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Selectivity of Codends with Standard 150, 160 And 170 mm Mesh Size in Greenland Halibut Trawl Fishery in Division 3L of the NAFO Regulatory Area and Possible Results of Mesh Size Increase in More than 130 mm

by

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Abstract

Given are the data on selectivity of codends with 152; 163 and 170 mm mesh size in the Greenland halibut target fishery in Div.3L of NAFO Regulation area.

The results from investigations were processed using **SELECT** model, by logistic and generalized logistic (Richard's) function of the likelihood of studied fish retention depending on their size. The parameters of functions were obtained by minimizing the likelihood function.

Selectivity parameters derived by authors for 152 mm mesh: fish length corresponding to 25% and 50% retention – L_{25} = 35.4 cm; L_{50} = 42.8 cm; selectivity coefficient K_S = 2.8; selectivity range SR = 14.8 cm; for 163mm and 170 mm mesh: L_{25} = 39.1 and 40.2 cm; L_{50} = 47.4 and 48.4 cm;
K_S = 2.8 and 2.9; SR = 15.9 and 15.4 cm, respectively.

Calculations of instantaneous losses showed that enlarging mesh size from 130 to 173 mm would result in efficiency decrease almost in 5 times, and minor long-term profits of up to 1-3% might be only obtained with fishing mortality growing in not less than 2-4 times, as compared to the current one.

Introduction

Nowadays, during the fishery of Greenland halibut in NAFO Regulation area (Div. 3LMNO), outside the economic zones of the coastal states, trawls with 130 mm minimal mesh size are applied. For this, 30cm commercial size has been established for halibut and maximal allowable by-catch of fish less than 30 cm must not exceed 10% by abundance in the whole catch (Anon., 2004).

In 2003, the Scientific Council of NAFO (Div. 3LMNO), again confirmed their recommendation on the reduction in fishing press on immature Greenland halibut (Anon., 2003), but it would be only possible with a significant increase in codend mesh size and halibut commercial size or complete ban of the trawl fishery and its replacement by other kinds, such as netting or long-lining.

Trawl fishery of Greenland halibut in Div. 3LMNO is, primarily, based on immature fish and considerable reduction in their catch may lead to stoppage of Greenland halibut fishing because of economical inefficiency. Therefore, it is important to estimate trawl selectivity regarding Greenland halibut in all kinds of fishing (target, in the first place) and to evaluate possible short- and long-term profits or losses caused by proposed enlargement of mesh size in codend.

Materials and Methods

Researches to estimate codend selectivity in the target fishery of Greenland halibut with an actual medium mesh size of 162.6 mm were conducted in September and with 152.2 mm and 173.0 mm size – in October-December 2003, in Div. 3L of NAFO Regulation area. Experiments were carried out aboard Russian trawler "Kapitan Naumov". The length of the vessel was 55 m; the width – 11 m, the tonnage – 1 104 registered tons; the power of the main engine – 2 210 kW.

In the research bottom 45.8 m trawl "Turbot-454" (Fig. 1) made of polyethylene, with 26 m horizontal and 5 m vertical opening was used. "POLY-ICE" trawl boards with the area of 8 m^2 and the weight of 2 800 kg were applied for trawl opening. Cable length was 165 m. The trawl was rigged by rockhopper with 500 mm diameter of bobbins on the groundline. The haul speed was 3.0-3.3 knots, fishing duration corresponded to that one adopted. Data on hauls are given in Table 1.

Aboard the trawler codends with standard 150, 160 and 170 mm mesh size, made of polyamide netting with 7.0 mm twine were tested. The length of cylindrical part of the codend amounted to 10 m, the perimeter – to 80 meshes. Codend mesh size was measured in the upper panel of the codend. Measurements were made in a row, which was parallel to longitudinal axis of the codend distant 10 meshes from linear joints and 5 meshes from the codline loops. A measurement was executed immediately after trawl lifting applying a wedge-shaped plate with 2 mm thickness, of ICNAF type, inserted into mesh with 50H effort. The measurements were made in the beginning and end of each test series.

Codend selectivity was estimated by method of small-meshed cover, using bag-shaped fish catcher with 80 mm mesh size, mounted at the codend conical part at the distance of 4-5 m, in front of the site of its joint with the cylindrical part of the codend. The perimeter of codend was larger than that one of its cylindrical part by 60%. After mounting fish catcher became 2-3 m prominent ahead of codend. All the fish from the codend and fish catcher were separately poured out to tank divided into two parts and measured with separation by species and sex. 300-400 halibut individuals from codend and fish catcher were measured. The rest unmeasured fish were completely counted, and the length series were corrected in a proper way.

The research data were collected and processed in accordance with the ICES Recommendations on study of trawl selectivity (Anon., 1996) and instructions issued in PINRO (Anon., 2001). The data were analyzed using computer programme based on **SELECT** model and the task was done applying **Solver-sel** method of iterations – (Tadashi Tokai, 1997; Tadashi Tokai and Takahisa Mitsuhashi, 1998) allowing us to estimate selectivity parameters by logistic or generalized logistic function of studied fish retention likelihood depending on their length.

The equation of Richard's generalized logistic function is described by equation (1)

$$r(l) = \{exp(a + b*l) / [l + exp\ (a + b*l)]\}^{l/d}, \qquad (1)$$

where $r(l)$ – likelihood of the retention of fish with length l;
a, b, d – parameters of function;
l – retained fish length.

The length of fish corresponding to 50% retention by codend with B-mesh size was calculated by the formula (2)

$$L_{50\%} = \frac{log\ it(0.5)^{d} - a}{b}. \qquad (2)$$

Selectivity range was calculated by the formula (3)

$$SR = L_{75\%} - L_{25\%} = \frac{log\ it(0.75^{d}) - log\ it(0.25^{d})}{b}, \qquad (3)$$

where $L_{75\%}$ and $L_{25\%}$ - fish length corresponding to 75% and 25% retention.

Estimates were derived by method of minimizing likelihood function (AIC). All the calculations were made using parameters derived with generalized logistic or logistic function having smaller estimate criterion of the function (AIC).

Selectivity coefficient K_S was calculated by the formula (4)

$$K_S = \frac{L_{50\%}}{B} \quad , \qquad (4)$$

where B – the internal size of codend mesh.

Standard errors of selectivity parameters were detected with the aid of methods used in mathematical statistics.

Change of possible efficiency of Greenland halibut fishing by trawls with a mesh different than 152 mm, was also evaluated by calculations of possible reduction in catch by trawl with a larger mesh as a result of its selectivity increase. The catch of each size group by trawl with a new mesh was estimated based on length composition of catch by trawl with 152.2 mm mesh and the difference in selectivity of 152.2 mm and the new mesh (162.6 and 173.0 mm). The catch taken with the use of 152.2 mm mesh was conditionally considered as 10 000 ind..

The weight of catches was calculated using mean long-term data on each Greenland halibut individual weight dependence on fish length and amount in catches by each codend with different mesh by the formula (5).

$$\sum_{1}^{n} P_{2i} = \sum_{i=1}^{n} N_{1i} \frac{S_{2i}}{S_{1i}} M_i \, , \qquad (5)$$

where P_{2i} – catch weight of i size group by a new mesh;
N_{1i}, N_{2i} – catch of the first size group by the previous and new mesh, respectively;
M_i – weight of the first fish from i size group;
S_{2i} and S_{1i} – selectivity in relation to fish from i size group of the trawls with new and previous mesh size.

To evaluate the long-term effect from bringing a new mesh into use the method based on the analysis of selective cohorts was applied (ASC method) (Blinov, 1981).

The data on catch by traditional mesh and corresponding mortality F for each age group calculated by XSA model for 2002, were taken from the paper by Darby (Darby *et al*., 2003). The catch corresponding to a new mesh size was calculated in accordance with selectivity coefficients for each size group.
Selectivity parameters were determined based on the results from the experimental research described above.

The initial fishing mortality F for each size group when using a new mesh was estimated as the new-previous mesh selectivity ratio.

While calculating the number of caught fish from every age group a modified (Blinov, 1981) equation of Beverton-Holt (6) was used

$$Ci = Ni_{nat\ bal} (1-e^{-F}), \qquad (6)$$

where $Ni_{nat\ bal}$ – the number of fish from i age group in the previous fishery period.

The number of fish in the first fishery year escaped through mesh was calculated by equation (7) (Blinov, 1981)

$$N(i+1)_{nat\ bal} = e^{-M} Nir, \qquad (7)$$

where M – natural mortality taken as 0.2 (Darby *et al*., 2003)

Nir – number of fish escaped in the first year of fishery applying new mesh and after the second year – by equation (9)

$$N(i+1)_{bal} = Nir\ e^{-(M+Fi)}, \quad (8)$$

where Fi – natural mortality of i age group in the fishery with new mesh size.

Losses in the first fishery year were calculated by the formula (10)

$$W_{los} = \sum_{i=i0}^{i=i} WiNir\ , \quad (9)$$

where Wi – weight of one fish from i age group derived by Bertalanfy equation, parameters of which were selected with the aid of length-age key (Vazquez, 2002).

Later, catch of fish escaped through a new mesh in the first fishery year were summed up and correlated with the losses of the first fishery year.

Estimation of Greenland halibut fishing efficiency in Div. 3L of NAFO Regulation Area as a result of enlarging mesh size in codend

2.1. Results from experimental research on 150-170 mm mesh size codends.

Research on selectivity of codend with 150 mm mesh size (actual mean codend mesh size – 152.2 mm) were conducted at 750-950 m depth. Data on hauls are given in Table 1 and the results from trawl codend mesh inner size measurement – in Table 2. In the codend catch varied from 0.20 to 0.63 t, in the fish catcher – from 0.17 to 0.99 t. The percentage of Greenland halibut in the catches by codend and fish catcher fluctuated from 77% to 95%. In by-catch red hake and roughhead grenadier occurred.

When conducting surveys Greenland halibut 28-90 cm in length were fished. Average size of caught males equaled to 39.4 cm, of females – to 40.2 cm, the summarized one of males and females – to 39.9 cm (Fig. 2a). The results of selectivity estimation are given in Fig. 2b and selectivity parameters, their standard error and the estimate criterion of the kind of function (logistic or generalized logistic) are presented in Table 3.

The analysis in Fig. 2b and Table 3 showed that codend selectivity (in relation to Greenland halibut males and females) had no reliable differences and was close to its selectivity without dividing individuals by sex. Richard's curve, for which the value of estimation criterion of the theoretical distribution difference from the actual one was somewhat lower than for the logistic function, is the most suitable for further analysis. According to that function of distribution, selectivity coefficient for 152.2 mm mesh size amounted to 2.8; fish length corresponding to 50% and 25% retention – to 42.8 cm and 35.4 cm, respectively, and the selectivity range was 14.8 cm.

Research on selectivity of codends with a standard 160 mm mesh size were carried out at 950-1050 m depth. The mean mesh size was equal to 162.6 cm (Table 2). In the codend the catches varied from 0.54 to 0.96 t, in the fish catcher – from 0.61 to 1.23 t and were, mainly, represented by Greenland halibut (Table 1). In the by-catch insignificant numbers of red hake occurred. Taken were Greenland halibut as long as 42.9 cm with the size of males and females 41.6 cm and 43.8 cm, respectively (Fig. 3a). In the codend the mean length of fish amounted to 45.3 cm under 43.9 cm for males and 46.0 cm for females. In the fish catcher the average length was less: (males - 40.4 cm and females - 42.2 cm). Selectivity indices for males and females did not differ confidently (Fig. 3b, Table 1).

The analysis of estimation criterion for the two kinds of functions (logistic and Richard's) showed that it was lower for Richard's function. Selectivity indices calculated using this function were: K_S = 2.9; L_{50} = 47.4 cm; L_{25} = 39.1 cm; SR =15.9 cm (Table 3).

The research on selectivity of codend with a standard 170 mm mesh size were performed at the depth of 750-1 100 m. The average mesh size amounted to 173.0 mm (Table 2). In the codend halibut catch varied from 0.15 to 0.49 t; in the fish catcher – from 0.26 to 0.81 t and they were, primarily, represented by Greenland halibut (80-97%). In the by-catch red hake and roughhead grenadier occurred. In that period Greenland halibut with the mean length of 41.4 cm (males – 40.5 cm, females – 41.9 cm) were fished. The average fish length was 43.7 cm (males – 42.5 cm; females – 44.2 cm) in the codend and 40.4 cm (39.7 cm and 40.7 cm), respectively, in the fish catcher (Fig. 4a). Selectivity indices of the codends with such a mesh for males and females did not differ confidently and the analysis of estimation criterion showed that Richard's function would be preferable (Fig. 4b). The selectivity parameters for codend with 173.0 mm mesh were: K_S = 2.8; l_{50} = 48.4 cm; l_{25} = 35.6 cm and the selectivity range SR = 15.4 cm (Table 3).

Thus, our data show that the selectivity coefficient for 152, 163 and 173 mm codends is within the range of 2.8-2.9; fish length corresponding to 50% of retention amounts to 42.8; 47.4; 48.4 cm, a selectivity range – to 14.8; 15.9 and 15.4 cm, respectively.

The comparison of these data with the results of the other researchers (Chumakov *et al*., 1981; de Cardenas *et al*., 1995; Huse and Nedreaas, 1995; Lisovsky *et al*., 2001, 2002; Lisovsky and Pavlenko, 2003; Nikeshin *et .al*, 1983; Walsh *et al*., 2000; Walsh and Hickey, 2000) shows that selectivity coefficient was the similar to the results having obtained before and the selectivity range was somewhat higher (Table 4). In the experiments of 2003, the length of fish with 25% and 50% retention was significantly less for 152 mm mesh size than in the other research. So, in the data from the paper (Lisovsky *et al*., 2002), L_{25} = 41.8 cm and L_{50} = 46.7 cm while in our experiments they were 35.4 cm and 42.8 cm, respectively. Such differences were, obviously, caused by the distinction in length composition of fished Greenland halibut concentrations.

In our experiments the mean length of fish (without dividing by sex) amounted to 39.9 cm while it was 43.7 cm by the data of the paper (Lisovsky *et al*., 2002). The larger selectivity limits resulted from the wider length range of fish caught by us in 2003 comparing to the data obtained before (Lisovsky *et al*., 2002). So, the length range of fish taken by the trawl with 152.2 mm mesh size was within 28-90 cm, whereas, by these authors' data, fish with the length of 38-64 cm occurred in catches.

2.2. Calculation of possible losses or profits of fishing when changing the mesh size in codends from 130 to 170 mm.

As it was mentioned in the previous section, selectivity of codends with 152.2 mm mesh size in relation to each size group of Greenland halibut was calculated by logistic function, but the generalized logistic one (Richard's) was used for 162.2 and 173.0 mm mesh size. The results of calculations of possible changes in Greenland halibut fishing efficiency as a result of codend selectivity variations conditioned by their mesh size increase are given in Table 5.

As the table shows, the efficiency of Greenland halibut trawl fishing efficiency will decrease by 57% and 61% with the increase of mesh size from 152 to 163 mm and 173 mm, respectively. With the allowance that already with the increase of the mesh size from 130 to 150 mm fishing efficiency reduces by 43% (Lisovsky and Pavlenko, 2003), when enlarging mesh to 173 mm there may be the total reduction of efficiency in almost five times.

The calculations of fishery profits as a result of enlarging codend mesh size from 130 to 173 mm when fishing Greenland halibut in Div. 3LMNO of NAFO Regulation Area indicate that the catch will almost twice decrease in the first 1-3 years and the long-term fishery profits after the introduction of enlarged mesh will not exceed 1-3%. A minor compensation of losses will occur not earlier than in 2-4 years (Fig. 5-8).

Darby also noticed the insignificant effect of enlarging the mesh size from 130 to 145 mm (Darby, 2001). The analysis of available data shows that the Greenland halibut commercial size of 30 cm (Anon., 2004) allowed for fishing (landing) does not correspond to 25% retention of the codend with 130 mm mesh size and may be enlarged to 34-35 cm. For this, the actual by-catch of individuals with the length of less than again established limits will amount to 34 cm – 0.4-5.2% and that one of fish to 36 cm in length – to 1.1-12.8%.

Thus, the minimal length of Greenland halibut allowed for fishing may be enlarged to 34-35 cm. For this, the by-catch of fish with the length of less than again defined landing size will not exceed 10% in number as agreed by Fisheries Commission at present (Anon., 2004).

Conclusion

The increase of the codend mesh size to the size of above 130 mm in the target fishery of Greenland halibut in Div. 3LMNO of the NAFO Regulation Area is not reasonable since brings no long-term profit for fishery and leads to significant decrease of fishing efficiency and possible stoppage of fishery as a result of economical inefficiency. The increase of mesh size from 130 to 150 mm will result in reduction of Greenland halibut fishing almost in 2.5 times, to 170 mm – in 5 times.

The long-term profits of fishing practically do not compensate the short-term losses as a result of the mesh size enlargement from 130 to 173 mm in the Greenland halibut fishery in Div. 3LMNO of the NAFO Regulation Area. Minor profits (1-3%) are only possible with the increase of fishing mortality in not less than 2-4 times in comparison with the current one, which is against sustainable fisheries.

The commercial size of Greenland halibut with the current mesh size may be enlarged to 34-35 cm. For this, the by-catch of fish with the length of less than again established landing size will not exceed 10 % adopted by Fisheries Commission at present.

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TABLE 1. The main data on hauls made when estimating selectivity of codends with 152-173 mm mesh size in Div. 3L of NAFO Regulation area, 2003

Number of hauls	Date	Position of haul		Time of catch, h min.	Haul duration, h min.	Haul course, degrees	Depth, m	Catch, kg			
		north latitude	west longitude					Greenland halibut		Other species	Total
								codend	cover		
Mesh size 152,2 mm											
1	10.12.0	48^{0}14'4	46^{0}14′6	06.40	7.20	190	750	554	742	95	1391
2	11.12.0	48'14'2	47^{0}53′9	07.10	7.10	210	800	578	742	69	1389
3	12.12.0	48^{0}05''7	46^{0}59′0	12.30	6.00	60	750	374	497	110	981
4	19.12.0	48^{0}07′9	47^{0}38′8	01.30	6.00	90	850	551	992	119	1662
5	20.12.0	48^{0}07′ 9	48^{0}08′1	12.00	6.00	270	900	443	283	87	813
6	23.12.0	48^{0}07 ' 9	47^{0}34′1	09.20	6.00	95	950	415	288	55	758
7	27.12.0	48^{0}07′7	47^{0}32′5	02.20	6.00	90	900	356	363	80	799
8	28.12.0	48^{0}08'9	46^{0}58′8	18.00	6.00	70	900	396	353	80	829
9	30.12.0	48^{0}08'1	48^{0}07′9	08.40	3.00	90	925	196	172	83	451
10	31.12.0	48^{0}07'8	47^{0}10′7	10.10	6.00	270	925	634	811	108	1553
Mesh size 162,6 mm											
1	30.08.0	48.08'6	47.34’7	12.30	7.00	90	1000	536	1013	94	1643
2	01.09.0	48.09'1	47.05’8	21.30	5.50	260	1020	955	1060	175	2190
3	03.09.0	48.08’5	47.36’7	12.00	7.00	90	1020	731	1088	147	1966
4	05.09.0	48.08’7	47.36’2	17.00	6.00	90	1050	680	868	48	1596
5	07.09.0	48.08’4	47.29’1	01.50	5.30	85	1050	758	769	144	1671
6	07.09.0	48.08’2	47.15’1	18.40	4.50	265	950	834	607	54	1495
7	08.09.0	48.08’6	47.36’1	15.30	5.00	90	1050	624	628	67	1319
8	09.09.0	48.08’8	47.37’7	06.40	7.00	90	1000	842	1234	105	2181
9	09.09.0	48.08’3	47.06’1	16.00	7.00	265	1000	536	785	115	1436
10	10.09.0	48.08’0	47.27’2	17.30	7.00	85	1000	621	632	94	1347
Mesh size 173,0 mm											
1	29.10.0	48^{0}08′0	47^{0}06′9	14.20	6.30	270	950	139	813	34	986
2	31.10.0	48^{0}04′4	47^{0}27′4	12.00	6.00	90	1100	177	338	61	576
3	01.11.0	48^{0}07′4	49^{0}59′3	14.00	6.00	70	800	222	380	67	669
4	02.11.0	48^{0}08′5	47^{0}05′7	06.00	6.00	70	850	203	445	27	675
5	06.11.0	48^{0}07′0	46^{0}59′4	13.20	6.00	70	800	318	644	62	1024
6	09.11.0	48^{0}08′2	47^{0}01′3	00.20	6.00	90	750	243	613	37	893
7	01.12.0	48^{0}07′9	47^{0}11′2	00.40	6.30	270	900	157	652	33	842
8	02.12.0	48^{0}06′4	46^{0}59′3	09.20	6.40	70	800	144	259	79	482
9	05.12.0	48^{0}07′2	46^{0}58′5	14.10	6.00	70	825	296	636	70	1002
10	06.12.0	48^{0}07′0	46^{0}59′6	08.10	6.00	70	800	488	569	92	1149

TABLE 2. Results of mesh measurement in codends with 150-170 mm standard mesh size in the research on Greenland halibut selectivity in NAFO Regulation area, 2003

No.	At the beginning of trials	At the end of trials	No.	At the beginning of trials	At the end of trials
		Standard mesh size 150 mm			
1.	152	152	11.	154	154
2.	151	150	12.	155	150
3.	153	153	13.	151	150
4.	155	149	14.	152	153
5.	151	150	15.	153	147
6.	150	152	16.	154	151
7.	157	153	17.	153	150
8.	154	150	18.	153	151
9.	150	151	19.	151	152
10.	152	153	20.	156	153
Mean				153,2	151,1
Mean actual					**152,2**
		Standard mesh size160 mm			
1.	163	160	11.	163	160
2.	165	165	12.	162	162
3.	164	160	13.	161	166
4.	164	162	14.	163	160
5.	162	157	15.	160	164
6.	163	162	16.	162	161
7.	163	164	17.	164	166
8.	163	160	18.	164	163
9.	168	162	19.	165	164
10.	164	163	20.	160	162
Mean				162,4	162,8
Mean actual					**162,6**
		Standard mesh size 170 mm			
1.	174	173	11.	178	170
2.	175	171	12.	177	171
3.	174	176	13.	172	175
4.	176	170	14.	173	172
5.	175	172	15.	175	168
6.	176	173	16.	174	174
7.	173	169	17.	174	171
8.	175	170	18.	171	170
9.	173	171	19.	176	171
10.	177	169	20.	175	172
Mean				174,7	171,4
Mean actual					**173,0**

Greenland halibut selectivity in NAFO Regulation area, 2003

TABLE 3 Selectivity parameters of codends with different mesh size in relation to Greenland halibut calculated by logistic and generalized (Richard's) functions, Div. 3L 3P NAFO, 2003

Function	Parameter	Males		Females		Males+females	
		Calculation, cm	Standard error, cm	Calculation, cm	Standard error, cm	Calculation, cm	Standard error, cm
				Mesh 152,2 mm			
Logistic	***$L_{25\%}$ =***	***35,4***	***3,1***	***35,4***	***2,1***	***35,4***	***0,6***
	$L_{50\%}$ =	***43,4***	***2,6***	***42,6***	***1,5***	***42,8***	***0,4***
	S.R. =	***16,0***	***7,8***	***14,3***	***4,5***	***14,8***	***1,2***
	Estimation criterion AIC	***32,7***		***39,7***		***87,4***	
Richard's	***$L_{25\%}$ =***	34,8	2,8	34,8	1,0	34,8	1,0
	$L_{50\%}$ =	43,8	1,3	43,0	0,5	43,3	0,5
	S.R. =	14,9	1,0	14,2	0,6	14,4	0,5
	Estimation criterion AIC			89,1		98,6	
				Mesh 162,6 mm			
Logistic	***$L_{25\%}$ =***	***39,5***	***2,3***	***38,7***	***2,3***	39,0	0,4
	$L_{50\%}$ =	***47,6***	***2,5***	***47,3***	***1,7***	47,4	0,3
	S.R. =	***16,1***	***6,1***	***17,4***	***5,0***	16,8	0.8
	Estimation criterion AIC	***37,5***		***47,3***		145,1	
Richard's	***$L_{25\%}$ =***	39,5	0,6	38,5	1,4	***39,1***	***0,4***
	$L_{50\%}$ =	47,6	3,9	47,5	5,3	***47,4***	***0,3***
	S.R. =	15,8	1,3	15,9	1,0	***15,9***	***0,7***
	Estimation criterion AIC	95,0		88,2		***129,1***	
				Mesh 173,0 mm			
Logistic	***$L_{25\%}$ =***	***40,2***	***3,1***	***35,6***	***3,5***	35.6	0.6
	$L_{50\%}$ =	***48,7***	***5,1***	***48,3***	***2,8***	48.4	0.5
	S.R. =	***17,1***	***10,7***	***16,5***	***6.5***	16.7	1.2
	Estimation criterion AIC	***32,2***		***43,0***		92.8	
Richard's	***$L_{25\%}$ =***	40,3	2,0	40,1	0,9	***40,2***	***0.7***
	$L_{50\%}$ =	48,6	1,0	48,3	0,5	***48,4***	***0.5***
	S.R. =	14,8	2,1	15,2	1,1	***15,4***	***1.0***
	Estimation criterion AIC	68,1		88,8		***91,3***	

TABLE 4. Selectivity parameters of trawl codends with different mesh size in the fishery of Greenland halibut in NAFO Regulation area derived by different researchers

Mesh size, mm	Number of hauls	Towing duration	L_{50}, cm	K_S	SR, cm	L_{25}, cm	References
121[1]	7	5	33,5	2,77	7,3	30,2	Lisovsky *et al.*, 2001
121[1]	7	5	35,5	2,93	6,5	33	Lisovsky *et al.*, 2001
127[2]	7	1,5	37	2,91	?	?	Chumakov *et al.*,1981 Nikeshin *et al.*, 1983
130[1]	7	5	38,5	2,96	7,1	31,8	Lisovsky *et al.*, 2001
130[1]	4	1	38,7	2,99	7,5	34,5	Cardenas *et al.*, 1995
130[1]	2	4	37,7	2,91	11,8	30,5	Cardenas *et al.*, 1995
130[1]	10	4-5	41,7	3,2	6,1	38,2	Lisovsky *et al.*, 2002
130[1]	10	4-7	40,3	3,1	9,6	35,9	Lisovsky and Pavlenko, 2003.
132[1]	9	5	40	3,03	10,5	34	Lisovsky *et al.*, 2001
133[2]	7	?	40,5	3,08	?	?	Chumakov *et al.*, 1981 Nikeshin *et al.*, 1983.
135[3]	14	4	42,0	3,1	9,6	37,2	Huse and Nedreaas, 1995.
135[1]	10	5	43,8	2,9	10,0	39,0	Lisovsky and Pavlenko, 2003.
136[1]	10	4-6	45,3	3,3	7,9	41,0	Lisovsky and Pavlenko, 2003.
145[3]	14	4	47,7	3,29	7,4	44	Walsh *et al.*, 2000.
145[3]	14	4	47,2	3,3	7,0	43,2	Walsh and Hickey, 2000.
145[1]	10	4	45,2	3,1	7,1	41,2	Lisovsky *et al.*, 2002.
145[1]	10	4-6	46,2	3,2	6,3	42,9	Lisovsky and Pavlenko, 2003.
150[1]	10	5	48,7	3,2	6,9	45,1	Lisovsky and Pavlenko, 2003.
150[2]	4	4	46,7	3,1	8,4	41,8	Lisovsky *et al.*, 2002
152[1]	10	3-7	42,8	2,8	14,8	35,4	This report.
163[1]	10	5-7	47,4	2,9	14,9	39,1	This report.
173[1]	10	6-7	48,4	2,8	15,4	40,2	This report.

Method of selectivity estimation:

[1] – bag-shaped cover;
[2] - cover of the ICES-type;
[3] – two cod-end bag.

TABLE 5. Calculation of Greenland halibut catch by trawls rigged with codends with 152.2 mm, 162.6 mm and 173.0 mm mesh size in relation to that one by codend with 152.2 mm mesh

Fish length, cm	Mesh size 152,2 mm			Mesh size 162,6 mm			Mesh size 173,0 mm		
	Frequency of occurrence	One fish weight, g	Weight of catch, kg	Retention ratio 162.6/152.2 mm	Number of fish in catch, ind.	Weight of catch, kg	Retention ratio 173/152,2 мм	Number of fish in catch, ind.	Weight of catch, kg
24	0	103	0	0.8	0	0	0.5	0	0
26	0	145	0	0.8	0	0	0.5	0	0
28	8	185	3	0.8	7	1	0.5	4	1
30	72	228	28	0.8	55	13	0.5	40	9
32	239	298	119	0.7	178	53	0.6	135	40
34	713	380	454	0.7	522	198	0.6	418	159
36	1065	423	755	0.7	766	324	0.6	644	272
38	2355	488	1926	0.7	1666	813	0.6	1465	715
40	1669	573	1602	0.7	1164	667	0.6	1065	610
42	1221	678	1387	0.7	844	572	0.7	797	541
44	1243	773	1610	0.7	858	664	0.7	829	641
46	469	895	703	0.7	327	293	0.7	319	286
48	447	998	748	0.7	320	319	0.7	311	310
50	208	1193	415	0.7	155	185	0.7	148	177
52	130	1295	282	0.8	102	133	0.7	96	125
54	77	1458	188	0.8	65	94	0.8	59	87
56	36	1583	95	0.9	32	50	0.8	29	46
58	21	1803	63	0.9	19	35	0.8	18	32
60	9	1998	30	1.0	9	17	0.9	8	16
62	6	2235	22	1.0	6	13	0.9	5	12
64	3	2420	12	1.0	3	7	0.9	3	7
66	0	2643	0	1.0	0	0	0.9	0	0
68	2	2885	12	1.0	2	7	1.0	2	7
70	0	3253	0	1.0	0	0	1.0	0	0
72	1	3478	7	1.0	1	4	1.0	1	4
74	0	3623	0	1.0	0	0	1.0	0	0
76	0	3918	0	1.0	0	0	1.0	0	0
78	0	4355	0	1.0	0	0	1.0	0	0
80	1	4695	9	1.0	1	6	1.0	1	6
82	1	5910	12	1.0	1	7	1.0	1	7
84	1	6145	12	1.0	1	7	1.0	1	7
86	1	6480	13	1.0	1	8	1.0	1	8
88	0	6805	0	1.0	0	0	1.0	0	0
90	2	7950	24	1.0	2	14	1.0	2	14
Total, ind.	10000				7108			6403	
Weight of catch, kg			10531			4504			4136
Catch ratio						**0.43**			**0.39**

Upper panel **Lower panel**

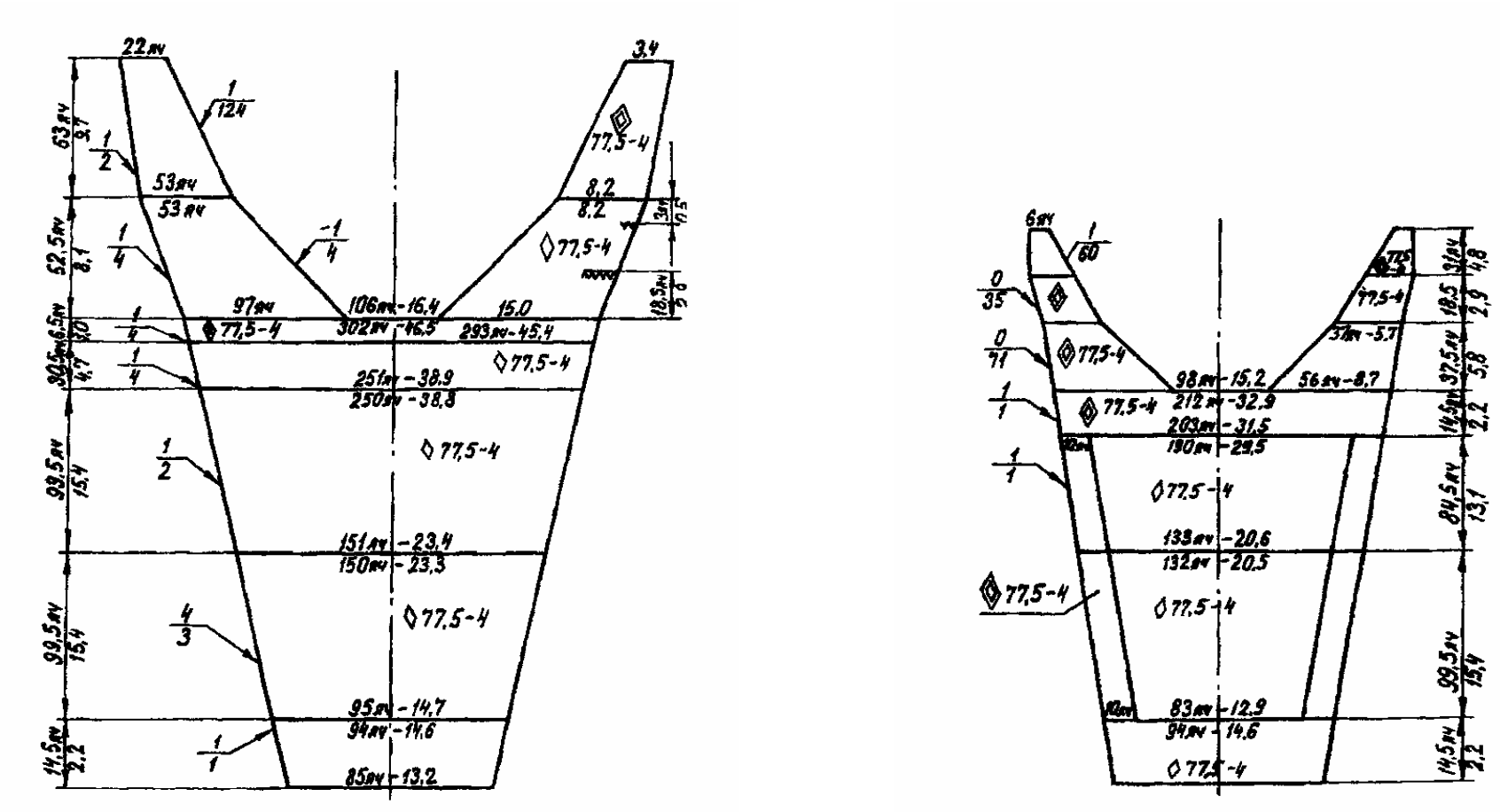

Fig.1 Cutting of bottom “Turbot”-454” 45.8 m trawl

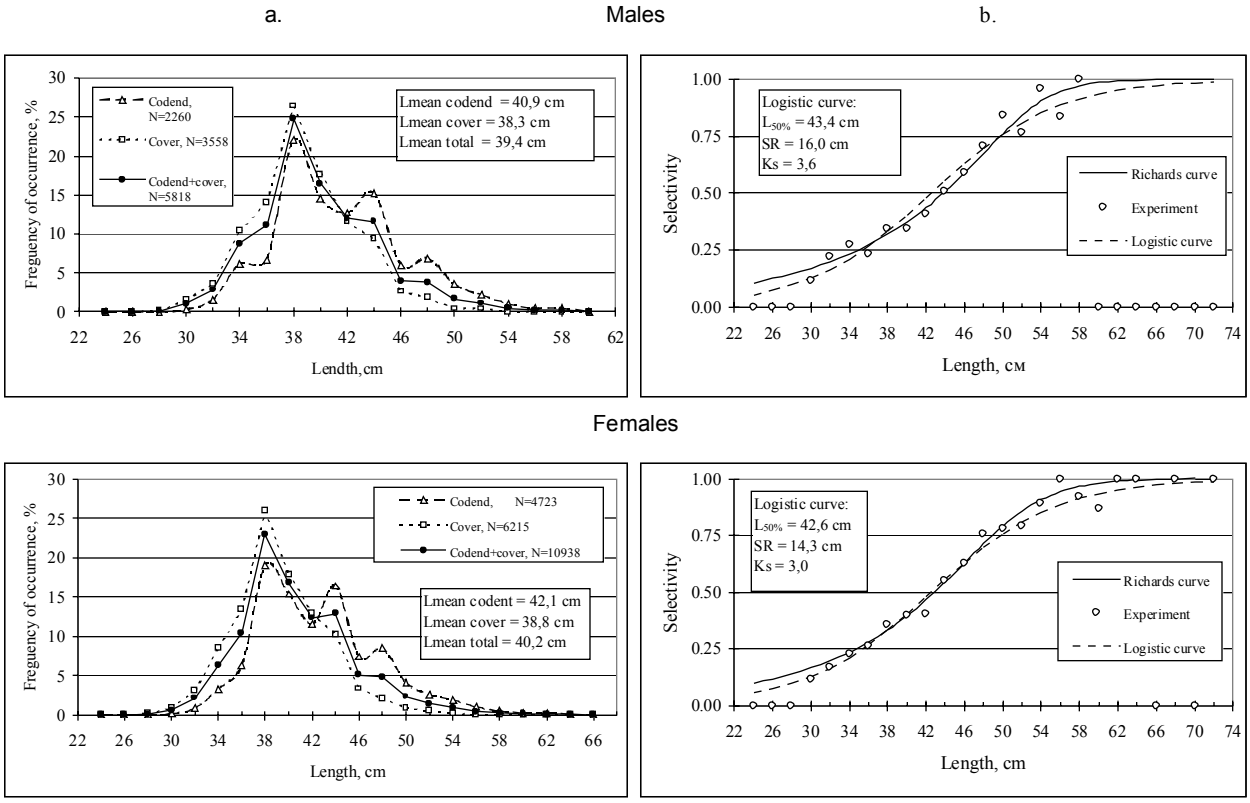

Fig. 2. Length composition of fish catch (a) and selectivity of codend with 152.2 mm mesh size (b) in relation to Greenland halibut with and without dividing by sex, Div. 3L of NAFO Regulation area, 2003.

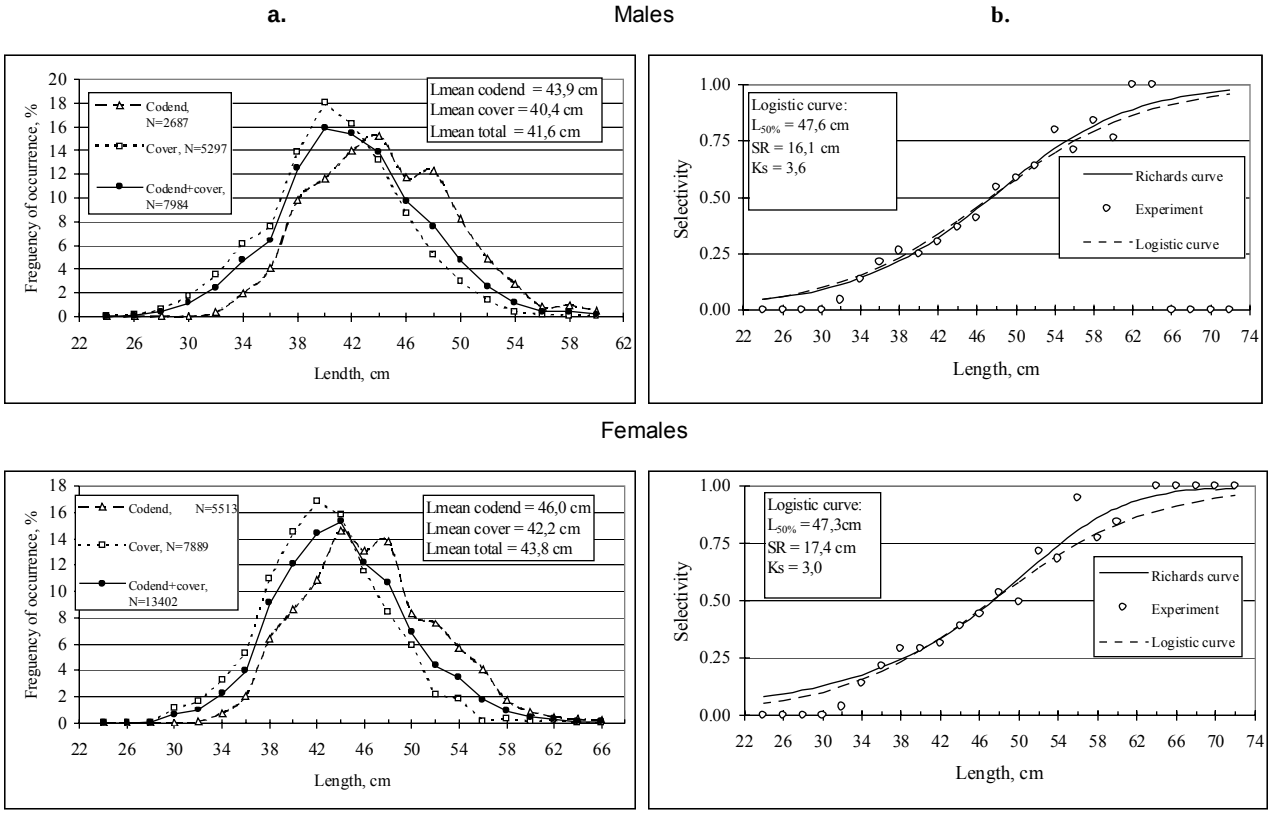

Fig. 3. Length composition of fish catch (a) and selectivity of codend with the length size of 162.6 mm (b) in relation to Greenland halibut with and without dividing by sex, Div.3L of NAFO Regulation area, 2003.

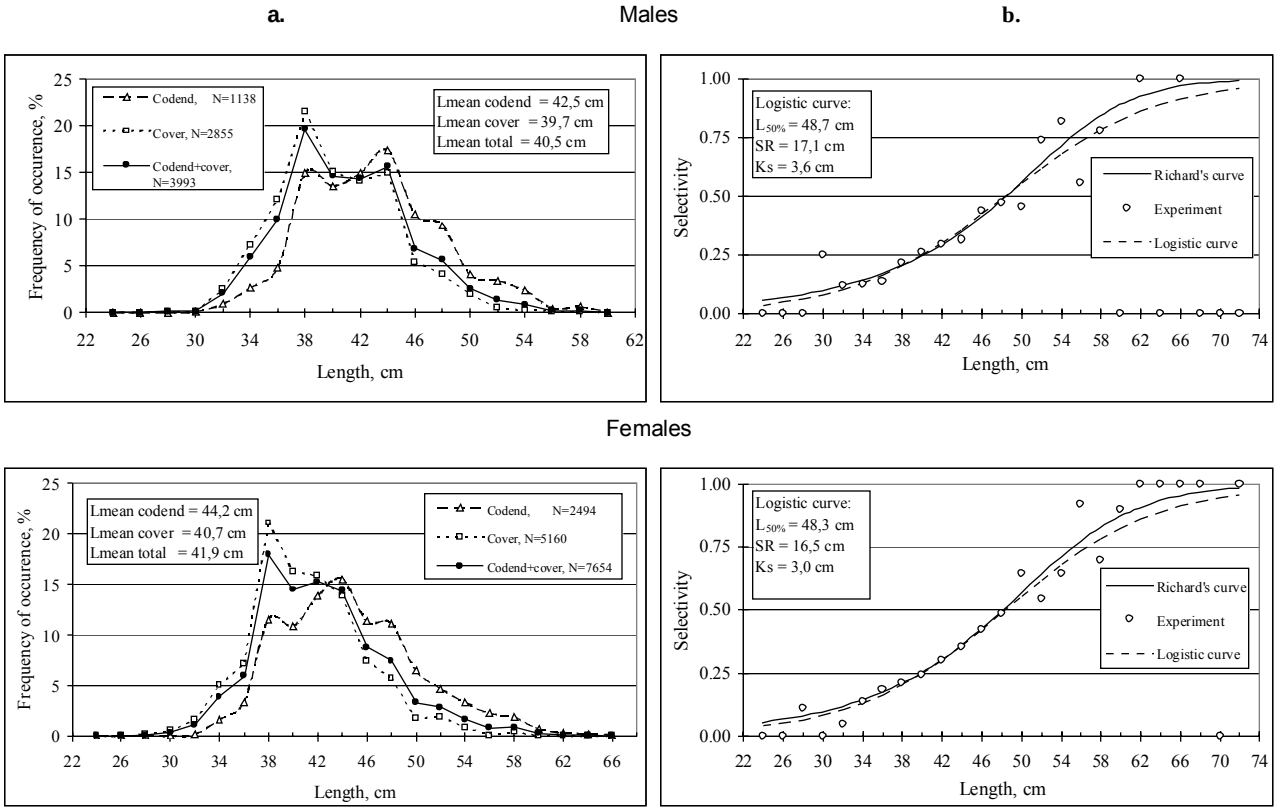

Fig. 4. Length composition of fish catch (a) and selectivity of codend with mesh size of 173.0 mm (b) in relation to Greenland halibut with or without dividing by sex, Div.3L of NAFO Regulation area, 2003.

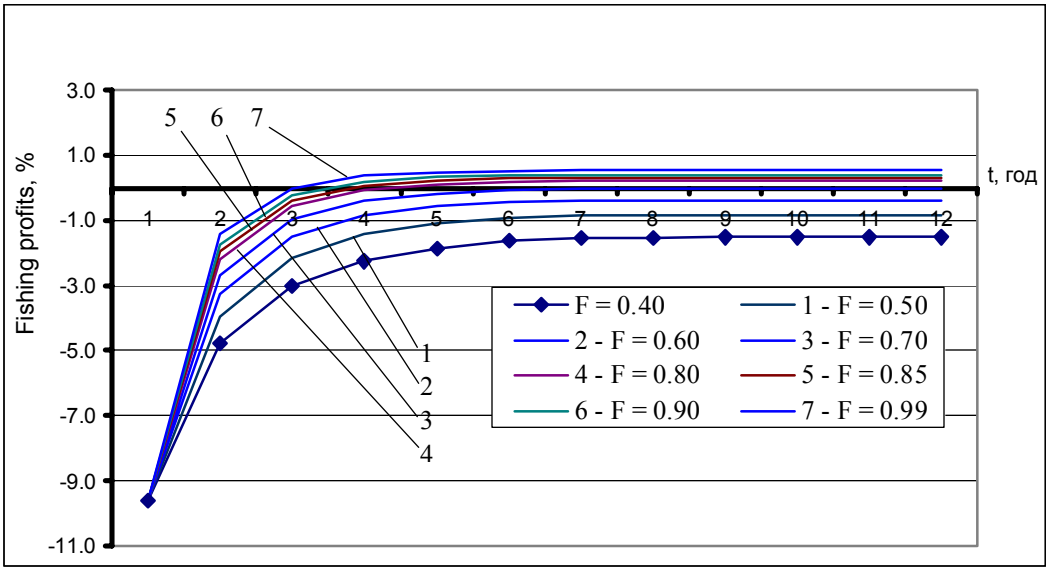

Fig. 5. Long-term profits of mesh size fishery as a result of the change of (from 130 mm to 135 mm) in Div. 3LMN of NAFO Regulation area with different fishing mortality FBAR 5-10

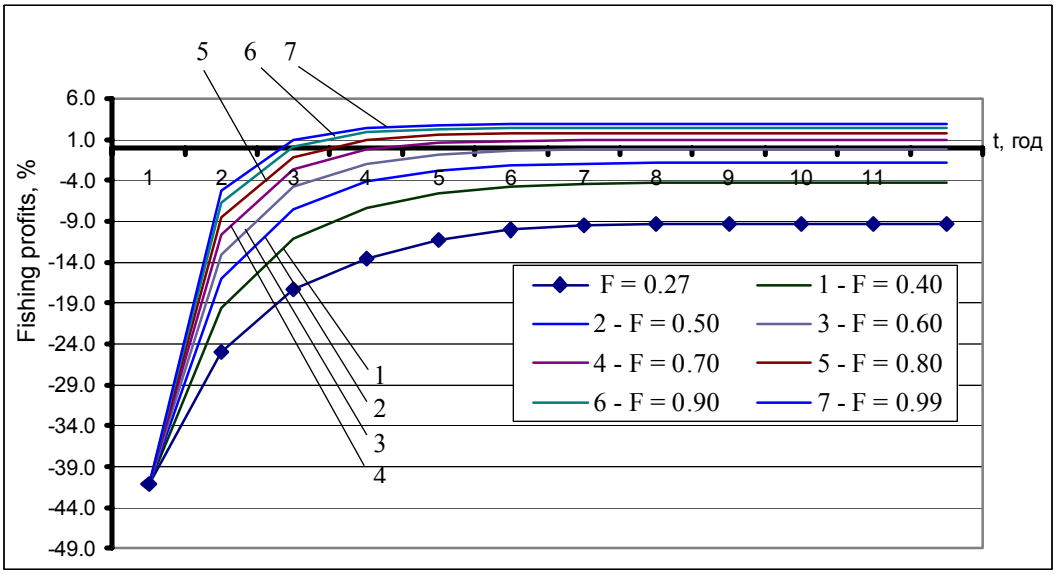

Fig. 6. Long-term profits of fishery when changing mesh size (from 130 mm to 150 mm) in NAFO Regulation area with different fishing mortality FBAR 5-10

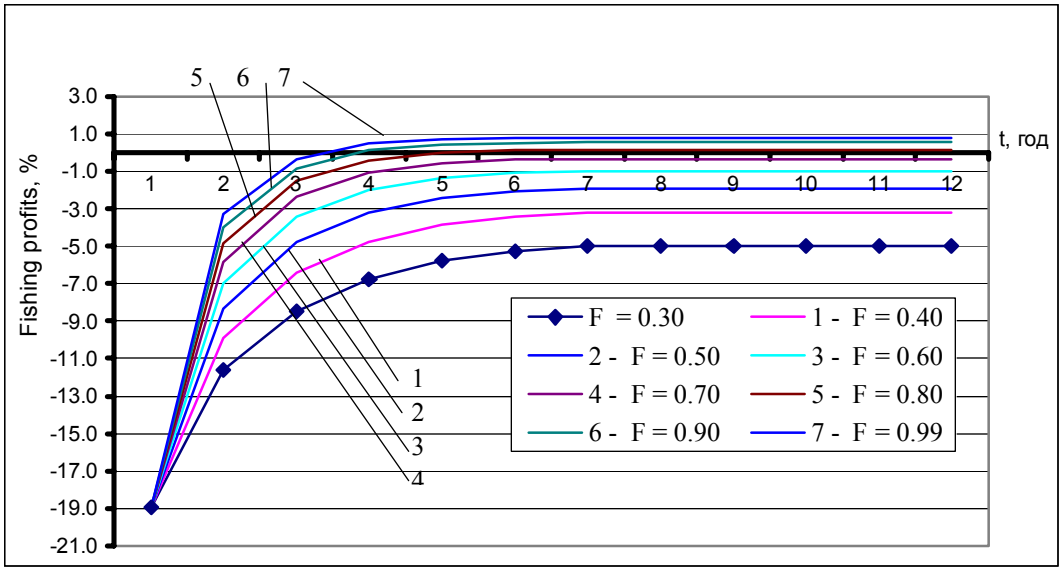

Fig. 7. Long-term fishery profits when changing mesh size from 152.3 mm to 162.6 mm in Div. 3LMN of NAFO Regulation area

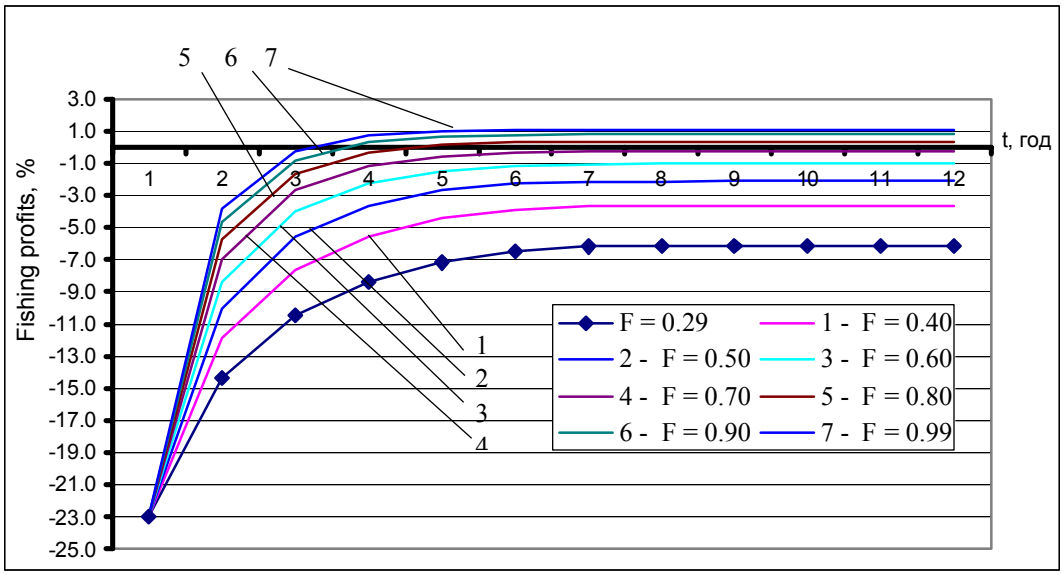

Fig. 8. Long-term fishery profits when changing mesh from 152.3 mm to 173 mm in Div. 3LMN of NAFO Regulation area with different FBAR fishing mortality