# THE VARIABILITY OF CATCHES IN VERTICAL PLANKTON HAULS*

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## Introduction

The plankton net has long been in common use in the plankton collection for its great convenience, but in the strictly quantitative sampling the method of net haul has not always been considered the best.

Kokubo & Tamura (1931) concluded the inadequacies of the use of net for the quantitative studies in comparison with the results of pumping method. Kurashige (1931) showed by experiments that the different types of the net filter the water in different ratios. Aikawa (1934) experimented on the variability of collection by plankton net, obtaining less than 30% of coefficient of variation for total catch and less than 15% for the composition of catch. Yanagisawa (1934) compared the catches between those by net and those by Nansen bottle, and discussed limitation of use of the net in the quantitative studies. Egusa (1948) pointed out that for certain species of phytoplankton the amount of catch by net differs to a certain extent with the size of individual organisms contained in the catch. According to the analysis on the variability of catch of the sardine eggs by Ito & Nishimura (1954), the percentage standard deviation of a single observation varies from 35% to 55%.

In foreign countries Hensen (1887) making parallel vertical hauls of net, calculated the coefficient of variation in total catches of 10% to 15%. Lohmann (1905) made a further analysis of Hensen's data and found that the variation reaches to 20% to 30% in the individual number of particular species, but in certain species the variation may be much greater. Herdman (1921) made similar experiments, obtaining percentage deviation ranging from 14% to 121%. Gardiner & Graham (1925) carried out a series of oblique hauls of Petersen's young fish trawl and obtained the percentage standard deviation ranging from 27% to 54%. Gardiner (1931) made an observation on the variability of the International Standard Net and concluded that about 75% of hauls will not deviate by more than 33% from the mean, but that isolated deviations may reach 90%. Winsor & Walford (1936) experimented on the vertical hauls with several types of net and concluded that the obtained results can be accounted for reasonably well from two assumptions that (1) the organisms have random distribution in the water and that (2) the volume of water filtered varies in each haul. Ricker (1937) dealing with lake plankton pointed out that a large variance of catches is mainly due to irregular aggregation of organisms. Langford (1938) has extended the work of Ricker and stated that some species of organisms aggregate in a certain area, while others can be considered as

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making a random distribution. Winsor & Clarke (1940) carried out an observation on the variability to be expected in replicate hauls using the several types of nets and different ways of haul, finding that the variation of catches is due to true sampling variations on the one hand but also to inadequacies of sampling technique on the other hand. Silliman (1946) analyzed the samples of the eggs of Pacific pilchard, and found that most of the variability of egg counts is due to real differences in egg concentration and that a single count may be considered significantly different from another if it is less than one half or more than double the other. Barnes (1949, 1951a, 1951b with Marshall) made a series of extensive studies on the variability of plankton sampling. He assumed that the sampling variation is not entirely accounted for by the technical error but can be explained as caused by a non-random distribution of the organisms collected. Prasad, Bapat & Tampi (1952) calculated about 12.9% of the standard deviation of haul to haul variation in the horizontal plankton hauls.

At present in Japan regular zooplankton sampling recommended by the Fisheries Agency, Ministry of Agriculture, has usually been represented by one vertical haul from 150 metre depth at each hydrographic station using the so-called "Marutoku Net" (45 cm in mouth diameter, approximately 100 cm in length, made of Japanese grit gauze no. 54, having 0.327 mm of approximate mesh aperture); then only the results of a single haul at each station are dealt with. However, little attention has been paid to the variability of catches by this method. The present experiments have been undertaken to estimate the variability of vertical hauls with this net, so as to have statistically valid sense in analyzing the quantitative distribution of plankton sampled by this method.

We wish to express our appreciation to fellow staff members of the University for the assistance through this study. We especially thank Mr. S. Nishizawa of the University for many valuable suggestions and for friendly discussion on the statistical matters. Thanks are due to the captains and crew of T. S. Oshoro Maru and T. S. Hokusei Maru of the University for affording facilities for collection of samples. Financial aid granted from the Fisheries Agency, Ministry of Agriculture, for this study is gratefully acknowledged.

## Experiments

### SERIES I

The first series of experiment was made from 11:00 to 11:30 a. m. on August 7, 1953, at a position off the northwest of Otaru Harbour, west coast of Hokkaido. A series of five replicate hauls from 150 metre depth to the surface by the Standard Marutoku Net was made. The hauling velocity was kept as nearly at 100 cm per second

as possible. The calm water permitted the wire to be suspended almost vertically.

The plankton organisms which were numerous enough for use in analysis were divided into the following six major groups, viz, (1) large Copepoda (2) small Copepoda such as *Paracalanus, Clausocalanus* and *Oithona* (3) small Copepoda such as *Oncaea* and *Corycaeus* (4) Amphipoda (5) *Sagitta* and *Oikopleura* and (6) others. Table 1 gives the numbers of individuals of the six major groups sampled in each haul.

Table 1

| No. of hauls | Large Copepoda | *Paracalanus Clausocalanus Oithona* | *Oncaea Corycaeus* | Amphipoda | *Sagitta Oikopleura* | Others | Total |
|---|---|---|---|---|---|---|---|
| 1 | 331 | 7680 | 92 | 181 | 185 | 7 | 8476 |
| 2 | 407 | 6680 | 74 | 197 | 121 | 18 | 7497 |
| 3 | 333 | 4888 | 73 | 146 | 113 | 12 | 5565 |
| 4 | 383 | 5302 | 84 | 151 | 171 | 12 | 6103 |
| 5 | 424 | 6200 | 117 | 298 | 149 | 27 | 7215 |

In analyzing the variances, according to Winsor & Clarke (1940) when the standard deviations in the various groups of organisms are roughly proportional to the mean catch, it seems appropriate to use logarithmic values of the catch numbers; therefore logarithmic values are used instead of the actual numbers in the present analyses. The analysis of variance is given in table 2.

Table 2

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Hauls (H) | 4 | 0.2235 | 0.0559 |
| Species (S) | 5 | 18.7666 | 3.7533 |
| Residual (H × S) | 20 | 0.4527 | 0.0226 |
| Total | 29 | 19.4428 | |

The mean square for hauls (H) is not significant when tested against interaction (H×S), so that it can be considered that identical populations are being sampled. Further analysis is made to determine the variance of a single observation. Here the logarithmic standard deviation is obtained for a single observation as $\sqrt{\frac{0.2235+0.4527}{4+20}} = 0.1679$, corresponding to a percentage standard deviation of 47%. Thus the 95% fiducial limits are roughly 46% and 217%.

## SERIES II

As the ratio between the area of mouth and the total area of cloth in the Standard Marutoku Net is smaller than in the ordinary type of plankton net, it is expected that the net longer than the Marutoku Net would yield less variation in catches because of high filtration ratio. The net used in the experiment of Series II was lengthened to

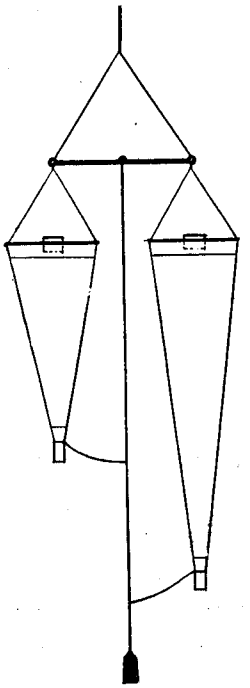

Fig. 1. Simultaneous haul of Standard Marutoku Net (left) and elongated net (right)

165 cm at the side. A net of standard pattern and an elongated one were connected to the wire end by being hung down at either end of a horizontal iron rod; thus both nets were lowered and raised simultaneously under quite the same conditions (fig. 1).

The experiment was made off Hakodate Harbour between 14:00-14:50 hours on November 11, 1954. Vertical hauls from 60 metre depth were repeated seven times. A moderate wind was blowing and the angle of the wire was roughly 25 degrees to the vertical line, and so the actual depth of sampling was about 54 metres. The velocity of haul was kept as constantly to be 130 cm per second as possible.

Two groups of animals were present in sufficient numbers for analysis; these are Copepoda and *Sagitta* (table 3).

Table 3

| | 1st haul | | 2nd haul | | 3rd haul | | 4th haul | | 5th haul | | 6th haul | | 7th haul | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long | Short | Long | Short | Long | Short | Long | Short | Long | Short | Long | Short | Long | Short |
| Large Copepoda | 125 | 60 | 50 | 40 | 65 | 42 | 96 | 40 | 105 | 62 | 75 | 43 | 53 | 32 |
| Small Copepoda | 1320 | 1145 | 1410 | 815 | 1050 | 810 | 1040 | 965 | 1870 | 1520 | 2220 | 1080 | 2420 | 1410 |
| *Sagitta* | 296 | 220 | 224 | 208 | 268 | 220 | 248 | 220 | 560 | 410 | 360 | 252 | 456 | 290 |
| Total | 1741 | 1425 | 1684 | 1063 | 1383 | 1072 | 1384 | 1225 | 2535 | 1992 | 2655 | 1375 | 2929 | 1732 |

Copepoda is divided into two subgroups according to their body size, that is, one includes the large forms such as *Eucalanus* (immature), *Calanus helgolandicus* and *Centropages* and the other the small forms such as *Paracalanus*, *Clausocalanus*, *Oithona*, *Oncaea* and *Corycaeus*.

The analysis of variance for this set is given in table 4.

Table 4

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Main effects: | | | |
| Species (S) | 2 | 12.9214 | 6.4607 |
| Hauls (H) | 6 | 0.3297 | 0.0550 |
| Nets (N) | 1 | 0.2656 | 0.2656 |
| First order interactions: | | | |
| S×H | 12 | 0.2597 | 0.0216 |
| S×N | 2 | 0.0345 | 0.0173 |
| H×N | 6 | 0.0079 | 0.0013 |
| Second order interaction: | | | |
| S×H×N | 12 | 0.0470 | 0.0039 |
| Total | 41 | 13.8658 | |

The values for S×N and H×N are not significant when tested against the second order interaction S×H×N, so that neither the percentage compositon of organisms caught by the nets during the experiment nor the proportion of catch of three groups together caught by the nets in the separate hauls can be considered to differ significantly. However, S×H is significant when tested against S×H×N (1% level), so that there is an indication of the changes in population sampled due to the passage of time or the shifting of the ship during the observation. The haul mean spuare (H) is not significant when tested against S×H in spite of being significant against the value of S×H×N, so that the high value of haul is considered to be due to the variation of S×H.

If the above results are accepted, they may be reasonably regrouped as in table 5.

Table 5

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 2 | 12.9214 | 6.4607 |
| Nets | 1 | 0.2656 | 0.2656 |
| S×H | 18 | 0.5894 | 0.0327 |
| Remainder | 20 | 0.0894 | 0.0045 |
| Total | 41 | 13.8658 | |

From the above table one gets

$$\sigma^2+2\sigma_{SH}^2=0.0327$$

whence

$$\sigma_{SH}^2=\frac{1}{2}\ (0.0327-0.0045)=0.0141$$

If one supposes that a particular group is picked at random, the variance of a single observation of either of the two nets is given by $\sqrt{\sigma_{SH}^2+\sigma^2}$, that is, 0.136. This is obtained from the logarithms of the catches; therefore as a percentage standard deviation,

or a coeffecient of variation, since

$$\log 1.37 = 0.136,$$
$$37\% = 137 - 100,$$

a value of 37% is obtained.

Then the 95% fiducial limits are calculated roughly as follows:

upper limit ..... $+0.136 \times 2 = 0.272 = \log 1.87.$

lower limit ..... $-0.272 = \log \frac{1}{1.87} = \log 0.53.$

Thus one catch cannot be recognized as significantly different from another one unless it is less than 53% or more than 187% of its value.

Next, the analysis for each net is made separately. The analysis of variance for 165 cm net (longer net) is shown in table 6.

Table 6

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 2 | 5.9171 | 2.9586 |
| Hauls | 6 | 0.1941 | 0.0324 |
| Residual | 12 | 0.2092 | 0.0174 |
| Total | 20 | 6.3204 | |

The mean square of the hauls is not significant against the interaction. If one seeks the logarithmic standard deviation of a single observation one has $\sqrt{\frac{0.1941+0.2029}{6+12}}=0.149$; from this one gets a percentage standard deviation of 41%.

The analysis of variance for the 100 cm net (standard net) is given in table 7.

Table 7

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 2 | 7.0388 | 3.5194 |
| Hauls | 6 | 0.1435 | 0.0239 |
| Residual | 12 | 0.0975 | 0.0081 |
| Total | 20 | 7.2798 | |

The mean square for hauls is again seen to be not significant. Here the logarithmic standard deviation of a single observation is $\sqrt{\frac{0.1435+0.0975}{6+12}}=0.115$, corresponding to a percentage standard deviation of 30%.

It should be noted that the amount of water filtered through the cloth of net possibly varies for each of the hauls according to variable hauling technique. If the revolutions of the flow metre held in the centre of the mouth ring of the net indicate the true amount of water filtered, it may be possible to eliminate one factor of variability by checking the results of count using the readings of flow metre.

The analysis is made for the individual numbers which are corrected by flow metre readings. The analysis of variance of 165 cm net is given in table 8.

Table 8

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 2 | 5.9303 | 2.9652 |
| Hauls | 6 | 0.3236 | 0.0539 |
| Residual | 12 | 0.2039 | 0.0170 |
| Total | 20 | 6.4578 | |

The logarithmic standard deviation of haul to haul variation will be $3\sigma_H^2+\sigma^2=0.0539$, then $\sigma_H=0.1109$, corresponding to a percentage standard deviation of 26.2%. The logarithmic standard deviation of a single observation will be $\sqrt{\sigma_H^2+\sigma^2}=\sqrt{0.0123+0.0170}=0.1711$; this corresponds to a percentage standard deviation of 48%.

Same analysis of the 100 cm net is given in table 9.

Table 9

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 2 | 6.6998 | 3.3499 |
| Hauls | 6 | 0.3339 | 0.0557 |
| Residual | 12 | 0.0676 | 0.0056 |
| Total | 20 | 7.1013 | |

The logarithmic standard deviation of haul to haul variation is obtained as $3\sigma_H^2+\sigma^2=0.0557$, so $\sigma_H=0.1292$, which corresponds to a percentage standard deviation of 34.7%. The value of logarithmic standard deviation of a single observation is obtained as $\sqrt{\sigma_H^2+\sigma^2}=\sqrt{0.0167+0.0056}=0.1493$, corresponding to a percentage standard deviation of 41%. Here the values of variation are rather increased when the count is corrected by flow metre readings over that in the case without such correction. So far as the above results are concerned, the use of readings of flow metre in vertical haul seem not to increase the validity of estimation.

The ratio of catches of 165 cm net to those of 100 cm net will next be considered. The mean of the differences of the logarithms of both catches is 0.1623, corresponding to an actual ratio of the catches of 1.45. The variance of the logarithm of this ratio is $2\times\frac{0.03274}{7\times3}=0.003118$, giving a standard deviation for the logarithm of 0.055. Hence 99% fiducial limits are gotten as $0.1623\pm3\times0.055=\bar{1}.9973\sim0.3273$. Then the actual ratios will lie between 0.99 and 2.12. On the other hand, the ratio of the filtering area (area of gauze) of 165 cm net to area of 100 cm net is 1.65, which is a little larger than the actual ratio of catches observed (1.45).

## SERIES III

The experiments were made off Cape Esan, south coast of Hokkaido, from 21 : 00 to 21 : 25 hours on October 20, 1954. A pair of different types of Marutoku Nets, viz., 165 cm and 100 cm in length, were hauled vertically three times in the same way as in the previous experiments. The speed of hauls was kept about 80 cm per second. Six groups of animals were taken in sufficient number for analysis, viz., large Copepoda (*Calanus helgolandicus*, *Eucalanus* spp., *Euchaeta marina*, *Metridia lucens* and *Calanus tenuicornis*); medium sized Copepoda (*Paracalanus*, *Clausocalanus*, *Oithona*, *Oncaea* and *Corycaeus*); Amphipoda (mainly consisted of *Themisto* sp.); Euphausiacea (consists of *Euphausia* and *Thysanoessa*); *Sagitta* and *Oikopleura* (table 10).

Table 10

| | 1st haul | | 2nd haul | | 3rd haul | |
|---|---|---|---|---|---|---|
| | Long | Short | Long | Short | Long | Short |
| Large Copepoda | 576 | 460 | 348 | 146 | 448 | 320 |
| Small Copepoda | 2160 | 960 | 1920 | 1200 | 3040 | 1040 |
| Euphausiacea | 62 | 62 | 59 | 50 | 51 | 23 |
| Amphipoda | 11 | 12 | 8 | 1 | 18 | 6 |
| *Sagitta* | 777 | 438 | 723 | 397 | 521 | 228 |
| *Oikopleura* | 768 | 80 | 192 | 132 | 352 | 96 |
| Total | 4354 | 2012 | 3250 | 1926 | 4430 | 1713 |

The analysis of variance for these hauls is given in table 11.

Table 11

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Main effects: | | | |
| Species (S) | 5 | 20.7199 | 4.1440 |
| Hauls (H) | 2 | 0.2554 | 0.1277 |
| Nets (N) | 1 | 0.9934 | 0.9934 |
| First order interactions: | | | |
| S × H | 10 | 0.5186 | 0.0519 |
| S × N | 5 | 0.0819 | 0.0164 |
| H × N | 2 | 0.0038 | 0.0019 |
| Second order interaction: | | | |
| S × H × N | 10 | 0.7727 | 0.0773 |
| Total | 35 | 23.3457 | |

It is clear that mean squares of hauls and each of the first order interactions do not differ significantly. Therefore the data on analysis of variance may be regrouped in table 12.

Table 12

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 20.7199 | 4.1440 |
| Nets | 1 | 0.9934 | 0.9934 |
| Remainder | 29 | 1.6324 | 0.0563 |
| Total | 35 | 23.3457 | |

The mean squares for nets and remainder show rather more high values than in Series II. An estimate of the logarithmic standard deviation of a single observation is 0.2372, corresponding to a percentage standard deviation of 72%; then 95% fiducial limits are calculated as 33% and 298%.

An analysis is made for long (165 cm) and short (100 cm) nets separately. The analysis of variance is given in tables 13 and 14 respectively.

Table 13

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 10.0814 | 2.0163 |
| Hauls | 2 | 0.0996 | 0.0498 |
| Residual | 10 | 0.3202 | 0.0320 |
| Total | 17 | 10.5012 | |

Table 14

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 10.7205 | 2.1441 |
| Hauls | 2 | 0.1762 | 0.0881 |
| Residual | 10 | 0.9544 | 0.0954 |
| Total | 17 | 11.8511 | |

In both tables the mean squares for hauls are not significant when tested against the residual. From table 13 the logarithmic standard deviation of a single observation for the long net is 0.186, or a percentage standard deviation of 53%. From table 14 the logarithmic standard deviation for short net is 0.3069 and the percentage standard deviation is 102%. The values of variation are also higher than those of Series II.

Again, it may be needful to consider the variation of a single observation of each net on the counts which are corrected by the readings of revolution of the flow metre. The analysis of variance for the long and the short nets is given in tables 15 and 16.

Table 15

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 10.1982 | 2.0398 |
| Hauls | 2 | 0.0947 | 0.0474 |
| Residual | 10 | 0.2118 | 0.0212 |
| Total | 17 | 10.5047 | |

Table 16

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 10.7503 | 2.1501 |
| Hauls | 2 | 0.1282 | 0.0641 |
| Residual | 10 | 0.8441 | 0.0844 |
| Total | 17 | 11.5944 | |

The mean squares for hauls are not significant when tested against the values of residual in each table. The logarithmic standard deviation of a single observation for long net is 0.159, giving a percentage standard deviation of 44%; that for a short net is gotten as 0.248 which corresponds to a percentage standard deviation of 92%.

The ratio for the catches of the long net to those of the short net is 0.3322 in logarithmic value, corresponding to an actual ratio of 2.15. The variance of this ratio is 0.0063, which corresponds to a standard deviation of 0.079; then 99% fiducial limits are 0.0952 and 0.5692, and therefore, the actual ratios will lie between 1.25 and 3.71. Although the ratio of area of filtering cloth of the long net to that of the short net (1.65) is smaller than the above actual ratio of catches between both nets, it lies within the three standard deviation limits of the ratio of catches.

## SERIES IV

This series was taken from the same depth half an hour after Series III the duration of the take being twenty-five minutes. The same abundant species were grouped into six as in Series III (table 17). The velocity of haul was kept 100 cm per second, somewhat faster than in the previous series.

Table 17

| | 1st haul | | 2nd haul | | 3rd haul | |
|---|---|---|---|---|---|---|
| | Long | Short | Long | Short | Long | Short |
| Large Copepoda | 410 | 300 | 400 | 272 | 390 | 335 |
| Small Copepoda | 4160 | 1440 | 2880 | 1620 | 2900 | 2050 |
| Euphausiacea | 48 | 32 | 87 | 72 | 81 | 98 |
| Amphipoda | 23 | 12 | 8 | 4 | 9 | 7 |
| *Sagitta* | 368 | 283 | 367 | 324 | 435 | 173 |
| *Oikopleura* | 96 | 80 | 272 | 128 | 275 | 110 |
| Total | 5105 | 2147 | 4014 | 2420 | 4090 | 2773 |

Analysis of variance runs (table 18):

Table 18

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Main effects: | | | |
| Species (S) | 5 | 19.7526 | 3.9505 |
| Hauls (H) | 2 | 0.0143 | 0.0072 |
| Nets (N) | 1 | 0.2971 | 0.2971 |
| First order interactions: | | | |
| S × H | 10 | 0.5222 | 0.0522 |
| S × N | 5 | 0.0765 | 0.0153 |
| H × N | 2 | 0.0038 | 0.0019 |
| Second order interaction: | | | |
| S × H × N | 10 | 0.1186 | 0.0119 |
| Total | 35 | 20.7851 | |

The values for both H and first order interactions are not significant when tested against the value of second order interaction. It seems therefore that there was not possible any change in the population during the period of sampling. Here the data from the above table may be regrouped into following one (table 19).

Table 19

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 19.7526 | 3.9505 |
| Nets | 1 | 0.2971 | 0.2971 |
| Remainder | 29 | 0.7354 | 0.0254 |
| Total | 35 | 20.7851 | |

From this table the logarithmic standard deviation of 0.159 is gotten, corresponding to a percentage standard deviation of a single observation of 44%; then 95% fiducial limits are 48% and 208%.

Secondly calculations may be made for two different nets independently. The analysis of variance for the long and the short nets is shown in tables 20 and 21 respectively.

Table 20

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 10.0990 | 2.0198 |
| Hauls | 2 | 0.0024 | 0.0012 |
| Residual | 10 | 0.3246 | 0.0325 |
| Total | 17 | 10.4260 | |

Table 21

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 9.7301 | 1.9460 |
| Hauls | 2 | 0.0157 | 0.0079 |
| Residual | 10 | 0.3162 | 0.0316 |
| Total | 17 | 10.0620 | |

As to both of the nets the mean squares of hauls are not significant when tested against the interactions. Here the logarithmic standard deviation for the 165 cm net is 0.165, corresponding to a percentage standard deviation of 46%. Again, the logarithmic standard deviation of 0.166 is gotten for the 100 cm net, giving a percentage standard deviation of 46%.

Similarly the analysis on the counts corrected by the flow metre readings is given in tables 22 and 23.

Table 22

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 10.0215 | 2.0043 |
| Hauls | 2 | 0.0115 | 0.0058 |
| Residual | 10 | 0.3174 | 0.0317 |
| Total | 17 | 10.3504 | |

Table 23

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 9.4519 | 1.8904 |
| Hauls | 2 | 0.0427 | 0.0214 |
| Residual | 10 | 0.2898 | 0.0290 |
| Total | 17 | 9.7844 | |

The values for hauls are also not significant against the interactions in each net. From table 22, the logarithmic standard deviation is 0.165, which corresponds to a percentage standard deviation of 46%. From table 23, the logarithmic standard deviation is 0.166, which gives a percentage standard deviation of 46%. Thus the percentage standard deviation for a single observation of both long and short nets does not vary by the correction by flow metre readings.

The mean of the differences of the logarithms for the catches of long and short nets is 0.1816, corresponding to an actual ratio of 1.52. The variance in logarithm of this ratio is 0.0028, giving a standard deviation for logarithm 0.052; then 99% fiducial limits 0.0226 and 0.3406 as lower and upper limits which correspond to the actual ratios of 1.05 and 2.19.

SERIES V

That there happens a loss in catch in the vertical divided hauls using the Nansen closing device has been noticed by the experiments of Barnes (1949). He pointed out that the use of Kofoid's cone net would tend to reduce the loss in catch. The junior author and his colleague (Nishizawa & Anraku, unpublished) have made direct visual observation on the flow of water around the mouth of the net by the aid of the Underwater Observation Chamber "Kuroshio" (Inoue *et al.*, 1953). They actually saw that the water as coloured by the dissolving potassium permanganate in the bag set in the net actually flowed up from the mouth of the net when the net was suddenly stopped in the way of vertical hauls. Change in velocity of hauling a plankton net is expected to happen frequently during the work at sea; especially when the net is closed.

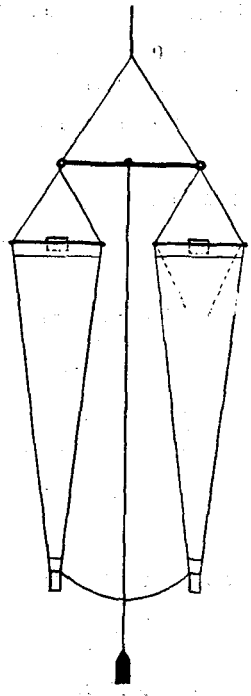

Fig. 2. Simultaneous haul of net without inner cone (left) and net with inner cone (right)

An inner cone 7 cm in lower mouth diameter and 31 cm in side length was designed; it was fastened inside the mouth margin of the 165 cm net. Two nets, one with inner cone and the other without, both of the same size, were hung at either end of the horizontal iron rod in the same way as in the experiment of Series II (fig. 2). Then the nets were hauled repeatedly to estimate the variation of catches of each net.

The experiments were made from 2:30 to 3:00 hours on October 21, 1954, off Cape Esan, south coast of Hokkaido. The speed of hauls was kept 80 cm per second. The net hauls were made three times and the counts of organisms were made on the six major groups, viz., large Copepoda, small Copepoda, Amphipoda, Euphausiacea, *Sagitta* and *Oikopleura* (table 24).

Table 24

| | 1st haul | | 2nd haul | | 3rd haul | |
|---|---|---|---|---|---|---|
| | with cone | without cone | with cone | without cone | with cone | without cone |
| Large Copepoda | 264 | 584 | 80 | 252 | 84 | 888 |
| Small Copepoda | 1360 | 5120 | 684 | 4050 | 840 | 7750 |
| Euphausiacea | 31 | 83 | 9 | 87 | 7 | 111 |
| Amphipoda | 3 | 11 | 1 | 7 | 3 | 20 |
| *Sagitta* | 90 | 348 | 75 | 443 | 61 | 910 |
| *Oikopleura* | 16 | 112 | 8 | 96 | 24 | 545 |
| Total | 1764 | 6258 | 857 | 4935 | 1019 | 10224 |

The results of the analysis of variance is given in table 25.

Table 25

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Main effects: | | | |
| Species (S) | 5 | 23.9431 | 4.7886 |
| Hauls (H) | 2 | 0.2207 | 0.1104 |
| Nets (N) | 1 | 5.2212 | 5.2212 |
| First order interactions: | | | |
| S × H | 10 | 0.5716 | 0.0572 |
| S × N | 5 | 0.0725 | 0.0125 |
| H × N | 2 | 0.4498 | 0.2249 |
| Second order interaction: | | | |
| S × H × N | 10 | 2.3997 | 0.2400 |
| Total | 35 | 32.8786 | |

The mean squares for hauls and the first order interactions are not significant when tested against the second order interaction, so the above table may be grouped again as follows (table 26):

Table 26

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 23.9431 | 4.7886 |
| Nets | 1 | 5.2212 | 5.2212 |
| Remainder | 29 | 3.7143 | 0.1281 |
| Total | 35 | 32.8786 | |

Here the variability of a single observation is obtained in logarithmic value as 0.357, corresponding to a percentage standard deviation of 127%, and 95% fiducial limits lie as wide as 19% and 518%.

Next, it may be interesting to compare the variability of catches of the two nets. Accordingly the analysis of variance is made independently on the samples from the two kinds of nets. An analysis of data from the nets with or without cone is given in tables 27 and 28.

Table 27

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 12.1613 | 2.4323 |
| Hauls | 2 | 0.1736 | 0.0868 |
| Residual | 10 | 0.7550 | 0.0755 |
| Total | 17 | 13.0899 | |

Table 28

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 11.8543 | 2.3709 |
| Hauls | 2 | 0.4969 | 0.2485 |
| Residual | 10 | 0.7132 | 0.0713 |
| Total | 17 | 12.5675 | |

The value of H of each net is not significant against the residual. For the cone net the logarithmic standard deviation of 0.278 is obtained which corresponds to a percentage standard deviation of 90%, and also the value of 0.317 is gained for ordinary net (without cone) which corresponds to 108% of percentage standard deviation.

Again, the data of both nets may be analyzed after the correction by the flow metre readings is made. The results are given in tables 29 and 30.

Table 29

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 12.5215 | 2.5043 |
| Hauls | 2 | 0.2900 | 0.1450 |
| Residual | 10 | 1.1197 | 0.1200 |
| Total | 17 | 13.9312 | |

Table 30

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 5 | 11.8297 | 2.3659 |
| Hauls | 2 | 0.4480 | 0.2240 |
| Residual | 10 | 0.2120 | 0.0212 |
| Total | 17 | 12.4897 | |

In this case also no significant relation is observed between the mean square for hauls and for interaction in table 29; then the logarithmic standard deviation of 0.342 is obtained for the cone net, which corresponds to a percentage standard deviation of 120% of a single observation. From table 30, the value of hauls is significant, whence the logarithmic standard deviation of haul to haul variation is gotten as 0.183, which corresponds to a percentage standard deviation of 52%. Again, the values of 0.234 and 72% are gotten for a single observation of the ordinary net.

The mean of the differences of catches of either net is 0.7616 in logarithmic value, corresponding to an actual ratio of 5.78; the variance of logarithmic value will be 0.0142, and this will give 99% fiducial limits of 0.4016 and 1.1216, which correspond to the actual ratios of 2.52 and 13.20.

## SERIES VI

The experiments comprised six hauls just as in Series V. The hauls were made during the daytime (10 : 50 – 12 : 05) on November 17, 1954, in Hakodate Bay, south coast of Hokkaido. Three hauls were made vertically from a depth of 50 metres to the surface at speed of 95 cm per second, and in the other three hauls the nets were raised from 50 metre depth to 10 metre depth, then the haul was stopped for two seconds after which the nets were raised to the surface. The wire carrying the nets was perpendicular throughout the observation. Small Copepoda and *Sagitta* were present in sufficient number for analysis (tables 31 and 32).

Table 31

| | 1st haul | | 2nd haul | | 3rd haul | | 4th haul | | 5th haul | |
|---|---|---|---|---|---|---|---|---|---|---|
| | with cone | without cone | with cone | without cone | with cone | without cone | with cone | without cone | with cone | without cone |
| Small Copepoda | 87 | 131 | 444 | 1024 | 131 | 832 | 145 | 1450 | 870 | 1450 |
| *Sagitta* | 4 | 3 | 31 | 66 | 32 | 45 | 18 | 68 | 55 | 84 |
| Total | 91 | 134 | 475 | 1090 | 163 | 877 | 163 | 1518 | 925 | 1534 |

Table 32

| | 1st haul | | 2nd haul | | 3rd haul | | 4th haul | | 5th haul | |
|---|---|---|---|---|---|---|---|---|---|---|
| | with cone | without cone | with cone | without cone | with cone | without cone | with cone | without cone | with cone | without cone |
| Small Copepoda | 1305 | 1124 | 1088 | 1305 | 104 | 656 | 53 | 330 | 138 | 1128 |
| *Sagitta* | 70 | 74 | 76 | 141 | 22 | 68 | 14 | 45 | 27 | 250 |
| Total | 1375 | 1198 | 1164 | 1446 | 126 | 724 | 67 | 375 | 165 | 1378 |

(a) continuous hauls

The analysis of variance for table 31 is given in table 33.

Table 33

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Main effects: | | | |
| Species (S) | 1 | 7.0567 | 7.0567 |
| Hauls (H) | 4 | 3.0951 | 0.7738 |
| Nets (N) | 1 | 0.6698 | 0.6698 |
| First order interactions: | | | |
| S × H | 4 | 0.1592 | 0.0399 |
| S × N | 1 | 0.1066 | 0.1066 |
| H × N | 4 | 0.3272 | 0.0818 |
| Second order interaction: | | | |
| S × H × N | 4 | 0.0717 | 0.0179 |
| Total | 19 | 11.4863 | |

In this table the mean square for hauls is significant when tested against the second order interaction. All of the first order interactions are not significant when tested against the second order interaction, so the above table may reasonably be summarized as below (table 34):

Table 34

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 7.0567 | 7.0567 |
| Hauls | 4 | 3.0951 | 0.7738 |
| Nets | 1 | 0.6698 | 0.6698 |
| Remainder | 13 | 0.6647 | 0.0511 |
| Total | 19 | 11.4863 | |

Here the logarithmic standard deviation of haul to haul variation is obtained as 0.409, corresponding to a percentage standard deviation of 156%.

Now the logarithmic standard deviation for a single observation is 0.481, corresponding to a percentage standard deviation of 202%, then 95% fiducial limits are 10% and 917%.

Then the separation of the original data is made according to the presence or absence of the inner cone of the nets. The analysis of variance for the cone net is given in table 35 and that of the ordinary net (without cone) in table 36.

Table 35

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 2.7144 | 2.7144 |
| Hauls | 4 | 1.2907 | 0.3227 |
| Residual | 4 | 0.1672 | 0.0418 |
| Total | 9 | 4.1723 | |

Table 36

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 4.4489 | 4.4489 |
| Hauls | 4 | 2.1317 | 0.5329 |
| Residual | 4 | 0.0636 | 0.0159 |
| Total | 9 | 6.6442 | |

Here the logarithmic standard deviation of haul to haul variation for cone net is 0.347, which corresponds to a percentage standard deviation of 137%; and the logarithmic standard deviation of a single observation is 0.426, corresponding to a percentage standard deviation of 167%. As the standard deviation in the logarithm for haul to haul variation of the ordinary net the value is 0.508, which corresponds to a percentage standard deviation of 222%, while the logarithmic standard deviation for a single observation is 0.523, which corresponds to a percentage standard deviation of about 233%.

The analysis of variance is made next concerning the data which are corrected by

the readings of revolutions of flow metre. The analysis of the cone net and the ordinary net is given in tables 37 and 38 respectively.

Table 37

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 2.7773 | 2.7773 |
| Hauls | 4 | 1.3121 | 0.3280 |
| Residual | 4 | 0.1847 | 0.0462 |
| Total | 9 | 4.2741 | |

Table 38

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 3.7826 | 3.7826 |
| Hauls | 4 | 2.6589 | 0.6647 |
| Residual | 4 | 1.2345 | 0.3086 |
| Total | 9 | 7.6760 | |

For the cone net the logarithmic standard deviation of haul to haul variation is obtained as 0.375, corresponding to a percentage standard deviation of 137%; and the logarithmic standard deviation of a single observation is 0.433 which corresponds to a percentage standard deviation of 171%. For the ordinary net values of 0.697 and 397% are obtained for a single observation.

Next a comparison of catches of both types of net is made. The mean of the differences of the catches is 0.446, which corresponds to an actual ratio of 2.79. The variance of this ratio as a logarithm is 0.1548, corresponding to a standard deviation of 0.393, and so 99% fiducial limits are $\bar{1}.287$ and 1.545, which correspond to the actual ratios of 0.24 and 35.08.

(b) hauls with a stop on the way

Regarding the individual numbers in table 32 the analysis is made as in table 39.

Table 39

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Main effects: | | | |
| Species (S) | 1 | 4.0952 | 4.0952 |
| Hauls (H) | 4 | 1.7215 | 0.4304 |
| Nets (N) | 1 | 1.1377 | 1.1377 |
| First order interactions: | | | |
| S × H | 4 | 0.2177 | 0.0544 |
| S × N | 1 | 0.0035 | 0.0035 |
| H × N | 4 | 0.6157 | 0.1539 |
| Second order interaction: | | | |
| S × H × N | 4 | 0.0549 | 0.0137 |
| Total | 19 | 7.8462 | |

The mean square for hauls is significant when tested against the second order interaction. The logarithmic standard deviation of haul to haul variation is 0.242, then a percentage standard deviation of 74% is obtained. Both S×H and S×N are not significant against S×H×N, but H×N is significant. However, the mean squares of hauls and nets are not significant when tested against H×N. So that, data in the above table may be reasonably grouped again as follows (table 40):

Table 40

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 4.0952 | 4.0952 |
| H×N | 9 | 3.4749 | 0.3861 |
| Remainder | 9 | 0.2761 | 0.0306 |
| Total | 19 | 7.8462 | |

The logarithmic standard deviation for hauls is 0.456, which corresponds to a percentage standard deviation of 186%, hence 95% fiducial limits are gotten as 15% and 817%.

The analysis of variance for each net is given in tables 41 and 42.

Table 41

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 1.9272 | 1.9272 |
| Hauls | 4 | 1.8198 | 0.4550 |
| Residual | 4 | 0.1977 | 0.0494 |
| Total | 9 | 3.9447 | |

Table 42

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 2.1715 | 2.1715 |
| Hauls | 4 | 0.5174 | 0.1294 |
| Residual | 4 | 0.0749 | 0.0187 |
| Total | 9 | 2.7638 | |

Regarding the haul to haul variation, the logarithmic standard deviation of 0.450 for the cone net, which equals to a percentage standard deviation of 182%; while the logarithmic standard deviation of a single observation is 0.502, corresponding to a percentage standard deviation of 217%. On the other hand, the values of haul to haul variation for the ordinary net are given as 0.235 and 71%; and those of a single observation are 0.272 and 87%.

The analysis for either net after making correction by flow metre readings is given in tables 43 and 44 respectively.

Table 43

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 1.9360 | 1.9360 |
| Hauls | 4 | 1.3662 | 0.3416 |
| Residual | 4 | 0.1978 | 0.0494 |
| Total | 9 | 3.5000 | |

Table 44

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square |
|---|---|---|---|
| Species | 1 | 2.1996 | 2.1996 |
| Hauls | 4 | 0.6174 | 0.1544 |
| Residual | 4 | 0.0786 | 0.0197 |
| Total | 9 | 2.8956 | |

Here the logarithmic standard deviation of haul to haul variation of the cone net is 0.382, corresponding to a percentage standard deviation of 141%, and those of a single observation will be 0.431 and 170%. The values of 0.259 and 81% are gotten for haul to haul variation, and 0.295 and 97% for a single observation of the ordinary net.

The mean of differences of catches for both nets is 0.478 in logarithmic value which corresponds to an actual ratio of 3.01. Then the variance of this logarithmic value is 0.0861, corresponding to a standard deviation of 0.29, hence 99% fiducial limits are $\bar{1}.608$ and 1.348. They correspond to the actual ratios of 0.41 and 22.29.

## Discussion

The results of the present studies may be conveniently summarized as shown in table 45.

Table 45

| Series of Experiment | Percentage Standard Deviation of a single observation of either of two nets (see p.156) | P.S.D. of a single observation of each net | | | | | | | | Ratio of catches between two nets | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | without correction by flow metre | | | | corrected by flow metre | | | | Ratio of catch obtained | 99% fiducial limits of the ratio |
| | | 100 cm net | 165 cm net | 165 cm net with inner-cone | 165 cm net without inner-cone | 100 cm net | 165 cm net | 165 cm net with inner-cone | 165 cm net without inner-cone | | |
| I | | 47 | | | | | | | | | |
| II | 37 | 30 | 41 | | | 41 | 48 | | | 1.45 | 0.99~ 2.12 |
| III | 72 | 102 | 53 | | | 92 | 44 | | | 2.15 | 1.25~ 3.71 |
| IV | 44 | 46 | 46 | | | 46 | 46 | | | 1.52 | 1.05~ 2.19 |
| V | 127 | | | 90 | 108 | | | 120 | 72 | 5.78 | 2.52~13.20 |
| VIa | 202 | | | 269 | 233 | | | 171 | 397 | 2.79 | 0.24~35.08 |
| VIb | 186 | | | 217 | 87 | | | 170 | 97 | 3.01 | 0.41~22.29 |

The percentage standard deviations of a single observation for three types of net (100 cm long net, 165 cm long net and 165 cm long net with the inner cone) in each series are ranged from 30% to 269%. On the other hand, according to the previous estimates (Winscr & Walford, 1936; Winsor & Clarke, 1940; Barnes, 1949; Prasad *et al.*, 1952; Ito & Nishimura, 1954, etc.) the standard deviation of a single observation in the vertical hauls made under good conditions has been reported from 40% to 50% in the mean. In spite of the fact that present experiments have been carried out with special attention to the treatment of samples, the values of standard deviation were often larger than those of the previous investigations. Both in Series II and IV, when the nets are hauled at a speed of more than 100 cm per second, the order of variation is equivalent to the preceding works. However, the values in the samplings in Series VI in which the hauling velocity is 95 cm per second are several times of them. The first order interaction S×H is not significant when tested against the value of the second order interaction S×H×N in all of the experiments except in Series II, so that the high values of variations obtained are considered to be not caused by the change of percentage in composition of population. The factor responsible for the high values of variations is supposed to be in some technical matter. According to the experiments made by Nishizawa & Anraku (unpublished) it has been shown that the inflow of water into the mouth of the plankton net varies to a certain extent even when the hauling velocity has only slightly changed during a haul. The speed that gives the steady inflow of the water to the net has been observed to lie at 100 cm per second or more. In the present experiments the speed of hauls has ranged from 80 to 130 cm per second. The experiments made at comparatively low speed of hauls (Series III, V, VI) yielded generally high values of variations. The variation of a single observation might be reduced to 30 to 50% if the nets were hauled carefully at a speed of 100 cm per second or a little more. This minimum variation is considered mainly due to the local swarming of organisms.

The variations are not always decreased when the counts are corrected by flow metre readings. It is suggested that so far as concerns the present experiments, the adjustment of amount of water by readings of flow metre did not always yield more valid results.

The first order interactions (S×N) for tables 11, 18, 25 and 33 are not significant when tested against the values of the second order interaction respectively, then there is general indication that both 165 cm and 100 cm Marutoku Nets appear to catch all the groups here discussed in the same proportion, and this is also the case between the cone net and ordinary net. It may therefore be supposed that under the condition of the present investigation differential selection for particular species by types of net does not occur.

The means of the ratios for the catches of both 165 cm and 100 cm nets in Series II, III and IV are 1.45, 2.15 and 1.52 respectively, and 99% fiducial limits ranged from

0.99 to 3.71. The ratios in Series II and IV for the catches are smaller than the ratio (1.65) of the cloth area of both nets, while the ratio for catches in Series III is a little larger than the ratio of the cloth area but lies within the 95% fiducial limits. Thus, any proportional increase of catch against the increase of the area of filtering cloth cannot always be expected by using the long net. In addition to the above facts just mentioned, the variations of catches of the long net are not always smaller than those of the short net.

The cone of cloth attached inside the net is expected to prevent the outflow of the content in the net when it is suddenly stopped or hauled at variable speeds. The ratio of catches for both nets used in Series VIa (non stop) is smaller than that in VIb (stop). This indicates that the inner cone is somewhat useful for retaining the catch inside the net when the haul is stopped on the way. In the experiment of Series VI, the data were rearranged for comparing the catches of the net when it was not stopped during the hauls with that of the same net when it was stopped; then the ratios are calculated as follows: The mean of the difference of catches in logarithm is 0.246 for the cone net, corresponding to an actual ratio of 1.76, then 99% fiducial limits are roughly 0.595 and 5.16, while the mean of the difference of the ordinary net is 0.038 which corresponds to an actual ratio of 1.09; here are found 99% fiducial limits of 0.437 and 2.72. According to this calculation the usefulness of inner cone is not proved. Thus the effectiveness of inner cone is indicated to be not always significant.

## Summary

(1) The variability of catches by vertical hauls with the Standard Marutoku Net and the similar types was calculated by repeated samplings at sea.

(2) In the experiment of Series I the percentage standard deviation of a single observation of a Standard Marutoku Net is calculated to be 47%.

(3) In Series II, III and IV the standard deviation of haul to haul variation is zero in both Standard Marutoku Net (side length 100 cm) and elongated net (side length 165 cm). The values for a single observation range from 30% to 102% in the standard net, and from 41% to 53% in the elongated net. It seems therefore that the values of long net are not always smaller than those of the short one.

(4) It might be expected, that the sampling variation is due largely to the local swarming (statistically non-random distribution) of the organisms.

(5) The proportion of major groups of organisms caught by the different types of nets does not vary. It is therefore indicated that under the conditions of the present investigation no differential selection with the size or shape of net is observed.

(6) The amount of catch is not always proportional to the cloth area of long and short nets having the same mouth diameter. The ratios of the mean in catches

of long net to short net are 1.45, 2.15 and 1.52 (ratio of filtering cloth area 1.65), and 99% fiducial limits of ratios range 0.99 to 3.71 (Series II, III, IV).

(7) The effectiveness of inner cone of the net which is expected to be useful in preventing the outflow of the content was tested, but significantly positive results were not obtained.

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