SOME EXPERIMENTS ON THE VARIABILITY OF HORIZONTAL PLANKTON HAULS AND ON THE HORIZONTAL DISTRIBUTION OF PLANKTON IN A LIMITED AREA*

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The patchiness in distribution of plankton has long been recognized by many workers. If it occurs in an area surveyed, the variability of catches may become more complicated by reason of this uneven distribution of plankton in addition to the technical errors. The present paper deals with the variability of catches in horizontal tows with fish-larva net and in high speed tows with Handy Underway Plankton Catcher, and with a preliminary observation whether the distribution of planktonic animals is statistically random or non-random in a limited area.

I. The variability of catches obtained with the two models of Handy Underway Plankton Catchers

Use of the underway plankton sampling apparatus has been expanded as a technique for ecological survey of marine plankton; as a matter of course the variability of catches by this method has been taken into consideration. Barnes (1951) made experiments on the two models of the Hardy Plankton Indicator, finding that the values of the coefficient of variation are not greater than those for horizontal net hauls. The present experiments pertain to the statistical analysis of catches of three series of tows with different types of Handy Underway Plankton Catcher, Models I and II (Motoda, 1954), so as to assess the sampling variation.

Barnes (1951) reported that the ratio of 1 : 6 between the area of mouth opening of the instrument and the area of filtering gauze was sufficient for filtering the theoretical quantity of water. The ratios of the opening to the gauze in the present catchers are much larger (1:37 in model I; 1:114 in model II) than those of the Hardy Indicator. The nets of both catchers were made of no. 32 silk grit gauze (31 meshes per linear inch), and it has been proved that there was almost complete absence of any clogging of silk gauze during the present experiments.

Two models of the catchers were towed simultaneously in parallel but about two meters apart. Each tow was continued for ten minutes at a nominal speed of 7 knots, and then the catches were kept separately for analysis. The catches taken with the small catcher were always multiplied by 6.25 (the ratio of areas of inner openings) for comparison with those taken with the large catcher throughout the present experiments. The

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logarithmic values of the catches were used instead of the actual number in the analysis of variance, since the standard deviation increases almost linearly with the mean catch.

Series I

A tow of ten minutes' duration repeated five times in the same course off the Port of Hakodate on October 7, 1954. Three groups of organisms, Copepoda, *Sagitta* and *Oikopleura*, were included enough for the analysis.

The details of the analysis of variance are given in the following table (table 1).

Table 1. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Main effects:			
Species (S)	2	0.8860	0.4430
Tows (T)	5	0.6809	0.1362
Catchers (C)	1	0.1961	0.1961
First order interactions:			
$S\times T$	10	0.4576	0.0458
$S\times C$	2	0.1382	0.0691
$T\times C$	5	0.0482	0.0096
Second order interaction:			
$S\times T\times C$	10	0.3450	0.0345
Total	35	2.7520	

The values for first order interactions, $S\times T$ and $T\times C$, are not significant when tested against second order interaction. The catcher mean square is significant when tested against $S\times T\times C$. However, it is not significant against $S\times C$, so that the high mean square for catcher seems to be largely due to a rather high $S\times C$, and probably indicates the differential selection for particular species with particular catcher.

Series II

Two models of catchers were towed together five times off Cape Esan, south coast of Hokkaido, on October 21, 1954. Each tow lasted ten minutes. Only three groups were present in sufficient individuals for analysis, namely, Copepoda, Amphipoda and *Sagitta*.

The analysis of variance gives data in table 2.

Table 2. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Main effects:			
Species (S)	2	8.7705	4.3853
Tows (T)	4	1.0532	0.2633
Catchers (C)	1	0.3830	0.3830
First order interactions:			
S × T	8	0.4299	0.0537
S × C	2	1.4587	0.7294
T × C	4	0.9564	0.2391
Second order interaction:			
S × T × C	8	0.6392	0.0799
Total	29	13.6909	

Now S×T is not significant but S×C is significant when tested against S×T×C. In this series, T×C is also slightly significant. The mean square for catchers is significant when tested against S×T×C, while it is not so against the values of both S×C and T×C, so that the high value of C appears to be largely due to the high values of both, especially to S×C. Thus the proportion of groups caught by each catcher throughout the tows again can be considered to differ significantly.

Series III

These catches were taken off the Port of Hakodate on November 26, 1954. A large and a small catcher were towed simultaneously during ten minutes. There were five separate tows, and the abundant species were as in the preceding series, viz., Copepoda, Amphipoda and *Sagitta*.

The analysis from this series gives data shown in table 3.

Table 3. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Main effects:			
Species (S)	2	0.6922	0.3461
Tows (T)	4	0.2592	0.0648
Catchers (C)	1	0.8670	0.8670
First order interactions:			
S × T	8	0.2446	0.0306
S × C	2	0.3828	0.1914
T × C	4	0.1507	0.0377
Second order interaction:			
S × T × C	8	0.2475	0.0309
Total	29	2.8440	

The values of C and S×C are significant against S×T×C. However, C is not significant when tested against the value of S×C. Thus, the results are very similar to those of the previous series. However, the mean square for catchers in this series is rather higher than in the preceding two series, suggesting that the catch ratio of the large catcher to the small one is a little lower than the ratio of the mouth areas as discussed below.

The significant or slightly significant values of C in the present three series have been ascribed to high values of S × C, indicating the proportion of all groups caught by each model of catcher differed significantly. It seems therefore that each catcher has its own selection for species. The percentage of mean catches for three species in each series (fig. 1) indicates that Copepeda is collected abundantly by the large catcher, while Amphipoda is caught efficiently by the small one. The differential selection of species might have been caused by 1) the probable difference of depth of water layers filtered by each catcher, which was not determined, but supposed to never exceed one meter, 2) the difference of the behavior of stream lines around the opening of each catcher or 3) other uncertain effects.

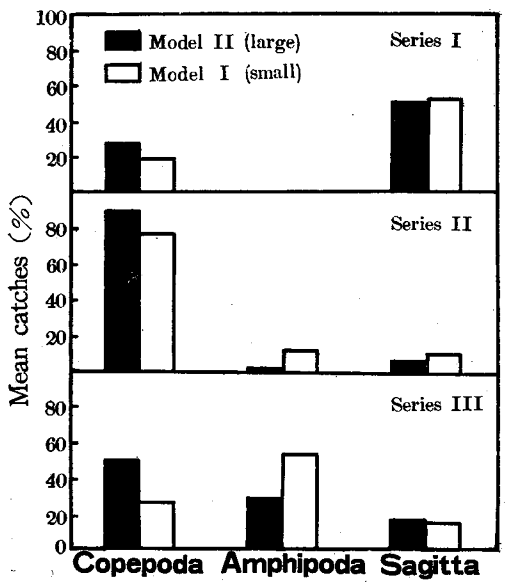

Fig. 1. The percentage occurrence of main species caught by each catcher
Oikopleura was abundant in Series I, but is excluded in this figure.

The percentage standard deviation of a single observation for each catcher was calculated respectively. The results are summarized in the following table.

No. of series	Large catcher (Model II)	Small catcher (Model I)
I	78.6	55.9
II	85.2	163.5
III	57.3	57.1

There is no remarkable difference between the values of the large and small catchers towed simultaneously in the same course except the value of small catcher in Series II.

The order of them is like that (76%) given by Barnes (1951) on the experiments using the small and the large models of Hardy Indicator, in ten-minute tows over the restricted area. Furthermore, it is of the same order as that (90%) shown by Winsor & Clarke (1940), when pairs of horizontal tows, taking half an hour, using nets of 12.7 cm in mouth diameter, are considered. It seems therefore that the plankton catchers give an estimate of the population as satisfactorily as nets in spite of their openings being smaller than those of the usual nets.

The values of variation of the large and small catchers in the other experiment made in Ishikari Bay in which simultaneous tows of both catchers were made five times successively along the course of the ship, that is, the tows were not made at the same area, were also calculated respectively as 350% (model II) and 735% (model I). These are much larger than those obtained in a restricted area. This increase in the values is caused by the change in population represented by the high value of $S \times T$ interaction. The results are identical with those obtained from experiments made by Barnes (1951).

A comparison of the amount of catches caught by the large and small catchers was then made concerning all the series. The mean ratios of the catches of the large catcher to those of the small one were obtained in logarithmic values and then converted into actual number. Three standard deviation limits were also calculated from the analyses of variance as the error to be attached to those ratios.

The results of calculations are given in the following table.

No. of series	Mean ratio of catches obtained	99% fiducial limits
I	3.03	1.30 - 7.08
II	4.31	1.73 -10.72
III	2.73	1.67 - 4.47

The ratio of the areas of inner openings between large and small catchers is 6.25. Assuming that the catchers are functioning effectively this ratio is used for comparison. The mean ratios of catches in each series are smaller than the ratio of the opening of both catchers, and this (6.25) lies outside the 99% fiducial limits in Series III. Therefore, it can be suggested that the larger catcher can not always catch the number of organisms proportional to its opening size as compared with the smaller one.

The Handy Underway Plankton Catcher is originally designed to use in simplest and easiest way for fishermen. It is not equipped with any sinking vane so that it may be hauled with ease by hand. One peculiarity of this instrument is in the structure of the opening on both sides of the head-piece to introduce inflowing water. It is constructed differently from the Hardy Indicator or other similar recent underway samplers. The complexity of way of inflowing water makes impossible the exact estimation of amount of water entering into the inside net in the present catcher which may vary with great complexity according to the towing speed.

II. Horizontal tows of stramin fish-larva net

At present in Japan, the horizontal surface tow of the stramin net is standardized as a routine procedure to collect the larvae or eggs of fishes. The standardized net is 130 cm in mouth diameter, 450 cm in length, made of stramin in the upper 300 cm and of bolting silk, GG 54, in the lower 150 cm.

Experiments were made to find out the difference of variability of catches between the standard 10 minutes' tow and the 20 minutes', so as to ascertain the reliability of standard ten-minute tow. Two nets of the same size were towed at the side of the ship, one on the starboard and the other on the port, each being kept about one meter distant from the side of the ship. The catches were kept separately for analysis. Logarithmic values of catches were used also in these experiments.

In the first place, ten-minute tows were repeated three times in the same course, and six independent samples were obtained. Secondly, one net was hauled up on board the ship ten minutes after the start, while the other one was towed continuously for an additional ten minutes. Collections in the same way were repeated three times, yielding six independent samples. In another area, there was an opportunity for making such collections, yielding twelve independent samples. Thus, sum totals of materials reached to twenty-four. For convenience in analysis two groups of organisms, fish eggs and fish larvae, were calculated for the study.*

Series I

The first experiments were carried out off Furubira, western Hokkaido, from 16:28 to 17:14 hours on June 28, 1955. Three tows, each tow lasting ten minutes, were taken as far as possible over the same course at constant speed (2 knots).

Firstly, the hypothesis that catches caught on each side were sampled from the same population was tested. The values of F_0 (the ratio of variance of catches on each side) for the species caught in sufficient number were calculated as 2.55 for mackerel eggs and 4.74 for unidentified eggs (probably eggs of plaice).

The value of F_2^2 (0.05) is 19.0, and the assumption that both species of eggs caught by the net of each side of ship belong to the same population is not rejected.

After the first series of experiments, three tows of the second experiments (starboard net - ten minutes; port net - twenty minutes) were made by running the same course from 17:27 to 18:44 hours. The same two species of eggs were used for analysis of variance under the above described assumption. The catches of ten-minute tows were doubled for comparison.

The analysis of variance gives data shown in table 4.

* Thanks are due to Mr. O. Sano of the Hokkaido Regional Fisheries Research Laboratory for counting this set.

Table 4. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Main effects:			
Species (S)	1	12.1002	12.1002
Tows (T)	2	0.0933	0.0467
Distances (D)	1	0.0184	0.0184
First order interactions:			
$S \times T$	2	0.1252	0.0626
$S \times D$	1	0.0184	0.0184
$T \times D$	2	0.0261	0.0131
Second order interaction:			
$S \times T \times D$	2	0.0856	0.0428
Total	11	12.4672	

The mean squares for tows and distances are not significant (the 0.05 level is accepted throughout) nor are the first order interactions when tested against the second order interaction, so that there was no significant difference between the tow or distance, that is, the catches were reasonably proportional to the distances of tows so far as the present materials are concerned.

Then the analyses of variance are made for ten- and twenty-minute tows separately. The results show that the tow mean squares are not significant against residuals in each case. The percentage standard deviation of a single observation for a ten-minute tow is then calculated as 81% and for a twenty minute tow as 35%.

Series II

The first experiments were carried on off Cape Shiriba, Yoichi, on the west coast of Hokkaido, from 00:05 to 00:52 hours on June 29, in the same way as in Series I. The values of F_0 for three abundant species, mackerel eggs, unidentified eggs and larvae of anchovy, are calculated respectively as 11.17, 1.18 and 3.38 ($F_2^2(0.05)=19.0$). Thus the catches of each side were considered to be taken from the same population as in Series I.

Just after the previous three repeated tows, second tows were carried out from 00:55 to 02:00 hours in the same course. The abundant three species were used in analysis for studying the difference between ten- and twenty-minute tows.

The analysis of variance is then given in table 5.

Table 5. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Main effects:			
Species (S)	2	6.1116	3.0558
Tows (T)	2	0.0489	0.0245
Distances (D)	1	0.0060	0.0060
First order interactions:			
S × T	4	0.2457	0.0614
S × D	2	0.0415	0.0208
T × D	2	0.1943	0.0972
Second order interaction:			
S × T × D	4	0.3468	0.0867
Total	17	6.9948	

The mean square for distance is not significant, so that there was no significant difference between the totals of catches of the different towing distances. None of the first order interactions are significant, so that the proportions of organisms caught did not vary with the tows or the distances, and further the proportion at two different distances did not vary with tows.

The analyses of variance for ten- and twenty-minute tows are then made respectively. The mean squares for tows are also not significant in each case. The percentage standard deviation of a single observation is 112% in the short tow and 52% in the long tow. The value of variation for ten minutes is about half that of twenty-minute tow.

The results of analysis of variance confirmed that the catches were proportional to the distances of tows, and there is no selection for species resulting from the difference of towing distance. Theoretically speaking, the percentage standard deviations of a single observation for twenty-minute tows should be half that of ten-minute, when one supposes that one twenty-minute tow is a random sample of two ten-minute tows.

In the present experiments the variation of the long tow is roughly $1/\sqrt{2}$ the short one, and the mean square for distances, when the catches of ten minute-tow were doubled, is not significant against the value of second order interaction. Accordingly, no significant differences are observed between the catches of the tows, notwithstaning the twenty minute tow is not conceivable as the random sampling of two ten minute tows in the present experiments. That is to say, the catches caught by the ten-minute tow at a speed of about 2 knots represent the average population of fish larvae and fish eggs in the areas surveyed. Thus the prolongation of the towing distance does not vary the mean value of catches significantly, while the variation is decreased inversely proportional to the square root of degrees of prolongation.

The total number of species caught in the experiments by ten- and twenty-minute tows in both series is tabulated as follows:

	Series I		Series II	
	10 minutes	20 minutes	10 minutes	20 minutes
1st tow	8	8	9	9
2nd tow	4	6	6	9
3rd tow	3	7	8	12

Generally the species which occurred in twenty-minute tows are more abundant than those of the ten-minute, however it does not always follow that the species collected in the short distance tows are found also in the catches of long distance tows.

Recently, Senta (1955) made an observation on the stramin fish-larva net, and assumed that Nicholson's Competition Curve, $\frac{dn}{dt} = a\ (N-n)$, was conformed reasonably to the relation between the distance (time) of tow and the number of species caught, and for this reason he assumed that the twenty-minute tows would be more useful than ten-minute. The application of the present data to the above exponential equation showed the value of a to vary to a large extent, which must be constant, although the present collections were made within a short time and in very restricted region as far as possible. It seems therefore that Nicholson's theoretical model is not always applicable.

III. Horizontal distribution of plankton in a limited area

The patchiness of plankton distribution has been shown by Hardy & Gunther (1935) for Antarctic plankton, and by Hardy (1944) and his co-workers for the North Sea plankton. The interests of these studies, however, lay in the distribution of organisms over a wide area. On the other hand, according to the recent works of Barnes (1949, 1951 with Marshall), the variability of catches of plankton tows is not entirely accounted for by technical errors, but partly depends upon a non-random distribution of the organisms themselves in a restricted area. From this, the horizontal distribution in the limited area becomes a problem to be statistically studied.

The samples were taken by a hand pump fitted with 2 cm rubber hose. An end of the hose was lowered 100 cm beneath the sea level through a hole bored at the center of a board with an area of about 100 cm². This board was kept at a point about seven meters distant from the stern of the ship by the help of a bamboo pole in order to avoid the disturbance of water by the ship.

There was a bright sky and the sea was calm, but the ship was drifted very slowly by light air. Thus the samplings were performed continuously along a line. To estimate the volume of water pumped the simplest technique consisting of filtering the water through a small net into a tank of known capacity was used in this study. After filling up a tank, the pumping was repeated into another tank so as to collect the samples continuously through the experiments. The time of pumping required to sample 20 liters of water was estimated at 90 seconds or so ($\pm$ 10 sec.). The plankton materials caught through a bolting silk net were washed off carefully and removed into a bottle. The variation of the volume of water pumped was controlled within as narrow limits as possible. All individuals of organisms were calculated carefully under the binocular microscope, and so there are no sub-sampling errors.

Series I

In this series twenty samples taken at about 90 seconds interval were collected from a single constant depth, off Furubira, western Hokkaido, starting at 15:50 hours on June 28, 1955. Relative movement of water and ship, measured by means of a float, was 3.5 - 5.4 m/min., which corresponds to the transfer of ship from 5.4 - 8.1 meters during the collection for a single sample, 108 - 162 meters for collecting twenty samples. This small area of water has been commonly considered to maintain the same population of plankton in the sampling by net haul or by other methods.

The number of organisms calculated is shown in table 6. In this series, *Oikoleura* occurred abundantly in all samples. Copepoda was represented by such small species as

Table 6. Number of organisms occurring in each twenty liters of water taken by a consecutive pump samplings on board a ship drifting along a straight line

Series I (Time: 15:50 to 16:20)

Order of Sampling	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Copepoda	5	9	1	4	3	3	7	3	2	4	1	5	8	5	7	10	7	5	11	10
Amphipoda		1																		
Oikopleura sp.	22	20	13	35	10	27	45	47	42	38	24	50	36	51	42	39	42	25	41	27
Limacina helicina		3		1			1	1	1			1				1	1		1	
Eggs of mackerel		16		3							1								1	
Eggs of anchovy		141	3	35		4	1	2		5		2		2						
Calyptopis larva of *Euphausia*														1						

Series II (Time: 19:23 to 19:53)

Order of Sampling	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Copepoda	73	41	57	53	37	52	38	56	51	37	43	65	64	44	71	124	94	84	95	71
Amphipoda	11		1		3							1	3		1	2	12	10	11	5
Oikopleura sp.	177	52	89	68	68	67	42	64	54	56	46	47	50	37	42	55	44	47	36	23
Sagitta sp.										1										
Limacina helicina	1																			
Aglantha sp.	1																			
Eggs of mackerel	5	2	2	1	2	1	2	2		2	2				2	3	3	1	2	3
Calyptopis larvae of *Euphausia*	1212		35		3		6		2				2							
Brachyuran zoea			1									1					2			

Paracalanus, *Clausocalanus* and *Oithona*. A small number of eggs of mackerel and anchovy, Amphipoda and the larvae of *Euphausia* were found. The occurrence of the main species is shown in Fig. 2.

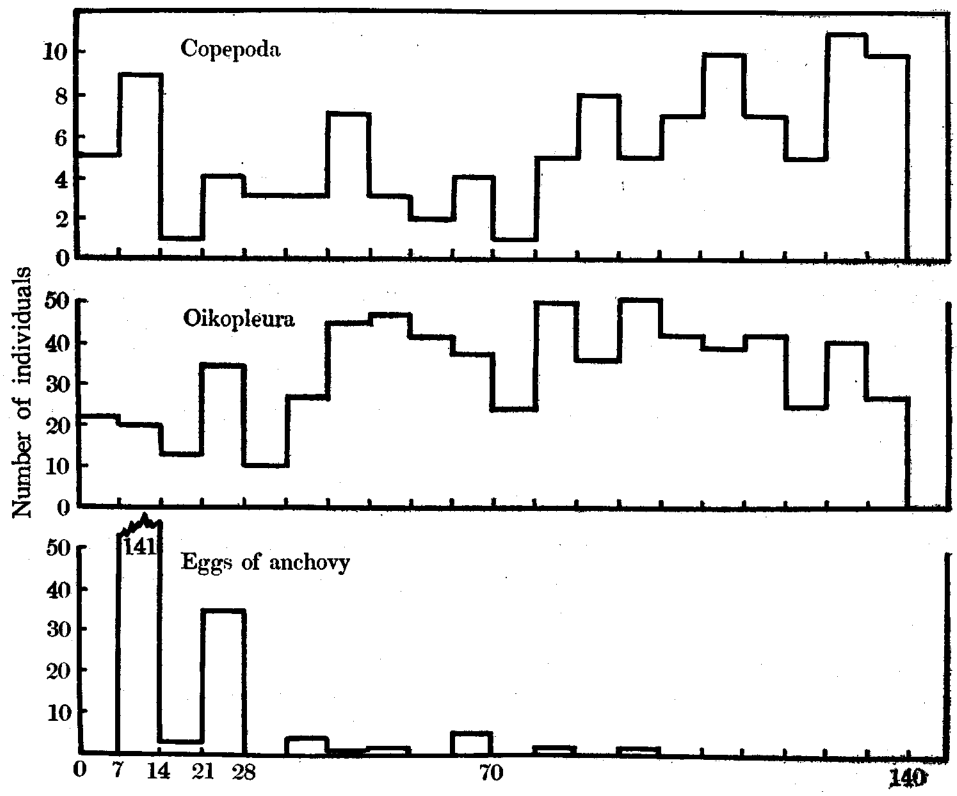

Fig. 2. The fluctuation of population density in each twenty liters of water taken with a continuous twenty pumpings on board a ship drifting along a straight line in the afternoon on June 28, 1955

The coefficient of variation of catches for *Oikopleura* (logarithmic values are used throughout these experiments, for the standard deviation is proportional to mean values of catches) is 34.1%, while that of Copepoda is 189 %. The value for eggs of anchovy is very high. Then the analysis of variance for *Oikopleura* and Copepoda is made as follows:

Table 7. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Species (S)	1	6.9973	6.9973
Pumpings (P)	19	1.6559	0.0872
Residual (S × P)	19	0.7899	0.0416
Total	39	9.4431	

$F_o = V/\bar{X} = 4.3$ for *Oikopleura*
1.7 for Copepoda $F^{19}_{\infty}(0.05) = 1.59$
104.3 for Eggs of Anchovy

The mean square for pumping is slightly significant when tested against S×P. The percentage standard deviaton of a single observation is calculated as 79.4%. Furthermore, the divergence coefficient, $F_o = V/\bar{X}$, is calculated so as to ascertain the degrees of dispersion from the Poisson distribution, and is shown under the variance table. The values for each species are significantly higher than unity, especially high in the eggs of anchovy.

Series II

Twenty samples were taken beginning at 19:23 hours, in the evening twilight of the same day in the identical region with Series I. The ship was allowed to drift, and distance of collection of a sample (20 liters) was estimated to be 5.4 to 8.1 meters.

Many species (groups), *Oikopleura*, Copepoda, Amphipoda and calyptopis larvae of *Euphausia*, increased their number in the twilight migration (table 6). A small number of *Sagitta* and brachyuran zoea also appeared, which were not found in the daytime collection (Ser. I).

The catches of *Oikopleura*, Copepoda and eggs of mackerel are shown in Fig. 3. The coefficient of variation of a single observation for *Oikopleura* is 22.4%, and 21.7% for Copepoda; these are much smaller than those of Series I. The results of analysis of variance for the above two species and the divergence coefficient of main species are given as follows:

Table 8. Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Species (S)	1	0.0265	0.0265
Pumpings (P)	19	0.3371	0.0177
Residual (S × P)	19	0.7409	0.0390
Total	39	1.1045	

$F_o = V/\bar{X} = 17.1$ for *Oikopleura*
8.3 for Copepoda $F^{19}_{\infty}(0.05) = 1.59$
1.2 for Eggs of Mackerel

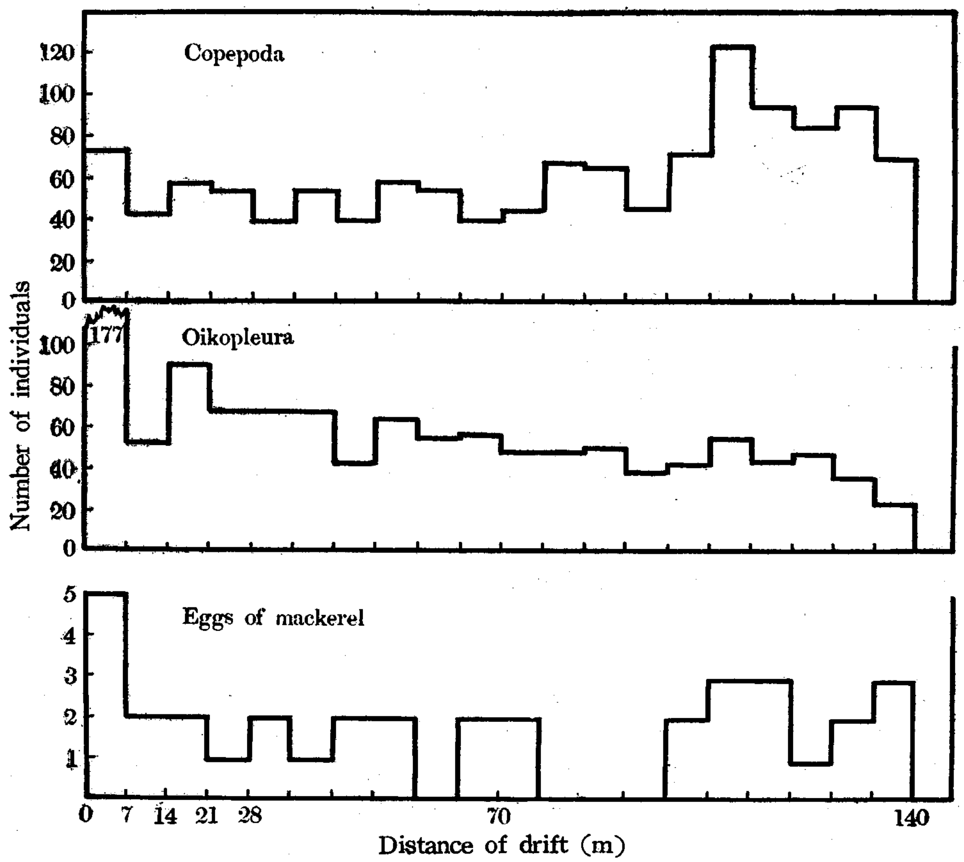

Fig. 3. The fluctuation of population density in each twenty liters of water taken with a continuous twenty pumpings on board a ship drifting along a straight line in the twilight on June 28, 1955

The mean square for pumping is not significant against S × P. The percentage standard deviation for a single observation is 47.4%. The divergence coefficients are significantly different from unity in both *Oikopleura* and Copepoda, while that for eggs of mackerel is not significant. It seems therefore that further examination is necessary for mackerel eggs owing to the low density of mean catches.

The two groups, *Oikopleura* and Copepoda which were abundantly collected, appeared in all samples, while such forms in low density as eggs of mackerel and anchovy, larvae of *Euphausia* and Amphipoda occurred very irregularly in the samples.

Motoda & Anraku (1955) have examined the variability of catches in replicate vertical plankton hauls, and found that the percentage standard deviations of a single observation vary from 30% to 250%. They suggested that the variability of catches in vertcal net hauls is largely due to a non-random distribution of the organisms rather than the technical matters. A similar order of variability has been reported by many workers.

The volume of water dipped by means of pump under a good condition, as in the present experiments, must be much more constant than the volume of water filtered by the net hauls. Accordingly the technical error in sampling the plankton from a certain volme of water may be much eliminated in the pumping method. Nevertheless, the variability of catches by pumping is not less than that of the net hauls, but also in the same order (about 50% or so). Thus the assumption may be held with reason that the variability of plankton collection is mainly due to some local variation in the distribution density of the plankton in a restricted area. Formerly, Barnes (1949) found the same order of variation in both pumping and net hauls and suggested that observed variability of net hauls is not entirely due to the variation in the volume of water filtered; the above assumption was confirmed by his further investigation (Barnes & Marshall, 1951), supporting the supposition of a 'contagious' distribution of plankton population.

The divergence coefficient ($F_o = V/\bar{X}$) is in all cases significantly larger than unity, indicating that individual plankton organisms are not distributed homogeneously in the restricted area but locally aggregated in some undetermined manner. The features of the distrbution of the organisms, of course, differ in each species, that is, the variance of *Oikopleura* differs considerably from those of Copepoda. On the other hand, the mean square for pumping calculated from the totals of both species is not significant. This insignificance is probably due to the counting of catches as a whole, without concern for separate species. A possible existence of the local swarming of each species is suggested strongly from Figs. 2 and 3. Such variability should not be considered as the variation of the residuals or inevitable errors.

A sample of the present experiments represents the mean catches for certain horizontal distance (5.4–8.1 m), but if the real volume occupied by swarming organisms is smaller than that of water tested in the present sampling, more detailed continuous sampling would be required to seek for fine features of distribution, and an extension of this type of work promises some future confirmation of conclusions in this paper.

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Summary

(1) The variability of catches caught by the two models of the Handy Underway Plankton Catchers was examined statistically by three series of experiments.

The percentage standard deviations of a single observation for the small catcher (Model I) are calculated as 55.6%, 163.5% and 57.1%, and those of the large catcher (Model II) are 78.6%, 85.2% and 57.3%. The order of deviations of both catchers is roughly the same, and the values are not greater than those previously reported for horizontal tows of Hardy Indicator or ordinary plankton net.

The mean ratios of catches of both catchers and three standard deviation limits of these values are obtained as 3.03 (1.30 - 7.08), 4.31 (1.73 - 10.72) and 2.73 (1.67 - 4.47); the ratio of the areas of openings in the head-piece between two catchers is 6.25. Thus, the amount of catch taken by the large catcher is not always proportional to that of the small one.

The difference of the proportion of each organisms caught with the two catchers over the tows indicates the differential selection of organisms with the type of machines.

(2) The twenty-minute horizontal tow with 130 cm stramin fish-larva net at low speed does not show a significantly different mean value of catches as compared with that of ten-minute tow with identical net. It is found that the approximate mean value of population of fish eggs and larvae is satisfactorily represented by the ten-minute tow. However, the percentage standard deviation of a single observation for catches in prolonged tow (20 min.) with such net is about one-half that of the short time tow (10 min.).

The twenty-minute tow usually can sample certain species that have not occurred in the ten-minute tow, but in some cases some of the species caught by the ten-minute tow are not found in the collection of the twenty-minute tow.

(3) A preliminary experiment on the horizontal distribution of plankton in a limited area was made by means of a hand pump method in which the amount of water sampled is accurately estimated. There was a certain extent of variability of catches similar to the case of net haul; this variability should involve other causes, more probably a non-random distribution of organisms themselves, rather than any technical error in the operation, which was well eliminated in the pumping method.

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