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Checking of Some Conventional Management Reference Points for the Cod Stock off Greenland

by

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Abstract

Based on reasonable relations between recruitment, spawning stock biomass, and temperature, stock developments were simulated under different conventionally applied management reference points in order to investigate their applicability. The simulations revealed that the cod stock off Greenland does not sustain continuous exploitation in long term at a level of the natural mortality. The low biomass production can be explained with the slow growth, late maturation, and emigration of Greenland cod to Icelandic spawning grounds. With the exception of F_{med}, the conventionally used management reference points $F_{0.1}$, F_{real}, F_{max}, and F_{high} led to a stock depletion within 20 years, a theoretical scenario which was observed during the late 60s. The present case study of the Greenland cod emphasizes the importance of the protection of the spawning stock biomass.

Introduction

Intensive discussions and new international management agreements arose from recent over-exploitations or collapses of numerous marine fish stocks. These ongoing processes resulted in the so called 'Precautionary Approach to Fisheries Management' for which appropriate management reference points are highly needed. These reference points must consider medium and long term consequences for stock sizes and catches to ensure sustainable levels (Anon., 1997 a; Serchuk et al., 1997).

The assessment of the cod stock off Greenland revealed that the stock collapsed 30 years ago and has shown no signs of substantial recovery in spawning stock size since then. Based on reasonable relations between recruitment, spawning stock biomass and temperature we simulated stock developments under different conventionally applied management reference points in order to investigate their applicability.

Materials and Methods

In order to investigate the consequences of different management strategies we created a virigin cod stock on a spreadsheet with 1 000 recruits and a natural mortality controlling the strength of the individual age groups. The Greenland cod are known to emigrate to Iceland. The natural mortality rates were increased from the standard value of 0.2 to 0.3 for age groups 5 and older in order to account for this emigration. In accordance with the procedures in VPA-based assessments, the cod were determined to recruit at age 3 years and were allowed to live for 11 years. Additional parameters for stock predictions were adopted from the most recent analytical assessment carried out in 1996 by the ICES North-Western Working Group (Anon., 1996). This assessment covers the period 1955-92. Weights at age, the proportions mature, and partial recruitment are listed in Table 1 and were used previously for calculations of yield per recruit (Anon., 1997 b). While the partial recruitment includes the exploitation pattern of the 3 most recent years, the mean weight at age and the maturity ogive represent long term means.

The recruitment at age 3 years was predicted from a model which is based on significant spawning stock biomass and temperature effects, both being positive. The spawning stock biomass was found to represent the highest regression weight in explanation of the recruitment variation, while the temperature relation was found to be weaker. We used the long term series of mean June temperature of the upper 50 m on top of the Fyllas Bank off West Greenland (oceanographic standard station 4) which was measured since 1950 (Buch and Stein, 1989). In order to decrease interannual variation, the data were smoothed by the 3-years-running mean. Both effects, the spawning stock biomass and the temperature, were combined by a multiple linear regression explaining 53 % of the observed recruitment variation. Model specifications can be found in Table 2. The quality of the model can be taken from the scattered plot illustrating calculated versus observed values (Figure 1). Applying this model, the recruitment was predicted 3 years later from the spawning stock biomass and a random temperature value which was selected from the range between the minimum and maximum observed, i.e. 0.5 and 2.7 °C, respectively. The resulting value of recruits was then allowed to vary randomly within a range of plus and minus 126 % taking into account the standard error of the model. In case of negative values, the estimated recruitment was corrected to 0. The stock development was predicted for a period of 100 years and 100 iterations were performed in order to estimate the probability of the results.

11 different scenarios of stock management were simulated. The first one was without any fishing with only the natural mortality controlling the stock's development. The remaining investigated management strategies were based on F_{med}, $F_{0.1}$, F_{real}, F_{max}, and F_{high} without and with an additional rule for closing the fishery in case of a reduction in spawning stock biomass by more than 50 % of its virgin weight. Respective F-values were taken from report of the ICES North-Western Working Group (Anon., 1997) and listed in Table 3. F_{real} represent the effective F during the late 60s when the Greenland cod stock collapsed. The resulting stock projections after 100 iterations were also enumerated in Table 3 and illustrated in Figures 2-7 as means plus and minus standard deviations in order to illustrate the variation in stock development.

Results and Discussion

The quality of medium and long term predictions for fish stocks and catches depend mainly on the quality of the information about future recruitment. The present paper is based on the available information on the recruitment of the cod stock off Greenland. The recruitment model is based on spawning stock biomass estimates derived from a VPA-assessment and temperature effects. The model explains 53 % of the variation in recruitment since the mid 50s and seems to allow long term stock predictions at a representative level (compared with observations).

The results of the iterated stock projections under each of the various management strategies are given in Table 3 and Figures 2-7. It can be taken from Figure 2 that the stock remains under equilibrium conditions for almost 50 years and then starts to grow quickly due to the power of the spawning stock effect producing increased recruitment. The increase might also be a result of the restriction of the recruitment model to 0 or positve values and a lack of an upper limit for the number of recruits representing the maximum capacity of the ecosystem. The probability for a reduction in stock abundance from the virgin size was less than 3 %, and no cases of a decline by more than 50 % were observed (Table 3).

Figures 3a and 3b illustrate the trend of the stock under the management strategy F_{med}. There is a high probability of the stock to decrease. After 100 years, the probability of a decrease was estimated to exceed 90 %. The management rule to stop fishing activities when the SSB reduction amounts to more than 50 % seems to be a very effective tool to avoid stock collapses. The probability of a stock decline to less than 25 % of the initial size was reduced from 0.37 to 0.

The remaining management strategies at $F_{0.1}$, F_{real}, F_{max}, and F_{high} resulted in stock depletions within a period of 20 years or less without the protection of the spawning stock biomass. The introduction of a fishing ban when reductions in spawning stock biomass exceeded 50 % was again demonstrated to be an appropriate action to avoid depletion. The probabilities of a stock decline by more than 75 % of the virgin abundance were reduced from 100 % to almost 20 %, respectively.

In summary, the simulations revealed that the cod stock off Greenland does not sustain continuous exploitation in long term at a level of the natural mortality. The low surplus production can be explained with the slow growth, late maturation, and emigration of Greenland cod to Icelandic spawning grounds (Hansen, 1949). With the exception of F_{med}, the conventionally used management reference points $F_{0.1}$, F_{real}, F_{max}, and F_{high} led to a stock depletion within 20 years, a theoretical scenario which was observed during the late 60s. The present case study of the Greenland cod emphasizes the importance of the protection of the spawning stock biomass.

Acknowledgements

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Table 1 Input parameters by age groups used for stock prediction.

Age group (years)	M	Weight at age (kilogram)	Proportion mature at age	Partial recruitment
3	0.2	0.815	0.001	0.122
4	0.2	1.255	0.004	0.335
5	0.3	1.863	0.150	0.507
6	0.3	2.549	0.449	0.735
7	0.3	3.295	0.795	0.845
8	0.3	4.157	0.946	0.904
9	0.3	4.967	0.990	1.000
10	0.3	5.836	1.000	0.811
11	0.3	6.447	1.000	0.811

Table 2. Specification of the multiple linear recruitment model for age group 3 years used for the stock prediction.

dependent variable f(x,y)=	recruitment (millions)
independent variable x=	spawning stock biomass (1 000 t)
independent variable y=	temperature (°C) 3-years-running mean of upper 50 m Fyllas Bank standard station 4

$f(x,y) = -100.782 + 0.218x + 72.470y$
$p<0.0001$, $n=34$, $r^2=0.53$, standard error=126

Table 3 Results of stock projections under different management strategies after 100 years for 100 iterations.

No. of scenario	Reference point	50 % SSB limit for fishing permission	probability of a reduction in stock size	probability of 50 %reduction in stock size	probability of 75 %reduction in stock size
1	no fishing		0.03	0.00	0.00
2	F_{med}=0.09	no	0.95	0.70	0.37
3	F_{med}=0.09	yes	0.91	0.34	0.00
4	$F_{0.1}$=0.297	no	1.00	1.00	1.00
5	$F_{0.1}$=0.297	yes	1.00	0.70	0.10
6	F_{real}=0.4	no	1.00	1.00	1.00
7	F_{real}=0.4	yes	1.00	0.77	0.12
8	F_{max}=0.722	no	1.00	1.00	1.00
9	F_{max}=0.722	yes	1.00	0.87	0.17
10	F_{high}=0.82	no	1.00	1.00	1.00
11	F_{high}=0.82	yes	1.00	0.83	0.25

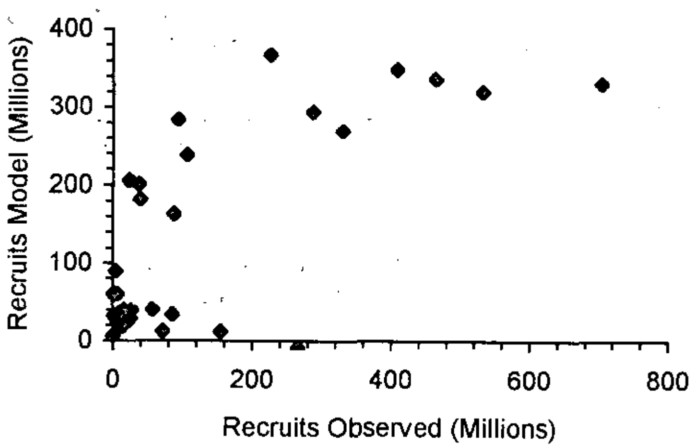

Fig. 1. Recruitment model for age group 3 years based on a multiple linear regression including spawning stock biomass and temperature effects as specified in Table 1.

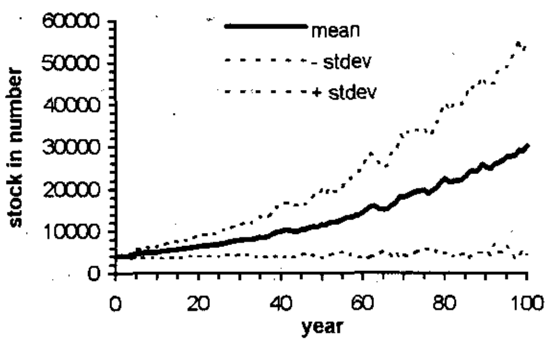

Fig. 2. Stock projection without exploitation (100 iterations).

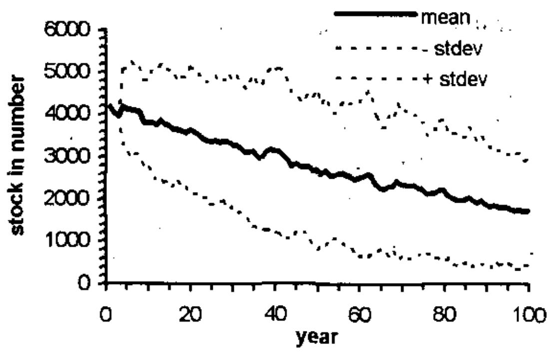

Fig. 3a. Stock projection (100 iterations), F_{med}=0.09.

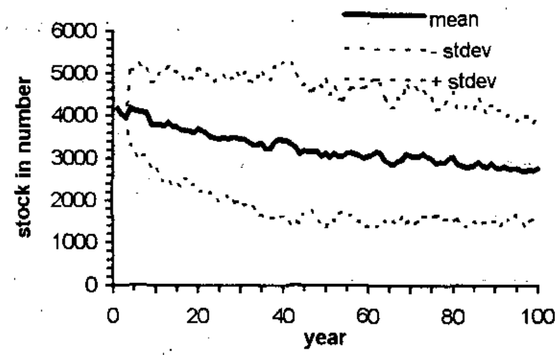

Fig. 3b. Stock projection (100 iterations), F_{med}=0.09, no fishing when SSB<50% of initial SSB.

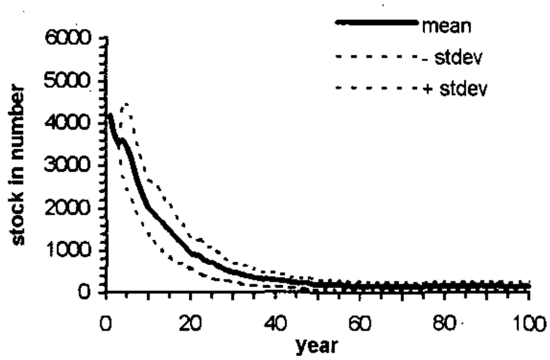

Fig. 4a. Stock projection (100 iterations), $F_{0.1}$=0.297.

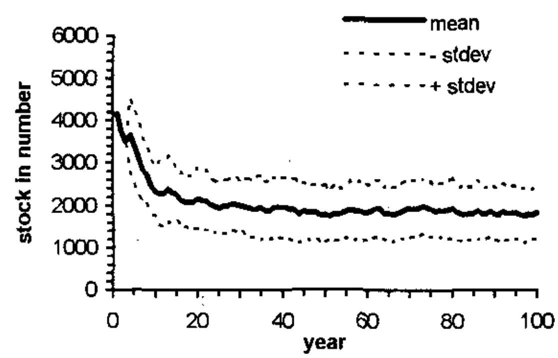

Fig. 4b. Stock projection (100 iterations), $F_{0.1}$=0.297, no fishing when SSB<50% of initial SSB.

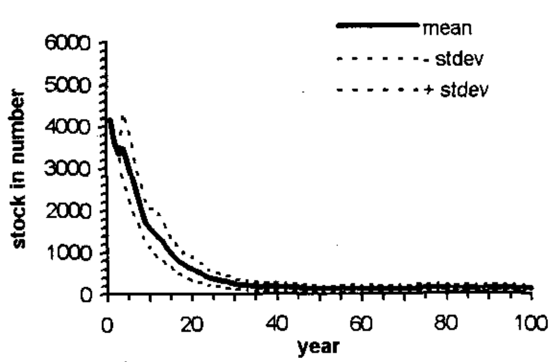

Fig. 5a. Stock projection (100 iterations), F_{real}=0.4.

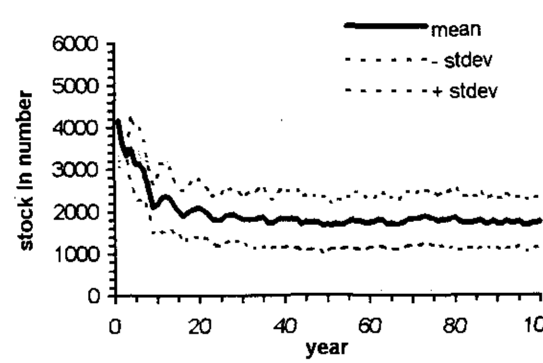

Fig. 5b. Stock projection (100 iterations), F_{real}=0.4, no fishing when SSB<50% of initial SSB.

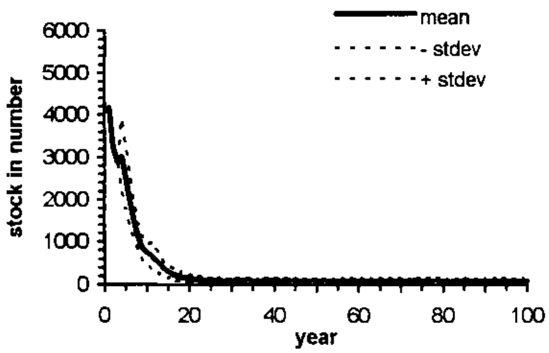

Fig. 6a. Stock projection (100 iterations), F_{max}=0.722.

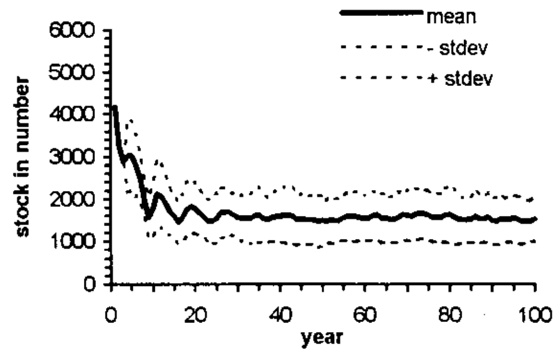

Fig. 6b. Stock projection (100 iterations), F_{max}=0.722, no fishing when SSB<50% of initial SSB.

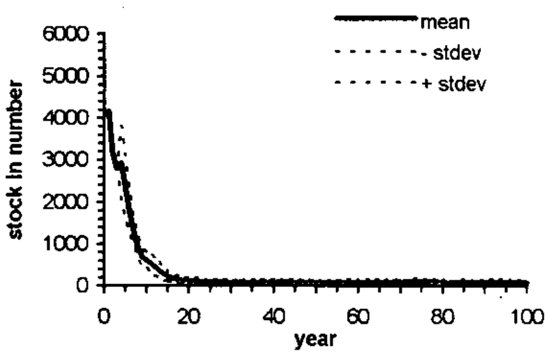

Fig. 7a. Stock projection (100 iterations), F_{high}=0.82.

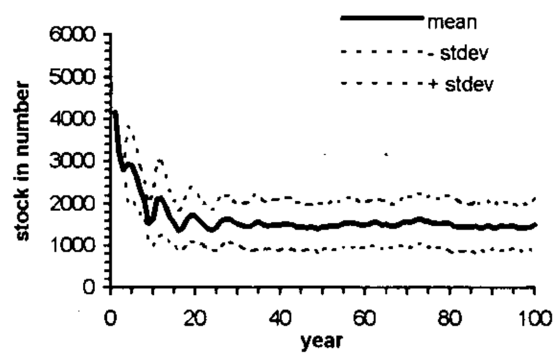

Fig. 7b. Stock projection (100 iterations), F_{high}=0.82, no fishing when SSB<50% of initial SSB.