Seasonal Changes in Bigeye Tuna Fishing Areas in Relation to the Oceanographic Parameters in the Indian Ocean

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In this report, the significant oceanographic factors influencing spatial-distributions for bigeye tuna species in the Indian Ocean were investigated on the basis of the data collected and accumulated in the past years. The results show that bigeye tuna are distributed in water with the optimum tempera ture in a range of 10°C-16°C irrespective of their sexual maturity and water mass. Accordingly, the vertical distribution of tuna is predicted by the temperature profile; the tunas are only found in the deeper layer in the tropical regin while they are distributed up to the shallower layer in the middle latitude.

On the other hand, the bigeye tuna reaching the maturity is found only beneath the layer between 0 and 50m where the sea water temperature exceeds 26°C.

The size of fishing ground in the tropical region decreases during the period between June and September. This decrease coincides with the decrease in sea area where the water temperature in the layer above 50m is warmer than 26°C. During this period, however, the size of the fishing ground in the middle latitude increases. Accordingly, the bigeye tunas in the middle latitude are younger and in the growing stage while those reaching maturity are dominate in the tropical region, and this bigeye tuna distribution is dependent on the vertical temperature profile of each sea area.

1 Introduction

Recently, international effort for assessing and controlling world marine resources has been made in order to utilize them for the sustainable food supply. Nevertheless, some resources which were overfished in the past are slow in recovery, and some such as tuna appear to decrease judging from marked declining in catch rate and relative increase of younger tuna in the total number of catch. Accordingly, we should take measures to recover them on the basis of ecological knowledges of the tuna. For this purpose, the first significant approach is to relate the tuna distribution as a function of time and space to the oceanographical parameters such as temperature and salinity. The results are useful for not only preserving the resources by limiting the tuna catch to grown-up tuna alone, but increasing efficiency of catch rate.

FAO reported that the bigeye tuna, *Thunnus obesus*, caught in the world in 1995 amounts to 326,130 ton and this is the second largest of all kinds of tunas, followed by 1,052,192 ton for yellowfin tuna, *Thunnus alabacores*[1]. In particular, the share of Japanese bigeye tuna

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catches in the world is 40% which is larger than 11% for the yellowfin tuna indicating the valuable fish in Japan where raw tuna meat is a delicacy.

In Asia, the bigeye tuna is distributed in the Pacific and the Indian Oceans. A larger number of researches have been carried out relating the bigeye tuna distribution in the Pacific Ocean to the oceanographical parameters. In case of the bigeye tuna in the Indian Ocean, however, only a little is known about the distribution in relation to the oceanographical parameters.

Quite recently, vertical and horizontal distribution of the bigeye tuna in the Indian Ocean was investigated by Mohri *et al.*[2),3)], and factors influencing the distribution were discussed by Mohri *et al.*[4)-7)]. Their results show that the bigeye tuna are distributed between 20°N and 40°S in the Indian Ocean, and the rich population is, particularly, found in two region: the tropical region extending from the southern Arabian Sea toward the Java island, and middle latitude regin around 30°S. They also show that the bigeye tuna are caught in the layer where the water temperature ranges between 10°C and 16°C, and also the distribution of the bigeye tuna reaching maturity is found in such the layer but is limited to the sea area where the water temperature above 50m exceeds 26°C.

Concerning the temporal distribution, Mohri *et al.*[8)] obtained the following results based on the catch records.

i) Size of fishing ground in the tropical and the middle latitude regions, varies with season. Besides, the size of the former increases as that of the latter decreases, and vice versa.

ii) Judging from the gonad index (defined by $G.I.=10^4\times W/L^3$ where W=gonad weight (g) and L=body length (cm)) of the bigeye tuna caught, most of spawning groups are distributed from October to March, only in the tropical region while the middle latitude region is populated by the younger bigeye tuna which is supposed to be in a stage of feeding migration and mostly appears in the period between April and September.

However, factors influencing this temporal variation are not yet clear because of insufficiency of available data. In this paper, the water temperature and sexual maturity of the bigeye tuna are focused to investigate their effects on the seasonal variation of fishing ground on the basis of the data gathered in the past along with the data having become available recently.

2 Data Sources and Processing

2.1 Data

Data used in this paper has been collected in the areas between 20°N and 50°S and between 20°E and 120°E in the Indian Ocean, as described below.

i) During a cruise of Koyo-maru, training ship of National Fisheries University, from October in 1987 through January in 1988, the author collected the bigeye tuna samples in the tropical waters of the Indian Ocean. At the same time, water temperature profile was also obtained with the reversing thermometer, and dissolved oxygen content in the water sampled by Nansen sampler was determined.

ii) Experimental data collected over six years from 1981 through 1986, are available from Japan Marine Research Center in the publications of "Exploited New Fishing Grounds for Tuna Longline", "Data of fish catches at hook depth in deep longline fisheries", "Measurements of fish size" and "Observations of water temperature in each layer".

iii) Data for the results of oceanographical observations in each water layer is available from Japan Oceanographic Data Center, which were accumulated over 84 years during a period of 1906 through 1989.

The data i) and ii) as described above were used to study the relation of fishing rate with vertical distribution, temberature and sexual

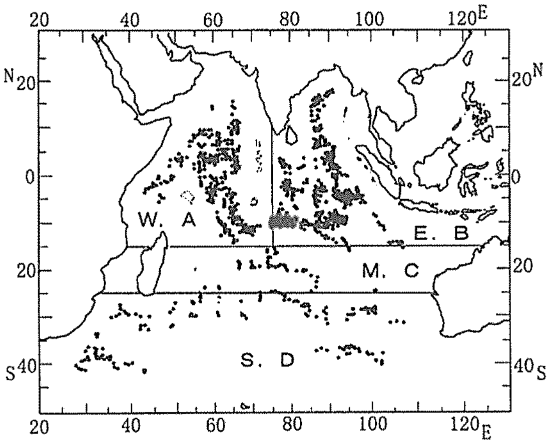

Fig. 1. Deep tuna longline fishing stations at which data were collected. Study area is divided into four sub-areas:
Western Tropical Area A (W.A), Eastern Tropical Area B (E.B), Mid-latitude Area C (M.C), Southern High Area D (S.D)

maturity. Fig. 1 shows location of sampling stations where the data i) and ii) were collected. The data ii) and iii) were used for investigating seasonal variation of water temeratures.

In this paper, the Indian Ocean is divided into four parts and they are denoted by W.A, E.B, M.C and S.D. As shown in Fig. 1.,W.A extends from the southern Arabian Sea to off the northern coast of Madagascar, E.B extends off the southern coast of Java towards off the eastern coast of Sri Lanka, S.D extends from off Fremantle to off Cape Town and M.C is located between 15°S and 25°S and also situated between W.A, E.B and S.D.

2.2 Data Processing

The shape of main line of the longlines underwater are assumed to be similar to a catenary curve. Accordingly, the depth of hook hanging from the main line through the branch line might be a function of horizontal distance of a point on the main line from which the brach line is suspended; 6th hook is deepest and lst and 11th hooks which are nearest to the floats are shallowest of the 11 hooks. The hook depths are calculated theoretically as described below.

i) For data collected by the Koyo-maru: First, the reduction rate of main lines is estimated by rationing the horizontal distance between the two floats telling the position of lst and 11th branch lines to the total length of mainline in air. The estimated reduction rate is used to calculated the hook depth on the assumption of the catenary curve as actual shape of the main lines.

ii) For data published by Japan Marine Research Center, the hook depth were obtained as follows.
The depths which appear in the reports published from 1981 to 1984 are based on the direct measurements or calculated results. The data collected in 1985 for a trial tuna fishing study on board of Koyo-maru are estimated from calculated depth range. The depths in 1986 are obtained by a similar way described in i).

The present study area was divided into grids of ground resolution of one×one degree. From the vertical distribution of water temperatures at i-th grid, temperature at the interval 1°C in each hook depth, was derived. Then, number of hooks (h_{it}) and number of tuna caught (C_{it}) at each grid were obtained as a function of the temperature at the interval of 1°C. The ratio of number of catches multiplied with 1,000 (R_t) to number of hooks at temperature (t) at the interval of 1°C are

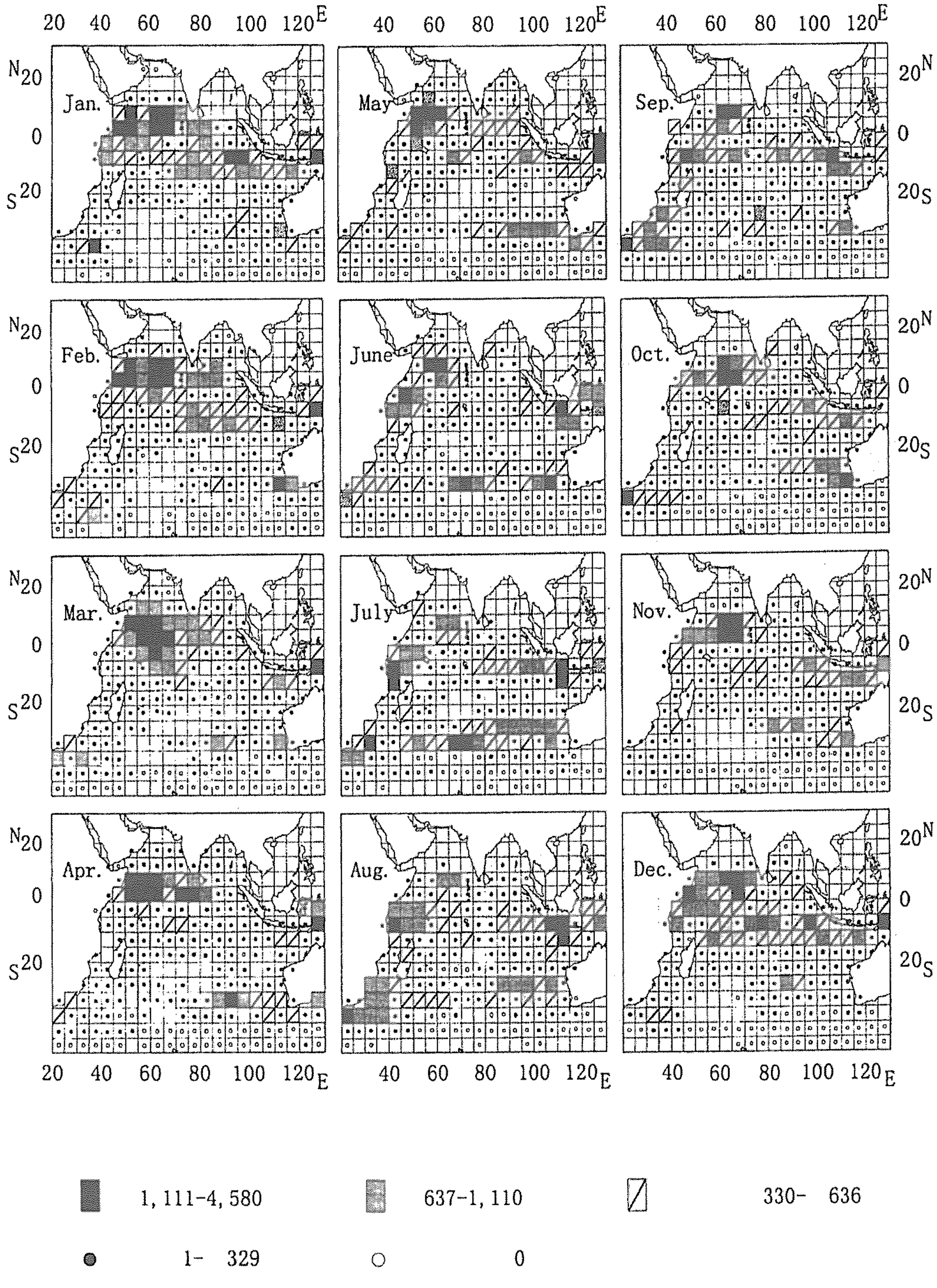

Fig. 2. Average number of bigeye tuna caught by Japanese tuna longline vessels over 25 years between 1967 and 1991 in each 5-degree grid and in each month.

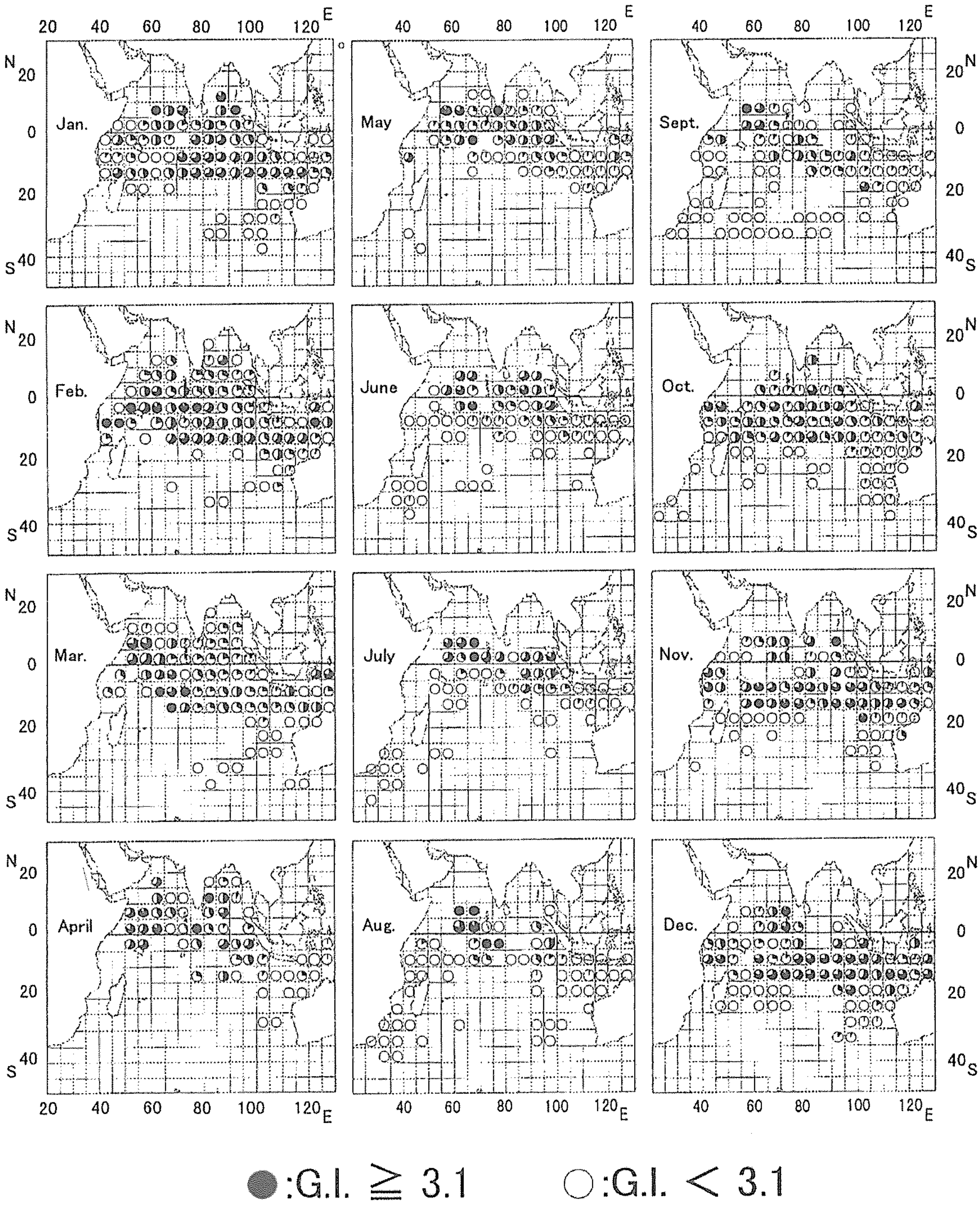

Fig. 3. Ratio of numbers of sexually matured bigeye tuna to total catche number of adult bigeye tunas. These are derived on the basis of to catch record between 1952 to 1987.

calculated.

$$R_t = (\sum_{i=1}^{n} C_{it} / \sum_{i=1}^{n} h_{it}) \times 1,000$$

where n is total sample number in temperature at the interval of 1°C at each grid

Finally the relationship between maturity condition and water temperature were examined by using the maturity index G.I. ≧ 3.1 (Kikawa[9),10)]) as reported in the previous papers by Mohri[5),7)].

3 Results and Discussion

3.1 Seasonal Changes in Size of Mojor Fishery Grounds and Matured Fish

Fig. 2 shows the catch numbers of bigeye tunas averaged over twenty five years in each month and each grid. Fig. 2 is based on the result obtained by Mohri *et al.* (1997)[8)] and also those collected by Japanese tuna longline vessels. From the figure, major fishing ground for bigeye tunas are observed in the following three sea regions: W.A, E.B, and S.D.

As is clear from the figure, size of three main fishing grounds varied with season. From April to September (winter in the southern hemisphere), the main fish ground is formed in the areas of the southern middle latitude around 30°S. One of them extends towards Java island in July and also towards the northern coast of Madagascar in June.

The main fishery grounds then gradually shifted towards the tropical waters W.A and E.B from the southern part of middle latitude area. In and around April, the main fishing grounds of the southern middle latitude areas recovered again. No main fishing ground is formed in M.C throughout a year.

Fig. 3 shows that ratio of number of matured fish (marked as ●) to total number of adult bigeye tuna caught in each month and each grid. The matured bigeye tuna is found north of 15°S (20°S east of 80°E) in the tropical oceans, and few bigeye tuna is found in the southern middle latitude area. The matured bigeye tuna off the northern coast of Madagascar and off the southern coast of Java are found during the period of 8 months from October to May, but not from June to September when the south western seasonal wind blows more strongly.

In Fig. 4, fish hook rate for bigeye tunas in

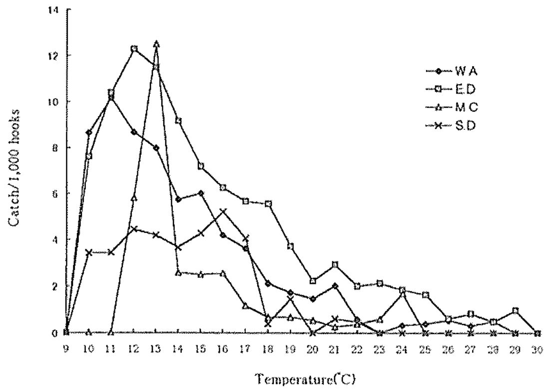

Fig. 4. Catch rate (catch per 1,000 hooks) are plotted against water temperatures at the catch depth.

each area are plotted against water temperature. High hook rate of bigeye tunas in all sea regions are observed in the temperature range of 10 to 16°C. This temperature range agrees well with the optimum temperature[4)] suggesting independence of water mass upon the optimum temperature for bigeye tuna.

As shown in Fig. 4, water temperature range where the hook rate of bigeye tuna is larger than 4.0 is wider in the tropical oceans and becomes narrower towards the southern areas.

3-2 Relationship between Water Temperature and Depth of Catch

Fig. 5 shows relation between water

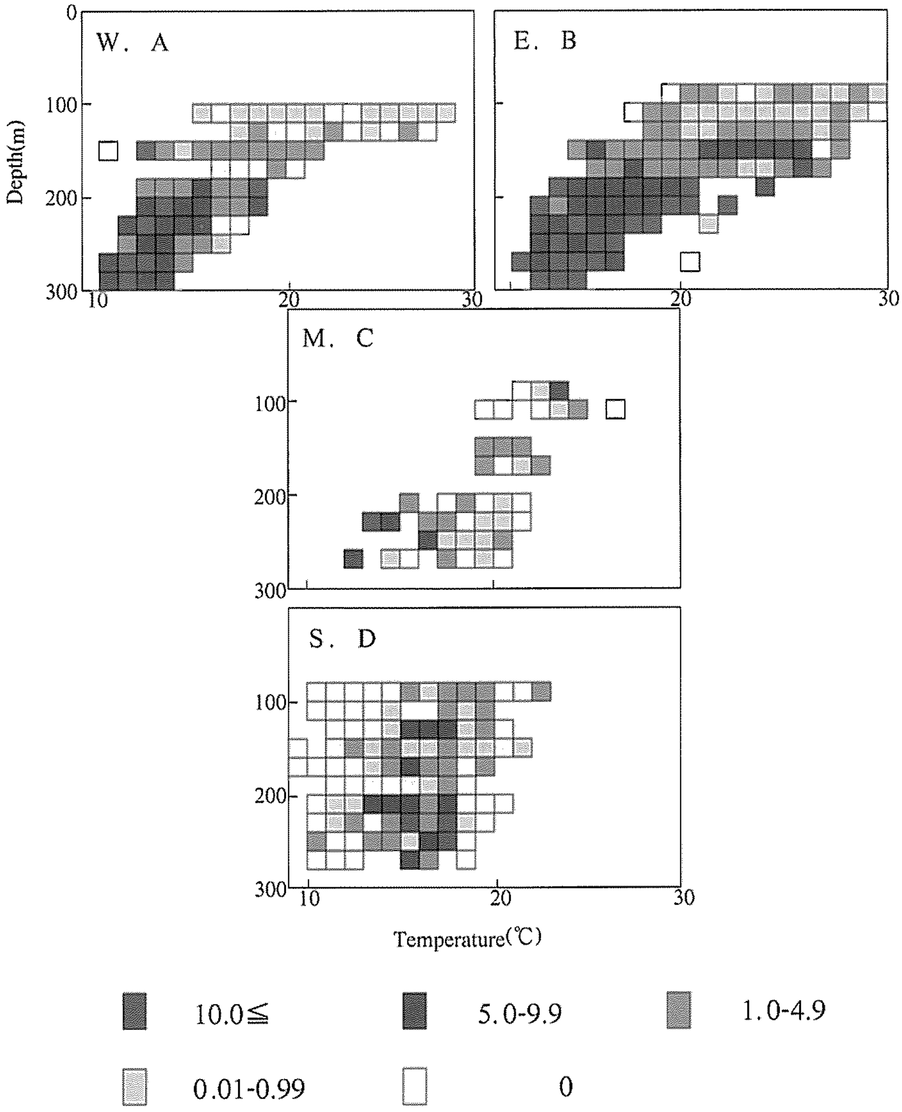

Fig. 5. Bigeye tuna hook rate as a parameter of temperature and hook depth.

temperature and depth for the fish catch. In the layer deeper than 200m in W.A and E.B, large R_t is found around the optimum temperature and the temperature in most layers shallower than 200m is higher than optimum temperature and R_t is small.

In contrast, the optimum temperature is found in thick layer from depth of 60m to 280m in S.D. There was not any remarkable dependency of the hook depth upon R_t, as seen in the case of tropical sea area.

Recently, Mohri *et al.*[3] studied the vertical distribution of bigeye tunas in the Indian Ocean, and showed that the hook rate has a tendency of gradual increase as the depth increases in the tropical sea area,whereas there is not any sign of dependency of catch deth in the southern latitude oceans.This agrees well with the results obtained in this paper as represented in Fig. 5. Accordingly we may conclude that the vertical distribution of bigeye tunas is affected by the vertical location of layer having the optimum temperature.

3.3 Relationship between Temperature and G.I. of Bigeye Tuna

As shown in Fig. 3. matured bigeye tuna distributed in the tropical zone located north of latitude 15°S (20°S east of 80°E), whereas few matured bigeye tuna were found in the middle latitude oceans.

It is noted that the water temperature near the sea surface shows increase and decrease toward north and south, respectively, from the latitude of 15°S (20°S)[11].

Judging from the distribution of both matured bigeye tuna and upper layer temperature, distribution of matured tuna may be determined by the water temperature of upper layer.

In Fig. 6, G.I. is plotted against the water temperature in the bigeye tuna catch layers in the tropical oceans. The temperature in the layer where the bigeye tuna were caught is distributed in rather wide range of 11°C to 28 °C, and G.I. ranges between 0-15 in W.A and between 0-10 in E.B without showing any correlation between G.I. and temperature in the catch layer.

The results of non correlation between G.I. and the water temperature agreed with that obtained in all over the Indian Ocean[7]. Accordingly, it is natural to consider that sexual maturity is independent on the water mass.

Harada (1974) reported[12] that the most important factor influencing the maturity of marine fishes is the water temperature. Concerning the bigeye tuna too, it was pointed out by Watanabe (1970)[13] and Ueyanagi (1969)[14] that the water temperature in the layer between 50m and the surface is far more important factor from sexual for eggs, larvae,

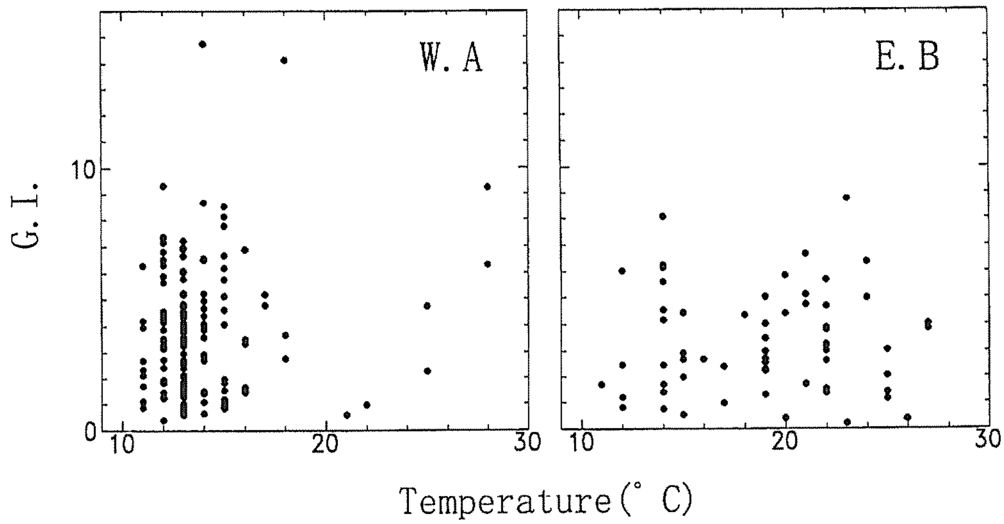

Fig. 6. Relation between tunas' sexual maturity and temperature at the hook depth in W.A (left hand panel) and E.B (right hand panel).

and juveniles rather than for the spawning adult bigeye tunas. Accordingly, the relation between the distribution of bigeye tunas and water temperature in the layer above 50m as stressed in the previous report[7] is again discussed below.

In Fig. 7, vertical distribution of temperature averaged over all the data collected in W.A and E.B are shown.

The average water temperature were highest at the surface; 28.2°C and 28.9°C in W.A and E.B, respectively. The lowest temperature were found at 50m; 27.8°C and 28.4°C in W.A and E.B, respectively.

Vertical temperature used in this report were measured only one place just before setting the lines. Accordingly, geographical location of hook is 0 to 70km away from the position where the temperature was measured, and also there is time lag of 0 hour to 9 hours between the observation and fish catch. Moreover, the hook depths were mostly estimated on the assumption that the shape of main line obeys the catenary curve as described before. Since Hanamoto (1974)[15] suggested overestimation of depth estimated under this assumption, some depths estimated in this paper might be deeper than actual hook depth. This leads to discrepancy between estimated temperature at hook depth and true temperature. Thus, errors in estimating temperature at hook depth are taken into consideration, and averaged temperature $(\bar{x})-3\times\sigma$ (where σ is standard division) is introduced to determine the minimal temperature of layer between 0m and 50m in the sea area where the matured bigeye tunas were distributed.

$\bar{x}-3\sigma$ in the 50m layers where the temperature is lowest above 50m, is 26.1°C in the western tropical oceans, and was 26.8°C in the eastern tropical oceans. Accordingly, we may conclude that 26.1°C is the minimal temperature of layer between 0 and 50m in the sea area where the matured bigeye tuna is distributed. This agrees well with the previous results obtained in the tropical Indian Ocean by Mohri (1998)[7]. Accordingly, the results which temperature larger than 26°C in the upper 50m layer is required by the matured bigeye tuna, is independent of geographical location.

3.4 Vertical Movement in 26°C Layer with Season

To study factors influencing temporal distribution of bigeye tunas, the seasonal change in depths of isotherms of 10°C and 16°C, and 26°C are investigated on the basis of the data obtained by Mizuno and Watanabe[16]. The results show that seasonal change of depths of 10°C and 16°C isotherms is not clear. On the other hand, seasonal change in the depth of 26°C isotherm is found in some sea area. This suggests possible influences of the seasonal change in a depth of isotherm upon the bigeye tunas' temporal distribution patterns. Accordingly, the monthly change of size of sea area where the temperature of layer above 50m is higher than 26°C is shown in Fig. 8. This "warm area" size decreases from June to September where the south-west seasonal wind dominates. This is, in particular, remarkable off the coast of Somalia. On the other hand, the warm area develops during a period of the north-east seasonal winds (strong winter in the northern hemisphere). Monthly change of warm area in Fig. 8 agrees well with the distribution of matured bigeye tunas as shown in Fig. 3.

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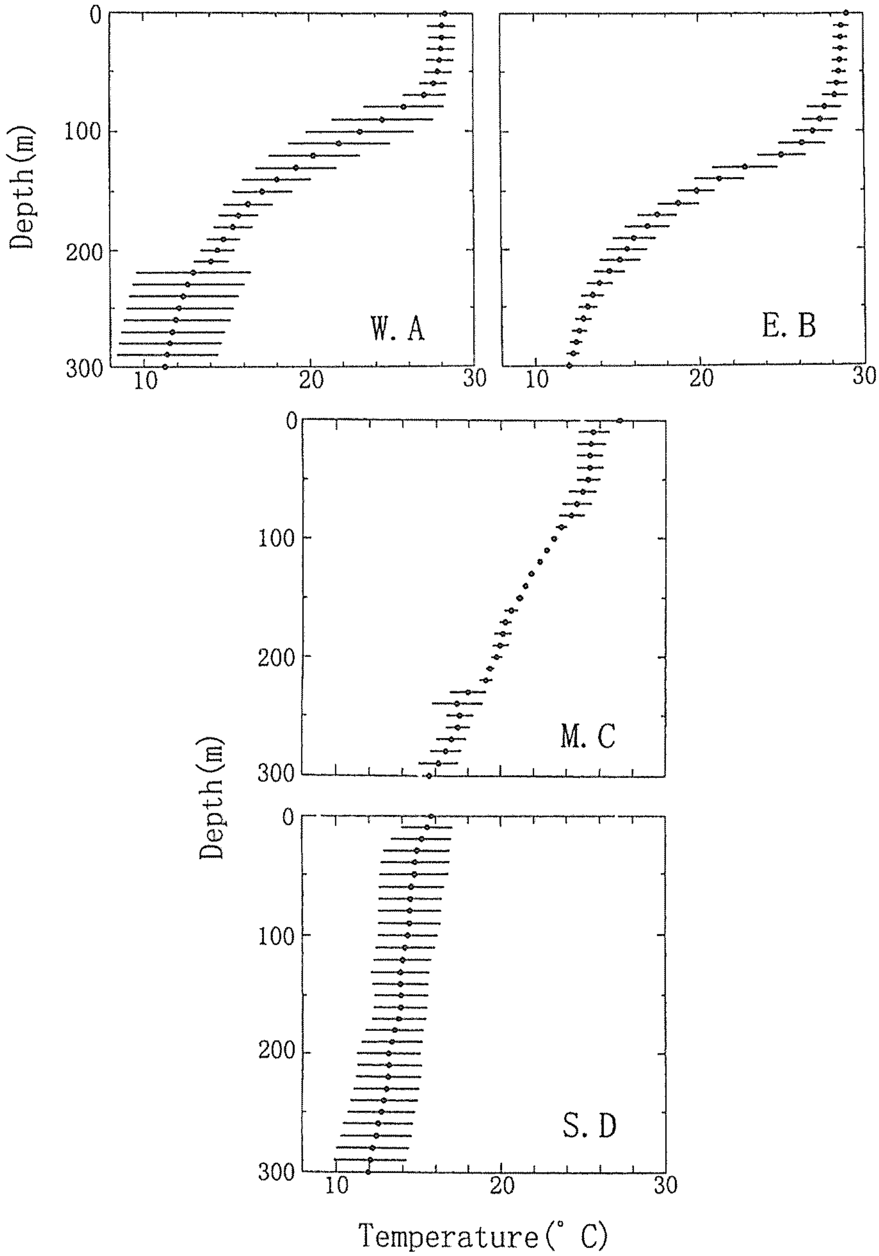

Fig. 7. Vertical profiles of averaged temperature in four areas.

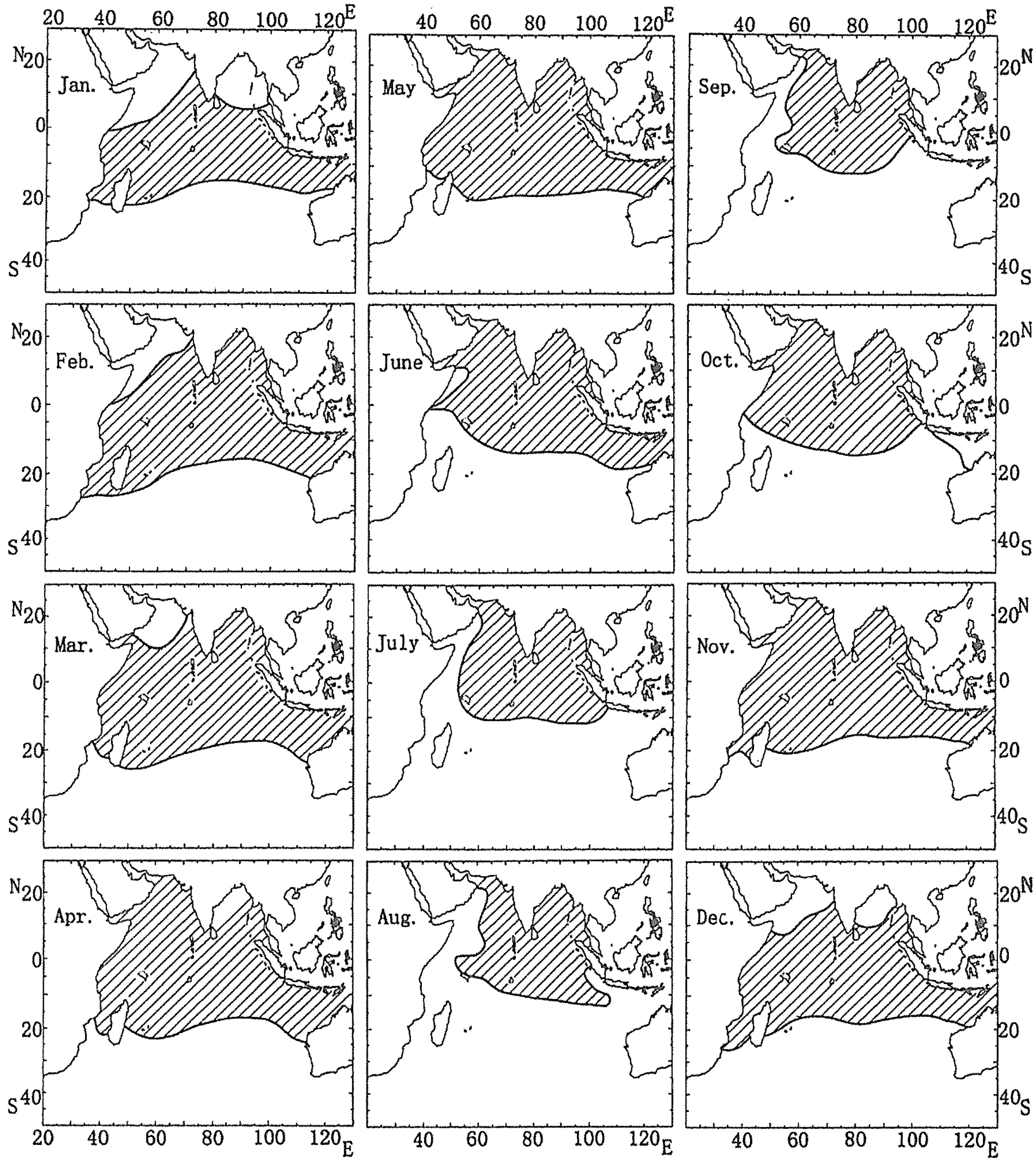

Fig. 8. Monthly variation of size of sea area where the temperature in the layer above 50m is larger than 26℃.

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インド洋におけるメバチ漁場の季節変化と環境要因との関係

毛 利 雅 彦

要旨：インド洋において海域別にメバチ時空間的分布を規定する要因を把握するため、成熟状態並びに水温が主漁場消長の季節に及ぼす影響を調べた。

その結果、メバチは成熟状態や海域の相違にかかわらず、10℃から16℃の適水温帯を中心に分布し、メバチの鉛直分布を規定しているものと推察された。メバチの成熟個体が分布する海域は、海域の相違にかかわらず、表面から50mにおける水温が26℃以上の海域であった。

熱帯海域において、メバチ主漁場、成熟個体が認められる海域、表面から50mにおける水温が26℃以上になる海域の3者について、消長の時期がほぼ一致していた。このことから、水温26℃以上となる範囲の季節的消長が、メバチ主漁場の時間的拡大、縮小に影響をおよぼしていたものと考えられる。