Variations in Selection Factors, and Mesh Differentials

By

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Introduction

When the selection of a trawl is measured, either by the use of covers, or, more particularly, when using alternate hauls, the results are often highly variable. For the alternate haul method a major source of variation is the difficulty of ensuring that successive hauls are made on the same population of fish. This difficulty does not occur with cover-net experiments, but even these can be variable. These variations are very important when, as on both sides of the North Atlantic, the main method of conservation of fish stocks is by regulation of the mesh size of trawls. The biological assessments are normally made in terms of size (length) of fish, and the selectivity of net has to be known reasonably precisely to determine the correct mesh size to be used. Often several countries, using nets of a variety of different materials, are fishing the same stock, and vessels using nets of certain materials (especially synthetics) are permitted to use meshes smaller than the basic regulation size (applicable to manila or sisal), because the selectivity of nets made of the synthetic material is greater (they allow bigger fish to pass through) than that of manila. There are two main questions related to the variability of selectivity data: firstly, whether the existing data are sufficiently accurate to determine whether or not a specific material should have a differential, and if so, how much; secondly, especially for a new type of material (e.g. a new synthetic), how much experimental work would be required to determine, with a sufficiently small risk of error, what differential, if any, would be appropriate. It was to provide the means of answering these questions that the present study was made.

Observed Variation

The extent of the variation in selection factor can be derived from the data presented by the ICES Mesh Selection Working Group (ICES, 1964), and similar data compiled by ICNAF (1962). For several species a number of observations (used here to refer to a set of one or more hauls made by the same ship with the same net) are available for the same material in one area, each

Table 1

Variation in selection factors from different experiments

Species	Area	Material	Number of experi-ments	Selection factor				
				Mean	Range	Variance	Standard deviation	Coefficient of variation
Whiting	North Sea	Manila/sisal	53	3·65	2·7 – 4·5	0·153	0·39	11·1
Whiting	North Sea	Cotton/hemp	20	4·08	3·6 – 4·8	0·131	0·36	8·9
Whiting	North Sea	Polyester/ polyamide......	18	4·02	3·3 – 4·8	0·149	0·39	9·6
Whiting	North Sea	Polyethylene......	11	3·66	3·1 – 4·2	0·083	0·29	7·9
Cod	Arctic	Manila...........	50	3·48	2·9 – 4·1	0·086	0·29	8·4
Cod	Arctic	Polyamide........	20	4·04	3·5 – 4·4	0·098	0·31	7·8
Cod	Baltic	Cotton/hemp	17	3·24	2·1 – 3·8	0·191	0·44	13·5
Cod	Nova Scotia	Manila...........	9	3·39	3·2 – 3·5	0·014	0·12	3·5
Haddock	North Sea	Polyester/ polyamide......	19	3·49	2·8 – 4·4	0·187	0·43	12·4
Haddock	Georges Bank	Manila...........	20	3·23	3·0 – 3·5	0·022	0·15	4·6
Hake	Georges Bank	Cotton...........	5	2·76	2·2 – 3·4	0·145	0·38	13·8
Redfish	Grand Bank	Manila...........	5	2·52	2·1 – 2·7	0·062	0·25	10·0
Plaice	North Sea	Manila/sisal	11	2·19	1·7 – 2·3	0·061	0·25	11·3
Sole	North Sea	Manila/sisal	14	3·33	3·0 – 3·7	0·029	0·17	5·1

giving an estimate of the selection factor. From these a mean selection factor, the variance, and the coefficients of variation (standard deviation divided by the mean × 100) have been calculated. Some of these are given in Table 1. The coefficient of variation is generally around 10% (on the east side of the Atlantic only that for sole is substantially less, though the estimates of the selection factor for cod and haddock from the west Atlantic are much more consistent). The sources of variation may be separated into the following factors:—

(a) Small-number variation; if 100 fish at the 50% selection size enter the net, it is unlikely that exactly fifty will go through, and the likely range of individuals escaping through the meshes is between forty and sixty.

(b) Random haul-to-haul variation; e.g. due to catches of weed obstructing the net, or to a large shoal entering the net near the end of the haul, and not having time to escape.

(c) Changes in the selectivity of the gear; e.g. at different towing speeds.

(d) Changes in the selectivity of the fish; e.g. greater girth when feeding and so escaping less easily.

(e) Experimental error; bad design of cover, or differences in methods of measuring the mesh size.

Small-Number Variation

The first source might be estimated in quantitative terms directly by using the binomial distribution, to give the variance of the proportion retained within each length group. This may lead to rather extensive calculations, and another approach was used. This was to fit the regression of proportion retained against length, for the data approximately between the 25% and 75%

points. In this range the regression may be taken as linear, and the variances etc., calculated in the usual way. This method was applied to data for cod from a single haul in the Hornsund Deep with a 131 mm covered manila cod-end by R. V. "Johan Hjort" (given in Table 15 of the ICES Working Group's report), in which 601 fish (347 in cod-end and 254 in cover) were caught in the selection range (37–46 cm). The lengths two standard deviations above and below that at which the mean value of y, the percentage retained, was 50%, were 38·0 and 42·2 cm. This corresponds to a standard deviation in the selection factor of 0·08 (= 2·6%), i.e. a variance of 0·006, which is much less than the observed variance between different observations given in Table 1 (0·086 for manila, and 0·098 for polyamide). The residual variance in the proportion retained about the regression line was 0·0093. The expected variance, from the binomial distribution, is $\frac{p(1-p)}{n}$; here p is between 0·3 and 0·7, and n (numbers caught in each length group) about fifty, so the expected variance is about $\frac{0{\cdot}25}{50} = 0{\cdot}005$. This is rather less than the calculated variance, but both agree in showing that variation due to uncertain definition of the 50% point from any haul with a fair number of fish can account for only a very small part of the total variance.

Even when the numbers of fish are quite small the variance does not increase very much. For instance, using data for whiting caught with manila cod-ends (pp. 114–116 of the ICES Working Group's report) the variances of selection factors from different experiments are:—

All hauls	0·153
Experiments with at least 300 fish within the selection range in cod-end and cover	0·112
Experiments with under 300 fish within the selection range in cod-end or cover	0·163

Between-Haul Variation

The variance between hauls during the same experiments was calculated for two sets of data from R. V. "Sir Lancelot" when fishing for whiting, one in the North Sea using a 74 mm cod-end, and the other off Southern Ireland, using 69 and 76 mm cod-ends. The variances in the selection factors were 0·030, 0·038 and 0·082 respectively, corresponding to coefficients of variation of 5·2, 5·3 and 7·3%. These are considerably larger than can be accounted for by the variance within a single haul, but are also smaller than the variance between experiments, especially considering that the selection factor for any one experiment will have been obtained from the pooled data from several hauls.

Between-Experiment Variation

The major sources of variation lie therefore in real differences between experiments. Some measure of the causes is given by analysing the differences between experiments made by the same person or on the same ship. Such an analysis of variance was made for the data of North Sea whiting caught by manila or sisal cod-ends, using the data of the ICES Working Group's report. The result is as follows:—

	Sum of squares	Degrees of freedom	Mean square
Within authors.....	3·267	37	0·088
Between authors....	4·695	15	0·313
Total	7·962	52	0·153

The result, showing the significantly greater variance between authors, is not very surprising, as data presented by the same author are likely to be derived from observations on the same ground as well as with much the same gear. Perhaps more interesting is the fact that the within-author variance is still quite considerable.

Variations due to the fish, e.g. fatter when feeding, will presumably occur as much among the commercial fleets as in experiments. Provided, therefore, that the experiments are spread through the different grounds and seasons in approximately the same proportion as are the commercial operations, the mean selectivity obtained from the experiments will be the same as the selectivity of the commercial fleet and the latter, of course, is the quantity which has to be measured.

Variations in the gear are more serious, as the mean selectivity of a series of experiments is unlikely to be the same as that of the commercial fleet. It is also possible that the selectivity of the commercial fleet may change from year to year with changes in the gear, e.g. different treatment of the twine.

Differences between experiments, and more particularly between authors, can arise through different experimental techniques. An important technique is the size of cover used and the way it is rigged. In recent work in the eastern Atlantic the size and type of cover has been more or less standardized, and differences between the type of cover used have probably not been an important cause of variation in recent experiments. Another possible source of difference which has received much attention is the method of measuring the mesh size. ICES has recently introduced a standard pressure gauge (1962), but previously a wide range of gauges was in use. From some of the published data the variation in the estimates of mesh size of a particular piece of netting by observers using different techniques can be estimated. The most variable were the series reported by BEVERTON and BEDFORD (1958), when six different observers used the simple wedge gauge, with no pressure device, and also the Lowestoft fixed-pressure gauge. The estimates using the wedge gauge had a coefficient of variation of 3–4%, compared with about 1% with the pressure gauge. However, three of the six observers had had no previous experience of using mesh gauges, and their results were more variable: the coefficient of variation for the three experienced operators was about 2½%. The corresponding coefficient of variation for the six operators using the pressure gauge was rather less than 1%. A similar precision (coefficient of variation of 0·7%) was reported by VON BRANDT and BOHL (1959) for four operators each using four different pressure type gauges (ICNAF, Polish, English and Scottish), while a rather greater degree of variation (coefficient of variation of around 2%) was found by PARRISH, JONES and POPE (1956), using three operators and four gauges, two of them not pressure-operated. The mesh size can therefore be measured quite accurately with a pressure gauge (regardless of the exact type), and even with the wedge gauge and inexperienced operators the degree of variation (4%) is small compared with the observed 10% coefficient of variation in selection factors. In fact, at their greatest, errors of mesh measuring can account for a proportion of $4^2 : 10^2$ i.e. about one-sixth, of the total variation in selection factor.

Differentials

Much recent selectivity work has been carried out to establish differences in selectivity between different materials, usually testing some new material against the traditional manila. This has generally been done in one of the following ways: either by using only the new material, and comparing the selection factor found with that established for the standard material from all previous experiments, or by making alternate hauls, or sets of hauls, with the old and new materials and comparing the selection factors so found. Another possible method which has apparently not yet been used would be a modification of the trouser trawl (RUSSELL and EDSER, 1926), using a trawl with twin cod-ends, one of each material. With the second method fewer hauls can be made with the new material, but it should be less subject to variations in fish or gear other than that being tested (the material). Assuming that the selection factor for manila has been established closely, with little variance, the variance in the first method is simply the variance in selection factors, given in Table 1, i.e. a coefficient of variation for one experiment of about 10%. The variance from the second method has been estimated for North Sea whiting (cotton/hemp versus manila and polyester/polyamide versus manila), and Arctic cod (polyester/polyamide versus manila), using the data from Part III of the ICES Working Group's report, and calculating the variances of the differences in selection factors reported for the two pairs of materials in the same set of experiments. These are given in Table 2, as are the variances of the selection factors for the cotton/hemp or synthetics taken from Table 1. (For the synthetics in the North Sea in one experiment the selection factor for manila was extremely low, and this caused a very large differential for that experiment, and hence a large variance; the variance omitting that comparison has also been calculated, and is given in parentheses.) Accepting the figure in parentheses as the better value, all the variances in the first column are smaller than those in the second, showing that, in analysing a past experiment, the differential is most accurately obtained by comparisons of the selection factors in the same set of experiments. However, when designing future experiments, it is reasonable to suppose that if no tests with manila are made then the number of sets of hauls with the synthetics could be doubled, i.e. the variances in the last column approximately halved. These are then less than those in the middle column; i.e. it is slightly better to do as many sets of hauls as possible, all with the synthetic material (spread over as many grounds as possible) and to compare the average selection factor so obtained with the mean selection factor for manila obtained from all previous experiments.

Whatever experimental design or method of analysis is used, the resulting estimate of the differential will not be exact. Using the values in the centre column of Table 2, the standard deviations of the difference in the selection factors are 0·29, 0·28 and 0·23, equal to between 6% and 8% of the selection factor for manila; i.e. the usual 95% confidence limits for the differential for a single experiment are about 15% each side. For example, the limits for the differential in selection factor between manila and polyester/polyamide for

Table 2

Variance in differences between selection factors of different materials

Stock	Material (compared with manila)	Variance of differences	Variance of cotton or synthetic
North Sea whiting	Cotton/hemp	0·085	0·131
North Sea whiting	Polyester/polyamide	0·311 (0·076)	0·149
Arctic cod	Polyester/polyamide	0·055	0·098

North Sea whiting are $0{\cdot}475 \pm 2 \times \frac{0{\cdot}076}{8} = 0{\cdot}475 \pm 0{\cdot}190$; i.e. the synthetics are between 8% and 19% more selective than manila. This result is quite satisfactory in establishing that the synthetics are more selective than manila, and also that one of the existing differentials in mesh size (70 versus 80 mm = 12% for single twines) lies within the probable range. However, the confidence limits are wide compared with the width of the steps (5 mm or about 6%) in the mesh differentials; that is, ignoring differences, if any, between single and double twines, the data are not sufficient to determine whether or not 65 mm (i.e. a difference of 19%) or 70 mm (12%) would be the more appropriate mesh size. This difficulty may not be serious for polyesters/polyamides, where the differentials are certainly large, but may be quite serious for other materials (e.g. polyethylenes) where the differentials may be quite small (e.g. 3%). Thus the data for courlene are probably only good enough to answer definitely one important question, is courlene statistically significantly less selective than the polyamide/polyester group? (it is); it is also not significantly different from manila, but the latter is not an important point. What is important is to determine how big (or how small) is the difference between manila and courlene, and in particular whether it is big enough to deserve a differential of 5 or 10 mm (6 or 12%). In the report of the Liaison Committee to the 1962 meeting of the Permanent Commission (ANON., 1962) it is estimated that nymplex and courlene are 3% more selective than manila. The data, based on five sets of hauls, are not good enough to estimate a variance satisfactorily, but using the estimate of 7% derived from polyester-manila comparison, the 95% confidence limits are $3 \pm 2 \times \frac{7}{\sqrt{5}}$, i.e. $3 \pm 6{\cdot}2$, i.e. courlene may be less selective than manila, or more than 9% more selective, and hence deserving a 5 mm mesh differential.

Another aspect of this variance is the number of observations required to determine a difference in selectivity with any desired precision. The precision required is not defined exactly, but with mesh differentials in 6% steps in the 80 mm area of the NE Atlantic, it is reasonable to require that the confidence limits (i.e. two standard deviations on each side) should be no wider than this, i.e. that the standard deviation should be less than 1·5%. The minimum number of observations is therefore $\left(\frac{7}{1{\cdot}5}\right)^2 = 22$. As each observation involves several hauls, preferably spread over several grounds and seasons, the work involved in determining the correct differential, even for one material on one species, is very considerable.

With the continual introduction of new materials, or materials in new forms (monofilament or braided, etc.), the big research effort required to determine the right differential (if any) would in itself be a strong argument against having mesh differentials, or in favour of having a uniform mesh size, appropriate to the least selective material.

A more basic objection to mesh differentials, or at least to those based solely on the material, is that the material by itself is not likely to be the only factor in the gear causing differences in selectivity. The earlier analysis showed a very large variation in the selection factors determined in different experiments, much larger in fact than that between even such different materials as terylene and sisal; a pair of extreme examples between the sets of data on North Sea whiting is given below:—

Date	Material	Mesh size	50% Length	Selection factor	Hauls	Total no. of fish Cod-end	Cover
September, 1956....	Double sisal	72·6	29·3	4·0	3	1,175	535
June, 1958.........	Single terylene	82·5	26·9	3·3	4	988	4,979

Some of the variation in the experiments, due to differences in the activity or girth of the fish, clogging by weed, large catches, etc. is likely to be reflected by equal variation in commercial fishing, and the mean value from the experiments will be close to the mean value in the fishery. These causes probably do not account for all the variation, and some is due to variations in the gear, either in the rigging of the net as a whole, or in the treatment of the material. For synthetic fibres in particular the way in which the material is made up – monofilament, braided, etc. – can make a very big difference in the feel of the material, which is very likely to be reflected in its selectivity. For instance, considerable differences in selection factor for whiting, 4·2 versus 4·6, though not for dab, have been reported for "stiff" and "normal" hemp (ROESSINGH, 1959). These variations in rigging or treatment may not be the same in the commercial fishery as in the experimental tests, and the mean differential for the commercial fleet may be quite different from the mean experimental differential, possibly even outside the experimental range. This danger would be reduced by careful planning, and by collecting good and full information on present commercial practice. There is, however, no guarantee that commercial practice will not change, so that with any given material the effective differential in the commercial fleet in future years could be different from the present differential.

Summary

The selection factor obtained from any one set of covered net hauls is quite variable, with typically a coefficient of variation of around 10%. Only a small part of this variation can be ascribed to small numbers of fish in cod-end and cover, at least for numbers over 300–500. A rather greater variance occurs between successive hauls, but even this gives a coefficient of variation of no more than 5–7%. The biggest source of variation is a real difference between sets of hauls, either in the fish (fatter when feeding, etc.) or in the gear, e.g. different treatment of the twine.

A corresponding variation occurs in the estimates of the differential between, e.g., manila and polyesters. If the selection factor for manila has been reasonably well estimated, it is slightly more efficient to carry out tests on the synthetic alone, and compare the selection factor so obtained with the standard manila selection factor, rather than to test the manila and synthetic in parallel. This is true provided that the extra hauls thus made available for testing synthetics are made under a range of conditions.

If the selectivity differential is to be estimated with a precision reasonably in agreement with the size of the steps in the mesh differentials commonly used, particularly in the 80 mm area of the NE Atlantic (5 mm), about twenty independent observations are required.

It is suggested that because some of the observed variation in selectivity is due to real differences in the gear, other than the actual material, e.g. in its treatment or in the way it is braided, the mean selection factor determined (even with good precision) from a set of research experiments may be different from the mean selection factor of the material as used in the commercial fleet, and that this latter may itself change from time to time.

Appendix

Scientific names of fishes mentioned in the text

Whiting	*Merlangius merlangus* (L.)
Cod	*Gadus morhua* L.
Haddock	*Melanogrammus aeglefinus* (L.)
Hake	*Merluccius bilinearis* (Mitch.)
Redfish	*Sebastes marinus* (L.)
Plaice	*Pleuronectes platessa* L.
Sole	*Solea solea* (L.)
Dab	*Limanda limanda* (L.)

References

ANON., 1962. "International Fisheries Convention of 1946. 10th Meeting of the Permanent Commission. Report of the Liaison Committee". Doc. No. P.C. 10/145 (mimeo.).

BEVERTON, R. J. H., & BEDFORD, B. C., 1958. "On the measurement of the bias and precision of mesh gauges". ICES, C. M. 1958, Comp. Fish. Comm., Doc. No. 112 (mimeo.), 4 pp.

BRANDT, A. VON, & BOHL, H., 1959. "Measurement of trawl-net meshes with pressure gauges". ICES, C. M. 1959, Comp. Fish. Comm., Doc. No. 10 (mimeo.), 14 pp.

ICES, 1964. "Report of the mesh selection working group, 1959–1960". Coop Res. Rep., No. 2. 156 pp.

ICNAF, 1962. "Compilation of selectivity data". ICNAF 1962, Meeting Doc. No. 6, Serial No. 941, 15 pp.

PARRISH, B. B., JONES, R., & POPE, J. A., 1956. "A comparison of mesh-measuring methods". J. Cons. int. Explor. Mer, **21**: 310–18.

ROESSINGH, M., 1959. "Recent experiments on gear and mesh selection in the Netherlands". ICES, C. M. 1959, Comp. Fish. Comm., Doc. No. 88 (mimeo.), 6 pp.

RUSSELL, E. S., & EDSER, T., 1926. "The relation between cod-end mesh and size of fish caught". J. Cons. int. Explor. Mer, **1**: 39–54.

WESTHOFF, C. J. W., POPE, J. A., & BEVERTON, R. J. H., 1962. "The ICES mesh gauge". Prospectus of the ICES mesh gauge. Published by ICES, Charlottenlund, 11 pp.