The Validity of Single Vertical Hauls of the International Net in the Study of the Distribution of the Plankton.

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With 2 Figures in the Text.

PLANKTON studies, to be of direct application to fishery problems, should be of such a kind as to enable comparisons to be instituted between the fluctuations in a fishery and those in the plankton itself. But the collection of data on such a scale raises a whole host of difficulties, not the least of these being the degree to which a single haul of a vertical net—a method with much to recommend it—can be considered to yield a representative sample.

In 1922 the late Sir William Herdman (**1**), using a Nansen net, showed, for the waters off the Isle of Man, that " . . . conclusions drawn from any one haul might be anything up to 50 per cent wrong in either direction."

In 1925 Gardiner and Graham (**2**) described an experiment on the same lines, but using in this case a Petersen Young Fish Trawl, which net, they found, compared favourably with the so-called quantitative net employed by Herdman. But, in both cases, the fact emerged that the catches of successive hauls in the same limited area differed considerably from one another, the spread measured by the Standard Deviation being in the nature of $\pm 50\%$ of the mean. In order to see whether this does represent a fair figure, two series of consecutive hauls made during 1926 have been examined. Both the collection of the material, and the subsequent enumeration were the work of Mr. R. E. Savage, to whom I am greatly indebted for permission to make use of them. My thanks are also due to Mr. Michael Graham and others of my colleagues at Lowestoft, and particularly to Mr. Edser of the Ministry's Statistical Section, to whom I am indebted for many helpful suggestions. The net used was the International Net (**3**), of No. 3 silk (60 meshes to the inch), fished vertically by the Wollaston method (**4**).

In the first experiment 40 hauls were made during the course of the night May 31st–June 1st, 1926, whilst drifting in an area centred on a position about 15 miles E.½N. from the Tyne (Lat., 55° 5′ N.;

Long., 1° 0′ W.). The wind was westerly and light (Force 2 on the Beaufort Scale = approx. 5 m.p.h.), and the sea smooth. Soundings varied during the experiment, the nets being fished from 62–80 metres to the surface. The first haul was made at 1755, and the last at 0951, G.M.T. The duration of each haul, in seconds, was measured by means of a stop-watch.

In the forty hauls copepoda comprised from 70–95% of the total catch, the mean being 86%. The dominant species were *Pseudocalanus elongatus* and *Paracalanus parvus*, which for our present purpose have not been separated. The next two species in order of abundance were *Temora longicornis* and *Calanus finmarchicus*. Of non-copepoda, the only species that occurred regularly in fair quantities were Oikopleura spp., but the numbers were not large.

The second experiment comprised 38 hauls of the International Net made some three weeks later during the night of June 24th–25th, 1926, in an area centred on a position about 16 miles E.½N. from the Tyne (Lat., 55° 4′ N.; Long., 0° 57′ W.). The wind was northerly and stronger than before (Force 3 on the Beaufort Scale = approx. 10 m.p.h.). The sea was "slight to moderate" (3–4). Soundings remained fairly constant, and all hauls were made from a depth of 70 metres to the surface. The first haul was made at 2023, and the last at 0750, G.M.T.

Copepods were both absolutely and relatively more abundant, comprising about 94% of the plankton captured by the net. Oikopleura spp. were no longer common. Sagitta spp. were regularly present, but the numbers again were not large.

For the enumeration of the catch in the Laboratory, a Hensen Stempel-pipette was used, and two, or more, separate samples were counted in the majority of cases, the factor being, usually, 50.

The numbers per metre depth of the selected organisms are set out in Tables I and II. The time at which each haul was made (in G.M.T.), the depth from which the net was fished, and the speed of hauling expressed as seconds per metre are included. For convenience in studying the tables, those observations lying close to one another in time are enclosed by brackets.

Before these data can be applied to the question before us, namely, to determine the reliability of a single haul of a vertical net, it is necessary to examine the conditions under which they were obtained. Both series of successive hauls were made from a drifting ship, and the time interval between the first and last haul was in one case about 16 hours, and in the other about 12 hours. There is no information as to the area of sea surface covered during the course of these experiments, but it must have been considerable. Further, owing to the wind, under the influence of which the vessel would tend to move independently of the main body of water, and to changes in level of the various species of the plankton, due

TABLE I.

FIRST EXPERIMENT, MAY 31ST/JUNE 1ST, 1926.

Times, Speeds, and Numbers per metre depth of Selected Organisms.

Haul No.	Time.	Depth.	Speed secs/metre.	Calanus.	Temora.	Pseudo-calanus + Para-calanus.	Total organisms.
1.	1755	80	1·3	6	21	12	50
2.	1805	80	1·1	14	37	22	80
3.	1820	80	2·0	12	29	27	80
4.	1825	80	1·9	2	9	12	46
5.	1940	80	1·8	18	26	32	93
6.		80	1·7	13	28	47	104
7.	1950	80	1·4	6	24	17	65
8.	2058	80	1·8	13	28	25	80
9.	2310	62	2·3	8	23	16	72
10.	0014	62	2·7	7	15	31	65
11.	0139	65	2·5	11	24	22	69
12.	0225	65	2·1	17	27	25	82
13.	0320	70	1·7	14	41	36	118
14.	0415	70	1·7	7	26	65	112
15.	0510	80	1·4	11	20	23	82
16.	0620	60	2·1	16	34	30	92
17.	0627	80	1·5	27	50	35	134
18.	0630	80	1·9	15	25	24	72
19.		80	1·8	20	45	29	110
20.	0647	80	2·2	32	62	61	180
21.	0650	75	2·0	38	44	42	142
22.	0655	75	1·5	5	32	27	85
23.	0700	80	1·7	28	27	51	120
24.		_80_*	1·7	8	30	31	80
25.		_80_	1·7	35	38	57	168
26.		80	1·6	10	23	33	79
27.		80	1·7	7	21	16	51
28.		75	—	23	33	29	93
29.		80	1·7	13	25	24	70
30.		75	1·8	9	20	19	54
31.		_75_	—	7	29	23	65
32.		70	1·6	17	32	30	97
33.	0908	65	1·8	10	20	25	72
34.	0912	65	1·6	5	13	18	46
35.	0916	65	1·7	8	37	55	130
36.	0923	65	1·6	8	23	28	78
37.	0929	65	1·6	12	14	36	79
38.	0934	65	1·5	11	16	30	66
39.	0939	65	1·6	6	17	26	76
40.	0951	65	1·6	6	25	19	58

* Depths in italics are interpolated, the actual depths having been omitted from the records.

TABLE II.

SECOND EXPERIMENT, JUNE 24TH/25TH, 1926.

Times, Speeds, and Numbers per metre depth of Selected Organisms.

Haul No.	Time.	Speed secs/metre.	Calanus.	Temora.	Pseudo-calanus + Para-calanus.	Total organisms.
1.	2023	1·9	56	22	47	146
2.	2200	1·6	69	13	61	174
3.	2205	1·8	46	15	55	198
4.	2220	1·8	37	8	84	141
5.	0125	2·1	36	19	47	112
6.	0130	1·9	25	15	66	122
7.	0137	1·9	98	44	159	355
8.	0145	1·9	64	38	51	219
9.	0155	2·0	58	20	112	232
10.	0245	2·0	92	15	111	261
11.	0254	2·1	139	26	132	332
12.	0305	1·9	139	28	142	359
13.	0315	2·2	95	31	193	380
14.	0323	2·0	155	50	134	379
15.	0350	2·0	95	36	169	352
16.	0355	2·0	159	61	139	444
17.	0402	2·3	156	43	206	492
18.	0408	2·3	150	49	208	496
19.	0415	2·2	166	57	237	544
20.	0420	2·1	91	46	229	406
21.	0426	2·3	116	39	—	446
22.	0433	2·3	101	43	161	367
23.	0500	2·1	89	46	73	246
24.	0507	2·0	111	59	77	275
25.	0515	2·3	72	61	102	279
26.	0520	2·1	90	30	89	265
27.	0525	2·1	108	45	154	356
28.	0532	2·3	119	47	—	308
29.	0535	2·3	151	53	132	384
30.	0645	2·3	104	44	192	394
31.	0700	2·3	101	71	154	352
32.	0708	2·4	146	84	231	539
33.	0712	2·4	113	74	199	458
34.	0720	2·4	115	62	137	365
35.	0730	2·4	111	58	234	461
36.	0736	2·4	143	44	169	404
37.	0745	2·2	114	50	151	381
38.	0750	2·4	102	47	164	391

to their own vertical migrations, it would be unwarrantable to assume that the same population has been sampled throughout the course of either experiment. Accordingly, to consider either series of experiments as a unit for subsequent statistical treatment would be to produce, in all probability, a false idea of the variation in numbers of individuals caught in successive hauls, and would tend unduly to lessen the degree upon which a single haul of a vertical net is to be relied. For this reason, then, although the full data for each experiment are given in Tables I and II, a certain proportion only has been utilised. The choice has been regulated as follows : No group of observations covers more than 1 hour ; no hourly group comprises less than 5 observations ; the observations within any group are not separated from one another by more than 12 minutes.

If Tables I and II are examined it will be seen that there are considerable variations in the catches of successive hauls, even where the time interval is short. The extent of this variation is most conveniently given by determining the mean number of individuals caught in groups of successive hauls, selected as above, and expressing the departure of each observation from this mean as a percentage deviation. These groups are shown in Tables I and II enclosed in brackets. The mean number of individuals captured in each group of observations has been called throughout the "group mean." In order readily to compare the extent of the variation within any one group with that in another, the Average Deviation within each group has been calculated.

The selected data treated in this way are set out in Tables III and IV.

It should be noted at this point that the whole of the variation between catches of successive hauls has apparently been assigned to the variability of the organisms themselves, and not to errors of the methodique. As will be seen later, this is in the main correct, the effect of such contributory errors as variations in the speed of hauling, the part played by light and darkness on the catching power of the net, and the magnitude of the enumeration error, being insufficient to account for the variation observed. The evidence in support of this is collected in an appendix, since by reason of its bulk it might otherwise appear to be the main burden of this paper.

By treating the data in such a way that the variations in the numbers of the more abundant species caught within periods of not more than one hour's duration are related to the mean of the period—the group mean—the observations are directly comparable one with another despite the fact that the density of population may be quite different. In this way, too, it may be possible to utilise observations from the two experiments as a unit for statistical treatment, if it can be shown that the degree of variation within the several groups is of about the same order of magnitude. Further, it may even be possible to consider all the species together.

TABLE III.

FIRST EXPERIMENT. PERCENTAGE DEVIATIONS OF SELECTED OBSERVATIONS FROM THE MEANS FOR THE PERIODS IN WHICH THE OBSERVATIONS WERE MADE, AND AVERAGE DEVIATION FOR THE PERIOD.

		Percentage Deviations from Group Means of :—		
Haul No.	Times.	Calanus.	Temora.	Pseudo- + Paracalanus.
16		30	15	19
17		17	25	5
18		35	38	35
19	0620	13	13	22
20	to	39	55	65
21	0700	65	10	14
22		78	20	27
23		22	33	38
Group Mean		*23*	*40*	*37*
Average Deviation		37%	26%	28%
33		25	5	17
34		38	38	40
35		0	76	83
36	0908	0	10	7
37	to	50	33	20
38	0951	38	24	0
39		25	19	13
40		25	19	37
Group Mean		*8*	*21*	*30*
Average Deviation		25%	28%	27%

N.B. The Group Mean from which the percentage deviations have been calculated is shown in italics.

TABLE IV.

SECOND EXPERIMENT. PERCENTAGE DEVIATIONS OF SELECTED OBSERVATIONS FROM THE MEANS FOR THE PERIODS IN WHICH THE OBSERVATIONS WERE MADE, AND AVERAGE DEVIATION FOR THE PERIOD.

		Percentage Deviations from Group Means of:—		
Haul No.	Times.	Calanus.	Temora.	Pseudo- + Paracalanus.
5		36	30	46
6	0125	55	44	24
7	to	75	63	83
8	0155	14	41	41
9		4	26	29
Group Mean		*56*	*27*	*87*
Average Deviation		37%	41%	45%

Haul No.	Times.	Percentage Deviations from Group Means of:— Calanus.	Temora.	Pseudo- ± Paracalanus.
10		26	50	22
11	0245	12	13	7
12	to	12	7	0
13	0323	23	3	36
14		25	67	6
Group Mean		*124*	*30*	*142*
Average Deviation		20%	28%	14%
15		26	23	12
16		23	30	28
17		21	9	7
18	0350	16	4	8
19	to	29	21	23
20	0433	29	2	19
21		10	17	No observation
22		22	9	17
Group Mean		*129*	*47*	*193*
Average Deviation		22%	14%	16%
23		16	6	30
24		5	20	27
25	0500	32	24	3
26	to	15	39	15
27	0535	2	8	47
28		12	4	No observation
29		42	8	26
Group Mean		*106*	*49*	*105*
Average Deviation		18%	16%	25%
31		14	16	14
32		24	38	28
33		4	21	11
34	0700	3	2	24
35	to	6	5	30
36	0750	21	28	6
37		3	18	16
38		14	23	9
Group Mean		*118*	*61*	*180*
Average Deviation		11%	19%	17%

In order to answer these points, the averages of the deviation within each group have been collected together in Table V, and the values examined from the following points of view :

(*a*) Does any one species exhibit throughout a greater tendency to vary than any other ?

(*b*) Is the degree of variability greater during any one period ?

(*c*) Is the degree of variability more marked in either experiment ?

TABLE V.

Comparison of Spread, Expressed as Average of the Deviations of the Selected Observations from the Group Means.

Species.	Spread within each of the selected periods in the two experiments.							
Calanus	1st Experiment :			37%			25%	
	2nd Experiment :	37%	20%		22%	18%		11%
Temora	1st Experiment :			26%			28%	
	2nd Experiment :	41%	28%		14%	16%		19%
Pseudo- +	1st Experiment :			28%			27%	
Paracalanus	2nd Experiment :	45%	14%		16%	25%		17%

It does not appear that one species exhibits greater variability than another.

During the first period of the Second Experiment, however, the Average Deviations are all bigger than obtained during the course of the remainder. They only differ, however, to a very small extent from those obtaining during the course of the First Experiment. On this account, therefore, there would seem to be no grounds on which any group of observations can legitimately be excluded. Nor does it appear to be unreasonable to treat all the observations as a unit for statistical treatment.

The problem may now be considered as follows : We have 145 attempts to obtain a measure of populations whose true values are given to us by the mean number captured in from 5–8 consecutive hauls of a vertical net. That is to say, we have sampled the population below a small area of the sea surface a number of times by a uniform method, and have determined the amounts by which any single haul differs from the mean of 5–8 hauls. This mean is taken, *faute de mieux*, to represent the actual number of organisms present, and is, in all probability, a close approximation to it. The same result would have been obtained had a special cruise been made, where, instead of the usual single haul at each station, a number of hauls at close intervals of time were taken, and the mean number of individuals used to give the density of population at each station. In view of the variability which has been shown to exist between successive hauls it would probably be desirable always to make up to 5 hauls at each station visited, but to do so would be to reduce the number of stations that could be visited in the course of a routine cruise.

If, however, the chance of a single haul giving a value within so much of the mean can be determined by some such method as that described above, we are enabled to state, with some degree of certainty, whether the resulting picture of the distribution of the plankton is more likely than not to be an accurate one.

In the two experiments under discussion we have been enabled, by the method adopted, to determine what proportion of our 145 observations lie within any desired amount of the mean. The point that arises now is to decide what latitude shall be allowed. To place the standard too low, and to say, for instance, that only those hauls lying within ±10% of the mean will be considered true values, is probably to aim at a degree of accuracy which, it is felt, is neither possible nor necessary. On the other hand, a standard placed at, say, ±50% allows, perhaps, too much latitude, and accordingly it has been placed at 33%. That is to say, any values lying within plus or minus 33% of the mean (or true) value, will be considered as near the truth as is necessary, taking into consideration their mode of collection, enumeration, and the use to which they are put.

The number of observations lying within 10%, 20%, 33% of the mean and the number above this amount are set out in Table VI.

TABLE VI.

FREQUENCY DISTRIBUTION OF PERCENTAGE DEVIATIONS (SIGNS IGNORED) OF ALL OBSERVATIONS FROM BOTH EXPERIMENTS.

Groups. %	Frequency.	Cumulative Frequency.	Percentage Cumulative Frequency.
0–9	33	33	23
10–19	33	66	46
20–33	46	112	77
34–39	13	125	86
40–49	7	132	91
50–59	4	136	94
60–69	4	140	97
70–79	3	143	99
80–89	2	145	100

It will be seen that of our 145 observations 112, that is 77 out of 100, lie within 33% plus or minus of the mean. Of the remainder, 13 out of 33 are within ±40%. Thus, in the area where the two experiments were carried out, it is to be expected that, approximately, four out of every five hauls would give a value which for all practical purposes may be considered a true one. There is, however, the chance of getting values outside 33%, which may be termed extreme values, and, further, that such extreme values as ±90% and even greater may be expected occasionally.

This result shows only limited agreement with that of Herdman (*loc. cit.*), and the question whether the degree of variability in the area where

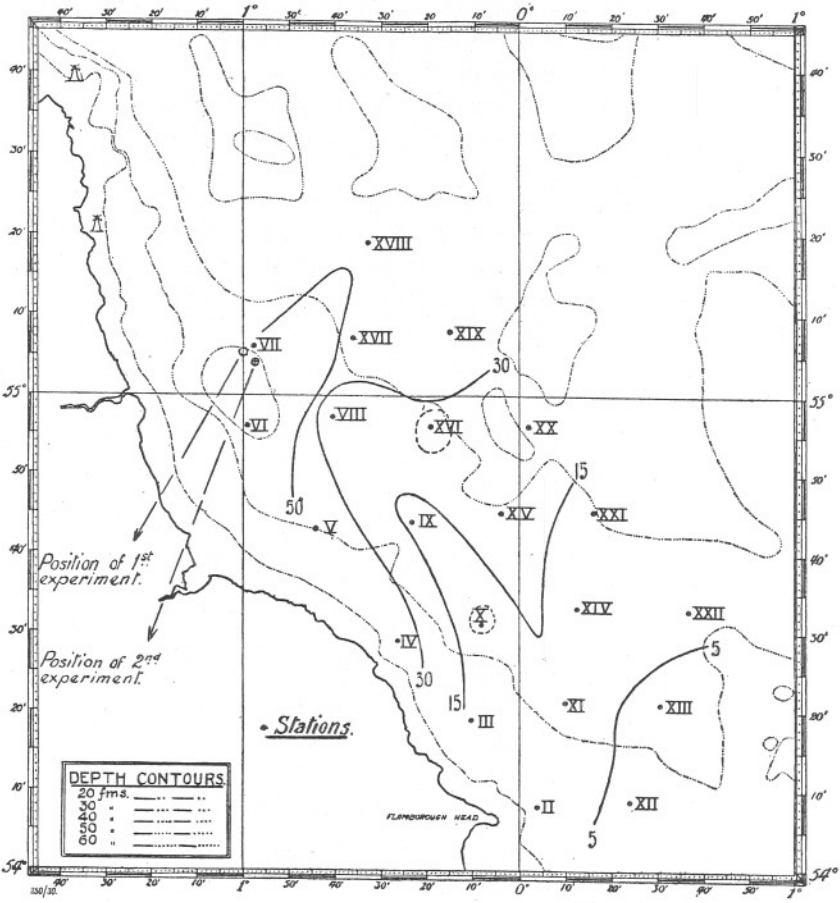

Fig. 1.—Position of Stations on Cruise 28 and Distribution of *Calanus finmarchicus*.

Roman numerals are station numbers. The distribution of Calanus is shown by contours according to the numbers per metre in a vertical haul. The observations of Stations X and XVI have been disregarded (see text, p. 461).

the experiments were performed *is peculiar to the area* must now be examined. In order to do so, the results obtained from a routine plankton cruise have been examined. The cruise selected (Number 28) was made immediately on the completion of our second series of experiments, and extended from June 26th–29th, 1926. At each of the twenty-one stations a haul was made with the International Net (No. 3 Silk), fished vertically; horizontal hauls at 10-metre intervals from the surface to the bottom, with the same net, were taken at the eleven even-numbered stations, II, IV, VI, etc., and hauls of the Petersen Young Fish Trawl, fished obliquely for 30 minutes from (near) the bottom to the surface, were taken at the ten odd-numbered stations, III, V, VII, etc.

The position of the stations worked is shown in Figure 1. It will be seen that they lie on four lines roughly parallel to the coast. The numbers of one species (*Calanus finmarchicus*) per metre depth caught in the 21 hauls of the vertical net are given in Table VII.

TABLE VII.

NUMBERS PER METRE DEPTH OF CALANUS TAKEN IN VERTICAL NETS ON THE ROUTINE CRUISE OF JUNE 26TH–29TH, 1926, AND MEAN NUMBERS AT EACH STATION OF HORIZONTAL HAULS AT 10-METRE INTERVALS.

	CALANUS.	
Station No.	Nos. per metre vertical.	No. per Haul horizontal.
II	8	715
III	13	
IV	39	7,560
V	33	
VI	72	42,484
VII	46	
VIII	24	3,167
IX	12	
X	3	4,791
XI	10	
XII	3	820
XIII	1	
XIV	8	1,100
XV	27	
XVI	2	4,675
XVII	39	
XVIII	40	9,788
XIX	38	
XX	19	3,306
XXI	8	
XXII	8	750

If this Table is studied in connection with Figure 1, it will be seen that the numbers of Calanus increase as we go from south to north, reaching a maximum at Station VI. The species remains fairly abundant at Stations VII and VIII, but declines thence as we go again to the southward. Turning now at Station XIII, and running northwards further offshore, the numbers rise with one exception till Station XVIII is reached. Going south again from here, Station XIX, the second on our last line, shows large numbers of Calanus, but further south the numbers decrease steadily. An attempt has been made to "contour" the distribution of the species (see Fig. 1), and it is obvious that Calanus is *apparently* more abundant both near the coast and in the northernmost water of the area

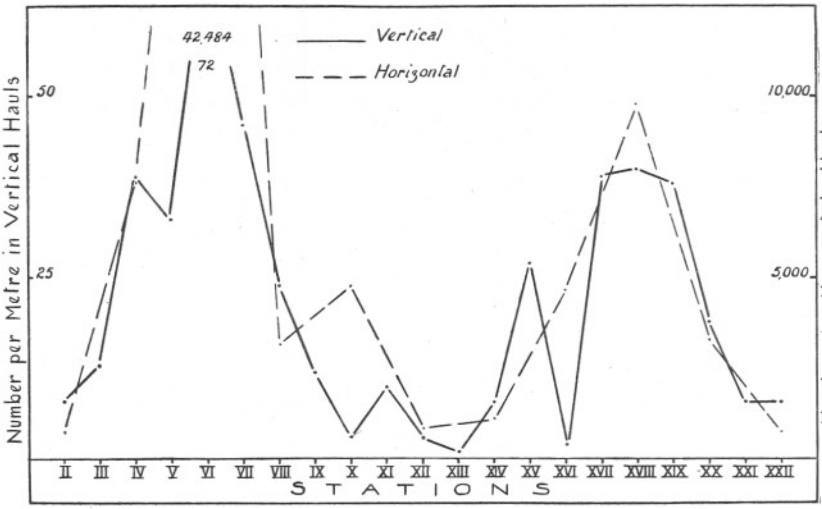

FIG. 2.—Numbers of Calanus taken in Vertical and Horizontal Hauls, Cruise 28.

sampled. This is shown equally clearly by Figure 2, which represents the numbers per metre of Calanus at each station, the stations being arranged in numerical order.

The unbroken line represents the numbers of Calanus captured in 21 vertical hauls. This gives, of course, the same apparent distribution as our contour. The chance that this distribution is a true picture is considerably enhanced by the continuity, and it can scarcely be the result of sampling an approximately uniform population by an unreliable method, or due to the fortuitous operation of chance in a population with no real geographical distribution.

The dotted line in Figure 2 represents the catches of eleven series of horizontal hauls with the same net at the even-numbered stations. This curve follows that of the vertical hauls so closely as to leave very little room for doubt that the distribution is no more to be considered "apparent," but is a true picture.

Further, very slight confirmation of this is given by the 10 hauls of the Petersen Young Fish Trawl at the odd-numbered stations. The mean number of Calanus taken in the 30-minute oblique haul was only 385, whereas the mean for the horizontal hauls with a net of mouth area considerably smaller was 7196, showing that by far the greater proportion of Calanus must pass through the meshes of the fish trawl. In general, the catches of Calanus with this net are so small as to be of little value, but it is interesting to record that the biggest catch (2160) occurred at Station VII, which is in our area of greatest concentration.

It may be claimed, then, for this one cruise, that the distribution of Calanus, as given to us by single hauls of a vertical net at each station, lends support to a belief that the degree of variability in the area sampled is about the same as that in the smaller area where the two experiments were made.

The result of these two experiments, it will be recalled, was to show that only about 1/5th of the observations would give extreme values. Actually, on the cruise of 21 stations it is to be expected that 16 of the observed values would be within 33% of the truth, and that of the remaining 5 some would give values so far removed from it as completely to upset any attempt at contouring the observations. There are two such values at Stations X and XVI respectively. For both of these there is evidence from the horizontal hauls that the value is probably much too low (see Table VII), and there is, accordingly, good reason to believe that the contour should stand, approximately as drawn, the two discordantly low values being omitted. It is interesting to record that the contours were drawn in the first instance without the information which was derived later from the horizontal hauls, the two discordant values being omitted in view of the positions at which they occurred and the good continuity shown by the remainder, and because of the knowledge that such very discordant values were to be expected in, probably, not more than 2–3 cases. The evidence provided later by the horizontal hauls confirmed the omission of these two observations and tended materially to strengthen the belief in the criteria adopted.

In the course of examining the available information for this paper, the geographical distribution of Temora on this same routine cruise, and of Calanus and Temora on a preceding cruise was determined. (These data will be available shortly in a paper by Savage (**5**), and to save repetition are not reproduced here.) From a study of the contours produced, it would appear that the chance of approximately 4/5ths of the observations lying within 33% of the mean, and so providing values on which contours can be based, may be taken as a fairly safe guide.

We are now in a position to sum up both the results which have been obtained and their application to the question of the degree to which single hauls of a vertical net are reliable.

I. The distribution of the copepods Calanus, Temora, Pseudocalanus, and Paracalanus is such that consecutive vertical hauls of the International Net will not catch each time the same number of individuals. The greater proportion of any such hauls, however, will give values within $\pm 33\%$ of the mean (or true) value.

The actual proportion determined was 77 per 100, or approximately 4/5ths. Of the remaining 1/5th, nearly one-half will lie within $\pm 40\%$ of the mean, but extreme values up to $\pm 90\%$ and higher are to be expected.

II. The results of a routine plankton cruise during which 21 stations were worked in that part of the North Sea between 54° N. and 55° 20′ N., from near the coast to a line approximately 40 miles from it, suggest that probably no larger a proportion of extreme values obtains in this area, since the results can be contoured with the exception of 2 discordant values only.

III. The criteria which it is suggested should be adopted to enable the probability of accuracy of any distribution picture derived from the use of single hauls of a vertical net to be gauged are (*a*) the continuity of the observations themselves, by which is meant the mutual support lent to each other by the observations at adjacent stations, and (*b*) the knowledge that, probably, no less than 4/5ths of the observations will lie within $\pm 33\%$ of the mean.

IV. It appears that extreme values of $\pm 50\%$ and upwards of the mean are to be expected occasionally, but probably not more often than once in ten, and on this account a single high or low value unsupported by similar values at adjacent stations is meaningless.

V. Where there is no continuity (see III (*a*) above) it must be taken to mean that the species itself has exhibited no clearly defined area-preference.

VI. Subject to the limitations of III and IV (above), the use of single vertical hauls to study the distribution of the plankton in both space and time may be expected to give reliable results.

APPENDIX A.

SOURCES OF ERROR WHICH MAY ACCOUNT ENTIRELY, OR IN PART, FOR THE VARIATION IN THE SIZE OF CATCH OF THE SUCCESSIVE HAULS CONSIDERED IN THE FOREGOING SECTION.

In this appendix it is proposed to examine those sources of error of the methodique to which the observed variations may be due. The main sources of error will be :—

1. Variations in the speed at which the net was hauled through the water.
2. The effect of light and darkness on the catch of the net.
3. The enumeration error.

Other, minor, sources of error are :—

4. Losses due to insufficient washing of the net, accidents in bottling the sample, etc.
5. Mistakes in identification during enumeration.

The two last-named may safely be considered unimportant, but the effects of the first three may have been considerable, and it is with these that this section will deal.

1. *Speed of Hauling.*

Robert (**6**) working in fresh water with a Fuhrmann Net, No. 20 silk, showed that the numbers of certain zoo- and phyto-planktons captured were directly proportional to the speed at which the net was fished. In both our experiments the speed varied between successive hauls, and it is desirable to see the effect of this, if any, on the catches. In the second series, owing presumably to the stronger wind resulting in the vessel drifting more during the haul, the mean time the net took to pass through 1 metre of water was slightly longer than in the first (2·1 seconds per metre, and 1·8 seconds per metre respectively). This, coupled with the fact that the population had increased, does not allow us to treat the two experiments together, which would be desirable in view of the relatively small number of observations.

In the first series the time of hauling per metre varied from 1·1 to 2·7 seconds, with a Standard Deviation of $\pm 0{\cdot}306$. In the second case, the speed was more uniform, the range being from 1·6 to 2·4 seconds per metre with a sigma of $\pm 0{\cdot}187$. If a correlation exists between variations in the speed of hauling and in the numbers of individuals captured, it should appear in the first experiment, and it is this series that has been examined. The data selected for this purpose were the totals of the four dominant copepods, whose abundance in each of the 40 hauls of this series has been related to the speed (metres per second) at which each haul was made, and the coefficient of correlation (r) determined. The value of r from these data was found to be inconsiderable, namely, $-0{\cdot}13$. It is, accordingly, a legitimate conclusion that the variations in the numbers of organisms captured are due to some other cause than changes in the speed of hauling.

2. *The Effect of Light and Darkness on the Catch of the Net.*

This question arises in view of the fact that there is some evidence that certain species are taken, even in vertical hauls, in greater numbers by night than by day. Whether this is due to the animals rising from those lowest layers which the vertical net does not sample, or whether, as suggested by Southern and Gardiner (**7**), certain forms can see and avoid a net by day, is outside the scope of this paper. But there is a possibility that the night catches may have differed in amount from those by day. Had it not been necessary, for the reasons given on page 453, to consider only those differences in the size of catch of hauls closely related to one another in time, the effect of light and darkness might have been considerable. As it is, it is unlikely that great changes in level are to be expected in the course of the short intervals of time separating the hauls within each group, and for the same reason it is not to be expected that changes in light intensity would be sufficiently great to influence the reaction of the organism towards the net.

In the first experiment, the selected catches were all made in daylight (see Table I). In the second experiment (Table II) the hauls of the first three groups were made at night, and those of the remaining two by day, the mean number of the selected copepods being as follows :—

Species.	Day.		Night.	
	No. of Hauls made.	Mean No. Captured.	No. of Hauls made.	Mean No. Captured.
Calanus	15	112	18	107
Temora	15	55	18	37
Pseudo- + Paracalanus	14	148	17	147

Apart from Temora, which is nearly 50% more abundant by day, the day and night means are to all purposes the same, and it is probably safe to assume that those species are not more abundant in hauls made at night, and that the possibility of this phenomenon vitiating our conclusions may thus be ignored.

The Enumeration Error.

It has long been recognised that a single sample withdrawn by means of a Hensen Stempel-pipette, and raised by the dilution factor, will not give the actual number of organisms present in the whole catch, and Hensen adopted a method of averaging to minimise the discrepancy, *vide* Jenkins (**8**). A large enumeration error might, of course, account for a great part of the differences that have been observed in the size of catches of successive nets, and, in order to gain an idea of the magnitude of the error when a single sample only is withdrawn for enumeration a series of test "counts" was made. One cubic centimetre was withdrawn, by means of a Hensen Stempel-pipette, 25 times from a stock sample of North Sea plankton, diluted to 200 c.c. After each "count" the organisms were drained, replaced in the flask, and 1·0 c.c. of water run in from a burette. In this way the " population " was kept constant.

The results of these 25 " counts " are set out in Table VIII. To get the total number of each species actually present in the sample the counts should be multiplied by the factor 200.

TABLE VIII.

RESULTS OF 25 TEST COUNTS.

Sample.	Calanus.	Pseudo- + Paracalanus.	Temora.	Total Organisms.
1.	39	51	11	115
2.	28	59	12	123
3.	38	47	16	131
4.	49	59	8	133
5.	43	60	17	134
6.	42	49	15	122
7.	51	57	12	138
8.	39	54	10	118
9.	41	44	13	115
10.	40	37	16	108
11.	36	59	8	118
12.	49	63	9	138
13.	38	42	7	103
14.	44	52	17	127
15.	36	50	16	113
16.	38	59	16	125
17.	39	60	13	127
18.	46	58	20	146
19.	43	65	11	135
20.	43	49	9	119
21.	40	61	9	122
22.	43	56	14	129
23.	38	60	13	125
24.	53	69	9	149
25.	34	57	9	119
Total	1,030	1,377	310	3,132
Mean	41·2	55·1	12·4	125·3
Mean × 200	8,240	11,020	2,480	25,060

To get a measure of the spread of this series of counts the Standard Deviations (σ) have been calculated, after raising each count by the dilution factor of 200, for the three copepod species and for all the organisms present. These are set out in Table IX.

TABLE IX.

STANDARD DEVIATION OF 25 TEST COUNTS.

(Given in Table VIII.)

Calanus.	Temora.	Pseudo- + Paracalanus.	Total Organisms.
1,088	1,472	690	2,179

TABLE X.

COMPARISON OF 25 HAULS FROM THE SECOND EXPERIMENT, SELECTED BY CHANCE, WITH THE 25 TEST COUNTS.

Actual Hauls.			Test Counts.		
Haul No.	Total Calanus.	Percentage Deviation from Mean.	Count No.	Total Calanus.	Percentage Deviation from Mean.
29	10,575	+ 40·5	1	7,800	− 5·3
13	6,675	− 11·3	2	5,600	− 32·0
36	10,025	+ 33·2	3	7,600	− 7·8
20	6,360	− 15·5	4	9,800	+ 18·9
4	2,600	− 65·5	5	8,600	+ 4·4
23	6,225	− 17·3	6	8,400	+ 1·9
7	6,900	− 8·3	7	10,200	+ 23·8
34	8,160	+ 8·4	8	7,800	− 5·3
18	10,500	+ 39·5	9	8,200	− 0·5
2	4,845	− 35·6	10	8,000	− 2·9
25	5,400	− 28·3	11	7,200	− 12·6
9	4,050	− 46·2	12	9,800	+ 18·9
32	10,200	+ 35·5	13	7,600	− 7·8
16	11,100	+ 47·5	14	8,800	+ 6·8
35	7,800	+ 3·6	15	7,200	− 12·6
19	11,640	+ 54·6	16	7,600	− 7·8
3	3,240	− 57·0	17	7,800	− 5·3
30	7,275	− 3·3	18	9,200	+ 11·7
14	10,875	+ 44·5	19	8,600	+ 4·4
33	7,920	+ 5·2	20	8,600	+ 4·4
21	8,100	+ 7·6	21	8,000	− 2·9
5	2,520	− 66·5	22	8,600	+ 4·4
28	8,325	+ 10·6	23	7,600	− 7·8
12	9,775	+ 29·9	24	10,600	+ 28·6
31	7,080	− 5·9	25	6,800	− 17·5
Mean	7,527	28·85	Mean	8,240	10·25

The results cannot be considered altogether satisfactory, and the possibility that part, at least, of the variation in the size of catch may be due to the enumeration error cannot be ruled out. That the variation found is not due solely to this cause is demonstrated by the following table, where the variation in the numbers of Calanus captured in 25 hauls of the 38 consecutive hauls of the Second Experiment is compared with that of this series of 25 test counts. The 25 hauls in Table X, opposite, were selected from the total of 38 hauls of Table II, by dealing out the first 25 cards from a pack of 38 numbered 1–38, the choice being in this way unbiased.

It will be seen at once that the degree of variation in the numbers of Calanus caught in the 25 hauls, selected from the series of consecutive hauls of the Second Experiment, is much greater than that of the test counts. Further, it must be remembered that column 5 shows the situation at its worst, for in both the actual experiments the factor, instead of 200, was usually 50, and the enumerated totals were based on an average of 2 (and sometimes more) separate counts. Turning again to Table IX, we see that sigma for Calanus was ± 1088, while $\frac{100 \cdot \sigma}{m}$ is $\pm 13{\cdot}2\%$. If now we compute sigma for the twenty-five counts taken two at a time, sigma becomes ± 715, $\frac{100 \cdot \sigma}{m}$ becoming $\pm 8{\cdot}7\%$. It may fairly be claimed, therefore, that although the enumeration error may be considerable, it is not sufficient to account for the differences observed in our two series of successive hauls.

SUMMARY.

In both the series of hauls made for the purpose of estimating the reliability of a single haul of the International Vertical Net, the possibility that the variation in the size of catch of successive hauls is due to errors of the methodique has been examined.

Errors due to variations in the speed of hauling, and to the effect of light and darkness on the catch of the net can be ruled out.

The enumeration error, even where the enumerated total rests on a single count, is insufficient to account for the major part of the variations found, and, having regard to the fact that such totals were derived from two, and sometimes more, separate " counts " from each sample, there is good reason to believe that the main cause of variation in the size of catch is to be sought elsewhere, the most likely being the lack of uniformity in the distribution of the organisms themselves.

APPENDIX B.

VARIATIONS IN THE COMPOSITION OF THE PLANKTON DURING THE COURSE OF THE TWO SERIES OF CONSECUTIVE HAULS.

A STUDY of Tables I and II (pp. 451 to 452), which give the numbers per metre depth of the selected species in each haul, shows that there was considerable variation in the numbers of individuals caught, even where the time interval between the hauls was quite short. Whether this variation was ever sufficiently great to warrant the statement that the plankton was patchy, or that the individuals comprising it occurred in swarms, will depend upon the interpretation placed on these somewhat vague terms. Apstein (**9**), for instance, defines a swarm as a local assemblage of animals of one species in waters where, elsewhere, this species is absent or very sparsely distributed. It will be seen, however, that he regards a swarm as composed of one species. With this definition in mind, the data have been examined to see whether or not a population has been sampled that, whilst varying in abundance, maintained a fairly uniform specific composition. The method adopted has been to express the numbers of the dominant copepods as plus or minus percentage deviations from their own means, in which way it has then been possible to see whether the species tend to increase or decrease separately or together. The data treated in this way are set out in Tables XI and XII.

TABLE XI.

NUMBERS OF CALANUS, TEMORA AND OF PSEUDO- AND PARACALANUS PER METRE DEPTH IN 40 CONSECUTIVE HAULS FROM THE FIRST EXPERIMENT, EXPRESSED AS PERCENTAGE DEVIATIONS FROM THEIR OWN MEANS.

(Hauls in which the numbers of the three genera did *not* rise or fall together are in italics.)

Haul No.	Calanus. + %	Calanus. − %	Temora. + %	Temora. − %	Pseudo- + Paracalanus. + %	Pseudo- + Paracalanus. − %
1.		57		25		61
2.	*0*	*0*	*32*			*29*
3.		*14*	*4*			*13*
4.		86		68		61
5.	*29*			*7*	*3*	
6.		*7*	*0*	*0*	*52*	
7.		57		14		45
8.		*7*	*0*	*0*		*19*
9.		43		18		48
10.		*50*		*46*	*0*	*0*

Haul No.	Calanus. + %	− %	Temora. + %	− %	Pseudo- + Paracalanus. + %	− %
11.		21		14		29
12.	*21*			*4*		*19*
13.	*0*	*0*	*46*		*16*	
14.		*50*		*7*	*110*	
15.		21		29		26
16.	*14*		*21*			*3*
17.	93		79		13	
18.	*7*			*11*		*23*
19.	*43*		*61*			*6*
20.	129		121		97	
21.	171		57		35	
22.		*64*	*14*			*13*
23.	*100*			*4*	*65*	
24.		*43*	*7*		*0*	*0*
25.	150		36		84	
26.		*29*		*18*	*6*	
27.		50		25		48
28.	*64*		*18*			*6*
29.		7		11		23
30.		36		29		39
31.		*50*	*4*			*26*
32.	*21*		*14*			*3*
33.		29		29		19
34.		64		54		42
35.		*43*	*32*		*77*	
36.		43		18		10
37.		*14*		*50*	*16*	
38.		21		43		3
39.		57		39		16
40.		57		11		39

TABLE XII.

NUMBERS OF CALANUS, TEMORA AND OF PSEUDO- AND PARACALANUS PER METRE DEPTH, IN 38 CONSECUTIVE HAULS, FROM THE SECOND EXPERIMENT, EXPRESSED AS PERCENTAGE DEVIATIONS FROM THEIR OWN MEANS.

(Hauls in which the numbers of the three genera did *not* rise or fall together are in italics.)

Haul No.	Calanus. + %	Calanus. − %	Temora. + %	Temora. − %	Pseudo- + Paracalanus. + %	Pseudo- + Paracalanus. − %
1.		46		48		66
2.		34		69		56
3.		56		64		60
4.		64		81		40
5.		65		55		66
6.		76		64		53
7.		*6*	*5*		*14*	
8.		38		10		63
9.		44		52		19
10.		12		64		20
11.	*34*			*38*		*5*
12.	*34*			*33*	*2*	
13.		*9*		*26*	*39*	
14.	*49*		*19*			*4*
15.		*9*		*14*	*22*	
16.	*53*		*45*		*0*	*0*
17.	50		2		48	
18.	44		17		50	
19.	60		36		71	
20.		*12*	*10*		*65*	
21.	*12*			*7*	No observation.	
22.		*3*	*2*		*16*	
23.		*14*	*10*			*47*
24.	*7*		*40*			*45*
25.		*31*	*45*			*27*
26.		13		29		36
27.	4		7		11	
28.	*14*		*12*		No observation.	
29.	*45*		*26*			*5*
30.	*0*	*0*	*5*		*38*	

Haul No.	Calanus. + %	Calanus. − %	Temora. + %	Temora. − %	Pseudo- + Paracalanus. + %	Pseudo- + Paracalanus. − %
31.		*3*	*69*		*11*	
32.	40		100		66	
33.	9		76		43	
34.	*11*		*48*			*1*
35.	7		38		68	
36.	37		5		22	
37.	10		19		9	
38.		*2*	*12*		*18*	

In the First Experiment (Table XI) all three of the selected species rise or fall together in 19 out of 40 cases. These are shown in ordinary type. In 15 of these cases the amounts are below the respective means, and in 4 they are above. Taken by itself, this is not perhaps very impressive, but the probability that it does indicate a tendency for the three species to behave similarly is heightened by a study of the figures themselves, which in several cases are of the same order of magnitude.

In one case, however, haul 14 (Table XI), the copepods Pseudo- and Paracalanus occurred in considerable numbers, whilst the numbers of Calanus and Temora showed a decrease, suggesting that here a definite aggregation of the species must have been sampled.

In the Second Experiment (Table XII), the three copepods rise or fall together on 19 occasions out of 36. On 10 occasions they have all fallen and on 9 they have risen together. Here again, particularly in hauls 1–6, Table XII, where the three species are all relatively scarce, the probability that the species have behaved in the same way is heightened by the similarity of the deviations.

In this series there is no evidence of a mono-specific swarm.

In conclusion, it would probably be unwise to attach too great weight to these somewhat scanty data, but it would appear that mono-specific aggregations are only exceptionally encountered, and that the population sampled has maintained a relatively constant composition.

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