in the western North Pacific Ocean. The chlo-a concentration in the sea area where Kuroshio or black (i.e. unproductive) current flows into, is lower than $0.25mg/m^3$, while the chlo-a concentration in the sea area where the Oyashio or parent current(i.e. productive) flows into, is commonly higher than $0.5mg/m^3$. And the highest productive area is found near the coast as the coastal waters is polluted by land-carriage materials and forms the different waters to the open oceanic waters. In the transition zone, the chlo-a concentration is between 0.25-$0.5mg/m^3$. Along the transition zone, the southern edge of the Oyashio and the northern edge of the Kuroshio maintain their own frontal systems. A chlo-a concentration front was observed along Japanese and Russian boundary (Russian 200 mile line) by the sharp change of the contour of $0.5mg/m^3$ to $0.75mg/m^3$. The contour of of $0.25mg/m^3$ shows many characters of the Kuroshio front. Two regions of north-southward shift, the "First Crest" and the "Second Crest", are found between 140˚ and 152˚E with a node near 147˚E by the contour of $0.25mg/m^3$ chlo-a concentration.
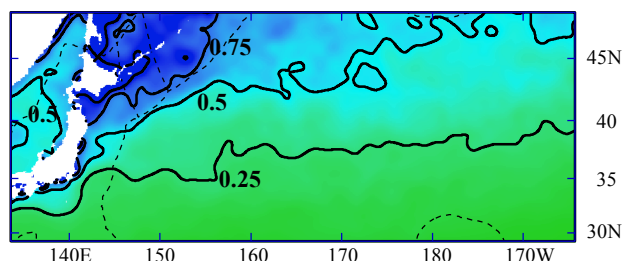

Figure4. The spatial distribution of chlorophyll a average level (1998-2001), yellow colour represents low value, blue colour represents high value, solid line indicate the isoline of chlo-a concentration(mg/m^3).

Sea gradients	Area(longitude)											
	140 -150˚E			150 -162˚E			162 -180˚E			180˚W -170˚W		
	H	M	L	H	M	L	H	M	L	H	M	L
SST												
strong	48	44	98	44	60	139	5	12	35			12
weak	48	40	79	58	84	168	12	10	52		2	7
none	142	90	201	227	278	612	24	50	186		7	25
Chlo-a												
strong	13	9	14	15	20	31	1	1	5		1	6
weak	27	9	13	21	47	69	5	5	19		1	4
none	30	13	23	187	255	496	28	59	157	1	5	27

Table1. The relationship between the O. bartrami and SST, chlorophyll a gradient at four sea regions

The spatial distribution of squid is almost included by 14˚C SST range line and 0.25-0.5mg/m³ chlo-a concentration. It locates almost in the transition zone. Eastern fishy locates not the most SST range but around the the most SST ranges where front caused. And the chlo-a concentration is higher than 0.5mg/m3. In the western sea area (140-150˚E), the two mighty stream meet south of Hokkaido, where the Tsugaru Warm Current also brings water from Japan Sea into the Pacific Ocean, and the region to the east of Tsugaru Strait displays extremely complicated hydrography. Between one and two cyclonic (warm-core) eddies are formed each year in the region. the sea condition is very complex, and stable eddy always found here, so forms good eddy fishery。 In the middle sea area (150-162˚E), Fig. 4 shows an apparent SST range tongue along Japanese and Russian boundary in the sea of 150-160˚E, here also the change of chlo-a is great for the intrusion of Oyashio to Kuroshio. This locates between the secondary and third offsets of Oyashio, the warm water of Korushio meets the third offsets and transition zone form. So the aclinic temperature gradient is great, filaments is strong, and good fishery may form。 To the east of 160˚E, the sea locates in the east to the third offset of Oyashio, and the transition zone is not apparent, the isotherm almost parallel to the latitude. In this sea area, the fishes migrate north-eastward for food and the mantle length of the species is longer than that of ones in the western fisheries (Squid jig working group of Shanghai Aquatic University, 2003).

4.4 Sea Gradient and the Relationship with Fishry

Ocean fronts are broadly understood to mark the boundary between two different water types and are therefore usually manifested as a region of strong horizontal gradients in temperature, salinity, and chlorophyll and concentration of zooplankton and phytoplankton. It is speculated that fronts are important habitat for squid, we provide evidence that describes the habitat of squid in the western North Pacific Ocean as being strongly linked to fronts.

With the help of GIS, the function of spatial analysis is extended to quantificationally construe the relationship between O. bartrami resources and ocean fronts providing a more delicate spatial analysis. Daily SST images and yield data were composed to the same temporal span with chlo-a images. The central location of each fishery was computed by equation 2. Then the arithmetic of edge detection was applied to composed SST and chlo-a images. Sea fronts were extracted from images where the fishery center locates.

Tab. 1 shows the relationship between O.bartrami fishery and SST gradient in different sea area. We can observe that in the western sea area (140-150˚E), about 40% higher fisheries located in thermal gradients. Strong fronts appeared in the western fisheries. In the middle sea area (150-162˚E), more than 30% fisheries located in fronts. The front direction from south-east to north-west with a high frequency found in this sea area indicated the filaments in this direction were strongest. And in absolute value, the fishery found in front is greatest in this area. In the far east sea area (180˚W -170˚W), where the catch begins in May, there is almost no fishery found in fronts. Tab. 1 also shows the relationship between fishery and chlo-a gradient in different sea area. The same conditions showed. In the west fishery, more than 50% fishing grids located in fronts, while in the middle and east sea area, the ratio was lower than 20%. In absolute value, the mount of fishery locates in fronts took the advantage in middle sea area. It is reasonable to assume that O. bartrami fishery was associated with areas of thermal gradients and Chlorophyll-a concentration gradients commonly seen at the interface of Kuroshio and Oyashio water.

Because of the availability of remotely sensed SST and Chlo-a data and temperature and chlo-a 's hypothesized importance in influencing spatial distribution of squid and other pelagic fish (C.Silva, ect., 2000), this paper mainly discussed the surface sea conditions, using the indicators of SST and Chlorophyll-a that conduced to the production of O. bartrami. Further research on the mechanism of O. bartrami fishing ground should be carried out collecting more information on deeper water such as temperature, salinity and chlorophyll.

5. CONCLUSIONS

In this paper, time series remote sensing data of SST and ocean colour are gathered and composed. And GIS is adopted to map and analyze spatial-temporal relationship between sea conditions and O. Bartrami fishing ground in the Kuroshio Extension and Kuroshio-Oyashio transition regions. We applied the local association rule to the research on the relationship between O. bartrami fishery and sea environment. SST and ocean colour images are used to be a suitable approach for effective interpretation of the marine environment around O. Bartrami fishing ground. Also, we apply the neighbour association rule to study the relationship between the squid fishery and ocean gradients. It provides a quantitative view of sea gradients (thermal gradients, chlo-a concentration

gradients) in the ocean. It appeared that O. bartrami fishery was associated with areas of thermal gradients and Chlorophyll-a concentration gradients commonly seen at the interface of Kuroshio and Oyashio water. The technique used in this analysis allows the overlay and analysis of physical oceanographic and fishery data with potential applications in fisheries management and operational fisheries oceanography.

REFERENCES

Akihiko Yatsu, Junta Mori, 2000, Early growth of the autumn cohort of neon flying squid, Ommastrephes bartramii, in the North Pacific Ocean. *Fisheries Research*, 45, pp. 189-194.

Akihiko Yatsu, Satoshio Midorikawa, Takahiro Shimada, Yuji Uozumi, 1997, Age and growth of the neon flying squid, Ommastrephes bartrami, in the North Pacific Ocean. *Fisheries Research*, 29, pp.257-270.

Akihiko Yatsu, Tomowo Watanabe, Junta Mori, Kazuya Nagasawa, Yukimasa Ishida, Toshiomi Meguro, Yoshihiko Kamei and Yasunori Sakurai, 2000, Interannual variability in stock abundance of the neon flying squid, ommastrephes bartramii, in the North Pacific ocean during 1979-1998:impact of driftnet fishing and oceanographic conditions. *Fisheries Oceanography*,9(2), pp.163-170.

Cairistiona I.H. Anderson, Paul G.Rodhouse , 2001, Life cycles, oceanography and variability: ommastrephid squid in variable oceanographic environments, *Fisheries Research*, 54, pp.133-143.

Cayula Jean-Francois, Peter Cornillon, Ronald Holyer, and Sarah Peckinpaugh, 1991, Comparative study of two recent edge-detection algorithms designed to process sea-surface temperature fields. *IEEE Transactions on Geoscience and Remote Sensing*, 29(1), pp.175-177.

Cayula Jean-Francois, Peter Cornillon,1995, Multi-Image Edge Detection for SST Images. *Journal of Atmospheric and Oceanic Technology*, 12, pp.821-829.

David S. Kirby,Yvind Fiksen and Paul J.B. Hart, 2000, A dynamic optimization model for the behaviour of tunas at ocean fronts. *Fisheries Oceanography*, 9(4), pp.328-342.

Dawn J. Wright and Darius J. Bartlett, 2000. *Marine and Coastal Geographical Information Systems*, Taylor & Francis, pp.25-36.

DFO, 1999, Neon flying squid. *DFO Science Stock Status Report,* C6-12 (1999).

Hays G.C., M. Dray, T. Quaife, T. J. Smyth, N. C. Mirronnet, P. Luschi, F. Papi and M. J. Barnsley, 2001, Movements of migrating green turtles in relation to AVHRR derived sea surface temperature, *International Journal of Remote Sensing*, 22(8), pp. 1403-1411

Jeffrey J. Polovina etc., 2001, the transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. *Progress in Oceanography*, 49, pp.469-483.

Jeffrey J.Polovina, Donald R. Kobayashi, Denise M. Parker, Michael P. Seki and George H. Balazs, 2000, Turtles on the edge: movement of logerhead turtles (Caretta caretta)along oceanic fronts, spanning longline fishing grounds in the central North Pacific,1997-1998. *Fisheries Oceanography*,9, pp.71-82.

Murata, M. and Hayase, S. ,1993, Life history and biological information on flying squid(Ommastrephes bartrami) in the North Pacific Ocean. *Bull. Int. Nat. North Pacific Fish. Comm.* 53, pp.147-182.

Pravakar Mishra, Hideo Tameishi, Takashige Sugimoto, 2001, Delineation of meso scale features in the Kuroshio-Oyashio transition region and fish migration routes using satellite data off Japan. Paper presented at the 22nd Asian Conference on Remote Sensing, 5-9 November 2001,Singapore.

Roper, C.F.E., Sweeney, M.J. and Nauen, C.E., 1984, Cephalopods of the world. And annotated and illustrated catalogue of species of interest to fisheries, *FAO Fish. Synop.* 3(125), pp.1-227.

Silva C., ect., 2000, Exploring the association between small pelagic fisheries and Seawifs chlorophyll and AVHRR sea surface temperature in the north of Chile, Presented at the Sixth International conference on remote sensing for Marine and Coastal Environments, Charleston, South Carolina.

Solanki H.U., R.M.Dwivedi and S.R.Nayark, 2001, Synergistic analysis of SeaWiFS chlorophyll concentration and NOAA-AVHRR SST feature for exploring marine living resources, *International Journal of Remote Sensing,* 22(18), pp.3877-38882.

Squid jig working group of Shanghai Aquatic University, 2003, The management of oceanic jig production and yield data gathered by the squid jig working group, 2002, China.

Takahashi M., Y. Watanabe, T. Kinoshita and C. Watanabe, 2001, Growth of larval and early juvenile Japanese anchovy, Engraulis japonicus, in the Kuroshio-Oyashio transition region. *Fisheries Oceanography*, 10(2), pp.235-247

Waluda C.M., P. G. Rodhouse, P. N. Trathan and G. J. Pierce, 2001, remotely sensed mesoscale oceanography and the distributin of Illex argentinus in the South Atlantic. *Fisheries Oceanography*, 10(2), pp.207-216.

ACKNOWLEDGEMENTS