A Tentative Analysis of the Distribution Pattern of Tuna Projected on the Long-line※

By

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Contents

※ Contribution from the Shimonoseki College of Fisheries, No. 293.
Received October 22, 1959.

Introduction

Generally speaking, people are apt to consider the fishes have the tendency to form schools; and actually we often see a considerably compact schools of not only various pelagic but also some benthonic fishes. At the same time, however, it has been believed on the other hand, that the school formation is a general habit found in animals of rather lower food ranks and cannot be observed in the animals ranked at the higher trophic levels, which live usually solitarily and sometimes show the territorial habit. Notwithstanding the above-mentioned general conception, there are some cases in which marine animals of higher food ranks swim in schools as we see such facts in porpoise and sharks, both very active and voracious predators. Then, what is about tuna ? —— The tuna, which seem to be situated in a little lower food rank than sharks, but they are as large as the latter. It is believed by Japanese fishermen that the albacore is the only member of tuna, which swims in school, while grownups of yellow-fin and big-eye have never been observed swimming in school in the open sea except for several rare cases under such exceptional circumstances as swimming with whale or drift timber (for example, observable at Sagami Bay in summer) settling around reef (observable around the Bonin Islands) or attacked by porpoise, although they can occasionally be observed in the solitary state. Here lies, however, a question: whether they do not form any school really or they have the tendency to form schools, but we cannot discern it, because their schools are formed in the scale too big to be conceived as schools by our general conception of schools. Their high activity and so quick swimming ability seem to induce the requirement of a wide space for every tuna, consequently schools of an enormous scale beyond our general conception of schools might be formed without being easily discerned by people. Only a few papers have been published on the problems concerning this question: the details of the distribution of individuals within respective limited areas which we call fishing grounds, for instance a problem whether fishes are distributed uniformly, randomly or forming schools in the fishing ground under consideration, or that whether the difference of the density found among the different fishing grounds is simply attributable to the difference of the density itself or, besides it, also to the difference of the distribution pattern. On other items such as the geographical distribution of catch rate*, the relation between catch rate and oceanographical conditions and so on, all are very important and effective to find out good fishing grounds, many valuable works have been already published. Thus, the study to make clear the most detailed distribution pattern of tuna within respective fishing grounds or along respective long-lines seems to be one of the unexplored but fundamentally most important fields in fishery ecology, because it might give us chances to understand some theoretical bases for improving gears and

*The words "catch rate" used in this report indicate the occupied probability of a hook by individual of a certain species.

evaluating fishing grounds and for sampling method and the statistical transformation of many variates obtained by respective operations. Also it will be very helpful for us to find out some clues to solve questions about the social habits of fishes and the variabilities found in gonad maturity, age composition, stomach contents, the degree of radioactive contamination and many other biological phenomena observable among the individuals caught by a row of gears. Actually, however, we can hardly find any direct method to know the distribution pattern of tuna in deeper layers, sometimes reaching more than 100 m deep, in vast ocean; even if the problem is limited within the range of a single row of gears, the area should reach more than 50 km in extent. Most probably any of the experimental methods, if we could find them, cannot be easily put in practice, because the scale of the experiment is so big, and consequently too expensive to do. For these reasons, it seems to be a practical and effective way to adopt here such indirect theoretical methods as the analysis methods of the insect population to analyze the distribution pattern of tuna. In the following, I want to try the analysis of the distribution pattern of tuna by using such an indirect theoretical method and I am going to forward the work as a new unexplored branch of fishery ecology rather than a branch of statistics or mathematics.

To judge whether the fishes are forming schools or living solitarily, it is a very common way to make the examination of frequency distribution of individual numbers caught in respective sections, comparing the results with those induced from some theoretical distributions such as POISSON'S, binomial, PÓLYA-EGGENBERGER'S, NEYMAN'S, COLE'S, or THOMAS' ones. But this method shows the following defects that the sections in each of which no individual is caught or those in each of which many individuals are caught might occur successively or at random——; in other words, when the unit division is too large, the existence of small schools cannot be detected by statistical treatment, and contrarily when it is too small, the large schools may be divided into several partitions and the characteristics of the schools become quite obsolete. To fill up this deficiency, it is necessary to use some other methods in which a row of distributions is treated individedly as a continuous one. On this standpoint, the works of MURPHY and ELLIOT (1954) and MORISITA (1950, 1954 a, 1957 and M. S.) cited here seem to be appraised very highly. MURPHY and ELLIOT (1954) analyzed the abovementioned relation by using the most probable number of runs, while MORISITA (1950) proposed a new trial —— one of the spacing methods —— for the analysis and illustrated the formulae representing the random movement or random distribution of individuals along the straight line, on the plane or in the space and applicable to the series of unit divisions in each of which from zero to infinite number of individuals can be included. And I also made an analysis of the distribution pattern of five species of salmons (dog, pink, red, silver, and king salmons) along the gill-net (1953) by using MORISITA'S formulae for the continuous series. However, in the case of treating the long-lines, there are some peculiarities that the points which can be occupied by individuals are distributed at regular intervals, the points $a(H+1)$ (here, H is the number of hooks attached to a long-line in a basket and a is a positive integer) in the order from the first point are hypothetical ones incapable of being occupied by any individuals and, moreover, at each point only a single individual or none can be caught. Thus I was obliged to endeavour to establish new formulae applicable to the long-lines with such peculiarities mentioned above. I constructed the formulae applicable to the long-line having the same catch rates vertically and horizontally and analyzed the distribution pattern of yellow-fin tuna along the long-line by using these formulae (1955). The method adopted by MURPHY and ELLIOT (1954), and also the correlogram, don't seem to be available for the examples, in which the catch rate increases with the soaking time as pointed out already by themselves. Actually in a considerable number of examples offered by the professional or research fishing boats, the catch rate seems to increase with the soaking time. Even in the examples where the regression coefficient of catch rate on number of baskets or lots can not be regarded as significant, we often cannot but suspect the existence of a weak tendency of increase of the catch rate, although such increases can not be regarded as significant on account of their irregularity. Besides the fact mentioned above, they also pointed out that the tendency of schooling of tuna might probably be greater than that deduced from the analysis by using the most probable number of runs for the following four reasons: (1) some hooks may be occupied by fishes other than tuna, (2) the effect of the existence of buoy lines, (3) all the hooks are not situated strictly at the same depth and (4) the decrease of the potential sequence of tuna caused by stealing of bait by fishes other than tuna. By adopting the spacing method, effect of the existence of buoy lines can be removed by making an assumption and the influence of the increase of catch rate with the soaking time and that of the difference of the situation of hooks in depth can be corrected by constructing the formulae applicable to respective circumstances.

In this report, at first the constructing-processes of the theoretical formulae representing the chance distribution, which are used for the present analysis and mostly established newly, the analytical processes of the distribution patterns of some examples of yellow-fin tuna and big-eye tuna, both of which are thought as being distributed nearly by chance, and albacore, the young individuals of which are thought to form schools, and appendantly those of a few examples of sharks and marlins, which are located in higher food ranks than tuna and caught together with tuna, are illustrated. Then, in the last half, the analytical processes of the distribution patterns and the examples of the positional inter-relations between yellow-fin tuna and big-eye tuna, tunas and marlins or tunas and sharks are illustrated, as I found that such relations can be easily analyzed by using the same formulae as those adopted for the analyses in the first half and, moreover, such relations seem to be very interesting for us marine ecologists.

Acknowledgement

Before entering into the subject, I must express here my sincere thanks to Prof. Dr. D. MIYADI of the Zoological Institute of Kyoto University and Dr. T. TOKIOKA of the Seto Marine Biological Laboratory for their kind guidance and advices given to me during the present series of works. Also I want to record here my hearty thanks to Dr. A. L. TESTER of the Pacific Oceanic Fishery Investigations, Honolulu, Hawaii, U. S. A., Prof. Dr. S. UTIDA of the Entomological Institute of Kyoto University, Dr. M. MORISITA of the Biological Institute of Kyushu University, Prof. Dr. I. MATSUI and Prof. S. ERA of the Shimonoseki College of Fisheries, who assisted me much in giving facilities and many valuable advices which were all very effective and useful for carrying out this work and to Mr. M. SEKINO and any other staffs of the Shizuoka Prefectural Fisheries Station, Mr. T. UCHIDA of the Miyazaki Oceanic Fisheries Station and all the crews and cadets of the Dai-fuji-maru (a training boat of the Yaizu Fisheries High School) and the Shinyo-maru (a training boat of the Miyazaki Fisheries High School), who so kindly submitted their precious data to my study shown in the present paper. Thanks are also due to Japanese Tuna Fisheries Association who gave me helpful support through Prof. S. TSURUTA's courtesy (Shimonoseki College of Fisheries) in publishing this article.

Historical

1. The outline of the tuna long-line fishery in Japan and the studies on tuna and tuna fisheries

Tuna long-line fishery, which is the most important method for fishing tuna in these days, has been prevalent since long ago in this country, although the operation had never extended beyond 25 miles off the coast before 1880 or thereabout. The application of modern internal combustion engines to the fishing boats, however, extended the fishing area to the unexpectable scale and also brought countless advances in the fishing system. In these days the tuna fishing boats over 500 tons and equipped with the radar, loran, magnetic auto-pilot *etc.*, are not rare in our country. These vessels go out for tuna fishing to the waters far east of the Hawaiian Islands, the waters near the Madagascar Channel or even to the Atlantic Ocean if some good catches can be expected there within a certain limit of time. Japanese fishermen can not hesitate to spend a considerably long time for the round trip to the fishing ground under present circumstances. The tuna fishing ground for Japanese fishermen thus has been extending year by year and now it covers nearly all the Pacific and Indian Oceans and even a part of the Atlantic Ocean.

NAKAMURA and his collaborators in the Nankai Regional Fisheries Laboratory, the staffs of the Kanagawa Prefectural Fisheries Station (1928—1959), SCHAEFER, SHIMADA, MURPHY and their associates in the Pacific Oceanic Fishery Investigations and the Inter-American Tropical Tuna Commission in the United States (1950—1959), YOSHIHARA (1951—1957), KUROKI (1956) and some others have published many valuable ecological or technical papers on tuna and the tuna long-line fishery. In these papers, the seasonal change of the geographical distribution of tuna, the geographical differentiation of morphological or biometrical characteristics, the problems of the stock, the horizontal and vertical distribution of fishes along the long-lines, the relation between the catch rate and the oceanographical or meteorological conditions, the food habits, the improvement of gears and many other problems are explained extensively. Of these works, those closely related to my present study are quoted in respective parts of this report.

2. Summaries of the biological studies done by using the similar method

The works in which the biological distribution is analyzed can be classified into the following two groups: one comprises the works in which the distribution is examined for the purpose of deducing the social habits or the mechanisms of dispersion from the basic assumptions constructing the theoretical distribution applicable to the actually observed distribution —— in other words these are **Ecological works**, while the other includes the works in which the distribution is examined as merely a preliminary procedure of a certain statistical treatment other than the ecological purpose —— in other words these are **Statistical works**.

1) Ecological works

The early works in this field were done mostly by entomologists. BEALL (1935) is the first person who adopted the theoretical frequency distribution. Then, RICHARDS (1936) reported that the first generation of the common cabbage butterfly (*Pieris rapae*) is distributed at random while in the later generations than the second the distribution is biased from random; MARSHALL (1936) found that the egg masses of the American bollworm (*Heliothis obsolata*) are distributed by chance; BEALL (1940) estimated the frequency distribution of larvae of *Loxostege stictialis* on the supposition that their distribution might follow NEYMAN'S type A, B or C. UTIDA (1943) reported that the frequency distribution of number of eggs of Azuki bean weevil, *Callosobruchus chinensis*, on respective bean is hyponormal when the population density is low but it follows POISSON'S distribution when the population density is neither low nor so high, or it becomes hypernormal when the population density is clearly high. Recently UTIDA and his collaborators (1952—1957) published a series of comprehensive works on the field populations, in which it is stated that the distribution of eggs of common cabbage butterfly (*Pieris rapae*) follows PÓLYA-EGGENBERGER'S distribution, while its larvae are distributed according to a compound type of POISSON'S and binomial ones, that the frequency distribution of the rice-stem borer, *Chilo simplex*, in the paddy field follows PÓLYA-EGGENBERGER'S distribution under the estimation of the frequency distribution supposing that it follows POISSON'S distribution, PÓLYA-EGGENBERGER'S or NEYMAN'S one of type A, that the frequency distribution of egg-masses of the spotted lady beetle, *Epilaclina sparsa orientalis*, follows POISSON'S distribution, and that the frequency distribution of the second or the third instars of larvae follows the distribution of NEYMAN'S type A but that of the fourth instar of larvae, pupae or adult beetles agrees well with the PÓLYA-EGGENBERGER'S distribution. And they deduced from these facts some knowledge upon the social habits and the mechanisms and processes of dispersal in these insects.

On the other hand, TORII (1952 and 1956) illustrated comprehensive and detailed descriptions of the estimating method for the distribution pattern of insect natural populations, in which he reported that the frequency distribution of egg-masses of *Promachurus yesoenus* born in the homogenous association in the lawn chiefly constituted of low-stemed Graminaceae follows POISSON'S distribution while that of those born on the barbed wire is hypernormal and then he estimated the frequency distribution of *Pyrousta nubialis* on the supposition that they follow the distribution of NEYMAN'S type A, B or C. He found also that the frequency distribution of *Anomala testaceipes* assembled each of 5 minutes around the lamp lighted for the first time follows convolute POISSON'S distribution, while it agrees with the POISSON'S one after the second night, and that the distribution pattern of *Stenocranus tateyamanus* living in the sedge vegetation may follow the gamma type of the compound POISSON'S distribution. He then analyzed the distribution patterns of many other insects by similar manner and gave careful consideration to the social habits and the mechanisms and processes of the distribution pattern and dispersal in respective cases.

COLE (1946) examined in detail the quantitative distribution of certain floor invertebrates —— spiders, isopods, diplopods and insects —— that live, among other place, under boards in the interface between the board and the ground, and found that spiders were only one group of animals which are distributed at random in all observational area for all seasons of the years, while for the other animals he constructed a type of convolute POISSON'S distribution and estimated the number of primary groups of respective size. Besides the above-mentioned works, many notable papers have been published by ROMELL (1930), BLACKMAN (1935), CLAPHAM (1938), ARCHIBALD (1948) and others on distribution of plants.

MORISITA (1950) noticed a considerable difference between the actually observed number and the estimated one when he compared the actually observed number of copulating pairs of *Gerris lacutis* with that estimated by using COLE'S distribution and proposed a new trial of spacing method, the details of which are already shown in the introduction of this paper. For the similar purpose, MURPHY and ELLIOT (1954) applied the analysis of sequence to the study on the distribution of yellow-fin tuna along the long-line, in which the most probable number of runs is determined from the total catch and the number of hooks.

As for other marine animals, YOSHIHARA (1953) analyzed the distribution of *Tectarius granularis*. KUROKI (1956) tried to estimate the size of albacore schools in the ocean. And I also analyzed the distributions of five species of salmons on the gill-net in the waters about 100 miles east off Cape Lopatka (1953) by using the POISSON'S distribution, PÓLYA-EGGENBERGER'S and THOMAS' one together with the spacing method and gave some consideration to the unit of salmon population. And in my earlier paper of this series of the studies on the analyses of the distribution of tuna along the long-line, I proposed new formula for the spacing analysis amended so as to fit to the special conditions of the long-line gears and analyzed the distributions by using them.

Before closing this paragraph, it seems to be necessary to cite here two more papers which are estimated very highly for their theoretically excellent basic idea on the problem of probability. UMESAO (1950 a and 1950 b) analyzed theoretically the experimental population of tadpoles and proposed the term "interference" for a certain character causing the distributions in which the repulsive or attractive tendency among individuals is observable, and MORISITA (1952) proposed a method to represent quantitatively the different influences of the environmental conditions upon the habitat preference of animals by converting the effective value of environments for a certain animal into the population density of that animal.

2) Statistical works in the field of fisheries

YOSHIHARA (1952) reported that the frequency distribution of catches of trawlers operated in the waters east to 130° E. (unit: 10 days), yellow-tail set nets (unit: a day) or skipjack anglings (unit: 1 trip) follows the logarithmic normal distribution. KITAGAWA and YAMAMOTO (1950) reported that the mode of the frequency distribution of catches by bream long-liners or angling boats per boat and per month is biased to the lower side; while KESTEVEN and BURDON (1952) stated that the frequency distribution of catches by "*Kelong*" and "*Jaring Hanyut*" per trip follows also the logarithmic normal and they thought the distortion of mode to the lower side is more conspicuous in the operation of unmovile gears than in the case of movile gears and thus this tendency might be one of the characteristics of the fishing operated rather in the shore waters. And MAKO (1955) said that the frequency distribution of number of boxes, *ca.* 15 kg of each kind of several benthonic fishes are contained in each box, per haul on trawlers working in the East Chinese Sea and the Yellow Sea follows PÓLYA-EGGENBERGER'S distribution and hence arc sin transformation is more recommendable than the sq uare root transformation when the analysis method of variance is applicable to treating this material. On the other hand, YAMAMOTO (1956) made a comprehensive work on the unit catches (catch per trip) of nearly all of the important fisheries in Japan and stated in his paper that, generally speaking, the distribution curve of the unit catches of the trawling or the long-line fishery resembles the normal or logarithmic normal distribution, those of the fisheries using the echo-sounder or the fish-gathering lamp, such as purse seines, dip nets or angling, accord to the logarithmic normal or the ultra logarithmic normal distribution and that of drift net or beach seine set for the visiting fish schools at the fishing ground follows the exponential distribution. On these results he gave some consideration to the coefficient of variation in the unit catches and the stability of fishing, the relation between the types of distribution of unit catches and the average catch per trip, the increase of tonnage of fishing boats and stability of fishing and factors influential on the quantity of catch per month in each fishing unit.

Besides the above-mentioned works, many other notable works were illustrated by BARNES and MARSHALL (1951), BARNES and BAGENAL (1951), SILLIMAN (1946) and WINSOR and CLARKE (1940).

Throughout the above-mentioned papers, however, the unit divisions adopted are fairly large as they are the total catches during one trip, those of a single boat per month, 10 days or a week or unit effort or haul. While in my papers, the unit divisions adopted are very small as they are respective sections of the gill-net, traps of the squid trap or hooks of the long-line; and so far as I am aware there is scarcely found the work in which such small divisions are taken up. Of course the unit divisions adopted in the statistical works by many authors are quite adequate for the purpose of the statistical investigations on fishing catches, but evidently seem to be too large for the studies of the distribution of fishes, which is the point we ecologists wish to know. As the studies of the distribution of fishes need more detailed data, the unit divisions should be smaller than one operation or haul, or rather the smaller they are, the better results are expected. Thus, the size of the unit division should be variable according to the purposes of the studies: —— either the distribution of catches is pursued as an ecological characteristic or as a preliminary step of the reasonable estimation of some variates of catches. The processes of treatment are superficially quite similar in these two groups of studies, although these two groups of studies differ essentially from each other. The necessity of the study on the distribution pattern of fish individuals along the gears is explained fully in the introduction already, but yet there is scarcely found such a work. It is very desirable that such studies will be investigated hereafter in the field of the fundamental biology as extensively as the distributions of catches in rather large unit divisions have been studied by this date in the field of the fishery statistics.

Material and Method

Each set of gears consists of *ca.* 360 main lines (a main line is usually represented in the word "a basket", because it is put in a basket when it is not in use) connected in a series and suspended in the water by buoy lines of 20 m long each attached at every joint. Each main line is 300 m long and provided with 4 or 5 branch lines of 25 m long set at regular intervals and each ending in a single hook. The interval between each pair of hooks on the same basket is from 50 to 60 m, while the interval between the distal hook of a certain basket and the adjacent one of the consecutive basket is from 100 to 120 m long. As the average buoy interval is shorter than the length of the main line in the actual operation, each main line of respective unit gears forms catenarian and thus hooks cannot be suspended at the same level but their situations are separated into two or three levels. The gears are set from one end and it takes about 4 hours to empty the whole baskets. The setting is usually begun at mid-night, the boat is let drift for about 3 hours near the final end of the whole gears and then the hauling of gears begins from the final end of the whole gears. This time, it takes about 12 hours to haul up the whole gears. Thus the immersion of the whole gears lasts generally for three hours from about 3 *a.m.* to 6 *a.m.* in the dawn.

A half of the data used for the present study was offered by the Dai-fuji-maru and contains the data about albacores obtained in the waters near New Caledonia and the Solomon Islands during the period from Aug. 22 to Oct. 16, 1954 and those about yellow-fin tuna, big-eye tuna and the correlation between these two fishes obtained

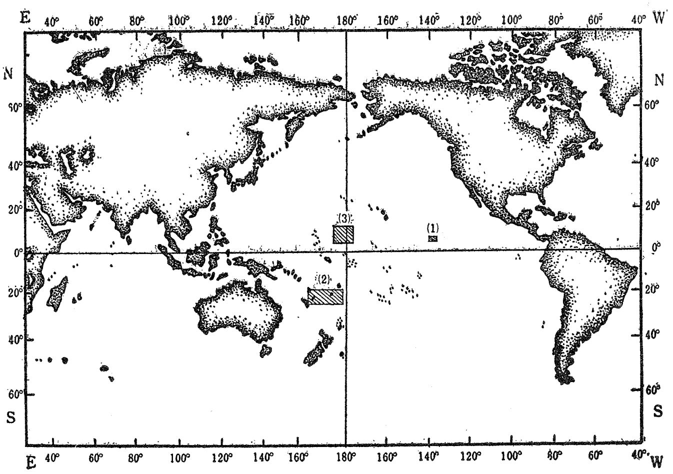


Fig. 1. Sketch chart of all fishing grounds under consideration.
Note : Numbers indicate the localities of the fishing grounds.

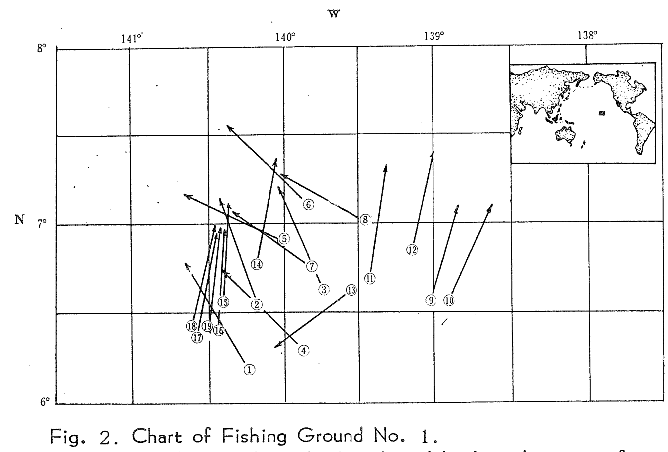


Fig. 2. Chart of Fishing Ground No. 1.
Notes : Arrows show the length and hauling direction of gears. Numbers represent the stations where the data about big-eye tuna and yellow-fin tuna and the correlation between these two fishes were obtained.

in the waters far east of the Hawaiian Islands during the period from Sept. 14 to Oct. 2, 1955, while another part was forwarded to me by the Shinyo-maru and includes the data about the correlation between tunas and marlins and that between tunas and sharks obtained in the waters east of the Marshal Islands during the period from Aug. 11 to Sept. 16, 1955. Sketch charts of the fishing grounds and the distribution of stations in respective fishing grounds are shown in Figs. 1—4. The situation of stations, number of gears used and the compositions of respective catches are given in Tables 1—3. Of these data, those about the operations, in which

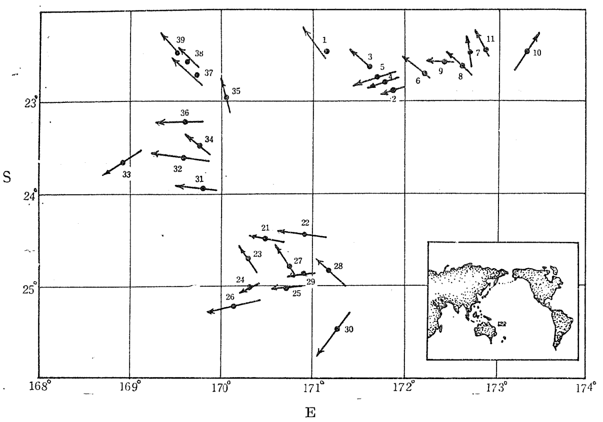


Fig. 3—1. Chart of Fishing Ground No. 2—1, 3 and 4.
Notes : Arrows show the length and hauling direction of gears. Numbers represent the stations where the data about albacore were obtained.

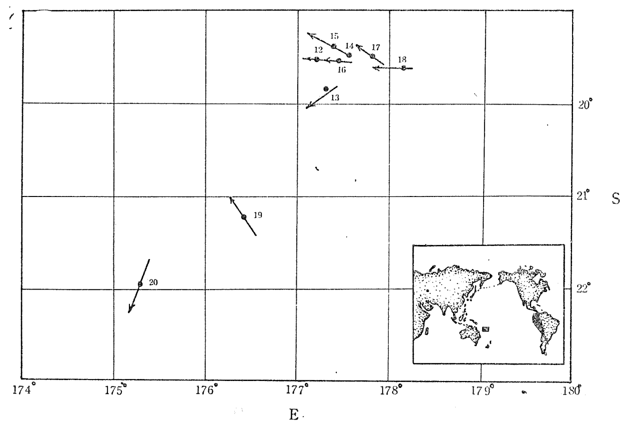


Fig. 3—2. Chart of Fishing Ground No. 2—2.
Notes are the same as in Fig. 3—1.

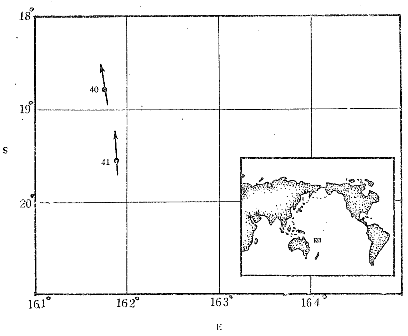


Fig. 3—3. Chart of Fishing Ground No. 2—5.
Notes are the same as in Fig. 3—1.

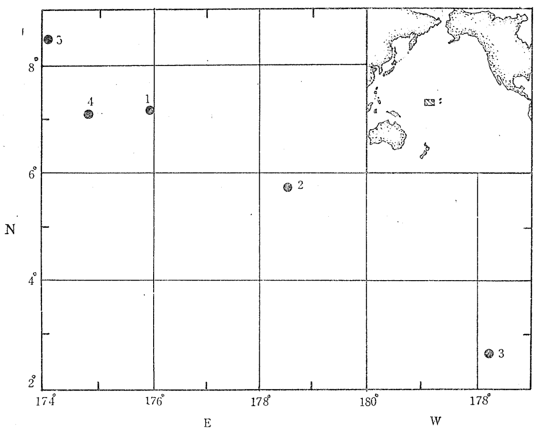


Fig. 4. Chart of Fishing Ground No. 3.
Note : Numbers indicate the stations where the data about the correlation between tunas and marlins or tunas and sharks were obtained.

Table 1. Position, number of gear used and catch composition at each station in Fishing Ground No. 1.

St.	Date	Position		Number of gear	Catch composition				
					Y.F.T.	B.E.T.	Marlins	Sharks	Others
1	Sept. 14, '55	6°29′ N	140°27′ W	364	**88**	**115**	10	29	5
2	15	6°51′ N	140°22′ W	357	**107**	**95**	14	24	7
3	16	6°58′ N	139°55′ W	341	**89**	**83**	12	14	5
4	17	6°30′ N	140°11′ W	352	**64**	**65**	8	21	3
5	18	6°59′ N	140°23′ W	358	**29**	**119**	6	29	5
6	19	7°20′ N	140°07′ W	359	**44**	**151**	14	13	6
7	20	6°53′ N	140°06′ W	362	**49**	**96**	12	14	7
8	21	7°08′ N	139°46′ W	360	**50**	**81**	7	22	10
9	22	6°50′ N	138°56′ W	360	**44**	**181**	12	14	14
10	23	6°52′ N	138°48′ W	355	**21**	**107**	12	22	4
11	24	7°02′ N	139°25′ W	358	3	**89**	26	36	6
12	25	7°06′ N	139°06′ W	351	15	**72**	12	23	6
13	26	6°36′ N	139°39′ W	354	7	**69**	15	28	7
14	27	7°03′ N	140°06′ W	356	14	**78**	17	32	8
15	28	6°50′ N	140°22′ W	357	23	**103**	16	26	15
16	29	6°40′ N	140°22′ W	358	13	**89**	9	31	5
17	30	6°37′ N	140°29′ W	359	17	**100**	26	39	3
18	Oct. 1, '55	6°27′ N	140°38′ W	359	11	**208**	24	16	4
19	2	6°26′ N	140°36′ W	317	21	**136**	10	21	8

The situation shown in the column of position indicates the point where the oceanographical observations were made and may be more or less apart from the start point of the hauling in respective operations. Y.F.T. : Yellow-fin tuna, B.E.T. : Big-eye tuna.

Table 2. Position, number of gear used and catch composition at each station in Fishing Ground No. 2.

Sub-fishing ground	St.	Date	Position		Number of gear	Catch composition				
						Albacore	Other tunas	Sharks	Marlins	Others
1	1	Aug. 22,'54	22°21.0' S	170°52.5' E	356	**83**	14	9	16	0
	2	23	22°50.0' S	171°48' E	250	**119**	6	4	2	0
	3	24	22°36.9' S	171°18.5' E	350	**161**	9	4	4	2
	4	25	22°38' S	171°19' E	370	**142**	12	8	7	3
	5	26	22°51' S	171°20.5' E	380	**148**	12	6	8	3
	6	27	22°55.5' S	171°53' E	380	**122**	14	6	10	7
	7	28	22°32' S	172°36' E	360	**110**	11	15	8	2
	8	29	22°38' S	172°40' E	388	**155**	8	8	5	3
	9	30	22°36' S	172°29' E	312	**97**	7	7	1	2
	10	31	22°28' S	173°25' E	370	**176**	6	1	8	1
	11	Sept. 1,'54	22°29' S	177°57' E	237*	**56**	7	7	7	4
2	12	8	19°31' S	177°12' E	363	**92**	27	0	6	1
	13	9	19°53' S	177°16' E	374	**86**	28	23	6	4
	14	10	19°32.5' S	177°28.5' E	366	**62**	14	1	16	3
	15	11	19°27' S	177°21' E	364	**78**	30	18	10	3
	16	12	19°34' S	177°24' E	367	**82**	25	1	14	3
	17	13	19°32.5' S	177°46' E	365	**29**	16	6	35	5
	18	14	19°49' S	178°01' E	330	**38**	20	4	15	3
	19	17	21°14.5' S	176°25.5' E	361	**58**	15	3	13	2
	20	18	21°57.5' S	175°17' E	330	**50**	13	1	12	0
3	21	20	24°32' S	170°30' E	364	**117**	18	7	18	2
	22	21	24°32' S	170°54' E	346	**126**	24	0	12	2
	23	22	24°39' S	170°22' E	370	**97**	16	3	8	2
	24	23	25°01' S	170°22' E	368	**86**	12	0	17	4
	25	24	25°03' S	170°42' E	370	**110**	13	2	14	3
	26	25	25°09' S	170°08' E	370	**72**	6	0	12	5
	27	26	24°50' S	170°45' E	367	**112**	7	6	16	3
	28	27	24°43.5' S	171°09' E	367	**79**	6	0	21	2
	29	28	24°53.0' S	170°52' E	366	**81**	6	7	8	5
	30	29	25°27' S	171°17.5' E	360	**76**	10	1	15	0
4	31	Oct. 3,'54	23°59' S	171°03' E	362	**53**	44	8	8	2
	32	4	23°33' S	169°23' E	366	**75**	14	0	13	0
	33	5	23°38.6' S	168°58' E	370	**61**	2	7	17	1
	34	6	23°29' S	169°46' E	361	**71**	9	0	13	4
	35	7	22°58' S	170°00.5' E	360	**74**	7	8	17	7
	36	8	23°13.8' S	169°34.5' E	370	**59**	8	0	13	2
	37	9	22°41' S	169°40' E	366	**105**	15	11	7	3
	38	10	22°34' S	169°36.5' E	370	**76**	7	0	22	4
	39	11	22°36' S	169°31' E	361	**59**	5	8	9	1

5	40	15	18°22' S	161°54' E	356	**47**	21	1	14	3
	41	16	19°46.5' S	161°50' E	370	**48**	25	4	5	10

Concerning the position, see the note under table 1.
* : Three hundred of baskets are soaked in all, but the baskets immersed after the 237th were entangled with the gears of the other fishing boat, and so they are omitted from the consideration.

Table 3. Position, number of gear used and catch composition at each station in Fishing Ground No. 3.

St.	Date	Position		Number of gear	Catch composition			
					Tuna		Marlins	Sharks
					Y.F.T.	Other tunas		
1	Aug. 11,'55	7°10.5' N	175°57' E	348	33	19	13	18
2	Aug. 15,'55	5°44' N	178°34' E	350	35	23	11	20
3	Aug. 18,'55	2°38' N	177°46' W	300	123	—	—	—
4	Sept. 4,'55	7°07' N	174°48' E	316	33		17	15
5	Sept. 16,'55	8°29' N	174°06' E	250	13		10	9

The position indicates the situation of the start point of setting gears.
Y.F.T. : Yellow-fin tuna.

the individual number caught in respective operations is not so large, are put aside the consideration, because the accidental errors of the observed values are too large in such cases. The data used in the further consideration are printed in gothic in tables.

Preliminary Consideration upon the Existence of Fish Schools of Large Scales

It is very natural to consider that the fishes are not distributed uniformly in ocean but their living areas are more or less limited; the largest scale of such limitations should be that of the geographical distribution. Further, it is also a well known fact that the uneven distribution of fishes occurs in the scale of a considerable extent which we call the fishing grounds. Indeed most of the efforts in the commercial fishing and the investigations on the distribution of tuna seem to be concentrated in finding any new or better fishing grounds. Then, are the distributions of various fishes quite uniform in respective fishing grounds ? Despite of the necessity to give answers to this question, the distribution pattern of fishes within the same fishing ground or within a series of gears seems to be still unclarified. The studies of the distribution pattern of fishes in the above-mentioned scale should be carried out in detail as well as the distribution in larger scales have been investigated. Thus, I began the studies to analyze the distribution pattern of fish individuals within the same fishing ground, especially that within a row of gears.

It is very doubtful that the aggregation of fishes as large in scale as the fishing ground constitutes a school, however large the fishes may be and however quickly they can swim. If the fish schools of the scale larger than the fishing ground or beyond the extent of one operation cruise of fishing boats may exist, we cannot find any clue to detect the existence of such schools. But, if the fish schools which are within the scale of the extent of one operation cruise of fishing boats, but yet larger than a row of gears may exist, the catch rates at some stations should be abruptly higher than at others and the distribution of such stations should, in most cases, be limited within a certain part of the fishing ground. If many schools of considerable width may be caught partly overlapping one another, then it is inevitable that the width of the overlapping parts might be mistaken for the width of schools; although judging from the fact that the catch rates are very low and relatively homogenous all over the fishing grounds examined, the existence of such a phenomenon mentioned above seems quite unlikely.

In the actual observations, in the Fishing Ground No. 1, in the waters far east of the Hawaiian Islands, the catch rates of yellow-fin tuna at Stations 1∼10 were higher than those at Stations 11∼19. But this does not indicate that the stations showing higher catch rates are located within a certain area, because the Stations 11∼19 were set in the same area covering Stations 1 to 10. The fishing boat moved at first from St. 1 to St. 10 (from west to east) along the current and then took her course against the current changing the stations from St. 11 to St. 19 (from east to west). The catch rates of big-eye tuna during the same period did not show any difference between the cruise along the current and that against the current. So, the existence of large schools of yellow-fin tuna or big-eye tuna, the width of which is smaller than the fishing ground but larger than a row of gears (longer than 50 km), cannot be expected in this fishing ground, because there is no definite evidence supporting the existence of any schools of such a scale. Only the possibility of the existence of schools of the scale shorter than a row of gears can be discussed on the data obtained in this fishing ground.

In the Fishing Ground No. 2, the catches of albacores showed the possibility of the formation of compact schools. The catch rates of albacore in the Fishing Ground No. 2—1,2 and 4 were higher than those in No. 2—3 and 5 and this seems to allude to the existence of a considerably large school of this fish, although it is some what doubtful that such large aggregations can be regarded as the school formation. If we may be admitted to regard them as schools, then their sizes estimated are as large as the extent of respective subdivisions of the fishing ground, namely 1° Long. × 3° Lat. (*ca.* 100 km× 300 km), 1° Long. × 1° Lat. (*ca.* 100 km× 100 km) and 2° Long. × 2° Lat. (*ca.* 200 km × 200 km), respectively. The data obtained in the Fishing Ground No. 3 don't seem to offer us any suggestions for the schooling, because the stations were not enough for the statistical treatment.

Then, in order to detect the existence of such schools, to estimate the mean width of the schools of the scale not exceeding the length of a row of gears and to clarify the spatial relation in detail as possible, the following analyses are pursued.

Consideration upon the Existence of Schools Having the Width not Exceeding the Whole Length of a Row of Gears

1. The basic assumption and the factors which should be taken into consideration

In a previous report of this series, I showed that the distance between the hooks and the composition of stomach contents are independent of each other. And the same relation is also known between the hook distance and gonad maturity or the former and the chemical properties of meat. During the Japanese Bikini Expedition held to research the after-influences of a series of atomic and hydrogen bombs, I met with the fact that the contamination degree by fission products was quite different in neighbouring individuals caught by successive hooks and sometimes some heavily contaminated individuals appeared when most of caught fishes were not contaminated at all or contrarily some non-contaminated individuals were found in some cases when most of fishes were heavily contaminated. Such phenomena seemed quite unreasonable for me at that time when I had kept already in my mind the possibility that yellow-fin tuna or big-eye tuna might swim in schools. The above-mentioned phenomena were frequently observed in a much large scale during the examination of the radio-active contamination of tunas and skipjacks landed at several main fishing ports in Japan. These facts may be explainable on the supposition that tunas are swimming almost solitarily. On the other hand, fishermen believe that they have seen neither the schooling yellow-fin tuna nor big-eye tuna larger than about 40 kg in body weight. Albacore and young yellow-fin tuna are said to swim in schools in the surface layer and caught some times by successive hooks in a manner as if it alludes to the existence of such schools, while spearfish or marlin, which are clearly seen swimming as solitary individuals in the surface layer, are always caught solitarily. Moreover, NAKAMURA (1949), MURPHY and ELLIOT (1954) and MURPHY and SHOMURA (1953) state out that there is no definite evidence of schooling habit of tuna living in the deeper layer, but there are many facts supporting their solitary life. For these reasons, the chance distribution should be accepted as the basic assumption of the theoretical distribution.

If most individuals are caught during the period when all units of gears are soaked, then the catch rate of all hooks at the same depth level must be throughout constant, while if a considerable number of individuals are caught during the course of setting or hauling, then the catch rates have to increase from one end to the other. Even in the latter case, if the population keeps the gradient of density opposite to the direction of increase of soaking time, the apparent distribution will take the form like that found in the former case. Actually, however, in so many examples, nearly all examples when emphasized, the catch rate of hooks increases with the soaking time. For such examples, the influence of the gradient of catch rate should be taken into consideration during the construction of formulae, otherwise the results of further analyses will be much more contagious than the actual.

Besides the facts mentioned above, the average buoy interval is shorter than the main line in actual operations, consequently the main line of each unit of gear forms catenarian and all hooks are by no means situated at the same level, but the situations are differentiated into the two or three levels according to the number of hooks, 4 or 5. And it is a well known fact that the catch rate of hooks differs at different depth levels, being higher at deeper levels. When the catch rates of hooks at different depth levels are not the same, the hooks showing higher catch rate appear at regular intervals, consequently this might mislead to suppose the existence of schools arranged at the intervals as long as a basket. Thus, the effect of different catch rates of hooks at different depth levels should be taken into consideration, too.

2. Constructing processes of the formulae used in the present study

1) The formulae representing the expected number of fish couples spaced by *k* section-intervals, when all individuals are scattered by chance

Let us set that N individuals are scattered by chance in M consecutive sections of equal length. Probability of occurrence of each individual at each section is $\frac{1}{M}$. Then the probability of occurrence of any two individuals being caught within a certain section ($k=0$) is $\left(\frac{1}{M}\right)^2$. And the expected number of such case, $X_{(0)}$, is represented as follows, because there are M sections and the number of combinations picking up any two individuals among N individuals is $\frac{N(N-1)}{2}$:

$$X_{(0)}=M\frac{1}{M^2}\cdot\frac{N(N-1)}{2}=\frac{N(N-1)}{2M} \qquad (1)$$

However, the expected number of two individuals (fish couples) being caught separately, one in a certain section and the other in the section spaced by k section-intervals, $X_{(k)}$ at $k \neq 0$, is represented as follows, the reasons are given below:

$$X_{(k)}=\frac{(M-k)N(N-1)}{M^2} \qquad (2)$$

The probability of occurrence of a certain individual in the ith or the $(i+k)th$ section is $\left(\frac{2}{M}\right)$. Therefore, that of any two individuals caught in the ith or the $(i+k)th$ section is $\left(\frac{2}{M}\right)^2$. In this case, however, the probabilities of both individuals being caught together in the ith or the $(i+k)th$ section are included: these are respectively $\left(\frac{1}{M}\right)^2$. Thus, the probability of any two individuals being caught separately in the ith and the $(i+k)th$ section is $\left(\frac{2}{M}\right)^2-2\left(\frac{1}{M}\right)^2=\frac{2}{M^2}$. i can vary from 1 to $(M-k)$, and the number of combinations picking up any two individuals among N individuals is $\frac{N(N-1)}{2}$.

Next formula is proposed by Dr. MORISITA (unpubl.) for the similar purpose, this is not yet published and I am very grateful to him for his kindness in permitting me to quote the formula before he publish it. By using this formula the probability of occurrence of other individuals within the *k'th* section from any section occupied by a certain individual, when individuals are scattered by chance, is computable.

Probability $$Q_{0-n}=\frac{(2k'+1)M-k'(k'+1)}{M^2}$$

Actually observed value $$X_{0-n}=\sum_{i=1}^{M-k'}(x_i\sum_{k'=1}^{k'}x_{i+k'})+\frac{1}{2}x_i(x_i-1)$$

but $$X_0=\frac{1}{2}x_i(x_i-1)$$

(X_i : number of caught individuals in the *ith* section)

Number of combination $$S=\frac{N(N-1)}{2}$$

Observed probability $$q_{0-n}=\frac{X_{0-n}}{S}$$

$$R_{0-n}=\frac{q_{0-n}}{Q_{0-n}}$$

Symbols are common to the formulae (1) and (2).

Here, it is easily noticed that the formulae (1) and (2) and $SQ_n=S\{Q_{0-n}-Q_{0-(n-1)}\}$ computed from MORISITA's formula take quite the same value. But, in order to construct the formula in which the influence of the gradient of catch rate is taken into consideration it seems more convenient to adopt the formulae newly established.

2) The formulae representing the expected number of fish couples spaced by *k* section-intervals, when catch rate increases with the soaking time

Let us set that the number of individuals caught in the *ith* section is $N_i=(N_0+i\Delta N)$ and the total number of individuals caught by a row of gears constituted of M sections is $N=\sum_{i=1}^{M}N_i$.

The probability of a certain individual being caught in the *ith* section is represented as $P_i=\frac{N_i}{N}=\frac{N_0+i\Delta N}{N}=P_0+i\Delta P$.

In the same manner as in the construction of formulae (1) and (2), the probability of any two individuals being caught in the *ith* section is $(P_0+i\Delta P)^2$. And the expected number of such a case, $X_{(0)}$, is represented as follows, because i can vary from 1 to M.

$$X_{(0)}=\frac{N(N-1)}{2}\sum_{i=1}^{M}(P_0+i\Delta P)^2$$

$$=\frac{MN(N-1)}{2}P_0^2\left[1+(M+1)\delta+(M+1)(2M+1)\frac{\delta^2}{6}\right]\cdots\cdots\cdots\cdots(3)$$

here $\delta = \frac{\Delta P}{P_0}$

because

$$\sum_{i=1}^{M} (P_0 + i\Delta P)^2 = \sum_{i=1}^{M} (P_0^2 + 2P_0\Delta Pi + \Delta P^2 i^2) = P_0^2 \sum_{i=1}^{M} (1 + 2\delta i + \delta^2 i^2)$$

$$= P_0^2 \left[M + \frac{2(M+1)M}{2}\delta + M(M+1)(2M+1)\frac{\delta^2}{6} \right]$$

$$= MP_0^2 \left[1 + (M+1)\delta + (M+1)(2M+1)\frac{\delta^2}{6} \right]$$

Probability of occurrence of a certain individual in the *ith* or the $(i+k)th$ section is $(P_0 + i\Delta P) + (P_0 + \overline{i+k}\,\Delta P)$; therefore that of any two individuals being caught in the *ith* or the $(i+k)th$ section is $\{(P_0 + i\Delta P) + (P_0 + \overline{i+k}\,\Delta P)\}^2$, but here the probabilities of both individuals being caught together in the *ith* or the $(i+k)th$ section are included, which are respectively $(P_0 + i\Delta P)^2$ and $(P_0 + \overline{i+k}\,\Delta P)^2$. Thus, the probability of any two individuals being caught separately in the *ith* and the $(i+k)th$ section is

$$\{(P_0 + i\Delta P) + (P_0 + \overline{i+k}\,\Delta P)\}^2 - (P_0 + i\Delta P)^2 - (P_0 + \overline{i+k}\,\Delta P)^2$$
$$= 2(P_0 + i\Delta P)(P_0 + \overline{i+k}\,\Delta P)$$

i varies form 1 to $M-k$. Accordingly, for the same reasons mentioned previously in the construction of formula (2), the expected number of any two individuals being caught separately in two sections spaced by k section-intervals, $X_{(k)}$, is given as follows:

$$X_{(k)} = \frac{N(N-1)}{2} \times 2 \sum_{i=1}^{M-k} (P_0 + i\Delta P)(P_0 + \overline{i+k}\,\Delta P)$$

$$= MN(N-1)P_0^2 \left[1 + (M+1)\delta + (M-k+1)(2M+k+1)\frac{\delta^2}{6} \right] \cdots\cdots\cdots (4)$$

here $\delta = \frac{\Delta P}{P_0}$

because

$$\sum_{i=1}^{M-k} (P_0 + i\Delta P)(P_0 + \overline{i+k}\,\Delta P) = \sum_{i=1}^{M-k} \left\{ P_0^2 + 2(i+k)\ P_0\Delta P + i(i+k)\Delta P^2 \right\}$$

$$= P_0^2 \sum_{i=1}^{M-k} \left\{ 1 + (2i+k)\delta + i(i+k)\delta^2 \right\}$$

$$= P_0^2 \sum_{i=1}^{M-k} \left\{ (1 + k\delta) + (2\delta + k\delta^2)i + \delta^2 i^2 \right\}$$

$$= P_0^2 \left[(M-k)(1 + k\delta) + \frac{(M-k+1)}{2}(M-k)(2\delta + k\delta^2) \right.$$
$$\left. + (M-k)(M-k+1)(2M-2k+1)\frac{\delta^2}{6} \right]$$

$$= P_0^2 (M-k) \left[1 + (M+1)\delta + (M-k+1)(2M+k+1)\frac{\delta^2}{6} \right]$$

The general tendencies of the theoretical values computed from four above-mentioned formulae are shown in Fig. 5.

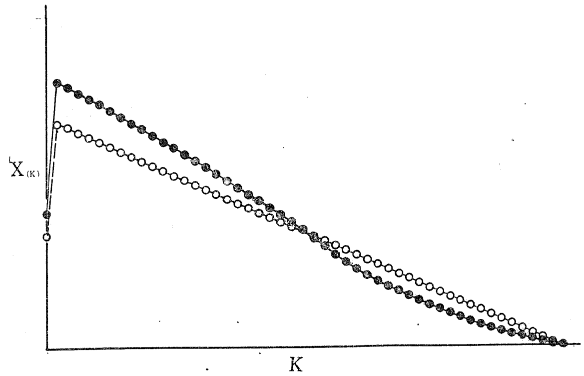


Fig. 5. General tendency of X(k)—k relation computed from formulae (1)—(4). Notes: White circles indicate the values computed from formulae (1) and (2), in which the influence of gradient of catch is put out of consideration. Filled circles show the values computed from formulae (3) and (4), in which the influence of gradient of catch is taken into consideration.

The formulae (1) and (2) can be derived from MORISITA'S formula applicable to the connected series of sections, while the formulae (3) and (4) are constructed for the purpose of taking the influence of the gradient of catch rate into consideration. Accordingly the latter two are applicable to the connected series of sections of equal width, in each of which from 0 to one or more individuals can be caught. When the unit length under the consideration is diminished as possible ultimately to 1 hook-interval (the word "hook-interval" used in this report indicates the mean interval between any two consecutive hooks located in the same basket), the conditions become similar to the peculiar conditions characteristic to the long-line gears as mentioned previously. Besides this, another factor, the influence of the different catch rates of hooks situated at the different depth levels must be taken up as the factor to be taken into consideration. Thus, there arises the necessity of constructing new formulae applicable to such a peculiar conditions, in which the influence of each or both of the difference of the catch rate due to the increase of soaking time and that caused by the difference of the depth level of hooks is taken into consideration.

3) The formulae representing the expected number of both of the two hooks spaced by *k* hook-intervals being occupied by fishes, when the fishes are scattered by chance

Let us set that N individuals are scattered by chance along a row of gears, which consists of m consecutive baskets of equal length and having H hooks respectively. k is represented as $k=a(H+1)+R$, when it is separated into the part divisible by the length of a basket and the remainder. Then the hooks spaced by k

hook-intervals from respective hooks in the *ith* basket are represented as shown in

Table 4. The hooks spaced by k hook-intervals from respective hooks in the *ith* basket ($H=4$).

R \ h	1	2	3	4
0	1	2	3	4
1	2	3	4	B
2	3	4	B	1′
3	4	B	1′	2′
4	B	1′	2′	3′

Note : h is hook number in the *ith* basket.
B indicates buoy-line.
k is represented by $a(H+1)+R$
1 : the first hook in the $(i+a)th$ basket.
1′: the first hook in the $(i+a+1)th$ basket.

Table 4. Here, a is a positive integer varying from 0 to m, while R varies from 0 to H. When $R=0$, there are H hooks in the $(i+a)th$ basket spaced by k hook-intervals from respective hooks in the *ith* basket (i varies from 1 to $m-a$), but no hook can exist in the $(i+a+1)th$ basket (i varies from 1 to $m-a-1$). When $R \doteqdot 0$, however, there are $(H-R)$ hooks in the $(i+a)th$ basket spaced by k hook-intervals from respective hooks in the *ith* basket and besides there are $(R-1)$ hooks in the $(i+a+1)th$ basket. On the other hand, the probability of each hook being occupied by fish is $P=\frac{N}{Hm}$, and the probability of any two hooks being occupied by fishes is P^2.

Accordingly, the expected number of two hooks spaced by k hook-intervals being occupied by fishes, $X_{(k)}$, is shown by the following formulae:

at $R=0$

$$X_{(k)}=H(m-a)P^2 \cdots\cdots (5)$$

at $R \doteqdot 0$

$$X_{(k)}=\{(H-1)(m-a)-(R-1)\}P^2 \cdots\cdots (6)$$

The values theoretically computed by using these formulae decrease gradually with the increase of k ; $X_{(k)}$ takes the same value at $k=a(H+1)+H$ and $k=(a+1)(H+1)+1$, while at $k=(a+1)(H+1)$ it is approximately $\frac{H}{H-1}$ times the value computed at $k=a(H+1)+H$ and $k=(a+1)(H+1)+1$.

4) The formulae representing the expected number of both of the two hooks spaced by *k* hook-intervals being occupied by fishes, when the catch rate increases with the soaking time

Let us set that k is represented by $k=a(H+1)+R$ in the same way as in the preceding paragraph, N individuals are distributed in m consecutive baskets respectively equipped with H hooks, and the catch rate shows some gradient. As for the gradient of catch rate, P_0 and ΔP are defined as that the catch rates of a hook in the *ith*, the $(i+a)th$ and the $(i+a+1)th$ baskets are represented respectively by $(P_0+i\Delta P)$, $(P_0+\overline{i+a}\,\Delta P)$ and $(P_0+\overline{i+a+1}\,\Delta P)$, in other words $N=H\sum_{i=1}^{m}(P_0+i\Delta P)$. Therefore, the probability of two hooks being occupied by fishes, one of which is found in the *ith* basket and the other is spaced by k hook-intervals from the former, takes $(P_0+i\Delta P)(P_0+\overline{i+a}\,\Delta P)$ or $(P_0+i\Delta P)(P_0+\overline{i+a+1}\,\Delta P)$. Accordingly, the expected number of two hooks spaced by k hook-intervals being occupied by fishes, $X_{(k)}$, is represented by next formulae:

at $R=0$

$$X_{(k)}=H\sum_{i=1}^{m-a}(P_0+i\Delta P)(P_0+\overline{i+a}\,\Delta P)$$

$$=HP_0^2(m-a)\left[1+(m+1)\delta+(m-a+1)(2m+a+1)\frac{\delta^2}{6}\right]\cdots\cdots(7)$$

at $R\neq 0$

$$X_{(k)}=(H-R)\sum_{i=1}^{m-a}(P_0+i\Delta P)(P_0+\overline{i+a}\,\Delta P)+(R-1)\sum_{i=1}^{m-a-1}(P_0+i\Delta P)(P_0+\overline{i+a+1}\,\Delta P)$$

$$=P_0^2\Big[\{1+(m+1)\delta\}\{(H-1)(m-a)+1-R\}$$
$$+\{(H-R)(m-a)(m-a+1)(2m+a+1)$$
$$+(R-1)(m-a-1)(m-a)(2m+a+2)\}\frac{\delta^2}{6}\Big]\cdots\cdots(8)$$

here $\delta=\frac{\Delta P}{P_0}$

because

$$\sum_{i=1}^{m-a}(P_0+i\Delta P)(P_0+\overline{i+a}\,\Delta P)=\sum_{i=1}^{m-a}\{P_0^2+(2i+a)P_0\Delta P+i(i+a)\Delta P^2\}$$

$$=P_0^2\sum_{i=1}^{m-a}\{1+(2i+a)\delta+i(i+a)\delta^2\}=P_0^2\sum_{i=1}^{m-a}\{(1+a\delta)+(2\delta+a\delta^2)i+\delta^2 i^2\}$$

$$=P_0^2(m-a)\left[1+(m+1)\delta+(m-a+1)(2m+a+1)\frac{\delta^2}{6}\right]$$

and

$$\sum_{i=1}^{m-a-1}(P_0+i\Delta P)(P_0+\overline{i+a+1}\,\Delta P)$$

$$=P_0^2(m-a-1)\left[1+(m+1)\delta+(m-a)(2m+a+2)\frac{\delta^2}{6}\right]$$

The values of $X_{(k)}$ theoretically calculated from this type at k which represents not so large intervals are a little higher than those estimated by using the formulae (5) and (6), although the outline of the variation with the increase of k is quite the same as that found in the former type except for the fact that the rate of decrease with the increase of k is sharper than in the case estimated from the former formulae.

5) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rate of hooks differs according to depth levels

The formulae illustrated in the preceding two paragraphs are applicable to any long-line gears, being quite irrespective of number of hooks attached to each basket; while those shown in the following two paragraphs vary according to the number of hooks attached to each basket. Next, two groups of formulae applicable to the long-lines respectively with 4 and 5 hooks in each basket are illustrated as examples.

a) The formulae applicable to the gears with 4 hooks in each basket

Let us set that N_1 and N_2 individuals are scattered by chance respectively at the shallower and deeper hooks in a row of gears constituted of m consecutive baskets.

Table 5. Catch rates of respective hooks shown in Table 4 ; here the influence of the catch rate varying according to the depth level of respective hooks is taken into consideration ($H=4$).

h / R	1	2	3	4
	P_1	P_2	P_2	P_1
0	P_1	P_2	P_2	P_1
1	P_2	P_2	P_1	0
2	P_2	P_1	0	P_1
3	P_1	0	P_1	P_2
4	0	P_1	P_2	P_2

Table 6. Probability of both of the two hooks related with each other as shown in Table 4 being occupied by tuna; here the difference of the catch rate due to the different depth levels of respective hooks is taken into consideration ($H=4$).

h / R	1	2	3	4
0	P_1^2	P_2^2	P_2^2	P_1^2
1	$P_1\ P_2$	P_2^2	$P_1\ P_2$	0
2	$P_1\ P_2$	$P_1\ P_2$	0	**P_1^2**
3	P_1^2	0	**$P_1\ P_2$**	**$P_1\ P_2$**
4	0	**$P_1\ P_2$**	**P_2^2**	**$P_1\ P_2$**

"i" in columns except for those printed in gothic should be $1 \leqq i \leqq (m-a)$, while "i" in columns printed in gothic should be $1 \leqq i \leqq (m-a-1)$.

The probabilities of occurrence of individual at each shallower and deeper hook are represented respectively as $P_1=\frac{N_1}{2m}$ and $P_2=\frac{N_2}{2m}$. Represent $k=a\ (H+1)+R$ in the same manner as shown in the preceding paragraphs, and the hooks spaced by k hook-intervals from respective hooks in the ith basket, the probabilities of occurrence of individual at respective hooks and the probabilities of both of two hooks spaced by k hook-intervals being occupied by individuals are respectively illustrated in Tables 4,5 and 6. Accordingly, the expected numbers of two hooks spaced by k

hook-intervals being occupied by individuals are represented as follows:

at $R=0$ $X(k)=(m-a)(2P_1^2+2P_2^2)$ ......(9)

$R=1$ $X(k)=(m-a)(2P_1P_2+P_2^2)$ ......(10)

$R=2$ $X(k)=(m-a)(2P_1P_2+P_1^2)-P_1^2$ ......(11)

$R=3$ $X(k)=(m-a)(2P_1P_2+P_1^2)-2P_1P_2$ ......(12)

$R=4$ $X(k)=(m-a-1)(2P_1P_2+P_2^2)$ ......(13)

The theoretical values, $X_{(k)}$, of this type decrease with the increase of k being distributed in 3 levels.

b) The formulae applicable to the gears with 5 hooks in each basket

Hooks are situated in 3 levels. Here, let us set that N_1, N_2 and N_3 individuals are scattered by chance respectively at the shallower, middle and deeper hooks in a row of gears constituted of m consecutive baskets. The probabilities of occurrence of individual at the shallower, middle and deeper hooks are represented respectively as $P_1=\frac{N_1}{2m}$, $P_2=\frac{N_2}{2m}$ and $P_3=\frac{N_3}{m}$. Then, representing $k=a(H+1)+R$ the hooks spaced by k hook-intervals from respective hooks in the ith basket and the

Table 7. The hooks spaced by k hook-intervals from respective hooks in the ith basket ($H=5$).

R \ h	1	2	3	4	5
0	1	2	3	4	5
1	2	3	4	5	B
2	3	4	5	B	1′
3	4	5	B	1′	2′
4	5	B	1′	2′	3′
5	B	1′	2′	3′	4′

The footnotes in Table 4 are available here, too.

Table 8. Catch rates of respective hooks shown in Table 7 ; the influence of the difference of catch rates due to the different depth levels of respective hooks is taken into consideration ($H=5$).

R \ h	1	2	3	4	5
	P_1	P_2	P_3	P_2	P_1
0	P_1	P_2	P_3	P_2	P_1
1	P_2	P_3	P_2	P_1	0
2	P_3	P_2	P_1	0	P_1
3	P_2	P_1	0	P_1	P_2
4	P_1	0	P_1	P_2	P_3
5	0	P_1	P_2	P_3	P_2

probabilities of occurrence of individual at respective hooks are given in Tables 7 and 8. Accordingly, the formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by individuals, $X_{(k)}$, are represented as follows:

at $R=0 \quad X_{(k)}=(m-a)\,(2P_1^2+2P_2^2+P_3^2)$ ··········· (14)

$R=1 \quad X_{(k)}=(m-a)\,(2P_1P_2+2P_2P_3)$ ··········· (15)

$R=2 \quad X_{(k)}=(m-a)\,(2P_1P_3+P_2^2+P_1^2)-P_1^2$ ··········· (16)

$R=3 \quad X_{(k)}=(m-a)\,(4P_1P_2)-2P_1P_2$ ··········· (17)

$R=4 \quad X_{(k)}=(m-a)\,(2P_1P_3+P_2^2+P_1^2)-(2P_1P_3+P_2^2)$ ··········· (18)

$R=5 \quad X_{(k)}=(m-a-1)\,(2P_1P_2+2P_2P_3)$ ··········· (19)

The theoretical values estimated by these formulae decrease gradually with the increase of k being distributed in 4 levels.

6) The formulae representing the expected number of both of the two hooks spaced by k hook-intervals being occupied by fishes, when the catch rates increase with the soaking time and they differ according to the depth levels

Next group of formulae are constructed for the purpose of taking the influence of increase of the catch rate with the soaking time and that of the catch rate varying according to the different depth levels of hooks into consideration, when the detailed spatial relation between individuals distributed along a row of gears is examined.

Table 9. Catch rates corresponding to respective columns of Table 4 ; the influence of the gradient of the catch rate and that of the difference of catch rates due to the different depth levels of respective hooks are taken into consideration ($H=4$).

R \ h	1	2	3	4
	$P_1+i\Delta P_1$	$P_2+i\Delta P_2$	$P_2+i\Delta P_2$	$P_1+i\Delta P_1$
0	$P_1+\overline{i+a}\Delta P_1$	$P_2+\overline{i+a}\Delta P_2$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$
1	$P_2+\overline{i+a}\Delta P_2$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0
2	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$
3	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$
4	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$	$P_2+\overline{i+a+1}\Delta P_2$

To represent the gradient of catch rates of hooks in respective depth groups, P_1, P_2, P_3, ΔP_1, ΔP_2 and ΔP_3 are defined as shown below. When there are 4 hooks in each basket, the catch rate of each shallower hook in the *ith* basket is represented as $(P_1+i\Delta P_1)$ and that of each deeper hook as $(P_2+i\Delta P_2)$, while when there are 5 hooks in each basket, the catch rate of each shallower hook in the *ith* basket is represented as $(P_1+i\Delta P_1)$, that of each hook in the middle layer as $(P_2+i\Delta P_2)$ and that of each deeper hook as $(P_3+i\Delta P_3)$; in other words, $N_1=2\sum_{i=1}^{m}(P_1+i\Delta P_1)$ and $N_2=2\sum_{i=1}^{m}(P_2+i\Delta P_2)$ when there are 4 hooks in each basket, while $N_1=2\sum_{i=1}^{m}(P_1+i\Delta P_1)$, $N_2=2\sum_{i=1}^{m}(P_2+i\Delta P_2)$ and $N_3=\sum_{i=1}^{m}(P_3+i\Delta P_3)$ when there are 5 hooks in each basket. Then, in the same way as shown in the conversion of formulae (1) and (2) into (3) and (4), replaced P_1 and P_2 of the formulae (9) ~ (13) or P_1, P_2 and P_3 of the formulae (14) ~ (19) into $(P_1+i\Delta P_1)$, $(P_2+i\Delta P_2)$ *etc.* or $(P_1+i\Delta P_1)$, $(P_2+i\Delta P_2)$, $(P_3+i\Delta P_3)$ *etc.*, the formulae representing the expected number of both of the two hooks spaced by *k* hook-intervals being occupied by individuals, when the gears have 4 or 5 hooks in each basket, are converted as follows:

a) The formulae applicable to the gears having 4 hooks in each basket

R = 0

$$X_{(k)} = 2\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1) + 2\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$= 2\left[P_1^2(m-a)\left\{1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right\}\right.$$

$$\left.+P_2^2(m-a)\left\{1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right\}\right] \cdots\cdots\cdots\cdots\cdots (20)$$

R = 1

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$+\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$= P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right] \cdots\cdots\cdots\cdots\cdots\cdots (21)$$

R = 2

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\,\Delta P_1)$$

$$= P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_1^2(m-a-1)\left[1+(m+1)\delta_1+(m-a)(2m+a+2)\frac{\delta_1^2}{6}\right] \cdots\cdots\cdots\cdots\cdots\cdots (22)$$

R = 3

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1) + \sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\,\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\,\Delta P_2)$$

$$= P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$

$$+P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right] \cdots\cdots (23)$$

R= 4

$$X_{(k)}=\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\,\Delta P_1)+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\,\Delta P_2)$$

$$+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\,\Delta P_2)$$

$$=P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_2^2(m-a-1)\left[1+(m+1)\delta_2+(m-a)(2m+a+2)\frac{\delta_2^2}{6}\right]\cdots\cdots\cdots\cdots\cdots\cdots\cdots(24)$$

here $\delta_1=\frac{\Delta P_1}{P_1}$ and $\delta_2=\frac{\Delta P_2}{P_2}$

because

$$\sum_{i=1}^{m-a}(P_I+i\Delta P_I)(P_{II}+\overline{i+a}\,\Delta P_{II})=P_IP_{II}\sum_{i=1}^{m-a}(1+i\delta_I)(1+\overline{i+a}\,\Delta\delta_{II})$$

$$=P_IP_{II}\sum_{i=1}^{m-a}\left[(1+a\delta_{II})+(\delta_I+\delta_{II}+a\delta_I\delta_{II})i+\delta_I\delta_{II}i^2\right]$$

$$=P_IP_{II}(m-a)\left[1+a\delta_{II}+\left\{(2m+a+1)\delta_I\delta_{II}+3(\delta_I+\delta_{II})\right\}\frac{(m-a+1)}{6}\right]$$

and

$$\sum_{i=1}^{m-a-1}(P_I+i\Delta P_I)(P_{II}+\overline{i+a+1}\,\Delta P_{II})$$

$$=P_IP_{II}(m-a-1)\left[1+(a+1)\delta_{II}+\left\{(2m+a+2)\delta_I\delta_{II}+3(\delta_I+\delta_{II})\right\}\frac{(m-a)}{6}\right]$$

here $\delta_I=\frac{\Delta P_I}{P_I}$ and $\delta_{II}=\frac{\Delta P_{II}}{P_{II}}$.

b) The formulae applicable to the gears having 5 hooks in each basket

Table 10. Catch rates corresponding to respective columns of Table 7; the influence of the gradient of the catch rate and that of the difference of catch rates due to the different depth levels of respective hooks are taken into consideration ($H=5$).

R \ h	1	2	3	4	5
	$P_1+i\Delta P_1$	$P_2+i\Delta P_2$	$P_3+i\Delta P_3$	$P_2+i\Delta P_2$	$P_1+i\Delta P_1$
0	$P_1+\overline{i+a}\Delta P_1$	$P_2+\overline{i+a}\Delta P_2$	$P_3+\overline{i+a}\Delta P_3$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$
1	$P_2+\overline{i+a}\Delta P_2$	$P_3+\overline{i+a}\Delta P_3$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0
2	$P_3+\overline{i+a}\Delta P_3$	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$
3	$P_2+\overline{i+a}\Delta P_2$	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$
4	$P_1+\overline{i+a}\Delta P_1$	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$	$P_3+\overline{i+a+1}\Delta P_3$
5	0	$P_1+\overline{i+a+1}\Delta P_1$	$P_2+\overline{i+a+1}\Delta P_2$	$P_3+\overline{i+a+1}\Delta P_3$	$P_2+\overline{i+a+1}\Delta P_2$

R = 0

$$X_{(k)} = 2\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1) + 2\sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$+\sum_{i=1}^{m-a}(P_3+i\Delta P_3)(P_3+\overline{i+a}\Delta P_3)$$

$$=2P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$

$$+2P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right]$$

$$+P_3^2(m-a)\left[1+(m+1)\delta_3+(m-a+1)(2m+a+1)\frac{\delta_3^2}{6}\right] \cdots\cdots (25)$$

R = 1

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_3+\overline{i+a}\Delta P_3)$$

$$+\sum_{i=1}^{m-a}(P_3+i\Delta P_3)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$=P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_2P_3(m-a)\left[2+(m+1)(\delta_2+\delta_3)+(m-a+1)(2m+a+1)\frac{\delta_2\delta_3}{3}\right] \cdots\cdots (26)$$

R = 2

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_3+\overline{i+a}\Delta P_3) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$+\sum_{i=1}^{m-a}(P_3+i\Delta P_3)(P_1+\overline{i+a}\Delta P_1) + \sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\,\Delta P_1)$$

$$=P_1P_3(m-a)\left[2+(m+1)(\delta_1+\delta_3)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_3}{3}\right]$$

$$+2P_2^2(m-a)\left[1+(m+1)\delta_2+(m-a+1)(2m+a+1)\frac{\delta_2^2}{6}\right]$$

$$+P_1^2(m-a-1)\left[1+(m+1)\delta_1+(m-a)(2m+a+2)\frac{\delta_1^2}{6}\right] \cdots\cdots (27)$$

R = 3

$$X_{(k)} = \sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2) + \sum_{i=1}^{m-a}(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)$$

$$+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\,\Delta P_1) + \sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\,\Delta P_2)$$

$$=P_1P_2(m-a)\left[2+(m+1)(\delta_1+\delta_2)+(m-a+1)(2m+a+1)\frac{\delta_1\delta_2}{3}\right]$$

$$+P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right] \cdots\cdots (28)$$

R = 4

$$X_{(k)}=\sum_{i=1}^{m-a}(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_3+i\Delta P_3)(P_1+\overline{i+a+1}\Delta P_1)$$
$$+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_3+\overline{i+a+1}\Delta P_3)$$
$$=P_1^2(m-a)\left[1+(m+1)\delta_1+(m-a+1)(2m+a+1)\frac{\delta_1^2}{6}\right]$$
$$+P_1P_3(m-a-1)\left[2+(m+1)(\delta_1+\delta_3)+(m-a)(2m+a+2)\frac{\delta_1\delta_3}{3}\right]$$
$$+P_2^2(m-a-1)\left[1+(m+1)\delta_2+(m-a)(2m+a+2)\frac{\delta_2^2}{6}\right] \cdots\cdots (29)$$

R = 5

$$X_{(k)}=\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)+\sum_{i=1}^{m-a-1}(P_3+i\Delta P_3)(P_2+\overline{i+a+1}\Delta P_2)$$
$$+\sum_{i=1}^{m-a-1}(P_2+i\Delta P_2)(P_3+\overline{i+a+1}\Delta P_3)+\sum_{i=1}^{m-a-1}(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)$$
$$=P_1P_2(m-a-1)\left[2+(m+1)(\delta_1+\delta_2)+(m-a)(2m+a+2)\frac{\delta_1\delta_2}{3}\right]$$
$$+P_2P_3(m-a-1)\left[2+(m+1)(\delta_2+\delta_3)+(m-a)(2m+a+2)\frac{\delta_2\delta_3}{3}\right] \cdots\cdots (30)$$

here, $\delta_1=\frac{\Delta P_1}{P_1}$, $\delta_2=\frac{\Delta P_2}{P_2}$ and $\delta_3=\frac{\Delta P_3}{P_3}$.

Theoretical values, $X_{(k)}$, of this type estimated at k, not so large, take a little higher values than those estimated by using the formulae (9)~(19), while the outline of variation with the increase of k is quite the same in both cases, although the rate of decrease with the increase of k is slightly sharper in the former than in the latter.

3. Analyses of the distribution pattern projected along the gears

If we analyze the spatial relation by using a very short length as the unit section, we are hardly able to find out the existence of any schools of a considerable size, because the scale of consideration is so short that it might result that even the shortest interval between the adjacent individuals is thought erroneously as consisting of more than one or two sections, individuals are misregarded to be scattered more evenly than by chance despite of the fact actually they consist of contagious schools when they are seen by using some longer units or the access to the clear conclusion is strongly interfered by the fine structure which may rather be regarded as intra-school (or sub-school) patterns, though we can be acquainted with the more detailed relations between individuals. Consequently, the longer the unit length should be, the more effective to examine the existence of large schools, as the interference of fine structures are removed. Accordingly, it is desirable to adopt longer intervals to clear out the outline of the spatial relation, yet it is desirable, on the other hand, that there are more than 10 sections at the last k in consideration in order to make free from the accidental error in the actual counting in the range of k from O to a considerable length. Nevertheless the total length of a row of gears is limited, although it is long enough, these days, as to need a whole day to soak in the whole of gears and then haul up it again. For these reasons, at first, the width of 5 consecutive baskets is adopted as the unit section; this is approximately 1 km long or 1/75 of total length of a row of gears. However, when the analyses are carried out by using such a long interval as the unit section, the outline of the spatial relation within the length of respective units or thereabout is left unrevealed. Hence another series of examinations is added; here the width of one basket (≒*ca.* 200 m) is used as the unit section for formulae (1)~(4), instead of 5 consecutive baskets in the preceding series. This is very significant, because the existence of schools or sub-schools of 1, 2 or mostly shorter than 5 units width (= 25 baskets ≒ 5 km) is detected in most examples by next series of examinations and it is necessary to examine the spatial relation in the shorter range and moreover it is indispensable as an intermediate step for finding out the conclusion common to the distribution patterns of respective examples, uniting the results of the preceding series of analyses pursued to clarify the outline and being significant rather ecologically with those of the following ones which are rather important as a theoretical basis for technical problems. The full scales in the relation diagrams of this series correspond to 10 notches, 1/5 of those of the preceding series, and 10 notches of this series correspond to the full scales of k of the following series. Moreover, the estimated values of this series are approximately 1/5 time those of the preceding series. It seems to be one of the characteristics of this series, that the amplitude of deviation of the observed values from the estimated ones is the largest of all these three series of analyses and this makes it easy to consider upon the spatial relation. And lastly, another series of analyses is tried, in which the unit length is shortened to a single hook-interval (≒ *ca.* 40 m), as this is not only necessary to clarify the elemental structure from the ecological points but also very important from the technical point of view.

Notes for decoding the diagrams and notation used in them

When the observed value at a certain k takes the same value as the estimated one, it is safely considered that the number of individuals occurring in the sections or at the hooks spaced by that k intervals from any occupied section or hook is as much as that being distributed by chance, while when the observed value is higher or lower than the estimated one, respectively more or less numerous individuals should be caught in the sections or at the hooks spaced by k intervals from any occupied

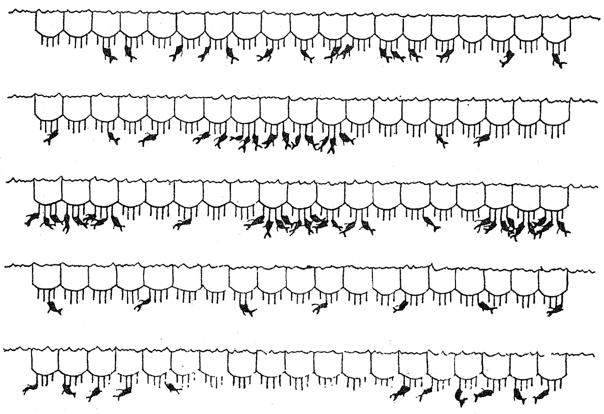
(1)
(2)
(3)
(4)
(5)


Fig. 6. Schematic representation of the distribution patterns of fishes along the long-line. Notes: S. L.: Sea Level. (1) Random distribution, (2) single contagious school, (3) many contagious schools, (4) single self-spacing school and (5) many self-spacing schools.

section or hook. But when the observed values are always equal to the estimated ones at any values of k, this means simply that the same number of individuals as that distributed by chance are caught in the sections or at the hooks spaced by k intervals from any occupied sections or hooks at any values of k. In this case no explanation is given to the positional relation which may be found in the distribution of the couples of individuals at respective intervals —— whether the couples of individuals at narrower intervals are gathered within several restricted parts along a row or they are distributed by chance. The last case can safely be considered to indicate that the distribution of individuals is quite by chance, because the observed values at k not so large should be higher than the estimated value and it is hardly possible that the observed values are the same as the estimated ones at any value of k if the distribution of the couples of individuals at narrower intervals is restricted. When the observed values in the range from $k=0$ to a certain value ($k=k_1$) are continuously higher than the corresponding estimated ones, it is deducible from this fact only that the couples of individuals spaced by shorter than k_1 occur more frequently than those in the case when they are scattered by chance. But, this gives no explanation to the positional relation between such couples nor that between such and other couples. Anyhow it can be cleared from this whether such narrowly spaced couples are observable within a restricted part or they are quite scattered; —— at least this shows distinctly that the contagiousness reaches k_1 intervals. Accordingly, one of the characteristics of the distribution pattern, perhaps it may be an average width of schools, may be expressed by k_1. If the couples spaced by the interval shorter than k_1 are observable mostly within a single restricted part, no observed value can be higher than the estimated one in the range $k>k_1$. But if they are not gathered within a restricted part, several patches of observed values higher than the estimated ones may occur and evidently these are reflecting another characteristics of the distribution pattern, perhaps the distribution pattern of such narrowly spaced couples. And the distance between the centers of adjacent patches can be considered as an average interval between schools. Thus, it is presumable whether the population is constituted of a single contagious school or many ones according to the question whether the observed values higher than the estimated ones are restricted within the range $k_1 \geqq k$ or not. Contrary to the above-mentioned pattern, there are some examples, in which the observed values in the range from $k=0$ to $k=k_2$ are continuously lower than the estimated ones; this means simply that less individuals than those being distributed by chance are observable in the sections or at hooks spaced by the interval shorter than k_2 from any occupied sections or hooks. In such examples, the observed values are raised till they exceed the estimated ones and then decrease again to lesser values with the increase of k. For the same reason mentioned above, the individuals in such examples are considered to be spaced one another more evenly than in the case when they are distributed by chance. But when more than one patch of such a pattern is met with along a single row, more than one peak is observable. Such a case can easily be recognized in the statistical treatment, but it seems rather difficult to understand such a case actually, although this can be expected when individuals show any territorial behavior or the length of unit section under the consideration is too short as compared with the distribution pattern of individuals; such a pattern is named as self-spacing, hyponormal or subnormal dispersion (TORII 1953, 1956, BEALL 1935, ROMELL 1930, BLACKMANN 1935, ASHBY 1935 and GRASGOW 1939). However, judging from the above-mentioned patterns, it must be noticed that the $X(k)-k$ relation diagram showing quite different contagious pattern can surely be obtained when a enough length is adopted as the unit interval under the consideration.

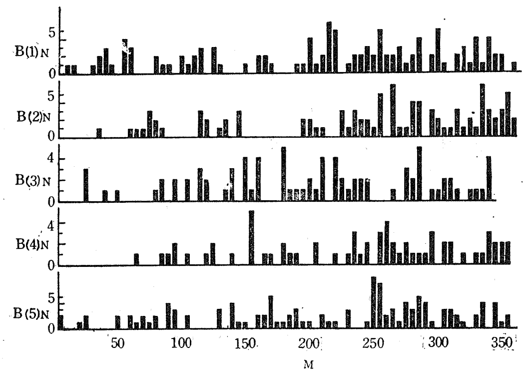
Besides, there might occur some errors to mistake the width of the overlapping parts for the width of schools when many schools of a considerable width are caught partly overlapping one another, although judging from the fact that the catch rates are actually very low and relatively homogenous the actual existence of such a case is not likely.

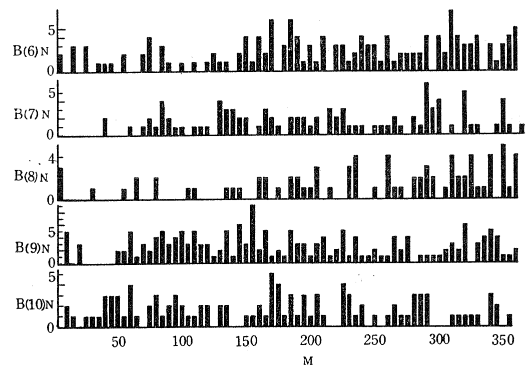
Then, if schools as compact as what are often met with and called as schools in a general sense are caught, the deviation of the observed values may extend from a few ten percents of the estimated ones to the several times of them. In actual cases, however, the deviation of the observed values from the estimated ones is rather small, although the inclination of deviation suggests that the population is composed of many very weakly contagious schools. Accordingly it is safely supposed that tuna is distributed approximately by chance, but its population is composed of many schools of negligibly weak contagiousness when it is examined in detail.

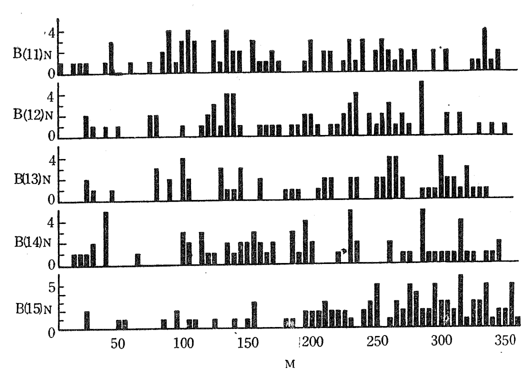
The series of figures noted as (I) in Figs. 8, 10 and 12 represent the results of the first series of analyses, in which the width of 5 consecutive baskets ($\fallingdotseq$ *ca.* 1 km) is adopted as the unit length, and the series II shows the results of the second one, in which the width of one basket ($\fallingdotseq$ *ca.* 200 m) is adopted as the unit length, while the series III illustrates the spatial relation diagrams, in which the unit length is one hook-interval (≒*ca.* 40 m). In these figures, the estimated values computed by using formulae (1) and (2) (in Series I and II) or formulae (5) and (6) (in Series III), on the supposition that individuals are simply scattered by chance, are represented by empty circles (……○……). While, those represented by black and white circles (------◐------) indicate those estimated by using formulae (3) and (4) (in Series I and II) or formulae (7) and (8) (in Series III) on the supposition that the catch rate increases simply with the soaking time and the chances of respective hooks being occupied by fishes or not are quite independent of one another. Besides, there are two other series of estimated values represented by ◑ and ◒ in Series III, the former comprises the values estimated by using formulae (9)～(13) in which simply the influence of the difference of the catch rate of hooks according to the depth levels is taken into consideration while the latter represents the values estimated by using formulae (20)～(24) in which both the above-mentioned influence and that of the increase of the catch rate with the soaking time are taken into consideration. When the values are quite similar between the cases when the above-mentioned influences are taken into consideration or not, or the difference between the values computed under respective conditions is hardly discernible on the diagrams, they are represented by the values calculated under the condition where the above-mentioned influences are not taken into consideration. The distribution pattern of tunas is deduced in the above-mentioned way, by comparing respective series of observed values, indicated by filled circles (—●—), with those estimated theoretically.

1) Big-eye tuna

Generally, the deviation of the observed values in Series II from the corresponding ones estimated under the condition where the influence of the gradient of the catch rate is taken into consideration is considerably large, while those in Series I and Series III from the corresponding values estimated under the condition where the influences of both factors are taken into consideration are nearly negligible. This means that the unit width in the first series, the width of 5 consecutive baskets, is too long to consider upon the existence of the most conspicuous schools, because there occur one or more maxima and minima within 5 consecutive baskets, consequently the apparent distribution assumes falsely uniformity. On the other hand, the unit length adopted in Series III, 1 hook-interval, is so short that merely the fine sub-school structures can be cleared out. Besides, it is noticeable that the extremely strong contagiousness is often observed between the adjacent hooks; this fact coincides with the fishermen's saying that big-eye tunas are caught usually in couple and seems to be one of the characteristics of the distribution pattern of big-eye tuna. More detailed examinations of respective examples seem to allude to the following tendencies:——


B(1)N
B(2)N
B(3)N
B(4)N
B(5)N
50
100
150
200
250
300
350
M


B(6)N
B(7)N
B(8)N
B(9)N
B(10)N
50
100
150
200
250
300
350
M


B(11)N
B(12)N
B(13)N
B(14)N
B(15)N
50
100
150
200
250
300
350
M

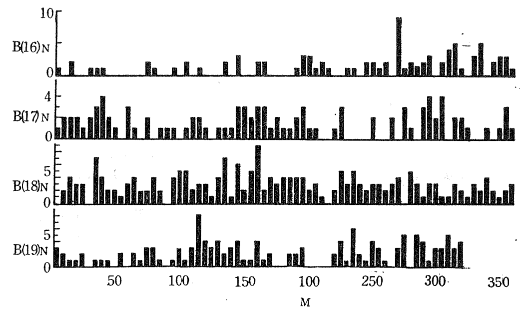


Fig. 7. Distribution of big-eye tuna in each of 5 consecutive baskets in respective examples.
Abbreviations :
M : basket number counted from the initial point of hauling.
N : number of individuals caught by respective consecutive 5 baskets.
B(x) : example of big-eye tuna obtained at the Station "x" in the Fishing Ground No. 1.

Exposition of particular example

Example B 1: When deducing from the diagram of Series Ⅲ, it becomes clear that the number of individuals caught at the hooks spaced by 6 or less hook-intervals from any occupied hooks is continuously higher than the expected one. Accordingly the elemental structure is considered as the clusters covering 6 hook-intervals (≒250 m), a little longer than the width of 1 basket, although this fact does not mean nothing else than that couples of individuals spaced by shorter than 6 hook-intervals are more frequently met with than theoretically expected. Here, it belongs to other problems whether any individuals are caught or not at hooks inserted between two occupied hooks spaced by shorter than 6 hook-intervals. The diagram of Series Ⅱ shows that most of the elemental clusters cover from 1 to 4 baskets width (≒200~800 m) and are located approximately at every 7 baskets (≒ 1,500 m). [The expression "nearly at every N hook-intervals (baskets or units)" is hereafter used to indicate that the clusters are observed frequently at N hook-intervals, but it does not mean that exactly every space at N hook-intervals is occupied by fishes, rather, in most cases, some

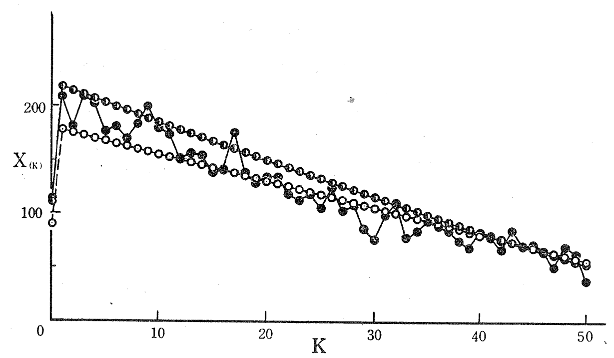


Fig. 8—1 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 1 in the Fishing Ground No. 1).

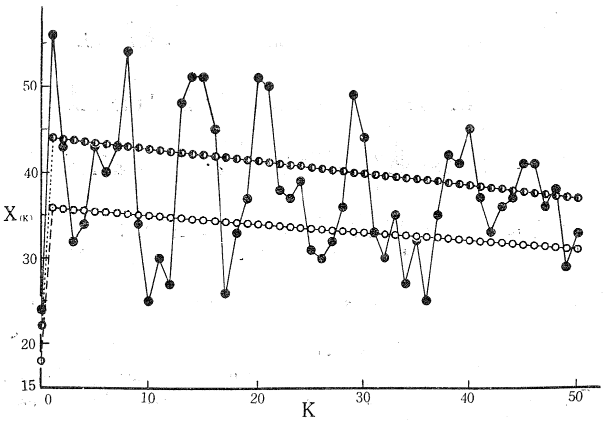


Fig. 8—1 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 1 in the Fishing Ground No. 1).

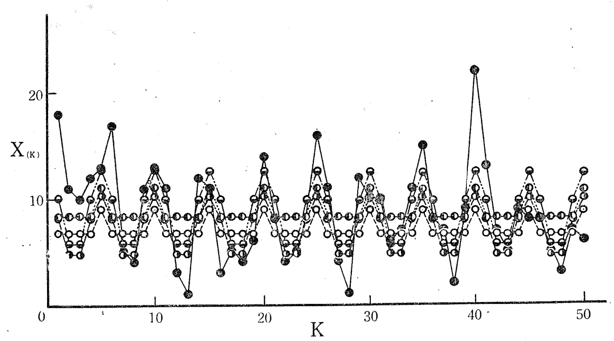


Fig. 8—1 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 1 in the Fishing Ground No. 1)

spaces are left vacant.] Most of the estimated values in Series Ⅰ under the condition that the influence of the gradient of the catch rate is taken into consideration are higher than the observed ones; possibly this is caused by over-estimation of each or both of P_0 and ΔP. The accurate values are considered to be a little lower, perhaps intermediate between the two estimated ones in the diagram. The existence of any distinct large schools is, however, hardly detectable even under the above-mentioned estimated values.

Example B 2 : The deviation of observed values in Series Ⅲ alludes to the existence of the elemental clusters covering a little longer space than 1 basket width (200 m) and spaced by *ca.* 6 or 9 baskets intervals (1～2 km). The same deviation is shown more clearly in Series Ⅱ, although it is reduced into one fifth of that found in Series Ⅲ.

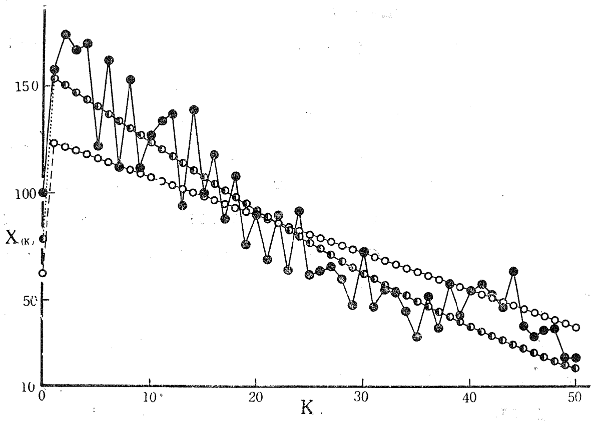


Fig. 8—2 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 2 in the Fishing Ground No. 1).

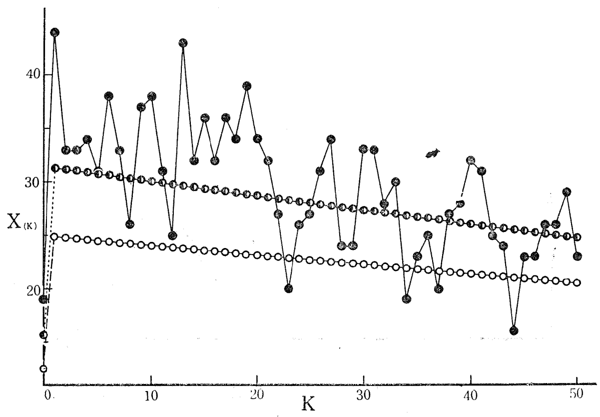


Fig. 8—2 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 1).

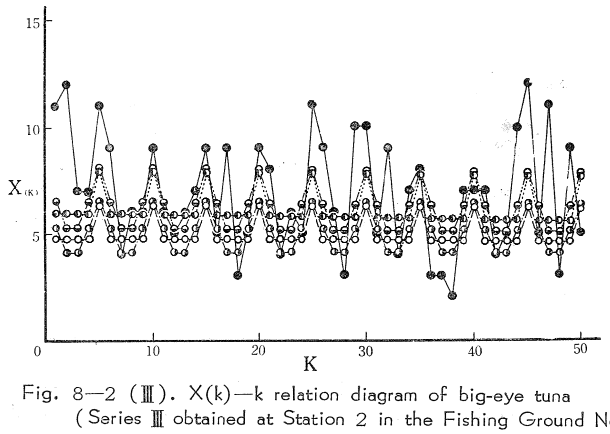


Fig. 8—2 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 2 in the Fishing Ground No. 1).

Besides, it is shown that these elemental clusters or bundles of them further form superior aggregations covering from 2 to 4 baskets width (400∼800 m) and spaced by 1 or 2 baskets width (200∼400 m). In the diagram of Series I, the deviation seems to represent two different periodicities, of which the longer one is of about 40 units (200 baskets width ≒ 40 km) long, while the shorter one is of about 2 units (10 baskets ≒ 2 km) long or thereabout. It is deducible from the above-mentioned facts that the population might be composed of two large schools located at about the 100th and 300th baskets respectively and further they consist of many smaller aggregations of the above-mentioned scale.

Example B 3 : Simultaneous catch at the two adjoining hooks is clearly shown in the diagram of Series III. The results of the analysis of the Series I show the nearly perfect periodicity of 2 units (2 km). But, when the units are divided into respective

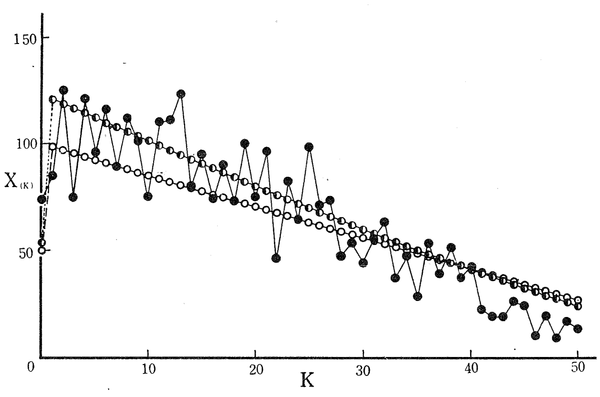


Fig. 8—3 (I). X(k)—k relation diagram of big-eye tuna (Series I obtained at Station 3 in the Fishing Ground No. 1).

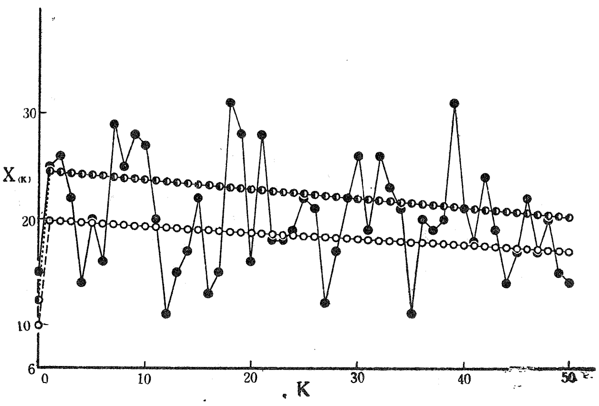


Fig. 8—3 (II). X(k)—k relation diagram of big-eye tuna (Series II obtained at Station 3 in the Fishing Ground No. 1).

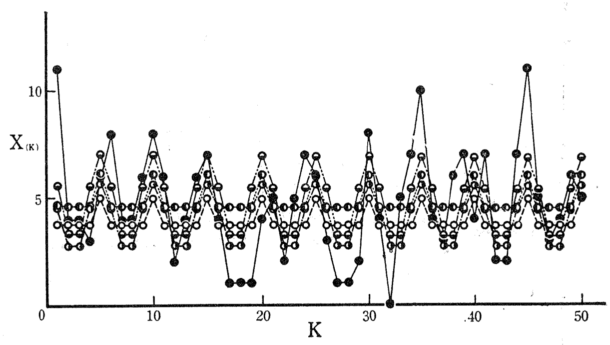


Fig. 8—3 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 3 in the Fishing Ground No. 1).

baskets (results in Series Ⅱ), the periodicity becomes obscure. This is attributable to the fact that the above-mentioned periodicity is a false one caused chiefly by the difference between the length of the unit adopted in Series Ⅰ and the distance between the centers of the adjoining schools and partly by the irregularity of contagiousness of schools. Most probably the real feature of the distribution pattern can be guessed as follows: the elemental clusters of the width shorter than 3 hook-intervals (*ca.* 100 m) (chiefly of the width of 1 hook-interval ≒ *ca.* 40 m) form many aggregations of the higher order covering from 1 to 4 baskets width (200~800 m) and the distribution of these aggregations shows an extremely weak self-spacing or rather the aggregations seem to be distributed by chance.

Example B 4 : The detailed examinations on the diagram of Series Ⅲ reveal that rather conspicuous elemental clusters covering shorter than 4 hook-intervals (*ca.* 150 m) are spaced by from 40 to 50 hook-intervals (1.5~2.0 km) and intervened by some obscure

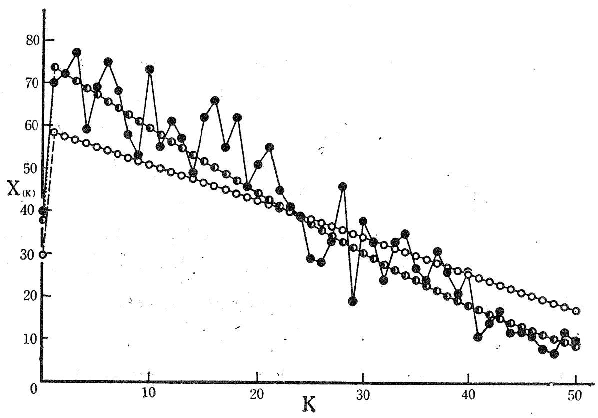


Fig. 8—4 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 4 in the Fishing Ground No. 1).

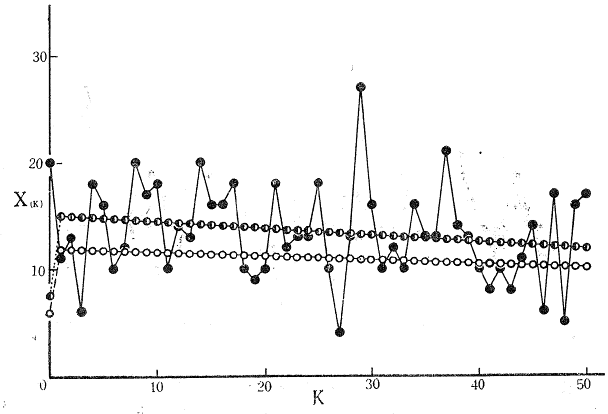


Fig. 8—4 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 4 in the Fishing Ground No. 1).

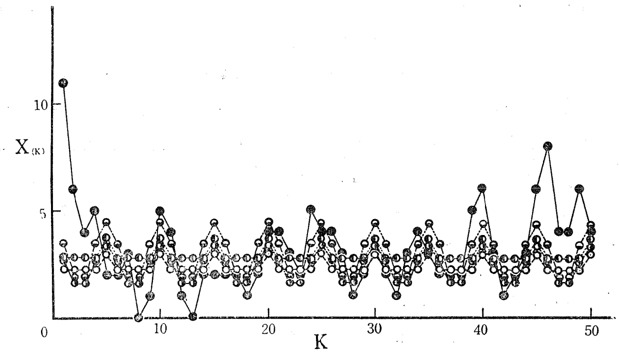


Fig. 8—4 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 4 in the Fishing Ground No. 1).

clusters (contagious degree of these clusters seems to be as high as in the preceding examples, although number of clusters is evidently fewer) at intervals. The diagram of Series Ⅱ suggests the existence of aggregations of 1 to 2 baskets width (200~400 m), of which 2 or 3 are distributed at every 10 baskets (2 km); this seems to indicate the same distribution pattern as that found in Series Ⅲ. The result of the analysis in Series Ⅰ suggests that the periodicity of the deviation of the observed values is irregular. Throughout the examinations on Series Ⅰ~Ⅲ, the distribution pattern of this example may be regarded as follows: the population seems to be constituted of many conspicuous elemental clusters covering the space shorter than 4 hook-intervals (*ca.* 150 m), spaced by *ca.* 5 baskets (1 km) and being accompanied with a few obscure clusters.

Example B 5 : The higher observed values in the range from $k=0$ to 13 hook-

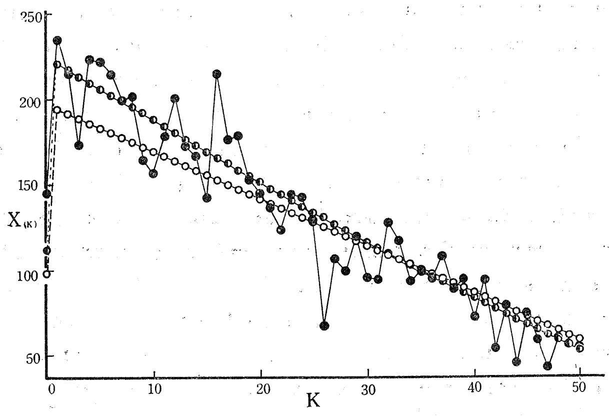


Fig. 8—5 (I). X(k)—k relation diagram of big-eye tuna
(Series I obtained at Station 5 in the Fishing Ground No. 1).

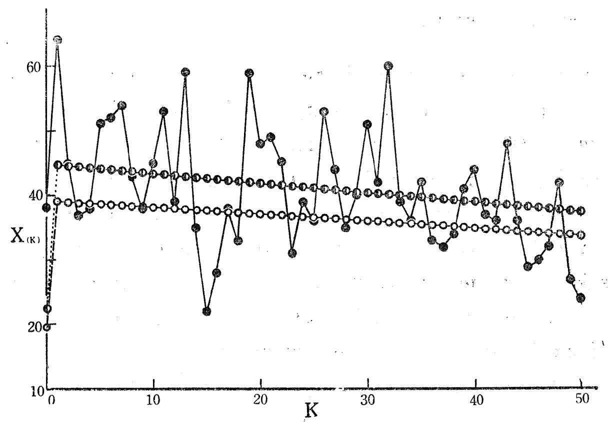


Fig. 8—5 (II). X(k)—k relation diagram of big-eye tuna
(Series II obtained at Station 5 in the Fishing Ground No. 1).

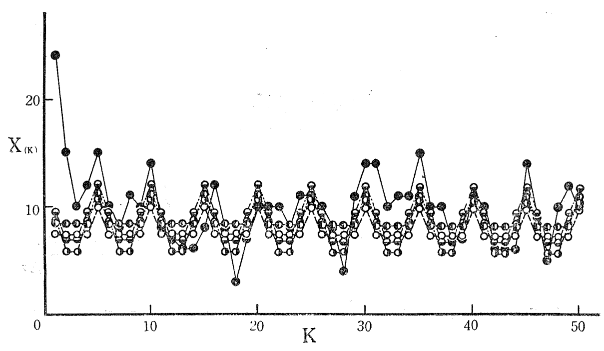


Fig. 8—5 (III). X(k)—k relation diagram of big-eye tuna
(Series III obtained at Station 5 in the Fishing Ground No. 1).

intervals in Series Ⅲ correspond to those in the range from $k = 0$ to 2 baskets in Series Ⅱ. The next group of higher values in the range from $k = 29$ to 38 hook-intervals in Series Ⅲ is corresponding to those in the range from $k = 5$ to 8 in Series Ⅱ. While the higher values in the range from $k=0$ to 13 baskets in Series Ⅱ correspond to those in the range from $k=0$ to 2 in the diagram of Series Ⅰ, the following lower observed values in the range from $k = 14$ to 18 baskets correspond to that at $k=3$ in Series Ⅰ, and again higher ones in the range from $k=19$ to 35 or 40 baskets are corresponding to those in the range from $k=4$ to 8 units in Series Ⅰ. It is deducible from these facts and diagrams that the population is constituted chiefly of many elemental clusters covering 2 baskets (400 m) and spaced by about 3 baskets (600 m). The words "elemental cluster" might easily be accepted, especially in such long clusters as in the case under consideration as being constituted of many individuals, but, actually, they consist mostly of couples of individuals spaced by shorter than a certain width, although isolated individuals may be included in them in some cases. However, the distribution pattern and the density considered altogether, they can be regarded as clusters.

Example B 6 : From the diagram of Series Ⅲ, it is recognizable that the contagiousness is extremely high at the adjoining hooks (40 m) and also a little higher at 5 successive ones (200 m). The continuously higher observed values are found around $k = 10$,30 and 45 hook-intervals (400 m, *ca.* 1.5 km, and *ca.* 2 km), consequently the width of such continuously higher values is estimated respectively as 6, 3, 11 and 8 hook-intervals which correspond to the length from 1 to 3 baskets. The diagram of Series Ⅱ shows the above-mentioned structure more clearly. The diagram of Series Ⅰ indicates that the population is constituted of loosely formed schools covering *ca.* 35 units (=175 baskets≒35 km), the contagiousness of which is nearly negligible. These schools are then subdivided into many subordinate schools of 1 unit width (1 km)

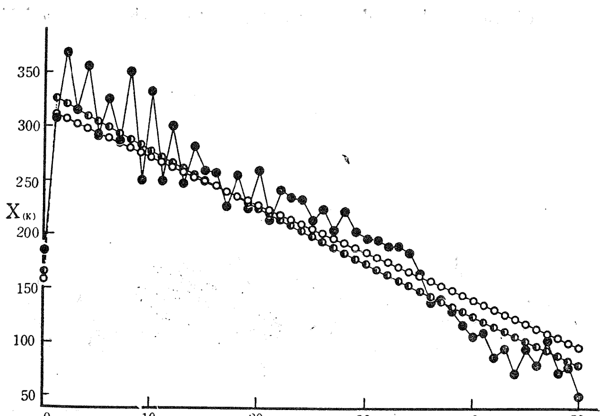


Fig. 8—6 (Ⅰ). X(k)—k relation diagram of big-eye tuna
(Series Ⅰ obtained at Station 6 in the Fishing Ground No. 1).

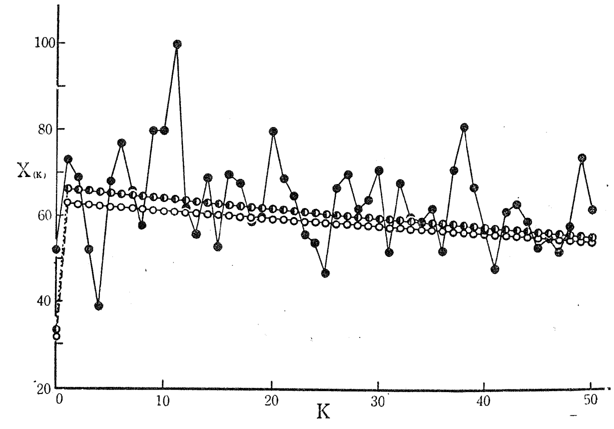


Fig. 8—6 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 6 in the Fishing Ground No. 1).

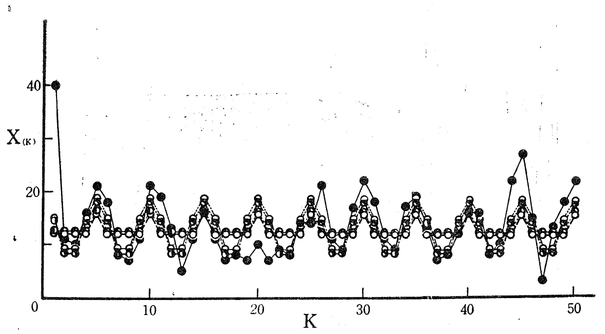


Fig. 8—6 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 6 in the Fishing Ground No. 1).

distributed approximately at every one unit. When the above-mentioned structure is considered together with the results of close examination on the diagram of Series Ⅱ, it becomes clear that the emergence of the subordinate structure is caused by the following mechanism:——when a row of population consisting of many clusters of 1 to 3 baskets width (200~600 m), distributed each 3 in every 10 baskets (2 km), is divided into sections of 5 consecutive baskets width (1 km), some sections may contain a couple or a single of large clusters, while others may include only a single small one. Thus, the above-mentioned data summarized, the distribution pattern of this example may be safely considered as follows: many elemental clusters of the width from 3 to 10 hook-intervals (100~400 m) are distributed rather uniformly within 175 baskets (35 km) and form as a whole a large school which occupies the principal part of the total catch.

Example B 7 : On the diagram of Series Ⅲ, the width of elemental clusters can be

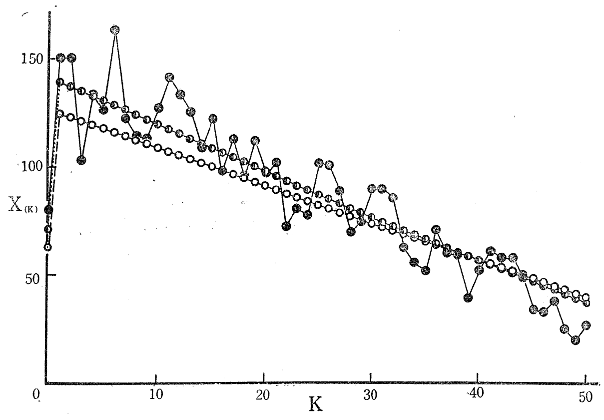


Fig. 8—7 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 7 in the Fishing Ground No. 1).

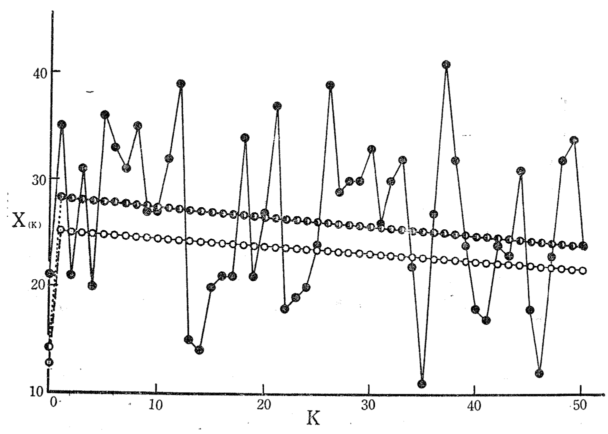


Fig. 8—7 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 7 in the Fishing Ground No. 1).

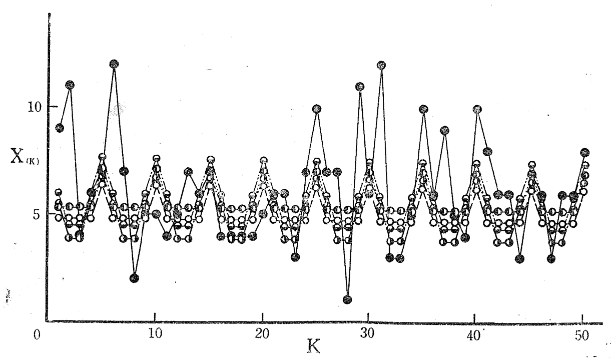


Fig. 8—7 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 7 in the Fishing Ground No. 1).

guessed as 3~7 hook-intervals (100~300 m), when the small deviations of the observed values, which can be regarded as accidental errors, are excluded. The diagram of Series II indicates that the elemental clusters detected in Series III are further bundled into a number of aggregations of superior order covering 1,2 or rarely 3 baskets width (200, 400 or 600 m), besides the general tendency of deviation quite the same as that represented in Series I. The diagram of Series I suggests that the above-mentioned aggregations are further bundled into schools of somewhat irregular width.

Example B 8 : The diagram of Series III suggests that the contagious degree is extremely high between the adjoining hooks and the size of the elemental clusters is estimated as 2~6 hook-intervals width (80~250 m). The diagram of Series II shows that

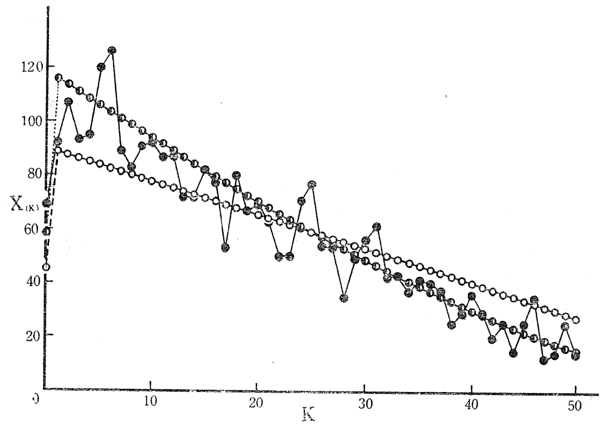


Fig. 8—8 (I). X(k)—k relation diagram of big-eye tuna (Series I obtained at Station 8 in the Fishing Ground No. 1).

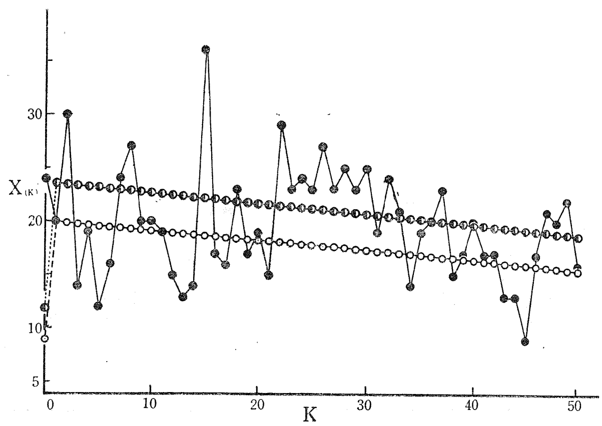


Fig. 8—8 (II). X(k)—k relation diagram of big-eye tuna (Series II obtained at Station 8 in the Fishing Ground No. 1).

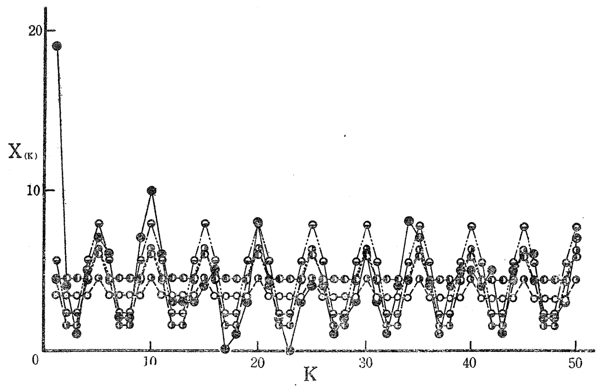


Fig. 8—8 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 8 in the Fishing Ground No. 1).

these elemental clusters, mostly couples of individuals caught at the adjoining hooks, and solitary individuals are further bundled into many aggregations of superior order covering 1 or 2 baskets width (200~400 m) and spaced by 1 or 2 baskets. And the diagram of Series Ⅰ indicates that the population is chiefly constituted of such relatively conspicuous bundles covering 1 or 2 units width (1~2 km) and being evenly distributed throughout a whole row of gears.

Example B 9 : The deviation of the observed values from the estimated ones is very small in all 3 series and this indicates that the distribution is almost by chance. But, the closer examination reveals that the diagram of Series Ⅱ shows that most elemental clusters are couples of individuals hooked side by side (spaced by 40 m) or those leaving a vacant hook between them (spaced by 80 m) and they are observable more frequently at the hooks spaced by 15, 30, 35 or from 45 to 50 hook-intervals (600, 1,200, 1,400, 1,800

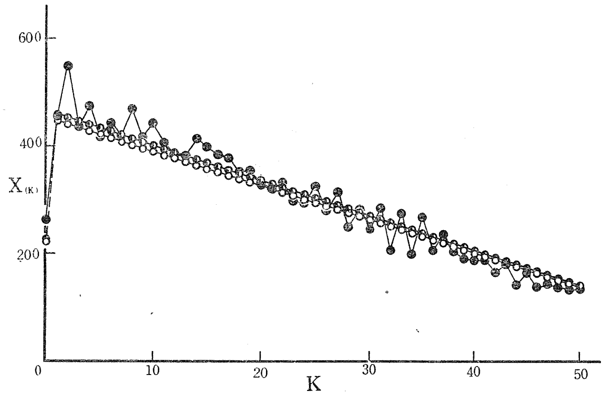


Fig. 8—9 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 9 in the Fishing Ground No. 1).

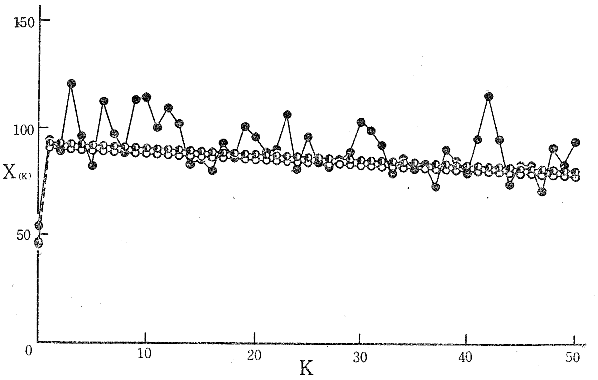


Fig. 8—9 (Ⅱ). X(k)—k relation diagram of big-eye tuna
(Series Ⅱ obtained at Station 9 in the Fishing Ground No. 1).

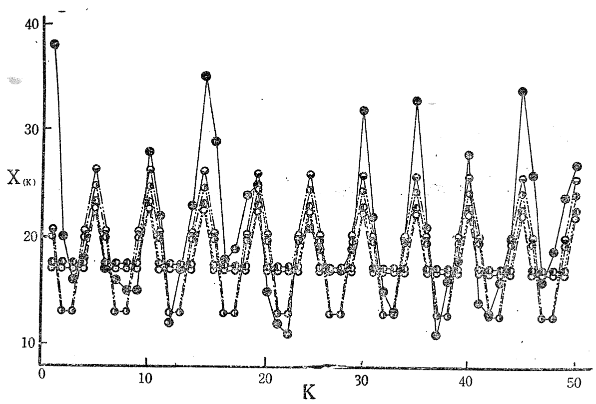


Fig. 8—9 (Ⅲ). X(k)—k relation diagram of big-eye tuna
(Series Ⅲ obtained at Station 9 in the Fishing Ground No. 1).

and 2,000 m) than at others. The diagram of Series Ⅰ alludes to the existence of large schools of negligibly weak contagiousness covering 20 units (20 km) and located around the 100th, 150th and 350th baskets; they are then consisting of many schools of lower order of the width covering 1 or 3 units (1∼3 km) and located approximately at every one unit. And the diagram of Series Ⅱ suggests that the subordinate schools found in Series Ⅰ and covering 1 unit (1 km) are, exactly speaking constituted of a single bundle of elemental clusters covering 3 baskets (*ca.* 500 m) or of 2 bundles covering 1 basket (200 m), while the schools covering 3 units (3 km) seem to consist of several bundles covering from 1 to 3 baskets (200∼*ca.* 500 m), although the contagious degree is extremely low in both kind of schools.

Example B 10 : The diagram of Series Ⅲ suggests that the finest structure of the population consists of many couples of individuals caught at the adjoining hooks (spaced by 40 m) and the diagram of Series Ⅱ suggests that the above-mentioned elemental

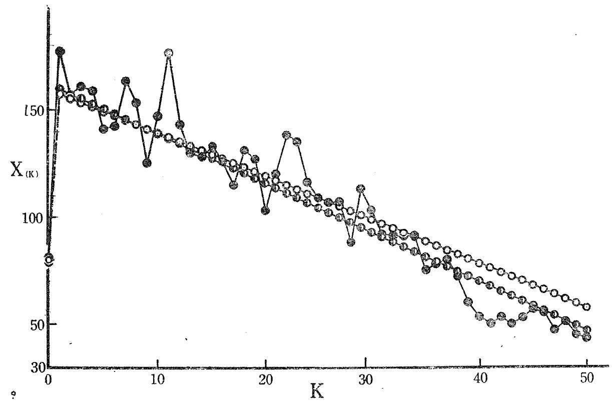


Fig. 8—10 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 10 in the Fishing Ground No. 1).

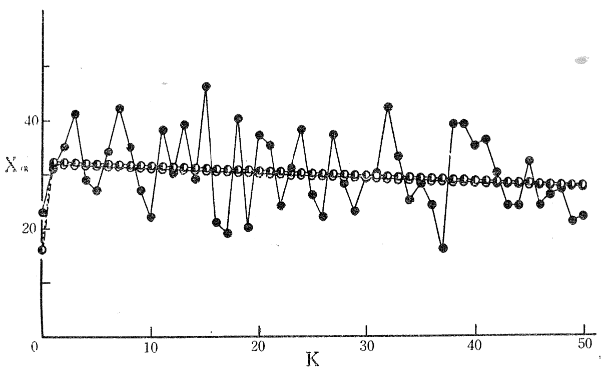


Fig. 8—10 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 10 in the Fishing Ground No. 1).

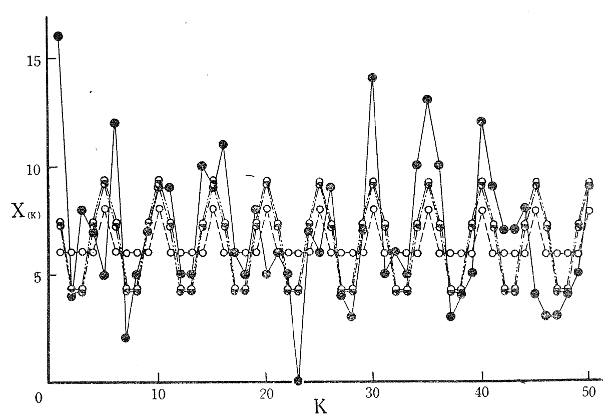


Fig. 8—10 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 10 in the Fishing Ground No. 1).

clusters are bundled into a number of aggregations of higher order covering from 1 to 4 baskets (200~800 m). It is clarified from the diagram of Series I that such aggregations are distributed irregularly and further form schools covering from 1 to 4 units (1~4 km), the smaller ones of which are constituted of a single aggregation or elemental cluster while the larger ones represent bundles of aggregations.

Example B 11 : Most of the elemental clusters are small but the contagiousness is rather strong, this indicates that the clusters consist of couples of individuals caught side by side at the adjoining hooks (spaced by 40 m). And the diagram of Series II suggests that most of these elemental clusters are bundled into aggregations covering from 2 to 4 baskets (400~800 m). Although the negligibly weak contagiousness extending to the width of *ca.* 30 units (30 km) is observable and this seems to indicate

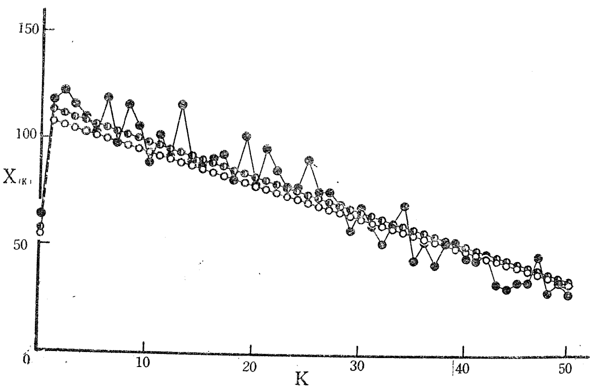


Fig. 8—11 (I). X(k)—k relation diagram of big-eye tuna (Series I obtained at Station 11 in the Fishing Ground No. 1).

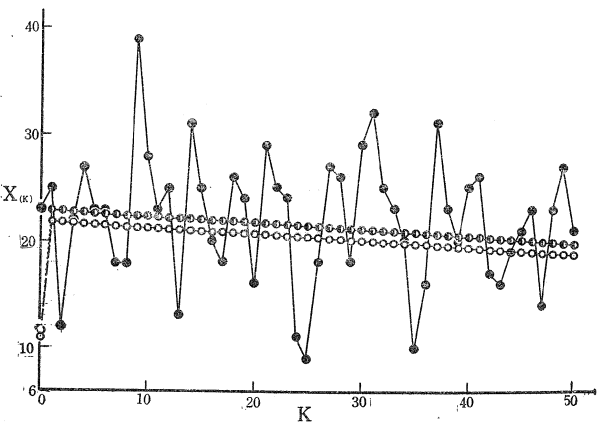


Fig. 8—11 (II). X(k)—k relation diagram of big-eye tuna (Series II obtained at Station 11 in the Fishing Ground No. 1).

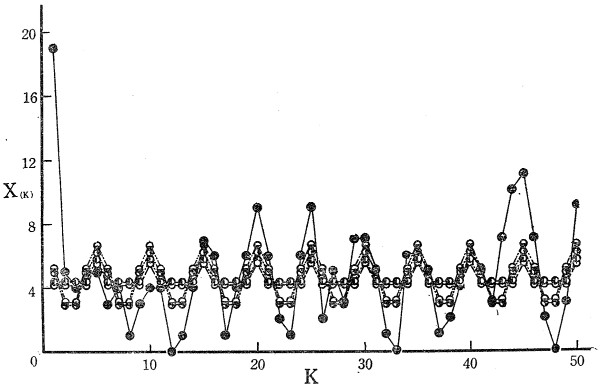


Fig. 8—11 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 11 in the Fishing Ground No. 1).

the existence of large schools located at the spaces from the 75th to the 180th basket and from the 200th to the 350th basket respectively, the structure of subordinate schools covering from 1 to 5 units (1～5 km) is much more conspicuous than the larger ones.

Example B 12 : Deviations of the observed values from the estimated ones are much larger in all 3 series of the present example than in the preceding two examples; this indicates that the schooling tendency is strong in this example. As the density of hooked individuals is low and the distribution is not quite homogenous, in treating the results of analysis of Series Ⅲ not only the couples of individuals caught side by side at the adjoining hooks (spaced by 40 m) but also even the couples of individuals caught at the hooks spaced by *ca.* 2 baskets width (400 m) can be regarded to show some

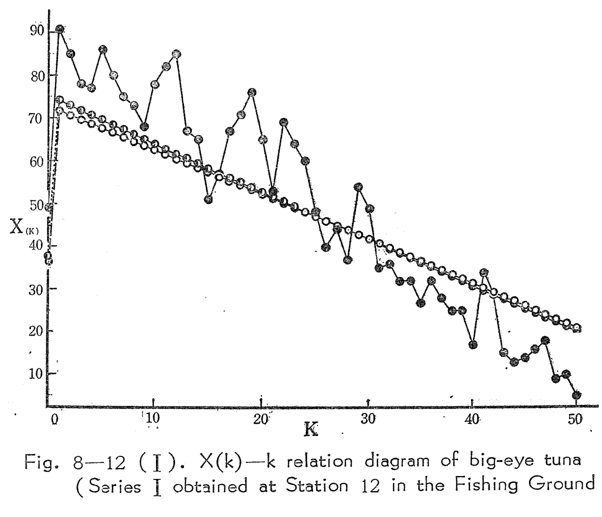


Fig. 8—12 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 12 in the Fishing Ground No. 1).

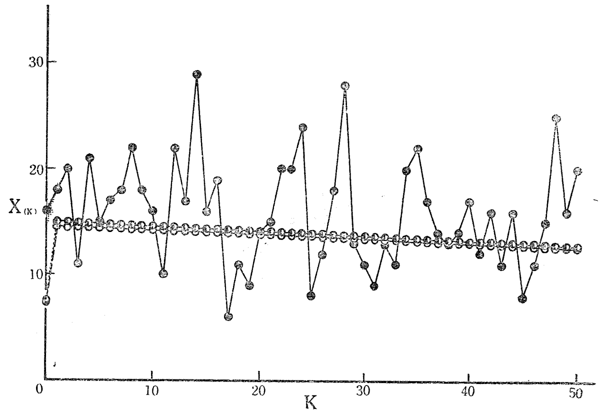


Fig. 8—12 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 12 in the Fishing Ground No. 1).

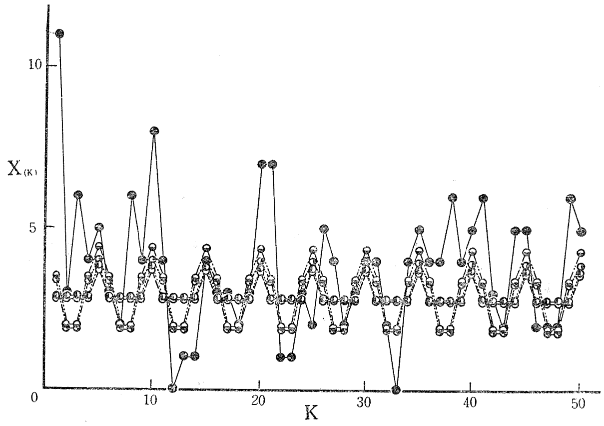


Fig. 8—12 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 12 in the Fishing Ground No. 1).

contagiousness rather than they are regarded as being distributed by chance. Thus they are recognized as elemental clusters. Although the deviation of the observed values from the estimated ones is somewhat conspicuous, no further fact other than those detected in Series Ⅲ and the formation of small bundles can be certified on the diagram of Series Ⅱ. However, the diagram of Series Ⅰ suggests that such elemental clusters and bundles of them further form a school covering the space of *ca.* 30 units (30 km), which corresponds to the part of the higher catch rate, from the 110th to the 260th basket. This school is then subdivided into 6 subordinate schools of 3 or 4 units width (3~4 km), which seem to represent the aggregations located around the 120th, 135th, 165th, 200th, 230th and 250th baskets, respectively.

Example B 13 : On the diagram of Series Ⅲ, it is discerned that elemental clusters of the population in this example consist mostly of couples of individuals caught side

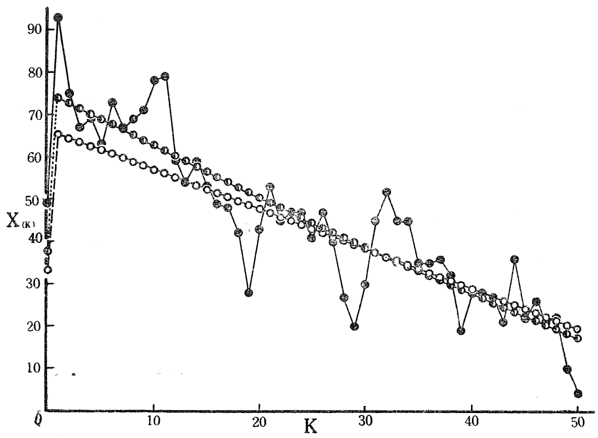


Fig. 8—13 (I). X(k)—k relation diagram of big-eye tuna (Series I obtained at Station 13 in the Fishing Ground No. 1).

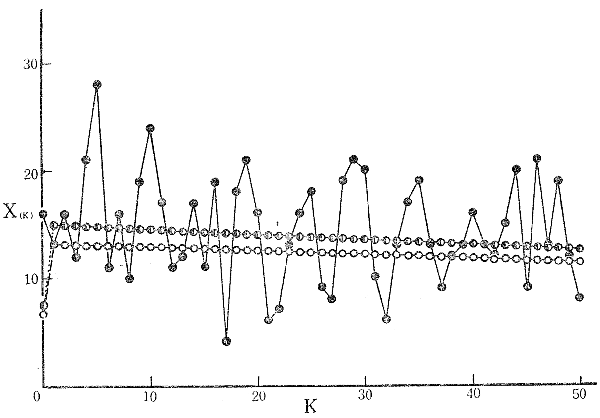


Fig. 8—13 (II). X(k)—k relation diagram of big-eye tuna (Series II obtained at Station 13 in the Fishing Ground No. 1).

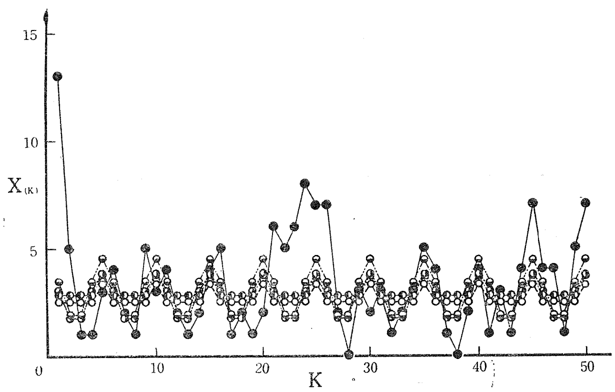


Fig. 8—13 (III). X(k)—k relation diagram of big-eye tuna (Series III obtained at Station 13 in the Fishing Ground No. 1).

by side (spaced by 40 m) and partly of couples of individuals caught at hooks being spaced by a hook (spaced by 80 m). And the diagram of Series II may add that elemental clusters themselves or small bundles of them form the aggregations of superior order covering from 1 to 3 baskets (200~*ca.* 500 m), when they are seen on a longer scale of 1 basket (200 m). Then the diagram of Series I seems to show that the above-mentioned aggregations are apt to form wide loose schools.

Example B 14 : The diagram of Series III shows that, besides many couples of individuals caught by adjoining hooks (spaced by 40 m), some couples of individuals caught by the hooks being spaced by 1 (200 m) or occasionally up to 3 or 6 baskets (500 m~1 km) are detected; these may be included in the elemental clusters when they are seen on the standpoint of the distribution as a whole. The diagram of Series II suggests the existence of loose bundles of elemental clusters, the detailed feature of which may be

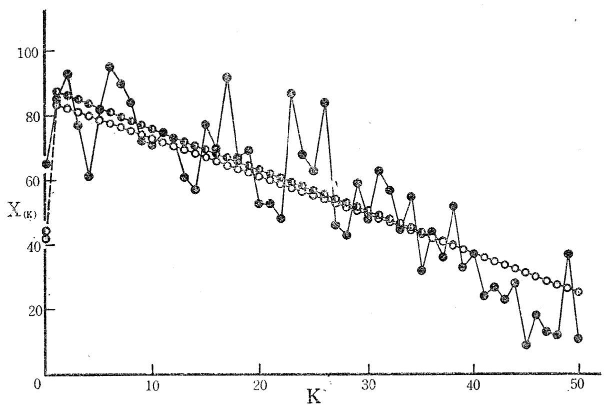


Fig. 8—14 (I). X(k)—k relation diagram of big-eye tuna (Series I obtained at Station 14 in the Fishing Ground No. 1).

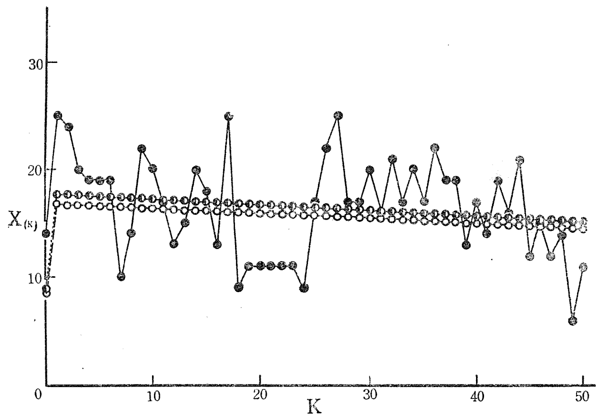


Fig. 8—14 (II). X(k)—k relation diagram of big-eye tuna (Series II obtained at Station 14 in the Fishing Ground No. 1).

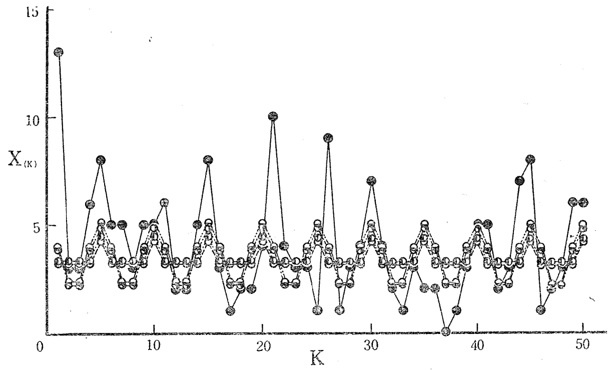


Fig. 8—14 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 14 in the Fishing Ground No. 1).

shown more clearly in Series Ⅰ. The diagram of Series Ⅰ does not show the possibility of the existence of any schools of a considerable width other than several schools covering about 5 units (5 km), which are considered to be located at the range from the 15th to the 40th, around the 150th, 200th and 300th and perhaps also around the 180th baskets.

Example B 15 : The diagram of Series Ⅲ indicates that the elemental clusters are mostly found as couples of individuals hooked side by side (spaced by 40 m) and that a few wider ones are observable being mingled with them. The diagram of Series Ⅱ hardly adds any facts other than that represented in Series Ⅲ. When we compare the observed values with the estimated ones in which the influence of gradient of catch rates is put out of consideration, the diagram of Series Ⅰ may seem to allude to the existence of a single wide and strongly contagious school, but, actually, this is nothing but a phenomenon caused by the strong gradient of distribution. Contrarily when the

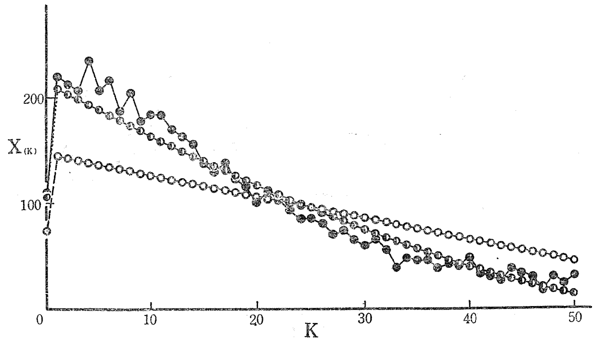


Fig. 8—15 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 15 in the Fishing Ground No. 1).

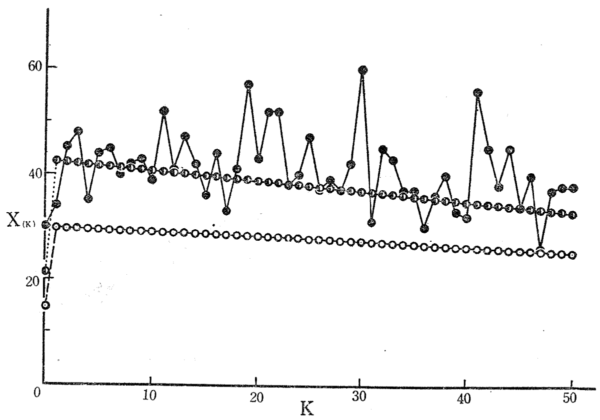


Fig. 8—15 (II). X(k)—k relation diagram of big-eye tuna
(Series II obtained at Station 15 in the Fishing Ground No. 1).

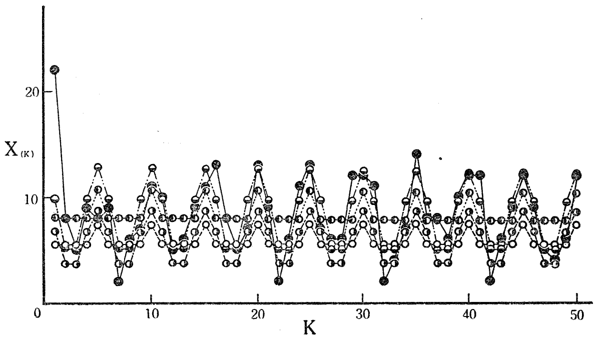


Fig. 8—15 (III). X(k)—k relation diagram of big-eye tuna
(Series III obtained at Station 15 in the Fishing Ground No. 1).

observed values are compared with the estimated values in which the influence is taken into consideration, the existence of weak but rather conspicuous schools covering each 15 units (15 km) may be suggested; and these are supposed to be located respectively around the 200th and 300th baskets, when the gradient of the distribution is considered together.

Example B 16 : The elemental structure of the population deduced from the diagram of Series III consists of the individuals hooked side by side (spaced by 40 m) or those caught at the hooks being spaced by from 1 to 3 baskets (200~500 m), which are also represented as peaks in the diagram of Series II. And also this diagram alludes to the formation of loose bundles of these elemental clusters, which is shown more clearly in Series I. The diagram of Series I suggests that the above-mentioned loose bundles of elemental clusters covering from 1 to 3 units (1~3 km) show the trends to form

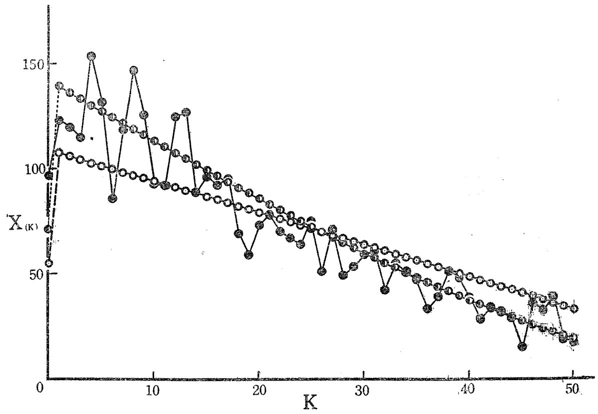


Fig. 8—16 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 16 in the Fishing Ground No. 1).

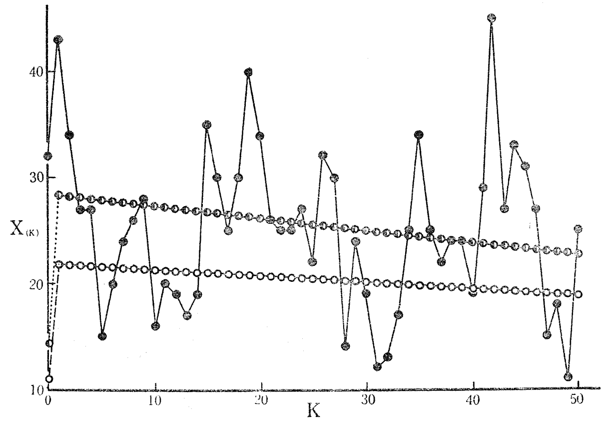


Fig. 8—16 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 16 in the Fishing Ground No. 1).

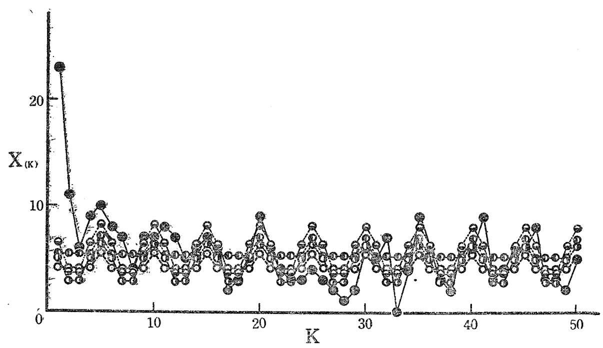


Fig. 8—16 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 16 in the Fishing Ground No. 1).

further a school covering 15 units (15 km), which is, however, so loose that the distribution of bundles within the school may be regarded as self-spacing.

Example B 17 : The examination on the diagram of Series Ⅲ reveals that the couples of individuals caught side by side (spaced by 40 m) and those caught at the hooks spaced by 1 basket (200 m) or thereabout are the principal components of the elemental structure. The spatial relation diagrams of Series Ⅰ and Ⅱ suggest that the population is composed of large schools having the width of 7 units (7 km) or longer and being separated by the distance of approximately 25 units (25 km) between the centers of adjoining schools. These schools are considered to be located around the 25th and 150th baskets and perhaps the part around the 300th basket where the higher catch rate was observed may be regarded as one of such schools; further it is shown that they consist of many subordinate aggregations covering 4-unit width (4 km), which

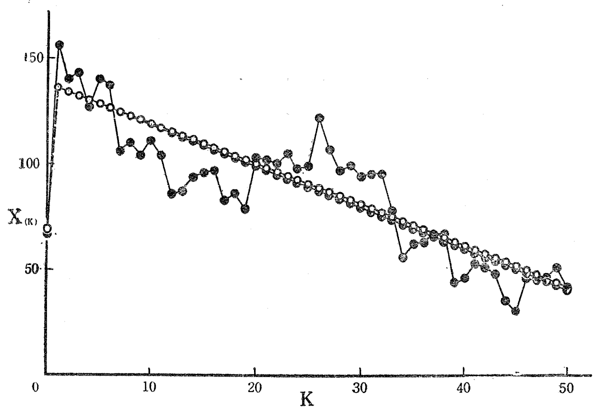


Fig. 8—17 (Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 17 in the Fishing Ground No. 1).

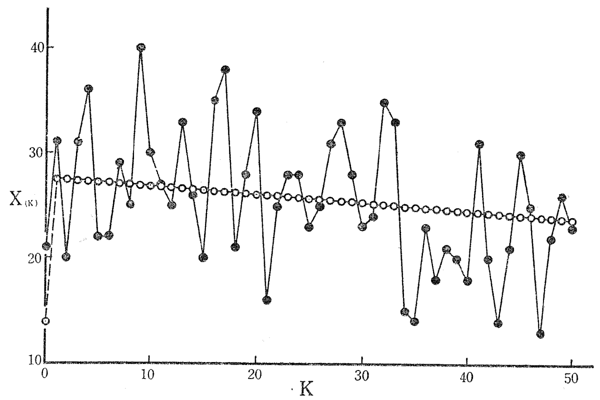


Fig. 8—17 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 17 in the Fishing Ground No. 1).

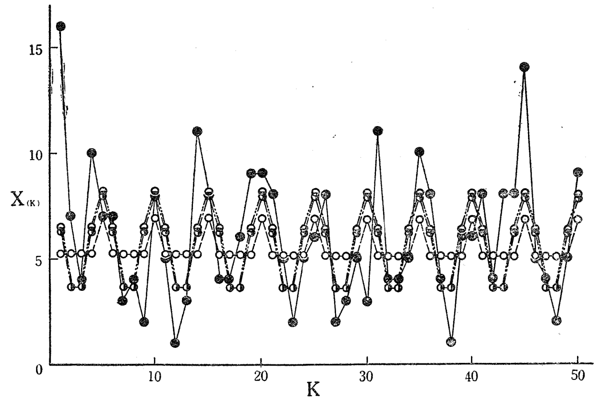


Fig. 8—17 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 17 in the Fishing Ground No. 1).

are considered, then, respectively as a single cluster covering 1 or 2 baskets (200～400 m) or bundles of the above-mentioned elemental clusters.

Example B 18 : The relation diagrams indicate rather clearly that the population contains a large school covering *ca.* 30 units (30 km), which seems to be located around the 150th basket. Then, this school can be subdivided into many subordinate schools of 1- or 2-unit width (1～2 km). And further they are composed of many aggregations covering from 1 to 3 baskets (200～500 m), which are, then, regarded respectively as a single elemental cluster or a bundle of them. The elemental clusters in this example consist of the couples of individuals caught side by side (spaced by 40 m), those caught at the hooks spaced by one hook (80 m) and occasionally some single individuals.

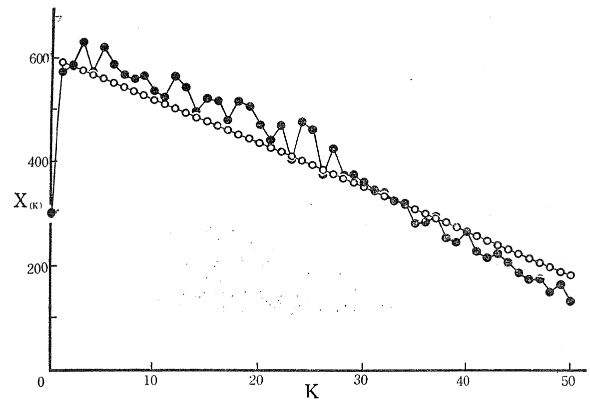


Fig. 8—18(Ⅰ). X(k)—k relation diagram of big-eye tuna (Series Ⅰ obtained at Station 18 in the Fishing Ground No. 1).

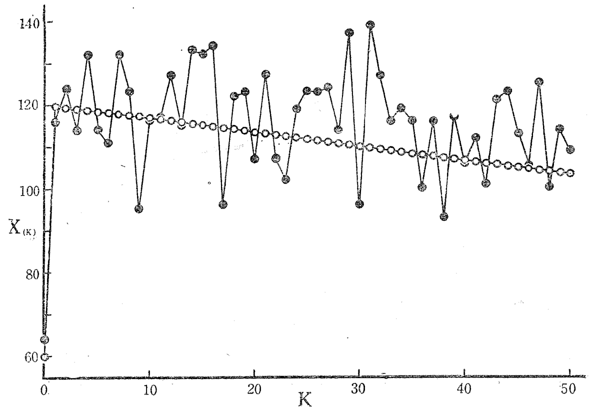


Fig. 8—18 (Ⅱ). X(k)—k relation diagram of big-eye tuna (Series Ⅱ obtained at Station 18 in the Fishing Ground No. 1).

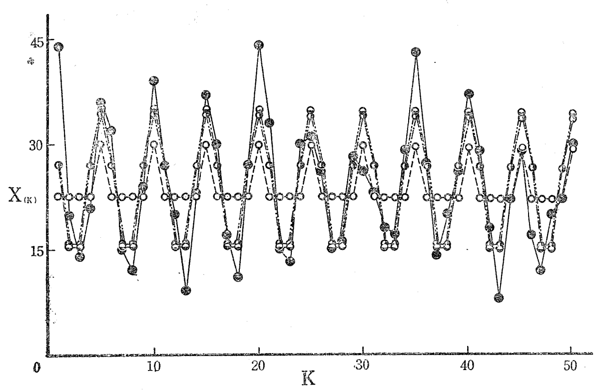


Fig. 8—18 (Ⅲ). X(k)—k relation diagram of big-eye tuna (Series Ⅲ obtained at Station 18 in the Fishing Ground No. 1).

Example B 19 : The elemental clusters in this example are a little wider than those in other examples, reaching a little beyond 1 basket (200 m) in width. The principal part of catches consists of 3 or more large schools covering 5 units (5 km) or longer and being separated by the distance of *ca.* 25 or 35 units (25~35 km) between the centers of the adjoining schools; and they are located around the 130th, 250th and 300th baskets. These schools seem, then, to be constituted of many elemental clusters or bundles of them.

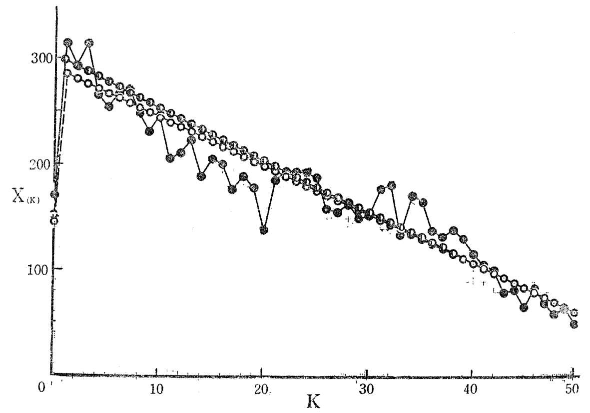


Fig. 8—19 (I). X(k)—k relation diagram of big-eye tuna
(Series I obtained at Station 19 in the Fishing Ground No. 1).

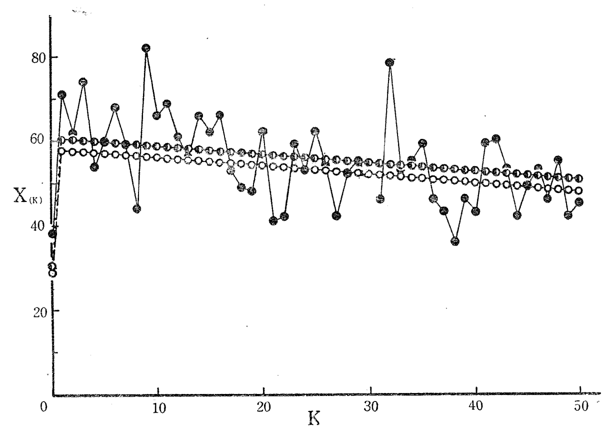


Fig. 8—19 (II). X(k)—k relation diagram of big-eye tuna
(Series II obtained at Station 19 in the Fishing Ground No. 1).

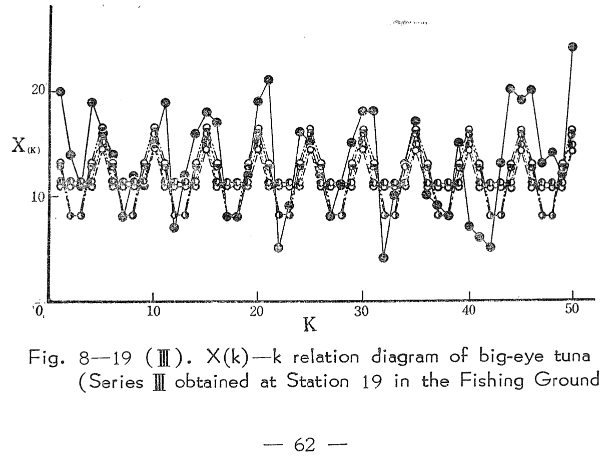


Fig. 8—19 (III). X(k)—k relation diagram of big-eye tuna
(Series III obtained at Station 19 in the Fishing Ground No. 1).

2) Yellow-fin tuna

The observed actual values and computed ones about yellow-fin tuna are shown in Figs. 10—1 ~10—10. In these figures, however, are included some figures in which it seems unnecessary to compute the values being taken the influence of gradient of the catch rate into consideration, because the gradient is not so prominent, consequently the difference between both series of estimated values, the influence of gradient of the catch rate is taken into consideration or not, is not so large. It may safely be concluded that the yellow-fin tuna is distributed roughly by chance, but exactly speaking, the population is composed of many contagious schools of negligible weakness. And it may be regarded as one of the characteristics of the distribution pattern of the yellow-fin tuna that the width of elemental clusters is remarkable.

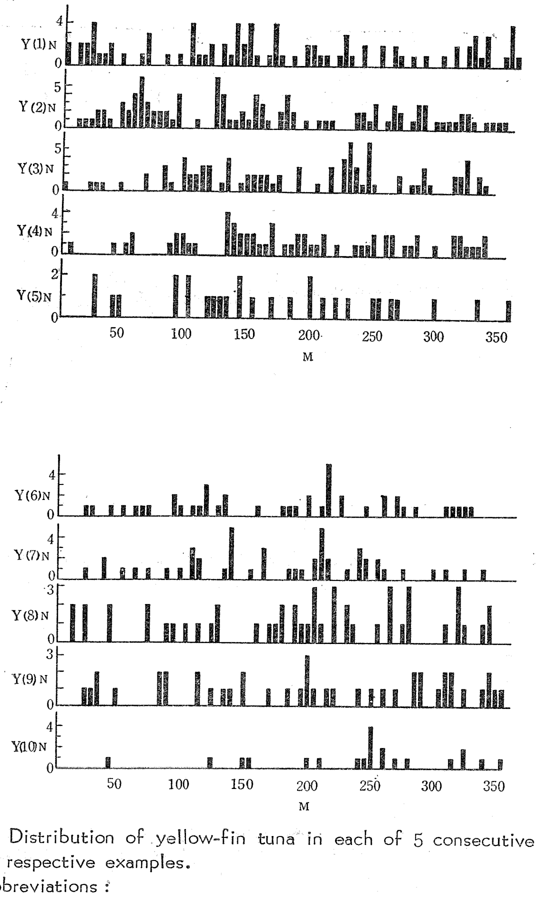


Fig. 9. Distribution of yellow-fin tuna in each of 5 consecutive baskets in respective examples.
Abbreviations :
M : basket number counted from the initial point of hauling.
N : number of individuals caught by respective consecutive 5 baskets.
Y(x) : example of yellow-fin tuna obtained at the Station "x" in the Fishing Ground No. 1.

Exposition of particular example

Example Y 1 : Most of the predominent elemental clusters are the couples of indi-

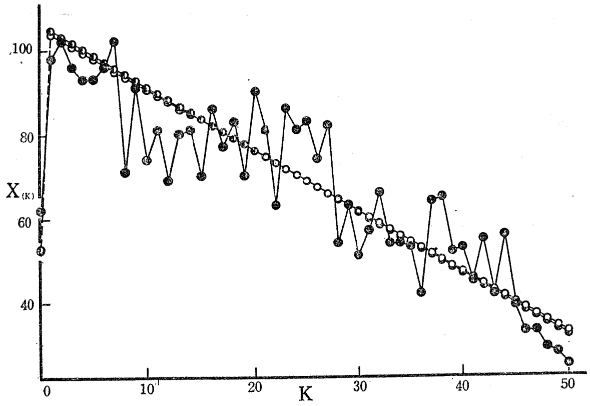


Fig. 10—1 (I). X(k)—k relation diagram of yellow-fin tuna (Series I obtained at Station 1 in the Fishing Ground No. 1).

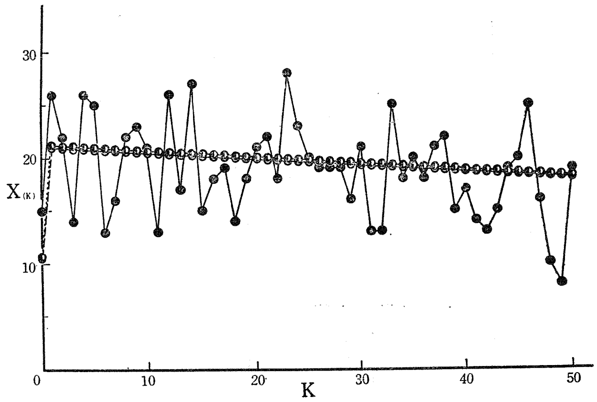


Fig. 10—1 (II). X(k)—k relation diagram of yellow-fin tuna (Series II obtained at Station 1 in the Fishing Ground No. 1).

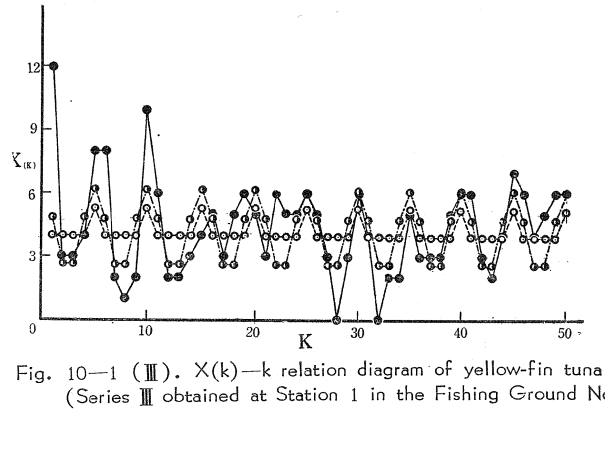


Fig. 10—1 (III). X(k)—k relation diagram of yellow-fin tuna (Series III obtained at Station 1 in the Fishing Ground No. 1).

viduals caught by the adjoining hooks (spaced by 40 m), although the existence of a certain number of couples of individuals spaced by 1 or 2 baskets (200~400 m) must be noticed. And the loose bundles of these clusters, including couples spaced widely, are scattered at self-spacing so weakly that their distribution looks nearly by chance.

Example Y 2 : A considerably long and rather strong contagiousness of the distribution is suggested in the diagram of Series Ⅱ. This diagram shows that the elemental clusters are elongated widely and many of them cover the width of 1 basket (200 m) or sometimes up to 3 baskets (*ca.* 500 m). The loose bundles of from 3 to 5 rather conspicuous aggregations, each of which is perhaps a single elemental cluster, form further small but conspicuous schools, the existence of which is shown more clearly in the diagram of Series Ⅰ and the width of which is about 2 units (2 km) or longer. Such schools are then distributed roughly two in every 10 units (10 km).

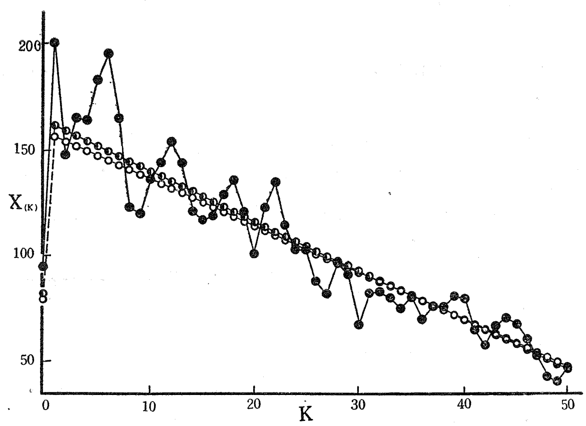


Fig. 10—2 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 2 in the Fishing Ground No. 1).

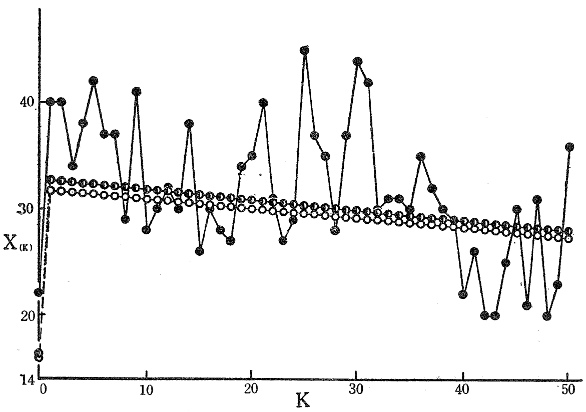


Fig. 10—2 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 1).

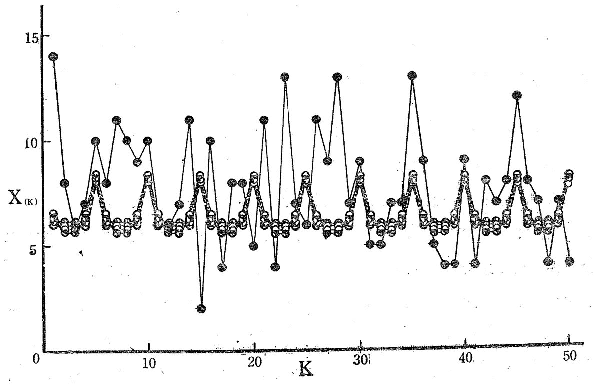


Fig. 10—2 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 2 in the Fishing Ground No. 1).

Example Y 3 : Continuously high values observed in the diagram of Series Ⅲ indicate that most of elemental clusters are diverse couples of individuals spaced by the distance from $k=1$ to 5 (40~200 m). The successively high values observed in this diagram extending in the range from $k=1$ to 20, when several discontinuous low values are disregarded, are corresponding to bundles of high values extending in the range from $k=0$ to 6 in the diagram of Series Ⅱ and bundles of high values covering the width extending from $k=0$ to 25 in the diagram of Series Ⅱ are represented in the diagram of Series Ⅰ by high values found intermittently; and on these the conspicuous structure of the highest order is thought to be the schools covering 1 or 2 units (1~2 km) and being observable at every 2 or 3 units (2~3 km). Besides, this diagram suggests the existence of loosely aggregated schools of a considerable width being spaced by *ca.* 20 units (20 km) and probably corresponding to the parts showing higher catch rates

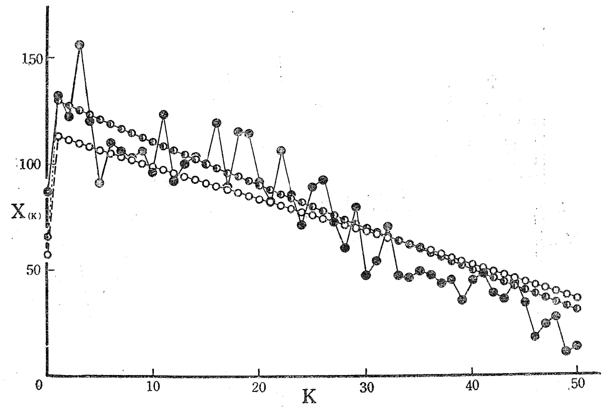


Fig. 10—3 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 3 in the Fishing Ground No. 1).

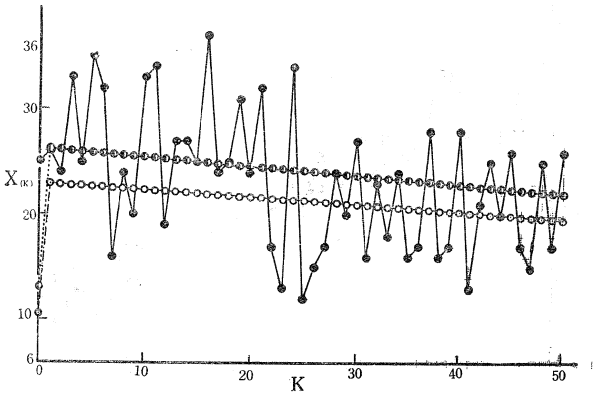


Fig. 10—3 (II). X(k)—k relation diagram of yellow-fin tuna (Series II obtained at Station 3 in the Fishing Ground No. 1).

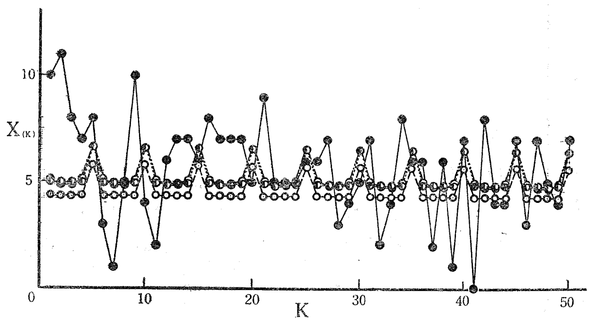


Fig. 10—3 (III). X(k)—k relation diagram of yellow-fin tuna (Series III obtained at Station 3 in the Fishing Ground No. 1).

around the 150th, 250th and 350th baskets, although this superior structure is rather obscure. Concerning the part of higher catch rates around the 100th basket, however, no significant explanation is given by any of diagrams.

Example Y 4 : Though the smallness of the total catch increases the possibility of the accidental errors being introduced, the diagram of Series III seems to show that the elemental structures consist of the couples of individuals caught side by side (spaced by 40 m) and those caught at hooks spaced by *ca.* 15, 20, 30, 40 and especially 25 hook-intervals (600, 800, 1,200, 1,600 and 1,000 m). The deviation of the short periodicity found in the observed values in the diagram of Series II shows the distribution pattern of the above-mentioned elemental clusters, while that of the long periodicity represents the feature of the superior structure, which is shown more clearly in the diagram of Series I. Namely, the population is thought to be constituted of many schools covering from 2 to 5 units (2~5 km) or thereabout. Further, this diagram also suggests conspicuously the formation of the school of higher order, which seems to be located in the range from the 140th to the 335th basket.

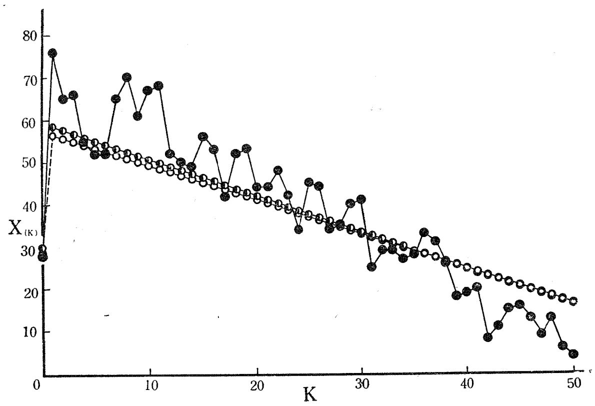


Fig. 10—4 (I). X(k)—k relation diagram of yellow-fin tuna (Series I obtained at Station 4 in the Fishing Ground No. 1).

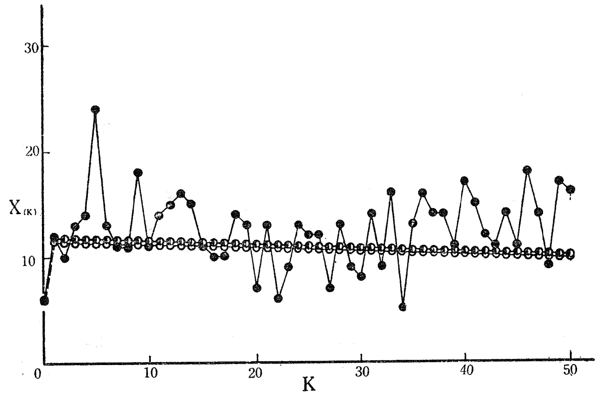


Fig. 10—4 (II). X(k)—k relation diagram of yellow-fin tuna (Series II obtained at Station 4 in the Fishing Ground No. 1).

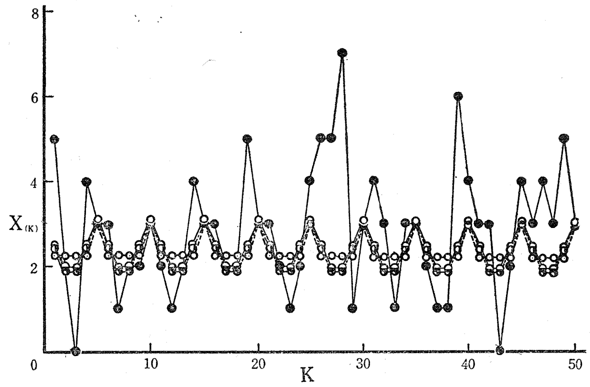


Fig. 10—4 (III). X(k)—k relation diagram of yellow-fin tuna (Series III obtained at Station 4 in the Fishing Ground No. 1).

Example Y 5 : Some accidental errors are inevitably expected in treating of this example in which the total catch is extremely low, moreover, most of peaks in the diagrams of Series Ⅱ and Ⅲ indicate merely individuals themselves. So, at present, only the diagrams of Series Ⅱ and Ⅲ are shown here and any of interpretations are reserved from being mentioned. However, the diagram of Series Ⅰ suggests the existence of a school, individuals of which are widely scattered in the range covering *ca.* 35 units (35 km) and their distribution is rather self-spacing; and this school is located in the range from the 100th to the 275th basket. Besides this, there are many clusters covering 1 or 5 units (1～5 km) as the subordinate structure, although most of them are merely single or coupled individuals and only a few of them are larger ones consisting of several individuals and representing extremely scattered clusters; all of these are thought to be of the elemental structure.

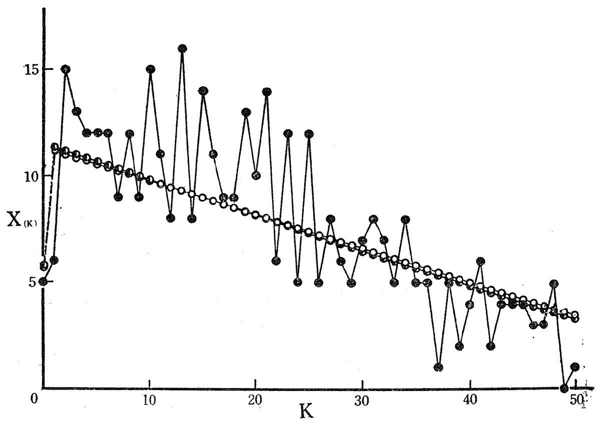


Fig. 10—5 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 5 in the Fishing Ground No. 1).

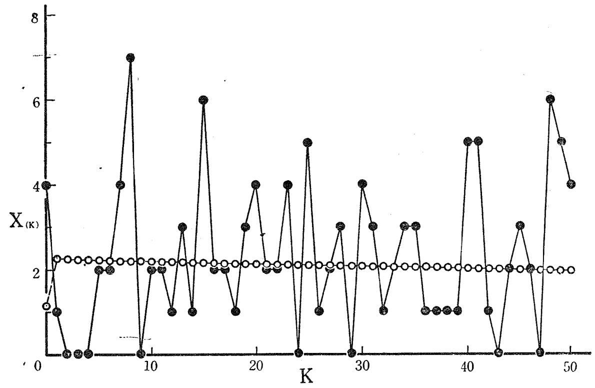


Fig. 10—5 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 5 in the Fishing Ground No. 1).

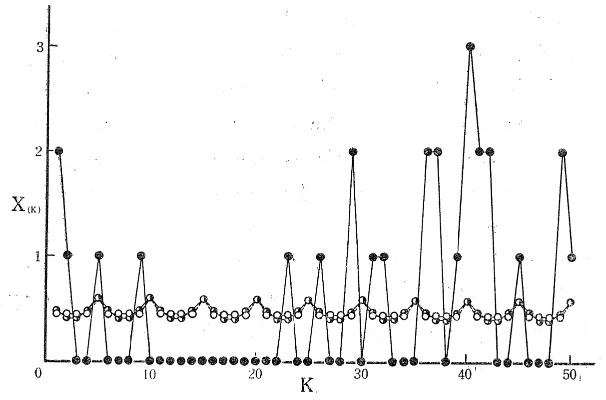


Fig. 10—5 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 5 in the Fishing Ground No. 1).

Example Y 6 : As for the diagram of Series Ⅲ, further discussions are retained, since the observed values are very scarce. Narrow peaks of the observed values in the diagram of Series Ⅱ indicate single individuals in such a case in which the catch rate is extremely low. Accordingly, the elemental structure must be deduced from the diagram of Series Ⅰ and the deviation of long periodicity found in the diagram of Series Ⅱ. And the structure consists of clusters covering from 1 unit (1 km) to 4 units (4 km) at the maximum, and most of these clusters are constituted of loosely aggregated 2 or 3 individuals, even the larger ones are constituted of less than 5 individuals. Further, the diagram of Series Ⅰ suggests the existence of schools covering 25 or 30 units (25 or 30 km) and probably being located in the ranges respectively from the 30th to the 130th basket and from the 200th to the 350th basket, although this is rather inconspicuous because of the lower catch rate.

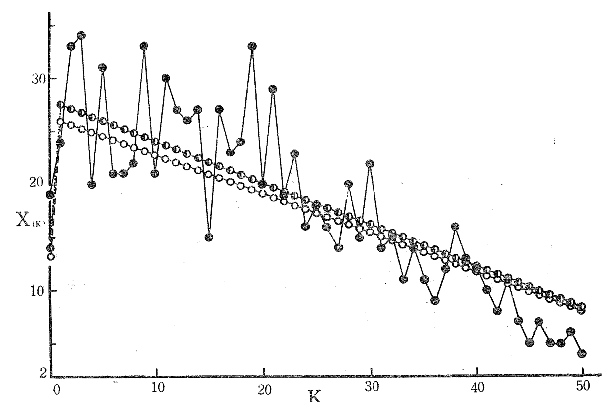


Fig. 10—6 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 6 in the Fishing Ground No. 1).

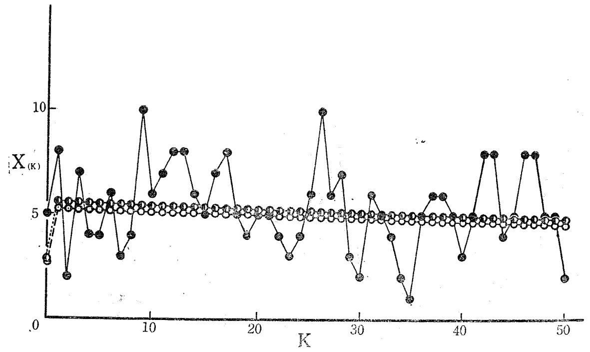


Fig. 10—6 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 6 in the Fishing Ground No. 1).

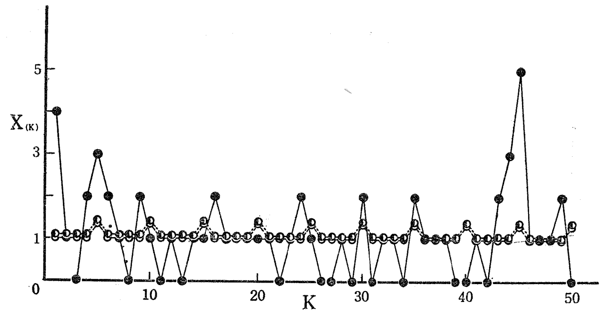


Fig. 10—6 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 6 in the Fishing Ground No. 1).

Example Y 7 : Concerning the diagram of Series Ⅲ, no explanation is given, because both the estimated and observed values are too small, although it seems to allude to the

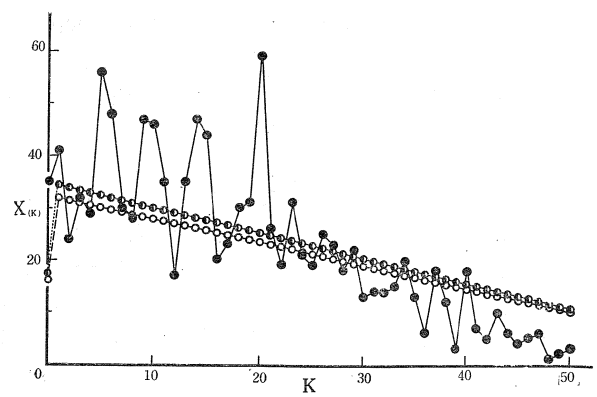


Fig. 10—7 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 7 in the Fishing Ground No. 1).

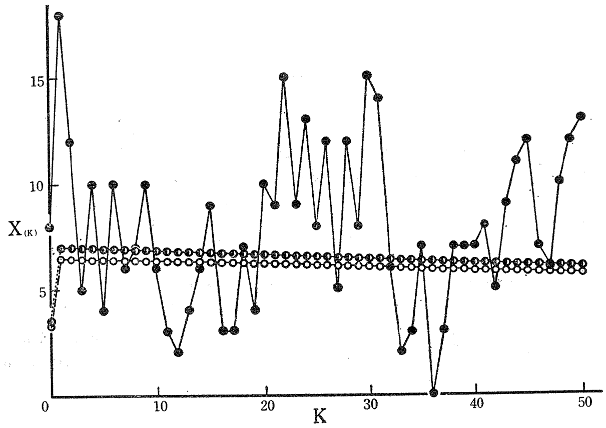


Fig. 10—7 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅱ obtained at Station 7 in the Fishing Ground No. 1).

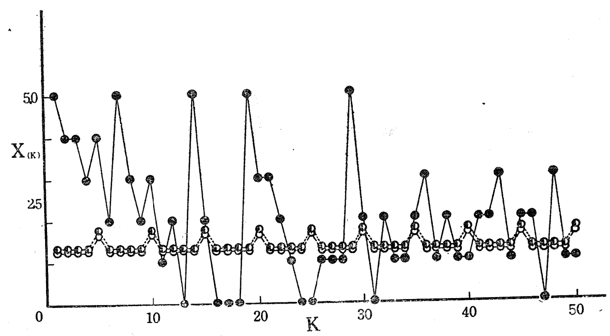


Fig. 10—7 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 7 in the Fishing Ground No. 1).

existence of large elemental clusters covering 1 or 2 baskets (200~400 m). The short periodic deviation of the observed values in the diagram of Series Ⅱ seems to indicate that the elemental structure consists of the couples of individuals caught within 2 or 3 baskets and besides them, some single individuals themselves caught widely apart from other individuals are also regarded to be bearing the character of elemental clusters. The long periodic deviation of the observed values in the same diagram and the short one in the diagram of Series Ⅰ show that the above-mentioned elemental clusters are loosely bundled into 7 or more aggregations which are, perhaps, located in the ranges from the 160th to the 180th, from the 185th to the 205th basket, around the 215th, 225th and 230th baskets, from the 255th to the 265th and from the 275th to the 280th basket. The long periodic deviation in the diagram of Series Ⅰ shows that 4 rather conspicuous and 3 obscure aggregations are, further, loosely bundled into a single widely scattered school located in the range from the 160th to the 280th basket.

Example Y 8 : Nothing is explained for the diagram of Series Ⅲ, because the occurrence of accidental errors caused by low catch rate is expected. The diagram of

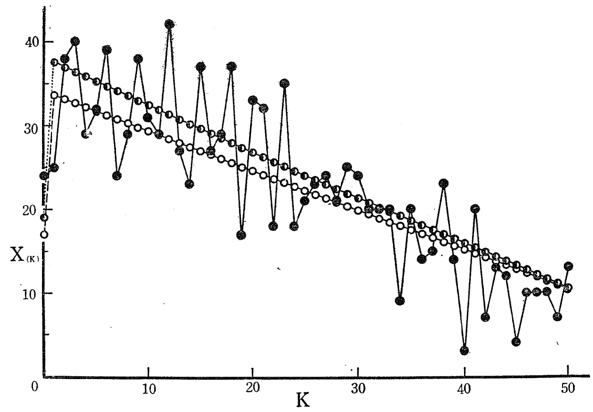


Fig. 10—8 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅰ obtained at Station 8 in the Fishing Ground No. 1).

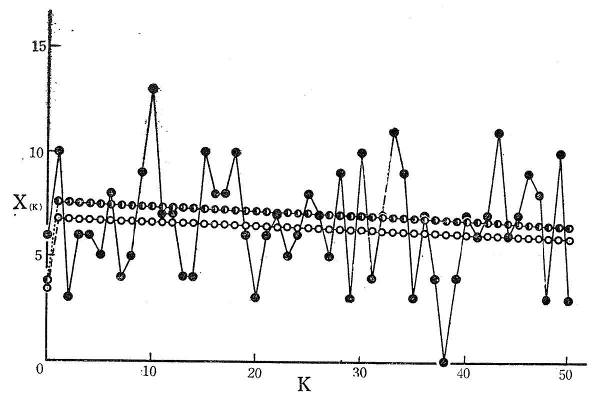


Fig. 10—8 (Ⅱ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅱ obtained at Station 8 in the Fishing Ground No. 1).

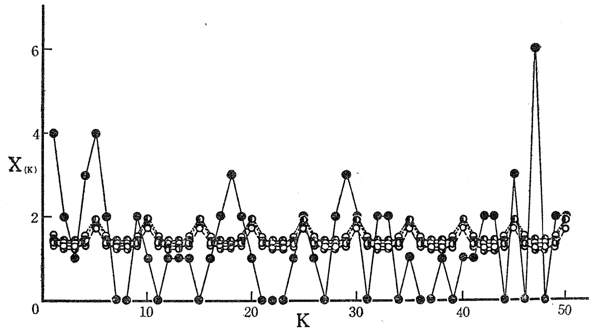


Fig. 10—8 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna
(Series Ⅲ obtained at Station 8 in the Fishing Ground No. 1).

Series I does not show any symptoms of the existence of any wide schools, although the existence of conspicuous aggregations covering 1 or 2 units (1~2 km) and being spaced by 1 or 2 units (1~2 km) is suggested. And the diagram of Series II shows that the above-mentioned aggregations are constituted of many subordinate clusters covering 1 or 2 baskets (200~400 m), most of which are, however, single individuals widely spaced and yet having the character of elemental clusters while a part of which is couples of individuals spaced rather widely.

Example Y 9 : The diagram of Series II alludes to nothing but that there are 6 couples of individuals caught side by side and this is 6 times as large as the estimated values, although a considerable accidental errors can be expected in this consideration. The diagram of Series I shows that the population seems to contain many conspicuous aggregations covering 1 or 2 and rarely 3 units. The deviation of the observed values

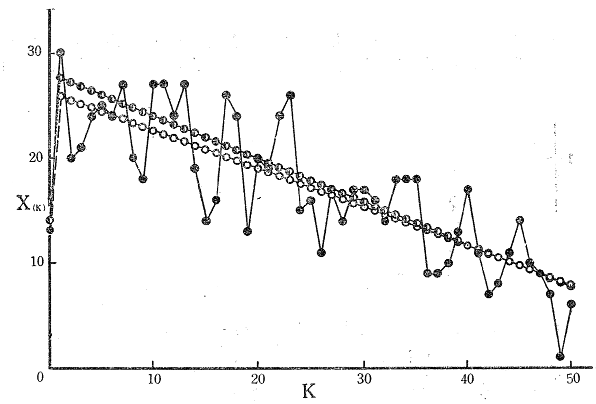


Fig. 10—9 (I). X(k)—k relation diagram of yellow-fin tuna (Series I obtained at Station 9 in the Fishing Ground No. 1).

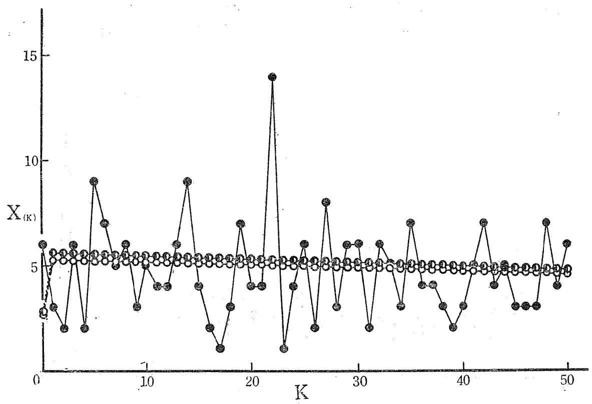


Fig. 10—9 (II). X(k)—k relation diagram of yellow-fin tuna (Series II obtained at Station 9 in the Fishing Ground No. 1).

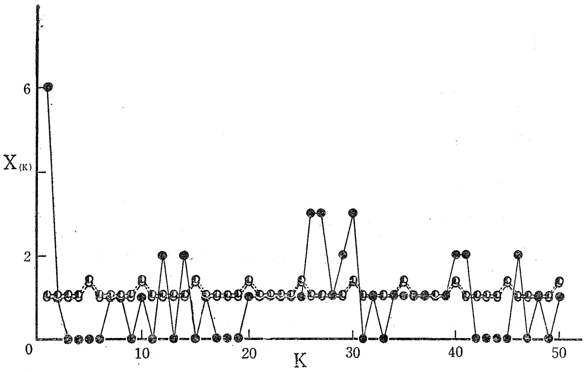


Fig. 10—9 (Ⅲ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅲ obtained at Station 9 in the Fishing Ground No. 1).

in the diagram of Series Ⅱ represents that the above-mentioned aggregations are the bundles of widely spaced single individuals and couples of individuals caught at the hooks located near by each other, and all these are regarded as elemental clusters.

Example Y 10 : This is the example in which the gradient of distribution is the strongest of all examples about yellow-fin tuna, yet the total catch is extremely low; accordingly some accidental errors are much expected in the observed and estimated values. So the description is confined here to only the fact that the population is constituted of many aggregations located at every one unit. The word "aggregations" is used here merely for convenience' sake; actually, however, most of the "aggregations" are single individuals widely spaced and yet having the character of elemental clusters. As the catch rate is extremely low, nothing can be deduced from the diagrams of Series Ⅱ and Ⅲ.

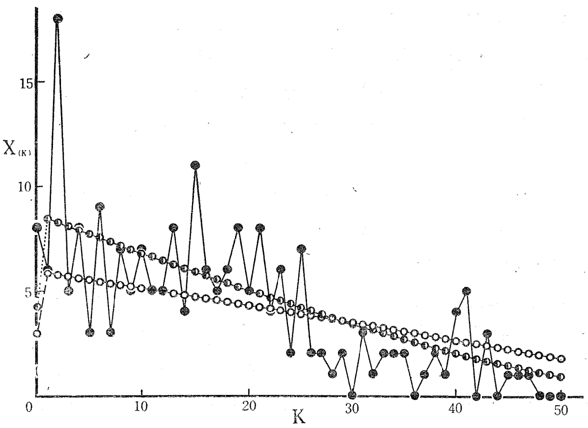


Fig. 10—10 (Ⅰ). X(k)—k relation diagram of yellow-fin tuna (Series Ⅰ obtained at Station 10 in the Fishing Ground No. 1).

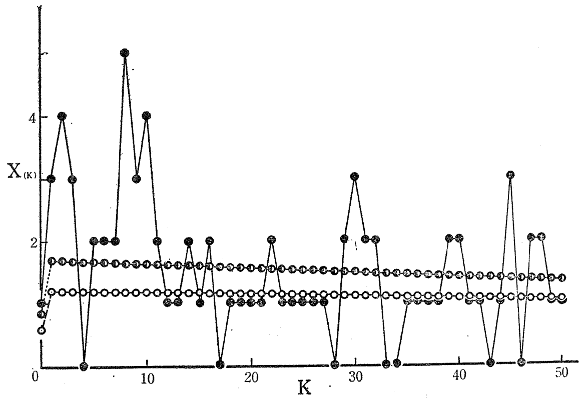


Fig. 10—10 (II). X(k)—k relation diagram of yellow-fin tuna (Series II obtained at Station 10 in the Fishing Ground No. 1).

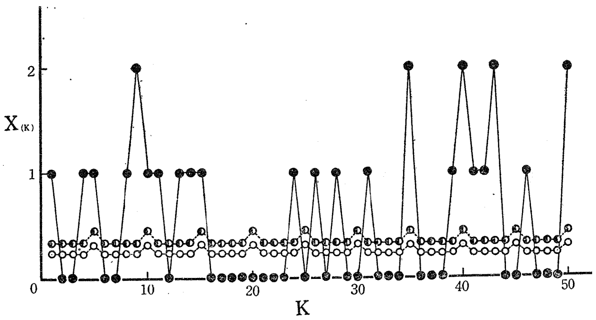
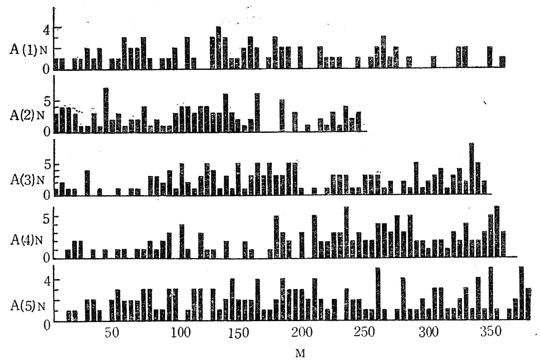
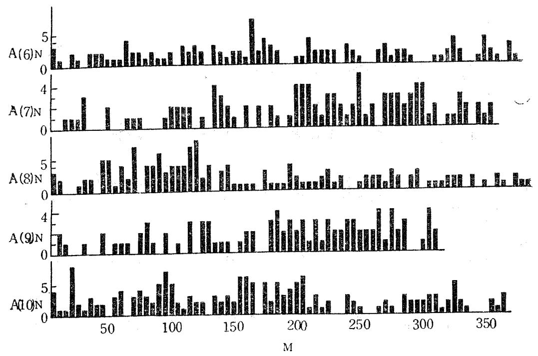


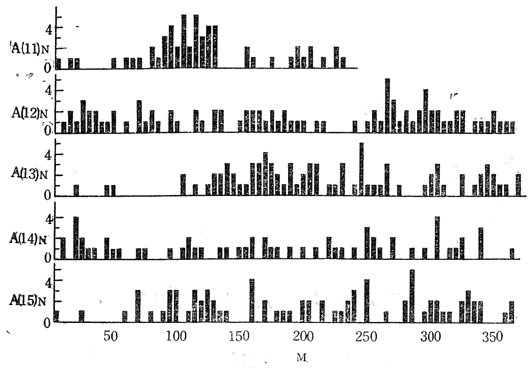
Fig. 10—10 (III). X(k)—k relation diagram of yellow-fin tuna (Series III obtained at Station 10 in the Fishing Ground No. 1).

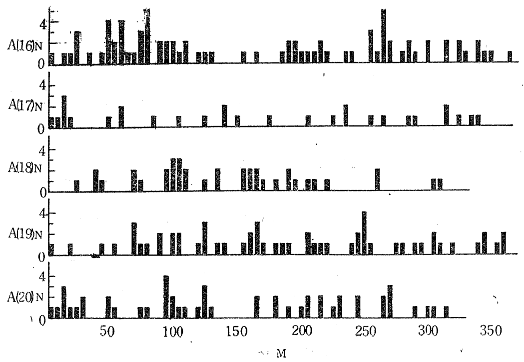
3) Albacore

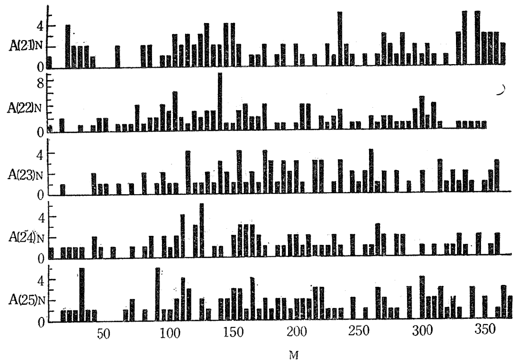
Albacore is the smallest of all commercially important kind of tuna, and considered to be a macro-plankton feeder against other tuna which are thought to be piscivora. And it is a well-known fact that the young stages of this fish can be caught by angling in the waters near the northern, or perhaps also southern, margin of its geographical distribution. But the older ones are caught only by long-lines in the waters in the inner side of its distribution range. Accordingly, this species is expected to show the highest contagiousness of the distribution pattern among all tunas. On the other hand, in order to ascertain whether the method used in this report can lead us to the right cognition of schooling tendencies of tunas or not —— in other words, to judge the results that big-eye tuna and yellow-fin tuna are distributed almost by chance —— it seems to be very adequate to examine whether the results of the examination on examples of the fish clearly forming schools and caught by the same fishing-method, long-line, show the existence of schools or not. The examples of albacore caught by long-line seem superficially to be the most suitable for this purpose. Actually, however, the examples of off shore albacore do not show any symptom of the school formation as shown in Fig. 11.

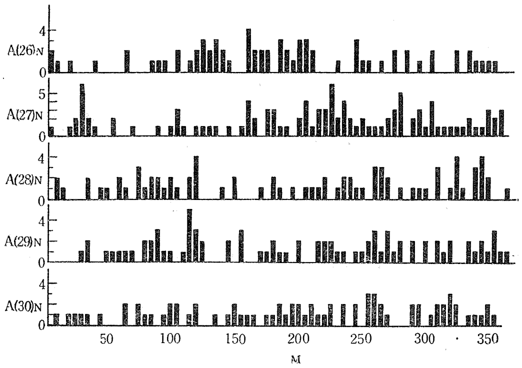







A(16)N
A(17)N
A(18)N
A(19)N
A(20)N
0
4
50
100
150
200
250
300
350
M


A(21)N
A(22)N
A(23)N
A(24)N
A(25)N
0
4
8
50
100
150
200
250
300
350
M


A(26)N
A(27)N
A(28)N
A(29)N
A(30)N
0
4
5
50
100
150
200
250
300
350
M

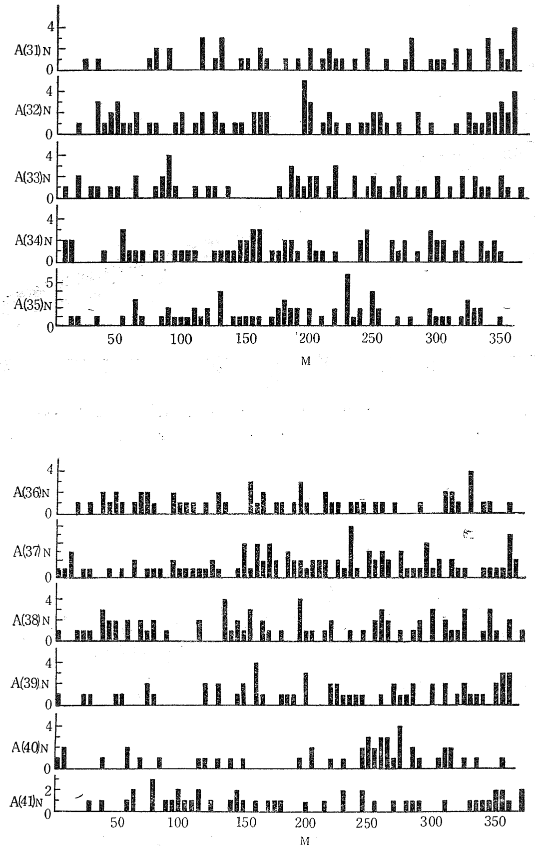


Fig. 11. Distribution of albacore in each of 5 consecutive baskets in respective examples.
Abbreviations :
M : basket number counted from the initial point of hauling.
N : number of individuals caught by respective 5 consecutive baskets.
A (x) : example of albacore obtained at the Station "x" in the Fishing Ground No. 2.

Thus, the examples of albacore are found unsuitable for the above-mentioned purpose, although they are worthy to be analyzed for the purpose of comparing the spatial relation of albacore with those of yellow-fin tuna and big-eye tuna. The distribution pattern of albacore is, thus, analyzed by the same method as that used in the cases of big-eye tuna and yellow-fin tuna. And the results show that it seems to be the characteristics of the distribution pattern of albacore that no conspicuous contagiousness is found between the two hooks arranged side by side and no elemental cluster covering wide range is observable, although its general pattern does not differ from those of big-eye tuna and yellow-fin tuna.

Exposition of particular example

Example A 1 : Small deviations of the observed values in diagrams of all 3 series indicate, together with the high catch rate which may secure less possibility of

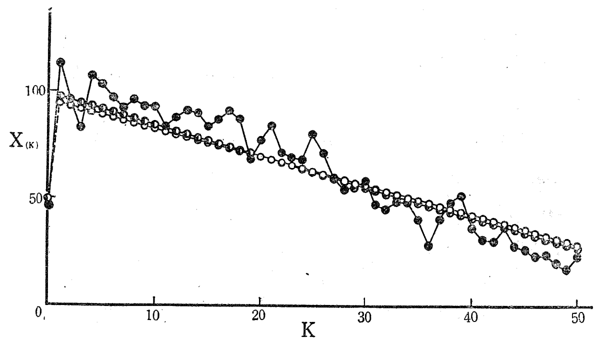


Fig. 12—1 (I). X(k)—k relation diagram of albacore
(Series I obtained at Station 1 in the Fishing Ground No.2).

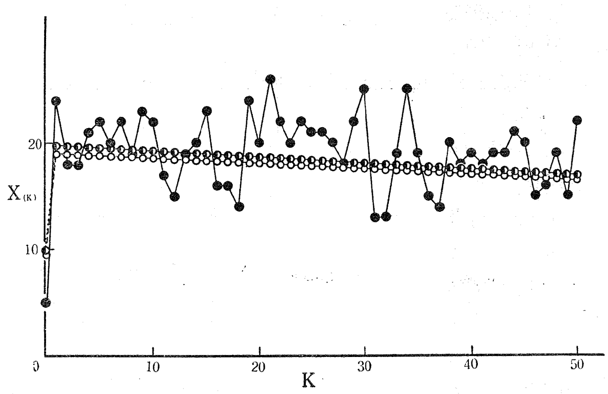


Fig. 12—1 (II). X(k)—k relation diagram of albacore
(Series II obtained at Station 1 in the Fishing Ground No.2).

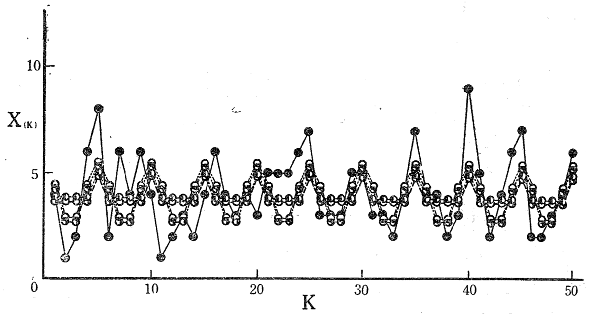


Fig. 12—1 (III). X(k)—k relation diagram of albacore
(Series III obtained at Station 1 in the Fishing Ground No.2).

accidental errors, that the discrepancy of this distribution pattern from the chance one is very small. No prominent structure observable within a short range is alluded to in the diagram of Series Ⅲ. While, the short periodic deviation of the observed values in the diagram of Series Ⅱ suggests the existence of clusters covering 2-basket width (400 m), which is respectively widely spaced single individuals or small groups consisting of less than 5 individuals, and all these are regarded as the elemental clusters. The long periodic deviation in this diagram, which corresponds to the short periodic one represented in the diagram of Series Ⅰ, suggests the weak bundle formation of these elemental clusters, covering 3 units (3 km), located at every 4 units and being constituted of 4 elemental clusters or thereabout. Bundles of elemental clusters are further aggregated into a wide but weakly contagious school covering *ca.* 25 units (25 km) and occupying the main part of the catch in this example, which may correspond to the high catch rate occurring in the range from the 60th to the 190th basket.

Example A 2 : The relatively small and interrupted deviation of the observed values in the diagram of Series Ⅲ does not allude to any structures within a short range. The distribution of peaks in the diagram of Series Ⅱ seems to represent the distribution pattern of elemental clusters which are each constituted of up to several individuals. And a single peak or a couple of peaks are corresponding to each peak in the diagram of Series Ⅰ. The long periodic deviation, though not so clear, in the diagram of Series Ⅰ alludes to the existence of 3 schools covering shorter than 10 units (10 km), which are loose bundles of the elemental clusters mentioned above; these schools seem to be located around the 10th basket, in the range from the 100th to the 150th and around the 250th basket.

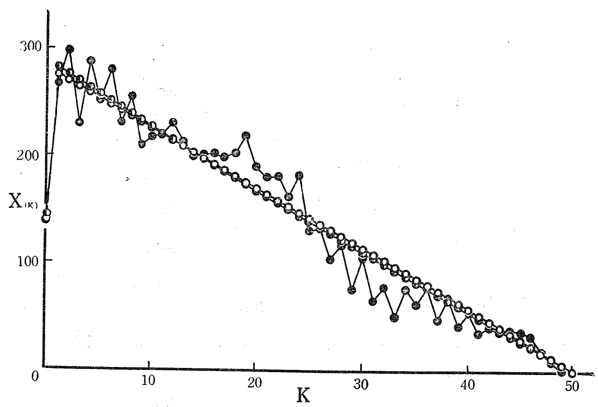


Fig. 12—2 (Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 2 in the Fishing Ground No.2).

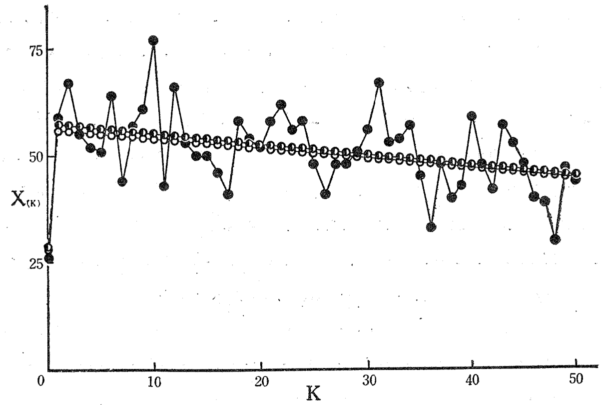


Fig. 12—2 (Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 2 in the Fishing Ground No.2).

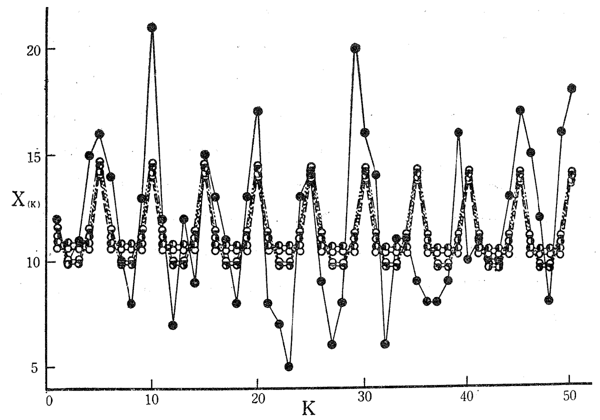


Fig. 12—2 (Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 2 in the Fishing Ground No.2).

Example A 3 : The diagram of Series Ⅲ does not show any detailed structures other than that shown more clearly in the diagram of Series Ⅱ. The short periodic deviation of the observed values in the diagram of Series Ⅱ shows the feature of the elemental clusters being scattered over 1 or 2 baskets (200～400 m) and mostly constituted of widely spaced single individuals, couples of individuals or occasionally up to 3～4 individuals. The long periodic deviation found in the diagram of Series Ⅱ, which corresponds to the short periodic one in the diagram of Series Ⅰ, represents the bundle formation of elemental clusters covering 1 or 2 units (1～2 km), though this is not so distinct. Besides the above-mentioned fact, the existence of 2 schools spaced by *ca.* 30 units (30 km) and other obscure ones being about 15 units (15 km) apart from each of the former is alluded to. The two schools seem to be located in the range from the 150th to the 200th and around the 350th basket, while the obscure ones indicate the portions around the 100th and 250th baskets.

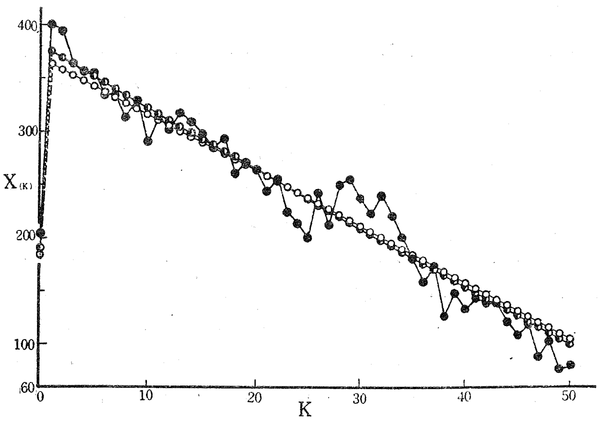


Fig. 12—3 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 3 in the Fishing Ground No.2).

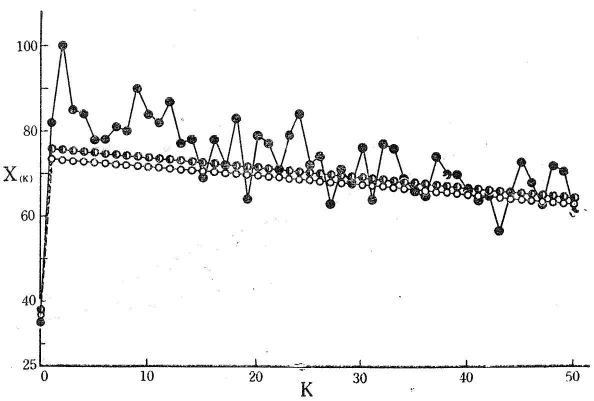


Fig. 12—3 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 3 in the Fishing Ground No.2).

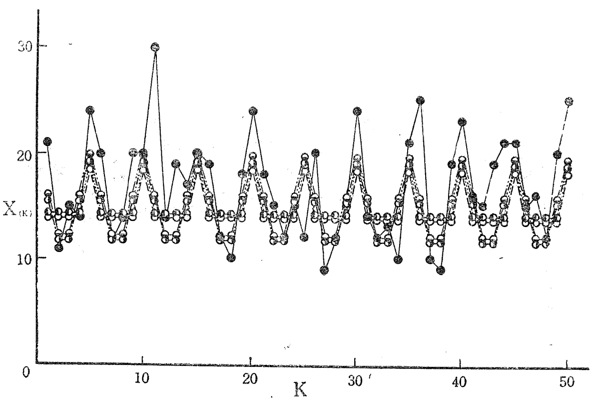


Fig. 12—3 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 3 in the Fishing Ground No.2).

Example A 4 : This is one of the typical examples in which the influences of the gradient of catch rate and the difference of catch rate according to the depth are prominent. Accordingly, the difference between the 2 series of estimated values, respectively the influence of the gradient in the diagrams of Series I and II is taken into consideration or not, and also the differences among the 4 series of estimated values in the diagram of Series III —— the influences of one or both of the two factors are taken into consideration or not —— are remarkable. Moreover, it must be also noted that the most of the observed values in the diagram of Series I are slightly lower than the estimated values in which the influence of the gradient is taken into consideration. The same fact is also shown in the diagrams of Series II and III, though somewhat obscurely this time. This may seem to be attributable to the over-estimation of the gradient. But, it is shown clearly in Fig. 11 that the catch rate increases abruptly around the 210th basket and it is more natural to regard this sudden increase as the influence of the existence of schools than to regard it as the

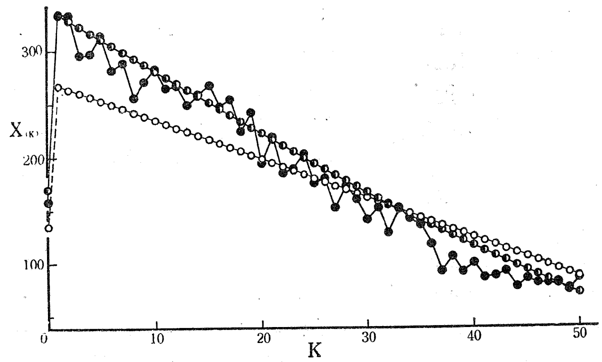


Fig. 12—4 (I). X(k)—k relation diagram of albacore (Series I obtained at Station 4 in the Fishing Ground No.2).

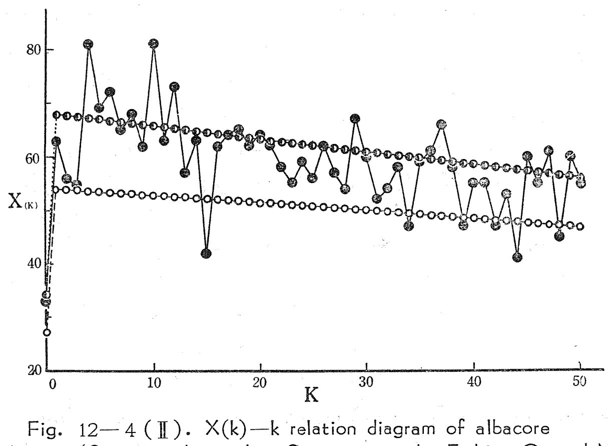


Fig. 12—4 (II). X(k)—k relation diagram of albacore (Series II obtained at Station 4 in the Fishing Ground No.2).

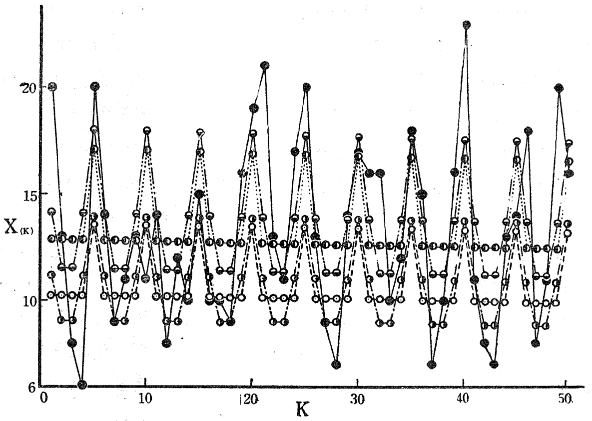


Fig. 12—4 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 4 in the Fishing Ground No.2).

effect of the increase of soaking time. And in such an example as this, the distribution is more uniform than the case in which the increase of the catch rate is simply proportional to the soaking time. Accordingly, when such a distribution is compared with the estimated value in which the increase of the catch rate is regarded as being simply proportional to the soaking time, it might be accepted as if it were self-spacing. The diagrams were decoded on the basis of the above-mentioned supposition.

The diagram of Series Ⅲ represents clearly how the estimated values are distorted by the influence of both the gradient of the catch rate and the difference of the catch rate according to depth, but it does not show anything about the distribution pattern, except that some of the elemental clusters are constituted of the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 hook (80 m), while others are covering a wider range. The distribution of peaks in the diagram of Series Ⅱ is faithfully reflecting the distribution pattern of the elemental clusters covering 1 or 2 baskets (200~400 m), and most of the clusters are actually couples of individuals spaced very widely or single individuals widely spaced and yet retaining the character of the elemental cluster. Further examination of this diagram reveals obscurely the bundle formation. The diagram of Series Ⅰ indicates that the above-mentioned elemental clusters or bundles of them show the trend to form a coarsely aggregated school covering 30 units (30 km) or more; and this school seems to be located in the range from the 200th to the 350th basket.

Example A 5 : The diagram of Series Ⅲ indicates that the number of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 basket (200 m) or thereabout is larger than that being distributed by chance and the diagram of Series Ⅱ shows that the number of individuals caught within the same basket is less than that being distributed by chance —— the occurrence of a single individual in one basket is more frequent but the occurrence of 2 or more individuals in one basket is less frequent than those found in the chance distribution. Besides the pattern given

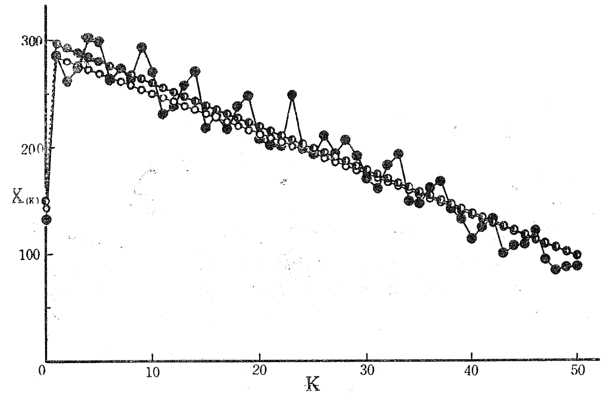


Fig. 12—5 (I). X(k)—k relation diagram of albacore
(Series I obtained at Station 5 in the Fishing Ground No. 2).

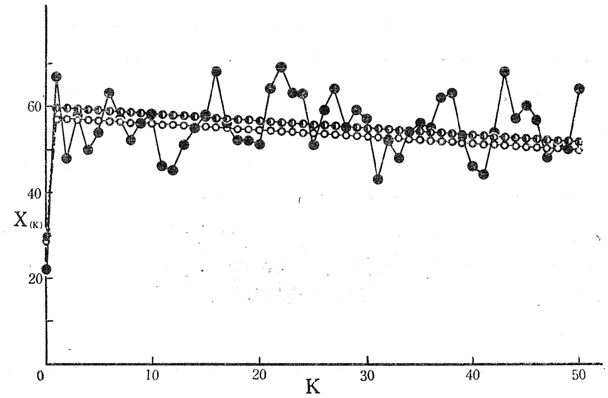


Fig. 12—5 (II). X(k)—k relation diagram of albacore
(Series II obtained at Station 5 in the Fishing Ground No. 2).

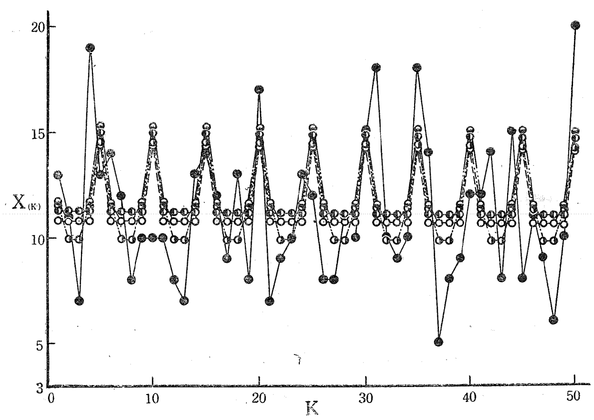


Fig. 12—5 (III). X(k)—k relation diagram of albacore
(Series III obtained at Station 5 in the Fishing Ground No. 2).

above, it is also clarified that the baskets occupied by fishes or those densely occupied by fishes are met with frequently at every one basket. In the diagram of Series I, the observed values at $k=0$ to 3 are a little lower. And this means that the number of individuals caught within 4 successive units is smaller than that estimated on the supposition that individuals are scattered by chance. While, the frequency of occurrence of the couples of individuals caught at the hooks spaced respectively by 5,9 and 10 units *etc.* is larger than that which should be found in the chance distribution. Thus, the distribution pattern is considered as follows: most individuals are scattered rather in a self-spacing manner. The number of individuals appeared even in the units where the fishes were caught densely is much less and moreover the number of such units itself is also far less than those found in the distribution in which individuals are scattered by chance; single or couples of such units are frequently observable at every 5 units or thereabout.

Example A 6 : Among the baskets occupied by fishes, those with only a single

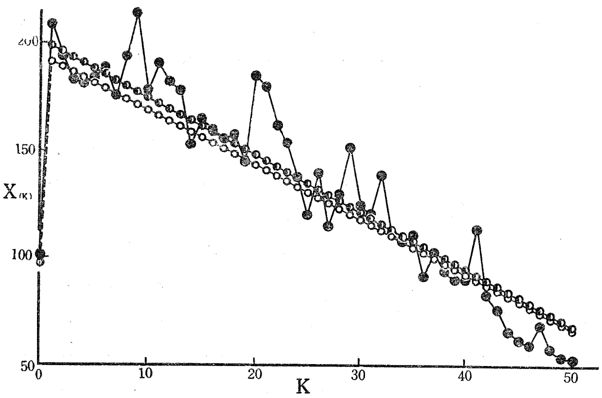


Fig. 12—6 (I). X(k)—k relation diagram of albacore (Series I obtained at Station 6 in the Fishing Ground No.2).

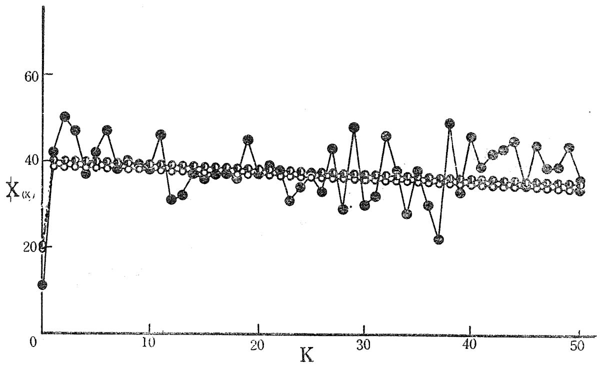


Fig. 12—6 (II). X(k)—k relation diagram of albacore (Series II obtained at Station 6 in the Fishing Ground No.2).

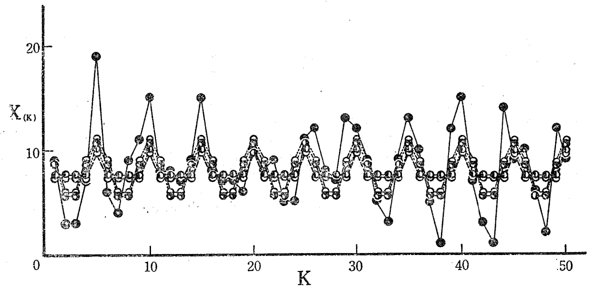


Fig. 12—6 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 6 in the Fishing Ground No.2).

individual in each are met with very frequently, while those with two or more in each are observed much less frequently, *i.e.*, the baskets are occupied in a self-spacing manner. These occupied baskets are found arranged successively or being spaced by 1 or 2 baskets (200~400 m), namely contagiously. Single of occupied baskets or bundles of them, which are all regarded as widely dispersed elemental clusters, are further aggregated into schools covering from 1 to 5 units (1~5 km) and located at every 5 units or thereabout. The existence of schools of such an order is seen rather clearly in Fig. 11.

Example A 7 : It is suggested, in the diagram of Series Ⅲ, that the elemental structure consists mostly of couples of individuals caught side by side (spaced by 40 m) or at the hooks being spaced by the width ranging from 15 to 25, about 35 and about 45 hook-intervals (600, 1,000, 1,400 and 1,800 m). The diagram of Series Ⅱ suggests that 2 or 3 successive or single isolated occupied baskets or aggregations of these baskets show the tendency to form the superior structure which is, however, constituted of merely less than several individuals. The diagram of Series Ⅰ indicates the existence of a school covering *ca.* 20 units (20 km), which seems to be constituted of 5 or 6 subordinate aggregations, mentioned above; the school seems to be located in the range from the 200th to the 300th basket, while its subordinate aggregations are

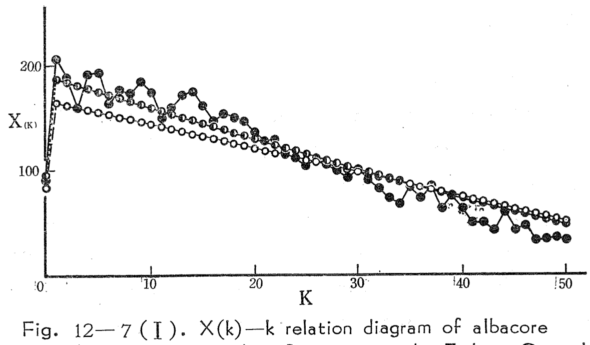


Fig. 12—7 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 7 in the Fishing Ground No.2).

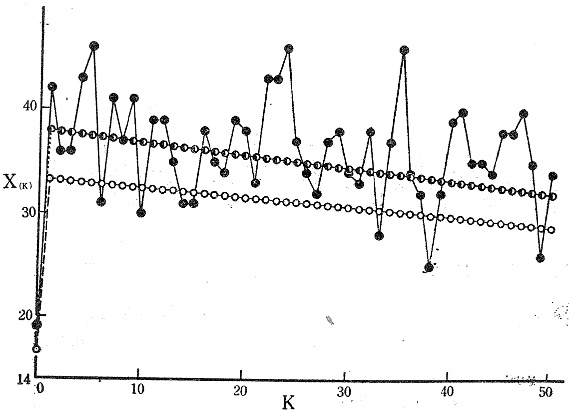


Fig. 12—7 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 7 in the Fishing Ground No.2).

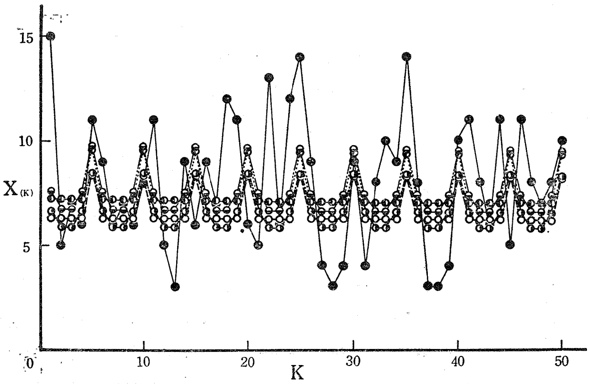


Fig. 12—7 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 7 in the Fishing Ground No.2).

situated in the ranges respectively from the 190th to the 210th basket, from the 215th to the 230th basket, from the 235th to the 260th basket, from the 270th to the 285th basket and from the 290th to the 310th basket. Such aggregations are also observable outside the school.

Example A 8 : Most of the observed values in the diagrams of Series Ⅱ and Ⅲ take a little higher values than the estimated ones on account of the existence of the conspicuous school mentioned below. Therefore, the above-mentioned fact must be kept in consideration, when the subordinate structure is pursued. Now the existence of considerably wide elemental clusters is certified by the analysis made on the diagram of Series Ⅲ. And the short periodic deviation of the observed values in the diagram of Series Ⅱ represents more clearly the distribution pattern of the elemental structure, which is shown only obscurely in the diagram of Series Ⅲ. Several clusters of 1 basket width (200 m), most of which are respectively a single isolated

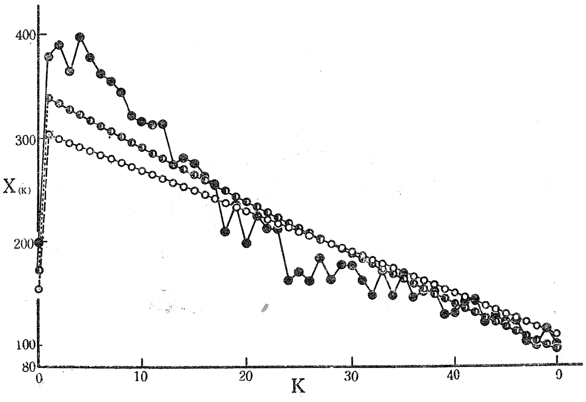


Fig. 12—8 (Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 8 in the Fishing Ground No.2).

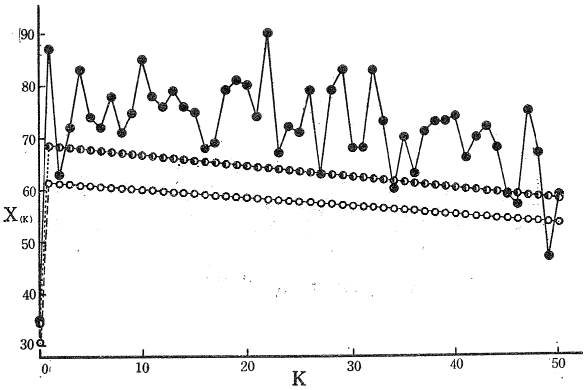


Fig. 12—8 (Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 8 in the Fishing Ground No.2).

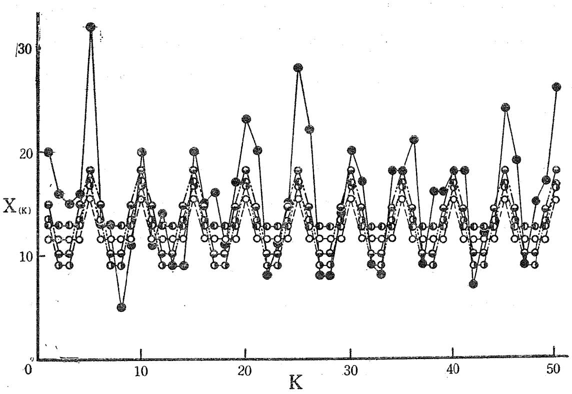


Fig. 12—8 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 8 in the Fishing Ground No.2).

individual or a couple of individuals regarded as the elemental clusters, and those of wider width regarded as the bundles of the above-mentioned clusters are further bundled into obscure aggregations which correspond to the short periodic deviation of the observed values in the diagram of Series I. The high observed values continuously found in the range from $k = 0$ to 17 in the diagram of Series I represent clearly the existence of a relatively strongly aggregated school covering 17 units (17 km), which seems to be situated in the range from the 50th to the 140th basket.

Example A 9 : The diagram of Series III does not show any clear structures. While, the diagram of Series II shows that several clusters of 1 basket width (200 m), most of which are single isolated individuals or couples of them, are bundled into aggregations covering from 1 to 3 units (1∼3 km) and being spaced by 1 unit (1 km); this can be seen more clearly in the diagram of Series I. The diagam of Series I indicates the existence of a loosely aggregated school covering *ca.* 20 units (20 km) and being

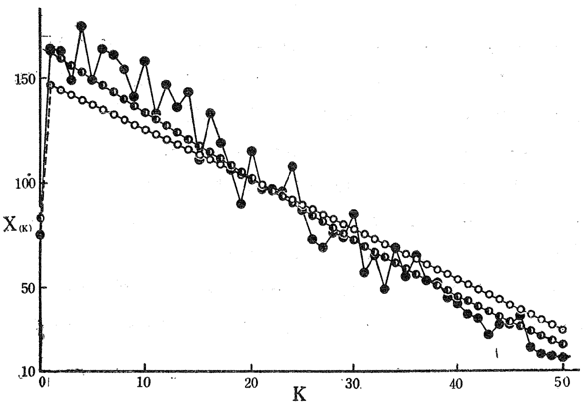


Fig. 12—9 (I). X(k)—k relation diagram of albacore
(Series I obtained at Station 9 in the Fishing Ground No.2).

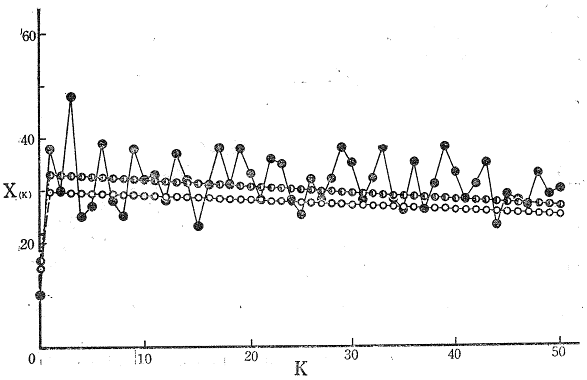


Fig. 12—9 (II). X(k)—k relation diagram of albacore
(Series II obtained at Station 9 in the Fishing Ground No.2).

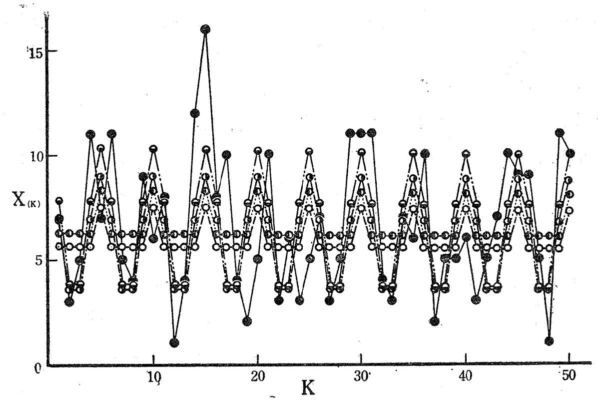


Fig. 12—9 (Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 9 in the Fishing Ground No.2).

considered to be located in the range from the 180th to the 280th basket.

Example A 10 : The contagiousness extending to a considerable width is suggested in the diagram of Series Ⅲ. This diagram and that of Series Ⅱ indicate that the elemental clusters covering from 1 to 4 baskets (200～800 m), of which single individuals and couples of them caught side by side (spaced by 40 m) or at the hooks spaced by 1 basket (200 m) are the principal ingredients besides some of longer width, are bundled into aggregations covering *ca.* 3 units (3 km) as seen also in the diagram of Series Ⅰ. This diagram of Series Ⅰ represents further that some of the aggregations are loosely gathered into a school covering *ca.* 30 units (30 km) and being considered to be located in the range from the neighbourhood of the 70th to the 230th basket.

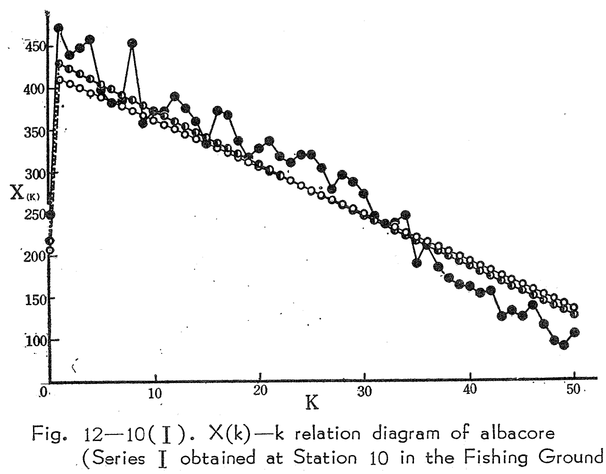


Fig. 12—10(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 10 in the Fishing Ground No.2).

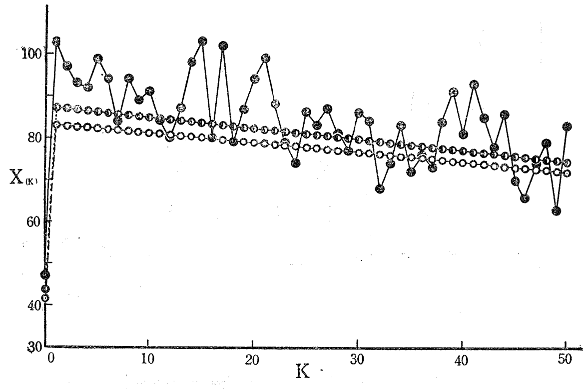


Fig. 12—10(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 10 in the Fishing Ground No.2).

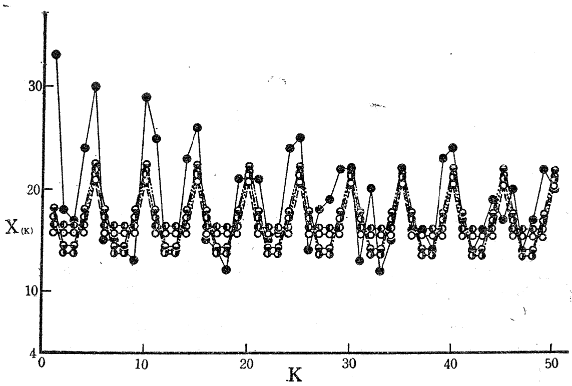


Fig. 12—10(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 10 in the Fishing Ground No.2).

Example A 11 : This is one of the typical examples in which the existence of schools is represented exactly. Namely the existence of conspicuous schools covering *ca.* 8

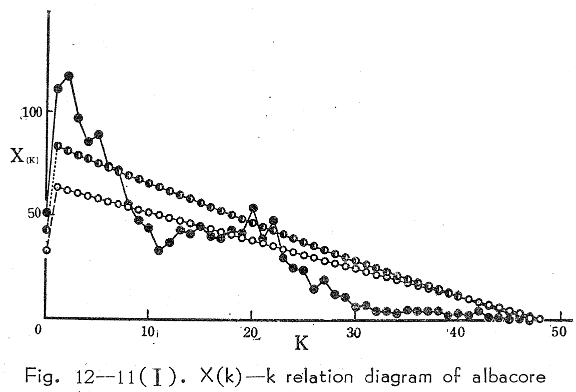


Fig. 12—11(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 11 in the Fishing Ground No.2).

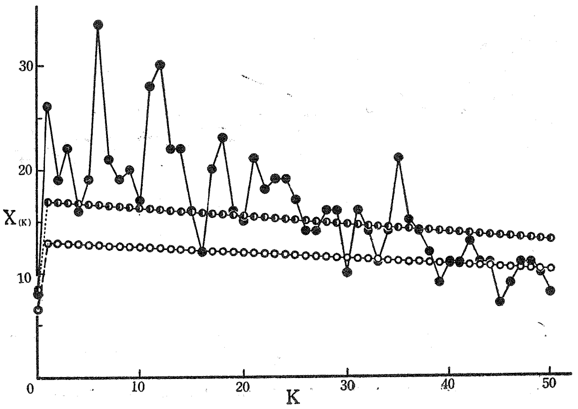


Fig. 12—11(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 11 in the Fishing Ground No.2).

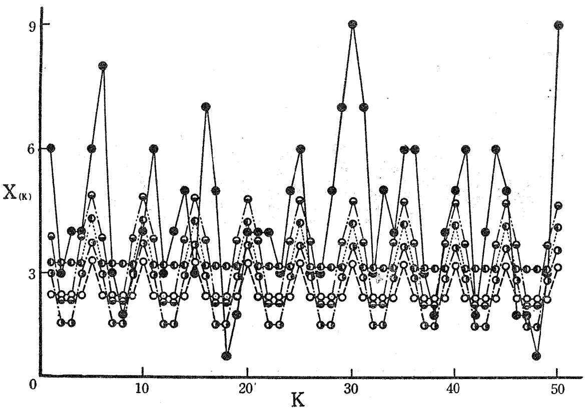


Fig. 12—11(Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 11 in the Fishing Ground No.2).

units (8 km) and being spaced by *ca.* 20 units (20 km) was confirmed, and the most distinct one of which is situated around the 100th basket, while the groups of individuals hooked around the first and the 200th basket may be regarded as obscure ones. The diagrams of Series Ⅱ and Ⅲ show that the above-mentioned schools are composed of many subordinate clusters covering from 1 to 5 baskets (200 m ~ 1 km) and being regarded as the elemental clusters.

Example A 12 : The diagrams of Series Ⅱ and Ⅲ show that principal ingredients of elemental clusters are single isolated individuals or couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 hook (80 m) and perhaps also couples of individuals caught at the hooks spaced by 5 (1 km) or more baskets. These elemental clusters are bundled so loosely that the number of individuals hooked within the same unit may be accepted as self-spacing. Such a pattern can be seen when a wide and dense school is caught and nearly all hooks are occupied by fishes, but the

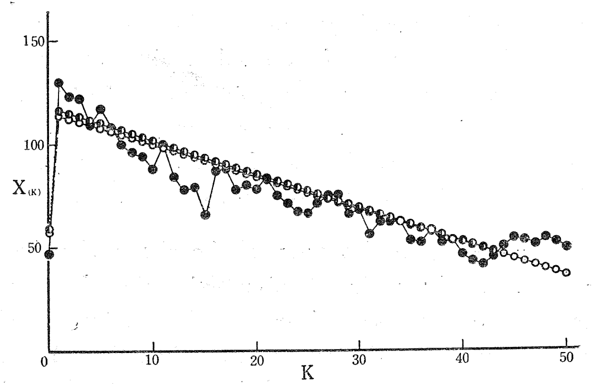


Fig. 12—12(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 12 in the Fishing Ground No.2).

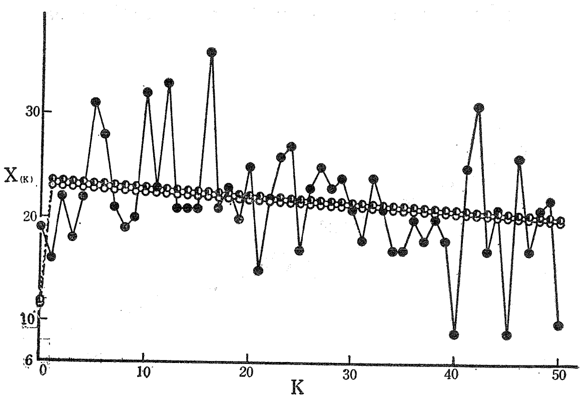


Fig. 12—12(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 12 in the Fishing Ground No.2).

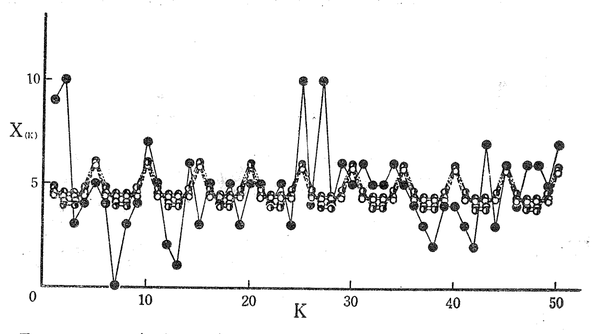


Fig. 12—12(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 12 in the Fishing Ground No.2).

number of individuals hooked in the same unit cannot reach beyond the number of hooks. But the more crucial examination of the data reveals that there are found unoccupied hooks even in the parts regarded as portions where a school was caught, consequently the above-mentioned self-spacing must be assigned to the essential pattern of the distribution. The existence of two relatively distinct schools, the centers of which are apart from each other about 50 units (50 km), and one somewhat obscure school-like aggregation located between them is sustained. These schools are considered to indicate the higher catch rates found around the 25th and 300th baskets, while the school-like aggregation corresponds to that around the 115th basket.

Example A 13 : The mode of the deviation of the observed values in the diagram of Series Ⅲ is shown more clearly in the diagram of Series Ⅱ, because the estimated values in the former contain the essential and regular deviation, while this is not the case about the latter. Thus, no information other than that shown in the diagram of Series Ⅱ can be deduced from the diagram of Series Ⅲ. The deviation of the observed values in the diagram of Series Ⅱ is regular and rather long as compared with that of other examples, and shows that elemental clusters, including single isolated individuals, are most frequently situated at every 3 or thereabout baskets. The diagram of

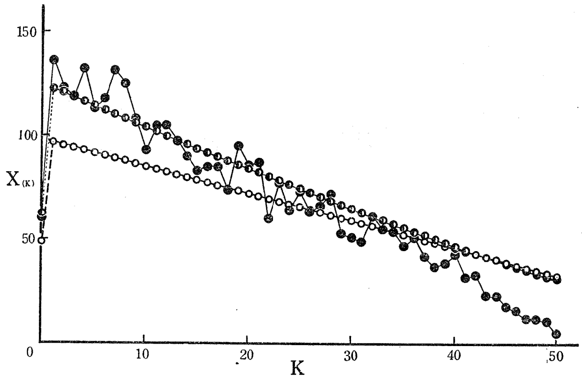


Fig. 12—13(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 13 in the Fishing Ground No.2).

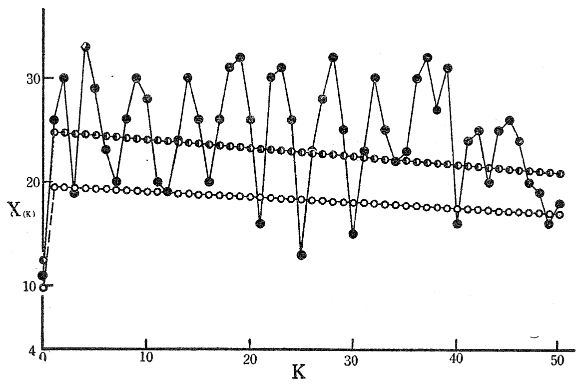


Fig. 12—13(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 13 in the Fishing Ground No.2).

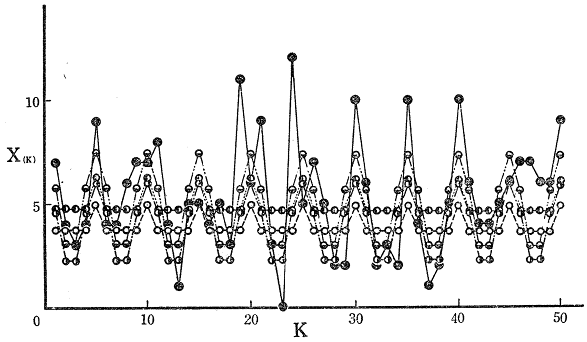


Fig. 12—13(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 13 in the Fishing Ground No.2).

Series Ⅰ indicates that these elemental clusters or bundles of them are further gathered into many aggregations covering from 1 to 3 units (1 ~ 3 km), although some of which are constituted each of a single of the above-mentioned components. Of these aggregations, those located around the 250th, 300th and 350th basket are corresponding to the high observed values at respectively $k=20$, 28 and from 32 to 36, while those located successively in the range from the 130th to the 210th basket are represented as the successive higher observed values at $k=0$ to 14 in the diagram of Series Ⅰ, which suggest the existence of a school of *ca.* 14-unit width (14km).

Example A 14 : This is an example of the intrinsically self-spacing population, so that even in most of the occupied units merely a single individual was caught, being mingled with a few extremely scattered schools of narrow width. The diagram of Series Ⅱ offers further data for the analysis and shows that, taking both the total catch and total number of hooks together into consideration, the essential structure consists of the couples of individuals caught in adjoining baskets (spaced by shorter than 400 m) or those being spaced by 10 baskets (2 km), although actual number of

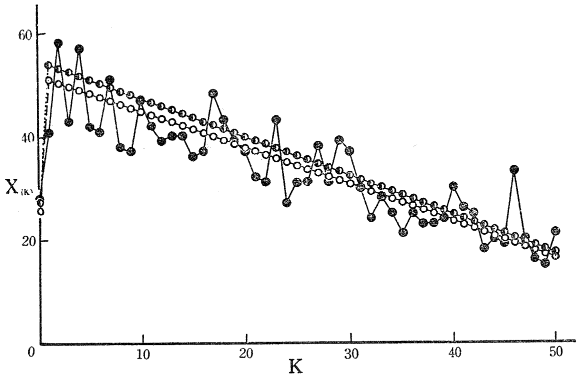


Fig. 12—14(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 14 in the Fishing Ground No.2).

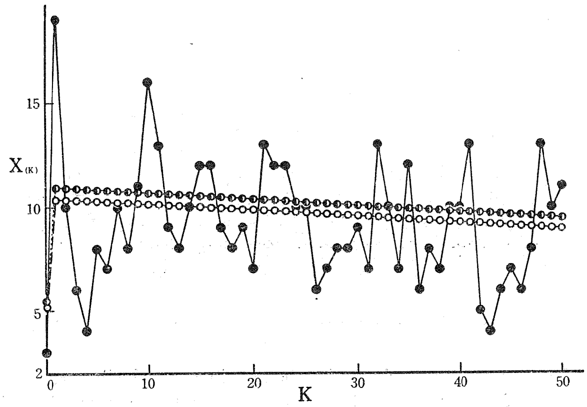


Fig. 12—14(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 14 in the Fishing Ground No.2).

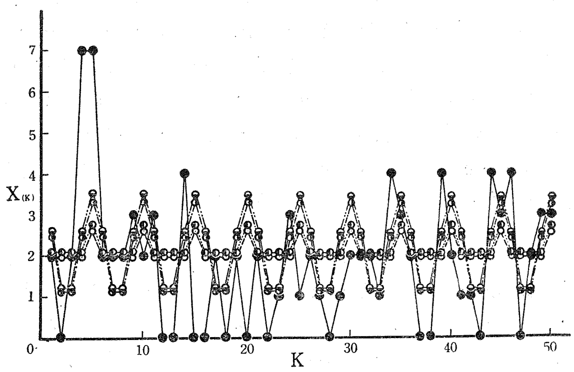


Fig. 12—14(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 14 in the Fishing Ground No.2).

such couples is not so large. And the diagram of Series Ⅲ, in which some accidental errors are highly expected, shows the average interval between the individuals of the former couples more in detail, which is estimated to be as long as 1 basket (200 m) or 1 hook-interval longer than that (240 m).

Example A 15 : The structure of this example is, roughly speaking, considered to consist of the basic population being composed of randomly distributed individuals and many aggregations which cover from 1 to 3 units (1~3 km) and are constituted of several individuals at the maximum. The details are supplemented by the diagrams of Series Ⅱ and Ⅲ and it becomes clear that the population and aggregations are constituted of many clusters covering shorter than 1 unit (1 km), in fact, most of them are merely isolated single individuals and the rests consist each of 2 or rarely more individuals. The principal ingredients of the clusters consisting of two individuals are couples of individuals caught at the hooks arranged side by side (spaced by 40 m) or at the hooks spaced by one basket (200 m) or by the distance longer than 2 but shorter than 3-basket width (400～600 m).

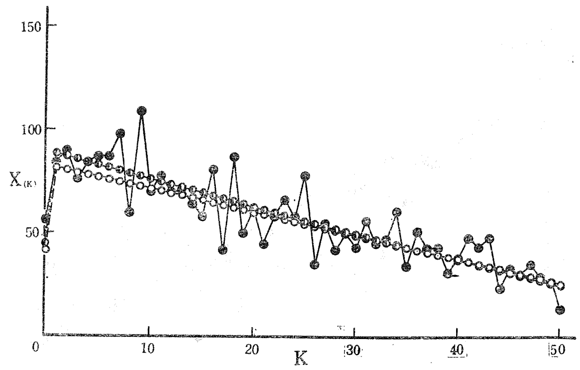


Fig. 12—15(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 15 in the Fishing Ground No.2).

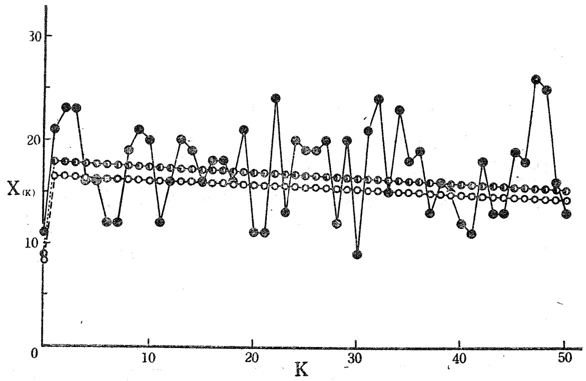


Fig. 12—15(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 15 in the Fishing Ground No.2).

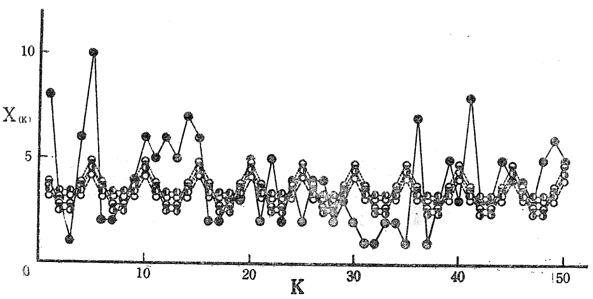


Fig. 12—15(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 15 in the Fishing Ground No.2).

Example A 16 : The diagrams of Series Ⅱ and Ⅲ, together with Fig. 11, give the following detailed structure that the population is constituted chiefly of isolated

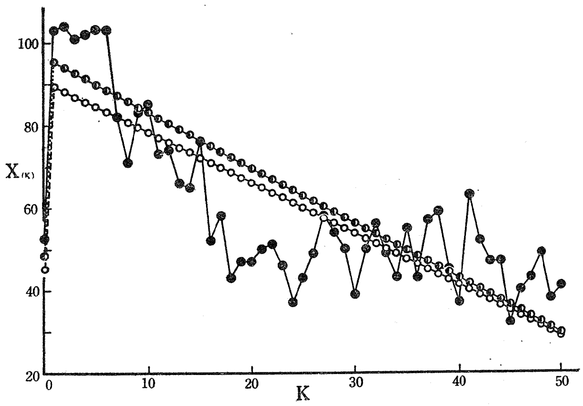


Fig. 12—16(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 16 in the Fishing Ground No.2).

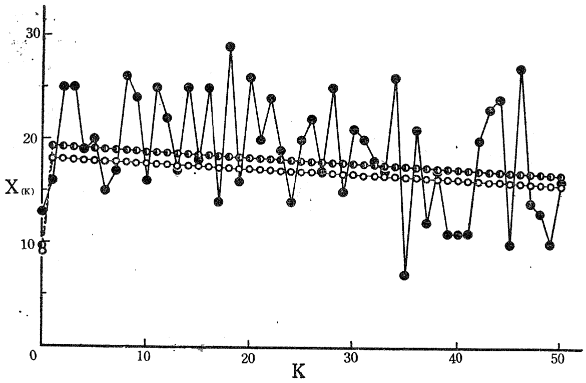


Fig. 12—16(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 16 in the Fishing Ground No.2).

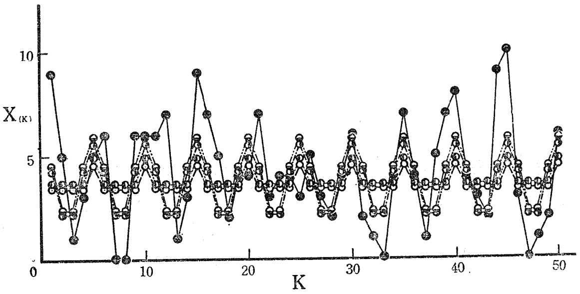


Fig. 12—16(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 16 in the Fishing Ground No.2).

single individuals and partly of couples of individuals or a little larger clusters, all of these are regarded as the elemental clusters. Moreover, the principal ingredients of the latter two are couples of individuals caught side by side (spaced by 40 m). The higher observed values at $k>10$ in Series Ⅱ indicate respectively about the inter-cluster structure, namely the above-mentioned elemental clusters are observed most frequently being spaced by 2 ~ 3 (400~600 m) or 8 ~ 9 baskets (1.6 ~ 1.8 km). The long periodic deviation of the observed values in the diagram of Series Ⅱ and the short periodic one in the diagram of Series Ⅰ show that bundles of elemental clusters or occasionally single isolated clusters themselves seem to form aggregations of superior structure covering from 1 to 4 units (1 ~ 4 km). The long periodic deviation in the diagram of Series Ⅰ represents clearly the existence of a school, a little conspicuous and covering 7 units (7 km) and located around the 60th basket, besides another school consisting of loose bundles of the above-mentioned aggregations, being spaced by about 30 units (30 km) from the conspicuous school and indicating the subsequent part after the 185th basket.

Example A 17 : The extremely low catch rate and the scarcity of the units in which

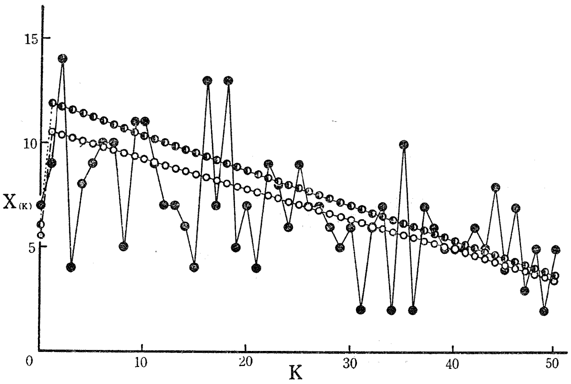


Fig. 12—17(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 17 in the Fishing Ground No.2).

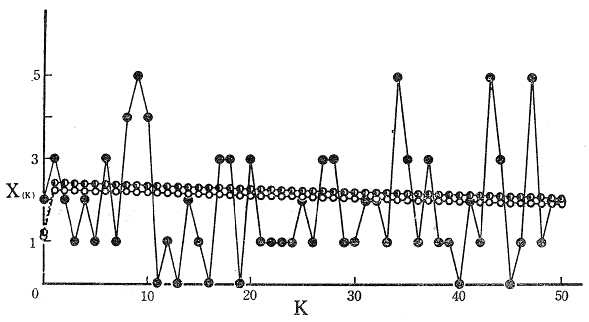


Fig. 12—17(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 17 in the Fishing Ground No.2).

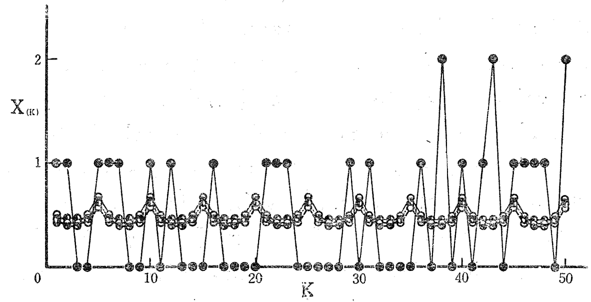


Fig. 12—17(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 17 in the Fishing Ground No. 2).

two or more individuals are caught, make it impossible to deduce any trends of the distribution pattern other than the population seems to be essentially self-spacing.

Example A 18 : In order to avoid the influence of the accidental errors, nothing is

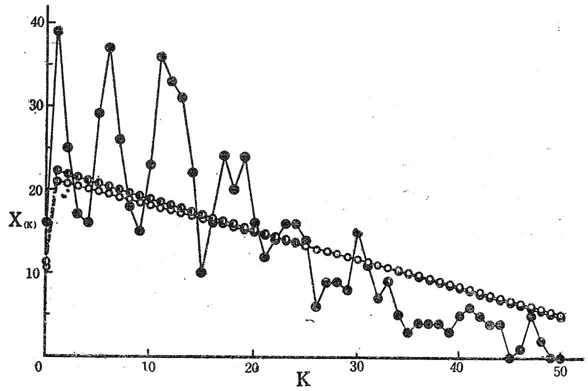


Fig. 12—18(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 18 in the Fishing Ground No. 2).

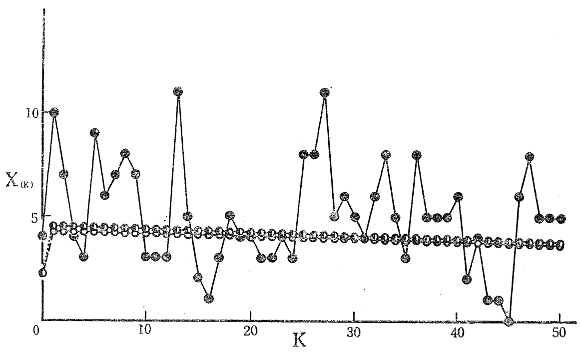


Fig. 12—18(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 18 in the Fishing Ground No. 2).

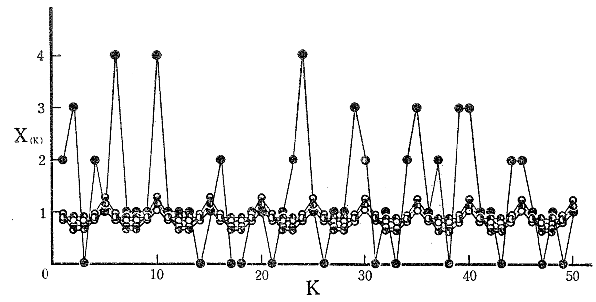


Fig. 12—18(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 18 in the Fishing Ground No.2).

explained here about the diagram of Series Ⅲ. The smaller peaks in the diagram of Series Ⅱ represent the distribution pattern of elemental clusters actually consisting mostly of single isolated individuals or couples of them, and the long periodic deviation of the observed values in the same diagram suggests the superior structure that the above-mentioned elemental clusters are rather compactly bundled into aggregations covering 3 or 4 units (3～4 km), the feature of which is shown more clearly in the diagram of Series Ⅰ. Besides, the existence of a school covering *ca.* 25 units (25 km) is certified by this diagram; this school is considered to be a loose bundle of the above-mentioned aggregations and may correspond to the part of higher catch rate in the range from the 100th to the 220th basket and the subordinate aggregations seem to be located around the 100th, 130th, 160th, 180th and 200th baskets.

Example A 19 : The scarcity of both estimated and observed values, which is attributable to the low catch rate, makes it impossible to give any consideration to the diagram of Series Ⅲ. In the diagram of Series Ⅱ, the part at $k>5$ seems to represent the inter-unit relation, while the part at $k<5$ indicates the intra-unit one. As there are only 13 units in which two or more individuals are caught, it is hardly

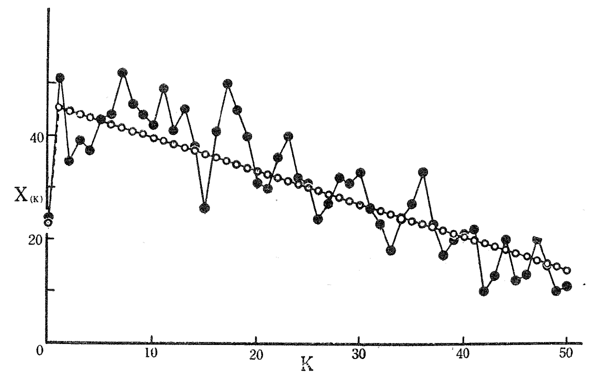


Fig. 12—19(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 19 in the Fishing Ground No.2).

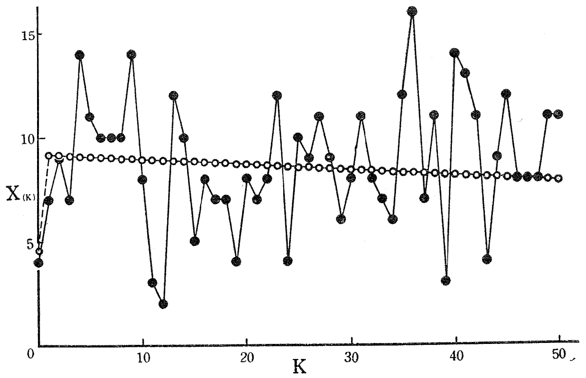


Fig. 12—19(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 19 in the Fishing Ground No.2).

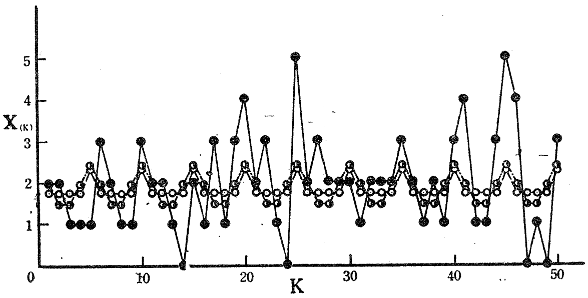


Fig. 12—19(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 19 in the Fishing Ground No.2).

possible to deduce out any facts about the intra-unit distribution other than it is rather self-spacing, namely judging from both of the total catch and the total number of units, the units respectively occupied by only a single individual occur more frequently, while those occupied by two or more individuals do less frequently than they are expected in the chance distribution. The population of this example seems to be composed of many aggregations covering from 1 to 4 units (1 ~ 4 km) and scattering along the whole row of gears. These aggregations are considered to be composed of several individuals at the maximum and represent respective blocks of occupied units found in Fig. 11.

Example A 20 : Nothing is deducible from the diagram of Series Ⅲ, because the accidental errors are highly expected. The long periodic deviation of the observed values in the diagram of Series Ⅱ shows that single isolated individuals, bundles of them or couples of individuals caught at the hooks spaced by 1,2 or 3 units (1,2 or 3 km), which are all regarded as the elemental clusters and represented by small peaks in this diagram, are loosely bundled and form aggregations covering from 1 to 3 units (1~3 km), which are shown clearly in the diagram of Series I and may correspond to respective blocks of occupied units found in Fig. 11.

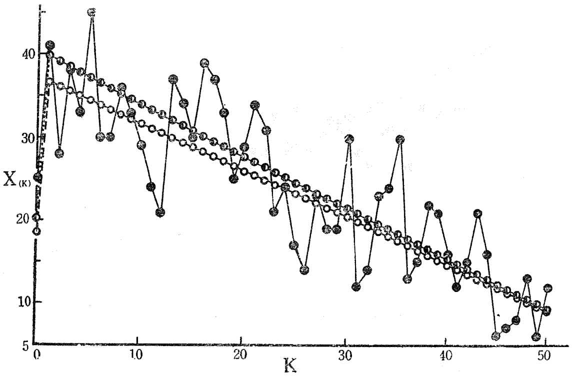


Fig. 12—20(I). X(k)—k relation diagram of albacore (Series I obtained at Station 20 in the Fishing Ground No. 2).

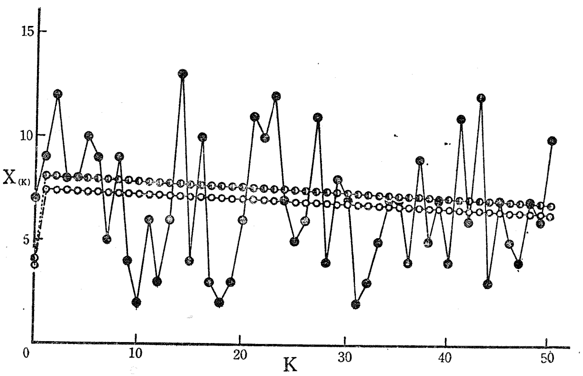


Fig. 12—20(II). X(k)—k relation diagram of albacore (Series II obtained at Station 20 in the Fishing Ground No. 2).

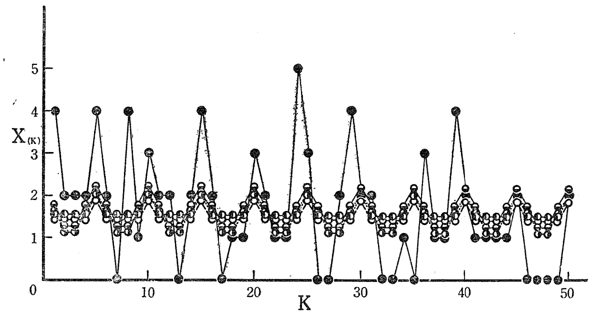


Fig. 12—20(III). X(k)—k relation diagram of albacore (Series III obtained at Station 20 in the Fishing Ground No. 2).

Example A 21 : The influence of the difference of the catch rate according to the

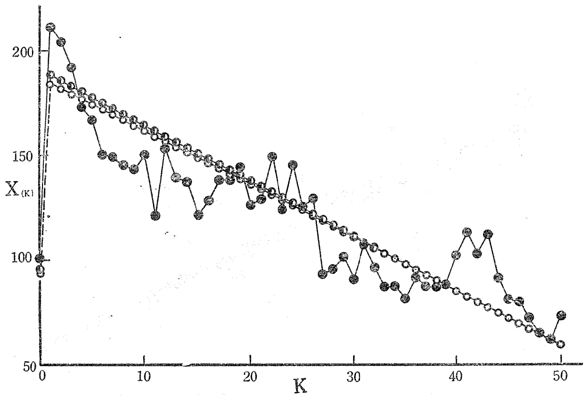


Fig. 12—21(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 21 in the Fishing Ground No.2).

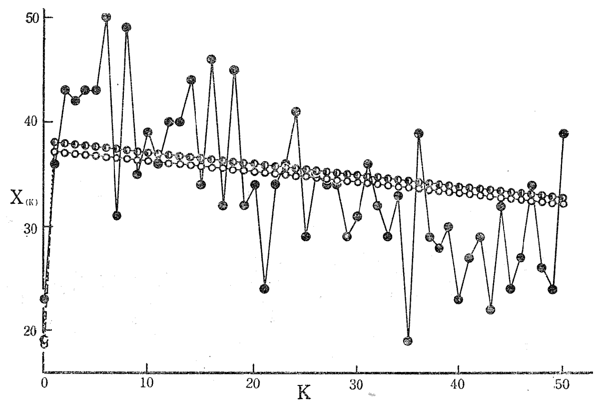


Fig. 12—21(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 21 in the Fishing Ground No.2).

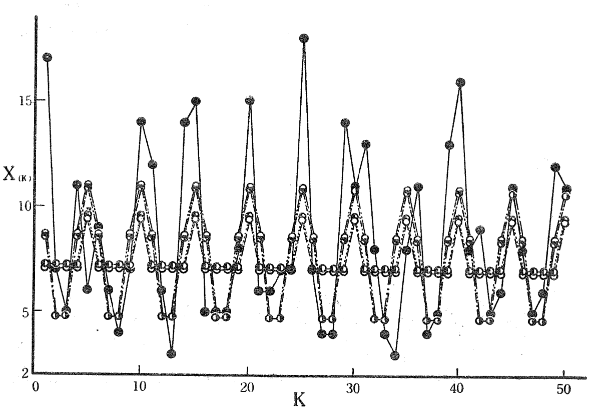


Fig. 12—21(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 21 in the Fishing Ground No.2).

depth is prominent. Accordingly, if we compare the series of the observed values with that of the estimated ones in which the influence of the difference of the catch rate according to the depth is not taken into consideration, the population will show a false 5 hook-interval (200 m) periodicity. However, when the observed values are compared with the series of the estimated values in which the effect of the depth is taken into consideration, this false 5 hook-interval periodicity becomes obscure, although the periodicity remains still very faintly. And it is deduced from the diagram of Series Ⅲ that the elemental structures comprise, besides single isolated individuals, many of the couples of individuals caught side by side or at the hooks spaced by 2, 3, 4, 5, 6, and 8 baskets. The short periodic deviation of the diagram of Series Ⅱ shows quite the same results as those described above somewhat more clearly. And the gradual decrease of the observed values in Series Ⅱ is also represented clearly in the diagram of Series Ⅰ. The higher observed values found at $k=0$ to 4 in the diagram of Series Ⅰ indicate that schools of 4 units width (4 km) or thereabout are contained in the population and they are considered to indicate the blocks of densely occupied units located around the 25th, 225th and 350th baskets. The existence of two other wide but loosely bound schools spaced by 24 (24 km) and 42 units (42 km) from the above-mentioned schools is suggested; they are considered to be located around the 125th and 275th baskets respectively.

Example A 22 : The observed values in the diagram of Series Ⅰ show a weak periodicity of the width a little shorter than 7 units (7 km). And this may be caused by the fact that the units densely occupied by fishes are found around the 75th basket —— (spaced by 6 units) —— the 105th —— (7 units) —— the 140th —— (7) —— the 175th —— (6) —— the 205th —— (6) —— the 235th —— (7) —— the 270th —— (8) —— the 310th baskets, namely at regular intervals in other words in the manner of self-spacing, although the units showing the catch rate at the same level are also found the 95th, 160th and 295th baskets. The subordinate structure is hardly deducible from the diagram of Series Ⅰ, but the details of the structure

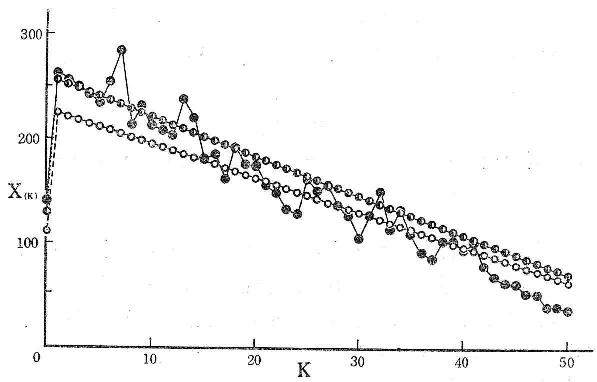


Fig. 12—22(Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 22 in the Fishing Ground No. 2).

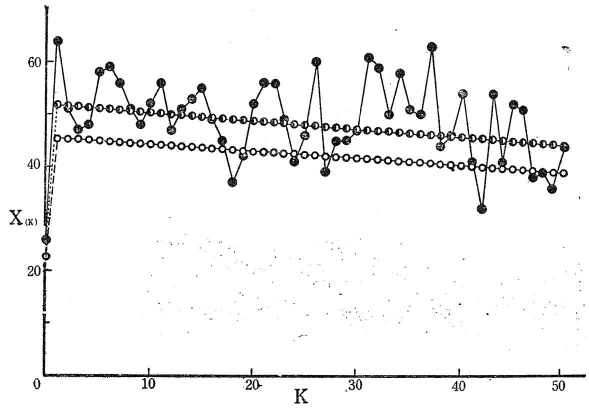


Fig. 12—22(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 22 in the Fishing Ground No.2).

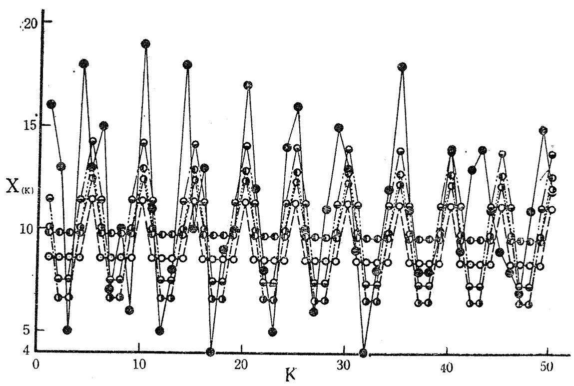


Fig. 12—22(Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 22 in the Fishing Ground No.2).

can be analyzed by treating the second and third series of analyses together; the population is considered to be constituted of many clusters of the shorter width than 1 unit (=5 baskets=25 hook-intervals = 1 km). And the clusters of such a size are regarded as single isolated individuals or couples of individuals, among the latter the couples caught side by side (spaced by 40 m), at the hooks spaced by 1 hook (80 m) or the pairs of hooks of the same order in several neighbouring baskets are the most abundant.

Example A 23 : Nothing is deducible from the diagram of Series Ⅲ other than the facts obtained in the range at $k=0$ to 10 in the diagram of Series Ⅱ. The diagram of Series Ⅱ shows that the population is considered to be the assemblage of many clusters of 1,2 or 3-basket width (200, 400 or 600 m), which are mostly single individuals or couples of them and bound so weakly that even the number of individuals caught within successive 3 baskets (600 m), including that within the same basket

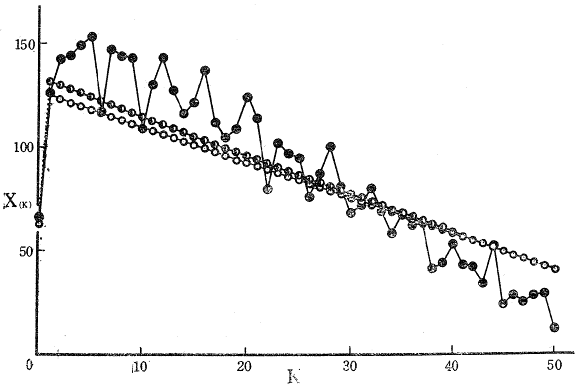


Fig. 12—23(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 23 in the Fishing Ground No. 2).

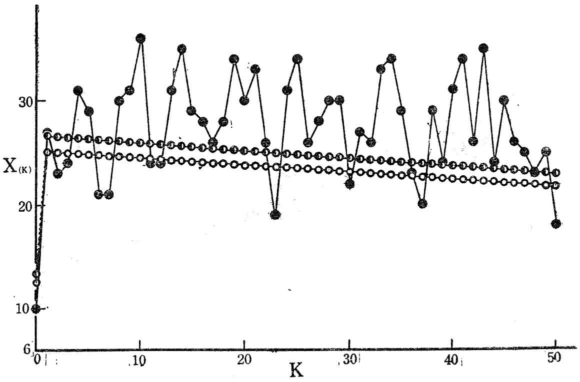


Fig. 12—23(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 23 in the Fishing Ground No. 2).

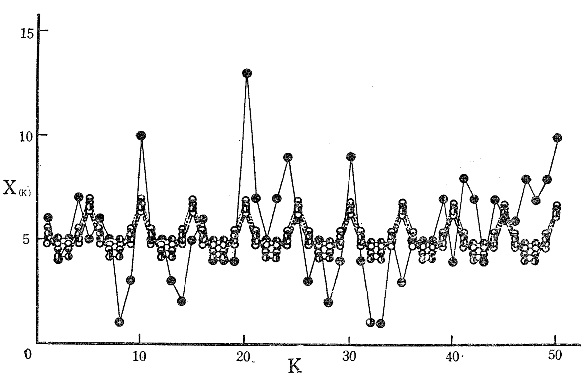


Fig. 12—23(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 23 in the Fishing Ground No. 2).

(200 m), is lower than that expected in the chance distribution. The continuously high observed values found in the diagram of Series I represent the existence of a school covering *ca.* 30 units (30 km) which is constituted of 8 subordinate aggregations of *ca.* 3-unit width (3 km); this school seems to be located in the range roughly from the 105th to the 260th basket and the subordinate aggregations are considered to be situated around the 115th, 140th, 155th, 175th, 200th, 215th, 230th and 260th baskets respectively.

Example A 24 : The diagram of Series II indicates that, besides many single isolated individuals, couples of individuals caught side by side (spaced by 40 m), at the hooks spaced by 1 hook (80 m) or at the pairs of the hooks of the same order in several successive baskets or the pairs formed by the hook of a certain order and that of the penultimate order in several successive baskets are prominent in the population. But, the diagram of Series II of this example gives quite the same results as those described in Example A 23. Namely, the population contains a school covering about

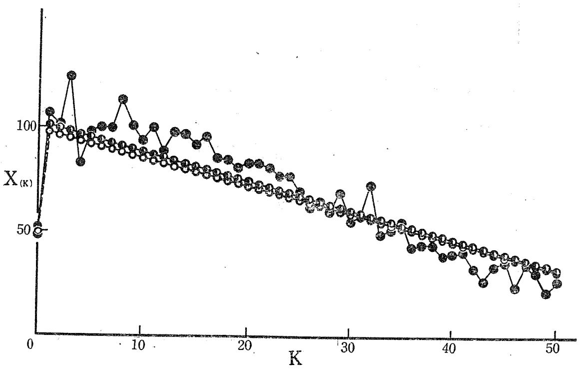


Fig. 12—24(I). X(k)—k relation diagram of albacore (Series I obtained at Station 24 in the Fishing Ground No.2).

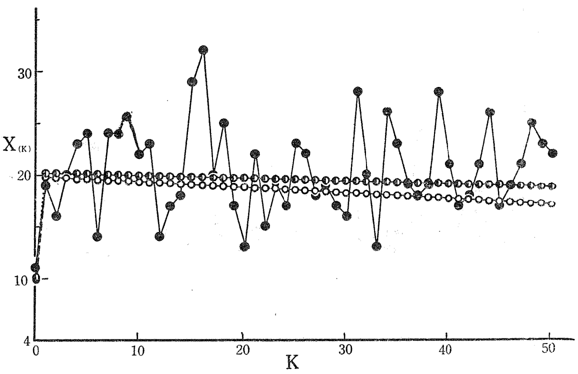


Fig. 12—24(II). X(k)—k relation diagram of albacore (Series II obtained at Station 24 in the Fishing Ground No.2).

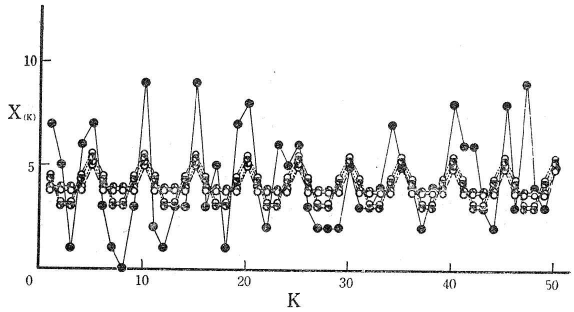


Fig. 12—24(Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 24 in the Fishing Ground No.2).

25 units (25 km) and being distributed in the range from the 100th to the 235th basket.

Example A 25 : The diagram of Series Ⅲ indicates that such elemental clusters as couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by shorter than 1 basket (200 m) or thereabout, 3 (600 m) or the width from 6 to 9 baskets (1.2∼1.8 km) are observed more frequently than those in the chance distribution. The long periodic deviation of the observed values in the diagram of Series Ⅱ suggests that several single individuals or elemental clusters mentioned above, which are represented by the short periodic one in the same diagram and the latter are constituted of less than 2∼3 individuals, are bundled to form aggregations represented by the short periodic one of the observed values in the diagram of Series Ⅰ. The diagram of Series Ⅰ alludes to the existence of a school covering *ca.* 35 units (35 km) and being constituted of loose bundles of rather longer subordinate aggregations. The consecutive units of higher catch rate in the range from the 140th to the 235th basket are considered to be an assemblage of several aggregations forming the main part of the school, while those around the 100th and 275th baskets are also taken each as a small part of the school; those around the 30th, 310th and 365th baskets

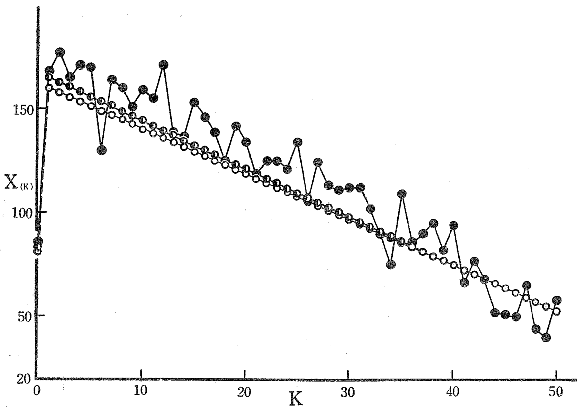


Fig. 12—25(Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 25 in the Fishing Ground No.2).

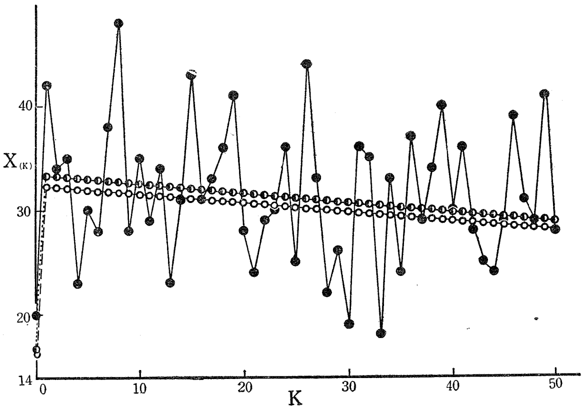


Fig. 12—25(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 25 in the Fishing Ground No.2).

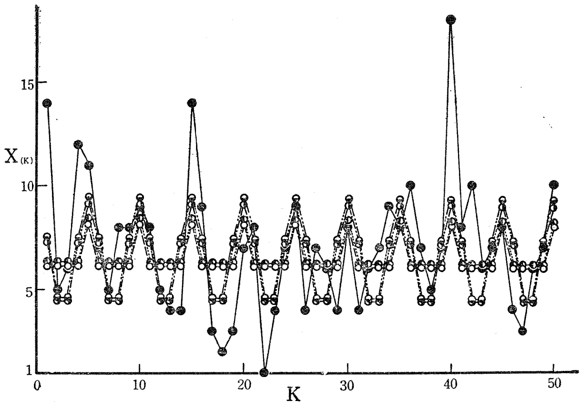


Fig. 12—25(Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 25 in the Fishing Ground No.2).

are thought to illustrate the existence of subordinate aggregations, although they are located outside the school.

Example A 26 : The diagram of Series Ⅲ suggests, although there are expected some accidental errors, that the elemental structure comprises a number of couples of individuals spaced by shorter than 1 basket (200 m) or the width of 2 ～ 3 or 7 baskets (400 ～ 600 m or 1.4 km) besides single isolated individuals; this is certified also by the large amplitude of the short periodic deviation of the observed values in the diagram of Series Ⅱ. The existence of a school covering *ca.* 20 units (20 km) is alluded to in the diagram of Series Ⅰ; this may indicate the units of higher catch rate observed in the range from the 115th to the 215th basket and is regarded as a loose bundle of subordinate aggregations of 1 unit width (1 km) or thereabout and representing single elemental clusters mentioned above or bundles of them.

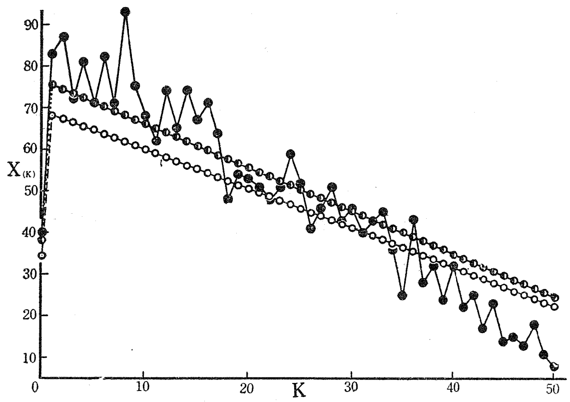


Fig. 12—26(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 26 in the Fishing Ground No.2).

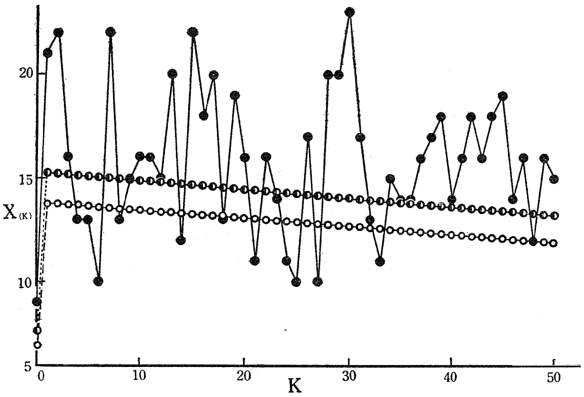


Fig. 12—26(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 26 in the Fishing Ground No.2).

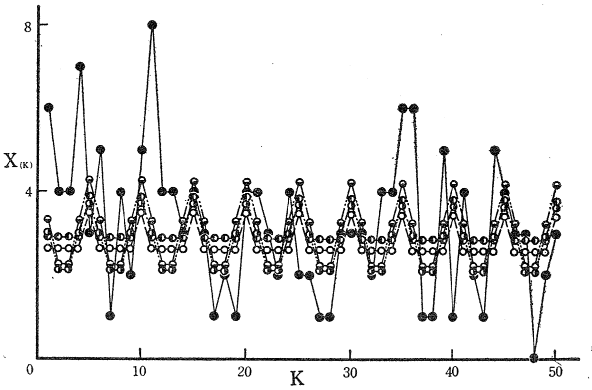


Fig. 12—26(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 26 in the Fishing Ground No.2).

Example A 27 : Although the distribution of individuals in Fig. 11 alludes to the existence of a school of a considerable width, this can be regarded as being caused by the gradient of the soaking time. Individuals tend to form many clusters covering from 1 to 3 units (1 ~ 3 km) or longer as it is assumable on the diagram of Series I. The diagram of Series II indicates that individuals are scattered more evenly within the same basket than in the chance distribution, but the number of individuals caught within 5 consecutive baskets or that caught in pairs at the hooks spaced by 7 ~ 9 (1.4~1.8 km) or 11~13 baskets (2.2~2.6 km) are observed more frequently than those in the chance distribution. By consulting the diagram of Series III, the above-mentioned feature becomes clearer in detailed structure, as the number of individuals caught at the 3 consecutive hooks next to respective occupied hooks is less, while that of individuals caught in couples at the hooks spaced by 1 ~ 3 baskets is more abundant than those in the chance distribution.

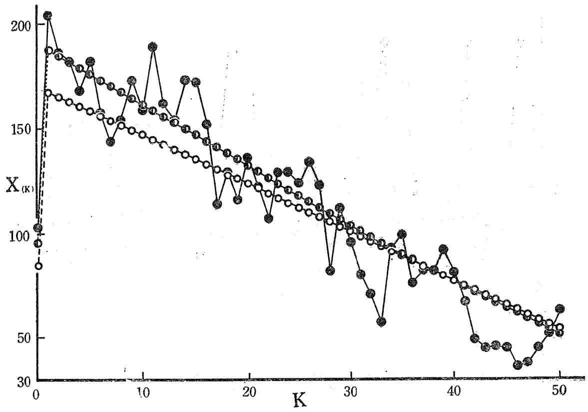


Fig. 12—27(I). X(k)—k relation diagram of albacore (Series I obtained at Station 27 in the Fishing Ground No. 2).

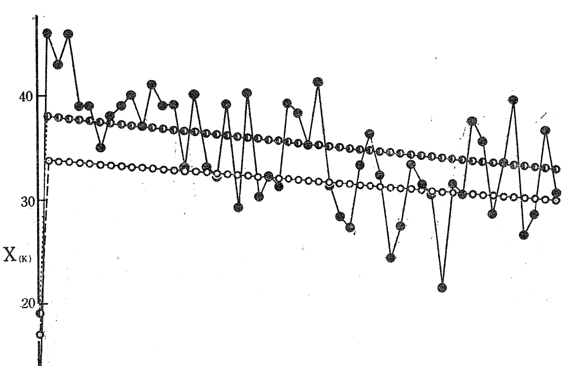


Fig. 12—27(II). X(k)—k relation diagram of albacore (Series II obtained at Station 27 in the Fishing Ground No. 2).

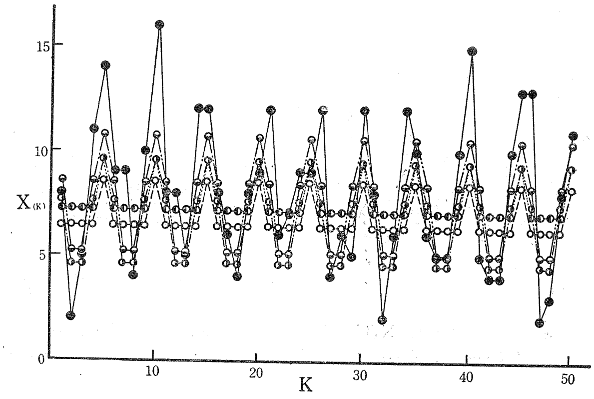


Fig. 12—27(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 27 in the Fishing Ground No.2).

Example A 28 : As for the third series of analysis, only the diagram is given here,

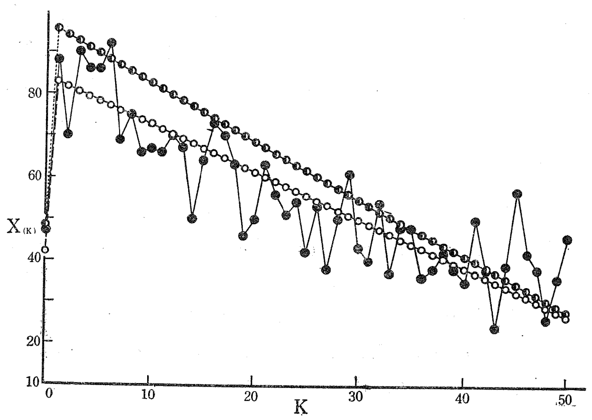


Fig. 12—28(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 28 in the Fishing Ground No.2).

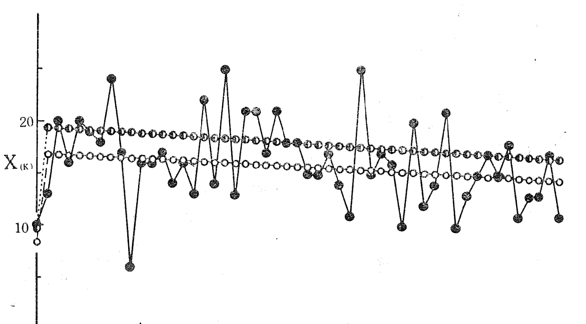


Fig. 12—28(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 28 in the Fishing Ground No.2).

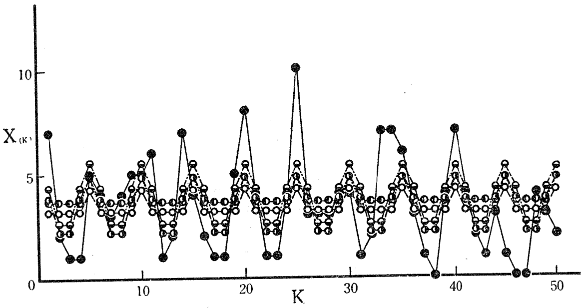


Fig. 12—28(Ⅲ). X(k)—k relation diagram of albacore (Series Ⅲ obtained at Station 28 in the Fishing Ground No.2).

although some detailed structure might be analyzed, since some accidental errors are expected. The diagram of Series Ⅱ suggests that the number of individuals caught within 6 consecutive baskets (1.2 km) is smaller, but that caught in couples at the hooks spaced by 7 baskets (1.4 km) is larger than those in the chance distribution and that the population seems to be constituted chiefly of many individuals or clusters, perhaps couples of individuals covering shorter than 1 basket (200 m). The diagram of Series Ⅰ indicates that in this example, individuals are distributed in respective occupied units more evenly and moreover, these are also spaced themselves more evenly than in the chance distribution.

Example A 29 : As it is possible that accidental errors occur, nothing can be discussed about the distribution pattern on the diagram of Series Ⅲ, except that couples of individuals caught at the hooks spaced by about 1, 4, 5, 9 or 10 baskets (0.2, 0.8, 1.0, 1.8 or 2.0 km) occur more frequently than those in the chance distribution. The diagram of Series Ⅱ, which also alludes to the above-mentioned trends, suggests that the aggregations shown in the diagram of Series Ⅰ contain several individuals or

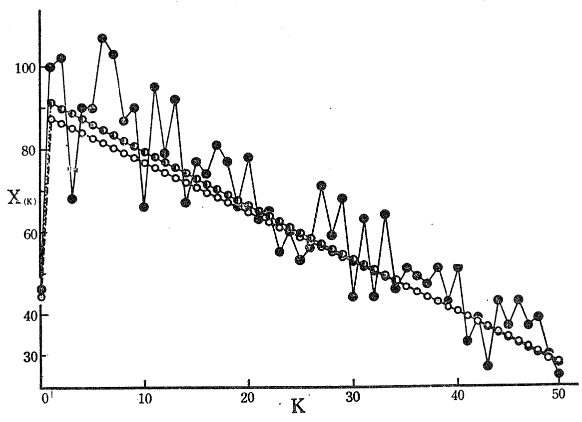


Fig. 12—29(Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 29 in the Fishing Ground No.2).

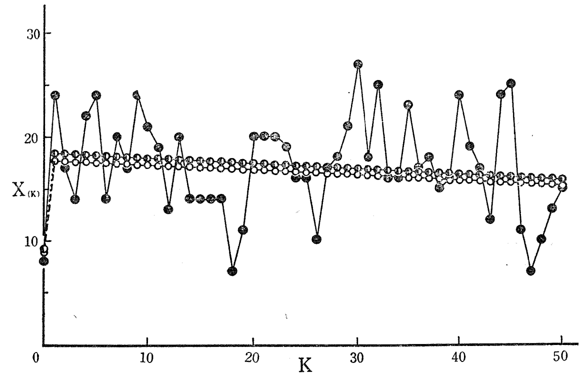


Fig. 12—29(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 29 in the Fishing Ground No. 2).

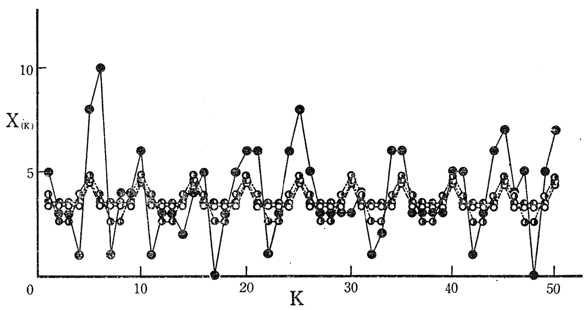


Fig. 12—29(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 29 in the Fishing Ground No. 2).

subordinate clusters which are considered most probably to be couples of individuals. In the population constituted of many individuals and aggregations covering 1 or 2 units (1 or 2 km), the presence of 3 schools is discerned; they are loose bundles of the above-mentioned aggregations, cover 20, 15 and 5 units (20, 15 and 5 km) and are arranged being spaced by 30 and 45 units (30 and 45 km) respectively between their centers, though they can not be said to be segregated from one another so clearly. They seem to indicate the consecutive units of higher catch rate observed in the ranges from the 50th to the 125th, from the 200th to the 250th and around the 350th baskets respectively.

Example A 30 : As shown in Fig. 11, the population is so scattered that the number of individuals caught within the same unit is less than that in the chance distribution. Yet, several schools covering from 2 to 4 units (2~4 km) are discernible in it and besides them, clusters of 1 unit width (1 km) representing mostly couples of individuals occur being mingled with them. From the diagram of Series Ⅱ, it is presumable that the number of other individuals caught within the same occupied basket and the next one is extremely scarce, *i. e.*, the individuals are distributed in a self-spacing

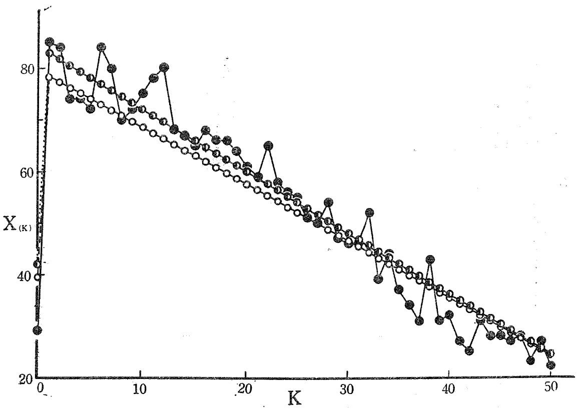


Fig. 12—30(I). X(k)—k relation diagram of albacore (Series I obtained at Station 30 in the Fishing Ground No. 2).

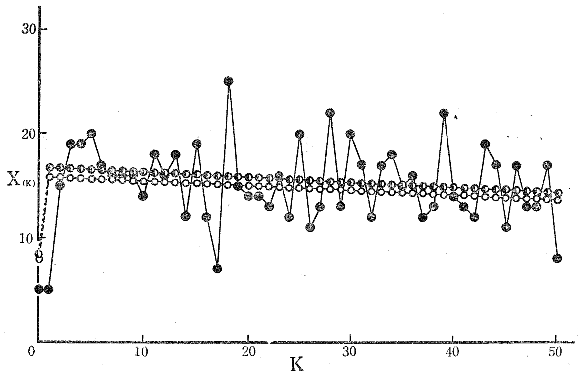


Fig. 12—30(II). X(k)—k relation diagram of albacore (Series II obtained at Station 30 in the Fishing Ground No. 2).

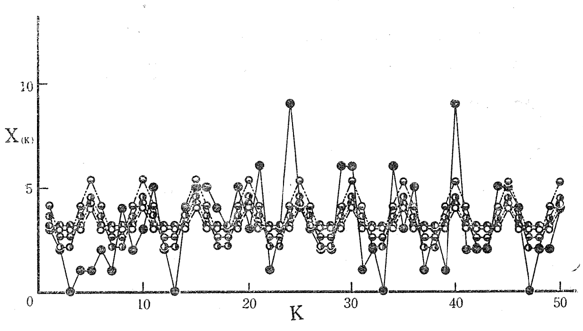


Fig. 12—30(III). X(k)—k relation diagram of albacore (Series III obtained at Station 30 in the Fishing Ground No. 2).

manner and that the population seems to be constituted of many single isolated individuals. As the self-spacing distribution covers a considerably wide hook-intervals and both the observed and estimated values are very low on account of the low catch rate, nothing is deducible from the diagram of Series Ⅲ.

Example A 31 : The low catch rate makes it impossible to give any consideration to the structure of the population upon the diagrams of Series Ⅱ and Ⅲ, except that couples of individuals spaced by about 10 (2 km), the width from 20 to 30 (4 ~ 6 km) and about 35 baskets (7 km) are rather remarkable. But, the diagram of Series Ⅰ makes it clear that the existence of clusters covering 1 unit (1 km) among the population showing the self-spacing distribution is discernible, although most of them are, in fact, single individuals or couples of them and even the largest ones among them are constituted of less than 4 individuals.

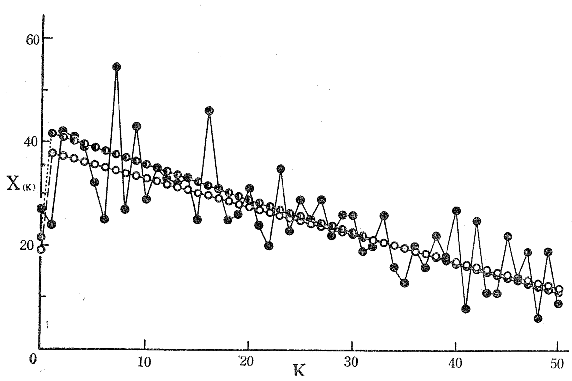


Fig. 12—31(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 31 in the Fishing Ground No.2).

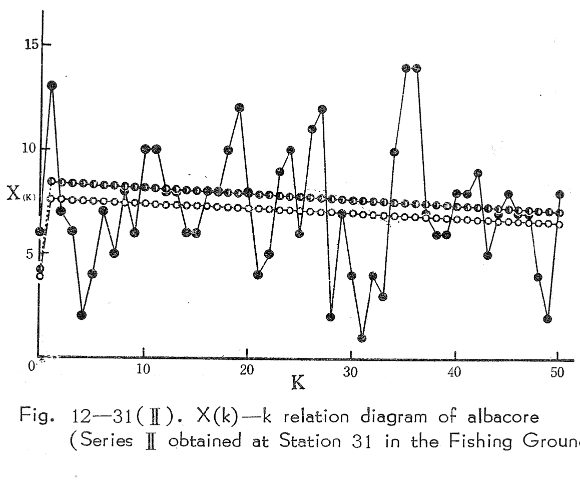


Fig. 12—31(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 31 in the Fishing Ground No.2).

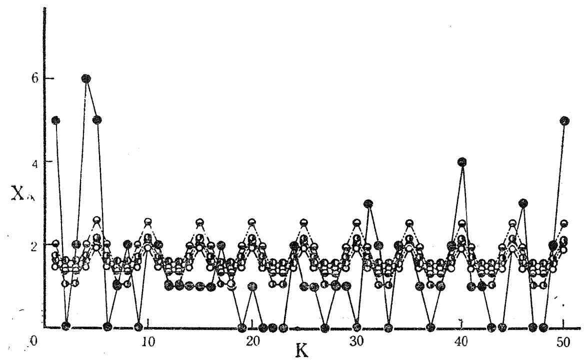


Fig. 12—31(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 31 in the Fishing Ground No. 2).

Example A 32 : The diagram of Series III shows that the deviation of the observed values measured by hook-intervals is mostly attributable to the difference of the catch rates according to the depth, although some accidental errors can be expected in the observed values. And the diagram of Series II reveals that the elemental clusters mostly represented by single isolated individuals or couples of them and indicated by the short periodic deviation of a large amplitude are bundled into rather wide aggregations. But, the following peculiar pattern of the distribution is suggested by the diagram of Series I: the population is constituted of many isolated individuals and clusters or aggregations covering from 1 to 3 units (1 ~ 3 km) and it contains some schools covering about 3 units (3 km) and being spaced by 20 units (20 km) when it is seen as the whole. These schools seem to indicate the blocks of higher catch rate located around the 50th, 150th, 250th and 350th baskets. Besides, the existence of a wider school being 30 units (30 km) apart from these schools is alluded to, although it is

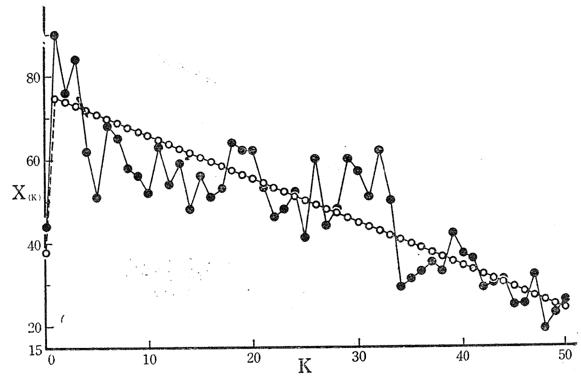


Fig. 12—32(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 32 in the Fishing Ground No. 2).

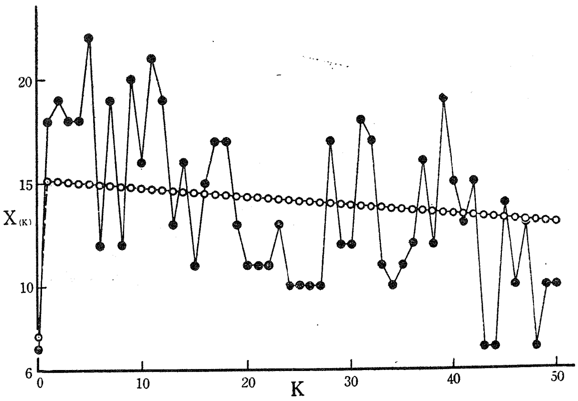


Fig. 12—32(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 32 in the Fishing Ground No. 2).

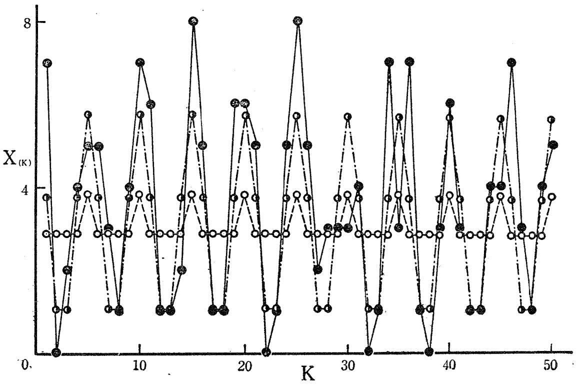


Fig. 12—32(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 32 in the Fishing Ground No. 2).

quite uncertain to which part this school is corresponding. Rather, this phenomenon is considered to be caused by the following fact. There is seen a rather continuous distribution covering the range from about the 50th to the 150th basket and another continuous distribution of individuals is observable after the interruption of the width of several consecutive units, in which individuals are arranged so as to keep the distance of *ca.* 30 units (30 km) from respective corresponding individuals in the former school. Accordingly the above-mentioned pattern can be expressed as follows: the population seems to contain two schools in which individuals show rather self-spacing distribution, one of them is located in the range from the 50th to the 150th, while the other in the range from the 200th to the 350th basket.

Example A 33 : It is impossible to develope any consideration upon the diagram of Series Ⅲ, because both the observed and estimated values are very low on account of the scarcity of the caught individuals. The extremely low observed value at $k=0$

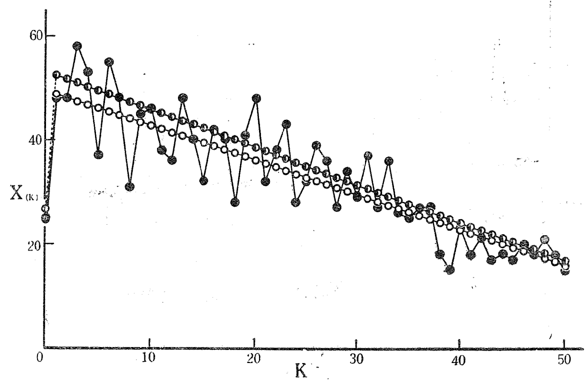


Fig. 12—33(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 33 in the Fishing Ground No.2).

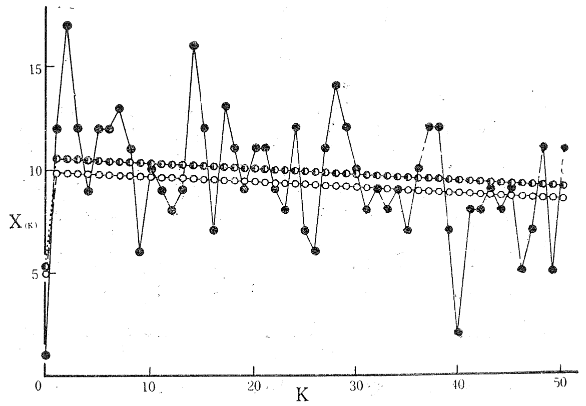


Fig. 12—33(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 33 in the Fishing Ground No.2).

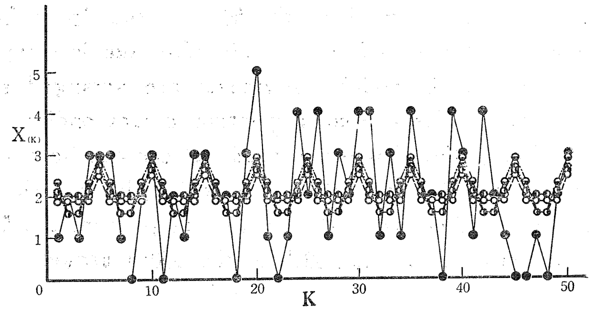


Fig. 12—33(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 33 in the Fishing Ground No.2).

in the diagram of Series Ⅱ seems to indicate that the density of individuals in occupied baskets is lower than in the chance distribution, in other words, individuals are scattered more evenly than distributed by chance. Such occupied baskets are, however, by no means distributed by chance, but they are frequently found in couples being spaced by 2,14 and 28 baskets (0.4, 2.8 and 5.6 km). The diagram of Series Ⅰ suggests the existence of many schools covering 1 or 2 units (1 or 2 km) in the population which is so scattered that the distribution of individuals caught within 3 consecutive units (3 km) next to respective occupied ones is rather regarded as self-spacing. Most of schools mentioned above are constituted of merely 2 individuals and even the largest ones contain less than 6 individuals.

Example A 34 : The low individual density makes it impossible to discuss upon the diagram of Series Ⅲ, though the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 6 ~ 7 hooks (240~280 m), 3 (600 m) and 8

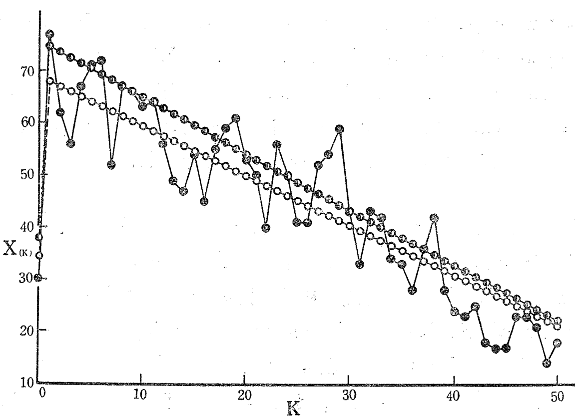


Fig. 12—34(Ⅰ). X(k)—k relation diagram of albacore (Series Ⅰ obtained at Station 34 in the Fishing Ground No.2).

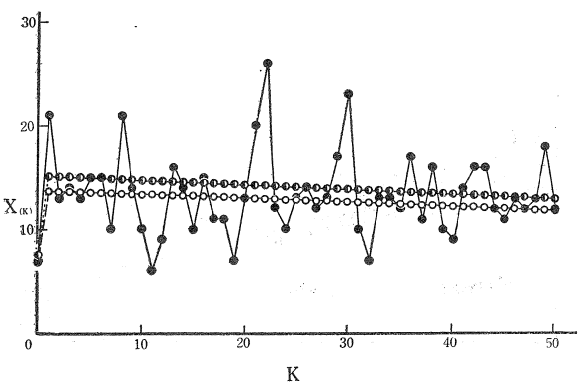


Fig. 12—34(Ⅱ). X(k)—k relation diagram of albacore (Series Ⅱ obtained at Station 34 in the Fishing Ground No.2).

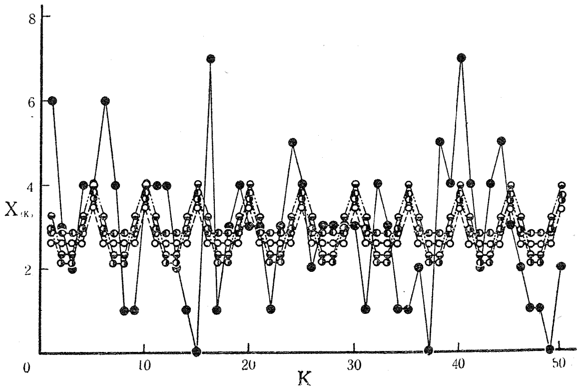


Fig. 12—34(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 34 in the Fishing Ground No.2).

baskets (1.6 km) seem to predominate over others. And the diagram of Series Ⅱ indicates that the couples of occupied baskets spaced by 1, 8, 22 and 30 baskets (0.2, 1.6, 4.4 and 6 km) are predominant. Mingled with this self-spacing population, there are found remarkable schools covering from 1 to 3 units (1 ~ 3 km), most of which are, however, constituted of less than several individuals.

Example A 35 : The diagram of Series Ⅲ shows that, besides single isolated individuals, couples of individuals caught side by side (spaced by 40 m), at the hooks spaced by 1, 2, 7 and 8 baskets (0.2, 0.4, 1.4 and 1.6 km) occur frequently than expected. The diagram of Series Ⅱ shows that besides single isolated individuals, there are clusters covering 2 baskets (0.4 km) and that the clusters or individuals are most frequently spaced by 7, 13, 21, 30, 42 and 50 baskets (1.4, 2.6, 4.2, 6.0, 8.4 and 10.0 km), namely roughly at intervals of 7 baskets (1.4 km). Among the population consisting of individuals or clusters distributed at intervals of 2 units (2 km) and several aggregations of 3-unit width (3 km) being constituted of less

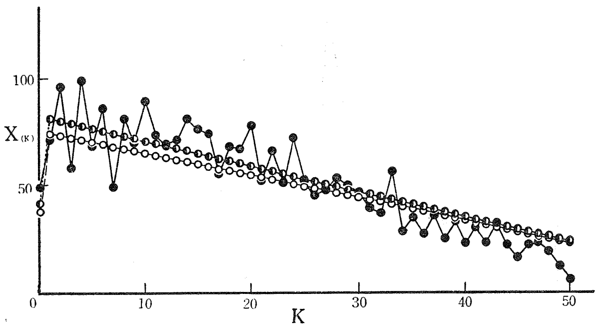


Fig. 12—35(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 35 in the Fishing Ground No.2).

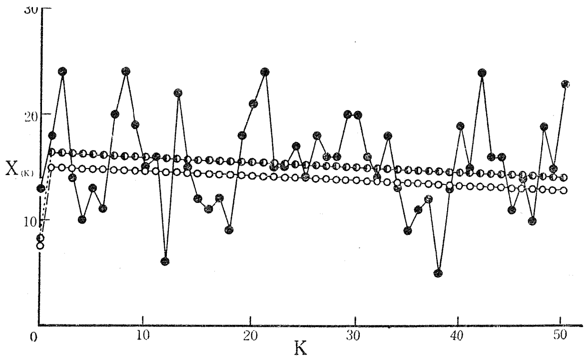


Fig. 12—35(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 35 in the Fishing Ground No. 2).

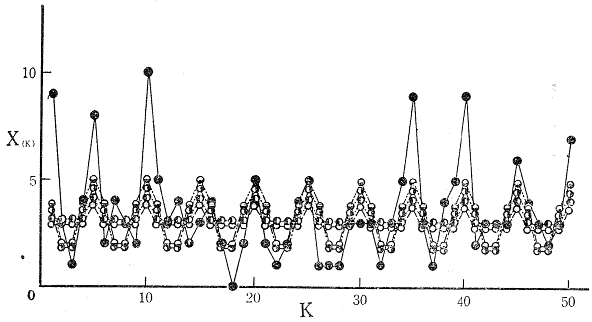


Fig. 12—35(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 35 in the Fishing Ground No. 2).

than several individuals, a school covering *ca.* 30 units (30 km) and indicating the parts extending from the 100th to the 250th basket is obscurely discernible.

Example A 36 : Despite of both the low observed and estimated values, it is sug-

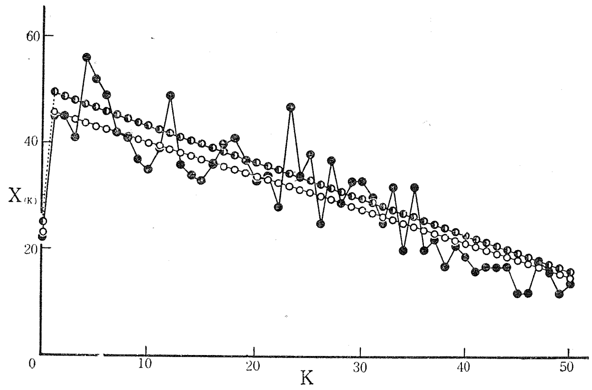


Fig. 12—36(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 36 in the Fishing Ground No. 2).

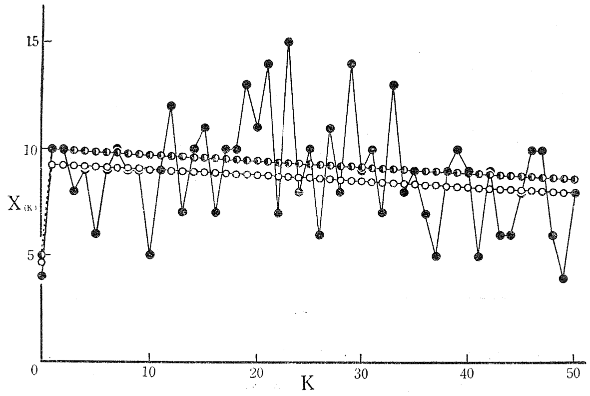


Fig. 12—36(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 36 in the Fishing Ground No. 2).

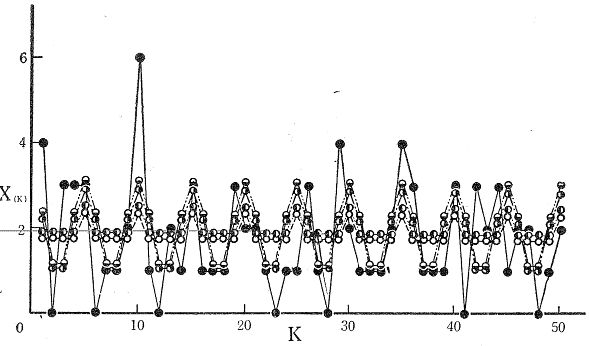


Fig. 12—36(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 36 in the Fishing Ground No. 2).

gested from the diagram of Series Ⅲ that the number of individuals caught at successive hooks (spaced by 40 m) or at the hooks spaced by 3 hooks (120 m), 2,6～7 or 8～9 baskets (0.4, 1.2 ～1.4 or 1.6～1.8 km) are more abundant than those in the chance distribution. The diagram of Series Ⅱ shows that the density of individuals within the 10 consecutive baskets (2 km) next to respective occupied ones is lower, while that within the range from 12 to 23 baskets (2.4～4.6 km) is higher than in the chance distribution. The diagram of Series Ⅰ illustrates that the population is so scattered that the number of individuals caught within the 4 successive units (4 km) next to respective occupied ones is less than that in the chance distribution, but it contains many aggregations covering from 1 to 3 units (1 ～ 3 km) and being constituted of only a few individuals.

Example A 37 : The diagram of Series Ⅲ illustrates that the single isolated individuals, the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 1 basket (0.2 km), 9 hooks (360 m), 5 or 10 baskets (1 or 2 km)

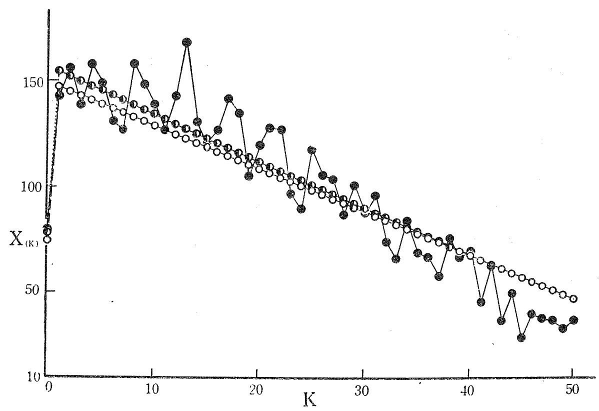


Fig. 12—37(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 37 in the Fishing Ground No. 2).

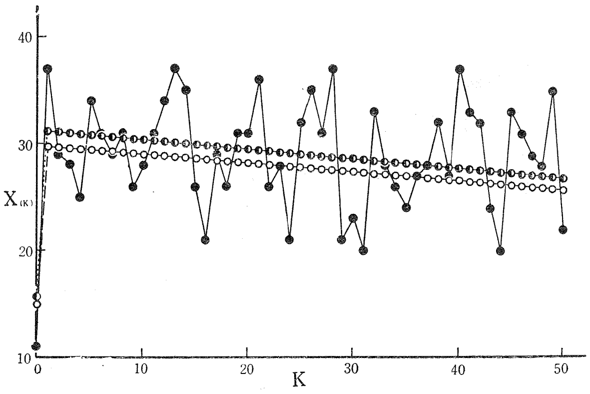


Fig. 12—37(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 37 in the Fishing Ground No. 2).

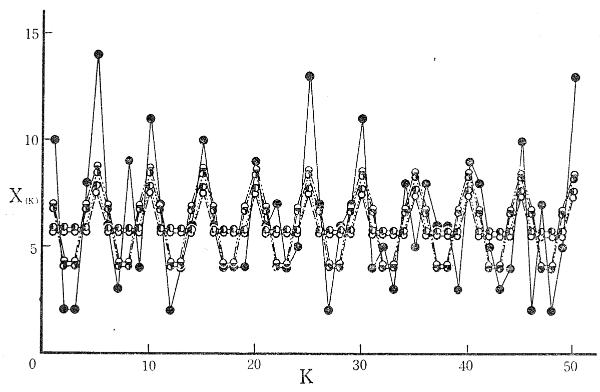


Fig. 12—37(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 37 in the Fishing Ground No. 2).

are observable more frequently than those in the chance distribution. And the diagram of Series Ⅱ shows that the number of individuals caught in the baskets spaced by 1, 5, about 12, 21, 27, 32, about 45 and 49 baskets (0.2, 1.0, *ca.* 2.4, 4.2, 5.4, 6.4, *ca.* 9.0 and 9.8 km) from respective occupied ones is more abundant than expected. The presence of a school of negligible weakness covering about 30 units (30 km) is alluded to in the diagram of Series Ⅰ, and this is regarded as a loose bundle of many subordinate aggregations covering from 1 to 3 units (1~3 km) and its situation is supposed to be in the range from the 150th to the 300th basket. The situation of these subordinate aggregations can be assumed in Fig. 11. The existence of other aggregations of the same order outside this school is suggested in the same diagram, and these are considered to indicate the parts of higher catch rates observed around the 100th and 350th baskets.

Example A 38 : As for the diagram of Series Ⅱ, no detailed consideration can be

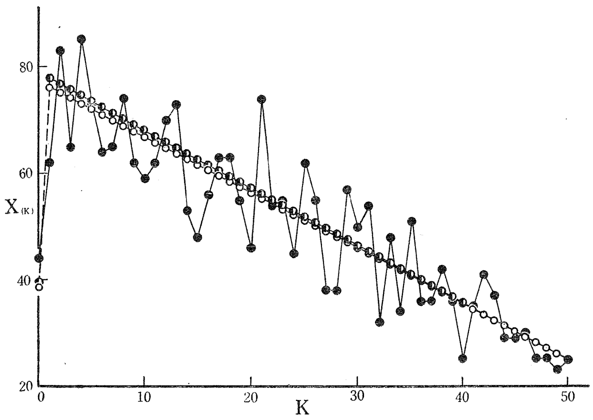


Fig. 12—38(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 38 in the Fishing Ground No. 2).

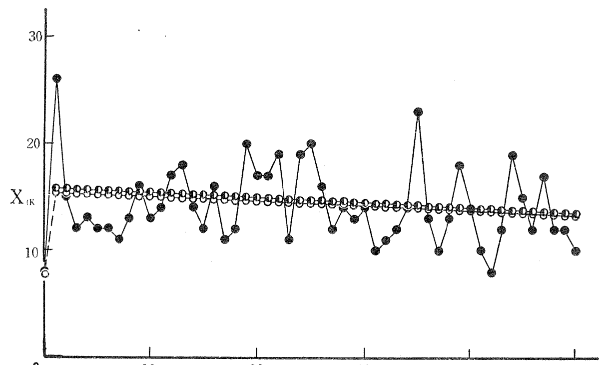


Fig. 12—38(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 38 in the Fishing Ground No. 2).

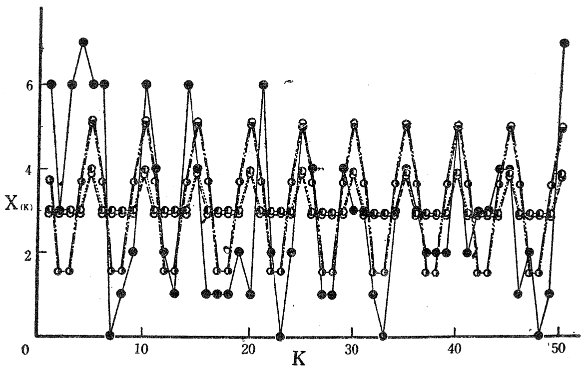


Fig. 12—38(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 38 in the Fishing Ground No. 2).

made, because both the observed and estimated values are very low, although it shows obscurely that the number of couples of individuals caught at the hooks spaced by 1～6, 14, 21 or 50 hook-intervals (40～240, 560, 840 or 1,000 m) is more abundant than those in the chance distribution. And the diagram of Series Ⅱ indicates that occupied baskets spaced by from 20 to 25, 35, about 40 and 45 baskets (4～5, 7, *ca.* 8 and 9 km) are observable more frequently than those in the chance distribution. While the diagram of Series Ⅰ shows clearly that many aggregations constituted of less than 10 individuals and covering from 1 to 3 units (1～3 km) are distributed by chance throughout the row of gears.

Example A 39 : Although the scarcity of the observed values makes it very hard to give any explanation about the distribution pattern on the diagram of Series Ⅲ, it seems fairly possible that the couples of individuals caught side by side (spaced by 40 m) or at the hooks spaced by 11, 14, 35, 44 and 45 hook-intervals (440, 560, 1,400, 1,760 and 1,800 m) are observed more abundant than those in the chance distribution. The

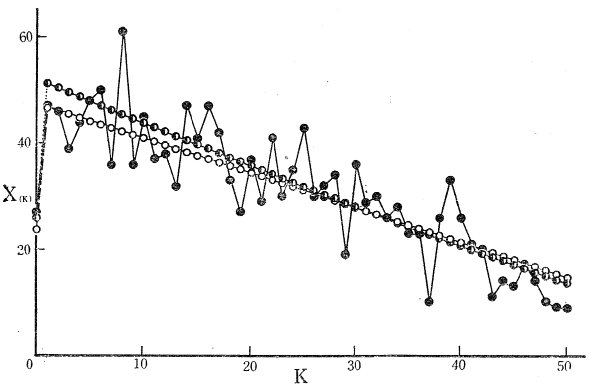


Fig. 12—39(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 39 in the Fishing Ground No. 2).

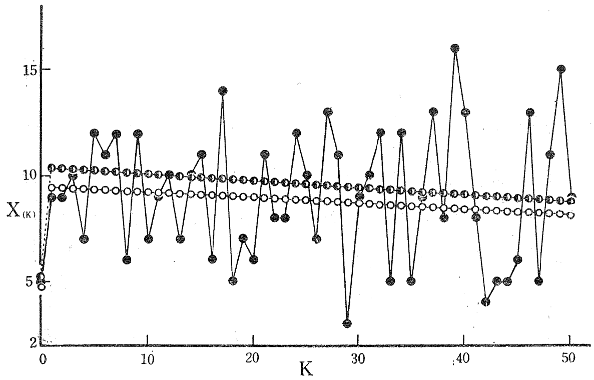


Fig. 12—39(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 39 in the Fishing Ground No. 2).

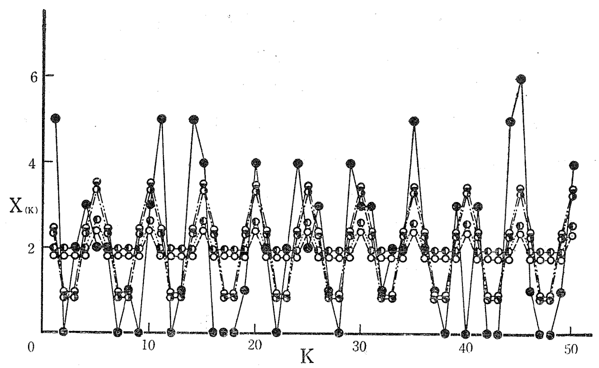


Fig. 12—39(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 39 in the Fishing Ground No. 2).

diagram of Series Ⅱ suggests that the population seems to be composed of many clusters covering 1 or 2 baskets (0.2 or 0.4 km) and mostly representing single isolated individuals, even the largest ones of these clusters are constituted of only 3 individuals or thereabout. The distribution pattern and feature of the aggregations covering from 1 to 3 units (1 ～ 3 km) and respectively represented by a single or bundle of the above-mentioned clusters which include single isolated individuals and clusters constituted of not so many individuals, are shown as a self-spacing portion extending from 5 to 7 units (5 ～ 7 km) in the diagram of Series Ⅰ.

Example A 40 : Despite of the scarcity of caught individuals, the diagram of Series Ⅲ seems to show that single isolated individuals and couples of individuals caught at the hooks spaced by about 1, 6, 7, 8, baskets (0.2, 1.2, 1.4, 1.6 km) or 4 ～ 5 baskets (0.8～1.0 km) are frequently observed. The existence of a conspicuous school covering *ca.* 15 units (15 km) is certified by the diagram of Series Ⅰ and this school is considered to be located in the range roughly from the 250th to 300th

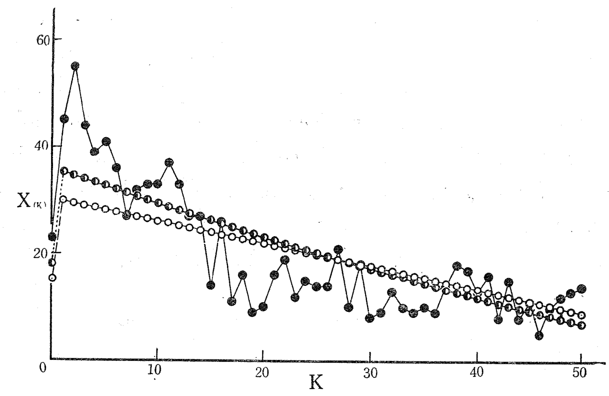


Fig. 12—40(I). X(k)—k relation diagram of albacore
(Series I obtained at Station 40 in the Fishing Ground No. 2).

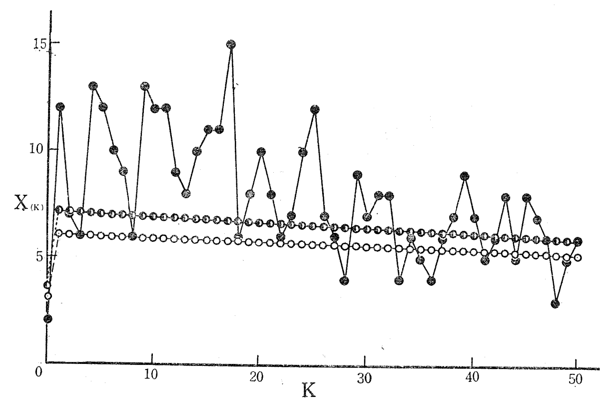


Fig. 12—40(II). X(k)—k relation diagram of albacore
(Series II obtained at Station 40 in the Fishing Ground No. 2).

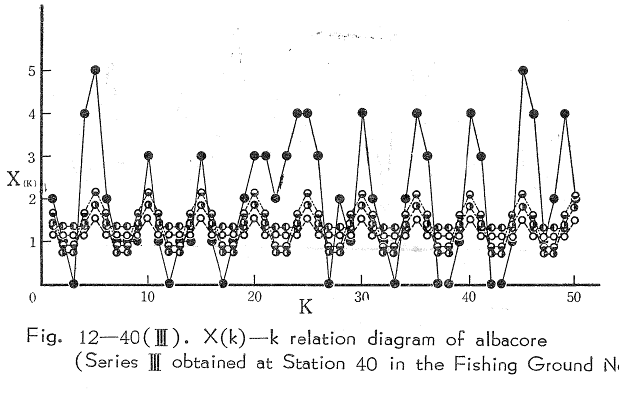


Fig. 12—40(III). X(k)—k relation diagram of albacore
(Series III obtained at Station 40 in the Fishing Ground No. 2).

basket. Although the individuals caught outside this school are rather few, the existence of other 3 small schools, centers of which are respectively *ca.* 30, 40 and 50 units (30, 40 and 50 km) apart from that of the above-mentioned school, is alluded to. Probably they indicate respectively small scattering clusters situated about the 5th, 50th and 150th baskets. The diagram of Series Ⅱ represents the subordinate structure, but here only the structure of the first single school is shown distinctly, because the number of individuals forming the latter 3 schools is far little as comparing with that forming the first one; this school seems to be composed of several rather conspicuous subordinate aggregations covering from 2 to 4 baskets (0.4～0.8 km).

Example A 41 : The low catch rate and the self-spacing distribution result in the scarcity of the observed number, and this makes it hard to deduce out any suggestions

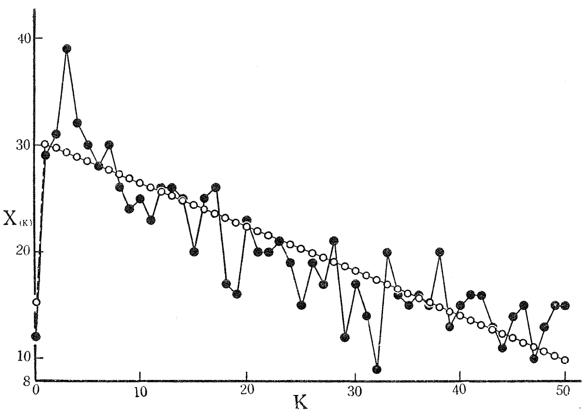


Fig. 12—41(Ⅰ). X(k)—k relation diagram of albacore
(Series Ⅰ obtained at Station 41 in the Fishing Ground No.2).

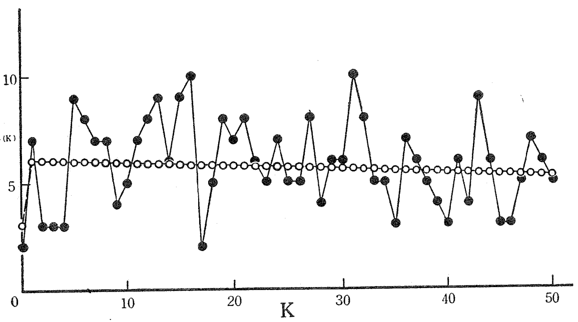


Fig. 12—41(Ⅱ). X(k)—k relation diagram of albacore
(Series Ⅱ obtained at Station 41 in the Fishing Ground No.2).

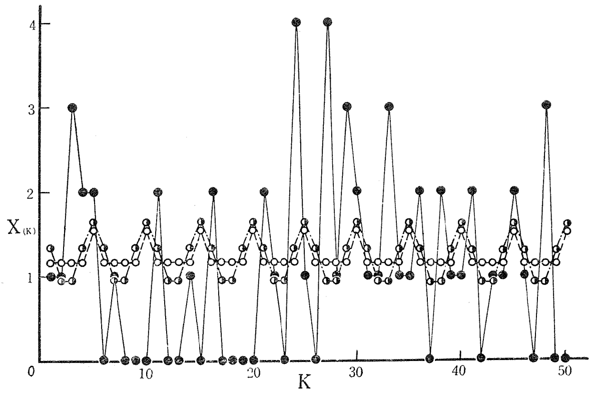


Fig. 12—41(Ⅲ). X(k)—k relation diagram of albacore
(Series Ⅲ obtained at Station 41 in the Fishing Ground No. 2).

about the structure of the population from the diagram of Series Ⅱ. The diagram of Series Ⅱ suggests that the number of individuals caught within 3 consecutive baskets (0.6 km) next to respective occupied ones is successively low, but those caught in the range from 5 to 16, around 20, 30 and 43 baskets (1.0~3.2, *ca.* 4, 6 and 8.6 km) are more abundant than those in the chance distribution. In the population, in which the individuals are distributed in a rather self-spacing manner, further the existence of a rather conspicuous school covering 7 units (7 km) and in which the individuals are also distributed in a self-spacing manner is certified. This school seems to be located around the 350th basket. Being apart from this by the distance from 34 to 50 units (34~50 km), several more schools are discernible, they are not so large and considered to indicate the consecutive units of higher catch rate located respectively around the 100th, 150th and 175th baskets and perhaps around the 80th basket, too.

Comparison of the distribution patterns among the 3 species of tuna

The difference or the similarity of the distribution pattern among the abovementioned 3 species of tuna might be considered to be one of the most important subjects of this article. Actually, however, no essential difference was found in the distribution pattern and hence only a few lines are spared to explain on this subject as follows.

In a word, individuals of these 3 species of tuna —— big-eye tuna, yellow-fin tuna and albacore —— are distributed nearly by chance along the row of gears. But, the data examined more in detail, it becomes clear that the proportion of examples, in which the existence of any contagious schools covering a considerable width, though they are of the negligible weakness, to the whole examples is almost constant throughout the three species, namely the existence of such schools is discernible in a half of the whole examples in each species. On the other hand, the self-spacing pattern is alluded to in about one sixth of examples of big-eye tuna and one third of examples of albacore, while in examples of yellow-fin tuna, the number of examples showing the self-spacing pattern is rather uncertain, because the catch rate was very low, consequently the observed values are also low, while the deviation of them is large and moreover much accidental errors are expected. However, the relative situation of occupied hooks within a short range —— several hook-intervals —— seems to be somewhat specific. Namely, the extremely strong contagiousness of the catch is observable in successive hooks (40 m) in nearly all examples of big-eye tuna, but the degree of the contagiousness is not so strong in the case of yellow-fin tuna; and such a pattern is quite indiscernible the examples of albacore. Moreover, the width of hook-intervals, where the observed values keep continuously the predominance over the corresponding theoretically estimated ones is rather large in yellow-fin tuna, but it is not so large in big-eye tuna. In albacore, the distribution pattern within such a range does not differ much from the chance distribution.

Consideration upon the Spatial Correlation Between respectively Yellow-fin Tuna and Big-eye Tuna, Tunas and Marlins and Tunas and Sharks

In the preceding chapter, the spatial relation among the individuals of the same species was discussed. It is a well known fact that the geographical distribution of the yellow-fin tuna is seen in the district of the lower latitudes, then comes that of the big-eye tuna and the albacore is distributed in the region of the higher latitudes among these 3 species of tuna. But actually when the catch composition of a row of gears is examined, there occur usually a few of the two species other than the predominant species in the district being mingled with many individuals of the latter, and here arises a question, whether the individuals of such a subordinate species are forming the common school together with the predominant ones, as generally understood, or they are distributed quite independently of or rather repulsively against the latter. On the other hand, it is also a well known fact that sharks and marlins are often caught together with tunas by the same row of gears and they are situated in a little higher food ranks than tunas; therefore, it is very probable that the distributions of tunas and sharks or marlins are interfering one another. Thus, the spatial relation between the individuals of the different species is worthy to be discussed fully as well as that among the individuals of the same species, because it is not only indispensable for considering upon errors, which might be brought into the spatial relation among the individuals of the same species by that the hooks are occupied by other species, but also it is very interesting from the ecological and practical point of view.

1. Construction of the formulae representing the expected number of the couples of individuals, respectively belonging to different species and spaced by k intervals

1) The formulae representing the expected number of the couples of individuals, respectively belonging to different species and spaced by k section-intervals under the supposition that both species are distributed independently of each other

Hereafter, the word "expected number" will be used for indicating the expected number of the couples of individuals, respectively belonging to different species and spaced by k intervals.

Let us set N_A individuals of Species A and N_B of Species B are distributed independently of each other, concerning both individuals and species, along M sections of gears. The probability of occurrence of each individual of each species in each section is $\frac{1}{M}$. Then, the probability of occurrence of a couple of individuals in a certain section is $\left(\frac{1}{M}\right)^2$. There are M sections under consideration and the number of combination to take one individual from Species A and the other from Species B is $N_A\,N_B$. Accordingly expected number, $C_{(0)}$, is represented as:

$$C_{(0)} = \frac{1}{M^2} M\ N_A N_B = \frac{N_A N_B}{M} \quad \cdots\cdots (31)$$

But, the probability of occurrence of each individual of each species in the *ith* or the $(i+k)th$ section is $\frac{2}{M}$ and that of any two individuals in the two sections is $\frac{4}{M^2}$: but in the latter case, the probability of both individuals being caught in the same section is included and it is $\frac{1}{M^2}$ for each section. Thus, the probability of any two individuals being caught in separated sections is $\frac{4}{M^2} - 2\frac{1}{M^2} = \frac{2}{M^2}$, in which i varies from 0 to $(M-k)$, and the number of combinations to take one individual from Species A and the other from Species B is $N_A\ N_B$. Accordingly, the expected number at $k \neq 0$ is represented as:

$$C_{(k)} = \frac{2\,(M-k)\,N_A N_B}{M^2} \quad \cdots\cdots (32)$$

On the other hand, the expected number of the couples being constituted of Species A and B may be represented by (expected number of the couples being constituted of Species A and B) —— (that of the couples being constituted of Species A only)——(that of the couples being constituted of Species B only). That is to say: at $k=0$

$$C_{(0)} = \frac{(N_A+N_B)(N_A+N_B-1)}{2M} - \frac{N_A(N_A-1)}{2M} - \frac{N_B(N_B-1)}{2M} = \frac{2N_A N_B}{2M}$$

$$= \frac{N_A\ N_B}{M}$$

while at $k \neq 0$

$$C_{(k)}=\frac{(M-k)(N_A+N_B)(N_A+N_B-1)}{M^2}-\frac{(M-k)N_A(N_A-1)}{M^2}$$
$$-\frac{(M-k)N_B(N_B-1)}{M^2}=\frac{2(M-k)N_AN_B}{M^2}$$

Thus, the two groups of formulae representing the expected number and obtained in different procedures, mentioned above, quite coincide with each other.

2) The formulae representing the expected number of the couples of individuals spaced by *k* section-intervals, when the catch rate of each species shows gradient, but both species are distributed independently of each other

Let us set that N_A individuals of Species A and N_B individuals of Species B are distributed along a row of gears constituted of M sections and the number of individuals caught in the ith section is represented as $(A_0+i\Delta A)$ for Species A and $(B_0+i\Delta B)$ for Species B. Here, $N_A=\sum_{i=1}^{M}(A_0+i\Delta A)$ and $N_B=\sum_{i=1}^{M}(B_0+i\Delta B)$. Through the same process which was shown in the case when the formulae (31) and (32) were constructed, the formulae representing the expected number are given as follows:

at $k=0$

$$C_{(0)}=\sum_{i=1}^{M}(A_0+i\Delta A)(B_0+i\Delta B)$$
$$=\sum_{i=1}^{M}\{A_0B_0+(A_0\Delta B+B_0\Delta A)i+\Delta A\Delta Bi^2\}$$
$$=A_0B_0\left[M+\frac{M(M+1)}{2}(\delta_A+\delta_B)+M(M+1)(2M+1)\frac{\delta_A\delta_B}{6}\right]$$
$$=A_0B_0M\left[1+(M+1)\frac{\delta_A+\delta_B}{2}+(M+1)(2M+1)\frac{\delta_A\delta_B}{6}\right]\cdots\cdots\cdots\cdots\cdots\cdots(33)$$

here $\delta_A=\frac{\Delta A}{A_0}$ and $\delta_B=\frac{\Delta B}{B_0}$,

while at $k\neq 0$

$$C_{(k)}=\sum_{i=1}^{M-k}(A_0+i\Delta A)(B_0+\overline{i+k}\Delta B)+\sum_{i=1}^{M-k}(B_0+i\Delta B)(A_0+\overline{i+k}\Delta A)$$
$$=A_0B_0(M-k)\left[2+(M+1)(\delta_A+\delta_B)+(M-k+1)(2M+k+1)\frac{\delta_A\delta_B}{3}\right]\cdots(34)$$

On the other hand, $C_{(0)}$ and $C_{(k)}$ are also obtained by the same procedure as the second constructing method of formulae (31) and (32); that is to say,

at $k=0$

$$C_{(0)}=\frac{1}{2}\sum_{i=1}^{M}\left\{(A_0+i\Delta A)+(B_0+i\Delta B)\right\}\left\{(A_0+i\Delta A)+(B_0+i\Delta B)-1\right\}$$

$$-\frac{1}{2}\sum_{i=1}^{M}(A_0+i\varDelta A)(A_0+i\varDelta A-1)-\frac{1}{2}\sum_{i=1}^{M}(B_0+i\varDelta B)(B_0+i\varDelta B-1)$$

$$=\sum_{i=1}^{M}(A_0+i\varDelta A)(B_0+i\varDelta B)$$

while at $k \fallingdotseq 0$

$$C_{(k)}=\sum_{i=1}^{M-k}\left\{(A_0+i\varDelta A)+(B_0+i\varDelta B)\right\}\left\{(A_0+\overline{i+k}\varDelta A)+(B_0+\overline{i+k}\varDelta B)\right\}$$

$$-\sum_{i=1}^{M-k}(A_0+i\varDelta A)(A_0+\overline{i+k}\varDelta A)-\sum_{i=1}^{M-k}(B_0+i\varDelta B)(B_0+\overline{i+k}\varDelta B)$$

$$=\sum_{i=1}^{M-k}(A_0+i\varDelta A)(B_0+\overline{i+k}\varDelta B)+\sum_{i=1}^{M-k}(B_0+i\varDelta B)(A_0+\overline{i+k}\varDelta A)$$

3) The formulae representing the expected number of the couples of individuals spaced by *k* hook-intervals, when individuals of both species are distributed independently of each other

Let us set that N_A individuals of Species A and N_B individuals of Species B are distributed independently of each other, and there are m baskets in a row. The probability of occurrence of an individual at a hook is $P_A=\frac{N_A}{Hm}$ for Species A and $P_B=\frac{N_B}{Hm}$ for Species B. The hooks spaced by k hook-intervals from respective hooks in the ith basket are illustrated in Tables 4 and 7. Thus when $R=0$, there are H hooks in the $(i+a)th$ basket, which are spaced by k hook-intervals from respective hooks in the ith basket, while there is no hook in the $(i+a+1)th$ basket. But when $R \fallingdotseq 0$ there are $(H-R)$ hooks in the $(i+a)th$ basket, which are spaced by k hook-intervals from respective hooks in the ith basket and there are still $(R-1)$ hooks in the $(i+a+1)th$ basket. Here, concerning the couples consisting of a hook in the ith basket and that in the $(i+a)th$ basket, i can vary from 0 to $(m-a)$, while for the couples composed of a hook in the ith basket and that in the $(i+a+1)th$ basket, i can vary from 0 to $(m-a-1)$. The expected number of the case in which an individual of Species A is caught at a hook in the ith basket and an individual of Species B at a hook in the $(i+a)th$ or the $(i+a+1)th$ basket is: ——

$$C_{(k)1}=H(m-a)P_AP_B \qquad (\text{at } R=0)$$

$$C_{(k)1}=\{(H-R)(m-a)+(R-1)(m-a-1)\}P_AP_B \qquad (\text{at } R\fallingdotseq 0)$$

Here, k is represented as $k=a(H+1)+R$ by the same way as that used to construct formulae (6) and (7). While, expected number of one individual of Species B is caught at a hook in the ith basket and one individual of Species A at a hook in the $(i+a)th$ or the $(i+a+1)th$ basket is also,

$$C_{(k)2}=H(m-a)P_BP_A \qquad (\text{at } R=0)$$

$C_{(k)2}=\{(H-R)(m-a)+(R-1)(m-a-1)\}P_BP_A$ (at $R\neq 0$)

Accordingly, the expected number, $C_{(k)}$, which is equal to $C_{(k)1}+C_{(k)2}$ is represented as follows:

at $R=0$ $C_{(k)}=2H(m-a)P_AP_B$ .... (35)

while at $R\neq 0$ $C_{(k)}=2\{(H-R)(m-a)+(R-1)(m-a-1)\}P_AP_B$ .... (36)

On the other hand, by the same manner as the second method to construct formulae (31) and (32), the formulae representing the expected number which is equal to (expected number of the couples being constituted of Species A and B)——(that of the couples being constituted of Species A only)——(that of the couples being constituted of Species B only) are constructed as follows:

at $R=0$

$$C_{(k)}=H(m-a)\{(P_A+P_B)^2-P_A^2-P_B^2\}$$
$$=2H(m-a)P_AP_B$$

while at $R\neq 0$

$$C_{(k)}=\{(H-R)(m-a)+(R-1)(m-a-1)\}\{(P_A+P_B)^2-P_A^2-P_B^2\}$$
$$=2\{(H-R)(m-a)+(R-1)(m-a-1)\}P_AP_B$$

4) The formulae representing the expected number of the couples of individuals spaced by *k* hook-intervals, when both species are distributed keeping some gradients

Let us set that k is represented as $k=a(H+1)+R$, being separated into the part divisible by a basket length and the remainder (R), and there are m baskets in a row. Represent the individual numbers of Species A or B being caught at one hook in the ith, $(i+a)th$ and $(i+a+1)th$ baskets as $(A_0+i\varDelta A)$, $(A_0+\overline{i+a}\varDelta A)$ and $(A_0+\overline{i+a+1}\,\varDelta A)$ or $(B_0+i\varDelta B)$, $(B_0+\overline{i+a}\varDelta B)$ and $(B_0+\overline{i+a+1}\,\varDelta B)$ respectively, and the expected number of two hooks spaced by k hook-intervals being occupied as that one of them is occupied by an individual of Species A, while the other by an individual of Species B, $C_{(k)}$, can be estimated by the following formulae:

at $R=0$

$$C_{(k)}=H\sum_{i=1}^{m-a}\left\{(A_0+i\varDelta A)(B_0+\overline{i+a}\varDelta B)+(B_0+i\varDelta B)(A_0+\overline{i+a}\varDelta A)\right\}$$
$$=A_0B_0H(m-a)\left[2+(m+1)(\delta_A+\delta_B)+(m-a+1)(2m+a+1)\frac{\delta_A\delta_B}{3}\right]\cdots(37)$$

while at $R\neq 0$

$$C_{(k)}=(H-R)\sum_{i=1}^{m-a}\left\{(A_0+i\varDelta A)(B_0+\overline{i+a}\varDelta B)+(B_0+i\varDelta B)(A_0+\overline{i+a}\varDelta A)\right\}$$
$$+(R-1)\sum_{i=1}^{m-a-1}\left\{(A_0+i\varDelta A)(B_0+\overline{i+a+1}\,\varDelta B)+(B_0+i\varDelta B)(A_0+\overline{i+a+1}\,\varDelta A)\right\}$$
$$=(H-R)A_0B_0(m-a)\left[2+(m+1)(\delta_A+\delta_B)+(m-a+1)(2m+a+1)\frac{\delta_A\delta_B}{3}\right]$$

$$+(R-1)A_0B_0(m-a-1)\Big[2+(m+1)(\delta_A+\delta_B)$$

$$+(m-a)(2m+a+2)\frac{\delta_A\delta_B}{3}\Big] \cdots\cdots (38)$$

here $\delta_A=\frac{\varDelta A}{A_0}$ and $\delta_B=\frac{\varDelta B}{B_0}$.

On the other hand, quite the same formulae can be obtained by (expected number of the couples being constituted of Species A and B)——(that of the couples being constituted of Species A only)——(that of the couples being constituted of Species B only). That is to say:

at R = 0

$$C_{(k)}=H\sum_{i=1}^{m-a}\Big[\Big\{(A_0+i\varDelta A)+(B_0+i\varDelta B)\Big\}\Big\{(A_0+\overline{i+a}\varDelta A)+(B_0+\overline{i+a}\varDelta B)\Big\}$$

$$-(A_0+i\varDelta A)(A_0+\overline{i+a}\varDelta A)-(B_0+i\varDelta B)(B_0+\overline{i+a}\varDelta B)\Big]$$

$$=H\sum_{i=1}^{m-a}\Big\{(A_0+i\varDelta A)(B_0+\overline{i+a}\varDelta B)+(B_0+i\varDelta B)(A_0+\overline{i+a}\varDelta A)\Big\}$$

while at $R \neq 0$

$$C_{(k)}=(H-R)\sum_{i=1}^{m-a}\Big[\Big\{(A_0+i\varDelta A)+(B_0+i\varDelta B)\Big\}\Big\{(A_0+\overline{i+a}\varDelta A)+(B_0+\overline{i+a}\varDelta B)\Big\}$$

$$-(A_0+i\varDelta A)(A_0+\overline{i+a}\varDelta A)-(B_0+i\varDelta B)(B_0+\overline{i+a}\varDelta B)\Big]$$

$$+(R-1)\sum_{i=1}^{m-a-1}\Big[\Big\{(A_0+i\varDelta A)+(B_0+i\varDelta B)\Big\}\Big\{(A_0+\overline{i+a+1}\,\varDelta A)$$

$$+(B_0+\overline{i+a+1}\,\varDelta B)\Big\}-(A_0+i\varDelta A)(A_0+\overline{i+a+1}\,\varDelta A)$$

$$-(B_0+i\varDelta B)(B_0+\overline{i+a+1}\,\varDelta B)\Big]$$

5) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when the catch rate differs according to depth in both species

Let us set that N_{A1} and N_{A2} individuals of Species A are caught respectively at the hooks arranged in two, shallower and deeper, depth levels along the row of gears being constituted of m baskets each having 4 hooks and N_{B1} and N_{B2} individuals of Species B are caught in the same manner as in Species A. The probabilities of occurrence of individuals of Species A or B at the shallower and deeper hooks are $P_{A1}=\frac{N_{A1}}{2m}$ and $P_{A2}=\frac{N_{A2}}{2m}$ or $P_{B1}=\frac{N_{B1}}{2m}$ and $P_{B2}=\frac{N_{B2}}{2m}$ respectively. Represent $k=a(H+1)+R$ by the same way as that shown in the previous sections, and the hooks spaced by k hook-intervals from respective hooks in the *ith* basket are represented in Table 4. And the formulae representing the expected number of two hooks being occupied as that one of them is occupied by an individual of Species A and the other by Species B is illustrated as follows:

at $R=0$ $C_{(k)}=2(m-a)(2P_{A_1}P_{B_1}+2P_{A_2}P_{B_2})$ ……(39)

$R=1$ $C_{(k)}=2(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2})$ ……(40)

$R=2$ $C_{(k)}=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-P_{A_1}P_{B_1}]$ ……(41)

$R=3$ $C_{(k)}=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-(P_{A_1}P_{B_2}+P_{A_2}P_{B_1})]$ ……(42)

$R=4$ $C_{(k)}=2(m-a-1)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2})$ ……(43)

On the other hand, they can be estimated by subtracting (expected number of the couples being constituted of Species A only) and (expected number of the couples being constituted of Species B only) from (expected number of the couples being constituted of Species A and B), and the process of this construction is shown below.

at $R=0$

$$C_{(k)}=(m-a)[\{2(P_{A_1}+P_{B_1})^2+2(P_{A_2}+P_{B_2})^2\}-(2P_{A_1}^2+2P_{A_2}^2)-(2P_{B_1}^2+2P_{B_2}^2)]$$
$$=2(m-a)(2P_{A_1}P_{B_1}+2P_{A_2}P_{B_2})$$

$R=1$

$$C_{(k)}=(m-a)[2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_2}+P_{B_2})^2-(2P_{A_1}P_{A_2}+P_{A_2}^2)-(2P_{B_1}P_{B_2}+P_{B_2}^2)]$$
$$=2(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2})$$

$R=2$

$$C_{(k)}=[(m-a)\{2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_1}+P_{B_1})^2\}-(P_{A_1}+P_{B_1})^2]$$
$$-[(m-a)(2P_{A_1}P_{A_2}+P_{A_1}^2)-P_{A_1}^2]-[(m-a)(2P_{B_1}P_{B_2}+P_{B_1}^2)-P_{B_1}^2]$$
$$=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-P_{A_1}P_{B_1}]$$

$R=3$

$$C_{(k)}=[(m-a)\{2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_1}+P_{B_1})^2\}-2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})]$$
$$-[(m-a)(2P_{A_1}P_{A_2}+P_{A_1}^2)-2P_{A_1}P_{A_2}]-[(m-a)(2P_{B_1}P_{B_2}+P_{B_1}^2)-2P_{B_1}P_{B_2}]$$
$$=2[(m-a)(P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_1}P_{B_1})-(P_{A_1}P_{B_2}+P_{A_2}P_{B_1})]$$

$R=4$

$$C_{(k)}=(m-a-1)[2(P_{A_1}+P_{B_1})(P_{A_2}+P_{B_2})+(P_{A_2}+P_{B_2})^2]$$
$$-(m-a-1)[2P_{A_1}P_{A_2}+P_{A_2}^2]-(m-a-1)[2P_{B_1}P_{B_2}+P_{B_2}^2]$$
$$=2(m-a-1)[P_{A_1}P_{B_2}+P_{A_2}P_{B_1}+P_{A_2}P_{B_2}]$$

6) The formulae representing the expected number of the couples of individuals spaced by k hook-intervals, when the catch rate increases with the soaking time and differs according to depth in both species

Let us set that the catch rates of individuals of Species A at shallower and deeper hooks in the *ith* basket are represented respectively by $(As_0+i\Delta As)$ and $(Ad_0$

$+i\Delta Ad$), while those of Species B are ($Bs_0+i\Delta Bs$) and ($Bd_0+i\Delta Bd$). The expected number of the occurrence of the couples of individuals spaced by k hook-intervals and being constituted of Species A and B is estimated by the following formulae which are each the sum of two formulae, in one of which ($As_0+i\Delta As$) and ($Ad_0+i\Delta Ad$) are substituted for ($P_1+i\Delta P_1$) and ($P_2+i\Delta P_2$) of formulae (20)~(24) and ($Bs_0+\overline{i+a}\Delta Bs$), ($Bs_0+\overline{i+a+1}\,\Delta Bs$), ($Bd_0+\overline{i+a}\Delta Bd$) and ($Bd_0+\overline{i+a+1}\,\Delta Bd$) are for ($P_1+\overline{i+a}\Delta P_1$), ($P_1+\overline{i+a+1}\,\Delta P_1$), ($P_2+\overline{i+a}\Delta P_2$) and ($P_2+\overline{i+a+1}\,\Delta P_2$), while in the other ($Bs_0+i\Delta Bs$) and ($Bd_0+i\Delta Bd$) are substituted for ($P_1+i\Delta P_1$) and ($P_2+i\Delta P_2$) and ($As_0+\overline{i+a}\Delta As$), ($As_0+\overline{i+a+1}\,\Delta As$), ($Ad_0+\overline{i+a}\Delta Ad$) and ($Ad_0+\overline{i+a+1}\,\Delta Ad$) are for ($P_1+\overline{i+a}\Delta P$), ($P_1+\overline{i+a+1}\,\Delta P_1$), ($P_2+\overline{i+a}\Delta P_2$) and ($P_2+\overline{i+a+1}\,\Delta P_2$).

at R = 0

$$C_{(k)}=2\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+2\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)$$
$$+2\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)+2\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$
$$=2As_0Bs_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_s}{3}\right]$$
$$+2Ad_0Bd_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_d}{3}\right] \quad\cdots\cdots(44)$$

R = 1

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a}\Delta Ad)$$
$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(Ad_0+\overline{i+a}\Delta Ad)$$
$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(As_0+\overline{i+a}\Delta As)$$
$$=As_0Bd_0(m-a)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_d}{3}\right]$$
$$+Ad_0Bs_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_s}{3}\right]$$
$$+Ad_0Bd_0(m-a)\left[2+(m+1)(\delta A_d+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_d}{3}\right] \quad\cdots\cdots(45)$$

R = 2

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bd_0+\overline{i+a}\Delta Bd)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a}\Delta Ad)$$

$$+\sum_{i=1}^{m-a}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bd_0+i\Delta Bd)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(As_0+\overline{i+a+1}\,\Delta As)$$

$$=As_0\,Bd_0\,(m-a)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_d}{3}\right]$$

$$+Ad_0\,Bs_0\,(m-a)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_d\,\delta B_s}{3}\right]$$

$$+As_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_s}{3}\right]$$

$$\cdots\cdots\cdots(46)$$

R = 3

$$C_{(k)}=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\,\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$=As_0\,Bs_0\,(m-a)\left[2+(m+1)(\delta A_s+\delta B_s)+(m-a+1)(2m+a+1)\frac{\delta A_s\,\delta B_s}{3}\right]$$

$$+Ad_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta A_d+\delta B_s)+(m-a)(2m+a+2)\frac{\delta A_d\,\delta B_s}{3}\right]$$

$$+As_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta A_s+\delta B_d)+(m-a)(2m+a+2)\frac{\delta A_s\,\delta B_d}{3}\right]$$

$$\cdots\cdots\cdots(47)$$

R = 4

$$C_{(k)}=\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\,\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\varDelta Ad)(Bd_0+\overline{i+a+1}\,\varDelta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\varDelta Bd)(Ad_0+\overline{i+a+1}\,\varDelta Ad)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\varDelta As)(Bd_0+\overline{i+a+1}\,\varDelta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\varDelta Bs)(Ad_0+\overline{i+a+1}\,\varDelta Ad)$$

$$=Ad_0\,Bs_0\,(m-a-1)\left[2+(m+1)(\delta_{Ad}+\delta_{Bs})+(m-a)(2m+a+2)\frac{\delta_{Ad}\,\delta_{Bs}}{3}\right]$$

$$+As_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta_{As}+\delta_{Bd})+(m-a)(2m+a+2)\frac{\delta_{As}\,\delta_{Bd}}{3}\right]$$

$$+Ad_0\,Bd_0\,(m-a-1)\left[2+(m+1)(\delta_{Ad}+\delta_{Bd})+(m-a)(2m+a+2)\frac{\delta_{Ad}\,\delta_{Bd}}{3}\right]$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(48)$$

here $\delta_{As}=\dfrac{\varDelta As}{As_0}$, $\delta_{Ad}=\dfrac{\varDelta Ad}{Ad_0}$, $\delta_{Bs}=\dfrac{\varDelta Bs}{Bs_0}$ and $\delta_{Bd}=\dfrac{\varDelta Bd}{Bd_0}$.

On the other hand, the formulae available for such conditions can be obtained by the same manner as the second method constructing the previously shown formulae representing the correlation and this procedure is shown below.

at $R=0$

$$C_{(k)}=2\sum_{i=1}^{m-a}\Big[\Big\{(As_0+i\varDelta As)+(Bs_0+i\varDelta Bs)\Big\}\Big\{(As_0+\overline{i+a}\varDelta As)+(Bs_0+\overline{i+a}\varDelta Bs)\Big\}$$

$$-(As_0+i\varDelta As)(As_0+\overline{i+a}\varDelta As)-(Bs_0+i\varDelta Bs)(Bs_0+\overline{i+a}\varDelta Bs)\Big]$$

$$+2\sum_{i=1}^{m-a}\Big[\Big\{(Ad_0+i\varDelta Ad)+(Bd_0+i\varDelta Bd)\Big\}\Big\{(Ad_0+\overline{i+a}\varDelta Ad)+(Bd_0+\overline{i+a}\varDelta Bd)\Big\}$$

$$-(Ad_0+i\varDelta Ad)(Ad_0+\overline{i+a}\varDelta Ad)-(Bd_0+i\varDelta Bd)(Bd_0+\overline{i+a}\varDelta Bd)\Big]$$

$$=2\sum_{i=1}^{m-a}(As_0+i\varDelta As)(Bs_0+\overline{i+a}\varDelta Bs)+2\sum_{i=1}^{m-a}(Bs_0+i\varDelta Bs)(As_0+\overline{i+a}\varDelta As)$$

$$+2\sum_{i=1}^{m-a}(Ad_0+i\varDelta Ad)(Bd_0+\overline{i+a}\varDelta Bd)+2\sum_{i=1}^{m-a}(Bd_0+i\varDelta Bd)(Ad_0+\overline{i+a}\varDelta Ad)$$

$R=1$

$$C_{(k)}=\sum_{i=1}^{m-a}\Big[\Big\{(As_0+i\varDelta As)+(Bs_0+i\varDelta Bs)\Big\}\Big\{(Ad_0+\overline{i+a}\varDelta Ad)+(Bd_0+\overline{i+a}\varDelta Bd)\Big\}$$

$$- (As_0 + i\Delta As)(Ad_0 + \overline{i+a}\Delta Ad) - (Bs_0 + i\Delta Bs)(Bd_0 + \overline{i+a}\Delta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a} \Big[\Big\{ (Ad_0 + i\Delta Ad) + (Bd_0 + i\Delta Bd) \Big\} \Big\{ (Ad_0 + \overline{i+a}\Delta Ad) + (Bd_0 + \overline{i+a}\Delta Bd) \Big\}$$

$$- (Ad_0 + i\Delta Ad)(Ad_0 + \overline{i+a}\Delta Ad) - (Bd_0 + i\Delta Bd)(Bd_0 + \overline{i+a}\Delta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a} \Big[\Big\{ (Ad_0 + i\Delta Ad) + (Bd_0 + i\Delta Bd) \Big\} \Big\{ (As_0 + \overline{i+a}\Delta As) + (Bs_0 + \overline{i+a}\Delta Bs) \Big\}$$

$$- (Ad_0 + i\Delta Ad)(As_0 + \overline{i+a}\Delta As) - (Bd_0 + i\Delta Bd)(Bs_0 + \overline{i+a}\Delta Bs)\Big]$$

$$= \sum_{i=1}^{m-a} (As_0 + i\Delta As)(Bd_0 + \overline{i+a}\Delta Bd) + \sum_{i=1}^{m-a} (Bs_0 + i\Delta Bs)(Ad_0 + \overline{i+a}\Delta Ad)$$

$$+ \sum_{i=1}^{m-a} (Ad_0 + i\Delta Ad)(Bd_0 + \overline{i+a}\Delta Bd) + \sum_{i=1}^{m-a} (Bd_0 + i\Delta Bd)(Ad_0 + \overline{i+a}\Delta Ad)$$

$$+ \sum_{i=1}^{m-a} (Ad_0 + i\Delta Ad)(Bs_0 + \overline{i+a}\Delta Bs) + \sum_{i=1}^{m-a} (Bd_0 + i\Delta Bd)(As_0 + \overline{i+a}\Delta As)$$

$R = 2$

$$C_{(k)} = \sum_{i=1}^{m-a} \Big[\Big\{ (As_0 + i\Delta As) + (Bs_0 + i\Delta Bs) \Big\} \Big\{ (Ad_0 + \overline{i+a}\Delta Ad) + (Bd_0 + \overline{i+a}\Delta Bd) \Big\}$$

$$- (As_0 + i\Delta As)(Ad_0 + \overline{i+a}\Delta Ad) - (Bs_0 + i\Delta Bs)(Bd_0 + \overline{i+a}\Delta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a} \Big[\Big\{ (Ad_0 + i\Delta Ad) + (Bd_0 + i\Delta Bd) \Big\} \Big\{ (As_0 + \overline{i+a}\Delta As) + (Bs_0 + \overline{i+a}\Delta Bs) \Big\}$$

$$- (Ad_0 + i\Delta Ad)(As_0 + \overline{i+a}\Delta As) - (Bd_0 + i\Delta Bd)(Bs_0 + \overline{i+a}\Delta Bs)\Big]$$

$$+ \sum_{i=1}^{m-a-1} \Big[\Big\{ (As_0 + i\Delta As) + (Bs_0 + i\Delta Bs) \Big\} \Big\{ (As_0 + \overline{i+a+1}\Delta As) + (Bs_0 + \overline{i+a+1}\Delta Bs) \Big\}$$

$$- (As_0 + i\Delta As)(As_0 + \overline{i+a+1}\Delta As) - (Bs_0 + i\Delta Bs)(Bs_0 + \overline{i+a+1}\Delta Bs)\Big]$$

$$= \sum_{i=1}^{m-a} (As_0 + i\Delta As)(Bd_0 + \overline{i+a}\Delta Bd) + \sum_{i=1}^{m-a} (Bs_0 + i\Delta Bs)(Ad_0 + \overline{i+a}\Delta Ad)$$

$$+ \sum_{i=1}^{m-a} (Ad_0 + i\Delta Ad)(Bs_0 + \overline{i+a}\Delta Bs) + \sum_{i=1}^{m-a} (Bd_0 + i\Delta Bd)(As_0 + \overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(As_0+\overline{i+a+1}\,\Delta As)$$

R= 3

$$C_{(k)}=\sum_{i=1}^{m-a}\Big[\Big\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\Big\}\Big\{(As_0+\overline{i+a}\Delta As)+(Bs_0+\overline{i+a}\Delta Bs)\Big\}$$

$$-(As_0+i\Delta As)(As_0+\overline{i+a}\Delta As)-(Bs_0+i\Delta Bs)(Bs_0+\overline{i+a}\Delta Bs)\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(Ad_0+i\Delta Ad)+(Bd_0+i\Delta Bd)\Big\}\Big\{(As_0+\overline{i+a+1}\,\Delta As)$$

$$+(Bs_0+\overline{i+a+1}\,\Delta Bs)\Big\}-(Ad_0+i\Delta Ad)(As_0+\overline{i+a+1}\,\Delta As)$$

$$-(Bd_0+i\Delta Bd)(Bs_0+\overline{i+a+1}\,\Delta Bs)\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(As_0+i\Delta As)+(Bs_0+i\Delta Bs)\Big\}\Big\{(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$+(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big\}-(As_0+i\Delta As)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

$$-(Bs_0+i\Delta Bs)(Bd_0+\overline{i+a+1}\,\Delta Bd)\Big]$$

$$=\sum_{i=1}^{m-a}(As_0+i\Delta As)(Bs_0+\overline{i+a}\Delta Bs)+\sum_{i=1}^{m-a}(Bs_0+i\Delta Bs)(As_0+\overline{i+a}\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(Ad_0+i\Delta Ad)(Bs_0+\overline{i+a+1}\,\Delta Bs)$$

$$+\sum_{i=1}^{m-a-1}(Bd_0+i\Delta Bd)(As_0+\overline{i+a+1}\,\Delta As)$$

$$+\sum_{i=1}^{m-a-1}(As_0+i\Delta As)(Bd_0+\overline{i+a+1}\,\Delta Bd)$$

$$+\sum_{i=1}^{m-a-1}(Bs_0+i\Delta Bs)(Ad_0+\overline{i+a+1}\,\Delta Ad)$$

R= 4

$$C_{(k)}=\sum_{i=1}^{m-a-1}\Big[\Big\{(Ad_0+i\Delta Ad)+(Bd_0+i\Delta Bd)\Big\}\Big\{(As_0+\overline{i+a+1}\Delta As)$$

$$+ (Bs_0 + \overline{i+a+1}\varDelta Bs)\Big\} - (Ad_0 + i\varDelta Ad)(As_0 + \overline{i+a+1}\varDelta As)$$

$$- (Bd_0 + i\varDelta Bd)(Bs_0 + \overline{i+a+1}\varDelta Bs)\Big]$$

$$+ \sum_{i=1}^{m-a-1} \Big[\Big\{(Ad_0 + i\varDelta Ad) + (Bd_0 + i\varDelta Bd)\Big\}\Big\{(Ad_0 + \overline{i+a+1}\varDelta Ad)$$

$$+ (Bd_0 + \overline{i+a+1}\varDelta Bd)\Big\} - (Ad_0 + i\varDelta Ad)(Ad_0 + \overline{i+a+1}\varDelta Ad)$$

$$- (Bd_0 + i\varDelta Bd)(Bd_0 + \overline{i+a+1}\varDelta Bd)\Big]$$

$$+ \sum_{i=1}^{m-a-1} \Big[\Big\{(As_0 + i\varDelta As) + (Bs_0 + i\varDelta Bs)\Big\}\Big\{(Ad_0 + \overline{i+a+1}\varDelta Ad)$$

$$+ (Bd_0 + \overline{i+a+1}\varDelta Bd)\Big\} - (As_0 + i\varDelta As)(Ad_0 + \overline{i+a+1}\varDelta Ad)$$

$$- (Bs_0 + i\varDelta Bs)(Bd_0 + \overline{i+a+1}\varDelta Bd)\Big]$$

$$= \sum_{i=1}^{m-a-1} (Ad_0 + i\varDelta Ad)(Bs_0 + \overline{i+a+1}\varDelta Bs)$$

$$+ \sum_{i=1}^{m-a-1} (Bd_0 + i\varDelta Bd)(As_0 + \overline{i+a+1}\varDelta As)$$

$$+ \sum_{i=1}^{m-a-1} (Ad_0 + i\varDelta Ad)(Bd_0 + \overline{i+a+1}\varDelta Bd)$$

$$+ \sum_{i=1}^{m-a-1} (Bd_0 + i\varDelta Bd)(Ad_0 + \overline{i+a+1}\varDelta Ad)$$

$$+ \sum_{i=1}^{m-a-1} (As_0 + i\varDelta As)(Bd_0 + \overline{i+a+1}\varDelta Bd)$$

$$+ \sum_{i=1}^{m-a-1} (Bs_0 + i\varDelta Bs)(Ad_0 + \overline{i+a+1}\varDelta Ad)$$

2. Analyses of the spatial correlation between individuals of two kind of fishes being distributed along the same row of gears

The above-mentioned formulae show the expected number of the couples of individuals belonging to different species and spaced by *k* section-intervals or hook-intervals, when individuals of both species are distributed independently of each other. And the series of the estimated values show the type of change according to the increase of k almost the same as that of the values computed by the formulae given in the preceding chapter. The estimated values of the preceding series, in which the influence of the gradient of the catch rate is taken into consideration, change following a weakly cubic curve and those computed within the range of k from 0 to not so large value are a little higher than those in which the influence of the gradient is not taken into consideration which follow a linear function, while the estimated values computed in the range of k from neither so small to nor so large value are slightly lower irrespective as to whether the catch rate is increasing or decreasing. But the relation between the two series of the estimated values of this analysis —— the influence of the gradient is taken into consideration or not —— is not always the same as the above-mentioned relation. The above-mentioned relation is seen between the two series of the estimated values only when the direction of the gradient is the same in both species, while when the direction of the gradient is opposite to each other in the two species, the relation is reverse, although the series in which the influence of gradient is taken into consideration follows also a weakly cubic curve and the series in which the influence of the gradient is put out of consideration changes along a linear function.

Before going further, it must be noted that the fishing method, long-line, itself is accompanied with a fundamentally unfavourable condition for the analysis of the spatial relation; when the catch rate is high partially or throughout the whole row of gears, the effect of the occupation of a hook by each individual, which naturally makes it impossible that the hook can be occupied by other individuals of the same or other species, becomes somewhat serious, and this results in the fact that the distribution of a single species or both species is misregarded as a little more self-spacing, or even as repulsive than actual, and moreover when each or both species are caught in dense schools and at the same time the unit length adopted in consideration is too short, the matter might occasionally be put into an insoluble confusion. The correlation diagrams were decoded on the basis of such preliminary knowledge.

1) Correlation between big-eye tuna and yellow-fin tuna

At Sts. 1—10 in the Fishing Ground No. 1, a relatively large number of individuals of yellow-fin tuna were caught mingled with big-eye tuna, both of these are commercially very important species. Thus, the spatial correlation between these two species was analyzed as an example. Generally, individuals of these species are distributed almost independently of each other, more exactly, their distributions are rather repulsive.

Exposition of particular example

Example C b–y 1 : This is the example obtained at St. 1 in the Fishing Ground No. 1. The catch of big-eye tuna increases with the soaking time, while that of yellow-fin tuna shows rather a negligibly weak decrease with the soaking time.

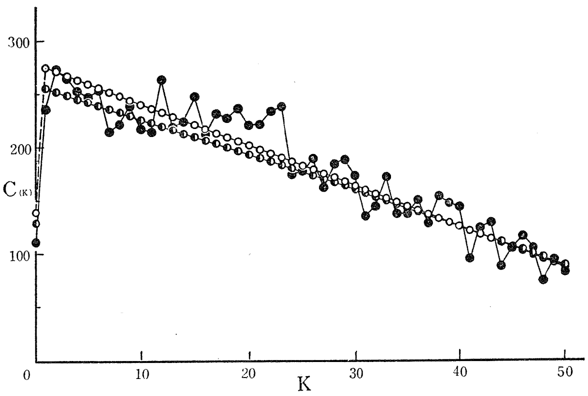


Fig. 13—1 (I). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series I obtained at Station 1 in the Fishing Ground No. 1).

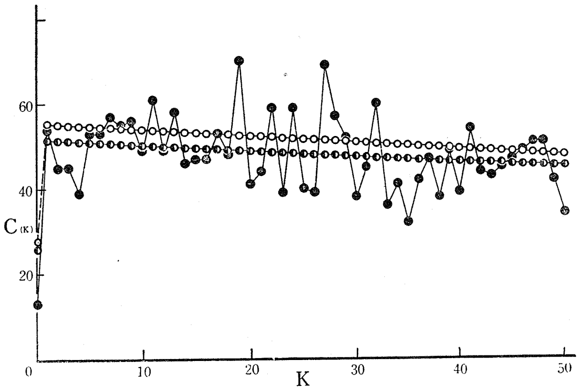


Fig. 13—1 (II). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series II obtained at Station 1 in the Fishing Ground No. 1).

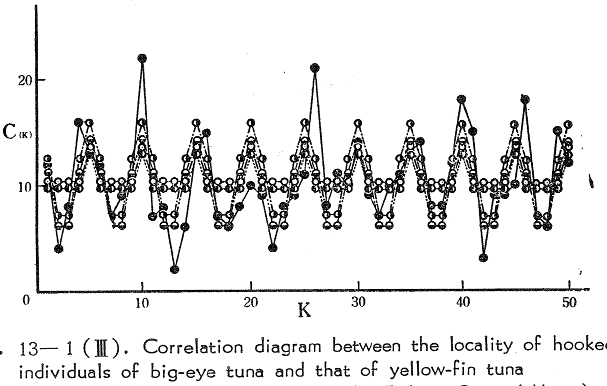


Fig. 13—1 (III). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series III obtained at Station 1 in the Fishing Ground No. 1).

Accordingly, when k is not so large, the series of the estimated values, in which the influence of the gradient of the catch rate is taken into consideration, shows slightly lower values than in the series in which the influence of it is put out of consideration. And as no large school is detected in both species, it is unnecessary to give any special consideration to the influence of the large school. Even when the influence of the gradients of opposite directions, which might cause the repulsive pattern of the distribution, is taken into consideration, there is shown still a repulsive pattern extending to two units (=10 baskets ≒2 km) in the diagram of Series I, in which the theoretical values are computed by formulae (31) ~ (34) taking 5 consecutive baskets (≒*ca.* 1 km) as a unit. The diagram of Series II, in which the estimated values are computed from formulae (31) ~ (34) shortening the unit length in consideration to 1 basket (≒*ca.* 200 m), indicates nothing else than the feature shown in the diagram of Series I, although it shows some deviation within the unit adopted in the Series I (= 5 baskets). The diagram of Series III shows the individuals of yellow-fin tuna caught at the hooks spaced by 10 or 26 hook-intervals (0.4 or *ca.* 1 km) from respective hooks occupied by big-eye tuna are more abundant than those in the independent distribution and that so strong repulsion cannot be observed within a short range between the individuals of yellow-fin tuna and big-eye tuna, although the diagram of Series II suggests that the number of individuals caught within the same basket is less than that in the independent distribution. This might seem to suggest that it is unnecessary, in this case, to give any consideration to the influence of the hooks being occupied, yet it might bring in some errors to think so instantly.

Example C b–y 2 : The direction of the gradient is opposite to each other in both species, and at a glance this seems to represent the influence of the hooks being occupied by individuals of respective species. In this case, however, the gradients were regarded as simple ones and the estimated values in which the influence was

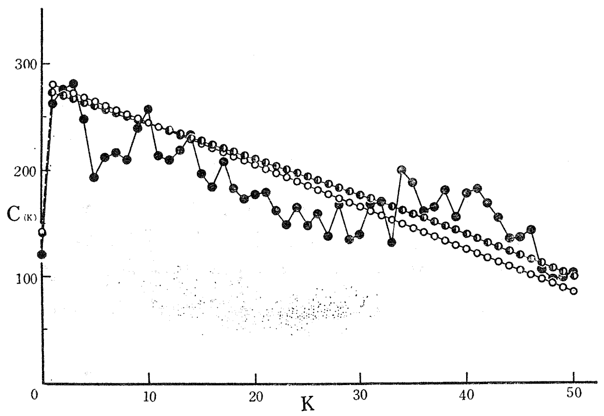


Fig. 13—2 (I). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series I obtained at Station 2 in the Fishing Ground No. 1).

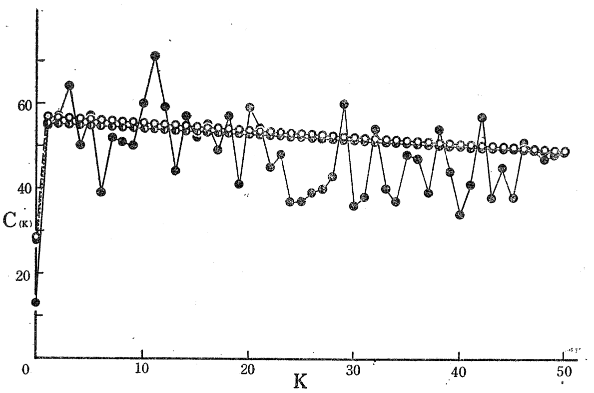


Fig. 13—2 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 1).

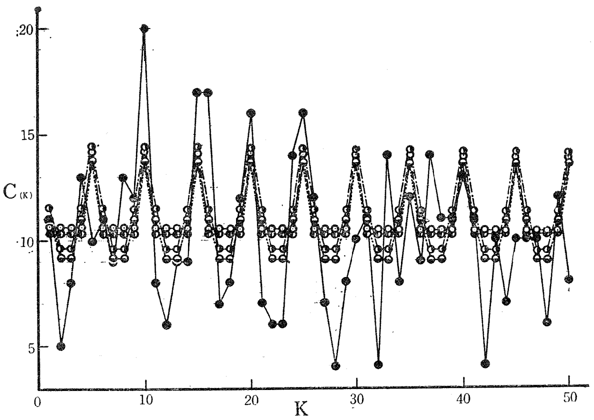


Fig. 13—2 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 2 in the Fishing Ground No. 1).

taken into consideration were computed. However, there still remains a repulsive pattern extending to *ca.* 40 units (40 km) as is seen in the diagram of Series Ⅰ, although this repulsive pattern might be attributable to the existence of a large school of big-eye tuna. But it is impossible to ascertain if this is really assigned to a large school of big-eye tuna. The diagram of Series Ⅱ does not show nothing else than the deviation within a small range. But the diagram of the Series Ⅲ illustrates that a relatively large deviation is observable within the shortest range, *i.e.*, a considerable number of individuals of yellow-fin tuna are caught at the hooks spaced by 8, 10, 15, 16, 24, 33 and 37 hook-intervals from respective hooks occupied by individuals of big-eye tuna, while the number of hooks occupied by yellow-fin tuna and spaced by shorter than 5, 11, 12, 17, 18, 21, 22, 23, the width from 27 to 32 and that from 39 to 50 hook-intervals is far less than those in the case in which individuals of respective species are distributed independently of each other.

Example C b–y 3 : As the direction of the gradient is the same in both species, the series of the estimated values within the range of k from 0 to not so large a value in which the influence of the gradient of the catch rate is taken into consideration, show values slightly higher than that in the series in which the influence of the gradient is put out of consideration. And it is unnecessary to pay any attention to the influence of the existence of large schools. The diagram of Series I suggests that the individuals of yellow-fin tuna caught at the hooks next to or in the units spaced by 3, 10, 19 and 22 units from respective units occupied by big-eye tuna are a little more abundant than those in the case in which both species are distributed independently of each other. While the individuals of yellow-fin tuna caught within the same units or

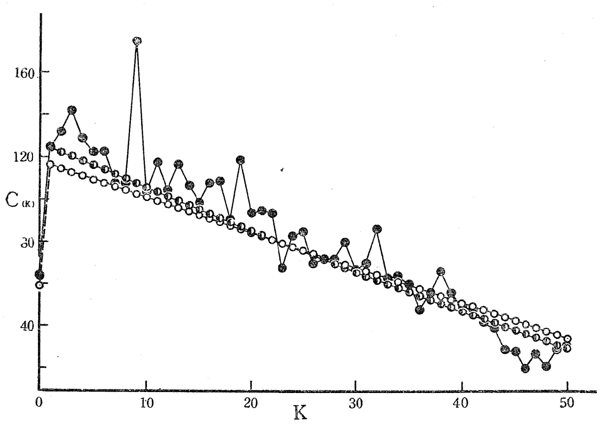


Fig. 13—3 (I). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series I obtained at Station 3 in the Fishing Ground No. 1).

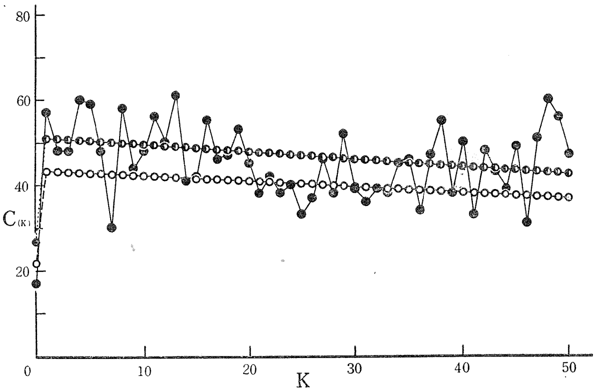


Fig. 13—3 (II). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series II obtained at Station 3 in the Fishing Ground No. 1).

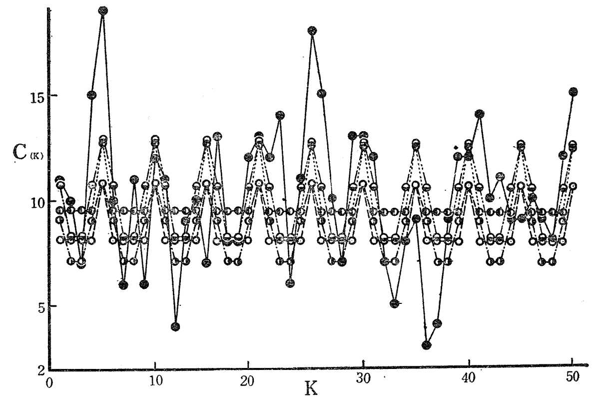


Fig. 13—3 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 3 in the Fishing Ground No. 1).

in the units spaced by 4~8 or longer than 25 units from respective units occupied by big-eye tuna are little less than those in the case in which both species are distributed independently of each other. The observed number of the couples of individuals being constituted of each of yellow-fin tuna and big-eye tuna and spaced by shorter than 20 or longer than 35 baskets is generally larger than the estimated number, while the number of those spaced by 20~35 baskets is a little smaller. The diagram of Series Ⅲ, in which the relation is considered to be shown most in detail, represents that the couples of fishes being constituted of different species and spaced by 4, 5, 22, 25 and 26 hook-intervals are observed more frequently than expected, while those spaced by 12 and 32~37 hook-intervals are less than expected.

Example C b-y 4 : In the relation diagram of Series Ⅰ, the existence of an aggre-

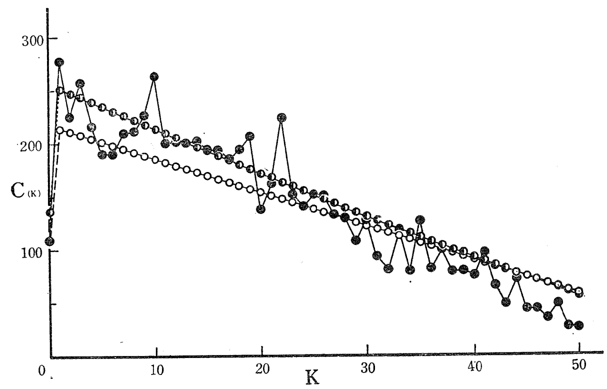


Fig. 13—4 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 4 in the Fishing Ground No. 1).

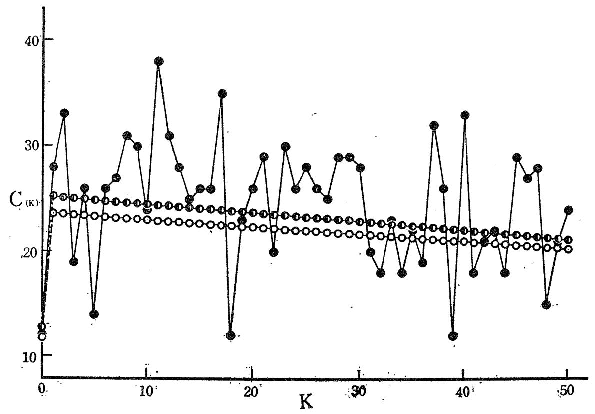


Fig. 13—4 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 4 in the Fishing Ground No. 1).

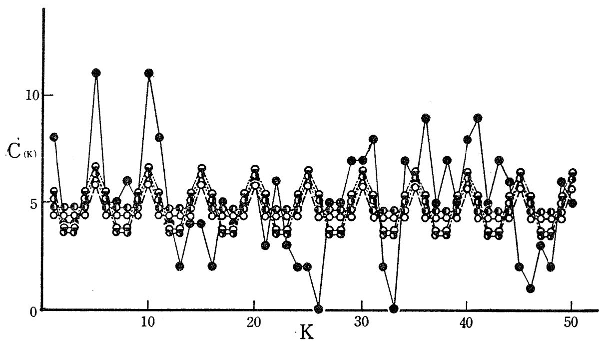


Fig. 13—4 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 4 in the Fishing Ground No. 1).

gative pattern extending to about 40 units (40 km) is suggested, but considering the spatial relation among the individuals of yellow-fin tuna, this pattern is regarded as being considerably affected by the distribution pattern of yellow-fin tuna showing the existence of a school covering about 40 units in the range from the 140th to the 350th basket. Besides this, the observed values are abruptly high in the units at $k=9$, and this seems to indicate some essential pattern. The observed values in the diagram of Series Ⅱ deviate rather conspicuously from the estimated ones, and this seems to indicate that the unit length adopted in consideration is most adequate. Individuals of yellow-fin tuna caught in the baskets spaced by 2, 8, *ca.* 11, 17, *ca.* 25, 37, 40 and *ca.* 45 baskets from respective baskets occupied by big-eye tuna are more abundant than those in the case when they are distributed independently of each other, while individuals caught in the baskets spaced by 6, 18 and 39 baskets from respective baskets occupied by big-eye tuna are lesser. The diagram of Series Ⅲ suggests that much more individuals of yellow-fin tuna are caught at the hooks spaced by shorter than 12, *ca.* 30 and 34~44 hook-intervals, especially at the hooks next to or spaced by 5 and 10 hook-intervals from respective hooks occupied by big-eye tuna. However, it is impossible to guess the hook-intervals maintaining low catch rate of yellow-fin tuna, because most of the estimated and observed numbers are fewer than 5.

Example C b-y 5 : The total catch of yellow-fin tuna is extremely low as compared with that of big-eye tuna, and this causes that the relation diagram, especially the variation of the observed values in it, is strongly affected by the distribution of yellow-fin tuna, and moreover, the influence of each individual of yellow-fin tuna upon the distribution pattern and the accidental errors concerning them are apt to be emphasized too much. Accordingly, it is necessary to pay cautious attention to this,

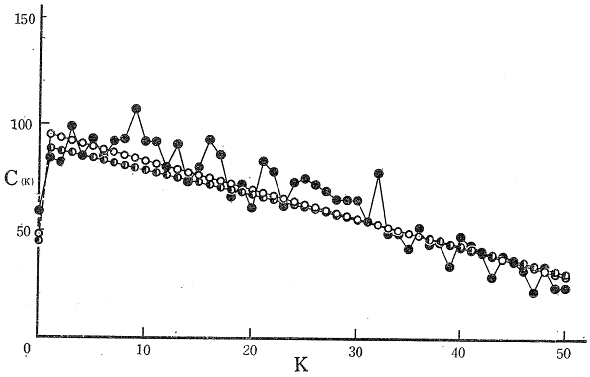


Fig. 13—5 (I). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series I obtained at Station 5 in the Fishing Ground No. 1).

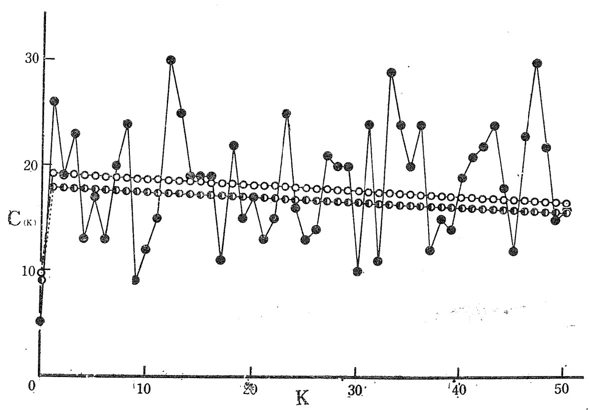


Fig. 13—5 (II). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series II obtained at Station 5 in the Fishing Ground No. 1).

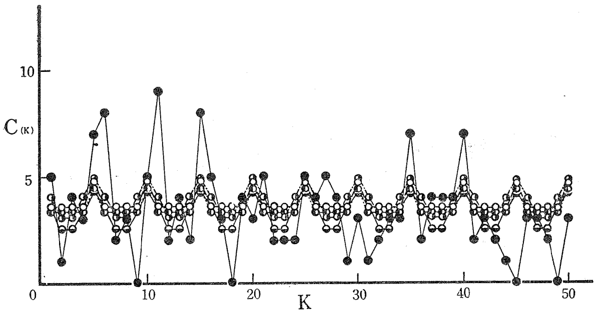


Fig. 13—5 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 5 in the Fishing Ground No. 1).

or rather, exactly speaking, such an example seems to be unsuitable for the analysis, although the observed values may look superficially to be available for the analysis. The diagram of Series Ⅰ seems to suggest that the aggregative pattern covering *ca.* 30 units (30 km) is present, but the existence of such an aggregative pattern seems to be doubtful, when we consider that this might be attributable to the wide school of yellow-fin tuna, the existence of which is, however, somewhat doubtful on account of the scarcity of caught individuals. The same doubt about the relation diagram seems to be increased in the relation diagrams of Series Ⅱ and Ⅲ, consequently no consideration about the distribution pattern is given to them.

Example C b–y 6 : Concerning the Examples C b–y 6 to 10, quite the same error as that mentioned in the preceding example is expected. Thus, the aggregative pattern covering *ca.* 30 units (30 km) in the diagram of Series Ⅰ seems also to be assigned to the distribution pattern of yellow-fin tuna, and consequently it is regarded as insignificant. The number of individuals of yellow-fin tuna caught within the 4 units (4 km)

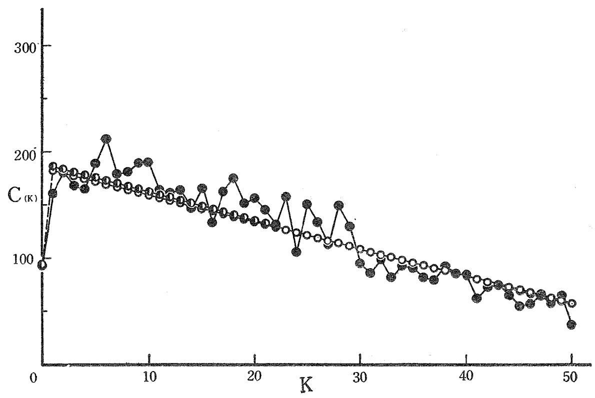


Fig. 13—6 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 6 in the Fishing Ground No. 1).

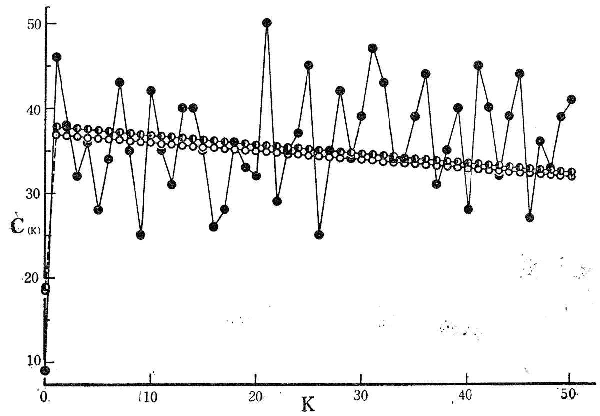


Fig. 13—6 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 6 in the Fishing Ground No. 1).

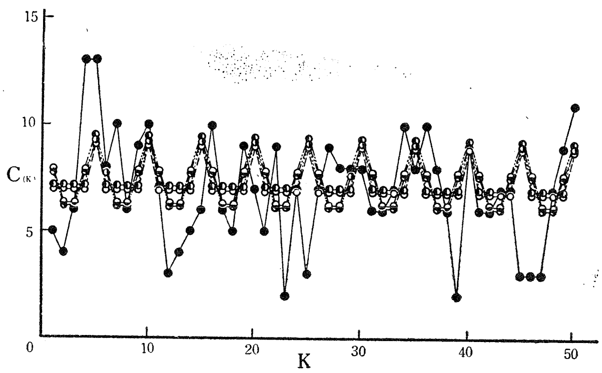


Fig. 13—6 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 6 in the Fishing Ground No. 1).

from respective units occupied by big-eye tuna is less than that in the case when individuals of both species are distributed independently of each other. The diagram of Series Ⅱ indicates that the distance between the individuals of yellow-fin tuna and big-eye tuna shows the periodicity of the length shorter than 3 baskets (600 m). The observed values in the diagram of Series Ⅲ show an apparent deviation of the small amplitude but of the rather long periodicity, but this is evidently caused by the scarcity of the caught individuals of yellow-fin tuna, consequently this distribution and the periodicity are regarded as insignificant.

Example C b-y 7 : The relation diagram of Series Ⅰ resembles closely that of the Example Y 7 holding rather few individuals caught. Namely, the spatial correlation between the big-eye tuna and yellow-fin tuna seems to be strongly affected by the distribution pattern of the subordinate species, yellow-fin tuna. Thus it is somewhat

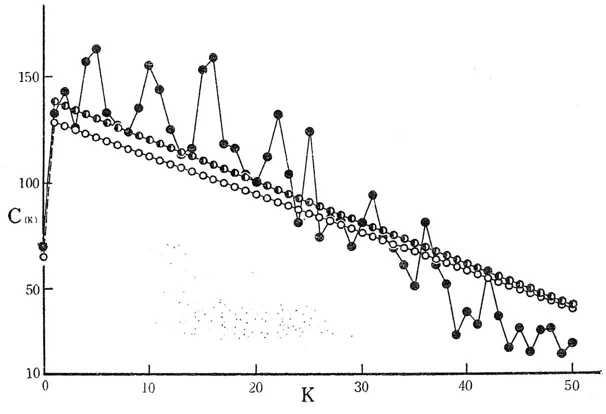


Fig. 13—7 (I). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series I obtained at Station 7 in the Fishing Ground No. 1).

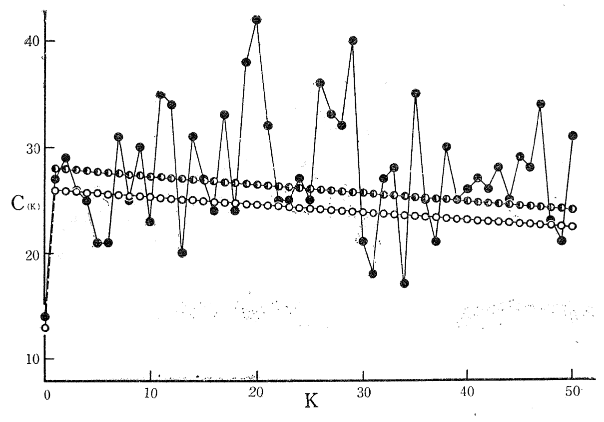


Fig. 13—7 (II). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series II obtained at Station 7 in the Fishing Ground No. 1).

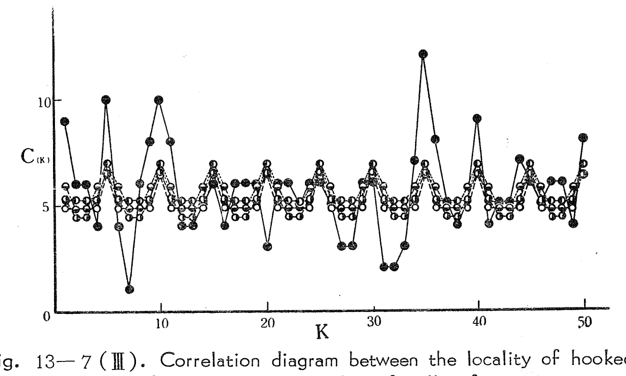


Fig. 13—7 (III). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series III obtained at Station 7 in the Fishing Ground No. 1).

doubtful whether this diagram is worthy to be analyzed or not. The diagram of Series Ⅱ suggests that the individuals of yellow-fin tuna caught in the baskets spaced by shorter than 6 baskets (1.2 km) from respective baskets occupied by big-eye tuna are lesser. While the individuals of yellow-fin tuna caught in the baskets spaced by about 11, 20 and 28 baskets from respective ones occupied by big-eye tuna are more abundant. The diagram of Series Ⅲ indicates that the individuals of yellow-fin tuna caught at the hooks next to or spaced by 5, 9, 10, 11, 35, 36 and 40 hook-intervals from respective ones occupied by big-eye tuna are a little more abundant than expected.

Example C b-y 8 : It is unnecessary to pay any attention to the analyzing of the diagram of Series Ⅰ, because both yellow-fin tuna and big-eye tuna do not form any

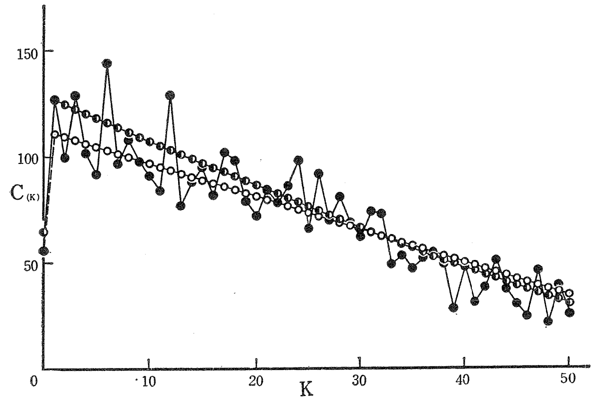


Fig. 13—8 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 8 in the Fishing Ground No. 1).

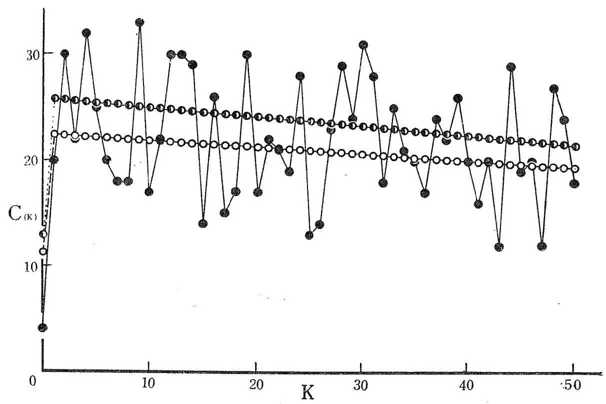


Fig. 13—8 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 8 in the Fishing Ground No. 1).

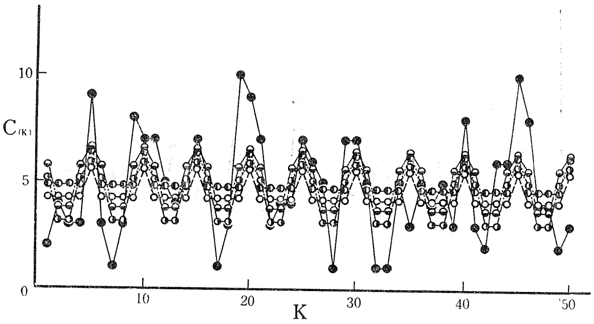


Fig. 13—8 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 8 in the Fishing Ground No. 1).

large schools in this example. The deviation of the observed values from the estimated ones alludes to the existence of a rather repulsive distribution extending to *ca.* 20 units (20 km) or a little longer between the individuals of both species, although some fairly conspicuous relation pattern within a shorter range is also suggested by this. The diagram of Series Ⅱ suggests roughly that the individuals of yellow-fin tuna caught in the baskets next to or spaced by 1, *ca.* 7, the width from 15 to 25 baskets *etc.* from respective ones occupied by big-eye tuna are slightly lesser. Both the estimated and observed values are low and some accidental errors are expected, but it seems to be said safely that more individuals of yellow-fin tuna than expected are caught at the hooks spaced by *ca.* 4 hook-intervals or 9 baskets from respective hooks occupied by big-eye tuna and contrarily lesser individuals of yellow-fin tuna are caught at the hooks spaced by shorter than 1½ baskets, 17, 28, 32 and 33 hook-intervals from respective hooks occupied by big-eye tuna.

Example C b-y 9 : Despite of the fact that the total catch of yellow-fin tuna is

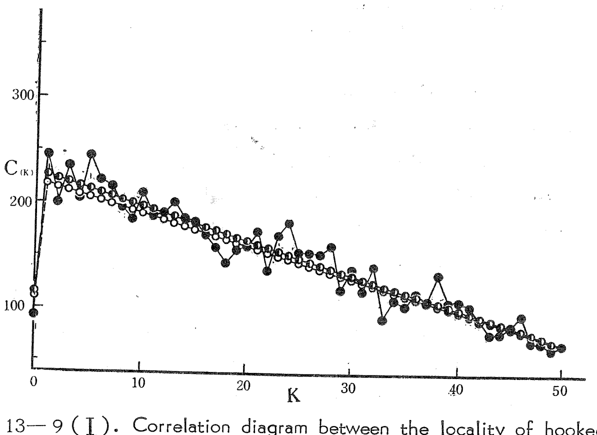


Fig. 13—9 (Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 9 in the Fishing Ground No. 1).

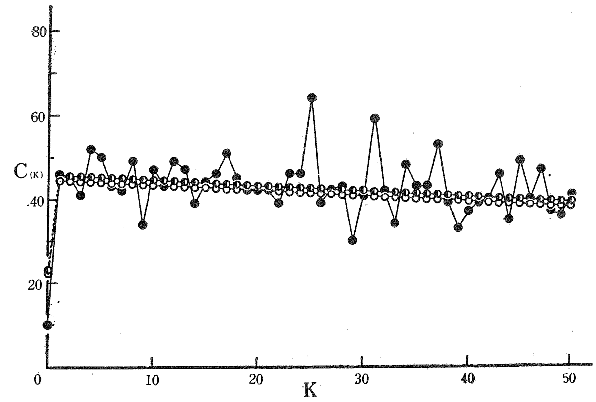


Fig. 13—9 (Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 9 in the Fishing Ground No. 1).

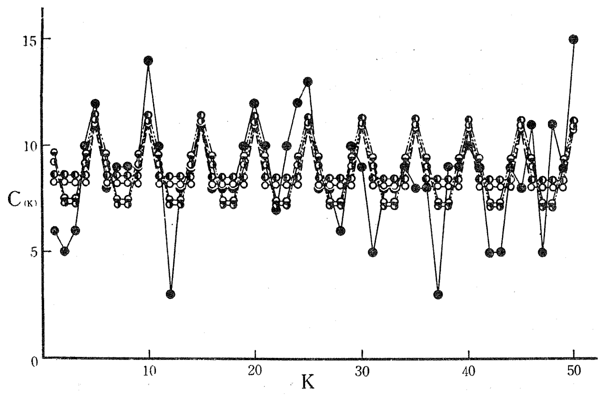


Fig. 13—9 (Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 9 in the Fishing Ground No. 1).

not so large and its observed values deviate much from the estimated ones, the influence of the distribution pattern of the subordinate species, yellow-fin tuna, is nearly invisible and quite a different relation diagram is obtained, which indicates that individuals of yellow-fin tuna and big-eye tuna are distributed almost independently of each other. The diagram of Series Ⅱ supports the above-mentioned fact and further shows that the number of individuals of yellow-fin tuna caught in the same baskets occupied by big-eye tuna is only a half of the expected number, but the number of individuals of yellow-fin tuna caught in the following 24 baskets next to respective ones occupied by big-eye tuna is almost as large as those in the case when individuals of both species are distributed independently of each other. While the number of individuals of yellow-fin tuna caught in the 25 successive baskets spaced by 24 baskets from respective ones occupied by big-eye tuna deviates much from the expected ones. The diagram of Series Ⅲ gives the more detailed structure that the number of individuals of yellow-fin tuna caught at the hooks spaced by shorter than 1 basket, 12, 31, 37, 42, 43 and 45 hook-intervals from respective hooks occupied by big-eye tuna is less than expected, while that at the hooks spaced by 10, 23∼25 and 50 hook-intervals is larger.

Example C b–y 10 : It seems unnecessary to pay any attention to the analyzing of the diagram of Series Ⅰ of this example for the same reason as mentioned about the Example C *b–y* 9. A rather strong repulsive pattern extending to 3–unit width (3 km) is observable, besides the existence of a rather long periodic but weak deviation of the observed values and that the individuals of yellow-fin tuna caught in the units spaced by 13∼18 unit-width from respective ones occupied by big-eye tuna are more abundant. The observed values in the diagram of Series Ⅱ, supporting the existence of the strongly repulsive pattern detected in the diagram of Series Ⅰ, show a deviation narrow but with large amplitude. As the observed and estimated values are scarce, it seems unreasonable to give any further consideration to the diagram of Series Ⅲ.

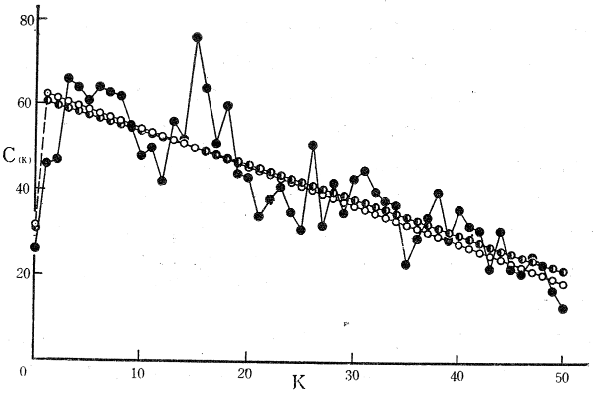


Fig. 13—10(Ⅰ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅰ obtained at Station 10 in the Fishing Ground No. 1).

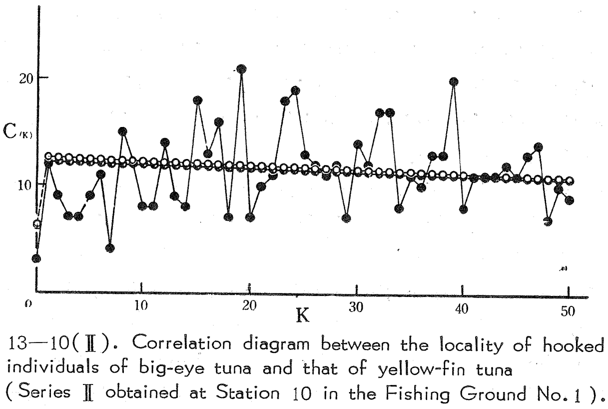


Fig. 13—10(Ⅱ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅱ obtained at Station 10 in the Fishing Ground No. 1).

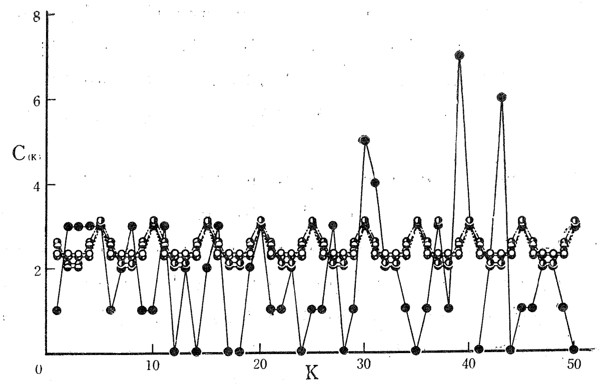


Fig. 13—10(Ⅲ). Correlation diagram between the locality of hooked individuals of big-eye tuna and that of yellow-fin tuna (Series Ⅲ obtained at Station 10 in the Fishing Ground No. 1).

2) Correlation between tunas and marlins

It seems to be very important and at the same time necessary for the ecological and commercial purposes to examine the spatial relation between the individuals of tunas and marlins or tunas and sharks. But the number of individuals of tunas of all the examples examined here is apart too far from that of marlins or sharks and this may result in the fact that the relation diagram is strongly affected by the distribution pattern of the subordinate species, as mentioned already in the preceding section. Unfortunately, there is no example, in which the catch rate of marlins or sharks is considerably high and nearly at the same level as that of tunas. Accordingly, all the examples are unsuitable for the present examination. Nevertheless, several examples, in which the catch rate of tunas is extremely low and nearly at the same level as that of marlins or sharks, are taken up for the purpose to remove the above-mentioned error and at the same time to show some examples obtained from the old fishing grounds of lower productivity, because most of the above-mentioned examples are all obtained from rather new fishing grounds.

The catch rate is very low in both tunas and marlins, consequently the observed values in Series Ⅲ, even in Series Ⅱ sometimes, become extremely low; thus the correlation diagram of Series Ⅲ is omitted from this paper and the consideration is made chiefly on that of Series Ⅰ. Besides the correlation diagrams, the relation diagrams of respective single speices are illustrated to aid the analyses, although no discussion is given here on them.

Although the correlation diagrams seem to show, as expected, some repulsive pattern, it is impossible to judge definitely whether this is an essential one or not and to know what the difference is between this relation and that between big-eye tuna and yellow-fin tuna, because the catch rate is too low. Yet, it is noticeable that the correlation diagram of Series Ⅰ of the Example C t-m 2 is one of the typical examples, in which the correction term for the influence of the gradients of the catch rates, the directions of which are opposite to each other, is extremely large.

Exposition of particular example

Example C t–m 1 : A rather typical repulsive pattern is observable in the diagrams

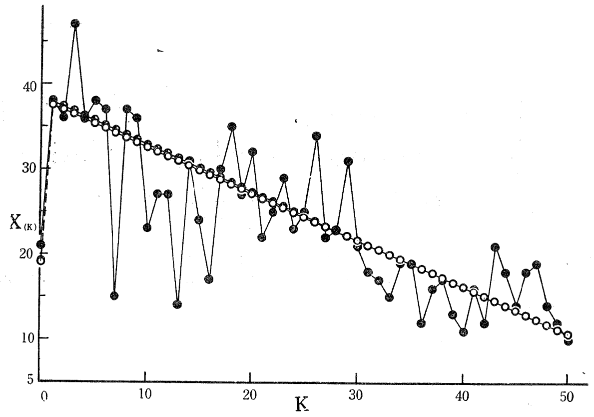


Fig. 14—1 (Ⅰ). X(k)—k relation diagram of tunas
(Series Ⅰ obtained at Station 1 in the Fishing Ground No. 3).

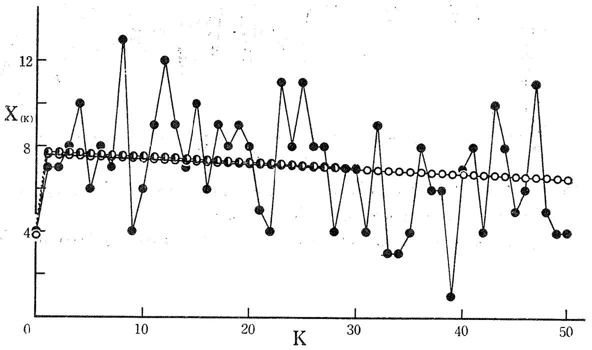


Fig. 14—1 (Ⅱ). X(k)—k relation diagram of tunas
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

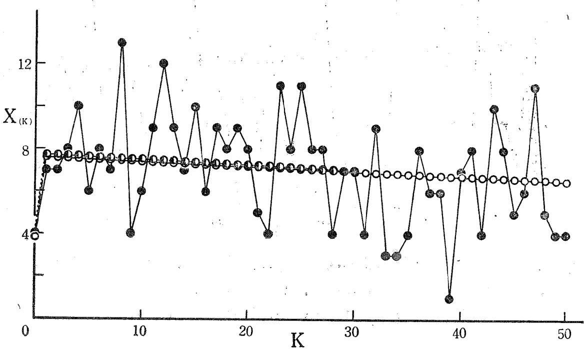


Fig. 15—1 (Ⅰ). X(k)—k relation diagram of marlins
(Series Ⅰ obtained at Station 1 in the Fishing Ground No. 3).

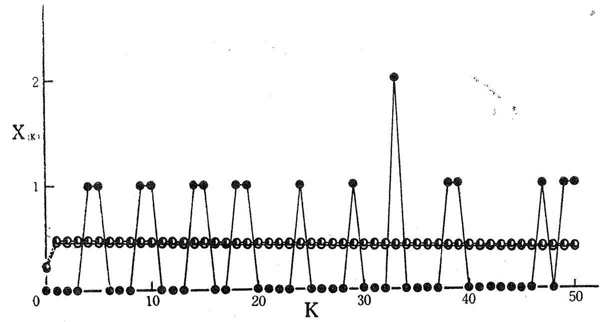


Fig. 15—1 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

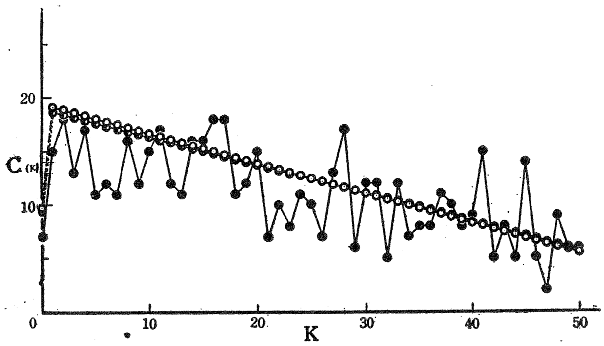


Fig. 16—1 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 1 in the Fishing Ground No. 3).

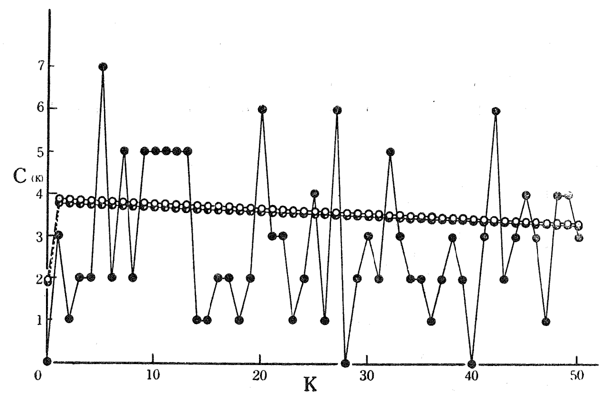


Fig. 16—1 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 1 in the Fishing Ground No. 3).

of Series Ⅰ and Ⅱ, although the short periodic deviations are observed and some accidental errors are expected.

Example C t–m 2 : As the gradient of the catch rate of marlins towards the opposite direction to the increase of the soaking time is conspicuous, the correction term of the theoretical values for the influence of the gradient becomes large, al-

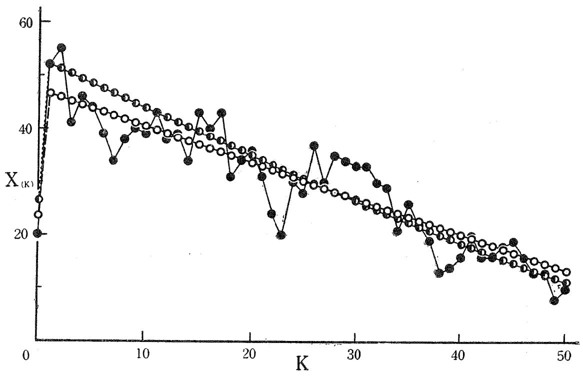


Fig. 14—2 (I). X(k)—k relation diagram of tunas
(Series I obtained at Station 2 in the Fishing Ground No. 3).

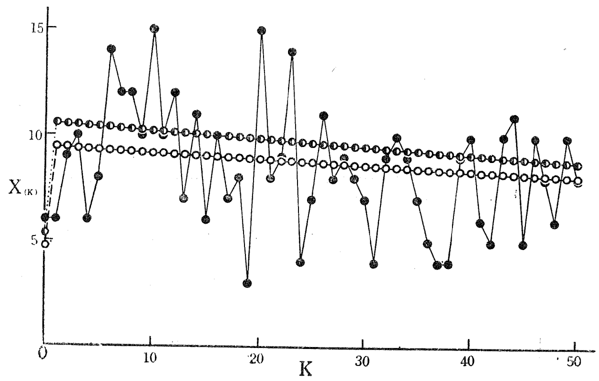


Fig. 14—2 (II). X(k)—k relation diagram of tunas
(Series II obtained at Station 2 in the Fishing Ground No. 3).

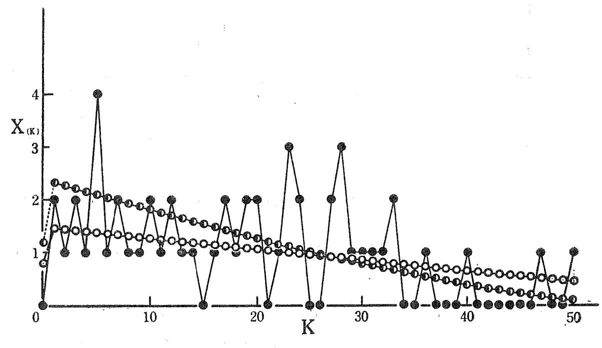


Fig. 15—2 (I). X(k)—k relation diagram of marlins
(Series I obtained at Station 2 in the Fishing Ground No. 3).

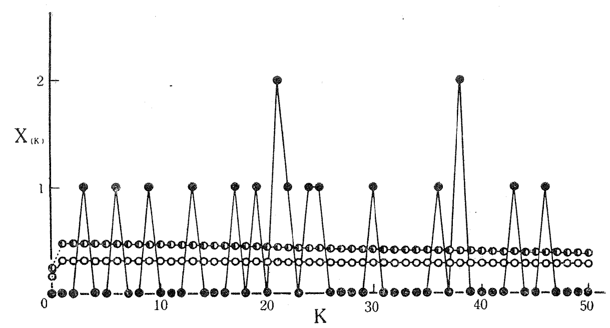


Fig. 15—2 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

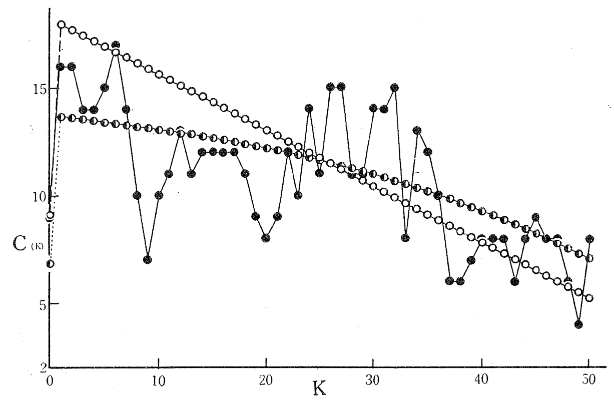


Fig. 16—2 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 2 in the Fishing Ground No. 3).

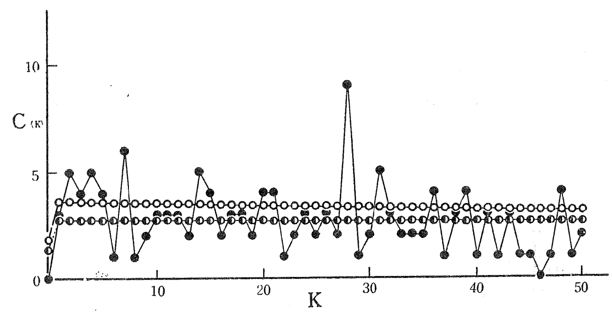


Fig. 16—2 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

though the gradient of marlins itself seems to contain some accidental errors, because the catch rate of marlins is so low. Accordingly the significance of the correction term might also be somewhat doubtful. For this reason, together with lower observed and estimated values, no discussion can be made upon the diagrams of this example.

Example C t–m 4 : As both the catch rate and observed values are low in both

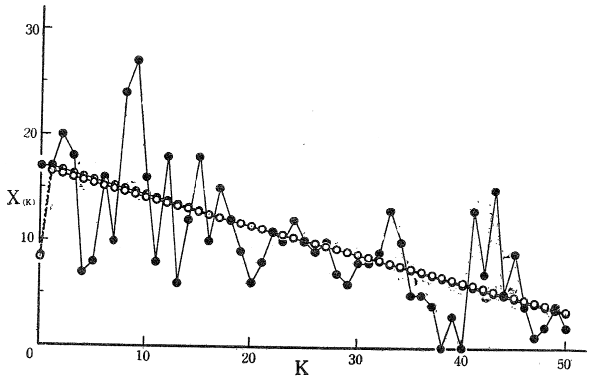


Fig. 14—4 (I). X(k)—k relation diagram of tunas
(Series I obtained at Station 4 in the Fishing Ground No. 3).

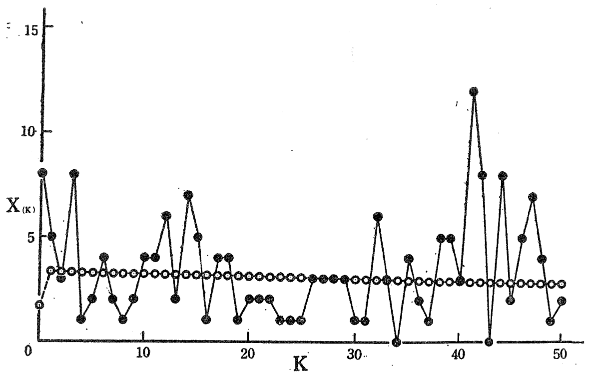


Fig. 14—4 (II). X(k)—k relation diagram of tunas
(Series II obtained at Station 4 in the Fishing Ground No. 3).

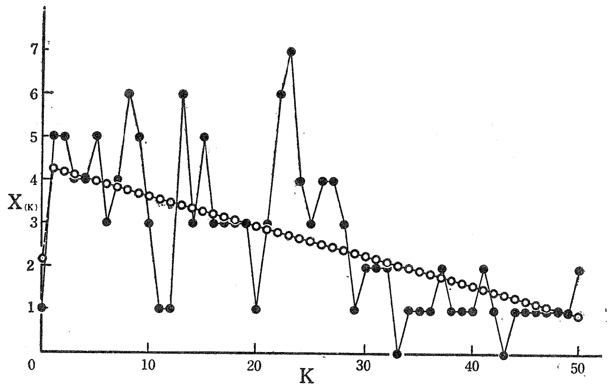


Fig. 15—4 (I). X(k)—k relation diagram of marlins
(Series I obtained at Station 4 in the Fishing Ground No. 3).

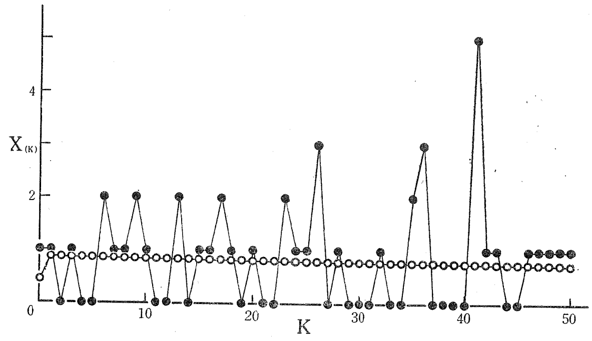


Fig. 15—4 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

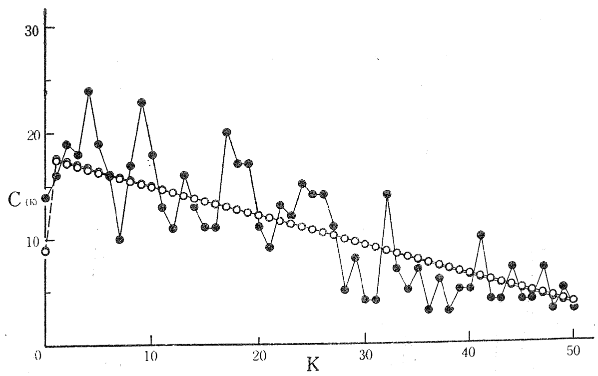


Fig. 16—4 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 4 in the Fishing Ground No. 3).

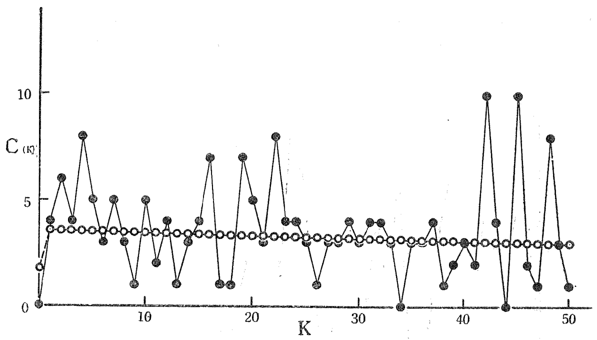


Fig. 16—4 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

species, the significance of the short periodic deviation of the observed values in the diagrams is highly doubtful and further consideration is set aside.

Example C t–m 5 : The long periodic deviation of the observed values in the diagram of Series I seems to allude to something like a distribution pattern, but the lower observed values make it impossible to progress the analyses further.

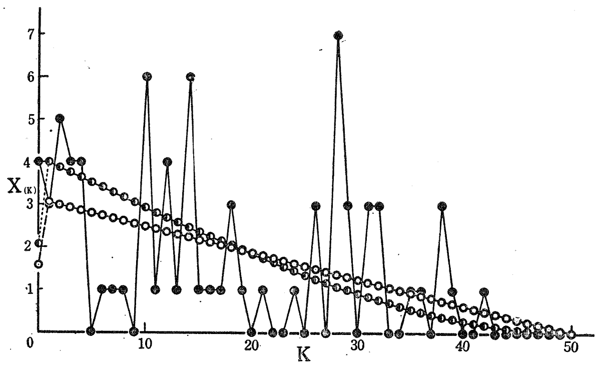


Fig. 14—5 (I). X(k)—k relation diagram of tunas
(Series I obtained at Station 5 in the Fishing Ground No. 3).

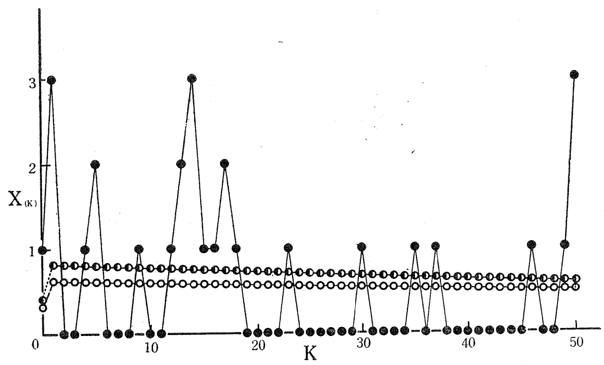


Fig. 14—5 (II). X(k)—k relation diagram of tunas
(Series II obtained at Station 5 in the Fishing Ground No. 3).

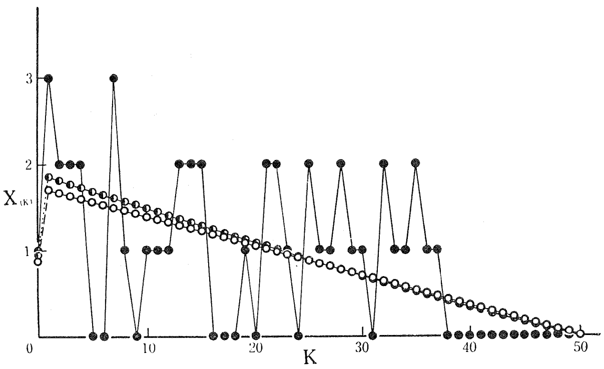


Fig. 15—5 (I). X(k)—k relation diagram of marlins
(Series I obtained at Station 5 in the Fishing Ground No. 3).

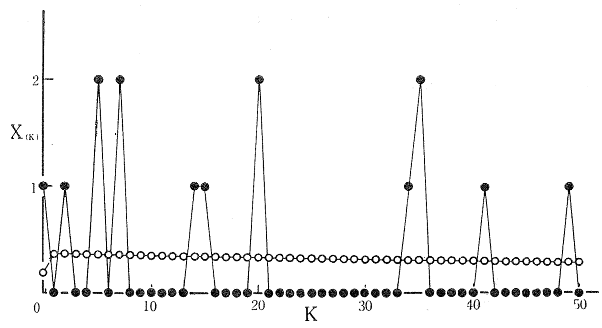


Fig. 15—5 (Ⅱ). X(k)—k relation diagram of marlins
(Series Ⅱ obtained at Station 5 in the Fishing Ground No. 3).

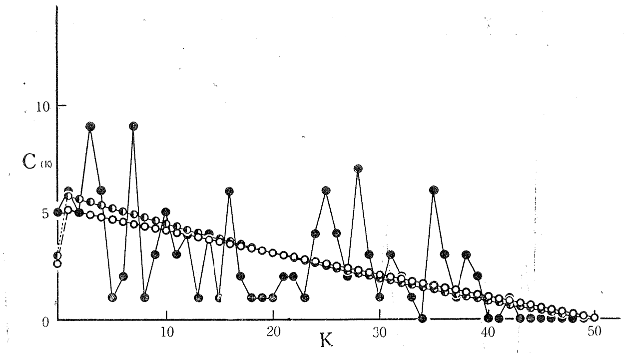


Fig. 16—5 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅰ obtained at Station 5 in the Fishing Ground No. 3).

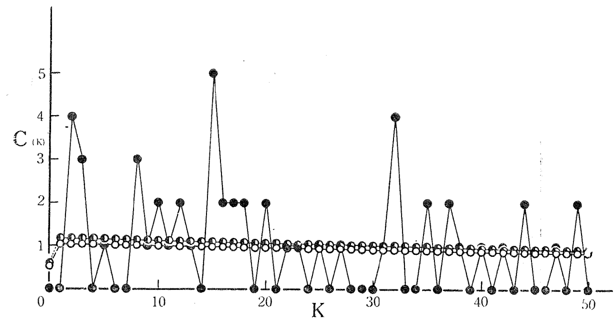


Fig. 16—5 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of marlins
(Series Ⅱ obtained at Station 5 in the Fishing Ground No. 3).

3) Correlation between tunas and sharks

The marlin is situated at a little higher food rank than tuna, but there is no direct predatory relation between them. While it is a well known fact that the hooked tuna is frequently damaged by sharks, although it is uncertain whether freely swimming tunas are attacked by sharks as well as hooked ones or not. Anyhow, there are cases in which many sharks are hooked around the parts where abundant tunas are hooked and contrarily the cases in which tunas are hooked avoiding the parts where abundant sharks are hooked. Indeed this is a very serious problem from the commercial point of view, because damaged tunas have no market value. Some adequate examples for the preceding analyses of the correlation between tunas and marlins may be obtainable, as the latter has the commercial value as high as or higher than the former, while it seems hardly possible to get any suitable examples for the analyses of the correlation between tunas and sharks, because it is quite unreasonable to set gears in the waters where a plenty of sharks, which have no commercial values and moreover damage tunas having high commercial value, are swarming, although we wish earnestly to clear out this relation.

Very unfortunatly, no example, sufficient and suitable for the analyses of this important but complicated relation, was obtained; only several instances are illustrated below as examples.

Exposition of particular example

Example C t–s 1 : The correlation diagram of Series I seems superficially to allude to some pattern, but when this is compared carefully with the relation diagram of sharks, it becomes clear that this correlation diagram is obtainable by simply amplifying the observed values in the relation diagram of sharks. And actually nothing else can be deduced from this diagram than that tunas and sharks are distributed almost independently of each other. No consideration was given to the diagram of Series II.

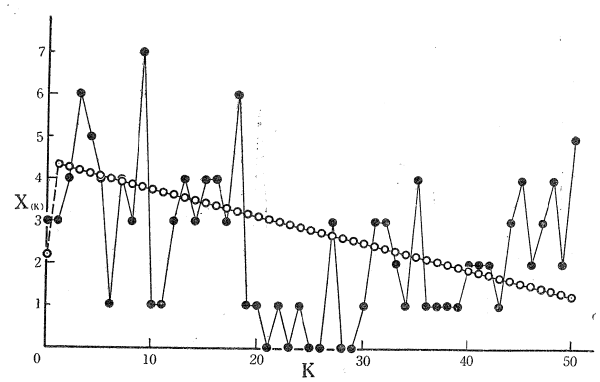


Fig. 17—1 (I). X(k)—k relation diagram of sharks
(Series I obtained at Station 1 in the Fishing Ground No. 3).

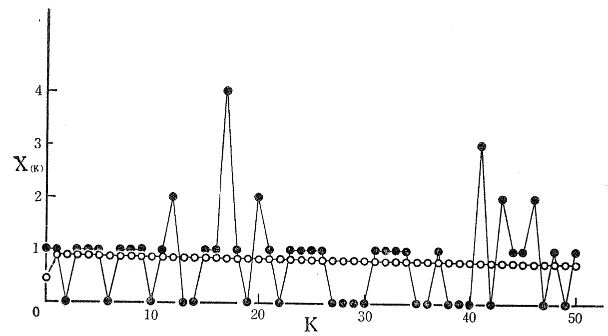


Fig. 17— 1 (II). X(k)—k relation diagram of sharks
(Series II obtained at Station 1 in the Fishing Ground No. 3).

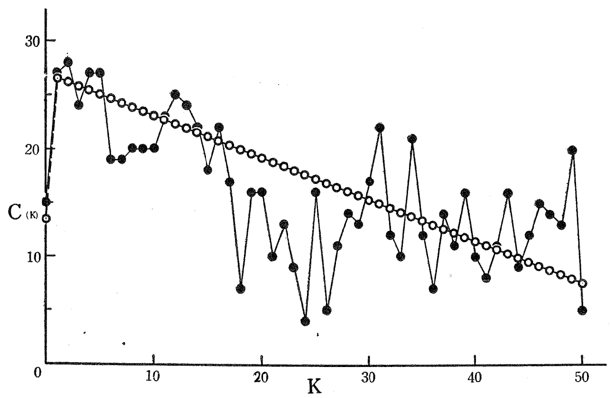


Fig. 18— 1 (I). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series I obtained at Station 1 in the Fishing Ground No. 3).

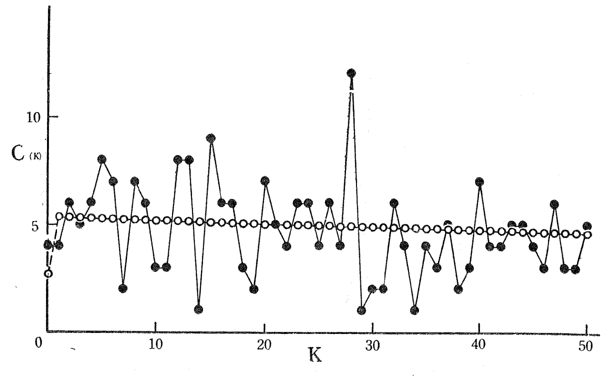


Fig. 18— 1 (II). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series II obtained at Station 1 in the Fishing Ground No. 3).

Example C t-s 2 : Although some accidental errors are expected on account of the scarcity of caught sharks, it seems likely that the individuals of tuna caught in the

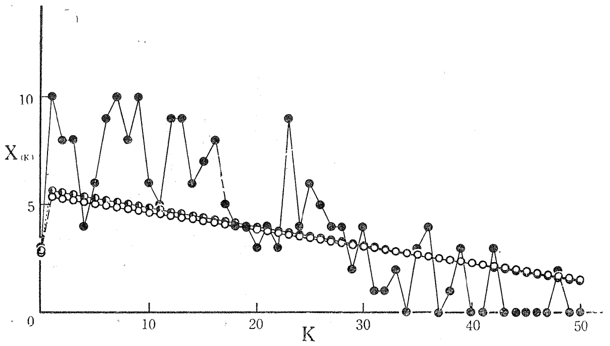


Fig. 17—2 (I). X(k)—k relation diagram of sharks
(Series I obtained at Station 2 in the Fishing Ground No. 3).

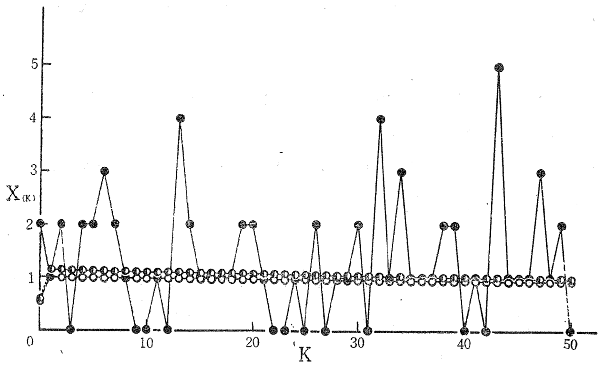


Fig. 17—2 (II). X(k)—k relation diagram of sharks
(Series II obtained at Station 2 in the Fishing Ground No. 3).

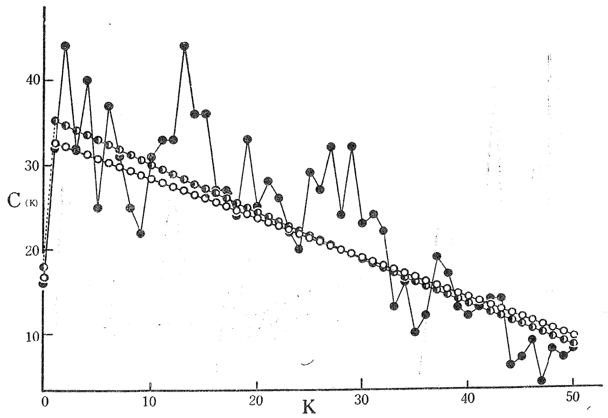


Fig. 18—2 (I). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series I obtained at Station 2 in the Fishing Ground No.3).

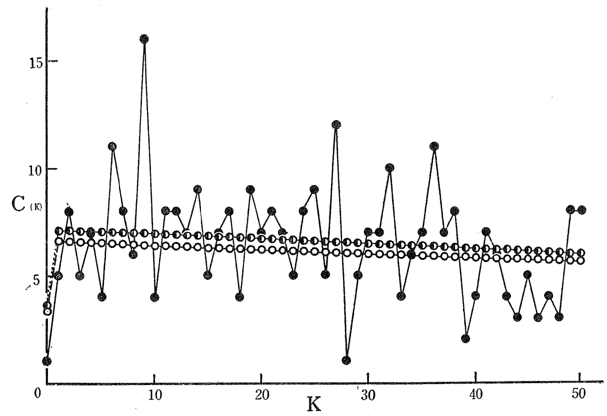


Fig. 18—2 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks (Series Ⅱ obtained at Station 2 in the Fishing Ground No. 3).

units spaced by about 13 or about 28 units (13 or 28 km) from the respective units occupied by sharks are a little more abundant and that sharks are distributed rather aggregatively in the ranges a little shorter than 20 units (20 km). No description is given for the diagram of Series Ⅱ.

Example C t–s 4 : As in the preceding example, it is very difficult to deduce any results from the correlation diagram of Series Ⅰ, because this seems to reflect too strongly the distribution pattern of sharks, which, however, may indicate some structures.

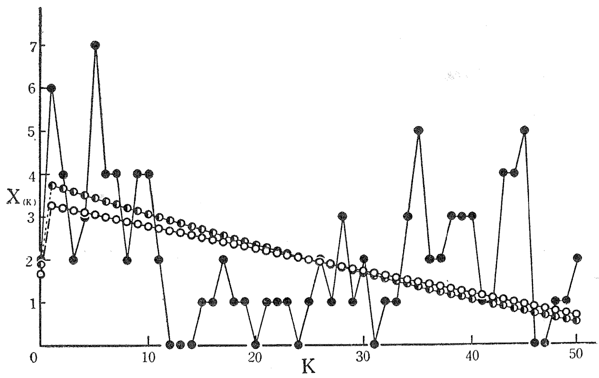


Fig. 17—4 (Ⅰ). X(k)—k relation diagram of sharks (Series Ⅰ obtained at Station 4 in the Fishing Ground No. 3).

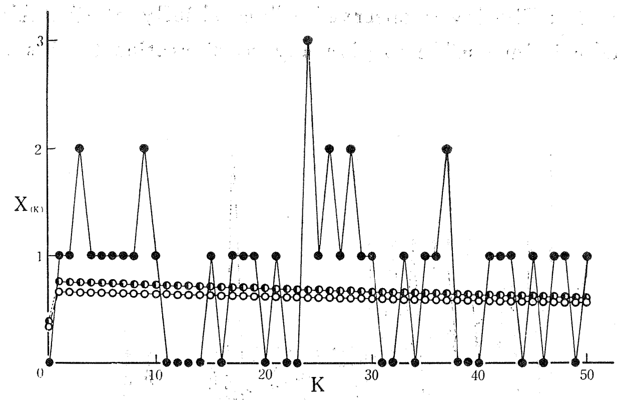


Fig. 17—4 (Ⅱ). X(k)—k relation diagram of sharks
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

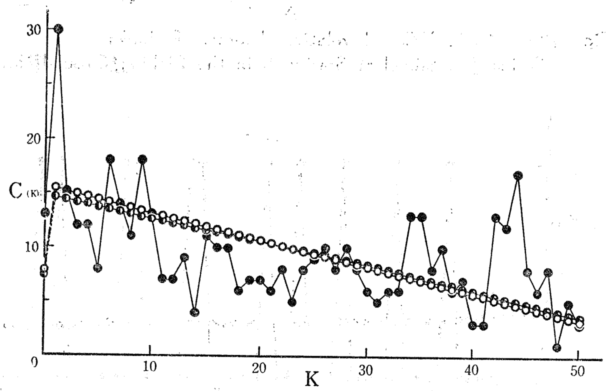


Fig. 18—4 (Ⅰ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅰ obtained at Station 4 in the Fishing Ground No. 3).

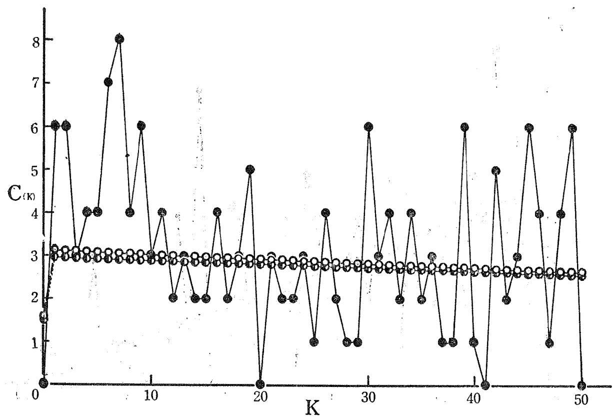


Fig. 18—4 (Ⅱ). Correlation diagram between the locality of hooked individuals of tunas and that of sharks
(Series Ⅱ obtained at Station 4 in the Fishing Ground No. 3).

Example C t-s 5 : The lower observed values chiefly attributable to the low catch rate of sharks make it impossible to give any consideration to this example.

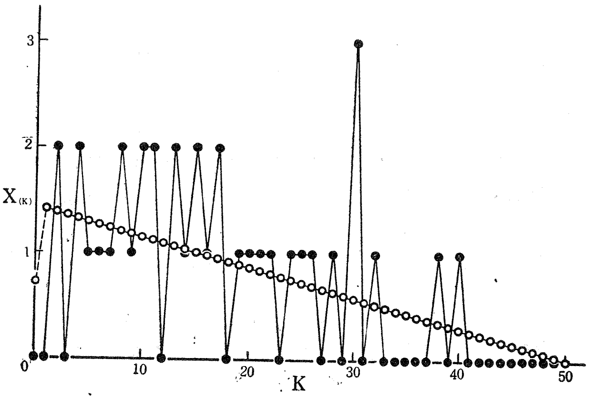


Fig. 17—5 (I). X(k)—k relation diagram of sharks (Series I obtained at Station 5 in the Fishing Ground No. 3).

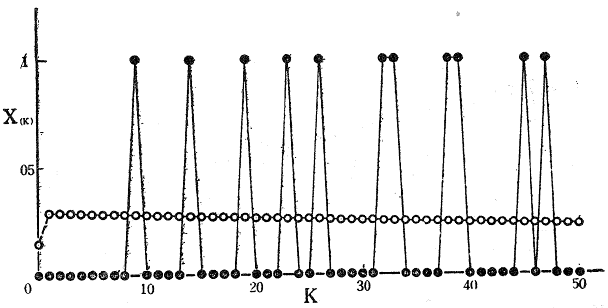


Fig. 17—5 (II). X(k)—k relation diagram of sharks (Series II obtained at Station 5 in the Fishing Ground No. 3).

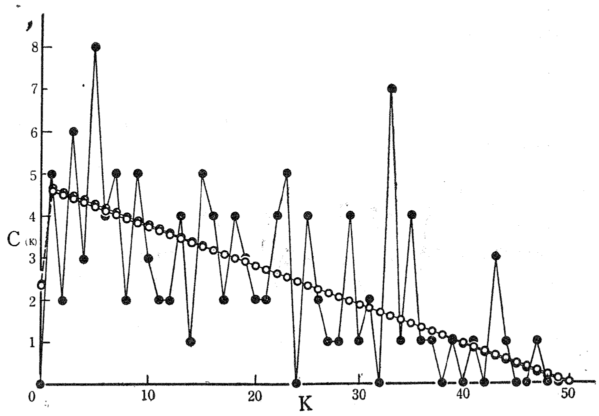


Fig. 18—5 (I). Correlation diagram between the locality of hooked individuals of tunas and that of sharks (Series I obtained at Station 5 in the Fishing Ground No. 3).

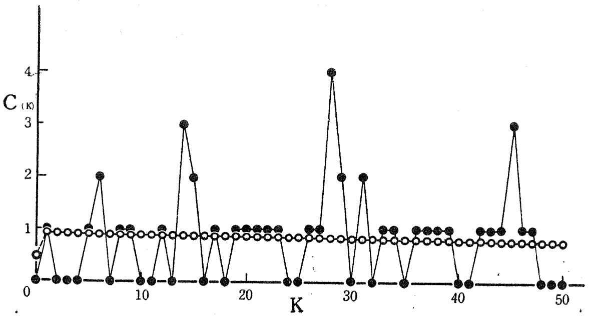


Fig. 18—5 (II). Correlation diagram between the locality of hooked individuals of tunas and that of sharks (Series II obtained at Station 5 in the Fishing Ground No. 3).

Discussion

1. Errors assigned to the fishing method

As mentioned already in the chapter of "method and material", the gears are set in about 3 hours and hauled up usually after 3 hours drifting, and it takes about 12 hours for a whole hauling. Accordingly, besides the influence of the gradient of the soaking time, which is corrected in the construction of formulae, the influence of the duration of the soaking time at respective parts of the gear must be taken into consideration. This means that the apparent distribution pattern along the long-line is considered to reflect exactly a section of the distribution of tuna in the ocean only when the swimming sphere of tuna during the soaking time is regarded to be negligibly small as compared with the scale of the distribution pattern under consideration. But such large pelagic fishes as tuna are commonly recognized as active swimmers, consequently it is necessary to give special consideration to the fact that there is no evidence supporting that individuals regarded to form apparent groups, especially the groups larger than those expressed in previous sections as aggregations, were caught within a limited period, because the distribution of tuna at respective parts along the row of gears represents the integrated pattern during the time from the setting to hauling of respective parts——3 hours in the shortest case and *ca.* 21 hours to up to a whole day in the longest one. It might be effective to find out some clue to clear up this problem, that some characteristics, such as the living or dead state, body length, stomach contents and the degree of the contamination by fission products, are compared with one another among the individuals caught at the neighbouring hooks. But actually, for the reasons mentioned below, the correlation coefficients between the distance among the localities of hooked fishes and these characteristics are too low, as already reported (MAÉDA, 1955) to be available to clear up the problem. The estimated values represent the expected values in the case when all individuals are distributed by chance, and the school formation affects only on the value (observed values — estimated ones). But (observed values — estimated ones) by estimated values is very small in most examples and this seems to support that the contagious or self-spacing degree is not so prominent. Moreover, if it is possible to distinguish the catch at successive hooks attributable to schooling from that caused by the chance distribution, there is still no distinct evidence supporting that various characteristics must resemble one another more closely among the individuals belonging to the same group than among the individuals belonging to different groups. However, it seems not to be so significant to give any definite solution for this problem, because the outline of the distribution pattern can be regarded as nearly by chance, although the distortion of the observed values from the estimated ones might be assessed too largely, as too much concerns were paid to emphasize the distortion of the distribution pattern from the chance distribution in every example of the particular exposition.

On the other hand, the analyzing method adopted in this paper is based on the assumption that only the individuals of a single species are fished by the long-line and the probability of respective hooks being occupied by fishes is quite constant. But actually, a small number of hooks are occupied by sharks, other species of tuna and other fishes, some of baits may be stolen or lost without fishes being hooked. Some fishes might come near the hooks but not attracted by baits, some might only take baits but not be caught by hooks, and some others might be caught once but soon escaped from the hook before they were hauled. Moreover there are probably some individuals which come across the long-line but pass through between the hooks without encountering with any hooks with bait. These factors for errors deform the distribution of fishes into a discontagious pattern and produce lower X(k) than that which can be seen under the ideal conditions. In order to estimate the influences of the above-mentioned factors, the correction must be made at every hook which is not availed for the above-mentioned reasons; and this is a very difficult and troublesome work, though not impossible, because the exact catch rate of respective hooks differs according to their situation in each basket, the order of each basket or both of them. Therefore, it is inevitable that the estimated values are not quite free from any of slight errors. I believe, however, that the trends deduced from the preceding analyses do not differ so much from the actual ones, because the above-mentioned unavailable hooks seem not to be so abundant as compared with the total number of hooks, although no adequate method has been found to check exactly the number of individuals passing through the long-line without being caught by the hooks and then to estimate its proportion to all individuals which might come across the gears.

In addition to the above-mentioned factors for errors, which are all effective to diminish the contagiousness of the observed values, another factor seeming somewhat specific to the long-line, must be taken into consideration. Namely, the occupation of hooks by the individuals makes those hooks unavailable for other individuals of the same species, thus the probability of individuals being caught is much decreased by the sections in which hooks are mostly occupied, this is especially pronounced in heavily occupied parts and in the course of analysis of Series II, because the number of hooks in respective sections is confined to 4, consequently the catch rate of respective sections is obliged to be unified more prominently than actually is, consequently the distribution pattern may be misregarded as less contagious. The tendency to keep a slightly self-spacing pattern as being suggested in Example A 12, A 30, A 33, A 34, A 36, and A 41, which are all considered to contain large schools, can be regarded as reflecting the above-mentioned process, although no decisive method is not yet known to distinguish the self-spacing patterns attributable to the above-mentioned process from those of the essential character.

Besides the above-mentioned errors due to the fishing method itself, there is another error effective on the observed values in Series I and caused by the difference of the way to take the series of catches within 5 consecutive baskets, because there are 5 ways to section a row of gears by 5 consecutive baskets differing according to the situation of the starting point to count the units, and slight differences are expected in the size of catches between these five ways. In order to confirm the degree of this error, several examples, randomly chosen, are sectioned by 5 consecutive baskets starting at various baskets, and the series of the observed values are illustrated in Fig. 19, which indicates that when the total catch is not so small, the general tendency of deviation does not differ so much, although the phase lag of 1 pitch or the appearance or disappearance of discontinuously high or low values may frequently be observed. Accordingly, the magnitude of the deviation considered together, the errors caused by the above-mentioned fact should be taken into consideration when the total catch is less than 60, although it is unnecessary to estimate the series of the observed values being started at baskets other than the first.

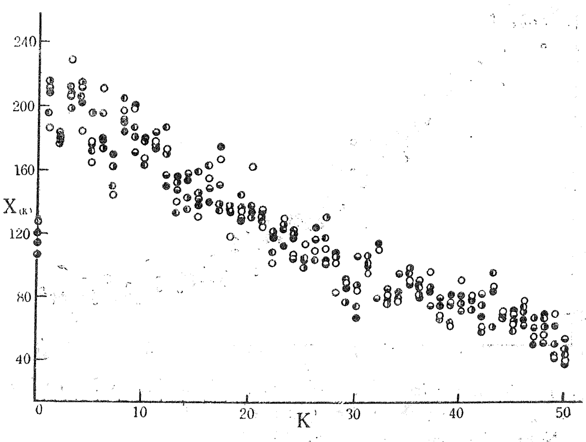


Fig. 19—1. Deviation of the observed values due to from where one starts counting the units (Example B 1).
Note : ● : from the first basket. ○ : from the 2nd basket.
◐ : from the 3rd basket. ◑ : from the 4th basket.
◒ : from the 5th basket.

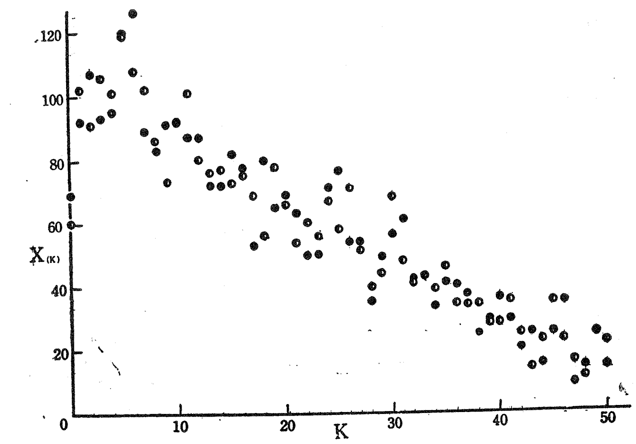


Fig. 19—2. Deviation of the observed values due to from where one starts counting the units (Example B 8).
Note : The same as in Fig. 19—1.

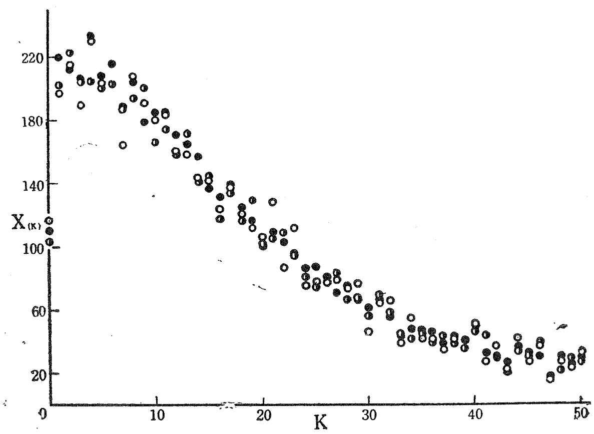


Fig. 19—3. Deviation of the observed values due to from where one starts counting the units (Example B 15).
Note : The same as in Fig. 19—1.

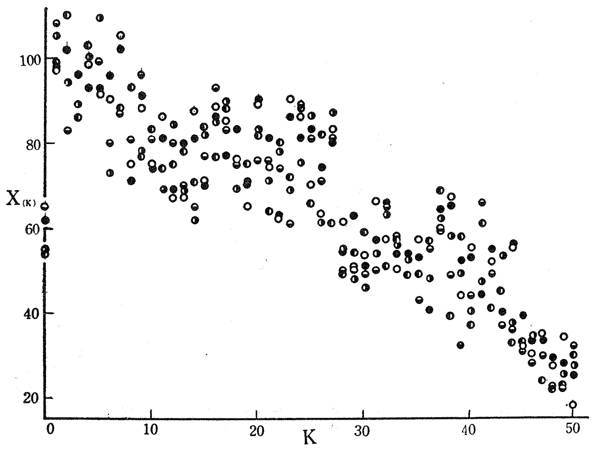


Fig. 19—4. Deviation of the observed values due to from where one starts counting the units (Example Y 1).
Note : The same as in Fig. 19—1.

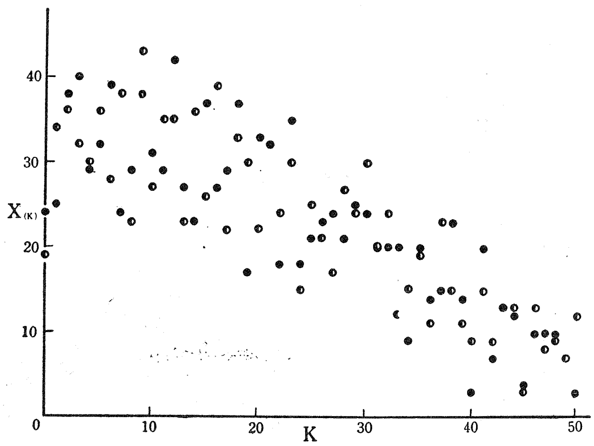


Fig. 19—5. Deviation of the observed values due to from where one starts counting the units (Example Y 8).
Note : The same as in Fig. 19—1.

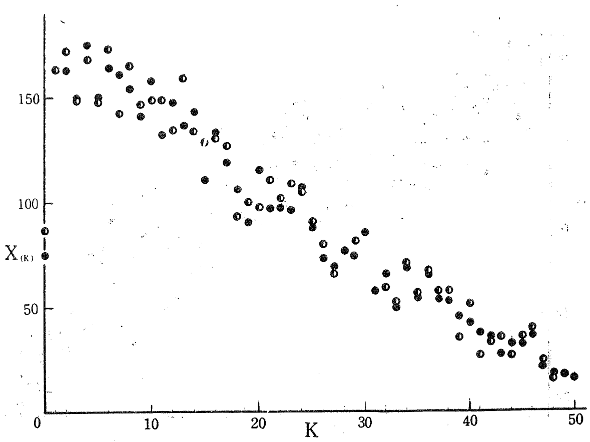


Fig. 19—6. Deviation of the observed values due to from where one starts counting the units (Example A 9).
Note: The same as in Fig. 19—1.

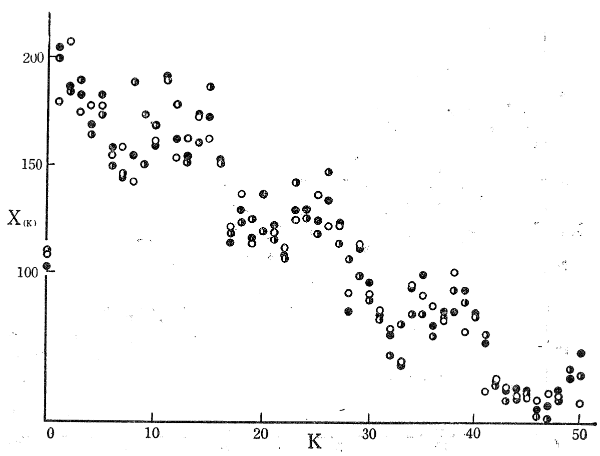


Fig. 19—7. Deviation of the observed values due to from where one starts counting the units (Example A 27).
Note: The same as in Fig. 19—1.

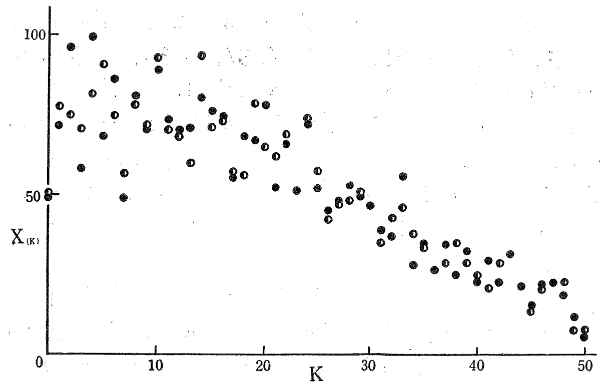


Fig. 19—8. Deviation of the observed values due to from where one starts counting the units (Example A 35).
Note : The same as in Fig. 19—1.

2. Errors contained in the estimated values and the necessity of correcting the influence of the gradient

Besides the errors contained in the observed values, the theoretically estimated values also contain some errors attributable to the uncertainty of constants computed from the actually observed distribution. In constructing the formulae, the gradient of the catch rate was regarded as being simply assigned to the gradient of the soaking time. But the existence of schools of various sizes was ascertained as shown in the results of analyses. Therefore, if some heavily crowded schools are caught at the parts other than the middle of a row, the coefficient of gradient, ΔP, may be frequently over-estimated or rarely under-estimated, because the examples containing schools with their centers in the latter half are observable more frequently than those with the centers in the former half. The typical case is seen in the Example B 1, consequently the effect of this fact must also be taken into consideration, and the distribution pattern in the examples in which large schools are caught in the latter half should be more contagious than supposed on the results of the analyses and *vice versa*.

Moreover, both constants, P and ΔP, contain some accidental and computation errors, because they are estimated on the regression line of the catch rate on the lot number (each lot contains 50 consecutive baskets in this report) and especially the last lot containing less than 50 baskets is excluded from the estimation of the regression line. And this is more influential in the examples showing lower catch rates, although the estimated values in such examples are low and the observed values deviate so widely that sometimes the effect of the above-mentioned errors might be overcome by this deviation or the examples are put aside consideration because of the expectation for large accidental errors, especially of the observed values. On account of the occurrence of these errors, the constants for the Examples B 17, B 19, Y 1, Y 5, A 19, A 21, A 29, A 31, A 32, A 37, A 38, A 39 and A 41 had to be re-estimated, because the estimated values in which the influence of the gradient is taken into consideration were shown incorrectly as if they were lower than the values in which the influence is put aside the consideration, the truth is, however, that the values taking the influence into consideration have to take theoretically higher values without regard to the direction of the gradients than those putting the influence aside the consideration.

In contrast with the formulae in which the influence of the gradients is taken into consideration, the formulae in which the influence of the gradients is put aside consideration are more or less rid of the errors due to the above-mentioned cause.

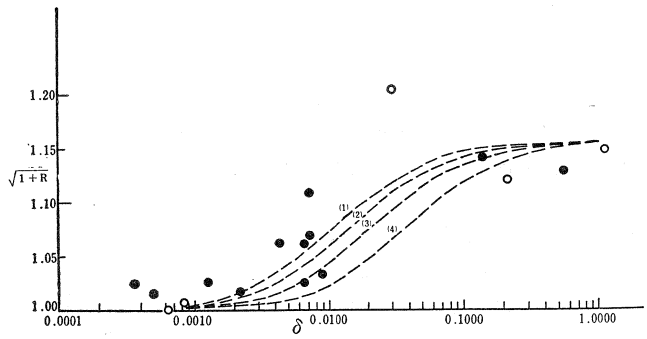


Fig. 20. $\delta - \sqrt{1+R}$ relation graph of big-eye tuna.
Note : Solid circle : δ is positive. White circle : δ is negative.
(1): M=400, (2): M=300, (3): M=200 and (4) M=100.

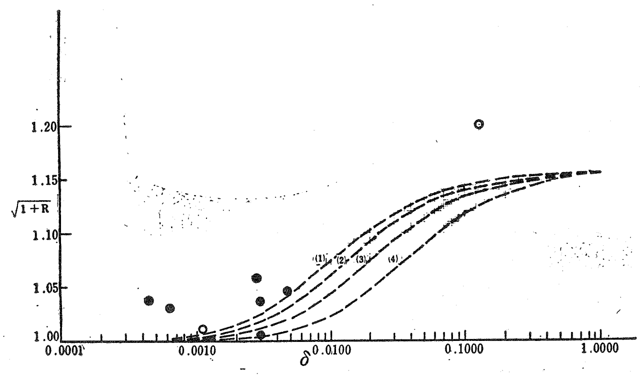


Fig. 21. $\delta - \sqrt{1+R}$ relation graph of yellow-fin tuna.
Notes are the same as in Fig. 20.

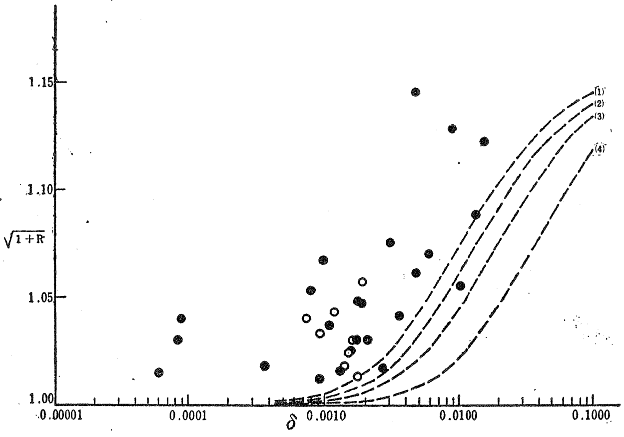


Fig. 22. $\delta-\sqrt{1+R}$ relation graph of albacore.
Notes are the same as in Fig. 20.

For this reason, in order to discuss upon the necessity of correcting the gradients in the corrected formulae which are considered to contain more accidental errors than the formulae in which the influence of gradients is put aside consideration, the relation between δ and square root of (corrected value / uncorrected value) at $k=0$ where the difference between both estimated values is the most pronounced was examined, as P and $\varDelta$P, consequently δ are represented as squares in the formulae. The results are shown in Figs. 20. 21 and 22. While, the corresponding rate can be estimated quite theoretically by the following procedures:

The corrected value : $\frac{mN(N-1)}{2}P_0{}^2\left[1+(m+1)\delta+(m+1)(2m+1)\frac{\delta^2}{6}\right]$

While the uncorrected value : $\frac{mN(N-1)}{2}\left(P_0+\frac{m}{2}\varDelta P\right)^2$

Set $$\frac{\text{corrected value}}{\text{uncorrected value}}=1+R$$

$$1+R=\frac{1+(m+1)\delta+(m+1)(2m+1)\frac{\delta^2}{6}}{1+m\delta+\frac{m^2}{4}\delta^2}$$

and $$\left(\frac{3R-1}{12}m^2-\frac{m}{2}-\frac{1}{6}\right)\delta^2+(mR-1)\delta+R=0$$

By substituting 400, 300, 200 and 100, for *m*, theoretical curves showing the relation between δ and the rate, (corrected value / uncorrected value), were pursued and they are also shown in these figures. If the computed values of the corrected formulae contain no computation error, the point should be located near the curve representing the relation at 400 baskets, but actually the computed values in these figures are higher than the theoretical ones, and this seems to indicate that the correction was made too much beyond the adequate degree. But two other examples of big-eye tuna (Fig. 20), the same number of other examples of yellow-fin tuna (Fig. 21) and nine other examples of albacore (Fig. 22), in which the rate is lower than 1.00, are not included in these figures for the reasons mentioned already. This fact considered together, it may be said safely that the actually computed values are considered to be distributed at both sides of the theoretical curve representing the relation at 400 baskets. Then, the ratio, $\frac{(1+R_{comp.})-(1+R_{theor.})}{(1+R_{theor.})}$ should be taken into consideration [here $(1+R_{comp.})$ indicates the rate (corrected value/uncorrected value) actually computed, while $(1+R_{theor.})$ indicates theoretically estimated one], the numerator of this term indicates the computation error. Then it becomes clear that there are many examples in which the computation error exceeds the theoretical ratio. Moreover, it is also suggested, from these diagrams, that most of the actually computed values and theoretical ones are not so large, and this seems to indicate that it is unnecessary to make any corrections for the influence of the gradients when the degree of the deviation of the observed values from the estimated ones is considered together. But, before the correction of the influence of the gradient is accepted as dispensable, a little more consideration must be paid. And here the relation among the rate between the both estimated values, the number of baskets and δ (per basket) was examined theoretically more extensively. The results are represented in Fig. 23, which seems

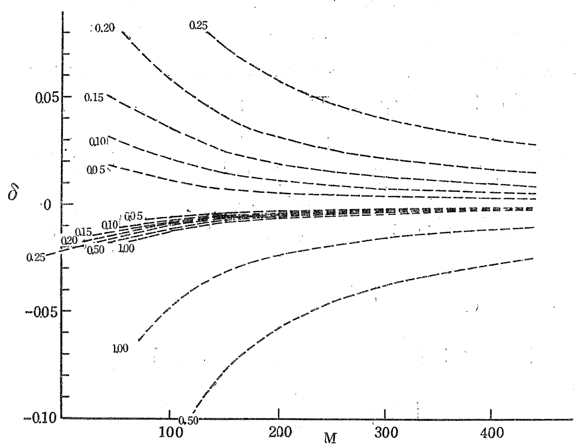


Fig. 23. Theoretical relation curves between M and δ.
Note : Numbers in the figure indicate various values of "R".

to show the following trends :

(1) Theoretical R does not exceed 0.15 at usual length ($300 < m < 400$) and at usual δ (smaller than 0.01).

(2) R never exceed 0.5 at any large δ.

(3) When $\delta < -0.05$, R is also smaller than 0.5.

(4) While, when $-0.003 < \delta < 0$, R increases sharply with decrease in δ.

(5) The highest R is expected at $-0.015>\delta>-0.030$.
Accordingly, when it is requested to show the values in the corrected type more acculately, one or all of the following methods will bring the satisfactory results:
(1) Judging from the last two of the preceding terms, when δ takes a negative small value, the corrected values are computed better by replacing ΔP and P_0 by $-\Delta P$ and $P_0(1+m\delta)$, respectively.
(2) To adopt one of the factor numbers of m as the length of lot for estimating the regression line is effective as the influence of the residual part is removed.
(3) Otherwise, at first estimate ΔP from the regression line, and then compute P_0 from the equation $N=\sum_{i=1}^{M}(P_0+i\Delta P)$. (The constants in Examples B 17, B 19, Y 1, Y 5, A 19, A 21, A 29, A 31, A 32, A 37, A 38, A 39 and A 41 were re-computed by this method).
(4) Compute the corrected values by $(1+R_{\text{theor.}})\times$(uncorrected one).

3. Consideration upon the more advanced method —— 1. Interval method

As mentioned already in the section about the notes for decoding the diagrams, X(k) represents merely the theoretical number of the occurrence of the couples of individuals caught at the hooks spaced by k section-intervals (or hook-intervals), but the question concerning whether some intermediate hooks are occupied or not is left quite intact. Accordingly, the distribution pattern cannot be analyzed solely theoretically, but it is necessary to refer to the original records in which the occupied or intact states of respective hooks are shown in detail. For this reason, in order to make it possible to analyze quite theoretically, the following devices are proposed newly, in which the theoretical number of the individuals spaced by k intervals from the adjoining ones is represented.

1) Uncorrected form

Let us set that N individuals are caught at hooks scattered by chance along a row of gears, being constituted of m consecutive baskets of equal length and respectively with H hooks. By representing k as $k=a(H+1)+R$, separating it into the part divisible by the basket length and the remainder, the hooks spaced by k hook-intervals from respective hooks in the ith basket are shown in Table 4. Here a is a positive integer and varies from 0 to m, while R varies from 0 to H. Thus, when $R=0$, there are H hooks in the $(i+a)th$ basket spaced by k hook-intervals from respective hooks in the ith basket (i varies from 1 to $m-a$), but no hook is present in the $(i+a+1)th$ basket (i varies from 1 to $m-a-1$). On the other hand, the probability of the occurrence of individual at each hook is $P=\frac{N}{Hm}$, and the probability of both terminal hooks being occupied by individuals is P^2. And, there are $(aH-1)$ hooks between the both terminal hooks and the probability of the occurrence of the cases when the hooks are not occupied successively is Q^{aH-1}, here

$Q=1-P$. Consequently, the expected number of the individuals, the adjoining individuals of which are caught at the hooks spaced by k hook-intervals from the former, $\psi_{(k)}$, is represented as follows :

$$\psi_{(k)}=HP^2Q^{aH-1}(m-a) \quad \cdots\cdots (49)$$

By the same way as this, the formula applicable to at $R\neq 0$ is represented as follows:

$$\psi_{(k)}=P^2Q^{aH+R-1}(H-R)(m-a)+P^2Q^{aH+R-2}(R-1)(m-a-1) \quad \cdots\cdots (50)$$

That is to say, these formulae are obtained multiplying the theoretical value in the spacing method by the continuous product of the probability of the intermediate hooks being not occupied by fishes. Accordingly, the formulae of the interval method of the corrected types are represented as follows, here the details of the constructing process are omitted.

2) The formulae in which the influence of the gradient of the catch rate is taken into consideration ($H=4$)

R = 0

$$\psi_{(k)}=\sum_{i=1}^{m-a}\Big\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4 \sum_{r=0}^{3}(Q-i\Delta P)^r(Q-\overline{i+a}\Delta P)^{3-r}\Big\} \quad \cdots\cdots (51)$$

R = 1

$$\psi_{(k)}=\sum_{i=1}^{m-a}\Big\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4 \sum_{r=1}^{3}(Q-i\Delta P)^r(Q-\overline{i+a}\Delta P)^{4-r}\Big\} \quad \cdots\cdots (52)$$

R = 2

$$\psi_{(k)}=\sum_{i=1}^{m-a}\Big\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4 \sum_{r=2}^{3}(Q-i\Delta P)^r(Q-\overline{i+a}\Delta P)^{5-r}\Big\}+\sum_{i=1}^{m-a-1}\Big\{(P_0+i\Delta P)(P_0+\overline{i+a+1}\Delta P)\prod_{b=1}^{a}(Q-\overline{i+b}\Delta P)^4\Big\} \quad \cdots\cdots (53)$$

R = 3

$$\psi_{(k)}=\sum_{i=1}^{m-a}\Big\{(P_0+i\Delta P)(P_0+\overline{i+a}\Delta P)\prod_{b=1}^{a-1}(Q-\overline{i+b}\Delta P)^4(Q-i\Delta P)^3(Q-\overline{i+a}\Delta P)^3\Big\}$$
$$+\sum_{i=1}^{m-a-1}\Big[(P_0+i\Delta P)(P_0+\overline{i+a+1}\Delta P)\prod_{b=1}^{a}(Q-\overline{i+b}\Delta P)^4\Big\{(Q-i\Delta P)+(Q-\overline{i+a+1}\Delta P)\Big\}\Big] \quad \cdots\cdots (54)$$

R = 4

$$\psi_{(k)} = \sum_{i=1}^{m-a-1} \left\{ (P_0 + i\Delta P)(P_0 + \overline{i+a+1}\Delta P) \prod_{b=1}^{a} (Q - \overline{i+b}\Delta P)^4 \right.$$

$$\left. \sum_{r=0}^{2} (Q - i\Delta P)^r (Q - \overline{i+a+1}\Delta P)^{2-r} \right\} \cdots\cdots (55)$$

here $Q = 1 - P_0$.

3) The formulae in which the influence of the difference of the catch rate according to the depth is taken into consideration ($\boldsymbol{H} = 4$)

P_1 : catch rate of the hooks located at the shallower depth level.
P_2 : catch rate of the hooks located at the deeper depth level.
$Q_1 = 1 - P_1$, $Q_2 = 1 - P_2$

R = 0

$$\psi_{(k)} = 2(m-a)(Q_1 Q_2)^{2(a-1)+1} (P_1^2 Q_2 + P_2^2 Q_1) \cdots\cdots (56)$$

R = 1

$$\psi_{(k)} = (m-a)(Q_1 Q_2)^{2a} (2 P_1 P_2 + P_2^2) \cdots\cdots (57)$$

R = 2

$$\psi_{(k)} = 2(m-a)(Q_1 Q_2)^{2a} P_1 P_2 Q_2 + (m-a-1)(Q_1 Q_2)^{2a} P_1^2 \cdots\cdots (58)$$

R = 3

$$\psi_{(k)} = (m-a)(Q_1 Q_2)^{2a} P_1^2 Q_2^2 + 2(m-a-1)(Q_1 Q_2)^{2a} P_1 P_2 Q_1 \cdots\cdots (59)$$

R = 4

$$\psi_{(k)} = (m-a-1)(2 P_1 P_2 Q_1 Q_2 + P_2^2 Q_1^2)(Q_1 Q_2)^{2a} \cdots\cdots (60)$$

4) The formulae in which the influences of both factors shown in sections 2 and 3 are taken into consideration ($\boldsymbol{H} = 4$)

$P_1 + i\Delta P_1$: catch rate of the shallower hooks in the *ith* basket.
$P_2 + i\Delta P_2$: catch rate of the deeper hooks in the *ith* basket.
$Q_1 = 1 - P_1$, $Q_2 = 1 - P_2$.

R = 0

$$\psi_{(k)} = \sum_{i=1}^{m-a} \left[\!\left[\left[(P_1 + i\Delta P_1)(P_1 + \overline{i+a}\Delta P_1) \left\{ (Q_1 - i\Delta P_1)(Q_2 - i\Delta P_2)^2 \right. \right. \right. \right.$$

$$\left. + (Q_2 - i\Delta P_2)^2 (Q_1 - \overline{i+a}\Delta P_1) \right\} + (P_2 + i\Delta P_2)(P_2 + \overline{i+a}\Delta P_2)(Q_1 - i\Delta P_1)$$

$$\left. (Q_1 - \overline{i+a}\Delta P_1) \left\{ (Q_2 - i\Delta P_2) + (Q_2 - \overline{i+a}\Delta P_2) \right\} \right]$$

$$\left. \prod_{b=1}^{a-1} (Q_1 - \overline{i+b}\Delta P_1)^2 (Q_2 - \overline{i+b}\Delta P_2)^2 \right]\!\!\right] \cdots\cdots (61)$$

R = 1

$$\psi(k)=\sum_{i=1}^{m-a}\Big[(Q_1-i\Delta P_1)(Q_1-\overline{i+a}\Delta P_1)\prod_{b=1}^{a-1}(Q_1-i+b\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2$$

$$\Big\{(P_1+i\Delta P_1)(Q_2-i\Delta P_2)^2\ (P_2+\overline{i+a}\Delta P_2)+(P_2+i\Delta P_2)(P_2+\overline{i+a}\Delta P_2)$$

$$(Q_2-i\Delta P_2)(Q_2-\overline{i+a}\Delta P_2)+(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)(Q_2-\overline{i+a}\Delta P_2)^2\Big\}\Big] \qquad \cdots\cdots (62)$$

R = 2

$$\psi(k)=\sum_{i=1}^{m-a}\Big[(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)(Q_1-\overline{i+a}\Delta P_1)(Q_2-\overline{i+a}\Delta P_2)$$

$$\prod_{b=1}^{a-1}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big\{(P_1+i\Delta P_1)(P_2+\overline{i+a}\Delta P_2)(Q_2-i\Delta P_2)$$

$$+(P_2+i\Delta P_2)(P_1+\overline{i+a}\Delta P_1)\ (Q_2-\overline{i+a}\Delta P_2)\Big\}\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[(P_1+i\Delta P_1)(P_1+\overline{i+a+1}\Delta P_1)\prod_{b=1}^{a}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big] \qquad \cdots\cdots (63)$$

R = 3

$$\psi(k)=\sum_{i=1}^{m-a}\Big[(P_1+i\Delta P_1)(P_1+\overline{i+a}\Delta P_1)(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)^2(Q_1-\overline{i+a}\Delta P_1)$$

$$(Q_2-\overline{i+a}\Delta P_2)\prod_{b=1}^{a-1}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big]$$

$$+\sum_{i=1}^{m-a-1}\Big[\Big\{(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(Q_1-i\Delta P_1)$$

$$+(P_1+i\Delta P_1)(P_2+\overline{i+a+1}\Delta P_2)(Q_1-\overline{i+a+1}\Delta P_1)$$

$$\prod_{b=1}^{a}(Q_1-\overline{i+b}\Delta P_1)^2(Q_2-\overline{i+b}\Delta P_2)^2\Big] \qquad \cdots\cdots (64)$$

R = 4

$$\psi(k)=\sum_{i=1}^{m-a}\Big[\Big\{(P_2+i\Delta P_2)(P_1+\overline{i+a+1}\Delta P_1)(Q_1-i\Delta P_1)(Q_2-i\Delta P_2)$$

$$+(P_2+i\Delta P_2)(P_2+\overline{i+a+1}\Delta P_2)(Q_1-i\Delta P_1)\ (Q_1-\overline{i+a+1}\Delta P_1)$$

$$+(P_1+i\varDelta P_1)(P_2+\overline{i+a+1}\varDelta P_2)(Q_1-\overline{i+a+1}\varDelta P_1)(Q_2-\overline{i+a+1}\varDelta P_2)$$

$$\prod_{b=1}^{a}(Q_1-\overline{i+b}\varDelta P_1)^2(Q_2-\overline{i+b}\varDelta P_2)^2\Big] \quad\cdots\cdots (65)$$

Thus, the influence of the intermediate hooks being occupied or not is theoretically solved, although the values in which the influence of gradient is taken into consideration are practically too complex to compute and moreover considerable errors are expected during computation.

4. Further consideration upon the more advanced method —— 2. Analyzing method for the order of the arrangement of the intervals

There remains still another factor which might evoke a confusion when the trends deduced from the results of analyses are applied to those observable in the actually recorded pattern. This is the order of the arrangement of individuals spaced by the respective intervals.

That is to say, even when all individuals are scattered by chance along the row of gears, there may occur some successively arranged short intervals, besides some other successive short intervals are formed by the school formation and their actual number is naturally to be estimated. To solve this, the following method is proposed under the name of "arrangement analysis".

Let us set that N individuals are distributed by chance along a row of gears being constituted of m consecutive baskets. The total number of intervals between individuals is $(N-1)$, while the number of intervals as long as or shorter than k hook-intervals is $\sum_{k=1}^{k}\psi_{(k)}$.

Accordingly, the expected number of the occurrence of W consecutive intervals, each is equal to or shorter than k, $S_{(W.k)}$, is represented as follows:

$$S_{(W.k)}=\{P_{i(k)}\}^W\{Q_{i(k)}\}[2+(N-W-2)\{Q_{i(k)}\}] \quad\cdots\cdots (66)$$

here $\dfrac{\sum_{k=1}^{k}\psi_{(k)}}{N-1}=P_{i(k)}=1-Q_{i(k)}$.

Here, when $\psi_{(k)ob.}$ which is the actually observed $\psi_{(k)}$ is continuously higher than $\psi_{(k)theor.}$ which is $\psi_{(k)}$ theoretically computed at k from 0 to k_1, $S_{(W.k_1)}$ at respective W can be computed theoretically by substituting k_1 for k. The corresponding observed values, $S_{(W.k_1)ob.}$, can also be obtained from the original record. Accordingly, the number of schools being constituted of $(W+1)$ individuals is theoretically shown to be $\{S_{(W.k_1)ob.}-S_{(W.k_1)theor.}\}$.

It is, however, very doubtful if the accurate results can be obtained from these two series of analyses, because not only the estimation of $\psi_{(k)}$, consequently $S_{(W.k)}$

too, in which the influence of the gradient is taken into consideration, is very difficult, but also the computation errors are highly expected, together with the fact that $S_{(W.k)ob.}$ at respective W are considered not to be so large and accordingly accidental errors are fairly expected. Thus, here only the above-mentioned theoretical method to correct the errors assigned to the conception of $X_{(k)}$ is shown.

5. Consideration upon the factors affecting the gradient and the difference of the catch rate according to the depth

1) Consideration upon the factors affecting the gradient of distribution

In the operations, the setting of gears is begun with a certain station at about mid-night and ended in the other station spending 3 or 4 hours, then the boat is let drift for 3 hours or thereabout near the ending terminal of the gears, and the hauling of the gears is carried on in the counter direction, namely from the ending point of the setting towards the beginning point spending 12 hours or longer. Consequently, all the gears are soaked for *ca.* 3 hours at dawn, while the portion of gears near the starting point of the setting is soaked for about 6 times as long as the portion near the ending point.

Accordingly, at first it is set that the feeding activity is rather invariable through out the whole day. (1) When the fishes take baits after the hooks reach the settled levels, the increase of the catch rate is simply proportional to the soaking time; (2) but when the baits are taken while they are still sinking or contrarily on the way of the hauling at the shallower levels than the settled ones, the catch rate does not increase with the soaking time, but it is assumed to be rather constant. If it is assumed that most individuals are caught in the limited time, for example at dawn and dusk, as commonly recognized in many coastal and pelagic fishes, while in other time the probability of the occurrence of individuals at the hooks per unit time is very low and invariable and that the fishes take baits at only the settled levels; (3) When the setting of gears is begun at dawn after the fishes fed actively and the hauling is finished in dusk before the beginning of the active feeding, though such a case is hardly met with during the actual operations of professional boats, the catch rate is low throughout, but increases with the soaking time. (4) When the whole gears are set before the beginning of the active feeding at dawn and hauled up after the active feeding at dusk——such a case is considered to be frequently met with in the actual operations of professional boats——, the catch rate must be high throughout and show abrupt increases after a certain part of the gears. (5) If the whole gears are set before the beginning of the active feeding at dawn and hauled up before the beginning of the active feeding at dusk or the active feeding is missing at dusk, the catch rate may be pretty high and slightly increase with the soaking time. (6) When the setting of gears is begun after the active feeding at dawn is through or the active feeding is missing at dawn and the hauling of gears is finished after the active feeding at dusk, the catch rate is high only near the last part of the hauling, but very low near the beginning parts. Now it is assumed that the baits are taken during the sinking or hauling up. (7) When the setting of gears is begun after the active feeding at dawn and the whole gears is hauled up before the beginning of the active feeding at dusk, the constant but extremely low catch rate may be observed throughout the whole row. (8) When the setting of gears is begun during the active feeding at dawn and the hauling is finished after the beginning of the active feeding at dusk, there must be shown the abruptly high catch rate at a certain part along the row, although the catch rate is pretty high throughout. (9) When the gears are set during the active feeding at dawn and wholly hauled up before the beginning of the active feeding at dusk, the catch rate may be kept uniformly without regard to the soaking time. (10) And when the setting of gears is begun after the active feeding at dawn and the hauling is finished after the active feeding at dusk, the catch rate is high only at the part being hauled up during the active feeding.

Here, in order to examine which of the above-mentioned cases is the most probable, the following consideration is made.

Set that the number of individuals caught in the *ith* basket from the beginning point of the hauling of the gears being constituted of m baskets is represented as $(P_0+i\Delta P)$. The number of individuals caught in the $0th$ basket is P_0 and that in the last basket is $(P_0+m\Delta P)$. Further it is assumed that the catch rate increases with the soaking time.

$$P_0+m\Delta P=6P_0$$

Consequently $\Delta P=\frac{5}{m}P_0$

Further $\delta=\frac{\Delta P}{P_0}=\frac{5}{m}\fallingdotseq\frac{5}{400}=0.0125$

But δ in the actual examples is much lower than this, although δ is regarded as significant in most examples, except for those which contain only several individuals. This seems to suggest that the initial catch rate (this means the catch rate per unit time while the whole gears are soaked.) is relatively higher, and the catch rate does not increase in proportional to the soaking time and also that the catch rate is mostly not constant, but increasing slightly with the soaking time. Accordingly, the cases (2), (3), (6) and (10) and also (1), (7) and (9) are rejected. While, when the individuals are caught in the manner shown in cases (4) or (8), the population may be misregarded as containing 2 schools respectively located around the first basket and the parts hauled up after or during the active feeding at dusk (at or after the 260th basket), because the influence of the gradient is corrected on the assumption that the individuals are hooked in the manner shown in case (5) ; consequently the increase of the catch rate outside the time when the whole gears are soaked is simply proportional to the increase of the soaking time and this affects so as to smooth the abrupt increase of the catch. While, Figs. 7,9 and 11 examined in detail, it becomes clear that there are a considerable number of examples supporting the gradual increase of the catch rate or showing an intermediate grade between the gradual and abrupt increases, but only a few examples clearly suggesting the abrupt increases. On the other hand, as there are many examples in which the existence of schools is recognized around the 250th basket, the existence of such schools was examined again carefully on Figs. 7, 9 and 11 on purpose to judge whether they are essential ones or attributable to that the basic assumptions are so different from the actual state. There are, however, scarcely any examples which are misregarded as containing a school around the 250th basket or the first one on account of regarding the abrupt increase of the catch as the gradual one. Accordingly, it seems not to be apart so far from the actual state to regard the increase of the catch rate as gradual, although to regard the catch increase as abrupt makes it easier to estimate the theoretical values in the interval method, consequently those of the arrangement analysis, in which the influence of the gradient of the catch is taken into consideration.

Next, there arises another question worthy to be examined carefully, what factors influence P_0. Here, P_0 is thought as the catch per basket during the time when the whole gears are soaked. Accordingly, the density of individuals, the duration of the soaking time and the lag of the time when the whole gears are soaked are considered to be strongly influential. Among these, however, the influence of the density, by which the total catch is determined, seems to be located aside the problem here treated

Table 11. Operation time, P_0/N and δ of respective operations (Big-eye tuna).

St.	Setting		Hauling		$\frac{P_0}{N}$	δ
	Begin	End	Begin	End		
1	23.47	03.40	06.31	21.42	0.001,26	0.007,084
2	23.40	03.20	06.30	21.54	−0.000,07	−0.216,079
3	23.31	03.02	06.40	19.50	0.001,21	0.008,958
4	23.37	03.13	06.27	19.30	0.000,03	0.543,507
5	23.30	03.05	06.57	20.25	0.001,25	0.007,107
6	23.30	03.05	06.40	20.11	0.001,24	0.006,625
7	23.48	03.27	06.30	21.53	0.001,60	0.004,288
8	23.45	03.28	06.30	19.35	−0.000,12	−1.272,854
9	23.50	03.28	06.38	21.54	0.002,59	0.000,488
10	23.44	03.24	06.21	20.03	0.003,32	−0.000,844
11	23.55	03.36	06.30	19.38	0.002,69	0.000,358
12	—	03.28	06.30	19.31	0.002,06	0.002,219
13	23.46	03.18	06.31	19.31	0.001,33	0.006,533
14	23.48	03.27	06.30	19.19	0.002,34	0.001,251
15	23.48	03.25	06.27	19.34	−0.000,62	−0.030,439
16	23.49	03.19	07.00	19.15	0.000,11	0.137,025
17	23.55	03.30	07.00	20.56	——	——
18	23.48	03.33	06.55	21.25	0.003,13	0.002,170
19	23.50	03.05	07.50	20.19	——	——

Table 12. Operation time, P_0/N and δ of respective operations (Yellow-fin tuna).

St.	Setting		Hauling		$\frac{P_0}{N}$	δ
	Begin	End	Begin	End		
1	23.47	03.40	06.31	21.42	——	——
2	23.40	03.20	06.30	21.54	0.003,51	−0.001,103
3	23.31	03.02	06.40	19.50	0.001,88	0.003,693
4	23.37	03.13	06.27	19.30	0.002,11	0.002,007
5	23.30	03.05	06.57	20.25	——	——
6	23.30	03.05	06.40	20.11	0.002,57	0.000,631
7	23.48	03.27	06.30	21.53	0.002,65	0.000,440
8	23.45	03.28	06.30	19.35	0.001,90	0.002,851
9	23.50	03.28	06.38	21.54	0.001,82	0.003,026
10	23.44	03.24	06.21	20.03	−0.000,13	−0.133,190

Table 13. Operation time, P_0/N and δ of respective operations (Albacore).

St.	Setting		Hauling		$\frac{P_0}{N}$	δ
	Begin	End	Begin	End		
1	03.20	08.00	11.00	03.10	0.003,76	−0.001,419
2	06.15	09.10	13.30	00.00	0.005,14	−0.001,771
3	03.35	07.00	10.25	01.00	0.001,94	0.002,701
4	03.25	07.15	10.30	00.30	0.000,72	0.015,591
5	03.32	06.45	10.30	00.30	0.002,07	0.001,541
6	03.40	05.10	10.55	01.40	0.002,88	−0.000,366
7	03.35	07.00	11.05	01.30	0.001,37	0.005,975
8	03.30	07.10	11.20	03.20	0.004,10	−0.001,909
9	05.00	08.20	13.05	01.20	0.001,23	0.010,197
10	04.00	07.40	11.05	01.00	0.003,73	−0.001,480
11	05.25	08.12	12.10	02.02	0.003,03	0.004,717
12	02.55	06.50	09.50	23.50	0.002,38	0.000,912
13	02.55	06.30	10.00	00.05	0.001,06	0.008,911
14	02.45	06.30	10.00	23.11	0.002,77	0.000,083
15	02.45	05.55	10.25	00.50	0.001,69	0.003,584
16	03.00	06.00	10.25	23.58	0.003,37	−0.000,930
17	02.53	06.18	10.04	03.00	0.003,29	−0.000,749
18	04.10	07.00	10.43	23.24	0.004,15	0.001,593
19	03.00	06.40	10.00	23.16	——	——
20	04.40	07.50	11.25	23.40	0.003,89	−0.001,176
21	02.50	06.30	10.00	23.20	——	——
22	02.55	07.50	10.55	23.43	0.002,63	0.000,964
23	03.45	07.13	10.00	23.28	0.001,99	0.002,076
24	02.50	06.24	10.20	01.30	0.002,73	0.000,061
25	03.15	06.42	09.50	23.43	0.002,20	0.001,299
26	02.40	06.40	09.50	23.55	0.002,47	0.000,803

27	02.50	06.20	09.50	23.55	0.001,48	0.004,839
28	02.50	06.30	10.00	01.20	0.001,84	0.003,051
29	02.50	06.20	10.08	23.46	——	——
30	03.00	06.30	10.00	23.25	0.002,18	0.001,672
31	02.50	06.40	10.00	23.00	——	——
32	02.45	06.30	09.50	23.30	——	——
33	02.50	06.30	09.55	00.28	0.002,31	0.001,115
34	03.30	07.10	10.32	00.30	0.002,19	0.001,749
35	03.00	06.30	10.25	00.55	0.002,15	0.001,889
36	03.10	06.25	10.23	23.40	0.002,77	0.000,088
37	02.55	06.10	10.10	01.05	——	——
38	03.05	06.30	10.02	23.25	——	——
39	03.05	06.30	10.15	00.05	——	——
40	03.25	06.50	10.25	23.20	0.000,82	0.013,670
41	03.25	07.00	10.57	00.37	——	——

consequently it is excluded in the following discussion. Accordingly, $\left(\frac{P_0}{N}\right)$ which indicates the catch rate per basket per individual of the total catch during the time when the whole gears are soaked, should be adopted in place of P_0. But the deviation of the duration and the lag of the time when the whole gears are soaked are very small in respective species [big-eye tuna, duration: 2 h 51 m —3 h 52 m, beginning of the time when the whole gears are soaked: 03.02—03.40, ending of the same time: 06.21—07.00, yellow-fin tuna, duration: 2 h 51m—(3 h 30 m)—3 h 52m, beginning of the whole soaking: 03.02—03.40, ending of the whole soaking: 06.21—06.57, albacore, duration: 3 h 00 m —(4 h 00 m)—5 h 45 m, beginning of the whole soaking: 05.10—(07.00)—09.10, ending of the whole soaking: 09.50—(11.00)—13.30]. Moreover, any clear relation is not recognizable between the duration or lag of the time of the whole soaking and $\left(\frac{P_0}{N}\right)$. Thus, these can not be the factors influential enough to cause the large deviation of $\left(\frac{P_0}{N}\right)$ [big-eye tuna: $-0.000{,}62 \sim 0.003{,}32$, yellow-fin tuna: $-0.000{,}13 \sim 0.003{,}51$, albacore: $0.000{,}72 \sim 0.005{,}14$]. On the other hand, it is quite obvious that $\left(\frac{P_0}{N}\right)$ increases with the decrease in δ or $\frac{\Delta P}{N}$ because $1 = \sum_{i=1}^{m} \frac{P_0}{N}(1+\delta)$. Accordingly, if the factors influential upon $\left(\frac{P_0}{N}\right)$ are searched for, then the factors influential on δ must be also taken into consideration. Thus, the length of the time spent for the whole work from the setting to the hauling and the lag of the time about these works may be supposed to be influential. But either of them can not be the factors causing the large deviation of δ, because there is no clear relation between δ and them and moreover the deviation itself is relatively small as presumable from the discussions made about the factors influential upon $\left(\frac{P_0}{N}\right)$.

Besides the above-mentioned factors, the locality of schools is also very probably influential, because P_0 and ΔP are computed from the regression line of the catch within respective lots consisting each of 50 consecutive baskets on the lot number. But, none of the so clear relations can be obtained here, either. None of the environmental factors were found influential on P_0/N and δ, although the vertical distributions of the temperature and chlorinity were observed near the respective ending points of the setting of gears. And this is attributable to the following two causes: (1) the environmental factors near the ending point of the setting of gears can not be regarded as representing the environmental factors throughout the row of gears, because the observed environmental factors deviate so widely notwithstanding that the changes found in the locality and the date of observations and moreover the distance between the adjoining stations of observations are small as compared with the considerable length of the rows of gears that frequently the distance between certain parts within a single row might exceed that between adjoining rows, and (2) $\left(\frac{P_0}{N}\right)$ and δ are represented as the average values throughout the row, along which, however, a considerable variation can very probably be found in environmental factors.

2) Consideration upon the factors influential on the difference of the catch rate according to the depth

Many factors, such as the distribution of prey organisms, chlorinity, temperature, light intensity, duration of the sinking time of baits from surface to the settled depth

Table 14. Catch rates of hooks located at two different depth levels and temperature at 100 m and 150 m layers (big-eye tuna).

St.	Catch rate		Temperature (°C)	
	P_1	P_2	100 m	150 m
1	0.0495	0.1085	27.5	17.91
2	0.0546	0.0784	27.57	16.03
3	0.0396	0.0821	26.9	15.4
4	0.0298	0.0625	26.83	17.49
5	0.0587	0.1075	27.3	25.69
6	0.0655	0.1448	27.2	22.2
7	0.0497	0.0829	27.3	23.64
8	0.0208	0.0917	27.25	18.75
9	0.0875	0.1639	26.8	16.85
10	0.0465	0.1042	27.22	19.05
11	0.0391	0.0852	26.6	24.1
12	0.0299	0.0726	26.31	14.50
13	0.0297	0.0678	26.71	26.63
14	0.0337	0.0758	25.43	15.42
15	0.0420	0.1022	26.78	18.55

16	0.0377	0.0866	27.1	26.34
17	0.0432	0.0961	25.6	25.73
18	0.0905	0.1992	25.65	16.55
19	0.0726	0.1420	25.85	15.9

Table 15. Catch rates of hooks located at two different depth levels and temperature at 100 m and 150 m layers (Yellow-fin tuna).

St.	Catch rate		Temperature (°C)	
	P_1	P_2	100 m	150 m
1	0.0357	0.0852	27.5	17.91
2	0.0686	0.0812	27.57	16.03
3	0.0645	0.0660	26.9	15.4
4	0.0369	0.0540	26.83	17.49
5	0.0182	0.0223	27.3	25.69
6	0.0320	0.0292	27.2	22.2
7	0.0331	0.0345	27.3	23.64
8	0.0319	0.0375	27.25	18.75
9	0.0292	0.0319	26.8	16.85
10	0.0155	0.0141	27.22	19.05

Table 16. Catch rates of hooks located at two different depth levels and temperature at 100 m and 150 m layers (Albacore).

St.	Catch rate		Temperature (°C)	
	P_1	P_2	100 m	150 m
1	0.0393	0.0772	22.62	(20.60)
2	0.1080	0.1300	21.70	(18.50)
3	0.0914	0.1386	22.40	(20.40)
4	0.0811	0.1108	22.50	(22.39)
5	0.0868	0.1079	21.90	(21.08)
6	0.0553	0.1053	20.83	20.98
7	0.0694	0.0833	21.62	22.50
8	0.0709	0.1289	22.60	21.46
9	0.0433	0.1122	22.20	21.51
10	0.0986	0.1392	21.42	21.43
11	0.0380	0.0802	21.86	21.40
12	0.0537	0.0730	22.65	20.14
13	0.0307	0.0842	22.35	21.72
14	0.0205	0.0642	22.50	21.80
15	0.0385	0.0687	22.61	22.45
16	0.0300	0.0817	21.25	20.72
17	0.0178	0.0219	22.20	20.98
18	0.0212	0.0348	22.49	22.09
19	0.0319	0.0485	22.40	21.12
20	0.0273	0.0485	——	——

21	0.0481	0.1126	21.00	20.08
22	0.0636	0.1185	20.50	19.60
23	0.0541	0.0770	20.62	20.01
24	0.0435	0.0734	20.20	20.00
25	0.0486	0.1000	——	——
26	0.0365	0.0608	20.07	19.52
27	0.0490	0.1035	21.70	20.25
28	0.0327	0.0749	20.96	19.81
29	0.0396	0.0710	20.12	20.43
30	0.0333	0.0722	19.50	17.90
31	0.0235	0.0497	21.46	20.38
32	0.0150	0.0874	20.85	20.68
33	0.0324	0.0500	21.00	20.38
34	0.0374	0.0609	21.80	20.82
35	0.0278	0.0750	21.90	20.92
36	0.0203	0.0595	21.41	21.31
37	0.0464	0.0970	21.00	20.40
38	0.0230	0.0797	21.05	20.37
39	0.0152	0.0665	20.93	20.20
40	0.0365	0.0955	25.40	23.50
41	0.0486	0.0811	23.80	24.50

Temperature enclosed in parentheses indicates that of 200 m layer.

etc., differ according to the depth. It is very probable that the vertical difference of the catch rate may be caused by certain factors which may differ markedly between the levels of shallower and deeper hooks at the stations showing large vertical difference of the catch rate, but not at the stations where the vertical difference of the catch rate is very small. Temperature, one of the actually observed factors, seems to satisfy the above-mentioned conditions. The temperature does not vary so conspicuously in the upper layer shallower than 100 m or in the lower layer deeper than 200 m, while it varies prominently near the level of 150 m, which shows the approximate situation of the thermocline in the surveyed fishing grounds. No clear relation is recognized, although the following trends are seen somewhat clearly. In respective species, the catch rates of the deeper hooks increase with those of the shallower hooks keeping the following relations:

Big-eye tuna : $P_2 = 1.9P_1 + 0.01$

Yellow-fin tuna : $P_2 = 1.25P_1 + 0.005$

Albacore : P_2 increases with P_1, but the deviation is rather large.

Here P_2 is the catch rate of the deeper hooks, while P_1 is that of the shallower hooks. Accordingly, however large or small $(P_2 - P_1)$ may be, $\frac{P_1}{P_2}$ is rather constant, consequently the ratio, estimated value in which the influence of the difference of catch rates is taken into consideration by that putting aside the consideration is rather invariable regardless of the degree of the difference between them. And this seems to make it difficult to find out the factors influential upon the vertical difference of the catch rate. Besides, it was also cleared that the catch rate of yellow-fin tuna at both shallower and deeper hooks increased with the decrease of temperature at 150 m deep, and this suggests that the deeper the thermocline is, the wider the fishes are scattered in the thicker layer, consequently the catch rate is lowered.

Appendix

Application of the method proposed in this paper to the analyses of the data obtained by the different fishing methods

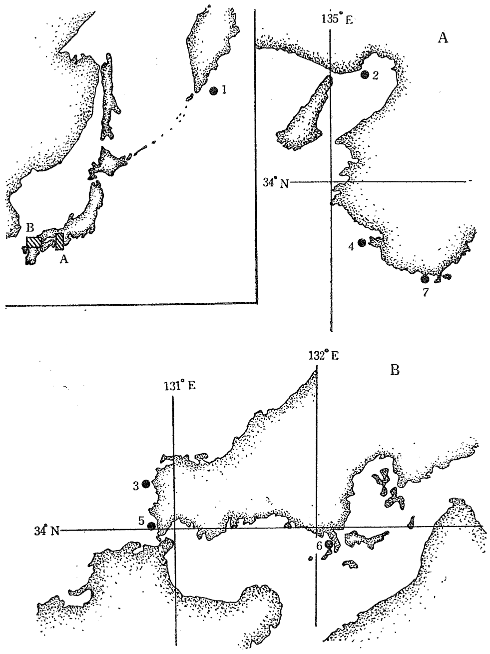


Fig. 24. Sketch chart showing the stations where the examples analyzed in the chapter "Appendix" were obtained.

Note 1 : East of Cape Lopatka (Salmons caught by gill-net).
2 : Off Kobe Harbour (Squids fished by squid-traps).
3 : Off Yatama (Squids angled under the fish-gathering lamp).
4 : Off Seto Marine Biological Laboratory (*Parapristipoma trilineatum* and *Leptscolopsis nagasakiensis* angled under the fish-gathering lamp).
5 : Off Shimonoseki College of Fisheries (*Chrysophrys major* and *Fugu rubripes* angled in the day time along the shore).
6 : Off Tana (*Muraenesox cinereus* caught by long-line).
7 : Near the Cape of Shionomisaki (*Gymnothorax kidako* and *Epinephelus fario* fished by long-line).

1. Application to the analyses of the salmon population caught by gill-net

The salmon off shore fishery of mother-ship type has been re-opened since 1952, and fortunately, I had an opportunity to gather the data of the distribution of fishes on gill-nets in the end of the first fishing season, from the 20th to the 22nd of July, 1952, on board the Hôsyô-maru No. 3, one of the surveying ships of the Nippon Suisan Co. Ltd., at about 100 miles east of Cape Lopatka. One hundred and twenty-eight or nine sections of net, each *ca.* 40 m long, 7.5 m deep and with meshes of about 15. cm sq., were united in a straight series and set in the direction of SSW from a certain fishing station at about 6 p.m. in the evening. The hauling of nets was begun at about 5 a.m. and it took about 4 hours to finish the work. The results of the analyses of the distribution pattern obtained by using MORISITA's method was already published (MAÉDA, 1953), but here a brief discussion is given after the values are converted into the values computed by formulae (1) and (2), in this case one section is adopted as the unit length; the results are shown in Figs. 25 (1) and (2).

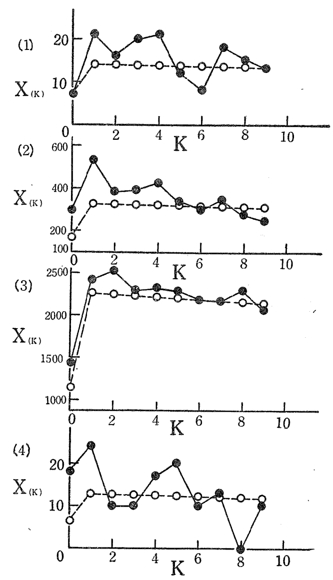


Fig. 25—1. X(k)—k relation diagram of salmons caught by gill-net (July 20—21, 1952).
Notes: (1) *Oncorhynchus nerka* (2) *O. keta* (3) *O. gorbuscha* (4) *O. kisutch.*

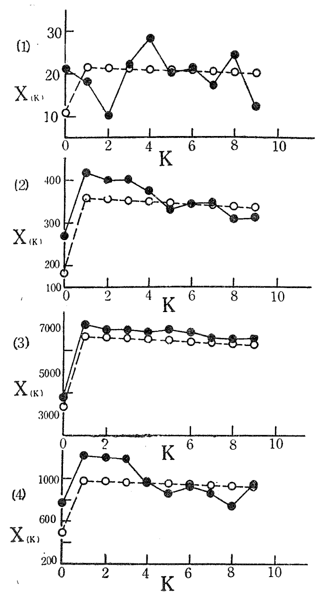


Fig. 25—2. X(k)—k relation diagram of salmons caught by gill-net (July 21—22, 1952).
Notes are the same as in Fig. 25—1.

From these figures, it becomes clear that each of salmon species shows rather specific distribution pattern, although all the species were caught mingled with one another on the same row of gill-nets at the same operation. Namely, *Oncorhynchus gorbuscha* are distributed forming wide, but very weakly contagious schools covering 6 sections or longer. Next, *O. keta* forms a pretty conspicuous, but slightly narrower schools covering 4 or 5 sections. While the populations of *O. nerka* and *O. kisutch* are constituted each of rather strongly contagious but narrow schools, although it is difficult to give any definite conclusions because of the scarcity of caught individuals and of analyzed examples.

2. Application to the analyses of the squid population caught by squid-traps

In the Inland Sea of Japan and the adjacent waters, a quantity of squids, *Sepia esculenta* HOYLE and *Sepiella japonica* SASAKI, are caught in winter or early spring by the somewhat strange fishing apparatus——series of traps set on the bottom of the shallow waters. The distribution pattern in these catches is analyzed here. On the other hand, like other squids, *Ommastrephes sloani pacificus* STEENSTRUP and *Onychoteuthis banksii* (LEACH) in the northern waters, *Doryteuthis kensaki* (WAKIYA et ISHIKAWA) and *D. bleekeri* KEFERSTEIN are caught at night in late spring or early summer by angling under the fish-gathering lamp, and the distribution of the time when the squid is angled will be analyzed in next section.

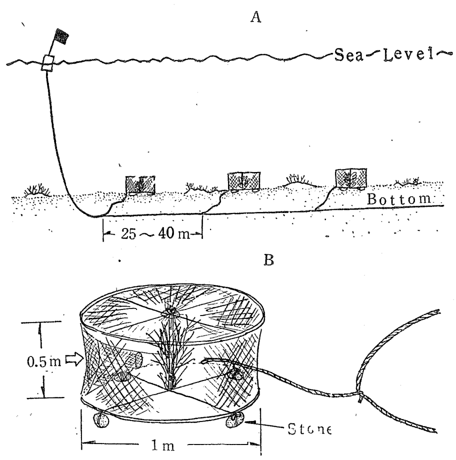


Fig. 26. A model of the squid-trap.
A. Schema showing the way of operation.
B. Structure of a trap.

The outline of gears is shown in Fig. 26, but the details differ more or less according to districts. Usually, twenty to forty traps are united into a series and set on the bottom at the beginning of the fishing season. And they are hauled up every one day to collect captured squids. The data recording the number of squids caught by respective traps of 4 series of gears on June 1st, 1955 near Kôbe Harbour were offered to my disposal by courtesy of Mr. T. FUMOTO of Kôbe University and now analyzed by using formulae (1) and (2), here the average interval between adjoining traps is adopted as the unit length.

The result of the analysis of Example 1 which is constituted of 17 individuals caught by 40 traps is represented in Fig. 27 — (1). This suggests that the population seems to be constituted of many strongly contagious schools covering one trap and being spaced by 2-trap intervals, besides a few wider ones covering about two traps,

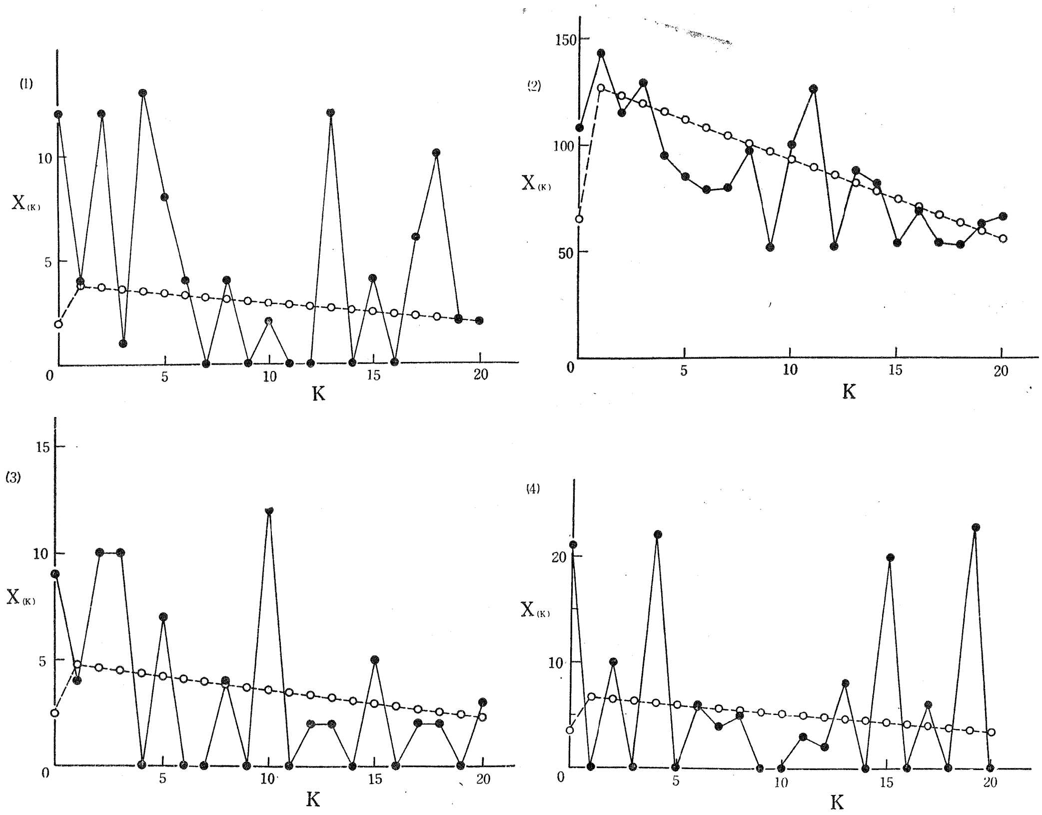


Fig. 27. X(k)—k relation diagrams of squids caught by squid-traps.
Note: Number enclosed in parentheses indicates the number of example.

although the scarcity of the total catch may introduce some accidental errors. While in Example 2 shown in Fig. 27—(2), the catch rate is 4 times as high as in Example 1 (68 individuals were caught by 35 traps) and here the schools seem to be less contagious and wider than those of Example 1. In Figs. 27—(3) and 27—(4) showing the results of Examples 3 and 4 in which the catch rate is as low as in Example 1 (Example 3 : 14 individuals were caught by 37 traps, Example 4 : 17 individuals were caught by 40 traps), the distribution pattern is nearly the same as that of Example 1.

3. Application to the analyses of the distribution pattern of the time when squids are angled under the fish-gathering lamp

In all examples concerning tunas, salmons and squids, the formulae were used to analyze the distribution pattern in space. But here the proposed method is used to analyze the time correlation.

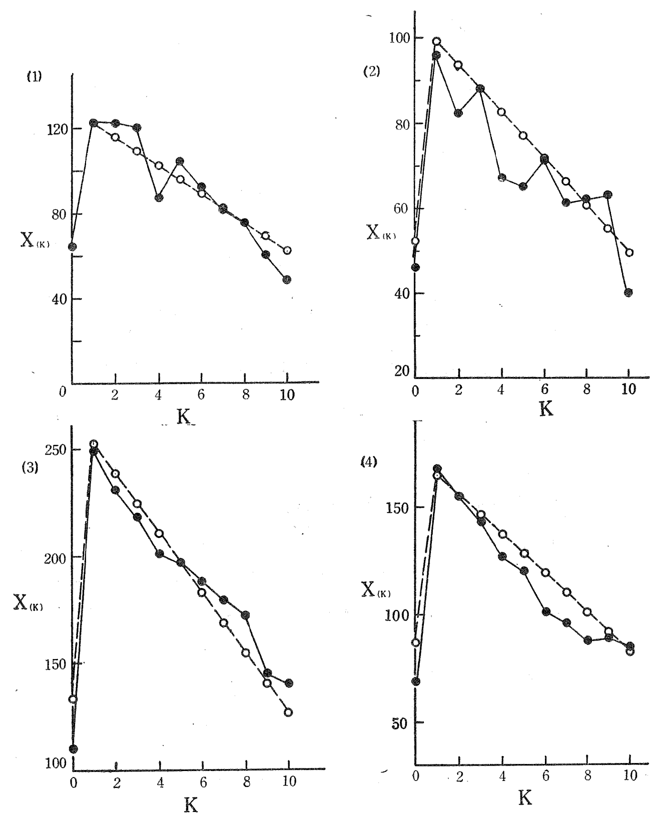


Fig. 28. X(k)—k relation diagrams of squids angled up under the fish-gathering lamp.
Note: Numbers in parentheses are representing the number of respective fishermen.

In treating of many examples in fisheries suitable for the analyses of the time distribution, the distribution of the time when fishes are angled during one operation is taken up in order to fit the order of the time analysis to that of the above-mentioned examples in which the spatial distribution within one operation is analyzed, although there is no way to convert the space into the time. On the other hand, in order to get the results containing less accidental errors, it is very desirable to analyze the data obtained by the angling of the fishes which are caught in abundance within a limited time. The squid angling, analyzed here, seems to be one of the examples most suitable for this purpose.

The records shown here were obtained off Yatama, near Shimonoseki, during the short period from 20.51 to 22.30 on June 2nd, 1955 by 4 fishermen on board the training boat No. 15 of our college. Fishermen No. 1 and No. 2 occupied their seats from stem to stern on the starboard, while Fishermen No. 3 and No. 4 sat on the port side. The gears were equipped with mimetic artificial preys and a fish-gathering lamp of

1 kw was put at the end of the over-hang of 1 m long at the middle on each side after it became quite dark. The catches by respective fishermen were recorded at every unit time of five minutes just since the light was put on.

If the density or the feeding activity of the squids under the light deviates prominently within an operation —— for example, small schools gather to lamp one after another, while most individuals of a certain school are caught before the next school comes there, or large schools pass through one by one staying under the light for a short time —— then the correlation coefficients among the number of individuals caught by respective fishermen in each unit time (5 min. in this report) have to take significant positive values and all the diagrams showing the contagiousness of the time of the fishes being angled should indicate the similar pattern. However, all correlation coefficients obtained actually, except for that between Fishermen No. 1 and No. 2, take low and insignificant values, moreover, the diagrams of the time contagiousness do not indicate the same pattern, despite of the fact that all fishermen were on board the same boat during the said period, consequently always the same population was fished by these four fishermen.

Besides, it is also alluded to in the diagrams that the most skillful fisherman, No. 3, angled squids at the self-spacing time intervals throughout the whole operation. The next veteran fisherman, No. 4, angled also at the self-spacing time intervals, although the correlation coefficient between the number of individuals caught by Fishermen No. 3 and No. 4 is insignificant. While the pattern assumable from the catches of the third fisherman, No. 1, shows quite a different feature which indicates the appearance of two schools, one was maintained for 20 minutes and the other appeared about 40 minutes later, but stayed there longer. And the diagram based on the catches by the last fisherman, No. 2, alludes to the appearance of several schools, although generally seeing the squids were angled up by him at the self-spacing time intervals.

Further, it is assumable that Fishermen No. 3 and No. 4 are skillful enough to angle up a quantity of squids even when the density is considerably low, but it requires at least 1 minute to haul up the caught squid, take it off the gear and set the gear again at the adequate depth, thus they can get squids at nearly constant time intervals, but never get more than 5 individuals within 5 minutes however high the density of squids may be. Fisherman No. 1 is not so skillful as them, but yet he is able to angle up many individuals when the density is higher. Fisherman No. 2 is considered not to be so skillful as Fishermen No. 3 and No. 4 but somewhat better than No. 1 at the angling under the lower density, though he can not do every treating so quickly as No. 1 even when the schools are under the light.

4. Application to the analyses of the distribution pattern of the time of the benthonic fishes being angled under the fish-gathering lamp

While waiting for small fishes assembling so densely under the light enough to be hauled by net, not only the pelagic fishes but also some benthonic ones are angled under the light. As an example of the above-mentioned cases, the results of the analyses, by using the formulae (1) and (2), on the records obtained during the period from August to September in 1950, when the food relation and several phenomena closely related with it were studied about the temporal community assembling under the light, are shown below:

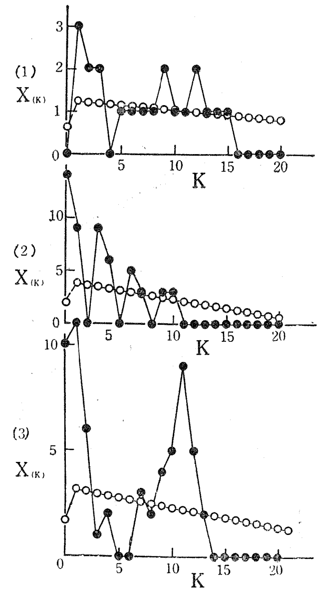


Fig. 29. X(k)—k relation diagrams of the angled time of benthonic fishes under the fish-gathering lamp.
Parapristipoma trilineatum (THUNBERG)
(1) Aug. 16, 1950. (2) Aug. 25, 1950 (3) Sept. 17, 1950.
Note: Theoretical values are estimated by formulae (1) and (2), in which the unit interval is 5 minutes.

The distribution pattern of the time of *Parapristipoma trilineatum* (THUNBERG) being angled is shown in Fig. 29. No discussion is made for Example 1, because considerable accidental errors due to the scarcity of the catch can be expected. While Example 2 suggests the appearance of 4 patches at 15 minutes intervals during the operation and the population of Example 3 seems to be constituted of 2 strongly contagious schools being spaced *ca.* 50 minutes from each other. Figure 30 representing the distribution patterns of the angled time of *Leptscolopsis nagasakiensis* (TANAKA) shows that the appearance of 4 less contagious patches is assumable during the operation of Example 1, the catch in Example 2 seems to be constituted of a single patch maintained so long but of such weak contagiousness that it can be regarded as a bundle of several shorter visits and the population in Example 3 shows quite the same feature

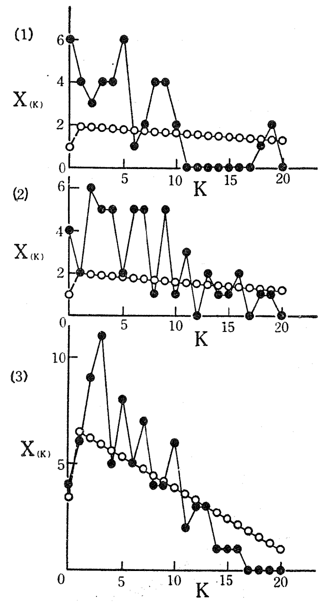


Fig. 30. X(k)—k relation diagrams of the angled time of benthonic fishes under the fish-gathering lamp.
Leptscolopsis nagasakiensis (TANAKA)
(1) Aug. 16, 1950. (2) Aug. 22, 1950 (3) Aug. 25, 1950.
Note: Theoretical values are estimated by formulae (1) and (2), in which the unit interval is 5 minutes.

as that of Example 2, although this cannot be considered to be free from accidental errors due to the scarcity of the catch.

5. Application to the analyses of the distribution pattern of the time when the fishes are angled in the day time along the shore

Here, the results of the analyses on the records of the day time angling by using formulae (1) and (2) are presented in Fig. 31 in a hope that it might be useful to understand the problem under the consideration. It is suggested that the catch of pogy, *Chrysophrys major* (T. et S.), is considered to be constituted of a single long visit of such weak contagiousness that it may be subdivided into 3 or 4 shorter visits; while the population of puffer, *Fugu rubripes* (T. et S.), seems to be constituted of 4 less contagious visits appeared regularly at 20-minute intervals.

6. Application to the analyses of the distribution pattern of benthonic fishes hooked along the coastal long-line

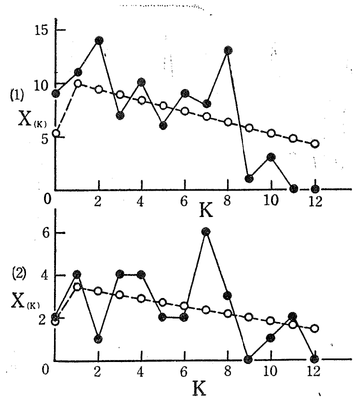


Fig. 31. X(k)—k relation diagrams of the angled time of benthonic fishes in the day time along the shore not so far from Shimonoseki College of Fisheries.
(1) *Chrysophrys major* (T. et S.)
(2) *Fugu rubripes* (T. et S.)
Note: unit interval is 5 minutes. Records during the period from 09.18 to 10.53, Sept. 12, 1955.

Since the old-time, the coastal long-line has been one of the most important fishing methods for Japanese fishermen living on the fisheries of a small scale along the coast and a considerable part of the catch in the coastal waters, especially from the benthonic layers, are got by this method. Accordingly, the distribution pattern of the fishes observed in the catches of this fishing method is quite worthy to be studied as well as that of the off-shore fisheries from the economical point of view. The gears for this fishery are, however, set respectively in a meandering course through the places to places which are regarded as good fishing spots by fishermen on their experiences, and usually very limited —— only a few meter in width, consequently the probability of the occurrence of fishes in respective parts along the row of gears cannot be considered to be compatible with the basic assumption of the proposed formulae and it is very probable that the dishomogeneity of the probability of the occurrence of individuals assigned to the environmental difference may frequently be misregarded as the distribution pattern shown by the fishes themselves. For these reasons, only a few of abundant examples are quoted in the followings.

Figure 32 represents the distribution pattern of a sea-eel, *Muraenesox cinereus* (FORSKÅL), along the long-line, here the theoretical values were computed by formulae (5) and (6). The theoretical values at $k=a(H+1)$ are $H/(H-1)$ times the values at $k=a\ (H+1)-1$ or $k=a\ (H+1)+1$ (here, H is the number of hooks attaching to each basket and a is a positive integer) just like the theoretical values computed about the tuna long-line. For the gears such as the sea-eel long-line with so large H, it seems unnecessary to correct the influence of the existence of the buoy lines, because $H\ /\ (H-1)$ is not so far from 1 as compared with the deviation of the observed values. Although most of the observed values are a little higher

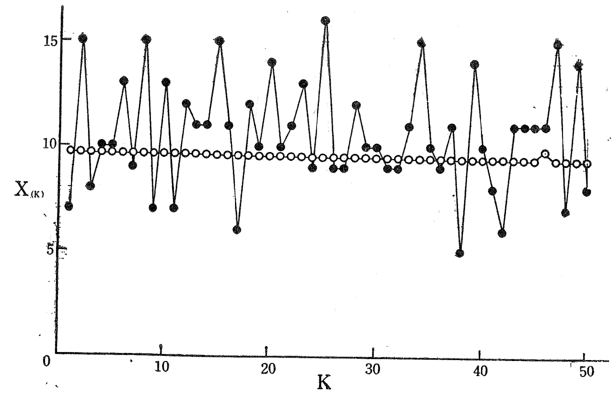


Fig. 32. X(k)—k relation diagram of *Muraenesox cinereus* (FORSKÅL).
Note: One hundred and twelve individuals were caught on Sept. 5, 1955 off Tana near Hiroshima, by the gears consisting of 29 baskets respectively with 45 hooks.

than the estimated ones and this seems to indicate that sea-eels are distributed contagiously covering more than one basket, yet this fish may be regarded as one of a few fishes of which the couples of individuals caught at the adjoining hooks are less than those in the chance distribution; anyhow some accidental errors are expected as the observed and estimated values are very low. The above-mentioned phenomena can be regarded as reflecting a certain habit of sea-eel, namely it is an active piscivore and possibly shows territoriality, consequently the fishes distribute being spaced more evenly than in the chance distribution.

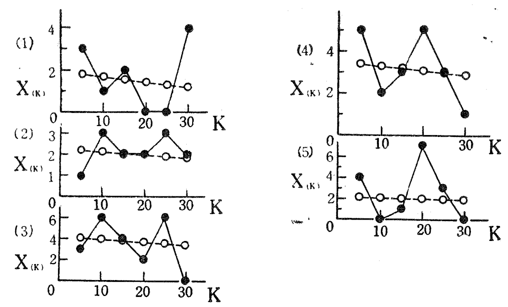


Fig. 33. X(k)—k relation diagrams of benthonic fishes caught by the coastal benthonic long-lines.
(1) *Epinephelus fario* (THUNBERG), Aug. 14, 1955.
(2) *Gymnothorax kidako* (T. et S.), Aug. 18, 1955.
(3) *E. fario*, Aug. 18, 1955.
(4) *G. kidako*, Aug. 20, 1955 (each basket with 80 hooks).
(5) *E. fario*, Aug. 20, 1955 (each basket with 80 hooks).
Note: The original records were obtained near the Cape of Shionomisaki, by the long-line consisting of 2 baskets each having 40 hooks and set on the bottom.

Figure 33 shows the examples of the distribution patterns of fishes caught by the benthonic long-line near the Cape of Shionomisaki and in which both observed and estimated values are counted at each of five consecutive k. As the influence of accidental errors due to the scarcity of the catch can be expected, no further discussion is made other than the following. The distribution patterns of *Gymnothorax kidako* (T. & S.) and *Epinephelus fario* (THUNBERG) caught by the same row of gears take the similar feature, but at least partly this might be a strange coincidence, for the correlation coefficients computed between them in the examples observed on August 18 and 20, 1955 are -0.181 and -0.167 and this suggests that both species are distributed independently of each other.

Summary and Conclusions

It is regarded as a part of the fields unexplored but with the basic importance in fisheries ecology to study the most detailed distribution pattern of tunas along the row of long-line, because this may offer some theoretical bases for various technical problems and at the same time some clues for several biological phenomena. But there are a few papers worked on the distribution of individuals along the row of long-line, whereas much efforts in the field of commercial fisheries and in the studies on the distribution of tunas have been made to find out some better fishing grounds, this can be regarded as the distribution pattern in a much greater scale. Actually it is practically impossible to carry out any direct experimental methods for the analyses of the distribution pattern of tuna along the long-line, because the tuna population fished by the long-line is situated approximately at the layer deeper than 100 m and moreover the length of a row reaches beyond 50 km. Therefore, it seems to be most effective to use some indirect methods adopted for the analyzing of the insect population in order to analyze the distribution pattern of tunas along the long-line. The analyses of the most detailed distribution pattern by using the indirect theoretical methods may be recognized as a new unexplored branch in fisheries ecology.

For the purpose of clarifying the distribution pattern, the frequency distribution of individuals caught in respective sections is usually examined and compared with some theoretical ones. But this method is lacking in the consideration upon the spatial relation among respective sections. To fill up this deficiency, it is recommended to adopt some other methods in which the distribution along the row of long-line is treated individedly as a continuous one. On this standpoint, the works of MURPHY and ELLIOT (1954) and MORISITA (1950, 1954 a, 1957 and M. S.) should be appreciated very highly. But the method adopted by MURPHY and ELLIOT, as well as correlogram, seems not to be available to the examples in which the catch rate increases with the soaking time, moreover the results are misregarded as less contagious than actual on account of the influences of the following 4 factors: (1) some hooks may be occupied by other fishes, (2) the existence of buoy lines, (3) all hooks are not set at the same depth level and (4) for instance the potential sequence of a certain species is broken since other species of tunas or fishes thieve the baits. Strictly speaking, MORISITA'S method, one of the spacing methods, is also unsuitable because of the same reason.

Thus, in order to analyze the distribution pattern of individuals along the long-line, it is indispensable to establish some new formulae in which the influences of the above-mentioned factors are taken into consideration.

The outline of the history of the tuna long-line fishery and the studies on tuna is given briefly. The papers treating of the distribution are classified into two groups: one comprises those in which the frequency distribution of the number of individuals caught within a relatively small section is examined for the purpose of studying the social habits or the mechanism of dispersal, while the other includes those in which the frequency distribution of the number of individuals or the amount of the catch within a rather large section is examined as a preliminary procedure of some other statistical treatment. Several of the former group chiefly treating of the distribution of terrestorial animals, especially insects, are presented. Concerning the latter only an example showing the frequency distribution of the catch per unit effort in various fishing methods is presented.

Generally the chapter "method and material" should include the detailed descriptions of the method used in the paper, but the method itself, the processes of the analyses, proposed in this paper is one of the principal subjects of this report as important as the results and thus it is excluded from the chapter which contains only the outline of the fishing method and the sources of the analyzed records.

Some preliminary consideration was given to the guessing of the existence of schools wider than the whole length of a row of gears, because the width of schools discussed in this report never reaches beyond the whole length of a row of gears.

The basic assumption of the theoretical distribution is set as the distribution is a chance one, because there is no evidence supporting the schooling habit of tunas living in the deeper layers of the ocean, whereas there are known many facts which seem to support their solitary life. And the formulae were constructed to be used under respective conditions mentioned below:

Sphere of application	Unit length	Factors, the influences of which are taken into consideration	Formulae
applicable to all serial gears	divisible by one basket (or section) length	none	(1) & (2)
		gradient of catch rate	(3) & (4)
applicable only to the long-line	hook-interval	none	(5) & (6)
		gradient of catch rate	(7) & (8)
		difference of catch rate according to depth	(9)～(13)[H = 4] (14)～(19)[H = 5]
		both of the above-mentioned factors	(20)～(24)[H = 4] (25)～(30)[H = 5]

Note : Formulae (1) and (2) were obtained from MORISITA'S formulae, while the others were newly established.

The analyses of Series I were carried out to catch the outline of the distribution pattern projected along the row of long-line, where the formulae (1)～(4) were used and 5 consecutive baskets were adopted as the unit length. In another series of analyses, one basket was used as the unit length in formulae (1)～(4). Besides the above-mentioned two, still another series of analyses was tried by using formulae (5)～(13) and (20)～(24) in which the unit length was made as short as possible, namely a single hook-interval was adopted, because it was considered to be very significant to clarify the elemental structure not only from the ecological but also from the technical point of view.

To make it easier to read the diagrams showing the results of the analyses, several notes were given in the section "Notes for decoding the diagrams and notation used in them".

Nineteen examples of big-eye tuna were analyzed and the results are shown in Fig. 8 which indicates that the extremely strong contagiousness of the catch between the adjoining hooks is one of the characteristics of the distribution pattern of this fish. Concerning the problems whether large schools are observable or not and whether the distribution pattern is contagious or self-spacing, no definite answer is obtaind, although about a half of examples alludes to the existence of large schools and 1/5 of examples shows the self-spacing pattern. However, generally speaking the individuals are thought to be distributed almost by chance.

The results of the analyses of ten examples of yellow-fin tuna are illustrated in Fig. 10. There are some examples, in which it is very difficult to deduce the outline of the distribution pattern, especially from Series Ⅲ, because the catch rate is very low consequently many accidental errors are expected and both the observed and estimated values are very low. Only the following trend can be regarded as a general feature : the difference between the two series of the estimated values, in one of which the influence of the difference of the catch rate according to the depth is taken into consideration, while in the other this influence is put aside the consideration, is very small and the similar trend can be seen concerning the influence of the gradient, although it is very probable that this is more or less attributable to the computation errors, especially those of constants due to the lower catch rate. The distribution as a whole is not apart so far from the chance distribution. Some grade of contagiousness of catch is observable between the adjoining hooks, although it is not so strong as that of big-eye tuna. It seems to be one of the characteristics of the distribution pattern of this species that there are some elemental clusters covering the width longer than 1～2 baskets, but this may be more or less due to the low catch rate, too.

The examples of albacore was increased up to 41, because the school formation is highly probable in this species as a considerable amount of younger individuals are caught by angling. But the essential pattern does not differ so much from those of big-eye tuna and yellow-fin tuna, *i.e.*, the grownups are roughly said to be distributed almost by chance. Contrary to the expectations that the school formation is highly probable, about 1/3 of examples showed the self-spacing pattern, although about a half of examples showed the contagious pattern. And it may be regarded as one of the characteristics of the distribution pattern of this species that no clear contagious pattern is observable within a short range in contrast with the cases of big-eye tuna and yellow-fin tuna (Fig. 12).

On the other hand, the relation among the localities of hooked individuals belonging to different species is also worthy to be analyzed as well as that found in the same species, because this problem is very interesting to ecologists, too. And the formulae were constructed to represent the expected number of individuals of a certain species (Species A) observable in the sections spaced by k section-intervals from the respective sections occupied by the individuals of another species (Species B) under the condition that both species are distributed independently of each other. This was made by summing the two formulae, in one of which the probability of the catch in the ith section or at each hook in the ith section in the spacing formulae was replaced by that of species A and those in the $i+kth$ and $i+k+1th$ (or $i+ath$ and $i+a+1th$) were replaced by those of Species B, while in the other *vice versa*, otherwise by subtracting (the expected number in the case when the population was constituted of Species A only) and (the expected number in the case when the population was constituted of Species B only) from (the expected number in the case when the population was constituted of Species A and B). That is to say, the correlation formulae corresponding to respective spacing formulae are as follows:

Spacing formulae	Correlation formulae
(1) & (2)	(31) & (32)
(3) & (4)	(33) & (34)
(5) & (6)	(35) & (36)
(7) & (8)	(37) & (38)
(9) ~ (13)	(39) ~ (43)
(20) ~ (24)	(44) ~ (48)

It is a well known fact as to the geographical distribution of the three species of tunas, that the yellow-fin tuna is living in the region of lower latitudes, next comes the big-eye tuna and albacore is distributed in the higher-latitudinal area. But yet a small number of individuals of other two species are usually caught by the same row of gears mingled with abundant individuals of a predominant species. Thus arises a question whether the individuals of the subordinate species join to the school of the individuals of the predominant species or are distributed independently of or repulsively to the latter. To clarify this problem, the relation between the localities of hooked individuals of big-eye tuna and yellow-fin tuna was analyzed on 10 examples. The results are shown in Fig. 13 which indicates the following tendencies: generally speaking, the individuals of both species are distributed, in most examples, repulsively for the width covering one~several to a considerable number of units. And the number of individuals of both species caught by the same basket was also less than that in the case when they were distributed independently of each other. However, when the unit length was shortened to one hook-interval, the existence of rather aggregative pattern extending to several hook-intervals at the maximum was alluded to in 3 examples, although the repulsive pattern was still maintained somewhat clearly in 4 examples.

On the other hand, the marlins are ranked at a little higher food rank than the tuna and often caught by the same row of gears mingled with the latter, but there is no direct predatory relation between these two. Contrarily, it is a well known fact that the hooked tunas are occasionally damaged by sharks which are caught by the same row of gears mingled with the former, although it is doubtful if freely swimming tunas are attacked by sharks as the hooked ones. Accordingly, the existence of some relations between the localities of hooked tunas and sharks is highly expected and this is evidently a very serious and interesting matter not only for the ecological but also for commercial purposes. Nevertheless, the catch rates of both species are apart from each other so far that the relation diagrams are apt to be strongly affected by the distribution pattern of the subordinate species, hence only several examples are illustrated in Fig. 16 (between tunas and marlins) and Fig. 18 (between tunas and sharks). In these examples the catch rate of tuna is extremely low as well as those of sharks consequently some accidental errors are inevitably expected. The correlation diagrams between the tunas and marlins seem to show a possible repulsive pattern, but the definite conclusion cannot be given, as the catch rate is very low. Either, nothing is deducible from the correlation diagrams between the tunas and sharks, because accidental errors are highly expected.

The method of analyzing the distribution pattern adopted in this paper is summarized as follows: at first the formulae representing the chance distribution are constructed, next the influences of the gradient of the distribution, the difference of the catch rate according to the depth and the existence of buoy lines are theoretically corrected in the formulae and lastly the distribution pattern is deduced from the deviation of the observed values from the corresponding estimated ones. However, some factors of errors still remain intact and on the other hand other factors of errors may be introduced during the computation or included in the basic assumptions. Namely, there is no evidence supporting that individuals belonging to the same school may be caught within a limited time, because the distribution of individuals at each part along the row of gears is represented as the pattern integrated during the period from the beginning of the setting to the end of the hauling of respective parts. On the other hand, this method is based on the assumption that the long-line fishes only individuals of a certain single species and that each baited hook shows the same probability of catching fishes or the probability shows gradient or differs according to the depth. But, practically, some factors of errors infringing the assumptions can be expected and these tend to make the distribution of fishes less contagious. Moreover, the effect of the occupation of hooks by individuals unifies the distribution even when the individuals belong to the same species and thus this must be taken into consideration when the whole or some parts of row are occupied very densely. Besides the above-mentioned factors of errors, another factor is influential on the observed values in Series I ——*i.e.*, series of the catches in each of 5 consecutive baskets may differ slightly according to the situation of the initial basket of counting the units. Consideration was given to each of these factors.

Besides the above-mentioned errors chiefly included in the observed values, some computation errors chiefly attributable to the uncertainty of constants computed from the actually observed distribution may be contained in the theoretically estimated values, especially those in which the influence of the gradient of the catch is taken into consideration. Special consideration was given to this.

Moreover, as mentioned already in the section of notes for decoding, X(k) simply represents the theoretical number of the occurrence of the couples of individuals spaced by k section-intervals (or hook-intervals), but is quite regardless as to whether some of the intermediate hooks are occupied by fishes or not. Accordingly, the distribution pattern cannot be analyzed purely theoretically, but it is indispensable to refer to the original records. To fill up this deficiency, another new device was proposed, in which the occupation of some of the intermediate hooks by fishes was taken into consideration. But still another factor remains and it brings the interpretation of the distribution pattern into a confusion, —— that is the order of the arrangement of the intervals spaced respectively. Still another method is proposed to solve this problem, although it is very doubtful whether accurate results are obtainable from the two series of analyses in this method or not, as it is very difficult to estimate the theoretical values, especially those in which the influence of the gradient is taken into consideration, computation errors are highly expected and moreover both the estimated and observed values in the last method are presumably very low.

Then, some consideration was given to the factors influential on the gradient and the difference of the catch rate according to the depth, but without any distinct results.

At the end of the article, several examples obtained by the different fishing methods were presented as appendices in which the distribution pattern in space or time was analyzed by the same method proposed in the proper part of this paper.

References

1) ARCHIBALD, E. E. A., 1948 : Plant populations. I. A new application of NEYMAN'S contagious distribution. *Ann. Bot. N. S.*, **12**, 221—235.

2) ASHBY, E., 1935 : The quantitative analysis of vegetation. *Ann. Bot.*, **49**, 779—802.

3) BARNES, H. & T. B. BAGENAL, 1951 : A statistical study of variability in catch obtained by short repeated trawls taken over an inshore ground. *Jour. Mar. Biol. Assoc.*, **29**, 649—660.

4) BARNES, H. & S. M. MARSHALL, 1951 : On the variability of replicate plankton samples and some application of contagious series to the statistical distribution of catches over restricted period. *ibid.* **30**, 233—263.

5) BEALL, G., 1935 : Study of arthropod populations by the method of sweeping. *Ecol.*, **16**, 216—225.

6) ————, 1939 : Method of estimating the population of insects in a field. *Biometrika*, **30**, 422—439.

7) ————, 1940 : The fit and significance of contagious distribution when applied to observations on larval insects. *Ecol.*, **21**, 460—474.

8) BEALL, G., 1942 : The transformation of data from entomological field experiments so that the analysis of variance becomes applicable. *Biometrika*, **32**, 243—262.

9) Blackman, G. E., 1935 : A study by statistical method of the distribution of species in grassland associations. *Ann. Bot.*, **49**, 749—777.

10) BLISS, C. I., 1941 : Statistical problems in estimating populations of Japanese beetle larva. *Jour. Econ. Ent.*, **34**, 221—232.

11) BOWEN, M. F., 1947 : Population distribution of beet leafhopper in relation to experimental field plot lay-out. *Jour. Agr. Res.*, **75**, 259—278.

12) CLAPHAM, A. R., 1938 : Over-dispersion in grassland communities and the use of statistical methods in plant ecology. *Jour. Ecol.*, **24**, 232—251.

13) COLE, L. C., 1946 : A theory for analysing contagiously distributed populations. *Ecol.*, **27**, 329—341.

14) COTTAM, G. & J. T. CURTIS, 1949 : A method for making rapid surveys of woodlands by means of randomly selected trees. *ibid.*, **30**, 101—104.

15) COTTAM, G., J. T. CURTIS & W. HALE, 1953 : Some sampling characteristics of a population of randomly dispersed individuals. *ibid.*, **34**, 741—757.

16) COTTAM, G. & J. T. CURTIS, 1955 : Correlation for various exclusion angles in the random pairs method. *ibid.*, **36**, 767.

17) ——————————, 1956 : The use of distance measures in phytosociological sampling. *ibid.*, **37**, 451—460.

18) GOODALL, D. W., 1952 : Quantitative aspects of plant distribution. *Biol. Rev.*, **27**, 194—245.

19) KESTEVEN G. L. & T. W. BURDON, 1952 : Fishery Survey Report, No. 1. An introduction to the fisheries survey of the colony of Singapore, with a consideration of the methodology employed. Fish. Bull., No. 2, Fish. Dept., Singapore.

20) KITAGAWA, T. & T. YAMAMOTO, 1950 : Sampling survey of fisheries catch in Fukuoka Prefecture. Statistics and Research Division, Min. Agric. Forest., Jap. Gov. (in Japanese).

21) KONO, T., *et al.*, 1952 : Pattern of spatial distribution of the rice-stem borer, *Chilo simplex*, in a paddy field. *Res. Pop. Ecol.*, **1**, 65—82 (in Japanese with English summary).

22) KUROKI, T., 1956 : Theoretical estimation of albacore-shoals dimensions in accordance with the characteristics of fishing rates. *Mem. Fac. Fish. Kagoshima Univ.*, **5**, 78—90.

23) MAÉDA, H., 1953 : Ecological analyses of pelagic shoals I. Analysis of salmon gill-net association in the Aleutians. (2) Distribution of fishes on the gill-net. *Bull. Jap. Soc. Sci. Fish.*, **19**, 305—318.

24) ——————, 1955 : Shoaling tendency in tuna observed in the Great Sunda Archipelago. IPFC/C55/Tech. 12.

25) MAKO, H., 1955 : A consideration on the density index of fish population. *Bull. Jap. Soc. Sci. Fish.*, **21**, 67—72 (in Japanese with English summary).

26) MARSHALL, J., 1936 : The distribution and sampling of insect populations in the field with special reference to the American bollworm, *Heliothis obsolata*. *Ann. Appl. Biol.*, **23**, 133—152.

27) MOOD, A. N., 1950 : Introduction to the theory of statistics. McGraw-Hill Book Co., 433 pp.

28) MORISITA, M., 1950 : Migration and population density of a water-strider, *Girris lacustris* L. *Contr. Ecol. & Physiol., Kyoto Univ.*, **65**, 1—149 (in Japanese with English summary).

29) ——————, 1952 : Experimental studies on the population density of an ant-lion *Glenuroides japonicus* M'. L. *Physiol. & Ecol. (Kyoto)*, **5**, 1—16 (in Japanese with English summary).

30) ——————, 1954 a : Estimation of population density by spacing method. *Mem. Fac. Sci., Kyushu Univ., Ser. E.*, **1**, 187—197.

31) MORISITA, M., 1954 b : Experimental studies on the population density of an ant-lion *Glenuroides japonicus* M'. L. II. *Jap. Jour. Ecol.*, **4**, 71—79 (in Japanese with English summary).
32) ——————, 1957 : A new method for the estimation of density by the spacing method applicable to non-randomly distributed population. *Physiol. & Ecol. (Kyoto)*, **7**, 134—144 (in Japanese with English summary).
33) ——————, 1959 : Measuring the dispersion of individuals and analysis of the distribution pattern. *Mem. Fac. Sci., Kyushu Univ., Ser. E*, **2**, 215—235.
34) ——————, 1951—59 : Personal communications.
35) MURPHY, G. I. & R. S. SHOMURA, 1953 : Long-line fishing for deep swimming tunas in the central Pacific July 1950—Sept. 1951. *Special Scientific Report No.* 98. *U. S. Dept. Interior, Fish and Wildlife Sev.*
36) MURPHY, G. I. & K. C. ELLIOT, 1954 : Variability of long-line catches of yellowfin tuna. *ibid.*, No. 119.
37) NAKAMURA, H., 1949 : The tunas and their fisheries. Takeuchi Shobo, Tokyo (translated by W. Van Campen, *ibid.*, No. 82, 1952).
38) NEYMAN, J., 1939 : On a new class of "contagious" distributions applicable in entomology and bacteriology. *Ann. Math. Stat.*, **10**, 35—57.
39) RICHARDS, O. W., 1936 : Some quantitative methods for analysis of insect associations. *Proc. Linn. Soc. London.* **146**, 33—36.
40) ——————, 1940 : The biology of the small white butterfly *Pieris rapae* with special reference to the factors controlling its abundance. *Jour. Anim. Ecol.*, **9**, 243—288.
41) ROMELL, G. I., 1930 : Comments on RAUNKIAER'S and similar methods of vegetation analysis and the "law of frequency." *Ecol.*, **11**, 589—596.
42) SILLIMAN R. P., 1946 : A study of variability on plankton townet catches of Pacific pilchard *Sardinops caerulea* eggs. *Jour. Mar. Res.*, **6**, 74—83.
43) TAGUCHI, K., 1959 : Studies on the estimate of the distribution density of salmon population of the high seas. *Bull. Jap. Soc. Sci. Fish.*, **25**, 335—341 (in Japanese with English summary)
44) TORII, T., 1952 : Stochastic method of analysis of insect populations. A treatise on ecology by N. YAGI and K. NOMURA, 216, 218, 237, 241, 244, 245, 255.
45) ——————, 1956 : The statistic approach in field population ecology. Jap. Soc. Promotion of Sci., Tokyo, 277 pp.
46) UMESAO, T., 1950 a : A quantitative representation of the social relation I. *Biol. Sci.*, **2**, 179—185 (in Japanese).
47) ——————, 1950 b : —————————————————— II. *ibid.*, **3**, 33—41 (in Japanese).
48) UTIDA, S., 1941—43 : Studies on experimental population of the azuki been weevil, *Callosobruchus chinensis.* I—VIII. *Mem. Coll. Agric., Kyoto Univ.*
49) UTIDA, S., *et al.*, 1952 : Pattern of spatial distribution of the common cabbage butterfly *Pieris rapae* in a cabbage farm. *Res. Pop. Ecol.*, **1**. 49—64 (in Japanese with English summary).
50) WINSOR, C. P. & G. L. CLARKE, 1940 : A statistical study of variation in the catch of plankton nets. *Jour. Mar. Res.*, **3**, 1—34.
51) YAMAMOTO, T., 1956 : On the characteristics of unit catch. Statistics and Survey Division, Min. Agric. Forest., Jap. Gov., 115 pp (in Japanese with English summary).
52) YOSHIDA, T. *et al.*, 1952 : On the distribution pattern of the spotted lady beetle *Epilachna sparsa orientalis. Res. Pop. Ecol.*, **1**, 83—93 (in Japanese with English summary).
53) YOSHIHARA, T., 1951—54 : Distribution of fishes caught by the long-line. I. Horizontal distribution, *Bull. Jap. Soc. Sci. Fish.* **16**, 367—369. II. Vertical distribution,

ibid., **16**, 370—374, Ⅲ. Swimming depth, *ibid.*, **18**, 187—190, Ⅳ. On the relation between κ and φ_0 with a table and diagram. *ibid.*, **18**, 1012—1014 (in Japanese with English summary).

54) YOSHIHARA, T., 1952: On the type of frequency curve of the catch. *ibid.*, **18**, 241—244 (in Japanese with English summary).

55) ——————, 1953: On the distribution of *Tectarius granularis*. *Res. Pop. Ecol.*, **2**, 112—122 (in Japanese with English summary).

56) ——————, 1954: On the distribution of catches by tuna long-line. *Jour. Tokyo Univ. Fish.*, **41**, 1—26.

57) ——————, 1957: On the mechanism of capture by the long-line. FAO/57/4/2314.