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Ecology and Stock of Southern Bluefin Tuna

Translated by M. A. Hintze

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ECOLOGY AND STOCK OF SOUTHERN BLUEFIN TUNA

Chiomi Shingu

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CONTENTS

Foreword

It is not long since the southern bluefin resources were first exploited by the Japanese fishing industry. Nevertheless, during the period of high economic growth in the latter half of the 1960's the fishery developed rapidly so that it has become the basis of the far seas tuna fishery today. At present, due to intense exploitation, the stock of the southern bluefin has fallen to a low level, and fishing has been voluntarily restricted by the fishing industry.

Because of the rapid expansion of the fishery, the basic data have not been thoroughly investigated. But, owing to the peculiarity of the distribution of southern bluefin, some of the biological characteristics are easier to analyse than those of other species of tuna. Nakamura (1965) gives a detailed account of southern bluefin in particular, and this was based on up-to-date data. The present author has written this account in order to disseminate his available information as widely as possible, but the contents may be rather fragmentary. There are areas about which the author lacks a thorough knowledge, and he wishes to hear opinions of people concerned with research on southern bluefin tuna.

In preparing the draft, the writer has received the kind assistance of Hisada Kochi, the technical officer at the Far Seas Fisheries Research Laboratory and others. Takashiba Aiji, the Director of the Japan Association of Fishery Resources Protection, who has previously helped the author with tuna studies, again troubled himself to help this project continuously. The author wishes to acknowledge his indebtedness to these people.

1. ECOLOGY

1.1 *Classification and distribution*

Until recently there was considerable confusion in the classification of the tuna group in some countries. In order to make a uniform system of these differing classifications Iwai *et al.* (1965) published the result of a taxonomic study of the tuna group. According to this study tuna can be classified into seven species in one genus (Table 1A). The standard Japanese name *Minami maguro* has, in fact, been proposed by these investigators. The same study also proposes a model of the affinity of these seven species which is indicated in Fig. 1. Based on the comparison of internal structures, they are classified into a group which includes *Thunnus thynnus, T. maccoyii* and *T. alalunga*, and a group which includes *T. albacares, T. tonggol* and *T. atlanticus*. *Thunnus obesus* is placed between the above two groups.

Today, there are many studies which adopt the above taxonomy both in Japan and in other countries.

Minami maguro is called in English the southern bluefin tuna (Australia, New Zealand, South Africa, etc.). In Japan at fish markets or among the fishermen it is simply called *'maguro'* and is often confused with *Kuromaguro (Honmaguro) = T. thynnus*. Sometimes it is called *'goshumaguro'* (Australian tuna) or *'Indo maguro'* (Indian tuna) according to where the fish is caught in order to distinguish them from each other, as the meat quality is different.

Southern bluefin tuna, as the name indicates, live only in the Southern Hemisphere. Except in some areas, they are distributed mainly from the frigid zones (the northern edge of

Table 1A. Classification of tuna group in the world (Iwai *et al.* 1965)

Scientific name	English name	Japanese name	Common name
Thunnus alalunga	Albacore	*Bin naga*	Bincho, Tonbo, ton
T. thynnus	Bluefin tuna	*Kuro maguro*	Honmaguro, Kuromeji, Yokowa
T. maccoyii	Southern bluefin tuna	*Minami maguro*	Maguro, Indo(Gōshū) maguro
T. obesus	Bigeye tuna	*Mebachi*	Daruma, Darumeji, Binta
T. albacares	Yellowfin tuna	*Kihada*	Kimeji, Kiwa, Hatsu
T. atlanticus	Blackfin tuna	*Taiseyo maguro*	Monte maguro, Mini maguro
T. tonggol	Longtail tuna	*Koshinaga*	

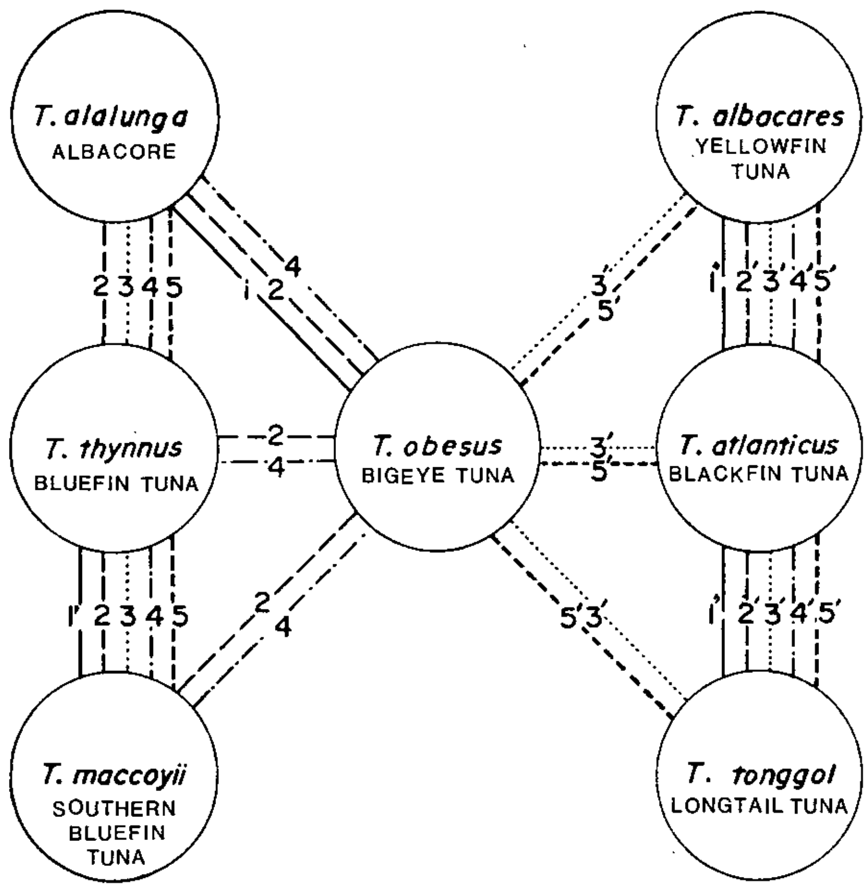


Fig. 1. The affinity of the seven species of tuna group viewed from the characters of nose, liver, vertebra and cutaneous vein system. (Iwai *et al.* 1965).

1. Fleshy process present on the edge of olfactory chamber and there is no notch on the olfactory plate.

1' No fleshy process present on the edge of olfactory chamber and the notch on the olfactory plate is small or non-existent.

1'' No fleshy process present on the edge of olfactory chamber, and many notches on the olfactory plate.

2. Vascular vein on the ventral surface of the liver.

2' No vascular vein on the ventral surface of the liver.

3. Complete blood vessel arc starts on the 10th vertebra.

3' Complete blood vessel arc starts on the 11th vertebra.

4. Hole under the centrum is small.

4' Hole under the centrum is large.

5. Cutaneous vein system starts at the position of the 5th vertebra.

5' Cutaneous vein system starts at the position of the 7th vertebra.

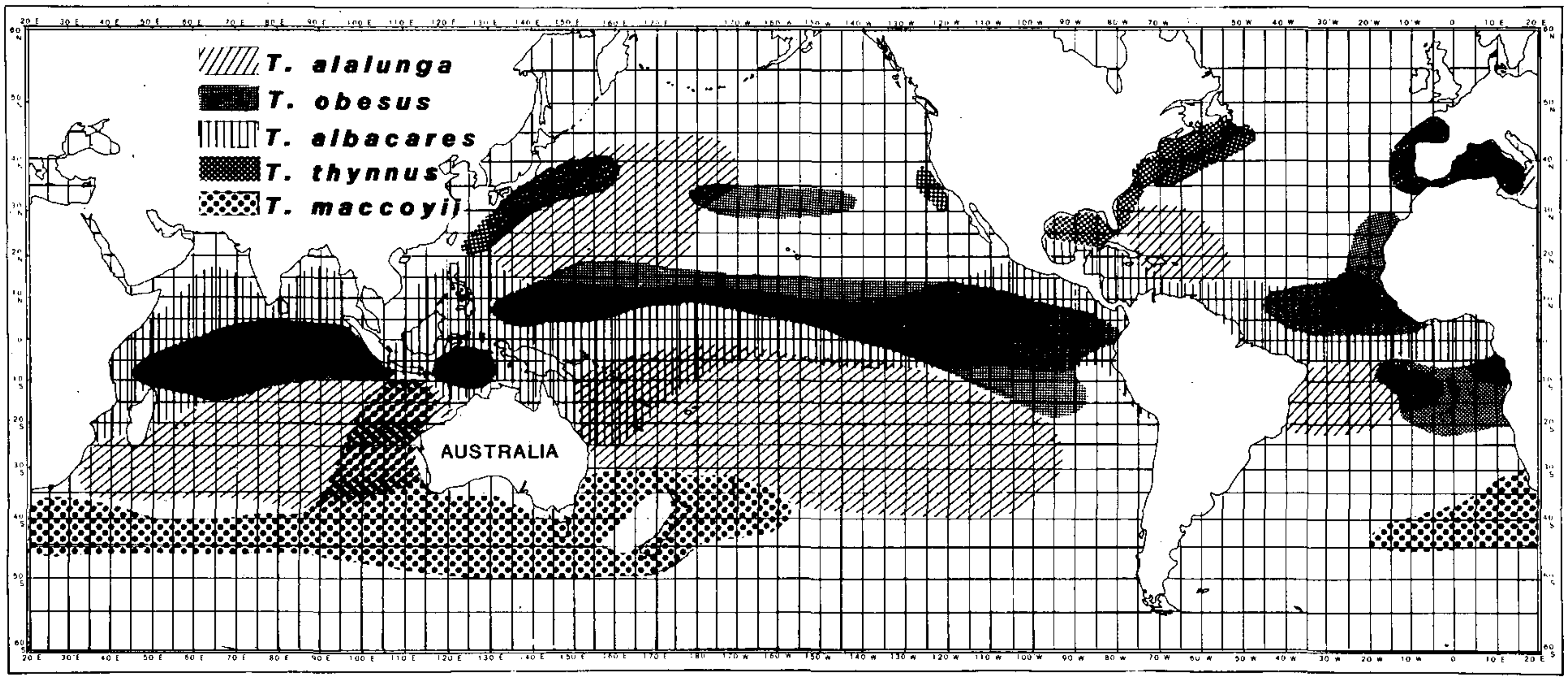


Fig. 2. Schematic diagram of chief distribution areas of tuna species.

Table 1B. Comparison of characters of southern bluefin and bluefin

Southern bluefin

Species	*Thunnus maccoyii*			*T.t. orientalis*
Character	Serventy (1956)	Iwai *et al.* (1965)	Gibbs and Collette (1967)	Talbot and Penrith (1963)
Caudal peduncle keels	yellow	yellow	yellow	yellow
Number of gill rakers on first branchial arch	31-37	31-37	31-37	31-36
Number of spines in the first dorsal fin	12-14	13-14	-	13-14
Anal rays	20-23	21-23	-	21-22
Pectoral fin length as against the body length (%)	-	22-23	20.2-23.0	20-23

the West Wind Drift) to the temperate zones; and they are to be distinguished clearly from the other species of the tuna family (Fig. 2). The distribution in the East-West direction extends from the offshore area east of Argentina over the southern part of the Atlantic, the Indian Ocean, offshore south of Australia and New Zealand to the coastal waters of Chile. But there are no fishing operations carried out in the areas east of 180° in the Pacific. Although the distribution of this species covers a wide area, the spawning grounds are found only in a limited area which lies to the northwest of Australia and south of Java.

Table 1B compares the characters of southern bluefin with those of *T. thynnus* which is the species most closely related to the southern bluefin.

1.2 *Age and growth*

There are very few studies of the age and growth of the southern bluefin. As in the tuna family in general, conditions for collecting the necessary data for studies in age and growth are not satisfactory. In order to gather samples on an appropriate scale, a tremendous amount of labour and time is required, under present circumstances. Thus, in estimating the age composition, etc., of the catch for each year, the relation between age and body length (weight) which has been previously determined, is used. A system by which the fish age can be determined directly by examining individual samples has not been established.

So far, several studies have been published on the age and growth of southern bluefin, based on length-

Bluefin

Species	*T. thynnus*	*T. thynnus*		*T.t. thynnus*
Character	Iwai *et al.* (1965)	Gibbs and Collette (1967)		Talbot and Penrith (1963)
		T.t. orientalis	*T.t. thynnus*	
Caudal peduncle keels	dark	dark	dark	dark
Number of gill rakers on first branchial arch	32-43	32-40	34-43	31-43
Number of spines in the first dorsal fin	13-15	-	-	-
Anal rays	20-23	20-25		-
Pectoral fin length as against the body length (%)	16.7-20.8	16.8-20.8	17.0-21.7	16-19

frequency, scale readings and tagging experiments.

Robins (1963) has analysed the changes in the length frequency made of 40-110 cm long bluefin tuna caught by surface fishing (mainly livebait and pole fishing) in Australian coastal waters, and has obtained the following Walford growth transformation

$\ell_{n+1} = 0.8677\ \ell_n + 29.44$, where ℓ_n = body length in the nth year (cm).

ℓ_∞ (maximum length) = 222.5 cm.

Based on this study by Robins, Shingu (1970) estimated the von Bertalanffy growth equation as

$$\ell_t = 222.5\ (1-e^{-0.14\ (t-0.011)}) \quad (1)$$

where ℓ_t = the body length at the early age t (cm)

$k = 0.14,\quad t_0 = 0.011$

Yukinawa (1970) has examined about 2500 southern bluefin of 38-184 cm length which were caught mainly by longline fishing around Australia. By means of scale reading he has estimated the growth formula as follows:

$$\ell_t = 219.7\ (1-e^{-0.135\ (t+0.04)}) \quad (2)$$

$k = 0.135$ (years)

$t_0 = -0.04$ (years)

Yukinawa reports that he was able to count rings on the scales of only 41% of the fish sampled. Scale ring counting was not possible with fish over 153 cm.

Recently Murphy (1976) has worked out a growth formula on the basis of tag recoveries of smaller southern bluefin in Australia.

$$\ell_t = 180.84\ (1-e^{-0.146074(t+0.011366)}) \quad (3)$$

$k = 0.146074$ (years)

$t_0 = -0.011366$

Table 2. Body length and weight of southern bluefin at the beginning of each

Author	Age	1	2	3	4	5	6	7
Shingu (1970)	length cm weight kg	28.9 0.6	54.2 3.4	76.3 9.2	95.4 17.7	112.1 28.3	126.6 40.3	139.2 53.0
Yukinawa (1970)	length cm weight kg	28.8 0.6	52.9 3.2	73.9 8.5	92.3 16.1	108.4 25.7	122.4 36.6	134.7 48.3
Murphy (1976)	length cm weight kg	24.8 0.4	46.0 2.1	64.4 5.6	80.2 10.7	93.9 16.9	105.7 23.8	115.9 31.2

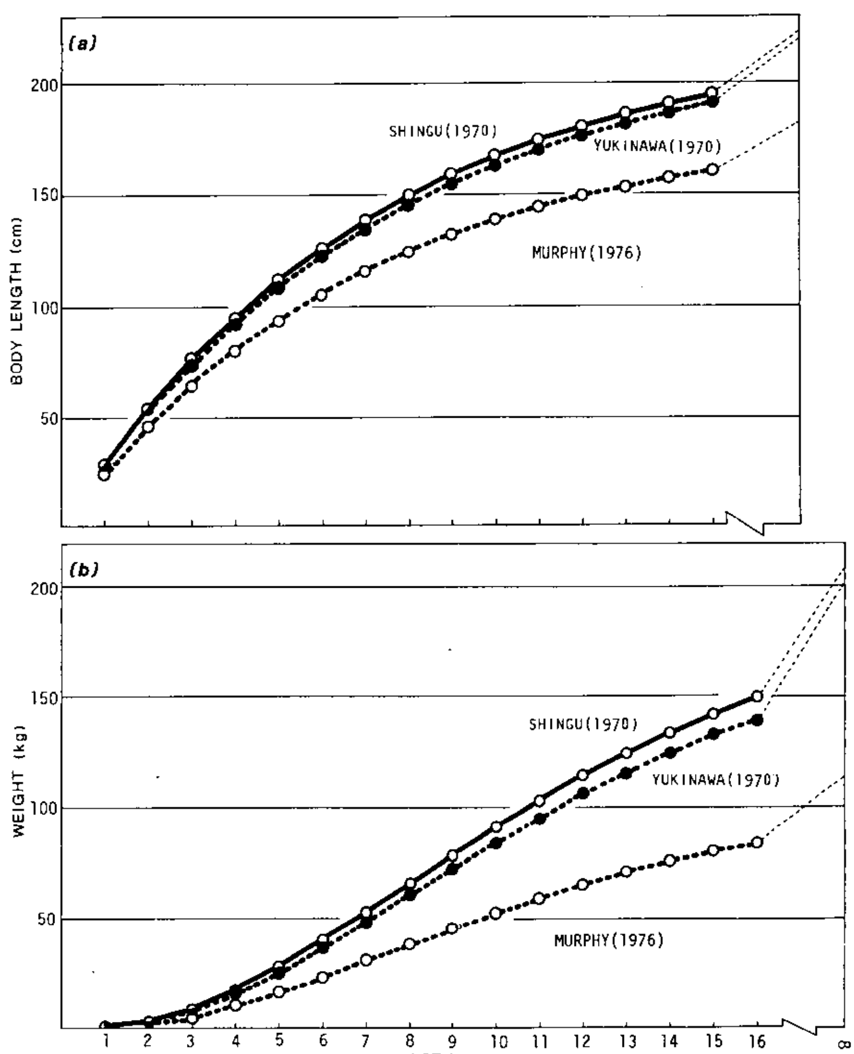


Fig 3A,B. The relations between age, body length and weight of southern bluefin age, computed by means of three growth equations

8	9	10	11	12	13	14	15	∞
150.1 66.0	159.7 79.1	167.9 91.5	175.1 103.3	181.4 114.5	186.8 124.7	191.5 134.0	195.7 142.7	223.0 208.6
145.4 60.4	154.9 72.5	163.1 84.3	170.2 95.4	176.5 106.0	181.9 115.7	186.7 124.8	190.9 133.1	219.7 200.3
124.7 38.5	132.4 45.9	139.0 52.8	144.6 59.2	149.6 65.4	153.8 70.9	157.5 75.9	160.7 80.5	180.8 113.5

The relationships between the age, body length and weight have been computed from the above three von Bertalanffy growth formulae and the result is given in Fig. 3A,B and Table 2. The formula for conversion of body length to weight is given by Robins (1963) as $W(kg) = 3.13087 \times 10^{-5} L^{2.9058}$ (cm).

When the figures are compared, the growth coefficient k is close to 0.14 in each of the three cases. For ℓ_∞, (1) indicates about 220 cm while (3) gives 180.84 cm, a difference of about 40 cm. ℓ_∞ indicates the theoretical maximum length and its relationship to the actually observed maximum length is not known. In any case, the difference between the theoretical figure and the actual figure should not be very great. The largest body length actually measured so far is 225 cm (Yukinawa 1970). Thus equations (1) and (2) appear to be closer to the actual figures. On the other hand, if tagging does not affect the growth of fish, the tag and recovery method can be used to measure the growth of each tagged fish and the growth of individual fish can be measured more directly than by the method using age-length formulae.

However, the value of the growth coefficient k is common to all three, which indicates that the growth of southern bluefin is relatively slow compared with the other species of tuna. In this account, figures based on equation (1) are used.

1.3 *Relation between body length and weight*

Warashina and Hisada (1970) have reported that the relationship between body length and weight of southern bluefin tuna changes at a body length of about 130 cm which marks the beginning of maturity of the southern bluefin. According to the above workers, when the length exceeds 130 cm, the relative increase of the weight to the body length increases, and the variability also becomes greater (Fig. 4). When the regression formula of weight is calculated in respect of the individuals under 130 cm and over 130 cm (see Fig. 4 Line B and Line A), the results are:

$$W(kg) = 0.00004159 L^{2.8160} \text{ (cm)}$$

$$W(kg) = 0.000002178 L^{3.4229} \text{ (cm)}$$

(Body weight is taken as the weight of body with gills and internal organs removed.)

With individuals of over 130 cm, a considerable difference of meat quality is observed before and after spawning. Individuals before spawning are fat and of good table

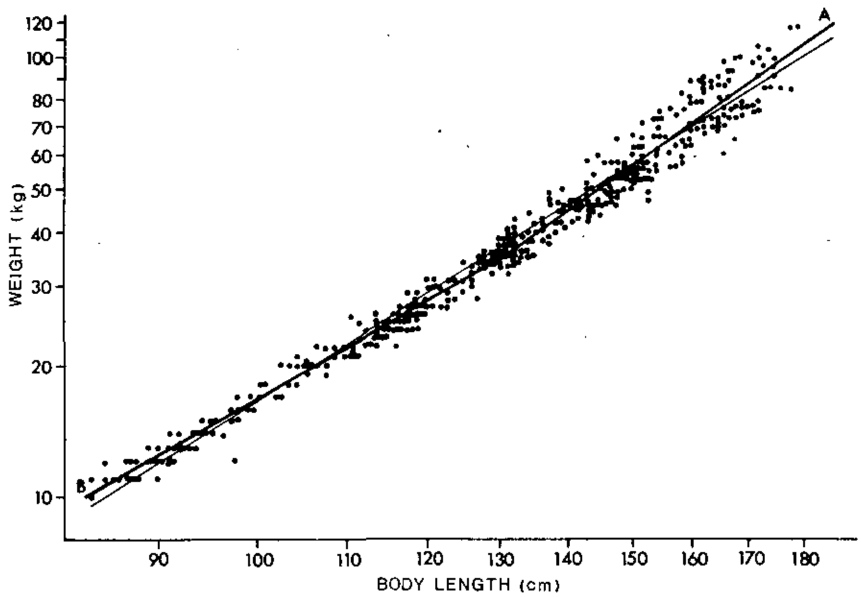


Fig. 4. The relation between body length and weight of southern bluefin (Warashina and Hisada 1970)

quality and after spawning these conditions are reversed. When the regression formulae of the weight is worked out for each of them, the results are as follows (Fig. 5).

$$W = 0.0000005392L^{3.7232} \text{ (cm)}$$

$$W = 0.000002942L^{3.3438} \text{ (cm)}$$

As can be seen clearly from the above, the difference between the two is quite remarkable. Therefore, in converting body length to weight, or weight to length, it is necessary to pay attention to the time of collection of the samples. Warashina and Hisada (1970) also investigated the movement of schools of southern bluefin by examining the relation between the meat quality of the individuals and the season and sea areas where they occurred. The outline of their discussion will be given later.

The abovementioned study is based on data of 1967 and the relationship between length and weight has been re-examined on the basis of the data for 1977, 10 years after the above study. Figure 6 indicates the changes of body weight in relation to the body length of the southern bluefin tuna caught in the same sea area near the spawning ground in September, which is the pre-spawning period, in December, which is the middle of the spawning period, and in March, which is the late spawning period. The solid lines (Fig. 6A-C) indicate the average regression line given by Warashina and Hisada (1970); the dotted lines (Fig. 6A and C) indicate the regression line for fat and thin fish, respectively. Individuals in the mid-spawning period are distributed evenly around the average values (Fig. 6B); but in the pre-spawning period, with the individuals over 130 cm, larger than average sized fish occur more frequently (Fig. 6A), and in the late spawning period, the smaller than average fish occur more frequently (Fig. 6C). Table 3 gives the weight against the body length for fat, medium, and thin fish.

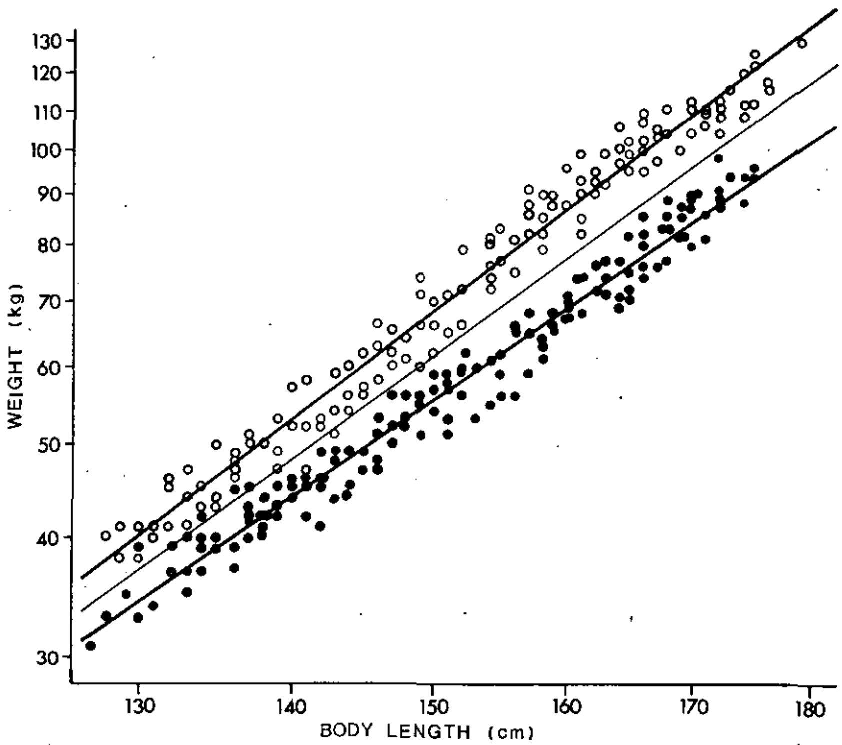


Fig. 5. Relation between body length and weight of the fat (o) and the thin (●) southern bluefin tuna over 130 cm long. (Warashina and Hisada 1970)

Table 3. Comparison between the body length, the age and the weight of southern bluefin tuna

Body length (cm)	Age (years)	Weight (kg) Thin	Medium	Fat	Body length (cm)	Age (years)	Weight (kg) Thin	Medium	Fat
62	2.3		4.6		122	5.7		31.2	
64	2.4		5.1		124	5.8		32.7	
66	2.5		5.5		126	6.0		34.2	
68	2.6		6.0		128	6.1		35.7	
70	2.7		6.5		130	6.3	34.5	37.3	40.0
72	2.8		7.1		132	6.4	36.3	39.2	42.4
74	2.9		7.6		134	6.6	38.1	41.3	44.8
76	3.0		8.2		136	6.7	40.1	43.5	47.4
78	3.1		8.9		138	6.9	42.1	45.9	50.0
80	3.2		9.5		140	7.1	44.1	48.3	52.7
82	3.3		10.2		142	7.2	46.3	50.7	55.6
84	3.4		10.9		144	7.4	48.5	53.3	58.6
86	3.5		11.7		146	7.6	50.8	56.0	61.7
88	3.6		12.4		148	7.8	53.2	58.7	64.9
90	3.7		13.2		150	8.0	55.6	61.6	68.2
92	3.8		14.1		152	8.2	58.1	64.6	71.6
94	3.9		15.0		154	8.4	60.7	67.6	75.2
96	4.0		15.9		156	8.6	63.4	70.8	78.9
98	4.1		16.8		158	8.8	66.1	74.0	82.8
100	4.3		17.8		160	9.0	69.0	77.4	86.7
102	4.4		18.8		162	9.3	71.9	80.9	90.8
104	4.5		19.9		164	9.5	74.9	84.5	95.1
106	4.6		21.0		166	9.8	78.0	88.0	99.5
108	4.7		22.1		168	10.0	81.2	92.0	104.0
110	4.9		23.3		170	10.3	84.5	95.9	108.7
112	5.0		24.5		172	10.6	87.9	100.0	113.5
114	5.1		25.8		174	10.8	91.3	104.2	118.5
116	5.3		27.1		176	11.1	94.9	108.5	123.7
118	5.4		28.4		178	11.4	98.5	112.9	129.0
120	5.5		29.8		180	11.8	102.3	117.5	134.5

Weight does not include gills and internal organs.

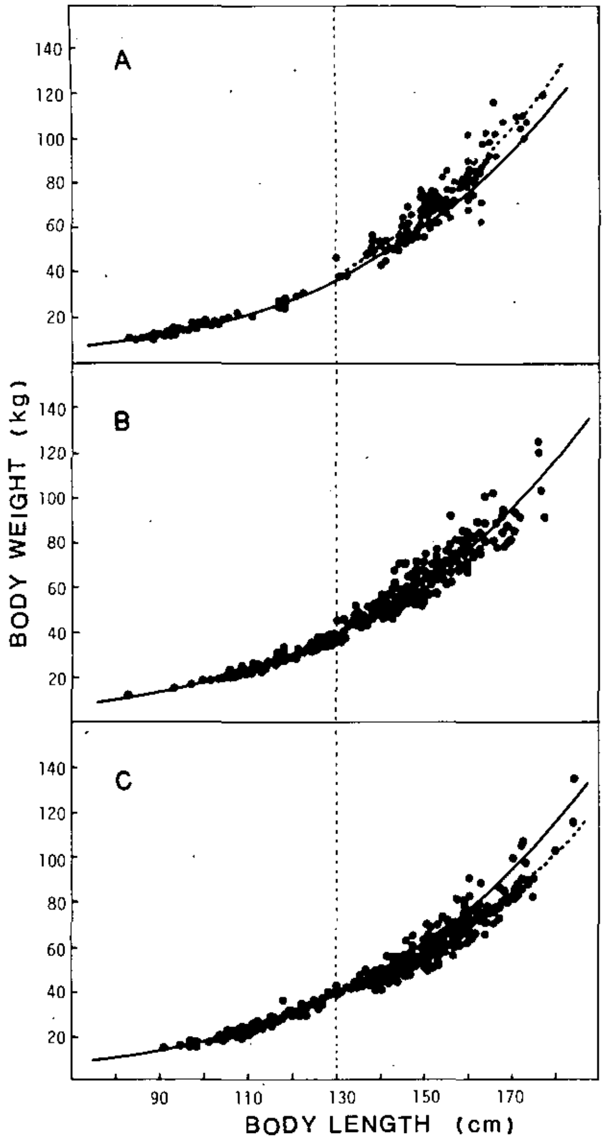


Fig. 6. The relation between the length and the weight of southern bluefin tuna in the pre- (A), mid- (B) and late (C) spawning period

1.4 *Maturation, spawning and occurrence of juveniles*

The spawning ground of southern bluefin is in the lower latitude sea area in the eastern part of the Indian Ocean (Fig. 11). It covers an area between about 100-125°E and 10-20°S and is extremely restricted. The area also represents the northern limit of the distribution of the southern bluefin. The spawning period is considered to last for about half a year from September to March of the following year (Kikawa 1964).

(i) Observation of the gonads. In judging the maturity of ovaries with the naked eye, five stages are usually distinguished in tuna. The factors which serve as a standard for judging maturity are: the size of the ovary, the degree of its dilation, the size of an ovum and degree of its transparency, and the development of blood vessels on the ovary surface. It is easy to distinguish an immature ovary, a fully matured ovary, and an ovary soon after the spawning. However, in other cases, for instance such as the ovary in the process of ripening, the judgment can differ from person to person. Therefore it is desirable to employ concurrently some other methods.

Kikawa (1964) measured the diameter of ripe eggs remaining in the ovaries of southern bluefin tuna with a body length of about 140 cm, and obtained the figures 0.66-1.05 mm (Table 4).

Further, Kikawa has observed the changes of the frequency of egg diameters, and has deduced an egg ripening sequence (Fig. 7).

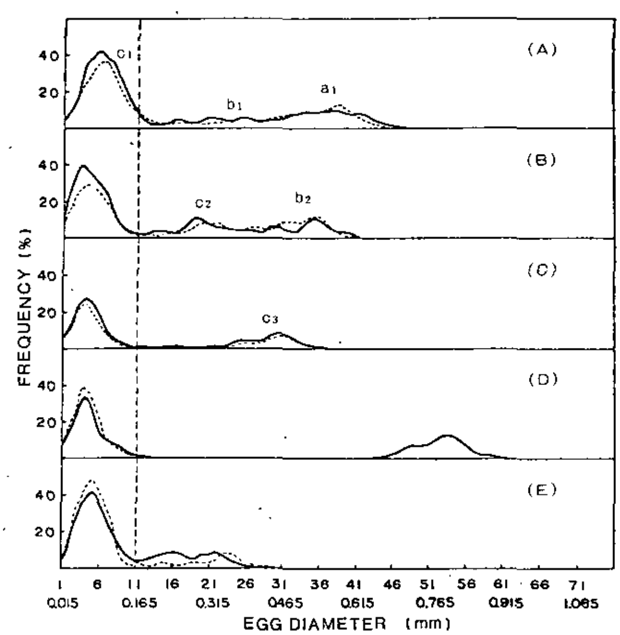


Fig. 7. Egg diameter frequency examined at each stage of growth of the southern bluefin (Kikawa 1964)

Table 4. Example of ripe egg diameter of southern bluefin (Kikawa 1964)

Egg diameter (mm)	No. 1801	No. 1841	Egg diameter (mm)	No. 1801	No. 1841
0.660		1	0.870	11	2
0.675		1	0.885	11	2
0.690		1	0.900	17	1
0.705	1	5	0.915	15	
0.720		6	0.930	5	
0.735		7	0.945	6	
0.750		8	0.960	3	
0.765	1	7	0.975	2	
0.780	1	10	0.990	3	
0.795	1	17	1.005	1	
0.810	3	12	1.020	1	
0.825	2	10	1.035	1	
0.840	8	7	1.050	1	
0.855	6	3	average	0.895	0.785

The frequency of egg diameters of southern bluefin is a multi-peak type with the largest peak at 0.015-0.165 mm. The figure suggests that egg groups move towards the direction of the eggs of larger diameter (Fig. 7 A,B,C). Based on these data Kikawa thinks that the ripening process of eggs in ovary in an individual southern bluefin may proceed in an order of c_1-c_2-c_3, b_1-b_2, a_1.

According to the histological observation of the ovary (Kikawa 1964), the egg group a_1 consists mostly of the eggs in yolk globule stage with some in the stage of the shifting of the blastocyst. The eggs in groups b_1 and c_2 are in the yolk granule stage. The smallest egg group, c_1, is in the stage of peri-nucleolus. It is known from histological observations that not all the ripe eggs are spawned; some of them remain within the tissue as unspawned eggs (Fig. 7D).

Kikawa (1964) has estimated the volume of spawning of an individual southern bluefin tuna, and the number of spawnings during one spawning period. According to his estimate, the number of eggs of a southern bluefin tuna of 140-160 cm is about 14-15 million. These eggs are spawned at two periods with about two-thirds of the total spawned on the first occasion.

(ii) Observation of gonad index. The gonad index and the maturity index are sometimes used synonymously. But, strictly speaking, they should be distinguished from each other. When the body length is given by L and the gonad weight is given by GW, the gonad index will be expressed by GW/L^3 (in the case of tuna the result should be multiplied by 10^4) and the maturity index is usually defined by α in $GW = \alpha L^b$. In the case where $GW = \alpha L^3$, there would be no problem. In the other cases, the estimate would be biassed to the extent of b-3. Maturity index has not been employed in this account.

Figure 8 shows the relation between body length and ovary weight of the southern bluefin samples caught in three different longline fishing grounds (Shingu 1970). The first of the three fishing grounds is the abovementioned spawning ground which

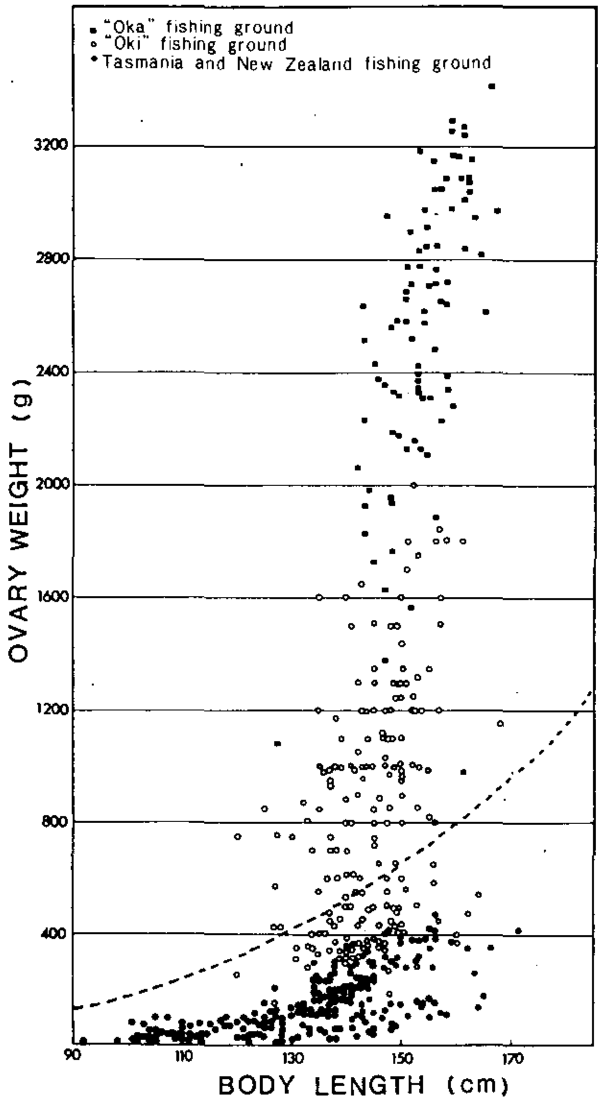


Fig. 8. Relationships between body length and ovary weight of southern bluefin classed by fishing grounds (Shingu 1970). Broken line indicates G.I. = 2.0

is usually called the 'Oka fishing ground'. The second is the adjacent sea area to the south west (20-30°S, 90-110°E) of the first and is called the 'Oki fishing ground'. The third is in the Pacific south east of Australia and east of New Zealand. As can be clearly seen in the figure, the range of the ovary weights can be divided into three classes corresponding with the different fishing grounds. In the Oka fishing ground individuals with ovaries in the range of 1600-3200 g are dominant. In the Oki fishing ground almost all individuals have ovaries in the range 300-1800 g, while on the Pacific side individuals with ovary weight over 400 g are very rare.

Judging from Kikawa's (1964) report, it is likely that the individuals possessing developed ovaries with Gonad Index (G.I.) exceeding 2.0 are fully matured and about to spawn. Thus G.I. = 2.0 (dotted line in Fig. 8) was taken as a standard line. Based on this standard, no individual of G.I. over 2.0 has been caught on the Pacific side. It is assumed that many of the southern bluefin tuna in the Oka and Oki fishing grounds are at the stage of spawning or immediately before spawning. From the fact that the samples in the Oka and Oki fishing grounds are over 130 cm long, and that when an individual exceeds this body length the change in the ovary weight becomes conspicuous, it seems that southern bluefin tuna attain maturity when they reach this size.

Figure 9 shows the frequency distribution of G.I. for each month, based on the samples caught in each of the three fishing grounds (Shingu 1970). The duration of the period when the data were collected corresponds exactly to the duration of the fishing period. The individuals with the highest G.I. occurred in the Oka fishing ground and their G.I. values were 2.0-14.0. Their G.I. were under 9.0 before October. During November-February individuals with well developed gonads with a G.I. exceeding 9.0 were found. In the Oki fishing ground, too, in the period from September to March, mature individuals (G.I. = 5.0) were observed. A conspicuous mode was observed in the vicinity of G.I. = 1.1-1.5 and its position was stable irrespective of the change of the seasons. On the Pacific side, G.Is. were under 2.0, as mentioned above, and showed no change in frequency in the seven months from May to November. Incidentally, CSIRO

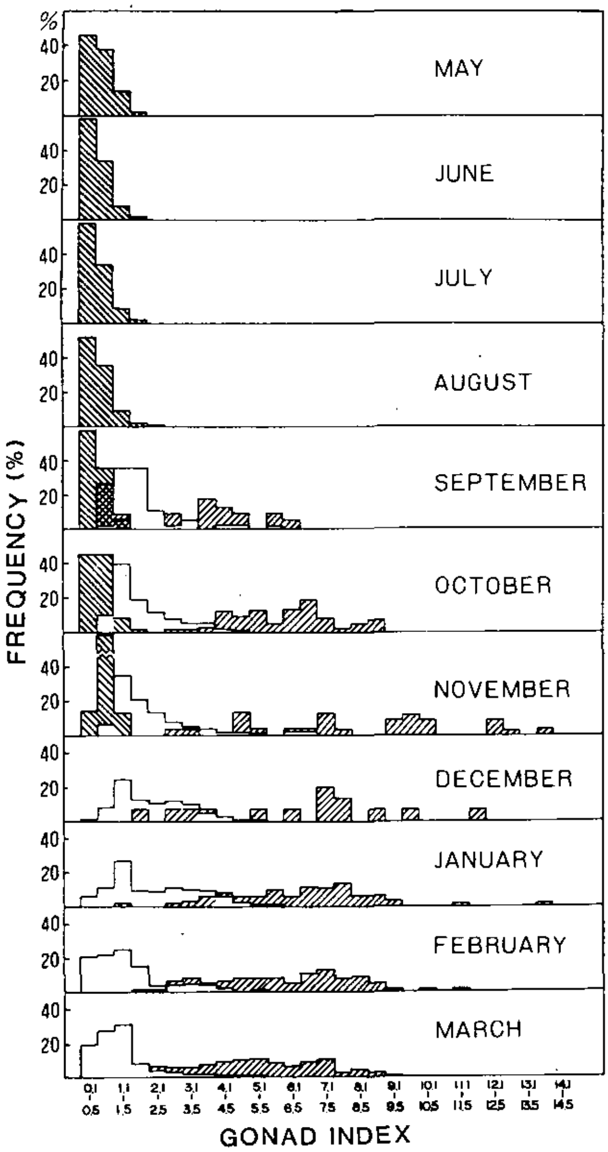


Fig. 9. Monthly change of G.I. frequency for each of the three fishing grounds of southern bluefin

Australia, New Zealand, east F.G.

'Oki' F.G. 'Oka' F.G.

Division of Fisheries and Oceanography (1963) studied the G.I. of southern bluefin caught in N.S.W. coastal waters, and the result was 0.031-0.428.

(iii) State of occurrence of the juveniles. It is easy to identify the species of adult tuna or of young specimens when they closely resemble the adult. But the identification of their juveniles requires a considerable skill as the standards for identification are delicate. Figure 10 shows three juvenile specimens of southern bluefin at different stages of growth. Yabe *et al.* (1966) describe their characteristics as follows.

At the stage when the full body length is about 4 mm, the head forms about 35% of the full length, the height is short (less than 30% of the body length), the anus opens in front of the middle of the body. Several tiny coniform teeth appear on both jaws. The spines are formed on the edge of pre-operculum. Fins are membraneous and not developed. The distribution of black chromatophores is limited to the parietal, the interior of the abdominal cavity and the tip of the lower jaw. Besides these, the characteristic features are one tiny black spot on the back and on the ventral side of the caudal section.

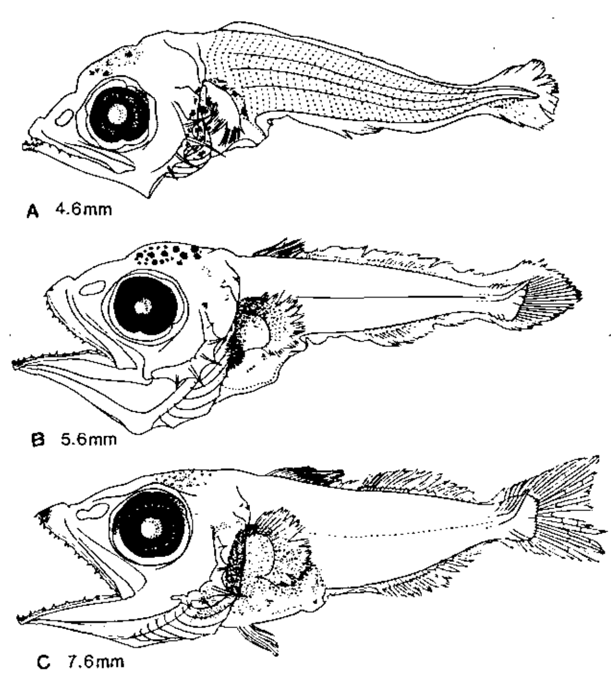


Fig. 10. Juveniles at different stages of growth. Total lengths indicated (Yabe *et al.* 1966)

At the stage when the body length is about 5 mm, the proportion of the head to the body becomes bigger (about 40% of the body), the depth becomes greater, too. The anus is further back and is situated behind the middle of the body. Membraneous fins remain to some extent on the peduncle section and behind the anus, but in the first dorsal fin and in the caudal fin, the fin rays are beginning to form. In the second dorsal fin and in the anal fin, fin rays begin to develop. The ventral fins begin to appear. The black chromatophores appear, in addition to the spots mentioned above, on the fin membrane of the first dorsal fin and on the tip of the upper jaw. In the caudal section one chromatophore is on the back and one on the ventral side. The one on the back situated on the peduncle section is very small.

At the stage of body length about 7 mm, the proportion of the head is similar to that at 5 mm, but the position of the anus is further back. The formation of all the rays is in progress, and the fin rays in the first dorsal fin, ventral fins, caudal fin, etc., have grown. The caudal fin is forked, the hypural plate is almost complete, the formation of fin rays is further advanced. The black chromatophores spread over the back of the head and the operculum, and their distribution in the first dorsal fin membrane become very dense. Of the chromatophores on the caudal section, the one on the back is situated at the joint of the caudal fin and is so small that it cannot be recognized unless it is magnified about 30 times and examined by a microscope.

A comparison of other features which signify the growth of an individual is given in Table 5.

Table 5. External measurements of the three juvenile southern bluefin tuna illustrated in Fig. 10 (Yabe *et al.* 1966)

Sample No.	A	B	C
Date of collection	19 Jan. 1965	17 Mar. 1962	17 Mar. 1962
Location of collection	12°00'S 103°00'E	11°22'S 102°06'E	11°22'S 102°06'E
	mm	mm	mm
Total length	4.6	5.6	7.6
Body length	4.5	5.15	6.6
Length of head	1.55	2.1	2.7
Length of snout	0.55	0.8	1.0
Diameter of eye	0.5	0.6	0.85
Diameter or orbit	0.6	0.7	1.0
Length of upper jaw	1.05	ca. 1.4	2.0
Height of body	1.2	ca. 1.7	2.2
Snout - first dorsal fin	1.9	2.25	3.1
Snout - anal fin	-	3.5	4.75
Snout - anus	2.0	2.7	3.8
Length of pectoral fin	ca. 0.6	0.6	ca. 0.75
Length of ventral fin	-	-	0.6
Length of first dorsal fin	-	0.35	1.0

In the Indian Ocean, the juveniles of the tuna family, except those of southern bluefin, occur all over the low latitude sea areas, while southern bluefin juveniles have been collected only in a very limited area (Fig. 11). In the past about 50 juveniles of 3-8 mm were collected in the eastern Indian Ocean spreading over 10-20°S and east of 100°E. According to Ueyanagi (1969), the period when the juveniles were collected was from November to March (in the southern summer). The temperature of the surface water where they were caught ranged between about 25° and 30°C. The oceanographic conditions of this season suggest that the area of occurrence of southern bluefin juveniles is quite limited, and the southern limit of the area is presumed to be in the vicinity of 25°S. The abovementioned 50 juveniles were all caught by a surface towed larval net, so no information is available about their vertical distribution.

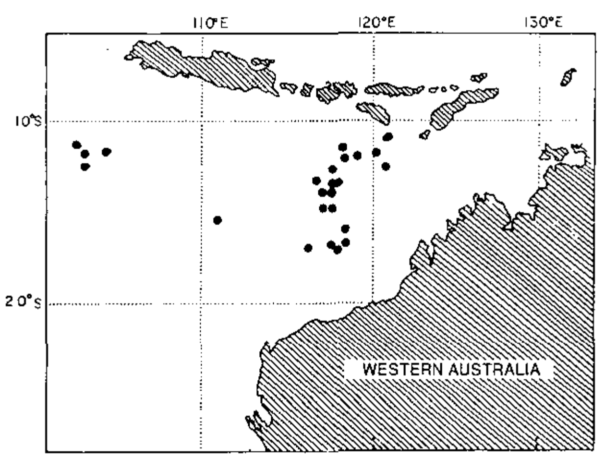


Fig. 11. Distribution of southern bluefin juveniles (based on Ueyanagi 1969)

According to Ueyanagi (1969), it is reported that a fish considered to be the juvenile of this species occurred outside of the Indian Ocean in coastal water north east of Australia 20°47'S, 156°11'E, but he added that its identification was doubtful. As mentioned earlier, judging from the condition of growth of the gonads, southern bluefin tuna do not spawn in this area.

1.5 *Behaviour*

(i) Feeding habits. There have been few studies on the feeding habits of southern bluefin. The results of stomach content analysis will be discussed here.

The result of stomach content examination made by Serventy (1956) are shown here (from Robins 1963).

Scientific name	English name
Trachurus novaezelandiae	Jack mackerel
Scomber australasicus	Mackerel
Sardinops neopilchardus	Pilchard
Engraulis australis	Anchovy
Trachurus declivis	Scad
Emmelichthys nitidus	Pearl fish
Nemadactylus sp.	Morwong
Thyrsites atun	Barracouta
Sphyraena novae-hollandiae	Pike
Arripis trutta	Salmon
Rexea solandri	King barracouta
Stolephorus robustus	Blue sprat, young marine eel
Family Myctophidae	Lantern fish
Macroramphosus molleri	Bellowsfish
Scombersox forsteri	Billfish
Caranx georgianus	Trevally
Gonorhynchus greyi	-
Zeus australis	John dory
Gnathagnus innotabilis	Star gazer, boxfish
Zanclistius elevatus	Boar fish
Ruboralga sp.	Rock cod
Atherina sp.	Hardyhead
Upeneichthys lineatus	-

Cephalopoda
Notodarus gouldi, Enoploteuthis galaxias, Calliteuthis miranda, Argonauta nodosa, Octopus australis

Crustacea
O. Euphausiacea : *Nyctiphanes australis*
O. Amphipoda : *Phrosina semilunata, Brachyschelus crusculum*
O. Stomatopoda : *Squilla laevis* (larvae)

Tunicata
O. Salpida : *Oikopleura* sp.
Chaetognatha : gen. and sp.
S. Cl. Siphonophorae : Diphyes sp.

Serventy has examined the stomach contents of small sized southern bluefin tuna under about 20 kg which had been caught in the coastal waters of eastern Australia and found fish, Cephalopoda, Crustacea and salps, in that order of importance. The fish are, as seen in the table, those of warm seas but the species cover a wide range and, as indicated by the existence of jack mackerel, mackerel, barracuda, *Diapus coerulus, Allanetta bleekeri*, etc., their distribution layers seem to be varied considerably. With Crustacea, too, there are cold water euphausiids as well as warm water and open sea species.

In the case of large southern bluefin caught by the longliners in the north east sea areas off New Zealand, the fish *Alepisaurus borealis, Polyipnus spinosus, Pseuopsis animala, Trachipterus*, etc., the crustacean *Funchalia woodwardi*, as well as squids and octopus are mentioned (Robins 1963).

In the stomach contents of southern bluefin caught in the abovementioned spawning ground, amphipods are the most common, followed by fish, cephalopods, salps, etc. (Robins 1963).

Talbot and Penrith (1963) examined the tuna family on the coast of South Africa from Saldanha Bay to Port Elizabeth. In the report of their investigation, the feeding and the stomach contents of southern bluefin are stated as follows.

From the result of experimental long-line operation carried out for each time zone, southern bluefin is presumed to feed in the early morning. This has been inferred from the fact that, in the experimental operation in which the longline was sunk at sunset and drawn up at dawn, the catch was small. Examination of the stomach contents of 263 individuals caught during the experimental operations revealed that southern bluefin ate *Merluccius capensis* and *Funchalia woodwardi* which are distributed in a fairly deep layer. Thus they report that the intake of food takes place probably at a certain depth. The result of the examination of the stomach contents volume in the same samples shows that about 24% of them had empty stomachs; 47% had less than 10 cc of stomach contents (Fig. 12). About 94% of feed animals were fish and *Funchalia woodwardi*, but the variety of species of the fish is notably less than in southern bluefin in the Australian coastal waters (Fig. 12).

Summarizing these examples we find that the feeding habits of southern bluefin tuna may indicate that they

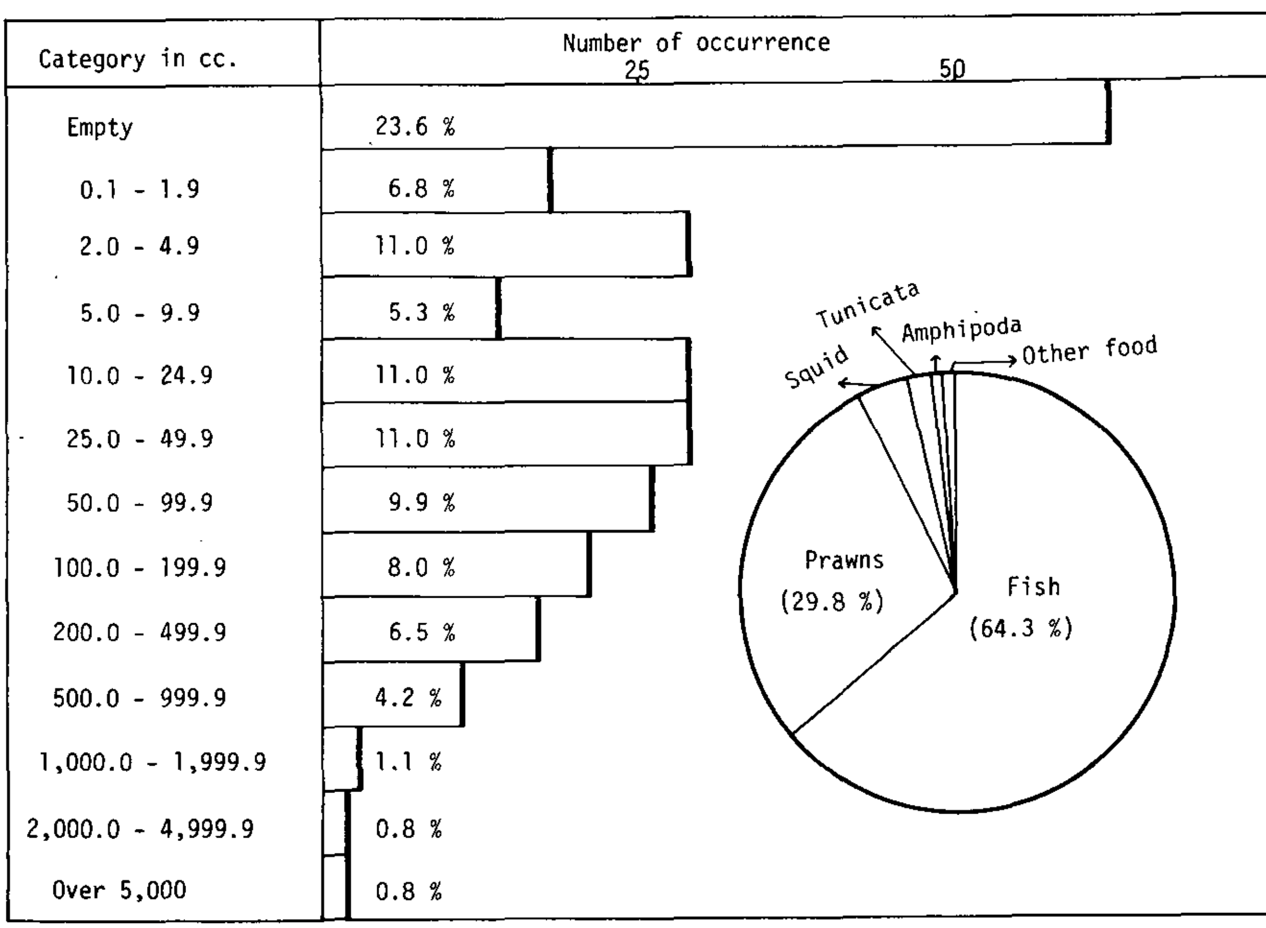


Fig. 12. Number of occurrences grouped by volume of stomach contents of southern bluefin tuna distributed along the coast of South Africa, and the frequency of food animals. (Based on Penrith 1963)

aim at animals characteristic of their habitat, and that they appear to be polyphagous and opportunistic.

(ii) Change of meat quality due to spawning. Here, the change of meat quality refers to the colour and the oiliness of fish meat; it is not based on chemical standards. The market price of southern bluefin tuna varies greatly according to the condition of the meat quality. Today it often happens that, due to the difference in meat quality, there may be a difference of over 100 million yen in the total catch price on landing between one trip and another. In order to be able to examine the meat quality, each individual at the Yaizu fish market has either its caudal section cut off or a cut is made in the body so that a piece of meat can be examined. The brokers examine the cut or meat piece and judge the meat quality and fix a price at auction.

It has been known for a long time that in bluefin tuna, which is a close relative of this species, changes of meat quality are closely related to spawning or the degree of fatness (Nakamura 1952). Bluefin tuna soon after spawning are very thin and their meat is darkish. Fishermen call them *"Rakkyo maguro"* ("scallion tuna"). in the case of the southern bluefin, for instance, the fat ones, some 165 cm and 134 cm long, weighed 102 kg and 45 kg respectively. But the thin ones of similar length, 169 cm and 133 cm were 81 kg and 36 kg in weight respectively (Warashina and Hisada 1970). Warashina and Hisada (1970) examined the quality of southern bluefin tuna landed at fish markets between February and December 1967, and compared the body length and the weight of those of good quality and those of inferior quality. Some of their results are given in Figs 4 and 5. The circles (o) in Fig. 5 indicate the body length and weight of the individuals judged as fine quality and the dots (•) of those judged as inferior. From these figures a close relationship between fatness and meat quality can be seen. However, according to Warashina and Hisada, the quality cannot necessarily be determined in respect of each individual. In some regions or in some seasons, there occur individuals which cannot be determined as either good or bad, and in some cases fat individuals have inferior meat. As indicated in Figs 4 and 6, among adult fish over 130 cm long, deviation in the body length-weight relationship becomes greater. It is easy to see that this deviation is caused by spawning. If this inference is correct, it is quite natural that the individuals with intermediate meat quality or intermediate fatness should occur in the spawning/feeding cycle. Thus, Warashina and Hisada divided the sea around Australia which includes the spawning ground, into five seas as indicated in Fig. 13, and they have examined the proportion of individuals with good and with inferior meat quality in the monthly catch in each of the five areas. They also measured the fatness of the same samples. The figure shows the meat quality with the black part in the figure representing the proportion judged as inferior. Their findings in the spawning ground (Oka fishing ground 10-20°S) were that before August-September, which coincides with the beginning of the fishing season, few thin individuals are found. However, although the individuals caught in this area are fat, their meat quality is rather inferior. The proportion of thin individuals increases after October when spawning becomes intense and reaches 100% from December to March when the fishing season ends. In the two sea areas (20-30°S and 30-40°S) which lie to the south of the Oka ground, the individuals with inferior meat begin to appear later than in the Oka fishing grounds and their proportion reaches 100% in March-April. In the West Wind Drift in the Indian Ocean and in the Tasman Sea fishing grounds (south of 40°S), a seasonal change

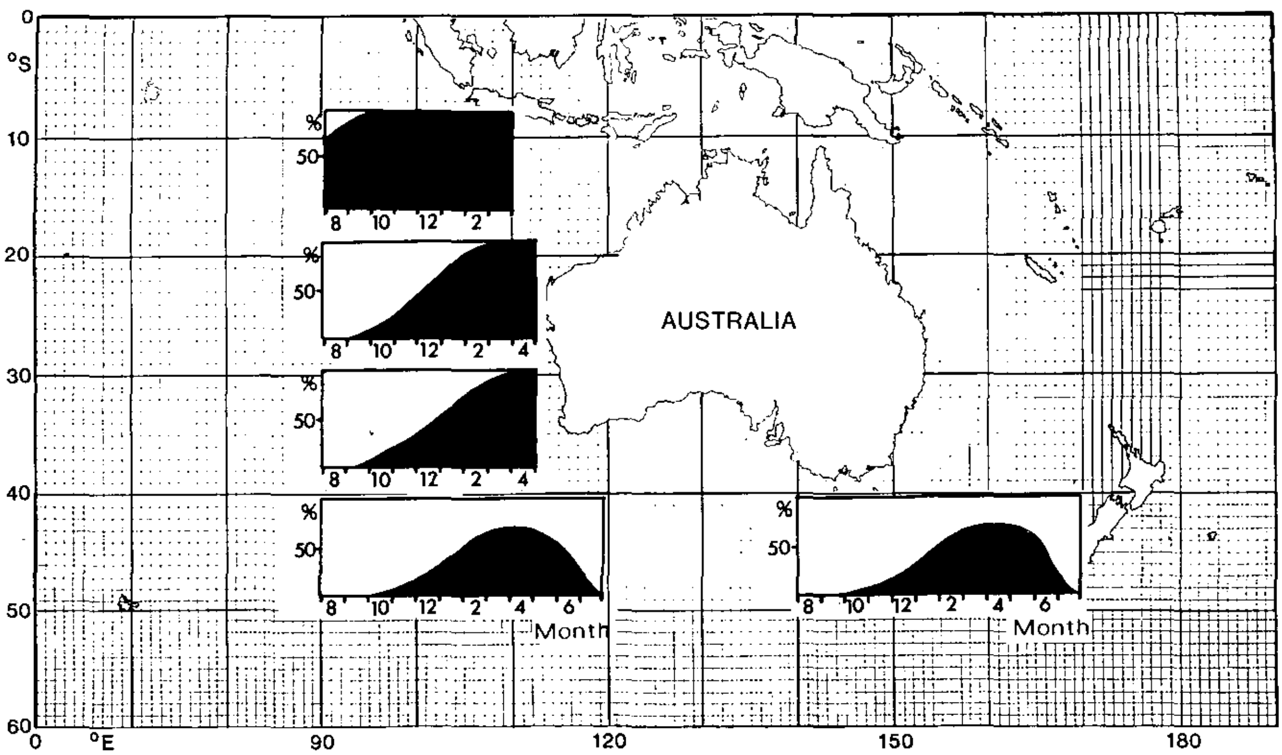


Fig. 13. Occurrence of southern bluefin of inferior meat quality arranged by month (Warashina and Hisada 1970). The dark part shows the proportion of individuals of inferior meat quality

similar to the above two areas is observed. But the percentage of individuals with inferior meat never reaches 100%, being at its highest value around April and decreasing gradually after that. This indicates that the spawning season extends over about six months and it causes a difference in the recovery of meat quality and fatness among individual fish.

In order to catch more individuals of good meat quality, there is a limit of time as well as area for operations. Nevertheless, because of the high market value of fat fish in recent years, fishing boats concentrate in the areas where the fat individuals are found.

In this section the change in weight has been discussed in relation to spawning. But it has been said that there is a difference in fatness observed in some areas even among the immature southern bluefin tuna. Therefore, in dealing with the question of fatness, it may be necessary to examine it from various angles including environmental conditions, food and so on, in addition to the abovementioned factors.

(iii) Changes of distribution areas due to growth, spawning and feeding. Nakamura (1965) mentioned a law to be observed in the distribution and migration of the tuna family. Its outline is as follows: In the tuna family, the distribution differs from species to species and is affected by migration in different oceanic current systems. (In recent years this can be replaced by water mass or water type (Nakamura 1965).)

The migration can be divided into two major types: migration within a current system and migration between current systems. The first type is migration without a change of ecology and is to be regarded as an intermediate stage. This migration is a reflection of the seasonal change of the current system rather than a movement of tuna masses. The second type is due to a change in ecology and is a positive movement of the tuna as such. This theory which is based on the oceanic current system seems to explain satisfactorily in principle the distribution and the migration of tuna species. But it has been pointed out that, when the border regions of the distribution or the special local fishing grounds are examined, there are cases which cannot be explained by the above theory alone, and relation to currents, topography, eddies and rising currents have been discussed as the causes for concentration and dispersion of tuna. There has also been an attempt to describe the distribution of water temperatures in the oceans inhabited by tuna.

As will be mentioned later, the habitats of different stages of growth, spawning and feeding of southern bluefin are relatively distinct. Figure 14 indicates the areas where southern bluefin tuna were caught in the past either by longliners or research vessels, and Figure 15 indicates the distribution and location of the fishing grounds of southern bluefin in Australian coastal waters (from Robins 1963). Since longline fishing operations have been carried out on a large scale in all the oceans, the fishing areas for southern bluefin in these figures can be regarded as representing generally the distribution of this species. The north-south distribution extends about 40° from 10°S to 50°S but, except in the east Indian Ocean where the northern limit is 10°S, the distribution extends only 20° from approximately 30° to 50°S. Within this latitudinal range, the longitudinal range is circumglobal but the distribution is not even. Between the continents in the central region of the ocean the distribution is sparse. In the Pacific particularly, to the east of 180° the distribution becomes thin and only in the area off Chile is there a concentration of the species. In the Atlantic, the distribution becomes thinner between 20° and 40°W. Consequently, the longline fishing operations are also limited to the area east of 20°W and west of 180°. The distribution in Australian coastal waters also seems to be limited to the southern half of the continent, and the two major fishing grounds are located to the south of approximately 35°S. The above information shows the sphere of the distribution of southern bluefin, but it is only an accumulation of the data collected over a long period. When the distribution is examined in respect of a particular season or month, remarkable changes of distribution are observed. This is because the species are distributed according to the stage of growth, spawning and feeding, as well as to the season. Here the distribution with respect to water temperature and salinity at different life history stages is discussed for the areas around Australia (cf. Fig. 14). In Figure 16, the southern bluefin of a fishable size have been grouped into five stages: young in the littoral stage (1); immatures and feeding adults moving off shore and in the northward (2) and southward (3) migrations; adults immediately before and after the spawning and the spawning group in the Oki (4) and Oka (5) grounds. The figure also indicates the changes in surface water temperature and salinity. The figure shows that the surface temperature over the distribution area has a range of 25°C from 5° to 30°C. However, within this range the temperature range in which each growth stage is found is relatively small. Young fish, which become the first target of the fishery, are found at 15-20°C (35.0-36.0‰). Northward migrating immatures and adults are found at the same temperatures but at surface salinities up to 37‰. On the other hand, at the southward migration stage they are found at 5-15°C, 34.0-35.0‰. It is suggested that adults change their distribution rapidly as spawning

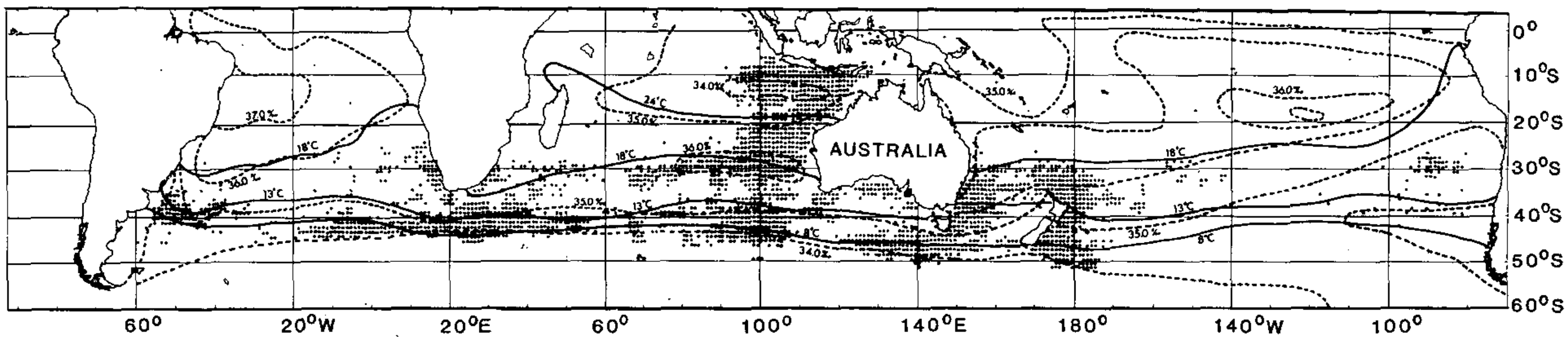


Fig. 14. The distribution of longline catches of southern bluefin (from Sverdrup 1959). Dotted line and solid line denote iso-saline and isothermal lines respectively at the surface in February

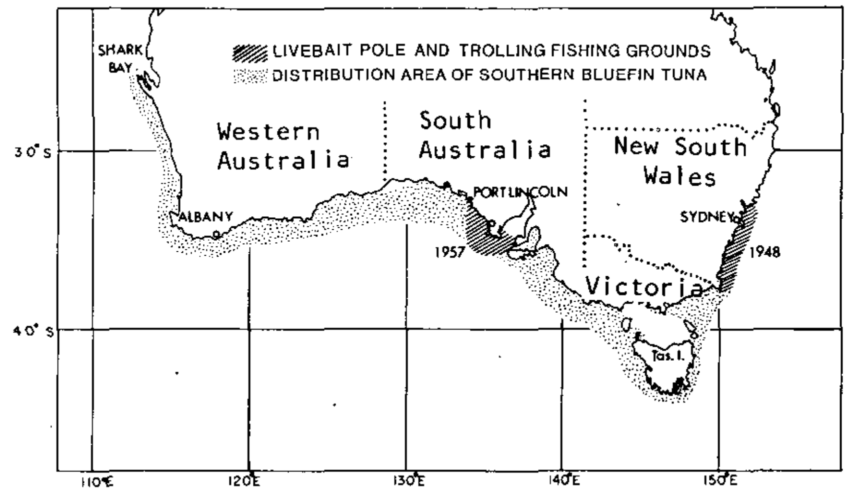


Fig. 15. The distribution area and the location of the fishing grounds of southern bluefin in Australian coastal waters

Livebait and pole and trolling fishing grounds

Distribution of southern bluefin in Australian coastal waters

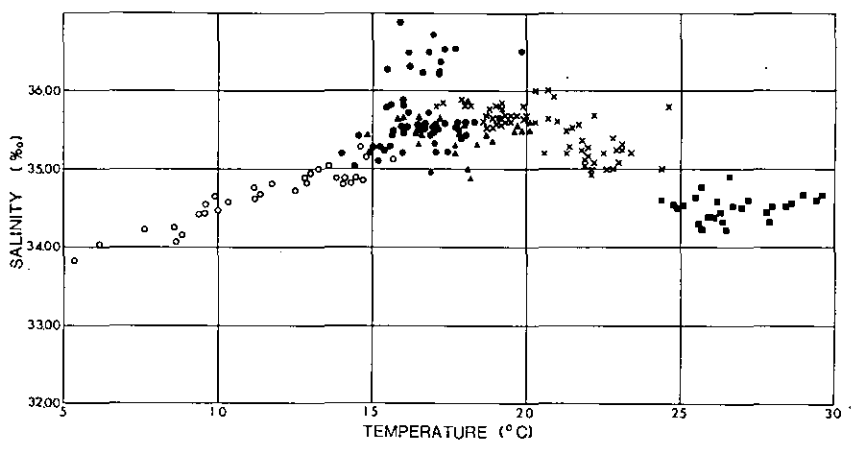


Fig. 16. Relationship between surface water temperature and salinity at the fishing grounds of southern bluefin at various stages of growth life history (Shingu 1970)

▲ : Young (Australia coast)

● : Northward migrating immatures and feeding adults (Tasmanian, New Zealand fishing ground)

o : Southward migrating immatures and feeding adults (West Wind Drift fishing ground)

x : Spawning adults (Oki fishing ground)

■ : Spawning adults (spawners) (Oka fishing ground) gets closer. In other words, from the feeding stage, they migrate to the area of 17-21°C and then to the area of higher water temperature 25-30°C, which is the spawning ground. Therefore it may be said that migration is rapid and frequent and is a response to the needs of spawning and feeding, rather than to the needs of growth and development.

On the other hand, it is natural to think that physiological changes might occur with the fish themselves in response to the ecological changes. The relationship between these changes and the migration will be a very interesting subject. Hanaoka (1977) reported that in *Scomber japonicus japonicus*, *Trachurus trachurus* and *Limanda yokohamae*, as the ovary develops from immature to mature, the osmotic pressure of body fluids rises gradually and reaches a maximum at the time of spawning. After the release of spawn, until the unreleased ripe spawn is absorbed, the osmotic pressure remains at a fairly high level, then falls gradually to the normal level (Chu and Hanaoka 1973). Figure 17A shows seawater osmotic pressure and temperature for the areas occupied by *Scomber japonicus* at different seasons, and shows that the fish move to areas of higher osmotic pressure between winter and spring. Spawning adults are caught in the area of highest osmotic pressure. With the rise in water temperature, the fish migrate to an area of lower chlorinity and lower osmotic pressure. Then from autumn to winter, as the water temperature falls, while retaining the same osmotic pressure, they migrate back to the higher salinity area. In the case of *Limanda yokohamae*, which spawns in the period of falling water temperature, the relationship is basically the same as for *Scomber*, but the direction of migration is reversed (Fig. 17B). Hanaoka (1977) calls this relationship 'the migration triangle'.

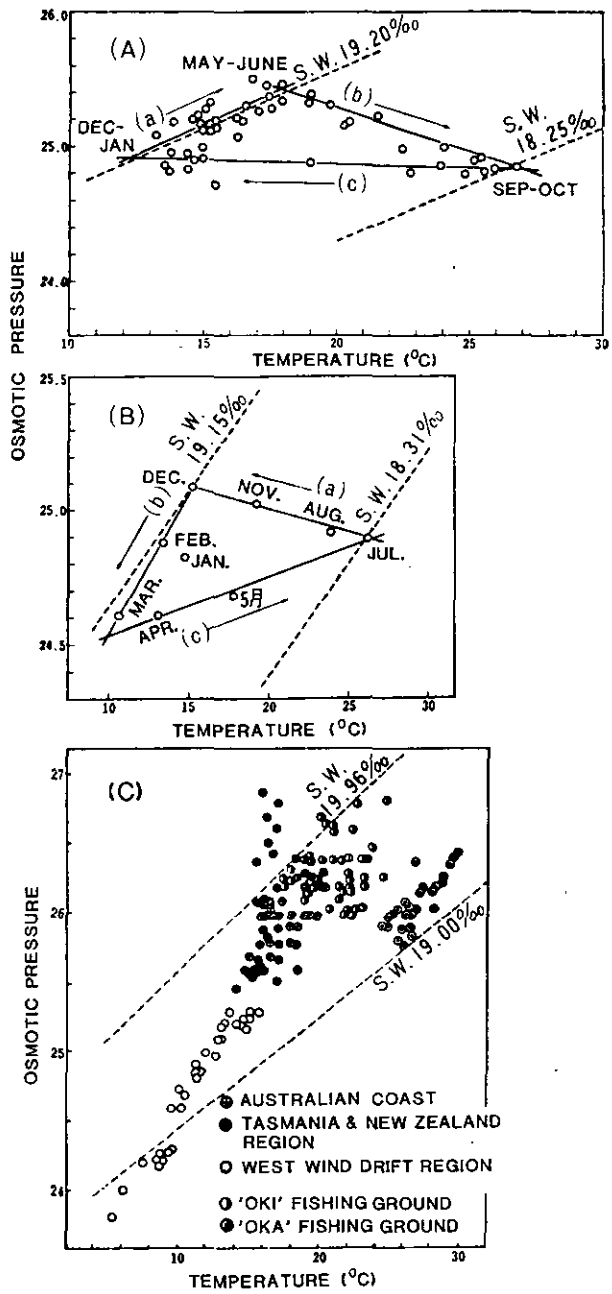


Fig. 17. The relationship between water temperature and osmotic pressure in the fishing ground of *Scomber* (A) and *Limanda* (B) at different seasons (Chu and Hanaoka 1973) and southern bluefin (C) (Hanaoka 1977)

⊕ Australian coast
● Immatures and feeding adults in the northward move (Tasmanian and New Zealand fishing ground)
○ Immatures and feeding adults in the southward move (West Wind Drift)
◑ Spawning adults (Oki fishing ground)
⊙ Spawners (Oka fishing ground)

No investigation has been carried out with tuna group to confirm the existence of such relationships, but Hanaoka has examined the relationship between the water temperature and the osmotic pressure of the waters of the fishing grounds of southern bluefin on the basis of the data in Fig. 16 and has observed the movement of the species at different stages of growth (Fig. 17C). He states that southern bluefin schools move to the area of higher water temperature and higher osmotic pressure, then return to the former lower temperature and lower osmotic pressure area. However, the ratio of the rise of osmotic pressure to the rise of water temperature in the fishing ground of the fish at various stages of growth is considerably higher than can be explained by the effect of temperature changes on the osmotic pressure of the water. This is explained by the large scale migration of the schools of tuna to different water systems at the time of spawning. He maintains that a similar relationship is to be observed, not only with the southern bluefin, but also with bigeye, yellowfin, albacore, etc.

From these findings, Hanaoka maintains that, although it is not possible to state the pattern of migration of every species at every stage of the life history, in the migration of marine fish there is a relationship between growth, osmotic pressure of body fluids, and migration.

1.6 *Distribution of surface water temperature in the fishing areas*

The sea areas in which the catch or the distribution of southern bluefin has been confirmed are extensive (Figs 14,15). However, the distribution of the fishing grounds in each particular year gives the impression that they are rather localized. Moreover, the fishing grounds where operations are intense have changed greatly in the past.

As stated in the previous section, the surface water temperatures in the distribution areas of this species range from 5° to 30°C. On the whole the isothermal lines in the distribution area run in the east-west direction (Fig. 14). But, when the water temperature distribution is examined in respect of each of the fishing grounds, the situation is not so simple. Even though the data are a little out of date, a graphic representation of the localities where southern bluefin were caught and of the isotherms at the surface are indicated for the four longline fishing grounds and a livebait-and-pole fishing ground around Australia, particularly during the months close to the peak of the fishing period. (Fig. 18A-D prepared by Warashina (Far Seas Fisheries Research Laboratories) and Fig. 18E (Fisheries Field Bulletin No. 87, CSIRO Div. Fish. Oceanogr. 1968)). The water temperature differs from one fishing ground to another; nevertheless, in each of the fishing grounds the spot where the operations are intensive and the catches (in the case of the longline fishing ground the catch is given by the number of fish per operation) are large is in the area where the isotherms lie in a tongue-like shape and the distance between the isothermal lines is small, that is, where the temperature gradient is great.

In the Oka spawning grounds (Fig. 18A) the fishing season begins in October when the concentration of the southern bluefin groups is intense. In the illustration the catches are large at the flexures of the 23°, 25°, and 26°C isotherms, while in the sea area between the above isotherms where the change of water temperature is gradual, fishing operations are sparse and productivity is low. The situation is similar in the Oki fishing ground (Fig. 18B) and the catches are large in the region where the cool water from the south and the warm water from the north come into contact.

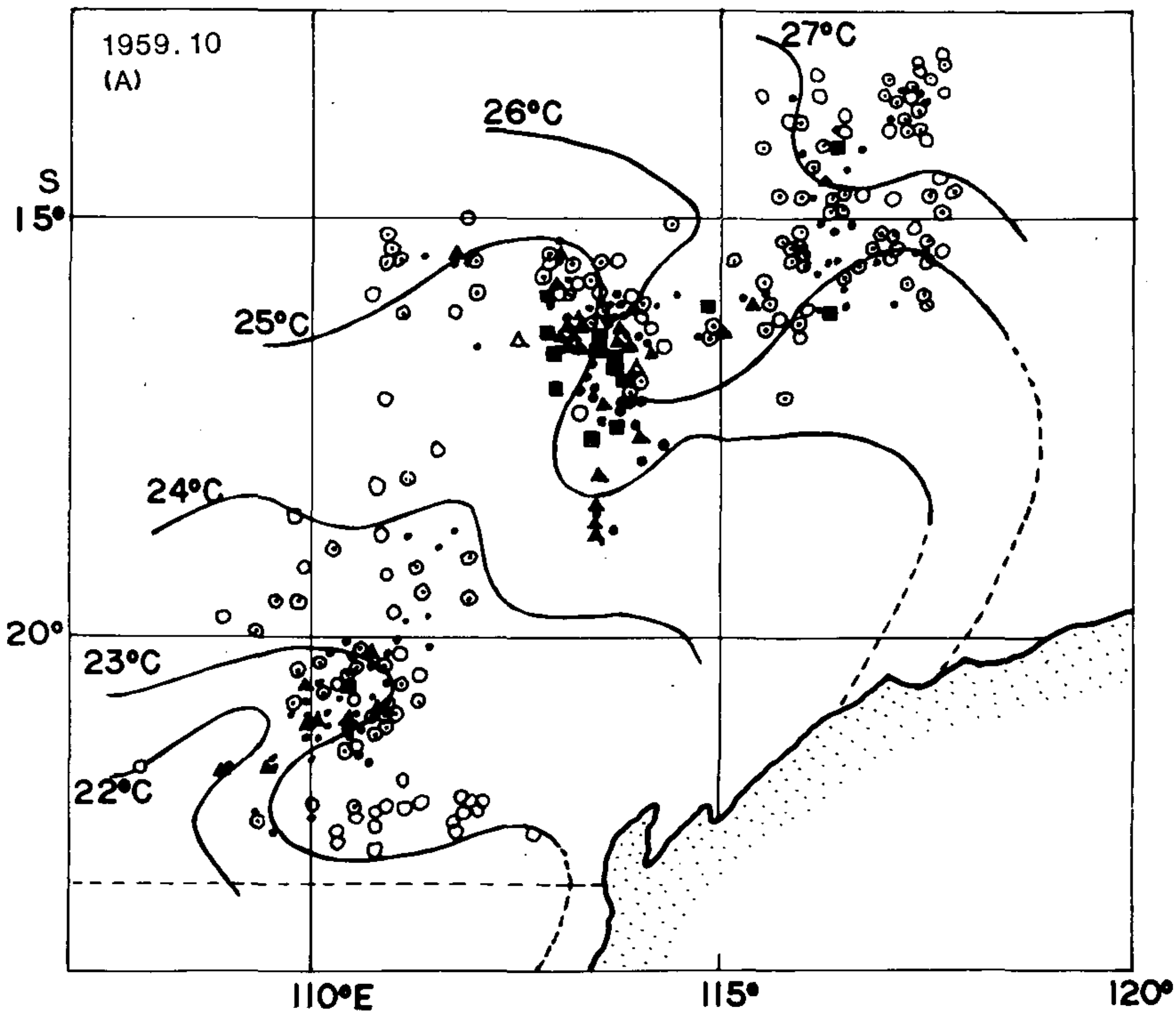


Fig. 18A. Location of catches of southern bluefin and distribution of surface temperature in the Oka fishing grounds in October

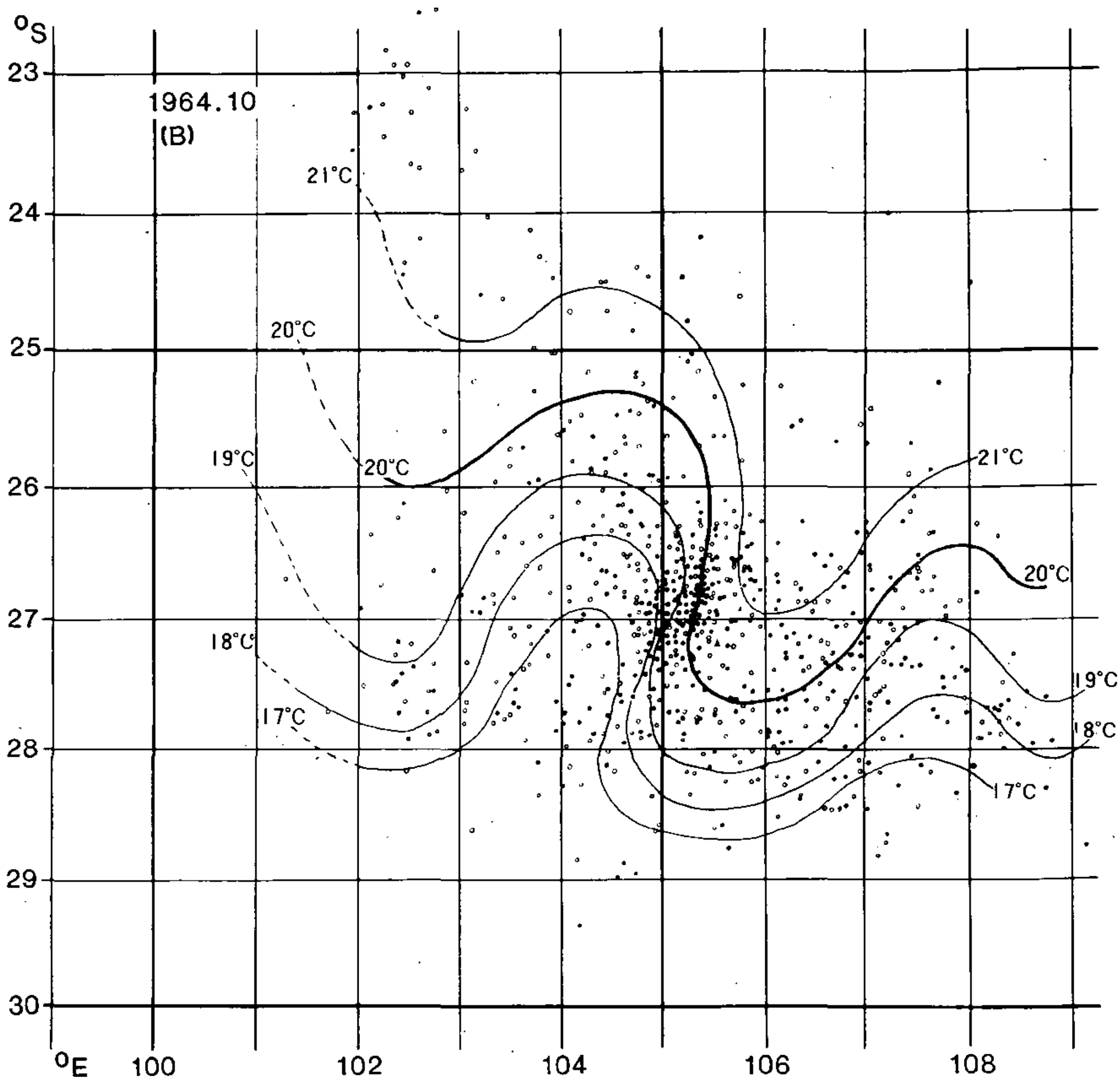


Fig. 18B. Location of catches of southern bluefin and distribution of surface temperature in the Oki fishing grounds in October

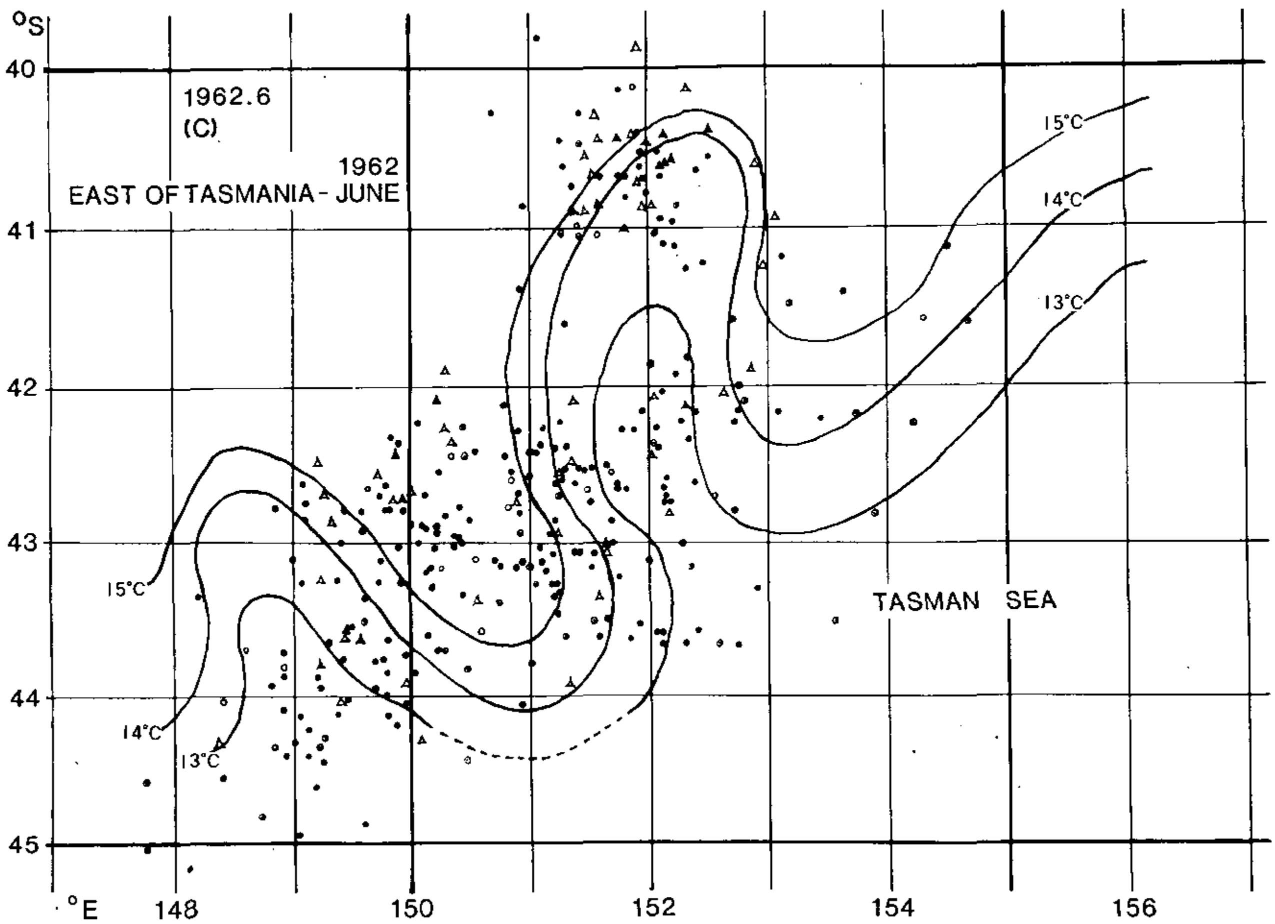


Fig. 18C. Location of catches of southern bluefin and distribution of surface temperature in the Tasmanian fishing grounds in June

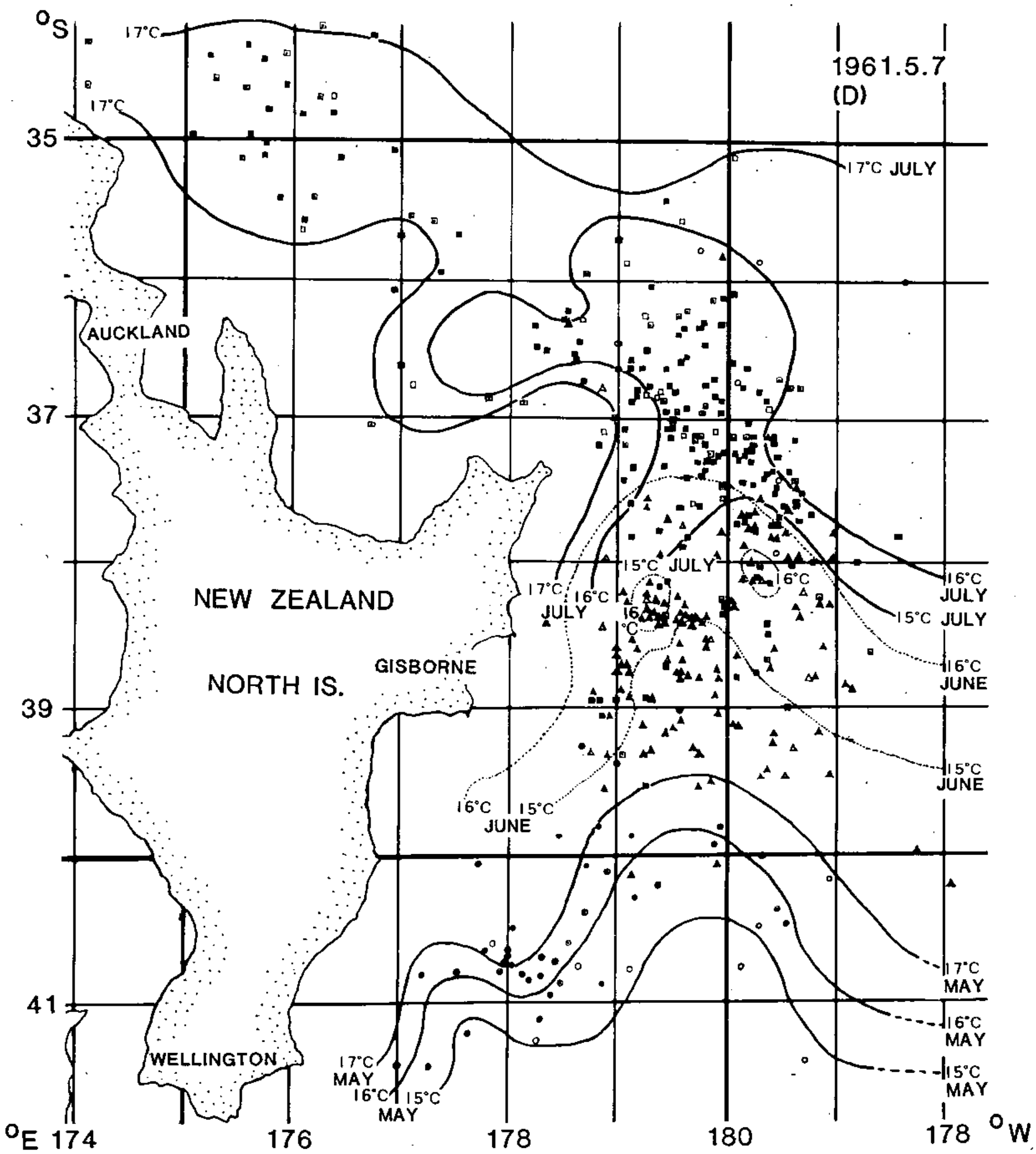


Fig. 18D. Location of catches of southern bluefin and distribution of surface temperature in the N.Z. fishing grounds during May-July

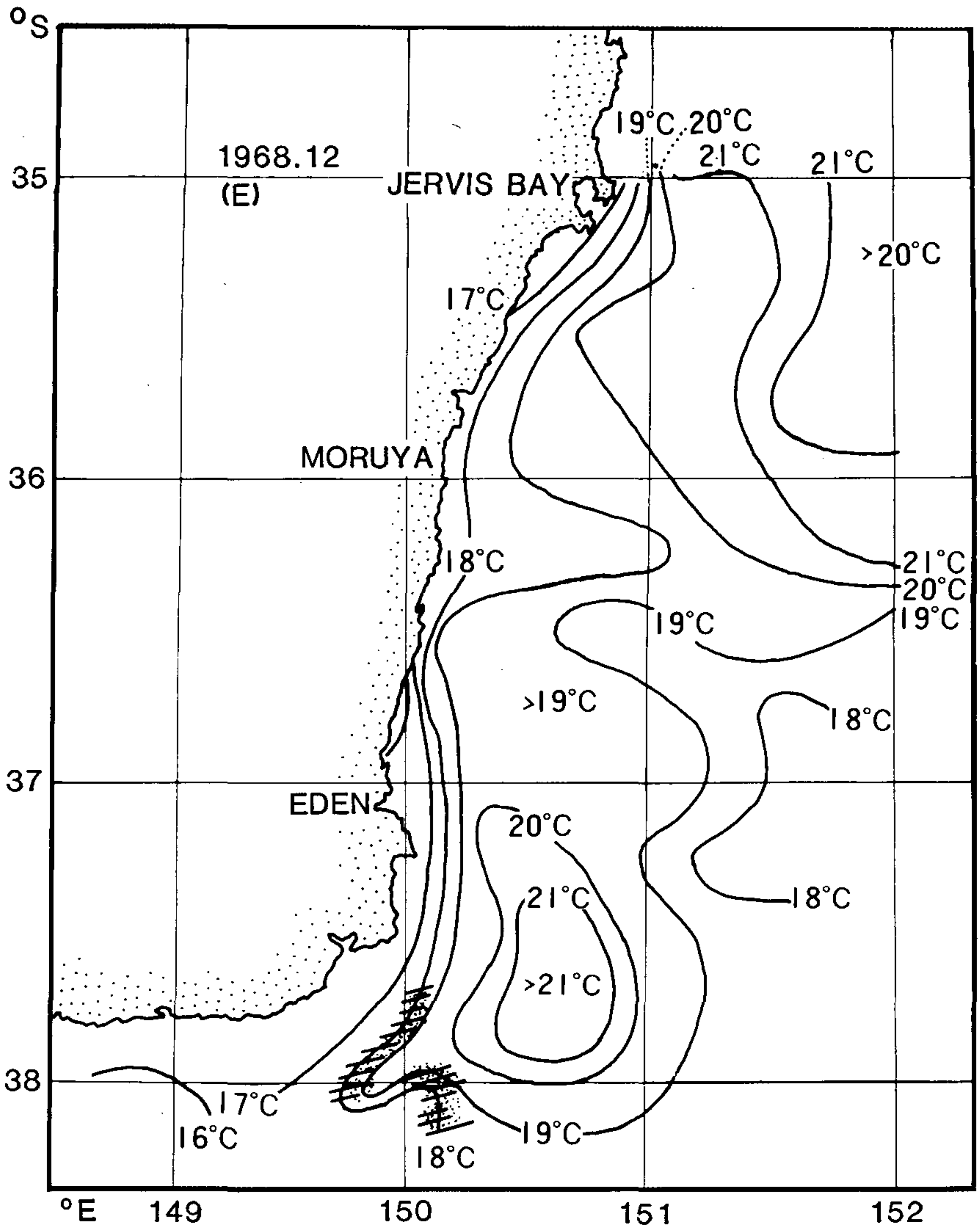


Fig. 18E. Fishing grounds of southern bluefin (shaded area) and the surface temperature distribution in N.S.W. coastal waters in December

The above two cases are concerned with the fishing grounds to which only the north travelling adult fish migrate, but immatures and feeding adults are also caught there. In the Tasman Sea and to the east of New Zealand the formation of the fishing ground is similar to the above cases (Fig. 18C,D). The graphic representation of the latter is given for the period of three months from May to July. This figure shows that the water at 15-17°C stretches northward in these three months in a pocket from the south of 40°S up to the vicinity of 34°S along the North Island, and the fishing is centred around the sea area inside the pocket. An excellent fishing ground can be recognized especially in the area between 36°S and 39°S where the change in water temperature is sharp. On the N.S.W. coast (Fig. 18E), which is one of the Australian livebait-and-pole fishing grounds, the peak of the fishing operations is in December. In 1968 the isotherms run in a north-south direction. Moreover, there is an inversion layer in the southern part which indicates the complexity of the water temperature distribution. The fishing ground is situated in the vicinity of 38°S where the 18-19°C isotherms are convoluted.

As can be seen from the foregoing, there seems to be a relationship between the very good fishing grounds and the pattern of the surface temperature distribution. Of course, they alone cannot be regarded as general guidelines for the mapping out of an operational plan or for detecting the fishing grounds themselves. But under the existing circumstances the water temperature distribution has, by experience, become an important yardstick for the operation. In longline fishing, instead of setting the 100 km longline in a straight line, it is sunk in various shapes according to the water temperatures in the fishing zone. In Australia, too, it has been reported recently that isothermal charts distributed to fishing boats did indicate the location of fish shoals coming to surface in the surface-fishing grounds. The use of these charts, it is reported, has improved the rate of encountering fish schools (Lucas 1974).

II. FISHING AND THE STOCK

II.1 *Structure of the stock*

(i) Seasonal changes in fishing grounds and hook rate. Since no fishing ground charts or charts of the surface fisheries on the Australian coast are available, the seasonal changes in fishing grounds are inferred from the seasonal changes in the catches. As mentioned earlier, there are two main surface fishing grounds in Australia. One is on the N.S.W. coast and the other is on the south coast of South Australia. There are reports of catches in the vicinity of Albany in Western Australia, but the size of the catch seems to be small and the fishing operation is on a local scale.

According to Robins (1963) and Hynd (1966) the fishing area on the N.S.W. coast extends northward during June and July and in August it reaches its most northerly point (approx. 34°S). After September it retracts southward and around December its northern limit is in the north-eastern waters off Tasmania. Some of the schools of southern bluefin in these areas move southwards (off Tasmania) after December to the fishing grounds on the South Australian coast, and another group goes northward again for a short distance, and accumulates near the Victorian coast (37-38°S).

During the northerly movement it is characteristic of the schools that the individuals are scattered and are subject to trolling, and during the southerly movement they are grouped and become the object of livebait-and-pole fishing.

As indicated in Fig. 19, the catches and the catch per boat in the N.S.W. fishing grounds reach their peak about December each year. Therefore it may be said that the fishermen in this sea area depend upon the schools of southern bluefin during their southerly migration.

The fishing season in the South Australian fishing grounds starts around January, following the closing of fishing in the N.S.W. fishing grounds, and comes almost to a close by May. The peak is considered to be in February-April. In both fishing grounds the fishing period lasts for 3-4 months and is markedly shorter than that of longline fishing. Consequently, the leisure season for fishing lasts for about half a year,

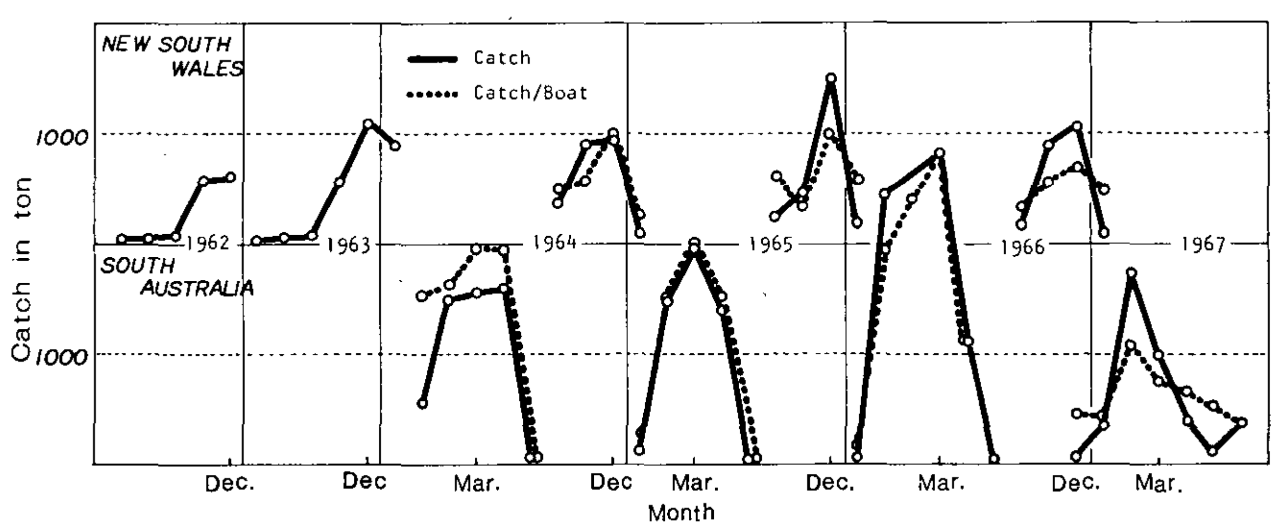


Fig. 19. Yearly and seasonal changes of catches (in tons) and catches per boat of southern bluefin in N.S.W. coastal waters (upper graph) and in South Australian coastal waters (lower graph)

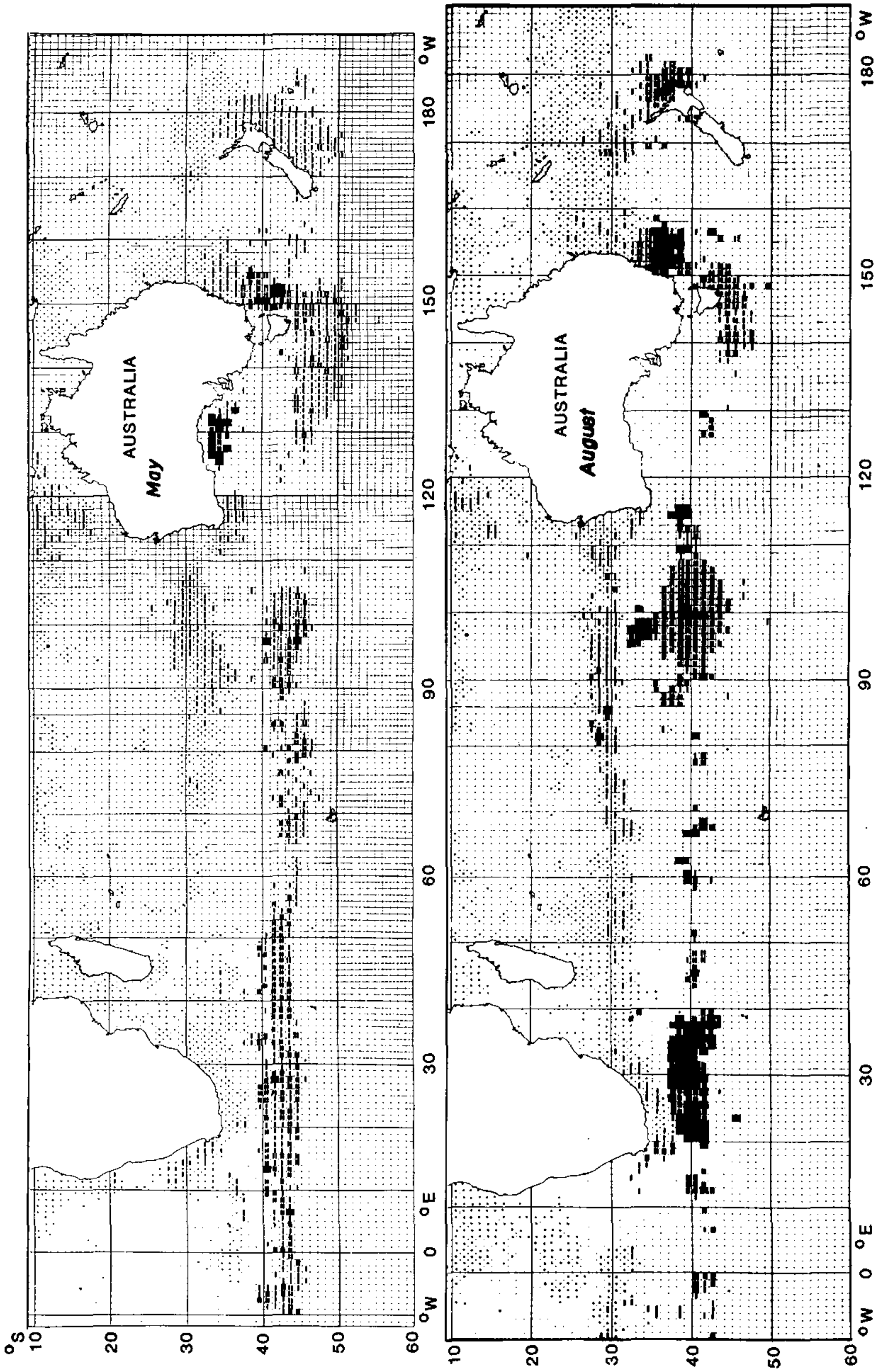
mainly in winter. Incidentally, in Australia the fishing of the southern bluefin when it began (in the 1950's to the early 1960's) was mainly trolling but, since the latter half of the 1960's when live-bait-and-pole fishing was introduced, it is reported that the catches were almost exclusively by this method (Hynd and Murphy 1976).

The main longline fishing grounds extend from 10°W to 170°W. Figure 20 shows the distribution of the hook rate (the number of individual fish for a unit of hooks, expressed as a percentage) for each 1° square according to the average figures for six years from 1967 to 1972. In order to deal with all four seasons, the figures for May, August, November and February have been chosen. As can be seen from the figures, the operations are conducted in some sea areas all the year round and there is no interval between the fishing seasons. Unlike the distribution in the areas where the species were caught, as indicated by Fig. 14, the centrepoint of the fishing ground is shifted towards the south, and several important fishing grounds are distributed at some distance from each other. In May all the fishing grounds are located in the south, in a belt south of 40°S from the Indian Ocean to the Atlantic. A dense fishing area is observed in the vicinity of 40°S, north east of Tasmania. There is a fishing ground with a high hook rate in South Australian waters. But in the livebait-and-pole fishing ground or its adjacent waters the catch consists mainly of small-sized fish. Thus the catch by longline fishing in that area is small. In addition to these fishing grounds, there are some catches in the fishing grounds east of New Zealand, at 30°S off the west coast of Australia and in the Oka fishing ground.

In August, which is the southern winter, and three months after the above period, the hook rate rises in every fishing ground. Furthermore, their location shifts northward of 40°S. In the east of Australia as well as off New Zealand, the areas of high hook rate shift clearly north of 40°S and their northern limit reaches 34-35°S. In the southwestern part of the Australian fishery, the zone of high hook rate shifts northward towards 30°S; moreover, a considerable catch is taken along the 30°S line. In the central part of the Indian Ocean, north of the Australian fishing grounds and along the 40°S line there are 1° squares of high hook rate. Further west, in the area off the south coast of South Africa an excellent fishing ground is located along 40°S; it has a width of approximately 5° and shows a very high rate of productivity as compared with the other fishing grounds. In comparison with the situation in May, every fishing ground appears to be more intensive in August.

In November, fishing grounds east of the Australian coast and east of New Zealand become less productive, and the catches in that region are limited to the south of Tasmania. On the other hand, in the region southwest of Australia the fishing grounds shift further north in comparison with August and the fishing stations range from 45°S to about 10°S in the Oka fishing grounds. To the south of 40°S the fishing ground stretches westward; and the fishing ground off the south coast of South Africa stretches eastward so that the fishing grounds border on each other. This season is early summer in the Southern Hemisphere and, except in the eastern part of the Indian Ocean, catches are rare north of 40°S.

In February, hook rate rises again south of Tasmania and east of the South Island of N.Z. 1° squares of high hook rate are to be found in the Great Australian Bight, also. This is considered, as already stated, to be an extension of the livebait-and-pole fishing ground. In the fishing grounds west of Australia, the central


AUSTRALIA
May
AUSTRALIA
August
°W 180 150 120 90 60 30 0 °E °W
°S 10 20 30 40 50 60

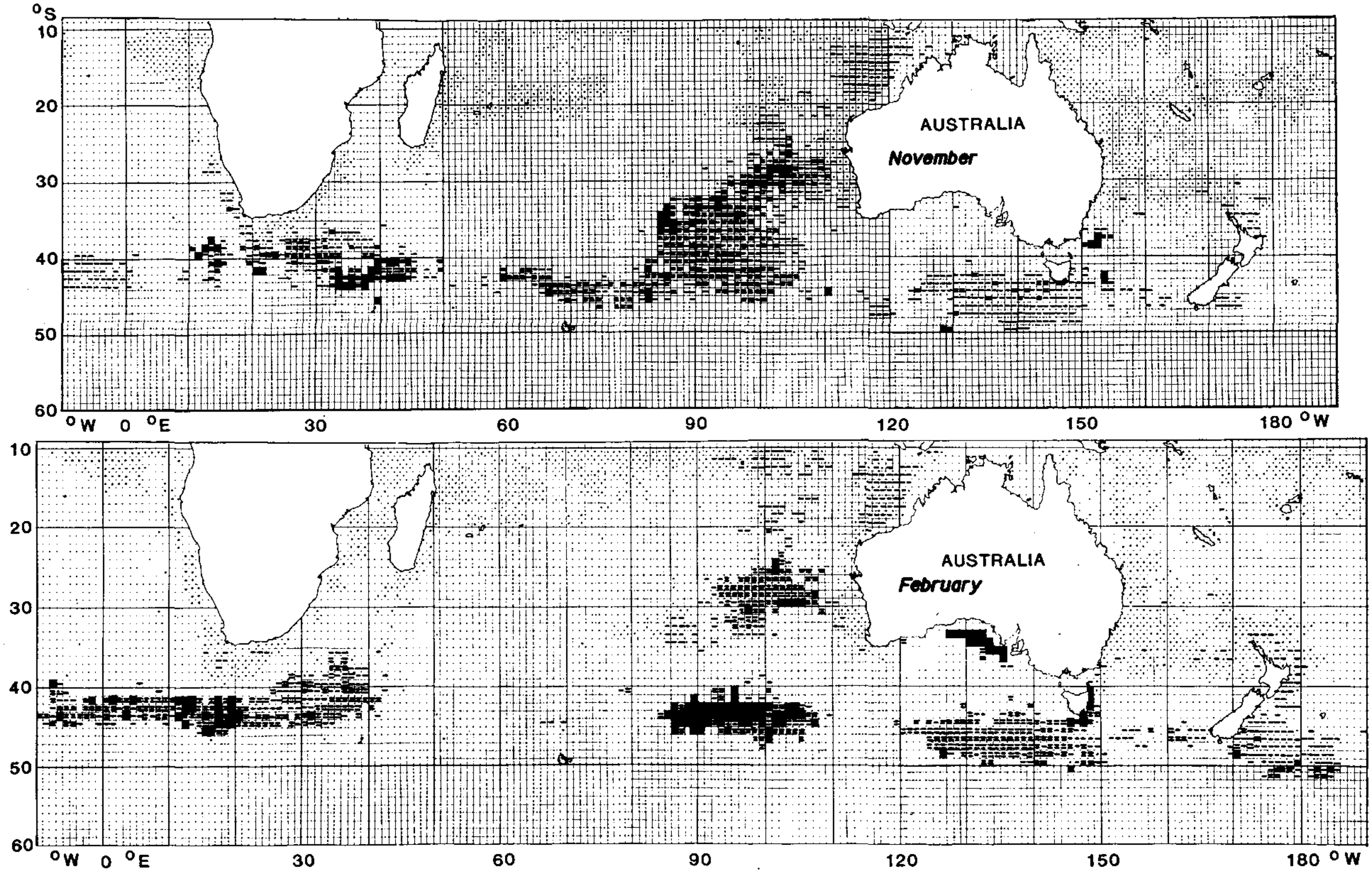


Fig. 20. Distribution of hook rate in the longline fishing grounds of southern bluefin (average for period 1967-1972)

no catch under 1% 1-2% over 2%

part is shifted south of 40°S, and the area within 30-40° which was part of the fishing grounds in November becomes deserted. In the area south of South Africa the central region of the fishing ground is shifted west of 20°E in contrast with the conditions in November. As a result, the catches in the central part of the Indian Ocean become smaller.

As described above, each of the fishing grounds of the longline fishery shows a clear pattern of expansion and contraction in north-south and east-west dimensions, which is considered to reflect the seasonal migrations of southern bluefin schools. When the time interval between the peak fishing periods in each of these fishing grounds is taken into account, it is considered that the fish groups which appear in each of these fishing grounds are closely related. When the 1° squares in the above longline fishing grounds are grouped together, and the average values of the hook rate in these fishing grounds are worked out, their changes for each month are as indicated in Fig. 21A-D. In recent years in the Oka and Oki fishing grounds, west of Australia, the fishery for southern bluefin has rarely been monitored. But when the average fishing results are examined for the period from 1952 to 1961 (Mimura and Warashina 1962, Fig. 21A,B) in each of the fishing grounds the peak of the average hook rate is observed around September-October and January-February. Moreover, about the middle of the fishing season the area where the fish are caught seems to expand in both of the fishing grounds.

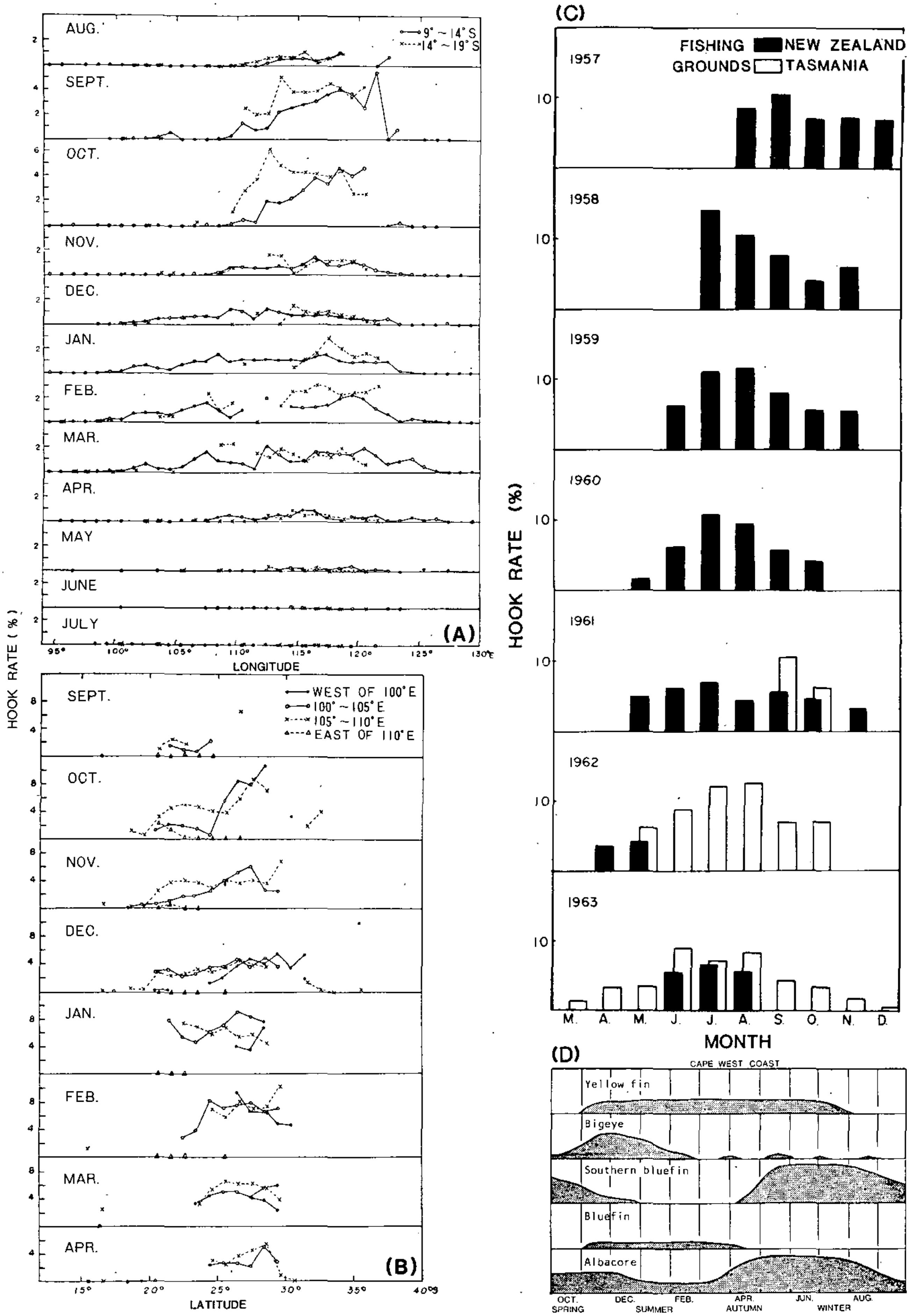
The monthly hook rate for Tasmanian and New Zealand waters for the period from 1957 to 1963 is given in Fig. 21C (Shingu 1965). The range of the operational months varies from year to year, but June-September is the period of intensive operations. In other words, it is the period when the fishing ground is shifted to its furthest north.

The longline fishing grounds off the coast of South Africa will be discussed later. Here the monthly change of hook rate in the coastal area of Cape Town will be examined. Little information is obtainable from the data on longline fishing. Figure 21D has been prepared by Talbot and Penrith (1968) on the basis of their experimental survey of longline fishing during 1960-1963, and shows monthly hook rates of five species of tuna. It shows that the southern bluefin is caught on the coast off Cape Town between April and December, with a maximum hook rate from May to August. This change is similar to the seasonal change of hook rate observed in the Tasmanian and New Zealand fishing grounds, and the fishing grounds south of 40°S are seen to be similar in many respects.

(ii) Changes in body length frequency of the catch with sea area, year and season. First, the change in the body length frequency of the catch due to differences in the fishing methods will be examined. Then the change in the body length frequency due to the differences in fishing grounds will be examined.

The body length frequencies of the catches in the three Australian coastal fishing grounds are shown in Fig. 22 (Robins 1963). The area where the smallest southern bluefin tuna are caught by both the livebait-and-pole and longline methods is on the Albany coast of Western Australia.

Fig. 21. Changes in hook rate.
(A) Southern bluefin, Oka grounds (Mimura and Warashina 1962);
(B) southern bluefin, Oki grounds (Mimura and Warashina 1962);
(C) Southern bluefin, New Zealand and Tasmanian grounds (Shingu 1965);
(D) Tuna species, Cape Town (Talbot and Penrith 1964)


(A)
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
9° ~ 14° S
14° ~ 19° S
LONGITUDE
HOOK RATE (%)
(B)
WEST OF 100°E
100° ~ 105° E
105° ~ 110° E
EAST OF 110° E
LATITUDE
(C)
FISHING GROUNDS
NEW ZEALAND
TASMANIA
1957
1958
1959
1960
1961
1962
1963
HOOK RATE (%)
MONTH
M. A. M. J. J. A. S. O. N. D.
(D)
CAPE WEST COAST
Yellow fin
Bigeye
Southern bluefin
Bluefin
Albacore
OCT. SPRING
DEC. SUMMER
FEB.
APR. AUTUMN
JUN. WINTER
AUG.

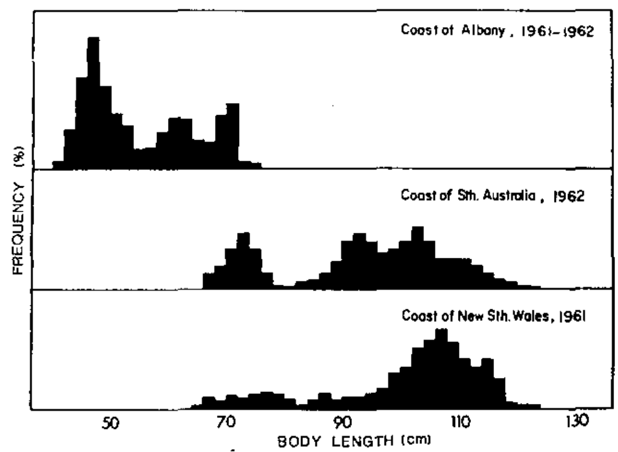


Fig. 22. Body length frequency of southern bluefin in Australian coastal fishing grounds

The range of the body length of the cathes there is 40-75 cm (1.5-3.0 years of age) but fish under 60 cm are prevalent. Individuals in the catch of the South Australian and the N.S.W. coastal fishing grounds range from 60 cm to 120 cm (2.3-5.5 years of age) but, in the case shown in Fig. 22, the percentage of smaller fish is larger in the South Australian coastal fishing grounds. Since these two grounds are the most important to Australian fishermen, 2-5 year old southern bluefin are the main component of the catch. Figure 23 (Shingu 1970) shows the longline fishery for the area from Australia to the areas offshore of South Africa broken down into blocks of 10° of latitude, by an appropriate longitudinal dimension. The dotted line marking 130 cm body length in the illustration indicates the approximate border line between adult and immature fish.

In the Oka and Oki fishing grounds (A and B in the figure) west of Australia, individuals under 130 cm rarely occur. In these two fishing grounds, the proportion of large-size individuals is greater in the former and the position of the mode of body length frequency is around 160 cm, but in the latter the mode in body length frequency is approximately 150 cm. Thus, even though the individuals in these areas are adults, in the latter (Oki) smaller-sized ones are predominant. In the sea areas between 30-40°S off the Australian coast and east of New Zealand, immatures as well as adults are caught in about the same proportion (C and D in the figure). The lower limit of the body length is around 80-90 cm which coincides approximately with the body length frequency in the catch of the livebait-and-pole fishing grounds. In the area south of 40°S, which extends from south of Tasmania to the central part of the Indian Ocean (mainly the West Wind Drift), the range of body length of the catch is the same as in C and D, but the proportion of individuals over 130 cm is larger and the adults constitute the main body of the catch (E, F, G in the figure). This tendency is more conspicuous on the western side of the area. In South African waters, data for the area south of Madagascar (H) and the area southwest of Cape Town (J) are given. Body length frequencies for these two areas are somewhat similar but in the former individuals over 130 cm constitute the majority, and in the latter those under 130 cm constitute the majority. The Cape Town waters are furthest from Australia geographically but the body length frequency there is rather close to that shown in C and D.

The body length frequency in the catch differs not only from sea area to sea area but also from season to season.

On the Albany coast an experimental fishing operation was conducted between 3rd May and 4th July 1962 at intervals of about one week. A series of body length frequencies obtained in this experiment appears in Fig. 24. The range of the body length of the catch is 50 to 80 cm. In the period to the beginning of June two groups of fish with modes in body length frequency at 65 cm and 75 cm respectively are found. After this the larger sized group diminishes and in early July only the group of

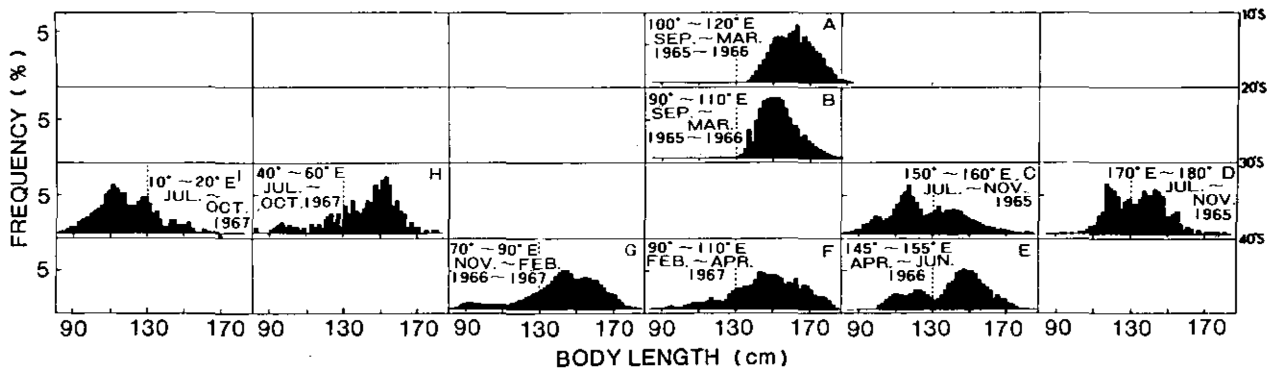


Fig. 23. Body length frequency of southern bluefin tuna caught in the longline fishing grounds, classed by different fishing grounds

A: Oka fishing ground; B: Oki fishing ground
C: Tasmanian fishing ground (north of 40°S)
D: New Zealand fishing ground (north of 40°S)
E: Tasmanian fishing ground (south of 40°S)
F,G: West Wind Drift
H: Sea area south of Madagascar
I: Sea area west of Cape Town

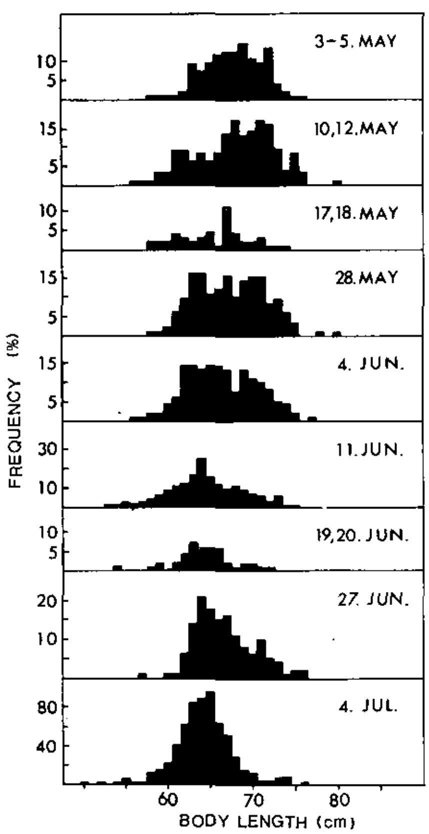


Fig. 24. Seasonal change of body length frequency of southern bluefin tuna on the Western Australian coast (Hynd 1965)

small-sized fish about 65 cm is found. This reflects, probably, the migration of a group of large specimens from the fishing grounds (Hynd 1965).

Figure 25 (left) shows length-frequency distributions of South Australian southern bluefin for four periods (CSIRO Div. Fish. Oceanogr. 1963). In the period from 28 January to 17 March, three groups, i.e. 60-80 cm body length (mainly 2 years old group), 85-100 cm (mainly 3 years old group) and 100-115 cm (mainly 4 years old group) are to be found. According to the same report, among each of the age groups, a further three groups consisting mainly of the individuals with body length marked by arrows in the figure can be distinguished. After the middle of March, the proportion of those over 80 cm in the catch falls conspicuously. Similar information for N.S.W. fish for the period 3 September to 21 December 1962 is presented in Fig. 25 (right). The main body of the catch in the first half of this period consisted of the 3 year old group with a mode of 80-90 cm. From the end of

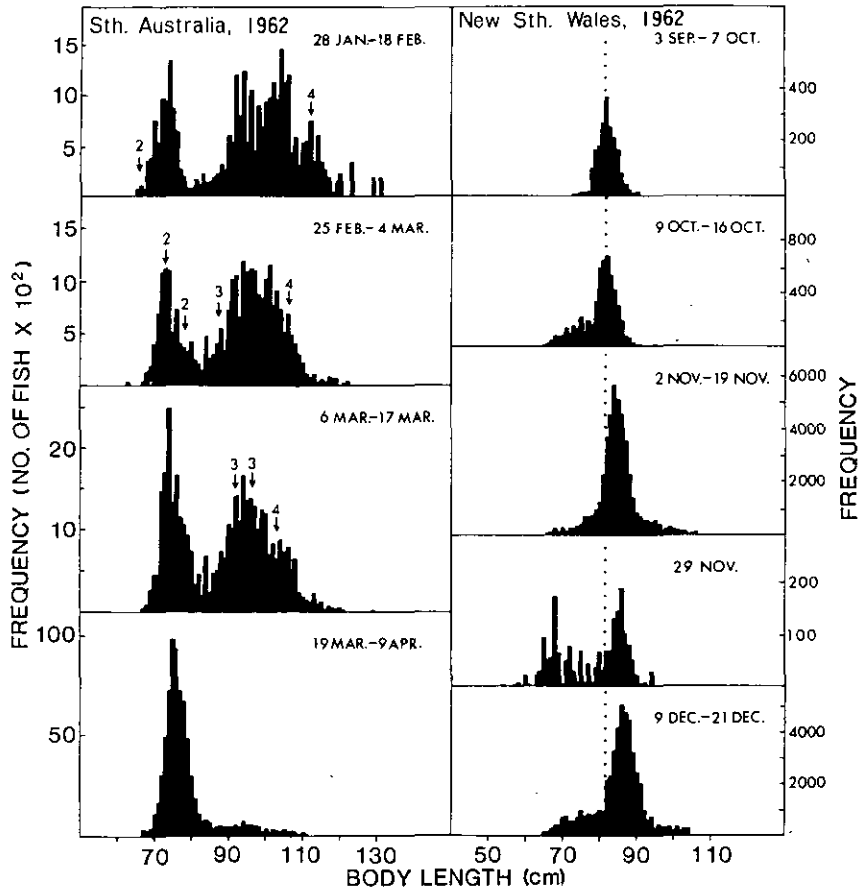


Fig. 25. Seasonal change of body length frequency of southern bluefin on the coast of South Australia and N.S.W.

November some individuals under 80 cm were also caught. In the fishing grounds in Western Australia and South Australia, schools of large-sized fish seem to disappear from the fishing ground with the change of the fishing season. But there is a suggestion that schools of small fish are recruited in the latter half of the fishing season. It is considered that the school of 80-90 cm individuals is the same school of 2 year old fish which was the object of fishing earlier on the South Australian coast (CSIRO Div. Fish. Oceanogr. 1963). On the other hand, the seasonal change of body length frequency indicates that the school of over 80 cm fish, which constituted one of the chief groups in South Australian waters, does not seem to have moved either east or west in large numbers.

Figure 26 shows the length-frequency relationships for fish caught by long-line in the Oka and Oki fishing grounds (Shingu 1970). The data are based on the information obtained from the surveys of the Public Agencies vessels (vessels belonging to the Fisheries Research Laboratories and to the Fisheries High Schools) in the period from August 1961 to April 1962. These data were intended for examination of the stock composition in both the fishing grounds and the hook rate for each 2 cm in body length has been used. A fairly distinct monthly change in body length frequency can be observed in both fishing grounds. In the Oka fishing grounds schools of individuals under 140 cm can hardly be found; but in the Oki fishing grounds they do occur during certain months. The hook rate by body length is

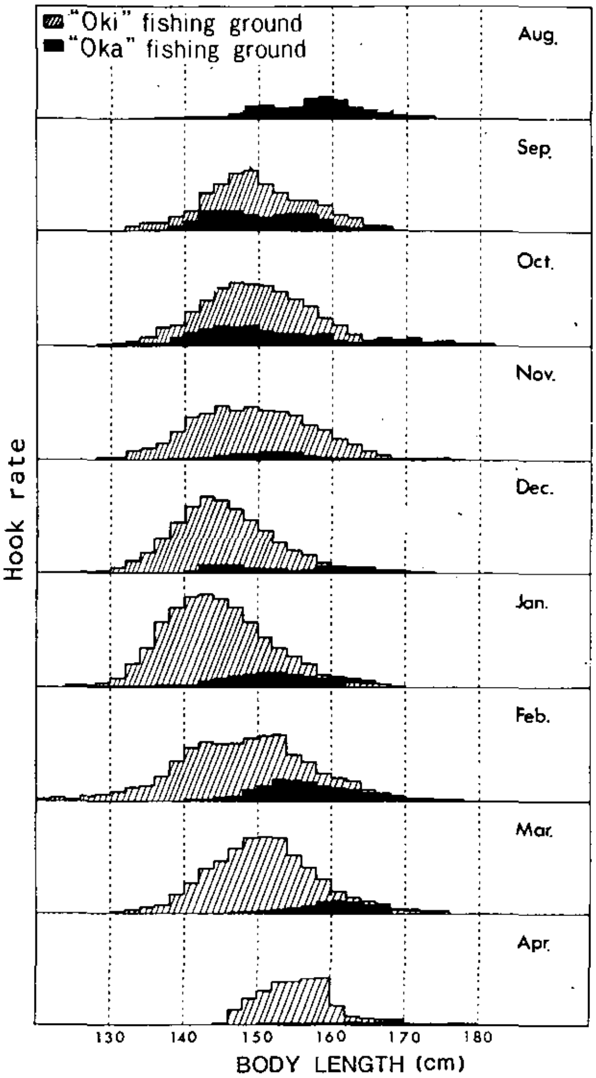
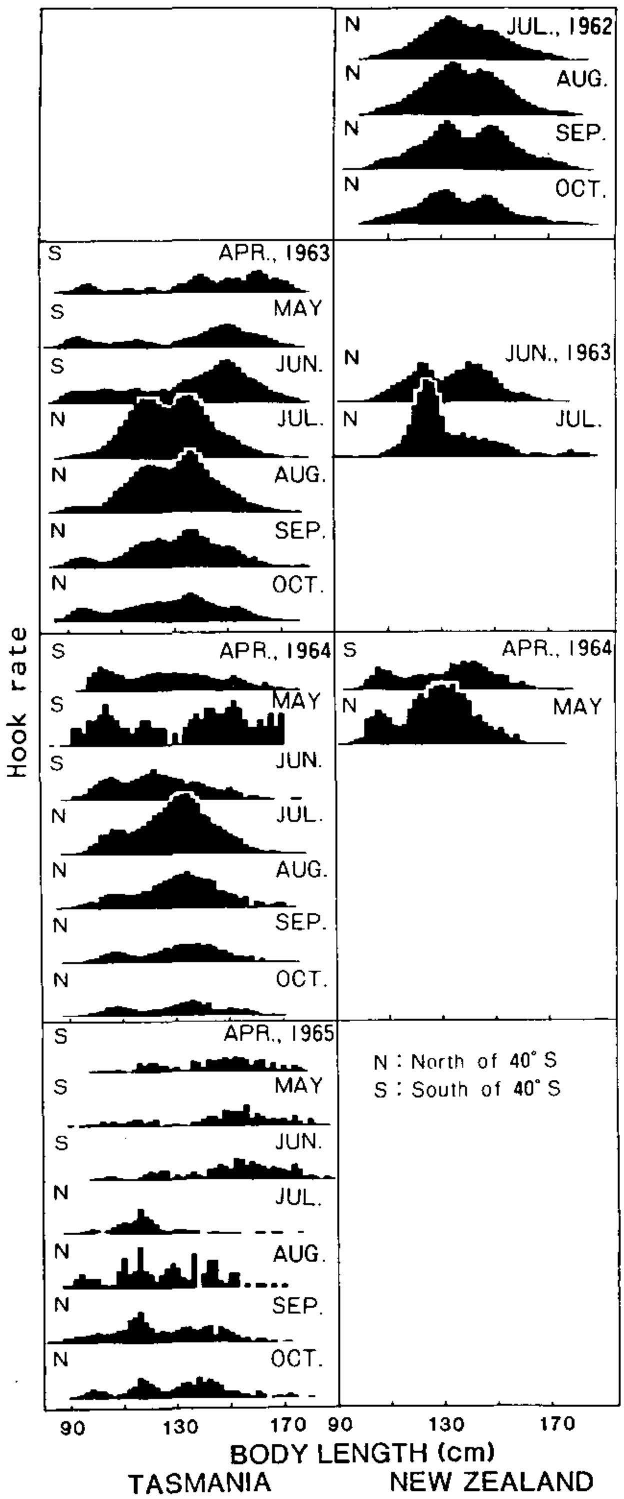


Fig. 26. Monthly change in hook rate of southern bluefin classed by body length for the Oka fishing ground (dark area) and the Oki fishing ground (shaded area)

conspicuously higher in the Oki fishing ground. This trend becomes more conspicuous during the latter half of the fishing season. Judging from the shift of the mode with the change of season, the migration of the 140-150 cm group to these fishing grounds seems to reach its height in the middle of the fishing season. The 150-160 cm group seem to be recruited about the beginning and the end of the fishing season. The migration from the fishing grounds appears to begin with schools of small fish.

In the case of the longline fishing grounds east of Australia and east of New Zealand, there is a difference between the body length frequency in the catch from north of 40°S and that from south of 40°S (Shingu 1965). Therefore a distinction between the north and the south has been made (Shingu 1967, Fig. 27). Unlike the Oka and Oki fishing grounds, on the Pacific side the catches consist of a wide range of body lengths from 80 cm to 180 cm, and in the catches from each of the other two fishing grounds two to four modes are found in the body length frequency. As stated above, these fishing grounds expand northward from south of 40°S during April-May, and reach their northern limit in August and September. During this period a conspicuous difference in body length frequency is observed between the fish from the south and the north of 40°S. In other words, in the catches south of 40°S the modes of the body length frequency are in the vicinity of 100 cm and 150 cm, while in the catches to the north the mode is found to be between the two above figures. Judging from this difference, it appears that not all the fish in the south migrate northward, but only fish of a particular body length. The fact that the modes show little monthly change, unlike those of the Oka and Oki grounds, also suggests that only groups of particular body lengths go northward. Nevertheless, while this relationship between south and north remains unchanged, the dominant body length seems to differ from year to year.

The longline fishing ground off South Africa is the most recently exploited southern bluefin fishing ground. As will be discussed later, the central part of this fishing ground is closed seasonally due to the voluntary restrictions on the part of the tuna fishery interests. It is, therefore, difficult to obtain data for the whole year. Figure 28 shows the monthly body length frequency for the period from February to October 1974 in this



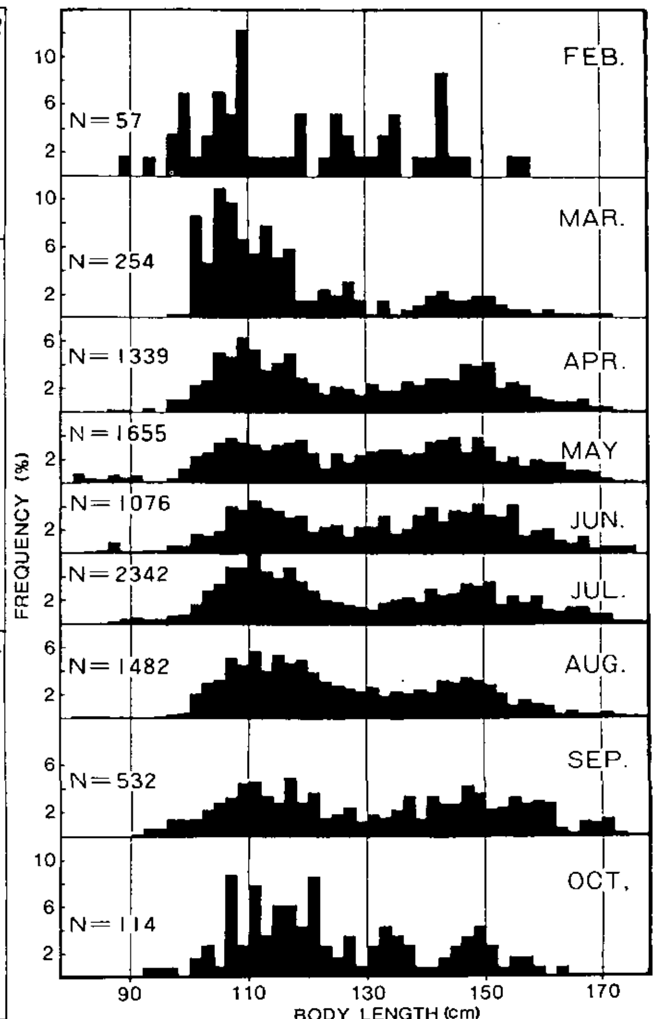


Fig. 28 (above). Monthly change of body length frequency of southern bluefin in the catch in the fishing grounds off South Africa

Fig. 27 (left). Monthly and yearly changes of hook rate of southern bluefin, classed by body length, in catches on Tasmanian and New Zealand fishing grounds

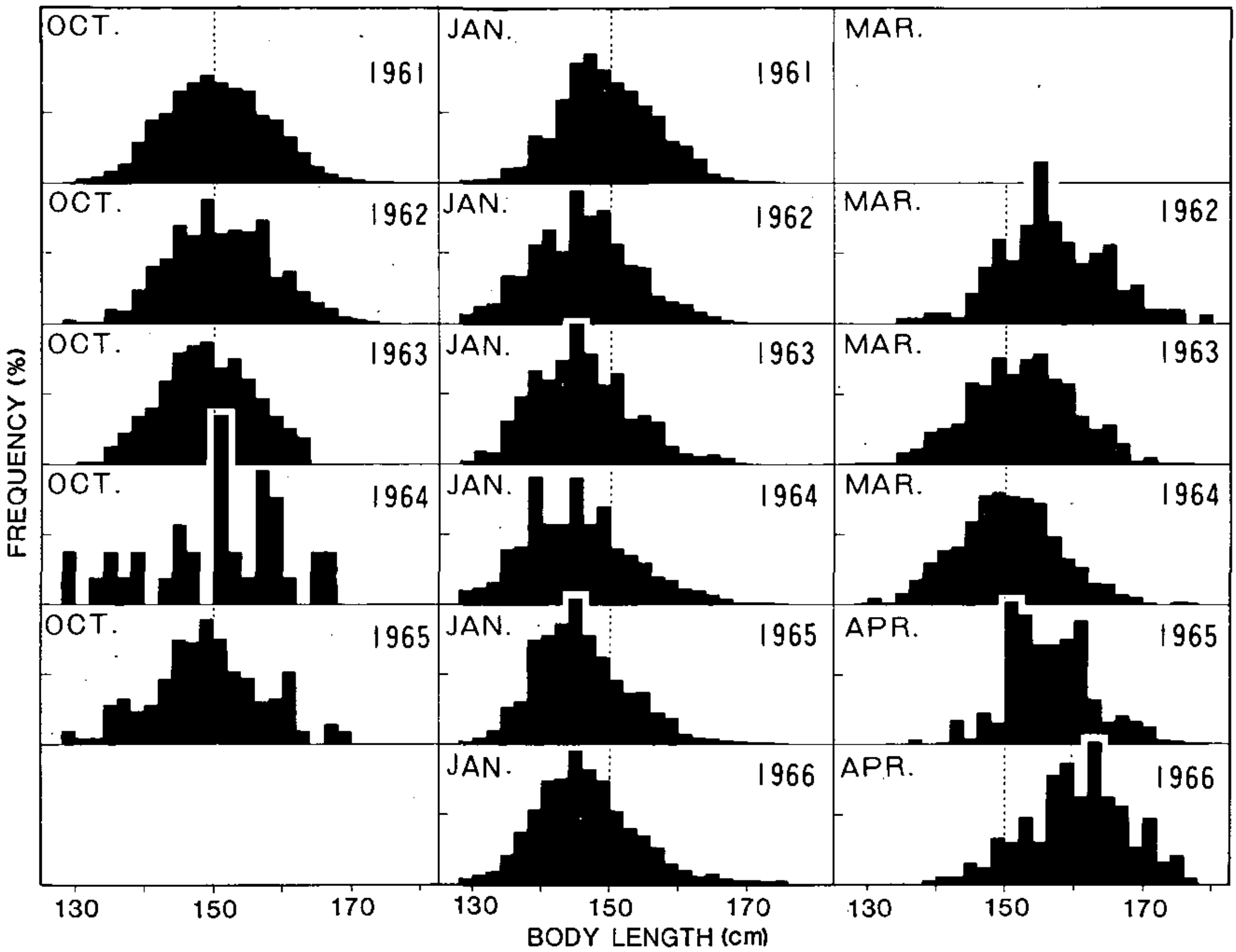


Fig. 29. Yearly change of body length frequency of southern bluefin in the Oki fishing ground in October, January and March/April

fishing ground. The area of the fishing operation is mainly to the south of 40°S but the composition of the catch for the whole area produces a pattern which is similar to the combination of two body length frequencies for the sea areas H and I in Fig. 23 which cover the area to the north of those fishing grounds. In the group of larger fish, the mode in each month is about 150 cm. In the group of smaller fish, the mode is about 110 cm. But, as the year progresses, the model length increases. During the nine months from February to October, it appears that the proportion of smaller fish is higher in the beginning and at the end, and the larger fish group seem to increase somewhat during May-June.

The above represents the change in body length frequency based on the different sea areas and seasons. Below a few examples of long term change of the body length frequency in the same fishing grounds will be given. The surface fishing grounds in Australia will be dealt with in a later chapter.

It is known for the Oka and Oki fishing grounds that there are no large changes in body length frequency from one fishing season to the next (Miura 1962; Shingu 1965). Nevertheless, although average body length frequency remains similar year to year, it is possible that there may be differences from year to year when seasonal changes are considered. Therefore, the Oki fishing ground, for which data are comparatively abundant, has been chosen and the yearly changes of body length frequencies for three months, i.e. October (beginning of the fishing season when the proportion of large fish is high), January (the middle of the fishing season when the proportion of small fish becomes higher) and March or April (the end of the fishing season when the proportion of large fish becomes higher again (see Fig. 26) will be given (Fig. 29). The data cover six years from 1961 to 1966. Figure 29 shows that the mode in October every year is 150 cm body length. This mode moves to the vicinity of 145 cm in the middle of the fishing season, which suggests that at this time every year adults of relatively small size migrate to this area. And by the end of the fishing season, this mode moves to 150 cm or larger. This indicates that southern bluefin migrating for spawning are of the same size each year and the same seasonal change is repeated.

In the case of the Tasmanian and New Zealand fishing grounds, there is no seasonal change of the position of mode in the body length frequency. Therefore all data which were obtained for the period 1957-1965 in the area north of 40°S in these two fishing grounds have been summed for each year (Fig. 30). As can be seen from the

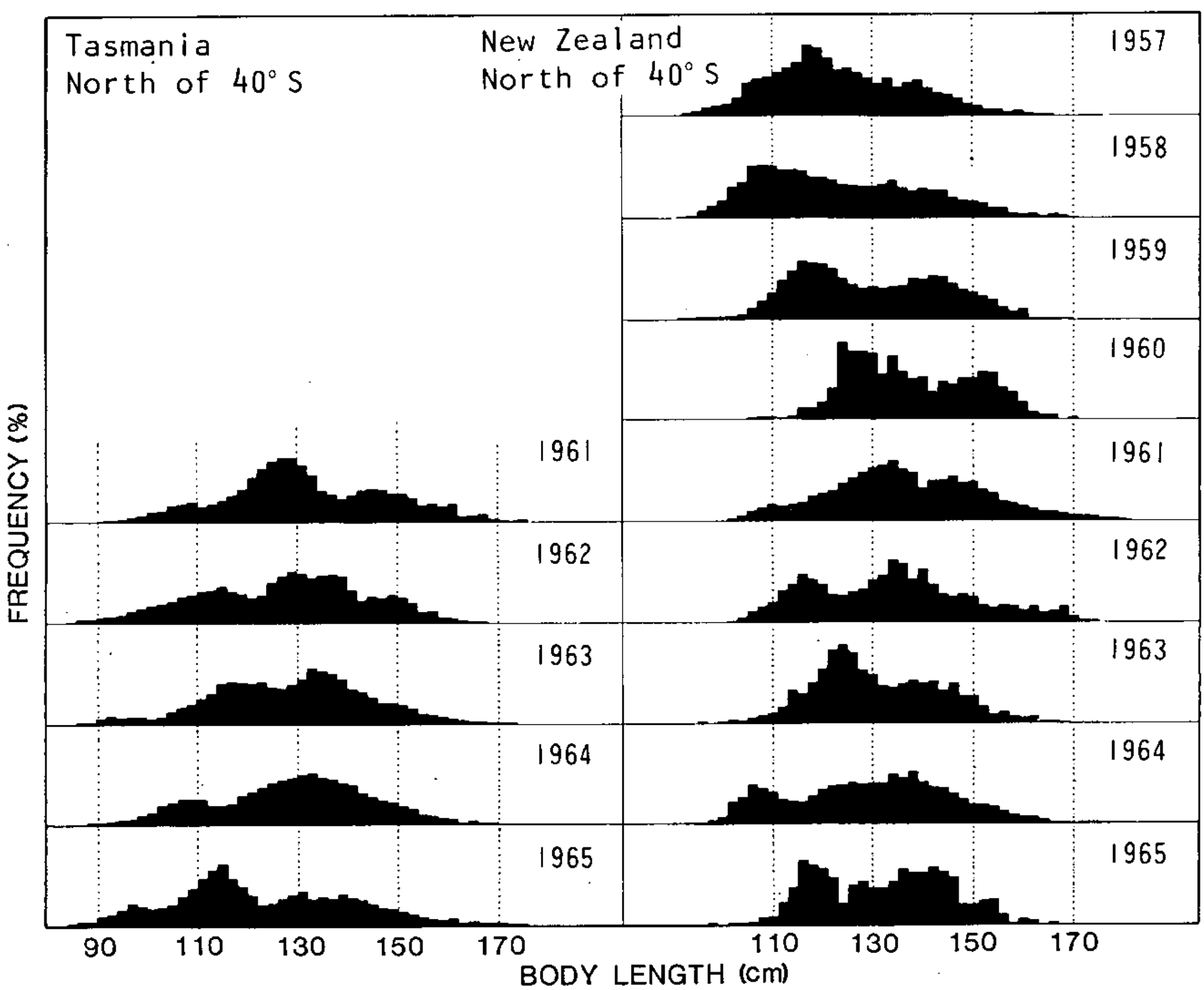


Fig. 30. Yearly change of body length frequency of southern bluefin in the Tasmanian and New Zealand fishing grounds

figure, in each of the fishing grounds the body length frequency shows a conspicuous change from year to year. The change is especially conspicuous in the small fish group with body length under 130 cm. The positions of the modes and their yearly changes appear quite similar to each other in these two fishing grounds. For instance, after a fish group occurs in the vicinity of 110 cm, the group seems to remain for 3 to 4 years as a noticeable group. If there is any such regularity, it may serve as a yardstick to forecast fishing prospects. When the seasonal and yearly changes of body length frequencies in these two fishing grounds are taken into consideration collectively, it is to be concluded that the change in the composition of the fish group must take place in the period when the fishing grounds are south of 40°S and the change must be completed before the figh migrate northwards.

(iii) Age composition in each fishing ground. It is natural that age composition is correlated with body length frequency. Here, for the purpose of estimating average age composition in each of the fishing grounds, the age composition has been computed from equation (1) which formulates the relationship between body length and age on the basis of body length frequency for each fishing ground (Fig. 31) for the period from 1952 to 1966. The results have been arranged in order of increasing age.

Age of fish from the different grounds range from 1 to 12 years. The youngest are caught in the surface fishery off Albany in Western Australia where only 1 and 2 year old fish are found. This fishery has the smallest range of ages. On the coasts of N.S.W. and S.A. (Port Lincoln), southern bluefin of 2 to 5 years of age are caught, the most prevalent age group being 1 or 2 years older than that in Western Australia. After the fish are 5 years old the chance of their being caught by surface fishermen seems to decrease significantly. In the longline fishing grounds, the fish from west of Cape Town, in Tasmania and in New Zealand are relatively young, ranging from 4 to 8 years with most about 5 and 6 years. In the Oka and Oki fishing grounds, the catches consist of fish over

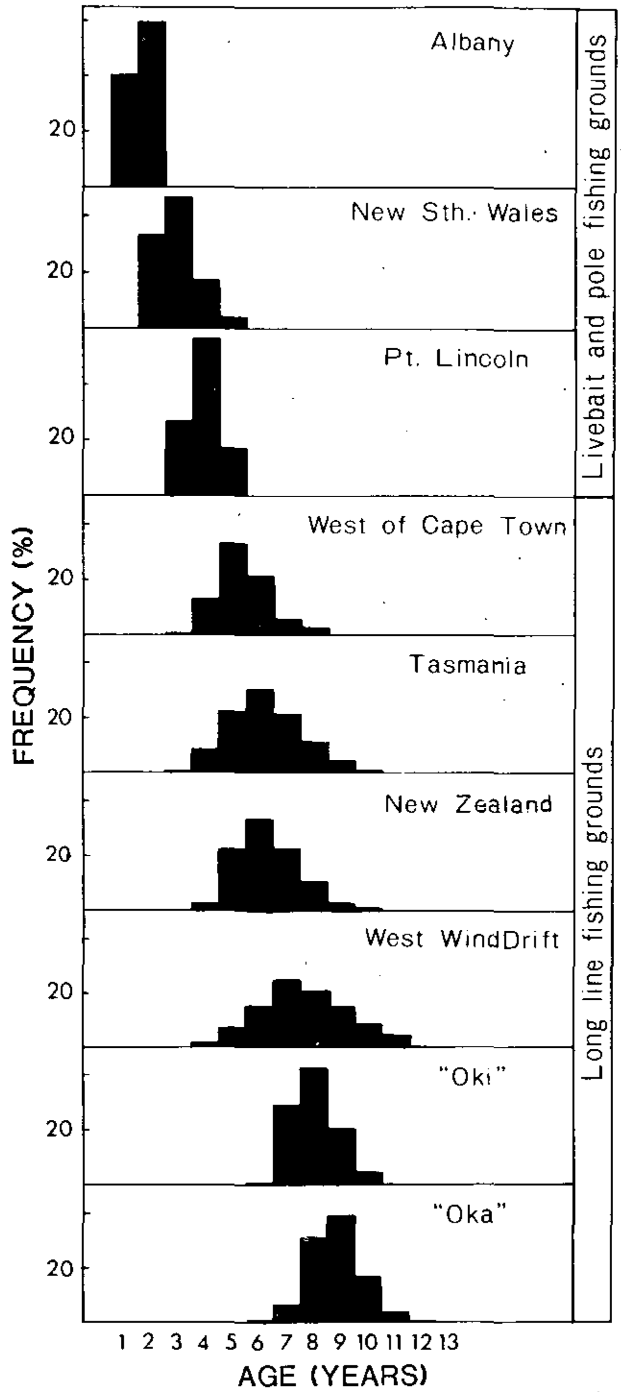


Fig. 31. Age composition of southern bluefin in each of the fishing grounds

7 years old. The prevalent age is highest in the Oka fishing ground (9 years); in the Oki fishing ground it is 8, and the catch rarely contains individuals over 12 years of age. As already mentioned, the West Wind Drift is the distributing area of the feeding adults and immatures. Consequently, the age frequency diagram, as to be expected, shows a wide range of ages, and the age composition there resembles the combined pattern of all the longline fishing grounds.

As discussed above, the age composition of southern bluefin for each of the fishing grounds can be divided into four major groups as follows: The group of under 4 years (in the surface fishery grounds); the group consisting of younger individuals in the longline fishing grounds as in the west of Cape Town, the Tasmanian and the New Zealand fishing grounds; the group in the West Wind Drift which represents an intermediate type; and the group in the Oka and the Oki grounds where the oldest age group is found.

(iv) Identification of genealogical groups. The study of genealogical groups is an important subject for researchers of marine life and of fisheries resources; however, the theory and its methods seems to be varied. In this paper the question of methodology will not be dealt with. The distribution and seasonal changes of southern bluefin are relatively distinct, and conditions seem to be favourable for an analysis of the various biological characteristics of the species.

In the following discussion we shall sum up the results of a comparative study of the external morphology and of tagging tests which have been carried out on southern bluefin. Then, taking into account the biological characteristics hitherto discussed, we shall study the migration pattern of the southern bluefin.

Biometric data for the study of external morphology are available for southern bluefin delivered in 1962 at the Yaizu fish markets and for those caught by experimental longline fishing operations carried out by R.V. *Shoyo Maru* in 1959 in the sea areas south of Australia. The sea areas where the data were collected consisted of the five districts indicated in Fig. 32. (The legend in each district denotes, from top to bottom, the designation of the area; the number of fish measured; the year of collection; the months of collection.) As the ranges of body length differ from area to area, the individual fish measured were limited to those between 130 and 170 cm body length, which were found commonly in all areas. Seven measurements were selected including those which are usually chosen in the studies of other species of tuna. The seven items are illustrated in Fig. 32.

The individuals delivered at the fish market have the internal organs removed and are frozen, and so it is impossible to tell the sex. The measurements were made after thawing. On the other hand, on research vessels the measurements were made immediately after catching.

In order to compare the relative growth of each part against the fork length, the difference between the regression coefficient and the size of each of the characteristics (modified average value) has been examined by analysis of variance. At the same time the actual differences of the sizes of each character between the sea areas have been compared (Shingu and Warashina 1965). Within the range of 130-170 cm body length, on which the measurements were based, the relative growth of each part was considered to be linear and linearity was not verified.

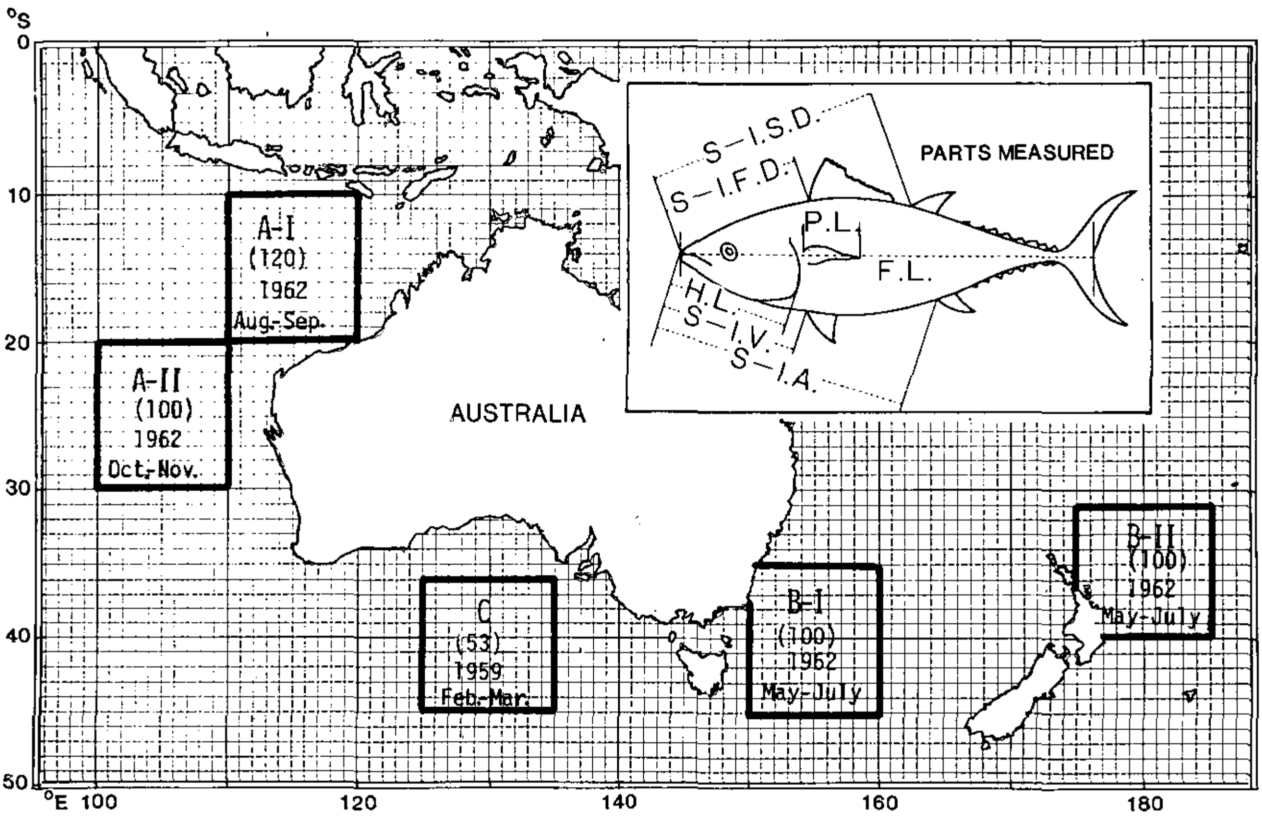


Fig. 32. Schematic presentation of the sea areas where the samples for morphological comparison were caught and the parts on the body measured for comparison

(1) Fork length (F.L.): Snout to the bottom of the tail fork along the median line
(2) Head length (H.L.): Snout to the back edge of operculum
(3) S-I.F.D.: Snout to insertion of first dorsal fin
(4) S-I.V.: Snout to insertion of ventral fin
(6) S-I.A.: Snout to insertion of anal fin
(7) Pectoral fin length (P.L.): Distance from the insertion to the tip.

Table 6 shows the results of the analysis of variance in respect of two combined sea areas out of the five sea areas where the samples were gathered. The table shows that significant differences were extremely scarce, and at the 1% significance level, only S-I.V. in the combination of A-I, A-II was significant. And at the 5% significance level, except the combination of the area C where the measuring standard is different, only H.L. in the combination of A-I, A-II and S-I.S.D. and S-I.A. in the combination of A-I and A-II were significant.

In the combination of sea areas C and other areas, significant differences have been found more frequently than in other combinations. (The description of results of S-I.V. and S.-I.A. is left out for the reasons to be mentioned later.) But they are all significant at the 5% level. Furthermore, the measuring standard is different. While the fish of C district were measured fresh, those from the other sea areas were frozen samples with the internal organs removed from the abdominal section. When these factors are taken into consideration, it is possible that S-I.V. or S-I.A. or the other parts

Table 6. Comparison of characters between different sea areas by variance analysis

Character	Area	A-I / A-II	A-I / B-II	A-I / B-I	A-II / B-II	A-II / B-I	B-II / B-I	A-I / C	A-II / C	B-II / C	B-I / C
H.L.	b	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	a	-	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
S-I.F.D.	b	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.	N.S.
	a	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-	*	N.S.
S-I.V.	b	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-	-	-	-
	a	**	N.S.	N.S.	N.S.	N.S.	N.S.	-	-	-	-
S-I.S.D.	b	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	a	N.S.	N.S.	*	N.S.	N.S.	N.S.	N.S.	*	N.S.	*
S-I.A.	b	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-	-	-	-
	a	N.S.	N.S.	*	N.S.	N.S.	N.S.	-	-	-	-
P.L.	b	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	a	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.	*	N.S.

* : significant at 5% level
** : significant at 1% level
N.S.: no significant difference
b : with regression coefficient
a : with modified average value

which may be affected by the above treatment would show some difference.

No significant differences are seen in respect of particular characters. Moreover, no special relationship is to be found between the degree of significance and the geographical distance between the sea areas.

Figure 33 examines the change in the size of each of the characters over all of the sea areas. It shows the size of each of the characters in respect of body length 150 cm (medium value in the range of body lengths measured) in each sea area, and their 99% confidence limits. The sea areas in the graph are arranged starting with A-I in order of geographic closeness. Each of the characters does not seem to form a cline in particular areas. The differences between each of them are so small that they all lie within the confidence limits. From these facts, it may be assumed that there is no need to treat the fish groups in these different sample areas separately from each other (Shingu and Warashina 1965).

In 1966, external morphology data were gathered for 70 southern bluefin caught by longline fishing west of Cape Town (examination carried out by the public agency vessel *Iwaki Maru*). The range of body lengths (90-170 cm) is different from the above and the results have been compared with those from the Tasmanian area (B-I) which shows a similar composition. Results

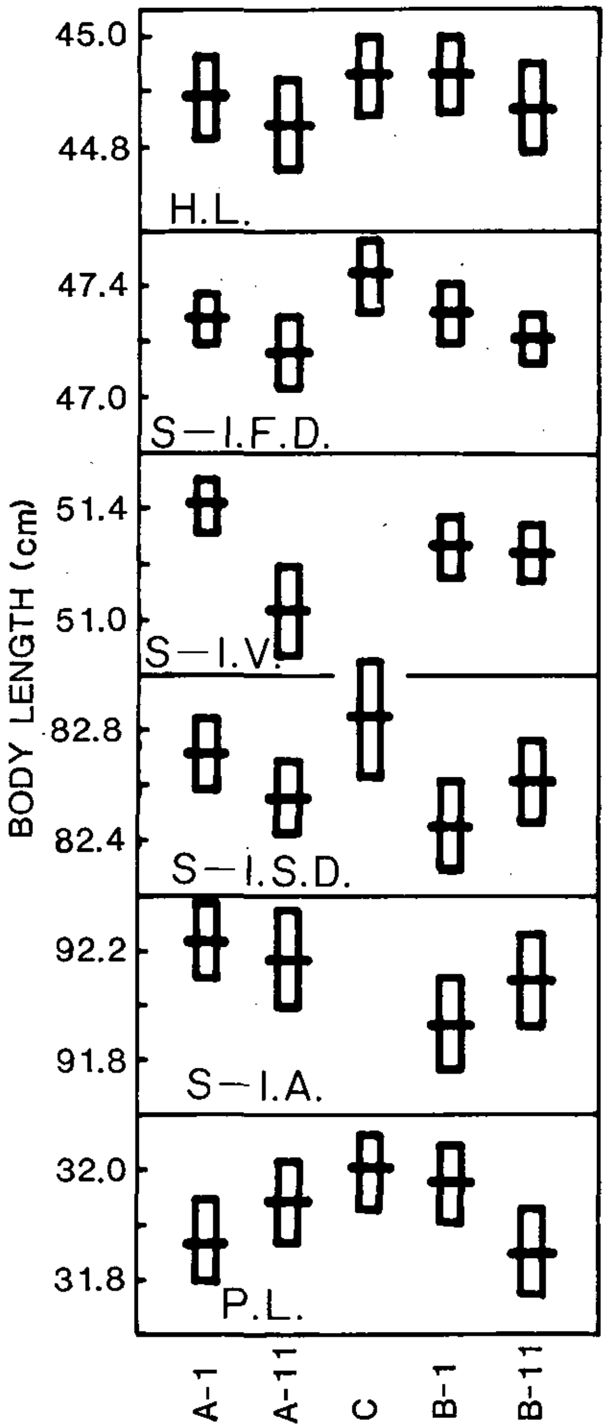


Fig. 33. The size of each of the characters classed by the sea areas (horizontal line, the value at body length 150 cm) and its 99% confidence limit (expressed by the bars over and under the horizontal line)

are shown in Fig. 34. In general, each of the measured values converge along the regression line for the values in B-I area and there is no suggestion of the existence of individuals having widely different morphology. Only in the case of pectoral fin length (P.L.) does the difference between the two appear to become wider in small fish. It may be questioned whether it is right to compare these two groups of fish, in which the range of body lengths was different.

Serventy (1956) compared the morphology of southern bluefin 30-90 cm in length collected in Australian waters, and was able to recognize three groups occurring in the same area. He suggested that fish hatched at different times or in different places would show variety in morphology during their young stages until they attained a certain growth stage.

Tagging experiments have been used as an effective means of keeping track of the movement, migration, mortality rate and so on of various stocks of fish. The usefulness of the technique varies depending upon the purpose of the test. For the purpose of a quantitative analysis of fish groups, this method does not seem to have gone through a thorough examination of the bias or error peculiar to it. It is also important to study whether a particular fishing method is suitable for a tag-test, before the test is carried out. In the longline fishing method, species of comparatively large individuals distributed in the middle layer depth are caught. Therefore the fish are apt to become weak and often they are hooked up dead, and longline fishing is not suitable for tagging experiments. With the species of tuna the fishing methods with actual records of tag-release tests in the past are the surface fisheries such as livebait-and-pole, trolling, round haul net, etc.

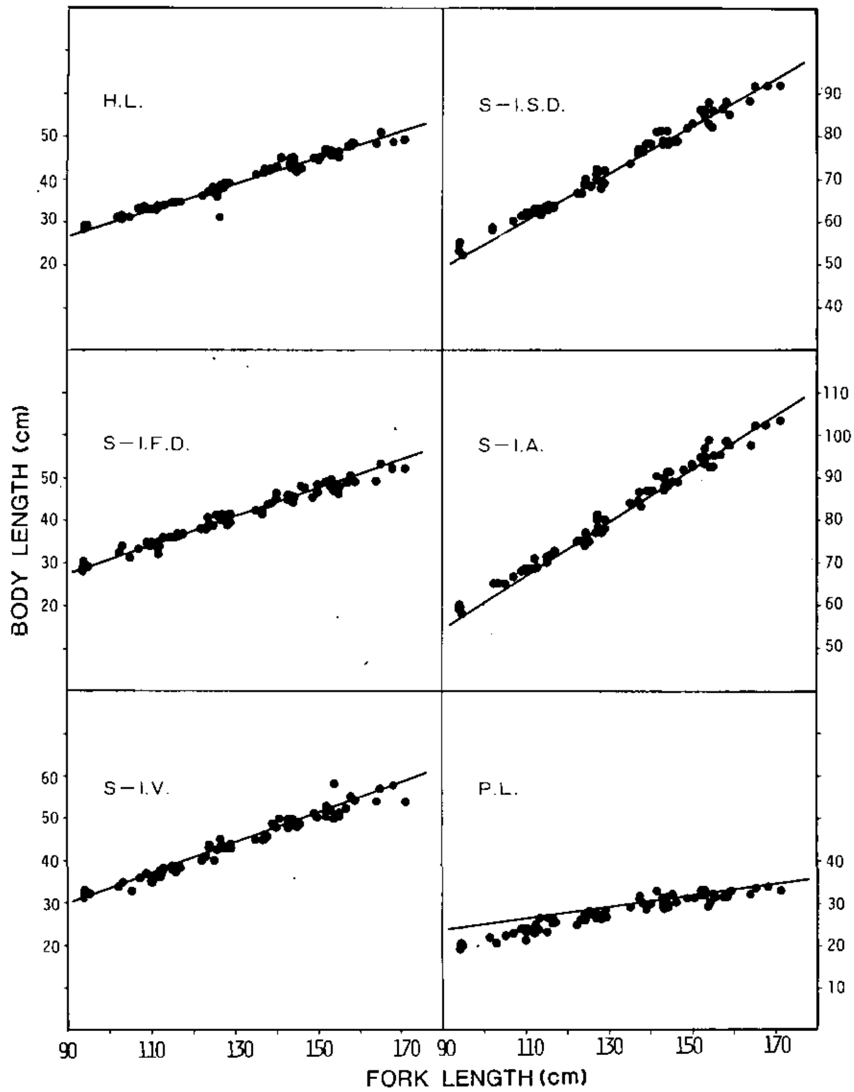


Fig. 34. The size of various characters against body length in southern bluefin caught in the area west of Cape Town (dots). The solid line indicates the regression line obtained for southern bluefin in the Tasmanian sea area

Tagging experiments with southern bluefin have hitherto been carried out exclusively by the Australians. Only very recently, some of the Japanese longline fishermen attempted tagging of small southern bluefin. The results of the test will be observed in the future.

The tag-and-release tests in Australia were started around 1960, and about 50,000 have been released. Those released were mainly individuals caught by livebait-and-pole fishing with ages ranging from 1 to 4 years. The sites of release were the three coastal fishing grounds mentioned earlier. The recapture of the tagged fish is made first by livebait-and-pole fishing. Then after a certain period the tagged fish are caught by the longliners.

Figure 35 shows the situation of recovery of tagged southern bluefin by longline fishing. This illustration gives no information about the size of the recaptured fish or the period between release and recapture but shows only the sites of release and

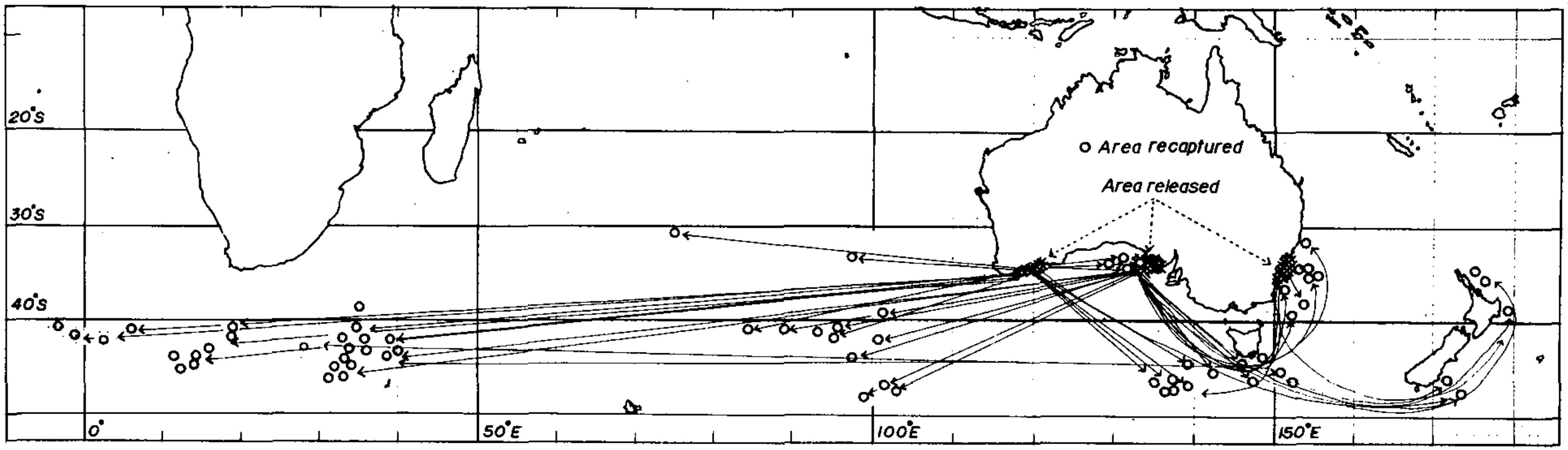


Fig. 35. The locations of recapture of tagged southern bluefin by longline fishing

recapture. Therefore it is not possible to plot their course of movement before recapture. But the scale of their movement can be roughly estimated. The illustration does not show all the cases of recapture. The recapture of about 290 fish by longline fishing had been reported by 1973. The area of the recapture of the tagged fish covers, as indicated by the figure, the area from 1-2°W to the east of New Zealand including almost all the main long-line fishing grounds. In other words, it is known that 1 to 3 year old southern bluefin from Australian waters begin to move in a vast area after some time. Moreover, the sea areas where the tagged fish are caught in a group are the central part of the longline fishing grounds mentioned earlier, which suggests that the southern bluefin in the coastal waters move *en masse* to these areas. So far, no recapture in the spawning grounds has been reported.

The recoveries by livebait-and-pole fishing in Australia are shown in Fig. 36. In two of the three fishing grounds (those in South Australia and N.S.W.) recaptures are made in the same season as the release. But, since those recovered include those released in the other fishing grounds as well as those released in the same fishing ground, it is suggested that there is a migration between fishing grounds and a revisiting by fish after a period of absence. On the other hand, in Western Australian coastal waters, the southern bluefin tuna released after tagging seem to move only in one direction; moreover, the tagged fish released in other fishing grounds are seldom recovered in West Australian waters.

Table 7 shows the same details as Figs 35 and 36 with greater numerical precision. The table shows the period between the release and the recapture of the tagged fish at the site of release (for instance N_1 and N_3 means a period of less than 1 year, over 2 years but less than 3 years, respectively) and also shows

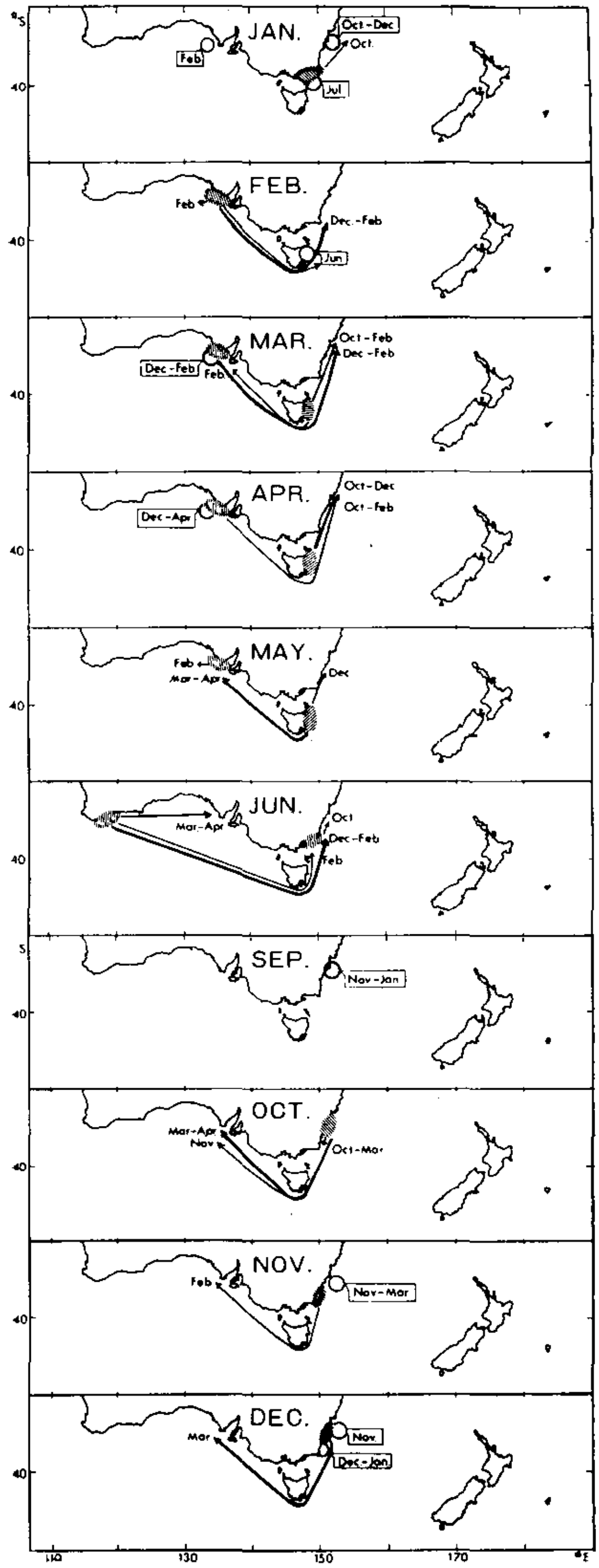


Fig. 36. Recoveries of southern bluefin within a year after tagging along the Australian coast (Data from CSIRO Fish. Field. Bull. 1964-67)
▨ : Area tagged (month of release in capitals)
▬ : Recoveries more than 40 fish
— : Recoveries less than 39 fish
Arrows with month show direction of movement of fish and recovery month.
Circles show that tagged fish were recovered in same area as release.

Table 7. The recoveries of tagged southern bluefin along the Australian coast, classed by the lapse of time between release and recovery as well as by areas of recovery

	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_9	N_{10}	N_{11}
West Australian coast (number of fish released 24 225)											
WA	254	71									
SA	1	172	115	22	2						
EA	1	57	153	12			2				
LT				7	6						
LS			3	2	11	4	2	1			1
LI	2			6	8	13	15		1		1
LP					1	4	2	2		2	
LA					5	2	2	1		1	
South Australian coast (number of fish released 8 791)											
SA	743	164	19	3							
WA	7										
EA	4	158	32	9	7						
LT		15	12	3	5	1					
LS	1	2	3	6	3	2	2	2	2		
LI		4	2	3	13	6		1			
LP			1	7	5	2	6	1	2		
LA		1		1	2						
N.S.W. coast (number of fish released 13 734)											
EA	2805	1335	213	11							
SA	57	42	14								
WA											
LT	1	9	10	10	3	1					
LS	1	3	5	5			1				
LI			2	3							
LP		1	5	4	1	1	1		1		
LA											

WA: West Australian coast - livebait-and-pole
SA: South Australian coast " "
EA: New South Wales coast " "

LT: Tasman Sea - longline fishing
LS: South Australia " "
LI: Indian Ocean " "
LP: Pacific Ocean " "
LA: Atlantic Ocean " "

the locations of recovery. The data are based on release reports for the period from 1959 to 1970 and on recovery reports up to 1973 (from CSIRO Div. Fish. Oceanogr., Australia). The number of tagged fish released is largest on the Western Australian coast (24,225 fish). Of those recaptured, the largest number were recaptured within one year of release and in the same area (254). But, after the second year or in the third year, the number of recoveries in South Australia or in N.S.W. exceeds that in Western Australia. After the third year, no recovery has been reported in the same area as the release. After the fifth year the recovery by livebait-and-pole fishing decreases markedly. On the other hand, recapture by longline fishing begins in the first year, but it is not until the fourth year that longline recoveries become important. Recovery rates seem slightly higher in the Indian Ocean than in other areas, but they appear to be scattered over all of the sea areas. In the past, there have been two cases of recovery after a long period of 11 years. In South Australian waters, 743 out of 8791 released were caught in the same area within a year. Unlike the case of Western Australia, recoveries in the same area are observed up to the fourth year, but their numbers decrease drastically. The recovery in Western Australia of fish released in South Australia is small (7). The number recovered in N.S.W. waters increases in the second year but declines after the third year. The state of recovery by longline fishing is also different from that of fish released on the W.A. coast, and they are caught as early as the second year. They are recovered from various scattered areas, but most often from neighbouring areas. While there are instances of recovery after 9 years, generally speaking the number recovered decreases as time passes. The number of tagged fish released on the N.S.W. coast is second largest after Western Australia (13,734) and most are recaptured in the same area in the first year (2805) or the second (1335). But in the third and fourth year the number decreases markedly. There is a considerable number of cases of their recapture within a year on the South Australian coast; this suggests the rapid movement of fish in a group. No fish released on the N.S.W. coast have been recovered in Western Australia. In the case of those released on the N.S.W. coast, recovery by longline fishing seems to be higher in the neighbouring sea areas.

Summing up the above accounts, it may be said that southern bluefin tuna, which is the main object of the fisheries in each of the coastal fishing grounds of Australia, gather and disperse repeatedly for a year or two in the same fishing grounds. But on the Western Australian coast, in particular, the fish leave almost completely in the second year and never come back. There are comings and goings of southern bluefin between the South Australian and the N.S.W. coasts, but the traffic is rather larger from South Australia to N.S.W. In these fishing grounds, too, at about 3 years, migration from the fishing grounds seems to increase conspicuously. There is no trace of any isolated fish group moving to the Western Australian coast. In about the third year, when the fish are considered to be leaving the coastal area, the number of recoveries by longline fishing begins to increase as recruitment to the longline fishery starts. Soon after they have left the coastal waters they are liable to be recovered in neighbouring areas. But as time passes they scatter over a wider area. The pattern of their scattering is, however, not regular. For instance, those released on the N.S.W. coast are seldom recovered in the Indian or the Atlantic Oceans.

Even though the seasonal movement of the southern bluefin, which is the object of the coastal fishery, to and from the fishing grounds has been known for some time, their actual

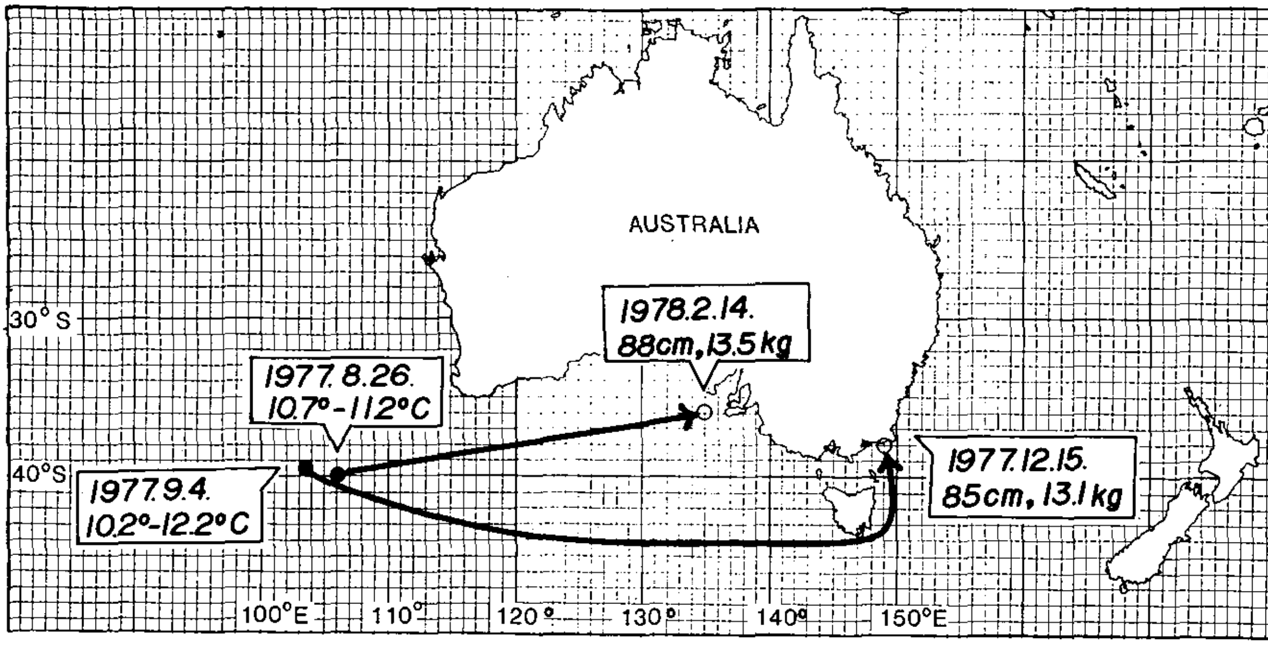


Fig. 37. Recovery by livebait-and-pole fishing of tagged southern bluefin caught and released by a longliner (Registered at Kochi Prefecture. *Daigo Kenkyu Maru No. 5*)

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distribution during the period outside the fishing season has not been well known in the past. In recent years, a Japanese longliner conducted a tag test on bluefin tuna caught in the area around 40°S, 150°E, and recovery of specimens tagged in Australian waters has been reported. Figure 37 shows the pattern of the test. Fifty-two individuals were tagged and released during August and September 1977. Their body length at the time of release was not known but, judging from the body length at the time of their recovery and the period of the recovery, most were approximately 3 years of age. Only two have been recovered so far. One report came from the South Australian coast and the other from the N.S.W. coast. The time of recovery in both cases was in the middle of the fishing season in the fishing grounds. The time of their release was 3-6 months before the recovery, outside the fishing season. Judging from these instances, it is thought that even those individuals far away from existing coastal fishing grounds seasonally come close to shore and become the object of fishing. In other words, it is possible that, after the closing of the fishing season, a group of southern bluefin tuna disperses over a wide area.

As observed in the foregoing, the distribution of southern bluefin can be distinguished relatively clearly by their occurrence and growth. The seasonal change in their distribution in each of the sea areas is also clearly recognizable. The distribution of adults due to spawning is also distinct. The scale and the scope of their movement have been estimated by tagging experiments.

It is possible therefore to presume the course of migration by tracing the changes of distribution areas corresponding to each stage of growth in the life history, by tracing the seasonal change of the distribution as well as the change of distribution area due to spawning and feeding. To begin with, if the process of change of the distribution area due to their growth is illustrated by a schematic diagram, the process is represented basically by the thick lines as in Fig. 38. The

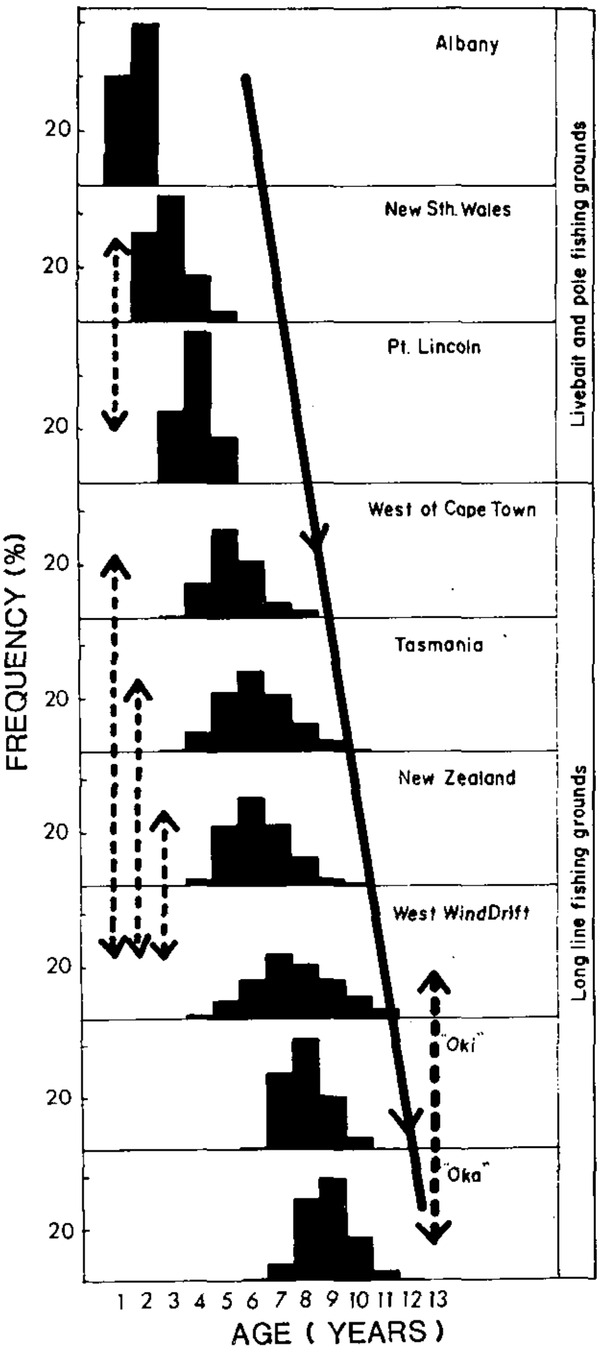

Fig. 38. Change of distribution areas of southern bluefin

Solid line: change during growth

Dotted line (thick): change during spawning and feeding

Dotted line (thin): seasonal change

stage from spawning to juvenile of southern bluefin is observed only in the Oka fishing ground, northwest of Australia. After that, when they grow to the age of 0-1 which is the youngest age, they are caught on the Albany coast, Western Australia. In this area, they spend the second year of their life. After that they move to the S.A. and the N.S.W. coast and there they become predominant as 3-4 year old fish. Between these two fishing grounds, there are seasonal movements of fish and in the process they are caught mainly by the livebait-and-pole fishing vessels along the coast of Australia. At 4 or 5 years of age they leave the coastal area and distribute themselves widely in the intermediate layer of the offshore area. These immatures distribute in the West Wind Drift until they become adults at 6-7 years of age, and seasonally move northward to the areas north of 40°S to the east of Australia, to the east of New Zealand, and to the offshore area south of South Africa. The season of their northerly movements is principally in the southern winter. When they have grown to the adult stage, they arrive between September and March, which is the spawning season, in the Oka fishing ground by way of the Oki fishing ground, west of Australia. There they start spawning. During the feeding stage they distribute in the West Wind Drift and some of them migrate seasonally northward in the same way as the immatures. The movements between the sea areas in different seasons and for spawning purposes are indicated by dotted arrows in Fig. 38. But the seasonal northward migration of the fish mentioned here does not mean that all the fish move from south to north, but it appears that the distribution area expands seasonally towards north. The spawning period, too, covers a long period of approximately half a year. Therefore, throughout the spawning period, adults are always to be found in the spawning grounds as well as in the West Wind Drift.

When a schematic diagram of the route of migration of southern bluefin, which has been dealt with above, is drawn, it would be as shown in Fig. 39. That is to say, the species distributing in the three oceans all originate from the same sea area. They spend their very early life in the Australian coastal waters, then they make the West Wind Drift their basic area of distribution, with seasonal changes of fishing grounds which is due to seasonal preference of locality. When they attain maturity they spawn at the area of their origin. In this sense, southern bluefin tuna are to be regarded as belonging to a single genealogy.

II.2 *Development of the fishery*

(i) The variation of total catches and total fishing effort. As mentioned earlier, the stock of southern bluefin has been exploited only by Japan and Australia. This may be because the species has little contact with the coastline of other countries. The countries with which southern bluefin does have contact are those which have contact with the West Wind Drift - Argentina, South Africa, Australia, New Zealand and Chile. Among these countries, the ones satisfying the conditions for the development of shore-based surface fisheries for small southern bluefin are: first Australia, then New Zealand and South Africa.

On the other hand, in Japan, the tuna fisheries have developed as "far seas fisheries". Therefore the southern bluefin stock has become the object of exploitation though the stock is located far from Japan. The reason why the fishing by the Japanese has been intensified is that the species is used for high class "*sashimi*", sliced raw tuna, the consumption of which is limited to the Japanese only. Furthermore, the demand for it has grown due to the high economic growth of Japan.

The southern bluefin fishery in Australia has a long history and it is said to have been started in 1938 (Hynd and Murphy 1976). In the early stages the only fishing method was trolling and the volume of the catch was insignificant. After livebait-and-pole fishing was introduced in 1952, the catches increased gradually and rose sharply after 1962. In 1974, round haul net fishing was also introduced.

Exploitation of southern bluefin by Japanese longliners started in 1952. At first, the operations concentrated on the Oka fishing ground, which is the spawning ground. Then the New Zealand fishing ground was exploited, followed by the Oki fishing ground. Thus the fishing grounds were gradually extended southwards. The catches in the beginning of the fishing operations were mainly intended as material for processing (Mimura and Warashina 1962). The species became the focus of attention as material for *sashimi* only in the latter half of the 1960's when the technique of low-temperature freezing was developed, and the longliners entered into the West Wind Drift where southern bluefin of good meat quality were distributed.

The fishery for southern bluefin in Australia started on the N.S.W. coast, and later, in the early years of the 1950's, the South Australian fishing ground was opened. The fluctuation of the catches in each fishing ground and of the number of fishing boats (10-300*m, 30-600 horse-power) up to the early 1960's is given in Fig. 40 (from Hynd *et al.* 1966). The total catch was under 1000 short tons (1 short ton = 0.9 tonne) until the South Australian fishing ground was developed. The size of the catch grew gradually and the total catch from both fishing grounds reached 5000-6000 short tons in the period from the late 1950's to 1960. The change of the size of the total catch after the above date is shown in Fig. 43. It rose with fluctuations from year to year, and in 1972 the

*sic

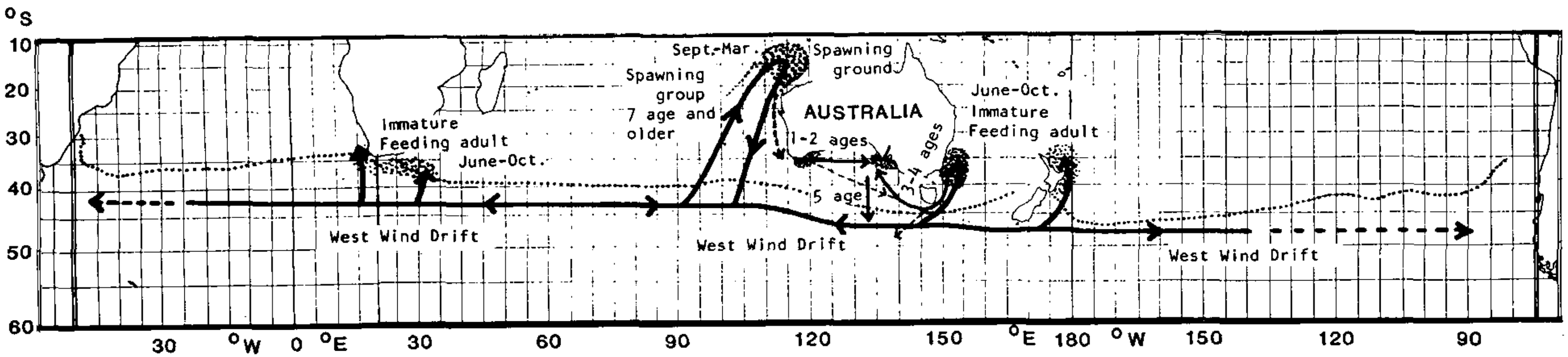

Fig. 39. Schematic diagram of the presumed course of migration of southern bluefin
Dotted line marks the northern boundary of the West Wind Drift

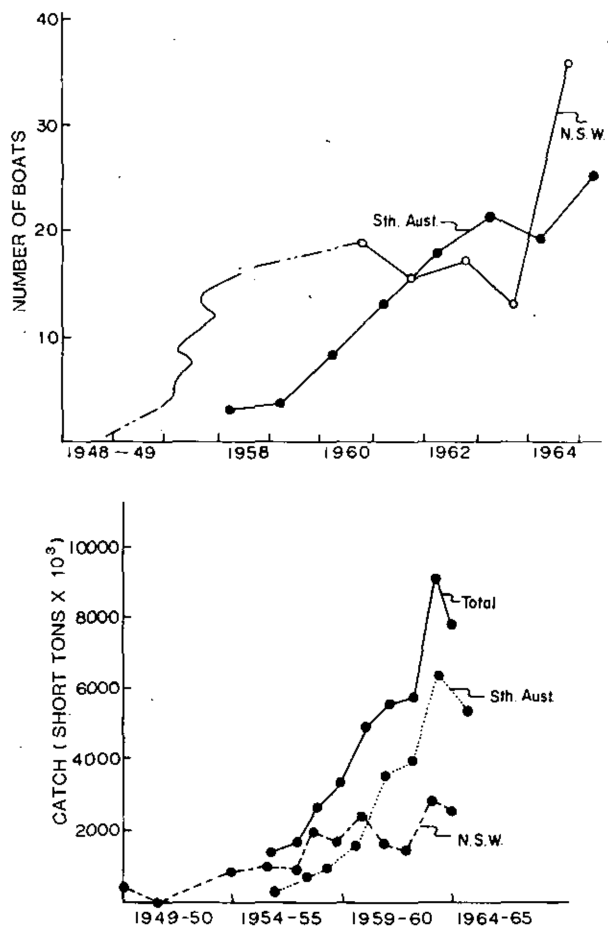

Fig. 40. Annual catch (bottom) and fishing effort (top) for southern bluefin tuna (from Hynd *et al.* 1966)

largest catch of approximately 12,000 short tons was recorded. In recent years the figures seem to vary within the range of 8,000-10,000 short tons (Hynd and Murphy 1976).

The number of fishing boats also increased with the growth of the fishery and by around 1964 their total number in both of the fishing grounds reached about 60. The later situation is not clear but, according to Hynd and Murphy (1976), it seems that at present about 100 boats are in operation. In Australia, among fishery products, southern bluefin comes first in weight of catch, and in value of catch it comes fifth, following rock-lobsters, prawns, oysters and scallops. Most of the catch is canned for consumption (Hynd and Murphy 1976).

The process of expansion of the Japanese longline fishing grounds for southern bluefin can be divided into several periods as shown in Fig. 41. Fishing started in the Oka fishing ground in 1952, and five years later in 1957 the longliners entered the N.Z. fishing ground and in 1958 the Oki fishing ground, and the nature of operations in the pattern established in 1959 lasted until 1961. After that, on the Pacific side, the area of operations extended to the west and to the coastal area to the east of Australia. The pattern of the operations given for 1963 lasted until 1965. In 1966, the extent of the operations expanded further south and from the central part of the Indian Ocean to the eastern part of the Atlantic, i.e. to the West Wind Drift. After that, fishing operations took place in the West Wind Drift fishing ground every year and in 1969, as can be seen in Fig. 41, fishing was widespread in the following four areas: west of N.Z., south of Tasmania, southwestern offshore of Australia (in the vicinity of 40°S, 100°E), and to the south offshore of South Africa. After 1970, up to the present (1978) the pattern of operations remained about the same. In the spawning area, which was fished in the early stage, no operations on southern bluefin are carried out now. This is due to the fact that the southern bluefin fish possessing good quality meat are not caught in this area, and also because the productivity has fallen.

The fishing effort by longliners in the fishing grounds for southern bluefin grew slowly at first and the hook number reached about 30 million in 1964 (Fig. 42). After that, with the expansion of the fishing grounds, fishing effort increased rapidly and, in 1968, the number of hooks used reached about 85 million. After 1969, the growth of the fishing effort appears to have slowed down.

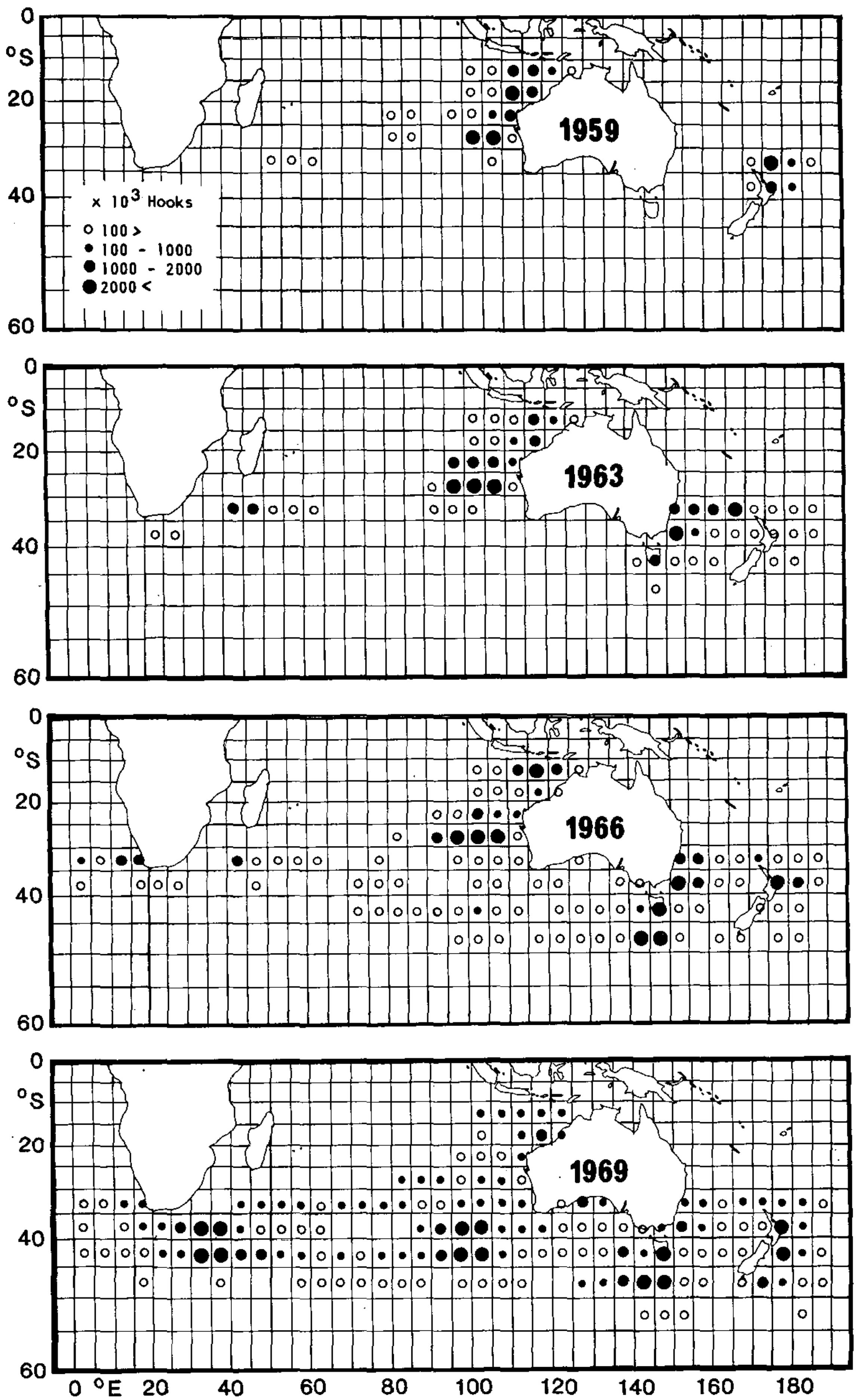

Fig. 41. Expansion of longline fishing grounds for southern bluefin (number of hooks per 5° square)

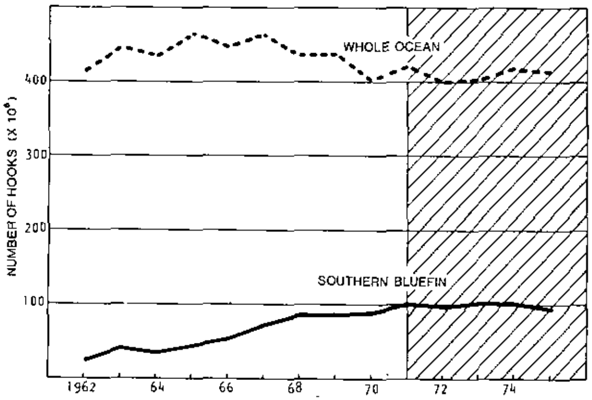

Fig. 42. Total hook number of the Japanese longliners (dotted line) and the hook numbers committed to the southern bluefin fishing grounds (solid line). (Shaded area indicates the years after the voluntary restrictions were introduced)

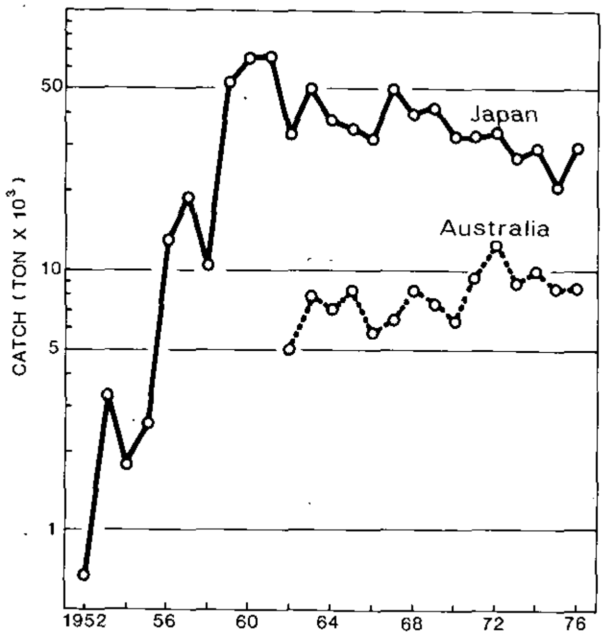

Fig. 43. Annual change of the catch of southern bluefin tuna in Japan and Australia

Nevertheless, up to 1975, the number fluctuated within the range of 90 to 100 million. In 1976, the number is estimated to have reached 110 million. The total number of hooks committed by Japanese longliners to all oceans since 1970 amounted annually to about 400 million, so the fishing effort in the southern bluefin fishing grounds in recent years constitutes about 25% of the whole effort (Fig. 42).

The volume of the catch of this species by longline fishing increased very rapidly between 1952 and 1960. The pattern of the increases shows sharp increases with intervals of about three years, which seems to correspond exactly with the expansion of the fishing grounds. The catch for the year 1960-1961 recorded the highest figure in the history of southern bluefin fishing (about 70,000 tons) (Fig. 43). After that the catch declined almost rectilinearly with some yearly change and in recent years the catch remains at about 25,000-30,000 tons.

(ii) Changes of the catch and fishing effort of longline fishing in each sea area. The fishing grounds for southern bluefin are divided into nine sea areas (as indicated by Fig. 44) according to the location, the fishing season, the characteristics of the catch, etc. (Shingu and Hisada 1971). The characteristic features of these nine sea areas are shown in Table 8. As the ages of the fish in the catch differ from one fishing ground to another, even though the size of the catch is the same, the effect of fishing on the stock must be different. From this viewpoint all the sea areas are classified in Fig. 45 into one of the following three areas: sea area where large fish constitute the main group; sea area where large and small fish are caught; sea area where small fish form the majority. The annual change of the number of hooks and the number of fish in the catch are also given in the figure. In this figure the

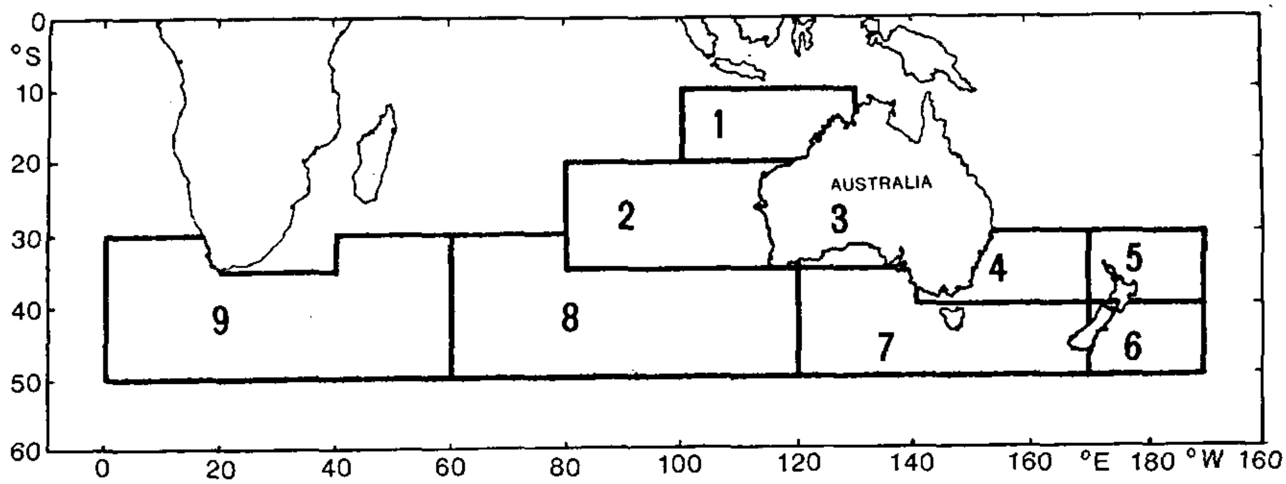

Fig. 44. Division of the fishing grounds for southern bluefin

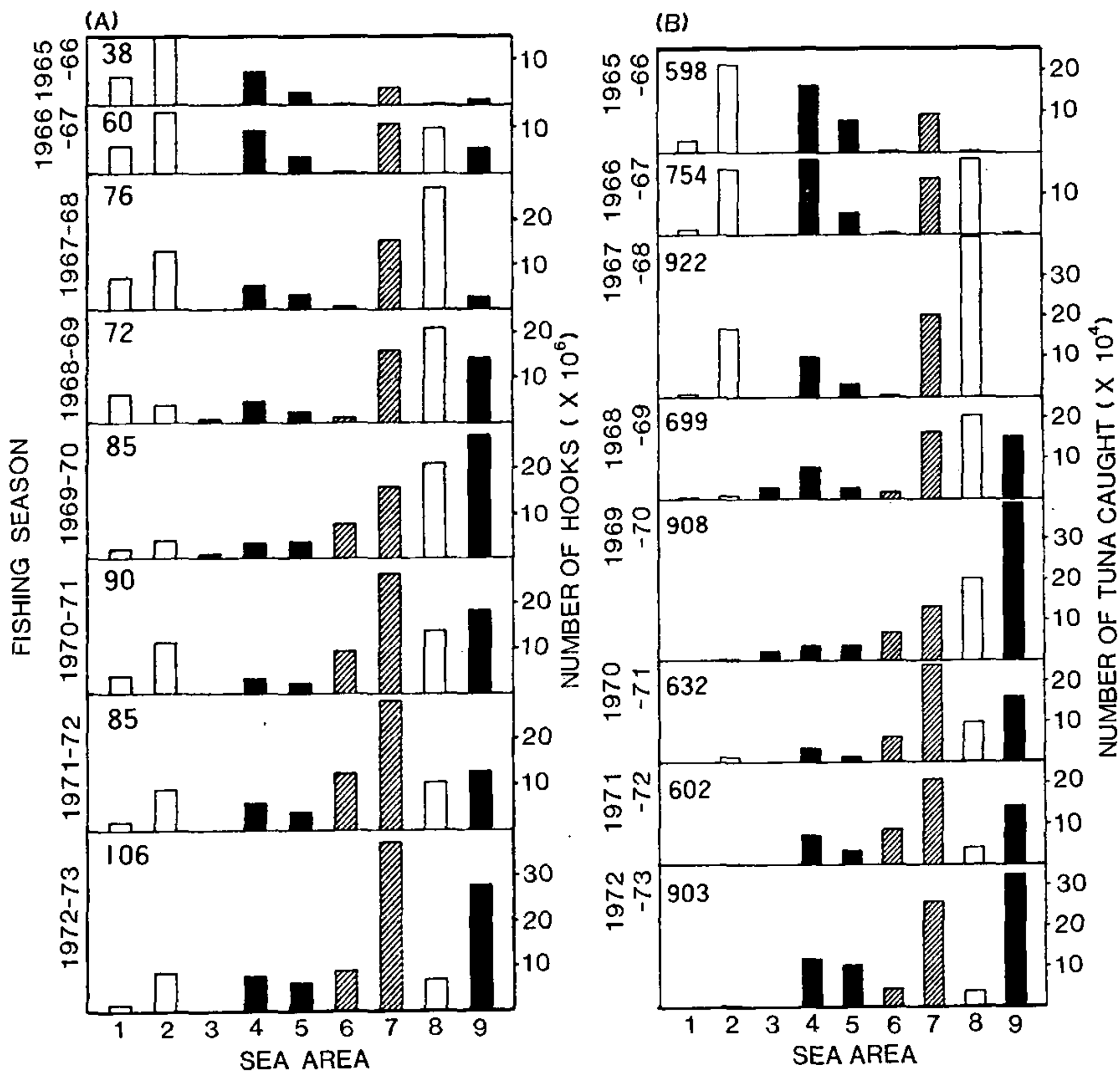

Fig. 45. Number of hooks used (A) and number of fish in the catch (B) in each of the southern bluefin fishing grounds

□ Area where mainly large fish are caught ▨ Area where both large and small fish are caught ■ Area where mainly small fish are caught

Table 8. Fishing grounds for southern bluefin and their characteristic features (from Shingu and Hisada 1971)

Fishing grounds	Location	Main ocean current	Year of operation	Fishing season *	Characteristic features of the catch
1. "Oka" fishing ground	10-20°S 100-130°E	South Equatorial Current	1952	III, IV, I	Spawning adults
2. "Oki" fishing ground	20-35°S 80-120°E	South Equatorial Current and West Australian Current	1958	III, IV, I, II	Spawning adults
3. Fishing ground along South Australia	North of 30°S 120-140°E	West Wind Drift with seasonal occurrence of warm waters	1968	I, II	Youngs and immatures (major fishing ground of surface fishery)
4. Fishing ground along New South Wales	30-40°S 140-170°E	Central Tasman waters and East Australian Current	1961	II, III, IV	Immatures and young (also major fishing ground of surface fishery in addition to longline fishery)
5. Fishing ground off north New Zealand	30-40°S 170°E-170°W	——	1956	II, III	Immatures
6. Fishing ground off south New Zealand	40-50°S 170°E-170°W	West Wind Drift	1967	I, II, III, IV	Feeding adults and immatures
7. Fishing ground around Tasmania	40-50°S 120-170°E	West Wind Drift	1962	II, III, IV, I	Feeding adults and immatures
8. Fishing ground in south-central Indian Ocean	35-50°S 60-120°E	West Wind Drift	1966	III, IV, I, II	Feeding adults and immatures
9. Fishing ground south of Africa	30-50°S 0-60°E	West Wind Drift	1967	II, III, IV, I	Feeding adults and immatures

* I: January-March; II: April-June; III July-September; IV: October-December

results given are only those obtained after 1965, when the changes of operations in each of the different fishing grounds became considerable (Warashina and Hisada 1974). As can be seen from the figure, since 1969 the fishing effort began to decline in sea areas 1, 2 and 8, where large fish are in the majority; in the fishing grounds where both large and small fish are caught, the fishing effort shows a tendency to rise. This can be seen more clearly with the examination of the number of fish in the catch. Until 1967-1968, the catch in sea areas 2 and 8 was greater than that in any other fishing grounds, but after 1968, the catch decreased rapidly. On the other hand, in sea areas 7 and 9, a marked increase of the catch is observed since about 1969.

(iii) Size and value of the longline fishery catch. An examination of the catch weight of tuna in Japan for a period of 11 years from 1965 to 1975 (Fig. 46) shows a gradual fall from about 430,000 tons in 1965 to below 300,000 tons in 1970. However, the figure shows a tendency to rise during 1971-1974 (Statistics and Information Department, Ministry of Agriculture and Forestry, 1977). On the other hand, the catch of southern bluefin has decreased since 1960, and its proportion of the entire tuna catch is getting lower. The average figure for the years 1971-1975 is about 9%. On the other hand, the value of tuna is different from catch weight and the figure is continually rising. It increased more than three times from 1965 to 1975 and exceeded 200,000 million yen. The monetary value of southern bluefin was not low in 1960 when the catch was large but in 1970 it showed a remarkable rise. The average value of southern bluefin for the years 1971-1975 constituted 27.5% of the total value of the tuna group.

This rise in value was coupled with the growth of demand for medium and high class fish and the high prices of fish in Japan. But as mentioned above the weight of the catch was already declining and there was a limit to the amount of fish available. Therefore it is understood that this rise in value was dependent solely on the trend of the high prices paid for fish. To illustrate the fluctuation of the fish price we shall examine the price-per-kg at the Yaizu Fish Market, the biggest market for southern bluefin in Japan (Fig. 47, Yaizu Fishery Cooperative Association, 1976). In 1961, the price-per-kg was approximately 100 yen for tuna, marlin and skipjack alike. The figures rose year after year, but the pattern of the rise differs from species to species.

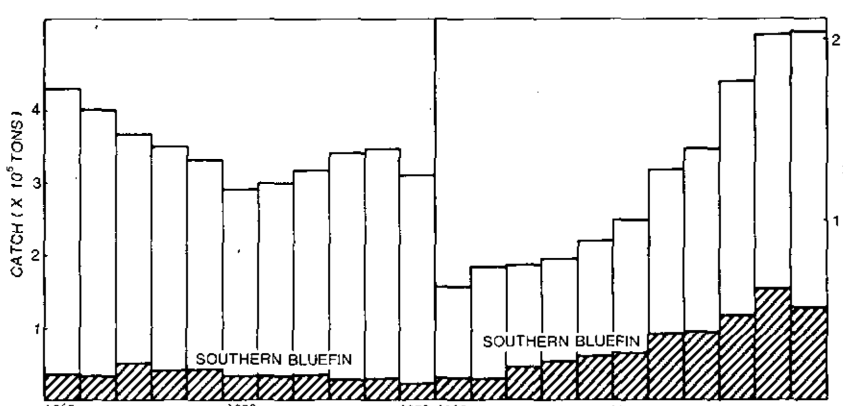

Fig. 46. Catch weight and value of southern bluefin. Respective figures for the entire tuna group catch in Japan

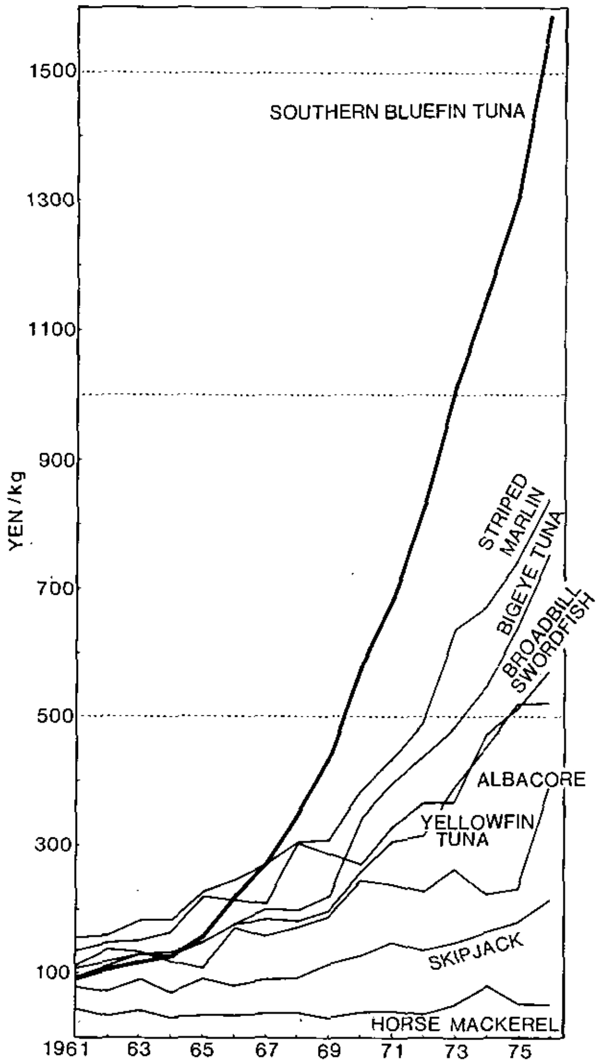

Fig. 47. Average fish prices (per kg) at Yaizu Fish Market and their fluctuations

Among them, the rise of average price for southern bluefin is the most conspicuous. It rose to 16 times its previous value in 16 years. The figures for striped marlin and bigeye which show the next most rapid rise increased only 7-8 times.

II.3 *Changes in the stock*

(i) Relationship between fishing effort and catch in the longline fishing ground. The relationship between the number of hooks in the whole area of the southern bluefin fishery and the catch in number of fish is shown in Fig. 48. From 1952 until 1958 the fishing effort was about 10 million hooks, and the catch for this effort was 400,000 fish at its peak. By 1961 the fishing effort increased to 20-30 million hooks and the catch, at a higher rate, reached 1.2 million fish. During 1962-1966, the fishing effort increased further to approximately 50 million hooks but the catch fell fairly rapidly. Except for the figure of about 1 million in 1963, the catch in number for the remaining four years was around 700,000. In 1967, when the longliners entered the West Wind Drift fishing ground, the total hook number rose to 70 million and the catch in number increased to nearly 900,000. But after that, while the hook number increased to 110 million by 1976, the catch kept on falling. The average catch in the last few years is about 600,000-650,000 fish which is about half of the catch in 1960-1961. Until 1958, the fishery may have been exploiting new grounds, but after operations were started on a full scale, the amount of the catch reached its peak in a very short period. As the fishing effort keeps on increasing, naturally the catch per effort (hook rate) is falling. In the early 1960's when the catch increased rapidly the hook rate was about 4% but in the 1970's the hook rate has fallen to as low as the level of 0.6% or slightly higher. It is presumed that the level of the stock has fallen in a similar way.

The increase in fishing effort with no increase of the catch means, in other words, waste of effort. This may not be economically wise.

(ii) Annual change of fishing effort and hook rate in each of the fishing grounds. The average hook rate for all fishing grounds is considered to have decreased at present, to about one-sixth of the hook rate at the beginning of the exploitation. An examination of the situation in respect of each of the fishing grounds shows the fall of the hook rate is by no means uniform. A summary of the fluctuation of the relationship between the effort and the hook

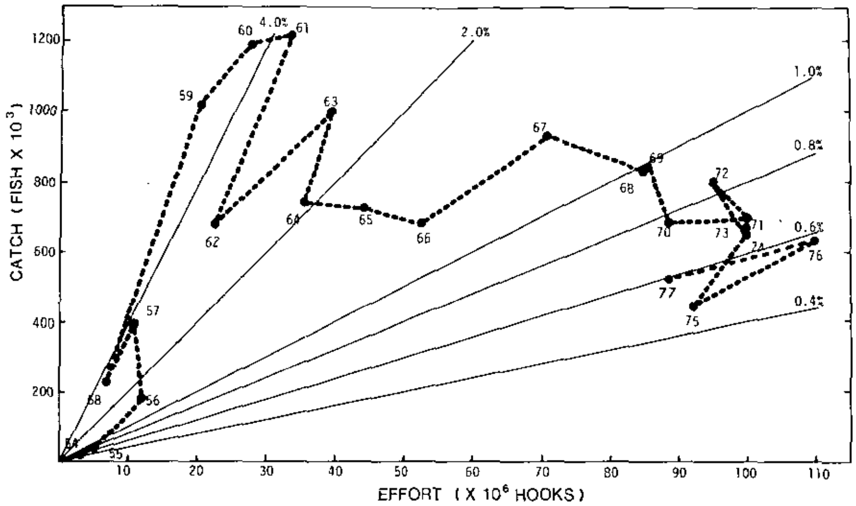

Fig. 48. The relationship between fishing effort (number of hooks) and catch (number of fish) in longline fishing for southern bluefin (Thin lines indicate the hook rate)

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rate will be given below. Since both fishing effort and catches in the sea areas classified in (*ii*) of the previous section are included here the area dealt with is much wider than the region of the main fishing grounds (Fig. 49).

(a) Spawning ground (the Oka fishing ground)

The greatest fishing effort in this fishing ground in the past was 10 million hooks, which is moderate. From the latter half of the 1950's to around 1968 the effort remained almost unchanged, but after 1969 it declined. The hook rate showed a rising tendency during the period from 1952 to 1959 and reached 3%. After 1960 it fell rapidly and in recent years in some cases the catch in number was several hundred a year. Since, in this fishing ground, there are no catches of southern bluefin tuna of good meat quality, the object of fishing operations was transferred to other species of tuna (Fig. 49A).

(b) The Oki fishing ground

The effort increased until 1965 when the hook number exceeded 20 million. After that the effort decreased rapidly. The hook rate in the beginning of the exploitation of this fishing ground was higher than that of the Oka fishing ground, and exceeded 5%. In this fishing ground, the fall in hook rate began soon after exploitation began, and the decline was faster than in the Oka fishing ground. The gradual fall over the period from 1967 to 1968 is considered to be due mainly to the movement of the fishing boats to the West Wind Drift fishing ground. Thus it does not seem to reflect the abundance of fish there. The fishing effort since that year was aimed mainly at the bigeye. Although the fishing season coincides with that of the southern bluefin, the area of the operations has shifted from the main distribution area of the southern bluefin (Warashina and Hisada 1974) (Fig. 49B).

(c) The Tasmanian fishing ground

This is a fishing ground in which exploitation commenced comparatively recently. The fishing effort shows a great fluctuation from year to year, but it generally increased until 1972 when it reached 30 million hooks. After that, the effort gradually decreased. The catch in this fishing ground consists mainly of feeding

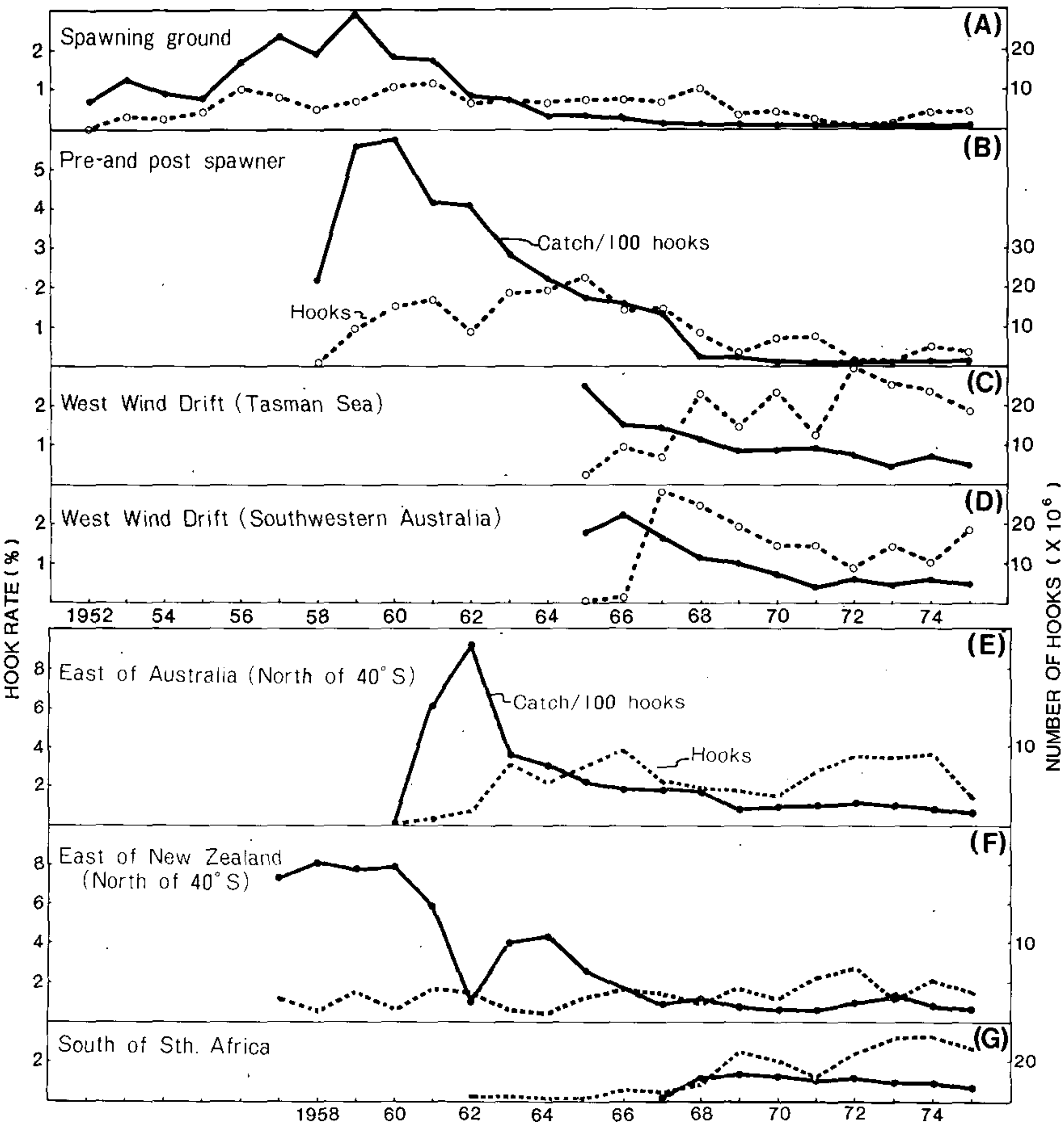

Fig. 49. Annual change of fishing effort and hook rate in each of the southern bluefin fishing grounds

adults. Compared with the hook rate of the spawning adults, even though they are both adult fish, the hook rate here (feeding adults) is considerably higher. The extent of the fall of the hook rate is also lower than that of the spawning adults in comparison with the periods for which data are available (Fig. 49C).

(d) The fishing ground southwest of Australia (sea area 8)

This fishing ground is in the West Wind Drift and adjoins the Tasmanian fishing ground. But the characteristics of the fish caught here are different. Here, mainly adults migrating northward to the Oka and the Oki fishing grounds are caught, and it may be described as the entrance to the spawning grounds. The change of annual fishing effort is the reverse of that of the Tasmanian fishing ground. The figure was the highest at the start of exploitation (nearly 30 million hooks in 1967). Then it decreased until 1972 and then showed a tendency to increase. The hook rate and its declining trend very much resemble that of the Tasmanian fishing ground. These two fishing grounds are usually included in the operational program for one trip, and it is possible to know on which of the fishing grounds the emphasis was placed in any particular year (Fig. 49D).

The above four are the fishing grounds where adults are in the majority. The hook rate in these areas in recent years shows a considerable difference between that during the spawning period and the feeding period. When the details of the fishing operations and the dates of the initial exploitation of these fishing grounds are examined, an overall examination seems to be necessary to assess the present level and the extent of decrease of the stock.

The annual change in the three fishing grounds where mainly small fish are caught are discussed below.

(e) East of Australia (North of 40°S; sea area 4)

In the early 1960's, which was the initial period of exploitation, and in the first half of the 1970's, the fishing effort was nearly 10 million hooks, but between these two periods the effort decreased by half. The hook rate was high (6-8%) in the first two years (1961-1962). After that it fell suddenly in 1963, and gradually declined further so that in the 1970's it was 0.7-1.0%. In 1975, the fishing effort decreased conspicuously. In this year the water temperature in that fishing ground as well as in the livebait-and-pole fishing ground on the coast was considerably higher than in the previous years, and in both of these fishing grounds the catch was extremely poor (Warashina, unpublished; Murphy, pers. comm.). Because of these poor conditions, the longliners stopped operations within a month and left the fishing ground (Fig. 49E).

(f) East of New Zealand (North of 40°S; sea area 5)

Since 1957, the first year of exploitation, the fishing effort shows either no marked fluctuations or a slight tendency to increase. In the past, in no one year did the number of hooks exceed 10 million. Similar to the case of the previously mentioned fishing ground, the hook rate was higher in the early stage of exploitation (about 6-8%) but after 1962 it fell conspicuously and until recently maintained a slow decline. In 1970, the hook rate was 0.7-1.0% (Fig. 49F).

(g) South of South Africa (sea area 9)

Full scale operations started in 1968 in this fishing ground which was the latest of the southern bluefin fishing grounds to be exploited. Nevertheless, this is at present the most important fishing ground. Consequently the fishing effort is large and during 1973-1974 the number of hooks exceeded 30 million. The hook rate was lower at first (1.2-1.3%). However, the decline in hook rate is the slowest of all the fishing grounds up to the present and this is now the most productive fishing ground. The size composition of this fishing ground consists mainly of smaller fish but, unlike the other fishing grounds of small fish, a year-round operation is possible, and seasonally large fish are also caught in some quantity (Fig. 49G).

Upon reviewing all the fishing grounds, we find that, in the fishing grounds where the operations started earlier, a high hook rate was recorded during the first two to three years after the start of the operations, but it inevitably fell sharply afterwards. On the other hand, in the fishing grounds where the exploitation started recently, such a change is not observed. Judging from these facts, the high hook rate observed during the early days of exploitation, as for instance in sea areas 2, 4 and 5, may be considered as reflecting the accumulation of the stock at the beginning of exploitation. If we accept this view, the accumulation must have been originally not very large, for, by the middle of the 1960's, exploitation was already well under way.

(iii) The tendency for body length reduction in southern bluefin catches. Along with the general decline of hook rates over the fishing grounds, the boats stayed in the fishing grounds longer, and operations tended to concentrate in the fishing grounds with smaller fish where the density of the fish was higher, in order to secure a desired catch weight (Warashina and Hisada 1974). The concentration of the operations is especially noticeable in the fishing ground off South Africa. Figure 50 (top) shows the annual change in catch by the longliners, divided into two age groups, 1-6 years and 7-14 years. The size of the catch of 1-6 year olds has shown a tendency to increase since the start of the

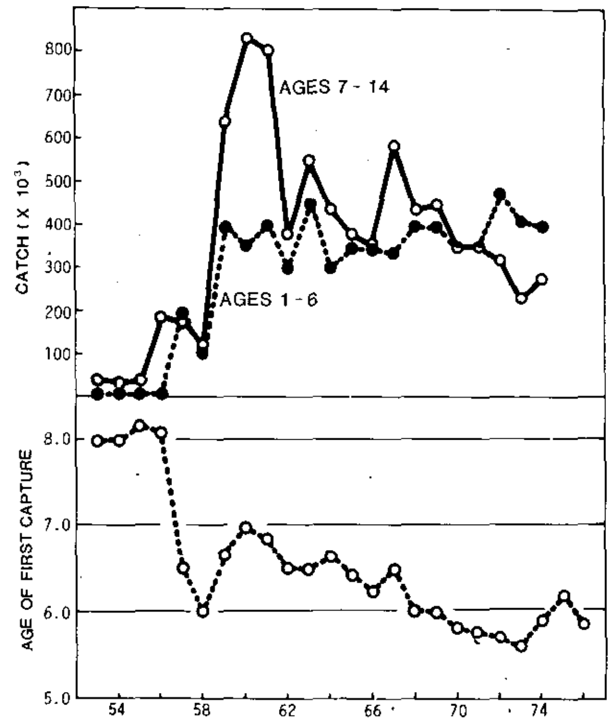

Fig. 50. Annual change of the catch of southern bluefin by longliners, classed by the age group of fish (top) and the annual change of the age of first capture (bottom).

fishing. The size of the catch of 7-14 year olds reached the peak at 650,000-850,000 fish in 1959-1961 when there was a large catch at the Oki fishing ground, but after 1962 the figure was similar to that of the catch of the 1-6 year olds and, after 1972, the positions of the groups were reversed. This seems to reflect the nature of the operations in the area to the east of Australia (sea area 4) and in the offshore area of South Africa.

Owing to this situation, the average age of first capture (deduced from the average weight of each age class of fish) declined year after year (Fig. 50 bottom), with the exception of the figures for the years up to 1958 when the catch was small; in the early years of operations about 7 years of age may be considered as the average age of first capture by longline fishing. After that year the age decreased rectlinearly until 1973 and reached the level of 5 to 6 years of age. In 1975-1976 it rose slightly to about 6 years.

(iv) Present position of the stock. As far as can be judged from the change of hook rate, the stock of southern bluefin tuna subject to longline fishing is considered to have decreased to about one-sixth of its early level, while adult stock has been reduced to the same or even lower level.

Later, the relationships between intensity of fishing, the optimum catch, and stock size will be examined. Among the tuna group this species is relatively slow in growth but long lived. Thus, under natural conditions, an individual fish is considered to reach its maximum size at 7 or 8 years of age (Hayashi *et al.* 1972). Accordingly, it may be said to be most rational to start catching them at an age a little lower than that. Hayashi (1974), acting on the assumption that all southern bluefin recruit to a longline fishery at the age of 5 years, showed that the catch per recruit in the light of the changes of the fishing coefficient (F) and the age at first capture would be represented by isometric curves given in Fig. 51 (left). The figure shows that the maximum yield occurs with an

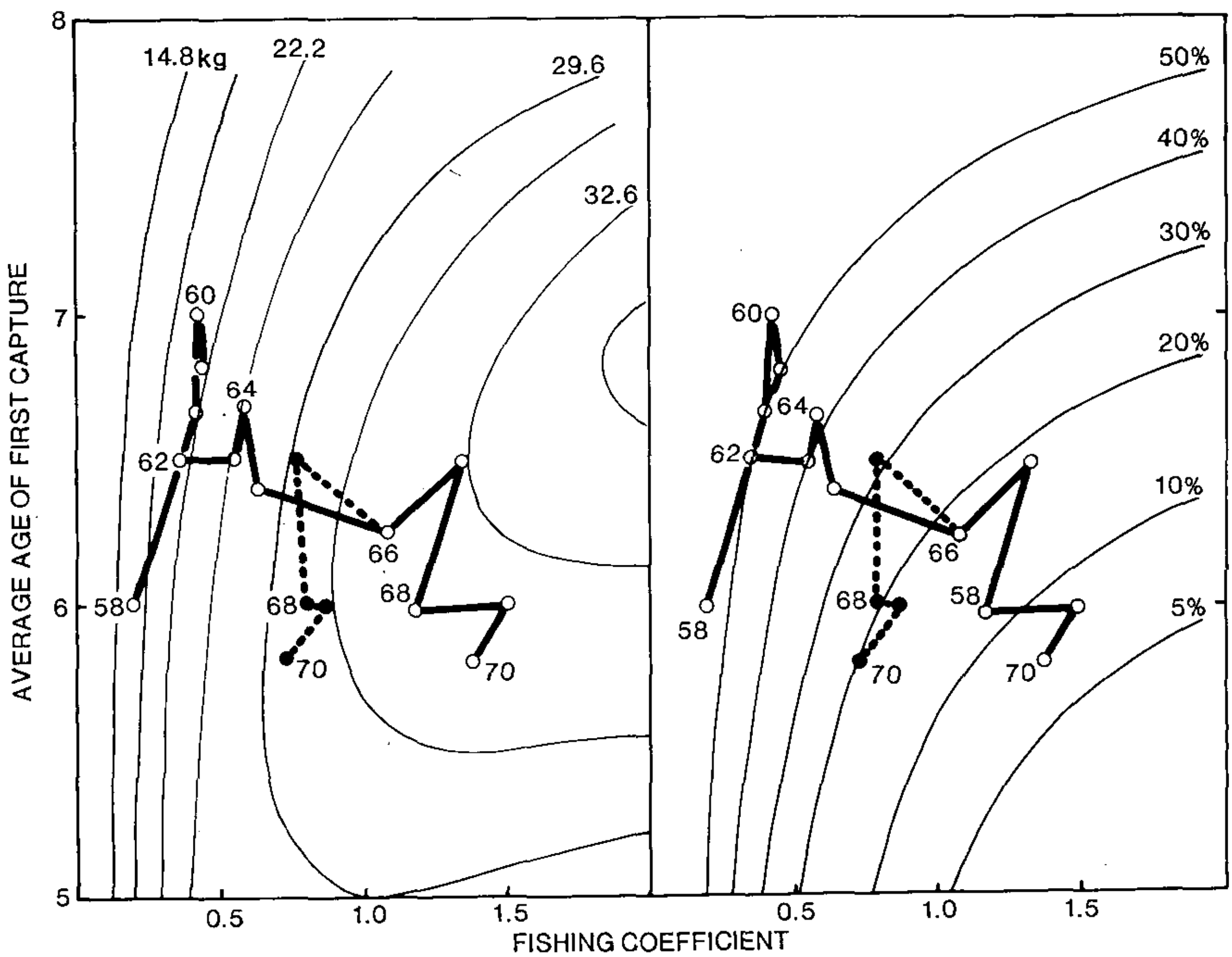

Fig. 51. Isometric curves of the yield of the recruits (left) and relative stock fecundity (right) against fishing coefficient and average age of first capture (Hayashi 1974). The solid line in the figure indicates the relationship between the yearly coefficient and the age of first capture in the longline fishery. The dotted line denotes the estimates by cohort analysis

age of first capture of 7 years. The fishing coefficient in that case is over 1.7. If the age of first capture is under 6.5 or over 7.5, the yield would be less. The relationship between fishing coefficient and the age of first capture for each year from 1958 to 1970 in the longline fishing catches which the above author has computed (the figures are given for the period up to 1972, but the figures for the last two years are tentative and are excluded here) is indicated by the solid lines in the figure. It shows that up to the first half of the 1960's the age of first capture was 6.5-7.0 and the fishing coefficient was about 0.5; after that the fishing took a course inclining towards the right, that is the age of first recapture was reduced and the fishing coefficient was increased.

The isometric curves of relative stock fecundity against age of first capture and F are also shown (Hayashi 1974). In this case, too, the relationship between age of first capture and F has been plotted. It can be seen that, if the pre-1965 conditions in the longline fishing had been maintained, more than 30% of the stock fecundity in natural conditions could be secured. However, the change in fishing operations after that took the course which would most effectively reduce the stock fecundity. Thus in 1970 the yield was under 10%.

The author states that the figures for F for recent years may have been overestimated. Thus another set of figures for F has been estimated (Japan-Australia Special Working Committee for Southern Bluefin, 1971, at Shimizu) by cohort analysis (generalized by Murphy 1964; Tomlinson 1970): it is given for the period 1967-1970 (dotted line, Fig. 51). According to this estimate F for the four years is 0.7-0.8. There is no guarantee that either of these values of F is valid. At any rate, the stock fecundity is presumed to have fallen to an unprecedented low level.

But what is the actual situation of recruitment every year? If its (approximate) trend could be known even roughly, some effective way of dealing with the yield per recruit could be found. Hayashi (1974) has calculated the recruitment to the longline fishing beginning at 5 years of age, on the basis of the estimated values of F and the yield in each year (Table 9). The table shows that recruitment during the first half of the 1960's amounted to 1.7-2.6 million fish, but in the latter half the figure fell to 1-1.4 million. In 1970 it was only 850,000. The numbers of recruits at 2 years, 5 years and 7 years of age which have been estimated by the abovementioned cohort analysis are given in Fig. 52. The dotted lines for 5 and 7 indicate the values when the number of recruits at age 2 years before 1954 and after 1963 is fixed as a constant. These two sets of estimates do not agree well with each other, but in the latter half their values are closer. There is no significant change of recruitment from which a trend may be inferred to be established with the 2 year old fish. But with the 5 year old recruits for longline fishing, a possibility of their decrease should be kept in mind. The question, however, is one of the problems concerning Japan and Australia as it concerns surface fishing in Australia which seems to catch the same stock before the longline fishery. It is an urgent task for the longline fishery to introduce measures so that the parent stock may be restored in order to ensure stock fecundity and increase productivity.

Table 9. Two sets of estimates (R_c and R_y) of recruitment of southern bluefin tuna to the longline fishery, at age 5 years

Fishing season	tc. Average age of 1st capture	F. Corrected fishing coefficient	C. Catch in number	R_c	Y. Yield in weight	R_y
			10^3	10^3	10^3	10^3
1958-59	5.62	0.191	471	1,091	25.9	1,455
1959-60	6.71	0.408	1,244	2,610	68.6	3,077
1960-61	7.02	0.414	1,195	2,655	71.5	3,421
1961-62	6.70	0.449	909	1,846	51.6	2,314
1962-63	6.68	0.351	787	1,725	44.3	1,987
1963-64	6.47	0.587	955	1,718	49.9	1,815
1964-65	6.49	0.571	759	1,381	40.0	1,455
1965-66	6.28	0.646	598	1,012	30.4	1,086
1966-67	6.17	1.085	734	1,098	37.8	1,178
1967-68	6.42	1.329	922	1,409	52.8	1,630
1968-69	5.88	1.178	699	975	36.0	1,132
1969-70	6.02	1.514	909	1,262	47.8	1,485
1970-71	5.85	1.387	632	854	33.5	1,054
Average				1,510		1,776

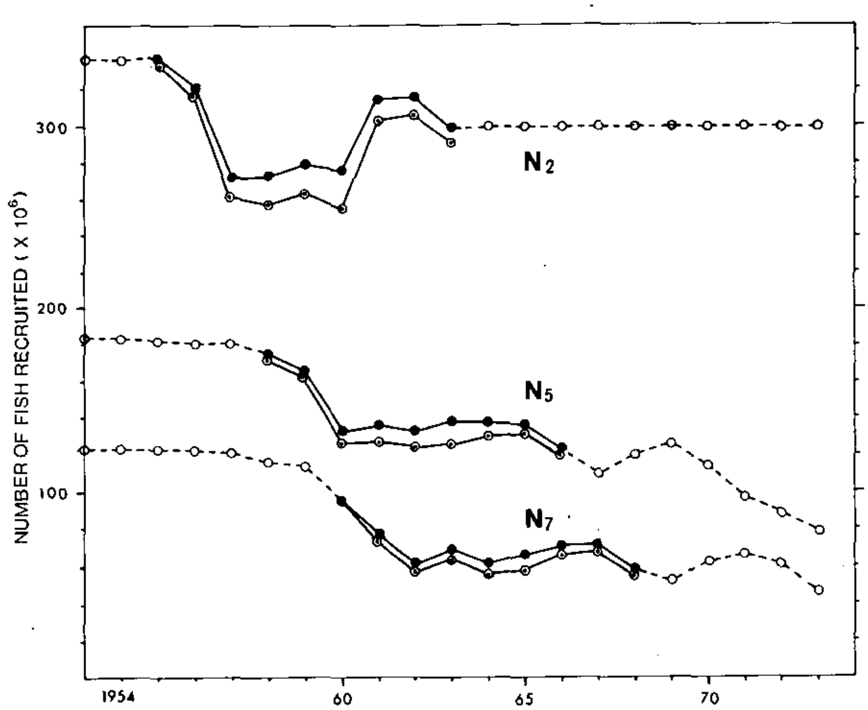

Fig. 52. The quantity of recruits at 2 (N_2), 5 (N_5) and 7 (N_7) age estimated by cohort analysis. (Dots)

11.4 *Voluntary restriction of long-line fishing for southern bluefin tuna*

Based on information about yield and fishing conditions of southern bluefin at their younger stage when taken by surface fishing, there is no evidence that reproductive rate is reduced. However, the size of the parent stock has already fallen to a low level and stock fecundity is assumed to have been reduced extremely. It is considered that a further increase in fishing effort and in the catch of small fish should be avoided. The fall in hook rate due to increase in the fishing effort causes voyages to be longer. Thus, the management of the fishery itself is faced with difficulties. In order to achieve an improvement of such conditions, it is advisable to restrict the catching of small fish which causes an effective reduction of fecundity; to reduce the fishing effort and to improve productivity. Even if the fishing effort were reduced to the level of the middle 1960's, and there was a temporary reduction of the catch, nevertheless in about four years, a catch equivalent to the size before the reduction can be expected (Far Seas Fish. Res. Lab. 1972) (Fig. 53).

Taking the viewpoint discussed above, the Japan Federation of Tuna Fishing Cooperative Associations and the Japan Tuna Fishing Industrialists Association decided in May 1971 to introduce a voluntary restriction of southern bluefin tuna fishing. The restriction has been in force since 1 October 1971. The detail of the restriction is as follows:

The Japan Federation of the Tuna Fishery Cooperative Associations and the Japan Tuna Fishing Industrialists Associations decided at their 'Ordinary General Meeting for 1971' held on 14 May 1971 to introduce voluntary restrictions as follows:

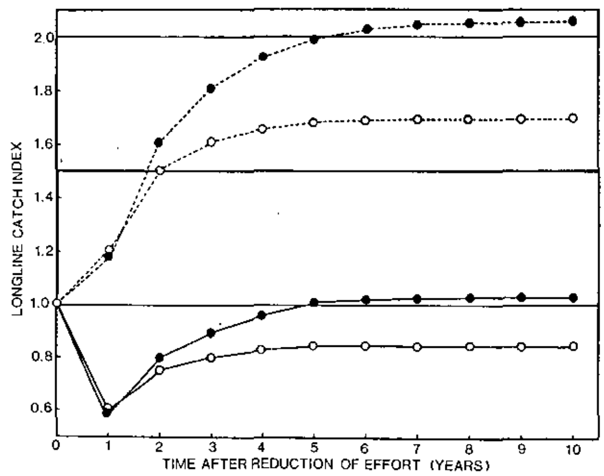

Fig. 53. Annual changes of the estimated yield (solid line) and the yield per unit of fishing effort (dotted line) for fishing coefficient 0.6-1.2 for longline fishing aiming at fish 4 to 13 years of age. In the calculation fishing coefficient of the surface fishery aiming at 2-4 year fish is taken as 0.20; growth coefficient of southern bluefin is taken as 0.15, natural death coefficient is taken as 0.20. (Fishing coefficient = 1.2 x longline catch index)

The start of the restrictions: 1 October 1971.

The method of restriction: Prohibition of longline operations (including hand-line fishing) for tuna in the sea areas during the periods mentioned below.

(i) The sea area demarcated by 120°E, 140°E, 40°S and by the Australian continent: from 7 October to 31 March of the following year, every year.

(ii) The sea area demarcated by 95°E, 110°E, 27°S and 20°S: 1 December to 31 March every year.

(iii) The sea area demarcated by 145°E, 151°E, 40°S, 35°S and by the Australian continent: 1 May to 31 July every year.

(iv) The sea area demarcated by 15°E, 35°E, 45°S and 38°S: 1 October to 31 January every year.

The main object of the restrictions is to close seasonally the fishing grounds indicated by Fig. 54 where the small fish gather and to prohibit fishing of small fish so that the age of first capture be raised and the size of parent stock be maintained at a certain level. In addition to that, the ban on operations has been imposed for a fixed period in the west of Australia and in the Oki fishing grounds where the spawning adults migrate from the south. This restriction does not include restriction of fishing effort. Therefore from the standpoint of the stock control it cannot be considered satisfactory. Nevertheless, it should be seen as an indication of the emergence of a central organization which would supervise a rational utilization of the tuna stock.

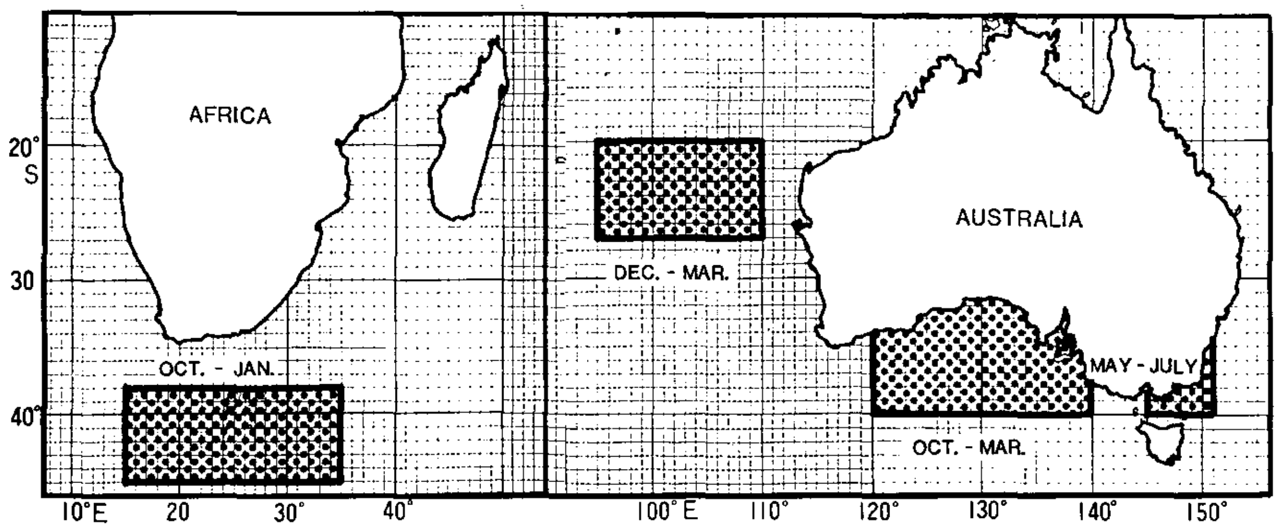

Fig. 54. Areas and periods of the southern bluefin fishing grounds closed by voluntary restrictions

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