Stock assessment of West Greenland Inshore cod 2012 – the Coleraine model

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1 Introduction

The Atlantic cod (*Gadus morhua*) population in West Greenland is made up of several distinct components. Tagging data from the last century (Storr-Paulsen et al. 2004), catch data from the fishery (Hovgård and Wieland 2008) and recent genetic studies (Pampoulie et al. 2011, Therkildsen et al. 2013) all suggest the presence of offshore and inshore components that mix outside of the spawning season, but spawn at isolated spawning sites. Until 2011 Atlantic cod from all of Greenland (including East Greenland) were assessed as one, but recognizing that multiple stocks are present in the area, the inshore cod was assessed separately in 2012, with separate advice given for the fishing year 2013 (ICES 2012).

In 2012 the assessment was based on preliminary model runs using the Coleraine statistical catch-at-age model with commercial catch and survey data, catch data and age data being used as input. Due to time constraints the model was not fully explored in 2012, especially with respect to the uncertainty of parameter estimates.

In this document we present a new Coleraine model run, estimates of uncertainty and summary information. This includes updated numbers on all input parameters, as well as improved data quality due to new age determinations of historical samples.

1.1 Data

The data used in the assessment (Table 1) are annual landings (Fig. 1), biomass index from the gill net recruitment survey (Fig. 2) and catch-at-age from both commercial and survey catches (Fig. 3). The survey is a gill net survey conducted in June/July. Using various mesh sizes (16-33mm) it targets primarily ages 2-3 year olds. The selectivity curve is considered step, and mature cod are only caught in low numbers. The commercial fishery is conducted with different gears, but throughout the period it has been dominated by pound net catches (>80%). The pound nets are set near shore in shallow water, and there is a tendency for larger fish to be unavailable to the fishery due to depth preferences.

Table 1: Data

Data	Years	N
Landings	1976-2012	37
Commercial catch-at-age	1976-97, 1999-2000, 2002-12	35
Recruitment survey biomass index	1985-98, 2002-06, 2010-12	22
Survey catch-at-age	1985-98, 2002-06, 2010-12	22

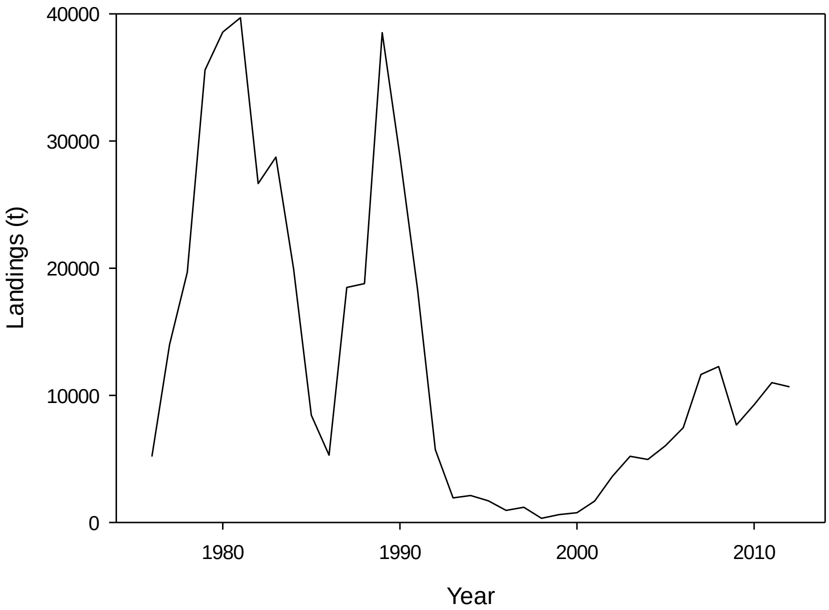

Figure 1: Annual landings.

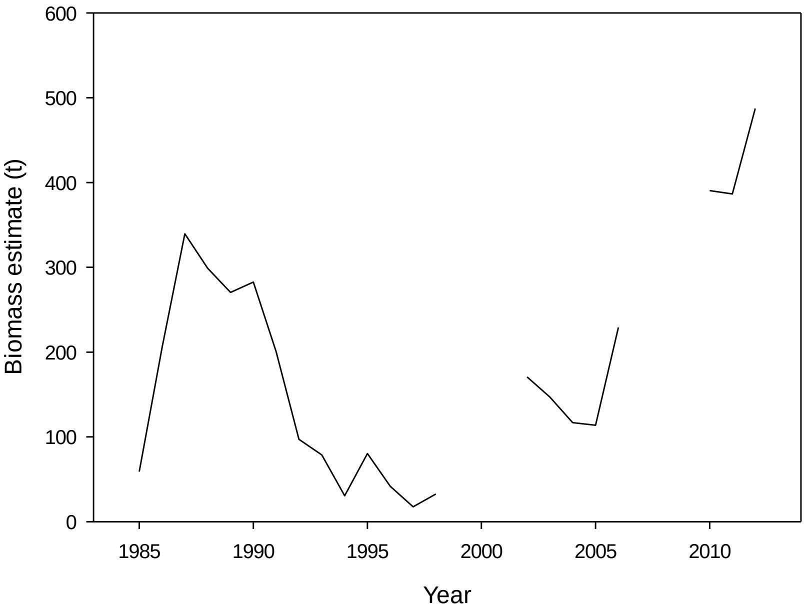

Figure 2: Biomass index from the gill net recruitment survey.

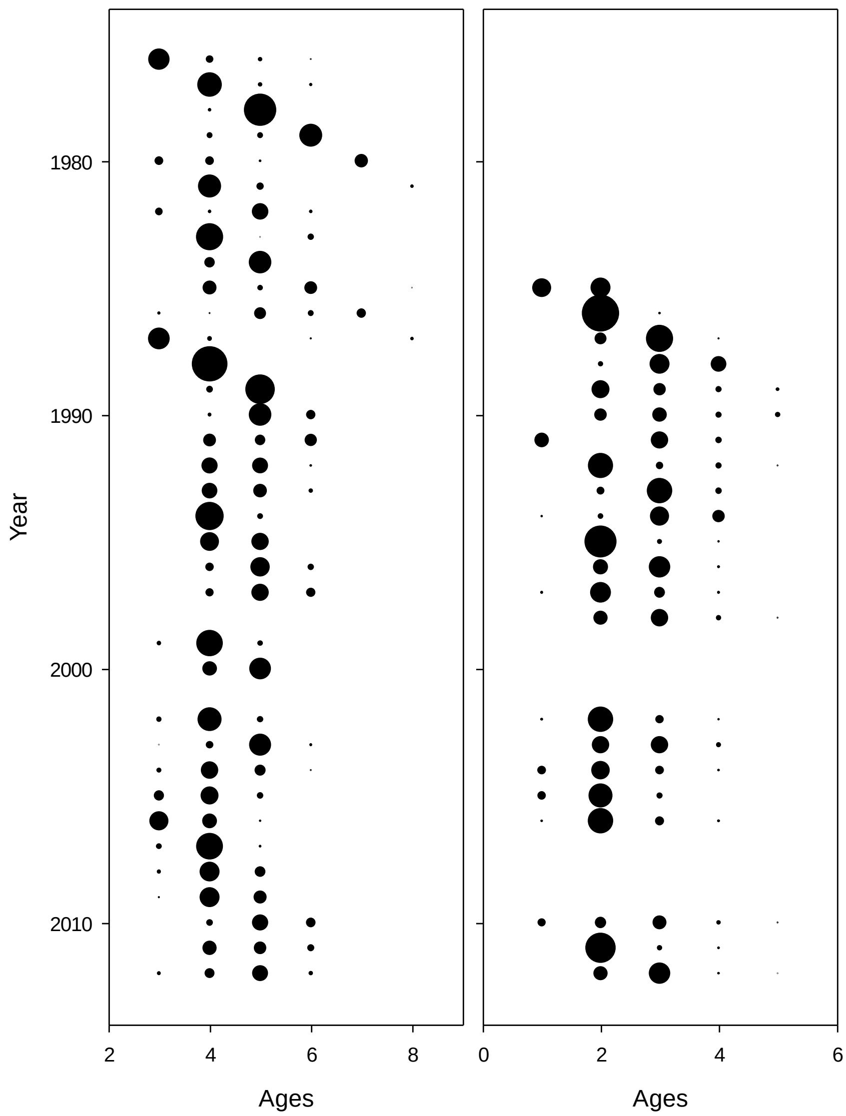

Figure 3: Commercial (left) and survey (right) catch-at-age. Circles represent relative frequency in each year.

2 Model

Coleraine (Hilborn et al. 2003) is a versatile environment for single-species statistical catch-at-age modelling. It can incorporate a combination of catch at age, catch at length, and abundance indices from different fisheries and surveys, allowing for missing years. Data and parameters can be sex- and gear specific. Future projections can be used to evaluate a range of harvest policies. The model is implemented in AD Model Builder (Fournier et al. 2012), supporting maximum likelihood or Bayesian estimation, using the delta method and/or Bayesian MCMC to analyze the uncertainty. Several variations of simple age-based Coleraine models have been described and analyzed in detail by Magnusson and Hilborn (2007).

The model used in this assessment is a simple age-based Coleraine model. Natural mortality (M) rate is assumed to be M =0.2, age 10 is a plus group, selectivity is constant between years and landings are assumed to be known without error. Due to model instability, it was not possible to run uncertainty analysis using the delta method or MCMC procedure. Instead, model uncertainty was evaluated by comparing several runs with variations in key input parameters.

2.1 Model dynamics

Population dynamics are governed by the equation:

$$N_{t+1,a+1} = N_{t,a} e^{-M}(1 - {}_{C}S_a u_t)$$

where $N_{t,a}$ is population size at time t and age a, M is the rate of natural mortality, ${}_{C}S$ is the selectivity of the commercial fishery, and *u* is the harvest rate. The oldest age group, A, is treated as a plus group:

$$N_{t+1,A} = N_{t,A-1} e^{-M}(1 - {}_{C}S_{A-1} u_t) + N_{t,A} e^{-M}(1 - {}_{C}S_A u_t)$$

Selectivity is an asymmetric normal determined by three shape parameters:

$$S_a = \begin{cases} \exp\left(\frac{-(a-S_{\text{full}})^2}{\exp(S_{\text{left}})}\right), & a \le S_{\text{full}} \\ \exp\left(\frac{-(a-S_{\text{full}})^2}{\exp(S_{\text{right}})}\right), & a > S_{\text{full}} \end{cases}$$

where S_{full} is the age at full selectivity, S_{left} describes the left hand slope of the curve, and S_{right} the right hand slope of the curve. Both the fleet and survey selectivity is thus allowed to be dome-shaped, since a priori, it seems likely that the pound net fleet and juvenile survey may not fully select the oldest fish.

Harvest rate is defined as the fraction removed from the vulnerable biomass in the middle of the fishing year,

$$u_t = Y_t / V_t$$

where Y is catch, vulnerable biomass is

$$V_t = \sum_a ({}_{C}S_a N_{t,a} w_{t,a}) e^{-M/2}$$

and *w* is body weight.

The population in the first year $N_{1,a}$ and annual recruitment $N_{t,1}$ are unconstrained parameter vectors. The default approach in Coleraine is to model the initial population and recruitment as deviates from the negative exponential and Beverton-Holt, respectively (Hilborn et al. 2003, Magnusson and Hilborn 2007). Due to high recruitment variability and general instability of the model, these constraints were not used in this assessment, except in one sensitivity model run.

2.2 Parameters

A total of 54 parameters were estimated (Table 2) including 47 recruitment deviates.

Table 2: Estimated parameters

Parameter	Meaning
$N_{1,a}$	Initial population (10 parameters)
$N_{t,1}$	Annual recruitment (37 parameters)
$_CS_{full}$, $_CS_{left}$, $_CS_{right}$	Fleet selectivity
$_SS_{full}$, $_SS_{left}$, $_SS_{right}$	Survey selectivity
q	Survey catchability coefficient

2.3 Estimation

The objective function for the parameter estimation is the sum of three components:

$$f = -\log L_I - \log L_C - \log L_S$$

The survey biomass index likelihood component is lognormal:

$$-\log L_I = \sum_t \frac{(\log I_t - \log \hat{I}_t)^2}{2\sigma_I^2}$$

where I and Î are observed and fitted abundance indices,

$$\hat{I}_t = qV_t$$

V_t is the biomass vulnerable to the survey selectivity, and σ_I is the standard error of the log residuals, one value across all years.

Catch-at-age data are provided to the model in the form of proportions at age. The robust normal likelihood for proportions (Fournier et al. 1990) is assumed for the commercial catch-at-age data,

$$-\log L_C = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_CP_{t,a} - {}_C\hat{P}_{t,a})^2}{2\left[{}_CP_{t,a}(1-{}_CP_{t,a}) + 0.1/A\right]{}_Cn_t^{-1}}\right) + 0.01\right]$$

as well as the survey catch-at-age data:

$$-\log L_S = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_sP_{t,a} - {}_s\hat{P}_{t,a})^2}{2\left[{}_sP_{t,a}(1-{}_sP_{t,a}) + 0.1/A\right]{}_sn_t^{-1}}\right) + 0.01\right]$$

where P and ^P are observed and fitted catch-at-age,

$$\hat{P}_{t,a} = \frac{S_a N_{t,a}}{\sum_a S_a N_{t,a}}$$

and n_t is the year-specific effective sample size.

2.4 Likelihood weights

This effective sample size for the commercial catch-at-age (n_t) was scaled according to the commercial catches (range 20-100), which was taken as a proxy of year-specific sample intensity. The survey effective sample size was set at 30 in all years.

The model was fitted with different values of survey biomass indices likelihoods (σ). 0.4 was chosen for all years, taking into consideration that the model fit was not optimal.

3 Results

3.1 Key quantities

The parameter estimates can be seen from table 3. Only point estimates are shown. No confidence intervals were available as the model fit did not allow for uncertainty runs.

Table 3: Parameter estimates.

Parameter	Estimate
${}_{C}S_{full}$	4.6
${}_{C}S_{left}$	0.1
${}_{C}S_{right}$	4.9
${}_{S}S_{full}$	2.1
${}_{S}S_{left}$	-0.8
${}_{S}S_{right}$	1.3
q	0.0155

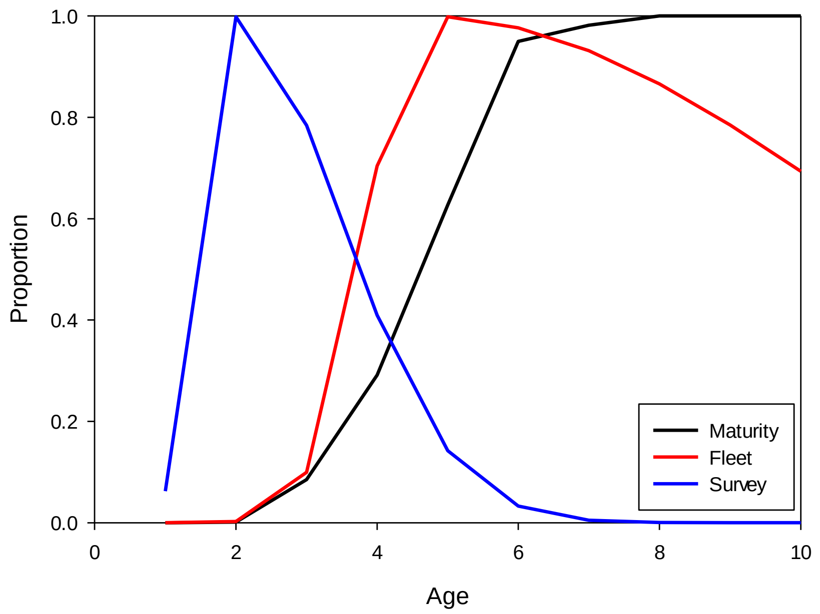

Figure 4: Selectivity for the survey and the commercial fishery and maturity.

3.2 Fit to data

The model fitted the data reasonably well. The largest discrepancies were in the early part of the survey time series (Fig. 5) and in a few of the survey years (e.g. 1991, Fig. 9).

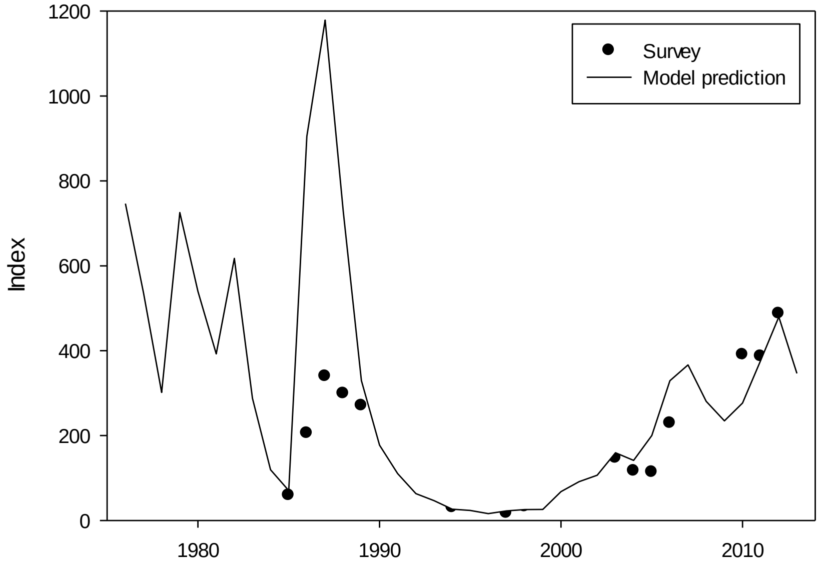

Figure 5: Model fit to the survey biomass index.

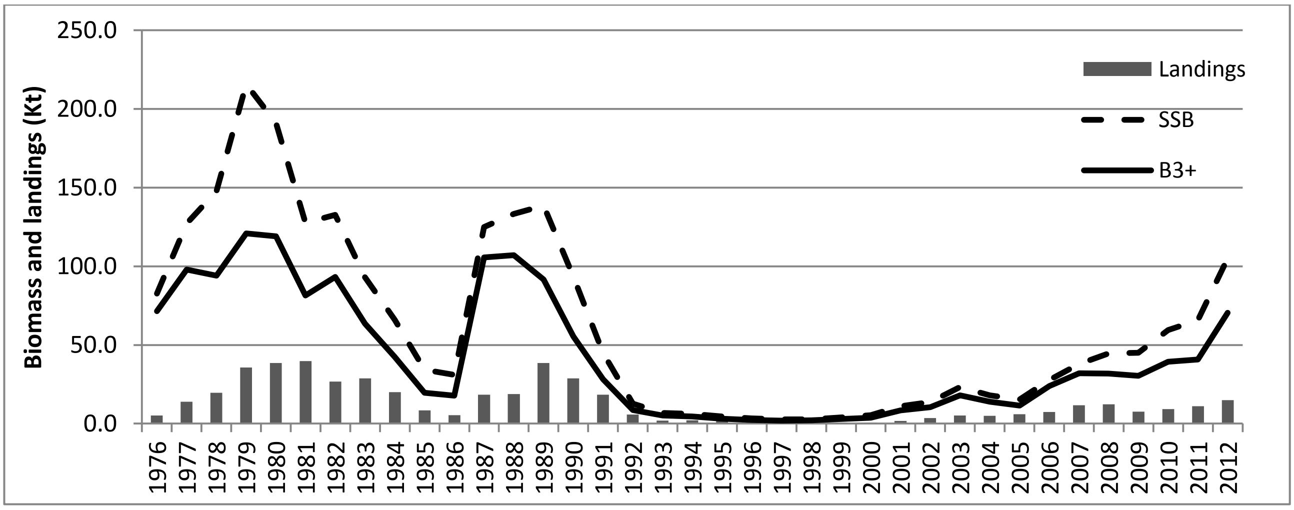

Figure 6: Landings, Spawning Stock Biomass (SSB) and biomass of fish older than 3 years (B3+)

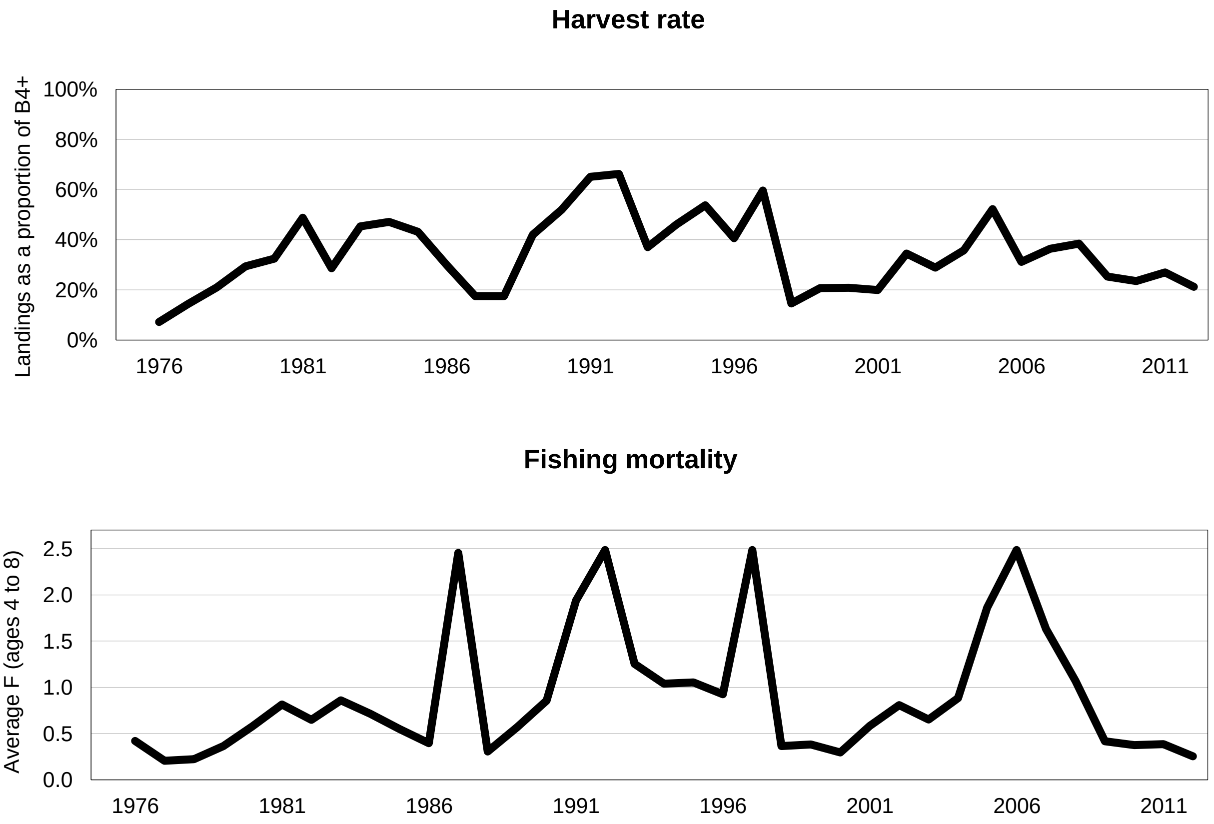

Figure 7: Top: harvest rate, calculated as the proportion of B3+ being caught by the fishery. Bottom: Average fishing mortality, averaged over ages 3-8.

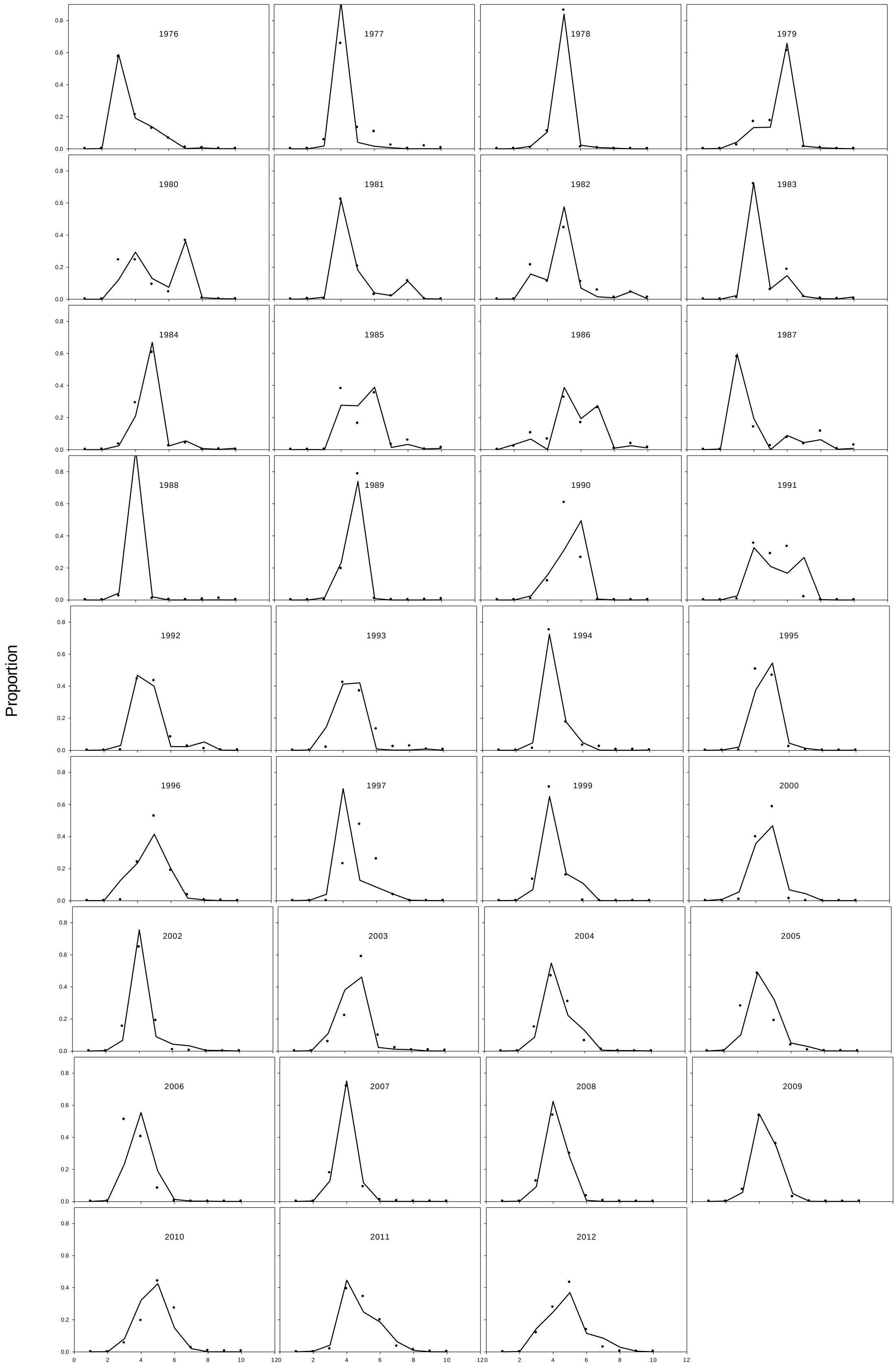

Figure 8: Model fit (line) to observed commercial catch-at-age (dots)

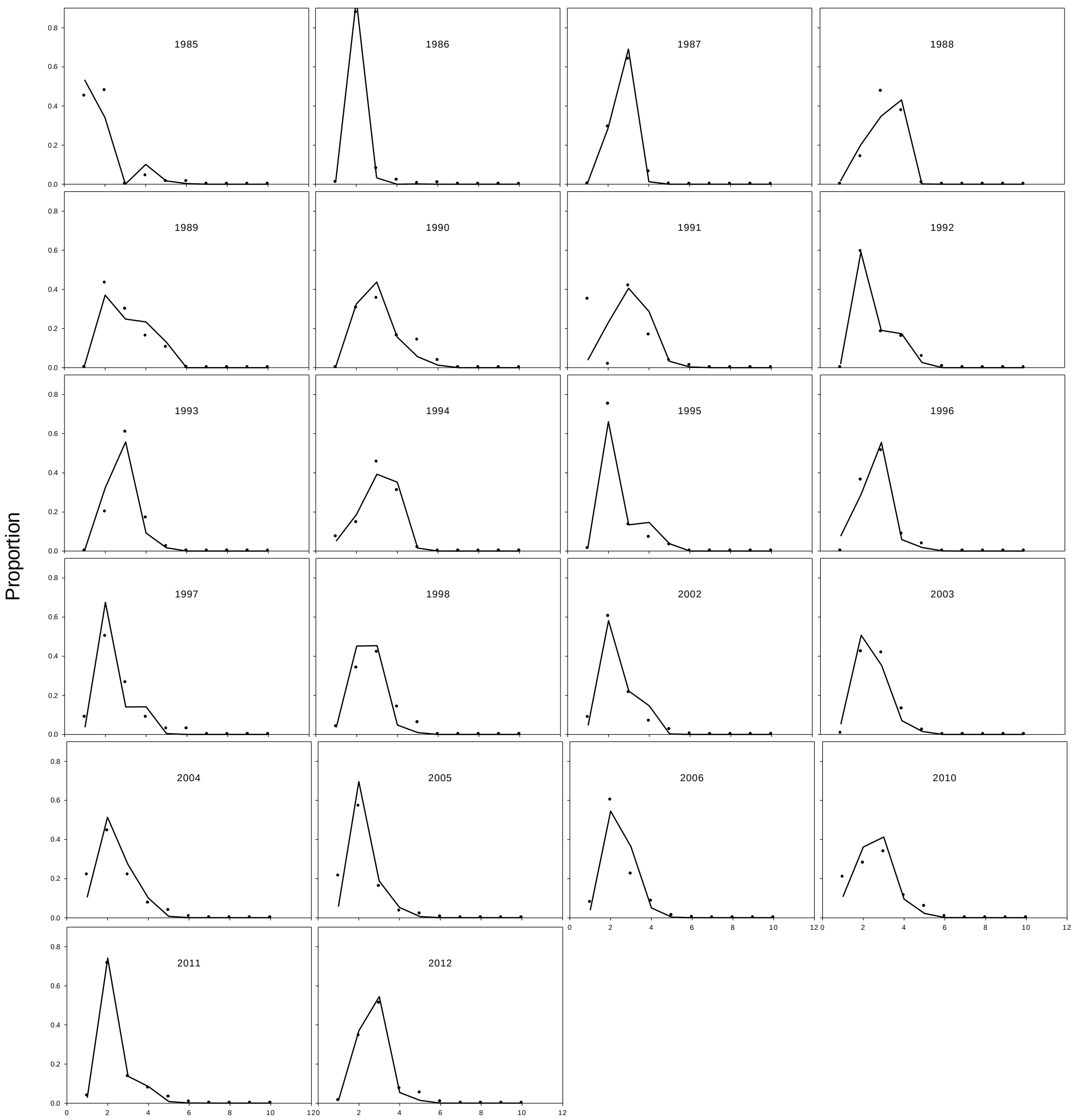

Figure 9: Model fit (line) to observed survey catch-at-age (dots)

3.3 Uncertainty

To assess model uncertainty, we compared the base model run to five diagnostic runs, representing different assumptions (table 2, Fig. 10) and evaluated the effect on current biomass (SSB_{2013}) and F_{2012}.

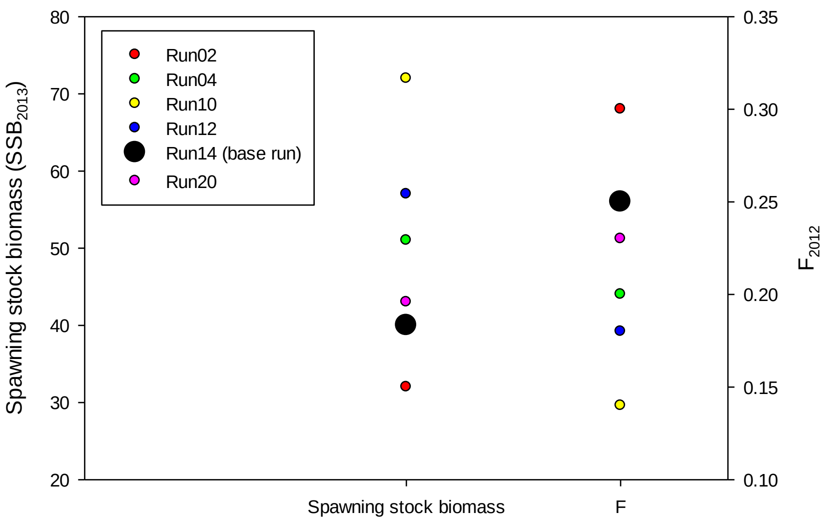

Figure 10: Spawning stock biomass in 2013 (SSB_{2013}) and current F (F_{2012}) from selected runs- Run14 is the base run presented here.

Table 2:

Run name	Description	SSB_{2013}	F_{2012} (ages 3-8)
Run02	• Recruitment estimated as deviations from Beverton-Holt (σ_R = 0.8)	32	0.30
Run04	• No Baysian priors.	51	0.20
Run10	• Survey biomass index weights (σ_I = 0.61). • Fixed effective sample sizes (commercial: 31 and survey: 30).	72	0.14
Run12	• Survey biomass index weights (σ_I = 0.40). • Year specific commercial effective sample sizes scaled according to catch (n_C: 1-79) and fixed effective sample size for survey (n_S =30).	57	0.18
Run14 (base run)	• No Baysian priors. • Year specific commercial effective sample sizes re-scaled (n_C: 20-100)	40	0.25
Run20	• Fixed recruitment in 1976 close to MLE (R_0=100,000)	43	0.23

4.0 Discussion

The model presented here is the first assessment model presented on the Atlantic cod in the Greenland inshore area. The chosen model run produced reasonable estimates, but model instability did not allow for uncertainty analyses. This indicates noise in the data, which may have several causes. The Greenland inshore area is to some extent a mixing zone for Icelandic, Greenland offshore and Greenland inshore cod. This may cause problems for two reasons. 1) The survey is a recruitment survey and therefore does not necessarily represent the cod caught in the commercial fishery as fish present in the recruitment survey may migrate out of the area when they mature, thus being unexpectedly missing from the fishery. 2) The fish may leave the area (and the fishery) when reaching maturity (age 5-6) inflating Z values although the fish have not been caught. Additionally, this effect may vary considerably between years, as the influx of larvae from the East Greenland/Iceland stock complex is a sporadic and unpredictable event. For instance, the large discrepancy between the model fit and data in the late 1980's may well be the result of such an event. Lastly, recent cohorts seen in the fishery have not been registered in the recruitment survey due to missing data in the survey time series in 2007-2009.

One joint characteristic of all reasonable runs was an increase in biomass in the later part of the time series (Fig. 6) irrespective of minor changes in model input parameters. This is also seen in the survey biomass estimate and current landings are increasing.

The survey and fleet selectivity were a priori allowed to be dome shaped. For the survey, this shape is fairly well known, as mesh size clearly excludes larger fish (> 3 year olds) from the catches. The commercial selectivity is however unknown. Current knowledge on cod life history suggests that the oldest cod (>8 year olds) prefer depths not covered by the dominant gear, pound nets. However, we are not able to ascertain if the fish indeed do survive but are unavailable to the fishery (forming a large plus group) or if they are simply caught, and that is the reason why we do not see many old fish in the catches (high F). Both the model estimate of current F (0.25) and the averaged historical F (0.91) is high compared to the much lower F considered sustainable for the offshore stock component (0.14, Hovgård and Wieland 2008), suggesting that the population has been overfished. This is also reflected in a high harvest rate (average: 34%).

We conclude that the present model is not stable enough to serve as the single basis for advice on the inshore Atlantic cod in Greenland. However, the model did converge to produce realistic estimates that are usefull, and may be used as a starting point in other analyses such as yield per recruit. This in turn could produce reference points.

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