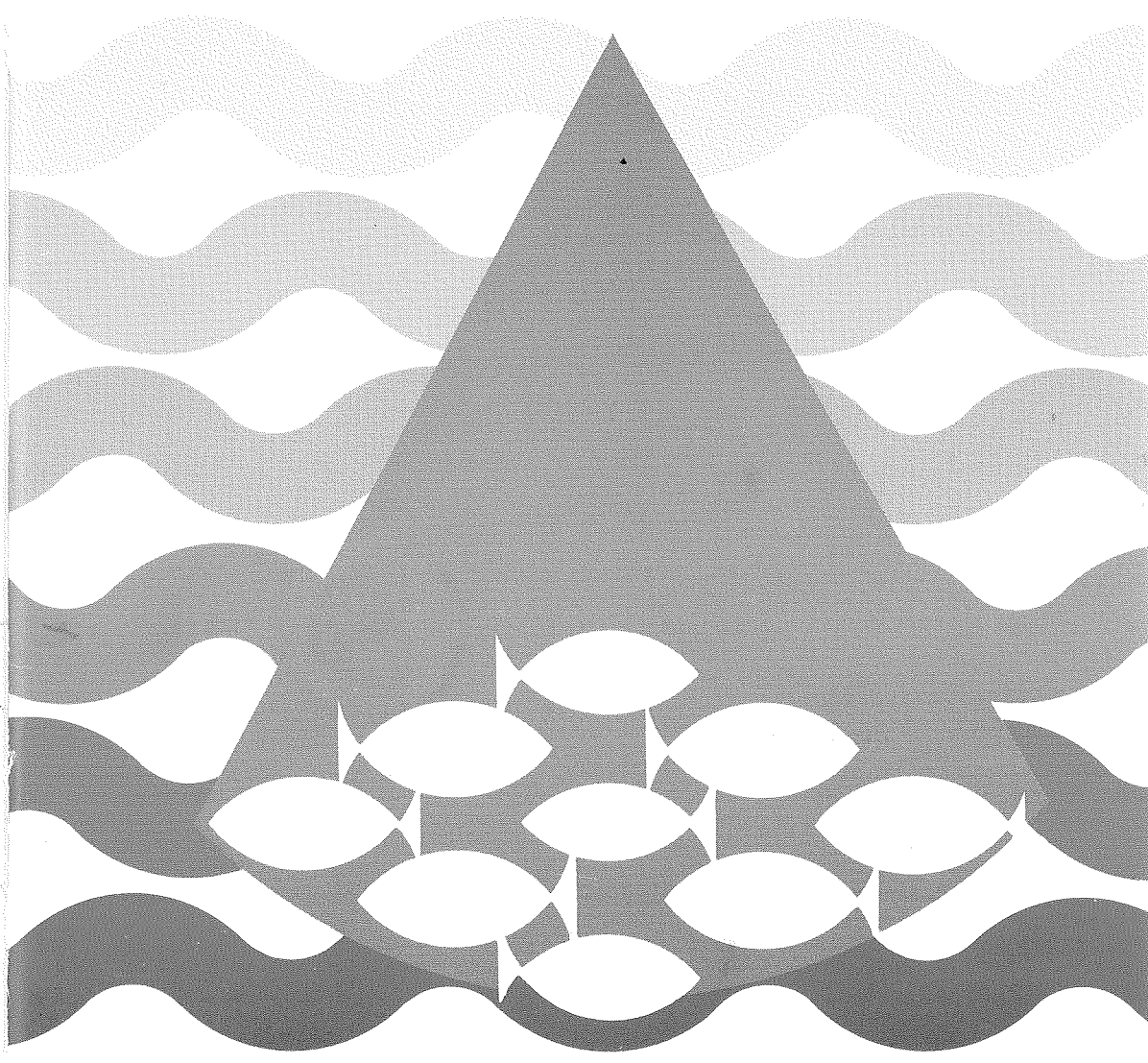


Hollev

FISKERIDIREKTORATETS SKRIFTER

SERIE HAVUNDERSØKELSER

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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

By

ARVID HYLEN and TORE JAKOBSEN

Institute of Marine Research, Directorate of Fisheries, Bergen

ABSTRACT

HYLEN, A. and JAKOBSEN, T. 1979. A fishing experiment with multifilament, monofilament, and monotwine gill nets in Lofoten during the spawning season of Arcto-Norwegian cod in 1974. *FiskDir. Skr. Ser. HavUnders.*, 16 : 531-550.

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 permissible, 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

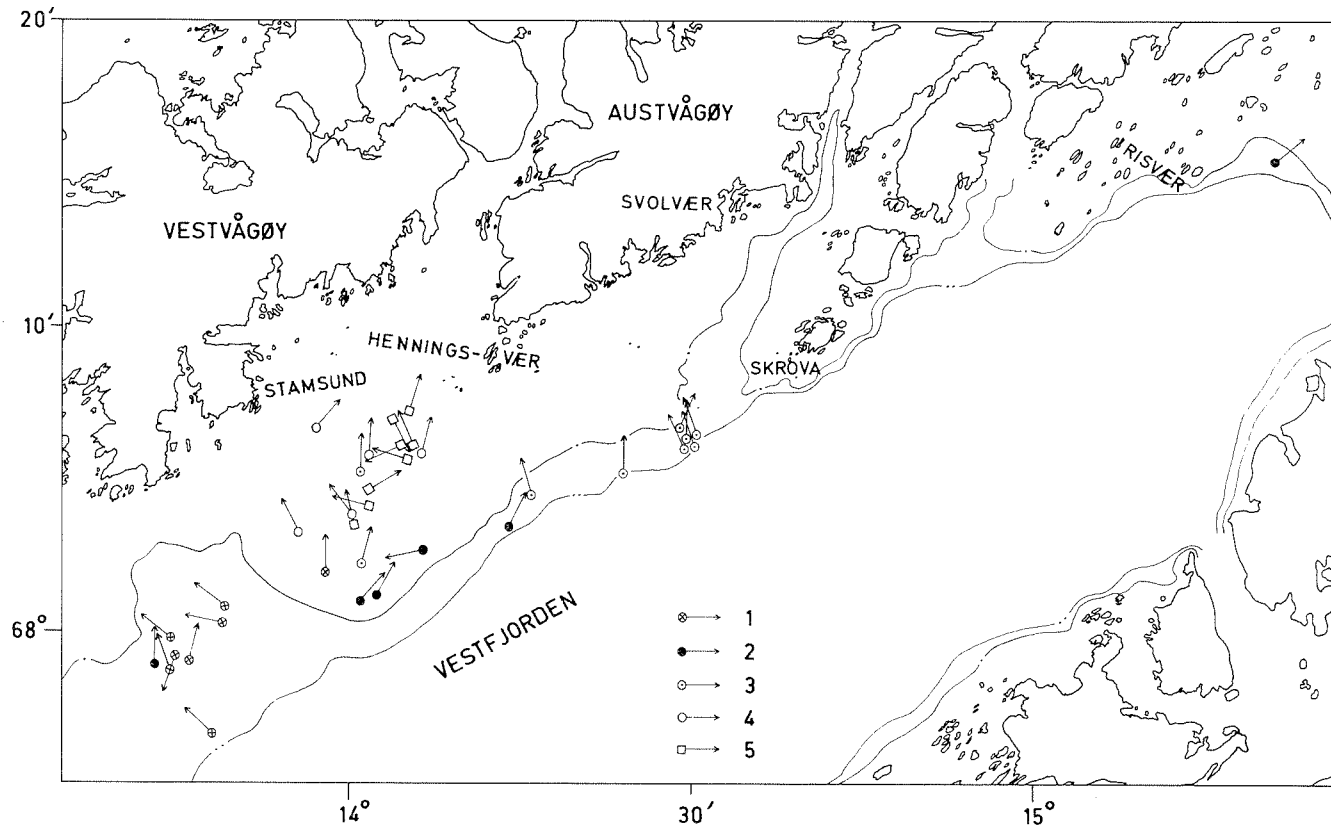


Fig. 1. Gill net settings during the comparative fishing experiment in Lofoten in 1974. 1) «Djupaskjær» 6—16 February, 2) «Djupaskjær» 18—28 February, 3) «Skarsjø» 4—15 March, 4) «Skarsjø» 18—27 March, 5) «Skarsjø» 15—30 March (Floating nets).

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	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 lump sucker, 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. Accord-

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). With sufficient 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 $\ln l$ and m the mean selection length corresponding to $\overline{\ln l}$. 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 efficiency 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 exists 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 $(\ln l_A - \ln m_A) = (\ln l_B - \ln m_B)$,

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

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, l_{nm} and the standard deviation can be calculated from the selection indexes based on the actual catches. When

$$lnl = l_{nm},$$

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 extension 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

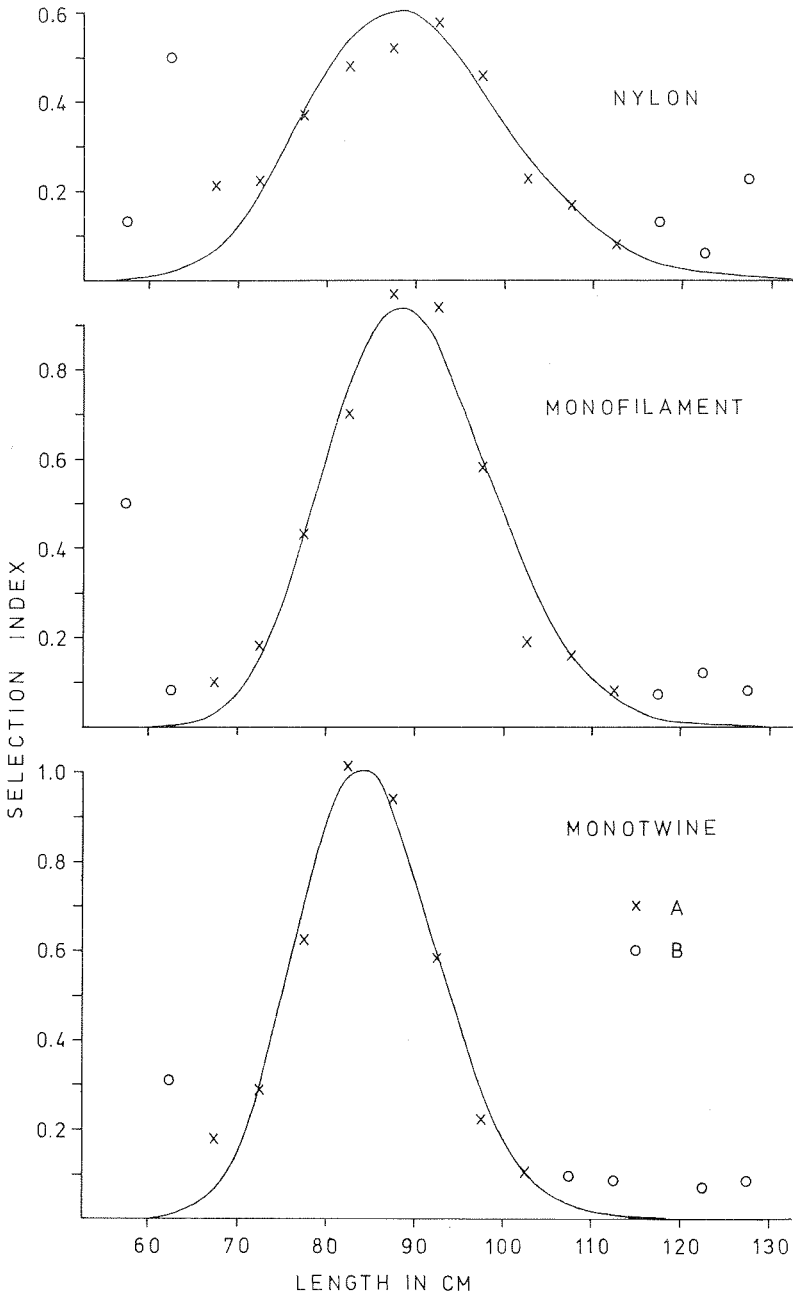


Fig. 2. Selection indexes and fitted normal and log-normal distribution selection curves for nylon, monofilament and monotwine gill nets based on fishing experiments in Lofoten 4–30 March 1974. A) Selection indexes included in the curve fitting. B) Selection indexes not included in the curve fitting.

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

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

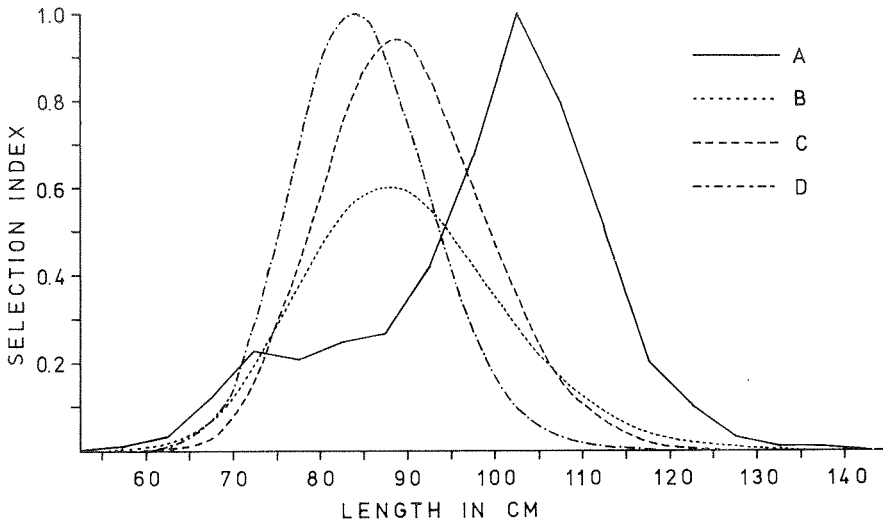


Fig. 3. Length frequency distribution (per cent) of cod caught with purse seine in Lofoten 5–28 March 1974 (A) and fitted log-normal distribution selection curves for B) nylon, C) monofilament and D) monotwine gill nets based on fishing experiments in Lofoten 5–30 March 1974.

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 integral 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

$$\int_0^{\infty} h e^{-\frac{(lnl-lm)^2}{2s^2}} dl = h \sqrt{2\pi} s e^{-\frac{2lm + s^2}{2}}$$

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

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

For $m_A = m_B$ the equation is reduced to

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

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-weight relationship defined by the formula

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

The theoretical catch by weight will then be proportional to

$$\int_0^{\infty} h e^{-\frac{(\ln l - \ln m)^2}{2s^2}} k_1 l^{k_2} dl.$$

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

$$\int_0^{\infty} h e^{-\frac{(\ln l - \ln m)^2}{2s^2}} k_1 2^{k_2} dl = h k_1 \sqrt{2\pi} s e^{-(k_2 + 1)\ln m + (\frac{1}{2}k_2^2 + k_2 + 1)s^2}$$

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

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

For $m_A = m_B$ the equation is reduced to

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

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 $\pm 1\%$ 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 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 efficiency 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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PUP PRODUCTION AND SUSTAINABLE YIELD OF WHITE SEA HARP SEALS

By

TERJE BENJAMINSEN

Institute of Marine Research, Directorate of Fisheries, Bergen

ABSTRACT

BENJAMINSEN, T. 1979. Pup production and sustainable yield of White Sea harp seals. *FiskDir. Skr. Ser. HavUnders.*, 16: 551-559.

Pup production from 1962 to 1965 was estimated by a survival index method from age composition of Norwegian samples of moulting harp seals collected in the southeastern Barents Sea from 1964 to 1972.

Pup production decreased from 130 thousand in 1962 to 98 thousand in 1965. From these estimates production was projected forward to give an estimate of 172 thousand pups produced in 1978, corresponding to a total stock of one year old and older harp seals of about 800 thousand. Both the projection and the number of adult females in the whelping patches estimated from Soviet aerial surveys give an annual increase of about 5% since 1968. The sustainable yield for 1978 is estimated at 98 thousand pups and 8 thousand one year and older animals.

INTRODUCTION

Populations of harp seals (*Pagophilus groenlandicus*) breed in the spring at Newfoundland-Labrador, in the Jan Mayen area of the Greenland Sea and in the White Sea. These populations are separate. The White Sea harp seal has an annual feeding migration into the Barents Sea and the Kara Sea and has been seen as far north as 79° in the eastern part of the Svalbard area in summer.

The harp seal has been exploited by aborigines for centuries along the coasts of the White Sea and the southeastern Barents Sea. Norwegian sealers started hunting harps in the White Sea in 1867, the catch increasing slowly to 40 thousand by 1900 (IVERSEN 1927). At the beginning of the 20th century large Russian ships were introduced in the hunt while the number of Norwegian ships increased. The resulting increased catch reached a maximum of 460 thousand in 1925 with a mean of 347 thousand per year in the period from 1923 to 1927 (YAKOVENKO 1967). After 1925 the catch decreased with a mean catch of 222 thousand seals taken per year in the period from 1933 to 1937. According to YAKOVENKO (1967) this drop could only be explained by a decrease in the size of the stock. Only small catches were

taken during the Second World War, and after the war Soviet catches increased to 195 thousand by 1950 while Norwegian catches in the southeastern Barents Sea were kept at a level between 10 and 35 thousand per year.

After 1950 the stock declined rapidly, and a quota of 100 thousand harp seals for the Soviet catch was introduced in 1955, being gradually reduced to 60 thousand in 1963. In 1965 a total quota of 34 thousand was put into force, of which Soviet landmen were allocated 20 thousand and Norwegian ships 14 thousand seals. In 1977 the total quota was increased again to 50 thousand, 34 thousand to Soviet and 16 thousand to Norway. Adult females have been protected in the whelping patches since 1963, and the Soviet catch of one year old and older seals was stopped in 1965.

Data on age and sex composition of Norwegian catches of moulting harp seals in the southeastern Barents Sea have been collected since 1963. Most of the age samples (sexed and dated) have been collected by observers from the Institute of Marine Research, some age samples without information on sex and date have been taken by sealers.

The purpose of this paper is to estimate pup production from Norwegian age samples of moulting seals and project the female population forward in order to calculate the present sustainable yield of the White Sea harp seal population. The projection is compared to aerial photography estimates of the number of adult females in the whelping patches as presented to the Northeast Atlantic Seal Commission (Norwegian-Soviet Seal Commission) by Soviet scientists.

MATERIAL AND METHODS

Catches of harp seals in the White Sea and the Barents Sea from 1958 to 1977 are listed in Table 1. The data are based on reports to the Seal Commission. The Table shows that catches were substantially reduced, in particular the catches of one year old and older animals, after the introduction of reduced quotas and other regulations in 1965.

Age group frequencies of moulting harp seals from Norwegian samples in the Barents Sea from 1963 to 1976, which have all been reported to the Seal Commission, are shown in Table 2.

Production estimates were obtained by a «survival index method» (SERGEANT 1971, ØRITSLAND 1971, BENJAMINSEN and ØRITSLAND 1975). The method involves a regression of the abundancy of successive year classes on pup catches of the same year classes. The survival index is expressed as the ratio of the relative frequency of each year class in individual samples to the mean relative frequency of the corresponding age group in all samples. To calculate the mean survival index for each year class, each age sample is weighted in proportion to the square root of the number of animals in the sample.

Table 1. Catches of harp seals in the White Sea and the Barents Sea from 1958 to 1977. Data on Soviet catches are from reports to the Norwegian Soviet Sealing Commission. (1 year + is catches of one year old and older animals).

	Norway		Soviet		Total	
	Pups	1 year +	Pups	1 year +	Pups	1 year +
1958	2 733	12 369	84 995	27 997	87 728	40 366
59	2 257	6 286	48 257	47 982	50 514	54 268
1960	2 474	8 222	60 579	28 736	63 053	36 958
61	2 903	8 254	41 827	51 676	44 730	59 930
62	1 325	6 981	67 633	39 327	68 958	46 308
63	405	12 944	54 861	7 603	55 266	20 547
64	3 109	11 477	47 008	15 771	50 117	27 248
1965	4 537	1 899	20 135	0	24 672	1 899
66	1 932	10 319	20 012	196	21 944	10 515
67	9 648	2 004	20 000	0	29 648	2 004
68	11 960	3 150	20 000	0	31 960	3 150
69	5 241	6 697	21 588	593	26 829	7 290
1970	4 230	8 734	24 328	1 262	28 558	9 996
71	7 028	1 596	26 666	1 002	33 694	2 598
72	4 229	8 209	30 635	500	34 864	8 709
73	5 657	6 661	29 950	813	35 607	7 474
74	2 323	5 054	29 006	500	31 329	5 554
1975	2 255	8 692	29 000	500	31 255	9 192
76	6 742	6 375	29 050	498	35 792	6 873
77	4 129	3 383	34 007	1 488	38 136	4 871

The survival indexes were calculated for age groups 1 to 5 in the Norwegian samples of moulting seals collected in the Barents Sea from 1964 to 1972. Frequencies of age group 1 were calculated from the number of seals in the total samples while frequencies of age groups 2-5 were calculated from the number of two year and older seals in the samples. By linear regressions of survival indexes on pup catches, average estimates of production were obtained from the intercepts of the regression lines on the X-axis. Production estimates for various mid-years were obtained by regressions of different year class intervals.

An estimate of the total number of productively mature females was obtained by dividing pup production by pregnancy rate. Starting with the most up-to-date estimate, the number of productively mature females for the next year was calculated by subtracting catch and natural mortality and then adding recruitment. Pup production was then calculated by multiplying by the pregnancy rate. In this way production was calculated for successive years. Recruitment was calculated by starting with a production estimate, subtracting catch and natural mortality each year to productive maturity.

Table 2. Age group frequencies of moulting harp seals in Norwegian samples collected in the Barents Sea from 1963 to 1976. *M* = male, *F* = female, *U* = not sexed.

Age group	1963	1964	1965		1968			1970		1972		1973	1974		1976	
	U	U	M	F	M	F	U	M	F	M	F	U	M	F	M	F
1	30	75	17	36	111	123	95	184	170	162	149	207	108	109	71	62
2	24	44	11	8	43	35	28	92	92	114	111	83	91	55	49	50
3	19	46	7	5	33	37	27	89	93	84	80	68	82	57	24	35
4	28	26	8	3	16	10	9	53	38	84	52	28	62	40	22	12
5	11	28	4	3	5	7	9	24	23	27	35	33	36	31	20	4
6	11	17	7	2	12	9	12	6	18	11	23	31	29	27	7	14
7	8	20	6	0	24	12	16	3	21	9	16	24	20	35	19	37
8	7	13	9	2	23	9	10	1	14	6	8	15	20	29	22	50
9	11	19	5	4	18	3	13	0	11	12	15	24	9	16	32	40
10	6	13	8	4	16	1	9	0	10	9	16	21	7	15	27	16
11	2	11	7	0	13	1	5	1	4	6	4	18	7	11	24	11
12	1	13	6	0	3	0	2	0	1	6	9	20	2	11	21	12
13	1	7	6	2	3	0	6	0	1	5	2	13	4	11	14	11
14	3	11	7	1	5	1	4	0	2	4	1	16	5	8	17	12
15	4	6	7	0	4	0	3	1	0	6	3	3	2	4	14	8
16	1	6	5	1	2	0	3	0	1	3	0	4	1	5	21	8
17	1	2	1	1	3	0	0	0	2	4	0	3	1	1	19	5
18	1	3	2	0	3	0	2	1	2	2	0	12	2	4	12	6
19	1	1	4	0	4	0	3	0	0	1	0	3	3	1	14	2
20	1	2	3	1	4	0	2	0	2	6	2	10	0	0	14	2
21	0	2	2	0	0	0	1	0	0	2	0	5	2	0	11	1
22	0	0	1	0	4	0	0	0	0	2	0	2	0	1	6	0
23	0	0	0	0	3	0	1	0	0	0	1	2	1	1	4	0
24	0	0	0	0	1	0	1	0	0	0	0	1	0	2	2	2
25	0	0	0	0	0	0	2	1	0	1	0	3	0	1	3	0
26+	0	0	0	0	3	0	0	2	0	4	0	3	2	2	8	0
Total	171	365	133	73	356	248	263	458	505	570	527	652	496	477	497	400

No attempt has been made to include any possible density dependent effect on age of sexual maturity, pregnancy rate or natural mortality.

Sustainable yield of pups can be estimated from the basic assumption that constant production requires an equilibrium between recruitment and mortality among productively mature females. For a stable population this may be expressed by the following equation:

$$\frac{1}{2} \cdot (B - C) \cdot S^a = \frac{B}{f} \cdot (I - S)$$

where B is pup production, C is sustainable yield of pups, S is survival rate, a is median age of first whelping and f is fertility rate. A median age of first whelping of 5 years (YAKOVENKO and NAZARENKO 1967) was used in the calculations. No estimate of fertility rate or natural mortality is available for the White Sea harp seal. Therefore a fertility rate of 0.90 (ØRITSLAND 1971) and an annual natural mortality of 10% (MERCER 1978) as found for Newfoundland-Labrador harp seals, were applied. Age distribution of the catch of one year old and older seals is assumed synonymous with the population structure as is an equal sex ratio. A 1:1 sex ratio of pups is also assumed on the basis of unpublished Norwegian data.

RESULTS

Pup catches and survival indexes for the year classes from 1959 to 1971 are listed in Table 3. The table shows that high pup catches before 1965 give survival indexes well below 1.00, and that the reduced pup catches from 1965 to 1970 produce indexes higher than 1.00. Weighted mean indexes were calculated for the year classes from 1960 to 1969. These are plotted against the pup catches of their respective year classes in Fig. 1. The intercept of the regression line on the X-axis gives an estimate of pup production in the mid-year 1964 of 103 thousand.

Pup production estimates with their 95% confidence interval for different mid-years from 1962 to 1965 are listed in Table 4. The estimates show that pup production decreased from 130 thousand in 1962 to 98 thousand in 1965, with corresponding lower confidence limits of 94 and 74 thousand pups.

Estimated and projected pup productions from 1962 to 1978 are plotted in Fig. 2, showing that production increased from 98 thousand in 1965 to 172 thousand in 1978. Included in Fig. 2 are the number of adult females in the whelping patches estimated from Soviet aerial survey data. The two curves have the same shape, and both show a mean annual increase of about 5% from 1968 to 1976.

From a production estimate of 172 thousand, the sustainable yield in 1978 is calculated at 98 thousand pups and 8 thousand one year and older seals.

Table 3. Pup catches of the White Sea harp seal and the survival of corresponding year classes expressed by a survival index (frequency in sample/average frequency). Below the year of sampling is given the number of specimens and the weight given to the sample in calculating the weighted mean for 1-5 year old seals.

Year class	Pup catch $\times 10^{-3}$	Survival index					Weighted mean
		1964	1965	1968	1970	1972	
		368	206	867	963	1 097	
		1.3	1.0	2.0	2.2	2.3	
1959	51	1.43					
1960	63	0.82	0.68				0.76
61	45	0.86	0.65				0.77
62	69	0.72	0.42				0.59
63	55	0.69	0.59	0.58			0.62
64	50		0.86	0.59			0.68
1965	25			0.97	1.14		1.06
66	22			0.93	1.36		1.16
67	30			1.27	1.62	1.17	1.35
68	32				1.42	1.57	1.50
69	27				1.23	1.13	1.18
1970	29					1.35	
71	34					0.95	

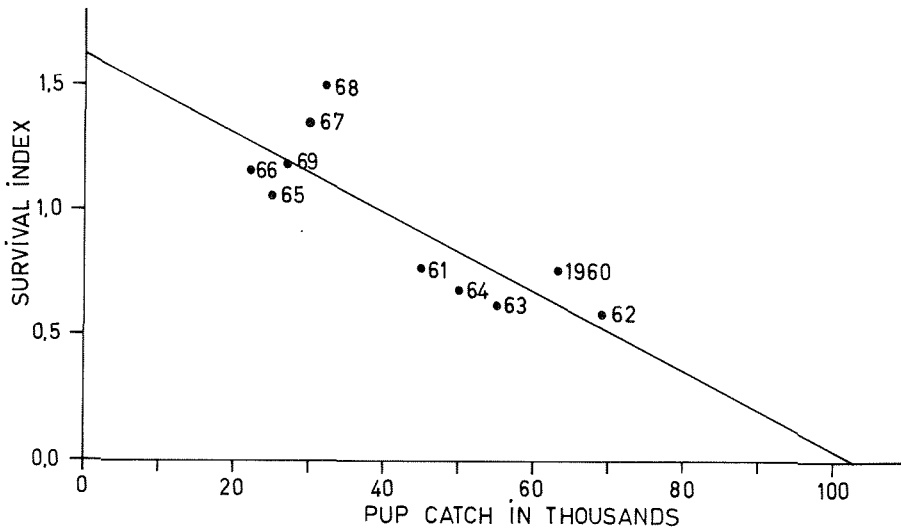


Fig. 1. Total catches of harp seal pups in the White Sea and the Barents Sea and the survival of the year classes 1960-1969 as indicated by weighted mean survival indexes from Norwegian samples of moulting seals collected in 1964-1972.

Table 4. Pup production estimates in thousands of harp seals in the White Sea calculated from linear regression of survival index on pup catch (*A*). *B* = the 95% confidence interval of pup production. *r* = correlation coefficient.

Period	Mid-year	Production		<i>r</i>
		<i>A</i>	<i>B</i>	
1960 - 65	1962	130	94 - 440	-0.87
1960 - 66	1963	118	94 - 186	-0.92
1960 - 67	1963	109	84 - 201	-0.86
1960 - 68	1964	103	79 - 211	-0.81
1960 - 69	1964	103	80 - 180	-0.82
1961 - 69	1965	97	74 - 194	-0.82
1962 - 69	1965	99	74 - 221	-0.82

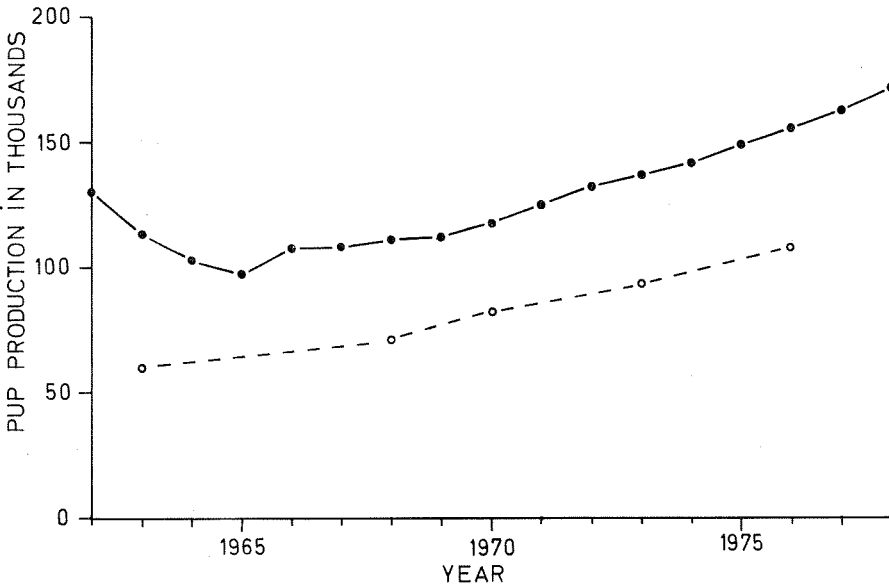


Fig. 2. Production of harp seal pups in the White Sea (closed circles) calculated up to 1965 by regression of survival indexes on pup catches. Production in 1966—1978 are calculated from a projection of the females population. For comparison, the number of adult females on the ice estimated from the Soviet aerial surveys is shown (open circles and stippled line).

DISCUSSION

The age and sex composition in the moulting lairs changes through the season as adult females gradually join the males and immature females through April and early May. Therefore the element of older animals in the Norwegian catches varies much from year to year, and survival indexes were only calculated for age groups 1 to 5.

BENJAMINSEN and ØRITSLAND (1975) showed that the moulting one year old harp seals of the Newfoundland–Labrador population to a large extent were segregated from older immatures and therefore were not sampled in any consistent relation to their abundance in the population. The one year olds therefore were not included in their calculations of survival indexes. The one year olds in the Barents Sea, however, seem to be well mixed in with the older seals in the moulting lairs. The correlation between the frequencies of one year old seals in the Norwegian samples of moulting seals in the Barents Sea from 1964 to 1972 and the pup catches of these year classes is strong ($r = -0.93$).

The survival index method is only useful if pup production does not change too much during the period which is studied. The regression estimates also should be made only for periods with as high as possible variation in pup catches. In order to combine these two requirements it was decided to use only the age samples collected from 1964 to 1972 in the calculations. Survival indexes therefore could only be calculated for the year classes 1959 to 1971.

The pup production estimates obtained from survival indexes and the projection is about 50% higher than the number of adult females on the ice in the breeding layers estimated from aerial surveys. This difference may be explained by the fact that some females are always in the water. POPOV (1967) writes that on clear and windless days 45–55% of the adult females are on the ice in the day-time and 70–80% in the evening.

The projection is very sensitive to the input parameters. Mean annual natural mortalities of 9% and 11% instead of 10% would change the production estimate in 1978 from 172 thousand to 208 and 142 thousand respectively. A median age of first whelping of 6 instead of 5 years produce an estimate of 141 thousand pups in 1978.

A projection based on the lower limit of the 95% confidence interval indicates that production will increase from 74 thousand in 1965 to 91 thousand in 1978.

With the present total quota of 50 thousand, the White Sea harp seal stock will probably continue to increase at a rate of about 5% per year. The population is still small compared to the size at the beginning of the 20th century, and during the first decade the increase will probably not have any noticeable effect on natural mortality, age of sexual maturity or pregnancy rate. The abundance of fish in the Barents Sea, however, may have an effect on these vital parameters.

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AN ISOPOD AS INTERMEDIATE HOST OF COD-WORM

By

ARNE J. BJØRGE

Institute of Marine Biology and Limnology, University of Oslo

ABSTRACT

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Ten cod (*Gadus morhua*), caught at 30-50 m depth in the Froan area (64°N) on the Norwegian coast in October 1977, held an average of 53 cod-worm (*Phocanema decipiens*) larvae in their muscles. Stomach contents included fish, amphipods and isopods. Of 87 isopods, 84 were identified as *Idothea neglecta* and from these one *P. decipiens* larva was recovered. The findings suggest that *I. neglecta* is a significant food resource for coastal cod, and that this isopod also is a first intermediate host of cod-worm.

INTRODUCTION

Cod-worm larvae (*Phocanema decipiens* Krabbe, synonyms: *Porocaecum*, *Terranova*) are found in fillets of cod (*Gadus morhua* L) and other commercially exploited benthic fishes from shallow waters around the North Atlantic. The larvae are causing severe economical problems for the fishing industry in several countries, particularly in areas where the grey seal, *Halichoerus grypus* (Fab.), is abundant. Together with other marine mammals, the grey seal is the final host of this parasitic nematode (YOUNG 1972).

Knowledge on the first intermediate host and its biology would give a better understanding of the distribution and incidence of cod-worm. Therefore the life cycle of *P. decipiens* has been extensively studied. SCOTT (1955) and MYERS (1960) have shown experimentally that *P. decipiens* eggs hatch in sea water. The eggs are hatched to larvae which are enveloped by a moulted cuticle (first stage cuticle) from which they cannot free themselves (SCOTT and BLACK 1960). These second stage larvae have a boring tooth (MYERS 1960).

Closely related parasitic nematodes have crustaceans as first intermediate hosts, and SCOTT (1950) suggested that also *P. decipiens* might develop in a crustacean. In 1958 SCOTT and BLACK (1960) collected 8500 Mysidacea in order to look for the first intermediate host of *P. decipiens*. Of the 71 nematodes found, all but 5 belonged to the genus *Contracaecum*. The remaining five were classified as belonging to the genera *Phocanema* or *Anisaksis*. Four of these were discovered in the mysids *Mysis mixta* and *M. stenolepsis*. The last

one came from a mysid which was so poorly preserved that it could not be identified. According to MYERS (1960) the nematode *Monohystera cameroni* Steiner, is a commensal of *Mysis mixta* and *M. stenolepsis*. Myers states that even under magnification this nematode resembles the larvae of *P. decipiens*.

SCOTT (1954) has demonstrated that fish can also become infected by eating other fish containing *P. decipiens*.

LOCALITY, MATERIALS AND METHODS

Froan is an offlying group of small islands, skerries and rocks northwest of the Trondheim fjord at about 64° latitude North, holding Norway's largest concentration of grey seals. It is estimated (personal observation) that at least 1000 grey seals inhabit the area from Halten light-house to Sauøy during the October-November breeding season. ØYNES (1964) roughly estimated that 300 female grey seals were breeding in the Halten-Froan area. FRENGEN and RØV (1976) assessed the number of pups born annually in the same area to be at least 300.

Within the Halten-Froan area at least 10 grey seal pups are born annually on Slettskjæra and Tindskjæra (64°06'N 09°08'E). On 12 October 1977 10 cod were caught by hook and line in shallow waters (30–50 m) near Tindskjæra. The otoliths were preserved in a mixture of glycerol and formalin, the stomachs with contents were fixed and stored in 4% formalin, and the fish were salted.

In the laboratory the cod were filleted, and the parasites removed by examination under transmitted light. Stomach contents were sorted and crustaceans present were dissected under a binocular microscope. Some of the crustaceans were too decomposed to be identified and were not included in the analysis.

Isopods from the cod stomachs were identified according to SARS (1899), and nematodes from the isopods were identified by Bjørn Berland, Zoological Laboratory, University of Bergen.

RESULTS

The nematode infestation of the cod fillets was high (Table 1) with an average of 53 larvae per fish. They were all identified as *P. decipiens*.

From the stomach contents listed in Table 1, 114 amphipods and 87 isopods could be identified. Of the isopods, 84 specimens were identified as *Idothea neglecta* Sars, and 3 specimens as *I. baltica* (Pallas). In addition to the contents listed (Table 1), the cod stomachs contained large numbers of the nematode *Contracaecum aduncum* (Rudolphi).

Table 1. The infestation by *Phocanema decipiens* and stomach contents of cod caught at Tindskjæra, Froan, on 12 October 1977.

Cod No.	Age (years)	Number <i>P. decipiens</i>	Stomach contents				
			<i>Idothea</i>	Amphipoda	Fish	Other	Empty
1	5	84	+	+	+		
2	4	76	+		+		
3	3	9	+		+		
4	4	19			+		
5	5	73	+	+		+ ¹⁾	
6	3	35					+
7	3	38		+	+		
8	4	14			+		
9	3	3	+	+			
10	5	177	+	+	+		

¹⁾ One *Munida rugosa* (Fabricius, 1775)

The 84 specimens of *I. neglecta* contained a total of three nematodes: two *C. aduncum* and one *P. decipiens*. No nematodes were found in the three *I. baltica*. A total of five nematodes were found in the amphipods, all being too small or shrunken for proper identification.

DISCUSSION

BENJAMINSEN, BERGFLODT and HUSE (1976) demonstrated that infestation of *P. decipiens* in cod was greater in shallow waters than at greater depths. SARS (1899) writes that *I. neglecta* is a benthic organism living at depths from upper sublittoral down to 20 fathoms (about 37 m). If *I. neglecta* is an important first intermediate host of *P. decipiens*, as suggested by this study, this may explain the apparent correlation between depth and the infestation of *P. decipiens* in cod.

Our knowledge of the life cycle of *P. decipiens* is still incomplete. However, the probable succession of events may be summarized in the following way: Eggs are excreted with the seal faeces and hatch in sea water to second stage larvae which are enveloped in their first stage cuticle. When eaten by an invertebrate first intermediate host (e.g. isopod) they are freed from their cuticle and probably moult to third stage larvae. Both second and third stage larvae have a cuticular boring tooth.

The larvae remain in the first intermediate host until it is eaten by a fish. The larvae, thus freed by digestion, penetrate the intestinal wall and migrate to muscle tissue where they encapsulate in their second intermediate host. If this fish is eaten by another fish, the larvae again migrate from intestine to muscle tissue and become encapsulated once more. In this case the fish acts as a carrying host, the larvae remaining unchanged in development although they may grow in size.

If, alternatively, the second intermediate or the carrying host is eaten by a mammal, the larvae rapidly moult to their fourth stage of development. These fourth stage larvae have well developed labia but lack the boring tooth. They are either attached to the stomach mucosa or lying free in the mucus. They later moult to their fifth stage of development and become sexually mature, thus completing the cycle.

The *C.aduncum* found in the isopods could either have been in the isopods before ingestion by the cod, or they could have penetrated the isopods within the digestive tract of the cod. Because of the quantities of *C.aduncum* in cod stomachs, this finding does not constitute evidence for amphipods as hosts of this nematode.

Working conditions during field work in 1977, particularly the time limits, prevented the use of a more appropriate collecting procedure for nematodes from the amphipods, *e.g.* to dissect out the nematodes while they are alive, and then to kill them in an extended position in hot alcohol or glacial acetic acid (BERLAND 1961).

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