Analysis of Greenland halibut *(Reinhardtius hippoglossoides)* CPUE using Pella-Tomlinson biomass models

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1 Introduction

The current ICES management advice for the Greenland halibut fishery is based on CPUE data from the Icelandic fishing fleet (ICES 2013, Thordarson 2014a), analyzed with a Bayesian biomass model (Hvingel and Kingsley 2006, Hvingel et al. 2008, ICES 2013, Boje et al. 2014).

During the 2014 NWWG meeting, the trends in the CPUE data were reviewed with respect to the absolute annual catches. The inherent problem with interpreting the data is that the CPUE index shows sharp rises and declines that are difficult to explain with changes in annual removals.

At the meeting, Thordarson (2014c) examined the time-varying r values from the Hvingel model. The model uses negative r values to fit to the sharply declining CPUE periods. For example, a negative r value causes the biomass in the model to drop by 200 kt between 1989 and 1990, when the catch was 60 kt. Overall, the 2014 NWWG agreed it was difficult to interpret the results from the Hvingel model, despite the clarifications provided by Hvingel and Kingsley (2014).

The analysis presented here uses the same input data as the Hvingel model, but simpler and more transparent models that are easy to interpret. The objective is to provide a basis for comparison with other data and model approaches and to support the ongoing discussion.

2 Methods

2.1 Data

Table 1. Greenland halibut catch and CPUE index.

Year	Catch	CPUE
1961	0.0	
1962	3.1	
1963	4.3	
1964	4.7	
1965	7.4	
1966	8.0	
1967	9.6	
1968	8.3	
1969	26.2	
1970	33.8	
1971	29.0	
1972	26.5	
1973	20.5	
1974	36.3	
1975	23.5	
1976	6.0	
1977	16.6	
1978	14.3	
1979	23.6	
1980	31.2	
1981	19.2	
1982	32.4	
1983	30.9	
1984	34.0	
1985	32.1	
1986	33.0	0.947
1987	46.5	0.969
1988	51.1	1.056
1989	61.4	0.994
1990	39.3	0.795
1991	38.0	0.793
1992	35.4	0.708
1993	40.8	0.569
1994	37.0	0.470
1995	36.3	0.378
1996	35.8	0.321
1997	30.2	0.338
1998	19.8	0.502
1999	18.6	0.551
2000	26.6	0.607
2001	27.3	0.638
2002	29.2	0.567
2003	30.9	0.407
2004	27.1	0.288
2005	24.2	0.315
2006	21.3	0.325
2007	21.8	0.361
2008	22.6	0.357
2009	27.0	0.330
2010	25.1	0.379
2011	26.2	0.403
2012	29.1	0.405
2013	27.2	0.447

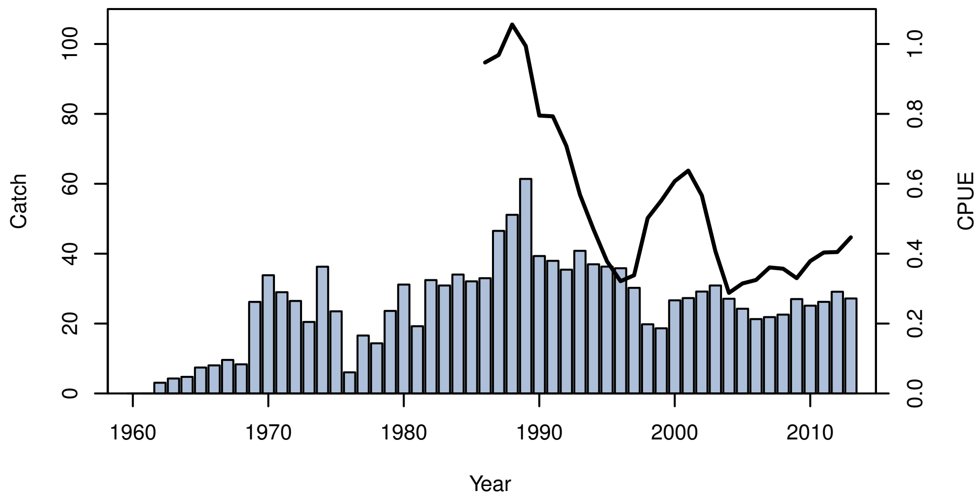

Figure 1. Catch and CPUE data.

2.2 Models

Three biomass models are used in the analysis: Schaefer (1954), Fox (1970), and Pella-Tomlinson (1969, using the Polacheck et al. 1993 parametrization). They all share the general form

$$B_{t+1} = B_t + g(B_t) - C_t \tag{1}$$

where B is biomass, t is year, g is a growth function, and C is catch.

The models are fitted in AD Model Builder (Fournier et al. 2012) by minimizing the objective function

$$-\log L = 0.5n\log(2\pi) + n\log\sigma + \frac{\sum(\log I_i - \log\hat{I}_i)^2}{2\sigma^2} \tag{2}$$

where L is likelihood, n is number of observed CPUE indices, σ is standard deviation of residuals, I is the observed CPUE index, i is a pointer to years that have a CPUE index, and $\hat{I}$ is the fitted CPUE index, calculated as

$$\hat{I}_i = qB_i \tag{3}$$

where q is catchability coefficient.

All models start at K in 1961.

Schaefer

$$g(B) = rB\left(1 - \frac{B}{K}\right) \tag{4}$$

4 estimated parameters: r, K, q, σ.

r is a growth parameter and K is carrying capacity.

Fox

$$g(B) = rB(\log K - \log B) \tag{5}$$

4 estimated parameters: r, K, q, σ.

Pella-Tomlinson

$$g(B) = \frac{r}{p}B\left[1 - \left(\frac{B}{K}\right)^p\right] \tag{6}$$

5 estimated parameters: r, K, p, q, σ.

Pella-Tomlinson is a generalized model that includes both Schaefer ($p = 1$) and Fox ($p \to 0$).

Note that the r growth parameter does not have the same biological meaning in the three models. The derived parameter u_{MSY} (optimal harvest rate) is a better quantity for comparing the estimated productivity between the models.

3 Results

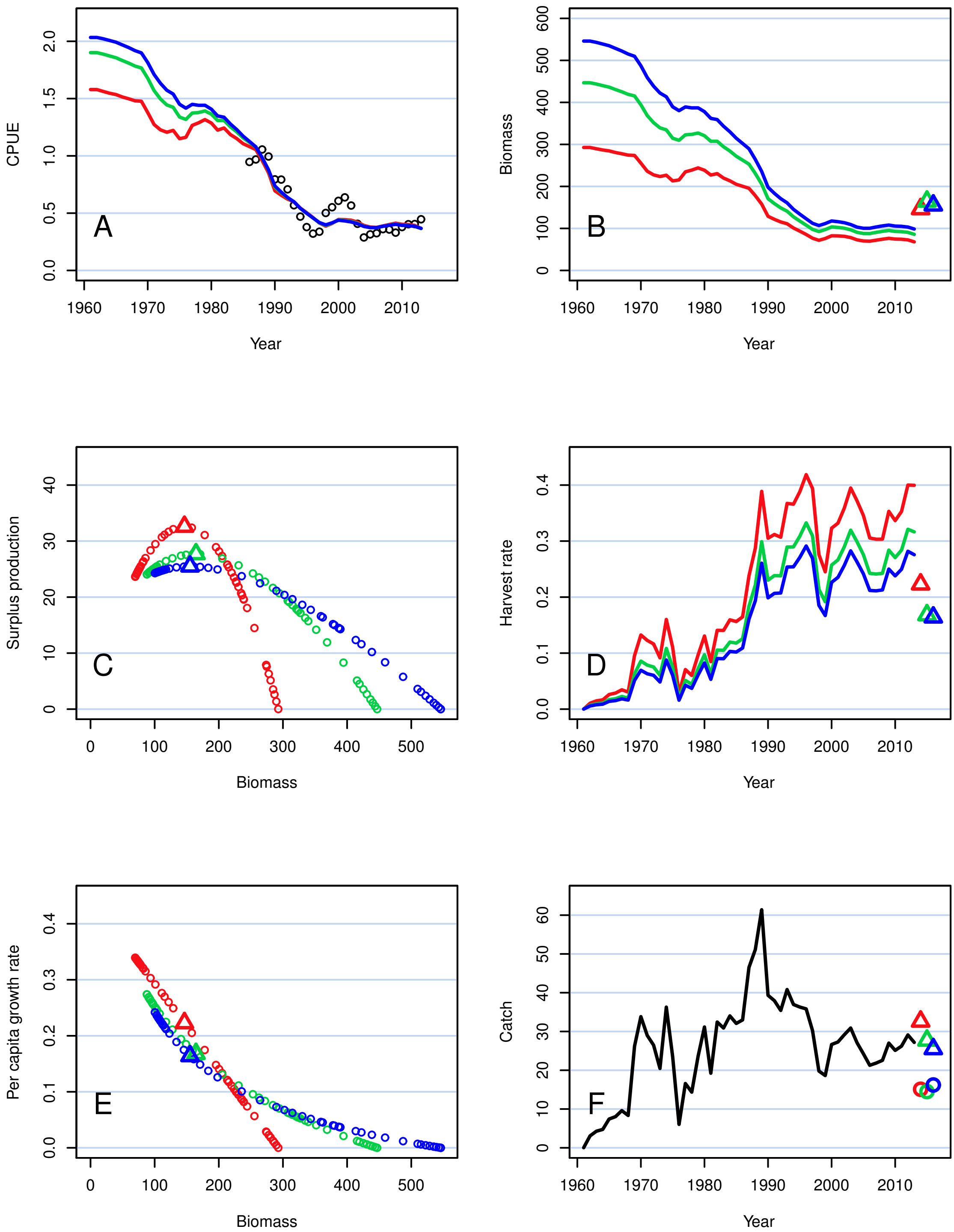

Figure 2. Comparison of model fit and estimates: **Schaefer** (red), **Fox** (green), and **Pella-Tomlinson** (blue). A: Fit to CPUE data. B: Biomass. C: Surplus production. D: Harvest rate. E: Per capita growth rate. F: Catch. Triangles indicate long-term MSY reference points. Circles indicate $u_{\text{MSY}} \times B_{\text{current}}$.

Table 2. Comparison of estimated parameters and reference points. npar: number of estimated parameters. B_{MSY}: stock size that maximizes the surplus production. MSY: maximum surplus production. u_{MSY}: optimal harvest rate. B_{current}: current stock size. Y_{current}: current catch.

	Schaefer	Fox	Pella
npar	4	4	5
$-\log L$	-5.3	-5.8	-5.9
r	0.45	0.17	0.10
K	290	450	550
q	0.0054	0.0043	0.0037
σ	0.20	0.20	0.20
p	·	·	-0.38
B_{MSY}	150	160	160
B_{MSY}/K	0.50	0.37	0.28
MSY	33	28	25
u_{MSY}	0.22	0.17	0.16
B_{current}	68	86	99
Y_{current}	27	27	27
u_{current}	0.40	0.32	0.28
B_{current}/K	0.23	0.19	0.18
$B_{\mathrm{current}}/B_{\mathrm{MSY}}$	0.46	0.52	0.64
$u_{\mathrm{MSY}} \times B_{\mathrm{current}}$	15	14	16

4 Discussion

The product $u_{\mathrm{MSY}} \times B_{\mathrm{current}}$ is an estimate of the optimal catch for the next year, if the objective is to adopt a fixed harvest rate that maximizes the long-term cumulative yield. This estimate, 14–16 kt, is quite low compared to the average catch of 25 kt over the last ten years, as the CPUE has increased somewhat during that time.

The models estimate that the long-term average catch is around 25–33 kt, when applying a fixed optimal harvest rate that is estimated around 16–22%. In other words, the low proposal of 14–16 kt is only temporary, while rebuilding the stock closer to B_{MSY}.

The models differ mainly in their estimated/assumed B_{MSY}/K ratio. In the Schaefer and Fox models, this ratio is fixed at 0.50 or 0.37, respectively, but in the Pella-Tomlinson model, the ratio is estimated at 0.28. As such, the models represent three scenarios and provide a measure of robustness against different assumptions about the stock dynamics.

It is not possible for the simple biomass models to follow the sharp rises and declines in the CPUE data. An age-structured model, on the other hand, could use weak and strong recruitment to produce more sudden changes in the biomass.

CPUE data are usually not seen as a reliable indicator of stock trends. The relationship might not be a proportional one, and the fleet might be fishing in hot spots and cause local depletion that is sharper than the overall population change.

Besides the *recruitment* hypothesis and the *local depletion* hypothesis, there is also a *migration* hypothesis, questioning whether stock components have moved in and out of areas that the observed data come from. The survey data, along with age and length data (or even length data alone), can be helpful to reject some of the hypotheses.

At present, the simple and unsophisticated models presented here can be seen as not much more flawed than the analysis based on the Hvingel model (Boje et al. 2014, Thordarson 2014c, Hvingel and Kingsley 2014) and the exploratory Gadget results that were found to be highly sensitive to assumptions about body growth parameters (Thordarson 2014b). At least the simple biomass models present a different set of flaws and, in terms of minimal parameter complexity, some "null models" to evaluate more complex models against.

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A Appendix: Brief look at the combined survey data

As a possible follow-up from this analysis, a similar approach was attempted with the combined Iceland-Greenland survey biomass index.

Starting in 1996 it is a shorter series, consisting of 18 datapoints instead of 28. On the other hand, survey data can be expected to be a more reliable indicator of stock trends, so an effort was made to fit biomass models to the survey biomass index data, but with limited success.

The first approach was to replace the CPUE index with the survey biomass index, while making as few changes to the model as possible. Overall, the estimated parameters in a Schaefer model are rather similar to the estimates from the CPUE data (Table 3).

Table 3. Results from the Schaefer model fitted to the combined Iceland-Greenland survey data.

r	0.42
K	310
B_{MSY}	150
MSY	32
u_{MSY}	0.21
B_{current}	91
u_{current}	0.30
B_{current}/K	0.29
$B_{\mathrm{current}}/B_{\mathrm{MSY}}$	0.59
$u_{\mathrm{MSY}} \times B_{\mathrm{current}}$	19

This could be interpreted as an indication that the survey and CPUE data are in relative agreement about the stock trends. However, the model fit to the survey data is even less convincing than the fit to the CPUE data. The observed survey index shows sharp rises and declines, but the model fit is a relatively flat horizontal line from around 1995 onwards.

The estimated biomass decline from 1961 to 1995 is rather similar to the model fitted to the CPUE data. It seems likely that some level of population decline occurred as the fishing increased from 1961 to 1990, but the survey data contain very limited information about the stock dynamics of that period.

The second approach was to start the model in 1996, to relax the restrictive assumption about stock dynamics from 1965 to 1995. In this approach the biomass in 1996 becomes an additional parameter. This model converged at implausible parameter values ($r = 1.31$ and $K = 78$) and was not pursued further.