THE DEPENDENCE OF MANAGEMENT STRATEGIES FOR BARENTS SEA COD AND CAPELIN ON THE RECRUITMENT MODELS

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ABSTRACT

The least studied subject in the assessment and management of Barents Sea cod and capelin is the management strategy. Using a cod-capelin-herring model, the uncertainty in the management strategy of cod and capelin arising from uncertainty in the spawning stock-recruitment relationship is investigated using stochastic methods.

INTRODUCTION

The Barents Sea ecosystem is to a large extent dominated by North-East Arctic cod, capelin and Norwegian spring spawning herring (Hamre 1990). Cod and capelin spend their entire life in the Barents Sea (although a part of the cod stock may spawn far south on the Norwegian coast and then return to the Barents Sea area) while herring larvae flows into the Barents Sea when there on irregular intervals are good recruitment conditions for herring. At about age 3 the herring leaves the Barents Sea. Capelin and herring are food items for cod. The consumption by cod is an important part of the natural mortality on cod and capelin.

The management strategy used at present for North-East Arctic cod and Barents Sea capelin does not utilize the biological knowledge at present available for the ICES Arctic Fisheries and Atlanto-scandian Herring and Capelin working groups.

The management of North-East Arctic cod has been discussed by Jakobsen (1993). He argues that there appears to be no argument for allowing fishing mortalities to be on the average above the F_{med}= 0.46 level, and that simulations using historical data indicate that it would be safer to aim at a somewhat lower level of exploitation. The spawning stock biomass should also be kept above a critical level of about 0.4 million tonnes, above which the recruitment has not failed. Trying to keep the cod stock at a high level may, however, backfire if there is not enough food to support it. The guidelines given in that paper are used in the management of North-East Arctic cod at present. There are, however, important data deficiencies in the historical time series of cod (Anon 1994a), which when corrected may give different results for the biological reference points underlying the management.

Keeping the fishing pressure at F_{max} would be a logical management rule if one ignored the effect the spawning stock has on the recruitment. If the recruitment is monotonically increasing with the spawning stock (Beverton-Holt type) one would expect that inclusion of recruitment considerations would lead to a lower target F-value than F_{max}. If there is a well-defined maximum (Ricker type) as would be the case if cannibalism were important, both a lower and a higher optimum F-value than

F_{max} could be possible. However, it is very unlikely that the value of the spawning stock giving maximum recruitment would be lower than 0.4 million tonnes. An argument against using F_{max} is its sensitivity towards the (guesstimated) natural mortality (Jakobsen 1993). The nearly non-systematical relations between recruitment and spawning stock obtained by running the standard tuned VPA have till date precluded any "fine-tuning" of the cod management procedure. The fact that all considerations lead to the conclusion that the fishing mortality should be lowered from the pre—1990 level has given sufficient rationale for the present management policy.

Now that the cod stock has increased and the food supply is diminished because of the recent capelin stock collapse, possibly leading to increased cannibalism, this may not necessarily longer be so. The present paper seeks to overcome some of the methodological difficulties connected with including recruitment processes into the management scheme for cod. The model used and the stochastic way of treating it in experimenting with management strategies may be a useful tool in the management of the North-East Arctic cod stock in the future.

The Barents Sea capelin stock has been managed using a constant escapement strategy, i.e. a quota has been set that allows a target amount of capelin to spawn. When the regulation of the capelin fishery started by the end of the 70's the target spawning stock was set to 0.5 million tonnes without any other justification than the biologists "gut feeling", there were simply not adequate data to estimate an optimal strategy. By the mid 80's a single species capelin model was developed that yielded an optimal spawning stock of about 0.4 million tonnes (Hamre and Tjelmeland 1982). In the present-day management of the capelin stock, the spawning stock is calculated by taking the effect of the predation from cod into account using the extensive PINRO-IMR stomach content data base and models for the gastric evacuation rate of cod (Bogstad and Gjøsæter 1994). However, no target spawning stock has yet been estimated taking into account the actual size of the cod stock, so that the former target spawning stock level of about 0.5 million tonnes is still used. A first attempt to estimate the target spawning stock level taking predation from cod into account, has been done by Tjelmeland and Bogstad (1993).

The present paper gives a method for including into the development of new management strategies the significance of uncertainties in spawning stock-recruitment relationships. This work is done with a new model and must be viewed as being preliminary. However, it is important that the method suggested in the paper for estimating management strategies is thoroughly discussed among scientists working with Barents Sea management problems.

THE AGGMULT MODEL

The Aggmult model is developed in connection with the Norwegian research programme "Multispecies management" initiated by the Norwegian Fisheries Research Council (later merged with other research councils to Norwegian Research Council) in 1990 and finished in 1994. The idea behind the programme was to link biological research with bioeconomical and social sciences research hoping to improve the management strategies used at present in the Barents Sea. At the initiation of the programme two multispecies models were in development at IMR, the Multspec model that is an area distributed multispecies model for the Barents Sea and the Capsex model that primarily is a capelin model, but that is augmented with some cod dynamics and herring influence on capelin recruitment. However, neither of these models could serve as the bridge between biological and economical modeling, the former because of its complexity rendering it impractical for direct use in bioeconomical management considerations and the latter because it is too restricted in scope. Therefore, it was decided to develop a new model that in essence would be an area- and length integrated version of the Multspec model: the Aggmult model.

Since an important goal of the programme was to incorporate species interactions into new management schemes it was mandatory to have a model that could be usable for experimenting with management strategies, both of short-term and long-term nature. That is, the model had to have the recruitment process for the various species as an integrated part, rooted in data as well as

possible. The focus for work with the Multspec model has to date been on cod-capelin interactions, and only little experience with this model was available for the recruitment processes. Therefore, the recruitment part of the Aggmult model had to be developed with no aid from Multspec.

A vital part of the Aggmult model is the plankton submodel. It serves two purposes: The plankton abundance 1) governs the growth of the plankton feeders and 2) serves as a buffer for the predation mortality. In the present paper, the emphasis is on the latter aspect. The feeding level halfvalue for the plankton feeders is set so low that the feeding level is close to 1 for all levels of plankton abundance that have been used. Therefore, the growth of the plankton feeders is totally determined by the historically observed growth rates. The predation mortalities, however, are dramatically influenced by the plankton levels, especially in the 0-group stages.

The biological entities in the Aggmult model are:

1. Small plankton organisms in the northern Barents Sea, primarily food for capelin.
2. Small plankton organisms in the southern Barents Sea, food for capelin and herring.
3. Large plankton organisms, food for cod, herring and capelin.
4. Herring, age distributed.
5. Capelin, age distributed.
6. Cod, age distributed.

A thorough description of the model and the estimation process is given in the model documentation (Tjelmeland 1995). Here, a more brief and sketchy overview of the model is given.

The time sequencing of the model is the same as for the Multspec and Capsex model. The time step is one quarter (three months) compared to one month in Multspec and Capsex. Aggmult uses 6 age groups (zero group and age 1–5) for capelin and 11 age groups (zero group and age 1–10) for cod and herring.

Single-species dynamics

Plankton

All three plankton 'stocks' have the same dynamics. The equation used is:

$$\frac{dB_{pl}}{dt} = P_{plprod}\left(B_{plmax} - B_{pl}\right) - C \tag{1}$$

where B_{pl} is the plankton biomass, C is the consumption rate from fish and P_{plprod} is a production parameter. B_{plmax} is the maximum plankton abundance. The parameters have different values in the different quarters of the year.

In the present model the plankton parameters have not been estimated from data. It should be an important future activity to relate the plankton development to observations. This might be done in two possible ways, either by using a fish-plankton model to evaluate the plankton production throughout historic years or by using the present model to estimate the plankton parameters using plankton measurements each year. Plankton data collected onboard Norwegian vessels during the joint IMR–PINRO autumn cruise since 1986 should be available for this purpose. For the present use of the Aggmult model the setting of the plankton parameters is somewhat arbitrary and represents a fundamental uncertainty. Therefore, a plankton scaling factor is introduced so the model can be tested against different levels of plankton abundance. Only the maximum plankton biomass is scaled.

Fish

Feeding level

The feeding level concept (Andersen and Ursin 1977) is crucial to the Aggmult modeling of growth and predation. The feeding level f is given by:

$$f = \frac{\varphi}{P_3 + \varphi} \tag{2}$$

where

$$\varphi = P_{23} + \sum_{j,a} S_{j,a} B_{j,a} \tag{3}$$

is the total perceived food abundance, i.e. the abundance of food organisms scaled with their suitability as food for the predator, and P_3 is a parameter, referred to as the feeding level half value parameter. This parameter determines the predation response to changes in food abundance. For cod, this parameter is taken from estimation work with the Multspec model (Bogstad and Tjelmeland 1992). For capelin and herring the parameter has been arbitrarily set to a relatively low value compared to the levels of plankton abundance used in the present paper. P_{23} is a parameter for other food, $B_{j,a}$ is the biomass abundance of prey item j at age a and $S_{j,a}$ is the suitability for prey item j at age a as food for the predator.

Growth

The growth in length is given by the equation:

$$\frac{dl}{dt} = P_4 f l^{P_5} \tag{4}$$

where l is the mean length in each age group and P_4 and P_5 are parameters.
The growth in weight is given by the equation:

$$\frac{dw}{dt} = P_8 (f - P_{10}) w^{P_9} \tag{5}$$

where w is the mean weight in each age group and P_8, P_9 and P_{10} are parameters. P_{10} is set to 0.15 for all species.

Maturation, spawning and recruitment
The proportion mature $m(l)$ is given by the equation:

$$m(l) = \frac{1}{1 + e^{4P_1(P_2 - l)}} \tag{6}$$

where l is the mean length in each age group and P_1 and P_2 are parameters. This equation is used to split each population into an immature and a mature part at January 1 where the mature part spawns at April 1 and the resulting number of recruits is given by the Beverton-Holt formulation:

$$R = P_{13} \frac{B_{sp}}{P_{14} + B_{sp}} \tag{7}$$

Before the recruits enter the fishable population they are preyed on by larger fish. Therefore, the spawning stock — recruitment relation arising from the above equation will not have a smooth or even monotonically increasing appearance even when the model is run deterministically. The recruitment of herring is drawn directly from the historical time series, as the herring stock is not modelled as adults when they are outside the Barents Sea. A spawning stock — recruitment relationship can thus not be applied for herring. However, there is work being done to connect Multspec to a herring model (Dommasnes and Hiis Hauge 1994). Since Aggmult is not length-distributed, the mean length has been used in formula 7. Tests indicate that the difference in numbers of mature fish by age between using the mean length and the length distribution is small.

Predation

The consumption per individual is given by the equation:

$$C = P_{22}(0)fw^{P_{22}(1)} \tag{8}$$

where w is the mean weight in an age group an P_{22} is a vector parameter of two elements.

The consumption is partitioned on the prey items (including plankton) according to their suitability scaled contribution to the total food abundance. Immature cod preys on capelin in all quarters. Mature cod preys on capelin only during the last quarter of the calendar year.

DATA

The model starts in 1972, i.e for all species data from 1972 have been used, if existing.

For cod, the outputs from the 1993 assessment has been used. As a consequence, the number at age input to Aggmult is dependent on the natural mortality M of 0.2 used by the Arctic Fisheries Working Group (Anon. 1994a). Another M-value would yield different Aggmult results. The sensitivity of Aggmult to the cod M-value has not been tested yet. Also, the weight at age and length at age are taken from the 1993 assessment. The weight at age data are not available prior to 1983. For historic catch, the F-values from the assessment have been used, rather than the actual catch. The recruiting age is 3 years. The cod input to Aggmult closely parallels the cod input to Multspec.

For herring, the abundance estimate obtained during the yearly cruise in the Barents Sea in May-June has been used for the input in number by age, length by age and weight by age. The recruiting age is 1 year.

For capelin, the abundance estimate obtained during the joint IMR-PINRO September cruise has been used for the input in number by age, length by age and weight by age. This is the same input as used for the Multspec model.

PARAMETER ESTIMATION

Most of the parameters get their values from an estimation process, and many parameters are estimated year by year, later to be drawn at random each year when the model is run into the future for experimenting with various management strategies. Here, the estimation processes are described in the same sequence as they were performed. Two different plankton scaling factors are used, 2.0 and 5.0. The estimation results are shown in tables in the appendix.

Growth

As a first step, the growth parameters P_4, P_5, P_8 and P_9 are estimated under the assumption that the feeding level is unity. Using the estimated values of P_4 and P_8 as start values and fixing the parameters P_5 and P_9, P_4 and P_8 are estimated year by year.

There is a severe problem with the growth in weight of cod. Weight data are not available prior to 1983, which leads to incorrect values of the cod stock size prior to 1983. This affects the simulated growth and predation on capelin. In particular, the historical values for the capelin spawning stock biomass may be severely in error, making it difficult to work out reliable spawning stock — recruitment relations. There is, however, a project under way to work up historic time series. Thus, there is some hope for improvement in the not too distant future.

Recruitment

The number of recruits as 0-group is entered at the beginning of the third quarter of the calendar year. The number of recruits are estimated annually by running the model forward to the recruiting age for each species and comparing to data.

The length and weight of the recruits are estimated annually by running the model to age 1 for each species and comparing to data.

The parameters of the recruitment function are not estimated in the traditional way, where constancy over the historic period is assumed. Rather, P_{13} is fixed at 1.1 times the highest estimated number of 0-group. P_{14} is then calculated for each year. Usually, one tries to fit spawning stock-recruitment data to a model where the recruitment is a function of the spawning stock and perhaps one or more environmental variables. The procedure of using halfvalues seems to have advantages when correlations between environment and the temperature is sought, which is illustrated in the following example:

Figure 1 shows the recruitment with time calculated from a Ricker model that is fit to VPA data. In working with cod the Ricker model seems appropriate since the effect of cannibalism is embedded into the functional form. Figure 2 shows the recruitment calculated by first calculating the yearly halfvalues and then fitting the halfvalues to a linear regression model where the temperature in the Kola section (Bochkov 1982) in September is the only variable in addition to the constant term.
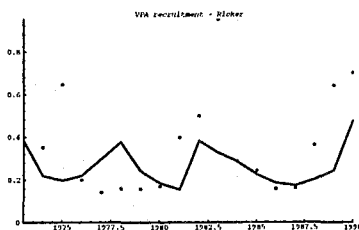
Figure 1 Recruitment using a Ricker model on VPA data
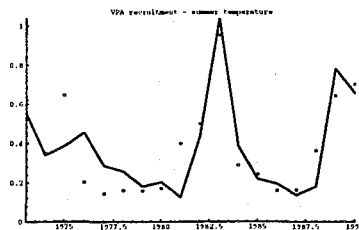
Figure 2 Recruitment using halfvalues calculated from VPA data regressed to temperature

In both cases there is a regression involving two variables, but regressing on halfvalues gives seemingly a better possibility of picking up environmental signals to the recruitment.

Figures 3 and 4 shows the time series of recruitments by regressing halfvalues to the Kola section September temperature for a plankton scaling of 2.0 and 5.0, respectively.
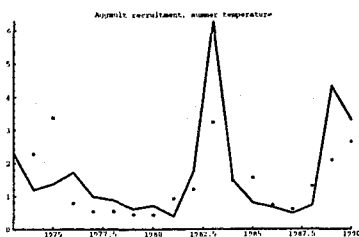
Figure 3 Recruitment using halfvalues calculated from Aggmult with plankton scaling 2.0 regressed to temperature
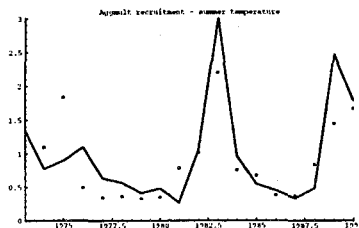
Figure 4 Recruitment using halfvalues calculated from Aggmult with plankton scaling 5.0 regressed to temperature

This analysis seems to give possibilities for strongly reducing the stochastic uncertainty in the model by drawing a temperature randomly (or autocorrelated) from a distribution that is modeled from historic data and calculating halfvalues from the regression formula, instead of drawing halfvalues from historically estimated halfvalues. The regression explained only 42% and 49% of the variance in halfvalues for plankton scaling of 2.0 and 5.0, yet the prediction of recruitment seems to be fairly good. However, further analysis where a variety of environmental indices are tried should be done before this method is adopted in management-related analyses. Also, more experience

with the Aggmult model is needed, especially with the fish-plankton interaction. The potential for a predation model like Aggmult to remove predation effects from the uncertainty around the stock-recruitment relation seems promising.

Residual natural mortality

The residual mortality, i.e. the mortality generated by other causes than predation from modeled species, is estimated year by year for fish older than recruiting age. Constancy over age for each year is assumed.

Maturation of capelin

The maturation of capelin has been estimated using the Capsex model (Tjelmeland and Bogstad 1993). However, because Aggmult uses mean length by age and Capsex uses a length distribution for each age group, these values are not readily transferred from Capsex to Aggmult. In the next version of Aggmult, the maturation parameters should be estimated using the Aggmult model.

Parameters that are not estimated

Plankton

The production parameter is set so that the plankton increase time, i.e. the time to increase from zero to half the maximum with no predation is one time step (quarter of year). The quarter number refers to the simulation cycle, i.e. the first quarter is the fourth quarter of the calendar year. Table 1 shows the unscaled values used in the model.

Table 1 Baseline plankton parameters.

Quarter	Plankton 1		Plankton 2		Plankton 3	
	P	B_{max}	P	B_{max}	P	B_{max}
1	1.0	15	1.0	25	1.0	30
2	0.5	15	0.5	25	0.5	30
3	1.0	15	1.0	25	1.0	30
4	2.0	15	2.0	25	2.0	30

Fish

Cod VPA M-value

For abundance data for cod, the outputs from the tuned VPA carried out at the 1993 meeting of the Arctic Fisheries Working Group (Anon. 1994a) are used. This precludes modeling any predation mortality on cod 3 years and older, since then there would be incompatibility with the M = 0.2 used in the VPA. The whole procedure hinges on the VPA guesstimates, and there is thus no way in the present model of assessing the uncertainty in the derived management decision rules with respect to the VPA assumption of a time and age constant M of 0.2 without redoing the estimate using a different M-value. However, recent work with the 'scenario' model for the Barents Sea (Anon. 1994b) yields some hope for systematically investigating the sensitivity of the management strategies to the VPA M-value.

Maturation of cod and herring

The maturation parameters P_1 and P_2 for cod and herring are not estimated from data. Values that seem "reasonable" have been selected. The sensitivity of Aggmult to changes in these parameters has not been tested, but is probably small. It should be possible to estimate these values from available maturation data.

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Suitabilities

The suitability variation that stems from size differences is shown in the appendix. The sensitivity of the final results to variations in these matrices are probably small. As for the inter-species suitabilities, the following assumptions are made, all of which should be tested in later versions of the model:

1. Herring and capelin have the same suitability for predation from cod.
2. The suitability of capelin as food for herring is set to 30 times the suitability of capelin as food for cod. This makes the capelin recruitment sensitive to herring abundance.
3. The suitability for plankton as food for fish is set to 0.5 the suitability of fish as food for fish. However, this uncertainty is probably of no significance, since this suitability could be viewed as a part of the plankton scaling factor. In later versions of the model where real plankton data are connected, it becomes of importance to assess this suitability correctly by using measurements of ambient plankton abundance together with stomach samples from plankton feeders.

Maximum consumption

For cod, the value of P_{22} that is estimated using Multspec is used (Bogstad and Tjelmeland 1992). For herring and capelin the value is calculated assuming that the ratio of consumption to growth is 5.0 at age 4. This value is somewhat arbitrarily set. The idea is that results from bioenergetic modeling could later be used to give reasonable values for P_{22} since it is difficult to use a combination of stomach content data and an evacuation rate model as it is done for cod. There simply is not enough data.

MODEL RUNS

When the model is run into the future the outcomes of the non-modeled processes are drawn from the historically estimated values. A "scenario year" is drawn at random from the range of years over which the estimation has been performed and the non-modeled processes for that year is used in the simulation. Figures 5 — 7 show 10 stochastic runs for a plankton scaling factor of 2.0 and no catch on any species.

In some cases there is a lack of estimated values (for instance, growth in weight of cod prior to 1983). Then the algorithm seeks the nearest value, which leads to an overemphasis on the year 1983 in the case of cod growth in weight.
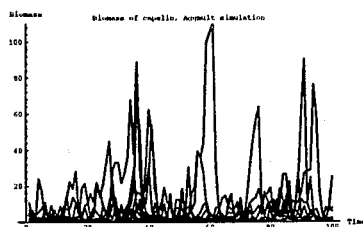
Figure 5 Stochastic development of capelin, million tonnes. Plankton scaling 2.0
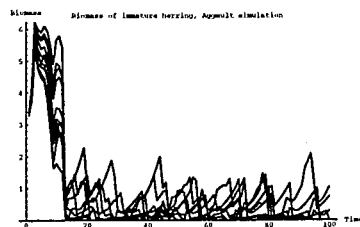
Figure 6 Stochastic development of herring, million tonnes. Plankton scaling 2.0
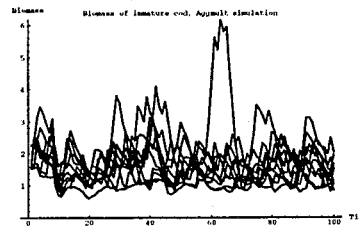
Figure 7 Stochastic development of cod, million tonnes. Plankton scaling 2.0

Figure 8 — 10 show 10 stochastic runs for a plankton scaling factor of 5.0 and no catch.
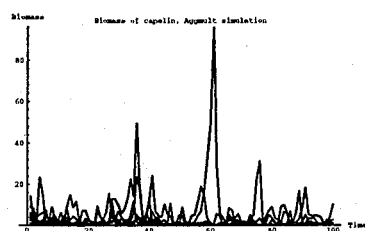
Figure 8 Stochastic development of capelin, million tonnes. Plankton scaling 5.0
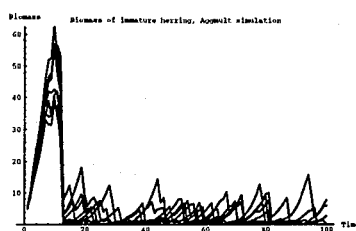
Figure 9 Stochastic development of herring, million tonnes. Plankton scaling 5.0
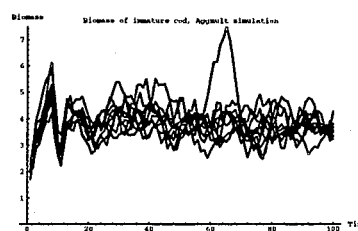
Figure 10 Stochastic development of cod, million tonnes. Plankton scaling 5.0

The maximum values for capelin are unrealistically high, showing that the recruitment relation does not give a realistic limit for abundance. The limiting factor in Aggmult is intended to be the plankton abundance, so unrealistically high capelin abundance points to a too stable plankton population. Probably, the problem lies in the food conversion factor of 5.0 being too small. However, when the model is used for evaluating management strategies this poses no problem, since then catch is applied.

Both the herring and cod stocks are on the average more abundant when a plankton scaling of 5.0 than when a plankton scaling of 2.0 is used. However, the peaks of the capelin stock show an opposite response to the plankton scaling.

For other uses of the model than experimenting with management rules in a stochastic environment, it is useful to have a standard deterministic run. It is no straightforward task, however, to define a set of deterministic parameters using the yearly estimated values. The yearly values were meaned with the exception of the recruitment halfvalues, for which the medians were used. However, using the obtained parameter values for capelin did not yield a sustainable stock when the model was run without catch. Then, the non-modeled natural mortality of capelin was tried set so that the mean value of the number of 2 year old capelin in the period 50–100 years after start of simulation was equal to the mean of the stochastic runs for that period. However, no non-modeled natural mortality meeting this demand led to a sustainable capelin stock. Therefore, the smallest non-modeled natural mortality that led to a sustainable stock was chosen. Figure 11 and Figure 12 show the deterministic runs for plankton scalings of 2.0 and 5.0, respectively. The deterministic parameter sets are shown in the Appendix.
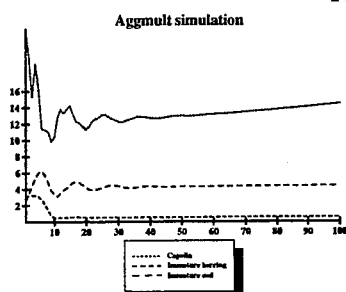
Figure 11 Deterministic run, million tonnes. Plankton scaling 2.0
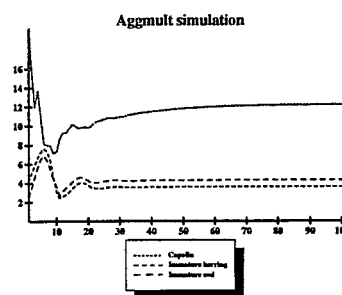
Figure 12 Deterministic run, million tonnes. Plankton scaling 5.0

In the deterministic regime, only the herring stock gets more abundant when the plankton scaling is increased from 2.0 to 5.0.

SEEKING MANAGEMENT DECISION RULES FOR COD AND CAPELIN

Figure 13 gives an overview of the method applied. For a fixed sequence of stochastic events the model was run 80 years into the future, each year applying a management rule for cod and capelin. Sampling of catch started after 20 years to avoid initial transients. This run was performed several times and an optimal strategy was found. Then the stochastic sequence was changed and a new optimal strategy was found. The process is very computer intensive, so it was only possible to obtain 10 different stochastic sequences. The analysis was done for plankton scaling of 2.0 and 5.0, using the same stochastic sequence in both cases.

The value of the random variables used for calculating the quotas are the same as the previous year, while the actual random variables used in advancing the model one year are drawn independently. In other words, the "managers" in the model made the assumption that the environmental (i.e. non-modeled) conditions in the future year would be the same as in the quota decision year. No autocorrelation is used, so we are applying a worst case scenario with respect to uncertainty: Next years random variables can be any of the historically measured random variables. In later use of the model, autocorrelation should be modeled from the historic series.

No attempt is made here to find a combined management rule for cod and capelin, which involves bringing in relative prices. Rather, a management rule for one species assuming a fixed management rule for the other species is sought. For the management of capelin it is tempting to make the management rule dependent on the size of the stock, assuming a higher price for a limited yield and a lower price for yield exceeding the limit, in an attempt to model the effect of two different markets for capelin: Human consumption and reduction. However, this is left for a future exercise.
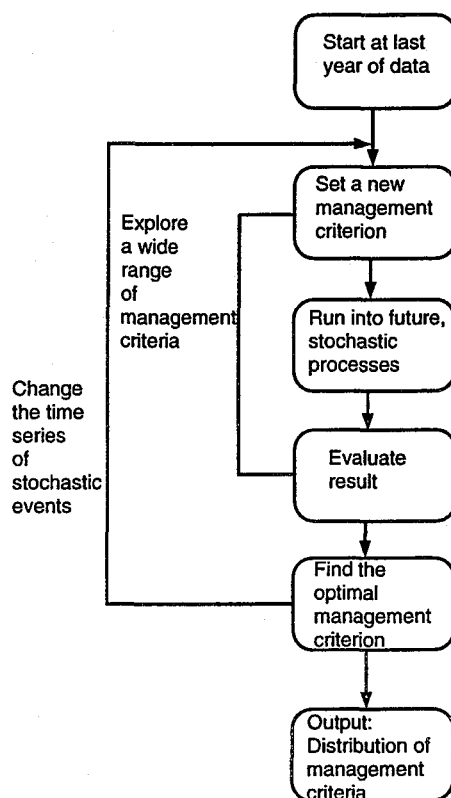
Figure 13 Illustration of the scheme for seeking management decision rules.

The management decision rule tried for cod is a target level of fishing mortality. The management decision rule tried for capelin is a target spawning stock, a rule that is much simplified from the rule recently tried using the Capsex model (Tjelmeland and Bogstad 1993). In operationalising the management rule for capelin runs one year ahead are made with different F-values and the F-value to use is calculated from the resulting F-value — spawning stock relation. During these runs the

same stochastic sequence of events that applied during the previous period are used. For capelin, there is only fishing on the mature capelin in the period January-March.

The management rules tried in this paper must be considered experimental. The main purpose is to establish the method. In later uses of the model management rules incorporating probabilities of prolonged periods of stock collapses should be tried so that a trade-off between long-term high yield and long-term safeguarding against stock collapses could be experimented with. This would be an important use of the model if a public discussion about the fishing industry should emerge along the same lines as the public discussion about management of minke whales.

It was earlier shown that the stochastic uncertainty might be reduced by regressing recruitment halfvalues to environmental indices. It would then be interesting to use such a relation with the "managers" in the model knowing it and building a management strategy upon this knowledge. This is, however, left for a future exercise.

RESULTS

Tables 3 — 5 give the main results. The unit for biomass is million tonnes.

Table 2 Plankton scaling 2.0. Optimal target capelin spawning stocks.

Cod F-value	Optimal target capelin spawning stock	Mean capelin catch
0.1	0.52±0.32	0.17±0.02
0.2	0.59±0.30	0.28±0.04
0.3	0.65±0.21	0.41±0.07
0.4	0.74±0.20	0.57±0.10
0.5	0.75±0.17	0.75±0.15

Table 3 Plankton scaling 2.0. Optimal cod F-values.

Target capelin spawning stock	Optimal cod F-value	Mean cod catch (negligible variation)
0.2	0.45±0.04	0.27
0.4	0.45±0.04	0.28
0.6	0.45±0.04	0.28
0.8	0.45±0.04	0.28
1.0	0.45±0.04	0.29

Table 4 Plankton scaling 5.0. Optimal cod F-values.

Target capelin spawning stock	Optimal cod F-value	Mean cod catch (negligible variation)
0.2	0.45±0.04	0.49
0.4	0.45±0.04	0.49
0.6	0.45±0.04	0.49
0.8	0.45±0.04	0.49
1.0	0.45±0.04	0.49

Table 5 Plankton scaling 5.0. Optimal target capelin spawning stocks.

Cod F-value	Optimal target capelin spawning stock	Mean capelin catch
0.1	0.43±0.34	0.11±0.03
0.2	0.40±0.28	0.16±0.04
0.3	0.47±0.27	0.21±0.06
0.4	0.52±0.27	0.27±0.07
0.5	0.57±0.28	0.34±0.10

For both values of the plankton scaling parameter the optimal cod F-values are independent and the mean catch of cod is only slightly dependent of the target spawning stock of capelin. The yearly estimated cod growth was low in the period 1983–1987, probably connected to low abundance of capelin (Tjelmeland and Bogstad 1993). This decrease is reflected in the yearly estimates of the parameters P_4 and P_8, see tables in the Appendix. These estimates were obtained using the

modeled feeding level value. If the decrease in growth of cod is caused by the capelin collapse, the modeled growth should be small due to small values of the feeding level. The decrease should not be reflected in the yearly estimated growth parameters. Thus, the model has not been capable of tracking the influence of capelin abundance on the cod growth, which explains the above results. The model yields an optimal F-value of 0.45, which is close to the present value of F_{med}.

The optimal spawning stock of capelin is strongly dependent on the F-value for cod, as expected. For a plankton scaling of 5.0 the optimal spawning stock for capelin is 26% lower than for a plankton scaling of 2.0, while the yield is 50% lower. Thus, there is smaller uncertainty in the management rule because of the ignorance of plankton effects than in the yield. This is particularly manifest for cod where an optimal F-value of 0.45 was obtained for both a plankton scaling of 2.0 and 5.0, while the yield was almost twice as high in the latter case. On the other hand, the uncertainty from the stochasticity of the model is much greater for the management rule than for the yield.

It might seem a little puzzling that the catch of capelin is smaller when the plankton scaling is 5.0 than when the plankton scaling is 2.0. The reason for this is probably that the cod stock is higher in the former case (see figures 7 and 10), leading to a higher predation mortality on capelin.

INADEQUACIES

In applying the procedure for evaluating management strategies using the present version of the Aggmult model, one should keep in mind that there is much that remains to be done in improving the data foundation and the parameter estimation. Of highest importance are:

1. Time series of cod weight at age prior to 1983.
2. Using real values of plankton data and, possibly, setting plankton production rates from output from a more sophisticated plankton model. This would enable setting the feeding level half value low enough to yield realistic plankton dynamics, not only using an overall plankton level as in the present paper.
3. Estimating the suitability for cod predation on capelin, herring and plankton from data.

For these reasons, the results (F-values, target spawning stocks, catches) obtained should be viewed merely as illustrations of the procedure, rather than serious suggestions for management strategies and possible outcomes of those.

SUMMARY AND CONCLUSIONS

In this paper, a method for evaluating management rules for cod and capelin in the Barents sea has been developed based on an age-distributed multispecies model. The processes in the model can be divided into modeled processes (for example maturation and predation) and non-modeled processes (for example non-modeled mortality). The non-modeled processes are estimated year by year using historic data and the estimated values are drawn at random when the model is run into the future.

A more profound uncertainty is connected to the recruitment function. In the model the plankton, besides being food for plankton eaters, partly shields the juveniles from predation. Thus, the modeled plankton has a nontrivial influence on the model spawning stock — recruitment relationship. It was not possible to connect the plankton model to data in any way, so the whole analysis was performed with two different levels of plankton abundance. It is difficult to assess whether the range in plankton abundance used covers the true uncertainty due to ignorance of plankton effects. At extremely high plankton values the model will in effect be a collection of single-species models because all three species eat some plankton in all age groups. At extremely low plankton values the fish-fish interactions become so strong that the three species hardly can coexist. More experimenting with the model is needed to find the exact range of admissable plankton abundance. The experiments made so far indicate that the chosen range covers a substantial part of the interesting area.

The difference between the results using a plankton scaling of 2.0 and a plankton scaling of 5.0 can be viewed as the non—tractable ignorance of the spawning stock-recruitment relation, and the expected future yield differ by a factor of about 2 in the two cases. However, the estimated optimal cod F-values and the estimated target spawning stocks of capelin differ to a much smaller degree, which illustrates the fact that a large predictive uncertainty not necessarily leads to a large uncertainty in the management decision. This could be interpreted in the following way: Over a great variety of possible situations the "best" action (quota) will be almost the same.

The uncertainty because of the stochasticity in the model, this might be coined the "tractable uncertainty" because it stems from the variation in yearly estimated values, has the opposite effect of being higher for the estimated optimal target spawning stock for capelin than for the estimated future yield of capelin. However, it is expected that this uncertainty might be reduced when models for the non-modeled processes are found. In particular, regressing recruitment halfvalues to environmental indices seems promising. For the cod stock, both for the optimal F-value and for the yield, this uncertainty is very small.

The present Aggmult model and the method applied for evaluating management strategies is a first attempt to give a scientific foundation for a multispecies management of the Barents Sea fish stocks. The uncertainties involved are large, but the variance can be reduced on the most vital points. However, considerable effort on constructing more refined submodels and improving the data foundation is needed before the work can be used in practical management.

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APPENDIX — ESTIMATED PARAMETERS AND RESIDUALS

Standard run parameters

The parameters that are used for the standard runs as defined earlier are given in table 6. The parameters in each box apply to cod, herring and capelin, respectively.

Table 6 Standard run parameters

	Plankton scaling 2.0			Plankton scaling 5.0			Used in stochastic runs?
	Cod	Herring	Capelin	Cod	Herring	Capelin	
P_1	0.6	0.6	0.6	0.6	0.6	0.6	Yes
P_2	60.0	31.0	13.8	60.0	31.0	13.8	Yes
P_3	0.009	0.018	0.018	0.009	0.018	0.018	Yes
P_4	3.70	0.0052	463	3.42	0.013	450	No
P_5	-0.13	1.00	-2.59	-0.13	1.00	-2.59	Yes
P_8	0.15	0.0087	0.00083	0.15	0.0037	0.00080	No
P_9	0.64	0.52	-0.15	0.64	0.52	-0.15	Yes
P_{10}	0.15	0.15	0.15	0.15	0.15	0.15	Yes
P_{13}	5.69	150	5294	2.47	150	5471	Yes
P_{14}	0.52	0.25	0.76	0.42	0.25	0.94	No
P_{20}	0.047	0.00022	0.04	0.047	0.013	0.101	No
P_{22}	(1.63 - 0.8)	calc.	calc.	(1.63 - 0.8)	calc.	calc.	Yes
P_{23}	0.002	0.002	0.002	0.002	0.002	0.002	Yes

Suitabilities fish-fish interactions

The suitability tables are big, so only rows containing at least one non-zero parameter are shown. At the beginning of each line, the predator species, prey species/maturity (e.g. Imcap = Immature capelin) and prey age is given. Then the suitabilities for the various age groups of the immature and mature part of the predator species follow, as indicated in the table heading. The first quarter refers to the last quarter of the calendar year, i.e. one yearly run starts October 1.

Quarter 1

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imher 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imher 2	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imher 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Cod Imcap 5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 2	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 3	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 4	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cod Macap 5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 2

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 3	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Quarter 3

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 3	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Quarter 4

	Immature											Mature										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod Imcod 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcod 2	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 1	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 2	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imher 3	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her Imcap 0	0.5	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 1	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Imcap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cod Macap 2	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3
Cod Macap 3	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3
Cod Macap 4	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3
Cod Macap 5	0.0	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3

Suitabilities fish-plankton interactions

The tables are structured in the same way as the fish-fish suitability tables, except that no prey age is given as the plankton stocks are not age-structured. The following abbreviations are used for the plankton stocks: Sps = Small plankton organisms in the northern Barents Sea, Spn = Small plankton organisms in the southern Barents Sea, Lpl = Large Plankton organisms.

Quarter 1

		Immature											Mature										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod	Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod	Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod	Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her	Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 2

		Immature											Mature										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod	Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod	Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod	Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her	Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 3

		Immature											Mature										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod	Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod	Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod	Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her	Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Quarter 4

		Immature											Mature										
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Cod	Sps	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Sps	1.0	0.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Sps	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cod	Spn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Her	Spn	1.0	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Spn	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cod	Lpl	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Her	Lpl	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cap	Lpl	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Plankton scaling 2.0

Spawning biomass halfvalues (P₁₄)

	Cod	Capelin
1973	0.028	2.639
1974	0.225	0.954
1975	0.091	0.228
1976	0.930	2.708
1977	2.016	1.743
1978	2.639	3.103
1979	1.946	1.484
1980	1.480	0.719
1981	0.520	0.712
1982	1.022	0.052
1983	0.148	0.761
1984	0.523	2.262
1985	0.405	4.027
1986	0.836	0.708
1987	0.982	0.292
1988	0.456	0.016
1989	0.287	0.158
1990	0.438	0.294

Recruits

	Cod	Herring	Capelin
1972	6.657	0.000	3022.177
1973	5.304	0.000	1402.451
1974	2.274	0.000	945.017
1975	3.377	0.000	665.925
1976	0.788	0.000	1309.633
1977	0.537	0.000	1959.028
1978	0.541	0.000	987.710
1979	0.450	0.000	1077.046
1980	0.440	0.000	2303.204
1981	0.934	0.000	3161.214
1982	1.214	0.000	4827.652
1983	3.237	27.803	1586.784
1984	1.476	0.000	508.103
1985	1.563	0.000	173.171
1986	0.732	0.000	252.699
1987	0.603	0.000	176.784
1988	1.308	0.000	1607.927
1989	2.095	5.605	1014.870
1990	2.648	33.210	1275.749

Length growth (P₄)

	Cod	Herring	Capelin
1972	4.505	0.000	386.742
1973	4.534	0.000	254.504
1974	4.526	0.000	261.872
1975	4.526	0.000	435.455
1976	4.521	0.000	415.552
1977	4.531	0.000	385.742
1978	4.537	0.000	421.098
1979	4.525	0.000	472.605
1980	4.536	0.000	442.968
1981	3.250	0.000	556.518
1982	5.270	0.000	477.750
1983	3.945	0.000	410.245
1984	3.708	0.000	328.196
1985	2.461	0.000	555.746
1986	2.278	0.000	632.180
1987	4.047	0.000	631.717
1988	5.204	0.000	707.746
1989	4.504	0.000	752.783
1990	4.564	0.000	330.978

Mvalues (P₂₀)

	Cod	Herring	Capelin
1972	0.049	0.000	0.000
1973	0.055	0.000	0.063
1974	0.052	0.000	0.037
1975	0.050	0.000	0.093
1976	0.051	0.000	0.051
1977	0.050	0.000	0.100
1978	0.049	0.000	0.203
1979	0.047	0.000	0.081
1980	0.048	0.000	0.256
1981	0.057	0.000	0.170
1982	0.049	0.000	0.462
1983	0.055	0.000	0.274
1984	0.049	0.000	0.446
1985	0.043	0.473	0.537
1986	0.047	0.000	0.338
1987	0.046	0.000	0.006
1988	0.052	0.000	0.405
1989	0.048	0.000	0.007
1990	0.050	0.005	0.007

Weight growth (P₈)

	Cod	Herring	Capelin
1972	0.000	0.000	0.001
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.001
1976	0.000	0.000	0.001
1977	0.000	0.000	0.001
1978	0.000	0.000	0.001
1979	0.000	0.000	0.001
1980	0.000	0.000	0.001
1981	0.000	0.000	0.001
1982	0.000	0.000	0.001
1983	0.091	0.000	0.001
1984	0.091	0.000	0.000
1985	0.091	0.000	0.001
1986	0.091	0.000	0.001
1987	0.183	0.000	0.001
1988	0.233	0.000	0.001
1989	0.201	0.000	0.001
1990	0.202	0.000	0.001

Length of recruits

	Cod	Herring	Capelin
1972	9.296	0.000	0.002
1973	9.271	0.000	0.000
1974	9.271	0.000	0.000
1975	9.272	0.000	0.000
1976	9.270	0.000	0.001
1977	9.270	0.000	0.000
1978	9.270	0.000	4.094
1979	9.271	0.000	2.945
1980	9.270	0.000	0.000
1981	9.267	0.000	0.002
1982	9.268	0.000	0.000
1983	9.271	8.260	0.001
1984	9.272	0.000	2.412
1985	9.272	0.000	4.032
1986	9.272	0.000	0.000
1987	9.272	0.000	0.000
1988	5.306	0.000	0.000
1989	8.904	8.778	0.001
1990	9.271	9.928	0.001

Weight of recruits

	Cod	Herring	Capelin
1972	0.000	0.000	0.000
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.000
1976	0.000	0.000	0.000
1977	0.000	0.000	0.000
1978	0.000	0.000	0.001
1979	0.000	0.000	0.000
1980	0.000	0.000	0.000
1981	0.000	0.000	0.000
1982	0.000	0.000	0.000
1983	0.027	0.000	0.000
1984	0.027	0.000	0.000
1985	0.027	0.000	0.001
1986	0.027	0.000	0.000
1987	0.027	0.000	0.000
1988	0.010	0.000	0.000
1989	0.025	0.000	0.000
1990	0.027	0.013	0.000

Plankton scaling 5.0

Spawning biomass halfvalues (P_{14})

	Cod	Capelin
1973	0.028	4.108
1974	0.187	1.310
1975	0.046	0.324
1976	0.599	3.284
1977	1.305	2.084
1978	1.625	3.487
1979	1.090	1.631
1980	0.765	0.798
1981	0.219	0.761
1982	0.404	0.055
1983	0.032	0.879
1984	0.477	2.600
1985	0.428	4.357
1986	0.677	0.939
1987	0.672	0.395
1988	0.267	0.023
1989	0.117	0.237
1990	0.177	0.460

Weight growth (P_8)

	Cod	Herring	Capelin
1972	0.000	0.000	0.001
1973	0.000	0.000	0.000
1974	0.000	0.000	0.000
1975	0.000	0.000	0.001
1976	0.000	0.000	0.001
1977	0.000	0.000	0.001
1978	0.000	0.000	0.001
1979	0.000	0.000	0.001
1980	0.000	0.000	0.001
1981	0.000	0.000	0.001
1982	0.221	0.000	0.001
1983	0.170	0.000	0.001
1984	0.160	0.000	0.000
1985	0.102	0.000	0.001
1986	0.099	0.000	0.001
1987	0.173	0.000	0.001
1988	0.222	0.000	0.001
1989	0.193	0.000	0.001
1990	0.193	0.038	0.001

Length growth (P_4)

	Cod	Herring	Capelin
1972	4.365	0.000	375.511
1973	4.371	0.000	247.189
1974	4.369	0.000	254.567
1975	4.369	0.000	423.239
1976	4.367	0.000	403.796
1977	4.370	0.000	374.808
1978	4.372	0.000	409.262
1979	4.369	0.000	459.326
1980	4.372	0.000	430.530
1981	3.135	0.000	540.584
1982	5.063	0.000	464.257
1983	3.789	0.000	398.520
1984	3.551	0.000	319.594
1985	2.349	0.000	540.503
1986	2.180	0.000	614.424
1987	3.874	0.000	613.727
1988	4.997	0.000	687.923
1989	4.344	0.000	731.789
1990	4.388	0.025	321.504

Recruits

	Cod	Herring	Capelin
1972	2.695	0.000	2313.402
1973	2.245	0.000	1336.903
1974	1.096	0.000	944.634
1975	1.838	0.000	674.337
1976	0.493	0.000	1327.077
1977	0.343	0.000	2000.352
1978	0.360	0.000	1022.014
1979	0.329	0.000	1117.714
1980	0.344	0.000	2352.319
1981	0.786	0.000	3260.529
1982	1.017	0.000	4973.341
1983	2.204	24.237	1539.275
1984	0.755	0.000	477.186
1985	0.671	0.000	169.189
1986	0.385	0.000	212.884
1987	0.364	0.000	148.704
1988	0.834	0.000	1447.015
1989	1.454	4.921	796.308
1990	1.671	28.259	1028.988

Mvalues (P_{20})   Weight of recruits

	Cod	Herring	Capelin
1972	0.049	0.000	0.000
1973	0.055	0.000	0.109
1974	0.052	0.000	0.088
1975	0.050	0.000	0.139
1976	0.051	0.000	0.091
1977	0.050	0.000	0.135
1978	0.049	0.000	0.238
1979	0.047	0.000	0.109
1980	0.048	0.000	0.280
1981	0.057	0.000	0.187
1982	0.049	0.000	0.475
1983	0.055	0.000	0.297
1984	0.049	0.001	0.492
1985	0.043	0.572	0.616
1986	0.047	0.000	0.415
1987	0.046	0.000	0.004
1988	0.052	0.000	0.453
1989	0.048	0.000	0.003
1990	0.050	0.002	0.003

Length of recruits

	Cod	Herring	Capelin			Cod	Herring	Capelin
1972	9.471	0.000	0.000		1972	0.000	0.000	0.000
1973	9.460	0.000	0.000		1973	0.000	0.000	0.000
1974	9.460	0.000	0.000		1974	0.000	0.000	0.000
1975	9.460	0.000	0.000		1975	0.000	0.000	0.000
1976	9.460	0.000	0.000		1976	0.000	0.000	0.001
1977	9.460	0.000	0.000		1977	0.000	0.000	0.000
1978	9.460	0.000	4.214		1978	0.000	0.000	0.001
1979	9.460	0.000	3.130		1979	0.000	0.000	0.000
1980	9.460	0.000	0.000		1980	0.000	0.000	0.000
1981	9.460	0.000	0.000		1981	0.000	0.000	0.000
1982	9.460	0.000	0.000		1982	0.000	0.000	0.000
1983	9.460	8.272	0.000		1983	0.027	0.000	0.000
1984	9.460	0.000	2.651		1984	0.027	0.000	0.000
1985	9.460	0.000	4.157		1985	0.027	0.000	0.001
1986	9.460	0.000	0.000		1986	0.027	0.000	0.001
1987	9.460	0.000	0.000		1987	0.027	0.000	0.000
1988	5.495	0.000	0.000		1988	0.010	0.000	0.000
1989	9.093	8.795	0.000		1989	0.025	0.000	0.000
1990	9.460	9.947	0.000		1990	0.027	0.013	0.000