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A FISHING EXPERIMENT WITH MULTIFILAMENT, MONOFILAMENT AND MONOTWINE GILL NETS IN LOFOTEN DURING THE SPAWNING SEASON OF ARCTO-NORWEGIAN COD IN 1974

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ABSTRACT

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From 6 February to 30 March 1974 during the spawning migration of Arcto-Norwegian cod, a fishing experiment with gill nets made of continuous multifilament nylon, nylon monofilament and nylon monotwine was carried out in Lofoten.

The different types of nets were combined to make up one gill net setting consisting of 40 to 92 single nets, half of which were multifilament nylon nets and one quarter each monofilament and monotwine nets. The sequence of the single nets was varied during the experiment.

The result for the total experiment was that the monofilament nets caught 26% (in numbers) more cod than the multifilament nylon nets and 38% more than the monotwine nets. For saithe the monotwine nets were apparently the most and the multifilament nylon nets the least efficient.

The average length of the captured fish was slightly higher for the multifilament nylon than for the monofilament nets whereas the fish caught by the monotwine nets were somewhat smaller.

Taking the length frequency of cod caught by purse seine in the same area during the experiment as representative for the cod available to the gill nets, a log-normal distribution selection curve was fitted for each of the three types of gill nets.

The mesh size used in the experiment (186 mm) was clearly too small to obtain maximum catches of the available cod. Assuming proportionality between mesh size and mean selection length gave optimum mesh sizes of 224 mm for nylon, 222 mm for monofilament and 234 mm for monotwine. The ratios between the theoretical maximum catches thus obtained were: Monofilament: Nylon = 1.46; Monotwine: Nylon = 1.48; Monotwine: Monofilament = 1.02.

Assuming that all length groups are equally numerous among the cod available to the nets, ratios between the catch efficiency of the three nets, which should represent a more general situation, were calculated, giving: Monofilament: Nylon = 1.23; Monotwine: Nylon = 1.15; Monofilament: Monotwine = 1.07. However, the accuracy and the general validity of these ratios are dependent on several factors of which the environmental conditions may be the most decisive.

INTRODUCTION

For nearly twenty years continuous multifilament nylon has been the common material in gill nets used in the Norwegian cod and saithe fisheries. During the last few years some fishermen have changed over to monofilament gill nets and the interest taken in these nets seems to be increasing. In Europe, monofilament gill nets have up till now been used mainly in freshwater fisheries and in saltwater fisheries for salmon. In some other areas, however, particularly in the Far East, they are widely used in marine fisheries.

A few experiments designed to compare the fishing efficiency of monofilament gill nets with gill nets made of other types of synthetic fibres have been carried out (e.g. MOLIN 1959, STEINBERG 1964, MAY 1970). In most cases the results imply that the monofilament gill nets are superior to the others, and the authors generally ascribe this to lower visibility of monofilament nets in water. Results of experimental fishing for gadoids have, however, to the best of our knowledge so far not been published.

Under the supervision of the Institute of Marine Research in Bergen, experimental fishing in order to compare the fishing efficiency of monofilament and multifilament nylon gill nets was carried out in Lofoten in 1974 during the spawning season of the Arcto-Norwegian cod. Also monotwine gill nets, which recently have been the object of some interest, were included in the experiment.

MATERIALS AND METHODS

The materials used for the gill nets were: Continuous multifilament nylon 210/12, nylon monofilament 14 (0.65 mm), and nylon monotwine 5/3. The basic characteristics of these materials regarding this experiment are as follows:

Monofilament is made of a single thin and nearly transparent thread which presumably has low visibility in water.

Continuous multifilament is made by a number of fibres spun into a yarn. The visibility in water is obviously higher than for the monofilament.

Monofilament is stiffer and more elastic than multifilament yarn. In case of strong water movement, the stiffness may help to prevent the meshes from closing.

The monotwine consists of a number of monofilament wires, in this case three, which are twisted into a twine. It is thicker than the corresponding monofilament, and the visibility in water is accordingly higher, but probably less than for the multifilament. The twisting reduces the elasticity.

For the sake of simplicity, continuous multifilament nylon is hereafter referred to as nylon only, nylon monofilament as monofilament, and nylon monotwine as monotwine.

The net units were 300 meshes long and 50 meshes deep. The dimension of the nets was the same for all three materials, corresponding to a mesh size of 186 mm. In practice, the mesh size of the different materials was in average (before and after use): Nylon: 188/192 mm. Monofilament: 185/182 mm. Monotwine: 184/180 mm. For all three types, however, considerable deviations from the mean mesh size were frequently observed.

One half of the units in the gill net setting were made of nylon and one quarter each of monofilament and monotwine.

It was suspected that the catch in addition to fishing efficiency of the different net types, might be influenced by the number of nets of the same type in sequence and also by the position of the nets in the setting and relative to the other types of nets (von Brandt 1955). To ensure that the experiment would give the best possible information about the influence of these factors, the sequence of units of different materials in the setting was chosen by the following procedure: The units of each material were assembled into groups of different numbers. Each group was joined to the corresponding groups of the other two materials to make up «triplets» of *n* monofilament units, *n* monotwine units, and *2n* nylon units. The sequence of materials in the «triplets» was the same throughout the gill net setting in order to make sure that groups of the same material were not joined. The sequence of the «triplets» was decided at random and was changed three times during the experiment. The number of units used in the settings varied from 40 to 92. Table 1 shows the sequence used at the different stations during the experiment. In addition, as often as practically permissable, the position of the setting relative to the main direction of the migration of the cod was changed so that one end alternatively would be nearest to or farthest away from shore.

Two fishing boats were hired for the experiment: «Djupaskjær» (64 ft.) 6–28 February and «Skarsjø» (62 ft.) 4–30 March.

The gill net settings made during the experiment are listed in Table 2 and charted on Fig. 1. The nets were always set by daylight and hauled in the morning before noon. In most cases they were left for one night, on five occasions for two nights, and twice for three nights. On eight occasions the gill nets were set as floating nets.

A record was kept of the fish caught in each net unit. All fish were measured.

Table 1. *Sequence of nets used at different stations during the fishing experiment in Lofoten in 1974.*
N = Continuous Multifilament Nylon, MF = Nylon Monofilament, MT = Nylon Monotwine.

Station No.	Sequence of nets	Total No.
1–2	6N – 3MF – 3MT – 10N – 5MF – 5MT – 4N – 2MF – 2MT	40
3–5	6N – 3MF – 3MT – 10N – 5MF – 5MT – 4N – 2MF – 2MT – 14N – 7MF – 7MT	68
6–8	6N – 3MF – 3MT – 10N – 5MF – 5MT – 4N – 2MF – 2MT – 14N – 7MF – 7MT – 1N	69
9–14	4N – 2MF – 2MT – 6N – 3MF – 3MT – 12N – 6MF – 6MT – 10N – 5MF – 5MT – 14N – 7MF – 7MT	92
15–23	6MF – 6MT – 12N – 3MF – 3MT – 6N – 7MF – 7MT – 14N – 5MF – 5MT – 10N – 2MF – 2MT – 4N	92
24–36	3MF – 3MT – 6N – 2MF – 2MT – 4N – 7MF – 7MT – 14N – 5MF – 5MT – 10N – 6MF – 6MT – 12N	92

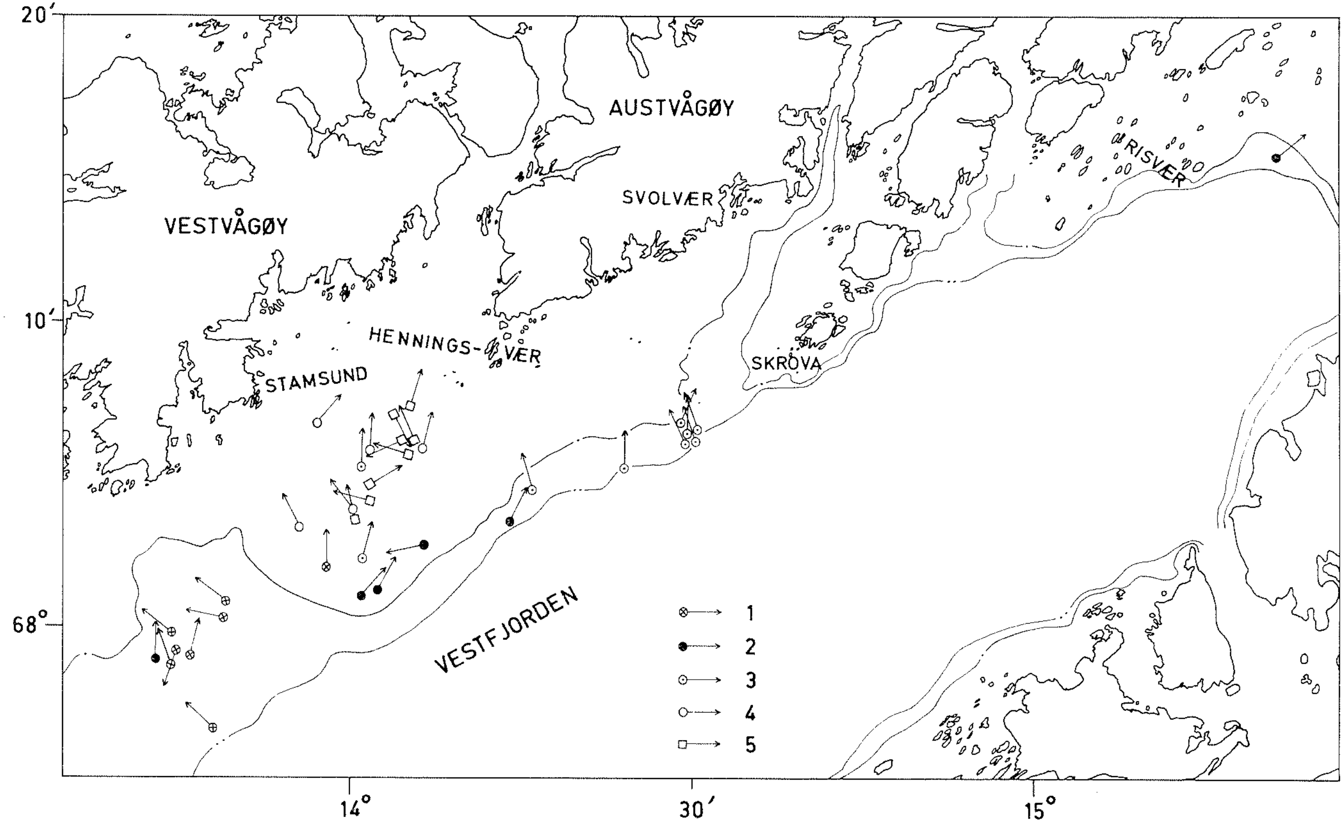

Fig. 1. Gill net settings during the comparative fishing experiment in Lofoten in 1974. 1) «Djupaskjær» 6—16 February, 2) «Djupaskjær» 18—28 February, 3) «Skarsjø» 4—15 March, 4) «Skarsjø» 18—27 March, 5) «Skarsjø» 15—30 March (Floating nets).

Table 2. Gill net settings and catches during the comparative fishing experiment in Lofoten in 1974. N = Continuous Multifilament Nylon, MF = Monofilament Nylon, MT = Monotwine Nylon, F = Floating net.

Station No	Fishing Vessel	Date	Position		Hours Fishing	Fishing Depth (Fath.)	No. of nets			Catch of cod				Catch of saithe			
										Total No.	No. per net			Total No.	No. per net		
			N	E			N	MF	MT		N	MF	MT		N	MF	MT
1	«Djupaskjær»	6– 7/2	68°03'	13°58'	20	60 – 88	20	10	10	13	0.10	0.40	0.70	2	—	—	0.20
2	»	7– 8/2	67°57'	13°47'	20	75 – 90	»	»	»	5	0.20	—	0.10	3	0.10	—	0.10
3	»	8– 9/2	67°59'	13°44'	21	60 – 72	34	17	17	31	0.29	1.06	0.18	9	0.03	0.18	0.29
4	»	9–11/2	68°00'	13°43'	44	56 – 64	»	»	»	47	0.74	0.88	0.41	25	0.29	0.53	0.35
5	»	11–13/2	68°01'	13°48'	44	52 – 70	»	»	»	33	0.50	0.71	0.24	74	0.68	1.35	1.65
6	»	13–14/2	68°00'	13°47'	21	58 – 70	35	»	»	29	0.40	0.41	0.47	71	0.63	1.06	1.82
7	»	14–15/2	67°59'	13°44'	21	54 – 70	»	»	»	14	0.20	0.29	0.12	36	0.37	0.88	0.47
8	»	15–16/2	68°00'	13°47'	20	55 – 68	»	»	»	65	1.03	1.24	0.53	19	0.12	0.47	0.41
9	»	18–19/2	68°00'	13°43'	17	55 – 65	46	23	23	84	1.20	0.61	0.65	13	0.02	0.13	0.39
10	»	19–20/2	68°03'	14°05'	18	47 – 50	»	»	»	45	0.52	0.43	0.48	8	0.09	0.13	0.04
11	»	20–21/2	68°02'	14°03'	20	45 – 60	»	»	»	67	0.76	0.91	0.48	8	0.04	0.13	0.13
12	»	21–23/2	68°02'	14°02'	44	62 – 68	»	»	»	170	1.33	3.26	1.48	12	0.02	0.13	0.35
13	»	23–26/2	68°04'	14°15'	67	56 – 67	»	»	»	55	0.63	0.57	0.57	10	—	0.13	0.30
14	»	27–28/2	68°16'	15°23'	20	54 – 70	»	»	»	98	0.93	1.48	0.91	1	—	—	0.04
15	«Skarsjø»	4– 5/3	68°07'	14°30'	16	52 – 64	»	»	»	163	1.83	1.83	1.61	21	0.13	0.30	0.35
16	»	5– 6/3	68°07'	14°29'	16	52 – 62	»	»	»	67	0.67	0.87	0.70	16	—	0.22	0.48
17	»	6– 7/3	68°06'	14°24'	13	45 – 80	»	»	»	61	0.72	0.91	0.30	9	0.02	0.17	0.17
18	»	7– 8/3	68°07'	14°30'	14	70 – 75	»	»	»	22	0.22	0.17	0.35	23	0.20	0.09	0.52
19	»	8–11/3	68°07'	14°30'	69	62 – 65	»	»	»	69	0.91	0.78	0.39	9	0.07	0.09	0.17
20	»	11–12/3	68°06'	14°01'	12	60	»	»	»	172	1.48	2.30	2.22	1	—	—	0.04
21	»	12–13/3	68°03'	14°02'	13	45 – 50	»	»	»	291	2.87	3.91	3.00	4	0.04	0.04	0.04
22	»	13–14/3	68°05'	14°16'	19	40 – 60	»	»	»	96	0.89	1.04	1.35	2	0.02	—	0.04
23	»	14–15/3	68°07'	14°30'	15	50 – 64	»	»	»	34	0.41	0.48	0.17	91	0.52	0.74	2.17
24	»	15–16/3	68°05'	14°03'	12	35 (F)	»	»	»	94	1.09	0.87	1.04	—	—	—	—
25	»	16–18/3	68°06'	14°05'	42	35 (F)	»	»	»	123	1.13	2.13	0.96	—	—	—	—

26	»	18–19/3	68°04’	14°00’	15	44 – 50	»	»	»	50	0.57	0.48	0.57	—	—	—	—
27	»	19–20/3	68°04’	14°00’	13	35 (F)	»	»	»	110	1.35	0.87	1.22	—	—	—	—
28	»	20–21/3	68°06’	14°02’	13	50	»	»	»	91	0.96	1.04	1.00	—	—	—	—
29	»	21–22/3	68°04’	14°00’	12	35 (F)	»	»	»	82	0.80	0.96	1.00	—	—	—	—
30	»	22–23/3	68°04’	13°55’	17	40 – 45	»	»	»	75	0.78	0.39	1.30	—	—	—	—
31	»	23–25/3	68°06’	14°07’	42	45 – 60	»	»	»	410	3.83	6.43	3.74	—	—	—	—
32	»	25–26/3	68°08’	14°06’	14	35 (F)	»	»	»	325	3.52	4.52	2.57	—	—	—	—
33	»	26–27/3	68°07’	13°58’	13	40 – 42	»	»	»	152	1.78	2.13	0.91	—	—	—	—
34	»	27–28/3	68°06’	14°03’	11	35 (F)	»	»	»	127	1.48	1.48	1.09	—	—	—	—
35	»	28–29/3	68°03’	14°05’	11	35 (F)	»	»	»	78	0.89	0.83	0.78	—	—	—	—
36	»	29–30/3	68°06’	14°04’	12	35 (F)	»	»	»	39	0.35	0.52	0.48	—	—	—	—

RESULTS

The total catch during the experiment was 3 487 cod, 486 saithe, 27 redfish, 8 anglers, 6 ling, 3 tusk, 2 haddock, 2 blue ling, 1 lumpsucker, 1 dogfish, and 1 ray. Thus, only cod and saithe were caught in quantities which might be sufficient to give significant information about differences in catch efficiency of the three types of nets used. Saithe smaller than 50 cm have been left out because the schooling behaviour of the small saithe resulted in a distribution of the catches which obviously could not be ascribed to differences in catch efficiency alone. The discussion is hence based on the catches of 3 487 cod and 467 saithe.

Total catch in numbers and catch per net unit of cod and saithe are given in Table 2 for each type of net and each setting. There was a large variation in total catch per setting. However, the distribution of the catches on the three types of nets was more consistent and in Table 3 the ratios between the catches from each type of net are given for each of the different net sequences used during the experiment (Table 1) and for the whole experiment. The ratios for saithe were much less consistent than for cod. This can probably be ascribed chiefly to the much higher number of cod caught.

The monofilament nets caught the highest number of cod per net, 26% more than the nylon nets and 38% more than the monotwine nets. The nylon nets caught 10% more cod than the monotwine nets.

The ratios for saithe show that there were large differences in the catch between the three types of nets. The monotwine nets caught the highest number of saithe per net, 50% more than the monofilament nets which in turn caught more than twice the number caught by the nylon nets. Accor-

Table 3. Ratios between the catch in numbers by nets of different material during the experiment in Lofoten in 1974. N = Continuous Multifilament Nylon, MF = Monofilament Nylon, MT = Monotwine Nylon.

	Station No.					TOTAL
	1 – 8	9 – 14	15 – 23	26, 28, 30, 31, 33	24, 25, 27, 29, 32, 34 – 36 (Floating net)	
Cod:						
MF/N	1.43	1.36	1.23	1.33	1.14	1.26
N/MT	1.35	1.17	0.99	1.05	1.17	1.10
MF/MT	1.97	1.59	1.22	1.40	1.33	1.38
Saithe:						
MT/N	2.40	7.00	4.89			3.46
MF/N	2.07	3.67	2.56			2.31
MT/MF	1.16	1.91	1.91			1.50

dingly, the monotwine nets caught nearly three and a half time the number of saithe caught by the nylon nets.

The mean length of the captured fish was different for the three types of nets. For cod the mean length was 94.29 cm for nylon, 93,23 cm for monofilament and 89.75 cm for monotwine. The corresponding figures for saithe were 86.39 cm, 86.09 cm and 84.78 cm. This means that the ratios between the catches from the different types of nets change when the catch is converted from numbers to weight. Thus, the catch of cod by weight from the monofilament nets was 20% higher per net than from the nylon nets and 57% higher than from the monotwine nets. Accordingly, the nylon nets caught 30% more cod by weight than the monotwine nets. Also for saithe the conversion to weight favours the monofilament and nylon nets, but the catch from the monotwine nets was still considerably higher.

In the period 5–28 March, as part of routine investigations, cod was caught in Lofoten by purse seine. This fishing took place in the same area and during the same period «Skarsjø» carried out the gill net experiment. During this period the length frequency of the cod did not vary much in either the gill net or the purse seine catches which on an average were taken at approximately the same depth (88 m and 81 m respectively). The mesh of the purse seine was small enough to prevent selection of the available cod.

DISCUSSION

There are several approaches to the problem of assessing the selectivity of gill nets. The simplest or direct method requires that the size frequency distribution of the fish vulnerable to the nets is known or reliably estimated (REGIER and ROBSON 1966). Thus, for a given net

$$S_l = \frac{n_l}{N_l}$$

where N_l is the absolute or relative number of fish of length stratum l vulnerable to the net and n_l is the number of fish of length stratum l caught by the net. If the selection index S_l is plotted for each l, a smooth curve can be drawn or a suitable mathematical function can be fitted to the points.

According to ROLLEFSEN (1953) there is good reason to believe that purse seine catches of cod in Lofoten give a nearly unbiased length composition of the fish present. This idea was persued by HOLT (1963) who used ROLLEFSEN'S (1953) data to find the selection curve for the gill nets used in Lofoten the same year. The data produced a nearly symmetrical distribution of selection indexes and HOLT (1963) chose to fit a normal distribution curve to the set of points.

BARANOV (1914) assumed that the selection curves for gill net could be adequately described by the normal probability distribution. Also GARROD (1961) stated that if the growth of the fish is isometric, then the selection for length by gill nets of a given mesh size may be expected to have a normal distribution.

In some gill net fisheries, as observed by OLSEN and TJEMSLAND (1963) and JENSEN (1977), significant numbers of fish outside the main size range of the selection curves were caught by other ways of attachment than the usual with head first. Observations on brown trout by JENSEN (1977) indicated further that fish larger than those caught head first in a single mesh are more frequently caught than those that are smaller. This could be expected to give a positive skew of the curves describing gill net selection.

A pronounced positive skew in a gill net selection curve was found for brown trout by JENSEN (1977). Less pronounced positive skews have been observed, e.g. for herring by OLSEN (1959) and for lake whitefish by REGIER and ROBSON (1966) and the observations on gill net selectivity indicate a considerable variation in selectivity for different species of fish. The selection curve may deviate significantly from one that can be adequately described by a reasonably simple mathematical function (OLSEN and TJEMSLAND 1963). Wiht sufficent data it will be possible to fit a selection curve by eye, a method described by GULLAND and HARDING (1961) and used by JENSEN (1977). However, if a mathematical expression for a selection curve with a reasonably good fit to the observed selection indexes can be found, this may facilitate further discussions on properties of gill net selectivity.

According to HOLT (1963), one might expect that the chance of a fish escaping the nets depends not on the absolute amount, but on the proportion, by which its size differs from that size for which the net is most efficient. If the growth of the fish is isometric, and two lengths l_A and l_B are related by the equation

$$(1)\quad \frac{m}{l_A} = \frac{l_B}{m}$$

where m is the mean selection length of the gill net, the selection index for fish of length l_A should be equal to the selection index for fish of length l_B. Introducing logarithms in *(1)* and squaring give

$$(ln m - ln l_A)^2 = (ln l_B - ln m)^2$$

or

$$(2)\quad (ln l_A - ln m)^2 = (ln l_B - ln m)^2$$

A log-normal distribution curve is defined by the formula

$$(3)\quad f(l) = \frac{1}{s\sqrt{2\pi}} e^{-\frac{(ln l - ln m)^2}{2s^2}}$$

where l is the length, s the standard deviation of lnl and m the mean selection length corresponding to $\overline{lnl}$. Applying (2) to (3) gives $f(l_A) = f(l_B)$, and a selection curve with a log-normal distribution is therefore in accordance with HOLT'S (1963) suggestion.

OLSEN (1959), MCCOMBIE and FRY (1960), and GULLAND and HARDING (1961) assumed that the mean selection length of a gill net is proportional to the mesh size. Thus, the mean selection lengths m_A and m_B for mesh size A and B respectively are related by the equation

$$(4) \quad m_B = cm_A$$

where $c = \frac{B}{A}$. HOLT (1963) suggested that the chance of a fish escaping the net is dependent on the proportion between the size of the fish and the mesh size. BARANOV (1914) assumed that the catch effeciency relating to the mean selection length is constant and accordingly independent of the mesh size. The selection indexes for a fish of length l_A and l_B will then be the same, if

$$(5) \quad \frac{l_A}{m_A} = \frac{l_B}{m_B}$$

Combining (4) and (5) gives

$$(6) \quad l_B = cl_A$$

and subtracting (4) from (6) gives

$$(l_B - m_B) = c(l_A - m_A)$$

i.e. the same proportionality excists between the length intervals $(l_B - m_B)$ and $(l_A - m_A)$ as between the mean selection lengths. The extension of the selection curve along the length axis is therefore proportional to the mean selection length and consequently to the mesh size.

For the log-normal distribution, keeping s constant, the selection indexes for l_A and l_B will be the same if $(lnl_A - lnm_A) = (lnl_B - lnm_B)$,

$$i.e. \quad \frac{l_A}{m_A} = \frac{l_B}{m_B} \ (5)$$

Consequently for a log-normal distribution curve the desired proportionality is obtained if the standard deviation is kept constant as the mean selection length varies, whereas for a normal distribution the standard deviation must be changed in proportion to the mean selection length to obtain corresponding results.

In the calculation of the selection indexes, the length frequency distribution of cod in purse seine catches from 1974 was used in basically the same way as HOLT (1963) used the data of ROLLEFSEN (1953). However, the cod caught with gill nets by «Djupaskjær» were on the average 2.38 cm longer than those caught by «Skarsjø». This is in accordance with previous experience that the cod in Lofoten usually is bigger during the first part of the spawning season. Therefore, when selection indexes were calculated, the purse seine data were combined only with the data from the «Skarsjø» gill net catches which were taken contemporarily.

On Fig. 2 it can be seen that there is a tendency for the selection indexes to stop decreasing at a certain level on each side of the selection range, especially for the bigger length groups. The level is apparently about the same for the three types of nets. It was assumed that the selection indexes for the length groups nearest to the mean selection length represent fish caught with the head first, although these values probably also to some extent are influenced by fish caught in other ways. The selection curves were accordingly chosen in order to give the best fit for the medium selection indexes, and the resulting curves should approximate the selective properties of the gill nets for fish caught with the head first in a single mesh, ignoring other ways of being caught.

Excluding the extreme values, tests show no clear evidence of skewness, but although the log-normal distribution has a slight positive skew, the fit to the selection indexes is good for all three types of nets (Fig. 2). As has been shown, the log-normal distribution is consistent with certain aspects of the theory of gill net selectivity, and the remainder of the discussion has been based on the assumption that gill net selectivity for cod may be adequately described by the log-normal distribution.

When fitting a log-normal distribution, *lnm* and the standard deviation can be calculated from the selection indexes based on the actual catches. When

$$lnl = lnm,$$

then

$$f(l) = \frac{1}{s\sqrt{2\pi}}$$

and this defines the maximum of the curve. To make it fit the selection indexes, the vertical extention of the curve must be adjusted according to the sum of the selection indexes. Thus, fitting a normal distribution would have required a multiplication of the formula by 5 to adjust for the use of selection indexes for 5 cm length groups when the unit is cm. In the log-normal distribution, the transformation to logarithms means that a length interval of 5 cm no longer represents a constant unit, because

$$[lnl - ln(l - 5)] > [ln\,(l + 5) - lnl].$$

The selection indexes must therefore be weighted by the size of the interval they represent. The maximum for the log-normal distribution is accordingly defined as

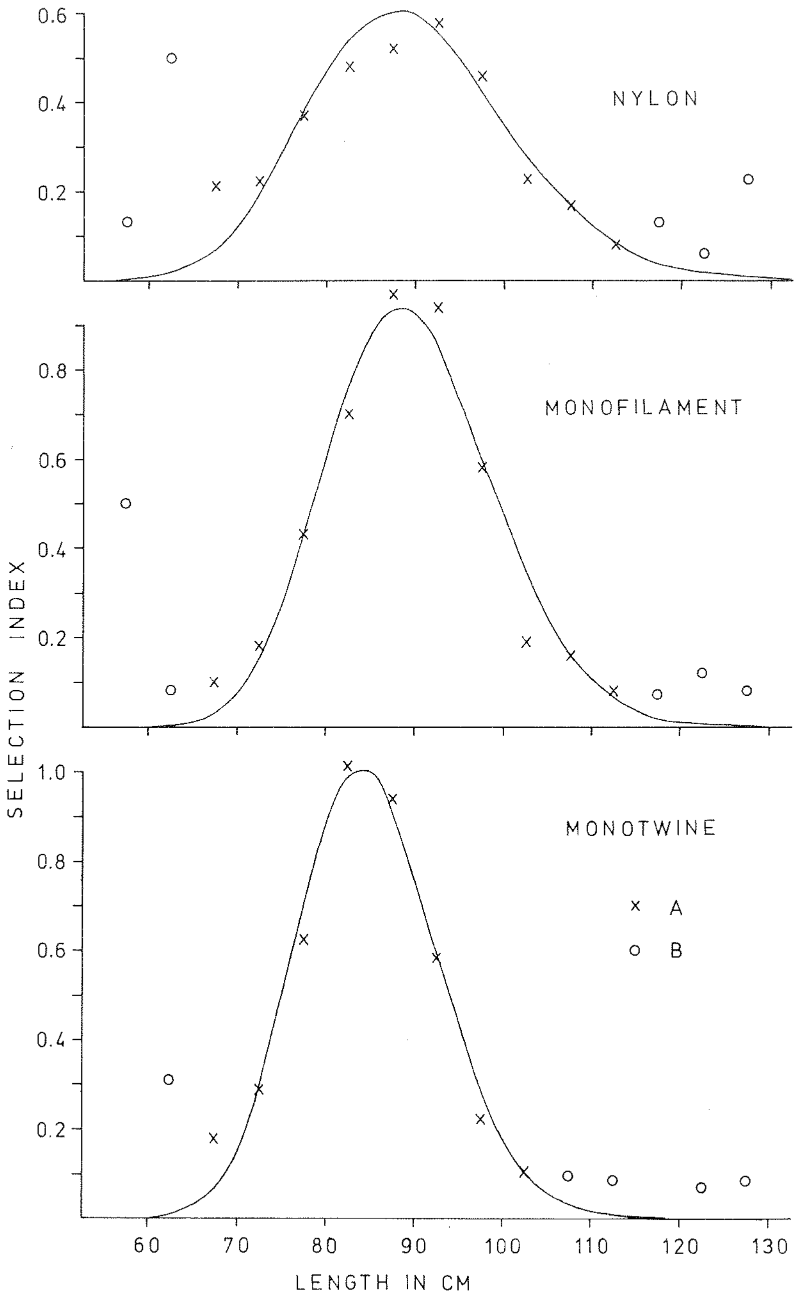

Fig. 2. Selection indexes and fitted normal and log-normal distribution selection curves for nylon, monofilament and monotwine gill nets based on fishing experiments in Lofoten 4—30 March 1974. A) Selection indexes included in the curve fitting. B) Selection indexes not included in the curve fitting.

$$f_{max} = \frac{\Sigma S_l \, [ln\,(l + 2.5) - ln\,(l - 2.5)]}{s\sqrt{2\pi}}$$

For each 5 cm interval l is defined as the middle length, i.e.

$$l = l_i + 2.5$$

where l_i is the lower limit of the interval.

The selection curves for the three types of nets are clearly different (Fig. 3). The parameters of the curves given in Table 4 show that the mean selection length is slightly (0.8 cm) higher for monofilament than for nylon whereas it is considerably higher (4.4 cm) than for monotwine. The peak efficiency (selection index for the mean selection length) is approximately the same for monofilament and monotwine. For nylon it is only about 60% of these values. However, the selection curve for nylon covers most length groups (has the largest standard deviation) whereas monotwine clearly covers least.

It is evident from Fig. 3 that the mesh used in the gill nets during the experiments was much too small to give maximum obtainable catches of the available cod. Taking the length frequency distribution of the purse seine catches as representative of the available cod, theoretical gill net catches obtained by varying the mesh size were calculated. The resulting theoretical maximum catches (by weight) were for nylon and monofilament respectively 1.9 and 2.2 times higher than the actual catches made by «Skarsjø». For monotwine the catches would have increased by a factor of 3.9. However, in practice the increase in catches would be expected to be slightly higher because there would have been additional fish caught in irregular ways, especially on the lower side of the selection range, which are not accounted for by the fitted selection curves. The optimum mesh sizes, neglecting the observed deviations from the official figure of 186 mm in the nets used during the experiment, were: Nylon: 224 mm, Monofilament: 222 mm and Monotwine: 234 mm. The theoretical maximum catches of monotwine and monofilament were not significantly different (MT: MF = 1.02) and both were considerably higher than the catches by nylon (MT: N = 1.48, MF: N = 1.46).

With the length range of the available cod in Lofoten in 1974, there was obviously a lot to be gained in catches by increasing the mesh size of the gill nets. However, the length distribution of the cod in 1974 was extreme, and the mesh size used will in an average year not by far deviate that much from the optimum.

The observed differences in catch efficiency between the three types of nets are valid only when the circumstances are very similar to those of the experiment. Probably the most obvious deviation from a general situation

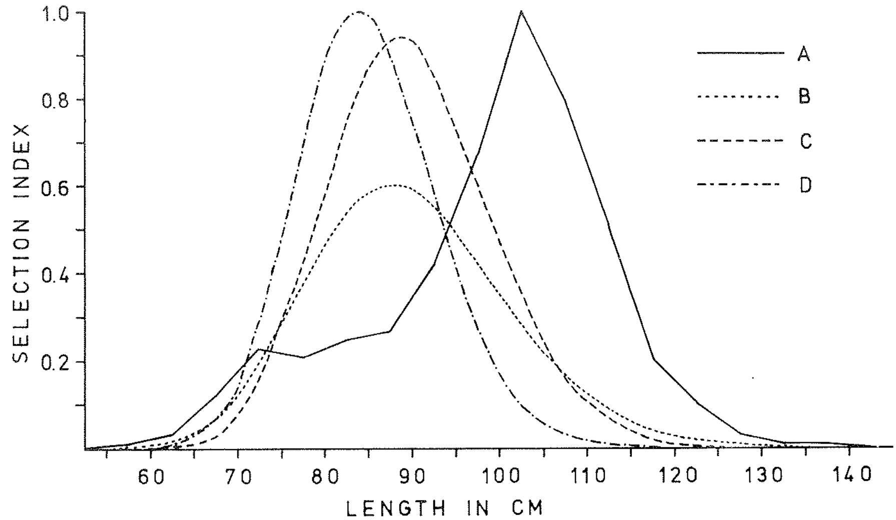

Fig. 3. Length frequency distribution (per cent) of cod caught with purse seine in Lofoten 5—28 March 1974 (A) and fitted log-normal distribution selection curves for B) nylon, C) monofilament and D) monotwine gill nets based on fishing experiments in Lofoten 5—30 March 1974.

Table 4. Parameters of log-normal distribution curves fitted to the calculated selection indexes for the three types of gill nets.

Type of net	Mean selection length (cm) [1]	Standard deviation	Maximum of curve
Nylon	87 612	0.12794	0.5993
Monofilament	88 394	0.10475	0.9395
Monotwine	83 950	0.09392	1.0000

[1]) This is the l corresponding to $\overline{lnl}$.

was the peaked length frequency distribution of the cod available to the nets which favoured the relative catch efficiency of nets with a narrow selection curve. However, a theoretical generalization of the relative catch efficiency of the nets can be made by assuming that all length groups are equally represented in numbers among the cod available to the nets. When the length intervals representing one length group are made infinitesimally small, the theoretical catch in numbers of fish by a gill net with a log-normal selection curve will be proportional to

$$\int_0^\infty h e^{-\frac{(lnl - lnm)^2}{2s^2}} dl$$

where h is the maximum, m the mean selection length and s the standard deviation of the selection curve. The intergral can be solved by substituting u for lnl which gives an integral of the form

$$C_1 \int_{-\infty}^{\infty} e^{-\frac{1}{2s^2} u^2} e^{B_1 u} \, du$$

which can be transformed into

$$C_2 \int_{-\infty}^{\infty} e^{-\frac{(u-B_2)^2}{2s^2}} \, du.$$

This allows the use of the equation

$$\frac{1}{s\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{(t-m)^2}{2s^2}} \, dt = \frac{1}{2} \left[1 + \operatorname{erf}\left(\frac{x-m}{s\sqrt{2}} \right) \right]$$

Further, applying the definition

$$\operatorname{erf} z = \frac{2}{\sqrt{\pi}} \int_{0}^{z} e^{-t^2} dt \text{ (error function)}$$

and the equation

$$\int_{0}^{\infty} e^{-t^2} \, dt = \frac{\sqrt{\pi}}{2}$$

the final result is

$$\int_{0}^{\infty} he^{-\frac{(lnl-lnm)^2}{2s^2}} \, dl = h\sqrt{2\pi}s \; e^{-\frac{2lnm + s^2}{2}}$$

The relative catch efficiency (CE) of two nets A and B with mean selection lengths m_A and m_B, standard deliations s_A and s_B and maxima of selection curves h_A and h_B respectively, will be

$$\frac{CE_A}{CE_B} = \frac{s_A\, h_A}{s_B\, h_B}\, e^{\frac{1}{2}(s_A{}^2 - s_B{}^2) + ln\frac{m_A}{m_B}}$$

For $m_A = m_B$ the equtión is reduced to

$$(7)\quad \frac{CE_A}{CE_B} = \frac{s_A\, h_A}{s_B\, h_B}\, e^{\frac{1}{2}(s_A{}^2 - s_B{}^2)}$$

Using (7) and the parameters of the selection curves given in Table 4, the following ratios in catch efficiency by number were found: $MF : N = 1.277$, $MT : N = 1.216$ *and* $MF : MT = 1.050$. This indicates for a general situation in gill net fisheries for cod that the catch efficiency in number of fish for monofilament is 28 % higher than for nylon and 5 % higher than for monotwine, and the catch efficiency of monotwine is 22 % higher than for nylon.

The theoretical catch by weight can be found by introducing a length-weigth relationship defined by the formula

$W_1 = k_1 \cdot l^{k_2}$

The theoretical catch by weight will then be proportional to

$$\int_0^{\infty} he^{-\frac{(lnl-lnm)^2}{2s^2}}\; k_1\, l^{k_2}\; dl.$$

The integral can be solved by the same procedure as for the catch in number. The final result is

$$\int_0^{\infty} he^{-\frac{(lnl-lnm)^2}{2s^2}}\; k_1 2^{k_2}\, dl = h\, k_1\, \sqrt{2\pi}\, s\, e^{(k_2 + 1)lnm + (\frac{1}{2}k_2{}^2 + k_2 + 1)\, s^2}$$

The relative catch efficiency *(CE)* of two nets, A and B, with mean selection lengths m_A and m_B, standard deviations s_A and s_B and maxima of selection curves h_A and h_B respectively, will be

$$\frac{CE_A}{CE_B} = \frac{s_A\, h_A}{s_B\, h_B}\, e^{(\frac{1}{2}k_2{}^2 + k_2 + 1)\,(s_A{}^2 - s_B{}^2) + (k_2 + 1)\,ln\,\frac{m_A}{m_B}}$$

For $m_A = m_B$ the equation is reduced to

$$(8)\quad \frac{CE_A}{CE_B} = \frac{s_A\, h_A}{s_B\, h_B}\, e^{(\frac{1}{2}k_2{}^2 + k_2 + 1)\,(s_A{}^2 - s_B{}^2)}$$

The ratio is strongly dependent on the values of s and h which define the selective properties of the nets, but it is independent on m, the mean selection length. The ratio is dependent also on the value of k_2 in the formula $W_l = k_1\, l^{k_2}$. The effect of increasing k_2, is to change the ratio in favour of the net with the highest standard deviation, i.e. the widest selection curve.

An implication of the theoretical basis for arriving at the ratio equation (8) is that the girth is proportional to the length. Assuming that the growth is isometric, the volume and accordingly the weight, will be proportional to the cube of the length, providing that the specific weight is constant. To avoid inconsistency, the length-weight relationship used in the ratio equation should therefore be $W_l = k_1\, l^3$, i.e. $k_2 = 3$. In practice, length-weight data indicate that the true value may deviate somewhat from 3. However, for the most important roundfish species, the deviation is not large, and values within the usual range of k_2 calculated for cod on other occasions would have produced errors in the calculated catch efficiency ratios of less than ± 1% if substituted in (8).

Using (8) with $k_2 = 3$ and the characteristics of the selection curves given in Table 4, the following ratios of catch efficiency were found: MF: N = 1.226, MT: N = 1.149 and and MF: MT = 1.067. This indicates for a general situation in gill net fisheries for cod that the catch efficiency of monofilament is 23% higher than for nylon and 7% higher than for monotwine, and the catch officiency for monotwine is 15% higher than for nylon. As would be expected, the transformation from numbers to weight favours the nets with the higher standard deviation.

The reliability of the catch efficiency ratios is difficult to assess. The errors caused by shortcomings in data and in assuming log-normal distribution selection curves for the fish caught with the head first are believed to be small. The assumptions about proportionality between mesh size and mean selection length and between mesh size and the width of the selection curves for all mesh sizes seem also likely to cause only relatively small errors, at least within the size range of cod normally caught by gill nets. The assumption that the selection index for the mean selection length is constant may be more questionable. Experiments by RICKER (1949) indicate that small meshes may be generally less effective than larger meshes. How this applies to cod is, however, unknown. An obvious error is caused by not including fish caught in irregular ways in the fitting of the selection curves. Including them would have tended to reduce the calculated differences in catch efficiency which therefore may be overestimated.

One factor which probably has had some influence on the results, is that the cod were spawning, and they were accordingly thicker around the middle than non spawning cod. It is therefore possible that the selectivity of gill nets is somewhat different for non spawning than for spawning cod. Another factor which may be important is that the three types of nets were combined during the experiment in one setting. This may have produced relative catch efficiencies which are different from those one would have got if each setting consisted of only one type of net.

It is not known to what extent environmental factors, especially light conditions, have influenced on the relative catch efficiencies. Fishermen who have used monofilament gill nets, often claim that it is much more efficient compared with nylon nets than the results from Lofoten indicate. If this is true, different environmental conditions may provide at least some of the explanation, and more research is clearly needed to establish the importance of environmental factors.

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