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Variation in Selection Factors, and Mesh Differentials.

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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 somewhat 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 very variable. The extent of this variation can be derived from the data presented by the ICES Mesh Selectivity Working Group. 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 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 x 100) have been calculated. Some of these are tabulated below.

Table 1. Variation in selection factors from different experiments

Species	Area	Material	Selection Factor				
			Mean	Range	Variance	Standard Deviation	Coefficient of Variation
Whiting	N.Sea	Manila/sisal	3.65	2.7-4.5	0.153	0.39	11.1
"	"	Cotton/hemp	4.08	3.6-4.8	0.131	0.36	8.9
"	"	Polyester/Polyamide	4.02	3.3-4.8	0.149	0.39	9.6
"	"	Polyethylene	3.66	3.1-4.2	0.083	0.29	7.9
Cod	Arctic	Manila	3.48	2.9-4.1	0.086	0.29	8.4
"	"	Polyamide	4.04	3.5-4.4	0.098	0.31	7.8
"	Baltic	Cotton/hemp	3.24	2.1-3.8	0.191	0.44	13.5
Plaice	N.Sea	Manila/sisal	2.19	1.7-2.3	0.061	0.25	11.3
Sole	"	" "	3.33	3.0-3.7	0.029	0.17	5.1
Haddock	"	Polyester/Polyamide	3.49	2.8-4.4	0.187	0.43	12.4

Though there are some differences, the coefficient of variation is generally around 10% (only that for sole being substantially less). 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 is between forty and sixty individuals escaping through the meshes.

(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 - e.g. bad design of cover, or differences in methods of measuring the mesh size.

The last source of variation was probably quite considerable in early mesh selection experiments, when both the general experimental technique and, especially, methods of mesh measuring, were still far from being uniform, but is probably quite small in recent work.

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 from a single haul with a 131 mm covered manila cod-end by R V JOHAN HJORT (given in Table 6 of the 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 cm 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 $\frac{0.25}{50}$ = 0.005. 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 taken with manila cod-ends 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

The variance between hauls during the same experiment was calculated for two sets of data from RV 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.

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 using manila or sisal cod-ends, using the data in the ICES Mesh Selection report.

	Sum of Squares	Degree 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 the experiments are spread through the different grounds and seasons in approximately the same proportion as the commercial operations, the mean selectivity obtained from the experiments will be the same as the selectivity of the commercial fleet - 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.

Differentials

Much recent selectivity work has been done to establish differences in selectivity between different materials, usually testing some new material against the traditional manila. This may be done in two ways; either to carry out the experiments using only the new material, and comparing the selection factor found with that established for the standard material from all previous experiments, or to carry out alternate hauls, or sets of hauls, with the old and new materials and compare the selection factors so found. With the latter 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 v. manila and polyester/polyamide v. manila), and for Arctic cod (polyester/polyamide v. manila), using the data from the 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 below, as are the variances of the selection factors for the cotton/hemp or synthetics taken from Table 1.

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

(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 brackets). Accepting the value in brackets 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 could be approximately halved. This is less than the variances 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 s.f. 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 s.f. 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 North Sea whiting are $0.475 \pm 2 \times \frac{0.076}{8} = 0.475 \pm 0.194$; 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 v. 80 mm = 12% for single twines) lies within the probable range. However, the confidence limits are wide compar with the width of the steps (5 mm or c. 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 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 it is estimated that nymplex and courlene are 3% more selective than manila, based on five sets of hauls. The data are not good enough to estimate a variance satisfactorily, but using the estimate of 7% derived from the polyester-manila comparison, the 95% confidence limits are $3 \pm 2 \times 7/\sqrt{5}$, i.e. 3 ± 3.1, i.e. courlene may be just less selective than manila, or mor than 6% 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 known exactly, but with mesh differentials in steps in the 80 mm of the N.E. Atlantic area, it is reasonable to require at 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 $\left(\frac{7}{1.5}\right)^2=22$. As each observations involve 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 mples between two 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
9/1956	Double sisal	72.6	29.3	4.0	3	1,175	535
6/1958	Single Terylene	82.5	26.91	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, size of catches etc, may occur equally 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 probably due to differences in the gear - either in the rigging of the net as a whole, or in the treatment of the material. These 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 side 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 been reasonably well estimated, it is slightly more efficient to carry tests on the synthetic alone, and compare the selection factor so obtained with the standard manila s.f., rather than to test the manila and synthetic in parallel. This is true provided that the extra hauls used in 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 differential commonly used, particularly in the 80 mm area of the N.E. Atlantic (i.e. 5 mm), about twenty independent observations are required.

It is suggested that because some of the observation 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 year to year.

Appendix

For the ICNAF meeting I have examined some of the ICNAF data in order to compare it with the results obtained on the ICES material. The data used were those given by Poulsen (1962 Meeting, Document No. 6, Serial No. 941). Apart from a series of U.S. haddock data, for no combination of species, area and twine material are there more than a very few estimates available; more particularly, each group of estimates was usually obtained by the same laboratory. There is nothing corresponding to some of the ICES data in the Arctic or North Sea where corresponding estimates have been made by a wide range of ships and laboratories. The result of the analysis of the available data is given in the table below.

Species	Area	Material	No. of Estimates	Mean S.E.	Variance	St. Dev.
Cod	4 V-W	Manila	4	3.3	.037	.192
	"	Nylon	3	3.9	.060	.245
	4 T	Manila	9	3.4	.014	.118
		Cotton	2	3.6	.005	.071
		Nylon	3	3.9	.003	.054
	Grand Bank	Manila	3	3.0	.145	.381
	All areas/materials				.031	.176
Haddock	4 V-W	Manila	9	3.2	.017	.130
		Nylon/Terylene	4	3.6	.149	.386
	4 X	Nylon	2	3.9	.020	.141
	Grand Bank	Manila	3	3.0	.012	.110
	5?(U.S.)	"	20	3.2	.022	.148
	All areas/materials				.032	.179
Hake	5	Manila	5	2.8	.208	.457
		Nylon	4	3.5	.063	.251
		Cotton	5	2.9	.145	.381
	All materials				.146	.382
Redfish	Grand Bank	Manila	5	2.5	.062	.249
	4 T	"	2	2.4	.005	.071
	5? (U.S.)	"	7	2.4	.023	.152
	All areas				.035	.187
Am.Plaice	Grand Bank	Manila	3	2.3	.003	.054
Witch	Newfoundland	"	2	2.0	.080	.283

Apart from the hake, these results show that the estimates of selection factor are rather less variable than those in the ICES area. For cod and haddock the standard deviation is around 5% of the mean selection factor, compared with 8-12% in the east Atlantic. However, considerably more estimates are available for the east side, so that the mean selection factor for all experiments has about the same variance on each side of the Atlantic (a standard error of 2-3%, giving confidence limits of about 0.1-0.2 each side of the mean s.f.). The reason for the smaller variance of the estimates from the western Atlantic cannot be determined precisely, but within each group of species/area in the table above, the estimates were apparently all obtained by the same laboratory, though sometimes using different ships. The consistency may therefore reflect a constant experiemental technique (which is a good thing), but may also be due to a consistent use of a particular method of rigging and operating the gear, and to this extent the experiments may fail to represent the range of selectivity occurring in the wide range of fleets operating in the ICNAF area.