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**ON THE MESH OF HERRING DRIFT-NETS
IN RELATION TO THE CONDITION FACTOR
OF THE FISH**

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On the Mesh of Herring Drift-Nets in relation to the Condition Factor of the Fish.

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IT is well known to herring fishermen that, in order to get the best returns, the mesh of their nets must correspond to the size of the fish on the grounds, but that this correspondence must take account of both the length and the weight or condition of the fish has not, I think, been clearly pointed out.

I have tried in this paper to express in definite figures a relationship between the size of the mesh and the condition and length of the fish taken together.

The lower limit of capture by a net is obviously the smallest fish which cannot push its way through the meshes. It is difficult to ascertain this size experimentally, as we cannot, as in the case of a trawl, arrange a fine-meshed net to retain the escaping fish. It is possible by fishing a train of nets of different meshes to ascertain the size of the fish on the grounds, and by comparing the lower limits of capture of the various nets comprising the train to tabulate the proportions of each size respectively retained and allowed to escape by each net. It has been shown in this way¹⁾ that there is not an absolutely sharp division between the sizes retained and escaping, but that of fish below a certain size a larger and larger proportion of each successive length can escape. A purse seine might also be used to give a true sample of the stock on the grounds.

The upper limit of capture of a net is the largest fish that can push its head sufficiently far through the meshes to be retained. These large fish may be meshed by the maxillary bones, by the vertical ridges on the preopercle, and by the operculum. It seems probable that the proportion of fish caught by the maxilla is insignificant. As regards the preopercular ridges it is easy to shake a fish meshed by the head out of the net, and the practice of fishermen is to haul the net with

¹⁾ Hodgson. *a.* Journ. du Conseil II, 3, 1927.

b. "The Natural History of the Herring". 1934. (Buckland Lectures for 1933.).

the side on which the fish are mainly meshed uppermost, to avoid the loss of these fish which would drop out into the sea. The number of fish caught in this way is also probably a small proportion of those striking the net. A fish, however, that has pushed its head through a net till the mesh has passed the operculum is secured until it is forcibly removed.

Figure 1. Girth behind gill cover and greatest girth shown as percentage of total length of fish of different condition (K) values.
Broken line, fish measured to vertical through tips of spread caudal fin.
Unbroken line, fish measured to tip of longest caudal ray.

The main range of sizes taken by a drift-net lies then, we may suppose, between these two limits, the smallest fish that cannot get through and the largest that can get its head through as far as the gill cover; and it was with a view to finding to what lengths this range would correspond for different values of K (i. e., 100 times the

weight in grammes divided by the cube of the length in centimetres) that the following measurements were made from time to time on a number of herrings; (a) length, (b) weight, (c) greatest girth, usually a short distance in front of the dorsal fin, (d) girth of head immediately behind the gill cover. The range of sizes measured was from 20 to 30 cm. and the condition from spent to spawning. The girth was measured by a piece of stout thread encircling the fish closely but not so closely as to constrict the body noticeably. Probably in actual practice the body of a meshed fish is definitely constricted but it would have been difficult to gauge the right amount of permissible tension if the thread had been allowed to constrict the body.

The fish were taken at various times in various localities round the coast of Ireland and were measured without regard to sex, so that the results give a general average which may not hold good in individual cases. The possibility of irregularities due to differences in the specific weights of male and female gonads has been ignored.

The length measurements were made in the first instance, as in Heincke's original method, to the vertical through the tips of the spread caudal fin, and the condition $K = \frac{100 W}{l^3}$ of each fish calculated

for this length. As the length measurement approved by the International Council (Lowestoft 1930) is to the tip of the longest caudal ray, bent up or down to the middle line, the equivalent value of K for the length thus expressed has been calculated on the assumption that the international measurement is longer than that of Heincke by 5 %, a figure which numerous duplicate measurements have shown to be reasonably accurate, and these revised values of l and K have been used throughout the paper except where otherwise stated.

In the two following tables are given the results of measurement of 235 fish arranged according to successive values of K, (a) the original figures based on the measurement to the tips of the spread caudal, (b) the equivalent values when the fish are measured to the tip of the longest caudal fin ray. The figures in brackets are the number of fish examined in each K group.

Table I.

(a) Herring measured to vertical through tips of spread caudal.

Range of K	Average K	Greatest girth, % of length	Girth behind operculum, % of length
101 — 105	101.9	54.0 (11)	39.9 (11)
96 — 100	97.8	52.6 (22)	39.8 (22)
91 — 95	93.1	51.2 (24)	39.6 (24)
86 — 90	88.0	49.2 (26)	39.4 (25)
81 — 85	83.1	47.6 (38)	39.0 (37)
76 — 80	78.4	46.1 (30)	38.2 (28)
71 — 75	72.3	43.3 (26)	37.7 (27)
66 — 70	67.6	41.8 (41)	37.2 (42)
61 — 65	64.1	40.6 (15)	36.7 (15)

Table II.

(b) Herrings measured to tip of longest caudal ray.

Average K	Greatest girth, % of length	Girth behind operculum, % of length
96	53.0	39.1
92.1	51.5	39.0
87.7	50.1	38.8
82.9	48.3	38.6
78.2	46.7	38.2
73.9	45.2	37.5
68.3	42.5	37.0
63.6	41.0	36.5
60.3	39.8	36.0

These figures are shown as a graph in Fig. 1.

Table III.

Upper Limits of Capture.

Rows to yard	Circ. of mesh cm.	% of L K = 65	36.7 70	37.2 75	37.7 80	38.2 85	38.7 90	38.9 95	39.1 100	39.2 105	39.2 ¹⁾
30	12.19	33.20	32.78	32.35	31.85	31.48	31.34	31.18	31.10	31.10	31.10
31	11.80	32.14	31.71	31.30	30.85	30.48	30.33	30.18	30.10	30.10	30.10
32	11.43	31.13	30.73	30.31	29.88	29.53	29.38	29.24	29.16	29.16	29.16
33	11.08	30.17	29.78	29.38	28.97	28.65	28.47	28.35	28.28	28.28	28.28
34	10.76	29.30	28.94	28.54	28.12	27.80	27.64	27.50	27.44	27.44	27.44
35	10.45	28.46	28.09	27.70	27.30	26.99	26.85	26.73	26.66	26.66	26.66
36	10.16	27.66	27.31	26.94	26.56	26.25	26.12	25.99	25.92	25.92	25.92
37	9.89	26.95	26.58	26.23	25.85	25.55	25.40	25.30	25.24	25.24	25.24
38	9.63	26.23	25.88	25.53	25.17	24.88	24.74	24.63	24.57	24.57	24.57
39	9.38	25.54	25.22	24.88	24.52	24.23	24.11	24.00	23.93	23.93	23.93
40	9.14	24.90	24.58	24.24	23.90	23.61	23.49	23.38	23.32	23.32	23.32
41	8.92	24.28	23.97	23.65	23.30	23.02	22.90	22.81	22.74	22.74	22.74
48	7.63	20.77	20.50	20.22	19.94	19.71	19.60	19.51	19.46	19.46	19.46

Table IV.

Lower Limits of Capture.

Rows to yard	Circ. of mesh cm.	% of L K = 65	41.5 70	43.4 75	45.6 80	47.4 85	49.2 90	50.8 95	52.6 100	54.3 105	56.1 ¹⁾
30	12.19	29.38	28.10	26.75	25.70	24.78	24.02	23.17	22.46	21.73	21.73
31	11.80	28.44	27.20	25.90	24.87	23.99	23.34	22.42	21.74	21.04	21.04
32	11.43	27.55	26.34	25.08	24.10	23.24	22.52	21.71	21.06	20.37	20.37
33	11.08	26.70	25.53	24.30	23.36	22.52	21.81	21.05	20.42	19.75	19.75
34	10.76	25.92	24.77	23.60	22.69	21.86	21.17	20.43	19.83	19.18	19.18
35	10.45	25.70	24.08	22.92	22.04	21.24	20.57	19.86	19.25	18.63	18.63
36	10.16	24.49	23.42	22.28	21.42	20.65	20.02	19.31	18.73	18.11	18.11
37	9.89	23.82	22.78	21.67	20.85	20.10	19.47	18.79	18.22	17.64	17.64
38	9.63	23.19	22.18	21.12	20.30	19.57	18.97	18.30	17.74	17.17	17.17
39	9.38	22.61	21.62	20.58	19.77	19.08	18.47	17.83	17.29	16.73	16.73
40	9.14	22.04	21.06	20.04	19.23	18.58	18.01	17.37	16.84	16.29	16.29
41	8.92	21.49	20.53	19.59	18.79	18.13	17.56	16.95	16.43	15.09	15.09
48	7.63	18.37	17.57	16.73	16.08	15.51	15.02	14.49	14.00	13.60	13.60

¹⁾ By extrapolation.

It will be seen from these tables that while the greatest girth of a fish may vary from about 40 to 53 per cent. of its length according to whether it is a spent or full fish corresponding to values of K of from 60 to 100, ripe males being usually heavier than females of the same length, the girth behind the gills shows a much smaller but appreciable range of 36 to 39 per cent.

As an illustration of the implication of these measurements, taking for instance a fish of a length of 25 cm., they show that in good condition, $K = 95$, the girth behind the gills will be 39.0 per cent. of the length, i.e. 9.5 cm., and the greatest girth 52.5 per cent., or 13.1 cm., but in poor condition, $K = 65$, the corresponding girths will be 36.7 per cent. and 41.5 per cent., or 9.2 cm. and 10.4 cm., which means that a fish in poor condition will go easily through a net which is well adapted to its capture when a full fish.

Considering the question in relation to the mesh of the net and assuming, as suggested above, that the girth behind the gills and the greatest girth represent the effective limits of capture, we find, to take an example, that a mesh of internal circumference of 10 cm., or approximately 36 rows to the yard, will take fish of between 19.0 cm. and 25.5 cm. in length if they are in good condition with $K = 95$, but if they are very thin, with $K = 65$, the range of sizes will be from 24.1 cm. to 27.2 cm. This relationship is shown in Tables III and IV, which give the upper and lower limits of capture, i.e., the lengths of the largest fish which would be meshed behind the gill cover and the smallest which would be meshed round the body, for nets with from 30 to 41 rows of meshes to the yard and for values of K from 65 to 105.

In these tables the percentages corresponding to the values of K are taken without correction from the graph, Fig. 1, given above. Also no allowance is made for the thickness of the twine in calculating the internal measurement of the mesh from the number of rows to the yard, i.e., the internal circumference of the mesh of a net of 36 rows to the yard is taken to be 4 inches or 10.16 cm.

In reality the size of the mesh must necessarily be smaller than the dimensions given in the table, probably by from 2 to 5 per cent. according to the thickness of the twine and whether it is barked or tarred. To get some idea of what the limits would be, rough measurements were made of three nets, two new barked nets of fine cotton and one old net heavily tarred.

A new net of barked cotton stretched by hand without excessive straining "on the diamond", i.e. with the meshes closed, gave 30½ rows to the yard. The internal diagonals of 30 meshes of this net, stretched between a fixed point and the point of a lead pencil, gave the following measurements: —

mm.	57	58	59	60
No.	1	3	15	11

Average: 59.20 mm.

The stretched diagonal without allowance for thickness of twine is 59.96 mm., which gives a difference of .76 mm. or 1.27 per cent.

An old net, heavily tarred and stiff, stretched as above, gave 31.5 rows to the yard and the measurements of 30 meshes were

mm.	53	54	55	56
No.	3	16	10	1

Average: 54.30 mm.

Average without allowance for thread: 58.06.

Difference: 3.76 mm. or 6.48 %.

A third net of barked cotton, unused, measuring, when stretched by hand as above, 32.5 rows to the yard, gave a range of sizes for 30 meshes

mm.	52	53	54	55	56	57
No.	2	2	1	11	13	1

Average: 55.13.

Average without allowance for thread: 56.20.

Difference: 1.07 mm. or 1.92 %.

These measurements besides giving an approximate indication of the actual size of the mesh also show what variation in size may occur in any one net.

This variation, as might be expected in a machine-made net, is comparatively small, too small to account to any great extent for the graduation in size of the fish escaping the net, though it may play a small part in this. In actual practice, as well known, there is not a sharp selection by the net in cases where it is clear that the mesh of the net is a limiting factor, but the division between the escaping fish and those retained is graduated over a wide range either at the upper or lower limits of capture by the net. If variation in the size of the mesh is rejected as an explanation of this graduation we may consider whether variation in the value of K may not be of importance in causing it.

Taking three examples from drift-net catches on the Irish coast and discarding the extremes, both large and small fish, which may have been subject to selection, the range of K is found to be considerable.

(a) Kinsale; 8th May 1928.

K	No.	%	
65	3	2.8	Length: 26.5 — 29.6 cm. Mainly recovering spents in stage VII — II.
70	21	19.6	
75	47	44.0	
80	30	28.0	
85	6	5.6	

(b) Howth; 26th June 1928.

K	No.	%	
75	1	1.4	Length: 25.5 — 27.5 cm. Mainly stages II and III.
80	3	4.3	
85	22	31.4	
90	27	38.5	
95	15	21.4	
100	2	2.9	

(c) Howth; 30th July 1930.

K	No.	%	
80	4	5.8	Length: 24.5 — 26.5 cm. Stages II to V, mainly III.
85	15	21.7	
90	23	33.3	
95	18	26.1	
100	6	8.7	
105	3	4.4	

These examples, taken at random, are representative of the normal variation of K in almost every case where its values have been worked out in Irish samples. Small errors due to *post mortem* shrinkage of the fish and to inevitable inaccuracies in weighing and measuring will have made the range appear a little wider than it is in reality. A difference of 1 mm. in the length of a fish is equivalent to 1.5 in the value of K in a small fish of 20 cm. and 1.0 in a large one of 30 cm. Direct measurements of the mesh of the nets by which the samples were taken were not made, so that it is necessary to take the best evidence available. Measurement of the girth of the fish where they are clearly marked by the net gives an indication of the mesh, not very satisfactory but probably often nearer than the fisherman's own estimate, which often differs widely from the size as shown by direct measurement, e. g., a net described to me as 36 rows to the yard has been found to measure 41 rows.

The Kinsale sample of 8th May 1928 was said to have been taken with nets of 31—32 meshes to the yard. Assuming that the net was of 31 rows, with an internal circumference of 11.80 cm., theoretically the catch in a uniform shoal with equal numbers of all sizes of fish would have been —

K	65	2.8 per cent.	between 28.44 and 32.14 cm.
70	19.6	" "	27.20 " 31.71 "
75	44.0	" "	25.90 " 31.30 "
80	28.0	" "	24.87 " 30.85 "
85	5.6	" "	23.99 " 30.48 "

Actually, the catch was just within these limits, the percentage composition being

cm.	24	25	26	27	28	29	30	31	32
%	.5	5.6	6.6	17.2	15.2	21.7	24.3	8.2	.5

This is shown in the graph (Fig. 2) where the highest point of the graph of the actual catch is made equal to 100 on the graph of the theoretical catch. It seems probable that in this case both the upper and lower limits of the catch were affected, if not determined, by the mesh of the net.

Figure 2. Kinsale, 8th May 1928. The broken line shows the theoretical limits of capture, the unbroken line the actual catch.

In the second example, Howth, 26th June 1928, the mesh of the net was not stated but measurements of the circumference of the fish, where they were marked by the net, indicated that the mesh probably had an average internal measurement of 10.7 cm. Taking this as 34 rows to the yard, or an internal circumference of 10.76 cm., the theoretical catch of the net would have been —

K	75	1.4	per cent.	between	23.60	and	28.54	cm.
	80	4.3	"	"	22.69	"	28.19	"
	85	31.4	"	"	21.86	"	27.80	"
	90	38.5	"	"	21.17	"	27.64	"
	95	21.4	"	"	20.45	"	27.50	"
	100	2.9	"	"	19.83	"	27.45	"

Actually the catch was —

cm.	22	23	24	25	26	27	28	29
%	.6	2.5	16.0	29.0	28.4	18.4	4.9	3.1

In this case again the actual catch was within the theoretical limits except for a small residue, ca. 3 %, of large fish which were probably meshed by the maxilla or preopercular ridges. This is shown in the graph (Fig. 3). In this case there were apparently no smaller fish present than those actually taken.

Figure 3. Howth, 26th June 1928.

In the third sample, (Fig. 4), Howth, 30th July 1930, the mesh of the nets was said to have been 30—31 rows to the yard but this was probably incorrect, though it may have been the original mesh when new, since measurement of the net-marked fish gave an average mesh of 10.99 cm. Taking this as 33 rows, the nearest whole number, or 11.08 cm, circumference, we get the theoretical limits of —

K	80	5.8	per cent.	between	23.36	and	28.97	cm.
	85	21.7	"	"	22.52	"	28.65	"
	90	33.3	"	"	21.81	"	28.47	"
	95	26.1	"	"	21.05	"	28.35	"
	100	8.7	"	"	20.42	"	28.28	"
	105	4.4	"	"	19.90	"	28.23	"

The composition of the actual catch was —

cm.	23	24	25	26	27	28	29	30
%	1.5	8.9	30.4	20.7	20.0	14.8	3.7	.4

The distribution of this within the limits is very similar to that of the previous Howth sample.

Though these examples do not prove the reliability of the measurements here put forward, they are not inconsistent with them; but to determine how far the figures set out in these tables and graphs will hold good in actual practice, extended experiments will be needed, made with carefully measured nets of definite mesh, the catch of each net being weighed individually as well as measured.

Hodgson¹⁾ has published some records of catches made in the course of two experiments with measured nets on the east coast of

¹⁾ l. c.

Figure 4. Howth, 30th July 1930.

England, but since particulars by which the value of K could be determined are not given, these experiments cannot be used as a definite test. It would seem, however, that most of his results can be brought within the scheme by selecting an appropriate value of K , but not all, for on two occasions, with a net of 48 rows in the first experiment and with a net of 35 rows in the second experiment, the sizes of the fish taken were larger than could have been accounted for by any possible value of K . On the first occasion this is explained by the comment of Buchanan-Wollaston¹⁾ on the experiment when he says that almost all the fish were caught by the nose, and possibly the same explanation may apply in the second case. Fish caught in this manner have been deliberately omitted from the measurements which I made.

Summary.

Measurements of the greatest girth of herrings and the girth behind the gill cover have shown that the girth is proportional to the condition factor, K , of the fish.

It follows from this that the catching power of a net is dependent on the condition of the fish as well as on the length.

An attempt is made in the paper to express in figures the relationship between the length and K of the fish caught and the circumference of the mesh, based on the observation that the greatest girth ranges from 41.5 % of l when $K = 65$ to 54.3 % of l when $K = 100$ and the girth behind the gill cover from 36.7 % to 39.2 % of l for the same values of K .

¹⁾ Journ. du Conseil II, 3. 1927.