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Consideration on horizontal and vertical distribution of adult yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on the Japanese tuna longline fisheries information

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Abstract: As results of data analyses of the Japanese commercial and experimental tuna longline fishing exploiting adult yellowfin tuna, following five points are suggested on their distribution: (a) high-density area of adult yellowfin tuna exists in the water off northern Madagascar Island in the western Indian Ocean, while in the eastern Indian Ocean, it is in the water off northwestern Australia, (b) high-density area in the western Indian Ocean occurs from January to May, then shrinks from June to August and expands again as month advances. In the eastern area, high-density fishing area expands to westward and is combined with the western area in May, and then shrinks as the months advances and stays in northwestern Australia, (c) mature yellowfin tuna constitutes the largest portion in north of 20° S, and only non mature individuals exist in southern area, (d) distribution of mature yellowfin tuna becomes less dense in April–September centering around the southwestern monsoon, and become denser in October–March centering on northeastern monsoon and (e) the main fishing depth stratum generally exist between 120m and 200m. In the low latitudes, it is the same as in the general case, while in the high latitudes south, it is at 180m and shallower.

Key words : *Tuna longline fishery, yellowfin tuna*

1. Introduction

In recent years, there has been a conspicuous tendency of declining fishing rates or smaller size of tuna with intensifying catch of tuna. This has created a worldwide concern about the status of its resources. There are seven commercially important tunna species, and yellowfin tuna is exploited extensively in the world's Oceans, including the Pacific, Atlantic and Indian Oceans. Of all tuna species, yellowfin tuna has tha fastest growth rate, reaching about 100cm in size at the age of two (FUJITA, 1998), and can become target of fishing in a shorter period after birth compared with other species. According to a report of ***FAO, about one million tons of yellowfin tuna were havested worldwide.

In the Indian Ocean, yellowfin tuna account for 60% fo the total catch of the major five tuna species, and a predominant part of the catch is harvested by means of longline (HONMA and SUZUKI, 1972). For this reason, the Indian Ocean constitutes the most important area for yellowfin tuna of all the three major Oceans in the world. Having this in mind, this study is intended to grasp horizontal and vertical fishing distribution of yellowfin tuna in the Indian Ocean with a view to abtain a guideline for conservation and management of this species.

Inthis study, analyses are conducted using the following two steps: (a) catch and gonad information are used to study horizontal distribution of adult and mature yellowfin tuna respectively, and (b) depth specific catch data are used to study vertical distribution of adult yellowfin tuna.

2. Materials and methods

2.1. Materials

In this study, the following three data

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***FAO (1998): Capture production. FISHSTAT Plus Ver. 2.30. Nara, JIFRS, CD-ROM.

sources are used, which are collected in the water surrounded by the area of 20° N–50° S and 20° E–130° E in the Indian Ocean : (a) "Annual statistical bulletin of tuna longline fisheries by fishing ground" pubished by the Fisheries Agency of Japan from 1967 to 1991, (b) "Data on fish size measurement" and "Ovary weight" from the experimental longline fishing conducted by the Japan Marine Fishery Resources Research Center(JAMARC) for the 1981–1986 period, and (c) "Data by depth of hook in deep longline" from the same source in (b). These information are used to examine the horizontal distribution of yellowfin tuna, to examine the horizontal distribution of mature yellowfin tuna, and to examine vertical distribution for yellowfin tuna.

2.2. Methods

2.2.1. Horizontal fishing distribution

"Annual statistical bulletin of tuna longline fisheries by fishing ground" published by the Fisheries agency of Japan are used to examine the horizontal distribution which are based on the 5-degree longitudinal and latitudinal square area (abbreviated as 5×5 area, hereafter). Using the 25 years of the data, overall average catch and monthly average catch by the 5×5 area are computed by the following equations respectively:

$$N_{jk} = (\sum_{i=1}^{N_k} N_{ijk})/n_k$$

$$N_k = (\sum_{j=1}^{m_k} N_{jk})/m_k$$

, where N : number of catch, i : i-the year, j : j-th month, k : k-th 5×5 area, m : number of month and n : number of years

Following method is applied to determine the boundary of four different classes of average catch to represent in the distribution maps: Catch data by 5-dagree square are accumulated starting from the greater numbers to lesser ones, and are divided into four classes, so that each may represent a quarter of number of the catch in each map. The uppermost quarter is assigned as Class 1 (highest to 25th value), followed by Class 2 (25th–50th value), Class 3 (50th–75th value) and Class 4 (75th value–0 or smallest value). In this study, Class 1 is designated as the highest density fishing area, while Class 1 to Class 3 as high-density fishing areas.

Secondarily, mature yellowfin is defined as follows: yellowfin tuna caught by the longliners are mainly adult (100cm or larger) and majority of fish are mature fish, while some fish are immature. To segregate between mature and immature fish, Gonad Index (*GI*) is used as a criterion to discriminate between immature and mature yellowfin tuna, which is expressed by $GI = W \times 10^4/L^3$, where W is the weight of ovaries of females in gram and L is its fork length in cm. It has been suggested since the 1950s that $GI \geqq 2.1$ as mature individuals (KIKAWA, 1957), and in the 1960s (KIKAWA, 1966), 1970s (SHUNG, 1973), and at present, this range is also considered as mature yellowfin tuna. Therefore, in this study as well, $GI \geqq 2.1$ is treated as mature individuals.

Weight data of ovaries are processed by year, season (quarter) and 5×5 area, in order to study seasonal distribution of mature yellowfin. In addition, the overall distibution without seasonal factor is also studied.

2.2.2. Vertical fishing distirbution

The structural chart of tuna longline gear is illustrated in Fig.1. This longline fishing gear has 11 hooks per basket, which can by reached as far as 300m in depth. Vertical distribution

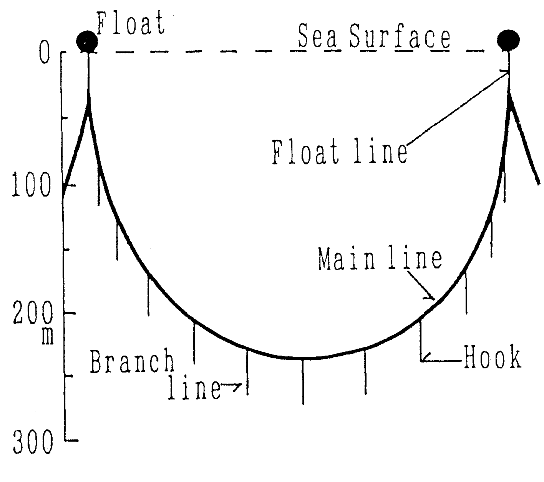

Fig. 1. Structure of tuna longline gear (in case of 11 hooks per basket).

for yellowfin tuna can be estimated indirecly by computing depths of hooks where fish is hooked. Then, three types of data are compiled in order to study vertical distribution of yellowfin, *i.e.*, location of the fishing operation, number of hooks used, and number of fishes hooked by branch line for each operation point. In order to estimate the depth of the hook, the theory based on catenaries curve is used (SAITO, 1992). If the depth meter is used to record the depth, such data are used. Depth specific hooking rates are computed by:

$$R_d = 1{,}000(\sum_{i=1}^{n} C_{id} / \sum_{i=1}^{n} h_{id})$$

,where d: d-th depth range. 20m is applied for the depth interval

R_d: hooking rates at d-th depth range

C_{id}: number of catch at the i-th fishing operation point and d-th depth range of dm

h_{id}: number of hooks used at the i-th fishing operation point and the d-th depth range

n: number of the data at the d-th depth range.

3. Results and discussions

3.1. Horizontal distribution

3.1.1. Distribution of average number of catch

The distribution map of average number of catch and hooks by 5×5 area during 1967–91 are shown in Fig. 2 and Appendix Fig. 1 respectively. According to Fig. 2, high-density fishing area of yellowfin tuna is centered around northern Madagascar Island and is found in the western area extending to the north and south directions along the eastern coast of the African Continent and the eastern area centering on northwestern Australia. In the area south of 40° S, the area with zero yellowfin tuna catch extended widely despite the fact that it is the

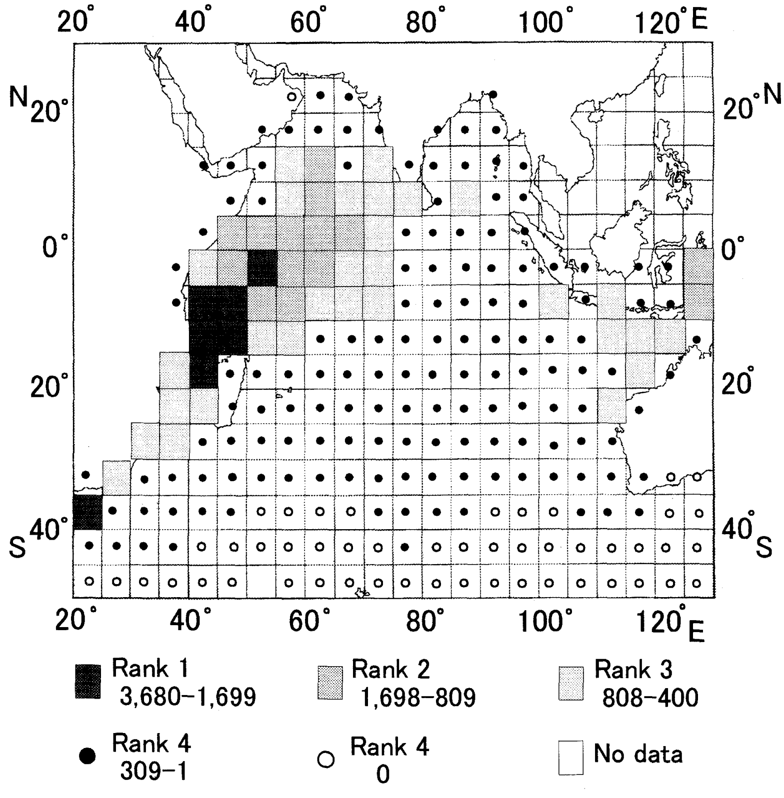

Fig. 2. Distribution of average number of yellowfin tuna catch based on the information of the Japanese commercial tuna longline fisheries operated in the Indian Ocean(1967–1991).

fishing area of southern bluefin tuna.

3.1.2. Distribution of monthly average number of catch

The distribution map of monthly average number of catch and hooks by 5×5 area during 1967–91 are shown in Fig. 3 and Appendix Fig. 2 respectively. Based on Fig. 3, distribution patterns are studied by separating the western area and the eastern area. First of all, with respect to changes in high-desnity fishing area in the western Indian Ocean, it expands its range to Arabian Sea and western Bay of Bengal from January to April, spreading to the largest extent in May. From June to August, high-density fishing area shrinks and stays in northern Madagascar Island. Thereafter, the high-density fishing area tends to expand gradually as the month advances. However, high-density fishing area is distributed throughout the year in the water off Cape Town. With respect to the eastern Indian Ocean, high-density fishing area gradually shrinks from January to April, and expands its distribution areas westward, which becomes largest in May, and links with high density fishing area in the western area. From June, high-density fishing area shrinks gradually and stays within a certain range of northwestern Australia from August to December. MORITA and KOTO(1971) suggest possibility of

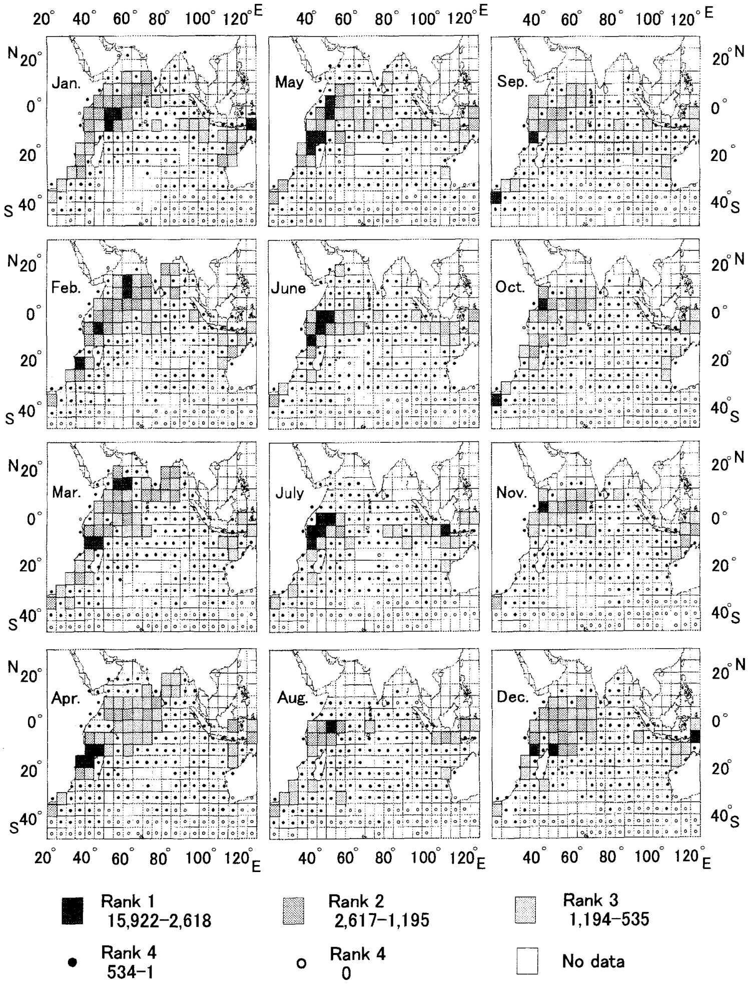

Fig. 3. Distribution of monthly average number of yellowfin tuna catch based on the information of the Japanese commercial tuna longline fisheries operated in the Indian Ocean(1967–91).

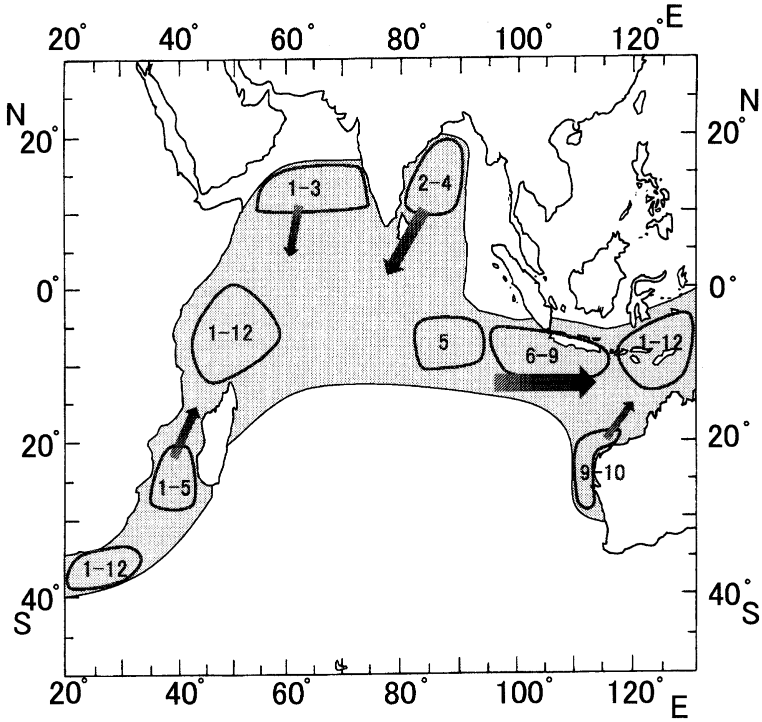

Fig. 4. Schematic map showing seasonal movements of adult yellowfin tuna in the Indian Ocean based on the catch distribution maps of Figs. 2–3.

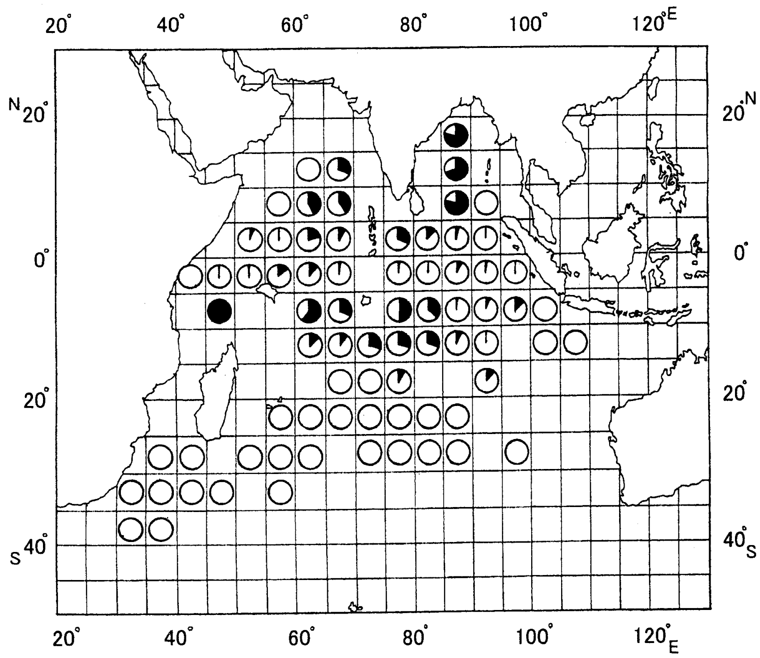

Fig. 5. Distribution of immature (○ : G.I.<2.1) and mature (● : G.I.≧2.1) yellowfin tuna by the 5×5 area in the Indian Ocean based on the information of the JAMARC experimental tuna longline fishing in the Indian Ocean (1981–86).

east–west mixing of fish schools in the Indian Ocean. This study also clarifies this possible mixing and suggests that it occurs in May.

3.1.3. Seasonal movement of high density fishing area

Based on monthly catch maps, we will now discuss the movement of adult yellowfin tuna by considering the patterns of high–density fishing areas. The possible seasonal movements is summarized in Fig. 4. The gray zone shows the range of high–density fishing area. Nunbers and circles show 'months' and 'locations' of high–density fishing area respectively. The arrow shows the direction into which the high–density fishing areas move thereafter. In the western Indian Ocean, high–density fishing areas move from southern Arabian Sea and western Bay of Bengal to the water off southwestern Madagascal Island during January to May. After June to August, high–density areas shrink and exist only in the water off northern Madagascar Island. After August, high–density fishing areas start to expand gradually as months advance. It is found that high–density areas are distributed throughout the year in the water off southern Cape Town. In the eastern Indian Ocean, high–density fishing areas expand distribution areas rapidly westward in May and link with the western area. In June and afterwards, high–density fishing areas shrink gradually to the direction shown by the arrow, staying at northwestern Australia.

3.1.4. Distribution of the mature fish

Fig. 5. shows the map depicting the proportion occupied by mature and immature yellowfin tuna by 5×5 area, i.e., the black part of the pie chart shows the composition of the mature fish ($GI \geqq 2.1$), while the white part is for the immature fish. It is understood that mature individuals are being fished in the area north of 20° S, and only immature individuals in the area south of that demarcation.

3.1.5. Seasonal distribution of the mature fish

Distribution of mature and immature individuals by quarter and the 5×5 area is shown

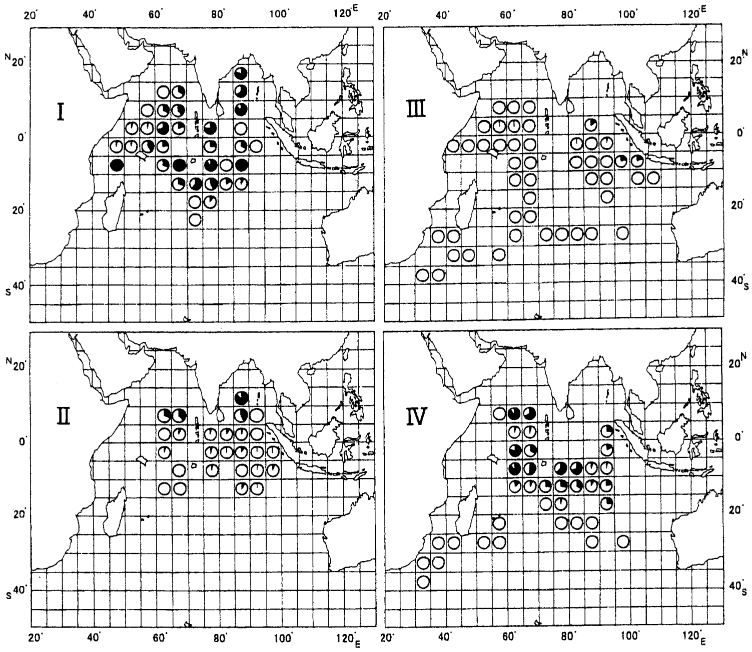

Fig. 6. Quarterly distribution of immature (○ : G.I.<2.1) and mature (● : G.I.≧2.1) yellowfin tuna by the 5×5 area in the Indian Ocean based on the information of the JAMARC experimental tuna longline fishing in the Indian Ocean(1981–86, I : Jan.~Mar., II : Apr.~June, III : July~Sep., IV : Oct.~Dec.).

in FIg. 6. According to SUDO (1994), the Indian Ocean is an area largely affected by monsoon. In the season centering on Northern Hemisphere summer, there are conspicuous impact of southwestern monsoon, and that of northeastern monsoon in the season centering on winter. When the southwestern monsoon is strong, the Somali current characterized by low temperature becomes conspicuous.

Observing the quarterly distribution map (Fig. 6.) and also taking the impact of monsoon into consideration, it is understood that mature individuals are fished in an extensive range in the first and fourth quarters where the impact of northeastern monsoon is strong, and that tendency is especially significant in the first quarter. Furthermore, in the second and third quarters in which the impact of southewstern monsoon is strong, there is low-level distribution of mature individuals and that tendency is especially significant in the third quarter. It is considered that particular distribution patterns in the third quarter, may be caused by the expansion of low water temperature brought by the Somali Current. There is need to clarify its details in the future study.

3.2. Vertical distributions

The sampling points of the data used to study vertical distribution of yellowfin tuna and also the sub-areas established for this study is shown in Fig. 7. According to the map of average catch distribution (Fig. 2.) and the monthly average map (Fig. 3.), conspicuous seasonal east-west changes of high-density fishing area accur in the area north of 15° S, with 75° E as a demarcation, and 25° S is the southern boundary of high-density fishing area in the eastern area. To make the comparison possible with the results of the study on

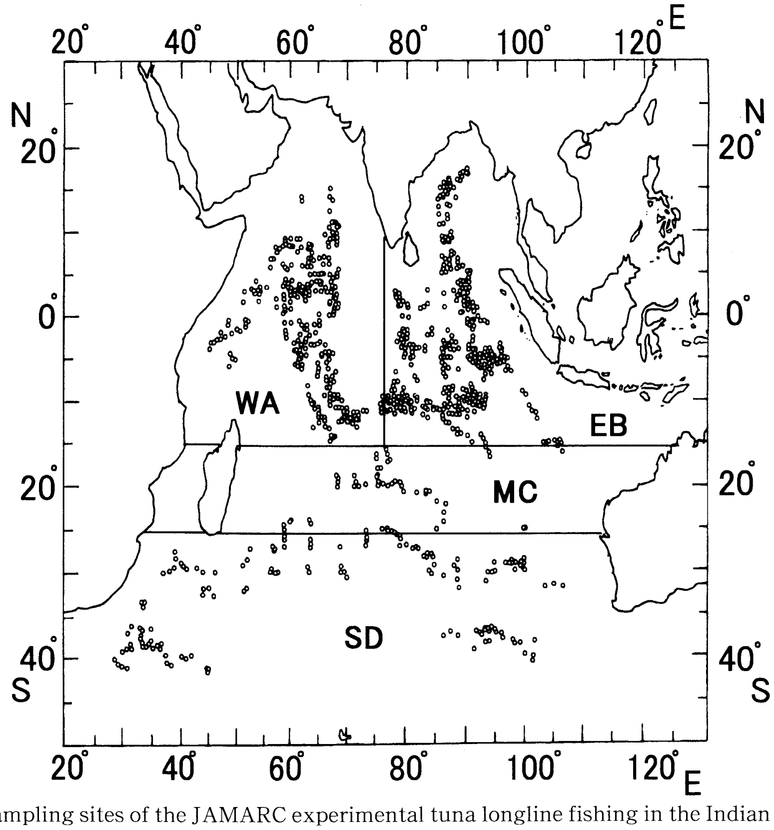

Fig. 7. Sampling sites of the JAMARC experimental tuna longline fishing in the Indian Ocean (1981–86) and four sub-areas defined to study depth specific hooking rates (WA: Western lower latitude area A, EB: Eastern lower latitude area B, MC: Mid-latitude area C, SD: Southern higher latitude area D).

vertical distribution of bigeye tuna in the Indian Ocean studied by MOHRI *et al.* (1997), same sub-areas (WA, EB, MC and SD) of their study are used to investingate the depth specific hooking rate by sub-area.

3.2.1. Depth specific hooking rates

The trends of number of hooks and hooking rates by depth is shown in Fig. 8. The left vertical axis shows the number of hooks and the right vertical axis shows hooking rates, while the horizontal axis shows depth. n_1 represents the number of hooks, while n_2, for the number of fish caught. The solid line shows hooking rates and the dotted line shows number of hooks.

As clearly understood from Fig. 8, hooking rates increase in accordance with depth up to around 60-160m, with the peak standing around 160-180m. In 160-180m and deeper, it shows the declining trend, in accordance with the depth. In the depth between 120m and 200m, 60% of the yellowfin tuna are fished, with hooking rates standing at a high level of over 8.0 Form this increasing trend in hooking rates, it is considered that the depth between 120m and 200m is the main fishing stratum for yellowfin tuna.

3.2.2. Depth specific hooking rates by sub-area

The trends of depth specific hooking rates in four sub-areas is shown in Fig. 9. There exist higher hooking rates between 120 m and 200 m in both WA and EB, and hooking rates declining in 200 m and deeper along with depth. In the sub area, MC, it is not possible to accurately illustrate the trend due to not enough data. In the sub area of SD, relatively high hooking rates appear in 180 m and shallower, and conspicuously between 100 m and 140 m, although they are low generally. In 180 m and deeper, hooking rates tend to lower along with the depth.

From these findings, it is resulted that optimum fishing depth for higher hooking rates is located at between 120 m and 200 m in low latitudes, and shallower than 180 m in the high latitudes south. The reason why there are different hook-setting depths by area, is that hooking rates are affected by environmental

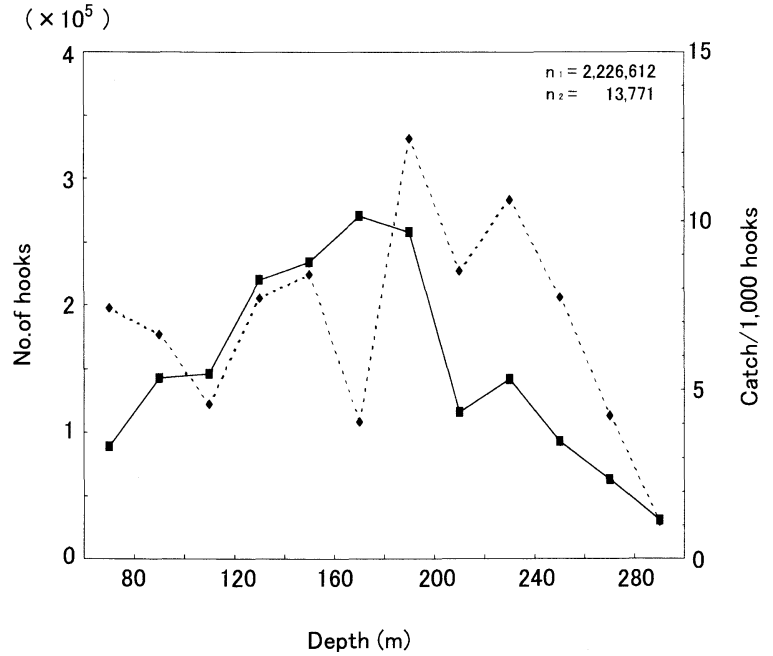

Fig. 8. Trend of depth specific hooking rates of yellowfin tuna based on the information of the experimental tuna longline fishing by JAMARC in the Indian Ocean (1981-86). n_1: number of hooks (◆), n_2: number of yellowfin tuna catch (■).

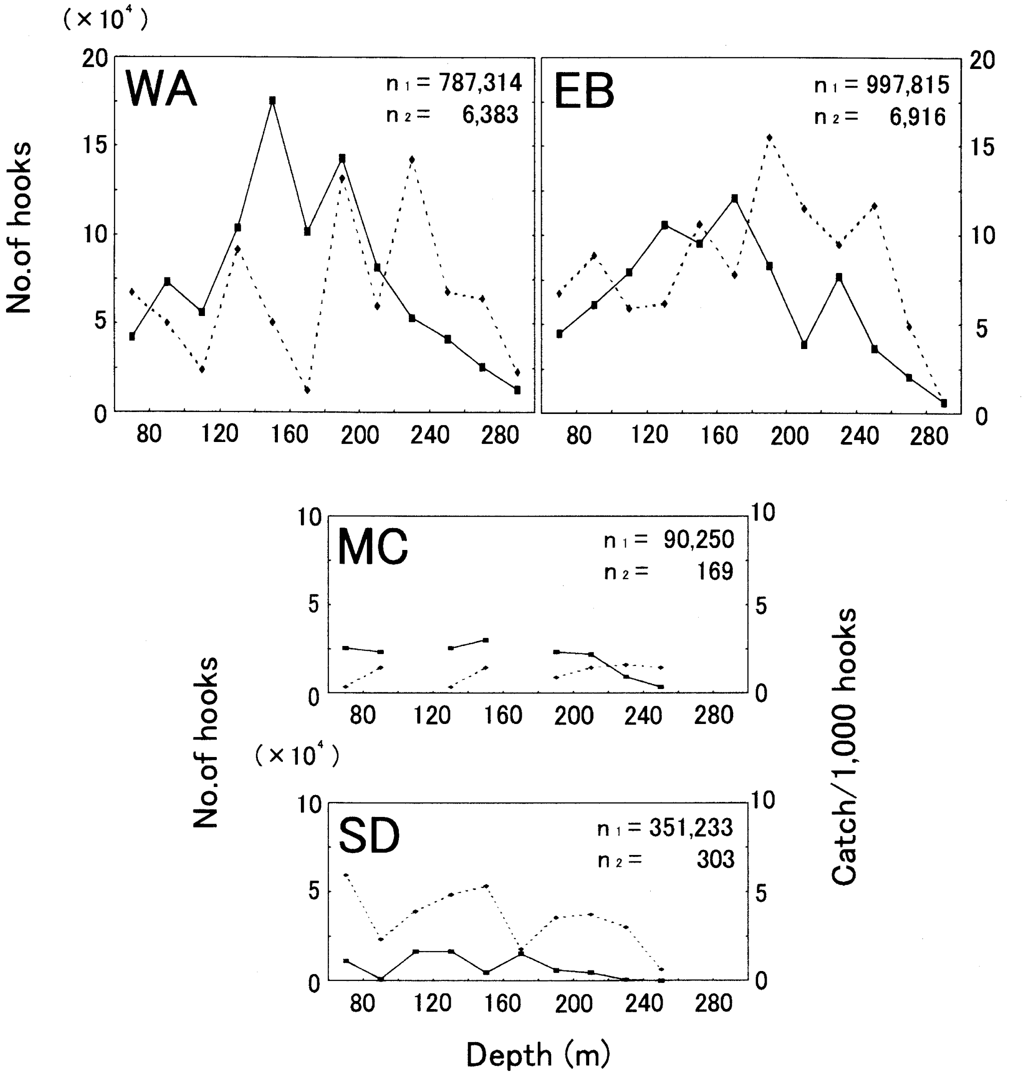

Fig. 9. Trend of depth specific hooking rates of yellowfin tuna by sub-area based on the information of experimental tuna longline fishing by JAMARC in the Indian Ocean (1981-86) n_1: number of hooks(◆), n_2: number of yellowfin tuna catch(■).

conditions such as water temperature and dissolved oxygen, which also vary by depth and area (SHIMAMURA and SOEDA, 1981). Further details on relationships between hooking rates and marine environmental conditions have been studied by MOHRI and NISHIDA (2002) and ROMENA *et al.* (2002).

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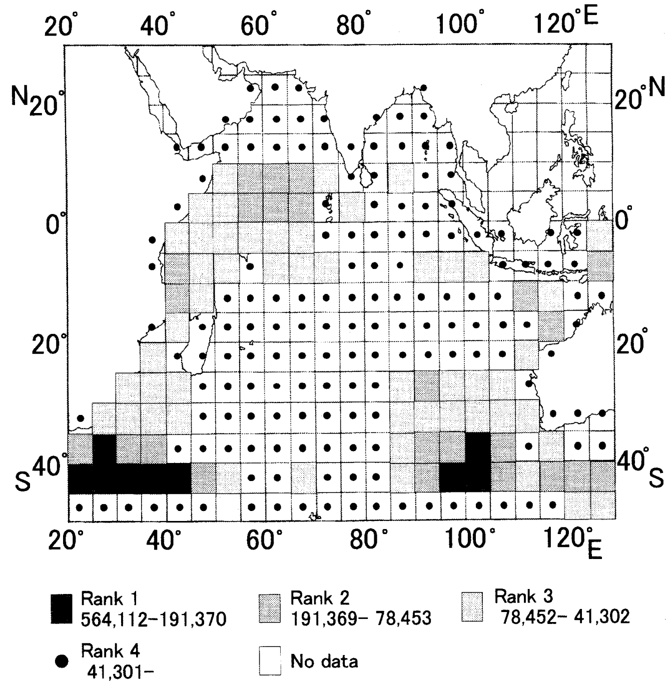
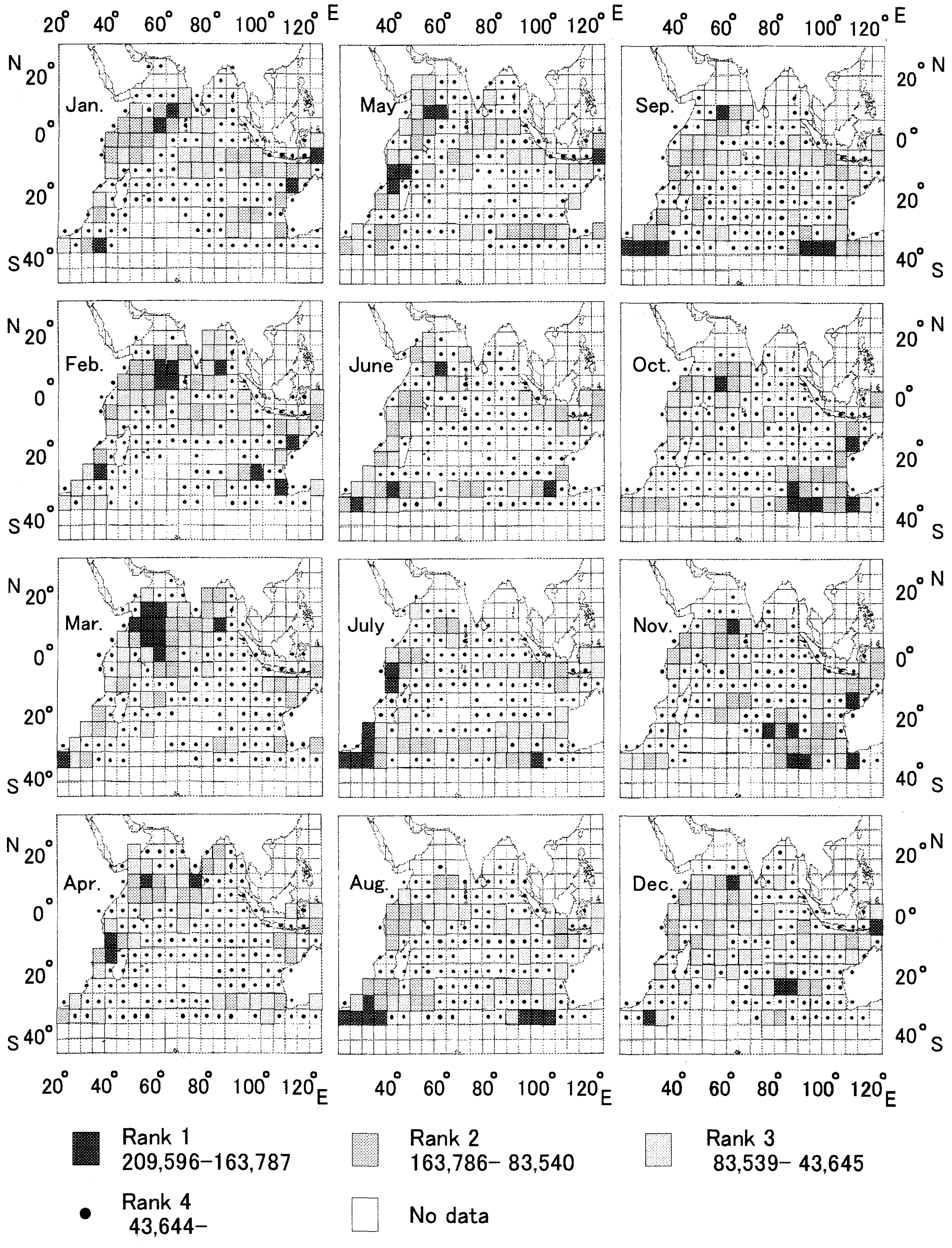


Appendex Fig. 1. Distribution of average number of hooks based on the information of the Japanese commercial tuna longline fisheries operated in the Indian Ocean(1967–1991).



Appendex Fig. 2. Distribution of monthly average number of hooks based on the information of the Japanese commercial tuna longline fisheries operated in the Indian Ocean(1967–91).