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SHOALING TENDENCY IN TUNA OBSERVED IN THE GREAT SUNDA ARCHIPELAGO

by

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Tuna-fishing by long-line, which is still the most important fishing method for tuna**, was prevalent long ago in Japan, although prior to 1880 or thereabout the area of operation had not extended beyond 25 miles from the coast. However the application of the internal combustion engine to fishing boats resulted in a great advance in the fishing system and extended the area covered. To-day, however far the fishing ground may be, fishermen will go there spending a considerably long time for a round trip, if they are able to obtain better catches. The fishing grounds thus extend from year to year.

During the oceanic training cruises of the *Shunkotsu-Maru*, the training ship of the Shimonoseki College, in the waters near the Great Sunda Archipelago during the period from December 1953 to February 1954, I endeavored to find some clues as to whether tuna form shoals, and if so, how the shoal-forming tendency and the rate of exploitation are correlated; for these two problems seemed indispensable for the estimation of the population density of tuna and also for the evaluation of the fishing grounds and the long range effect of fishing upon the population. In this report, I shall take up, as preliminary studies for the estimation of the size of shoals; the question as to whether the distribution of fishes and the composition of stomach contents change horizontally and vertically, and whether the fishes form shoals. Some conclusions are also given on the relation between the rate of exploitation and the shoal-forming tendency.

SURVEYED AREA AND COMPOSITION OF THE LONG-LINE ASSOCIATION

The outline of the fishing ground covering the stations where the long-lines were set up is shown in Fig. 1. All fishes caught by the same long-line are considered to be swimming about at the same depth in the same area and taking common bait. Accordingly, all of these fishes may be regarded as constituting an ecological unit which is called here for convenience an 'association'. The associations in the waters near the Great Sunda Archipelago consisted of the following animals in the respective fishing grounds:

(1) Near Great Nicobar I. (Stations 1 and 2)
Neothunnus albacora (Lowe)
Sharks
Makaira marlina Jordan & Hill
Xiphias gladius Linne

(2) Off the northern end of Sumatra (Station 3)
† *Neothunnus albacora* (Lowe)
Parathunnus obesus (Lowe)
† Sharks
Makaira marlina Jordan & Hill
Acinacea notha Bory et St., Vincent

(3) Near Nias I. (Stations 4-8).
† *Neothunnus albacora* (Lowe)
Parathunnus obesus (Lowe)
Thunnus alalunga (Bonnaterre)
Makaira marlina (Jordan & Hill)
Xiphias gladius (Linne)
Histiophorus orientalis (Temminck et Schlegel)
† Sharks
Lepidocylium flavo-brunneum (Smith)
Coryphaena sp.
Sphyraena picuda Bloch et Schneider

(4) South of Lombok I. (Stations 10-15)
† *Neothunnus albacora* (Lowe)
Parathunnus obesus (Lowe)
Thunnus thynnus (Linne)
Xiphias gladius (Linne)
Histiophorus orientalis (Temmink & Schleger)
† Some kinds of Sharks
Coryphaena sp.
Sphyraena picuda Bloch et Schneider
Alepisaurus borealis (Gill)
Serranus sp.

Abundant animals are marked with a †; *Thunnus thynnus* is called by Japanese fishermen 'Indian tuna'.

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** The word 'tuna' used hereafter indicates exclusively *Neothunnus*.

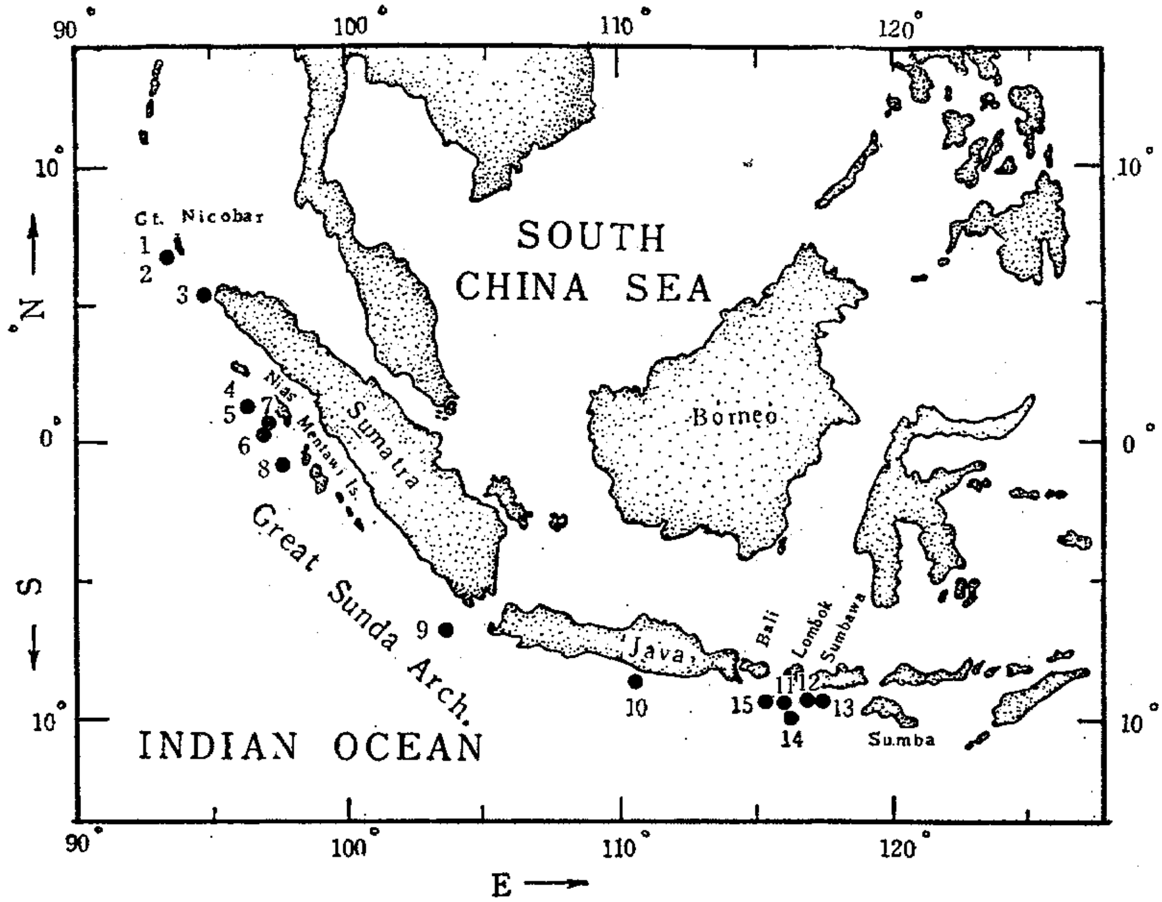

Fig. 1. Chart showing Station Positions.

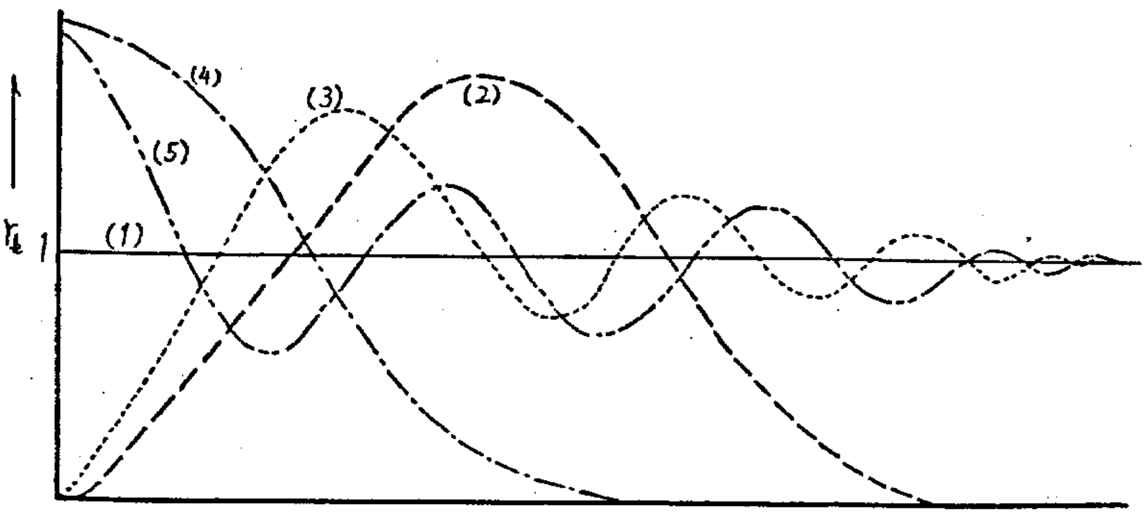

Fig. 2. $k-\gamma k$ relation diagram of each type of ideal shoals.

FOOD HABITS OF TUNA AND SPEARFISHES

The compositions of the stomach contents of the major fishes are represented in Fig. 3(A)-1 to (G)-4* in which the respective preys taken by each fish are shown in wet weight. The food of *Neothunnus* and other tuna consists mainly of fishes—mostly small file fishes and bramiform fishes—and partly of crustaceans, most of which are larval forms such as Erichthus and Megalopa of shrimps like *Metapenaeus*. The spearfishes take chiefly larger fishes such as skipjacks and large tetradontid fishes and only a small amount of crustaceans. The figures show that the main food of *Neothunnus*, the most abundant fish in the surveyed area, differs in accordance with the fishing grounds.

VERTICAL DISTRIBUTION OF FISHES

In the long-line gear the main line is longer than the average flag interval, consequently all hooks are by no means situated at the same depth, but are supported at several levels. Yoshihara (1954) made some observations on the depth of the hooks of such a long-line gear under the supposition that the form of the main line is catenarian and discussed the relation between the situation of hooks and the number of fishes actually caught by the hooks, leading to the conclusion that the rate of exploitation changes very sharply according to the relative depth of hooks. Therefore, it is necessary, before the horizontal distribution of fishes is discussed, to examine whether in the present cases the rate of exploitation changes significantly in accordance with the relative depth of hooks. Each basket of gear used in the present study contained 5 hooks, hooks No. 1 and 5 being situated at about 60 m., No. 2 and 4 at about 80 m., and No. 3 at about 100 m. The number of fishes actually caught by the respective hooks seems superficially to differ in accordance with their relative depth, although such differences in the exploitation rate are doubtful, because the exploitation rate at each hook is very small. In order to obtain more information, the following experiment was carried out.

The hooks were divided into five groups in order. Although it is usual in such cases to divide the hooks into three groups, the degree of freedom is too small in this trisected case, about a half of that obtained when divided into five groups. Thus, the homogeneity of the orders of hooks in respect of the ratios (*a*) *Neothunnus* : sharks : spearfishes : other fishes : no catch and (*b*) *Neothunnus*: remainders, was examined. It was found that the composition of long-line association did not differ vertically, neither did the exploitation rate differ in accordance with the order of the hooks and consequently with depth.

VERTICAL DIFFERENCE IN THE COMPOSITION OF STOMACH CONTENTS

Although the exploitation rate did not differ with depth, it is still uncertain whether the stomach contents of tuna caught in different layers would differ from one another. To determine if the differences in the composition of stomach contents between some groups of fishes are significant or not, it must be examined whether the interclass differences of the z-transformed values of the weight percentages of respective prey organisms taken by respective individuals are significant or not, as compared with the intraclass differences of the same values. We can learn, by this method, whether the quantitative differences in each type of prey organisms are significant or not, but we are not yet able to reach the conclusion about the stomach contents as a whole, when the results of the examination of the respective prey organisms are not alike.

To make good this deficiency, I adopted for trial, as a simple method treating the stomach contents as a whole, the z-transformed values of the correlation coefficients between the composition of stomach contents of the first individual and those of respective ones of other individuals, instead of the weight percentages of respective prey organisms. In this case, the vertical differences in the stomach contents are regarded as significant, if the correlation coefficients between the compositions of stomach contents of the first individual and those of the fishes caught by hooks kept in the depth where the first individual was caught are significantly higher than the coefficients between the first individual and the fishes caught by hooks situated in different layers, namely when the stomach contents of the fishes caught at the same depth are similar to one another more significantly than those of the fishes caught from the different layers. The results of the analysis of variances are shown in Table III. It is assumed that, as the null hypothesis, the average value of the coefficients calculated between the individuals caught in the same layer is the same as that obtained between the individuals caught from the different layers. F_0- values are far smaller in all cases than the corresponding values shown in the F-table. Consequently, it is not necessary to estimate more accurately all correlation co-efficients reciprocally to deduce the conclusion.

From the results of the above-mentioned method, it may safely be said that the compositions of stomach contents of tuna do not differ in accordance with the relative depth where fishes are caught.

* Available at the Indo-Pacific Fisheries Council Secretariat.

Relations between the number of Sharks and the number of Tunas in the same horizontal plane and between the former and the damage rate of Tuna by Sharks

When I considered in my previous paper (1953) the horizontal relations between the habitats of several sorts of salmons which have no predatory relation to one another, I used the correlation coefficient between the individual numbers of respective species caught in each section of the net in each haul. But in the present case, a conspicuous predatory relation is observable between tunas and sharks. The latter attacks the former. Consequently, it is possible that the distribution of sharks is alterable by the distribution of tuna and *vice versa* and that the proportion of damaged individuals to the total individual number of tuna may differ in accordance with the distribution of sharks. Therefore, I computed, as in the case of the salmon gill-net, the correlation coefficients between the number of sharks and that of tunas caught in 3, 4 and 5 baskets of the long-line, which were used as the unit length. The results are shown in Table IV, in which most values are slightly negative, but cannot be regarded as significant. Thus, tunas and sharks are considered to be distributed independently of each other and also the number of sharks and the individual number of damaged tuna or the damage rate to tuna by sharks, are independent of each other.

It was concluded that the distribution of sharks is not dependent on the distribution of tuna and the damage rate of tuna by sharks does not necessarily reflect the distribution of sharks.

The relation between the composition of stomach contents and the horizontal distance between the positions where Tunas were caught.

Although I have reported above that the composition of stomach contents does not differ with the relative depth where the fishes were caught, it is necessary to pay some attention to the relation between the composition of stomach contents and the distance between the positions on the long-line, where respective individuals are caught, as a preliminary step to estimating the size of shoals. For the examination of this problem, I used for convenience the same method as in the case of the vertical distribution of the stomach contents. Thus I examined whether the regression coefficient of the z-transformed values of the correlation coefficients between the composition of stomach contents of the first individual and those of respective ones of other fishes, to the distance between the first individual and respective ones of other fishes, is significant or not. Thus, I examined whether the composition of the stomach contents differs according to the distance between fishes or not, though it was not known what components increase or decrease from one end of the long-line towards the other end. The results of the examination are shown in Table V.

The distance of the hooks and the nature of the composition of the stomach contents were found to be independent of each other.

ANALYSIS OF THE DISTRIBUTION IN SPACE

Although the different hooks are not situated in a layer of exactly the same depth, it would seem safe in the present case to consider the data irrespective of the difference in depth; because neither the rate of exploitation nor the composition of the stomach contents differed with depth. As the usual methods for determinating the statistical distribution of frequencies do not take into account the special relation among the numbers of individuals caught by respective units of gear, it is necessary to examine the distribution in space, before we consider the statistical distribution type of frequencies. Thus I employed Morisita's second method for the analysis of distribution in space in the case of the salmon distribution on the gill-net. His first method is applicable when the exact position of each individual is known and the points capable of being occupied by individuals are continuous, while his second method is suitable in cases where the points capable of being occupied by individuals are distributed at regular intervals and the number of individuals obtainable at each point may vary widely. In the case of the long-line, the points capable of being occupied by individuals are distributed at regular intervals, but the point $z\,(n+1)$ in order from the first hook are hypothetical ones incapable of being occupied by any individual (here, n is the number of hooks in one basket, z is 0, 1, 2 ...... and the actual length of $n+1$ is about 250 m). Besides, zero or one individual may be caught at each point. For the reasons mentioned above, it is proposed to establish a new formula under such a peculiar condition (unit length under consideration is the mean interval of hooks).

$$P_{(k)} = \frac{N - k - 2(m-a) + (m-b)}{\dfrac{m\,n\,(m\,n-1)}{2}}$$

Here m = number of baskets used in respective operations.

n = number of hooks in one basket.

$$N = m(n+1) + 1,\ \frac{k}{n+1} = a > \frac{k}{n+1} - 1,$$

$$b = \frac{k}{n+1}.$$

$P_{(k)}$ = probability of occurrence of other individuals at the point k in order from a certain point occupied by an individual.

a must be a regular number.

The value b must be treated as zero when this value is not a regular number. As actually observed, the following value is obtainable:

$$P(k) = \frac{X_k}{\frac{T(T-1)}{2}}$$

Here, T is the total number of fish caught. X_k is the number of pairs of fish at the interval of k. Then, the following value is used more conveniently, when the distribution in space is considered:

$$\gamma_k = \frac{p(k)}{P(k)}$$

When the fishes are distributed at random, r always becomes 1 (represented by type 1 in Fig. 2). When there is a single but self-spaced shoal it is indicated by type 3. When there is a single continuous shoal it is shown by type 4, while it is represented by type 5 when there are many continuous shoals.

(Fig. 4(1) to (8)* show the values of γ_k actually observed and Fig. 5 (10) to (14)* represent the actually observed values of X_k in the cases when the total number of caught fishes is far less than in the cases represented in Fig. 4(1) to (8) and p(k) is considered to include considerably accidental errors, because values of X_k are mostly one or two.)

It was concluded that the distribution of fishes appears in most cases to be rather at random, although it is somewhat difficult to obtain definite conclusions from these figures—especially from Fig. 5 (10) to (14), because most of the values of X_k actually observed are very few and consequently accidental errors are very likely.

THE DISTRIBUTION TYPE OF FREQUENCIES OF THE INDIVIDUAL NUMBERS OF FISHES CAUGHT BY GEARS OF 1, 2 AND 3 BASKETS

It has been shown above that the rate of exploitation does not vary with the depth of the hooks, thus the numbers of tunas and sharks caught in each part of the gear are independent of each other, and that the distribution of tuna does not exhibit any horizontal continuity. It may, therefore, be possible to obtain the approximate distribution of frequencies of the individual numbers caught by gears of 1, 2 and 3 baskets by the following process: where the probability of exploitation at each hook is $p = T/mn$ and the probability of unexploitation as $q = (1-p)$, then the random samplings of n, $2n$ and $3n$ are tried (here, n is the number of hooks in a basket). The frequency distribution, with which N individuals may be caught by gear of one basket is given by the following equation:

$$P_N = n\,C_N\,p^N q^{n-N}$$

The actually observed frequencies and the estimated ones of individual numbers obtainable by gears of 1, 2 and 3 baskets which are used respectively as the unit length of the long-line under consideration are shown in Fig. 6 (1)-1 to (14)-3.*

Comparing the actually observed distribution of frequencies and the estimated one with each other, it is found these are not so different from each other in cases when the p values are not large, but as the p value increases the difference between the actually observed distribution of frequencies and the estimated one grows rather conspicuously and the former begins to show a slight continuity.

THE RELATION BETWEEN THE RATE OF EXPLOITATION AND THE DIFFERENCE OF THE OBSERVED DISTRIBUTION OF FREQUENCIES FROM THE RANDOM DISTRIBUTION

The conclusion of the previous section led to attention being paid to the relation between the rate of the exploitation and the difference of the observed distribution of frequencies from the estimated distribution. For the analysis of the above-mentioned relation the whole or each term of the frequencies must be taken up. However, it is very difficult to treat the distribution as a whole and also it is confusing to attempt to deduce the conclusion for the distribution as a whole by taking each term into consideration. So, I treated only the O-term this time and used the value (d)—observed frequency / estimated one—of the O-term as an index of the distortion. This value may be regarded as an abbreviated index of continuity, although it is more or less uncertain, in such cases when all of the terms are only of the weakly continuous type. To ascertain whether d changes in accordance with p, the rate of exploitation, I examined whether the regression coefficient of d on p *is* significant; the results obtained are shown in Table VIII. The shoaling tendency of fishes is higher in the area where the exploitation rate is higher.

So far as the rate of exploitation observed in the present study is concerned, the shoaling tendency varied with the rate of exploitation, although the rate was not high.

* Available at the Indo-Pacific Fisheries Council Secretariat.

SUMMARY

1. Observations regarding the shoaling of tuna and the relation between the rate of exploitation and the shoaling tendency are discussed on the basis of data obtained during December 1953 to February 1954 in the waters near the Great Sunda Archipelago.

2. The outline of the fishing grounds and the composition of the catches made by the tuna long-line are furnished.

3. The Compositions of the stomach contents of the chief fishes is given.

4. Vertical differences in the ratio, *Neothunnus* : sharks : spearfishes : other fishes : naught, and of the rate of exploitation of tuna are found to be of no significance.

5. The composition of the stomach contents of tuna and the depths from which they are caught have no relation.

6. Tuna and sharks are distributed independently of each other and the damage rate of tuna by sharks is also independent of the number of sharks.

7. Horizontal distance between individuals of tuna caught and the nature of the stomach contents are independent of each other.

8. With the help of a new formula, distribution of tuna in space is shown to be mostly at random in the present cases.

9. The distribution of tuna does not differ much from Bernoulli's distribution, when the exploitation rate is not high, while a difference between the observed distribution and Bernoulli's distribution increases with an increase in the rate of exploitation with which is also associated a rather continuous distribution.

10. The shoal forming inclination changes in accordance with the rate of exploitation within the range of moderate exploitation studied.

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TABLE I

Date, number of tuna caught and gear used at each station

St.	Date	No. of gear	Total catch of tuna[2]
1	Dec. 26, '53	60	52
2	27	56[1]	64
3	29	80	43
4	31	61	62
5	Jan. 2, '54	60	29
6	3	80	28
7	4	80	28
8	5	80	28
9	8	40	4
10	16	80	10
11	18	80	13
12	19	80	20
13	20	100	8
14	21	80	8
15	22	80	1

Note :—Position of each station is shown in Fig. 1.

(1): The total number of gear used in this operation was 60, of which the last 4 were omitted, because they were tangled and the accurate position of the fishes was not clear.

(2): Damaged individuals are included.

TABLE II

An example of actually observed ratio, Neothunnus : *sharks : spearfishes : nought, in each order of hooks (St. 2)*

Order hook	1	2	3	4	5	Total
Neothunnus	11	14	14	12	13	64
sharks	5	8	13	17	10	53
spearfishes	0	1	0	0	1	2
other fishes	0	0	0	0	0	0
naught	40	33	29	37	32	171

TABLE III

Results of the examinations of the equality of the mean values of similarities of the composition of stomach contents of fishes caught in different layers.

St.	No. of observed individuals in respective layers					F_0	n_1	n_2	$F^{n_1}_{n_2}(0.05)$
	Shallower-2	Shallower-1	f.1.	Deeper-1	Deeper-2				
1	3	4	2			0.07	2	6	5.14
2	5	6	2			0.23	2	10	4.10
3			11	10	2	1.24	2	20	3.49
4	12	10	8			0.17	2	27	3.35
5		8	8	1		0.21	2	14	3.74
6			5	7	2	0.20	2	11	3.98
7			5	4	2	0.57	2	8	4.46
8		5	6	0		1.19	1	9	5.12
11			3	4	1	1.09	2	5	5.79
12	5	2	3			2.34	2	7	4.74

Note :—The stations where the samples of stomach contents were too scarce are not included.

f.l. : The numbers in this column show the individuals caught in the layer where the first individual was caught. The number of samples obtained from a little shallower or deeper layer than the f.1. (fixed layer) is shown in the column of shallower-1 or deeper-1 and that from much more shallow or deep layer is given in the column of shallower-2 or deeper-2.

TABLE IV

Correlation coefficients between the number of sharks and that of tunas and between the former and the damage rate of tuna by sharks in 3, 4 and 5 baskets of gears.

St.	No. of gear under consideration	Correlation coefficients		
		T-S	D-S	Dr. - S
1	3	- 0.43	- 0.48	0.05
	4	- 0.59	- 0.60	0.45
	5	- 0.53	- 0.52	0.32
2	3	- 0.04	0.19	0.46
	4	- 0.08	0.33	0.72x
	5	- 0.01	0.15	0.23
7	3	0.11		
	4	- 0.07		
	5	- 0.02		
10	3	- 0.30		
	4	- 0.28		
	5	- 0.13		
11	3	0.23		
	4	0.11		
	5	0.34		
12	3	- 0.09		
	4	- 0.20		
	5	- 0.10		

Note:—The values, not shown in this table, are excluded because the number of tuna or shark was too small in those areas. The values with asterisk are regarded to be significant at 0.05 level of significance.

T : *Neothunnus*, S : sharks D : damaged individuals of *Neothunnus* Dr. : damage rate of *Neothunnus* by sharks.

TABLE V

Results of the examination on the regression coefficient of the z-transformed values of the correlation coefficients between the composition of stomach contents of the first individual and those of the subsequent ones, on the distance between the first and the subsequent individuals

St.	F	n_1	n_2	$F^{n_1}_{n_2}(0.50)$
1	0.41	1	7	5.59
2	0.06	1	11	4.84
3	1.58	1	21	4.32
4	1.23	1	28	4.20
5	0.18	1	15	4.54
6	0.11	1	12	4.75
7	0.92	1	9	5.12
8	2.52	1	9	5.12
11	0.15	1	6	5.99
12	6.41*	1	8	5.32
14	3.42	1	8	5.32

Note :—The cases not shown in this table are omitted since they were very few. The value with asterisk is regarded to be significant at 0.05 level of significance.

TABLE VI

Results of the examination whether the regression coefficient of d *on* p *is significant*

Unit of gear under consideration	n_1	n_2	F_0	$F^{n_1}_{n_2}(0.05)$	A	B
1	1	11	5.73	4.84	0.98	0.59
2	1	10	11.90	4.96	1.45	3.57
3	1	10	9.95	4.96	0.38	15.61

Note : $d = A + Bp$