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Harvesting control rules and future development of the precautionary approach – Northeast arctic cod as an example

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Introduction

There are basically two different considerations in management of straddling and highly migratory fish stocks. On the one hand, these stocks should be managed in compliance with international demands that the stocks are not put into jeopardy by excessive fishing (Anonymous 1995). To this end a set of criteria based on the precautionary approach has been developed, although their basis in scientific knowledge are often obscure. On the other hand, merely complying with precautionary approach in the sense that the stock should have a small risk of immediate collapse or recruitment failure is in itself a long-term management rule that could be sub-optimal. Thus, the question arises what is the "best" management. For many stocks an initial lowering of quotas may lead to a growth that would yield higher quotas in the long term than would have been obtained just by keeping the stock above the danger level.

The effect of fishing in the long run is to diminish the spawning stock and thereby reducing the expectation value of the number of recruits. The single most important problem to solve for an optimal harvesting control rule to be established is therefore that of estimating a stock-recruitment relation from data. The difficulties associated with inferring such a relationship from erratic "shot-gun" plots have precluded the establishment of an optimal harvesting control rule for most fish stocks. For the stocks in the Barents Sea one have until present day tried to regulate only the capelin stock by a management rule based on the principle of maximising long-term yield and using a simulation model and a stock-recruitment relation estimated from data (Hamre and Tjelmeland 1982).

In autumn 1991 ICES changed the form of management advice. ACFM now defines its objective to be: "To provide the advice necessary to maintain viable fisheries within sustainable ecosystems" (Serchuk and Grainger 1992). If the stock is considered "within safe biological limits", ICES only provides options, i.e. calculations of stock and catch trajectories a few years into the future. The strategy for keeping the stock on safe grounds is to try to maintain an F-value low enough for the stock not to be driven into collapse. A "dangerous" F-value – referred to as F_{lim} is defined as the F-value that will lead to a collapse or the F-value that will during static conditions produce the smallest observed spawning stock biomass. Then the quota is set at a level that gives a small probability for this F-value to be realised taking into account the uncertainties connected to the assessment and the population dynamics in the short run. See the work of the ICES study group on the precautionary approach (Anonymous 1998) for technical details.

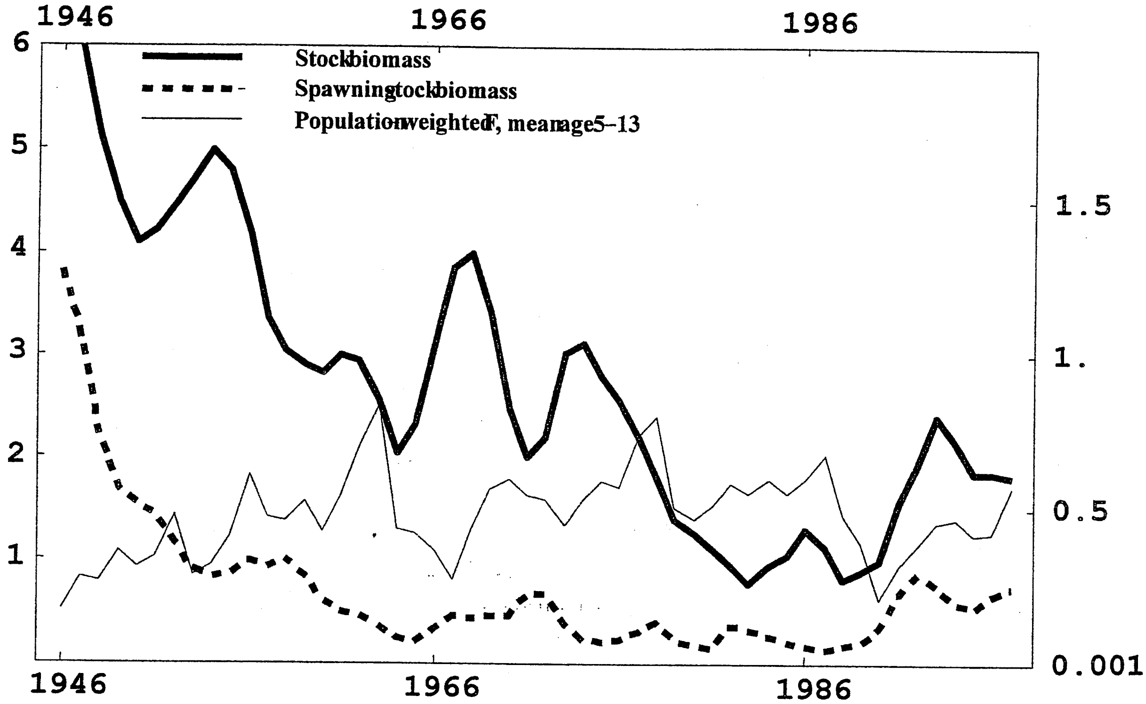
Corten (Corten 1993)strongly argues that managers may tend to regard MBAL (Minimum Biologically Accepted Level, a forerunner to the present-day B_{lim} , which is a biomass equivalent of F_{lim}) as a lower bound on management objectives, rather than as a limit below which great damage to the stocks can occur. This should be avoided at all costs.

The present paper focuses on the discrete uncertainty from conflicting but plausible assessments and on the generalised method for evaluating harvesting control rule.

Management of the Northeast arctic cod stock

Figure 1 shows the recent stock history of the Northeast arctic cod stock. Since the 1950s there was a gradual although fluctuating downwards trend until the rich 1983 yearclass gave rise to a recovery of the stock. The downward trend is concurrent with an increasing trend in fishing mortality. This may be interpreted as evidence of mis-management, too high catches led to stock decline through recruitment overfishing.

Figure 1. Recent stock history of Northeast arctic cod. Stock biomass (million tonnes) left axis, F-values right axis



Part of the problem has been that recommendations have not been strictly adhered to (Nakken 1998). The advice from ICES was to bring the F-value down towards F_{max}, which is the fishing mortality that gives the optimal catch if the recruitment is independent of the spawning stock. The F-values actually generated on the stock were substantially larger. However, the philosophy behind F_{max} only deals with optimising a balance of gain from increased weight and loss through natural mortality. The real danger is recruitment overfishing, which never was signalled from ICES bodies. The reason for this is that the spawning stock-recruitment plots at the time gave little evidence for larger recruitment with larger spawning stock, such an effect was totally masked by recruitment fluctuations due to random change of environment.

If the declining trend is due to recruitment overfishing the rationale behind using F_{med} as a guideline for management fails. F_{med} is thought of as the fishing mortality that in the long run will lead to the stock replenishing itself. But if F_{med} is calculated using data from a period when the stock did not replenish itself the calculated F_{med} would probably be too high. However, the stochasticity in the spawning stock – recruitment relation works the opposite way: the strong year-classes influences more on the positive side than do the weak year-classes on the negative side, which can be shown by simulation. It is therefore difficult to a priori judge how the F_{med} calculated from the above time series will work in the long run.

The precautionary approach

With the UN convention on straddling fish stocks and highly migratory fish stocks agreed biological reference points are important for a successful international management. The UN convention defines a precautionary reference point as "- an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management" (Anonymous 1995). The FAO document divides reference points into limit reference points "within which the stocks can produce maximum sustainable yield" and target reference points that are intended to meet management objectives.

The precautionary approach to management of fisheries states in essence that the more uncertain the assessment is, the lower the quota should be. This is achieved by demanding that the probability that the stock falls below a certain limit does not exceed some prescribed value. Thus, it is essential to evaluate the uncertainty both in the perceived stock and in the processes that affects the stock development. In addition, the limit value of the stock and the associated probability should be based on simulation experiments. In summary, the following entities must be determined:

1. The probability distribution of the present stock
2. The probability distribution connected to parameters in the equations that describe the stock dynamics, such as natural mortality, weight at age, exploitation pattern
3. The length of the prognostic runs
4. The limiting value and the associated probability

Methods for developing the necessary probability distributions for cod has not yet been developed, although this process has started in the ICES Arctic Fisheries Working Group (hereafter called WG) in that the medium-term forecast made the autumn 1998 was made probabilistic with an assume CV on the assessment of 0.3 on log-scale.

In order to elucidate the significance of a precautionary approach to the management of the cod stock in the present paper several of the necessary probability distributions will be developed. Also, uncertainties connected to the model formulation will be dealt with, i.e. the assumption made in the WG that the natural mortality for fish of age 3 and older is constant for all ages, for all years and equal to 0.2 will be challenged.

Changing role for managers?

Broadly speaking, the role of the scientists may by the managers have been perceived as suggesting a quota based on biological criteria, while the managers' role has been to adjust the quota if they have found it appropriate to take into consideration other non-biological factors or biological factors other than those considered by the scientists. An example of the former is that for many years ACFM kept giving advice on reducing the F-level of Northeast arctic cod to F_{max} while the quota set by the Mixed Russian-Norwegian Fishery Commission corresponded to a considerably higher F. This can be perceived as discounting the stock on socio-economic grounds. An example of the latter is the quota on capelin set by the Commission in 1986, where the quota was reduced with respect to that proposed by the scientists, probably because the capelin's role as source of food was considered.

With the inclusion of the precautionary approach the role of the managers changes even deeper, and the new paradigma poses large challenges to managers. Because the managers should be responsible for formulating the objective function underlying target reference points and for the maximum allowed probability for exceeding reference points, they should acquire a deep understanding of the methods and models underlying the reference points. A better dialogue between managers and scientists is called for.

Uncertainties in the assessment

The uncertainties associated with the yearly assessment fall into two categories: uncertainties in parameters estimated through the tuning procedure and uncertainties regarding the models chosen for the population dynamics and for the observation model.

The uncertainties associated with estimated parameters are expressed in the form of probability distributions that are easily implemented into procedures for evaluating harvesting control rules and performing medium-term predictions. Uncertainties as to which models for the population dynamics and observations are the most appropriate are more difficult to handle. If not convincing arguments can be given from inspection of residuals or from independent information one inevitably is left with different scenarios.

The assessment model

The assessment model XSA (Darby and Flatman 1994) that has been used for Northeast arctic cod is based on calculating the catchability parameters and the F-values in the terminal year and for the oldest age group by least-squares after taking logarithms. This method has advantages as to computer speed, but since it does not use a likelihood function it is difficult to evaluate the statistical properties. In the present paper the assessment model is the same as was used for tuning Norwegian spring spawning herring in 1998, which enables a comparison between different assumptions about the error structure of the observation model. Two different structural assumptions will be used: gamma with constant CV and lognormal, where the latter should give comparable solution to the XSA. A change from basic XSA assumptions were made regarding how the catchability depends on age. XSA uses a power function in addition to a subjectively determined age above which the catchability is independent of age. In the present implementation the function 1 – Exp(-age/par) was used which achieves approximate linearity with age for old fish without the subjective assumption of a cut-off age. This formulation is an advantage that cannot be implemented in XSA where parameters are by taking logarithms and solving a linear system of equations, but at the cost of greatly increased computer time because of the comparably slower process of parameter estimation. XSA uses also dependence on abundance, which was not tested in the present implementation.

The XSA has proved to be unstable, giving very different results for different plausible parameter settings. Because of this work has been undertaken to improve the assessment by constructing a length-based assessment model based on maximising a likelihood function, where also the catches are modelled. The basic analytical tool for the cod assessment is therefore likely to be changed in the near future.

Natural mortality

The perhaps most unsatisfying feature of the current assessment of the stock is that the natural mortality – decided to be 0.2 – is assumed constant for all fish of 3 years and older, and constant for all years. Furthermore, this value is not based on any estimation from data. Based on research work done at PINRO (Tretyak) we have substituted the constant natural mortality of 0.2 with estimated values (Table 1). Consequently, we have performed 4 different assessments, using to different assumptions on the distribution of the surveys and two different assumptions on the natural mortality.

The variable M is based on the assumption that the natural mortality changes throughout the life of a fish according to the formula

$$\frac{dM(t)}{d(t)} = -a\frac{\left(t-\overline{t}_s\right)}{\left(t-t_e\right)}$$

where t_s is the mean age of spawners and t_a is the oldest attainable age. a is a constant to be estimated. The solution is the function

$$\mathbf{M(t) = a \cdot (- t - (t_e - \overline{t_s}) \cdot \ln(t_e - t)) + b}$$

Which is dome-shaped, with a minimum at t_s. Table 1 gives the estimated values.

Table 1. estimated natural mortality for Northeast arctic cod

Age, years	Generation, years 1950	Fishing years 1952	1951-1953	1968-1970	1987-1989	1988-1990	1989-1991	1990-1992	1991-1993	1992-1994	1993-1995	1994-1996	1995-1997	1984-1997
3	0.230	0.225	0.245	0.251	0.159	0.165	0.162	0.112	0.099	0.079	0.060	0.041	0.050	0.077
4	0.219	0.214	0.234	0.238	0.139	0.153	0.151	0.101	0.087	0.065	0.043	0.024	0.032	0.060
5	0.210	0.204	0.224	0.227	0.123	0.143	0.143	0.093	0.078	0.055	0.031	0.011	0.019	0.049
6	0.203	0.197	0.217	0.218	0.111	0.137	0.139	0.088	0.073	0.050	0.025	0.004	0.011	0.042
7	0.199	0.192	0.212	0.211	0.105	0.135	0.138	0.089	0.073	0.050	0.024	0.004	0.010	0.041
8	0.197	0.190	0.210	0.206	0.104	0.138	0.140	0.093	0.078	0.056	0.030	0.010	0.015	0.046
9	0.197	0.190	0.211	0.204	0.110	0.144	0.147	0.103	0.089	0.068	0.044	0.024	0.029	0.058
10	0.201	0.194	0.214	0.205	0.123	0.157	0.159	0.119	0.107	0.088	0.066	0.048	0.052	0.078
11	0.208	0.201	0.222	0.209	0.145	0.175	0.177	0.142	0.132	0.116	0.097	0.081	0.084	0.108
12	0.218	0.213	0.232	0.217	0.176	0.200	0.200	0.173	0.166	0.155	0.140	0.127	0.129	0.148
13	0.232	0.228	0.248	0.228	0.218	0.232	0.231	0.213	0.210	0.204	0.195	0.187	0.188	0.200
14	0.251	0.249	0.268	0.244	0.273	0.274	0.269	0.263	0.265	0.267	0.267	0.263	0.264	0.267
15	0.275	0.276	0.293	0.264	0.344	0.327	0.318	0.326	0.335	0.347	0.356	0.360	0.360	0.352
3-15	0.218	0.213	0.233	0.225	0.164	0.183	0.183	0.147	0.138	0.123	0.106	0.091	0.096	0.117

Based on the above estimates of the natural mortality there seems to have been a declining trend with the declining stock, however not sufficient to counteract the negative impact from the high fishing pressure.

We will thus consider 4 different assessments: 1) an assessment close to the traditional XSA assessment, 2) using gamma distribution with constant CV for the surveys, 3) using the above estimated variation of natural mortality and 4) using both gamma distribution of surveys and variable natural mortality. The first variant is hereafter referred to as the standard assessment.

Future: Optimal F in addition to precautionary measures?

The present management situation for Northeast arctic cod is that – as for most stocks – ICES recommends an F-value in a range that will bring the spawning stock below B_{lim} only with a low probability. B_{lim} is by definition a limit value below which there is a noticable probability of recruitment failure. Based on an inspection of the stock-recruitment plot from the assessments made by the Arctic Fisheries Working Group (hereafter Arctic WG) B_{lim} has been set to 400 000 tonnes. For spawning stocks above this level there seems not to have been recruitment failure (Jakobsen 1993). Mace (Mace 1994) suggested that the spawning stock that yields half the maximum recruitment in a theoretical stock-recruitment model should be used as a reference point that should be exceeded with a very small probability. Myers et al (Myers; Rosenberg; Mace; Barrowman, and Restrepo 1994) studied a wide range of reference points and found that $B_{50\%}$ was most reliable and robust. This reference point, although somewhat arbitrary is clearly understandable and operational and will be used in the present paper for that reason. However, some words of caution may be needed. Stocks for which there have been very good recruitment at low values of the spawning stock (Barents Sea capelin is an example) may have the $B_{50\%}$ estimated close to zero, which renders this reference point useless.

However, complying to this rule every year taking as high a catch as possible would be a suboptimal management in terms of maximising yield, the stock would never get a chance of rebuilding to a size where good catches can be expected.

Rule-based management

The yearly objective for management is to achieve certain numerically expressed goals, i.e. the spawning stock should be above 500 000 (Bogstad; Sandberg; Steinseide, and Steinshamn). However, if one is faced with different scenarios giving radically different perceptions of the stock development, expressing the management goal in numeric terms may become a problem because the different scenarios will be conflicting. However, if the management goal is expressed as a rule, the conflict may be greatly reduced. For instance, two scenarios where the stock development differ by a factor of 2, will give management goals that also differ by a factor of 2. But if the management goal can be expressed as a rule, for instance the F-value that in the long run gives the highest yield, the numerical value between the different scenarios will still be large, but the corresponding quotas may be close to each other. The reason for this is that the historic catch that generated the two different historic developments is the same.

Similarly, there may be uncertainties in the assessment due to decisions that must be taken with regard to choice of models for the stock dynamics and error structure of the tuning indices, leading to several alternative assessments that may be equally valid. The perception of the stock situation may thus be conflicting. However, if the management is conducted using a rule, the parameters in the rule may differ accordingly and the final decision of the quota may not necessarily differ so much.

Finally, the present management is presented to the managers in terms of technical terms like F that carry little or no meaning to the decision makers. In contrast a rule-based management will be more easily understood. Continuous development of methods on the scientific level may thus be transparent to the manager, who only needs to consider the rationale behind the management rule.

Maximum sustainable yield

The concept of maximum sustainable yield has been one of the more important guidelines for management, although in recent years guidelines intended to safeguard the stock against collapse in the medium-term have got more attention. However, for reasonably healthy stocks this does not give much advice to the managers, that possibly will tend to advice catches that on the long run are too high for the stock to be maintained at the most productive level.

Maximum sustainable yield is traditionally based on calculations using the replacement line and the stock-recruitment relationship and ignoring trends or fluctuations in the data that are used to calculate these two entities. Instead we will base the calculations on a stochastic model.

A formal optimal management rule based on first principles has not yet been established for the Northeast arctic cod stock. Using a multispecies model Tjelmeland (Tjelmeland 1995) found an optimal F-value of about 0.4, this was however based on outputs from the standard assessment of the stock using XSA. In the present paper the assessment model is made more realistic by introducing an age-dependent natural mortality, which also is used in the simulation model.

In a real management situation the goal of maximum long-term yield should be modified by taking into account price elasticity, which was done by Sandberg et al (Sandberg; Bogstad, and Røttingen 1998) in the medium term. The method and model used in this paper lend themselves readily for such an analysis, but this will not be pursued here, it is the general principles of establishing an optimal rule that is of primary interest.

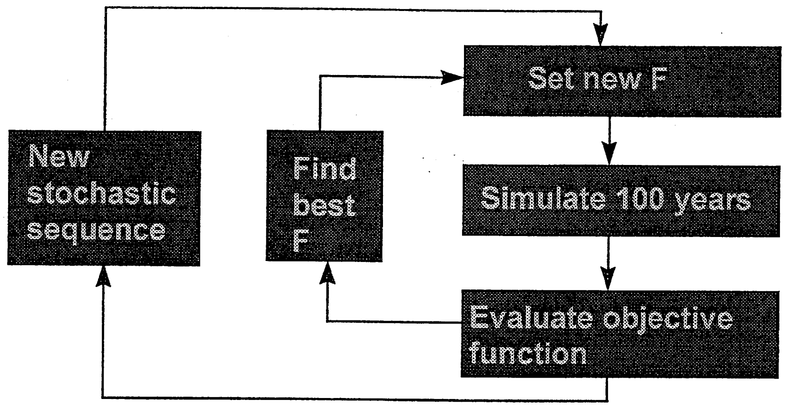
Managing through F

Walters and Parma (Walters and Parma 1996) showed using simple stochastic models that a fixed F policy in general will achieve at least 85% of what would have been achieved if the fluctuations in environmental conditions were known in advance and is thus a fairly robust harvesting control rule. In this paper the optimal F for Northeast arctic cod will be found for 4 different situations: assessment made with gamma or log-normal distribution of tuning series indices and with the natural mortality be constant and equal to 0.2 or being estimated exogeneously.

Scheme for evaluating a harvesting control rule through simulations

The evaluation of a harvesting control rule is outlined in figure 2. The simulation model is started using a fixed initial stock and conducted using a fixed value of the fishing mortality. In the present paper the simulations were run over 300 years and data during the first 30 years were not used to avoid effects of the arbitrary initial stock. Then the objective function is evaluated and another run is made for a new value of the fishing mortality but using the same sequence of stochastic events, i.e. the spawning success is the same in all years. By varying F systematically the F-value that in the long run gives the best outcome is found. In the present paper the best outcome is simply the highest long-time catch, but the method readily lends itself to an elaboration of the success criterium. For instance, a high stability of catches could be valued. Also, the proposed harvesting control rule, which in fact merely is a biological reference point and the stochastic equivalent of F_{MSY} could be elaborated. For instance Scweder et al (unpublished manuscript) have shown that setting a catch ceiling increases the economic benefit of the fishery.

Figure 2. Scheme for evaluating harvesting control rules



Having found the optimal F-value for one set of stochastic events the procedure is re-iterated for another set of stochastic events. A set of optimal Fs are thus found, making it possible to control the uncertainty level of the calculations.

Simulation model

The basic simulation model is the same as used in the assessment. The dependence of F on age is taken as that of the last year in the assessment. The weight at age and proportion mature at age are considered dependent on abundance and interpolated between historic values using the total number of fish in the age range 8-13. Thus, the only major source of uncertainty is the spawning stock – recruitment relation.

Recruitment is modelled by a Beverton-Holt function:

$$Recruitment = Max\,Recruitment \frac{SpawingStock}{SpawningStock + B_{50\%}}$$

The number of recruits calculated using the above formula are further modified by cannibalism, temperature effect and the effect of the mean age of the spawning stock by the expression:

$$Modified\,Recruitment = Recruitment \times e^{-ImmatureBiomass/Cann}\, e^{-Temperature/Temp}\, e^{MeanAgeSpawningStock/Age}$$

where Cann, Temp and Age are parameters to be estimated. A large value for these parameters means that the corresponding effect is not important. The parameters are estimated by assuming lognormal errors. The parameters and the percent variation explained (R2) are shown in Table 2.

Table 2. Estimates of parameters in the spawning stock - recruitment relation for 4 different assessment scenarios

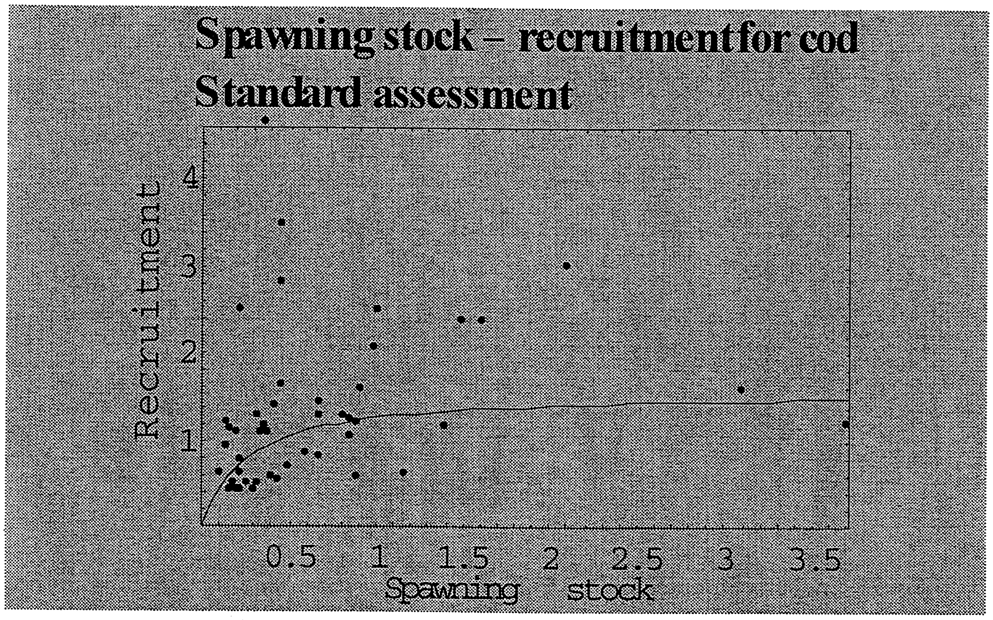
Summary of different cod assessments

	B50	Cann	Temp	Age	R2	B98 rel. stand.
Standard	0.256	16.718	1.711	97.693	0.355	1.000
Gamma surveys	0.201	8.658	1.638	8.883	0.370	0.923
Variable M	0.234	2397.975	2.067	4.009	0.454	0.999
Gamma surveys, variable M	0.324	5.266	1.777	2.890	0.509	1.023

Generally, the variation in the recruitment is poorly explained by the model. Using variable M gives a clearly better fit. The low values of the parameters for cannibalism, temperature effect and mean spawning stock age effect shows that all these effects are important, with the exception of the age effect in the standard assessment and the cannibalism effect in the assessment using log-normal distribution of surveys and variable M. $B_{50\%}$ is close and in the range 200 to 250 thousand tonnes, with the exception of the assessment with gamma distribution of surveys and variable M, where $B_{50\%}$ is markedly higher. B98 is the 1998 spawning stock biomass relative to what it is in the standard assessment. It is seen that the present perceived stock situation differ little among the different assessment scenarios.

Figure 3 shows the spawning stock – recruitment points in the standard assessment, corrected for cannibalism, temperature effect and mean spawning age effect together with the estimated Beverton-Holt relationship.

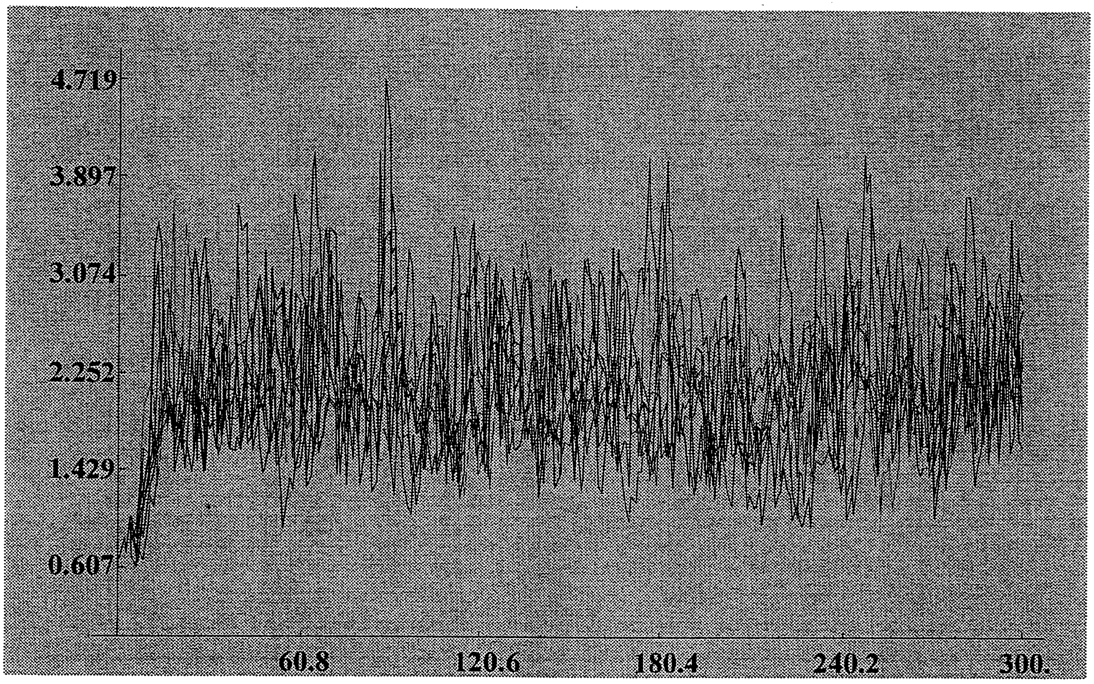
Figure 3. Spawning stock - recruitment points and estimated Beverton-Holt relationship for the standard assessment



There is clearly an increase of recruitment with increasing spawning stock, but the signal is not very strong. Since the above relation is of paramount importance for defining harvesting control rules research into finding improved models should be encouraged.

Figure 4 shows an example of the typical variation for the spawning stock over the simulation period, taken from the standard assessment and for the optimal F-value. It is seen that the spawning stock rapidly builds up to about 2.5 million tonnes and that there is a considerable range of variation.

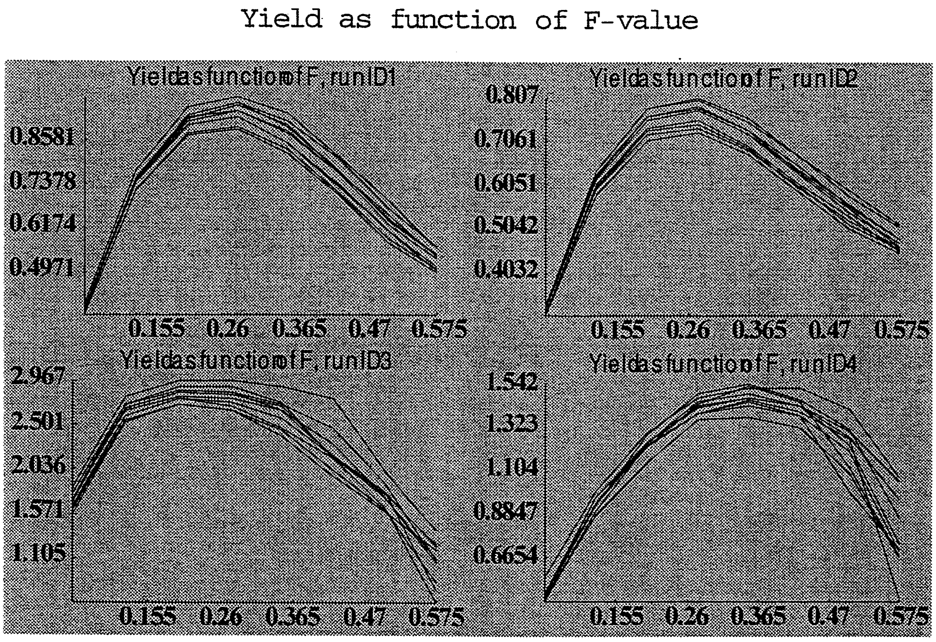
Figure 4. Simulated spawning stock timeseries, standard assessment, optimal F-value



Estimates of F_{opt}

Figure 5 shows the long-term yield as function of F-value for 10 different sequences of stochastic events for the standard assessment (upper left), gamma distribution of surveys (upper right), variable M (lower left) and both gamma distribution of surveys and variable M (lower right).

Figure 5. Yield as function of F for different stochastic sequences and 4 different assessment scenarios



It is seen that the two assessment scenarios with constant M are similar, with an optimal F around 0.27. Using variable M makes the two different assumptions about survey distribution give different perceptions about what is the optimal F-value.

It is interesting to note that the optimal F-values from figure 5 compares favourably with the value of 0.26 obtained by Garrod and Jones(Garrod and Jones), as is the declining trend at F-values above 0.42, which Garrod and Jones maintained would lead to an extinction of the stock in the long run.

Also, the obtained optimal F-values fall into the range 0.25 – 0.45 indicated by Nakken (Nakken; Sandberg, and Steinshamn 1996) using a yield per recruit analysis, an analysis that in addition to the consideration that the spawning stock should be above 500 000 tonnes is used in present-day recommendations for the stock (Bogstad and others).

Simulations made during the 1999 meeting of the ICES Comprehensive Fishery Evaluation WG (Anonymous 1999) indicated an optimal F-value below 0.24. However, cannibalism was not included in the recruitment model used.

Using the harvesting control rules and biological reference points – The short-term simulation

To see how the two reference points will work in practice 200 simulations were made over one year for different quotas. A standard error of 0.3 on the assessment was assumed, in accordance with present practise. It should be noted however that it is possible to evaluate the uncertainty in the assessment using replacement simulation or – when the assessment is statistically based - sampling from the likelihood function using Markov Chain Monte Carlo techniques. The latter method has previously been used in the assessment of Norwegian spring spawning herring (Anon. 1998). For each quota the probability of the spawning stock after one year to be smaller than $B_{50\%}$ and the probability for the realised F-value to be larger than the optimal value found from figure 5 were calculated. The results are shown in figure 6 for each of the 4 assessment scenarios.

Figure 6. Probability of realised spawning stock biomass being smaller than $B_{50\%}$ (broken) and the realised F-value for being larger than the long-term optimum(solid lines) for the standard assessment (upper left), gamma distribution for surveys (upper right), variable M (lower left) and both gamma distribution and variable M (lower right)

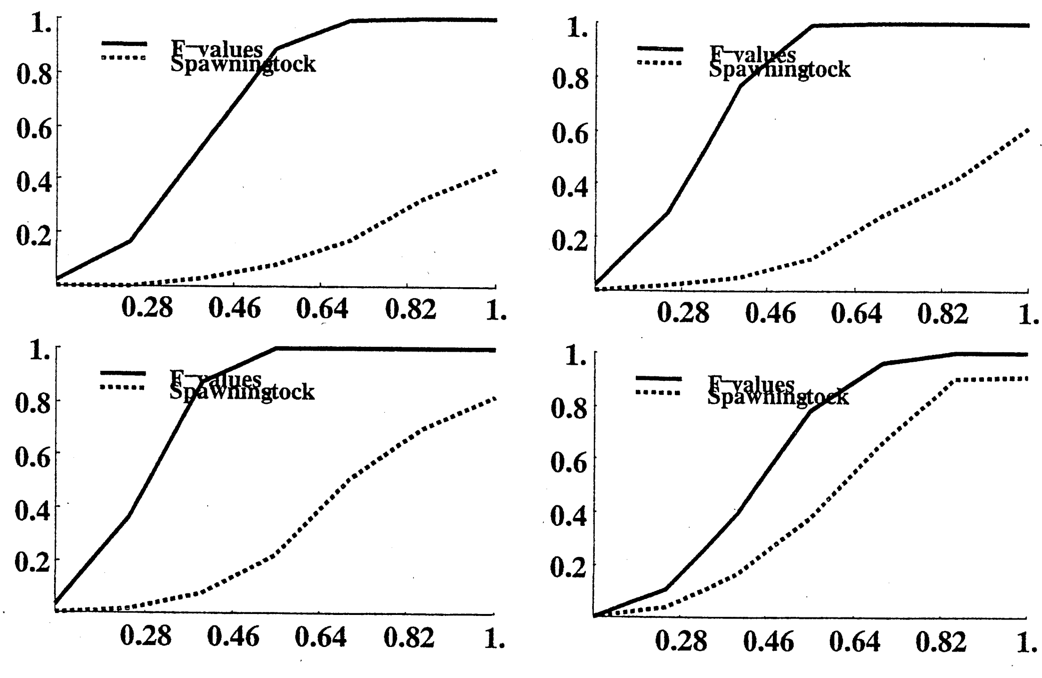


Figure 6 represents the communication of the assessment to the managers. It would be natural to use a 50% probability for the realised F to be smaller than the optimal (target) F and a low probability (less than 10%) for the realised spawning stock to be smaller than the (limit) $B_{50\%}$ spawning stock level. Then it is seen that the target strategy corresponds to the smallest quota in all cases, which one would expect.

All relevant information from the 4 very different assessments are condensed into figure 6. Although the 4 assessment scenarios are based on radically different principles the final outcome of the analysis does not differ very much between the 4 cases.

A note of warning: Multispecies effects

It should be observed that the simulations made in the present paper are strictly single-species. Inclusion of multispecies affects may change the results substantially. When the capelin stock collapsed in the period 1983-1989 the individual growth of the cod decreased (Bogstad and Mehl 1997). Management rules that on the average give a very high stock of cod may thus be too optimistic, in that the average food abundance will not sustain the stock at the perceived level.

PINRO and IMR have conducted joint multispecies research in the Barents Sea since 1985 and several multispecies models have emerged by which species interrelations of importance to managers can be studied (Tjelmeland and Bogstad 1998). These models have not yet resulted in versatile tools for management. Research is ongoing however, and it is expected that the basic philosophy behind the development of harvesting control rules in the future will be essentially multispecies. In view of the biological complexities and parameter estimation difficulties involved, rapid progress in terms of operational harvesting control rules should not be expected.

There has been an attempt of evaluating optimal harvesting control rules for capelin using the capelin-cod model CAPSEX (Anonymous 1998), in which the recruitment to the capelin stock is to a large extent controlled by inflow of occasionally large yearclasses of herring into the Barents Sea. The attempt failed, however, because there was an inconsistency in the input data that led to a vanishing spawning stock of capelin in some years. One of the problems with this model – as with all multispecies models for the Barents Sea that are used for the period before 1984 – is that there are no stomach content data before 1984. If the overlap between the species or the amount of other food were different in, say, the 1970s than from 1984, then errors will be made.

In recent years it has been possible through a joint effort between PINRO and IMR and with sponsoring from the Norwegian Ministry of Foreign Affairs to make parts of the Russian retrospective data base available for joint research (Shleinik; Ushakov, and Tjelmeland 1999). If it is possible to continue this co-operation there may be promise for a future quantification of species interrelations also for the period before 1984. Then multispecies models may come stronger into force when it comes to management of fish stocks in the Barents Sea, resulting in a possibly more rational harvesting from the ecosystem.

Living with discrete uncertainty – a better co-operation between managers and scientists is called for

The decision about what are the most appropriate assumptions to be used in the assessment has been taken by the scientists in the ICES working groups. However, in a precautionary framework the responsibility for decisions and for handling uncertainty is left to the managers, the scientists will decide on what are the most appropriate models and make parameter estimates. If a decision about the error structure of the surveys can be made, this should be viewed as a part of the overall uncertainty in the management and the managers should take responsibility for handling it properly.

Simulation tools can be of great help in this work. In order for the managers to obtain the best possible insight into the uncertainties connected to the assessment and the development of harvesting control rules scientists and managers should find room for to some extent working together using appropriate simulation tools. The suite of simulation tools should contain models that view the ecosystem from different perspectives:

- Single-species models that aim at establishing elementary harvesting control rules, as is the case with the model used in the present paper.
- Multispecies models in which all the parameters are estimated and which are directed towards immediate management use (Tjelmeland and Bogstad 1998),(Tjelmeland and Bogstad 1998).
- Multispecies models that are all-embracing and in which not necessarily all parameters are attempted estimated from data in a formal way (Hamre and Hatlebakk 1998),(Hagen; Hatlebakk, and Schweder 1998). These models may be used in testing "what-if" scenarios.

A working method worth considering is that of setting up a simulation laboratory based on running the models over Internet for certificated users.

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