CONSIDERATION ON DISTRIBUTION OF ADULT YELLOWFIN TUNA *(THUNNUS ALBACARES)* IN THE INDIAN OCEAN BASED ON JAPANESE TUNA LONGLINE FISHERIES AND SURVEY INFORMATION

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ABSTRACT

The relationship between distribution of adult yellowfin tuna caught by the Japanese tuna longliners and the physical environmental factors (temperature and dissolved oxygen by JODC) in the Indian Ocean were examined. As a result, following three results were obtained: (a) Optimum water temperature catching yellowfin tuna was 13^0C-24^0C, (b) Minimum dissolved oxygen at the catching depth was 1 ml/l and (c) The depth of the upper limit of optimum water temperature (24^0C) was around 80m in the equatorial region, which became shallower as departing from the equator to the north-south directions and reached the surface at the high latitudes south (around 30^0S). The depth of the lower limit of optimum water temperature (13^0C) was about 200m in the equatorial region, which became deeper as departing from the equator to in the north-south directions and reached 300m -400m at the high latitudes south (around 30^0C).

1. INTRODUCTION

It is well known that horizontal and vertical distributions of tuna are different by species [1)]. There are a number of factors affecting tuna distributions such as temperature, salinity, water pressure, feed etc. There are only a few factors that widely cover distribution areas of tuna with enough sample sizes, which are 'water temperature', 'salinity' and 'dissolved oxygen'. In the past, we examined the relationships between distribution of bigeye tuna *(Thunnus obesus)* caught by the Japanese longliners vs. 'water temperature' and 'dissolved oxygen' in the Indian Ocean [2)]. In this paper, we will examine the relationships between distribution of yellowfin tuna (*Thunnus albacares*) caught by the Japanese longliners vs. 'water temperature' and 'dissolved oxygen' in the Indian Ocean.

2. MATERIALS AND METHODS

Two types of information were used and they were from: (a) "Feasibility study and development research for tuna longline fishing grounds for the period of 1981-1986" published by JAMARC (Japan Marine Research Center) and (b) "Depth specific oceanographic observation data for 1906-1989" by JODC (Japan Oceanographic Data Center).

We studied the relationships between hooking rates and the water temperature. Initially, we described the vertical profiles of water temperature at the fishing operation points (i). The vertical profiles were based upon the oceanographic observations conduced at same points (i) almost simultaneously with the fishing operations. From these vertical profiles, we read off the water temperature values at depths where the hooks were deployed. From this information, we complied the number of hooks (h_{it}) and number of catch (C_{it}) in every 2^0C. Finally, we computed the hooking rates (C_{it}) (fish/l000 hooks) by the following equation:

$$Rt = 1{,}000\left(\sum_{i=1}^{n} Cit \Big/ \sum_{i=1}^{n} hit\right)$$

where

h_{it}: number of hooks at water temperature t^0C in the fishing operation point i

C_{it}: number of yellowfin tuna catch at the water temperature t^0C in the fishing operation point i.

n : sample size at the water temperature t^0C

(Note) t^0C refers to every two degrees.

About the relationships between the hooking rates and the dissolved oxygen, we used the data from the eastern part of the Indian Ocean, where the sample sizes of operations and oceanographic observation have been enough and satisfactory. We made seven sub-areas (A to G) stretching from north to south. Then, we examined the number of hooks and the hooking rates by depth and sub-area, which were compared with the vertical profiles of average dissolved oxygen, in order to determine optimum dissolved oxygen necessary for yellowfin tuna catch.

3. RESULTS AND DISCUSSION

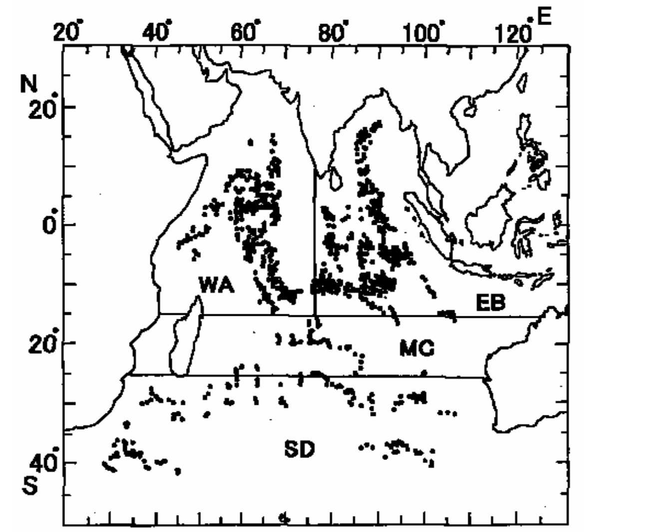


Fig. 1 shows the data collection points and five survey areas established by the JAMARC [3].

Fig. 1 Data collection points and survey areas (WA; Western Lower Latitude Area A, EB; Eastern Lower Latitude Area B, MC; Mid-latitude Area C, SD; Southern Higher Latitude Area D)

Fig.2 shows hooking rates (Rt) , number of hooks and catch by every 2^0C of the water temperature. Temperature range widely spanned from 9^0C-30^0C. Among this range, number of hooks (?) was the largest at the 11^0C-15^0C. Number of hooks at the lower temperature rage (< 11^0C), showed a sharp decrease trend, while it showed a gradual decline at the higher temperature range (15^0C <). The temperature range where yellowfin tuna was fished (?) was also wide, ranging from 11^0C - 28^0C. The number of fishes hooked was the largest at the 13^0C-15^0C. Number of fish hooked at the lower temperature rage (< 13^0C), showed a sharp decrease trend, while it showed a gradual decline at the higher temperature sides (15^0C <).

It was resulted that the hooking rates (?) peaked at the 15^0C-17^0C. The hooking rates at the lower temperature range (<15^0C), showed a sharp decrease trend, while they showed a gradual decline at the higher temperature range (17^0C<).

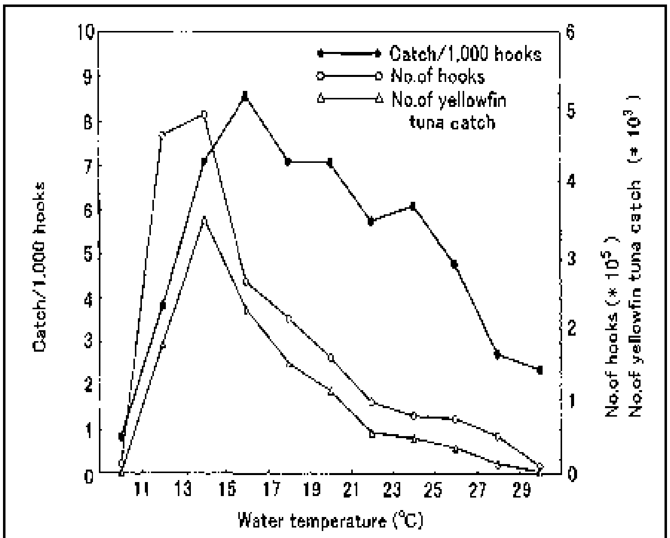


Fig.2 Distribution of hooking rates, fishing effort (number of hooks) and catch by 2^0C of water temperature.

In this study, the hooking rates of 5.0 or over were selected as the good fishing conditions, as were in previous studies 4), 50 that the optimum temperature range among different tuna species could be compared. Then, the temperature range of 13^0C-24^0C was resulted as the optimum temperature for yellowfin tuna in the Indian Ocean. The range was wider than bigeye tuna [5] in the Indian Ocean.

Fig.3 shows the hooking rates (Rt) per 2^0C by sub-area defined in Fig.1. According to Fig. 3, the range of hooking rates of 5.0 or over in the western lower latitudes (WA) and eastern lower latitudes (WB) were almost the same as those for the entire Indian Ocean, as shown in Fig.2.

The hooking rates were at the high level in the temperature range of 11-27^0C in the middle latitude south (MC), but they showed the decreasing trend in the 17-19^0C range. The high hooking rates in the high latitude south (SD) occurred in the higher temperature range (15-17^0C) than in the lower latitudes south.

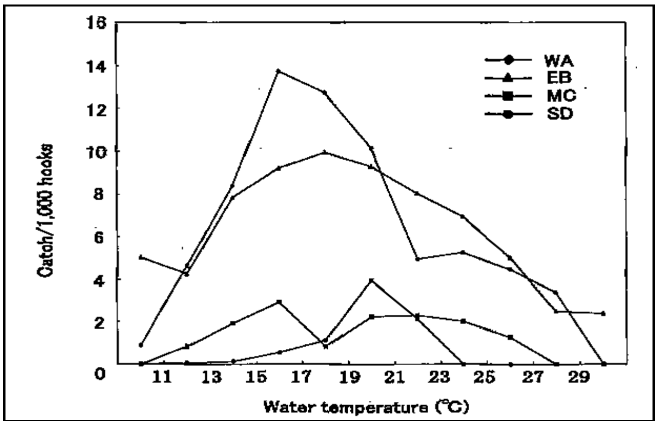


Fig.3 Hooking rates by 2^0C of water temperature and survey area (WA; Western Lower Latitude Area A, EB; Eastern Lower Latitude Area B, MC; Mid-latitude Area C, SD; Southern Higher Latitude Area D)

Fig.4 shows the data collection points by JAMARC and seven sub-areas (A-G) of 5-degree square established to examine effect of the dissolved oxygen on the hooking rates. The 5-degrees square area was adopted to have it correspond to monthly average maps of catch and hooking rates [3]. The reason for establishing seven north-south sub-areas is that dissolved oxygen is lower at further north of the Indian Ocean and higher in the south [6] Ishizuka [7] explained reasons for this result as follows: In the rainy season in June-October, a large amount of eroded soil flow into rivers and in the ensuing short interval, it flows into the Bengal Bay and also into the Arabian Sea from the rivers as huge amount of sediment. The sediment that flowed into the oceans and organic substances at the sea bottom are whirled up and organic substances are oxidized in the seawater. For this reason, dissolved oxygen amount at about 160m and deeper in the Indian Ocean is lower at further north and higher at further south [6]

With this fact in mind, "distribution of effort (i.e. number of hooks) and hooking rates by sub-area and depth" (Fig.5) were initially investigated. They were compared with vertical profiles of average dissolved oxygen (Fig.6) to study the optimum dissolved oxygen to catch yellowfin tuna.

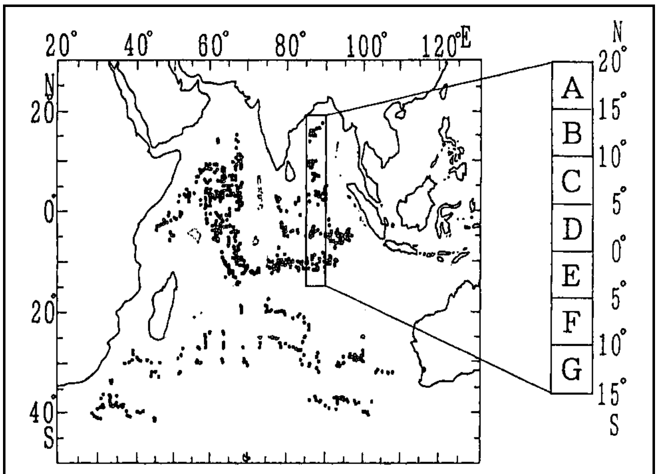


Fig.4 Seven sub-areas of the data collection points (A-G)

Figs. 5 shows depth-specific effort (number of hooks) and hooking rates by sub-area (A-G) respectively, which is located in order from north to south. From Fig. 5, it is understood that, in sub-areas A-C, higher hooking rates (>5 fish /1000 hooks) occur at the water depth shallower than 140-180m range and they declines at the water depth deeper than that depth range. On the other hand, in sub-areas D-G; the higher hooking rates occurred at the water depth shallower than 200m and they start to decline at around 140-180m.

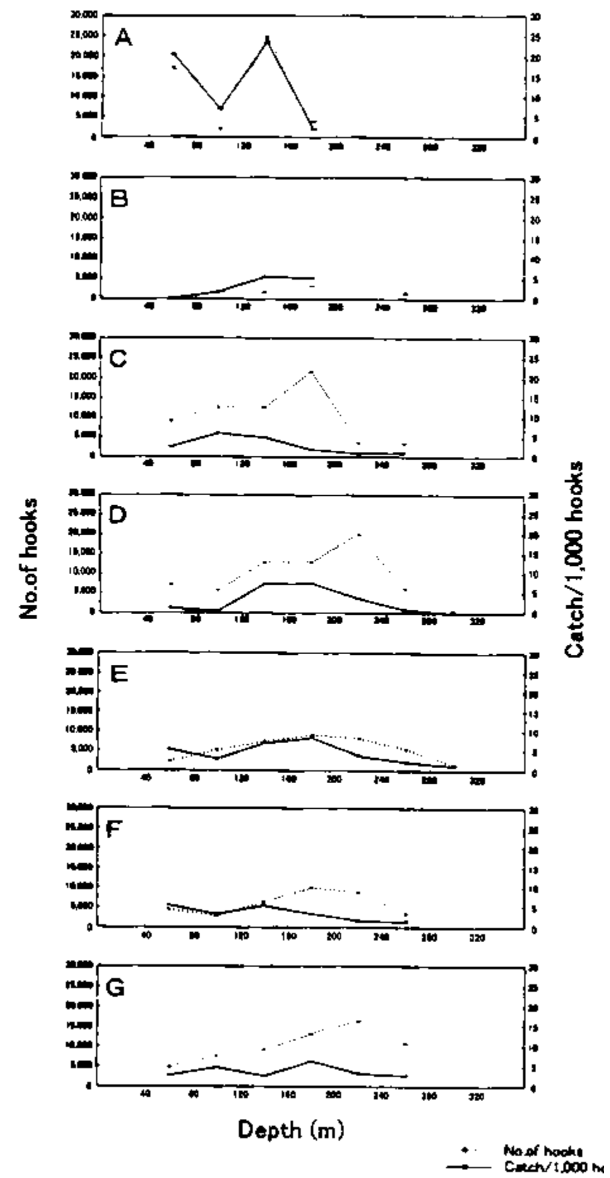


Fig.5 Distribution of fishing effort (number of hooks) and hooking rates by sub-area (A-G) and depth

Fig. 6 (upper panel) shows the vertical profile of average dissolved oxygen along the longitude line at the 85^0 E, which extends from 20^0 N to 5^0 S (lower panel of Fig. 6). This vertical profile shows that dissolved oxygen is reduced to below 1 ml/l as it advances northward at around 160m and deeper, while at 5^0S or south, it increases to over l ml/l as it advances southward at any depth.

We examined the dissolved oxygen (Fig.6) between two areas, A-C and D-G, where hooking rates in A-C were high in the shallower water than 160-180m, while those in D-G were high in deeper water (Fig.5). Then, it was concluded that the dissolved oxygen was less than l ml/l in the areas of A-C, while it was higher than l ml/l in the D-G area. For any creatures, some level of oxygen is essential. For the case of yellowfin tuna, the minimum oxygen is considered to be l ml/l, based on Figs. 5 and 6.

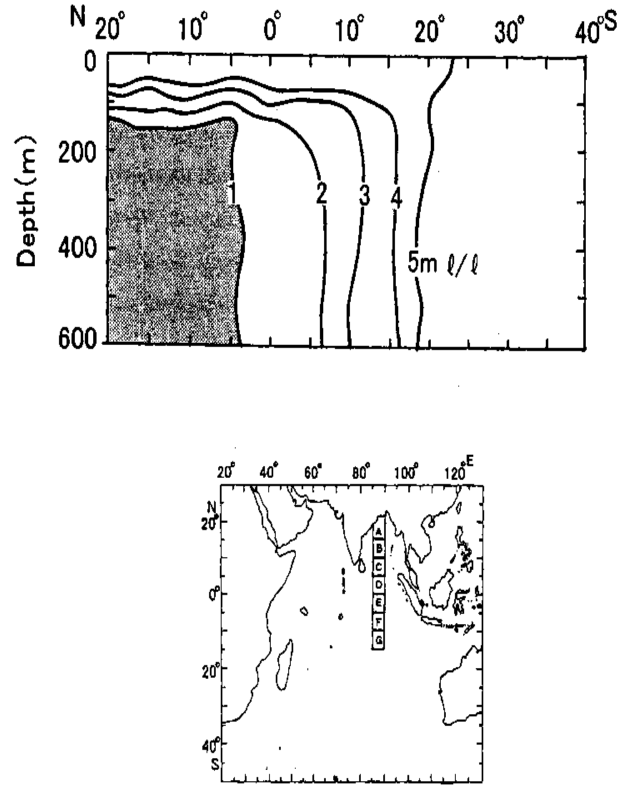


Fig.6 Vertical profiles of average dissolved oxygen along the longitude lines.

Based on this result, it is concluded that the minimum dissolved oxygen necessary to catch yellowfin tuna is set at 1 ml/l. Kurita et al.[8] reported the minimum dissolved oxygen necessary for tuna in general is at the l ml/l level, while Shimamura et al [9] and Kim et al.[5] reported it at 1ml/l or lower. Therefore, the minimum dissolved oxygen of l ml/l established in this study, is considered to be the plausible value.

Fig.7 shows locations of oceanographic observation points (represented by dots by lx1 degree square) based on the JODC database. It also shows locations of seven lines to study vertical profiles of water temperature. Each line either belongs to each sub-area of low latitudes, middle latitudes and high latitudes in the southern hemisphere or is a section crossing them.

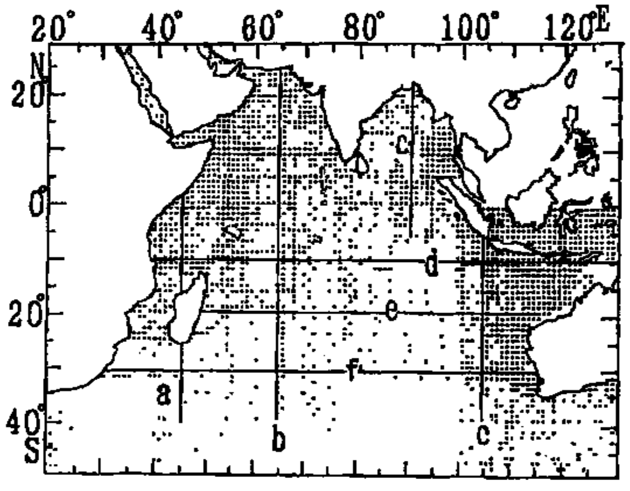


Fig.7 Locations of the water temperature observation points by 1 degree square area and locations of lines to investigate vertical profiles of water temperatures.

We estimated the water temperature at 16 standard depths [10] (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250, 300, 400, 500, 600 m) by the liner interpolations among observed data. Then, the average temperature by 1 degree square and standard depth 10) were computed, which were used for the further analyses and discussion.

Fig.8 shows the distribution maps of depth contours representing the isotherm of water temperature at 24^0C (above) and 13°C (below) that are the upper and the lower limit of optimum water temperature respectively.

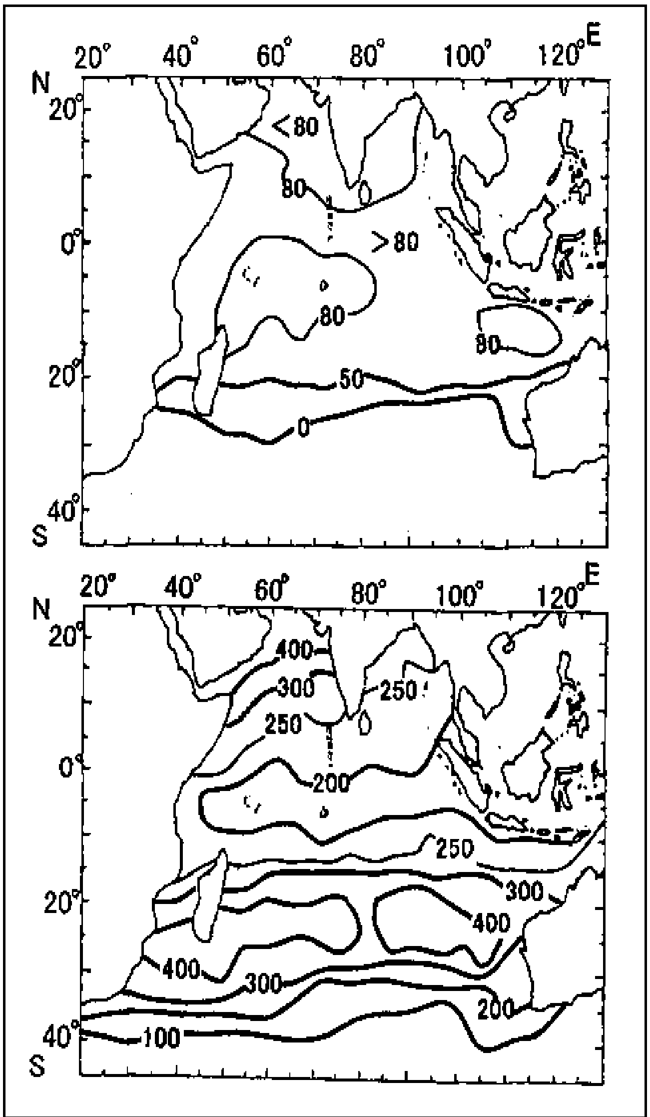


Fig.8 Isothermal depth of 24^{0}C (upper) and 13^{0}C (lower)

Depth contours of the upper limit (24^{0}C) are located at around 80m in the equatorial region, which become shallower as departing from the equator to north or south direction and reach the surface at about 30°S. On the other hand, depth contours of the lower limit (13^{0}C) are located at around 200m in the equatorial region and become deeper as departing from the equator to north or south direction and reach the 300m-400m depth level in the Arabian Sea or in the waters at around 30°S, then depth contours become shallower again at around 100m in the waters around 40^{0}S

Fig. 9-1 shows three vertical profiles of average water temperature in the north-south directions (line a, b and c) which locations are shown in the map (at bottom) and also in Fig.7. The screen tone represent the depth zones of optimum water temperature between 13^{0}C-24^{0}C. Each vertical profile crosses low, middle and high latitudes in the southern hemisphere except line a which does not cross the middle latitude because of existence of Madagascar Island. As in Fig. 9-1, the upper limit of 24^{0}C is found at around 80m in the equatorial region and becomes shallower as it extended into north-south directions and reaches the surface in the high latitudes south. The lower limit of 13^{0}C is found at around 200m in the equatorial region, and becomes deeper in the north-south directions and reaches the 300m – 400 m depth level.

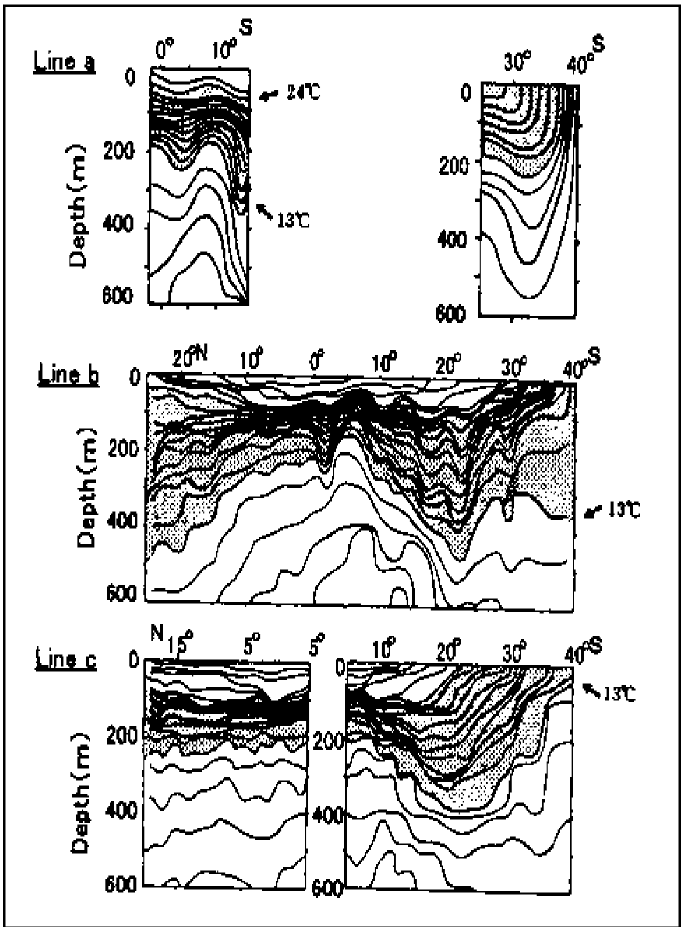


Fig.9-1 Vertical profiles of average water temperatures in line a-c.

Fig. 9-2 shows three vertical profiles of average water temperature in the east-west directions (line d, e and f). Screen tone in three vertical profiles represent the depth zone of optimum water temperature between of 13°C 24°C in low latitudes, middle latitudes, and high latitudes area of the southern hemisphere, respectively.

From Figs. 9-1 and 9-2 are summarized as follows. At 10°S, the lower limit of 13°C is distributed at about 200m-300m in depth, while the upper limit of 24°C, at about 50m-80m. At 20°S, the lower limit of 13°C is distributed at around 300-400m, while the upper limit of 24°C, at around 20m. At 30°S, the lower limit of 13°C is distributed at around 140-500m, while there is no the upper limit of 24°C and the temperature on the surface is about 17-20°C.

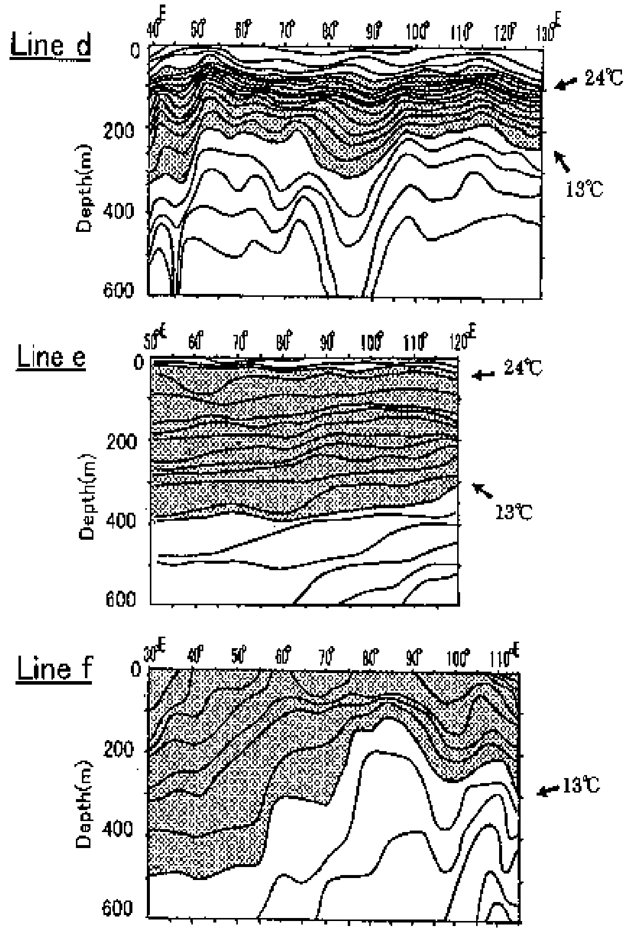
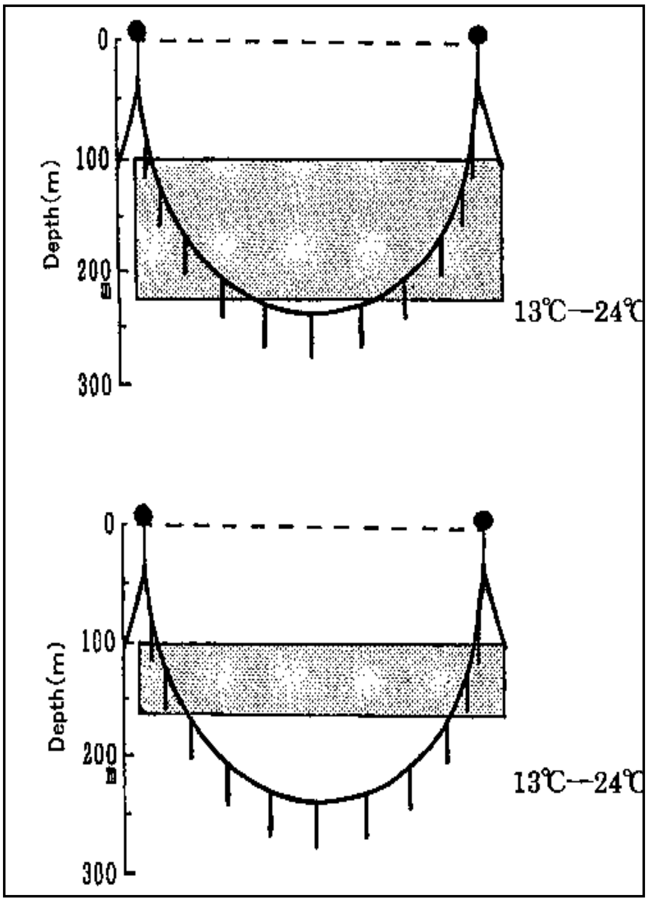


Fig.9-2 Vertical profiles of average water temperatures in line d-f.



FUTURE PROSPECT

Fig. 10 shows the ranges of optimum water temperature to catch yellowfin tuna in low latitudes (upper panel) and high latitudes south (lower panel), as well as the relationships between tuna longline gear and depth. As observed in Fig. 10, tuna longline gear is usually deployed at 100m - 300m. However, as depth range of optimum water temperature for fishing changes from area to area. As shown in Fig. 10, the optimum water temperature for fishing is distributed at about 100-220 m in the low latitudes area, while in high latitudes south, it is at about 100 - 180m. Therefore, the depth of the optimum water temperature affects yellowfin tuna catch, i.e., more yellowfin tuna is expected to be caught in the shallower water in high latitudes south than in the low latitudes waters [3].

For this reason, in order to promote conservation and management of yellowfin tuna resources in the Indian Ocean, it would be necessary to reduce fishing effort by decreasing the number of tuna longline vessels to avoid excess catch at the deeper waters where there are more yellowfin tuna because of existence of the optimum water temperature. This means to use more regular longlines at the lower latitude waters.

In this study, fishing distribution of vertical direction was examined, but seasonal changes were ignored. In the future, there may be needed to examine changes also from temporal point of view taking seasonal changes into account [11), 12)].

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