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On the General Features of the Tuna-Fishing Grounds in the Eastern Indian Ocean-I.

Oceanic and Fishing Conditions in the Western Region of the Sumatra Island

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Abstract

The following items were clarified, as the results of examining the general features of the tuna fishing grounds; based on the data of the oceanographical observations made by the "Keiten Maru" (308.03 tons), training ship of the Faculty of Fisheries, Kagoshima University, in the Western region of Sumatra Island, latitude 3°N～4°S, longitude 93°E～96°E, from 1966 to 1968.

The results obtained are as follows:

1). In the fishing ground spreading between 94°E and 96°E near the equator there is a remarkable 'line of convergence' and in this region it is possible to observe the local upwelling.

2). In the layer less than 50 m deep, there exists the mixing surface-water with the temperature more than 29.0°C., while in the layer between 50 m and 150 m in depth, there exists a very remarkable thermocline.

3). The water-mass in this region may be divided into four main groups.

4). The proportion of the catch-fish in this fishing-ground was as in the following: the hold of the yellowfin tuna was about 50 %, that of the bigeyed tuna and a species of marlin, about 20 %, and that of the miscellaneous ones, about 10 %, respectively.

5). The depth fit for the tuna to swim was estimated as in the following: in case of marlin, it was the mixed-surface-water, in the yellowfin tuna, the region near the upper layer of the thermocline; and in the bigeyed tuna, the thermocline or the intermediate layer below the thermocline.

Introduction

About the tuna fishing in the East Indian Ocean, there were some reports by Nakamura[1], Mimura[2], Yamanaka[3], and others.

The tuna-long-line operations and the oceanographical observations of the fishing ground have been practised by the authors, on board of the "Keiten Maru", the training ship of the Faculty of Fisheries, Kagoshima University, over the seafronts near the equator of the western region of Sumatra Island every summer for 3 years since 1966.

Consequently, a conspicuous formation of the tuna-fishing ground along the tide-rip was confirmed on both the northern and southern sides of the equator, and some examinations were made on the actual conditions, formation factors,

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and their relationship with the fishing conditions; the results of which are as in the following:

Data and Method of Investigation

As shown in Fig. 1, some oceanographical observations and tuna-long-line trial

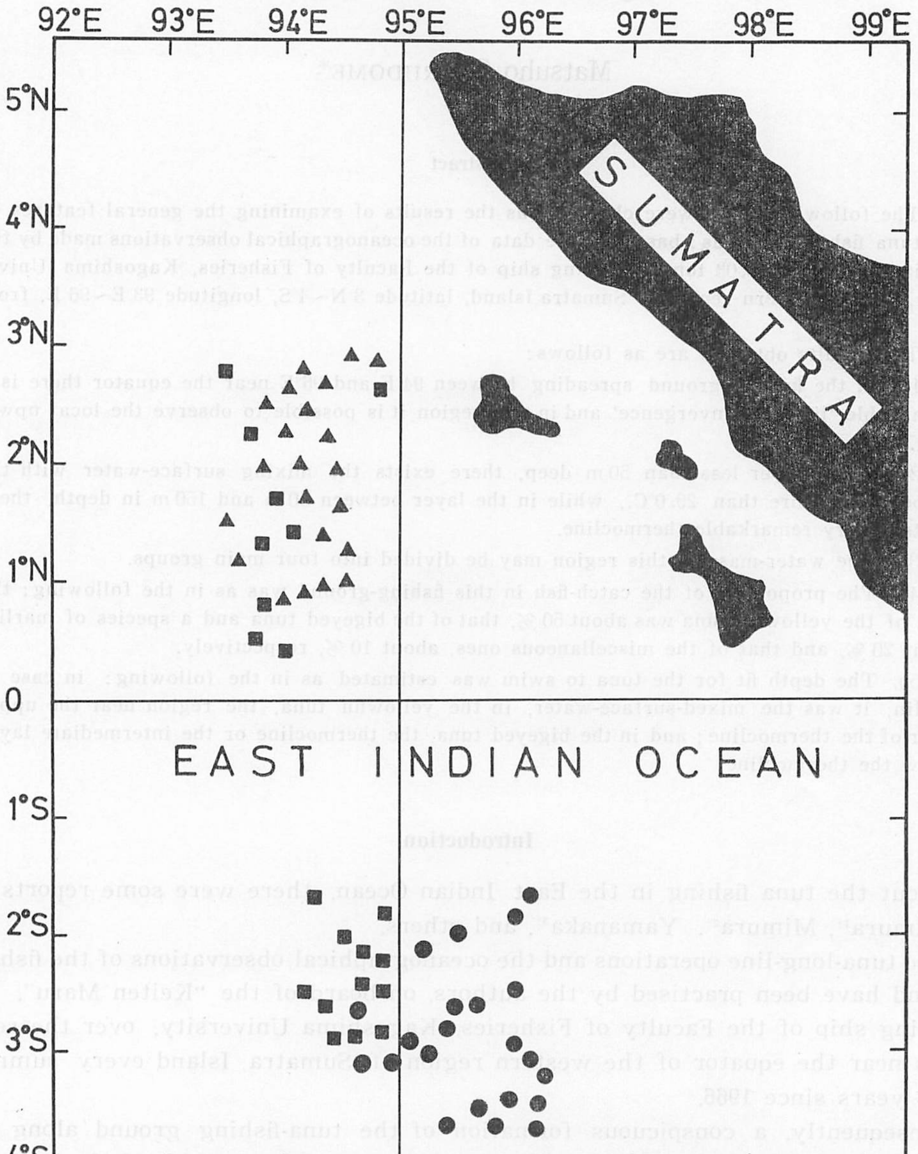


Fig. 1. Locations of the observing station and the tuna fishing position occupied the "Keiten Maru".

● 1966 ▲ 1967 ■ 1968

operations were made by the "Keiten Maru", training ship of the Faculty of Fisheries, Kagoshima University (the number of the operation being 22 times per year) on the fishing ground near the equator, between latitude 3°N and 4°S, longitude 93°E and 96°E, during the fixed season, from June to July in 1966-1968.

While, the catching rate of the respective species tunas was calculated, and the serial oceanographical observations of the temperature and the salinity from surface to the layer 600 m deep, and BT observations were made at the eighty stations, in every 30 minutes, latitude.

By the way, the construction of the tuna long-line (used in the present opera tion) per one basket was as shown in Table 1.

Table 1. Construction of the tuna long line gear used in fishing experiment. (per one basket)

Name of part	Material	Length	No.**
Main line	Mansen (#58 Dia 6.5mm)	290m*	1
Branch line	Mansen (#9 Dia 5.2mm)	12m	5
Sekiyama	Lon-Yar (Dia 3.5mm)	6m	5
Tsurimoto wire	Steel wire (#28 3×3)	3m	5
Hook	Steel	12.5cm	5
Float line	Mansen (#58 Dia 6.5mm)	22m	1

* Length per one basket
** Number used for one faskst

Results of Investigations and Some Considerations

1). Oceanic conditions

1966

In Fig. 2 (a, b, c, and d) is shown the horizontal distribution of the water temperature in the layer 100 m deep.

At the western part of the fishing ground there exists the low temperature water-mass with the temperature 20.5°C., and at the eastern part of the fishing ground there exists the high-temperature water-mass with the temperature 29.5°C.

These two water-masses are closely contacted mutually at the part between latitude 2°S and 3°S, along the meridian of 96°E, the isotherms being more closely gathered near the meridian of 96°E, and, there appeared the so-called 'line of convergence' parallel to the meridian of 96°E.

In Fig. 3 (a and b) is shown the vertical distributions of water temperature (a) and salinity (b).

Near the surface layer, there exists the well-mixed surface water of high temperature and salinity (temperature about 29.0°C., salinty, less than 34.60 ‰); this layer is 60 m deep at 94°-30′E and 75 m at 96°-30′E, being deeper on the eastern part on than on the western part.

Near the meridian of 96°E, there is a sharp and sudden decline in the isot-

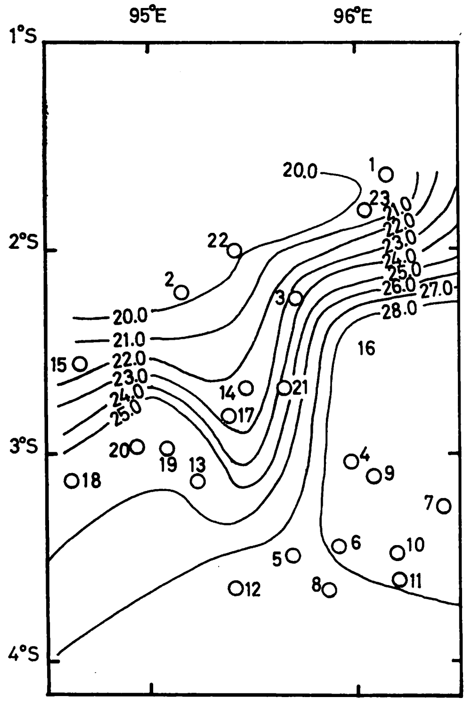


Fig. 2. (a)

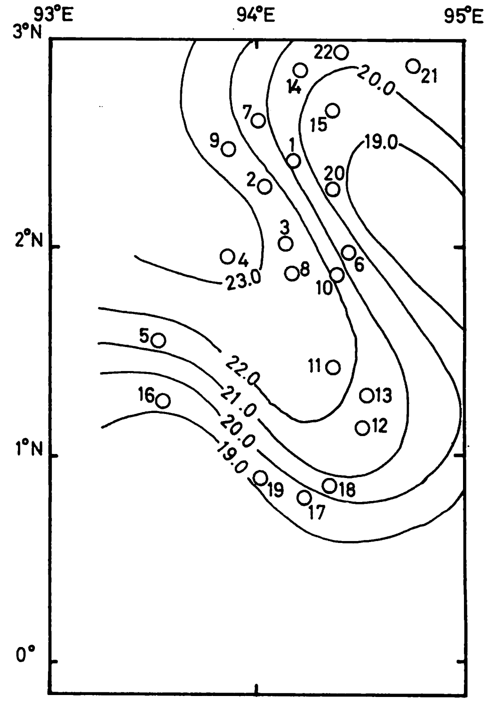


Fig. 2. (b)

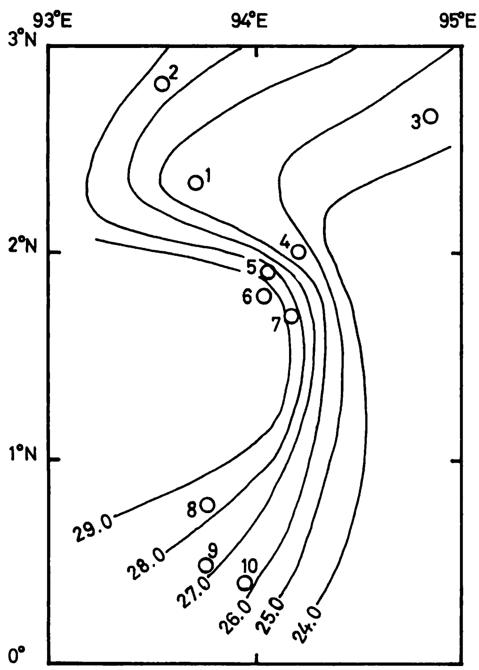


Fig. 2. (c)

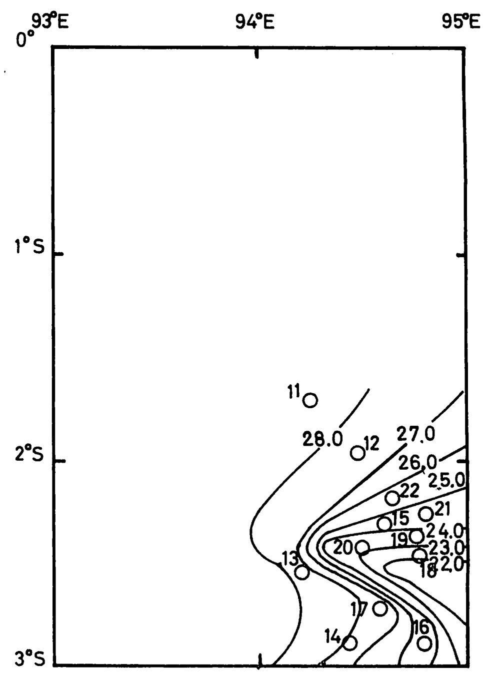


Fig. 2. (d)

Fig. 2. Horizontal distributions of water temperature in the fishing ground (100 meters layer).
(a) 1966 (b) 1967 (c) 1968 (d) 1968

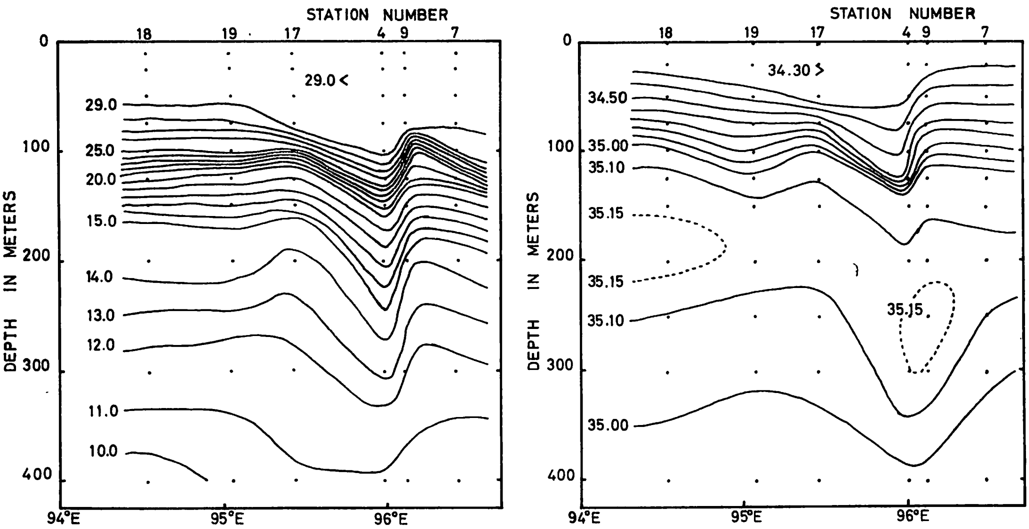


Fig. 3. (a) Fig. 3. (b)

Fig. 3. Vertical distributions of the temperature and the salinity in 1966.
(a) Temperature (b) Salinity

herms, which suggests that there is a sharp sinking of the well-mixed surface water, accompanied by a strong current.

Some comparatively remarkable thermoclines where the isotherms are gathered closely appear at the layer between 75 m and 125 m deep, the difference of water temperature between these thermoclines being 14.0°C.

At the part near 96°E, this thermocline, too, slopes down sharply.

Below this thermocline the slant of water-temperature is slight, the maximum salinity (higher than 35.15 ‰) appears near the part 94°-30′E and 96°-00′E, between the fronts 200 m and 300 m deep, respectively.

1967

In Fig. 2 (b) is shown the horizontal distribution of the water temperature in the layer 100 m deep. Some tongue-like isotherms of a comparatively low temperature, extend from the north-west part to the south-east part in the fishing ground.

Though the slant of water temperature is slight, at the region near the point 2°N, 94°E, the isotherms are more or less closely gathered, and the line of convergence is likely to have been formed between the cold water mass and the warm-water-mass of the surrounding region.

In Fig. 4 (a and b) is shown the vertical distributions of the water temperature (a) and salinity (b).

Near the surface layer, there exists the well-mixed surface water of high temperature (about 29.0°C.) and low salinity (less than 34.50 ‰.).

There is some ascending slant of isotherms of 29.0°C. towards the 1°N in the

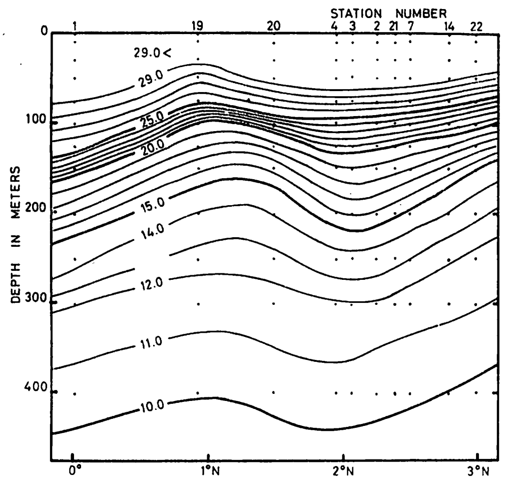


Fig. 4. (a)

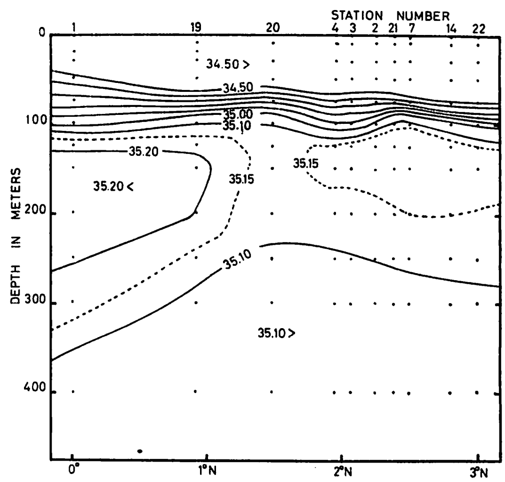


Fig. 4. (b)

Fig. 4. Vertical distributions of the temperature and the salinity in 1967.
(a) Temperature (b) Salinity

neighbourhood of the equator.

The existence of a current-rip running to east and west is suggested by these convexity isotherms.

At the part more northern than this, the isotherms continue to be declining, until, near the 1°N, the well mixed surface layer reachs its minimum, which is 30 m in depth. To the northern and southern parts, from here, the well-mixed surface layer becomes thicker and thicker, showing the depth of about 75 m near the 2°N and the equator.

Below this layer, there appears a quite remarkable thermocline similar to the one seen last year between the two parts, about 75 m and 100 m deep, respectively.

This thermocline, too, is of the ascending tendency towards the 1°N starting from the equator, the declining being slight from here to the point 2°N.

This fluctuation of the thermocline shows the upwelling and the sinking of the water-masses, which induces us to assume that the nutritive salt of the lower layer raised by the up-welling of the lower water-mass was the cause to make the fishing ground fertile.

Below this thermocline, a tonguelike protuberance of which the maximum salinity is higher than 35.15 ‰. extends from south and north towards the point 1°-30′E in the layer between 125 m and 250 m in depth.

From this fact it was assumed that there exist two water masses near the equator and 2°N along the meridian of 94°E, each of which is in possession of different characters.

This water with maximum salinity exists in the region with the temperature between 15.0°C. and 20.0°C., the numerical value of the water with the maximum salinity being higher than that of northern part by 0.50‰.

Below this layer, the declining of the water temperature being slight, the change of salinity being almost zero, the water temperature, 15.0°C., salinity, 35.20‰.

1968.

In Fig. 2 (c and d) is shown the horizontal distribution of water temperature in a layer 100 m deep.

In the northern fishing ground of the equator, the low-temperature-water exists at the eastern part, and the high temperature one exists at the western part, making the meridian of 94°E as their border line.

Each isotherm presents a figure resembling a form of letter "S", and the balance of the power of water-mass is ripped in the neighbourhood of the area 2°-30′N, 93°-30′E, and the low-temperature-water-mass, existing in the eastern part of the fishing ground, prevails over the high-temperature-water-mass, existing in the western part of the fishing ground.

The fluctuation of the water-temperature is comparatively sharp, the gathering of the isotherms being closest at the part between 1°N and 2°N along the meridian of 94°E.

In the southern fishing ground of the equator, at the region between 2°S and 3°S, 94°E and 95°E, there appears the isotherms of 22.0°C∼27.0°C., the water tempeature of which is very sharp, and in these isotherms, the low-temperature-water of the eastern part is to be seen flowing, in a wedge like figure, into the high-temperature-water.

This was supposed to have been brought forth through the following process: the subsurface-water-mass upwelling in the neighbourhood of this region was mixed up with the surface-water staying piled up, near the west coast of Sumatra Island to the formation of the fertile fishing ground along the currentrip between the low-temperature upwelling water-mass and the warm temperature water-mass of the surrounding water.

In Fig. 5 (a and b) is shown the vertical distributions of temperature (a) and salinity (b).

As in the case of last year, the so-called well-mixed surface water (temperature, about 29.0°C., salinity, less than 34.50‰) exists near the surface layer, the layer of the well-mixed surface water is the shallowest near the southern side of the equator, 2°S, with the depth about 50 m; and at the region 3°S and 1°-30′N, it becomes deeper, reaching the depth, about 100 m.

Below the surface layer, as in the last year, there exists the thermocline, the depth of which is bigger than that of the last year, being about 50 m.

In the lower layer of this thermocline observable between the two parts 150 m and 300 m deep respectively, a tonguelike protuberance of water-mass, with salinity higher than 35.20‰, extends from south to north, near latitude 2°N, making the water-layer with maximum salinity appear in this region.

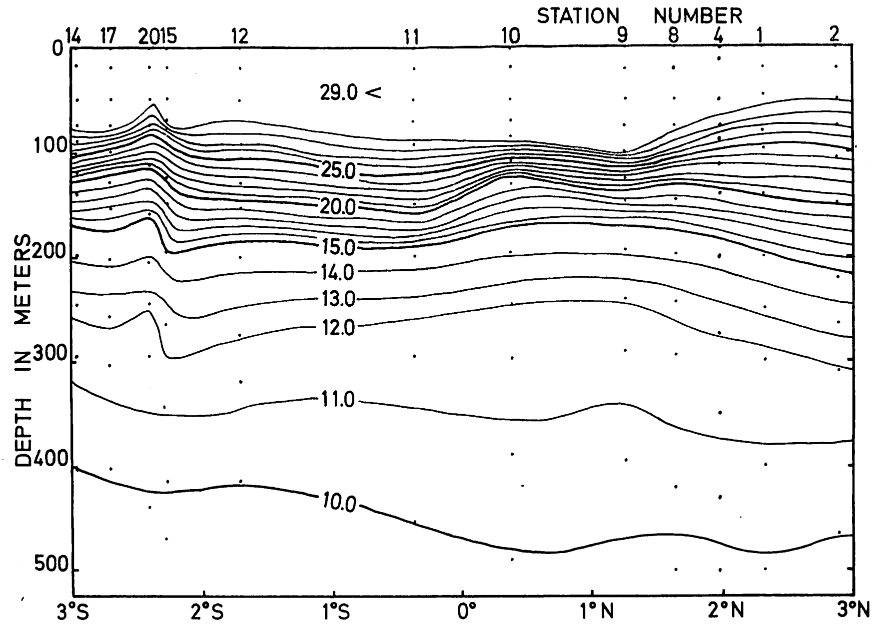


Fig. 5. (a)

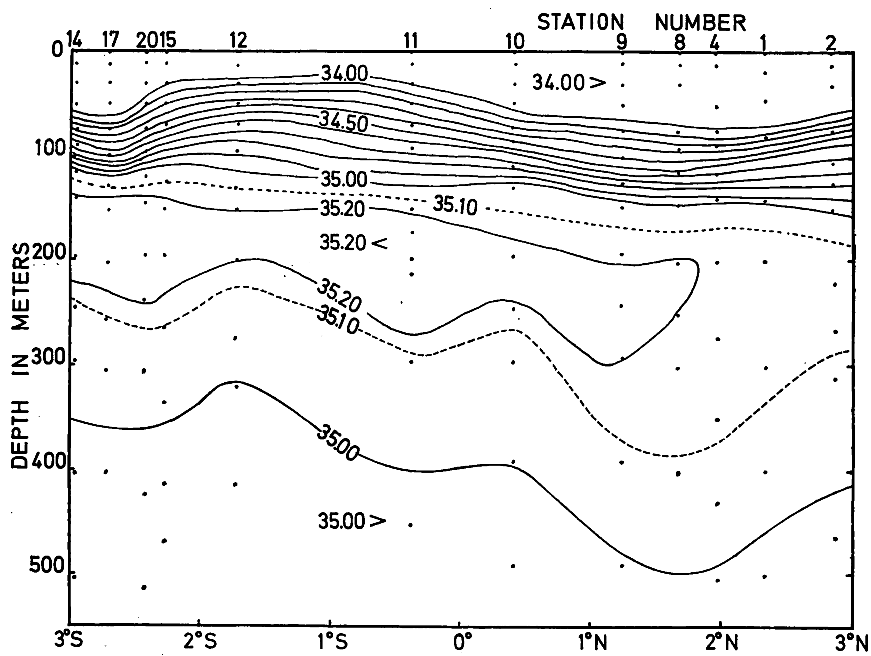


Fig. 5. (b)

Fig. 5. Verical distributions of the temperature and the salinity in 1968.
(a) Temperature (b) Salinity

The core of the water-mass with maximum salinity corresponds with the isotherm of 15.0°C.

Below this layer, both the isotherm and isohaline are in the rising tendency shifting from north to south, describing the gentle and wave-like curves.

As described above, the oceanic condition in this region may be summarized as in the following, namely a remarkable line of convergence is formed when the cold-temperature-water-mass flowing to south-east along the west coast of Sumatra Island comes into contact with the warm-temperature-water-mass flowing to west near the equator, and, though locally, there can be seen the appearance of the upwelling of the water-mass of the lower layer with low temperature.

In the vertical direction, there exists the well-mixed surface water of high temperature with low salinity (temperature 29.0°C., salinity, less than 34.60 ‰) near the surface layer less than 75 m in depth.

Because of the influence from the monsoon, this width of the well-mixed surface water varies every year.

In the region below this layer between 50 m and 150 m in depth, there exists an extremely remarkable thermocline.

This thermocline is caused by the fever brought forth by the actions of whirlpool and convection, showing the limit of the vigorous action of mixture, and is maintained by the downward propagation of the fever that comes in from the surface and from the slight upwelling of the cold-temperature-water below the thermocline.

In the Eastern Indian Ocean, below the depth of 150 m, the slant in the water-temperature is slight and the salinity maximum in the water amounts the point higher than 35.10 ‰.

2). Classification of water mass.

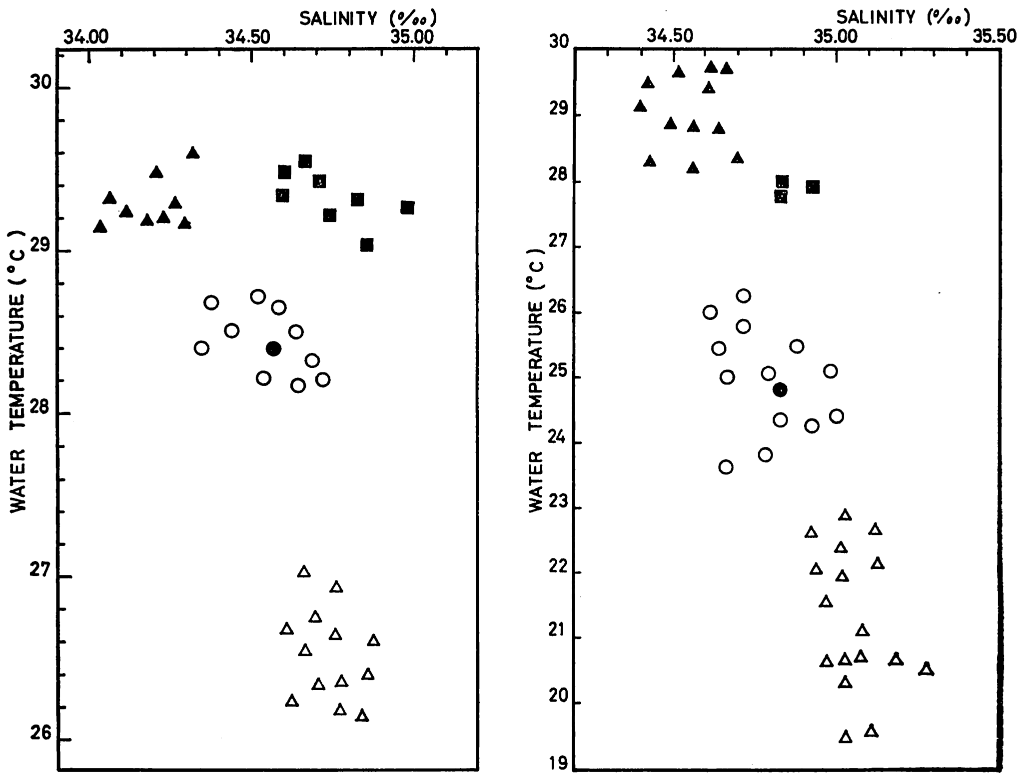
Judging from the comparison and investigation of the values of the temperature and salinity in the respective depth, the water masses in this region can be divided into the four groups, as shown in Fig. 6 (a and b).

"A type" water-mass consists of those with temperature about 29.0°C., salinity, about 34.50 ‰ in the parts 75 m and 100 m deep; which is higher by 4.0°C. in temperature and 0.30 ‰ in salinity than the average value of temperature and salinity observable in the region 100 m deep. By this fact it is shown that the water-mass with high temperature and low salinity observable in a layer 75 m deep is submerged down to the layer 100 m deep.

In "B type", there may be seen a difference in temperatures and salinitys observable in the layers 75 m and 100 m deep.

That is to say that in the regions 75 m and 100 m deep, the numerical value of temperature is lower than the average one by about 3.0°C., and the salinity is higher than the average one by 0.25 ‰.

Accordingly it happens that the numerical values of temperature and salinity



ig. 6. (a) Fig. 6. (b)

Fig. 6. Temperature and salinity diagram.

(a) 75 meters layer.
(b) 100 meters layer.

● Average value ▲ A type
△ B type ○ C type
■ D type

in a layer 75 m deep correspond to the average values of those in a layer 100 m deep, and the numerical values of temperature and salinity in the layer 100 m deep are almost the same with the average value of the layer 125 m deep.

By this fact it was shown that the water-mass of low temperature and high salinity in the lower layer has been upwelled near the region 75 m deep.

"C type" is the aboriginal one in this region and the numerical values of the temperature and salinity in the respective depth is almost the same with the average value.

This type of water-mass has been distributed all over this region and is confirmed to be the water-mass flowing from west to east near the equator.

In "D type" the numerical value of the water-temperature in the region 75 m deep is almost the same with the average value, but the numerical value of salinity is quite different from the average value of that in the region 75 m deep, and in the region 100 m deep, the numerical value of the salinity is the same with the average value, while the numerical value of the temperature is quite different from the average value.

This fact seems to show the irregularity in the change of value of the temperature and salinity, together with the process in which the intermediate water with low-temperature and high salinity upwelling from the low layer is mixed with the surface water with high temperature and low salinity sinking from the surface layer.

3). **Fishing condition**

The proportion of catch fish in this region is as in the follows: the yellowfin tuna hold is about 50 %, which forms the greater part, the bigeyed tuna and a kind of marlin hold are 20 % respectively, counting less than onehalf of the yellowfin tuna, and the miscellaneous fish hold is about 10 %.

The hooking rate of the catch fish in 1966 is as in the follows: the maximum value of the hooking rate of the catch fish was 4.24 %, the minimum value was 0.94 %, average value being 2.14 %.

As in Fig. 7, showing the hooking rate of the catch fish, the one on the St.

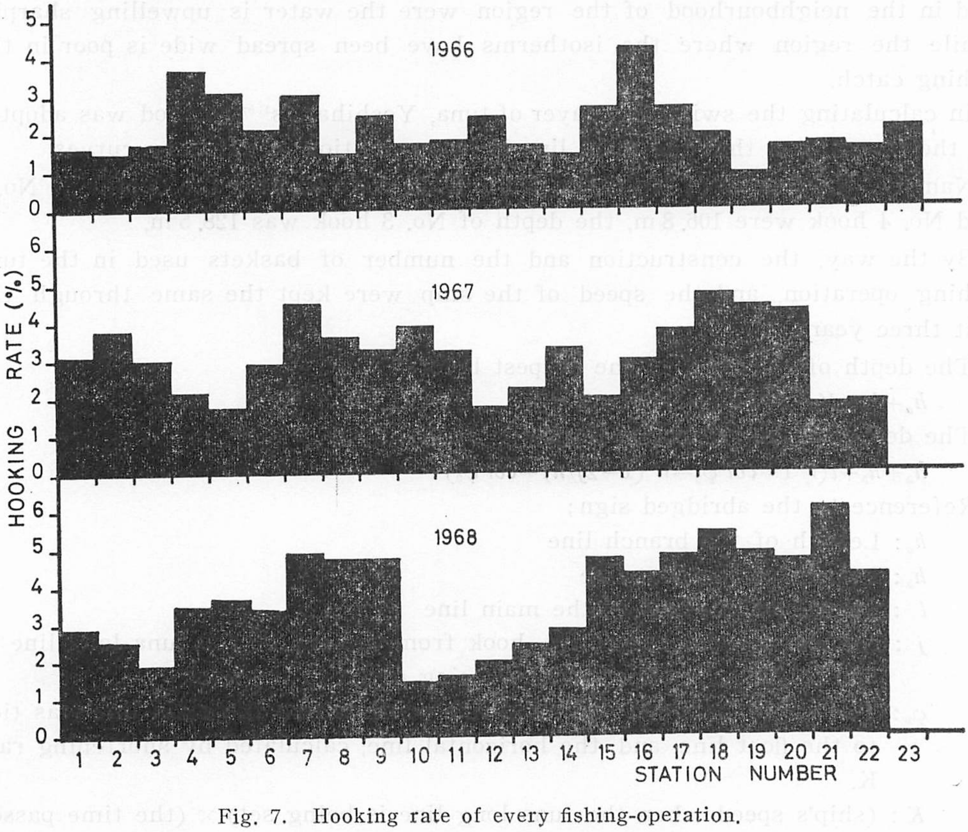


Fig. 7. Hooking rate of every fishing-operation.

No. 4 and 16 was highest, and that on the St. No. 5 and 7 was comparatively high, and that on the St. No. 1, 2, 3, 8, 13, 14, 19, 20, 21, and 22 was low.

The hooking rate of the catch fish in 1967 is as in the follows: the maximum value of the hooking rate of the catch fish was 4.76 %, minimum value was 1.74 % and the average value was 3.12 %, which was higher than that of the last year. As shown in Fig. 7, the hooking rate of the catch fish on the St. No. 7, 8, 19, and 20 was high, and that on the St. No. 4, 5, 15, 21, and 22 was low.

The hooking rate of the catch fish in 1968 is as in the follows: the maximum value of the hooking rate of catch fish was 6.06 %, the minimum value of that was 1.43 %, and the average value of that was 3.52 %.

As shown in Fig. 7, the hooking rates of the catch fish on the St. No. 7, 8, and 9 were comparatively high, and those on the St. No. 1, 2, 3, and 10 were low, in the northern side of the equator.

The hooking rates on the St. No. 11, 12, and 13 were low, and those from St. No. 15 to St. No. 22 were extremely high in southern side of the equator.

Judging from the result of the examinations of this fishing condition from Fig. 2 (a, b, c, and d), the most prosperous fishing condition is to be found on the so-called line of covergence where the isotherms are gathered quite closely and in the neighbourhood of the region were the water is upwelling sharply, while the region where the isotherms have been spread wide is poor in the fishing catch.

In calculating the swimming layer of tuna, Yoshihara's[4)5)] method was adopted on the assumption that the main line is in a condition of catenary curves.

Namely, the depths of No. 1 and No. 5 hook were 65.3 m, the depths of No. 2 and No. 4 hook were 106.8 m, the depth of No. 3 hook was 128.5 m.

By the way, the construction and the number of baskets used in the tuna fishing operation, and the speed of the ship were kept the same through the last three years.

The depth of the hook at the deepest layer=

$$h_a+h_b+l(\sqrt{1+\cot^2\varphi_o}+\cot\varphi_o)$$

The depth of the respective hook=

$$h_a+h_b+l(\sqrt{1+cot^2\varphi_0}-\sqrt{(1-2j/n)-cot^2\varphi_0})$$

Reference to the abridged sign;

h_a: Length of the branch line

h_b: Length of the float line

l : Length of one-half of the main line

j : Number of the respective hook from the end of the tuna long line in one basket, the series number being given to the hook

φ_0: The angle between the main line point where the main line was tied to the float line, and, the horizontal line, calculated by shortening rate K.

K : (ship's speed when the tuna long line is being set) $\times$ (the time passed while the tuna long line is set) / (the length of the main line in one basket) × (the number of baskets used during the tuna fishing operation)

In spite of the possible assumption that, in the calculation of the depth of long line hook, between the calculated and the surveyed values, there may be a remarkable difference due to the influence from the current, which is to be seen in the report by Hamuro[6], this method was adopted for the estimation of the relationship with the fishing condition, relying on the theory made by Nakagome[7][8], that calculated value has a conspicuous reliability, asserted in the thesis in which a comparative study was made on the difference between the calculated value and the surveyed value.

By the way, the different value of the depth of the respective hook was regarded as the swimming depth of the kind of tuna.

In other words it was estimated that the marlins were swimming in large number in the well-mixed surface water, the yellowfin tuna swimming in large number near the upper layer of the thermocline and the bigeyed tuna was swimming in large number in the thermocline or the intermediate water below this layer.

So, it might be concluded that the effort, first, to find and fix the line of convergece and the upwelling, and, the the next, to ascertain the relation between the depth of hook and the thermocline should be a factor that will be indispensable to decide the quality of the fishing condition in tuna fishing-operation in this region.

Acknowledgement

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