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Effect of Oceanographic Environment on Bigeye Tuna Distribution*

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Abstract

The effect of oceanographic environment, such as temperature, salinity and dissolved oxygen, on the distribution of bigeye tuna, *Thunnus obesus*, was examined in order to promote the effective utilization of the species. Emphasis was placed on determining the depths at which bigeye tuna were caught and the corresponding temperatures at those depths, by using fishing and temperature data collected simultaneously by government vessels during fishing operations. The results of the study were as follows:

1) The optimum temperatures for bigeye tuna lie between 10°C and 15°C. Bigeye tuna are generally distributed throughout the Pacific in waters of these temperatures. However, they are not found where the dissolved oxygen content is less than 1 m*l*/*l*.
2) It is believed that the horizontal distribution of bigeye tuna in the Pacific extends roughly between lat. 40°N and 40°S; while the vertical distribution ranges from the surface to a depth of around 600 m. However, the vertical distribution varies greatly with area. Nevertheless, the tuna longline gear fishes only a very narrow segment (within the limits of the hook depths) of the bigeye tuna vertical distribution. Thus, the so-called "productive bigeye tuna longline fishing grounds" are nothing more than areas where the hook depths happened to coincide with the optimum temperature layer and where the amount of dissolved oxygen happened to be greater than the minimum required for bigeye tuna (1 m*l*/*l*), and are not necessarily representative of areas of higher fish concentrations. These facts suggest that the catch distribution obtained from tuna longline fishing is not a good representation of the real distribution of bigeye tuna.
3) In the future, experimental fishing and fish finder surveys should be carried out in waters where the optimum temperature layer lies deeper or shallower than the hook depths of the longline gear (100-250 m) in order to determine whether or not bigeye tuna are actually distributed within the optimum temperature layer.

Introduction

Because of their excellent meat quality, the tunas are in great demand throughout the world. The annual world catch of tunas exceeds one million tons. Japan's tuna catch amounts to about 400 thousand tons, or roughly 40% of the world catch. Presently there is an important problem on the status of the tuna stocks because of the greatly increased fishing intensity. A decline in the tuna stocks is suggested by decreased catch rates as well as by the decreased average size of the fish being taken. The urgency of a need to conserve the tuna resources has thus arisen. Various international agencies, such as IATTC (Inter American Tropical Tuna Commission), ICCAT (International Commission for the Conservation of Atlantic Tunas), IPFC (Indo-Pacific Fisheries Commission), and so on, have been involved in the management of these valuable resources.

It is interesting that tunas are valued differently between Japan and most of the other countries. In Japan, for example, the bluefin tuna, *Thunnus thynnus*, and bigeye tuna are especially prized because of their excellent meat quality (high fat content) for use as "sashimi", while in other countries, yellowfin tuna, *Thunnus albacares*, and albacore, *Thunnus alalunga*, are most sought as raw materials for canning.

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While bigeye tuna are highly esteemed in Japan, they are of relatively little interest in other countries simply because they are unsuitable for canning. Consequently, bigeye tuna have been little studied in foreign countries, unlike some of the other species of tuna. Hence, it is important that Japan assumes the lead role in carrying out fundamental studies on bigeye tuna in order to promote their effective utilization. The distribution of bigeye tuna and its relation to the oceanographic environment are one of the most fundamental of such studies.

Information on the relationship between environmental factors and the distribution of fishes has always been of great practical interest to fishermen. Various environmental factors, both physical and biological, are believed to influence fish distribution. Furthermore, these factors may also have varying effects on the different developmental stages of the fish. Therefore, it is necessary to find out how each of the environmental factors affects fish distribution, in order to identify the key factors. The importance of such information to fishermen is obvious.

In a former study (HANAMOTO, 1987), the long-term mean geographical distribution of bigeye tuna in the entire Pacific Ocean was examined by using Japanese tuna longline fishing data collected over a 15-year period (1964–1978). In this study, temperature, salinity and dissolved oxygen were selected from among the various oceanographic environmental factors largely because of the relative abundance of such data, and their effect on the distribution of bigeye tuna was examined.

It is very difficult to conduct detailed fishery and oceanographic observations simultaneously. For this reason, most of the past studies have been limited to the use of surface temperature data in describing the relationship between fish distribution and the environment. However, in the case of bigeye tuna, this is not entirely satisfactory since this species also occurs at considerable depths (HANAMOTO, 1976). Since the temperature of the surface water varies greatly from that at greater depths, the environment of the bigeye tuna habitat can not be adequately discussed on the basis of surface temperature alone.

For the present study, the author utilized fishery data and oceanographic data that had been collected simultaneously by government research vessels. Emphasis was placed on determining the depths at which bigeye tuna were caught and on the corresponding temperatures at those depths.

Data and Methods

1. Catch of bigeye tuna by specific hook position and the corresponding water temperature

In Japan, fishery data, biological data, and oceanographic data are being collected simultaneously during fishery research operations by government vessels such as the training ships of the fisheries high schools and the research vessels of the national fisheries laboratories. These include deta on the catch of bigeye tuna by specific hook position, the hook depth, and the corresponding water temperature obtained at the time of fishing. From these data, it is possible to determine the temperature at the depth of capture of bigeye tuna.

Since it requires many hours at sea, much manpower, and difficult working conditions to collect these data, there not many investigative organizations involved in such data collection. Therefore, the amount of data collected is not always sufficient. However, since there is only one type of data that provides satisfactory information on the temperature at the depth of capture of bigeye tuna, such data were collected over as long a period (June, 1977—June, 1982), and from as wide an area (mainly in the South Pacific), as possible. In all, such data were collected from 600 stations and included observations on 940, 000 hooks and a catch of 3, 500 bigeye tuna. The vessels that collected the data for this study (bigeye tuna catches by hook depths and associated water temperatures at depths of capture) are listed in Table 1.

The hook depths were calculated by using YOSHIWARA's (1951) formula. A vertical temperature profile was drawn for every experimental fishing station from which data were obtained. Data on water temperature, the number of hooks fished, and the numer of bigeye tuna caught at the calculated hook depths, were

Table 1. List of Vessels that collected data used in the study of optimum water temperature (bigeye tuna catches by hook depths and associated water temperatures).

Name	Survey period	Survey Area			DR*
Aomori Maru	Feb.-Mar., 1981	2-10°S,	115-119°W,	East of Marquesas Is.	ST
	Mar., 1978	4- 5°N,	119-120°W,	Northwest of Galapagos Is.	
Kaki Maru No. 1	June-Sep., 1977	18-25°S,	138-135°W,	South of Tahiti Is.	JA1
	July, 1977	27-30°S,	169-175°W,	Northeast of New Zealand	
	July-Aug., 1977	23-36°S,	173°E-169°W,	South of Fiji Is.	
Kaki Maru No. 1	July-Aug., 1978	20-27°S,	170°E-170°W,	South of Fiji Is.	JA2
	Aug.-Oct., 1978	20-27°S,	150-165°W,	South of Tahiti Is.	
	Aug.-Oct., 1978	27-32°S,	175°E-150°W,	Northeast of New Zealand	
	Nov.-Dec., 1978	20-30°S,	120-135°W,	West of Easter Is.	
	Apr., 1979	9-16°S,	170-175°E,	Northwest of Fiji Is.	
Kaki Maru No. 1	July-Aug., 1979	17-40°S,	71-90°W,	Off Chile	JA3
	Dec.-Jan., 1980				
	Oct.-Nov., 1979	22-35°S,	100-114°W,	Near Easter Is.	
	Feb., 1980	5-8°S,	84-86°W,	Off Peru	
	Feb.-Mar., 1980	3-9°S,	101-110°W,	Southwest of Galapagos Is.	
Kaki Maru No. 1	June-Dec., 1980	20-30°S,	75-90°W,	Off Chile	JA4
	July-Aug., 1980	10-20°S,	80-100°W,	Off Peru	
	Jan., 1981				
	Jan.-Feb., 1981	4°S-3°N,	84-96°W,	Off Ecuador	
Shonan Maru	Apr.-June, 1982	10-15°N,	159°W-180°,	Southwest of Hawaiian Is.	SN
Shoyo Maru	Nov.-Dec., 1979	2-10°N,	140-152°E,	Western Tropical Pacific	SH1
	Dec., 1980 -Feb., 1981	1°S-16°N,	156°E-180°,	Western Tropical Pacific	SH2

DR*: Data Reference, ST: SAITACHI Tomio (1979), JA1: Japan Marine Fishery Resource Research Center (1978), JA2: Japan Marine Fishery Resouce Research Center (1979), JA3: Japan Marine Fishery Resource Research Center (1980), JA4: Japan Marine Fishery Resource Research Center (1983), SN: Shonan Maru (Misaki Fishery High School, Kanagawa Prefecture) Data (unpublished), SH1: Fisheries Agency of Japan, Res. Div. (1980), SH2: Fisheries Agency of Japan, Res. Div. (1981).

obtained for each station. Moreover, the number of hooks fished and the number of bigeye tuna caught were summarized by temperature intervals of 1°C for all fishing stations. The catch rate (Rt) for each temperature interval of 1°C was calculated as follows:

$$Rt=(\sum_{i=1}^{n} C_{it}/\sum_{i=1}^{n} H_{it})\times 1000 \qquad (1)$$

where H_{it} is the number of hooks fished and C_{it} is the number of bigeye tuna caught at temperature t°C, at experimental fishing station i (n is the number of data points at a certain value of temperature t°C).

The catch rates, by water temperature and by depth of capture, were examined in this manner, and the temperatures with high catch rates were further investigated. The temperatures with the high catch rates were regarded as the "high catch temperature", or "optimum water temperatures" for bigeye tuna.

2. Oceanographic data

To examine the oceanographic environment such as the distribution of temperature, salinity and dissolved oxygen in the Pacific Ocean, records from 1,400 hydrographic stations occupied during 135 oceanographic voyages made between 1929 and 1981 were employed. These stations were occupied by 51 Japanese and foreign research vessels during various international surveys (CSK, EQUAPACK, IGY, NORPAC, *etc.*). Included in the above are also data from the

Eastropac Atlas (DENT *et al.*, 1975), Scorpio Expedition (REID, 1973), and serial data file belonging to the Japan Oceanographic Data Center (Offer No. 83-027; file code SD2-83G).

3. Size of fish

The bigeye tuna discussed in this report were fish 2-years old (80 cm) and older; all were taken on tuna longline gear.

Oceanographic environment of bigeye tuna

1. Optimum water temperature

The locations of the tuna longline fishing stations at which data were obtained on bigeye tuna catches by specific hook depths, as well as water temperatures at the depths of capture, are shown in Fig. 1. Figure 2 shows the catch rates, the catch in number of bigeye tuna, and the number of hooks fished, by water temperature at depth of capture.

As shown in Fig. 2, bigeye tuna were taken in waters ranging widely in temperature from 9°C to 28°C. However, there was a striking peak in the catches between 11°C and 14°C. Furthermore, 50% of the catches were made within the temperature range of 10°C and 15°C, and 70% were within 10°C and 18°C. The catches decreased slowly on the higher side of this peak and more rapidly on the lower side. No bigeye tuna were caught at temperatures below 9°C. These results indicate that the optimum temperatures for bigeye tuna are mainly between 10°C and 15°C or between 10°C and 18°C.

There are some variations in temperature at the fishing depths because of the influence of internal waves and thermocline. For example, the internal waves on the anchor station of the "Meteor" (16°48′N, 46°17′W) can be taken as a more detailed example (DEFANT, 1960). The discontinuity layer was found at 100 m depth. And the temperature at the depth of 100 m varied in the range of 20.5°C to 24°C in a day

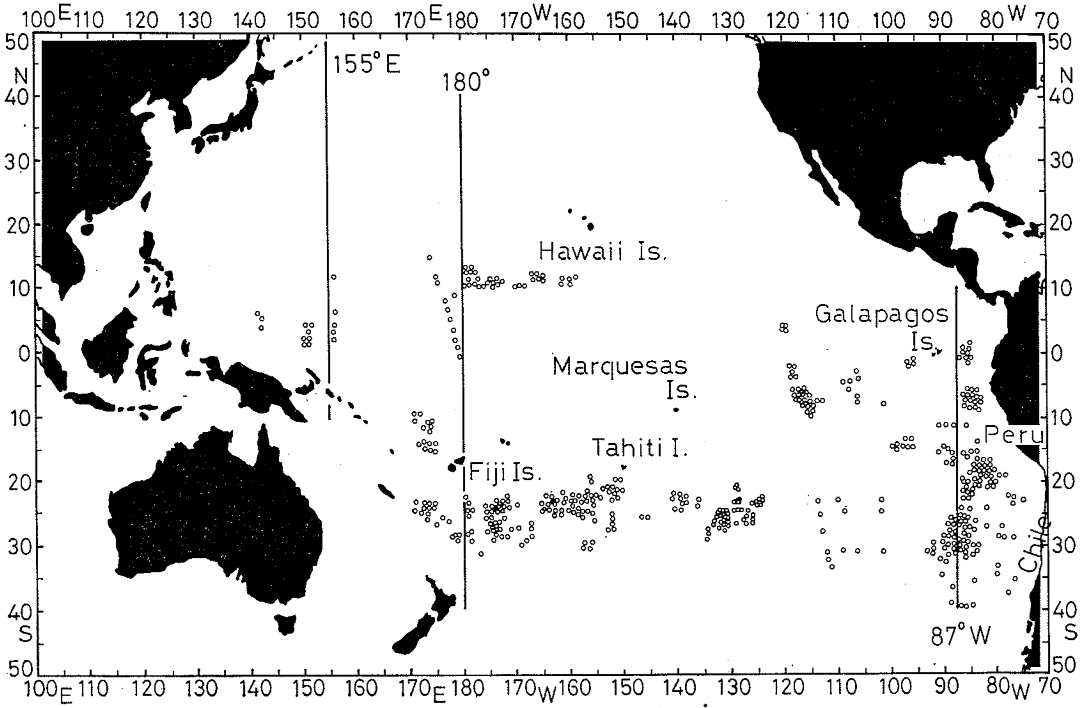

Fig. 1. Tuna longline fishing stations at which data were obtained on bigeye tuna catch by specific hook depths as well as on water temperature at the depth of capture. The three straight lines are station lines. Data from these station lines are shown as vertical profiles of temperature and dissolved oxygen in Figures 3, 7 and 9.

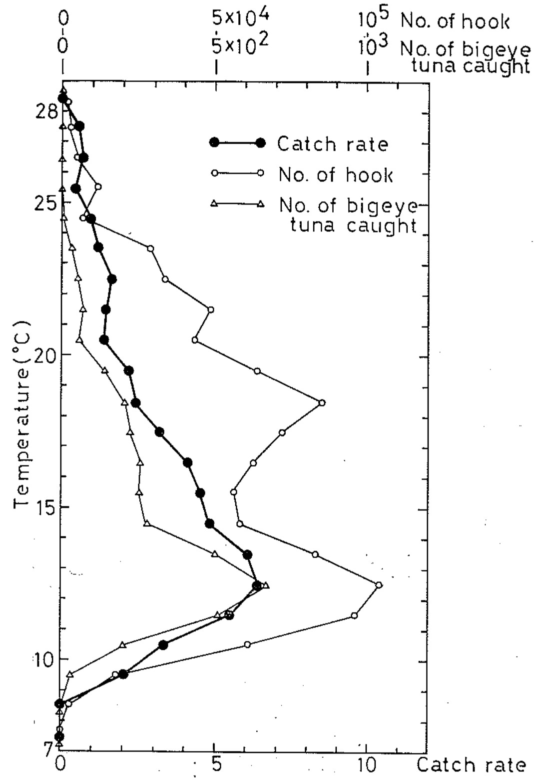

Fig. 2. The catch rates (catch per 1,000 hooks), catch in numbers (N=3,513) of bigeye tuna, and the numbers of hooks (N=943,631) fished, shown by water temperatures at the depths of capture.

(14 Feb.). There are also some differences between the actual depth of capture and the calculated depth used in this study, because calculated depths are generally deeper than the real hook depths as mentioned in next chapter. Considering these facts, there is really not much difference between the two temperature ranges (10°C and 15°C, and 10°C and 18°C). Therefore, the narrower range of 10°C and 15°C was selected as the "high catch temperature", or the "optimum temperature" for bigeye tuna.

This is lower than the previously reported optimum temperature of 20°C, which was derived from a study of surface temperatures (UDA, 1957; LAEVASTU and ROSA, 1963; SUDA *et al.*, 1969), by 5°C to 10°C. It is also lower than the optimum temperature range obtained from the mean temperature field at the depth of capture by HANAMOTO (1975) and reported as "between 12°C and 27°C, or perhaps even lower than 12°C", and also by SAITO (1975) as "between 11°C and 15°C". It is believed that the difference was due to the fact that previous results were based on surface temperature data or data obtained from the mean temperature field, whereas in the present study, the optimum temperature was derived directly from data on depth of capture and corresponding temperature obtained simultaneously at time of fishing.

2. Characteristics of the distribution of optimum temperatures and the distribution of bigeye tuna as inferred from the optimum temperature distribution

As inferred from the optimum temperatures, it is believed that bigeye tuna are distributed mainly between the depths of the 15°C and the 10°C surfaces. To examine the characteristics of the optimum temperature distribution, the vertical profile of temperatures along the 180th meridian, and the depth contours of the 15°C and 10°C isotherms were shown in Figs. 3, 4 and 5 respectively.

As illustrated in these figures, the optimum temperature layer was found to be shallow in the lower latitudes centered around lat. 10°N (150-200 m in Fig. 3), and gradually deepened toward the middle latitudes, centered on around lat. 25°N and lat. 25°S (250-400 m and 350-500 m, respectively, in Fig. 3). The layer again became shallower from the middle latitudes toward the higher latitudes and appeared at the surface at around lat. 40° in both hemispheres as shown in Fig. 4. Longitudinally (Figs. 4 and 5), the layer was shallower in the eastern side of the Pacific (100-400 m in the waters along the equator), and deeper in the western side (200-400 m in the waters along the equator). It was especially deep around the middle latitudes on the western side of the Pacific, where it reached 400-600 m in waters east of Japan.

If it is postulated that bigeye tuna are distributed within the optimum temperature layer, then the data suggest that the fish are distributed horizontally between lat. 40°N and 40°S, and that their vertical distribution, though varying with area, ranges from the surface to the depth of 600 m.

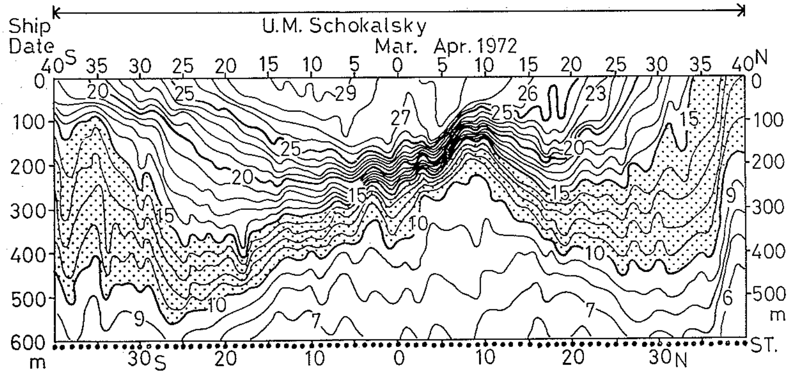

Fig. 3. Vertical profile of temperatures (°C) along the 180th meridin. The black dots represent stations where temperature data were obtained. The station line for this vertical profile is shown in Fig. 1.

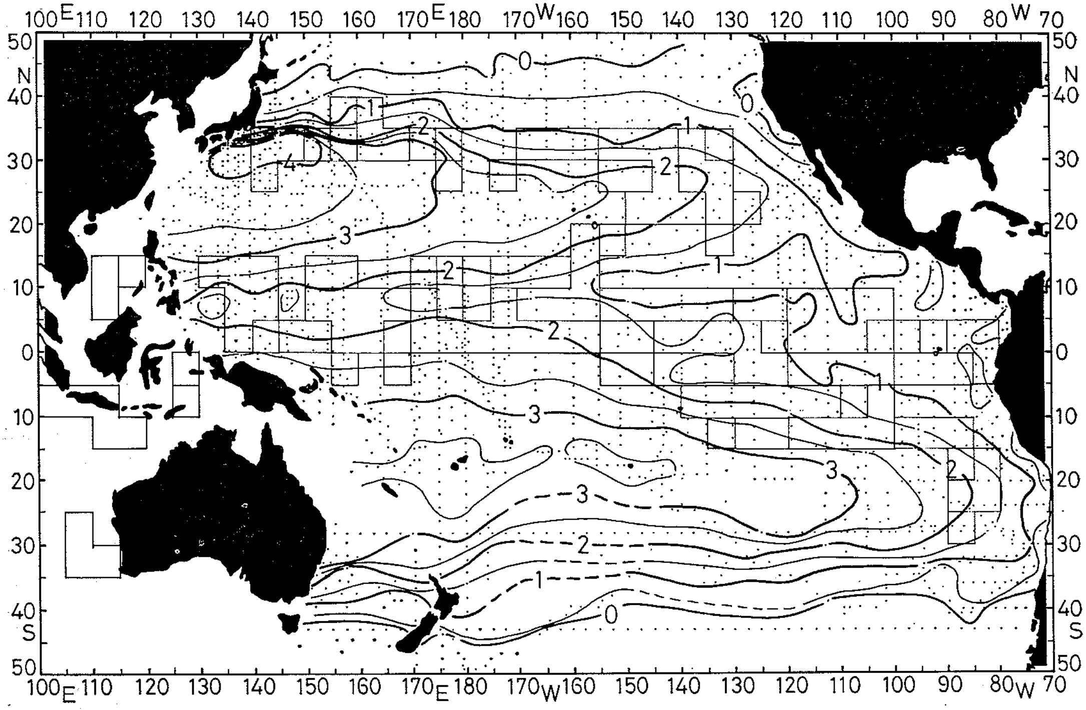

Fig. 4. The depth contour of the 15°C isotherm (depths indicated in 100-m units). The dots show positions where data were obtained. The squares and rectangles denote high catch 5-degree squares taken from HANAMOTO (1987).

3. Salinity

It is widely known that there is a high correlation between temperature and salinity and that the relationship is expressed by the T-S diagram. With the exception of the surface water which is directly affected by the atmosphere, the upper water down to a depth of a few hundred meters, may be divided broadly into two general groups; the central water and the equatorial water, in the areas between lat. 40°N and 40°S (SVERDRUP *et al.*, 1942). Figure 6 shows the temperature-salinity relations of the

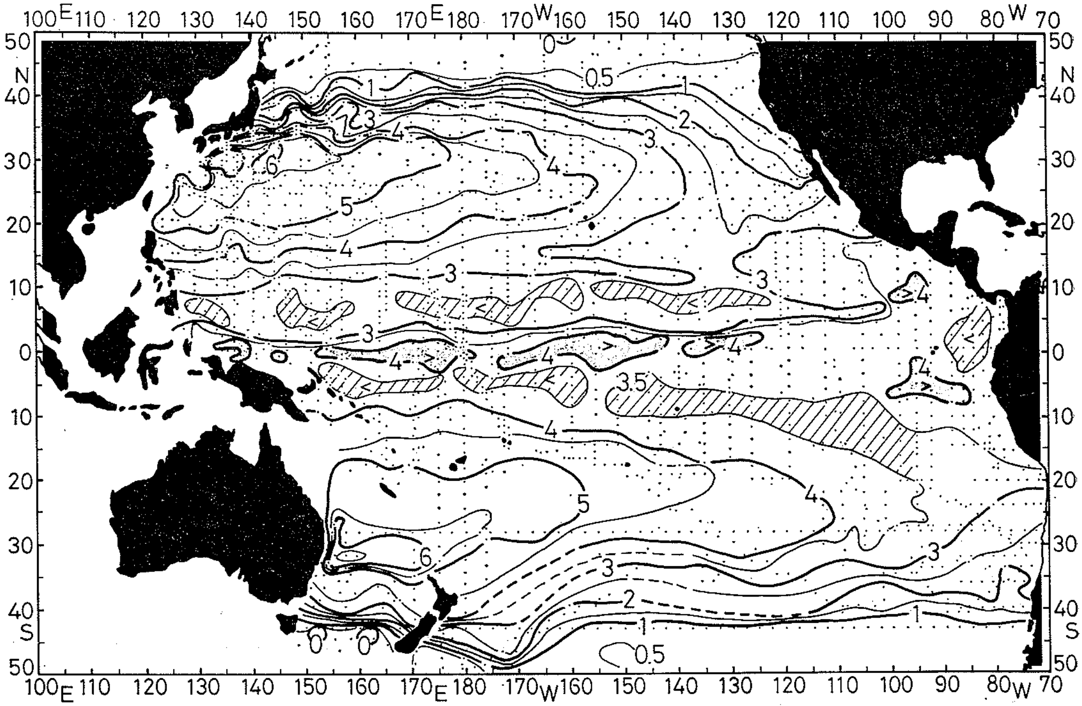

Fig. 5. The depth contour of the 10°C isotherm (depths indicated in 100-m units). The dots show positions where data were obtained. The oblique lines indicate the thermal ridge and the shaded (light black) areas indicate the thermal trough.

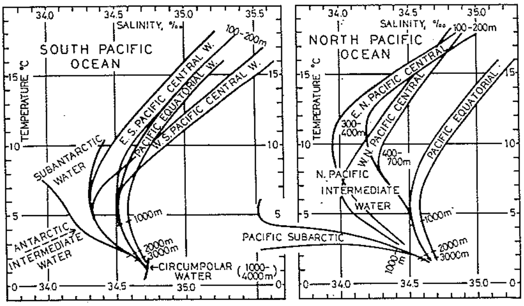

Fig. 6. Temperature-salinity relations of the principal water masses of the Pacific (SVERDRUP *et al.*, 1942).

principal water masses of the Pacific by SVERDRUP *et al.*, (1942). The optimum temperature range of 10°C and 15°C for bigeye tuna corresponds to the straight line portion on the T-S diagram. Salinity was low on the low-temperature side and high on the high-temperature side. Moreover, since temperature and salinity has a 1 : 1 relationship within this temperature range of 10°C and 15°C in the Pacific, a discussion of temperature is equivalent to a discussion of salinity.

The optimum salinities of bigeye tuna (corresponding to the optimum temperatures) were between 34.5‰ and 35.5‰ in the South Pacific, between 34.0‰ and 34.7‰ in the North Pacific, and between 34.7‰ and 35.2‰ in the equatorial Pacific, as inferred from the T-S diagram (Fig. 6). The salinity in the South Pacific was therefore slightly higher than in the North Pacific.

Effects of tuna longline hook depths and oceanographic environment on the distribution of bigeye tuna catches

1. Hook depths of tuna longline gear

The tuna longline gear is normally set so that the hooks reach depths of 90 m to 150 m (HANAMOTO, 1974). However, Japanese tuna fishing vessels which desire to catch bigeye tuna more effectively have recently begun setting longline hooks much deeper. This method of fishing is known as "deep tuna longlining". The components of the deep longline gear are more or less uniform, as follows: float lines, about 20 m in length; branch lines, about 30 m; distance between branch lines, about 50 m; and number of branch lines per basket, 13 (SUZUKI *et al.*, 1977).

The calculated theoretical hook depths for this gear, assuming a "contraction rate" of 0.60 (contraction rate is the ratio of the distance between the float lines to the length of the mainline in one basket of gear; FUJII and OKAMOTO, 1971; HANAMOTO, 1974), were about 100 m for the shallowest hook and about 300 m for the deepest hook, according to YOSHIWARA's (1951) formula. However, as reported in various studies, the actual hook depths, as observed by depth recorder, were shallower by 10% to 20% than these calculated depths due to the effects of current and wind (HAMURO and ISHII, 1958; FUJII and OKAMOTO, 1971; SAITO, 1973; HANAMOTO, 1974; Japan Marine Fishery Resource Research Center, 1978; Fisheries Agency of Japan, Research Division, 1980; MURAI, 1982).

On considering these facts, the hook depths of deep tuna longline are thought to be around 80-90 m for the shallowest hooks and about 240-270 m for the deepest hooks. In the present study, it was assumed that bigeye tuna are mainly taken at hook depths between 100 m and 250 m.

2. Effect of tuna longline hook depths and water temperature on the distribution of bigeye tuna catches

The tuna longline gear is normally set so that the hooks reach depths of 100 m to 250 m. Thus, bigeye tuna that are distributed between these depths are caught. It is apparent that this depth range is extremely narrow in relation to the extensive vertical distribution of bigeye tuna as inferred from the optimum water temperature layer, as shown in former chapter. In other words, the tuna longline gear is able to adequately cover the horizontal distribution of bigeye tuna but seems entirely inadequate in covering the vertical range. From this information on the distribution of the optimum temperature layer and hook depths, it can be surmised that the so-called "productive bigeye tuna fishing grounds" are formed only in areas where the hook depths (100-250 m) happen to coincide with the depths of the optimum temperature (10°-15°C) layer, and are not necessarily true representations of higher fish densities.

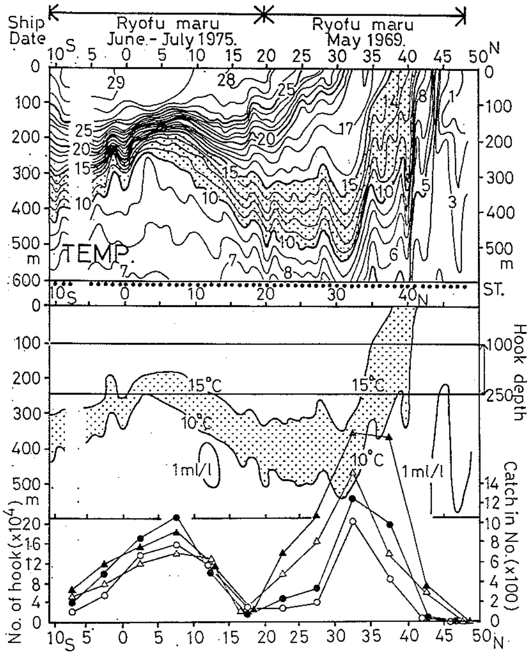

Fig. 7. Vertical profile of temperature, suitable bigeye tuna habitat (dotted) as inferred from the presence of optimum temperatures (10-15°C) and minimum requirement of dissolved oxygen (more than 1 m*l*/*l*), along long. 155°E, shown in relation to tuna longline hook depths (100-250 m) and the mean number of bigeye tuna caught, by 5-degree squares, derived from HANAMOTO (1987). The areas examined for the bigeye tuna catches were:

open circle, long. 150°-155°E; closed circle, long. 155°-160°E; and the numbers of hooks fished, by 5-degree squares (HANAMOTO, 1987) were for following areas:

open triangle, long. 150°-155°E; closed triangle, long. 155°-160°E. The black dots in-between the two panels represent stations where temperature and oxygen data were obtained. The station line for this vertical profile is shown in Fig. 1.

Figure 7 shows vertical profile of temperatures along long. 155°E, and also, the tuna longline hook depths (100-250 m), the mean number of bigeye tuna caught, and the numbers of hooks fished by 5-degree squares (HANAMOTO, 1987) are shown in this figure. The figure shows that some of the bigeye tuna caught were influenced by the depths of the optimum temperature layer and of the hooks. That is, the more productive areas were formed where the hook depths happened to coincide with the depths of the optimum temperature (10°-15°C) layer, such as between lat. 0° and 10°N, and between lat. 30°N and 40°N. Conversely, poor fishing areas were found where the optimum temperature layer was deeper than the hook depths (contour of 15°C isotherm is deeper than 250 m), as seen at lat. 15°-30 °N, as well as where the layer was shallower than the hook depths (contour of the 10°C isotherm is shallower than 100 m), such as seen o the north of lat. 40°N. These results suggest that the productive bigeye tuna fishing grounds are formed only in the areas where the hook depths happen to coincide with the depths of the optimum temperature layer.

In order to examine this relationship further, the areas in the Pacific where the optimum temperature layer (10°-15°C) occured at depths between 100 m and 250 m (corresponding to the hook depths) were determined from Figs. 4 and 5, and these areas were compared with the more productive areas for bigeye tuna (based on "Distribution of bigeye tuna catch in the Pacific Ocean"; HANAMOTO, 1987) in Fig. 8. As expected, the results showed that the higher bigeye tuna catches occured in the areas where the optimum temperature layer was situated between 100 m and 250 m. Therefore, this indicate that the good tuna longline fishing grounds for bigeye tuna are not necessarily areas

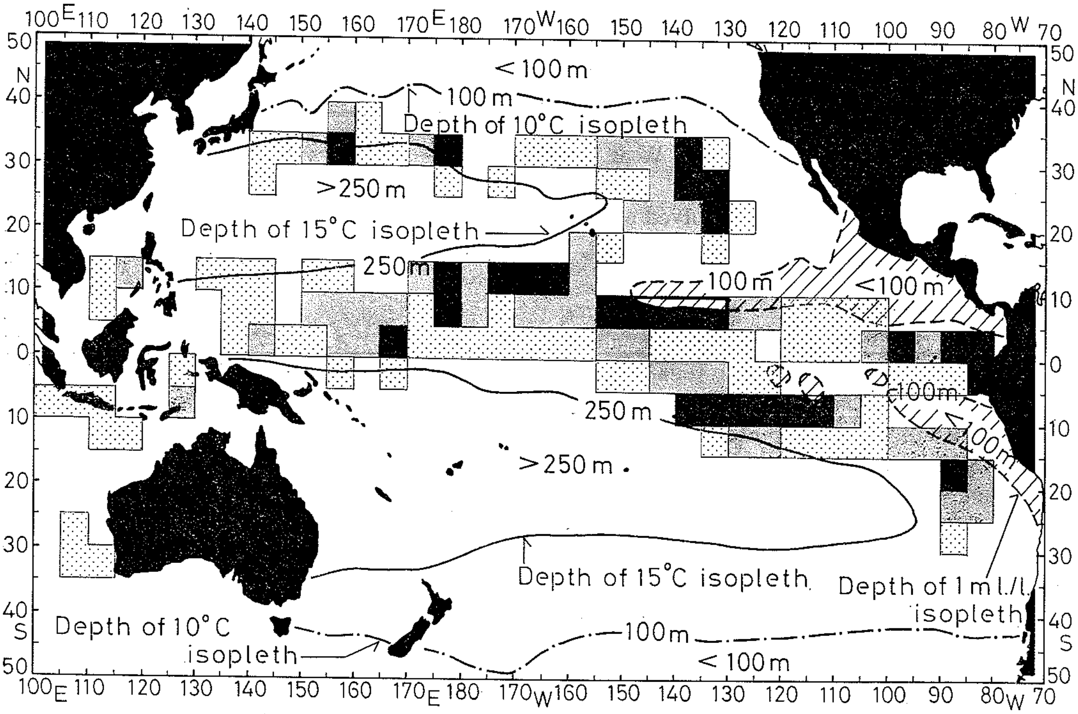

Fig. 8. The 100-m and 250-m contour lines correspond to the depths of the 10°C and 15°C isopleths, respectively. Thus, the optimum temperatures for bigeye tuna (10-15°C) coincide with the hook depths (100-250 m) in the area between these two contour lines. The broken line indicates the 100 m contour line corresponding to the depth of 1 ml/l isopleth of D.O. The oblique lines show areas where waters with 1 ml/l dissolved oxygen are at depths shallower than 100 m. High catch areas (HANAMOTO, 1987) are shown by squares and rectangles.

of higher fish concentrations. Instead, they are nothing more than areas where the hook depths happened to coincide with the optimum temperature layer.

These results indicate that temperature is one of the key oceanographic factors that exerts great influence on the distribution of bigeye tuna. However, there were two areas where the bigeye tuna catches were poor in spite of the suitable condition (hook depths coincide with optimum temperature layer), were present as shown in Fig. 8.

(1) In the South Pacific Ocean between lat. 30°S and 40°S. In this area, the fishing effort, as well as the catches, are very small (HANAMOTO, 1987). However, judging by the distribution of the optimum temperature layer, the presence of larger number of bigeye tuna seems very likely. Therefore, if greater fishing effort is expended in this area, it is impiled that larger bigeye tuna catches may well result.

(2) The eastern Pacific, along lat. 10°N, extending from the North American continent west to the vicinity of long. 150°W, as well as the area from off Chile to long. 120°W at the equator.

3. Effect of hook depths and dissolved oxygen content on the distribution of bigeye tuna catches

Figure 9 shows the vertical profiles of temperature and dissolved oxygen content along long. 87°W, shown in relation to tuna longline hook depths (100–250 m), the mean number of bigeye tuna caught, and the number of hooks fished, by 5-degree squares. The depth of the main thermocline is generally shallower than 100 m in the eastern tropical Pacific (HANAMOTO, 1975). As shown in the figure, the depth of the thermocline generally coincided with that of the oxycline. The dissolved oxygen content decreased rapidly within the thermocline, and was very low below the thermocline at less than 2 ml/l near the equator and less than 1 ml/l in the tropical areas, except near the equator. In the areas of lat. 10°N and 10°S along long. 87°W (Fig. 9), there were poor bigeye tuna catch areas in spite of the suitable conditions (hook depths coinciding with optimum temperature layer) were present. The poor

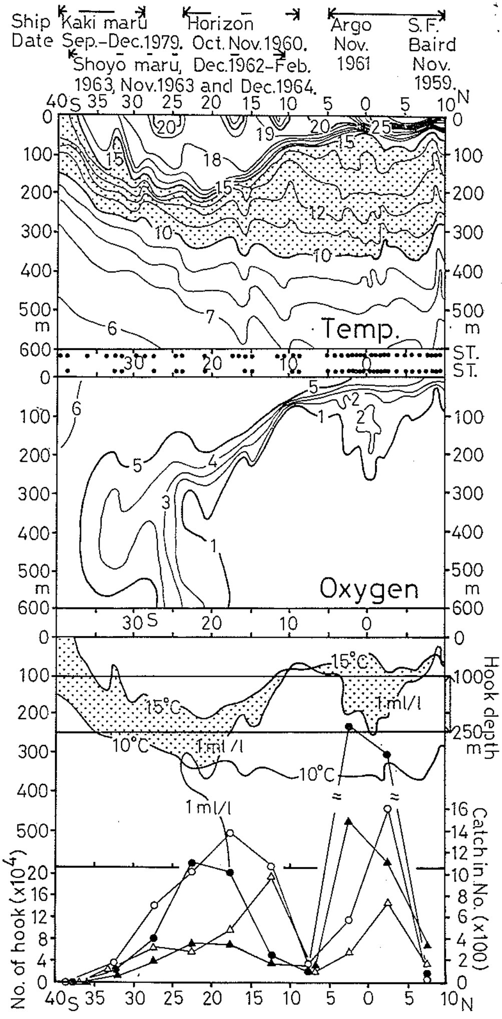

Fig. 9. Vertical profiles of temperature (°C, upper panel), dissolved oxygen (ml/l, middle panel) and suitable bigeye tuna habitat (dotted) as inferred from the presence of optimum temperatures (10–15°C) and minimum requirement of dissolved oxygen (more than 1 ml/l, lower panel), along long. 87°W, shown in relation to tuna longline hook depths (100–250m) and the mean number of bigeye tuna caught, by 5-degree squares, derived from HANAMOTO (1987). The areas examined for the bigeye tuna catches were:

open circle, long. 80°–85°W; closed circle, long. 85°–90°W; and the number of hooks fished, by 5-degree squares (HANAMOTO, 1987) were for the following areas:

open triangle, long. 80°–85°W; closed triangle, long. 85°–90°W. The black dots in-between the two panels represent stations where temperature and oxygen data were obtained. The station line for this vertical profiles is shown in Fig. 1.

catch areas, however, coincided with the areas of low dissolved oxygen of less than 1 ml/l at depths of about 100 m to 600 m at least.

To examine this relationship, the depth of the 1 ml/l surface of dissolved oxygen was first plotted for the entire Pacific in Fig. 10. It was seen that the areas in the Pacific where the depth of the 1 ml/l surface of dissolved oxygen is shallower than 100 m were located in the eastern Pacific, along lat. 10°N, extending from the North American continent west to the vicinity of long. 150°W, as well as in the area from off Chile to long. 120°W at the equator. Departing from these two areas, the depth of the 1 ml/l surface of dissolved oxygen deepend gradually. Next, the areas in the Pacific where the depth of the 1 ml/l surface of dissolved oxygen is shallower than 100 m were indicated by oblique line in Fig. 8. From this, it is seen that such areas coincided with the poor bigeye tuna fishing areas as seen from the long-term average longline catch data (HANAMOTO, 1987). These areas were along lat. 10°N from the North American continent west to the vicinity of long. 150°W, and in the South Pacific from off Chile to long. 120°W near the equator.

In terms of the relation between bigeye tuna and dissolved oxygen, HANAMOTO (1975) showed that the minimum requirement of dissolved oxygen for bigeye tuna was 1 *ml/l*. SHARP (1978) also showed that the oxygen requirements of tunas, based on swiming energetics at their respective minimum sustained speeds for maintaining hydrodynamic equilibrium, varied by species and fish size and that the figures for bigeye tuna were 0.52 ml/l and 0.65 ml/l for 50 cm and 75 cm fish (folk length), respectively. Also, according to resistance experiments carried out on bluefin tuna, the limit of dissolved oxygen at time of suffocation was reported to be 1.1 ml/l (HARADA, 1980). From these results, it is thought that dissolved oxygen of about 1 ml/l is the minimum requirement for bigeye tuna, although the minimum requirement in tuna

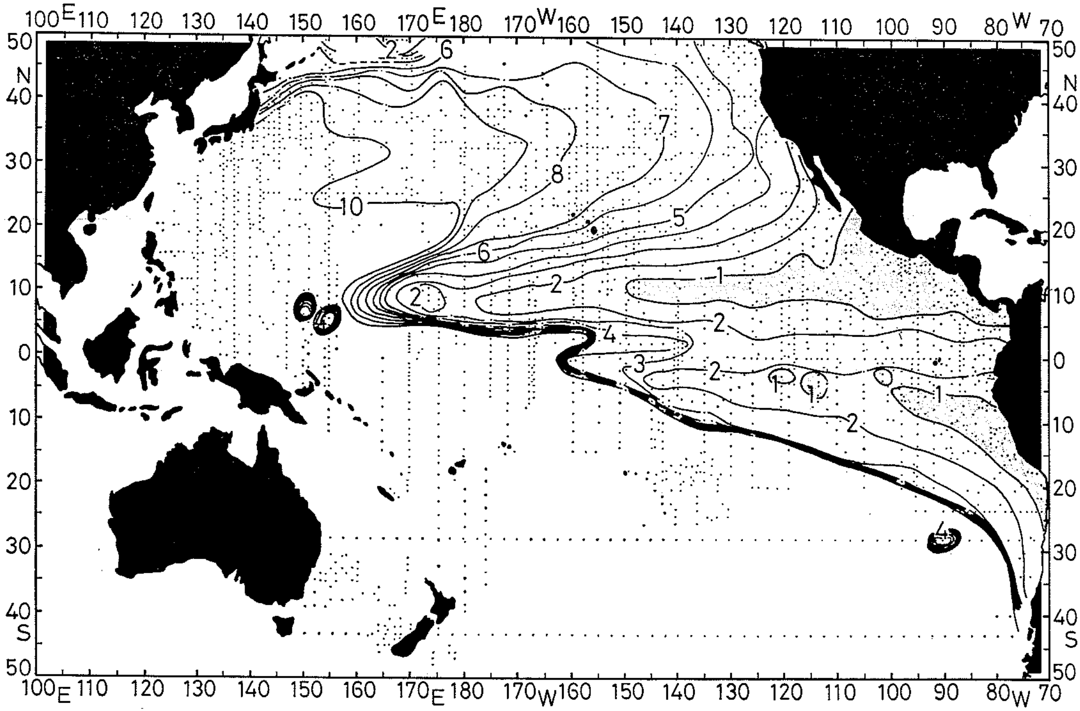

Fig. 10. Depth of the 1 ml/l surface of dissolved oxygen content (depth in 100-m units). Dots show positions where data were obtained. The light black shaded areas are where the depths are shallower than 100 m.

varies by species and by size.

Therefore, these results suggest that the volume of dissolved oxygen may be the limiting factor in the distribution of bigeye tuna.

Discussion

Studies on the distribution of bigeye tuna have generally depended on tuna longline catch data. This is satisfactory if the tuna longline gear samples bigeye tuna randomly from the entire distributional area of the fish. However, this study has shown that the bigeye tuna are horizontally distributed between lat. 40°N and 40°S, and vertically from the surface to a depth of around 600 m, as inferred from the optimum temperature distribution of the fish. Although the vertical distribution appears to vary greatly with area, it is clear that the tuna longline gear fishes only a very narrow segment (within the limits of the hook depths) of the vertical distribution of bigeye tuna. The so-called "productive bigeye tuna longline fishing grounds" are nothing more than the areas where the hook depths happened to coincide with the optimum temperature layer of bigeye tuna, and where the dissolved oxygen content happened to be greater than the minimum requirement for bigeye tuna (1 m*l*/*l*), and therefore are not necessarily representative of areas of higher fish concentrations. These facts suggest that the catch distribution by tuna longline is not a good representation of the real distribution of bigeye tuna. Thus, studies on the distribution and migration of bigeye tuna, based on tuna longline catch data, may not be very accurate if the tuna longline catch data are used without considering the peculiarity of the data.

Previously, NAKAMURA and YAMANAKA (1959) reported that the main areas of bigeye tuna distribution were in the northern and southern edges of the North Equatorial Countercurrent in the central and western tropical Pacific Ocean. As shown in the vertical profile of water temperatures and the number of bigeye tuna caught by 5 degree-squares along long. 155°E (Fig. 7), the bigeye tuna catches were indeed high at the northern edge of the North Equatorial Countercurrent near lat. 7°N. However, in the vicinity of lat. 7°N also happened to be an area where the longline hook depths coincided with the depth of the optimum temperature layer.

KAWAI (1969) indicated that the main fishing grounds for bigeye tuna were found in the current boundary along the current axis of the Subtropical Gyre in the North Pacific, and that in tropical waters, they are found along the thermal ridges along the equator, as well as near the current boundary along the northern edge of the North Equatorial Countercurrent. The bigeye tuna catches were certainly high at the boundary of the Subtropical Gyre between lat. 30°N and 40°N, at the northern boundary of the North Equatorial Countercurrent between lat. 5° and 10°N (Fig. 7), and in the waters of the boundary around the thermal ridge at the equator (Fig. 9). However, these high catch areas were also areas where the hook depths coincided with the depths of the optimum temperature layer, as recognized in these Figures (Figs. 7, 8 and 9).

According to SUZUKI *et al.* (1977) and SUZUKI and KUME (1981), new bigeye tuna fishing grounds were found by deep longlining in the peripheral areas of the established fishing grounds, such as in the aeeas between lat. 15°N and 20°N, and between lat. 0° and 5°S along the 180th meridian. It is understood that the deep longline is more efficient than the ordinary longline in these areas because the depth of the optimum temperature layer is quite deep, ranging from 250 m to 400 m.

The bigeye tuna catches were poor in the middle latitudes, centered around lat. 20°N, both in the North and the South Pacific, and also in the high latitudes of the South Pacific, between lat. 30°S and 40°S. However, Since the optimum temperature layers have been found at the great depths of 250–500 m and 100–500 m, respectively, in these areas, it is believed that bigeye tuna may also occure at these depths. For this reason, if the longline is fished deeper, there is a possibility of obtaining good bigeye tuna catches.

These results suggest that bigeye tuna may be distributed in deeper waters than can be caught by ordinary longline, and in a much broader area as well. In the future, in order to find out whether or not bigeye tuna are actually distributed within the optimum temperature layer, it is necessary to carry out experimental fishing and fish finder surveys in waters where the optimum temperature layer lies deeper or shallower than the hook depths of the longline gear.

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海洋環境がメバチの分布に与える影響

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要旨: 水温，塩分，酸素量等の海洋環境因子がメバチの分布に与える影響を追究した．特に，漁業と水温測定が同時に実施された資料から，漁獲深度における水温を明らかにした．得られた結果は次の通りである．(1) メバチの適水温は 10-15°C であり，同種はその適水温帯に一様に分布している．しかし，酸素量が 1 m*l*/*l* 以下の所には分布していない．(2) 水平的には緯度南北40° 以内に，鉛直的には海面から約600m深までに分布している．しかし，延縄ではこの鉛直分布範囲のごく一部分(釣鉤の設置深度内)のメバチしか漁獲していない。延縄の好漁域は釣鉤の設置深度と適水温層が一致した海域で，酸素量が 1 m*l*/*l* 以上の海域にすぎない．これらのことは，延縄の漁獲分布は見かけの分布でしかないことを示す．(3) 今後，適水温が釣鉤の設置深度 (100-250 m) 外に存在する所で漁獲試験，魚探調査等を行い，メバチが実際に分布しているか否か確認する必要がある．

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