International Council for
the Exploration of the Sea

ICES CM 2000/V:01
Theme session on Medium-Term
Forecasts in Decision-Making

The use of Medium-Term Forecasts in advice and management decisions for the stock of Norwegian spring spawning herring (*Clupea harengus* L.)

By

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ABSTRACT

Medium-term simulations on the stock development of Norwegian spring-spawning herring (*Clupea harengus* L.) have been carried out since 1994 by the ICES «Atlanto-Scandian Herring and Capelin Working Group», in 1996 renamed «Northern Pelagic and Blue Whiting Fisheries Working Group. The results of the simulations have been used as a basis for advice on harvest control rules for Norwegian spring spawning herring. The present paper reviews developments of medium-term simulations carried out on this stock and results from medium-term forecasts carried out in 1995 and 1999 are used as examples. Emphasis is put on the usefulness of the medium-term simulations in the process towards reaching an agreement on a harvest control rule in 1999.

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1. INTRODUCTION

The stock of Norwegian spring spawning herring (*Clupea harengus* L.) sustained a large fishery in the 1950s and the 1960s. Poor recruitment and a high fishing mortality in the 1960s eventually led to the collapse of this stock, and a moratorium was introduced in the early 1970s. During the latter half of the 1970s and in the 1980s the fishable part of the stock occurred within Norwegian waters and a limited fishery for human consumption was allowed. The total allowable catch from the mid 1980s was targeting on a fishing mortality of 0.05.

The recruitment of this stock has been very variable. Since 1950 recruitment has in most years been poor, but a few large yearclasses have occurred. The fishery has been based on the exploitation of these yearclasses. In the rebuilding phase of the stock, recruitment was high only in 1983. That yearclass eventually moved the spawning stock above what the International Council for the Exploration of the Seas (ICES) then considered as the Minimum Biological Acceptable Level (MBAL) - 2.5 million tonnes (Dragesund and Ulltang 1975). In 1991 and 1992 the stock again produced very good recruitment. Having detected the survival of these strong yearclasses it was clear to the management authorities that the stock once again would grow to the size it had in the 1950s.

To the managers, this development raised the question of appropriate harvesting policy or how to fix the total allowable catch (TAC). Acknowledging the variability in the recruitment of this stock and the objective of achieving a sustainable fishery, it was clear that the annual level of exploitation should be based on a long-term harvest control rule (HCR). This paper describes shortly the process of establishing such a rule for this stock, and in so doing - the use of medium term forecasts.

2. PROCESS OF ESTABLISHING A HARVEST CONTROL RULE IN 1995

The process of establishing an HCR for Norwegian spring spawning herring started in the autumn of 1995. This was during the years when ICES only gave specific advice for stocks considered to be outside safe biological limits. Regardless of that, the Atlanto-Scandian Herring and Capelin Working Group made medium-term forecasts of stock development for various HCRs. The Advisory Committee on Fisheries Management (ACFM) gave their advice, and Norway presented a suggestion for harvest control rule at the annual meeting of the Northeast Atlantic Fisheries Commission (NEAFC).

2.1 Work done by the ICES working group

The Atlanto-Scandian Herring and Capelin Working Group carried out a 10 year prediction on the development of the herring stock. HCRs tested were;

- a fixed fishing mortality during the period (F=0.166)
- a fixed catch during the period (0.97 m.t. and 1.03 m.t.)

For none of the HCRs were F reduced at low stock levels. The predictions were carried out by using the equation:

$$N_{y+1,a+1} = N_{y,a} e^{-F_{y,a} - M_{y,a}}$$

where $N_{y,a}$, $F_{y,a}$ and $M_{y,a}$ are the population number, fishing mortality and natural mortality of fish of age *a* in year *y*.

The performance measure chosen was the development in catch and spawning stock biomass as well as the risk of spawning stock biomass (SSB) falling below 2.5 million t (MBAL) within the period. The predictions were run for age groups 0-16+. The same input data were used for the 10-year predictions as for the ordinary short-term predictions. The Excel add-on program @RISK was used for this purpose, drawing from the distributions on the input data 300 times to find the distribution of the performance measures. For runs with a fixed catch, a third-order series expansion was used to calculate the F value corresponding to a given catch. This algoritm was developed at the Institute of Marine Research in Iceland (G.Stefansson, pers.comm.) The table below summarizes the assumptions made about uncertainty in various factors in 1995:

Table 1 Assumptions regarding uncertainty for medium term predictions (1995).

Uncertainty M	Standard dev. 0.05
Uncertainty maturation	Normal distribution (CV=0.1) on age 4 fish
Uncertainty weight at age	None
Uncertainty fishing pattern	None
Uncertainty spawning stock/recruit	1: Beverton-Holt model with error on log scale, retaining all data or deleting the 1950, 1959 and 1983 year classes 2: Calculating historical half values in Beverton-Holt equation, with autocorrelation taken into account
Uncertainty initial stock	CV =0.25 on age 6 and younger. Uncertainty on 1983 and 1988 year classes taken from 30 runs of tuning procedure (0.08 and 0.167 billion, respectively).
Uncertainty annual assessments during simulations	None

The results from the HCR with constant F is illustrated in Figure 1:

Figure 1 **Development of Spawning Stock Biomass during the period 1996-2005 when fishing with a constant fishing mortality (F=0.17).**

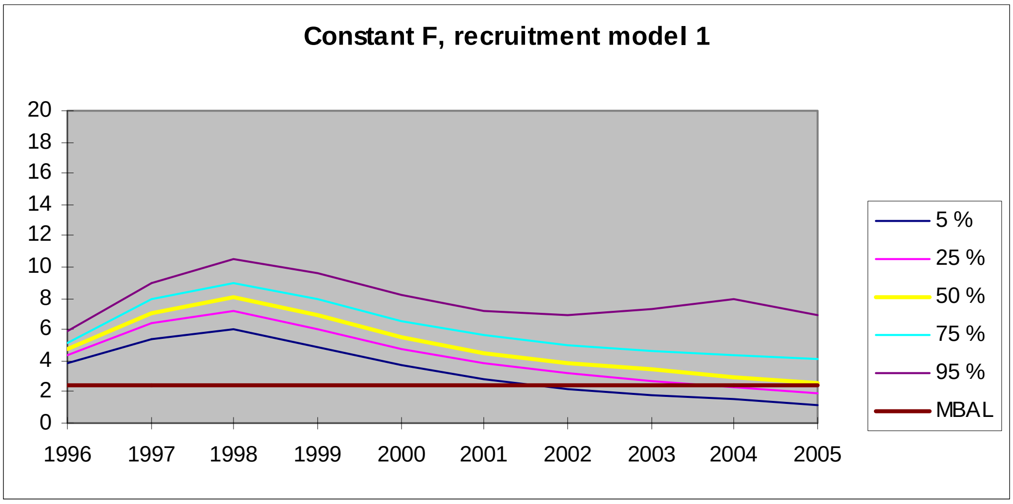


Figure 1 shows that the spawning stock was expected to exhibit large variations during the 10-year period (1995-2004). As a consequence of how the various HCRs performed in these runs, the Atlanto-Scandian and herring working group in 1995 argued that: ".. The choice of a harvesting strategy for 1996 (and for coming years) should **not** be made on the basis of the short term prediction table. Rather, the choice should be made on the basis of the medium term development of the stock, and keeping in mind the important role this stock has in the Barents and Norwegian Sea ecosystems (ICES 1996)."

The working group argued that the year class success in the beginning of the 1990s would probably be followed by a series of weaker year classes. The main arguments advocating for such a development were:

- A forthcoming colder period in the Barents Sea (Ottersen et al. 1994)
- Cannibalism when the strong year-classes of 1991 and 1992 left the Barents Sea (Holst 1992)
- A prediction of large concentrations of young cod in the Barents Sea in the coming years that might increase the natural mortality for the juvenile herring in the coming years (ICES 1995).

This was taken into account in the stock recruitment relation giving the medium term development seen in Figure 1. It can be seen that there is a certain risk of reaching MBAL in the medium term with a constant F=0.17, even if there is observed a considerable growth in the spawning stock in the short term.

2.2 Advice given by ACFM

As mentioned, strong year classes of Norwegian spring spawning herring occurred in 1991 and 1992. It was expected a large increase in the spawning stock in the short term, and the stock was by 1995 above the MBAL level of 2.5 million tonnes. This is reflected in the management option table given {although only one catch option, (F95=F94), was given in the November 1995 report from ACFM}[1].

Table 2 Management option table presented by ACFM in 1995

Scenario	Basis	F96	SSB 96	Catch 96	Lndgs 96	SSB 97
A	1.0 F94	0.125	4792	966	966	6753

A growth representing a yearly increase in the spawning stock of 2.0 million tonnes including a catch of 1.0 million tonnes is rather unique, and it would be expected that such a short term development would be interpreted very optimistic when the TAC for 1996 was to be decided upon.

The forecast given by ACFM in the autumn 1995 report was: «The SSB is estimated to be well above the minimum acceptable level (MBAL) of 2.5 million tonnes in 1996, and the forecast increase of the spawning stock in 1997 is due to the expected recruitment of the strong year classes 1991 and 1992».

Further, the Advice on Management was:" ACFM advices that the fishery on this stock should be managed to ensure that the SSB is kept above the MBAL level of 2.5 million t." Thus, in accordance with the philosophy and format of ICES advice in the mid 1990s, when the spawning stock was above MBAL it was left to the management agencies to decide on preferred objectives and corresponding TAC (Serchuk and Grainger 1992). This, of course, represented a challenge to the management agencies and stressed the need for basing the TAC on medium-term predictions.

2.3 Work done by management bodies in Norway

To facilitate discussion on management of the stock, the Norwegian Institute of Marine Research (IMR) and Directorate of Fisheries (DoF) made a study (Anon 1995) building on the medium term simulations made by the Atlanto-Scandian and Capelin Working Group in October 1995 (ICES 1996).

However, the Norwegian study did not include measures of uncertainty and was therefore a pure deterministic analysis. Two HCRs were tested:

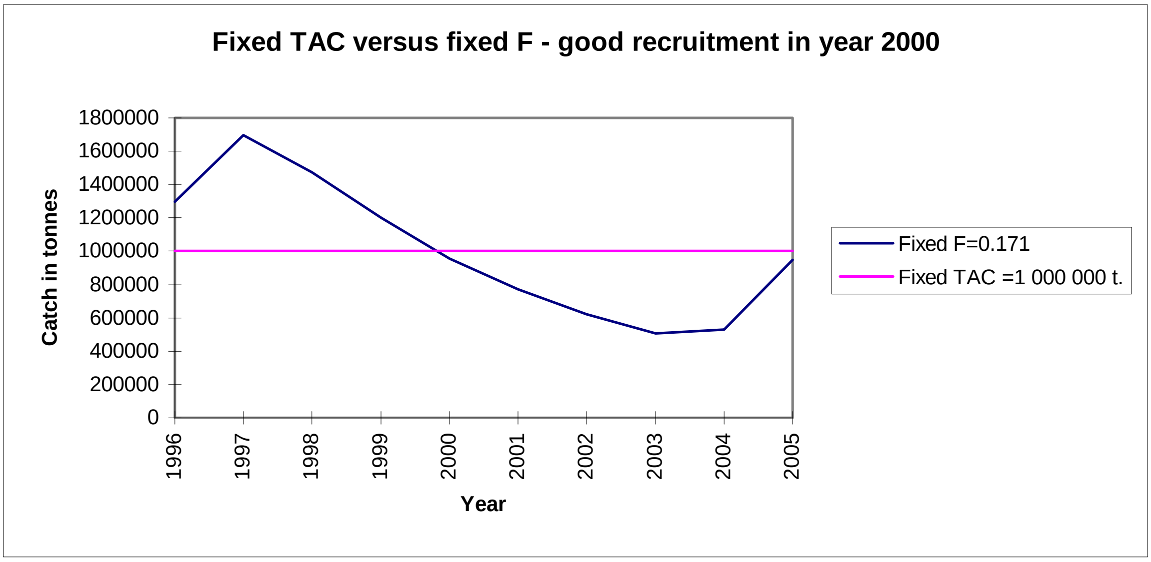
- Exploitation with a constant fishing mortality (F=0.17)
- Exploitation with fixed catches. (catch quota of 1.0 million t)

The time period chosen was 10 years, the spawning stock biomass was set as a point estimate (equal to ICES' assessment of the spawning stock in 1994). As the past had shown variable recruitment characterised by long periods of low recruitment broken by a good year class from time to time, recruitment was set equal to the low level of 1994. However, to include the anticipated good year class from time to time, recruitment in 2000 was set equal to recruitment in 1992.

[1] Catch and the SSB estimates are given in thousand tonnes.

The calculations gave the following catch profiles:

Figure 2 **Development of TAC by following HCR characterised by either a fixed TAC or a fixed fishing mortality.**



The figure illustrates that different strategies will have a very different impact on the catches over a 10-year (medium term) period. The group from IMR and DoF concluded that a management objective of stabilising catches were preferable to this stock. The main arguments were of economic nature, such as:

- More stability for the fishing industry
- Reduced incentives for investment in overcapacity

The proposal put forward by IMR/DoF were presented as a Norwegian working paper at the annual meeting of NEAFC in 1995.

3. PROCESS OF ESTABLISHING HARVEST CONTROL RULE IN 1999

Since 1997, five parties have been central in the management of Norwegian spring spawning herring. The EU, Faroe Islands, Iceland, Norway and Russia have each year held a meeting to agree upon the level of TAC next year. In the minutes from the meetings of 1997 and 1998, the five parties have requested ICES to produce medium-term analysis of consequences of various HCRs. They also agreed to set up a specific working group to discuss the findings of ICES and include, as appropriate, economic and other relevant considerations for the purpose of applying medium and long term strategies in the consultations on the stock.

3.1 Work done by the ICES working group

There were differences in the actual stock situation in 1999 compared to 1995. By 1999 the individual growth potential in the important 1991 and 1992 year classes had terminated and these year classes had been exploited for several years in the international fishery. The year classes following 1991 and 1992 were, as anticipated, weaker. Thus the medium term simulations indicated, in contrast to the medium term simulations in 1995, a stock which would decrease in the nearest years (Figure 3). In the figure it can be seen that, compared with the medium term simulations from 1995, the MBAL reference level from 1995 is replaced by the new reference levels connected to the precautionary approach, *i.e*. Blim and Bpa. For Norwegian spring spawning herring, Blim is set equal to the MBAL level of 2.5 million tonnes, whereas Bpa is set to 5 million tonnes (Røttingen, 2000).

As requested by the five parties, the ICES working group performed analysis of various HCRs. The table below summarizes the assumptions made about uncertainty as well as HCRs used and the performance measures, which were calculated (ICES 1999).

Table 3 Assumptions regarding uncertainty for medium term predictions (1999).

Time period for simulation	5 and 10 years
Harvest control rules	F=0.100, 0.125, 0.150, 0.175 combined with catch ceilings of 1.0, 1.25 and 1.5 million t
Reduction of F at low stock levels	Linear decrease in F from 0.15 at Bpa (5 million t) to 0.05 at Blim (2.5 million t), alternatively no reduction or red. to F=0 at B=3.75
Performance measures	Average annual yield, risk of falling below Blim/Bpa, stability in catches
No. iterations risk	1000
Uncertainty M	None
Uncertainty maturation	None
Uncertainty weight at age	None
Uncertainty fishing pattern	None
Uncertainty spawning stock/recruit	Beverton-Holt model with CV of 1.9, upper bound on recruitment of 1000 billion at age 0
Uncertainty initial stock	CV=0.4 on log scale for age 4 and older (from quality control sheets), linearly increasing CV to 1.8 at age -1
Uncertainty annual assessment	CV=0.4 on log scale, uncorrelated between age groups

Figure 3 **Development of Spawning Stock Biomass in the period 2000-2010 by following HCR where TAC is restricted by either F=0.15 or Catch ceiling = 1.5 million tonnes.**

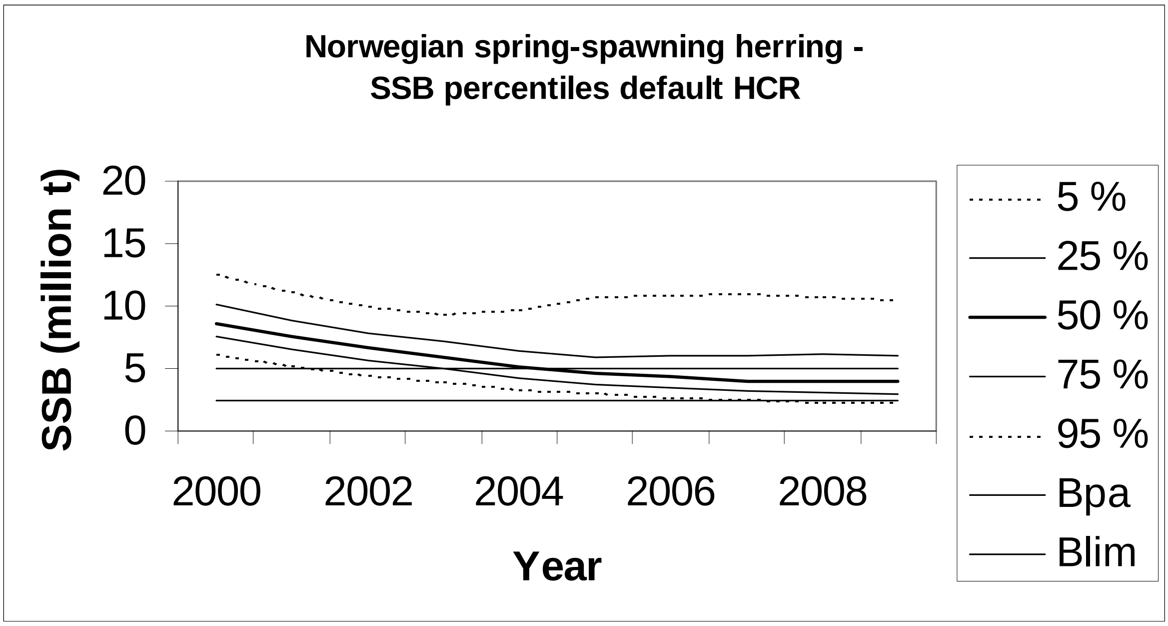


Figure 4 **Development of yield in the period 2000-2010 by following HCR where TAC is restricted by either F=0.15 or Catch ceiling = 1.5 million tonnes.**

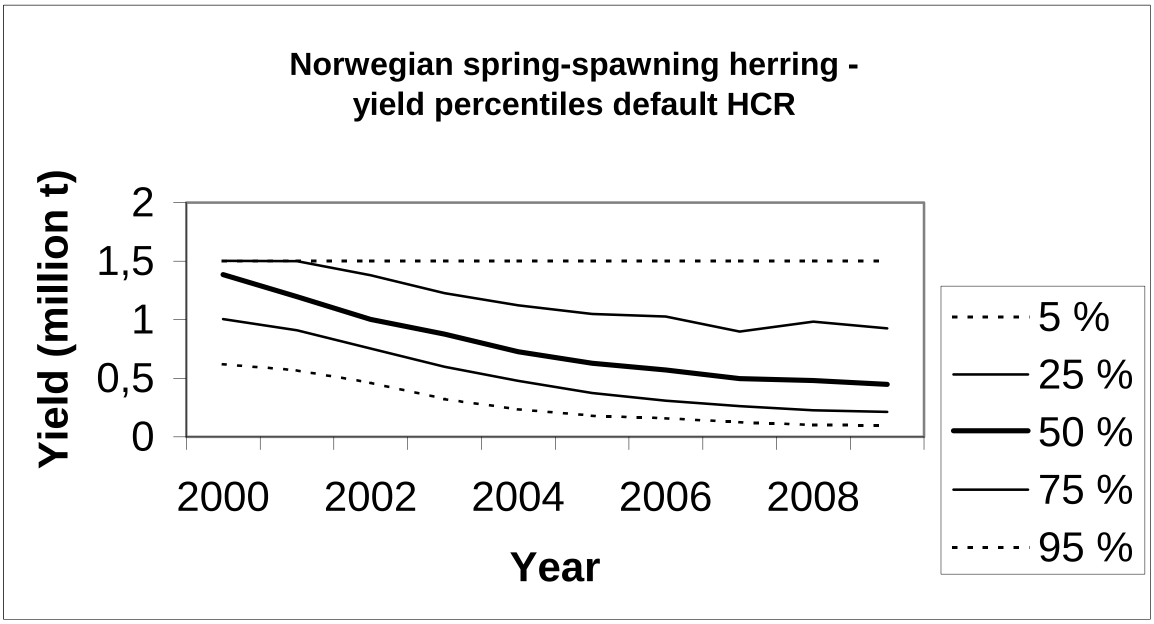


Figure 3 and 4 illustrates the consequences on SSB, yield and the inherent uncertainty around these indicators by applying the HCR where the annual level of TAC is restricted by either a fishing mortality of 0.15 or a catch ceiling of 1.5 million tonnes.

3.2 Advice given by ACFM

ACFM gave the advice that total allowable catch should be restricted by either a TAC-ceiling of 1.5 million tonnes or by a fishing mortality of 0.15. In accordance with these restrictions, catches should be restricted to 1.5 million tonnes for 2000. Furthermore, they pointed out that the recruiting year classes were weak and that this should be taken into account when deciding on the catch for 2000.

3.3 Advice given by the expert group of the five parties

The group which were established by the five parties consisted of biologists and economists from the parties managing the stock. The group reviewed the findings of ICES and evaluated how the various HCRs performed according to the following objectives:

1. Highest sustainable yield
2. Low risk of stock collapse
3. Stability in yield

Four HCRs were picked to represent the variety of rules which had been analysed by ICES. The medium term simulations gave a possibility to consider the effects which different fishing mortality levels and catch ceilings had on the average TAC, the variability in catch and the probability of reaching the Blim level of 2.5 million tonnes. The results are given in the table below[2].

Table 4 Consequences of various HCRs

HCR	Average TAC	Difference in catch	P(SSB<2.5 m.t.)
Fish. mort=0.15 TAC ceil. 1.5 m.t.	840.000 t	1.120.000 t	19%
Fish. mort=0.15 TAC ceil.1.0 m.t.	750.000 t	620.000 t	16%
Fish. mort=0.10 TAC ceil.1.5 m.t.	710.000 t	990.000 t	9%
Fish. mort=0.10 TAC ceil.1.0 m.t.	660.000 t	660.000 t	6%

The medium term simulations indicated two relationships:

- The performance measure of stability "Difference in catch" is more affected by a reduction in TAC ceiling than by a reduction of fishing mortality.
- The probability that the stock should fall below 2.5 million tonnes is more reduced by a reduction in fishing mortality than by a reduction in TAC ceiling.

[2] The «Difference in catch» is given as the difference between the highest and the lowest catch within the 10 year period.

The working group concluded that the level of fishing mortality and the catch ceiling should be reduced from F=0.15, TAC=1.5. The main argument for lowering the fishing mortality was to lower the risk of falling below 2.5 million tonnes (Blim). The argument for lowering the catch ceiling was to stabilize the catches (Anon 1999).

3.4 Management decision of the five parties

The results above formed the basis for the discussion in October 1999 on harvest control rule. Two important decisions were made:

- The TAC for 2000 was fixed to 1.25 m.t. which was less than the maximum level suggested by ACFM (1.5 m.t.).
- An HCR was established to guide the levels of TAC from 2001. According to the HCR chosen, TAC should be based on fishing mortalities less than 0.125. However, no measures were taken to stabilise catches.

4. SUMMARY ON THE IMPORTANCE OF THE MEDIUM TERM SIMULATIONS

Norwegian spring spawning herring is, for the time being, a stock assessed to be well above biological reference points like Blim or Bpa. The natural variability of the stock is first and foremost determined by the recruitment process, whereas the total development of the stock also depends on the exploitation rate.

To managers, seeking the best possible tradeoff between objectives like "highest sustainable catch", "stability" and "low risk of stock collapse", analysis of consequences of various HCRs are essential. The existence of such analysis makes it possible to evaluate short-term gain against long term losses and degree of stability against loss of income. Such knowledge is of course important when choosing the right HCR (Sandberg et al. 1998).

The performance measure which ICES calculated last year by following various HCRs were seemingly instrumental for the five parties when they made an agreement on rule at their meeting in 1999. Utilising the best available medium term forecasts is therefore important to improve resource management in order to achieve sustainable fisheries.

Simultaneously, as such forecasts are used in practical management decisions, it is important to stimulate research in order to improve the forecasts. Concerning probabilistic medium term forecasts of Norwegian spring spawning herring, the following items will be central to understand in the years to come:

It is important to establish a more elaborate spawning-stock recruitment relation. The traditional assumption of a Beverton-Holt relation with errors normally distributed on log scale does not seem appropriate for this stock. The underlying environmental mechanisms determining recruitment success remain to be understood and if revealed can lead to a more appropriate recruitment model.

A better understanding of the environmental changes on medium scale could lead to probabilistic prognoses of weight at age and maturation at age being adapted to the current trend in environmental conditions and research in this respect should be encouraged.

The present HCR should be tested against alternatives using long-term simulation. Research in this respect should be encouraged as well as research to identify possible relationships between the size of the annual catches and the price obtained for the landings. Concerning the latter, it should be noted that such relationship may vary between the countries participating in the fishery.

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