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A PRELIMINARY ASSESSMENT OF THE EFFECTS OF INTRODUCING A GRID IN THE TRAWL FISHERY FOR NORTH-EAST ARCTIC COD *

by

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Abstract

A number of studies have dealt with the testing of alterations of existing gears meant to reduce by-catch of non-target species or sizes. Such alterations can for example be changes in mesh size, mesh shape or introduction of sorting devices (grids, outlets etc.). Some of these gear alterations have also been implemented in the fishery. In the fishery for North East Arctic cod, e.g., the use of an approved sorting grid became mandatory in 1997. However, an assessment of what one should expect to gain concerning stock size, stock composition and thus yield by introducing a new gear has usually not been done, probably because it is difficult to do such assessments with age-structured stock models. Lately, however, there has been an increasing demand for studies dealing with these aspects. The aim of the present work is to simulate the effects on fishing mortality, stock size and yield by introducing a sorting grid in the trawl fishery for North East Arctic cod. Results from selectivity studies with ordinary commercial trawls with mesh size 135 mm in the codend, both with and without a sorting grid (Sort-X, single grid) mounted in the extension, are used in an age-length structured stock model, Fleksibest, to simulate these effects.

Introduction

By-catch of non-target species and sizes is a serious problem in fisheries (Alverson & al. 1994, Hall 1996), and an estimate of the yearly discard in commercial fisheries is between 17.9 and 39.5 million tons (Alverson & al. 1994). A number of studies to improve selectivity in existing gears by changing for example meshes (size, shape), introducing sorting devices (grids, outlets) etc. have been completed. Many of these gear alterations have also been implemented in the fishery. For example, the use of an approved sorting grid became mandatory in the fishery for North Arctic cod in 1997. Before such introductions characteristics of the gear, like catch (selectivity, loss of target species etc.), survival of individuals escaping and user-friendliness of

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the new gear are usually studied (Broadhurst 2000). However, the perhaps most important issue of them all, what one could expect to gain in stock size, composition and thus yield by introducing this new gear, has usually not been studied.

Stock effects of gear changes should always be assessed before introduction. In stocks with large year-to-year changes in recruitment, growth or mortality, like North East Arctic cod (Mehl 1991, Mehl & Sunnanå 1991, Nakken 1994), the effect of introducing a new gear cannot be assessed by comparing stock characteristics before and after the implementation. One problem of introducing a new gear without simulating stock effects in advance, is that if the stock size and thus quotas decline after the introduction, as observed in North East Arctic cod after 1997, the fishermen will naturally become more and more unwilling to use the new gear. Lately, the increasing criticism of the grid in Norway has consequently enhanced the demand for results showing how the use of a sorting grid influences the state of the cod stock.

An age-length structured stock model, Fleksibest (Frøysa & al. in press), have been developed to handle for example the large variations in size at age observed e.g. for NA cod (Mehl 1991, Mehl & Sunnanå 1991). Fleksibest models biological processes like growth, maturation and mortality as a function of length instead of age. In addition, Fleksibest contains an optimisation tool, changing model parameters to give the best possible fit between observed data (catch, surveys) and the model. The model part of Fleksibest can also be used alone as a pure simulation tool. In our study Fleksibest is used as a pure simulation tool, but the input for the simulations are real data from the best available optimisation run. Fleksibest is well suited for simulating stock effects of using different fishing gears, since selectivity is linked to size (and length is a good proxy for size) whereas most stock models are structured by age. Our study compare simulated stock size (total stock, spawning stock), catches and fishing mortality for a fishery with an ordinary cod trawl against a fishery with a sorting grid mounted in the extension ahead of the codend. In our simulations, all parameters but the selectivity are kept constant.

Material and methods

SELECTION EXPERIMENTS

The selection curves used in our simulations come from data from selectivity studies on mesh selection and grid selection (Table 1). For the mesh selection, a logistic selection curve gave the lowest deviance. For each of the 16 hauls, a logistic selection curve was fitted to the data by CC2000 (ConStat) and then a mean curve (Table 2) for all hauls was calculated by EC (ConStat). The grid selection curve is calculated by Isaksen & al. (in press), and is a mean curve for the selection studies comparing single grid (Sort-V) and Sort-X (Table 1). The selection curves for the two grids were not significantly different, and all the hauls were thus combined. The common mean selection curve (Table 2) was calculated by the same method as described for mesh selection.

Table 1 The selection experiments. Vessel: Anny Kræmer, selection curve: logistic.

Date	Area	Survey	Experiment	# hauls	
25. August - 5. September 1989	East of Rybackya Bank, Barents Sea	Mesh selection	Covered codend	16	Isaksen & al. (1990)
15. - 28. August 1997	Around Bear Island	Grid selection	Cover bag over grid and blinded codend	19	Isaksen & al. (1998), (in press)
3. -16. August 1998	Around Bear Island	Grid selection	Cover bag over grid and blinded codend	29	Isaksen & al. (1998), (in press)

Table 2 Selection parameters for mesh and grid selection (see also figure 1)

Selection curve	Experiments	l_{50}	SR	α	β
mesh	1989	47.09	13.36	-7.74	0.1645
grid*	1997, 1998	51.95	12.08	-9.45	0.1819

* from Isaksen & al. (in prep.)

The formula for the logistic selection curve is

$$r(l)=\frac{1}{1+e^{-\alpha-\beta l}}$$

where r(l) is the retention probability, and α and β are parameters.

l_{50}, the length where the probability of retention is 50 %, is calculated as

$$l_{50}=-\frac{\alpha}{\beta}$$

and the selection range, SR, as

$$SR=l_{75}-l_{25}=\frac{2\ln(3)}{\beta}$$

In our simulations we are interested in fleet selectivity, but we only have information about the gear selectivity and use this instead since the aim of the study is to compare trawl fisheries with and without grid. The difference between fleet and gear selectivity is probably the same whatever gear used, and these simulations should thus be valid for comparisons.

We are interested in the total selection of the gear (within the net), but in the selectivity experiments with grid only grid selectivity has been examined. We thus do not know anything about the potential selectivity in the codend when a grid is mounted. To get a realistic estimate of the total selection we have included two possible scenarios of selection in a trawl with grid:

1) Exclusively grid selection, no selection in codend

2) Grid and codend selection independent (i.e. the grid does not influence the selection in the codend). The total selection thus becomes the product of the retention in the grid (1997, 1998) and the retention in the codend (1989) resulting in a logistic times a logistic selection curve (see figure 1).

The truth is probably somewhere in-between, and in June this year both grid and codend selection was be examined simultaneously.

This gives 3 different simulations:
1) Mesh selection
2) Grid selection
3) Mesh and grid selection

In the simulations only the selection curves (figure 1) are varied.

For the simulations we need a stock model, and chose Fleksibest.

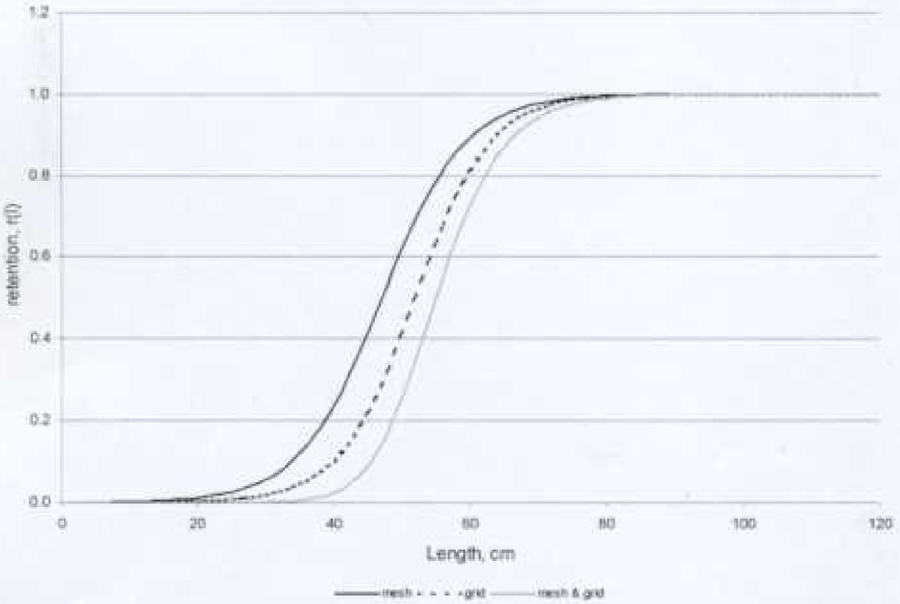

Figure 1 The selection curves used in the 3 simulations

FLEKSIBEST

Fleksibest is an age-length structured stock model, where a self-contained population model is fitted to observed data as reported landings, survey indices and stomach data (Frøysa & al. in press). The different age-length classes are kept track of by the model's matrix structure. Stock models are usually age structured, but in boreal systems variations in inter-annual growth and consequently size at age are large (Mehl 1991, Mehl & Sunnanå 1991). Since most biological processes, like growth, mortality and reproduction are closer related to length than age, stock models in such areas should be length structured (Frøysa & al. in press). This is also favourable when simulating changes in the selectivity of a fishery, since selection is connected to size which length is a good proxy for.

The current version of Fleksibest divides the cod stock into an immature and a mature cod stock, uses one area and four equal time steps a year. Each length class is 2.5 cm and true age is used for all age classes except for the 12+ class, which is a plus group. The length span is 5-135 cm and the age span 3-12+. The immature stock includes age classes 3-10 years, and the mature stock 5-12+ years. Length classes are 5-120 cm for the immature stock, and 45-135 for the mature stock. These settings are, however, flexible. Fleksibest contains models for growth, predation due to cannibalism, fishing mortality and maturation (Frøysa & al. in press). During a stock assessment with Fleksibest observed and modelled stock and fisheries characteristics are compared, and the model parameters are optimised to minimize the deviance between modelled and observed data giving the best possible fit of all chosen parameters at the same time.

Growth

The quarterly mean growth is modelled as (figure 2)

$$\Delta l(s,y,t) = k(s) \times k(y) \times \Delta t$$

where s is stock (immature, mature), y year, t time step, Δl growth in cm, k(s) a stock factor (immature: 1, mature: 0.8), k(y) yearly growth (cm year^{-1}) and $\Delta t = 0.25$ year. Based on the mean growth, the cod in a length group is transferred to new length groups in the next time step. For more details see Frøysa & al. in press.

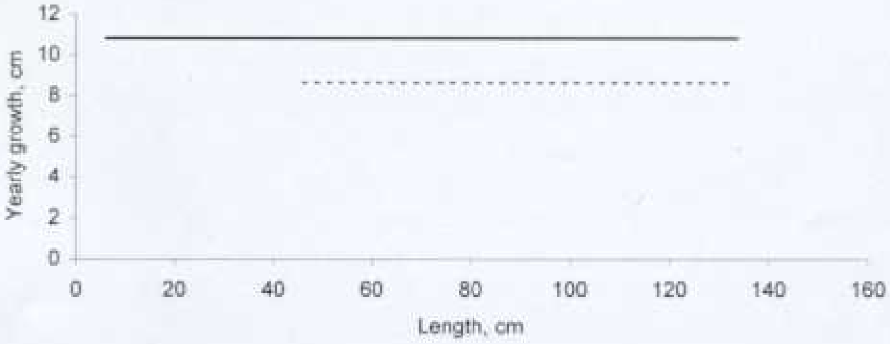

Figure 2 The growth is not length-dependent, and the figure show the yearly growth of the immature (solid line) and mature (broken line) stock for 1999. k (1999) = 10.8 cm year^{-1}.

The growth in weight is not modelled explicitly. Mean weight for each length group at each time step is given by observations.

Maturation

The maturation is modelled by a logistic function (figure 3)

$$P(l) = \frac{1}{1+e^{-4\alpha(l-l_{50})}}$$

where l is length, P(l) the probability of maturation (i.e. being moved from the immature to the mature stock) for a given length, l_{50} the length with a 50 % probability of maturation (78.44 cm) and α a parameter deciding the slope of the maturation curve (0.03). In addition there is a minimum age of maturation (5 years), working by returning "maturing" fish (fish moved from the immature to the mature stock) younger than five years back to the immature stock.

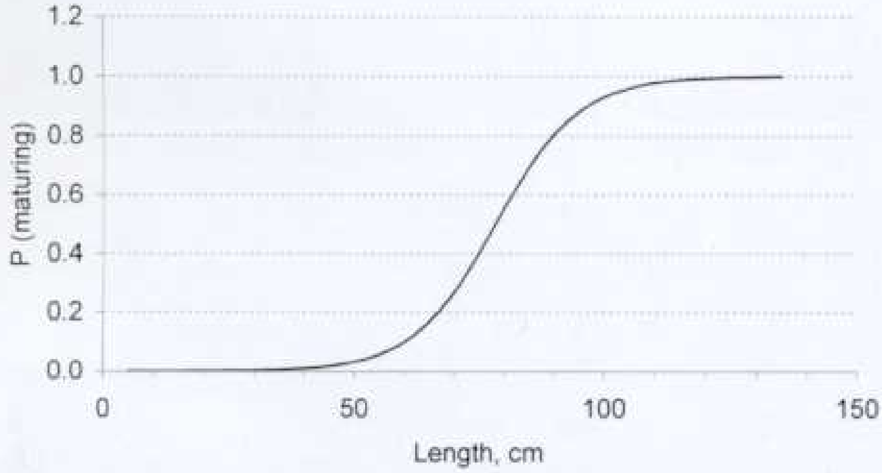

Figure 3 The maturation model used in the simulations. Note that P (maturing) is the probability of being moved from the immature to the mature stock for a given length, and thus not the proportion of mature individuals in the entire stock.

Mortality

The quarterly mortality is modelled as

$$Z(l,t) = F(l,t) + M(l,t)$$

where l is length, t time step, Z(l,t) total mortality (quarter^{-1}), F(l,t) fishing mortality (quarter^{-1}) and M(l,t) natural mortality (quarter^{-1}).

Further, fishing mortality is modelled as

$$F(l,t) = \sum_{f=1}^{N_f} d(f,t) \times S(f,l)$$

where l is length, t time step, f fleet (1 fleet = trawl in these simulations), d(f,t) the fishing pressure of a specific fleet during time step t and S(f,l) the fleet selection curve. The three simulation runs are equal in every aspect (models, input) but the selection curves. d(f,t) is defined as

$$d(f,t) = \theta(f,t) \times \phi(f,y)$$

where y is year, $\phi(f,y)$ yearly level of fishing mortality for fish lengths fully recruited to the fisheries of a specific fleet and $\theta(f,t)$ a factor distributing $\phi(f,y)$ on time steps by observed weight of catch (see Frøysa & al. in press).

The natural mortality is modelled as

$$M_s(l,t) = M1(l) + M2_s(l,t)$$

where s is stock (immature / mature), l length, t time step, M total natural mortality, M2 natural mortality due to cannibalism (only for immature stock) and M1 residual mortality (0.05 time $step^{-1} = 0.2\ year^{-1}$).

The cannibalism mortality fish of length l is exposed to is modelled as

$$M2(t,l) = \frac{\alpha e^{-\beta \times l^{\gamma}} \times B(t,2l_+)}{V(t)^{\delta}}$$

where t is time step, l length, $B(t,2l_+)$ biomass (ton) of cod with length 2l and larger, V(t) capelin biomass (ton, food for cod). The cannibalism mortality increase with decreasing capelin biomass and increasing biomass of large cod, $B(t,2l_+)$. In our simulations cannibalism mortality range from 0.0169 to 0.3000 $year^{-1}$ for 3 year old cod and from 0.0047 to 0.0934 $year^{-1}$ for 4 year-olds.

INPUT FOR THE SIMULATIONS

The aim of this work was to study the effects of introducing the sorting grid in the cod fishery by modelling the stock development from 1985-2000 for a trawl fishery both with and without grid. All input parameters and models but the selection (see equation for fishing mortality) was kept constant between the three simulations. The Fleksibest model used as a pure simulation tool needs information about:

- Initial year: number and length distribution (defined by a normal distribution) for all ages, distributed among the immature and mature stock
- Recruits (3 year-olds): number and length distribution (normal) every year
- Yearly fishing mortality for each fleet
- Mean growth each year
- Residual natural mortality
- Maturation: maturation model (estimate of l_{50}), and
- Total biomass of capelin each time step for calculation of cannibalism mortality

Our simulations cover the period 1985-2000, and the input needed (see table 3-4 and the text describing the model) comes from the best available assessment run with Fleksibest.

Table 3 Input for Fleksibest in our simulations. Initial numbers and length distribution (defined by a normal distribution) for the immature and mature stock in the first time step in the first year (1985).

	Immature			Mature		
Age	Number, 10^7	Mean length, cm	SD(mean length), cm	Number, 10^7	Mean length	SD(mean length), cm
3	52.390	40.6	5.1			
4	31.610	48.7	4.1	0.000	51.0	14.9
5	8.780	61.3	4.9	0.868	59.6	1.1
6	2.980	71.1	5.3	1.680	71.1	6.7
7	0.920	81.2	5.4	1.130	79.0	3.2
8	0.100	85.7	8.7	0.540	88.2	5.1
9	0.010	90.0	8.7	0.300	97.3	3.1
10	0.000	90.0	8.7	0.190	105.2	5.4
11				0.040	114.0	10.6
12+				0.030	114.0	3.3

To do these simulations we had to do some assumptions:

- Fleet selection assumed equal to gear selection
- All the catch was taken by one fleet, the trawler fleet (with or witout grid, depending on simulation)
- No escapee mortality after gear contact
- Recruitment and growth not influenced by gear type (with or without grid) and potential consequences of using this gear
- Yearly fishing mortality experienced by fish lengths fully recruited to the fishery identical between simulations

Table 4 Input for Fleksibest in our simulations. The growth factor, k(y), numbers and mean length of recruits (3 year-olds), total fishing mortality for lengths fully recruited to the fishery, $\phi(y)$, and capelin biomass (the value for the first time step each year is shown, but the input is for each time step).

Year	k(y), cm year^{-1}	# recruits, 10^7	Mean length recruits, cm	$\phi(y)$, year^{-1}	Capelin biomass, tons
1985	9.4	*	*	0.70	1884000
1986	7.0	103.94	34.3	0.87	510000
1987	4.7	28.67	32.0	0.95	156000
1988	9.2	20.47	30.0	0.98	115000
1989	13.3	17.27	33.5	0.67	718000
1990	12.6	24.27	38.8	0.28	2011000
1991	8.4	41.15	42.6	0.32	6307000
1992	9.1	71.39	40.0	0.45	7406000
1993	6.1	89.66	35.5	0.55	3777000
1994	10.1	81.48	30.4	0.87	737000
1995	8.5	64.82	29.9	0.79	156000
1996	9.7	43.43	28.3	0.70	313000
1997	9.7	73.1	28.6	1.04	779000
1998	10.7	89.44	29.3	0.93	1240000
1999	10.8	58.51	29.0	0.96	2376000
2000	10.8	71.15	28.7	0.96	2264000

* see table 3

Results

These simulations show that with our assumptions, the use of a grid in the trawl fishery reduces the fishing mortality (figure 4) for 3-6 year old fish with between 0.05 (only grid selection) and 0.1 (both grid and mesh selection). The fishing mortality for fish aged 7-12+ stays the same.

Concerning total stock biomass (figure 5), the modelled gain by using a grid is between 150 000 (only grid selection) and 300 000 tons (both grid and mesh selection) at the end of the simulation period. For the spawning stock (figure 5), the modelled increase is between 50 000 (only grid selection) and 100 000 tons (both grid and mesh selection).

When looking at the weight of total catches (figure 6), the first 2 years of the period (1985-1986) the catches would be lower (maximum 50 000 tons) when using a grid in the trawl compared to no grid. However, already in 1988 the modelled catches are higher in the simulated fishery with grid. This can be explained by the observed increase in stock biomass when fishing with a grid. When splitting the catches by age, we can see that with a grid there is much lower modelled catch of 3- and 4-year-olds, whereas the catches of 5-year-olds are about the same in all the three simulations. For fish of age 6+, the catches after 1986 are higher in the simulated fishery with grid, which can be explained by higher stock biomass. The observed catches are also included in the figures (figure 6), and coincide quite well with the modelled total catches and catches of age 5+. However, for 3- and 4-year-olds there is a large mismatch between observed and modelled catches.

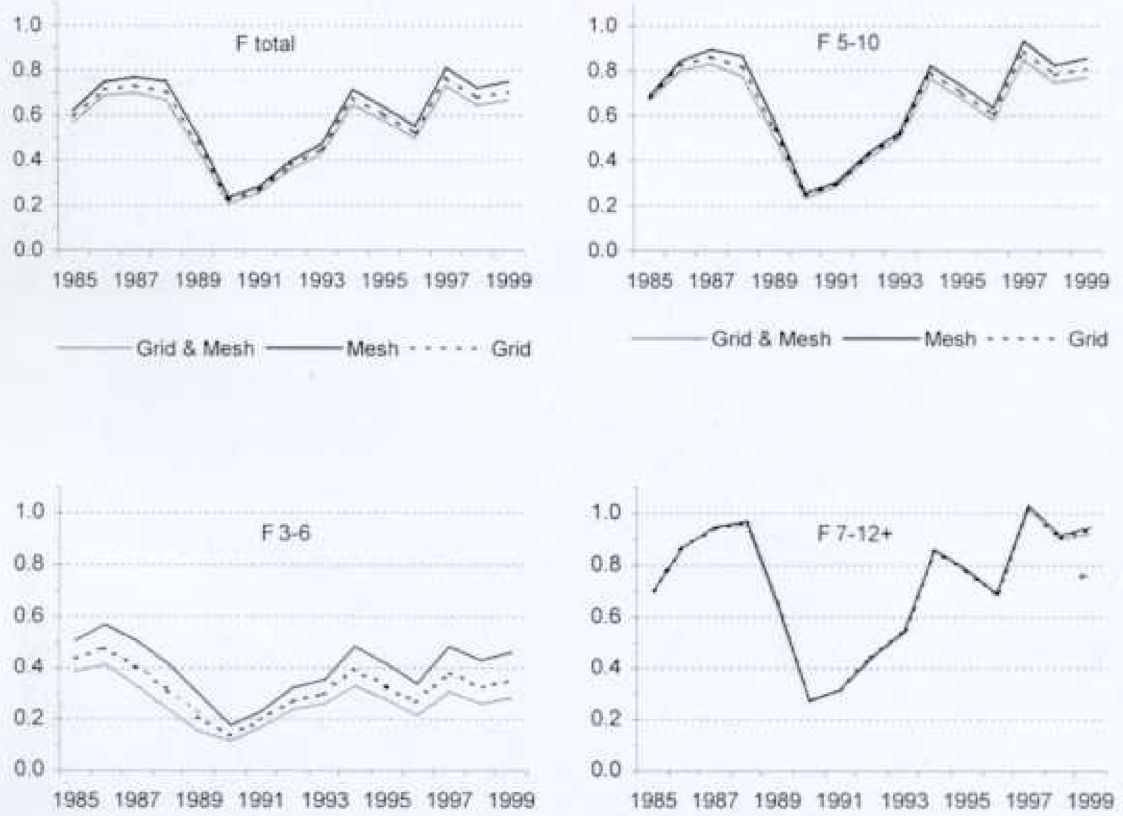

Figure 4 The fishing mortality in each of the 3 simulations (mesh, grid, mesh & grid – see selection experiments, material and methods) for each year in the period 1985-1999. F total is the arithmetic mean fishing mortality for all age classes (3-12+ years), F 5-10 for age 5-10, F 3-6 for age 3-6 and F 7-12+ for age 7-12+.

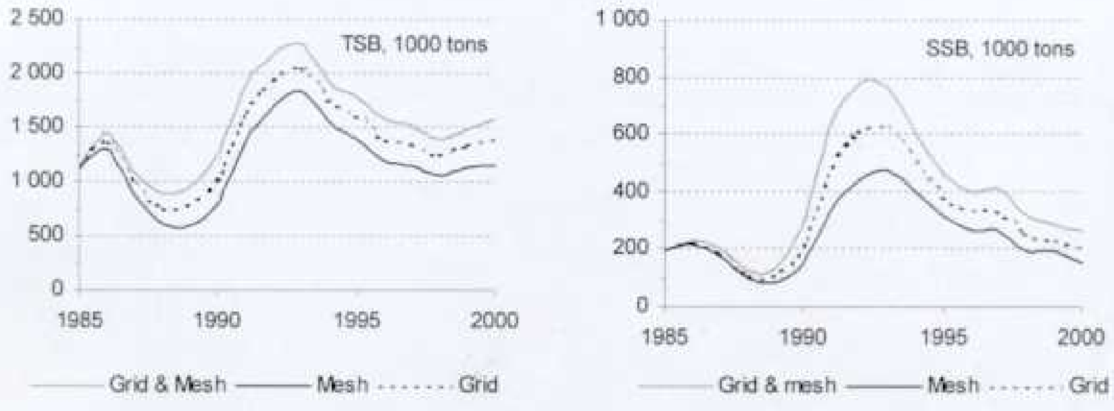

Figure 5 Total stock biomass (TSB) and spawning stock biomass (SSB) in thousand tons for each of the three simulations (mesh, grid, mesh & grid – see selection experiments, material and methods) each year in the period 1985-2000.

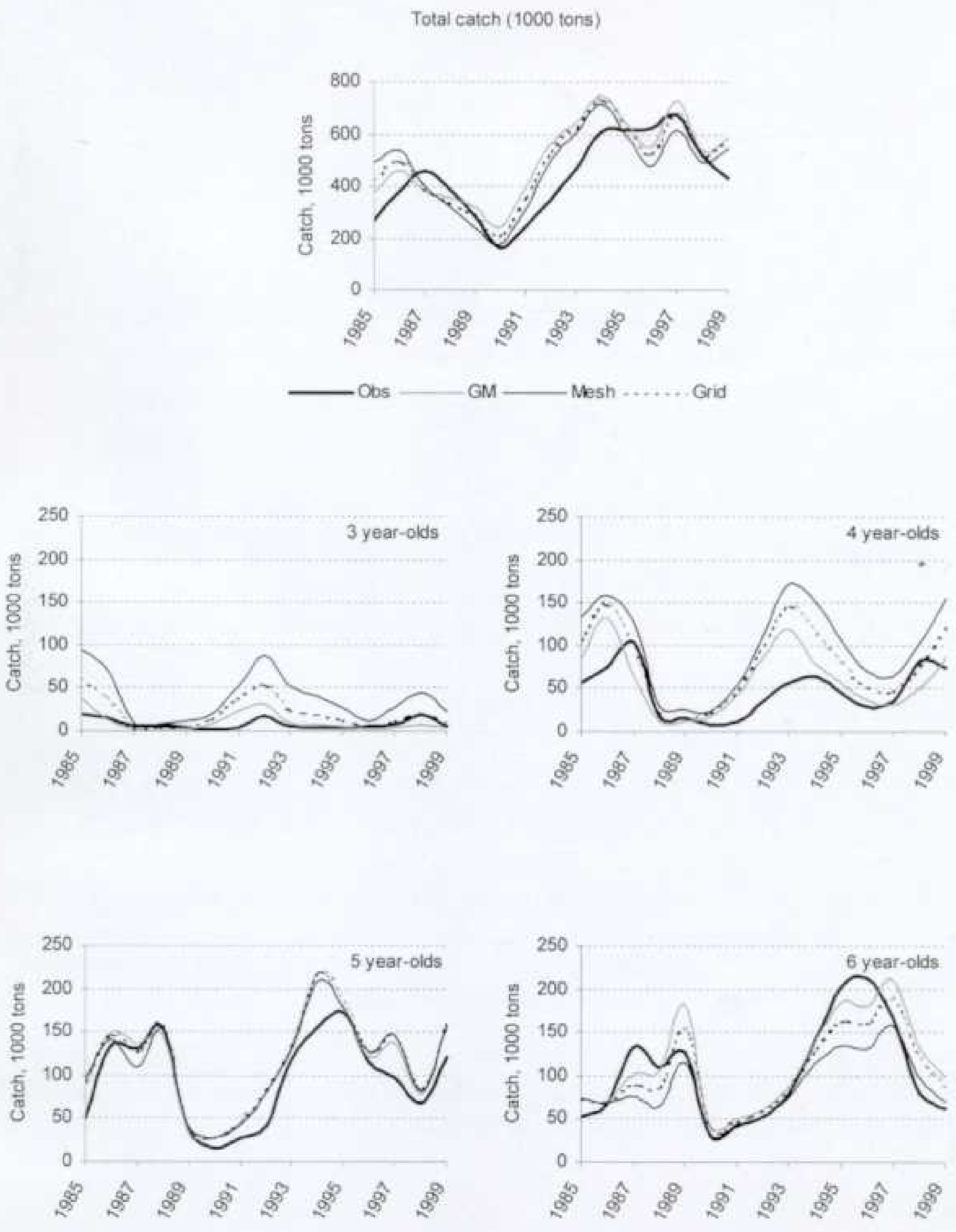

Figure 6 Observed catches (Obs) and modelled catches (for each of the three simulations: mesh, grid, grid & mesh (GM) – see selection experiments, material and methods) in thousand tons for each year in the period 1985-1999. The total catches and the catches of 3-, 4-, 5-, and 6-year-olds are shown.

Discussion and further work

This preliminary assessment of the effects of introducing a grid in the trawl fishery for North-East Arctic cod, indicate that the effects are positive. In our simulations, the fishing mortality of 3-6 year-olds was reduced, leading to an increase in stock biomass after about 3 years (1988). The total catch decreased the first 2 years, but subsequently increased as the general increase in stock biomass compensated for the loss of 3- and 4-year-olds in the catches. It thus seems that by saving 3- and 4-year-old fish and reducing the fishing pressure on 5- and 6-year-old fish, a reward in stock biomass is achieved within a few years. We might thus speculate that the state of the North East Arctic cod stock might have been even worse than today without the introduction of the grid in the trawl fishery.

There is a large mismatch between modelled and observed (reported) catches, especially for 3- and 4-year-old fish. The most obvious reasons for this mismatch may be the use of gear selection instead of fleet selection in the simulations, the use of only one fleet in the simulations and discard / misreporting. The most likely explanation is a combination of all these factors. If the fishermen deliberately avoid areas with much small fish, the fleet selection will mirror this by being located further to the right, with a higher l_{50}, than the gear selection. The use of only one fleet, the trawler fleet, in these simulations can also explain the difference. The gillnet fishery for example, also contribute much to the catches of cod (Toresen & al. 2000). This fishery is mainly located in the cod's spawning area, and by omitting this fleet the catches of small cod were overestimated. Discards and misreporting of catches can also explain the differences between modelled and observed catches.

The selection experiments, which the selection curves in the simulations are based upon, are all done at about the same time of the year and with the same vessel, but in different years (1989, 1997, 1998) and partly in different areas (mesh: east of Rybachya Bank - Barents Sea, grid: around Bear Island). However, in all the experiments the catches were quite high and the size distribution of cod good (both small and large fish). The difference in year and area may, however, have affected the comparability of the selection experiments (Wileman & al. 1996), and in June this year a selection experiment looking at both mesh and grid selectivity at the same time was carried out in the area around Bear Island. The data are now being analysed.

In the simulations, certain assumptions are made. The gear selectivity from each selection experiment is used as fleet selectivity in the simulations. Thus, the results must be considered as indices of differences between fisheries with and without grid instead of absolute differences. If the fishermen's behaviour do not differ too much when using grid compared to when not using grid, the error of using gear selectivity as fleet selectivity should be similar in all these simulations, thus providing comparability. The use of only one fleet in the simulations overestimates the effect of introducing a grid, and future simulations will be run with several fleets (handline, gillnet, Danish seine, trawl). The assumption of no escapee mortality should be reasonable, as nearly 100 % survival has been observed for cod after escaping from a trawl (Soldal & al. 1993). The input for the simulation period, 1985-2000, (numbers, mean and SD of length for 1985 [initial year] and recruits, yearly growth, cannibalism and maturation model) come from an assessment run of Fleksibest, where the models of Fleksibest are fitted in the best possible way to the observed data (survey indices, reported catches and stomach data for cod) (see Frøysa & al. in press), and the input should thus be reasonable. The residual natural mortality was set to 0.2 $year^{-1}$, which is the value used by the AFWG. The yearly recruitment and growth were input to the model (model estimates from observed data), and there were large year-to-year variations (table 4). The input was kept constant for all simulations, as no model for a stock - recruitment or a stock size – growth relationship is included in the model. The existence of such relationships would influence the stock in opposite directions, and some of the bias added to the simulations by keeping recruitment and growth constant between simulations would thus cancel out. A large spawning stock should, in the long run, give a higher recruitment than a small spawning stock (Pitcher & Hart 1982), and the growth may decrease if the stock size increases. The uncertainties about the model foundation for stock – recruitment and stock size – growth relationships may cause a choice of a certain model linking the parameters to stock size to create more uncertainty than keeping these parameters constant between simulations.

In the near future, further simulations on the subject of estimating the effects of introducing a grid will be run. More fleets (gillnet, handline, Danish seine, trawl) will be included in the following runs. We will also run a simulation with a theoretical mesh selection curve with the same l_{50} as for grid, to evaluate if similar results as for grid could be achieved by increasing mesh size. By now, the fishermen are allowed to take out the grid when the weather is bad, and this can be modelled by splitting the trawler fleet into two fleets. It is also possible to include escapee mortality in the simulations to see how this might affect the benefits of using a grid.

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