

SEASONAL CHANGES IN BIGEYE TUNA FISHING AREAS IN RELATION TO THE OCEANOGRAPHIC PARAMETERS IN THE INDIAN OCEAN

Masahiko Mohri ^{1/} and Tom Nishida ^{2/}

1/ National Fisheries University, Shimonoseki, Yamaguchi, Japan

2/ National Research Institute of Far Seas Fisheries, Shimizu, Shizuoka, Japan

ABSTRACT

In this report, 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 temperature 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 region 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.

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 over fished 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 knowledge 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 oceanographic 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 albacares* ¹⁾. In particular, the share of Japanese bigeye tuna 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 oceanographic parameters. In case of the bigeye tuna in the Indian Ocean, however, only a little is known about the distribution in relation to the oceanographic 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 regions: the tropical region extending from the southern Arabian Sea toward the Java island and middle latitude region 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.

- 1 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.
- 2 Judging from the gonad index (defined by $G.I. = 104 \times W / L^3$ 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.

DATA SOURCES AND PROCESSING

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.

- 1 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.
- 2 Experimental data collected over six years from 1981 through 1986, are available from Japan Marine Resources 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".
- 3 Data for the results of oceanographic 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, temperature and sexual 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 temperatures.

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.

Data Processing

The shape of main line of the longline underwater is 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 branch line is suspended; 6th hook is deepest and 1st and 11th hooks which are nearest to the floats are shallowest of the 11 hooks. The hook depths are calculated theoretically as described below.

- 1 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 1st and 11th branch lines to the total length of mainline in air. The estimated reduction rate is used to calculate the hook depth on the assumption of the catenary curve as actual shape of the main lines.
- 2 For data published by Japan Marine Resources Research Center, the hook depths 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 calculated.

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

,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 (Kikawa⁹⁻¹⁰) as reported in the previous papers by Mohri⁵⁻⁷).

RESULTS AND DISCUSSION

Seasonal Changes in Size of Major 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.

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 R_t) 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 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.

Relationship between Water Temperature and Depth of Catch

Fig. 5. shows relation between water 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 depth 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.

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, 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 report⁷⁾ 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 was measured only one place just before setting the lines. Accordingly, geographical location of hook is 0 to 70 km 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 $(\bar{x}) - 3 \times s$ (where s 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.

$\bar{x} - 3s$ 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.

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 Watanabe¹⁶⁾. 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 southwest seasonal winds dominant. This is, in particular, remarkable off the coast of Somalia. On the other hand, the warm area develops during a period of the northeast 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.

ACKNOWLEDGEMENTS

This work was supported by the crewmembers of training ship Koyo-maru, Japan Marine Resources Research Center (JAMARC) and Japan Oceanographic Data Center. Their valuable guidance and advice given to the author through the present work, and every information and data useful to the author would be greatly acknowledged.

REFERENCES

- FAO: FAO Year Book, Fishery Statistics-Catches and Landings 1995, 80, FAO, Rome, pp.321-350 (1997).
- M. MOHRI, E. HANAMOTO AND S. TAKEUCHI: Nippon Suisan Gakkaishi, 57, 1683-1687 (1991).
- M. MOHRI, E. HANAMOTO, M. NEMOTO AND S. TAKEUCHI: Bull, Japan, Soc. Fish. Oceanogr. 61 10-17 (1997)
- M. MOHRI, E. HANAMOTO AND S. TAKEUCHI: Nippon Suisan Gakkaishi, 62, 761-764 (1996).
- M. MOHRI AND N. MIYABE: Report on study of Tuna Resources, 166-175 (1996).
- M. MOHRI AND Y. TAKEDA: J. National fish. Univ., 46, 13-20 (1997).
- M. MOHRI: J. National Fish. Univ., 46, 175-181 (1998).
- M. MOHRI, E. HANAMOTO, M. NEMOTO AND S. TAKEUCHI: Report from Kanagawa Suisoken Kenpo Bull. 2, 13-19 (1997).
- S. KIKAWA: Bull. Nankai Reg. Fish. Res. Lab., 1, 1-10 (1953).
- S. KIKAWA: Bull. Nankai Reg. Fish. Res. Lab., 5, 145-157 (1957).
- WYRTKI K.: Oceanographic Atlas of the International Indian Ocean Expedition, 1, National Science Foundation, Washington D. C., 1971, p.535.
- T. HARADA: Report on Maturity and Spawning of Fish-Its fundamentals and Applications (ed. By Nippon Suisan Gakkai), 1st Edition by Koseisha-Koseikaku Tokyo, 1974, pp.66-75.
- T. WATANABE: Bul. Tokai Regional Fish. Res. Lab., 62, 1-283 (1970).
- S. UEYANAGI: Bull. Far Seas Fish. Res. Lab., 12, 177-256 (1969).
- E. HANAMOTO: La Mer, 12, 128-136 (1974).
- K. MIZUNO, A. WATANABE: Report on Water Temperature Vertical Profiles in the Indian Ocean. (Report No.301 compiled by Far Seas Fish Research Laboratory), 1, 1-102 (1993).

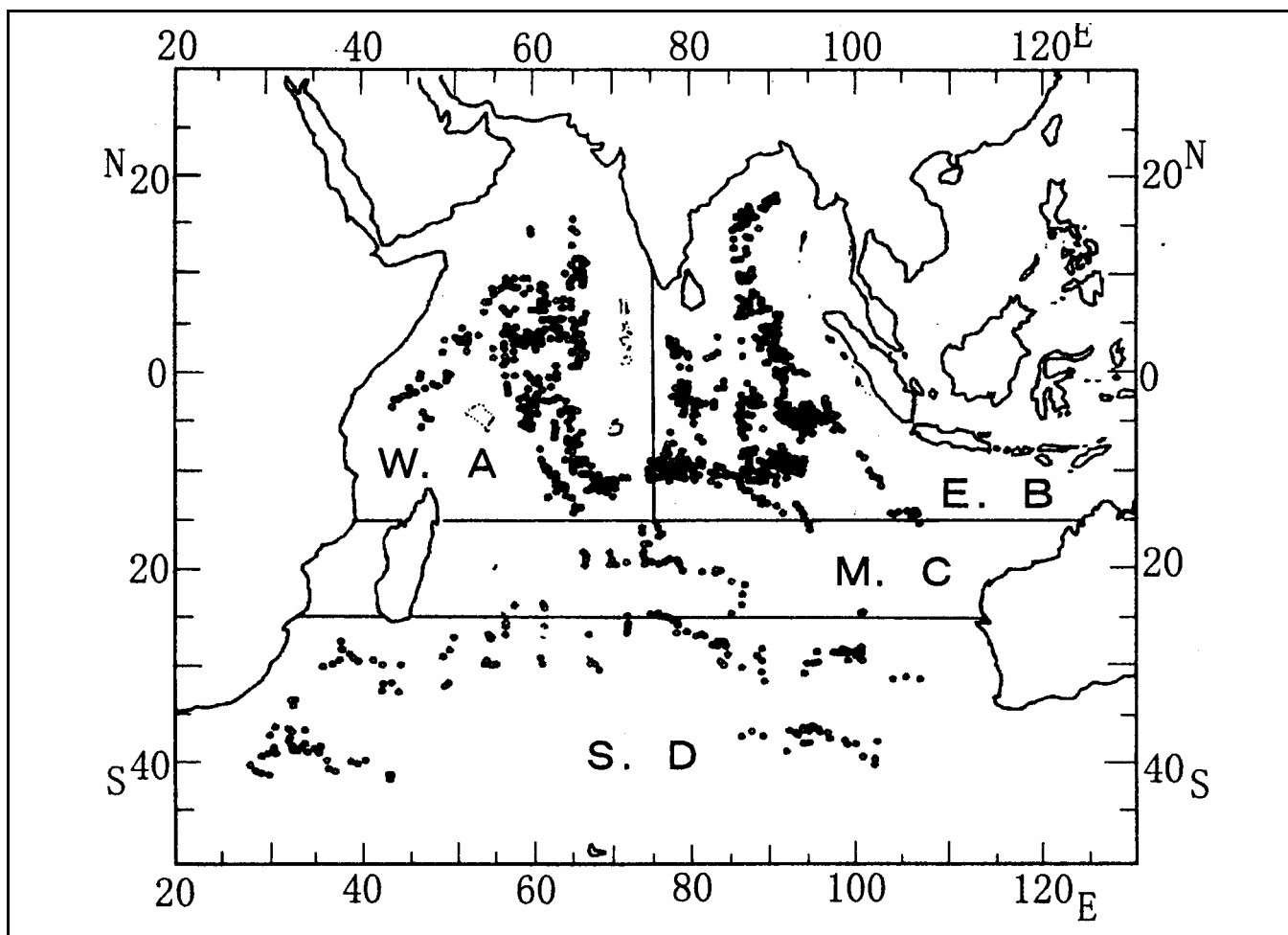


Fig. 1 Deep tuna longline fishing stations at which data were collected. Study area is divided into four sub-areas.

W.A. : Western tropical area A

E.B. : Eastern Tropical area B

M.C. : Mid-latitude area C

S.D. : Southern High area D

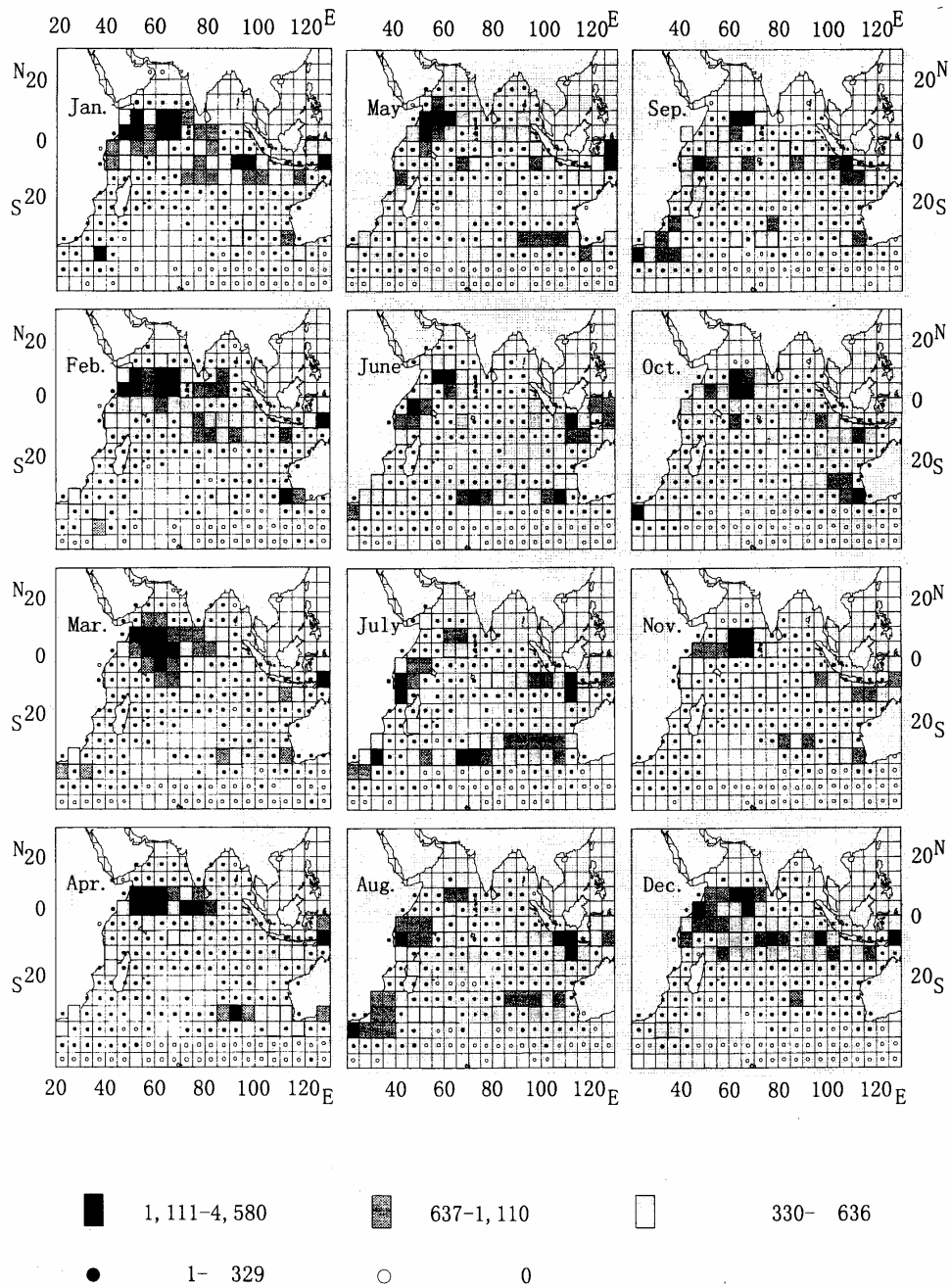


Fig. 2 Average number of bigeye tuna caught by Japanese tuna longline vessels over 25 year between 1967 and 1991 in 5-degree grid and in each month

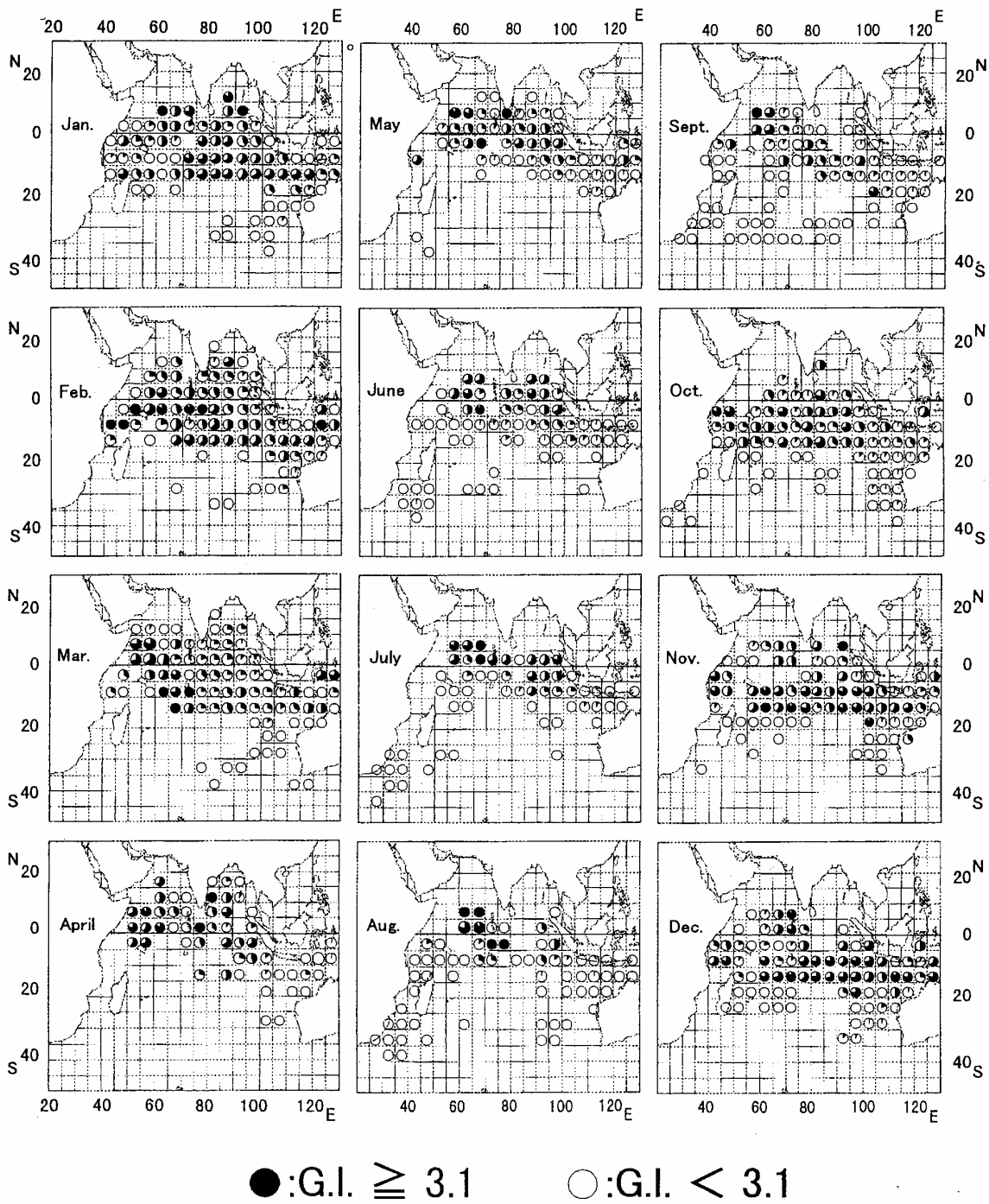


Fig. 3 Ratio of numbers of sexually matured bigeye tuna to total catches number of adult bigeye tuna. These are derived on the basis of catch record between 1952 and 1987.

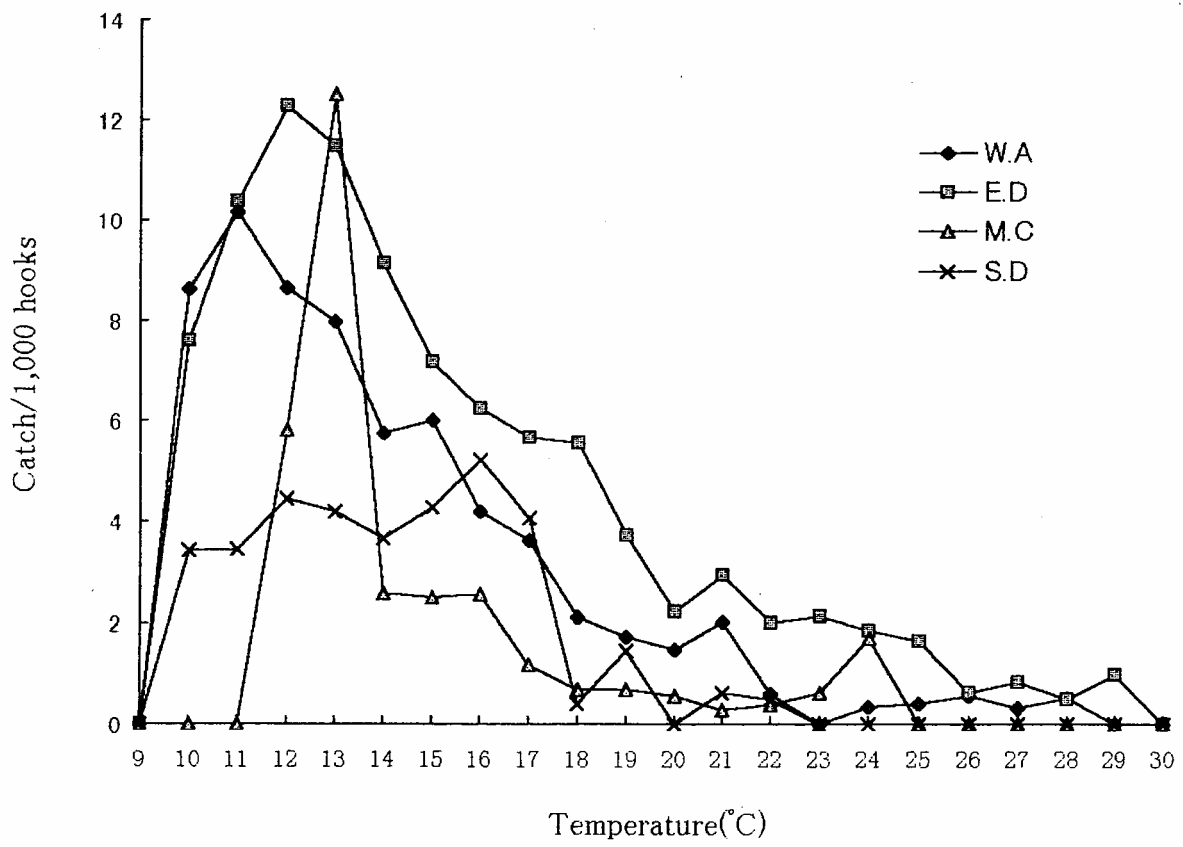


Fig. 4 Catch rate (catch per 100 hooks) is plotted against water temperatures at catch depth.

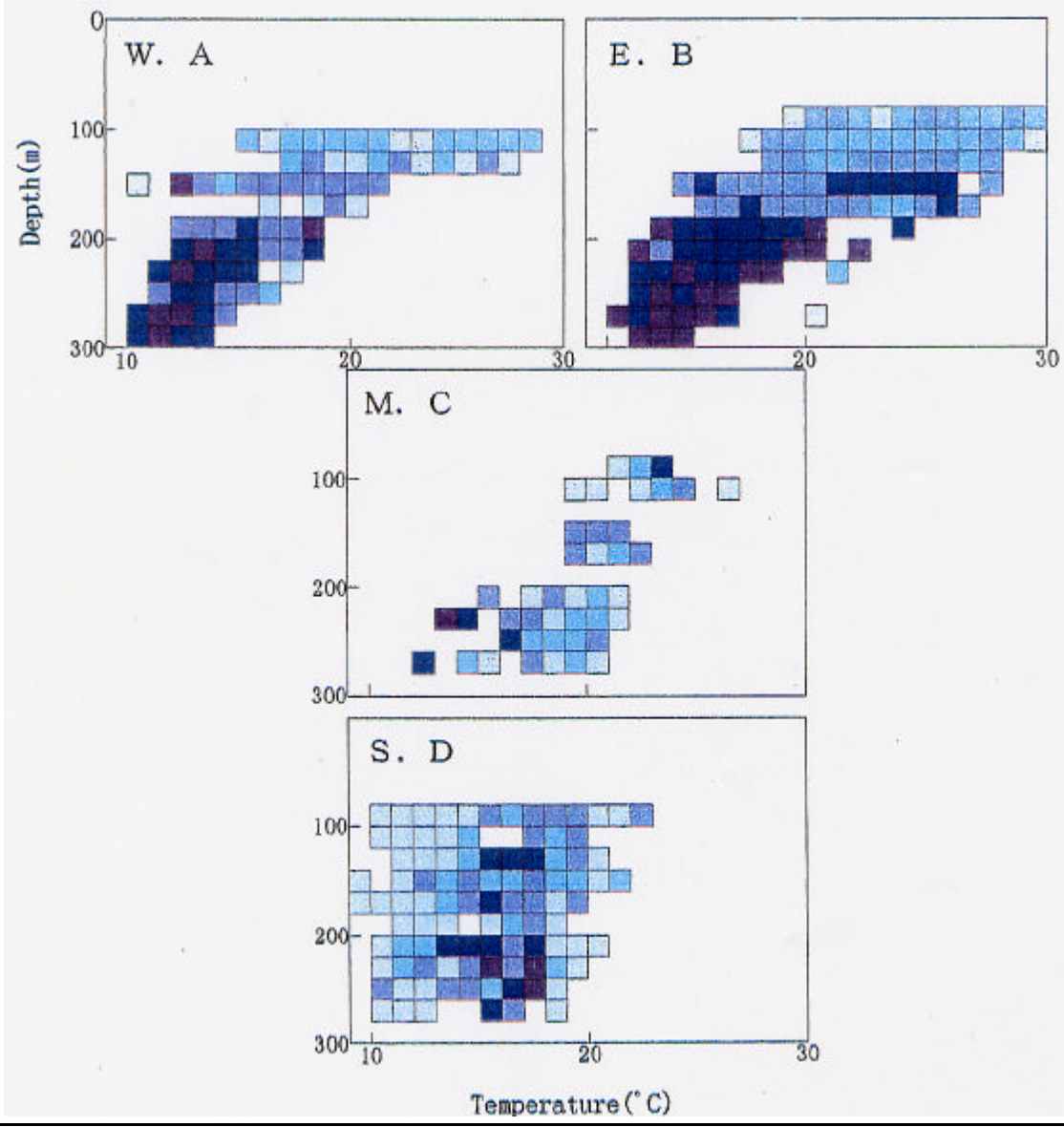


Fig. 5 Bigeye tuna hooking rates as a parameter of temperature and hook depth.

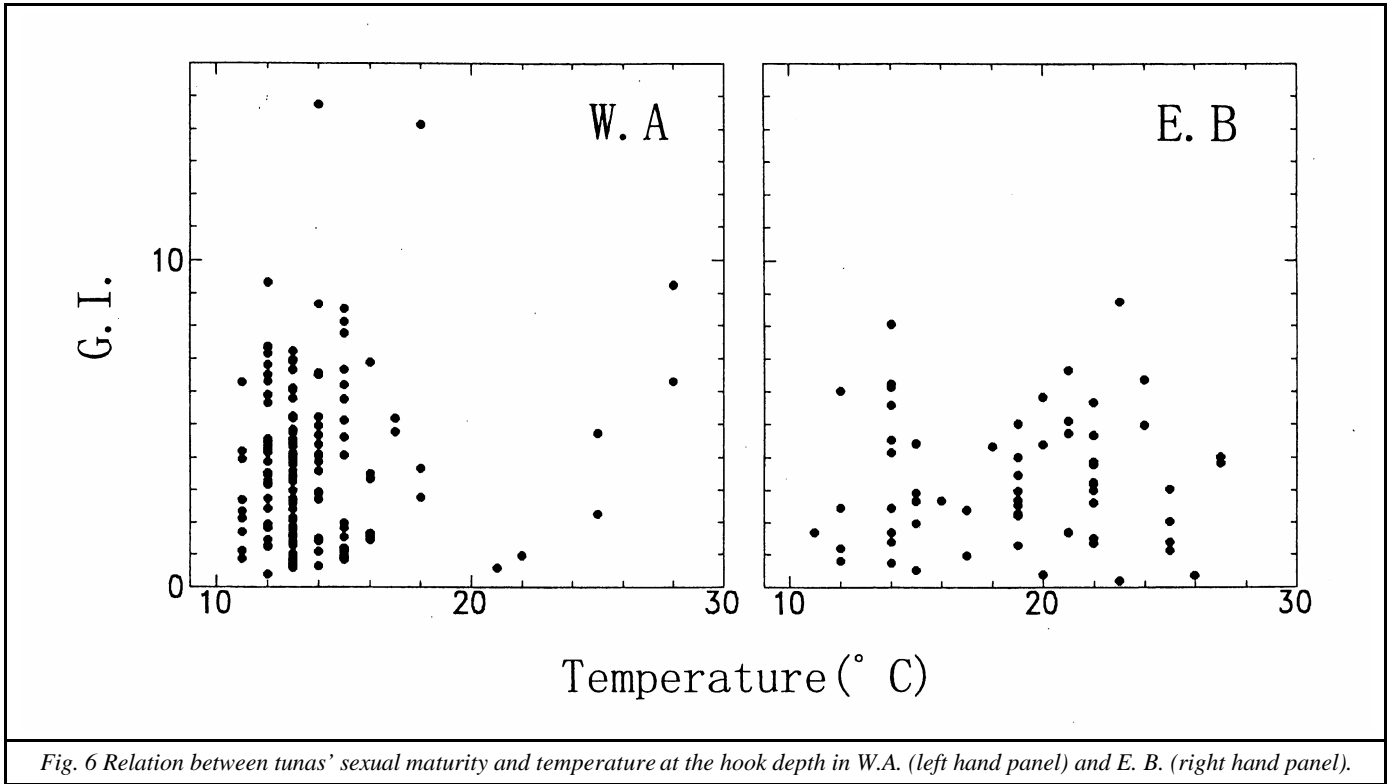


Fig. 6 Relation between tunas' sexual maturity and temperature at the hook depth in W.A. (left hand panel) and E. B. (right hand panel).

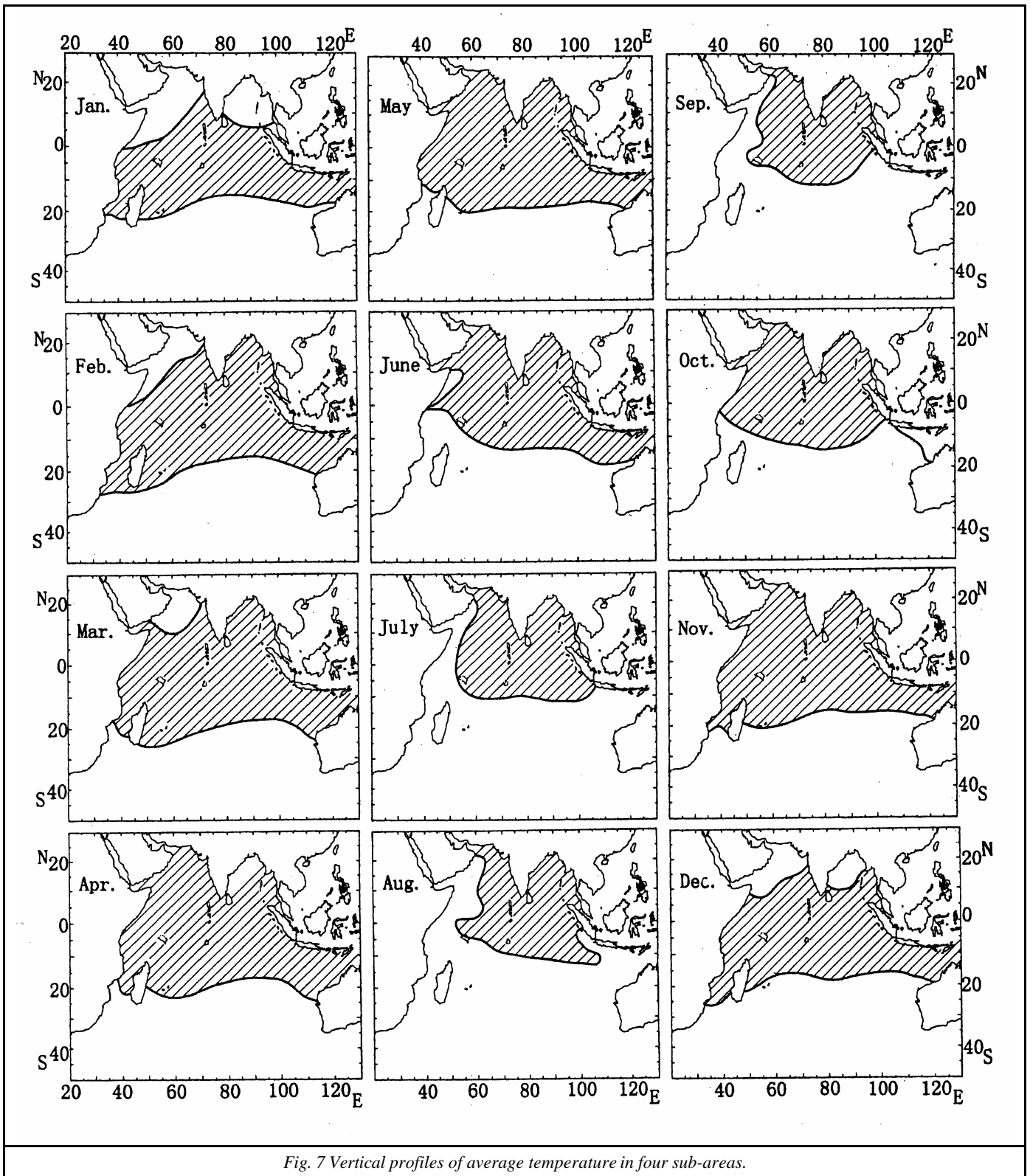


Fig. 7 Vertical profiles of average temperature in four sub-areas.

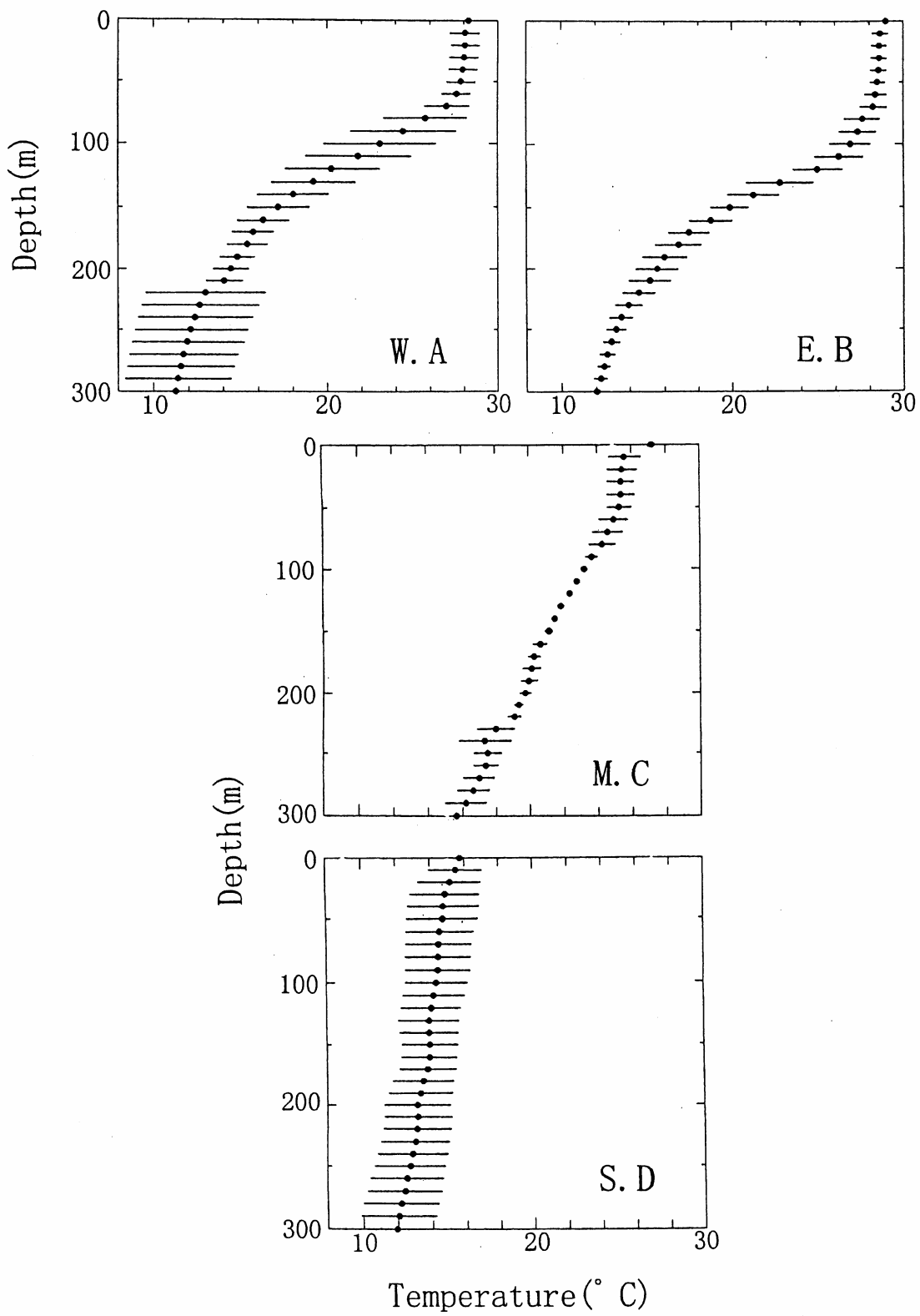


Fig. 8 Monthly variation of size of sea area where the temperature in the layer above 50 m is larger than 26° C