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Investigation of the Tuna Hand-line Fishing Grounds and some Biological Observations on Yellowfin and Bigeye Tunas Caught in the North-western Coral Sea

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Translated by Ron Green†

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Investigation of the Tuna Hand-line Fishing Grounds and some Biological Observations on Yellowfin and Bigeye Tunas Caught in the North-western Coral Sea

by

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Translator's note: This article was originally published in 1973 in the *Bulletin of the Far Seas Fisheries Research Laboratory* 8: 35-69. The translation is published with the kind permission of Mr Hisada and the Far Seas Fisheries Research Laboratory. I have attempted to make a fiathful trans-lation of the text. Where possible, the sentence structure and expression of the Japanese text are retained. However, I have modified the original text where necessary for comprehension. No attempt was made to check the data, literature or other material cited in the paper. The abstract is as published in the original paper.

ABSTRACT

In 1965 Japanese longliners tried and found it profitable to exploit pelagic shoals of yellowfin and bigeye tunas in the northwestern Coral Sea during the limited period between October and December. This fishing operation, called hand-line or tezuri, depends almost exclusively upon the two species, while the longlining catches various tunas and billfishes distributed there.

The surface hand-lining is limited in time and space of operation. The catch records for five years including 1965, 1966, and 1968 through 1970 show that the fishing activity lasted for only 13 to 39 days within an area between Lat. 14°S and 18°S, Long. 145°E and 148°E (Figs. 1-3, Table 1). In 1968, sporadic operations appeared in the waters between Lat. 18°S and 20°S, Long. 152°E and 153°E. Each year bigeye tuna dominate in the very beginning of the hand-lining period at surface temperature of about 26°C, and yellowfin tuna take the place during the later warmer period (Fig. 17). The hand-line is more efficient, in the limited time and space, than longline for catching yellowfin and bigeye tunas. Average value of catch-per-boat-day of hand-line was about 4 times of that of longline for yellowfin tuna and about 26 times for bigeye tuna.

There is found a considerable difference in size composition and ratio of matured fishes in the catch due to type of fishing. Yellowfin tuna specimens taken by hand-line coincide in range and modes of body length composition with those by longline in the same period of season (Figs. 6 and 7). But "matured fish" with gonad index of 1.6 or above comprised 70 percent in hand-line catch while only limited portion in longline catch from the same area in the same month (Fig. 11).

Difference in size composition by type of fishing is conspicuous in bigeye tuna. Most of hand-line catch are between 80 and 120 cm in body length, and a single mode appears around 90 to 110 cm. Large-sized individuals over 120 cm are abundant in catch by longline, which exhibit two modal groups of about 100 cm and 130 cm (Fig. 9). "Matured fish" with a higher gonad index than 3.0 comprise only a limited portion in the catch from the Coral Sea, 15 percent in hand-line catch and 5 percent in longline catch (Table 4). Dominant group consists of "maturing fish" with gonad index between 1.1 and 3.0 in hand-line catch, but "not-maturing individuals" with the index less than 1.1 in longline catch (Figs. 13 and 14).

Both hand-lining and longlining may depend on the same stocks of yellowfin tuna which are in the course of southward migration off the east coast of Australia as indicated by fairly good coincidence of fishing season and by resemblance of length composition of catch. Space and time variations of gonad index of the species indicate that the following explanation is possible for the surface concentration of the "matured fish" in the waters under discussion. Yellowfin tuna spawn in warm water of 26°C and above as already reported by some authors, and also as shown by present observations that the "matured individuals" dominate in the hand-line catch from the warm surface water, and increase even in the longline catch as the isotherm contour descends toward subsurface layer where the longline hooks are set. It is probable that the "matured

yellowfin tuna" are concentrated in the upper layer during the hand-lining period when the warm water covers there. As the warmer water expands, not only horizontally but also vertically, the distribution range of "matured fish" may be expanded to the deeper layer and they appear in the longline catch then the catch of hand-line in the surface layer decreases substantially.

Most of bigeye tuna in the hand-line catch are small in size and are supposed to be distributed mainly in the surface layer. Short duration of dominance of this species in the catch implies that the small bigeye tuna are concentrated close to the 26°C front near the surface, and are captured by the surface gear only when the front passes through the fishing area (Fig. 17).

Further examinations must cover the distribution of whale shark and topographic features of the area in relation to the concentration of the tunas. It is also required to survey whether or not the tunas are densely distributed nearer to the surface in other area outside of the hand-line fishing grounds where the 26°C front extends in the shallow layers.

INTRODUCTION

The yellowfin tuna fishery of the Coral Sea was opened up by the Japanese in 1952. In 1954 and 1955 it was observed that large black marlin visited the western part of this area between October and December. Now every year, between October and January, many medium-sized longliners fish in the Coral Sea for yellowfin and black marlin (Kamimura and Honma 1959; Warashina 1969a, 1970b; Unpublished material).

From November to December of 1965, longliners operating in the area 16° S, 146° E caught large quantities of surface schooling yellowfin and bigeye tunas with hand-lines. This is the first record of a hand-lining operation in the Coral Sea (Hanamoto 1966; Kume 1969). The hand-line fishery is an extremely small operation, covering an area of less than 200 square miles, with a substantial part of the operation being conducted within a 100 square mile zone. Although the relationship between the bathymetric features of the area and the presence of this fishery is not clear, each year about 10 to 20 longliners are involved in the hand-lining operation (Warashina 1969a, 1970a,b,c, 1971b,c; Unpublished material).

From 1969, pole-and-line vessels (Tanaka 1969; Warashina 1969b) and, since 1970, purse-seiners (Tanaka 1970b; Warashina 1970c) have been catching large quantities of surface fish between October and December. Thus, this fishery is characterised by its being very small, having a very short fishing season, and by the surface schools of tuna being caught by hand-lining, pole-and-line and purse-seining methods. Furthermore, the hand-line catch is characterised by biological features that are not observed in other hand-line fisheries.

In this report, data on the location and duration of the hand-line, pole-and-line and longline fishing operations, and the length-frequency and gonad index of the catches between 1965 and 1970 will be discussed in relation to water temperatures. Also, an investigation of the ecology of the yellowfin and bigeye tunas will be conducted. Appropriate data on the purse-seining operation could not be obtained and therefore it is not discussed in any detail in this paper.

1. THE HAND-LINING TECHNIQUE

Tuna have for a long time been caught by hand-lining in the coastal waters of Japan in an area extending as far as the Bonin Islands. However, the Coral Sea hand-lining operation is conducted on a far larger scale. It uses the snoods from the longlining gear for lines. There is also special hand-lining gear; however, this does not seem to be any more efficient than the snoods. Finely chopped saury is scattered on the surface of the water and is used as bait. The internal organs of the bigeye and yellowfin tunas have also been used as bait. As the Coral Sea fishery is extremely limited in duration and area of operation, most boats seem to use the snood technique. The fish caught by hand-lining and longlining are larger than the pole-and-line catch.

The fish were first caught by hand-lining when they were observed to be following whale sharks (Rhincodon typhus) and when their presence was indicated by the flocking of birds at the water surface. Sometimes, dense schools of fish have been observed on an echo sounder at depths of about 80 m and have then been brought to the surface by spraying water and chumming. The fish can be caught throughout the day, but usually early morning or the evening are the most effective times.

2. DATA

This report is based on catch records, length-frequency data and gonad index data from the hand-line, longline and pole-and-line fishing operations in the Coral Sea, and on observations on the relationship of the fishery to water temperature.

2.1 Catch records

Hand-line catch records for the Coral Sea have been collected since 1965; however, it was not possible to obtain any data on the 1967 hand-line operation. The 1965, 1966 and 1968-1970 data were derived from 86 voyages by fishing boats and government vessels, and account for the major part of the fishing operations during this period. The data were separated into one-degree-square zones over five-day periods (for instance, from day 1 to day 5, day 6 to day 10) and the catch-per-boat-day for each zone was obtained.

The distribution of fish density was shown by the "hook rates"* per month and per one-degree-square area. As there have been few recent longline operations in the Coral Sea (Warashina 1969a, 1970; Unpublished material), the seasonal distribution of fish each year is assumed to have not changed very much, so the previously published diagrams of the distribution of longline hook rates for yellowfin (compiled by Kamimura and Honma in 1959) and bigeye (compiled by Kume and Shiohama in 1965) have been used. The catch-per-boat-day from 1965 to 1970 was calculated from the hand-line data in the Annual Reports of Effort and Catch Statistics by Area on the Japanese Tuna Longline Fishery (1967-1972).

Translator's note: * "Hook rate" is not defined in the Japanese text but is assumed to be the number of fish caught per 100 hooks. See: Nakagome, J. (1961) Bulletin of the Nankai Regional Fisheries Research Laboratory **27**:302

Complete catch records on pole-and-line fishing effort in the Coral Sea could not be obtained; however, from the landed catch of seven vessels (which had been operating in the Coral Sea in 1969 and 1970) it was possible to get a daily breakdown of the catch of the different species.

2.2 Body length

There are length data on 6089 yellowfin and 4650 bigeye caught by hand-lining in the Coral Sea.

The length data on the longline catch between October and December for 1965 to 1970 were obtained from 15965 yellowfin from the area 10° to 20° S, 140° to 150° E and from 2255 bigeye from the area 10° to 20° S, 140° *f* to 160° E. Bodylength data on 679 yellowfin and 510 bigeye caught by pole-and-line were also obtained.

From these data, which include body length measurements of the catches of the government vessels, from fish at the fish market and data calculated from the weight of caught fish, the body-length frequency for each method of fishing was determined.

The hand-line and longline fish length measurements were recorded at 4 cm intervals, with the first interval at 41-44 cm. The length measurements of the pole and line catch were made at 2 cm intervals, with the first interval at 41-42 cm.

2.3 Gonad weight

The boats of the official agencies have measured gonad weight as well as the length frequencies of the catch. The ovary weights of 589 yellowfin and 438 bigeye caught by hand-lining and of 3194 yellowfin and 224 bigeye caught by longlining have been obtained. The gonad index was then calculated from the ovary weight, based on a method used by Kikawa (1966). The results were combined into increments of 0.5, from 0.1 to 0.5 0.6 to 1.0, etc. Kikawa (1966) stipulated that yellowfin with a gonad index greater than 1.6 and bigeye with a gonad index greater than 3.1 are mature. In addition, Sakamoto (1969) has stipulated that bigeye with a gonald index less than 1.0 are non-mature fish, while fish with a gonad index of 1.1 to 3.0 are maturing fish. These stipulations are followed in this work.

2.4 Water-temperature data

Bathythermograph measurements and noon surface-water temperatures were obtained from the government vessels working in the Coral Sea region between October and December of 1965 to 1970.

3. RESULTS

Comparisons were made of the body length and gonad index of bigeye and yellowfin tunas, of daily catch rates, of the location of fishing grounds and of the durations of the fishing season with respect to the type of fishing operation. Also, observations were made on the effect on the hand-line catch of changes in surface-water-temperature and the temperature of water between 0 and 250 m depth.

3.1 Fishing grounds and fishing season

3.1.1 *Hand-lining*

The hand-line fishery typically extends over ten one degree square areas, between 14° and 18° S, 145° and 148° E, and includes the area as far west as the east coast of Australia between Cooktown and Townsville. In addition, hand-lining was conducted in the area 18° - 20° S, 152° - 153° E in 1968 (Figure 1).

The fishing season is from October to December each year. The first day of fishing was on 27 November 1965, but since then the starting date has become earlier and earlier. In 1969 the season opened on 23 October, and in 1970 on 30 October. The fishing season is also very short, lasting between 13 and 39 days (Table 1).

Table 1. *Period, duration and number of boats of hand-line operation* made by longliners in the Coral Sea, 1965-1970.

Year	Period	Duration in days	Number of boat
1965	27 Nov. - 9 Dec.	13	21
1966	4 Nov. - 27 Nov.	24	29
1967	No available data		
1968	3 Nov. - 18 Nov.	16	15
1969	23 Oct. - 30 Nov.	39	13
1970	30 Oct. - 16 Nov.	18	8

The number of operations, and the resultant catch, increases in the middle of the season. The catch also changes with the number of operations and the number of one-degree-squares fished (Figure 2; Appendix 2).

Annual seasonal changes in the period of the fishing season and the catch-per-boat-day are explained below (Figure 3). In 1965, fishing operations were conducted for 13 days from 27 November to 9 December. The catch-per-boat-day of yellowfin was between 100 and 150 fish. It reached a peak of 150 fish between 1 and 5 December. For bigeye the catch-per-boat-day in the early part of the season was greater than for yellowfin, and reached 220 fish by 30 November. However, by 5 December this fell to 110 fish, and by 9 December it was only 30 fish.

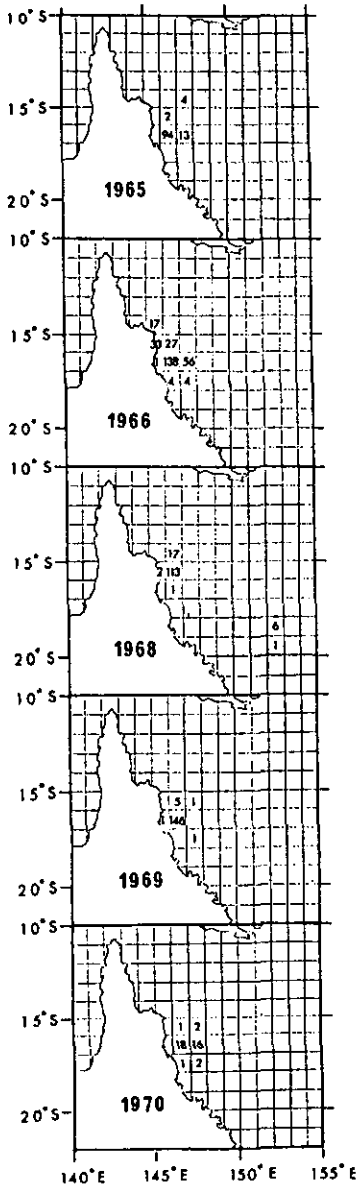

Fig. 1. Distribution of fishing effort of hand-line operations, compiled by one-degree square, in terms of boat-days, in the Coral Sea, 1965, 1966, and 1968-1970.

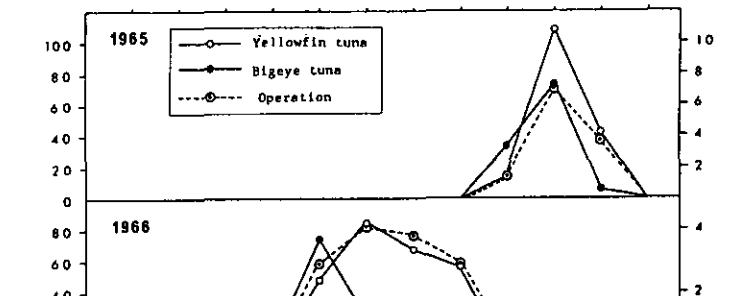

Fig. 2. Number of boat-days of hand-line operations, and resultant catch of yellowfin and bigeye tunas compiled by five-day period, in the Coral Sea, 1965, 1966, and 1968-1970.

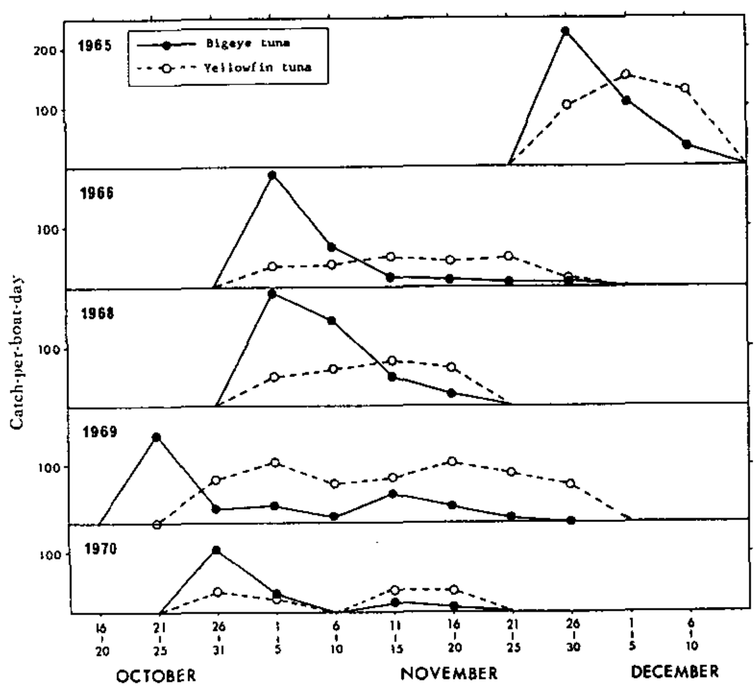

Fig. 3. Catch-per-boat-day of yellowfin and bigeye tunas, compiled by five-day period, in hand-line operations in the Coral Sea, 1965, 1966, and 1968-1970.

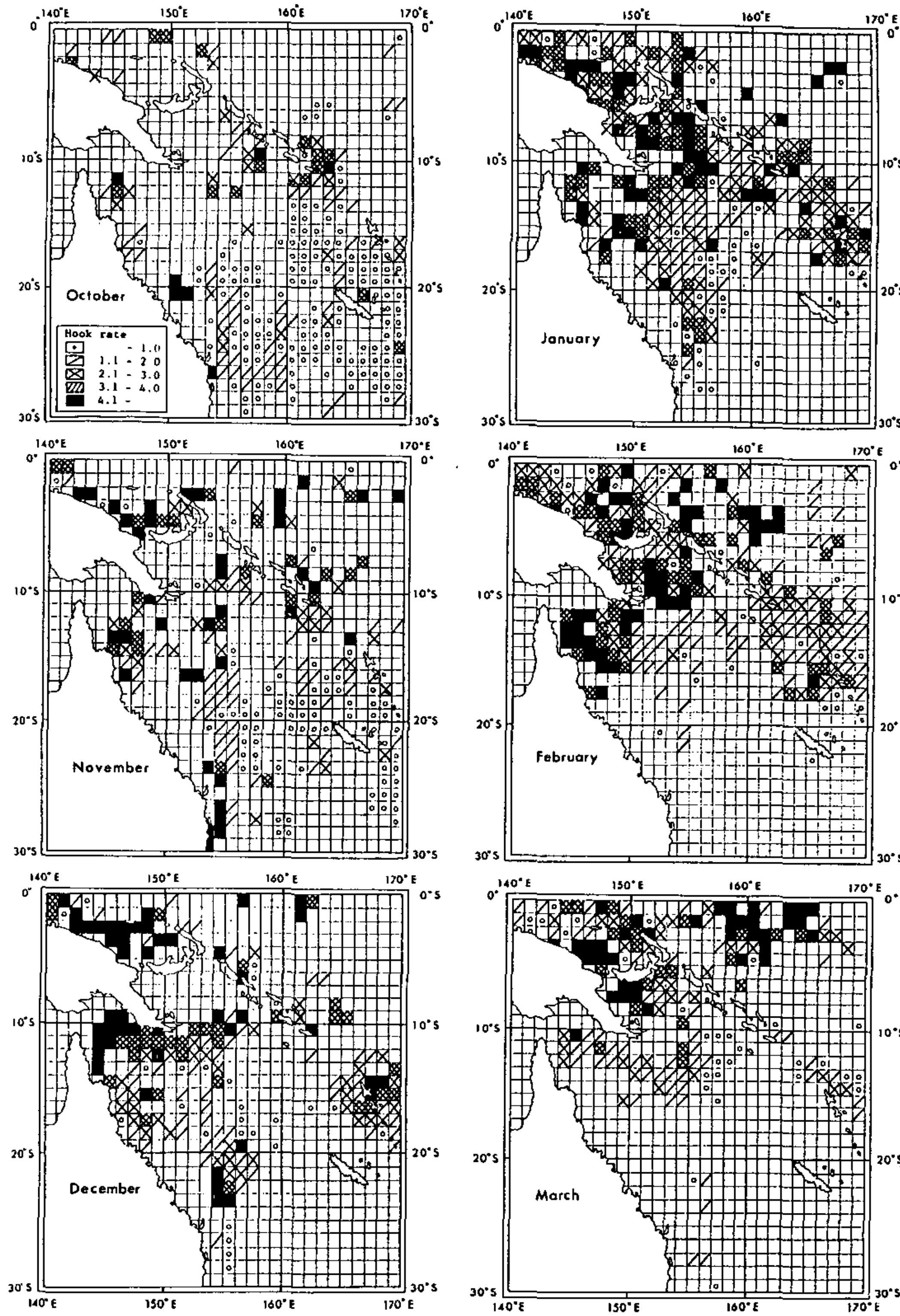

Fig. 4. Average distribution of hook rates of yellowfin tuna in longline fishery, compiled by one-degree square, in the southwestern Pacific Ocean, October–March.

After KAMIMURA and HONMA (1959).

In 1966 fishing operations were conducted for 24 days from 4 to 27 November. The yellowfin catch-per-boat-day increased from 25 fish prior to 5 November to about 50 fish for the three five-day periods from 11 to 27 of November. By the end of the season the catch-per-boat-day had dropped to 10 fish. For bigeye, the catch-per-boat-day exceeded that for yellowfin, reaching 200 fish for the five-day period to 5 November, but dropped to 150 fish for the period ending 10 November. The catch rate continued to drop gradually towards the end of the season, reaching only 15 fish for the period ending 15 November.

In 1968, fishing operations were conducted for 16 days from 3 to 18 November. The catch-per-boat-day of yellowfin increased from 50 fish at the start of the season to 80 fish for the period 11 to 15 November, and the season closed with a catch rate of 70 fish. The catch-per-boat-day of bigeye at the beginning of the season was superior, at 200 fish; however, this rapidly dropped to 25 fish by the end of the season.

In 1969, the season lasted for 39 days from 23 October to 29 November, which was by far the longest period of operation over the five years. Prior to 25 October, hardly any yellowfin were caught; however, by 5 November the catch-per-boat-day was being maintained at between 60 and 100 fish. In contrast, for the period before 25 October, the bigeye catch reached 150 fish; however, after 26 October this had dropped to well below the catch rate of yellowfin.

In 1970, the season lasted for 18 days from 30 October to 16 November, although it appears that there were no operations between 6 and 10 November. The reason for the catch-per-boat day of yellowfin being less than 40 fish is unclear. The bigeye catch followed the usual pattern, with good early-season catches of 100 fish per boat day, which dropped to 30 fish by November.

The species composition of the catch shows a clear seasonal trend, with the yellowfin catch-per-boat-day increasing gradually towards the middle of the season and then stabilising, while for bigeye the early-season catch rate increases rapidly and then drops after the middle of the season.

3.1.2 *Longlining*

The average distribution of hook rates of yellowfin tuna in the longline fishery in 10°-20°S, 140°-150°E, which includes the hand-line fishery, was found to increase from October to February and then to decrease in March.

Considering the change in hook rates with latitude, it was found that the October hook rate was higher north of latitude 14°S. However, south of latitude 14°S, the hook rate gradually increased from November, and by January was about the same as in the region north of 14°S. However, in March it suddenly dropped (Kamimura and Honma 1959).

It can be seen from Figure 4 that the longline yellowfin hook-rate increases at the time and in the location (14° - 18°S) where the hand-line fishery operates. In contrast, the bigeye hook-rate is extremely low, averaging less than 0.4%, and does not appear to undergo clear seasonal changes (Figure 5).

3.1.3 *Pole-and-line*

In 1969, four boats operated in the area 15° - 16° S, 146° - 149° E between 3 and 28 November. In 1970, three boats operated in the area 15° - 17° S, 146° - 147° E from 29 October to 16 November (Tanaka 1969, 1970a,b, 1971). Thus, it can be seen from the above and from Figure 1 and Table 1, that the duration and location of the pole-and-line operation coincide quite closely with those of the hand-line and longline operations. The notable feature of the pole-and-line catch was that, in 1969, 50% of the gross weight consisted of skipjack, and the number of small (80 cm length) yellowfin and bigeye tuna was very high (Warashina 1969b, 1970a; Tanaka 1970a). However, in contrast to 1969, hardly any skipjack were caught in 1970 and yellowfin and bigeye dominated the catch.

3.2 The efficiency of the different fishing methods

The hand-line operation is aimed chiefly at yellowfin and bigeye: however, occasionally skipjack and small black marlin and blue marlin are also caught. For the five-year period from 1965 to 1970 (excluding 1967), the average catch-per-boat-day of yellowfin was 71.6 fish and for bigeye 49.2 fish (Table 2).

Table 2. Number of boat-days, catch in number and catch-per-boat-day of yellowfin and bigeye tunas in hand-line operation made by longliners in the Coral Sea, 1965-1970.

Year	Number of boat-days	Catch in number			Catch-per-boat-day		
		Total	Yellowfin	Bigeye	Total	Yellowfin	Bigeye
1965	113	27,186	15,756	11,430	240.6	139.4	101.2
1966	280	19,288	12,937	6,315	68.9	46.3	22.6
1967	-	-	No available data		-	-	-
1968	140	22,785	9,692	13,093	162.8	69.2	93.5
1969	154	16,232	12,643	3,589	105.4	82.1	23.3
1970	40	2,340	989	1,351	58.5	24.7	33.8
Total or average	727	87,831	52,053	35,778	120.8	71.6	49.2

In contrast, longlining resulted in catches of almost every type of tuna and billfish species that has been reported from this fishery. The catch has included: albacore, swordfish, striped marlin, blue marlin, black marlin, sailfish and spearfish, as well as yellowfin and bigeye tunas. The catch-per-boat-day of each species over the five-year period is shown in Table 3. The yellowfin catch-per-operation rate was the largest at 18.1 fish, followed by black marlin at 11.5 fish. The catch rate of the remaining fish averaged less than 2 fish per operation and the total catch rate of these species was 34.7 fish.

Table 3. Number of operations, and catch-per-operation of tunas and billfishes of longliners in the northwestern Coral Sea (Lat. 10°S–20°S, Long. 140°E–150°E) during the fourth quarter (October–December), 1965–1970.

Year	Number of operations	Catch-per-operation								
		Total	Albacore	Bigeye	Yellow-fin	Sword-fish	Striped marlin	Blue marlin	Black marlin	Sailfish & Spearfish
1965	872	37.5	3.8	2.4	15.9	0.3	0.1	0.4	13.9	0.7
1966	1,142	37.6	2.5	3.2	24.4	0.1	0.2	0.4	6.4	0.3
1967	313	29.8	0.9	0.5	12.8	0.3	0.2	0.5	14.2	0.5
1968	450	30.5	0.7	2.5	15.4	0.4	0.1	0.4	10.5	0.5
1969	652	33.2	0.7	1.6	16.3	0.3	0.1	0.4	13.1	0.7
1970	739	39.7	1.7	1.0	23.9	0.4	0.2	1.1	10.8	0.6
Average	-	34.7	1.7	1.9	18.1	0.3	0.2	0.5	11.5	0.6

Data from Fisheries Agency of Japan (1967-1972)

In terms of the catch-per-boat-day, hand-lining is 4 times more efficient than longlining for yellowfin and 26 times more efficient than longlining for bigeye. In particular, it is worth noting that although bigeye are caught in very limited numbers by longlining, they are caught in large quantities by hand-lining. The total average catch-per-boat-day for pole-and-lining was 6-8 tonnes, while for hand-lining it was only 1-4 tonnes. The number of pole-and-lining boats has recently begun to increase.

3.3 Body length frequency

3.3.1 *Yellowfin*

The length of the fish caught by hand-lining was between 70 and 160 cm. The mode of the catch in 1965, 1966 and 1970 was about 100 cm and in 1968 and 1969 it was about 120 cm (Figure 6).

The longline fishery is quite large and therefore the length-frequency data have been divided into two groups by area (10° - 15°S, 140° - 150°E and 15° - 20°S, 140° - 150°E; Figure 7).

It can be seen that each year the modes of the length-frequency data for the hand-lining and longlining catches are quite comparable. Furthermore, the modes do not change very much by month or by the area of the fishery.

In contrast, in 1969 and 1970 the yellowfin caught by the pole-and-line method were much smaller than the fish caught by longlining or hand-lining: they were between only 50 and 70 cm long (Figure 8).

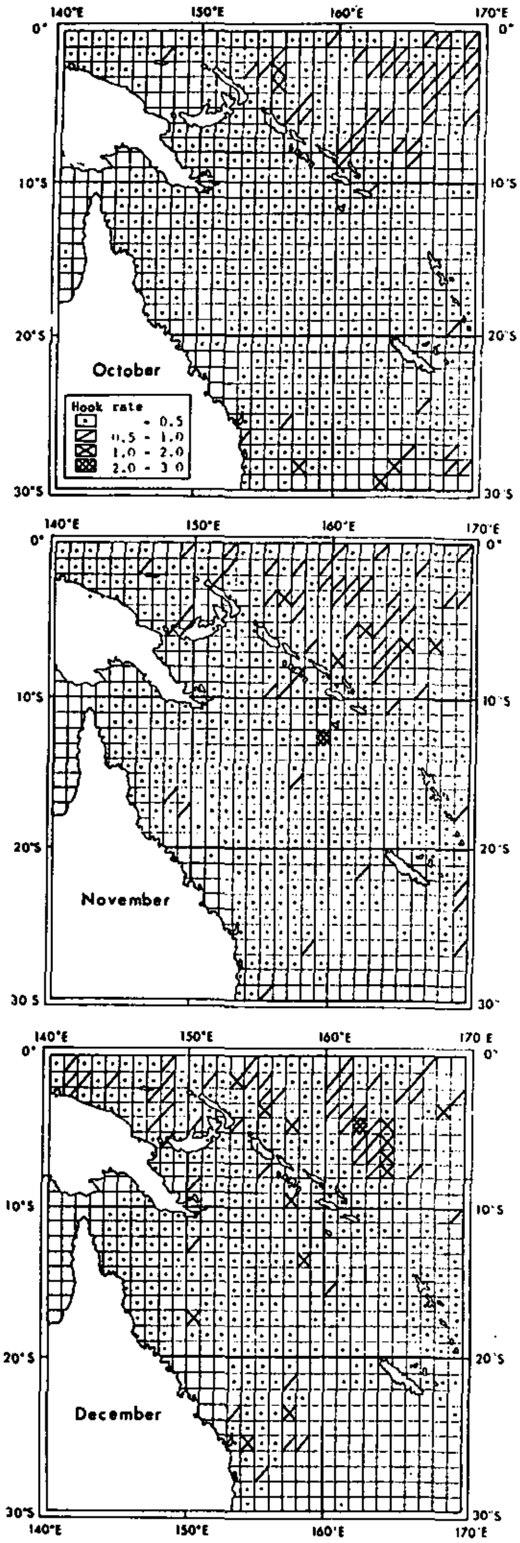

Fig. 5. Average distribution of hook rates of bigeye tuna in longline fishery, compiled by one-degree square, in the southwestern Pacific Ocean, October-December.

After KUME and SHIOHAMA (1965).

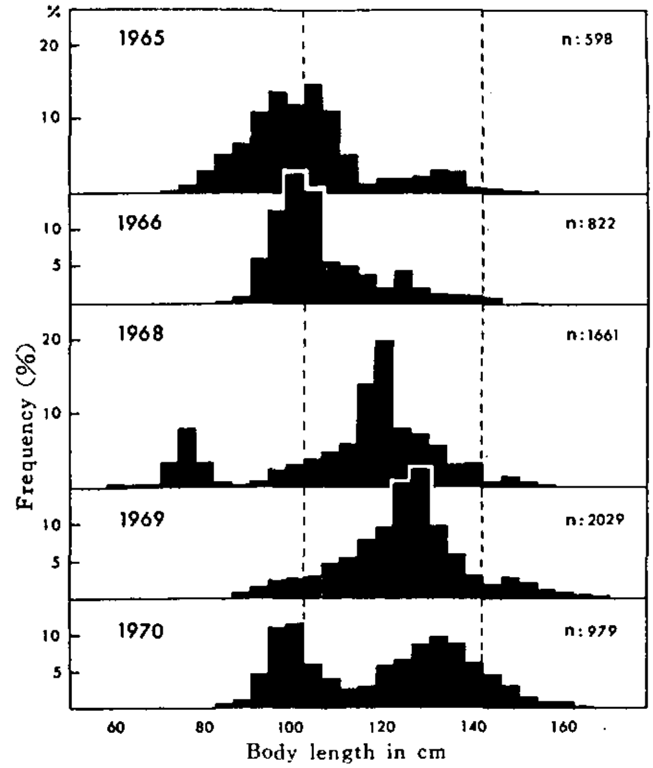

Fig. 6. Body length composition of yellowfin tuna in hand-line operation in the Coral Sea, 1965, 1966, and 1968-1970.

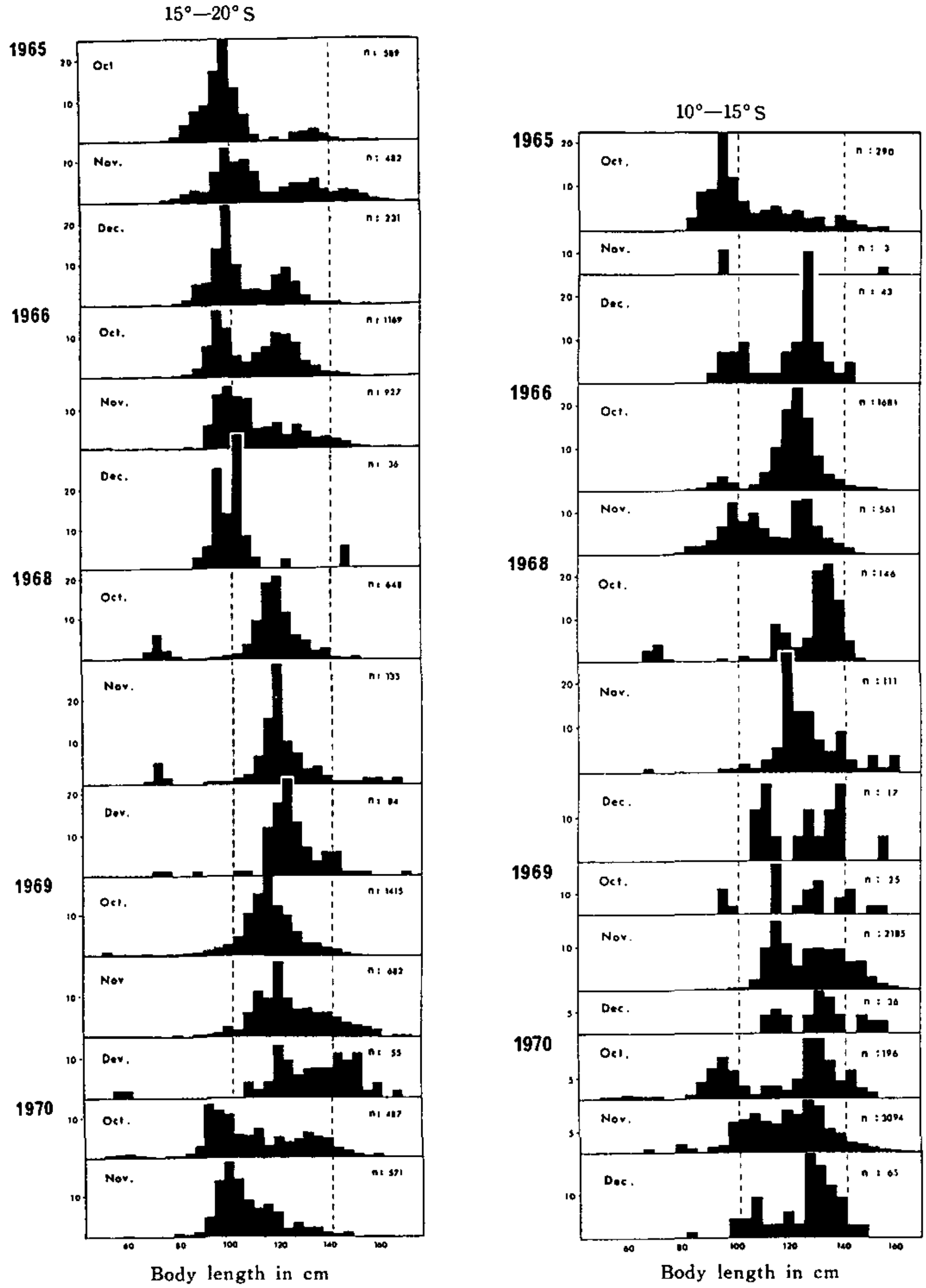

Fig. 7. Body length composition of yellowfin tuna in longline operation in the Coral Sea, 1965, 1966, and 1968–1970.

3.3.2 *Bigeye*

The bigeye caught by hand-line were between 60 and 160 cm in length. In 1965 and 1966, the mode of the catch was about 100 cm. In 1968 it was 110 cm and in 1969 and 1970 it was 90 cm. Except for 1970, individuals with a body length greater than 120 cm were rare.

The fish caught by longlining were between 50 and 170 cm long; however, over half the catch was at least 120 cm in length. The modal length of the catch in 1965 and 1966 was about 95 cm, in 1968 about 100 cm, in 1969 the catch was bimodal at 100 and 140 cm, and in 1970 it was 90 and 140 cm (Figure 9).

The bigeye tuna caught by pole-and-line were smaller than the hand-line or longline catch -- between 60 and 80 cm in length (Figure 10).

3.4 Gonad Index

3.4.1 *Yellowfin*

The hand-line catch consisted of 70-95% mature fish having a gonad index (GI) greater than 1.6. The mode of the index in 1965 was 0.6 - 1.0, in 1966 2.1 - 3.0 and in 1968 to 1970 2.1 - 3.5 (Figure 11).

The longline fishery is much larger in area and therefore the GI data have been presented as a function of the latitude and month of the catch (Figure 12). Although the length frequency did not vary very much with the time and location of the catch, from this diagram the variation in GI is quite clear. For the same month the proportion of individuals with a high GI increases northwards and for the same latitude the proportion of individuals with a high GI increases towards December. Fish with a GI of 2.1 - 3.5 were caught between 10° and 12°S in October; however, by November such fish were caught throughout the fishery.

3.4.2 *Bigeye*

In general the hand-line catch consisted of smaller but more mature fish than the longline catch (Figure 13). The GI does not, however, only vary with the method of fishing used but is also a function of the length of the fish (Figure 14). Of the fish less than 100 cm in length, 81% of the hand-line catch consisted of maturing fish having a GI of 1.1 - 3.0, while only 3% of the catch were mature and had a GI of greater than 3.1. In contrast, the longline catch contained no fish with a GI greater than 2.1, and 88% of the catch consisted of immature fish having a GI less than 1.0. Among the fish over 100 cm in length, there was considerable variation in GI; the relationship of GI to type of fishing operation was unclear. However, the hand-line catch generally consisted of maturing fish while the longline catch consisted of immature fish (Table 4). Mature individuals with a GI greater than 3.1 comprised 12% of the hand-line catch and 5% of the longline catch.

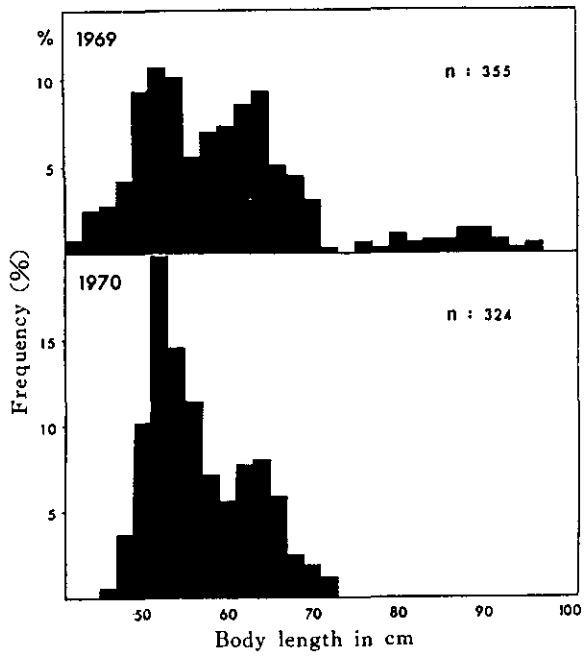

Fig. 8. Body length composition of yellowfin tuna in pole-and-line operation in the Coral Sea, 1969 and 1970.

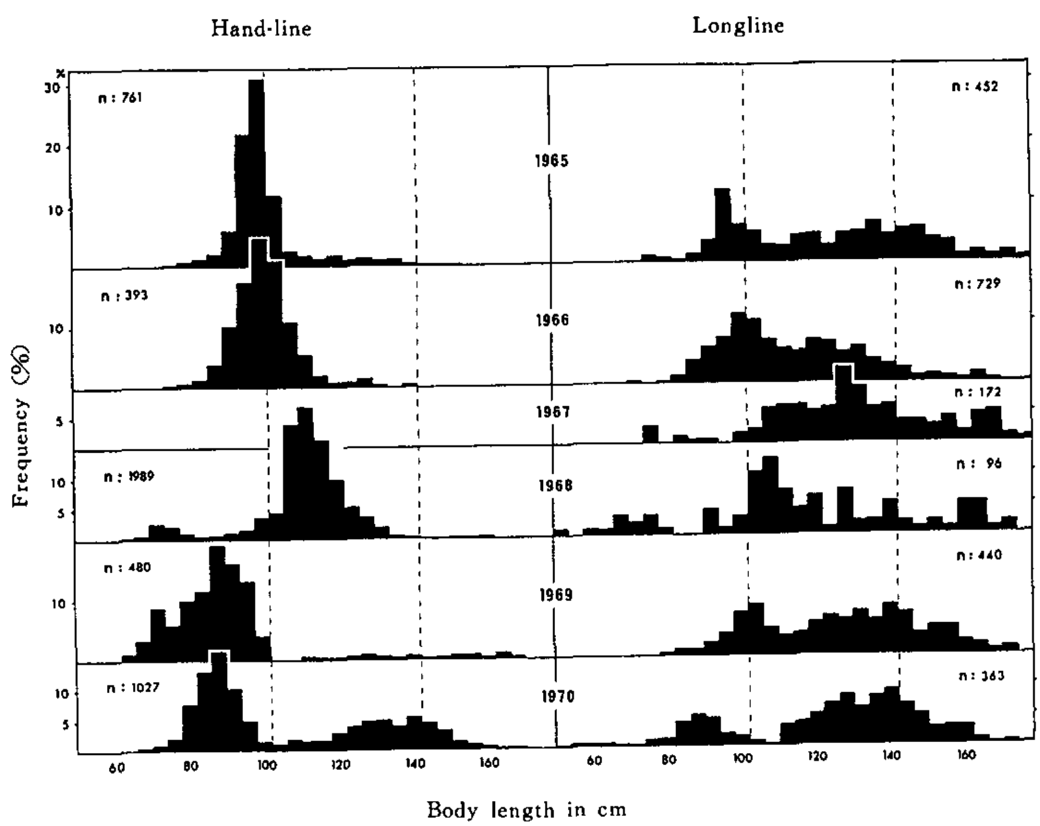

Fig. 9. Body length composition of bigeye tuna in hand-line and longline operations in the Coral Sea, 1965–1970.

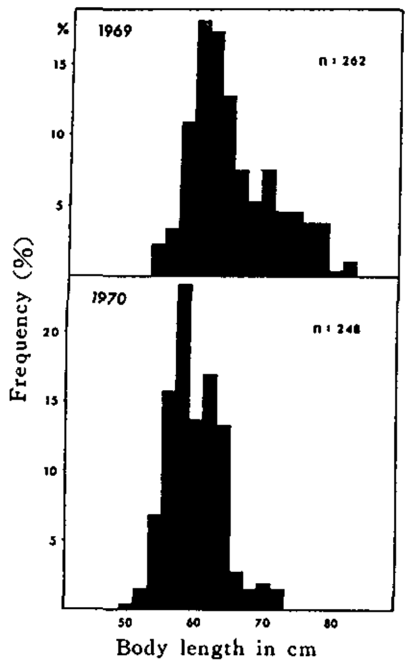

Fig. 10. Body length composition of bigeye tuna in pole-and-line operation in the Coral Sea, 1969 and 1970.

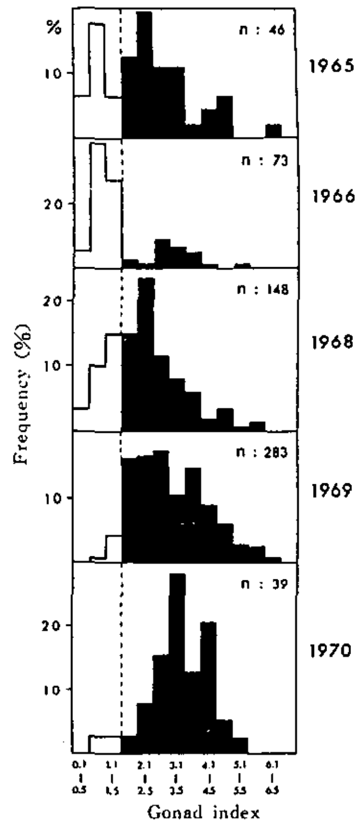

Fig. 11. Gonad index composition of yellowfin tuna in hand-line operation in the Coral Sea, 1965, 1966, and 1968-1970.

Shade denotes gonad indices over 1.5.

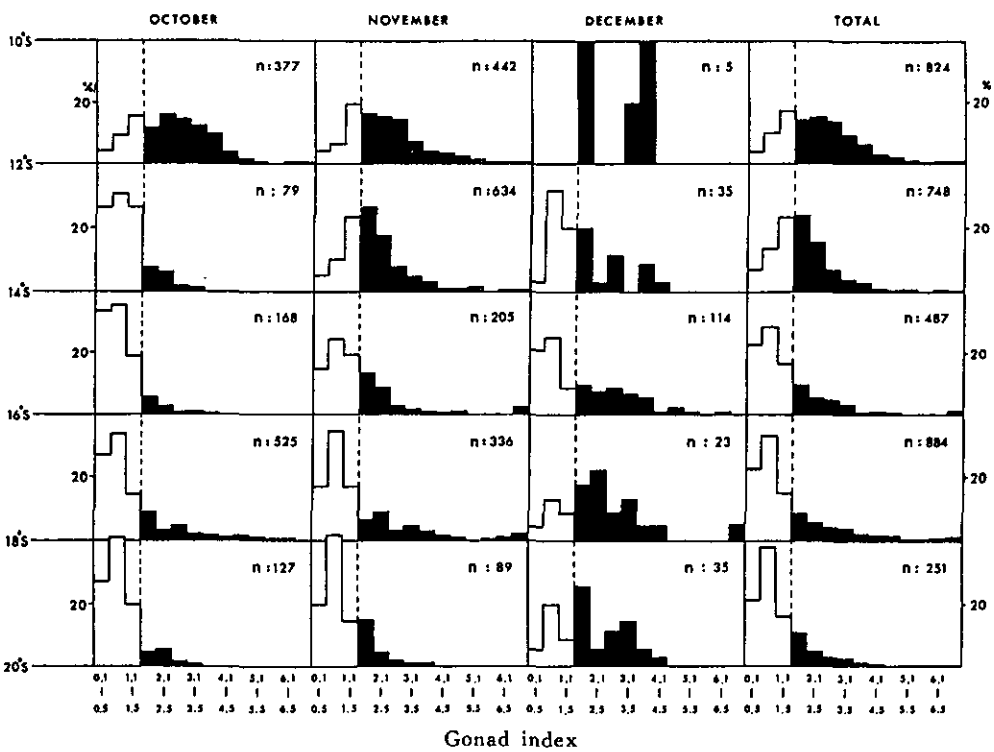

Fig. 12. Latitudinal change of monthly gonad index composition of yellowfin tuna in longline operation in the northwestern Coral Sea, Lat. 10°-20°S, Long. 140°-150°E, 1965-1970.

Shade denotes gonad indices over 1.5.

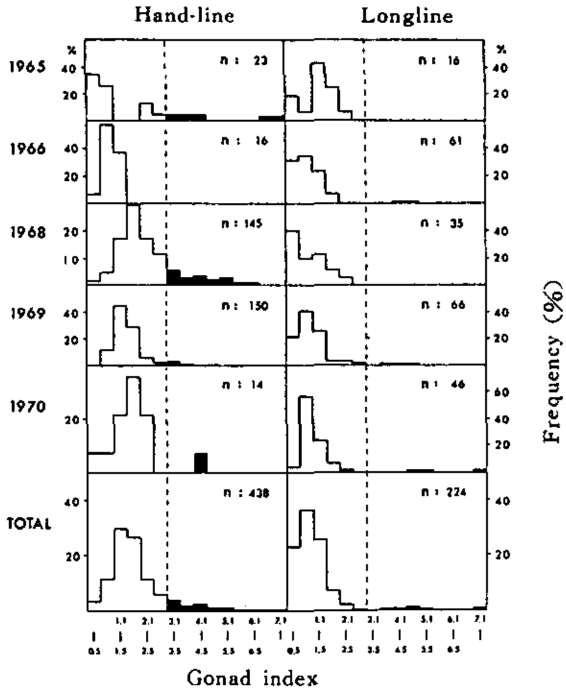

Fig. 13. Gonad index composition of bigeye tuna in hand-line and longline operations in the northwestern Coral Sea, Lat. 10°-20°S, Long. 140°-150°E, 1965, 1966, and 1968-1970.

Shade denotes gonad indices over 3.0.

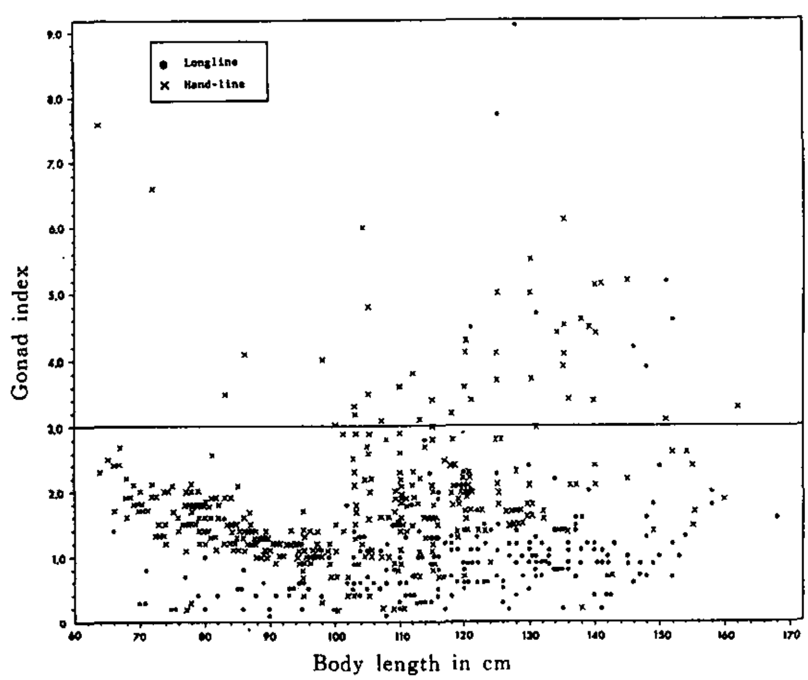

Fig. 14. Relationship between body length and gonad index of bigeye tuna in hand-line and longline operations in the Coral Sea, 1965-1970.

Table 4. Gonad-index composition of big-eye tuna over 100 cm in body length taken by hand-line and longline in the Coral Sea, 1965, 1966, 1968-1970.

Gonad index	Hand-line (%)	Longline (%)
0.1 - 1.0	13%	55%
1.1 - 2.0	43	37
2.1 - 3.0	25	4
3.1 and higher	19	5
Number of specimens	188	189

3.5 Changes in water temperatures on the hand-line fishing grounds

According to bathythermograph measurements taken at the centre of the hand-line fishery (16°S, 146°E), the (vertical) water-temperature gradient is not very steep, with the surface temperature being 25° - 28°C, at 50 m depth 25° - 26°, and at 100 m depth 24° - 26°C.

The difference in water temperature between the start and end of the fishing season at depths from 50 to 250 m was usually less than 1°C. Even in 1970, when the temperature fluctuations were particularly large, the difference in temperature did not exceed 2°C. However, at the surface the temperature ranged from 25°C at the start of the season to between 27° and 29°C at the end of the season (Figure 15).

The relationship between the duration of the hand-line fishing season and changes in surface water-temperature in the area 14° - 18°S, 144°-148°E is very noticeable. The average surface-water temperature rises very gradually from 25°C to 26°C at the start of the fishing season, followed by a period when the temperature rises rapidly from 26°C to over 27°C. The time when the surface temperature passes 26°C varies each year. In 1965 it occurred between 26 and 30 November, in 1966 between 6 and 10 November, in 1967 on 21 and 25 October, in 1968 between 1 and 5 November and in 1969 between 26 and 31 October (Figure 16). The start of the hand-lining operation each year corresponds well with this change in surface water-temperature. For instance in 1965, when the rise in water-temperature was late, the start of hand-lining operations was also delayed. Conversely, in 1969 and 1970 when the surface water-temperature passed 26°C in early October, the hand-lining operations started early.

The time of the start of the fishing season for bigeye and yellowfin tuna depends on the water temperature. Bigeye usually appear when the temperature is between 25.8° and 26.7°C, and yellowfin when the temperature is between 26.7° and 28.4°C. However, there are exceptions to this, such as between 26 and 31 of October 1965 when, although the water temperature was 25.8°C, the catch consisted of 74% yellowfin. Another exception occurred on 1 to 5 November 1970 when, despite the surface water temperature being 27.5°C, bigeye made up 58% of the catch. Examples such as this usually occur when there is a rapid rise in water temperature

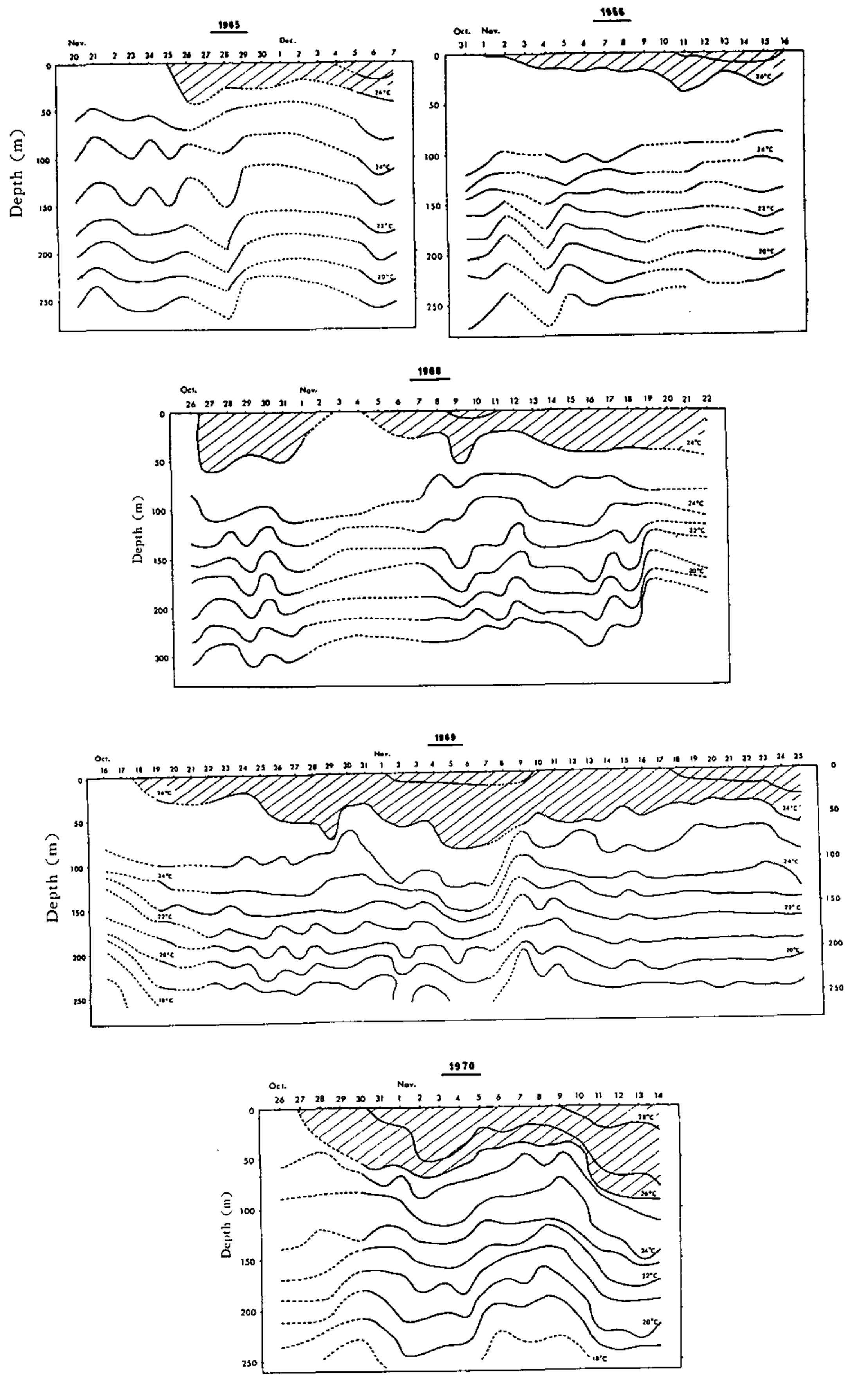

Fig. 15. Daily change of vertical distribution of water temperature at selected stations around Lat. 16°S, 146°E, the Coral Sea, 1965, 1966, and 1968–1970.

Shade denotes temperature over 26°C.

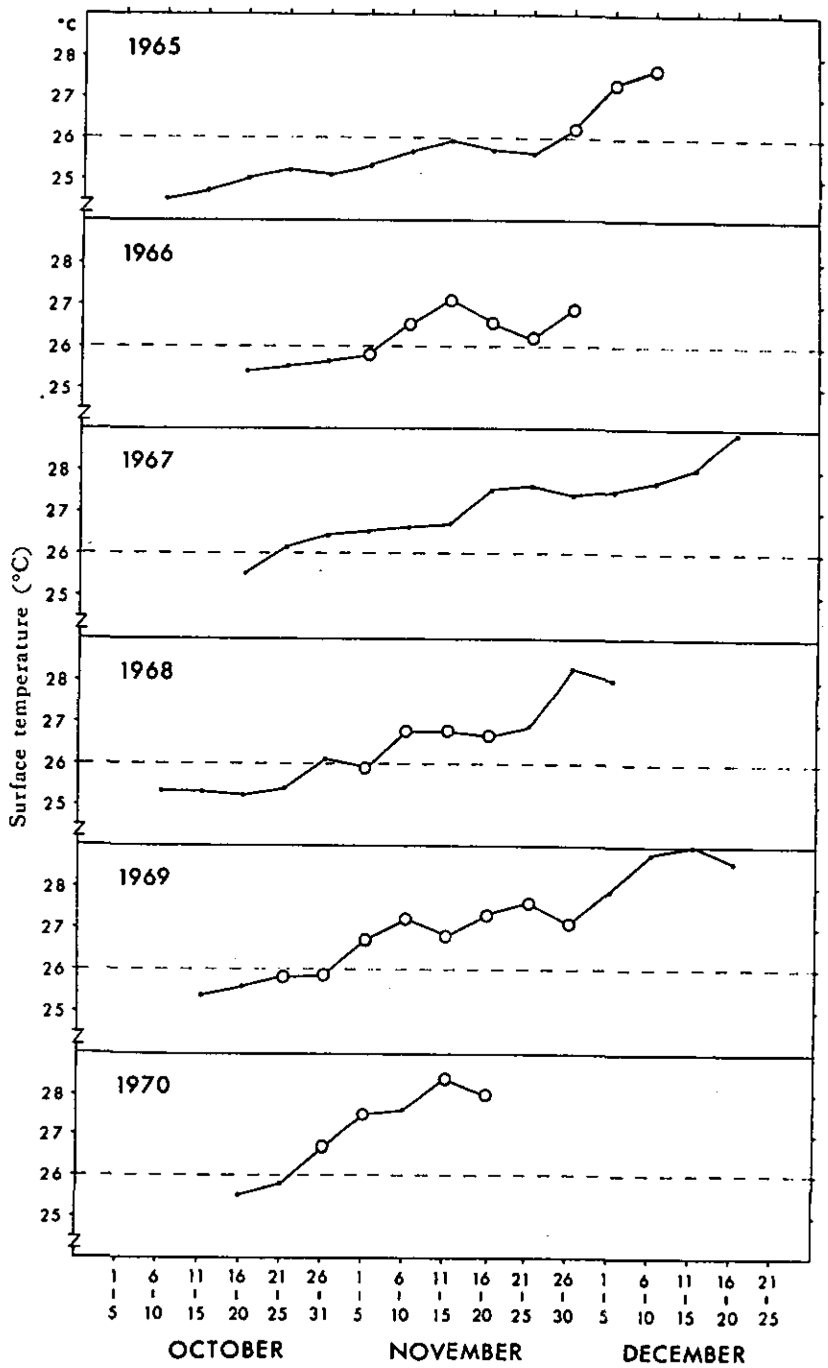

Fig. 16. Five-day average of surface temperature in the selected area covering hand-lining ground, Lat. 14°-18°S, Long. 144°-148°E, the Coral Sea, 1965-1970.

Open circles denote presence of hand-line operations.

(Figure 17). However, it is also possible that, because the temperature and catch data are being compiled in five-day intervals, a loss of the relationship between the temperature and catch data may result. Generally, when the surface temperature is around 26°C, bigeye are caught; when the temperature is above this level, yellowfin are caught.

4. THE CHARACTERISTICS OF THE HAND-LINE FISHERY

Although the same hooks and bait are used for the yellowfin and bigeye surface hand-lining and sub-surface longlining operations, there are differences in the fish length and GI of the catch. Using this information, an attempt was made to understand what ecological factors cause the fish to school at the surface. Also, the environmental conditions that are associated with the seasonal changes in the hand-line fishery were considered. From the relationships between the biological data on the catch and the temperature distribution, a hypothesis was proposed for why bigeye and yellowfin school at the surface and why a hand-line fishery exists in the Coral Sea.

4.1 Biological aspects of the fishery

4.1.1 *Yellowfin*

From the longline hook-rate statistics, it is thought that the yellowfin tuna move south as the East Australian Current (which is a branch of the South Equatorial Current) strengthens and moves south between October and January (Kamimura and Honma 1959, Warashina 1969a, 1970a, 1971a). The hand-line fishing operation follows the yellowfin tuna down the western part of the Coral Sea. Furthermore, the hand-line catch length-frequency data agree closely with those reported for the catch of the longlining operations in the area. Thus, the hand-lining and longlining operations are probably directed at the same aggregation of southward-migrating yellowfin tuna. However, at a given time and location, the hand-line catch consists of mostly mature fish, while the longline catch consists of mainly immature fish. Thus it appears that, as the fish approach spawning, they move from the middle to the upper layer. If this hypothesis is correct, it implies that the hand-line fishing operation is directed at the mature fish that are schooling at the surface.

According to Kikawa (1966) the numbers of mature fish caught by longlining increase during periods of high water temperature, with this trend being particularly noticeable in areas where there are large seasonal changes in water temperature. Thus, when the temperature rises in the subsurface waters at the depths where the longline hooks are set (50 - 250 m), there should be a corresponding increase in the percentage of mature fish in the longline catch. On the other hand, according to Ueyanagi (1969), Richards (1969) and Richards and Simmons (1971), yellowfin larvae can be found when the surface water-temperature is about 24°, with most larvae being collected from waters above 26°C.

Calculations from Ueyanagi's data (1969, Appendix 2) on the number of ichthyoplankton net hauls, the number of hauls successfully collecting yellowfin tuna and the number of larvae per successful haul, grouped by

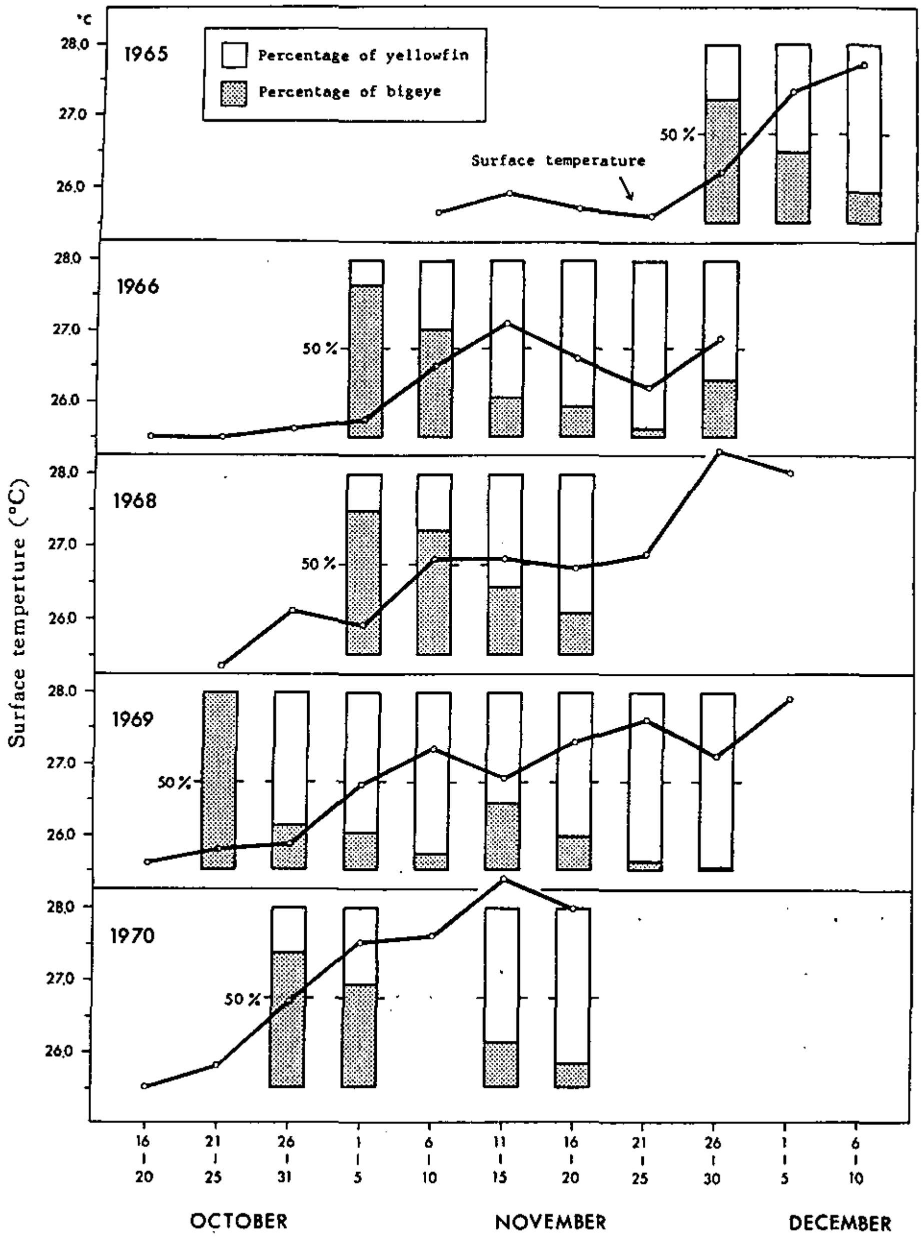

Fig. 17. Five-day average of ratio of yellowfin and bigeye tunas in hand-line catch and of surface temperature, in the selected area covering, hand-lining ground Lat. 14°-18°S, Long. 144°-148°, 1965, 1966, and 1968-1970.

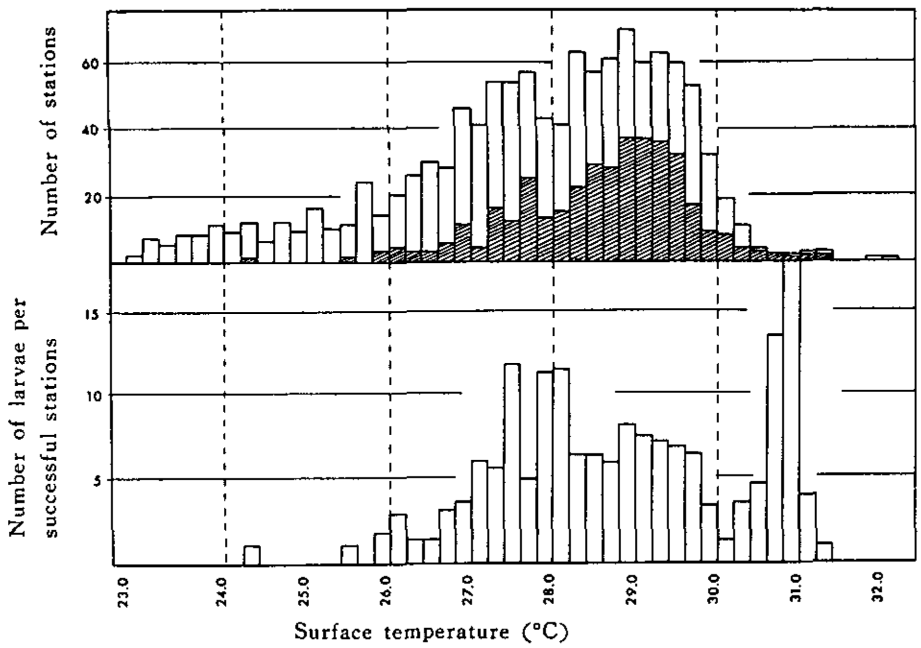

Fig. 18. Number of larva-net hauls (open square of upper panel), number of hauls successfuly collecting larval yellowfin tuna (closed square of upper panel) and number of larvae per successful haul (lower panel) at stations grouped by surface temperature in 13 survey cruises of *R. V. Shunyo Maru* in the western Pacific Ocean, 1960-1967.

Data from UEYANAGI (1969)

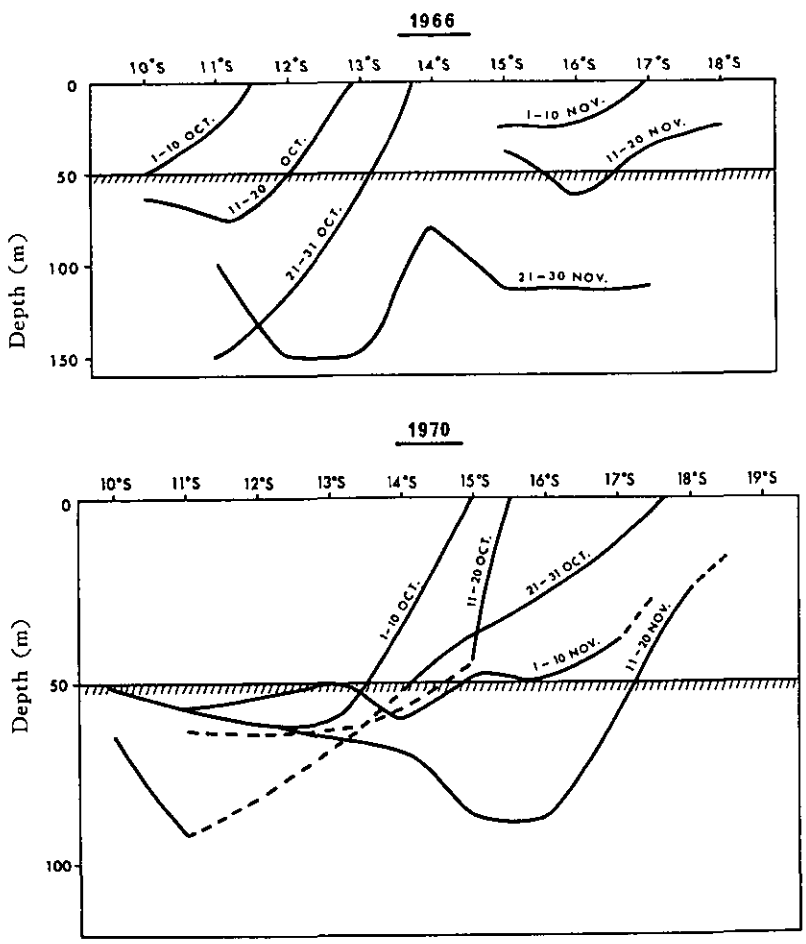

Fig. 19. Latitudinal and vertical distribution of 26°C-isotherm in the northwestern Coral Sea, Lat. 10°-20°S, Long. 140°-150°E, for every ten-day period, 1966 and 1970.

surface temperature, show that the larvae are plentiful in waters above 26°C and are particularly abundant when the water is 27°C or above (Figure 18).

During periods of rising water temperature, schooling mature fish are caught in the Coral Sea. In October, the percentage of mature fish in the longline catch from the northern side of the hand-line fishery, between 10° and 12°S, was 71%. This is similar to the percentage of mature fish in the hand-line catch, which was about 70 - 95% for all years except 1966. However, south of 12°S, only 12° - 25% of the longlining catch was mature. The area where more than 50% of the longline catch consisted of mature fish moved south from 10° - 12°S in October to 12° - 14°S in November, and in December it was even further south. It is possible to interpret this observation either as the movement of mature fish south or the gradual maturing of fish as the temperature of the water increases. At any rate, it is clear that the horizontal and vertical distribution of the mature fish is restricted to the subsurface waters north of 12°S in October, but expands towards the end of the year.

4.1.2 *Bigeye*

Although bigeye are not caught in large quantities by longlining, the catch records show that hand-lining for a short period at the beginning of the season is a very effective technique for obtaining large catches. There is a significant difference in the length frequency and GI composition of the fish caught by hand-lining and longlining. However, almost no difference exists in the length range of the catch. The longline catch consists of two modal groups at about 80 to 110 cm and 130 cm. The hand-line catch had a single mode at about 80 to 100 cm and, except for 1970, schools of large fish were rare.

The pole-and-line caught fish were clearly much smaller than the hand-line or long-line caught fish, being between 50 and 80 cm in length. These catch-length statistics are consistent with the hypothesis that, as the fish develop, they move from the surface to subsurface waters (Suda et al. 1969).

A slightly greater fraction of the fish caught by hand-lining were mature than was the case for the longline catch; however, this difference was not as great as had been observed for the yellowfin, and it did not exceed 15%. However, other sources (Kikawa 1953, 1966; Kume 1962; Inamura 1971; Nojima et al. 1972) quote a maturity level in the hand-line catch of 60 - 90%. Thus, it appears that, in the Coral Sea, mature bigeye are quite scarce.

4.2 Oceanographic aspects of the fishery

Large-scale equatorial tuna surface fisheries are found in the eastern Pacific, western Pacific and the eastern Atlantic. In the western Pacific fishery, which extends from New Guinea to the Marianas, skipjack as well as small quantities of yellowfin and bigeye less than 80 cm in length have been caught by pole-and-lining (Kume and Morita 1967; Kikawa and Warashina 1972). In the eastern Pacific and eastern Atlantic, not only are surface skipjack and small surface yellowfin and bigeye caught by pole-and-lining but catches of much larger fish, such as would have been caught by long-lining, have been reported (Barrett and Kume 1965; Honma et al. 1969; IATTC 1972; ICCAT 1972). The major reason for the existence of such fisheries, and for the surface schooling of fish, is the presence of a water-temperature front (Bennett 1963; Broadhead and Barrett 1964; Le Guen et al. 1965; Kato 1966; Honma et al. 1969; Suda et al. 1969; Honma and Hisada 1971). However, such a distinct water-temperature front has not been observed in the Coral Sea fishery (Figure 15).

In the Coral Sea hand-line fishery, the annual variation in temperature is quite clear and as soon as the surface water-temperature reaches 26°C, the fishing season opens. This suggests that the warm water, which seems to have originated to the north of the hand-line fishery (henceforth such water will be called the "equatorial surface water"), moves south and covers the hand-line fishing grounds during the fishing season. Rochford (1959) showed that the south Equatorial Current reached the northern part of the area (5° - 40°S, 140° - 180°E) between August and October and that between November and January a major branch of this current reached Queensland.

Relatively complete bathythermograph measurements of the horizontal and vertical distribution of the 26°C isotherm, taken at 10-day intervals in 1966 and 1970, demonstrated the southward movement of the equatorial surface water that is associated with the hand-line fishing season.

The 26°C isotherm reached a depth of 50 m at 10°S between 1 and 10 October 1966, while at the surface the isotherm was north of 12°S. During the period 11 to 20 October 1966, the 26°C isotherm at 12°S reached a depth of 50 m and at 13°S was at the surface. From 21 to 31 October, the 26°C isotherm at 13°S reached a depth of 50 m. By November, the 26°C isotherm at the surface was at 17°S, and it had moved to 18°S by 11 to 20 November. However, at 50 m depth the water that was at 26°C or above was restricted to the area around 16°S. During the period 21 to 30 November, the 26°C isotherm included the surface and subsurface layers at least as far south as 17°S.

In 1970, a cross-section of the 26°C isotherm in the area from 10° to 13°S did not show any clear trend. However, by 1 to 10 October the isotherm had reached a depth of 50 m. South of 14°S, the 26°C isotherm could be seen to be moving southwards. Between 1 and 10 October, the water temperature at 50 m depth was greater than 26°C as far as 14°S, while the surface waters were at this temperature north of 15°S. From 11 to 20 October, the 26°C isotherm at 50 m depth had reached 15°S and at the surface was at 15°S to 16°S. Subsequently, from 21 to 30 October, the isotherm at the surface spread to 17° - 18°S, and the isotherm at 15°S rose from 50 m to 30 - 40 m depth. For the period of 1 to 10 November, the isotherm approached the 50 m layer at 16°S; by 20 November, all the water to the depth of at least 50 m had reached 26°C.

Thus, in October of 1966 and 1970 the 26°C isotherm had reached a depth of 50 m at latitude 10° - 14°S. However, it was not until the end of November that the isotherm extended past 14°S at this depth. Although no data are available, it is likely that from December onwards the 26° isotherm continues to move south and to greater depths.

If the hypothesis that the 26° isotherm corresponds to the front line of the Equatorial Surface Waters is correct, it is possible to explain the situation in the hand-line fishery. Furthermore, if the concept of such a 26°C front has any meaning from the oceanographic point of view, the hypothesis discussed in the next section on the structure of the fishery can be supported.

4.3 The formation of the fishery - a possible explanation

4.3.1 Yellowfin

On the basis of the assumption, discussed in section 4.1, that the mature yellowfin are distributed in warm waters that are at or above 26°, it is possible (from the horizontal and vertical water-temperature range) to explain the presence or absence of the fish in the hand-line fishery. From October, the equatorial surface waters gradually spread southwards and at 16°S the 26°C isotherm is detected at the surface, and soon after reaches a depth of 30 - 50 m.

Mature fish comprise 70 - 95% of the hand-line catch but less than 25% of the longline catch, thus indicating that, as the fish mature, they move towards warmer waters and generally tend to school at the surface. It is these surface schools that are the target of the hand-line fishing operation.

Associated with the horizontal expansion of the Equatorial Surface Water is a gradual increase in the depth to which the 26°C isotherm extends. In October, 50% of the longline catch in the fishery north of 12°S consisted of mature fish. However, this area had expanded to include the area north of 14°S by November. This observation can probably be attributed to an increase in the depth of the 26°C isotherm. As this happens, the schools of fish disperse into the subsurface layers and the catch rate of the hand-line fishery falls. However, even if the 26°C isotherm is shallow, it does not necessarily mean that there will always be a hand-line fishery. Rather, as in the case of the Coral Sea fishery, hand-lining has for some reason been restricted to the area 14° - 18°S, 145° - 148°E, as well as a limited operation in 1968 in the area 18° - 20°S, 152° - 153°E. It is not clear if hand-lining can be conducted in other areas and if other factors besides the movement of the 26°C isotherm are related to the formation of the fishery. Unfortunately, it was not possible to obtain information that could be used to investigate this issue. However, it appears that the bathymetric features of the fishing grounds and the distribution of whale sharks, which are associated with the schools of yellowfin caught by hand-line, would be worth considering. There are no data that could be used to show what unique bathymetric features of this area are associated with the hand-line fishery, however hand-lining has been conducted in the vicinity of the Bonin Islands for a long time and it is not unlikely that a viable hand-line fishery may in some way be associated with the presence of coral.

4.3.2 Bigeye

The fish caught by hand-lining are smaller than longline catches, with a mode of 80 - 110cm. However, the fish are larger than those fish caught by pole-and-line, which had a mode of 50 - 80 cm.

The density of bigeye in the Coral Sea is not very high, although for a short time the hand-line catch of bigeye greatly exceeds that of yellowfin. A possible explanation for this is as follows. Suda et al. (1969) and Kawai (1969) have reported that bigeye, which are the target of the longlining operation, are concentrated at the edge of the equatorial and subtropical water masses. It appears that it is not possible to explain the bigeye catch results in terms of the vertical movement of a particular isotherm, but rather it appears that the bigeye are concentrated close to the 26°C front near the surface and are captured by surface gear only when the front moves through the fishery. Once the front has passed through the fishery and the temperature of the water increases, the bigeye catch drops and the yellowfin catch increases. The fact that, for the same size fish, the GI of the hand-line catch is higher than that of the longline catch is probably due to the hand-lining operation catching fish from warmer waters.

As for yellowfin, it is also necessary to investigate the distribution of whale shark and the bathymetric features of the area that might affect the bigeye catch.

5. SUMMARY

The following results were obtained from an investigation of the Coral Sea hand-line and longline fishery.

1) The area and duration of the handline operation are extremely limited. Hand-lining is conducted between October and December for between 13 and 39 days in the area 14° - 18°S, 145° - 148°E. Even during such a short season, there are changes in the species composition of the catch. For a short time at the beginning of the season, the catch of bigeye far exceeds the yellowfin catch. However, by halfway through the season, the bigeye catch has dropped and yellowfin predominate in the catch.

2) Although the hand-line catch consists mainly of bigeye and yellowfin, various other species of tuna and billfish have been caught in the Coral Sea area. The average value of the hand-line catch-per-boat-day of yellowfin is 4 times greater than that of the longline catch and for bigeye, 26 times greater. Thus, in this fishery the hand-lining technique is much more efficient than longlining.

3) Generally, the annual length range of the yellowfin catch and of the length-frequency mode was the same for hand-line and longline catches. However, for a given time and location in the fishery, 70% of the hand-line catch consisted of mature fish, while most of the longline catch was immature.

4) There is some difference between the length-frequency data for the bigeye hand-line and longline catches. Most of the hand-line catch are between 80 - 120 cm in length and a single mode appears around 90-100 cm. The longline catch consists of comparatively larger fish, over 120 cm in length and having modes at 100 and 130 cm. Differences in the state of maturity of the bigeye catch taken by longling and hand-lining were not as clear as had been observed for the yellowfin catch; however, for both methods, immature fish comprised the major proportion of the catch.

5) The timing of the start of the hand-line fishing operation varies between years, although it generally coincides with the time when the surface waters in the fishery exceed 26°C. The bigeye catch improves when the temperature is above 26°C, while the temperature must be a little higher for yellowfin. This indicates that perhaps there is a difference in the areas where the two species are distributed.

6) The observations that the ratio of mature fish in the yellowfin longline catch increases when water temperature at the depth where hooks are set increases to 26°C, and that most fish caught by hand-lining are mature and have a GI greater than 1.6, agrees with research that shows that yellowfin spawn in waters above 26°C. The hand-line fishing operation starts when the mature fish gather in the warm waters at the surface on the fishing grounds. As the warm water spreads vertically and horizontally, the distribution of the mature fish expands. Consequently, more fish are caught by longlining and the efficiency of the hand-lining operations drops. Thus, it is considered that the main factor that determines the location and season of the hand-line fishing operation is the vertical and horizontal movement of warm water. However, the effect of whale sharks, which are associated with the surface schools of yellowfin, and the bathymetric features of the area must also be considered.

7) The bigeye in the hand-line fishery are small in size and mainly restricted to the surface waters. The catch rate of bigeye is good for only a short period at the beginning of the season and they appear to be concentrated at the 26°C isotherm as it moves south through the fishery. As for yellowfin, it also is necessary to investigate the distribution of whale sharks and the bathymetric features of the area that might affect the bigeye catch.

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Warashina, Y. (1970a). Tuna Fishing NS 6

Warashina, Y. (1970b). Tuna Fishing NS 10

Warashina, Y. (1970c). Tuna Fishing NS 16

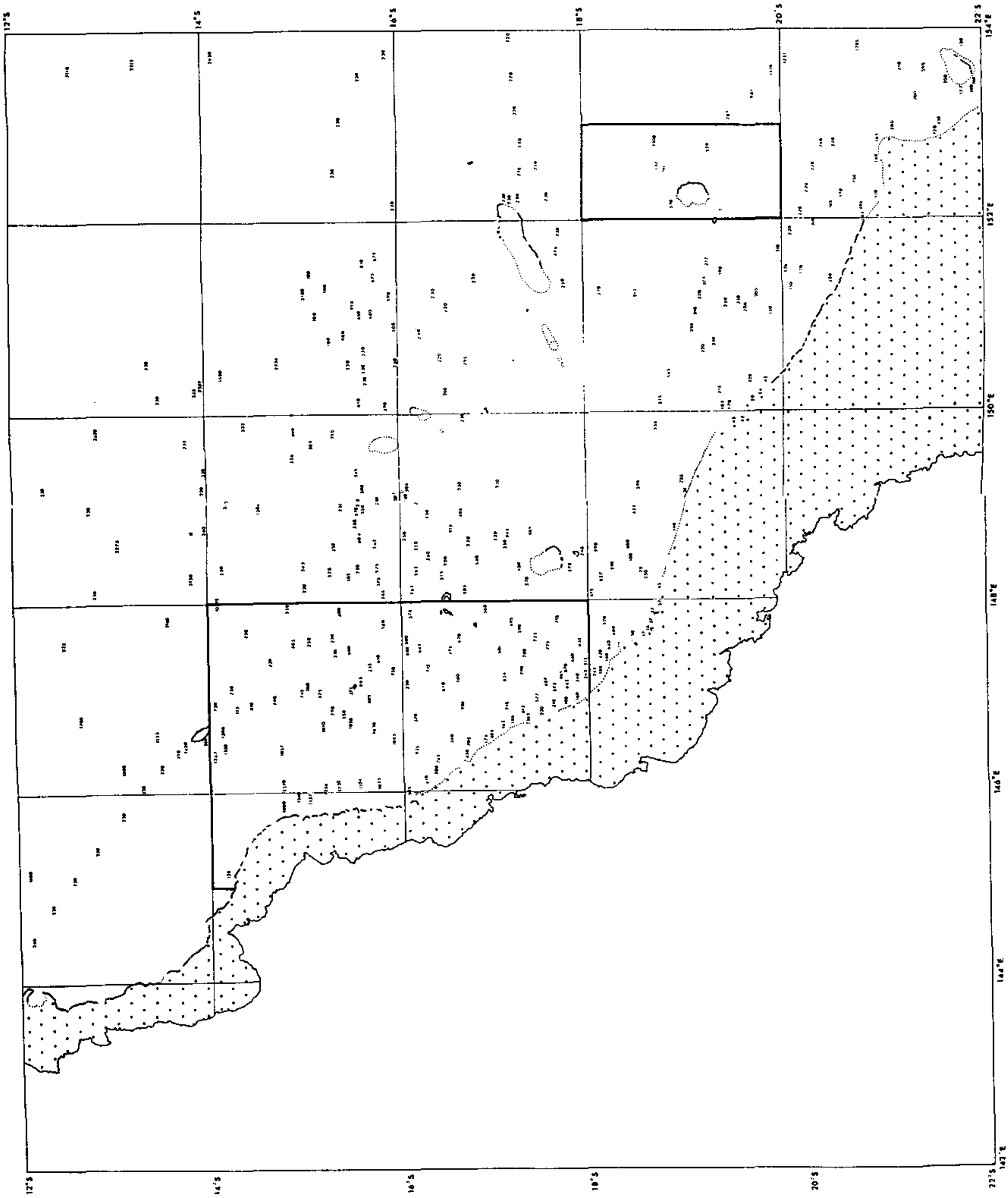
Warashina, Y. (1971a). Tuna Fishing NS 24

Warashina, Y. (1971b). Tuna Fishing NS 26, 27

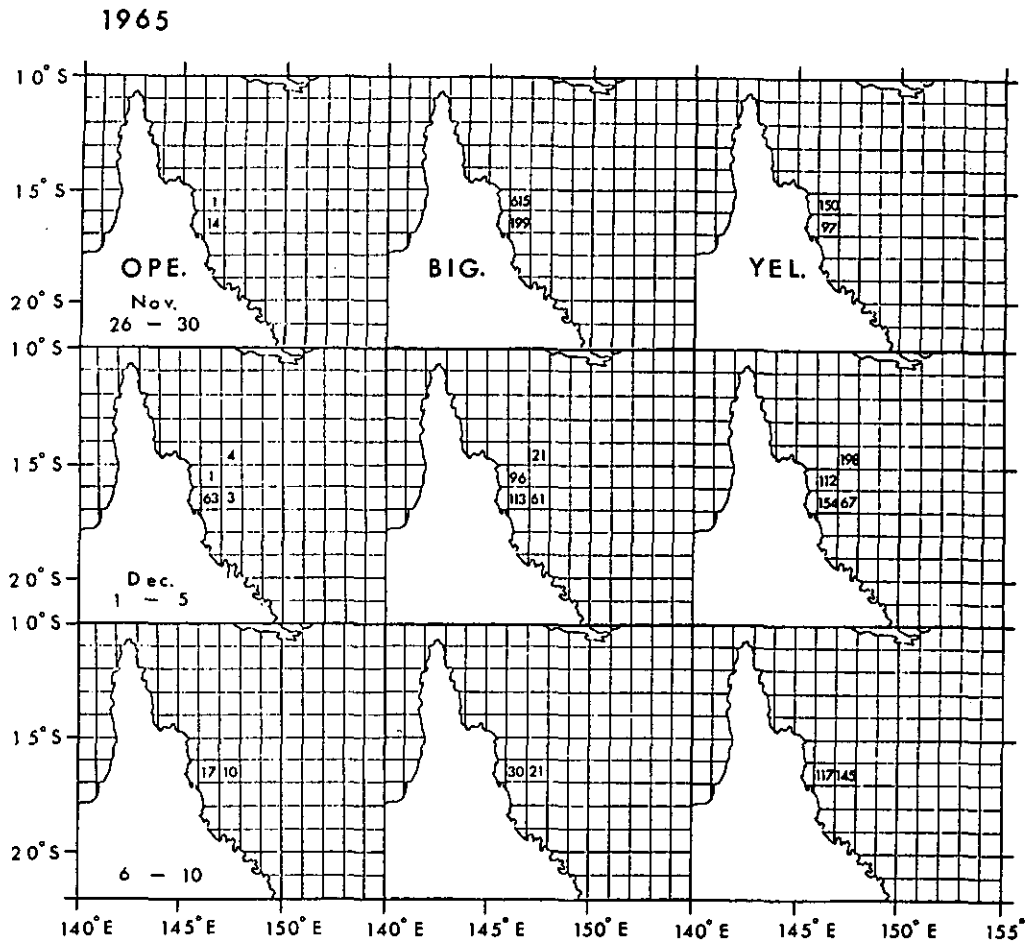
Warashina, Y. (1971c). Tuna Fishing NS 28

Warashina, Y. Unpublished material (1967). Landings of Indian and Pacific tuna in the Yaizu point.

Appendix Figures

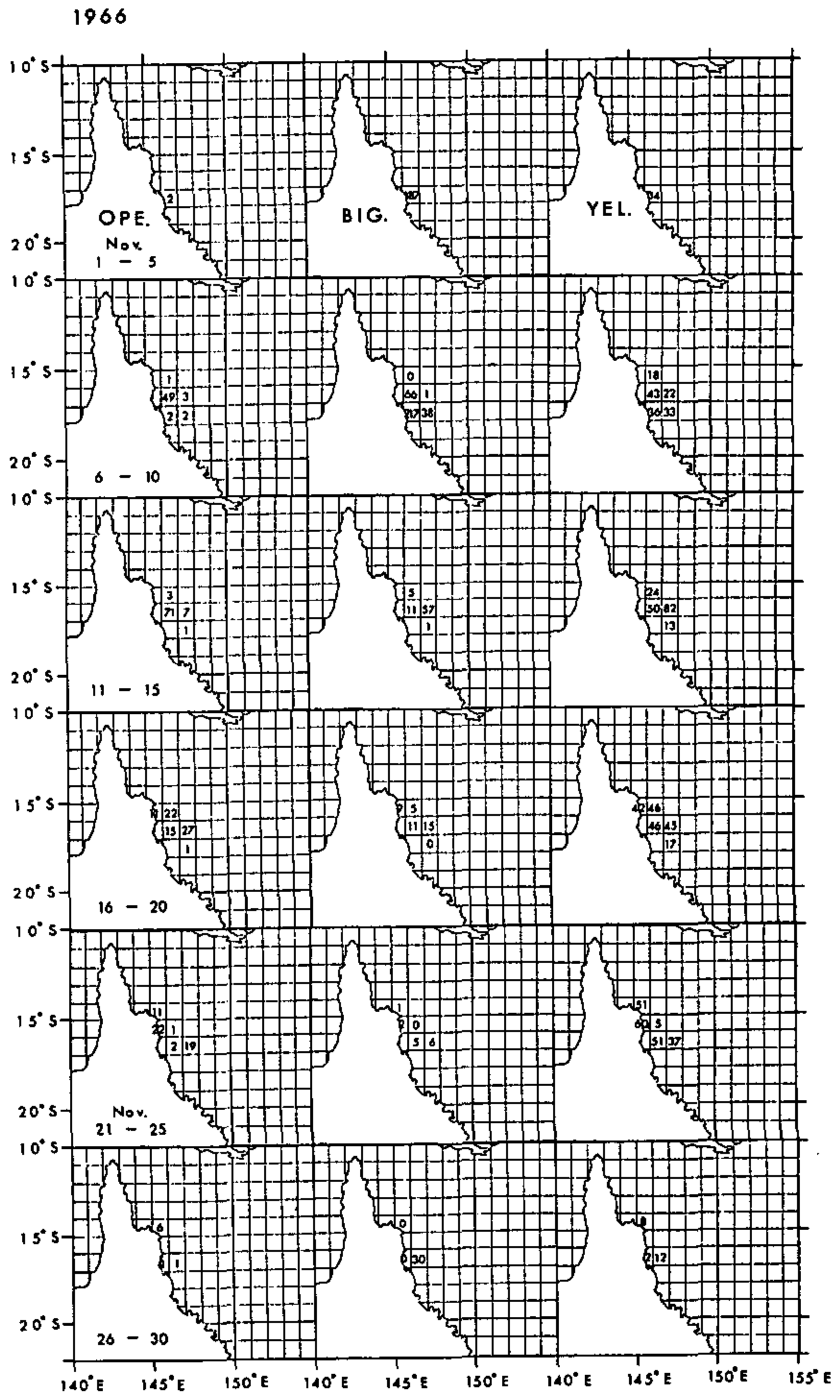


Appendix figure 1. Hand-line fishing areas and adjacent waters.
Bold quadrangles denote hand-line fishing areas, shaded area covers coastal side of The Great Barrier Reef or the 100-fathom contour, and numerals denote depth of the sea in fathom (1.829m). Produced from the Japan Hydrographic Office Charts Nos. 816 and 824.

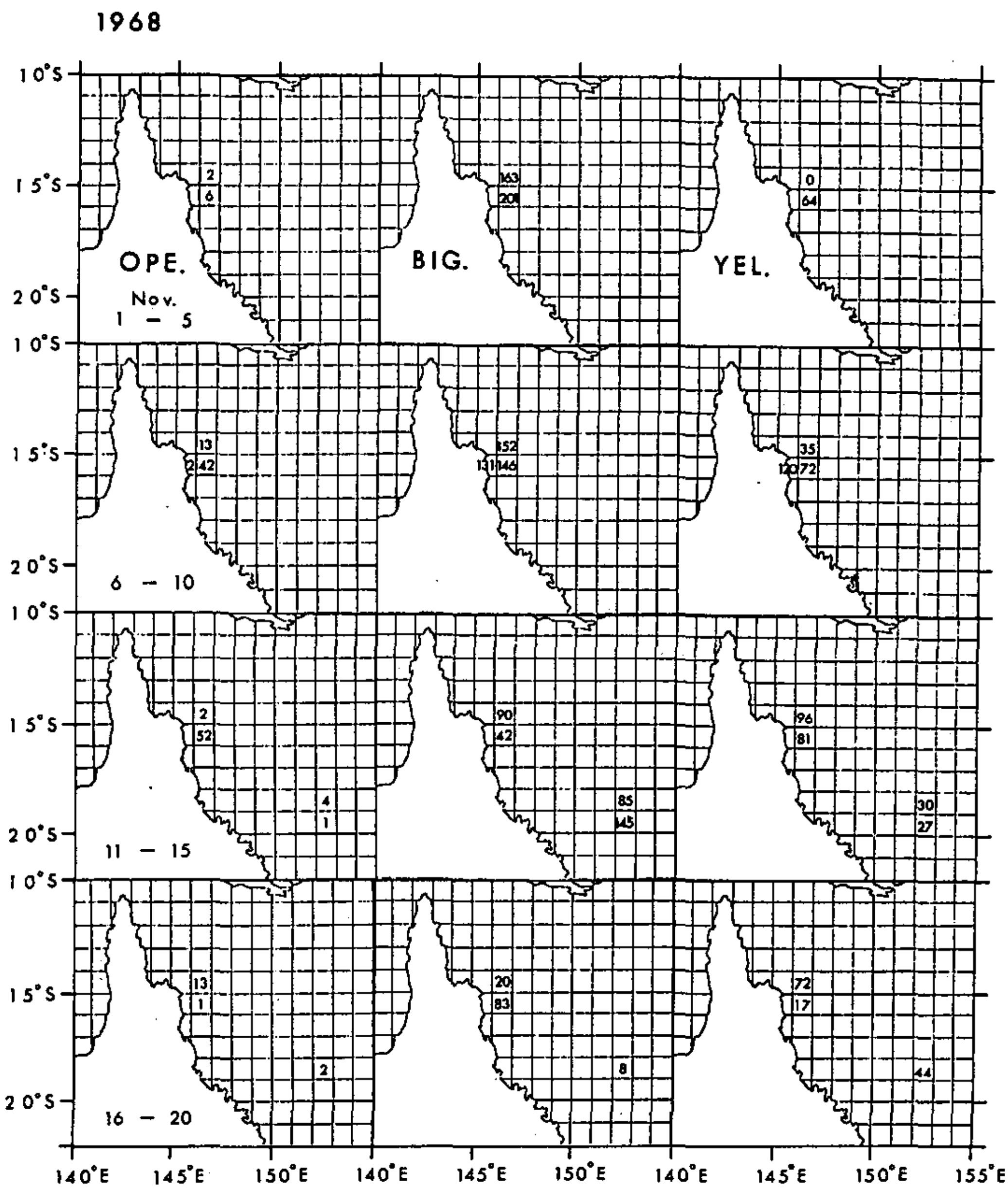


Appendix figure 2. Distribution of operations and catch-per-boat-day of yellowfin and bigeye tunas of hand-line operations by five-day period and by one-degree square in the Coral Sea, 1965, 1966, and 1968-1970.

OPE;	Number of boat-days.
BIG;	Catch-per-boat-day of bigeye tuna.
YEL;	Catch-per-boat-day of yellowfin tuna.



Appendix figure 2. (Continued)



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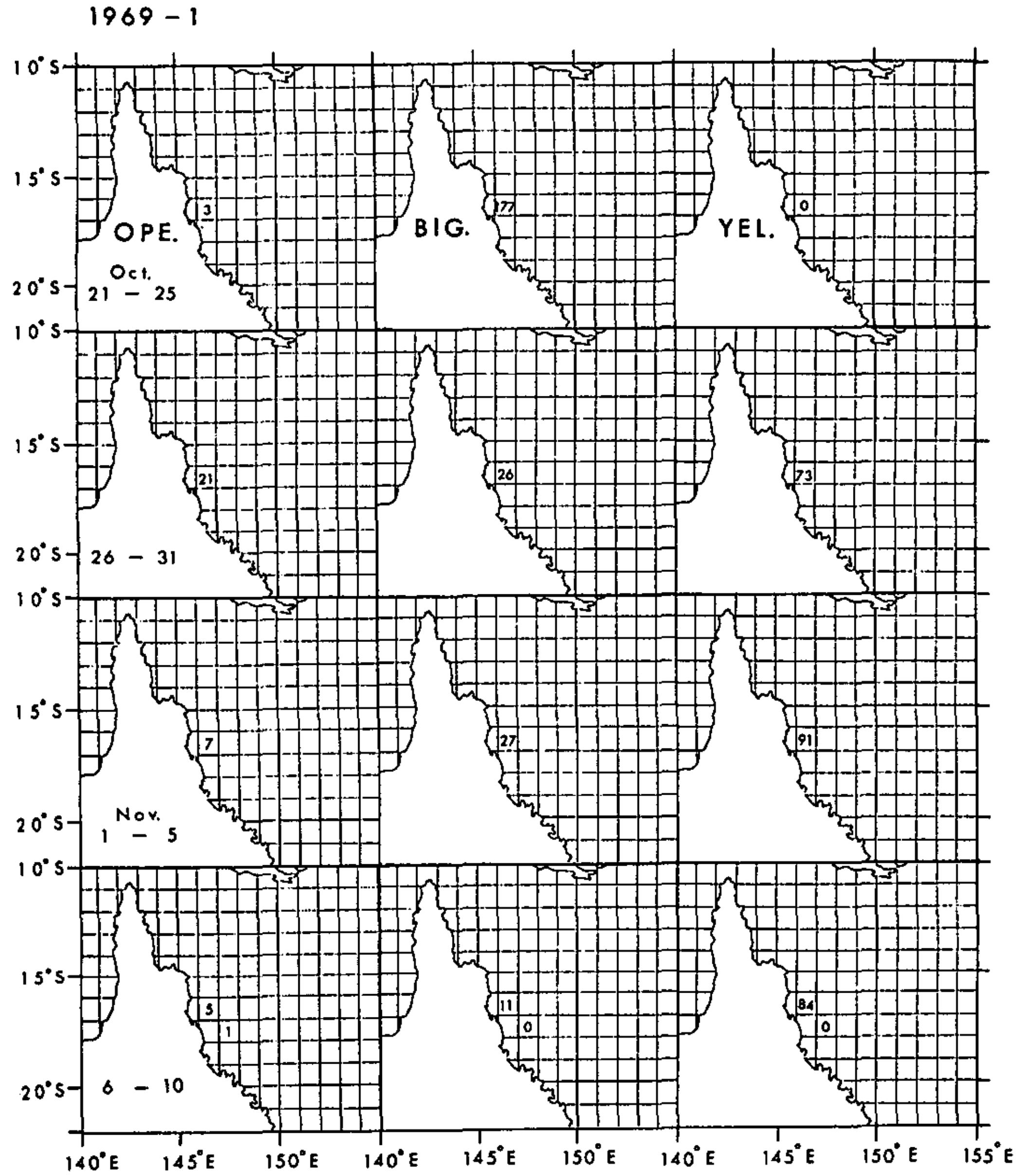

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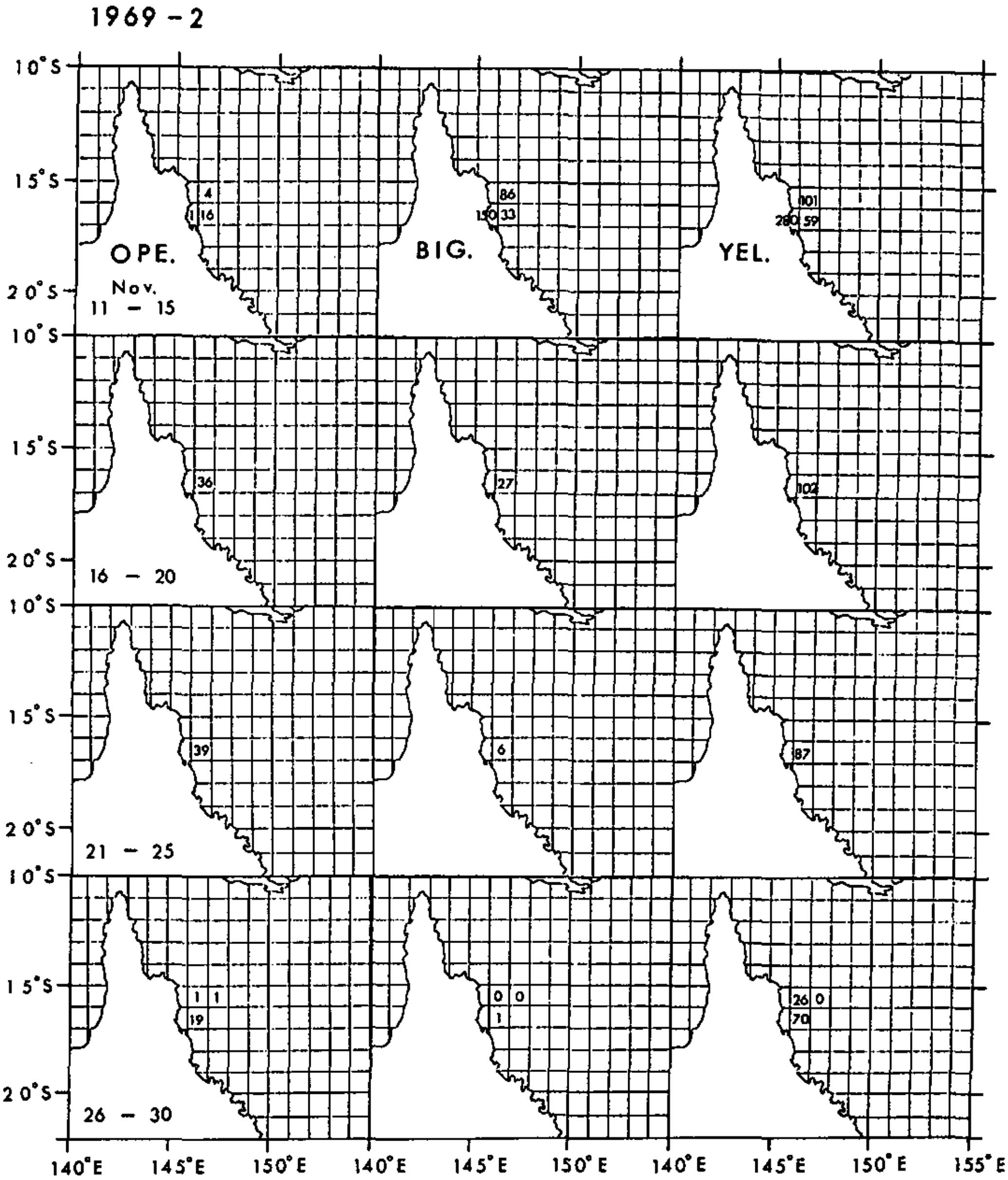

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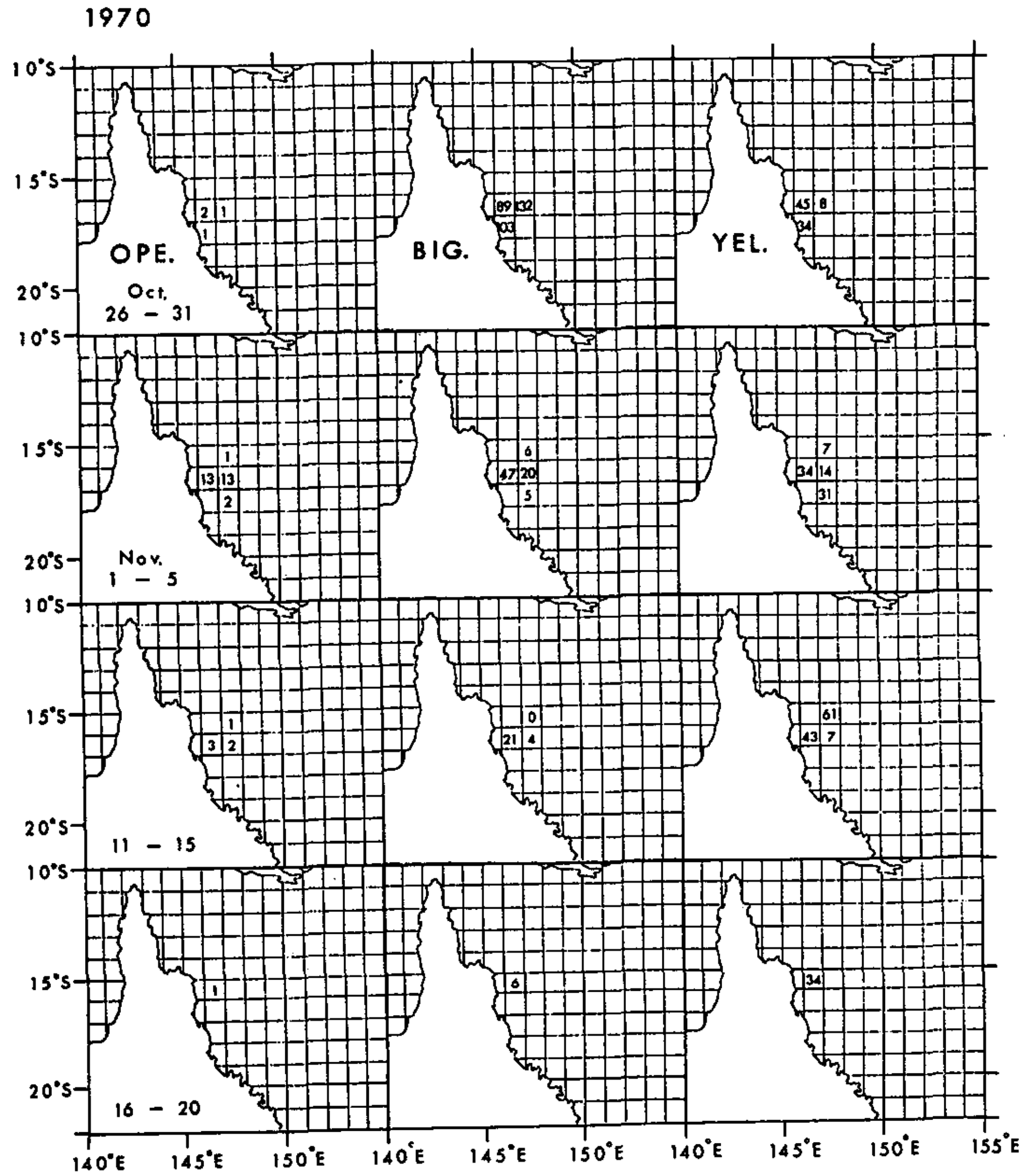

Appendix figure 2. (Continued)

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