

A STATISTICAL STUDY OF VARIABILITY IN CATCH OBTAINED BY SHORT REPEATED TRAWLS TAKEN OVER AN INSHORE GROUND

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(Text-figs. 1-3)

INTRODUCTION

The numerous quantitative studies on various types of fishing gear have always been chiefly directed to the relation between the proportion of size-groups in the sample and in the population, and to the effect of mesh size on this relation. There have been only a small number of controlled experiments on the variability of replicate samples. While the former type of information is fundamental in fishery investigations, the latter, equally necessary, becomes an essential preliminary in a detailed ecological approach to fishery problems, for it is then necessary to know whether hauls taken at different times or in different places have given significantly different catches.

Thompson (1928) considered sampling problems in his extensive haddock investigations. Data are given from two series of hauls (using a 60 or 50 ft. otter trawl), each series extending over several days; and he points out that these samples (1 hr. trawling, *c.* 350 fish per catch) gave an adequate representation of the proportion of size-groups. Using logarithmic values of his catches (see below) the coefficients of variation were 27 and 51% for the two series.

Hickling (1933), using a full-sized trawl and working on hake, also gives data for repeated hauls taken under various conditions, although like Thompson he was more particularly concerned with the size-frequencies in his samples. The coefficient of variation for catches (log values) of hake varied from 25 to 88%, this range including results from R. V. *George Bligh* and from commercial trawlers.

Gardiner & Graham (1925) have considered the working error of Petersen's young fish trawl, and the design of these experiments was similar to that of the present work. They counted a number of species in ten replicate hauls and they give coefficients of variation calculated on actual numbers varying from 27% for *Euthemisto compressa* to 54% for *Aglantha digitalis*. The analysis of variance of their data (log values) using those animals occurring in all samples is given in Table I.

The mean square for hauls is significant when tested against $H \times S$ and the estimated log standard deviation for a single observation $\sqrt{s_H^2 + s_{HS}^2}$ is 0.1936, corresponding to a coefficient of variation of 56%.

TABLE I

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (H)	9	0.9835	0.1093
Species (S)	6	28.2730	4.7120
Residual			
$H \times S$	54	1.3792	0.0255
Total	69	—	—

This present work consists of the analysis of the variability of a series of replicate hauls taken over a prescribed ground with the same gear and as far as possible under controlled conditions. In order that the results shall be of value to other workers it is necessary to describe both the gear and working conditions in some detail.

METHODS

The Gear and Method of Working

A standard type V.D. trawl, as described by Davis (1936, p. 104), was used, the detailed specifications being as follows: doors, 7 ft. 3 in. \times 3 ft. 10½ in.; bridles, 20 fathoms; headline (fitted in part with Phillips's patent plane floats), 54 ft.; foot rope, 72 ft.; size of meshes, wings 5 in., square 5 in., belly 3½ in., cod-end 3 in.

The trawl was shot and hauled in the usual manner (Davis, 1936) from the M.V. *Calanus* under the supervision of Captain R. Souter.

The Ground and Working Conditions

The area trawled was an inshore ground on the east side of Bute, in the vicinity of Scoulag Point (full Kilometre National Grid Reference 26/1160-1159). A dan buoy was laid down and each haul was made on a somewhat elliptical course over the ground, starting and returning to the buoy. Positions were also checked by conspicuous objects on the shore. The bottom, which is here a sandy mud at 20 fathoms, shelves towards the centre of the channel. Tidal currents in this area are of the order of 1½ knots. During the trawling echo-soundings were taken, and are shown in Fig. 1, which indicates that each set of hauls was consistently taken over similar ground.

Three series of four replicate hauls were taken. Each haul lasted 30 min.; including shooting and hauling, each set of four hauls, all taken between 10.30 and 14.30 hr., occupied 3 hr. The weather conditions during all three series were moderate to good.

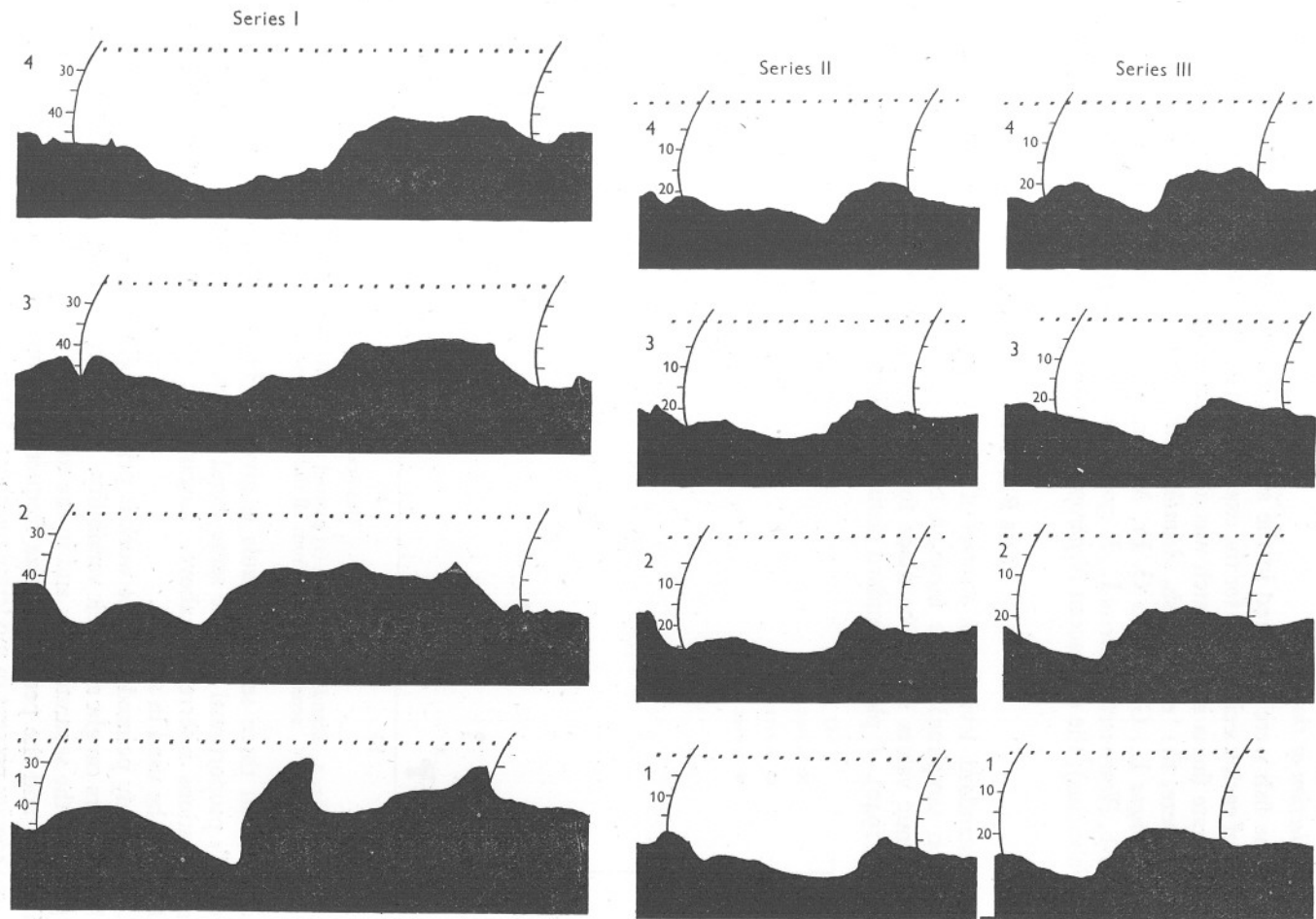


Fig. 1. Echo-soundings for hauls 1-4, series I-III. Series I time-marks at minute intervals; depth in metres. Series II (the echo-sounder was changed during the experiments) and III time-marks at 2 min. intervals; depth in fathoms. Marks at shooting and hauling.

The Collection of the Data

All the fish were measured in the standard manner, and a representative sample of each species taken for the examination of the stomach contents. The invertebrate fauna in each catch was also identified and counted. The major species were, the 'round' fish, *Acanthias vulgaris* Risso, *Gadus callarias* L., *G. merlangus* L., *G. minutus* O. Fr. Müller, *Merluccius merluccius* (L.); the 'flat' fish, *Pleuronectes platessa* L., *P. cynoglossus* (L.), *Drepanopsetta platessoides* (O. Fabricius); the crustacean *Nephrops norvegicus* L.

THE RESULTS

If the standard deviation of a series of catches is roughly proportional (as in plankton sampling) to the mean, a transformation from actual catches to logarithmic values should be made for the analysis of variance (Winsor & Clarke, 1940). A plot of standard deviation against mean catch for all species

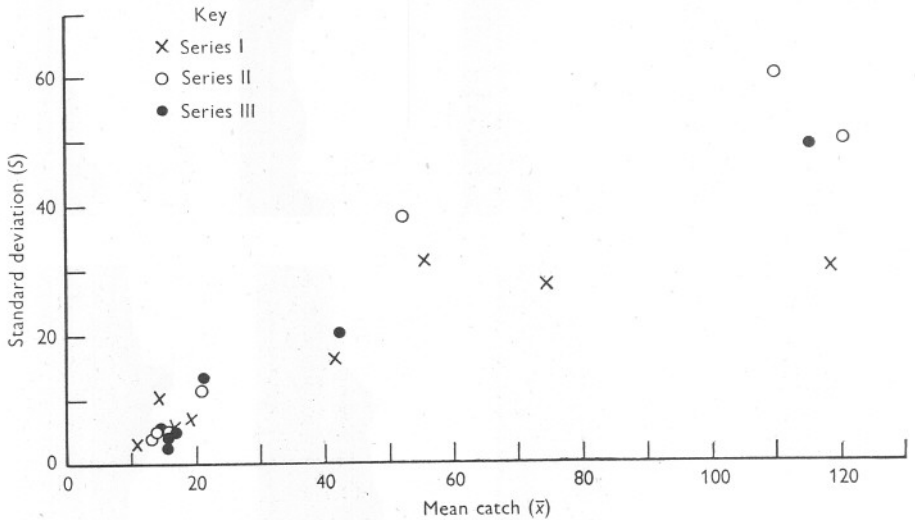


Fig. 2. Standard deviation (s) plotted against mean catch (\bar{x}) for each separate species from all the hauls of series I-III.

taken in all three series of hauls is given in Fig. 2. The two values are roughly proportional and the same trend is seen in the results of the earlier investigations referred to above. Logarithmic values of the catches will therefore be used in analysis.

As already pointed out, the work is primarily directed to a comparison of the numbers caught and their variability. However, the mean length for each species in the separate hauls and in the total catch are shown for all series in Table II and the percentage size frequency curves are given in Fig. 3, for some species present in moderate numbers. Since in some the number caught

TABLE II. THE MEAN LENGTH AND GRAND MEAN LENGTH (CM.) FOR SPECIES IN THE SEPARATE HAULS COMPRISING SERIES I-III

Species	Series I					Series II					Series III				
	Haul				Grand mean	Haul				Grand mean	Haul				Grand mean
	I	2	3	4		I	2	3	4		I	2	3	4	
Dogfish	—	—	—	—	—	61.8	60.4	61.9	59.2	60.8	—	—	—	—	—
Cod	40.0	36.5	45.7	48.9	43.8	45.0	47.6	47.7	51.5	48.0	49.9	48.7	45.4	35.8	45.0
Whiting	24.1	23.8	24.4	22.7	23.8	22.0	22.8	24.3	24.6	23.4	24.6	23.3	23.6	22.5	23.5
Poor Cod	18.3	16.3	14.2	16.0	16.2	15.3	19.0	19.0	17.8	17.8	—	—	—	—	—
Hake	37.6	36.2	39.1	27.8	35.2	—	—	—	—	—	39.0	35.9	35.1	37.1	36.8
Plaice	38.1	36.1	36.8	38.0	37.3	40.9	41.0	38.5	39.1	39.9	39.7	37.4	37.2	34.3	37.2
Witch	29.4	28.4	27.1	29.2	28.5	—	—	—	—	—	28.9	26.4	26.6	26.6	27.1
Long Rough Dab	20.0	20.2	20.2	19.4	20.0	18.1	18.9	20.0	19.9	19.2	19.0	20.5	20.2	20.9	20.2
<i>Nephrops</i>	16.5	15.5	14.2	14.1	15.1	14.0	14.1	14.0	14.2	14.1	15.0	14.9	15.5	15.7	15.3

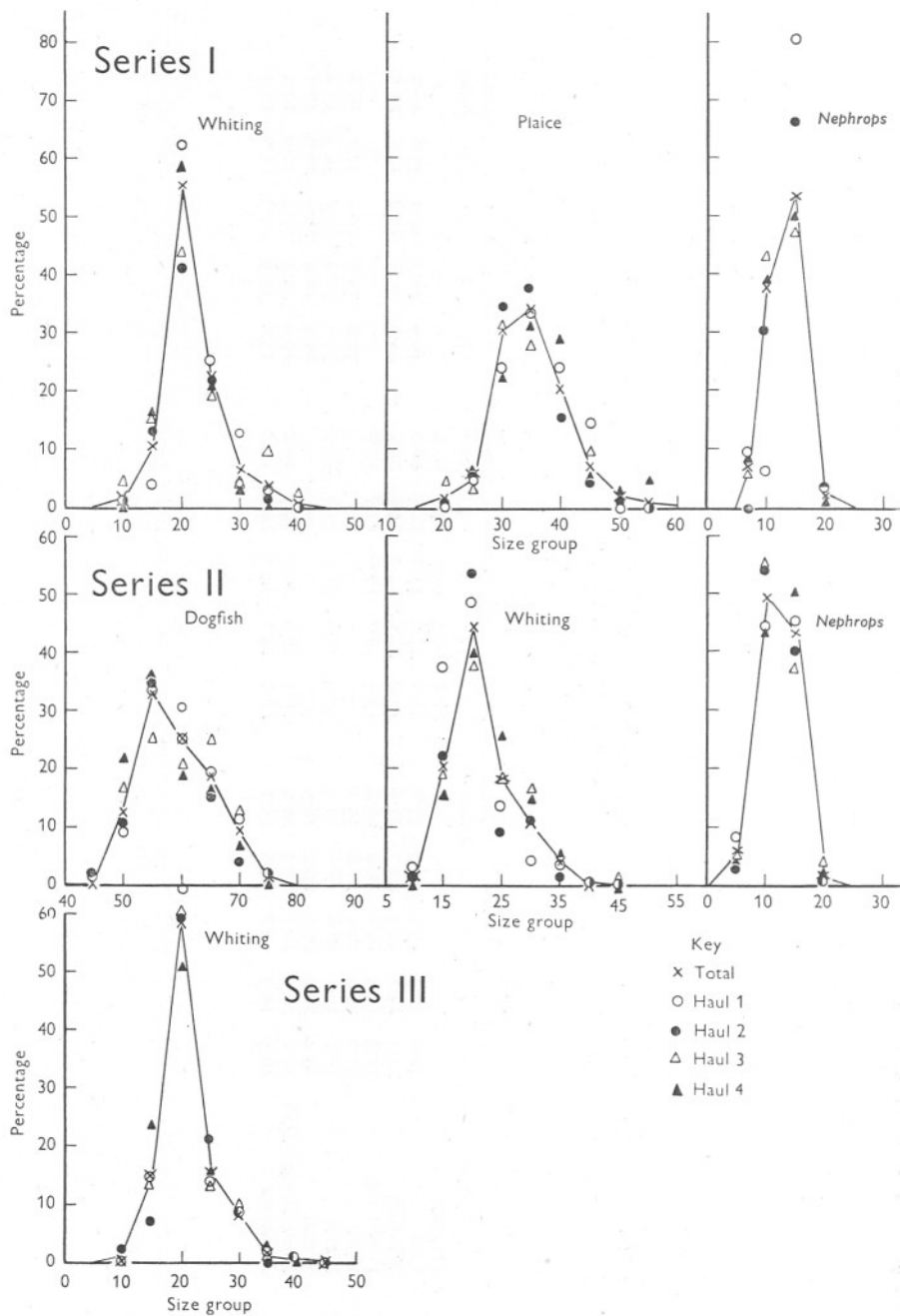


Fig. 3. Percentage frequency distribution of size-groups. Values shown for totals and separate hauls of a given series.

was small and since in others more than one population (as regards size-groups) was sampled in one haul, quantitative deductions regarding size-frequency in sample and in population have not been made. It is clear, however, that the figure and table strongly suggest that a similar population as regards size-distribution was being sampled throughout any given series.

Series I

In series I the species caught in adequate numbers for analysis were the 'round' fish (cod, whiting, poor cod, hake) and the 'flat' fish (plaice, witch, long rough dab) together with *Nephrops*.

In haul I of this series a moderate number of haddock was taken (39), although in subsequent hauls the numbers of this fish were very small (2, 3, 0). It is suggested that during part of the first haul a somewhat different ground had been sampled; this suggestion is substantiated both by the occurrence in

TABLE III

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (<i>H</i>)	3	0.1088	0.0363
Species (<i>S</i>)	3	1.6688	0.5563
Residual			
<i>H</i> × <i>S</i>	9	0.5334	0.0593
Total	15	—	—

TABLE IV

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (<i>H</i>)	3	0.4521	0.1507
Species (<i>S</i>)	3	0.9466	0.3155
Residual			
<i>H</i> × <i>S</i>	9	0.3985	0.0443
Total	15	—	—

this haul only of large numbers of *Asterias rubens* and *Metridium* sp., indicating somewhat harder ground, and by the echo-sounding records seen in Fig. 1, where the trace of haul I is somewhat different. It is therefore of interest to note that the stomach contents of the haddocks caught in this first haul consisted largely of the remains of *Ophiura* sp., indicating hard-ground feeding, whereas in contrast, the stomach contents of the species common to all the hauls correspond to the invertebrate fauna of the sandy mud.

The 'round' fish and 'flats' (together with *Nephrops*) are considered separately. The analysis of variance for 'round' fish is given in Table III. The error variance of a single observation (*H* is less than *H* × *S*) is 0.0593 corresponding to a log standard deviation of 0.2436 or a coefficient of variation of 75.3%, for a given species.

For the second group, 'flat' fish plus *Nephrops*, the analysis is given in Table IV. The mean square for hauls is not significant and an estimate of the error variance is obtained by pooling H and $H \times S$. This gives the variance of a single observation as 0.0708 or a log standard deviation of 0.2663, corresponding to a coefficient of variation of 84.7%.

The catches of *Nephrops* were more irregular than the 'flat' fish, and analysis of the latter separately gives a coefficient of variation of 59.7%. There were large enough numbers of witch in this series to consider two separate size-groups, namely greater and less than 25 cm. An analysis of variance of these two size-groups considered by themselves gives a coefficient of variation of 48.9%.

Series II

In this series, taken 6 days later, there was some change in the major species caught. The hake were negligible, whilst large numbers of spur-dogs were taken. The division into 'round' (which includes the latter) and 'flats' plus

TABLE V

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (H)	3	0.3293	0.1098
Species (S)	3	1.8083	0.6028
Residual			
$H \times S$	9	0.3596	0.0400
Total	15	—	—

TABLE VI

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (H)	3	0.1178	0.0393
Species (S)	2	2.1836	1.0918
Residual			
$H \times S$	6	0.1428	0.0238
Total	11	—	—

Nephrops has been maintained. For the 'round' fish the analysis of variance is shown in Table V. Again pooling H with $H \times S$ since the former is not significant, gives a mean square of 0.0574, or a log standard deviation of 0.2396 corresponding to a coefficient of variation of 73.7%.

For the second group ('flat' fish plus *Nephrops*) the analysis of variance is shown in Table VI. The value for H is not significant; pooling gives an estimated error variance of a single observation of 0.0290, a log standard deviation of 0.1703 and a coefficient of variation of 48%.

Series III

In this set dogfish were again absent and haddock were very few, the remaining species being as before, with a noted absence of hard-bottom fauna. Analysis of the 'round' fish is given in Table VII. Again the value for hauls is not significant; the variance of a single observation after pooling is therefore given by 0.0203, a log standard deviation of 0.1425 and a coefficient of variation of 39%.

TABLE VII

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (<i>H</i>)	3	0.0786	0.0262
Species (<i>S</i>)	2	1.8816	0.9408
Residual			
<i>H</i> × <i>S</i>	6	0.1041	0.0174
Total	11	—	—

TABLE VIII

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Hauls (<i>H</i>)	3	0.0968	0.0323
Species (<i>S</i>)	3	0.5172	0.1724
Residual			
<i>H</i> × <i>S</i>	9	0.3006	0.0334
Total	15	—	—

The analysis with the 'flats' plus *Nephrops* is given in Table VIII. The value for hauls is less than that for interaction so that the latter may be taken as the required error variance; this is equivalent to a log standard deviation of 0.1828 corresponding to a coefficient of variation of 52%.

DISCUSSION

The coefficient of variation, which although in the first instance is strictly applicable only to the present results, has been found to vary from 40 to 85% and this includes values for both 'round' and 'flat' fish. There is no reason, however, to believe that the value is other than adequately representative of this type of sampling of inshore populations. As Winsor & Clarke (1940) pointed out, with such high log standard deviation it is usually better to work on log values throughout, but if 2σ limits are set from these logarithmic values (see Silliman, 1946, for pilchard eggs), then taking 75% as a representative value for the coefficient and converting to actual catches the fiducial limits would be 30–300% for a single observation from a single haul. The catches of a given species from two separate hauls could not, on this basis, be considered significantly different unless one was less than a third or greater than three times the other. In attempting to 'contour' fish populations these limits would also be observed.

The mean catches for all the more abundant species for the three series are given in Table IX. In series I an invasion of haddock into the area, or sampling from a somewhat different ground, has been noted. In the second series there was an incursion of dogfish on to the grounds, the fish being present in reasonable numbers in all four hauls; in contrast to the haddock in series I these dogs were therefore distributed over the whole sampling area. The stomach contents were in an advanced state of digestion, suggesting that they had not been recently feeding on this ground. The cod, whiting, poor cod and hake of the

TABLE IX. MEAN CATCHES OF CHIEF SPECIES IN SERIES I-III

	I	II	III
Dogfish	0	52.3	(1)
Cod	16.5	13.8	16.5
Whiting	74.5	110.0	115.3
Poor Cod	11.0	21.0	(12)
Hake	14.5	(9)	15.8
Plaice	56.5	14.0	42.5
Witch	41.8	(8)	14.5
Long Rough Dab	19.3	15.8	16.0
<i>Nephrops</i>	118.5	120.5	21.3

TABLE X

Source of variation	Degrees of freedom	Sum of squares	Mean square
Main effects			
Dates (<i>D</i>)	2	0.1423	0.0712
Hauls (<i>H</i>)	3	0.0108	0.0036
Species (<i>S</i>)	3	5.2682	1.7561
First-order interactions			
<i>D</i> × <i>H</i>	6	0.1106	0.0184
<i>D</i> × <i>S</i>	6	0.5190	0.0865
<i>H</i> × <i>S</i>	9	0.2347	0.0261
Residual			
<i>D</i> × <i>H</i> × <i>S</i>	18	1.1577	0.0643
Total	47	—	—

'round' fish have shown a constant population over the whole sampling period of 4 weeks. This is indicated by the results in Table IX, and confirmed by analysis (Table X), using the catches for the three separate dates.

The second-order interaction is high; none of the first-order interactions are significant, and the mean squares for dates and hauls are not significant. The population can therefore be considered unchanged throughout the period. The small value for hauls indicates that no significant changes took place as a result of successive hauls over the 'same' ground.

The greatest differences are shown in the two 'flat' fishes, plaice and witch, and the crustacean *Nephrops*. The catch of plaice showed a significant fall in series II. Examination showed that the gonads were almost ripe and that the fish had not been feeding; and it was suspected at the time that, as might be

expected at this season, the fish were moving to deeper water for spawning. However, the catches rose again in series III, and this 'recovery' was maintained in later hauls not given. A similar 'recovery' was also found in the witch and *Nephrops*. The reason for these changes is not clear, since when compared with the 'round' fish less mobility would be expected in bottom-living species.

These results give no evidence on the origin of the variability in replicate hauls, that is, how much is due to inadequacies of technique and how much is inherent in sampling variation dependent upon the population distribution. It is of interest to note that as with plankton sampling, the standard deviation is roughly proportional to the mean, whilst the variance is greater than and increases with the mean. This suggests that the population is aggregated into groups, so that much of the sampling variation may be inherent in the population distribution, and this problem is now under consideration.

For ecological work, in order to investigate a particular habitat it may be desirable to sample a large number of small areas in a short time. It was for this reason that half hour hauls were made. Comparison of such short hauls has been made with hour hauls, alternating the order of trawling. In view of the high variability of results it is clear that in order to compare the ratio with that expected (1:2) it is necessary to have a number of counts. Using the results from a number of trawls, with thirty-two separate values of the ratio the mean was 1:1.96. Clearly this value is within the limits expected.

It should be emphasized that the results refer to variations with the *same* gear tested under as far as possible similar working conditions; it might be expected that the variability with a modified gear would be of the same order. The results provide no information regarding the variations which result when different or modified gear is used over the same ground.

SUMMARY

The variability in catch of a series of hauls with a V.D. trawl taken under, as far as possible, controlled working conditions has been determined.

For analysis the species were divided into 'round' fish and 'flat' fish together with *Nephrops*; for both groups the coefficient of variation varied from 40 to 85%. Taking 75% as a representative value, the 2σ fiducial limits are 30-300% for a single species from a single haul of half an hour duration.

It has been found that the standard deviation is roughly proportional to the mean, and that the variance is greater than the mean and increases with the mean. This suggests aggregation of the population.

The species are considered over the whole sampling period (4 weeks). Except for haddocks and dogfish the 'round' fish constituted a constant population. Changes were found in the other groups and their origin is discussed.

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