STUDIES ON FISHING OF ALBACORE, *THUNNUS ALALUNGA* (BONNATERRE) BY EXPERIMENTAL DEEP-SEA TUNA LONG-LINE

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I. Introduction

The tuna fishery is one of the most economically important fisheries in Japan. The total harvests is more than 700,000 tons which is equivalent to about 10% of total catch of Japan. Albacore, *Thunnus alalunga* (Bonnaterre) is second to yellowfin tuna, *Thunnus albacares* (Bonnaterre) in amount of catch. This species is widely distributed in the oceans. The albacore in the Pacific Ocean includes two groups living in the sea of Northern and Southern Hemispheres, they may be classified into different populations.[1)2)]

The area of the fishing ground for the South Pacific albacore is widespread within the zone between 10° to 30°S latitude.[3~6] About 160 long-liners sail out from Fiji Islands, Samoa Islands and New Hebrides Islands throughout a year. In May and June, the fishing ground is formed at about 30°S latitude where small sized albacore are usually caught, it then shifts gradually northward in late September to January. It is at 14°~20°S latitude where large sized albacore are caught. From February to May, the fishing ground moves toward the northern limit of the area, and in May to June the fishing grounds change repeating the same cycle mentioned above.

Taking a view of the world wide general tuna fishery, every good fishing areas in the surface layer has been explored. Consequently, the catch has decreased since 1961,[7] probably due to over fishing. It is urgent to increase the catch and to exploit new fishing grounds. Recently it has been discovered that albacore can live in the unexploited deep layer.[8][9] Because of inadequate techniques for deep-sea long-line fishing, fishing the deep layer has not been successful. This leads to an urgent problem of how to investigate and fish the deep-sea tuna.

Recent advances in the fish-finder has brought progress in tuna fishery technology in connection with the estimate of this resource[10] and oceanographical environmental factors.[11~15] Some recorded patterns by fish-finder indicate the presence of tuna, in deeper than 300 m.[8][9] Physical evidence has not been provided to confirm the fish-finder observation. Actual fishing is necessary to identify the patterns and determine the hooked depth in order to ascertain the presence of tunas as recorded on the fish-finder.

Yoshihara,[16~20] has theoretically calculated the hook depth of tuna long-line assuming that a long-line forms a catenary in water. Kamijo[21] simplified Yoshihara's equation and showed a convenient nomograph by which the depth of attaching points of branch lines on the main line could be easily obtained when both values of the length and shortening rate of the main line were given. Kumasawa[22] has reported an equation showing the form of the main line influenced by a standing water current. Morita *et al.*,[23] Tanoue,[24] Shomura and Otsu,[25] Iversen and Yoshida,[26] and Graham and Stewart[27] have studied the fished depth by attaching a chemical tube to a branch line, and comparing the obtained value with the theoretically calculated value. Hashimoto and Maniwa,[11] Nishimura,[12][13] Shibata,[15][28] Shibata and Yada,[29] Kawaguchi et al.,[30][31] Murphy and Shomura,[32] Bullis[33] and Wathne[34] have reported the form of the long-line in the water by using of fish-finder. In the above studies, long-lines were designed to fish at a depth less than 140 m.

In actual fishing experiments, the depth calculated from the shortening rate of a main line were compared with those obtained from the attached chemical tube by Morita et al.,[23] Nakagome[35] and Yoshihara.[36] The results varied according to the sea condition and to the hook position in one basket. Hamuro and Ishii,[37] and Kamijo[38] have estimated the shape of the skewed long-line drifted by the sea current by using an automatic depth meter. Mie Prefectural Fisheries Experimental Station has tried to lengthen the float line in order to catch tunas in deeper layer, but did not succeed in reaching a depth greater than 140 m.[39] Kanagawa Prefectural Fisheries Experimental Station has also tried to use a vertical long-line for actual tuna fishing. Their maximum fishing depth reached to 230 m.[40] Morita[41~43] and Bullis[33] have reported that the fishing efficiency varies with the position of hooks in the gear system, in other words, to the relative depth of the hook in one basket. Hirayama[44] has also discussed the fishing efficiency with various long-line system of different sizes.

In above papers concerning tuna long-lining, the fishing depth was not below 140 m with long-line or below 200 m with vertical long-line. Few fishing experiment, have been conducted in deeper layers where tuna may be concentrated. An attempt was made in the present study to make a deep-sea long-line and a vertical long-line, with an attached depth meter, with the objective of catching large sized albacore, during the spawning season, in the deep layer, and to ascertain the hooked depth.

The experiments were carried out in every fishing season from 1964 to 1969, at sea area west of Fiji Islands, using various long-line designed by the author for trial aboard "Hokusei Maru", the training ship of the Faculty of Fisheries, Hokkaido University. This paper will report the construction and function of the designed long-lines, by which good fishing efficiency of albacore was obtained, and also be reported the estimation of the hooked depth at which tuna were caught.

Before going further, the author wishes to express his harty thanks to Professors Drs. Seiji Kanamori, Kiichiro Kobayashi, Tokimi Tsujita, of the Faculty of Fisheries, Hokkaido University, for their helpful guidances and criticisms in regard to the problems discussed in this paper. Moreover, I wish to express my obligation to Dr. Eiichi Tanikawa, the former Dean of Faculty of Fisheries and the present Superintendent of Mercantile Marine College of Toba, for his kind encouragement. The author also wishes to express his thanks to Dr. Ken ichiro Kyushin, Dr. Terushige Motohiro and messrs. members of crews of "Hokusei Maru" for their kind aids in these experiments.

II. Theory and construction of tuna long-line

1. *General construction of tuna long-lines*

The construction of a tuna long-line is shown in Fig. II–1, there are variations according to the species of tuna. Table II–1 gives an itemized statement of the parts of a tuna long-line.

Almost all investigators have quoted the following equation (1), assuming the form of the main line in water must be catenary.

Then;

$$y=\frac{a}{2}\left(e^{x/a}+e^{-x/a}\right)=a\cosh\frac{x}{a} \quad (1)$$

Where, (a) is a constant, and it is expressed as (T/W); (T) is the tension at bottom of the catenary: (W) is weight in water per unit length. From equation (1), Yoshihara has determined the depth of hooks (D) in a basket from equation (2), using the total length of main line $(2l)$ and the angle of inclination (φ_o) at the supporting point of the main line:

$$D=h_a+h_b+l\left\{\sqrt{1+\cot^2\varphi_o}-\sqrt{\left(1-2\frac{j}{n}\right)^2+\cot^2\varphi_o}\right\} \quad (2)$$

Here, (h_a) is the total length of branch line (in m), (h_b) is the length of the float line (in m), (j) is a series of numbers of hooks from one side of the basket (e.g. No. 1 hook, No. 2 hook, No. 3 hook), (n) is number of main line in one basket. The main difficulty in applying equation (2) is the estimation of (φ_o) in actual fishing. The shortening rate (k) of the main line can be employed as in equation (3).

$$k=\cot\varphi_o \sinh^{-1}\cdot\tan\varphi_o \quad (3)$$

Thus, the value of (φ_o) will be calculated from the value of (k). When (φ_o) is substituted into equation (2), the depths of hooks is obtained. Here, the shortening rate (k) is defined to be the ratio of the distance between flag floats to the total length of the main line.

Kamijo[21] has simplified equation (3) as follows:

$$k=\sqrt{\frac{(\lambda+1)^2-n^2}{(\lambda-1)^2-n^2}}\left\{\frac{(\lambda+1)^2-n^2}{(\lambda-1)^2-n^2}\right\}^{-1}\cdot\log_e\frac{(\lambda+1)^2-n^2}{(\lambda-1)^2-n^2} \quad (4)$$

Here, $\lambda=d/l$, thus, he has calculated the depth (d) of the attaching point of branch line.

The author has calculated the depth of the hook by applying Yoshihara's equation, and, when necessary, added corrections to these values because it was ascertained from model experiments that the form of the main line is not necessarily true catenary owing to the weight of branch lines installed with steel wire and metal hooks.

2. *Constructional factors influencing the depth of hooks in the sea*

2.1 *Shortening rate (k) of a main line*

From the above equation, the depth (d) of the attaching point of branch line on the main line varies with lengthening the main line length $(2l)$, or with shortening of the distance between flag floats, and the variations of the depth are determined

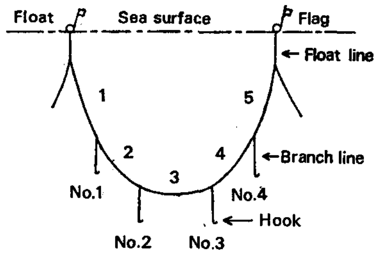


Fig. II–1. Schematic figure of a long-line in sea water (catenary form).
1, 2, 3, 4, 5: Main line

Table II–1. *General construction of a tuna long-line.*

Name of part	Material	Length	Number used for 1 basket
Main line	Cremona (20 S, 55×3×3)	250 m	(50 m)×5
Branch line	Cremona (20 S, 55×3×3)	11.5 m	4
Sekiyama	Steel wire (28 #, 3×3) wrapped with thread (No. 5)	8 m	4
Kanayama	Steel wire (28 #, 3×3)	2 m	4
Hook	Steel	11.5 cm*	4
Float line	Cremona (20 S, 55×3×3)	23 m	1
Flag float	Flag, bamboo & float (glass ball or synthetic resin ball)	—	1

*: 11.5 cm=3.8 sun

with the length of main line ($2l$), shortening rate (k) ($0<k<1$) and the value of (n) which means the number of attaching point of the branch line in one basket. It is difficulty to express these variations with a simple equation.

The author has calculated the depth of the attaching points of branch lines for two kinds of long-line (Type A and B) by using Yoshihara's equation (2), and the values were plotted Figs. II–2 and II–3.

Type A long-line: Total length ($2l$) is 322 m, consisting of 7 main lines each 46 m long and each basket having 6 branch lines.

Type B long-line: Total length ($2l$) is 414 m, consisting of 9 main lines each 46 m long and each basket having 6 branch lines.

Both types of long-lines are illustrated in Fig. III–1. As seen in Fig. III–1, in the type A long-line, which has equal distances between each attaching point of the branch line on the main line, the depth of the attaching points of No. 3 and No. 4 branch lines equal and deepest. As the total length of a main line is $2l$, the length from the end of the main line to the center is l. The length of the main line can be devided into 7 intervals, thus the length from the end of the main line to the attaching point of No. 1 branch line is $2/7\,l$. Similarly, the lengths from the end of the main line to the attaching points of No. 2 and No. 3 branch lines are $4/7\,l$

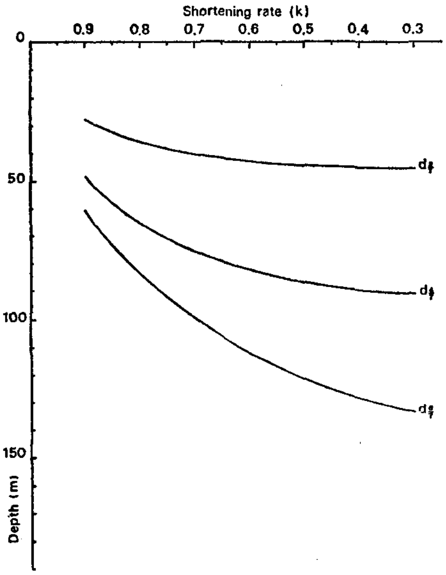


Fig. II–2. Relationship between shortening rate and depth of main line in the case of type A long-line.
$d_{2/7}$: Depth of attaching point of No. 1 (No. 6) branch line on main line
$d_{4/7}$: Depth of attaching point of No. 2 (No. 5) branch line on main line
$d_{6/7}$: Depth of attaching point of No. 3 (No. 4) branch line on main line

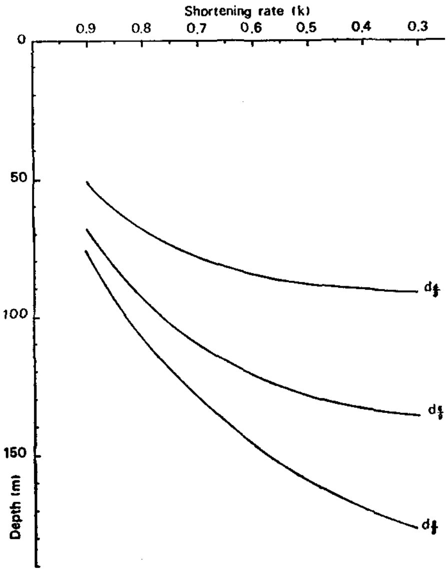


Fig. II–3. Relationship between shortening rate and depth of main line in the case of type B long-line.
$d_{4/9}$: Depth of attaching point of No. 1 (No. 6) branch line on main line
$d_{6/9}$: Depth of attaching point of No. 2 (No. 5) branch line on main line
$d_{8/9}$: Depth of attaching point of No. 3 (No. 4) branch line on main line

and $6/7\,l$ respectively. The depth of the attaching points of the branch lines are denoted as $d_{2/7}$, $d_{4/7}$ and $d_{6/7}$. In the type B long-line, the depths are $d_{4/9}$ for the attaching points of No. 1 and No. 6 branch lines, $d_{6/9}$ for No. 2 and No. 5, $d_{8/9}$ for No. 3 and No. 4, respectively.

In Figs. II–2 and II–3, it is shown that when the shortening rates are reduced from 0.65 to 0.35, the distance between the flag floats will be shortening from 209 m to 113 m in the type A long-line, and from 269 m to 145 m in the type B long-line. Therefore the depth of the deepest attaching points of branch lines on the main line is calculated to be $\Delta d_A = 25$ m in the type A long-line and $\Delta d_B = 35$ m in the type B long-line. For the purpose of increasing the depth of the attaching points of branch lines, the effect of shortening the distance between the flag floats causes an increase of 26% in the type A long-line and 28% in the type B long-line. Thus the effect of shortening the distances between the flag float does not solve the problem of reaching below 140 m.

2.2 The effect of lengthening the float line (h_b)

For the purpose of increasing the depth of hooks in the sea, lengthening the float line must be taken in consideration. There is a certain limit for the lengthening the float line, because it causes a difficulty hauling the main line. The lengthened float lines will be flow toward the stern of the vessel, making way through the sea, and may foul the screw of the vessel. In addition, it causes an inconvenience in the operation, for example, before the one float line is hauled, another float line comes to the line-hauler. If the float line is too long, the form of the main line becomes incomplete, the main line may become tangled during setting and the resistance of water during hauling becomes larger. Thus there are operational restrictions on the length of the float line.

2.3 Length of the branch line (h_a)

The increasing the depth of hook would be proportionally obtained by lengthening the branch line. From the standing point of the line hauling operation, there is also a certain limit for lengthening the branch line. For example, if the branch lines are longer than the length of main line between two branch lines, a second branch line will come to the line-hauler causing tangling of the gear. If the branch lines are too long, they may be tangled by the current. In general practice, existing branch lines are about 21.5 m in length. It takes about 20 seconds to haule up a set of branch lines by hand, and about 25 seconds for a main line.

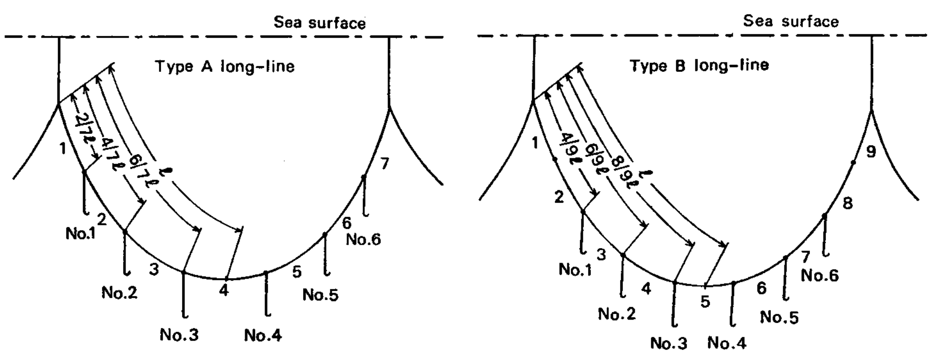


Fig. III–1. Construction of experimental deep-sea tuna long-line.

Hook position { Shallow hooks : No. 1, No. 6
Intermediate hooks : No. 2, No. 5
Deep hooks : No. 3, No. 4 }

Type A long-line: 7 main lines, 6 branch lines
Type B long-line: 9 main lines, 6 branch lines

2.4 Skewing of the form of main line by current

The form of the main line in the water is not necessarily a normal catenary due to the skewing of the form of the main line by the sea currents. In order to prevent the skewness, the material of the main lines are required to have high specific gravity and thin diameter. If the direction of setting of line is at right angles to the sea current, the form of main line becomes an approximate catenary on an inclined plane. The branch line, however, is not necessarily on the same inclined plane, because it is installed with metal materials. If the direction of the setting of line is parallel with the current, a difficulty arises in calculating the depth of hooks.

III. Design and construction of experimental deep-sea long-line

For the earlier (1964) experiments, for investigating albacore, the author employed a general type tuna long-line. This type of tuna long-line could not reach a depth below 140 m, even when the shortening rate of the main line was made as small as possible. Therefore, the following year, with accumulated experimental data, the author made an improvement in the long-line to reach the deeper layers. A deep-sea tuna long-line was designed which would fish to a depth of about 300 m. The principal dimensions of the tuna long-lines used during experimental years are shown in Table III–1. The construction details are shown in Table III–2. The deep-sea tuna long-line is classified into 9 groups (Table III–3). The important notices and the experiments for the demonstration are as follows.

Table III–1. *Principal dimensions of experimental deep-sea tuna long-line used in the experiments.*

Year	Main line			Branch line		Length of float line (m)
	Length (m)	Number	Total length (m)	Total length (m)	Number	
1964	50	5	250	21.5	4	23
1965	46	7	322	21.5	6	23, 46, 69
1966	46	7	322	21.5	6	23, 46
	46	9	414	21.5	6	23, 46
1967	46	7	322	21.5	6	23, 46
	46	9	414	21.5	6	23, 46, 69, 92, 115, 138
1968	46	7	322	21.5	6	23, 46
	46	9	414	21.5	6	23, 46, 69, 92, 115, 138, 161
1969	46	7	322	21.5	6	23, 46
	46	9	414	21.5	6	23, 46, 69, 92, 115, 138, 161

Table III-2. *Construction and dimensions of experimental deep-sea tuna long-line.*

Name of part	Material	Length	Number used for 1 basket
Main line	Cremona (20S, 55×3×3)	322 m	(46 m)×7
	〃 (20S, 58×3×3)	or	or
	〃 (20S, 60×3×3)	414 m	(46 m)×9
	〃 (20S, 62×3×3)		
	Spun tetoron (22S, 50×3×3)		
	〃 (22S, 55×3×3)		
Branch line	Cremona (20S, 55×3×3)	11.5 m	6
Sekiyama	Steel wire (28 #, 3×3) wrapped with Cremona thread (20S, 5×3×3)	8 m	6
Kanayama	Steel wire (28 #, 3×3)	2 m	6
Hook	Steel	11.5 cm*	6
Float line	Cremona (20S, 55×3×3)	23 m	1
	〃	46 m	
	〃	69 m	
	〃	92 m	
	〃	115 m	
	〃	138 m	
	〃	161 m	
Flag float	Flag, bamboo & float (glass ball or synthetic resin ball)	—	1

*: 11.5 cm=3.8 sun

Table III-3. *Specifications of experimental deep-sea tuna long-lines.*

Class	Float line		Main line			Number of basket used	Depth of deep hook* (m)	
	Length (m)	Weight in water (g)	Length (m)	Materials	Weight in water (g)		D_c	D_o
1	23	98	322(46×7)	Cr, (20S, 55×3×3)	1365	13	166	149
2	46	195	322(〃)	Cr, (〃)	〃	13	189	169
3	23	98	414(46×9)	Cr, (〃)	1755	13	204	183
4	46	195	414(〃)	Cr, (〃)	〃	13	227	203
5	69	293	414(〃)	Cr, (〃)	〃	26	250	224
6	92	390	414(〃)	Cr, (20S, 58×3×3)	1840	13	273	244
				St, (22S, 50×3×3)	1636	13		
7	115	448	414(〃)	St, (22S, 55×3×3)	1822	13	296	265
8	138	585	414(〃)	Cr, (20S, 60×3×3)	1900	13	319	286
9	161	683	414(〃)	Cr, (20S, 62×3×3)	1960	13	342	306
G.F.	23	—	250(50×5)	Cr, (20S, 55×3×3)	—	—	—	—

D_c: Calculated hook depth　D_o: Hook depth measured by depth meter
Cr: Cremona　St: Spun tetoron　*: Shortening rate (k)=0.5
G.F.: General construction of tuna long-line

1. On the construction of experimental deep-sea long-line

1.1 Materials

The important physical characteristics of the main line are high specific gravity, small resistance to water (i.e. thin diameter), and high tensile strength. Materials satisfying those requirements, Cremona and Spun tetoron (commercial names for synthesized threads) have been employed, of which the details are shown in Table III–4. The strength of those threads are described in a later part of the paper.

1.2 Float line

The depth of the hooks depends partially on the length of the float line. In order to get the hooks to a deeper layer, the author has made seven lengths of float lines in geometrical progression from 23 m to 161 m. The material used in construction of the float lines was Cremona 20 S, 55×3×3. The tensile strength of this line need not be as strong as the main line, therefore the author has employed the worn-out Cremona rope for main line. The longest float line was 161 m long, which was found to be the maximum for setting and hauling the long-line.

1.3 Main line

Two kinds of main line····46 m×7=322 m (Type A long-line) and 46 m×9 =414 m (Type B long-line)····were used for the actual fishing experiments at various depths. The type B long-line consisting of 9 main lines was added to the type A long-line consisting 7 main lines with one each main line at each end in order to have the effect of float line. The construction design is shown in Fig. III–1. Materials data and dimensions are given in Tables III–2, III–3 and III–4. The specific gravities of the employed lines are shown in Table III–4. From data in Tables III–3 and III–4, weight of a set (basket) of main line consisting of Cremona 20 S, 55×3×3, 414 m long, was computed to be 1.755 kg in water.

1.4 Branch lines

The branch lines are made of synthesized threads, Cremona 20 S, 55×3×3, installed with "sakite" (a swivel line), "sekiyama" (steel wire wrapped with threads), steel wire, are 21.5 m long and weigh 175 g in water. Therefore, the weight of 6 branch lines attached to type A long-line is 1.05 kg in water which is about 60% of the weight of the main line.

1.5 Calculation of the depth of the deep hook

The depths of the deep hooks (No. 3 and No. 4 hooks) of two kinds of the deep-sea tuna long-line were calculated by Yoshihara's equation when the shortening rate is assumed to be 0.5. The results obtained are shown as D_c in the

Table III–4. *Details of material used for experimental deep-sea tuna long-line.*

Class	Material	Weight per unit length (g/m)	Specific gravity	Diameter (mm)	Tensile strength (kg)
1	Cr, 20S, 55×3×3	21.5	1.28	6.1	320
2	〃	〃	〃	〃	〃
3	〃	〃	〃	〃	〃
4	〃	〃	〃	〃	〃
5	〃	〃	〃	〃	〃
6	Cr, 20S, 58×3×3	22.5	〃	6.3	333
〃	St, 22S, 50×3×3	18.6	1.38	5.2	342
7	St, 22S, 55×3×3	20.7	〃	5.5	376
8	Cr, 20S, 60×3×3	23.3	1.28	6.5	350
9	Cr, 20S, 62×3×3	24.0	〃	6.7	380

right column in Table III–3. The values of D_o are calculated from the values of D_c by the method described in a later part of the paper.

2. *Measurement of the tension on the long-line during retrieving*

Low resistance and high tensile strength in water are required for the long-lines. For the selection of main line, and for knowing the remained strain in the main line, the author has measured the tension of various lines during retrieving.

2.1 *Principle for measuring of tension on the line and the apparatus*

A sheave, on which a line is put, is set at point (O), as shown in Fig. III–2. When tension (T) is loaded to the line, the force lifting the sheave (P) is expressed approximately by equation (4),

$$2\,T \sin\theta = P \qquad (4)$$

Where, (θ) is an angle of the line with plane, and when θ is 30°, $T=P$······(5)
When (P) is measured, the value of (T) is obtained. Fig. III–3 shows the actual apparatus, in which (P) is measured as a force pushing a load cell, and is recorded automatically by the ocsillograph through a strain meter. The number of revolution of the pulley of the line-hauler is also recorded automatically by the oscillograph through a micro-switch, therefore the hauling speed is also determined. Figs. III–4, III–5 and III–6 show the construction of the tension measuring apparatus, and Fig. III–7 shows its system schematically.

The accuracy of this apparatus was ascertained by comparing the weight loaded on the load cell with the tension caused by a steel wire (2.7 mm diameter) attached weight through the apparatus. The results obtained are shown in Fig. III–8. Good agreement was obtained between range of 30～80 kg.

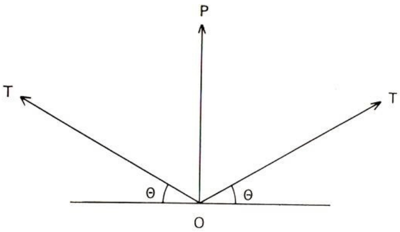


Fig. III-2. A principle for mesuring of tension on main line.

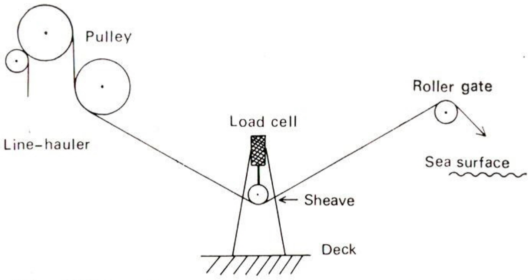


Fig. III-3. A method for measuring of tension on main line.

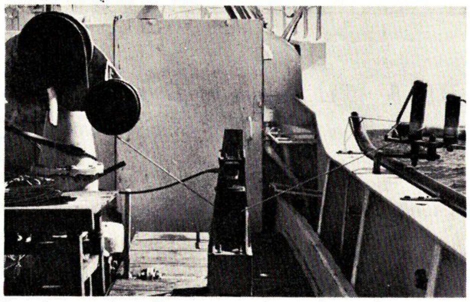


Fig. III-4. Apparatus for measuring of tension on main line.

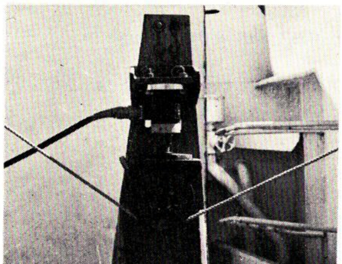


Fig. III-5. Load cell and sheave.

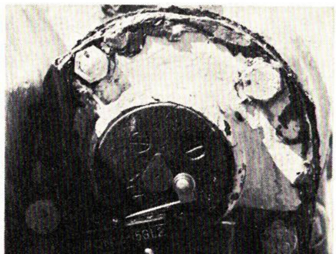


Fig. III-6. Cam and micro-switch for recording of revolutions of pulley.

2.2 *Experiment aboard ship for measuring of tension of long-line during retrieving*

Under moderate sea conditions of wind scale 3, wave scale 3 and swell 2 (by Beaufort wind scale), nine classes of long-lines shown in Table III-3 were set at calculated shortening rate of 0.5, and hauling speed, tension in lines and times

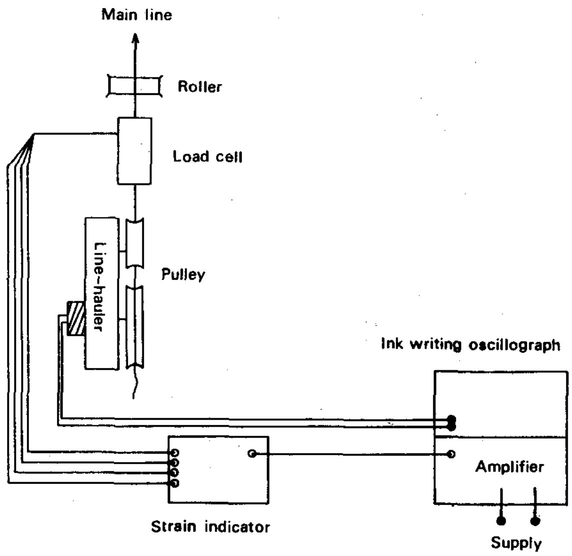


Fig. III–7. Diagram of apparatus for measuring of tension.

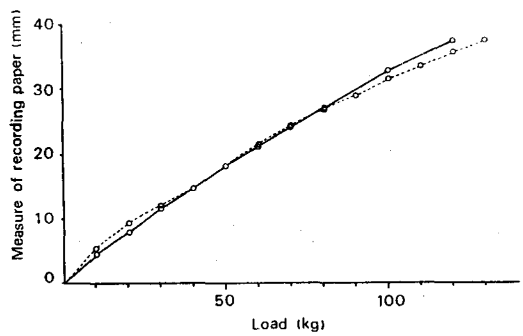


Fig. III–8. Calibration curves of the apparatus for measuring of tension.
--○--: Characteristic curve of the apparatus
—○—: Characteristic curve of the load cell

were measured. The hauling speed is expressed by the number of revolutions of the pulley of the line-hauler. This number is influenced by the tension in the line, the author ordered an experienced line-hauler operator to make the hauling speed as usual as possible.

2.2.1 Measurements of the tension on the hauling line without fish and the analysis of the results

Among 5 baskets of each of Classes 1, 2, 4, 5, 6 and 8 of long-lines, 3 baskets of each having no hooked fish were measured for tension on the main line. The number of revolutions of the pulley at 2 second intervals was taken from the

Table III–5. *Appeared frequency, mean value and variance of tension as recorded during hauling line.*

Class	1		2		4		5		6		8	
Number of basket	3		3		3		3		3		3	
Tension (kg)	Frequency		Frequency		Frequency		Frequency		Frequency		Frequency	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0～ 10	2	1.2	1	0.5	1	0.5	1	0.4				
10～ 20	17	9.9	12	6.6	6	3.2	9	3.6	1	0.4	1	0.5
20～ 30	49	28.5	20	10.9	38	20.5	19	7.6	4	1.5	3	1.5
30～ 40	73	42.4	78	42.6	92	49.7	72	28.8	24	9.1	25	12.6
40～ 50	27	15.7	55	30.1	32	17.3	77	30.8	100	38.0	72	36.2
50～ 60	4	2.3	16	8.7	14	7.6	46	18.4	41	15.6	26	13.1
60～ 70			1	0.5	2	1.1	21	8.4	20	7.6	15	7.5
70～ 80							3	1.2	13	4.9	18	9.0
80～ 90							2	0.8	27	10.3	15	7.5
90～100									24	9.1	14	7.0
100～110									7	2.1	8	4.0
110～120									2	0.8	1	0.5
120～130											1	0.5
Total	172	100.0	183	100.0	185	100.0	250	100.0	263	100.0	199	100.0
Mean value of tension	31.8		37.3		35.7		43.5		59.0		58.5	
Variance	94.1		107.0		95.6		172.2		439.4		465.3	

record charts. The frequency distribution by 10 kg tension intervals was plotted.

The mean values and the variance of the tensions are shown in Table III–5. The results of F-test and t-test are shown in Table III–6. From the results of F-test in the variance, no significant differences were detected between Classes 1, 2 and 4, while there were highly significant differences between Classes 5, 6 and 8 and Classes 1, 2 and 4. There were highly significant differences between Class 5 and Classes 6 and 8, but no difference was detected between Classes 6 and 8.

A t-test was made on Classes 1, 2, 4 and Classes 6 and 8 having no significant differences, and t′-test were made on other classes having significant differences. From t-tests and t′-tests, there were no differences between Classes 2 and 4, and between Classes 6 and 8. There were highly significant differences among other classes.

From the results of the tests, the tension is not only influenced by the operation of hauling lines and the number of revolution of the pulley, but also by the increasing in class number. The range of the appeared tension becomes wide in proportion to increasing of mean value of tension.

Morita[48] reported that the tension in the main line is in proportion to the hauling speed. Kamijo[49] estimated that the sinking velocity of the long-line is

Table III–6. *Statistical comparison on mean values and variances of tension.*

Class		1	2	4	5	6	8
Class	$\bar{x}$ \ s^2	94.1	107.0	95.6	172.2	439.4	465.3
1	31.8		F=1.137 d.f.: 171, 182 0.10<P<0.25	F=1.015 d.f.: 171, 184 0.25<P<0.50	F=1.829** d.f.: 171, 249 P<0.005	F=4.669** d.f.: 171, 262 P<0.005	F=4.944** d.f.: 171, 198 P<0.005
2	37.3	t=5.157** d.f.: 353 P<0.001		F=1.119 d.f.: 182, 184 0.25<P<0.50	F=1.609** d.f.: 182, 249 P<0.005	F=4.106** d.f.: 182, 262 P<0.005	F=4.348** d.f.: 182, 198 P<0.005
4	35.7	t=3.778** d.f.: 355 P<0.001	t=1.524 d.f.: 366 0.10<P<0.20		F=1.801** d.f.: 184, 249 P<0.005	F=4.596** d.f.: 184, 262 P<0.005	F=4.867** d.f.: 184, 198 P<0.005
5	43.5	t′=10.531** d.f.: 420 P<0.001	t′=5.501** d.f.: 431 P<0.001	t′=7.110** d.f.: 433 P<0.001		F=2.551** d.f.: 249, 262 P<0.005	F=2.702** d.f.: 249, 199 P<0.005
6	59.0	t′=18.279** d.f.: 433 P<0.001	t′=14.457** d.f.: 444 P<0.001	t′=15.764** d.f.: 446 P<0.001	t′=10.097** d.f.: 511 P<0.001		F=1.058 d.f.: 262, 198 0.25<P<0.50
8	58.5	t′=15.724** d.f.: 369 P<0.001	t′=12.404** d.f.: 381 P<0.001	t′=13.499** d.f.: 382 P<0.001	t′=8.625** d.f.: 447 P<0.001	t′=0.250 d.f.: 460 P<0.50	

s^2: Variance $\bar{x}$: Mean value of tension **: Highly significant

Table III-7. *Appeared frequency and mean values of*

Class	1		2		4	
r.p.m.	Freq. (%)	Average tension (kg)	Freq. (%)	Average tension (kg)	Freq. (%)	Average tension (kg)
30- 45						
45- 60			0.5	18.0		
60- 75					1.0	18.5
75- 90						
90-105					0.5	39.0
105-120	1.8	20.3	0.5	35.0	1.5	21.6
120-135	2.3	13.2				
135-150	2.3	30.2	3.2	27.8	2.6	29.4
150-165	2.9	29.8	3.7	31.7	12.1	32.0
165-180	11.1	33.1	39.0	36.5	35.7	28.4
180-195	45.0	30.6	17.6	26.6	12.6	31.5
195-210	5.3	26.6	1.6	44.3	1.5	30.0
210-225	14.6	36.8	22.9	45.9	28.9	42.6
225-240	14.6	30.9	10.6	32.6	3.1	39.1
Maximum tension	57		60		64	
Number of basket	3		3		3	

r.p.m.: Number of revolution per minute Freq.: Frequency

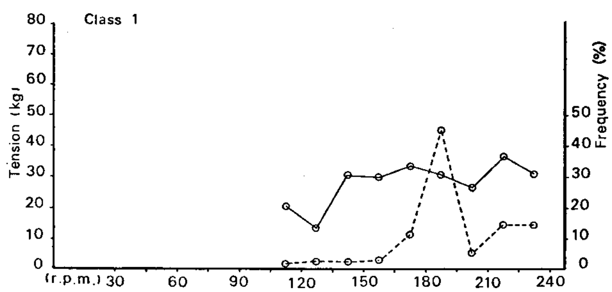
6 ~10 m/mim. Therefore, if the hauling speed is relatively slow, the hauling of the main line of the deep-sea long-line would not exert a large dragging force and the gear could be hauled more smoothly.

The author has examined the correlation of number of revolutions of pulley with the tension on the main line. The number of revolutions of the pulley were divided into ranges of 15 r.p.m., and the frequency and the mean values of the tension appearing at each range were examined from the recorded patterns. The results are shown in Table III-7. The relationship between tension on the main line and number of revolutions of the pulley in each range during the hauling of the long-line are shown in Fig. III-9.

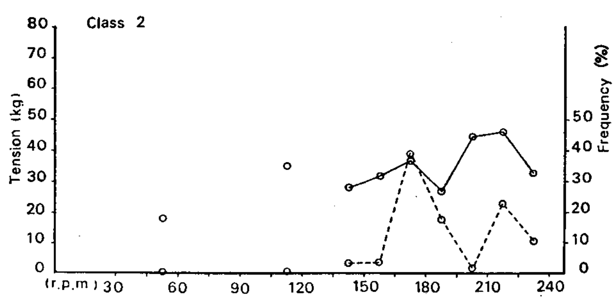
The results show that there is little correlation between the number of revolutions and the tension. It is noticeable that there were two peaks in the revolution frequency curve. The peak at low r.p.m. was the result of breaking action by the line-hauler operator when the attaching points of the branch lines approached the line-hauler. The main line was hauled at high r.p.m., therefore the peak 210 to 225 r.p.m. although the hauling speed was relatively constant at 2.2 m/sec. There was some difference due to individual operators. The tension on the main line in Class 1 was about 30 kg, which is almost the same as the usual long-line; the tension on the Class 8 deep long-line was about 30 kg greater than the usual long-line.

The tensile strength of "Cremona 20 S, 55×3×3", the usual raw material of *tension at each range of revolutions of pulley.*

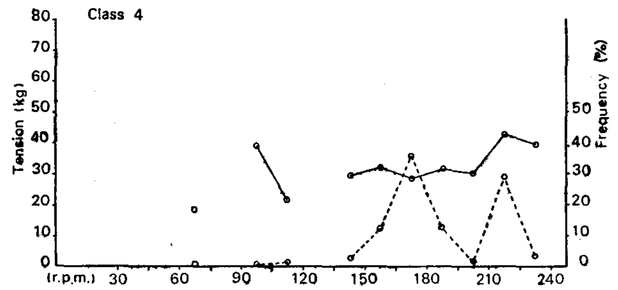
5		6		8		Total	
Freq. (%)	Average tension (kg)	Freq. (%)	Average tension (kg)	Freq. (%)	Average tension (kg)	Freq. (%)	Average tension (kg)
0.4	16.0	0.3	49.0	0.5	52.0	0.2	39.0
0.4	19.0			0.5	46.0	0.2	24.3
0.4	34.0	1.5	38.2	2.0	41.5	0.8	35.5
1.2	16.6	1.1	40.6	3.5	45.0	1.0	37.5
		1.5	39.2	6.0	43.0	1.3	41.9
1.2	26.3	9.8	47.1	21.6	43.9	6.2	42.5
1.6	31.5	26.2	45.0	14.1	43.6	8.3	43.0
10.4	38.9	15.9	41.2	3.5	47.0	7.1	39.0
29.6	37.4	3.0	52.5	1.0	43.0	9.4	36.8
14.8	34.5	1.1	72.6	2.0	56.5	16.1	34.1
2.0	34.4	1.1	66.6	4.0	64.3	11.9	32.5
1.2	39.3	2.2	63.6	2.0	55.5	2.2	42.3
34.0	55.8	33.8	80.4	37.2	76.3	29.4	61.5
2.8	49.4	1.9	78.0	2.0	76.2	5.3	40.3
81		119		123		—	
3		3		3		18	



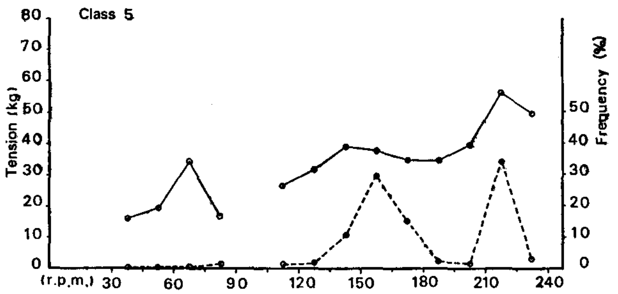
Class 1



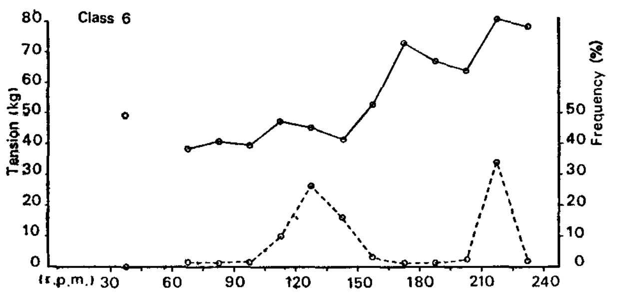
Class 2



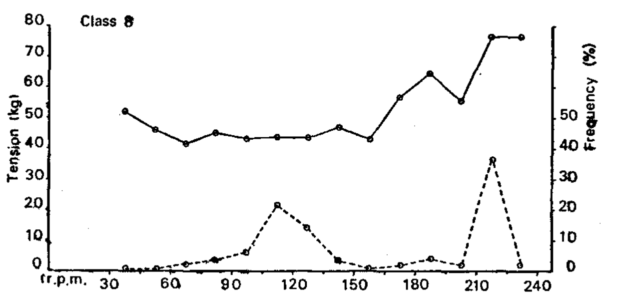
Class 4



Class 5



Class 6



Class 8

Fig. III-9. Relationship between tension on main line and revolution of pulley during hauling line (Classes 1, 2, 4, 5, 6 and 8).
O——O: Mean value of tension at each range of revolutions
O- - -O: Frequency of revolutions

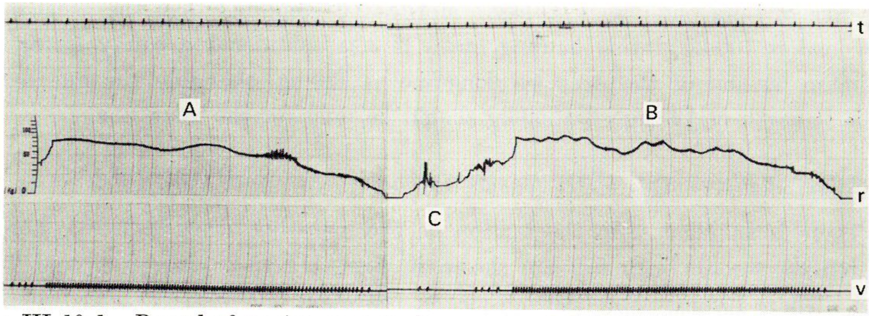


Fig. III-10-1. Record of tension on main line as recorded by the pen-oscillograph (Class 6).
A: Record with no fish
B: Record of increased tension caused by a hooked live albacore
C: Tension record at attaching point of branch line on main line
t: Time mark in second
r: Revolutions of pulley

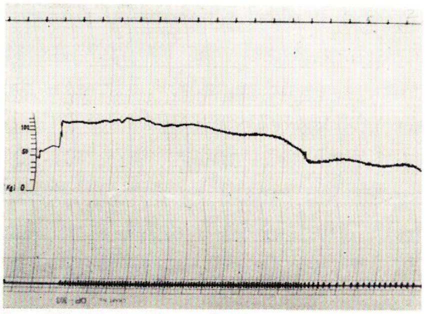


Fig. III-10-2 Record of increased tension caused by a hooked live albacore (Class 8).

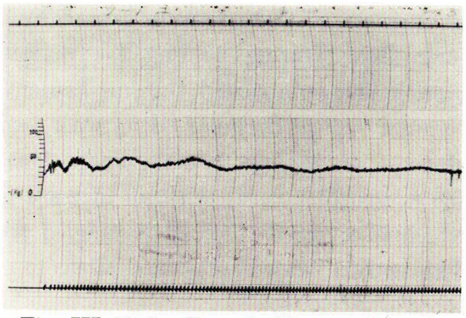


Fig. III-10-3. Record of increased tension caused by a hooked live albacore (Class 5).

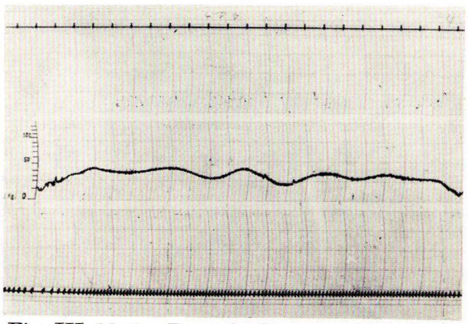


Fig. III-10-4. Record of increased tension caused by a dead and reversed albacore (Class 1).

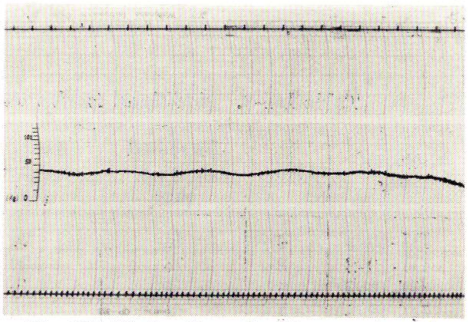


Fig. III-10-5. Record of increased tension caused by a dead albacore (Class 8).

main line of tuna long-line is 320 kg. Morita[45~47] reported that the usual maximum load is 100 kg during hauling line. If 3 is considered a safety factor, the maximum tension of the deep-sea long-line is 120 kg, therefore the line having tensile strength of 120 kg$\times$3=360 kg should be used for the main line.

2.2.2 Measurements of the tension in hauling line with hooked fish

There is an increase in the tension on the main line when fish were hooked. The tension records with fish are shown in Figs. III–10–1 ~III–10–5, and Table III–8. These records show the tension on the main line with a hooked albacore (body weight of about 20 kg) per basket.

The right hand oscillograph record in Fig. III–10–1 shows the regular curve with an increase of 14 kg tension caused by an alive albacore on a Class 6 main line. The average dragging force is 75 kg and the maximum dragging force is 100 kg. The left hand record in Fig. III–10–1 shows the smooth curve, when there is no fish on the same class main line. In this case the dragging force is 75 kg while the maximum dragging force is 80 kg. Fig. III–10–2 shows an irregular curve with an increase of 18 kg tension caused by fighting of a hooked albacore on a Class 8 main line. During hauling the maximum dragging force was 120 kg. As the branch line approached the line-hauler, the curve became regular. Fig. III–10–3 shows a typical irregular curve with an increase of 6 kg tension caused by an alive albacore on a Class 5 main line. The dragging force was 40 kg. Fig. III–10–4 shows irregular curve with an increase of 24 kg tension caused by a dead albacore which is reversed (the tail is tangled with wire). Fig. III–10–5 shows a constant 8 kg tension caused by a dead albacore on a Class 8 main line during hauling at low speed (120 r.p.m.).

From above records, it is seen that tension curve is smooth when there is no fish on the line, however, in the case of hooked fish, the curves become irregular due to struggling by the fish and its resistance. The height of the curve depends the hooking conditions and whether the fish is dead or alive. For example, when the fish died and reversed, the increase in tension was 24 kg, but normally the increase

Table III–8. *Additional tension on main line caused by hooked albacore.*

No. of Fig.	Class	Increased tension (kg)	Average tension* (kg)	Average revolution** (r.p.m.)	Dead or alive	State of hooking fish
III-10-1	6	14	75	220	Alive	Normal
III-10-2	8	16	120	220	〃	〃
III-10-3	5	6	40	180	〃	〃
III-10-4	1	24	35	200	Dead	Reversal
III-10-5	8	8	37	120	〃	Normal

*: Average tension during hauling **: Average revolution during hauling

was about 10 kg. Generally, the rate of the increase of the tension in hauling line is not so large, in other words, the influence on the increased tension on the tensile strength of the main line is not so large.

2.3 Measuring experiments on the residual strain of main line

When a large load is applied to the main line at hauling, the line will stretch and after the load is removed, the strain would remain. When the initial length of the main line is $2\,l$, and the remaining elongation is $2\Delta\, l$, the residual strain E will be expressed by the equation (5).

$$E = \frac{\Delta\, l}{l} \times 100\,(\%) \qquad (5)$$

As the residual strain is an elongation of the main line, this strain effects the depth of the hook. Therefore, it is necessary to know the residual strain during an actual fishing. Tests were conducted to measure the residual strain. The lines tested, shown in Fig. III–11, were of the 12 kinds of raw materials used for every class of main line. Test segments of the main line were 45 cm long. For the comparison, new articles of 3 lines (Cremona) were also employed. These 15 kinds of lines were soaked in sea water, in a closed vessel having hydraulic pressure of 30 atm, until the materials were saturated. This hydraulic pressure corresponds to about 300 m depth. The estimated distance between two marks on the lines was 300 mm. The stretching velocity was 1.5 mm/sec. The maximum applied force was 60 kg, and after the maximum force was obtained the load was released instantly. The test room temperature was 24°C. The experimental instrument was Universal Testing Machine RH–10 TV.

The results obtained are shown in Table III–9. Ten kinds of line from A to K made of "Cremona" fibre had been used for fishing 30∼70 times. The elongated strain did not depend on size.

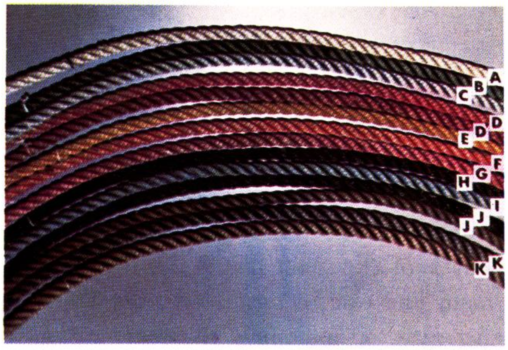


Fig. III–11. Main lines used for measuring of residual strain.

The elongation of lines H and J, made of "Spun tetoron", had significant difference with size, but the residual strains had no difference with the size. The elongation and the residual strain of new lines X,Y,Z made of "Cremona" were large.

From those results, the more times a line used is, the more stiff the line becomes (Honda[50] called this fatigue of line), and the less the elongation and the residual strain become. The residual strain of the lines is slightly recovered after 16 hours. Those results show reological characteristics of the fibre materials. Summarizing the above results, lines used over certain number of operations have about 2% residual strain, if the lines receive over 60 kg dragging force. Consequently, it is most important to keep the initial length of the main lines, especially for the new articles.

Table III-9. *Experimental results of measurement for residual strain of main lines.*

Mark	Material of lines	Lapse of year	N	Elongation (%)	Residual strain (%) Time (hour) 0	16
A	Cr, 20S, 55×3×3	5	70	17.6	1.6	1.3
B	〃	5	70	17.5	1.3	1.3
C	〃	4	54	16.2	1.7	1 7
D	〃	4	54	16.5	2.3	1.9
D′	〃	4	54	16.8	2.2	1.9
E	〃	3	42	17.3	1.7	1.7
F	〃	3	42	16.0	2.6	2.2
G	〃 58	2	30	15.9	1.6	1.6
I	〃 60	2	30	15.1	1.6	1.6
K	〃 62	2	30	15.5	2.3	2.3
X	〃 55	0	0	21.7	—	—
Y	〃 58	0	0	20.4	7.6	7.3
Z	〃 60	0	0	19.6	—	—
H	St, 22S, 50×3×3	2	30	10.4	1.9	1.3
J	〃 55	2	30	10.5	1.3	1.0

N: Number of operation Time: Lapse of time after unloading

IV. Experiments on measuring of hook depth

1. *Estimation of shortening rate*

The shortening rate is the ratio of the shortened length (distance between flag floats) to the total length of the main line. The depths of the attaching point of branch line on the main line can be estimated from the length of the main line, $2l$, and the shortening rate, k, assuming the sagging form of the main line is catenary.

It is difficult to measure the distance between flag floats of individual baskets during an actual fishing at sea. In the past, the distance between the flag floats of the entire set of the long-line was estimated by the distance run by the vessel while making the set. Recently radar detecting methods[51)52)] have been taken place of the following method of measurement.

The distance of the long-line laid is measured by detecting both ends of the entire set of long-line on the radar scope, and the distance of one unit of the gear (one basket) is obtained by division. Therefore, this method is not so accurate. In order to increase the accuracy, it is necessary to measure each distance divided into several section. The author has measured each distance by using an electromagnetic log, radar reflector and radar buoy at same time.

1.1 Measuring method using an electromagnetic log

As seen in Table III–3, each class (one set) of long-line consists of 13 baskets (Classes 5 and 6 consist of 13 baskets×2). The entire set of the long-line consist of eleven sets was laid as shown in Fig. IV–1. The measurement by an electromagnetic log was made on the distance in which each set of long-line was laid.

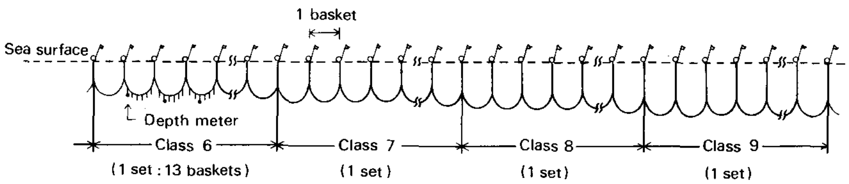


Fig. IV–1. Schematic diagram of experimental deep-sea tuna long-line in sea water.

1.2 Measuring method by radar reflector

A small reflector, which has low wind resistance was installed at each 3 sets of the long-line. The distances between each reflector were measured by means of radar after the completion of setting (Fig. IV–2–a, Fig. IV–2–b). The records obtained by the radar were compared with those obtained by the electromagnetic log.

1.3 Measuring method by radar buoy

The measuring method by radar buoy has the same accuracy as that of the radar reflector, and the former is detectable at a greater distance than the latter. As the maximum measuring distance by this method is about 10 miles, the author installed radar buoys on the set of long-line at a greater distance which is could not be measured by the radar reflector method, and measured the distance.

Fig. IV–2–a. Echo images on the P.P.I. scope showing flag floats and corner reflectors mounted on long-lines.

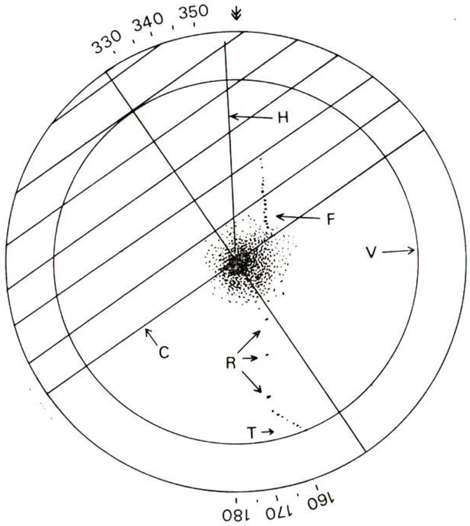


Fig. IV–2–b. Diagram for echo images on the P.P.I. scope (Range: 6 miles).
F: Flag floats
R: Reflector (long-line)
T: Reflector (vertical long-line)
H: Heading line
V: Variable marker
C: Cursor
Sea condition: Wind direction NE, wind scale 2, swell NE–1

1.4 Results

The laying distance of the entire set is about 16 miles, therefore, few set of long-lines were out of range of the ship's radar at which the entire set of the long-line has completed to set. The distances estimated by the electromagnetic log were converted to the distances measured by radar, and the shortening rates were calculated.

The distances between the flag floats of the 3 sets of the long-lines selected for the measurements were measured by both radar and electromagnetic log, and the ratios of the both measurements were calculated on all such occasions. These ratios are shown in Table IV–1. The difference observed between 1968 and 1969 is considered to be instrument error.

It is difficult to set many baskets over a long range with equal distance between flag floats of individual baskets. In order to obtain an equal distance between flag floats of 1 ~3 sets, the setting operation of these sets was conducted repeatedly with same hand in 1968 and 1969. The shortening rates of 300 sets were observed, and the frequency distribution of the shortening rates are shown

Table IV–1. *Experimental results of measurement of shortening rate.*

Year	n	$\frac{L}{R}\times 100$	
		$\bar{x}$	s
1968	14	99.4	5.6
1969	34	98.7	5.8

L: Distance measured by electro-magnetic log
R: Distance measured by means of radar
s: Standard deviation
n: Number of measurement

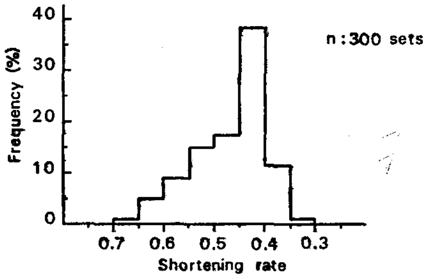


Fig. IV–3. Frequency distribution of observed shortening rate.

in Fig. IV–3. As seen in Fig. IV–3, 97.7% of the sets were in the range of 0.35 ~ 0.65. This fact is important in order to lay the long-line as deep as possible. From those values of the shortening rate obtained, the hook depths of each basket of one set (Class) were estimated.

1.5 Accuracy of shortening rate

As the estimation of the depths of attaching point of branch line on the main line was calculated under the assumption that the main line of each basket sags respectively in water to be catenary, some error would not be taken into consideration. In order to compare the calculated depths with the actual fishing depths, the author conducted some experiments on measuring depths by instruments.

When the main line of each basket is set evenly, the estimated accuracy can be computed as follows. The accuracy of the distance measured by means of the radar (Tokyo Keiki, MR–120 D, range accuracy: ±0.05 mile) is reported to be ±0.05 mile (±92.6 m). The error in distance between the 3 set unit as measured by means of the radar in the experiments can be computed by the formula,

$$\pm 92.6\times\frac{1}{13\text{ baskets}\times 3\text{ sets}}=\pm 2.37\text{ m}\cdots\cdots\text{measured error per one basket.}$$

Here, if the usual shortening rate is employed to be 0.5, the accuracy could be calculated for each two kinds of the long-line used for the experiment as follows.

$$\text{Type A long-line: }\frac{\Delta L}{L}=\frac{2.37}{161}\fallingdotseq 0.0147$$

$$\text{Type B long-line: }\frac{\Delta L}{L}=\frac{2.37}{207}\fallingdotseq 0.0114$$

Where, L (m) is the distance between flag floats of one basket, and ΔL (m) is measured error per one basket. The accuracy estimated of shortening rate is ±1.5% and ±1.1%, respectively which is very accurate.

2. *Measuring of hook depth by depth meter*

2.1 *By some instrument*

2.1.1 *By chemical tube*

The chemical tube is a sounding instrument (glass tube) invented by Kelvin. It is 640 mm long with an inner wall of a water-soluble chemical, and is closed at one end. When this glass tube is hung with the closed end upward in the sea, the sea water pours into the glass tube by corresponding water pressure of the depth and dissolves the chemical coating. The depth can be measured by scaling the line of demarcation. In the past, this instrument has been employed to measured the hook depth of an usual long-line. This glass tube can not be re-used, therefore, the accuracy of the instrument can not be estimated beforehand.

The author has estimated the accuracy of this instrument as follows. Each bundled 4 chemical tubes were attached to the sounding wire (2.7 mm dia.) at 10 m intervals. The lowest tubes were lowered to 170 m depth. After hauling up the wire, each demarcation line was read from a calibration scale. This experiment was carried out at calm sea. When the sounding wire was lowered in the sea, the incidence angle was measured. Correction was made on the depth that is related to the incidence angle and the reading of the meter wheel (error: 0.7 %) in order to obtain more accurate measurement.

The result obtained are shown in Fig. IV–4, in which errors are variable. It is thought that the errors are caused by lack of uniformity of the glass tube and uneven demarcation line as shown in Fig. IV–5. As the scaling is exponential with depth, the scaled error becomes larger with increasing the depth. The reliability is considered to be below 140 m depth.

As weight of the glass tube itself is 21 g, and that of the protector is 215 g, the total weight is 236 g in the air and 202 g in the sea water. The sounding

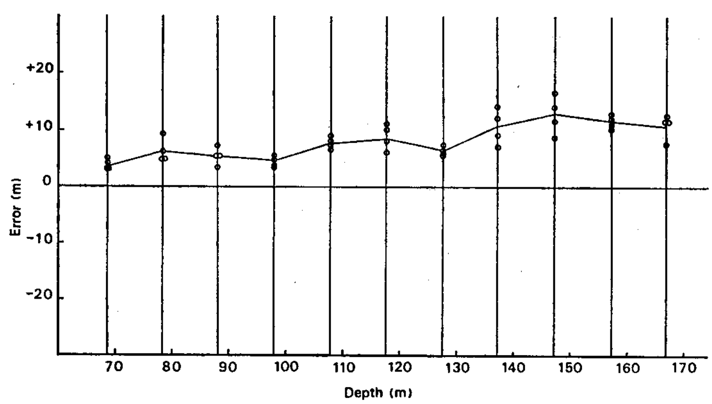


Fig. IV–4. Measured error of chemical tubes at various depths.

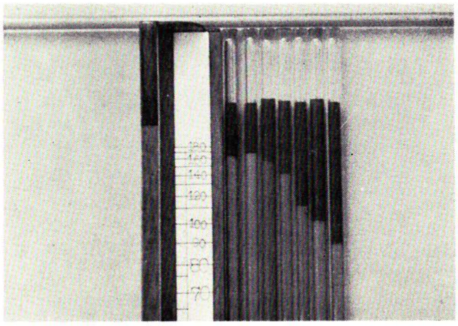


Fig. IV–5. Demarcation line in chemical tubes.

instrument is heavier than the branch line. The attaching of a chemical tube to the branch line would probably influence the sagging form of the main line in the sea. Consequently, it is important to decrease the weight of the sounding instrument.

2.1.2 By T.S.-depth recorder

In the past, T.S.-depth recorder has been employed for investigations of oceanography and biology. The author applied this instrument to measure the hook depth of the long-line by reducing the weight. As shown in Fig. IV–6, this recorder is 123 mm long and 60 mm outside diameter. The deflection of the bourdon tube by water pressure corresponding to sea depth are recorded on a smoked glass. Maximum depth of the long-line and the depth at which a fish is hooked are measured by this instrument. The bourdon tube is small and has little temperature induced error.

This instrument was calibrated for depth under various water pressure, in a calibration tank (15°~20°C) and the temperature error was examined between -2° and +35°C. The temperature error was within 1% by employing a 500 m full scale.

A correction was also made on the observed value by the following experiment. The sounding wire (2.7 mm dia.) to which the T.S.-depth recorder was attached, was lowered to various depths. The depth were checked by a fish-finder (shown in Table IV–5) having a frequency attenuator (NJD 2310, Nippon Musen Co., Ltd.). The incidence angle of the wire provided a correction factor.

The author improved this depth recorder by using light weight plastic case (323 g in the air, 138 g in sea water). This depth recorder is highly accurate, but has a disadvantage of being expensive. During this study, several instruments were used for ascertaining the depth of hooked tunas.

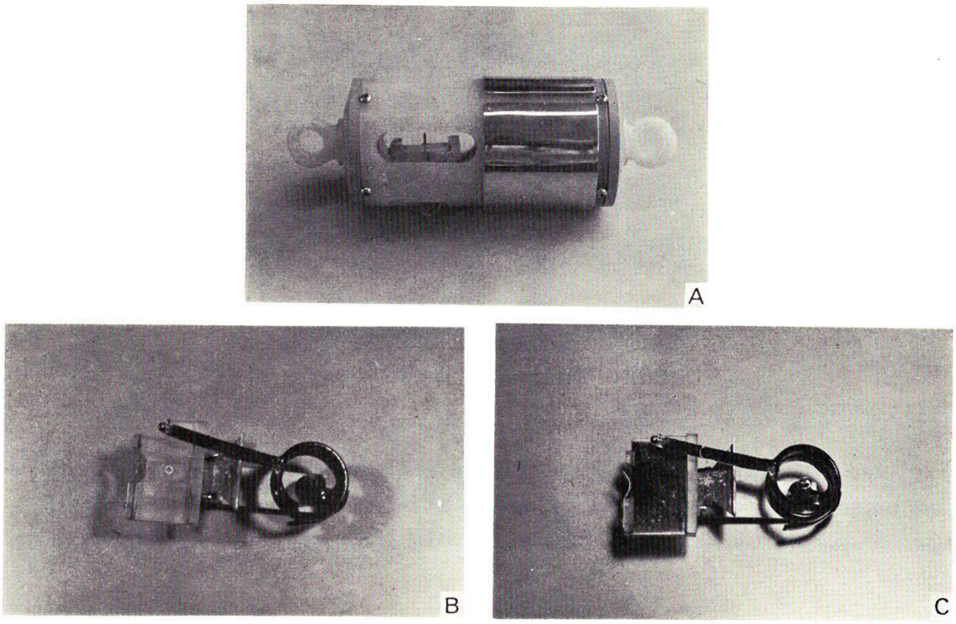


Fig. IV-6. T.S.-depth recorder.
A: External view B: Bourdon tube (upper side)
C: Bourdon tube and inserted smoked glass

2.1.3 By automatic depth meter

Hamuro's automatic depth meter[37] was reconstructed for the purpose of measuring the hook depth to 500 m in sea water. A description of this instrument is given in Table IV-2. In actual fishing, a glass ball is fastened to this depth meter to reduce its weight in sea water. This depth meter was used for measuring the time and the depth of albacore hooking.

The principle of the automatic depth meter shown in Fig. IV-7 is that when the rubber diaphragm receive water pressure, silicon oil in the spring housing is

Table IV-2. *Performance of automatic depth meter.*

Range of recording	10~500 m
Submersible limit	800 m
Accuracy	±1%
Chart speed	1 mm/min.
Accuracy of chart speed	±0.8%
Recording time	20 hours
Weight in air	2.7 kg
Weight in water	1.3 kg
Height	22.0 cm
Outer diameter	9.0 cm

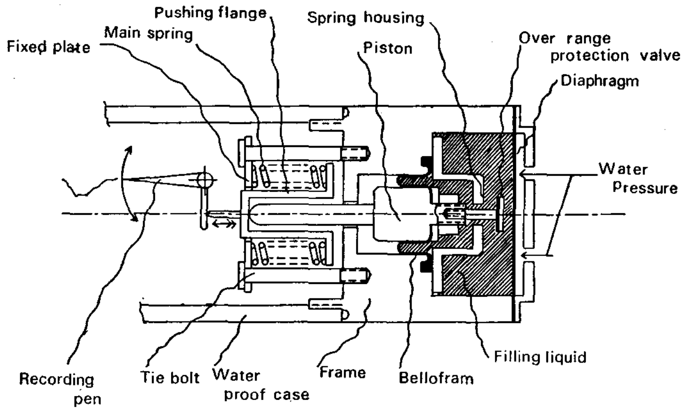


Fig. IV-7. Diagram of the automatic depth meter.

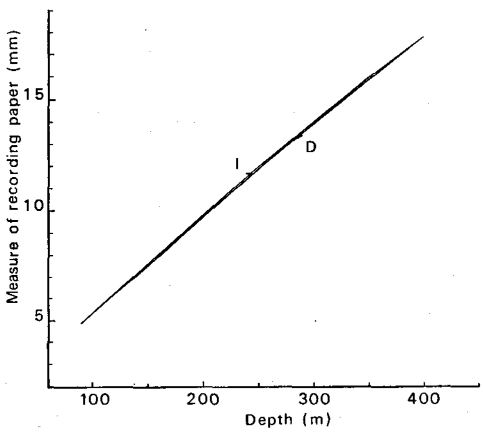


Fig. IV-8. Calibration curve of the automatic depth meter.
I ∕: Increasing pressure D ∕: Decreasing pressure

pressed, and the pressure is transmitted to the bellofram (bellofram has a characteristic of bellows and diaphragm together). The piston connected to the bellofram receives a force which is the product of the effective area of bellofram and the water pressure. The piston moves until it is equilibrium with the power of the spring. This motion of the piston operates the recording pen.

The author has tried to obtain correction factor for this depth meter at the sea. The results obtained are shown in Fig. IV-8. According to Fig. IV-8, the difference of read values between increasing and decreasing of pressure at the same depth was within 0.1 mm on the recording paper, and both values are linear.

The effect of temperature induced error are shown in Table IV-3. Here, the ratios of the indicated depth (ΔD) with the temperature change (ΔT) are shown as follows;

Table IV–3. *Temperature effect on automatic depth meter.*

Actual depth (m)	100		150	
Indicated depth (m)	100.0	101.4	148.0	151.5
Reading of indication (mm)	5.35	5.40	7.55	7.70
Temperature (°C)	17.0	28.5	14.0	23.0

Table IV–4. *Maximum and minimum temperature at various depths in the fishing area.*

Depth (m)	Temperature (°C)		
	Min.	Max.	Max.–Min.
0	24.8	27.0	2.2
100	22.0	24.7	2.7
200	19.1	21.3	2.2
300	15.6	18.0	2.4
400	12.3	14.1	1.8

$$\frac{\Delta D}{\Delta T}=\frac{101.4-100.0}{11.5}=\frac{1.4}{11.5}\fallingdotseq 0.12\ \mathrm{m/^\circ C}$$

$$\frac{\Delta D}{\Delta T}=\frac{151.5-148.0}{9.0}=\frac{3.5}{9.0}\fallingdotseq 0.38\ \mathrm{m/^\circ C}$$

The variations of temperature at the same depth between 0 ~400 m for different location at the fishing area is within 1.8 ~2.7°C as shown in Table IV–4. Therefore, the temperature change has a slight influences on the error of the depth change, and consequently the accuracy of this depth meter is high. Because of high cost, it is difficult to employ many of these instruments for the experiments.

2.1.4 *By fish-finder*

Observations on the hook depth of the long-line by a fish-finder has been reported by investigators in the foreign countries[32~34] and also in Japan.[14)28~30] The results indicated that the observing may be possible under good sea conditions. Measurements, however, have only been carried out above 140 m depth, because usual long-line did not fish below 140 m.

The author has tried to observe the hook depth of the experimental long-line by using a fish-finder. It is difficult to observe the reflection of the long-line itself. Therefore, some targets that increase the reflection effect of the long-line were attached for detecting by the fish-finder. For this purpose, aluminium balls and glass balls were used. A calm sea condition was selected to carry out the experiment. The specification of the fish-finder is shown in Table IV–5. The targets described in Table IV–6 were attached to the sounding wire at two meter intervals,

Table IV–5. *Specifications of Model D–70 fish-finder.*

Ultra sonic frequency	24 kHz		
	Recorder range (m)		Pulse recurrence rate (per minute)
	Base	Max.	
Shallow	0-100	500	90
	0-200	1000	45
Deep	0-250	1250	36
	0-500	2500	18
Directivity (at a quarter power)	Fore to aft		6°
	Left to right		12°
Pulse length (ms)	Long		5.0
	Short		0.5
Driver out put (W)	Long pulse		2800
	Short pulse		3500

Table IV–6. *Targets examined for detecting of long-line depth by fish-finder.*

Order of hanging	Targets	Diameter (mm)	Weight in water (g)	Number
1 (Upper)	Aluminium ball	60	244	1
2	〃	40	54	1
3	〃	40	54	2
4	Glass ball	60	—	1
5 (Lower)	〃	60	—	2

The sounding wire was lowered to various depths and the echo patterns were observed on the recording paper.

The two aluminium balls of 40 mm diameter gave the most clear reflection pattern. This target is 108 g weight in sea water, and approximates the 112 g weight of metal parts of the branch line in sea water. There was a deep scattering layer, but it was possible to detect the targets attached to the wires to a depth of 300 m (Fig. IV–9, Fig. IV–10).

In the fishing area two aluminium balls, 40 mm diameter, were attached to end of the branch lines of the deep-sea long-line (in this case sekiyama, hooking wire and hook were removed), this gear was set in the moderate sea (wind scale 3), and detection was tried with the fish-finder. The depth of point attached with aluminium balls at branch lines was presumed to be 200 m by calculation from the shortening rate of the main line, but it could not be detected by the fish-finder. Detecting the target in deep layer by fish-finder is difficult, because it is difficult to situate the vessel just above the branch line because of deforming of the catenary of main line by the sea current. Detecting is especially difficult

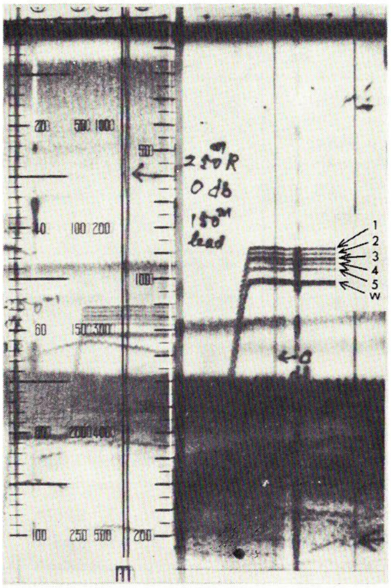


Fig. IV–9. Echo chart of targets obtained by using a 24 kHz.
1: 89 m depth (1 aluminium ball of 60 mm in diameter)
2: 91 m depth (1 aluminium ball of 40 mm in diameter)
3: 93 m depth (2 aluminium balls of 40 mm in diameter)
4: 95 m depth (1 glass ball)
5: 97 m depth (2 glass balls)
w: 102 m depth (weight)

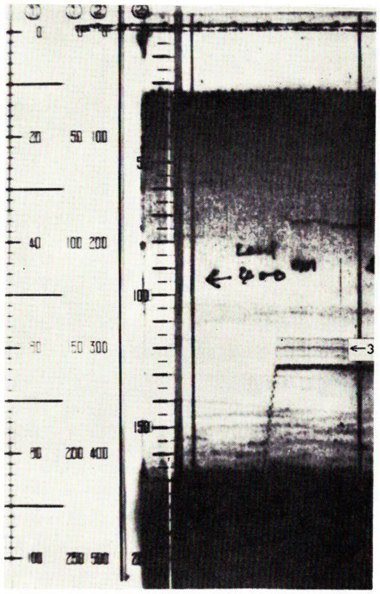


Fig. IV–10. Echo chart of targets obtained by using a 24 kHz.
3: 300 m depth (2 aluminium balls of 40 mm in diameter)

under sea condition of strong wind and the presence of the deep scattering layer which attenuates the propagation of even low frequency waves. From the results, detecting the deep-sea long-line below 300 m depth by a fish-finder is not feasible.

2.2 Experimental depth meter (SS type depth meter)

The author has designed and constructed a depth meter which consists of a straight bourdon tube (pressure receiver), an indicator tube (liquid column) and an outer tube (scale tube). The indicator tube and scale tube were made of acrylic plastic. The weight is 170∼210 g in the air, and 75∼110 g in sea water.

The principle of this instrument is as follows. The pressure receiver shown in Figs. IV–11 and IV–12 is connected at its lower part to a liquid pressure pump shown in Fig. IV–13. By pushing the piston of this pump, the pressure receiver is compressed, then the liquid in the indicator tube flows out from the top, and adds to the liquid in the well. The body is reversed, and then the pressure is

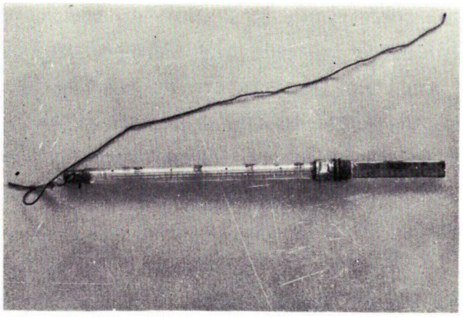


Fig. IV–11. SS type depth meter (experimental depth meter).

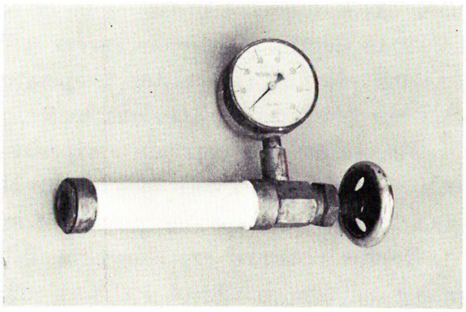


Fig. IV–13. Resetting pressure pump fit for SS type depth meter.

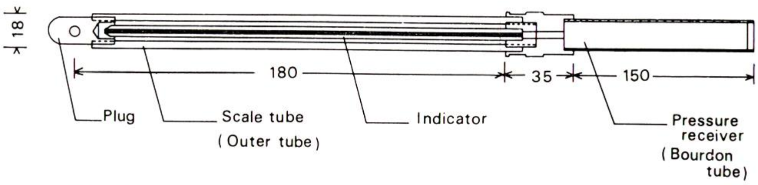


Fig. IV–12. Schematic construction of SS type depth meter. Dimension: mm

gently reduced, the indicator tube is filled with the liquid. When this depth meter is lowered into sea, the pressure receiver reacts to the water pressure, and the quantity of the liquid corresponding the water pressure is forced out. During hauling, the pressure is reduced to the initial state, the liquid flows down in the indicator. The depth is determined from the level of liquid in the indicator.

When using a bourdon tube, the error caused by temperature is important. In order to reduce the error, the wall of the bourdon tube must be as thin as possible, and the content of the tube must be made small (1.25∼1.80 cc). The composition of the liquid is as follows.

Water: surface active agent: alcohol=100: 14: 0.5

To examine the error induced by temperature, the expansion coefficient β of water is assumed to be as follows,

$$\beta=0.2\times10^{-3} \quad \text{(mean value between } 16^\circ\sim36^\circ\text{C)}$$

The difference of the volume in the bourdon tube between before and after the expansion by temperatures is,

$$V'-V=V\beta\,(t'-t)=0.0072\ \text{cc}$$

Where, V' is the volume in the bourdon tube after the expansion, V is that before the expansion (1.8 cc). t' is maximum temperature (36°C), t is minimum temperature (16°C). The indicator is marked for the volume about 0.10 cc of indicator tube. As a difference of 0.0072 cc in volume corresponds to 2 units on the scale (i.e. 20 m depth). Therefore, every 1°C difference between the temperature at receiving pressure (sea water temperature) and the temperature at reading the scale (air temperature), i.e. one meter, must be added to the indicated depth.

The author has conducted experiments on the effect of temperature on the reading. The depths corresponding to the water pressure increased were calculated using 1.025 as the specific gravity of sea water at of 20°C.

Results obtained are shown in Table IV–7 and Fig. IV–14. According to those results, a change of 1°C was equal to 0.6 m (mean value). The difference between the minimum temperature (14°C) at measuring of depth and the temperature (24 ~28°C) at reading of scale on the fishing grounds was 10 ~14°C, therefore the maximum indicated error of the depth by the difference of temperature is estimated to be 6.0 ~8.4 m.

The accuracy of the SS type depth meter was tested at sea under the condition

Table IV–7. *Temperature effect on SS type depth meter.*

No.	Loading pressure kg/cm^2	Testing temperature (°C)	Estimated depth (m)	Error (m) Temperature at reading 10°C	20°C	30°C	40°C
1	35	20	341	+3	0	−6	−13
2	30	〃	293	+5	0	−5	−13
3	30	〃	293	+6	0	−6	−18
4	35	〃	341	+6	0	−7	−23
5	35	〃	341	−12	0	−7	−22
6	35	〃	341	+5	0	−7	−24
7	40	〃	390	+3	0	−6	−21
8	35	〃	341	+4	0	−4	−13

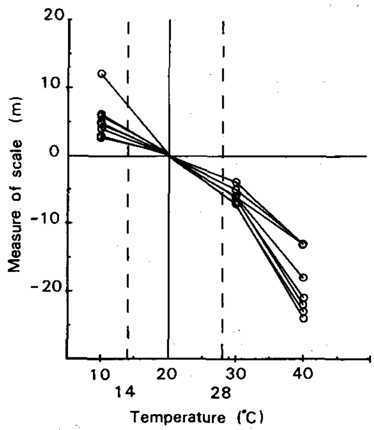


Fig. IV–14. Temperature characteristic of SS type depth meter.

Table IV–8. *Experimental result of accuracy of SS type depth meter.*

Depth (m)	100	150	200	250	300	350	400
$\bar{x}$ (%)	3.4	2.6	2.2	2.0	2.2	2.2	2.0
s (%)	2.42	2.06	2.11	1.82	1.85	1.13	0.98
n	28	28	28	27	26	16	6
Temperature (°C)	17.0	14.0	11.5	10.0	9.2	8.3	7.2

Air temperature: 20.5°C $\bar{x}$: Mean value of accuracy
s: Standard deviation n: Number of depth meter used

as given in Table IV–8 using the method written in 2.1.2. The bundled depth meters were attached to a sounding wire, and was lowered to 400 m depth. Tests were duplicated to determine reproducibility. The temperature induced error were corrected by using +0.6 m/°C. The accuracy of the SS type depth meter is about 2.0~3.4%, as shown in Table IV–8. The mean value of the differences between 1st and 2nd experiments at each depth is very small, 0.35 m, and the results are stable.

The SS type depth meter is not expensive, it was employed at once. Because this depth meter is small and light in sea water, it does not influence the catenary of the main line in the sea. In the later experiments, this instrument was employed for obtaining a correction value for each layer fished. There are some differences between the hook depths observed by a depth meter and the hook depths calculated by mean value of shortening rate. It is important to estimate the relation between the mean value of shortening rate and the hook depth observed by using many depth meter.

3. *Model experiment on catenary form of main line*

The hook depth can be calculated under the assumtion that a main line should form a catenary in water when there is no current. In the past, the hook depths calculated from the shortening rate of the main line have been compared with those obtained by the actual measurements of the chemical tube method. It is assumed that the main line is not actually an ideal catenary because of the weight of metal part of the branch line and the sea current. It is, therefore necessary to check up the form of catenary by a model of a long-line. Two kinds of the long-line (Type A and type B long-lines) were modeled 1/300 scale model using aluminium chain (a link is 3.9 mm in diameter). The weight was proportional to that of the long-line in sea water. The ends of the aluminium chain were pinned on section paper allowing the chain to sag freely to form a catenary. The form of the catenary of the aluminium chain at different shortening rates were plotted on the section paper as shown in Figs. IV–15 and IV–16.

Fig. IV–15 shows the catenary of the main line without the branch line, and Fig.

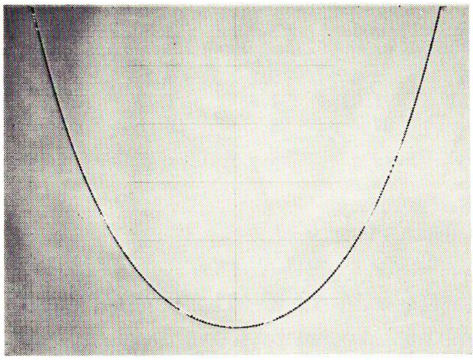


Fig. IV–15. The scale model, of aluminium chain, representing the main line of one basket of long-line.
Natural scale: 1/300 $2l$: 414 m
k: 0.50

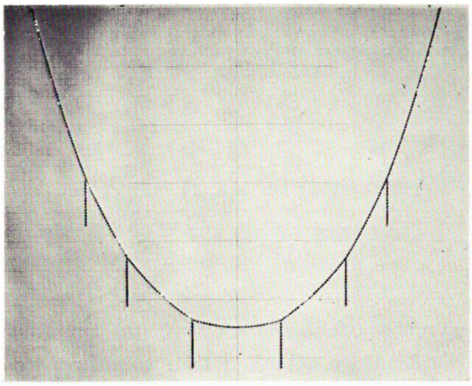


Fig. IV–16. The scale model, of aluminium chain, representing the main line and branch lines of one basket of long-line.
Natural scale: 1/300 $2l$: 414 m
k: 0.50

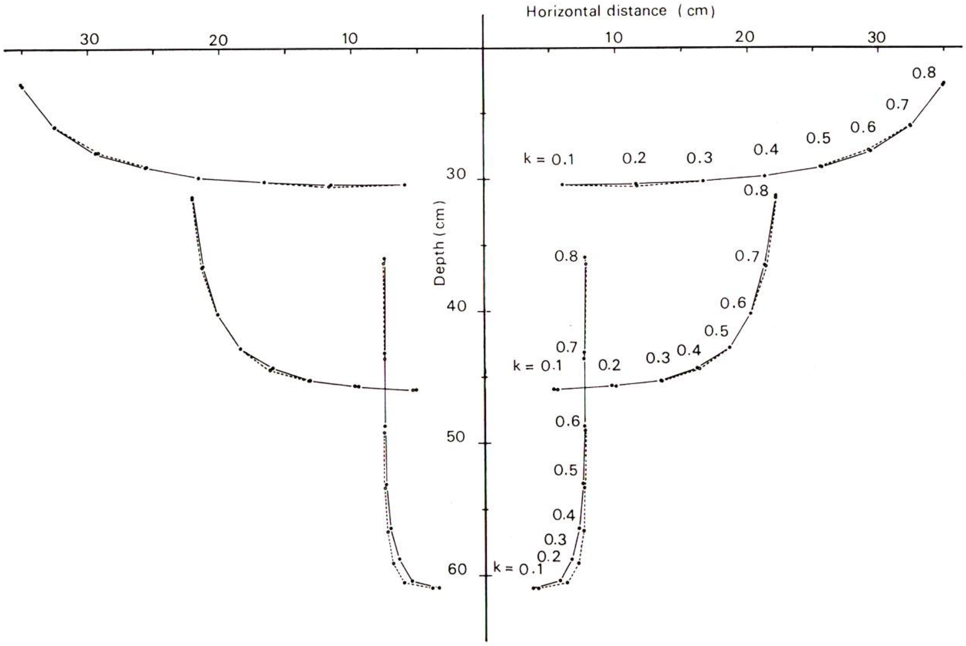


Fig. IV–17. Relationship between shortening rates and depth of attaching points of branch lines on main line (Type B long-line: $2l$=414 m).
•——•: Without branch line o- - -o: With branch line

IV–16 shows that of the main line with the branch lines. Fig. IV–17 shows the difference between the attaching points of branch line on the main line with and without the branch line, and obtained values from this difference by each shortening

Table IV-9. *Correction factors for depth of attaching points of branch line on main line.*

k	$2l$=322 (m)			$2l$=414 (m)		
	D_1	D_2	D_3	D_1	D_2	D_3
0.1	0	0	0	0	0	0
0.2	0	0.03	0.30	0	0	0.38
0.3	0.03	0.10	0.64	0	0.03	0.80
0.4	0	0.18	0.81	−0.03	0.20	1.05
0.5	0	0.15	0.90	−0.14	0.36	1.10
0.6	0.02	0.24	0.93	−0.14	0.45	1.14
0.7	0.04	0.27	0.84	−0.06	0.48	1.14
0.8	0.04	0.30	0.60	0.60	0.57	1.20

D_1: Correction value for attaching point of No. 1 branch line
D_2: Correction value for attaching point of No. 2 branch line
D_3: Correction value for attaching point of No. 3 branch line

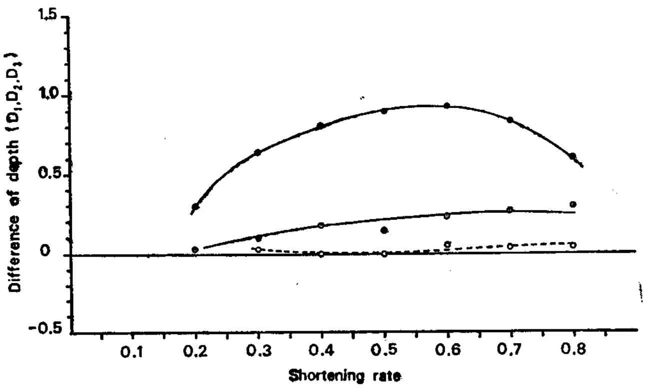


Fig. IV-18. Correction diagram for the depth of attaching points of branch lines ($2l$= 322 m).
○: $d_{2/7}$ ⊙: $d_{4/7}$ ●: $d_{6/7}$

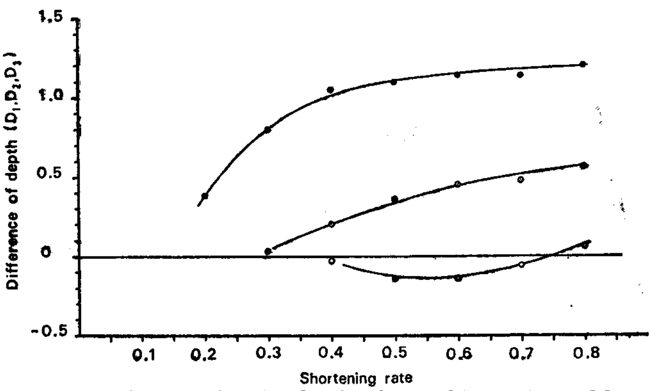


Fig. IV-19. Correction diagram for the depth of attaching points of branch lines ($2l$= 414 m).
○: $d_{4/9}$ ⊙: $d_{6/9}$ ●: $d_{8/9}$

rate are expressed in Table IV–9 and shown in Figs. IV–18 and IV–19. On converting these results to main lines, $2l=322$ m and $2l=414$ m, the maximum errors of depths were within 0.9 m and 1.1 m respectively which is not large.

4. *Relation between calculated and observed hook depths*

The observed hook depths are different from the calculated depths because of deforming of the catenary by currents and the entanglement of a long-line during operation. These differences are not constant. For the convenience, the actual hook depth at a certain period and a fishing area might be derived from shortening rate, and the author has statistically treated the relation between the calculated and observed values.

4.1 *Experimental method*

The SS type depth meter was attached to the end of the branch line from which the metal parts had been removed. In order to decrease the influence of the weight of each branch line on the catenary, the SS type depth meter was attached to No. 1 branch line of the first basket, No. 2 branch line of the second basket, and No. 3 branch line of the third basket as shown in Fig. IV–1.

The depths of No. 1, No. 2 and No. 3 branch line of Classes 1 ~9 of the long-line were measured for each fishing experiment through the entire fishing area. The observed depths of Hook-1, Hook-2 and Hook-3 were obtained by addition of 10 m (the total length of "sekiyama" and hook wire).

4.2 *Results*

The depths that were calculated from the shortening rate and corrected, are D_c and those measured by the SS type depth meter are D_o. During the experimental period, the geostrophic current was 0.4 kt at the surface, and 0.2 kt at the 200 decibar surface.[53)54)] The resultant influence of the tidal current and drift current by the trade wind will effect the form of the long-line in the sea. As it is considered that the resultant influence increase in proportion to the increasing the hook depth. The relation between the values of D_c and those of D_o obtained from 338 experiments in 1968 (the 5th experiment), is determined by methods of least squares as the following equation.

$$D_o = 0.893 \times D_c \qquad (4.2.1)$$

The relation is shown in Fig. IV–20. The experiment was repeated in 1969 (340 measurements), and the following equation was obtained.

$$D_o = 0.897 \times D_c \qquad (4.2.2)$$

The relation is shown in Fig. IV–21. The coefficients of the both equations are almost the equal, therefore the following correction factor was used to calculate D_o from D_c.

$$D_o = 0.9 \times D_c \qquad (4.2.3)$$

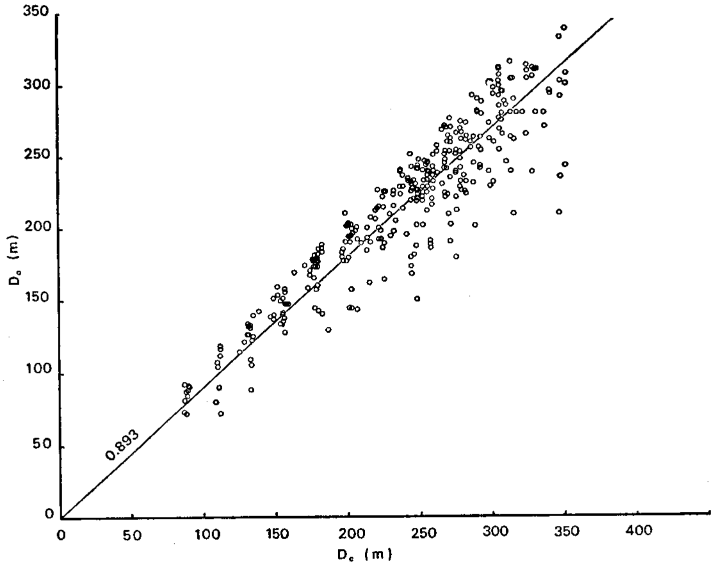


Fig. IV-20. Relationship between calculated and measured values of hook depth.
D_0: Measured value of hook depth　　D_c: Calculated value of hook depth

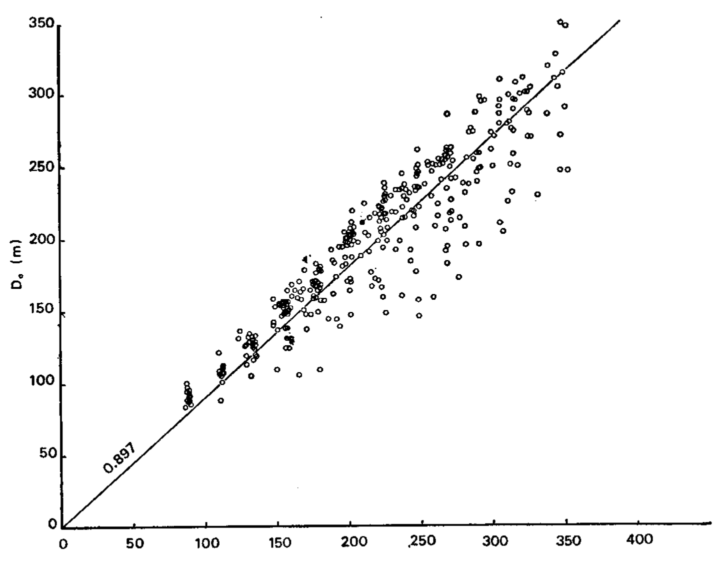


Fig. IV-21. Relationship between calculated and measured value of hook depth.
D_0: Measured value of hook depth　　D_c: Calculated value of hook depth

4.3 Examination of true hook depth

The author has examined the accuracies of the values of D_c and D_o. About 2% of the change of the length of the main line by the residual strain effects the values of both D_c and D_o. This influence can be corrected by removing the length of the residual strain. The value of D_c is also influenced by the accuracy of the measuring of the shortening rate. For example, if the shortening rate is 0.5, which is a typical value in the range of habitual use, the accuracy of the type A long-line and type B long-line are 1.4% and 1.1%, are 2.2 m and 2.3 m depth respectively. Those values correspond 0.7~1.3% of the values of D_c in Classes 1~9 long-line.

The error of the values of D_o is 2.0~3.4% according to the capacity of the SS type depth meter as shown in 2.2. The error in D_o measured by the SS type depth meter is 0.6 m/°C by temperature. For employing the SS type depth meter, the correction value is obtained by sounding wire at the center of the fishing area and this value is added to the estimated value, and only slight error by temperature could be obtained. At the same depth, the temperature difference between stations was about 2°C. A cause of error is temperature at reading, and the difference between the maximum and minimum was 4.7°C. The change of ±2.4°C corresponds to an error of ±1.4 m. This error of ±1.4 m of D_o in the case of k=0.5 in Classes 1~9 of the long-line corresponds the error of ±0.8~±0.4% of D_c. Therefore, the accuracies of D_c and D_o are almost the same.

In actual fishing the following unknown errors must be considered. The current varies by area and depth. The shortening rate is a mean value and there are differences between individual baskets. Tangles of float line or main line at setting and the change of depth caused by the hooked fish also occur. Under those conditions, the real value of observed hook depth is not stable. The observed variations are shown in Figs. IV-20 and IV-21.

4.4 Simplified calculation of true hook depth

Since it was troublesome to calculate the value of D_c from the shortening rate, a nomographs was made showing the relation between the shortening rate and values of D_c. Fig. IV-22 shows the depth (d) of the attaching point of the branch line on the main line ($2l$=322 m) without float line, and Fig. IV-23 shows that for $2l$=414 m. From these figures, the value of (d) can be easily and quickly obtained. To this value the correction factors which are obtained from the forming of catenary, lengths of the branch line and float line, must be added. Now the calculated value (D_c) can be obtained. The lengths of the branch line and seven kinds of the float line are shown in Table IV-10. The value of D_o can be obtained by multiplying the value of D_c into 0.9. For example, in the case of type

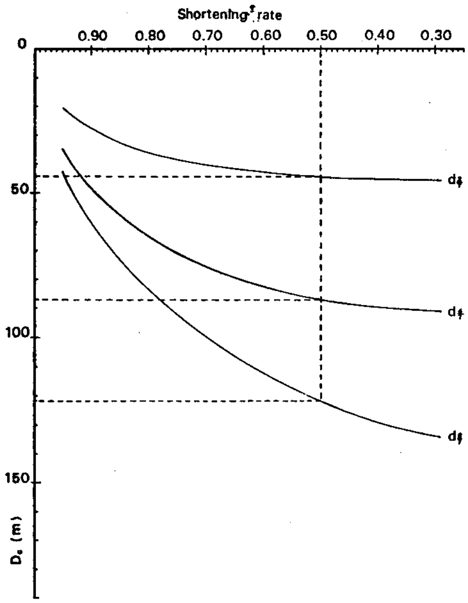


Fig. IV–22. Change in depth of attaching points of branch lines by shortening rate (2 l=322 m).

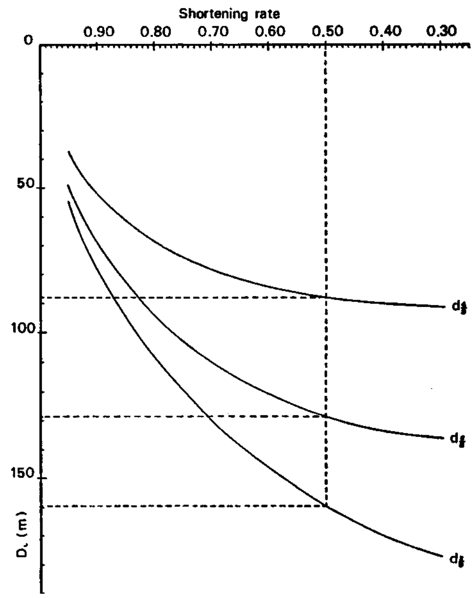


Fig. IV–23. Change in depth of attaching points of branch lines by shortening rate (2 l=414 m).

Table IV–10. *Total length of float line and branch line for each class of long-line.*

Type of long-line	Main line (m)	Class	Float line (m)	Branch line (m)	Total length (m)
A	322	1	23	21.5	44.5
〃	〃	2	46	〃	67.5
B	414	3	23	〃	44.5
〃	〃	4	46	〃	67.5
〃	〃	5	69	〃	90.5
〃	〃	6	92	〃	113.5
〃	〃	7	115	〃	136.5
〃	〃	8	138	〃	159.5
〃	〃	9	161	〃	182.5

A long-line, if k is 0.5, the value of (d) can be obtained in Fig. IV–22, $d_{2/7}$=44.0 m, $d_{4/7}$=87.0 m, $d_{6/7}$=122.0 m. In the case of type B long-line, $d_{4/9}$=88.0 m, $d_{6/9}$= 128.5 m and $d_{8/9}$=159.5 m, as shown in Fig. IV–23.

V. Fishing experiments by experimental deep-sea long-line and vertical long-line gears

1. *Experimental method*

Fishing experiments were conducted six times by the long-line (1st, 2nd, 3rd, 4th, 5th and 6th experiment), and three times by the vertical long-line (4th, 5th and 6th experiment) for 6 years from 1964 to 1969 in the middle and end of November of every fishing season in the area west of Fiji Islands, 15°S ~20°S, 170°E ~177°E as shown in Figs. V–1 and V–2.

The usual long-line gear as shown in Table II–1, and the experimental deep-sea long-line gear as shown in Fig. III–1, Tables III–1, III–2, III–3 and III–4 were employed. In order to ascertain the depth of the long-line at which tunas were

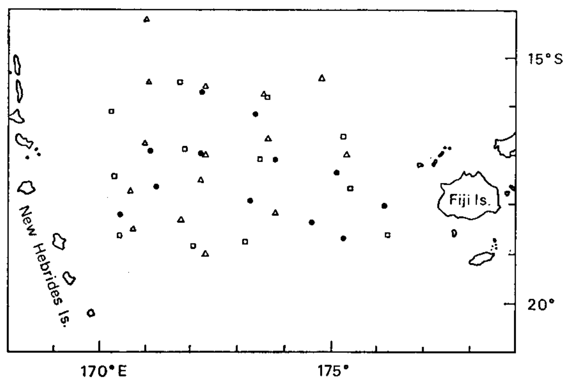


Fig. V–1. Location of fishing experiments (By long-line).
△: The 1st experiment (1964) □: The 2nd experiment (1965)
●: The 3rd experiment (1966)

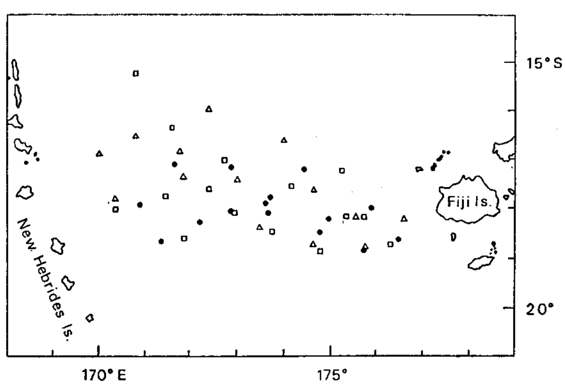


Fig. V–2. Location of fishing experiments (by long-line and vertical long-line).
△: The 4th experiment (1967) □: The 5th experiment (1968)
●: The 6th experiment (1969)

hooked, the experimental vertical long-line gear[55] was also employed in 1967, 1968 and 1969.

The experiments were done from sunrise to sunset. The hauling of the long-line began from the basket that was set last. Because of the influence of the soaking time upon the hooking rate, the order of setting of long-line was changed for each class in every fishing.

2. *Results and considerations*

The hooks in one basket with the same depth were classified into Hook-1 (No. 1 and No. 6 hooks: shallow hooks), Hook-2 (No. 2 and No. 5 hooks: intermediate hooks) and Hook-3 (No. 3 and No. 4 hooks: deep hooks). After 3rd experiment, the shortening rate, the hook depth and number of hooked fish for one set of long-line (13 baskets) were estimated. Therefore, the hooked rate was estimated per unit of 26 (2×13 baskets) hooks $\left(\text{i.e. CPUE: } \frac{\text{number of fish caught}}{2\times 13}\times 100\right)$. The hook depth, D_o obtained from the equation (4.2.3) were grouped into 20 m intervals. Eleven sets (9 Classes) of the long-line gear in the 4th and 5th experiments, and 9 sets (9 Classes) in the 6th experiment were repeated 13～15 times per year.

2.1 *Pattern of distribution of hooked rate*

Among from the 1st to the 6th fishing experiment, the hooked rates of albacore in the 4th experiment, in which the deepest hook reached to 280 m, and those in 5th experiment, in which reached to 300 m, was tested for the pattern of distribution in each classified layer. The frequency distribution of number of fish caught in each depth layer is shown in Table V–1. In each depth layer, the distribution is located extremely in less number of fish caught.

The pattern of distribution by depth layer was tested by the divergence coefficient of poisson type. In the 4th experiment (1967), a poisson distribution was observed at 70～130 m and 250～310 m layer, and a negative binomial distribution was observed at 130～250 m layer. The results for the 5th experiment (1968) showed a possion distribution at every depth (Table V–2).

According to the test of fit of the distribution pattern, the frequency distribution at 70～130 m and 250～310 m layer in the 4th experiment and 70～310 m layer in the 5th experiment were shown a poisson distribution, and that at 130～250 m layer in the 4th experiment was shown a negative binomial distribution (Table V–3).

2.2 *First experiment (1964)*

By employing an usual long-line gear (4-hook gear), the distribution of albacore was investigated and results obtained are as shown in Table V–4.

Table V–1. *Frequency of catch per one set of long-line at each layer.*

Depth (m)	X	4th experiment (1967)				5th experiment (1968)			
		Hook-1	Hook-2	Hook-3	Total	Hook-1	Hook-2	Hook-3	Total
70-130	0	31	4		35	35	13		48
	1	5	3		8	7	2		9
	2	1	0		1	0	0		0
	Total	37	7	–	44	42	15	–	57
130-190	0	85	38	19	142	49	30	13	92
	1	19	10	11	40	21	12	15	48
	2	6	7	5	18	5	2	4	11
	3	0	2	0	2	0	0	0	0
	4	0	0	1	1	0	0	0	0
	Total	110	57	36	203	75	44	32	151
190-250	0	14	48	52	114	31	36	23	90
	1	3	26	35	64	12	24	29	65
	2	1	14	17	32	2	11	14	27
	3	0	3	5	8	0	3	3	6
	4	0	0	1	1	0	1	2	3
	5	0	0	0	0	0	0	0	0
	6	0	0	1	1	0	0	0	0
	Total	18	91	111	220	45	75	71	191
250-310	0		6	8	14		20	30	50
	1		2	6	8		9	17	26
	2		2	3	5		0	11	11
	3		0	1	1		1	3	4
	Total	–	10	18	28	–	30	61	91

X: Number of catch per one set of long-line

Table V–2. *Pattern of distribution in catch per one set of long-line at each layer.*

Experiment	Depth (m)	$\bar{x}$	V_0	$V_0/\bar{x}$	d.f.	Pr.
4th (1967)	70~130	0.227	0.226	1.004*	∞, 43	>0.50
	130~190	0.424	0.542	1.278	202, ∞	0.005~0.01
	190~250	0.736	0.898	1.220	219, ∞	0.01 ~0.05
	250~310	0.750	0.787	1.049	27, ∞	0.25 ~0.50
	70~130 250~310	0.431	0.502	1.165	71, ∞	0.10 ~0.25
	130~250	0.586	0.750	1.280	422, ∞	<0.01
5th (1968)	70~130	0.158	0.135	1.170*	∞, 56	0.10 ~0.25
	130~190	0.464	0.397	1.169*	∞, 150	0.10 ~0.25
	190~250	0.780	0.836	1.072	190, ∞	0.25 ~0.50
	250~310	0.659	0.738	1.120	90, ∞	0.10 ~0.25
	70~310	0.588	0.639	1.087	489, ∞	>0.05

$\bar{x}$: Mean V_0: Variance *: $\bar{x}/V_0$ d.f.: Degree of freedom Pr.: Probability

Table V–3. *Distribution of catch per one set of long-line, fitted poisson and negative binomial distribution and test of significance.*

4th experiment (1967)								
X	Depth: 70～130, 250～310 (m) Mean: 0.431				Depth: 130～250 (m) Mean: 0.586 V_0: 0.750			
	f	P (Poisson)	F (Poisson)	χ^2	f	P (N.B.)	F (B.N.)	χ^2
0	49	0.64987	46.79	0.104	256	0.59640	252.28	0.055
1	16	0.28009	20.17	0.862	104	0.27309	115.52	1.149
2	6	0.06036	4.35	0.626	50	0.09239	39.08	3.051
3	1	0.00867	0.62 ⎤	0.139	10	0.02757	11.66	0.236
4		0.00101	0.07 ⎦		2	0.00768	4.01 ⎤	1.357
5					1	0.00107	0.45 ⎦	
Total	72	1.00000	72.00	1.731	423	1.00000	423.00	5.848
		d.f.: 2,	0.25<Pr.<0.50			d.f.: 3,	0.10<Pr.>0.25	

5th experiment (1968)				
X	Depth: 70～310 (m) Mean: 0.588			
	f	P (Poisson)	F (Poisson)	χ^2
0	280	0.55546	272.18	0.225
1	148	0.32661	160.03	0.904
2	49	0.09602	47.05	0.081
3	10	0.01882	9.22	0.066
4	3	0.00277	1.36 ⎤	1.441
5		0.00032	0.16 ⎦	
Total	490	1.00000	490.00	2.717
		d.f.: 3,	0.25<Pr.<0.50	

f : Frequency of occurrence
P(Poisson): Probability of poisson distribution
F(Poisson): Theoretical frequency of poisson distribution
P(N.B.) : Probability of negative binomial distribution
F(N.B.) : Theoretical frequency of negative binomial distribution

Table V–4. *Results of the 1st experiment of albacore fishing (1964).*

Hook position	Number of hooks	Hooked rate (%)
1	4968	1.09
2	4968	3.02

According to the results, the hooked rate was 1.09% for Hook-1 and 3.09% for Hook-2. This experiment demonstrated that the fishing area was suitable for further experimental fishing and the hooked rate of Hook-2 was higher than that of Hook-1.

2.3 Second experiment (1965)

In this experiment, the type A long-line (6-hook gear), as shown in Tables III–1, III–2, III–3 and III–4, were employed. Comparing the baskets having

Table V–5. *Results of the 2nd experiment of albacore fishing (1965).*

Hook position	Float line (m) 23		46		69	
	Number of hooks	Hooked rate (%)	Number of hooks	Hooked rate (%)	Number of hooks	Hooked rate (%)
1	3046	0.59	120	1.67	120	2.50
2	3046	2.86	120	4.17	120	2.50
3	3046	5.68	120	6.67	120	10.00
Average		4.93		4.17		5.00

46 m float lines with those having 69 m float lines, the hooked rates were 4.2 % and 5.0 % respectively. The hooked rate of deeper hook has a tendency to be higher than that of shallower hook (Table V–5).

2.4 *Third experiment (1966)*

In this experiment, the long-line as shown in Tables III–1, III–2, III–3 and III–4, was employed. This gear could fish deeper than previous gear. The results are shown in Table V–6. The relationship between the hooked rate and the hook depth is shown in Fig. V–3.

Table V–6. *Number of hooks and catches at various depths (The 3rd experiment, 1966).*

Depth (m)	Hook-1		Hook-2		Hook-3		Total		
	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Hooked rate (%)
70～ 90	24	2					24	2	0.32
90～110	36	6	2	0			38	6	0.60
110～130	24	7	22	10	2	3	48	20	1.60
130～150	24	20	40	29	19	28	83	77	3.56
150～170			26	22	37	54	63	76	4.63
170～190			18	20	28	35	46	55	4.59
190～210					18	28	18	28	5.98
210～230					4	4	4	4	3.84

As seen in Fig. V–3, the hooked rate increased steadily from 80 m to 160 m, and reached a maximum at a depth of 200 m. The hooked rates by the hook position are shown in Table V–7 and Fig. V–4.

Hook-1. The hooked rate was low from 80 m to 120 m layer, and increased sharply to 3.2 % having small standard deviation.

Hook-2. The hooked rate increased gradually to 4.2 % from 120 m to 180 m layer.

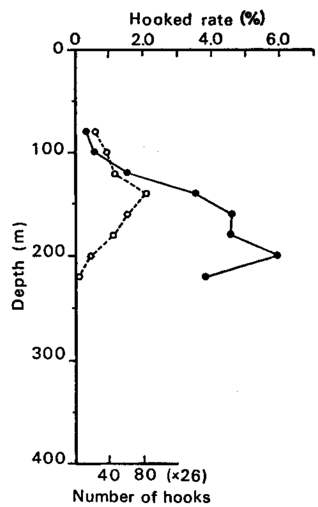


Fig. V-3. Vertical distributions of hooked rate and number of hooks (The 3rd experiment).
•——•: Hooked rate
o- - -o: Number of hook

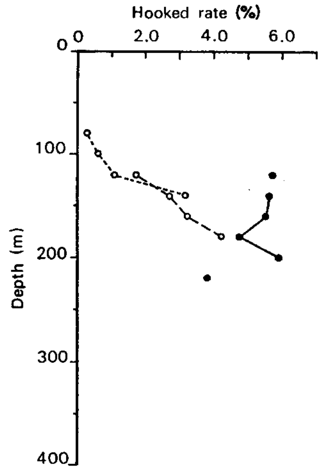


Fig. V-4. Mean value of hooked rate, by hook position and depth (The 3rd experiment).
- - - o - - -: Hook-1
— —o— —: Hook-2
——•——: Hook-3

Hook-3. The hooked rate shows high and is about 5.5% from 140 m to 200 m layer, and it lowered in 220 m layer owing to small amount of data.

The hooked rate increased generally from Hook-1 to Hook-2 and from Hook-2 to Hook-3 in order. As Morita[41~43] suggested, the hooked rates were considered to make a difference in the position of hook, in other word, in the relative depth of hooks in a basket.

Table V-7. *Mean values and standard deviation of hooked rate, by hook position and depth (The 3rd experiment, 1966).*

Depth (m)	Hook-1			Hook-2			Hook-3		
	n	$\bar{x}$ (%)	s	n	$\bar{x}$ (%)	s	n	$\bar{x}$ (%)	s
70~ 90	24	0.30	1.00						
90~110	36	0.61	1.42	2	0.0				
110~130	24	1.11	3.26	22	1.73	3.26	2	5.76	2.69
130~150	24	3.19	2.80	40	2.76	3.23	19	5.65	4.30
150~170				26	3.23	4.42	37	5.57	5.61
170~190				18	4.26	3.46	28	4.80	3.96
190~210							18	5.96	6.46
210~230							4	3.86	3.11

n: Number of sets (number of hooks=26×n)　s: Standard deviation
$\bar{x}$: Mean values of hooked rate

From the results obtained through the 1st to the 3rd experiment, it was clarified that an albacore can be hooked even in 200 m layer, which is deeper than 140 m layer considered to be a limit of reaching an usual long-line. These results encouraged to extend the depth of fishing to the deeper layers.

2.5 *Fourth experiment (1967)*

By employing the experimental deep-sea long-line gear as shown in Tables III–1, III–2, III–3 and III–4, further fishing experiments were carried out to the 290 m layer in which albacore may be living. The results obtained are shown in Table V–8 and Fig. V–5. As seen in Table V–8 and Fig. V–5, the hooked rate increased linearly with the number of hooks from 80 m to 220 m layer, and maintained a high level, in spite of decrease in the number of hooks from 220 m to 280 m layer. The hooked rates by the position of hooks are shown in Table V–9 and Fig. V–6.

Table V–8. *Number of hooks and catches at various depths (The 4th experiment, 1967).*

Depth (m)	Hook-1		Hook-2		Hook-3		Total		
	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Hooked rate (%)
70∼ 90	7	0					7	0	0.00
90∼110	21	5					21	5	0.91
110∼130	7	1	7	3			14	4	1.09
130∼150	25	5	22	7	5	1	52	13	0.96
150∼170	27	9	6	4	21	17	54	30	2.13
170∼190	51	17	25	19	8	7	84	43	1.96
190∼210	5	1	33	22	24	23	62	46	2.85
210∼230	11	4	45	39	32	29	88	72	3.14
230∼250			7	2	48	39	55	41	2.86
250∼270			9	8	7	9	16	17	4.08
270∼290					9	6	9	6	2.56

Hook-1. The hooked rate was low, about 1%, from 100 m to 220 m layer.

Hook-2. The hooked rate was comparatively high, and was 2.5∼3%, and while it lowered in 240 m layer, it increased again in 260 m layer, but it illustrated the large amount of scatter.

Hook-3. The hooked rate showed high and was about 3.5%. The percentage was found from 160 m to 240 m layer, but it became 4.9% and 2.5%, in 260 m and 280 m layer, respectively. It illustrated the large amount of scatter.

2.6 *Fifth experiment (1968)*

A fishing experiment was carried out in the deep layer of 300 m deep, by the

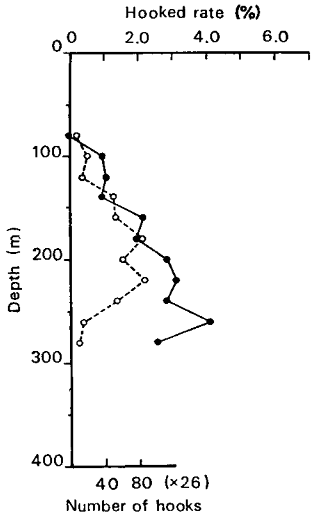


Fig. V–5. Vertical distributions of hooked rate and number of hooks (The 4th experiment).
•——•: Hooked rate
o- - -o: Number of hook

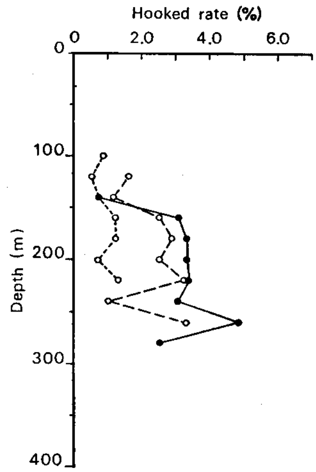


Fig. V–6. Mean value of hooked rate, by hook position and depth (The 4th experiment).
- - - o - - -: Hook-1
— —o— —: Hook-2
—— • ——: Hook-3

Table V–9. *Mean values and standard deviation of hooked rate, by hook position and depth (The 4th experiment, 1967).*

Depth (m)	Hook-1			Hook-2			Hook-3		
	n	x̄ (%)	s	n	x̄ (%)	s	n	x̄ (%)	s
70～ 90	7	0.0							
90～110	21	0.88	2.06						
110～130	7	0.53	1.45	7	1.61	2.05			
130～150	25	0.76	1.92	22	1.19	2.48	5	0.76	1.71
150～170	27	1.26	2.12	6	2.53	3.96	21	3.11	3.96
170～190	51	1.26	2.38	25	2.92	3.72	8	3.34	3.20
190～210	5	0.76	1.71	33	2.53	3.41	24	3.65	3.66
210～230	11	1.38	2.58	45	3.30	3.33	32	3.49	3.56
230～250				7	1.07	1.87	48	3.11	4.80
250～270				9	3.38	4.88	7	4.92	3.65
270～290							9	2.53	3.32

experimental deep-sea long-line gear. The results obtained are shown in Table V–10 and Fig. V–7.

As seen in Table V–10 and Fig. V–7, the hooked rate increased with the number of hooks from 80 m to 160 m layer. The hooked rate increased to 3 % from 200 m to 240 m layer, and lowered to 2.2 % at the 280 m layer, and increased again at the 300 m layer. The hooked rates by the position of hooks are shown

Table V–10. *Number of hooks and catches at various depths (The 5th experiment, 1968).*

Depth (m)	Hook-1		Hook-2		Hook-3		Total		
	Number of hooks (× 26⁻¹)	Number of catch	Number of hooks (× 26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Number of hooks (×26⁻¹)	Number of catch	Hooked rate (%)
70～ 90	14	1					14	1	0.27
90～110	12	3					12	3	0.96
110～130	16	3	14	2			30	5	0.64
130～150	14	5	14	6	3	1	31	12	1.48
150～170	28	12	13	5	16	12	57	29	1.95
170～190	28	13	15	5	12	9	55	27	1.88
190～210	14	5	28	22	13	16	55	43	3.00
210～230	14	4	28	28	17	16	59	48	3.12
230～250	14	7	14	8	37	41	65	56	3.31
250～270			15	3	26	26	41	29	2.72
270～290			13	9	17	8	30	17	2.17
290～310					13	13	13	13	3.84

in Table V–11 and Fig. V–8.

Hook-1. The hooked rate was low and about 1% from 80 m to 120 m layer. It was within the range of 1～1.7% from 140 m to 220 m layer, then increased somewhat to 1.9% in 240 m layer.

Hook-2. The hooked rate was about 1.5% from 140 m to 180 m layer. It

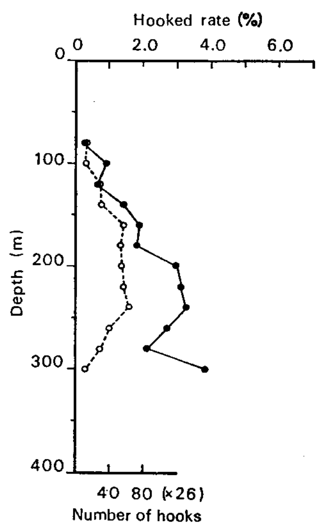


Fig. V–7. Vertical distributions of hooked rate and number of hooks (The 5th experiment).
•——•: Hooked rate
o- - -o: Number of hook

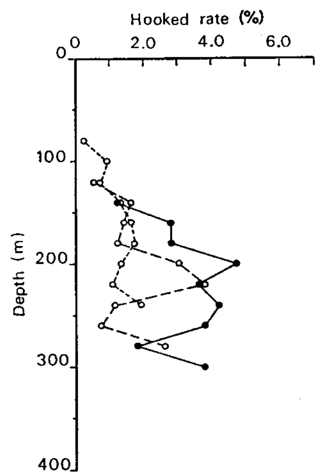


Fig. V–8. Mean value of hooked rate, by hook position and depth (The 5th experiment).
- - - o - - -: Hook–1
— —o— —: Hook–2
—— • ——: Hook–3

Table V-11. *Mean values and standard deviation of hooked rate, by hook position and depth (The 5th experiment, 1968).*

Depth (m)	Hook-1			Hook-2			Hook-3		
	n	$\bar{x}$ (%)	s	n	$\bar{x}$ (%)	s	n	$\bar{x}$ (%)	s
70~ 90	14	0.27	1.00						
90~110	12	0.96	1.73						
110~130	16	0.72	1.53	14	0.55	1.38			
130~150	14	1.37	2.42	14	1.65	2.46	3	1.28	2.19
150~170	28	1.65	2.42	13	1.48	1.92	16	2.88	2.61
170~190	28	1.78	2.42	15	1.28	2.34	12	2.88	2.88
190~210	14	1.37	1.88	28	3.02	3.80	13	4.73	5.23
210~230	14	1.10	1.76	28	3.85	3.88	17	3.62	2.84
230~250	14	1.92	2.88	14	2.20	2.46	37	4.26	3.57
250~270				15	0.77	1.57	26	3.85	3.88
270~290				13	2.66	3.26	17	1.81	2.38
290~310							13	3.85	3.84

increased to 3.8% giving essentially in a straight line from 180 m to 220 m layer. It showed the straight down from 2.2% to 0.8% from 240 m to 260 m layer. It increased again to 2.7% in 280 m layer.

Hook-3. The hooked rate was about 3% from 160 m to 180 m layer, and it increased to about 4% from 200 m to 260 m layer. But it lowered sharply to 1.8% at 280 m layer, and it increased again to 3.8%, illustrating the large amount of scatter.

2.7 Sixth experiment (1969)

In the 6th experiment, the same deep-sea long-line gear are employed as the

Table V-12. *Number of hooks and catches at various depths (The 6th experiment, 1969).*

Depth (m)	Hook-1		Hook-2		Hook-3		Total		
	Number of hooks ($\times 26^{-1}$)	Number of catch	Number of hooks ($\times 26^{-1}$)	Number of catch	Number of hooks ($\times 26^{-1}$)	Number of catch	Number of hooks ($\times 26^{-1}$)	Number of catch	Hooked rate (%)
70~ 90	15	4					15	4	1.03
90~110	15	2					15	2	0.51
110~130	15	3	15	10			30	13	1.67
130~150	15	7	15	5	7	4	37	16	1.66
150~170	15	12	15	8	17	12	47	32	2.62
170~190	15	3	15	15	11	8	41	26	2.44
190~210	15	15	15	10	15	12	45	37	3.16
210~230	15	11	16	11	17	15	48	37	2.96
230~250	15	15	14	9	21	30	50	54	4.15
250~270			16	11	15	19	31	30	3.72
270~290			14	9	18	13	32	22	2.64
290~310					14	14	14	14	3.85

5th experiment. The results obtained are shown in Table V–12 and Fig. V–9.

As seen in Table V–12 and Fig. V–9, the hooked rate increased from about 1% to 3% from 80 m to 200 m layer, giving essentially in a straight line, and increased further to 4% from 240 m to 300 m layer.

The hooked rates by the position of hooks are shown in Table V–13 and Fig. V–10.

Hook-1. The hooked rate increased sharply to 3% from 80 m to 160 m layer, and lowered sharply to 1% at 180 m layer and it increased again to 3∼4% from 200 m to 240 m layer, illustrating the large amount of scatter.

Hook-2. The hooked rate increased linearly from 120 m to 180 m layer as well as the data obtained in the previous experiment, and it was 4% at 180 m layer. It was about 2.5% between 200 m and 280 m layers.

Hook-3. The hooked rate was about 3% from 140 m to 220 m layer. It increased to 5% from 240 m to 260 m layer, illustrating the large amount of scatter, but it lowered to 3∼4% between 280 m and 300 m layers.

Considering the results obtained from the experiment, as Morita[41∼43] has reported, the reason why the hooked rates of Hook-1 and Hook-2 may less than that of the deepest Hook-3 is perhaps not owing to the difference of the hook depth, but to some hindrance for prey due to different distances between the main line and branch line in a basket. In the results obtained, the differences in the

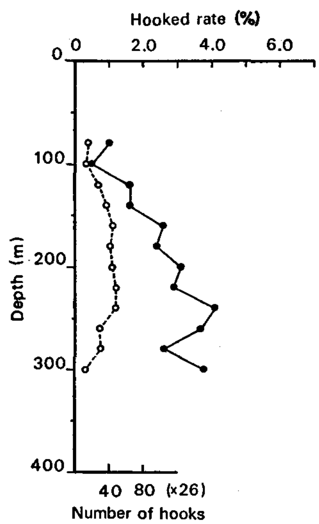


Fig. V–9. Vertical distributions of hooked rate and number of hooks (The 6th experiment).
•——•: Hooked rate
o- - -o: Number of hook

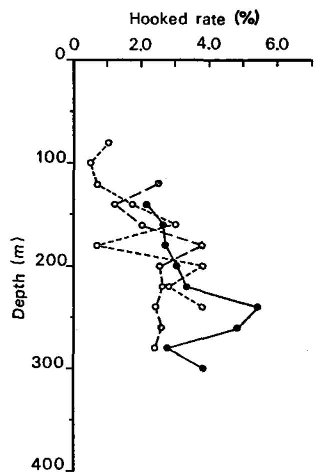


Fig. V–10. Mean value of hooked rate, by hook position and depth (The 6th experiment).
- - - o - - -: Hook-1
— —o— —: Hook-2
—— • ——: Hook-3

Table V–13. *Mean values and standard deviation of hooked rate, by hook position and depth (The 6th experiment, 1969).*

Depth (m)	Hook-1			Hook-2			Hook-3		
	n	$\bar{x}$ (%)	s	n	$\bar{x}$ (%)	s	n	$\bar{x}$ (%)	s
70∼ 90	15	1.02	2.28						
90∼110	15	0.51	1.35						
110∼130	15	0.76	2.15	15	2.56	2.78			
130∼150	15	1.79	1.98	15	1.28	1.87	7	2.19	3.02
150∼170	15	3.07	2.60	15	2.04	2.45	17	2.71	2.63
170∼190	15	0.76	1.59	15	3.84	2.90	11	2.79	2.48
190∼210	15	3.84	3.55	15	2.56	2.37	15	3.07	3.61
210∼230	15	2.81	3.69	16	2.64	2.70	17	3.37	3.56
230∼250	15	3.84	4.81	14	2.46	3.56	21	5.49	5.64
250∼270				16	2.64	3.05	15	4.86	4.46
270∼290				14	2.46	3.23	18	2.77	3.43
290∼310							14	3.84	3.37

hooked rates between hooks position were also observed.

Through the 4th, the 5th and the 6th fishing experiment, Hook-3 which has reached to 300 m depth, had the highest hooked rate. The hooked rate of Hook-3 was about 3 % from 160 m to 200 m layer, and the best rate, 3 ∼5 %, was obtained at 200 m to 260 m layer showing stable values, but the hooked rate between 280 m and 300 m layers was 2 ∼4 %, and was highly variable. Considering from these results, the distribution of albacore, throughout the fishing grounds tested, is most dense between 200 m and 260 m layers, and it is sometimes more dense between 280 m and 300 m layers than above 200 m layer.

3. *Depth of albacore hooking by experimental vertical long-line gear*

As above written, in order to examine the vertical distribution of albacore, especially in the deep layer, the author has tried to fish actually the albacore by the experimental deep-sea long-line. On the other hand, for the same object, fishing experiments were conducted by the experimental vertical long-line gear[55] and to ascertain the depths at which fish are hooked.

Kanagawa Prefectural Fisheries Experimental Station[40] has tried experimental fishing by the fishing gear, the construction of which was only a vertical type of the usual long-line gear. This gear was not effective below 200 m.

A vertical long-line was made with different construction from the former, as shown in Fig. V–11. Each experimental vertical long-line was placed in a separate basket to be set and hauled by itself.

Since 1967 (the 4th experiment) the experimental vertical long-line gear was employed in conjunction with the deep-sea long-line gear. In 1969 (the 6th experiment) a part of the vertical long-line gear redesigned and higher catches

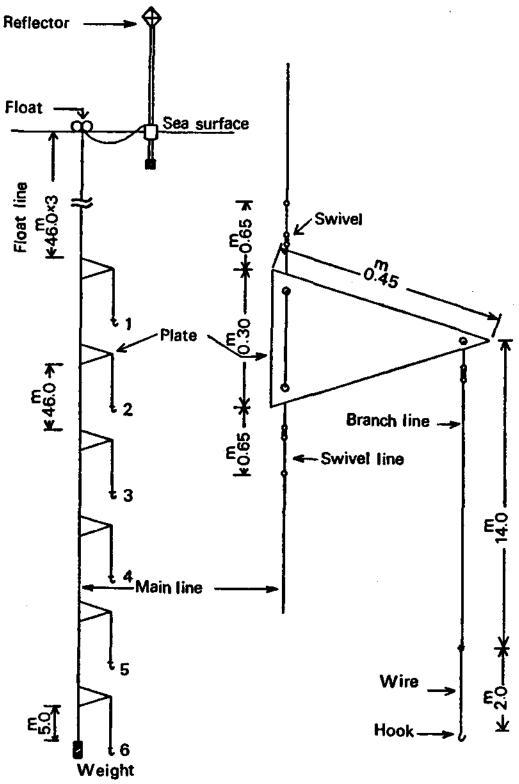


Fig. V-11. Schematic diagram of the experimental vertical long-line.

were obtained. The depths at which albacore were hooked were estimated chiefly during the 6th experiment.

In 15 fishing experiments, 10 baskets of the vertical long-line gear were employed for every fishing operation. The results of the fishing experiments are shown in Table V-14, and the hooked rate of albacore by depth is shown in Fig. V-12. As seen in Fig. V-12, the hooked rate was 4.7～5.4% at 200 m～300 m layer, the 3.4% hooked rate at 380 m layer was the deepest recorded depth for this species and is significantly higher than the (2.7%) at the 150 m layer.

The depths of albacore hooked were estimated by the automatic depth meter attached to the bottom of the main line, and the results are shown in Table V-15. The actual depth corresponded to about 97% of the calculated depth. The depths at which albacore were hooked were corrected by that amount. In the area of the fishing experiments, the geostrophic current was 0.4 kt at the surface and 0.2 kt at 200 decibar surface in November.[53)54)] In such a circumstance, it was ascertained that the hook of the vertical long-line reached to 380 m layer. It is troublesome, however, to watch the gear drifting at sea, and to haul up

Table V–14. *Catches by the vertical long-line fishing in 1969.*

		1	2	3	4	5	6
Hook position		1	2	3	4	5	6
Number of hooks		148	148	147	147	146	146
Hooked rate (%)*		2.70	4.73	4.76	5.44	0.68	3.42
Catch	Albacore, *Thunnus alalunga* (Bonnaterre)	4	7	7	8	1	5
	Bigeye tuna, *Thunnus obesus* (Lowe)					1	1
	Yellowfin tuna, *Thunnus albacares* (Bonnaterre)	1					
	Striped marlin, *Tetrapturus audax* (Philippi)					1	
	Sword fish, *Xiphias gladius* Linné						1
	Moon fish, *Lompris regius* (Bonnaterre)						3
	Shark	2		1			
	Other fish	2	1	1		1	1

*: Hooked rate for albacore

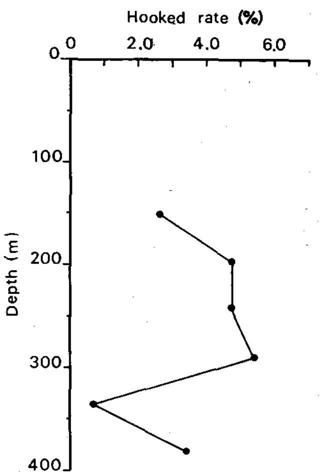


Fig. V–12. Vertical distribution of hooked rate of albacore caught by the experimental vertical long-line.

Table V–15. *Hook depths of the experimental vertical long-line.*

Hook position	D_c (m)	D_0 (m)
1	154.8	150.5
2	202.4	196.7
3	250.0	243.0
4	297.6	289.3
5	345.2	335.5
6	392.8	381.8

the line for comparison with those of the usual long-line. Because of this, it may be unsuitable for commercial fishing, excepting for experimental uses.

4. Examination of depth at which albabore were hooked by experimental deep-sea long-line

In the fishing of albacore, the time hooked and depth hooked must be examined, then the depth of albacore hooked can be ascertained. In the past, there have been few actual experiments the hooking time and depth. The depths of tunas hooked have been assumed by commercial fishing by means of the long-line.

The author[55] has obtained a record of hooking time and depth by employing an automatic depth meter.

Since 1968 (the 5th experiment), automatic depth meters were attached to No. 3 and No. 4 branch line of Classes 6 and 7 of the long-line, which had the highest hooking rate for albacore. Recorded patterns were obatined, in which the hooked and struggling of the albacore were recorded by time. One of the records is shown in Fig. V–13. This albacore was hooked at 207 m and it floated up to 160 m, and sank again to 239 m in 14.2 minutes, at which time it was attacked by a killer whale. From such a record pattern, the time hooked and depth hooked can be ascertained. Twenty four hooked records were analyzed by time and are shown in Fig. V–14.

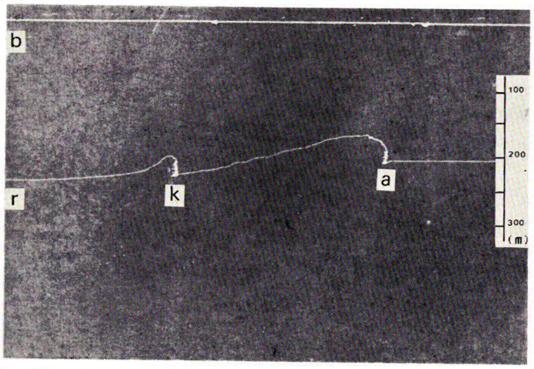


Fig. V–13. Record of hooking of albacore recorded by automatic depth meter.
a: Shows hooking of albacore (207 m depth) k: Shows case attacked by killer whale (239 m depth) r: Recorded line b: Base line

With one exception, all albacore were hooked after the completion of the sinking of the long-line. Recently, Kanagawa Prefectural Fisheries Experimental Station[56] reported that albacore was hooked after the completion of the sinking of the long-line. The result in Fig. V–14 agreed with that from Kanagawa Prefectural Fisheries Experimental Station.

The recorded pattern of the sinking of the long-line and the vertical long-line is shown in Figs. V–15 and V–16. The time required to reach the fishing depth of the long-line averaged about 20 minutes. The data are shown in Table V–16. The sinking time was about 5 mintues for the vertical long-line. The time required to haul up one basket of the long-line or the vertical long-line is 4 ~5 minutes. Therefore, albacore is probably not hooked during the sinking or the hauling of lines, but after the completion of the sinking of a long-line or vetical long-line. The depth at which the albacore is hooked is assumed to be

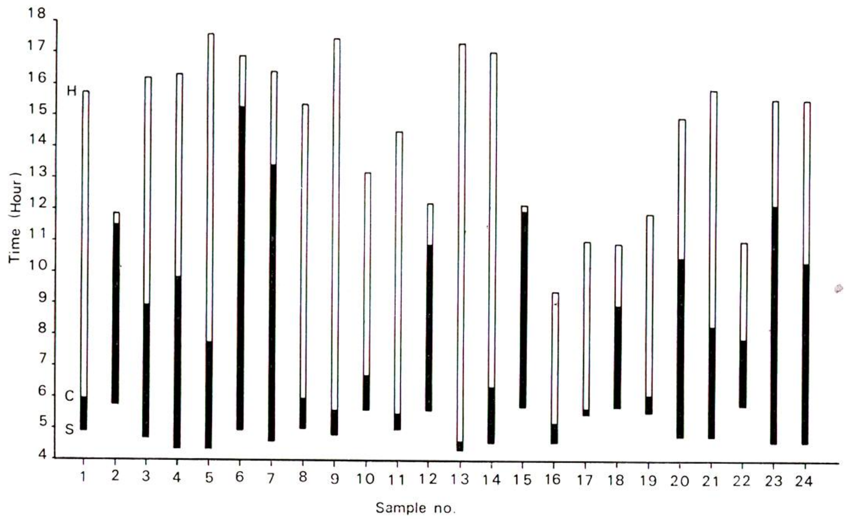


Fig. V–14. Hooked time of albacore as obtained by automatic depth meter.
s: Time started to set line c: Time as albacore was hooked
h: Time finished to haul line

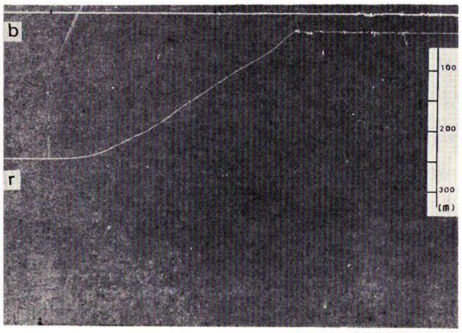


Fig. V–15. Sinking of long-line recorded by automatic depth meter.
r: Recorded line b: Base line

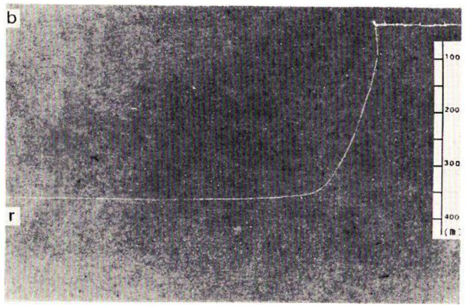


Fig. V–16. Sinking of the vertical long-line recorded by automatic depth meter.
r: Recorded line b: Base line

depth of the hook after the completion of the sinking of the long-line. Sivasubramaniam[57] reported that the yellowfin tuna was mainly hooked when the gear is sinking to the settling depth or when being hauled to the surface. This is based on the fact that the yellowfin catch is not proportional to the soaking time of the long-line. The results by the author show apparently that the albacore was different from the yellowfin tuna in the hooking time.

5. *Swimming depth of albacore*

From the results of fishing experiment by the experimental deep-sea long-line gear, the depth of albacore hooked is considered to be its swimming depth.

Table V–16. *Experimental results of sinking of long-line.*

Sample no.	Time taken for sinking (min)	Settled depth (m)
1	26	265
2	37	275
3	16	185
4	24	259
5	11.5	186
6	19	230
7	25	251
8	26	215
9	17	196
10	12.5	199
11	16	168
12	15	146
13	10	100
Average	19.62	205.77

The results of both the deep-sea long-line with the vertical long-line, the swimming depth may be summarized as follows. The swimming depth of the large sized albacore (South Pacific albacore) in day time in November, in the sea west of Fiji Islands, is between the 80 m and 380 m depth which was a depth limit of sinking of the vertical long-line. From this it is known that the swimming depth is very vertically wide. The distribution of albacore above 140 m layer, which is a depth limit of sinking of commercial long-line, is light.

The distribution increases gradually from 160 m to 200 m, and it is the most dense from 200 m to 260 m. It decreased from 280 m to 300 m and becomes unstable. Therefore, the center of the vertical distribution is considered to be from 200 m to 260 m layer.

6. *Hooking effect of experimental deep-sea long-line*

As the most dense distribution of albacore is from 200 m to 260 m layer, the depth of the deep hook (Hook-3) having high hooking rate should be examined. The values of D_c and D_o of the deep hook of the experimental deep-sea long-line (assuming 0.5 as the usual shortening rate) are shown by classes of long-line (Table V–17), and Classes 4 ~7 will reach the most dense distribution layer. If the hooking rates of the intermediate hooks (Hook-2) and shallow hooks (Hook-1) are taken into consideration,Classes 6 to 7 would provide the most hooks in the dense distribution layers (Fig. V–17). Therefore, the most effective and efficient long-line for the fishing of large sized albacore in deeper layer would be Classes 6 and 7. Therefore, the long-line of Classes 6 or 7 would result the most effective fishing.

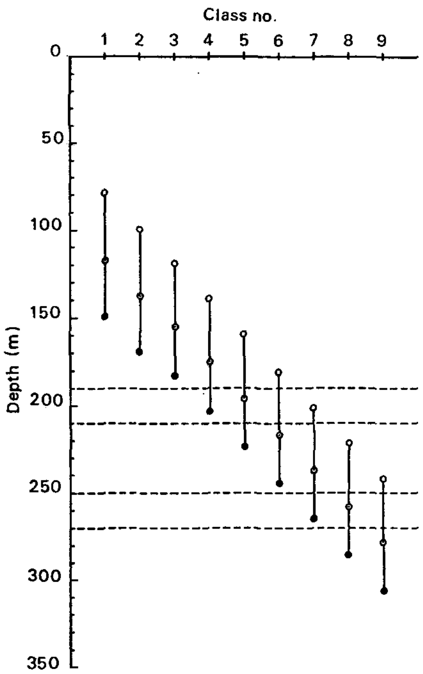


Fig. V–17. Vertical distribution of actual depth of hooks on each class of long-line ($k=0.5$).
o: Shallow hook (Hook-1)
⊙: Intermediate hook (Hook-2)
•: Deep hook (Hook-3)

Table V–17. *Calculated depth and actual depth of deep hooks for each class of long-line.*

Class	Depth of deep hooks (m)	
	D_c*	D_o
1	166	149
2	189	169
3	204	183
4	227	203
5	250	224
6	273	244
7	296	265
8	319	286
9	342	306

*: $k=0.5$

7. *Biological characteristics of large sized albacore and its sea environment*

Though there is much information on the albacore in the north Pacific Ocean, only a few papers have been published on this species in the south Pacific Ocean. This is because of its short history of exploitation. Ishii and Inoue,[58] Honma and Kamimura,[6] Nakagome,[59] Koto[4] and Koto and Hisada[5] have reported biological studies and Yamanaka,[3] Sato et al.,[60] Nakagome and Isobe,[61][62] Nakagome[63] and Tsuchiya[64] have reported on oceanographical studies.

In the present study the biological characteristics and the sea environments of swimming layer of the large sized albacore, which were hooked in the south Pacific Ocean in the 1st to the 6th fishing experiment (1964 ~1969), were investigated.

7.1 *Composition of fork length of albacore caught*

A total 1705 albacore consisting 472 fish of female and 1233 fish of male was caught during 1964 to 1969 fishing seasons. The annual length frequency

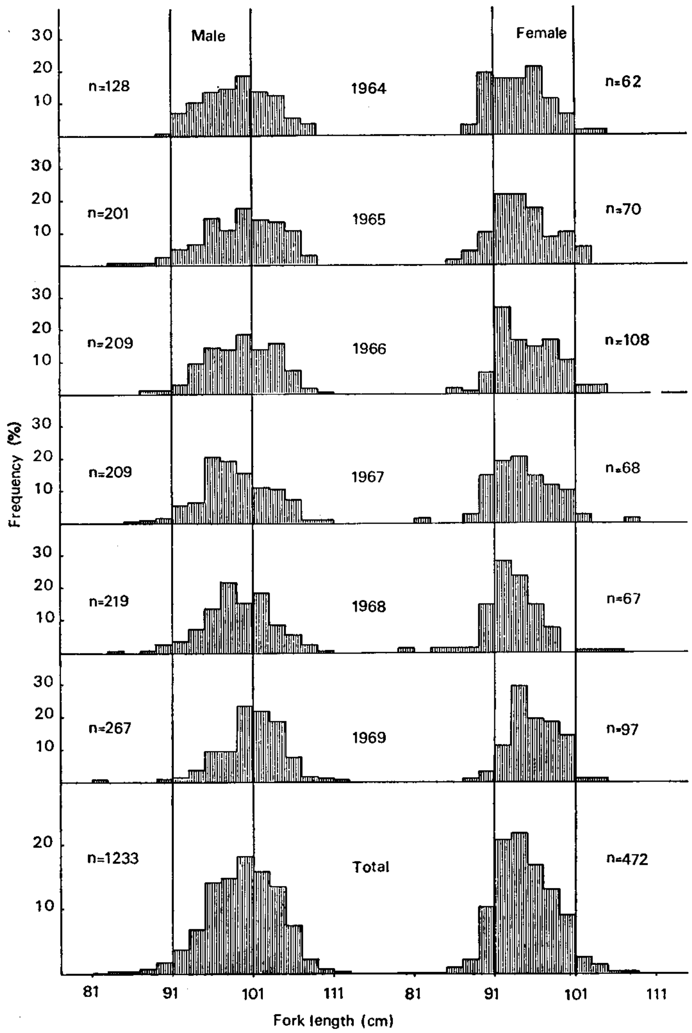
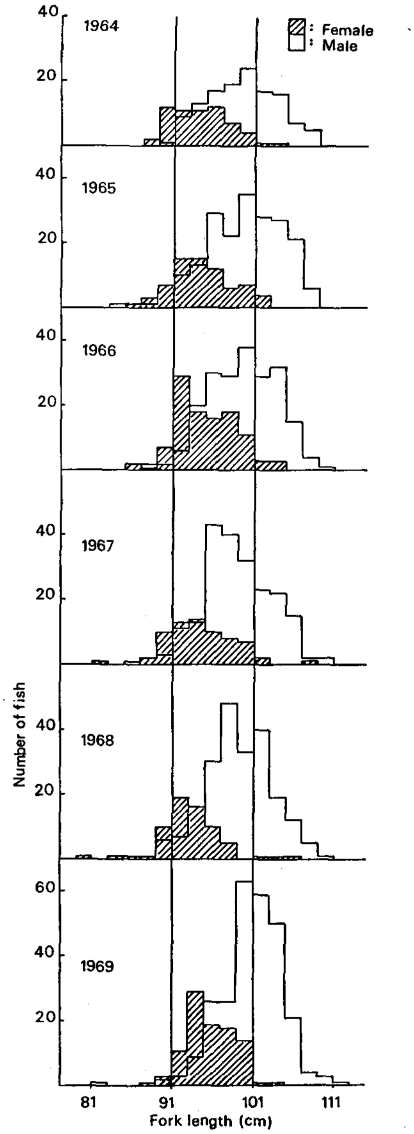


Fig. V–18. Annual length frequency distribution of albacore caught by fishing experiments.
n: Number of fish measured

distribution of the albacore caught is shown in Fig. V–18. As seen in Fig. V–18, the fork length was within the range of 89 ~ 101 cm for 92% of the females, and 91 ~ 107 cm for 94% of the males. The peak of length frequency of females is between 91 ~ 97 cm, and that of males is between 95 ~ 105 cm. The size composition is almost the same in every year from 1964 ~ 1969. The same group of albacore having the same age composition is considered to migrate to the fishing area every year.

Yukinawa[65] suggested that there are no differences in the age and growth of



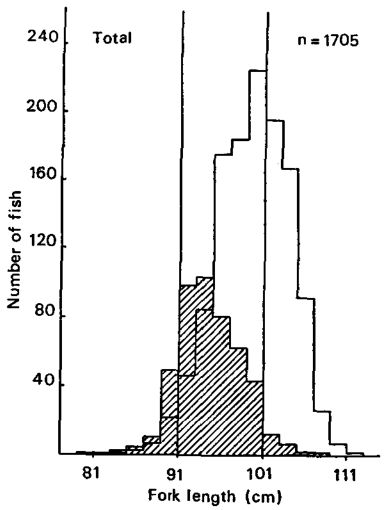


Fig. V–20. Length distribution of all albacore caught by fishing experiments.
□: Male (n=1233)
▨: Female (n=472)

Fig. V–19. Annual length distribution of albacore caught by fishing experiments.

southern bluefin tuna, *Thunnus maccoyii* (CASTELNAU) by sex. According to the growth curve of albacore obtained by Yabuta and Yukinawa,[66] from Figs. V–19 and V–20, the females are considered to be single age group being 6-year-old fish, and the males are mixed age group being 6-year and 7-year-old fish.

7.2 Sex ratio and gonad

The sex ratio of albacore caught was female: male=1: 2.6, as seen in Fig. V–

Table V–18. *Sex ratio of the albacore caught in the sea west of Fiji Islands.*

Year	Number of fish		Sex ratio
	Female	Male	
1964	62	128	1 : 2.1
65	70	201	1 : 2.9
66	108	209	1 : 1.9
67	68	209	1 : 3.1
68	67	219	1 : 3.3
69	97	267	1 : 2.7
Total	472	1233	1 : 2.6

18. This was almost the same in every year. According to Suda,[67] the sex ratio of the albacore in the south Pacific Ocean is similar to that in the North Equatorial Current area (Fig. V–19).

The mean values of gonad weight by fork length at 2 cm intervals and the 90% confidence limits are shown in Table V–19 and Figs. V–21 and V–22. As seen in Table V–19 and Figs. V–21 and V–22, the majority of the female gonads were over 200 g. This is a mature group in the spawning season (Ueyanagi[68]). The majority of male gonads were over 150 g. These males were mature. There were some immatured male having gonads less than 150 g. The weight of female gonad was in proportion to the fork length, while that of male was not in proportion to the fork length.

Table V–19. *The 90 % confidence limits and mean values of gonad weight by fork length.*

Fork length (cm)	Female			Male		
	n	$\bar{x}$ (g)	$\mu(t_{\cdot 10})$	n	$\bar{x}$ (g)	$\mu(t_{\cdot 10})$
83～85				2	110.0	
85～87	3	91.3		2	72.5	
87～89	9	206.9	±52.8	7	89.0	±23.3
89～91	44	246.0	±20.1	19	123.3	±17.8
91～93	88	258.3	±14.7	42	134.1	±12.1
93～95	75	269.9	±17.4	76	149.7	± 8.3
95～97	63	305.2	±19.4	149	152.3	± 6.1
97～99	44	288.8	±24.6	154	158.0	± 6.2
99～101	28	350.4	±29.8	160	160.3	± 6.4
101～103	11	363.7	±52.1	134	164.1	± 7.6
103～105	4	369.3		117	171.3	± 8.1
105～107				68	183.6	±12.5
107～109				22	174.2	±25.2
109～111				4	145.5	

F.L.: Fork length n: Number of fish $\bar{x}$: Mean value of gonad weight

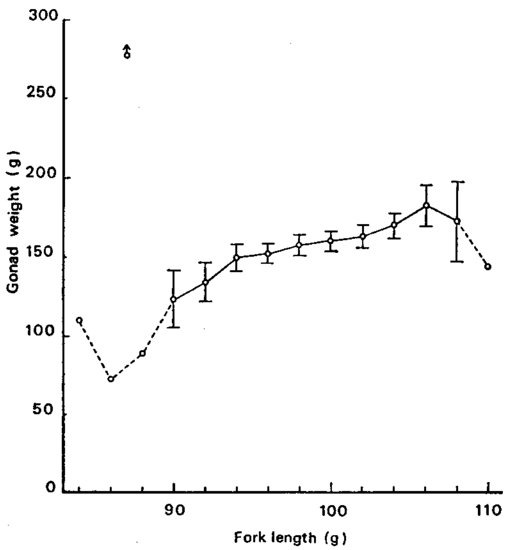


Fig. V–21. Relationship between gonad weight and fork length (Males).

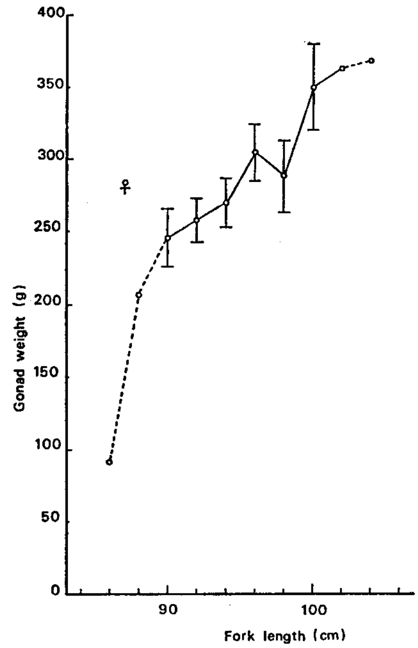


Fig. V–22. Relationship between gonad weight and fork length (Females).

7.3 Stomach contents of hooked albacore

Though food habit of the southern tunas has been studies by Koga[69)70)] and Watanabe,[71)] few papers have been published on food habits of the albacore. The stomach contents of albacore caught in the 5th experiment were analyzed by depth layers. The total weight of stomach contents and food organisms (pisces, mollusca and crustacea) were examined on albacore hooked in three depth layers of 80 m ~200 m, 200 m ~260 m and 260 m ~380 m respectively. Those samples are shown in Plate I.

Average weight of stomach by fork length is shown in Table V–20. As seen in Table V–20, there was no difference by fork length and sex. The average weight of stomach contents was 15.07 g with 212 stomachs. This is 16.7 ~20.0 % of the average weight of a stomach. The weight of stomach contents was small (less than 20 g) in the majority (70 %) of albacore caught in the fishing area. This fact has also been reported by Koga.[69)]

The number of albacore, by weight of stomach contents in three layers above mentioned are shown in Table V–21 and a frequency distribution of these data is shown in Fig. V–23. The weight of stomach contents was less than 5 g in few albacore hooked in 260 m ~380 m layer. This fact would suggest that there is few albacore being starving in such deep layer. The frequency of appearance and

Table V–20. *Average weight of stomachs by fork length.*

Fork length (cm)	Female		Male	
	Ave. weight of stomach (g)	N	Ave. weight of stomach (g)	N
87～ 91	61.9	10	81.4	5
91～ 95	79.4	29	75.2	14
95～ 99	70.6	18	83.5	52
99～103	70.8	2	87.6	54
103～107	79.2	2	95.2	18
107～111	—	—	81.6	4

N: Number of stomachs examined

Table V–21. *Distribution of number of fish, by weight of stomach contents and depth layers.*

Weight of stomach content (g)	Depth (m)			Total
	80～200	200～260	260～380	
0～ 5	27	37	5	69
5～10	15	13	6	34
10～15	8	18	8	34
15～20	6	14	4	24
20～25	2	7	3	12
25～30	2	4	3	9
30～35	2	8	2	12
35～40	1	3	1	5
40～45	2	0	1	3
45～	4	5	1	10
Total	69	109	34	212

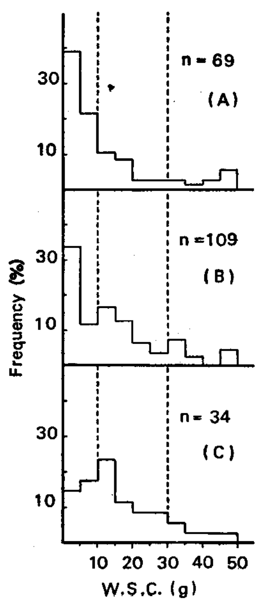


Fig. V–23. Frequency distribution of number of fish by weight of stomach content and depth layers.
n: Number of stomachs examined
W.S.C.: Weight of stomach contents
(A): 80～200 m
(B): 200～260 m
(C): 260～380 m

the chi-square test of albacore having empty stomachs by the three layers are shown in Table V–22. As seen in Table V–22, there is a significant difference between 260 m ~380 m and 80 m ~200 m layers. Therefore, albacore hooked in 260 m ~ 380 m layer are considered to have eaten much more food than those in 80 m ~200 m layer. Pisces, mollusca and crustacea were weighed separately for the three layers. The results are shown in Table V–23. As seen in Table V–23, there was little difference between the weight of pisces and mollusca, while some difference between the weights of crustacea and the others. More crustacea are eaten by albacore living in the deeper layer. There was a slight difference in food composition between 80 m ~200 m layer and 260 m ~380 m layer. From the above results, it could be considered that feeding is more active in the deeper layers.

Table V–22. *Frequency of occurrence and chi-square test of empty stomach by depth layers.*

Depth (m)	f (%)	χ^2	d.f.	p
80~200	39.9	0.294	1	0.500~0.750
200~260	33.9	5.255	1	0.010~0.025
260~380	14.7	3.743	1	0.050~0.100

Table V–23. *Average weight of food organisms by depth layers.*

Food organisms	Depth (m)		
	80~200	200~260	260~380
	(g)	(g)	(g)
Pisces	3.52	2.94	3.50
Mollusca	3.88	4.45	3.51
Crustacea	0.31	0.67	1.19
Total	7.71	8.06	8.20

7.4 Oceanic environment

In November, there is southeast trade wind of 3 ~4 scale (Beaufort scale) in the area west of Fiji Islands (14°S ~20°S, 167°E ~177°E) which is the main fishing ground. The air temperature is 24.0 ~28.7°C and the water temperature is 24.8 ~27.0°C at the surface.

According to Sverdrup *et al.*,[72] the South Equatorial Current flows west and reaches the Solomon Islands. It then flows southeast to the fishing grounds. Into this area the west stream flows from the east and mixes with the South Equatorial Current.

The center of this fishing ground is located between 15°S and 20°S, the grounds extend from the east to west. Tsuchiya[64] has examined the distribution of temperature and salinity in the fishing ground. Yamanaka[3] has suggested that the waters structure of this region is discontinuous from the south to the north.

The author has observed the vertical structure of the waters in this region in order to relate the water properties to the distribution of albacore. The horizontal distribution of temperature and salinity showed that the isotherms and isohalines lay east-west, in a macroscopic limit, and in the surface, the temperature of the north is higher than that of the south, and the salinity of the former is less than that of the latter.

The vertical distribution of temperature in the longitudinal section in the center of the fishing ground is shown in Figs. V–24, V–25 and V–26. According to those data, in the layer from the surface to 300 m depth, the temperature became lower from the north to the south, showing a gradient of the isotherm, and below 300 m layer the difference of the temperature is small. Above the 300 m layer, the temperature of northern waters is high than that of southern waters.

The vertical distribution of salinity in the same longitudinal section as that of temperature is shown in Figs. V–27, V–28 and V–29. According those data, high salinity water masses extended from the north to the south and the peak was observed in the layer between 150 m and 200 m depths. Above this layer, the waters of northern region is of low salinity and that of southern region is of high salinity. Below 300 m layer, the difference of salinity is not so pronounced.

T-S curves obtained in 1967 and 1968 are shown in Figs. V–30 and V–31, respectively. The each five stations in these figures show the typical state in this fishing area. From those results, the temperature adjacent the surface was higher than that of the lower layer and the salinity of the former was less than that of the latter, and at 150 m ~250 m layer the temperature dropped to 20.0 ~23.0°C, while the salinity became higher to 35.6 ~35.8 ‰, and further below 300 m layer, the changes of the temperature and the salinity became less, showing almost the stable curves.

Considering the vertical distribution of temperature and salinity, as northern high temperature and salinity water masses extended to southern low temperature and low salinity water masses, this fact is considered to have discontinuous oceanic structure in the direction from the south to the north. Therefore, the extending of high salinity water mass showing a peak in 150 m ~200 m, forms a discontinuous surface against the low salinity water mass of the 200 m ~400 m layer.

The depth layer in which shows the dense distribution of albacore, i.e., 200 m ~260 m layer, conforms to the lower surface at the discontinuity. The prey animals would be living in the discontinuous waters which are formed by the extending high temperature and high salinity water mass. Therefore, the lower environs of the extending water mass would be suitable fishing ground for albacore.

The estimated maximum and minimum temperatures of the depth layer in

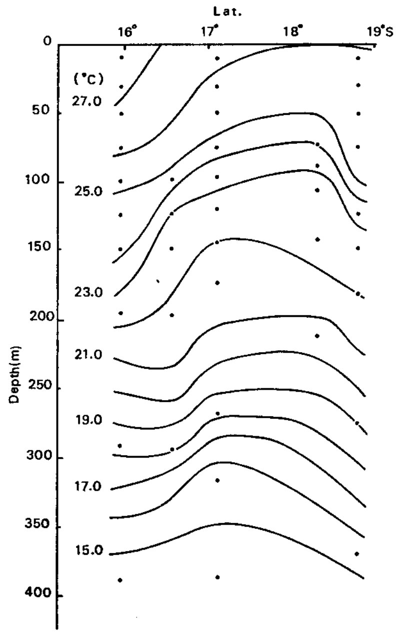


Fig. V-24. Vertical distribution of temperature in the longitudinal section (along 174°E, 1965).

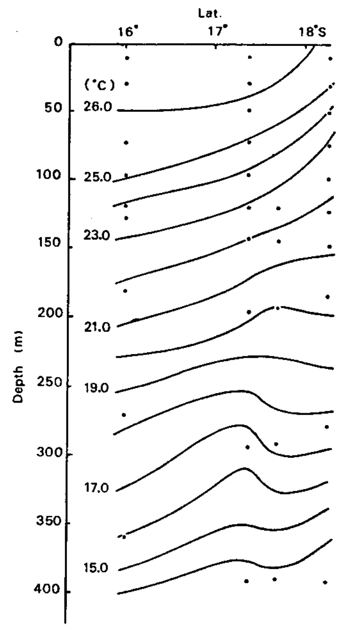


Fig. V-25. Vertical distribution of temperature in the longitudinal section (along 173°E, 1967).

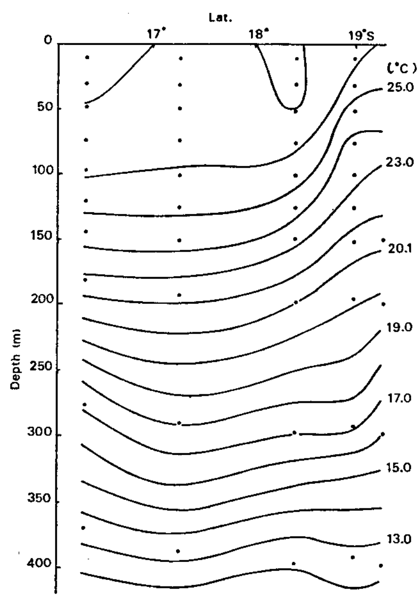


Fig. V-26. Vertical distribution of temperature in the longitudinal section (along 172°E, 1968).

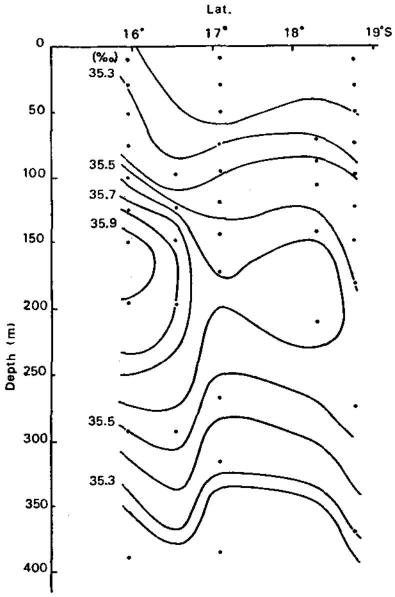


Fig. V-27. Vertical distribution of salinity in the longitudinal section (along 174°E, 1965).

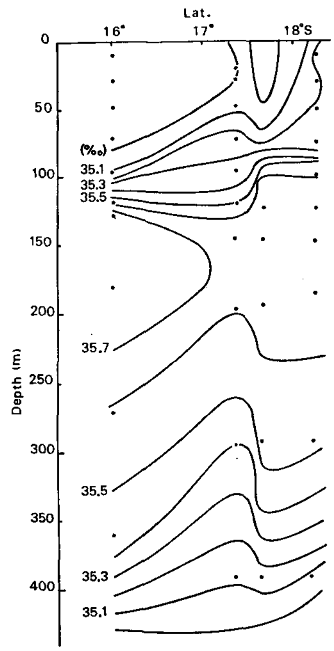


Fig. V-28. Vertical distribution of salinity in the longitudinal section (along 173°E, 1967).

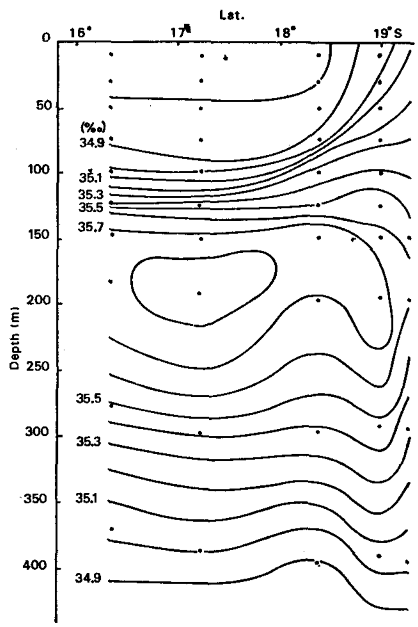


Fig. V-29. Vertical distribution of salinity in the longitudinal section (along 172°E, 1968).

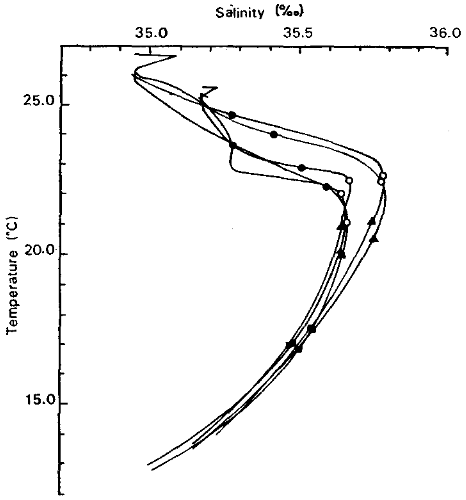


Fig. V–30. Temperature-salinity curves (1967).
•: 100 m o: 150 m
▴: 200 m ▪: 300 m

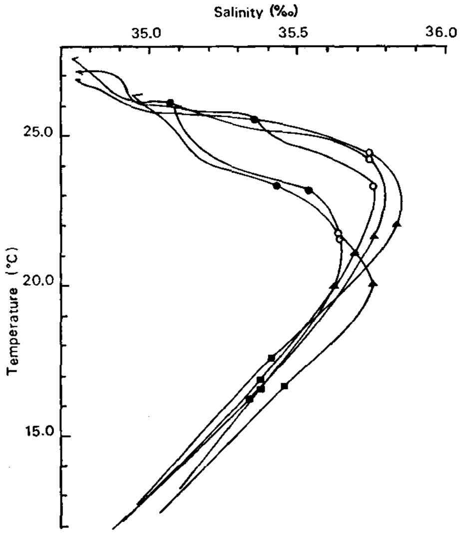


Fig. V–31. Temperature-salinity curves (1968).
•: 100 m o: 150 m
▴: 200 m ▪: 300 m

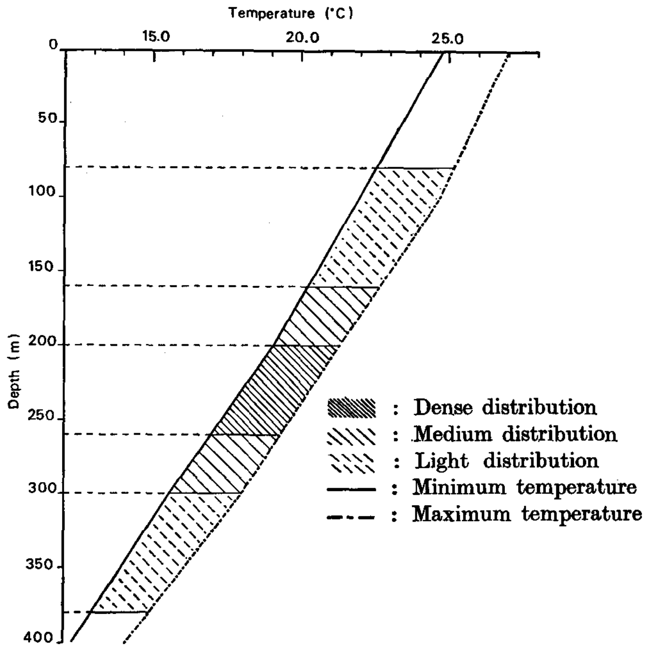


Fig. V–32. Maximum and minimum temperature at swimming layers of albacore.

which albacore is living are shown in Fig. V–32. Fig. V–32 shows the difference of the temperature in the highest density layer of the distribution of hooked albacore. The upper layer (200 m layer) was 19.1 ~21.3°C, and the lower layer (260 m layer) was 16.9 ~19.2°C. Therefore, the difference of maximum and minimum temperatures was about 4°C. On the other hand, the maximum and minimum temperatures in the deep layer (300 m layer) at which albacore has been hooked by the experimental deep-sea long-line was 15.6 ~18.0°C. The temperature of that (380 m layer) by the experimental vertical long-line was 14.7 ~ 13.5°C. Those temperatures are lower than the temperature, 16.3°C, which has been called environmental resistance for an albacore by Inoue.[73)74)]

According to Suda[75)], other factors besides the temperature would have influence upon the distribution of albacore. As the range of temperature of the swimming layer of albacore is wide, 25.2 ~13.5°C, as seen in Fig. V–32, the author would also considered that other factors besides the temperature would have influence upon the distribution of albacore.

VI. Summary

Though tunas were thought to live in the deeper layer, hooking of them had been considered almost impossible in the past. This is perhaps due to the fact that were few investigations on the vertical distribution, and slow improvement of fishing techniques and gears for the deeper layer.

The albacore is one of the commercially important species, because of fish-finder records, this species has been thought to be live even layer below 300 m. Few studies, however, have demonstrated the presence of albacore in such a deep water.

The limit of sinking depth of usual long-line is considered to be 140 m. Then, the author has made an experimental deep-sea long-line gear, in order to fish albacores and ascertain the distribution in the deeper layer, and furthermore to develop the fishing gears and techniques.

A deep-sea long-line gear and a light weight, cheap depth meter was made after theoretical and experimental examinations of the influences on the hook depth of a long-line. Employing those fishing gears and meters together with automatic depth meter, fishing experiment of albacore was carried out to examine the time and depth at which fish were hooked.

Investigations were also conducted in order to clarify the biological characteristics of hooked albacore and their oceanic environment.

The deep-sea long-line used by the author was designed to reach to 300 m layer, and it was classified into 9 classes by fishing depth. The fishing experiments were carried out in the day time each November from 1964 to 1969, at the area west of Fiji Islands in the southern Pacific Ocean.

The result obtained by the fishing experiment are summarized as follows.

(1) The deep-sea long-line has been completed after the resolution of tangling of lines caused by current and tensile strength of main line. In order to let the hooks reach to 300 m, the float line length was calculated with the consideration of material of the main line. The experiments were carried out at sea employing the long-lines of 9 classes. Classification was based on lengths of float line.

(2) On measuring of tension on the main line during hauling, it was found that the deeper the long-line reaches, the larger the tension becomes. The Class 8 long-line which reaches into the deeper layer was found to require a dragging force of 60 kg on the average.

The large tension of the main line which reaches to 300 m can be easily overcome by controlling the speed of hauling line. Even when an albacore is hooked, the increase on the tension is small. Therefore, the material of the main line having 370 kg tensile strength is sufficient for the deep-sea long-line.

(3) If 60 kg tension is applied to the main line of the deep-sea long-line during hauling, about 2% of the residual strain remain in the main line. Larger residual strain is caused in new lines. In order to reduce the influence of the residual strain upon the hook depth of the long-line, it is important to maintain the initial length of the main line.

(4) In order to calculate the hook depth of the long-line, the shortening rate, in other words, the ratio of the shortened length by sagging of the main line to the initial length of the main line, must be estimated. It is difficult to measure the shortening rate of individual basket of the long-line. In the past, the shortening rate was estimated by the distance of the long-lines laid from the running vessel at a known speed. In this experiment, in order to reduce the differences between the shortening rate of individual basket and the mean value of shortening rate of one set of the long-line, the estimation was carried out by measuring smaller units. The measurements were made over the distance of one set of long-line (13 baskets) by means of a radar and electromagnetic log, and the value obtained was divided by 13 to obtain the average shortening rate. The accuracy of the estimated distance by the radar was $\pm 1.1 \sim \pm 1.4\%$ in the case of 50% of the shortening rate, if the setting of the main line was uniform.

(5) To measure the hook depth, chemical tubes were employed, but this instrument has a narrow range of sounding depth and the error of the depth is not previously known. T.S.-depth recorder, by which it is possible to measure the maximum depth and an automatic depth meter, by which the change of the hook depth could be measured, are somewhat large size and too expensive to employ in large numbers. The difficulty of detecting the hook depth of deep-sea long-line by the fish-finder was cleared by the experiments. Therefore, the author has made an experimental depth meter (SS type depth meter), which is light weight

and did not deform the catenary form of the main line in water. This instrument has the additional advantage of being inexpensive. This SS type depth meter can measure the hook depth to 350 m ~400 m. In order to reduce the difference of calculated hook depth due to the difference between individual shortening rates of every basket and the mean value of the shortening rate, it is necessary to employ many depth meters to obtain many measured values. The author's experimental SS type depth meter fits those requirements.

(6) Experiments on the accuracy of the SS type depth meter were conducted. The results obtained showed that the error in depth induced by temperature was +0.6 m/°C in the range of 10 ~30°C, and the accuracy of this meter was 2.0 ~ 3.4 %. In the actual fishing experiment, the depth measured by SS type depth meter was corrected by the correction value obtained at fishing ground with the fish-finder and the sounding wire. Therefore, the error of the depth due to change of temperature at reading was ±1.4 m. In the last analysis, the error of the value of D_o was ±0.8 ~±0.4 % of the value of D_c.

(7) The hanging form of the main line of the long-line in the water, may be effected by the weight of branch line having metal parts. By model experiments, the author has shown that the hanging form is not necessarily catenary, but is indefinitely deformed and a correction value for estimating the calculated value of hook depth was obtained.

(8) In order to clarify the relation between the calculated depths and actually observed depths, 338 and 340 hook depths were measured in 1968 and 1969 respectively. As it is considered that resultant influence in the sea increase in proportion to the increasing the hook depth. A correction coefficient was calculated by the least square method to correct the resultant influence, and the following equation was obtained.

$$D_o = 0.9 \times D_c$$

It is important to know the relation between D_o and D_c in a certain fishing area during a certain period. It is convenient to obtain the actual hook depth from the calculated shortening rate of the main line. The author has made a nomograph showing the hook depth from the estimation of the shortening rate.

(9) From the fishing experiments, the hooked rate was calculated for hooks having different efficiencies, i.e., different positions on the main line, from the number of albacore hooked and from number of hooks by each set of the long-line. And the vertical distribution of hooked rates was obtained. The hooked rate was found to increase in 150 m ~200 m layer, and highest hooked rate was obtained in 200 m ~260 m layer. The hooked rate in 260 m ~300 m layer was higher than in above 200 m layer, but was highly variable.

(10) In order to confirm the hooking depth of the long-line, the author developed an experimental vertical long-line on which the sea current had little

effect. Each vertical long-line was set separately. Since the 4th experiment (1967), the vertical long-line was employed. A large number of albacore were hooked in 200 m ~300 m depth layer, and they were caught as deep as 380 m.

(11) In order to determine the hooked depth of albacore, the hooked time was ascertained by an automatic depth meter. An automatic depth meter was attached to the branch line and it was shown that the hooked time is not during the sinking of lines, but after the completion of sinking. Therefore, the depth of albacore hooked can be obtained by measuring the hook depth of the long-line.

(12) The distribution of albacore was most dense in the 200 m ~260 m depth layer, and the most suitable long-line was found to be Classes 6 or 7 (the length of the float line was 92 m or 115 m respectively). Therefore, the author has had the confidence that albacore can be fished in the deeper layer by the experimental deep-sea long-line.

(13) The composition of fork length and the sex ratio of albacore caught in the deep layer in every year during 6 years 1964 ~1969 were almost the same, and the albacore are considered to be on their spawning migration as deduced from the weight of the gonad, and to belong to the same age group.

According to the investigation of the stomach contents of hooked albacore, the albacore hooked below 260 m layer was found to have taken foods more active than those above the 200 m layer, and therefore, the albacore is considered to live in the deep layer. There appears to be hope to exploit the deeper fishing area of albacore in future.

(14) The vertical oceanic environment in which albacore is living, is characterized by a northern high salinity warm water mass extending into the southern low salinity cold water mass, and at the contact area, especially below the extended water mass a discontinuous zone was formed in which the good fishing ground would be found. This discontinuous zone corresponds to 200 m ~300 m layers, in which the albacore are living.

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Explanation of Plates

PLATE I

A. Photographs of stomach of albacore caught at 165 m depth (Fork length: 103 cm).
   A–a. Longitudinal section of stomach (Saury for bait).
   A–b. A portion of stomach contents (Mollusca).
B. Photographs of stomach of albacore caught at 200 m depth (Fork length: 100 cm).
   B–a. Logitudinal section of stomach.
   B–b. A portion of stomach contents (Pisces, mollusca and crustacea).
C. Photographs of stomach of albacore caught at 270 m depth (Fork length: 103 cm).
   C–a. Longitudinal section of stomach.
   C–b. A portion of stomach contents (Crustacea).

SAITO: Fishing of Albacore by Deep-sea Long-line