Exploratory biomass model assessment of the Icelandic slope redfish *(Sebastes mentella)*

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Abstract

Two biomass models are fitted to the Icelandic slope redfish stock: the Schaefer model and the replacement yield model. Both models lead to the same conclusions, with point estimates of interest including $B_{1978} = 1406$ and $B_{2010} = 544$ thousand t. The productivity of the stock is estimated to be very low, with annual surplus production more likely to be below 10 thousand t than above it. Uncertainty analysis based on profile likelihood shows great uncertainty about all estimated quantities.

Contents

1 Introduction

Relatively little is known about the status of the Icelandic slope redfish stock, in terms of current or historical biomass levels. The annual report (MRI 2011) presents no formal assessment, only landings from 1978 and biomass indices from the autumn survey since 2000. The biomass indices fluctuate between years but indicate a decline of around 30% from 2000 to 2010, although the annual landings since 2000 amount to only half of the annual landings during the 1990s (Table 1, Figs 1 and 2).

The existence of catch and biomass index time series prompted the author to try to fit a biomass model to the data. The main objective is to quantify the uncertainty about current biomass and depletion level, i.e. explore the range of possible values, given the limited data and applying the restrictive assumptions of a biomass model. Two biomass models are considered: the logistic model (Schaefer 1954) and the replacement yield model (Butterworth and Geromont 1996).

2 Data

Table 1. Landings, autumn survey biomass index, and nominal coefficient of variation.

	Catch (1000 t)	Index	CV
1978	3.902		
1979	7.694		
1980	10.197		
1981	19.689		
1982	18.492		
1983	37.115		
1984	24.493		
1985	24.768		
1986	18.898		
1987	19.293		
1988	14.290		
1989	40.269		
1990	28.429		
1991	47.651		
1992	43.414		
1993	51.221		
1994	56.720		
1995	48.708		
1996	34.741		
1997	37.876		
1998	33.125		
1999	28.590		
2000	31.393	138.9	0.145
2001	17.230	164.0	0.172
2002	19.045	96.9	0.137
2003	28.478	64.6	0.127
2004	17.564	98.4	0.164
2005	20.563	114.9	0.249
2006	17.208	124.5	0.172
2007	17.373	85.5	0.183
2008	24.123	82.7	0.139
2009	19.430	99.7	0.183
2010	17.668	81.8	0.149

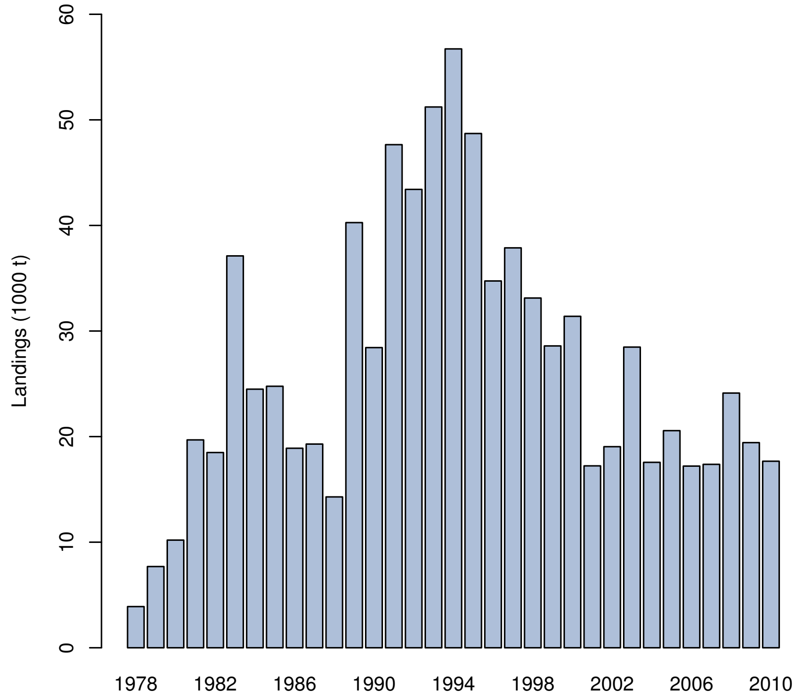

Figure 1. Landings.

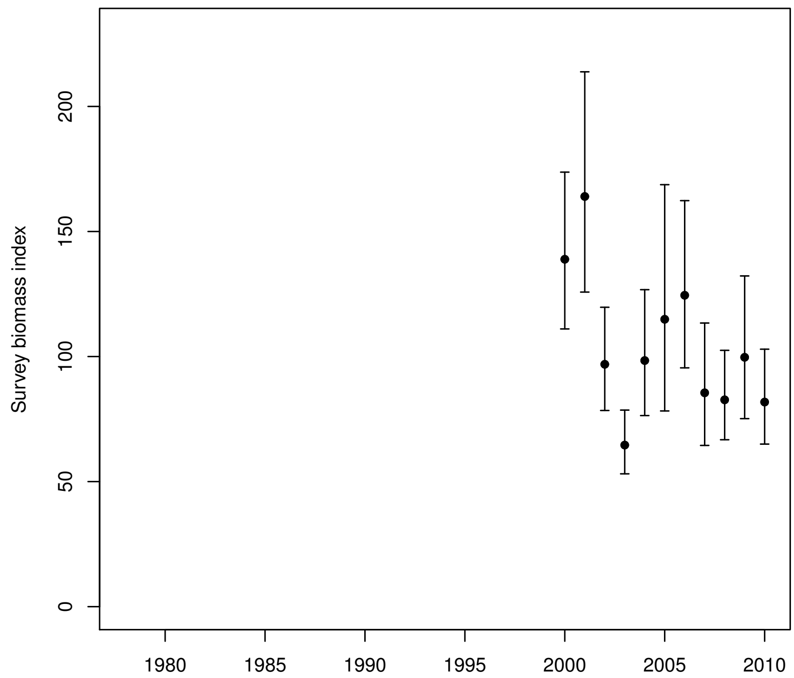

Figure 2. Autumn survey biomass index, with nominal standard error (lognormal).

3 Models

3.1 General approach

The biomass in the first year is an estimated parameter B_{init}. In subsequent years,

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

where $g(B_t)$ is a surplus production function (see next subsection) and C_t is catch.

The biomass index is predicted as

$$\hat{I}_t \quad = \quad qB_t \tag{2}$$

where q is a catchability coefficient.

Assuming lognormal uncertainty, the objective function is

$$-\log L \quad = \quad 0.5n\log(2\pi) \quad + \quad \sum \log\sigma_t \quad + \quad \sum \frac{(\log I_t - \log \hat{I}_t)^2}{2\sigma_t^2} \tag{3}$$

The data come with nominal coefficients of variation that describe the uncertainty about the observed biomass indices. These are not used as absolute σ_t in the objective function, but rather as relative coefficients ξ_t that are multiplied with an estimated scaler τ to predict σ_t:

$$\sigma_t \quad = \quad \xi_t\tau \tag{4}$$

3.2 Schaefer

The Schaefer (1954) model models annual surplus production with two parameters,

$$g(B) \quad = \quad rB_t\left(1 - \frac{B_t}{K}\right) \tag{5}$$

where r is maximum growth rate and K is carrying capacity.

The population is assumed to be at carrying capacity in the first year,

$$B_{\text{init}} \quad = \quad K \tag{6}$$

resulting in four estimated parameters: r, K, q, τ.

3.3 Replacement yield

The replacement yield model (Butterworth and Geromont 1996) models annual surplus production with one simple parameter,

$$g(B) \quad = \quad \gamma \tag{7}$$

where the annual surplus production γ is the same in all years, with no density dependence. During estimation, γ is constrained to be positive.

Four estimated parameters: B_{init}, γ, q, τ.

4 Results

4.1 Model fit

The two biomass models produce perfectly identical biomass predictions, and therefore fit the data equally well (Fig. 3) using the same number of parameters.

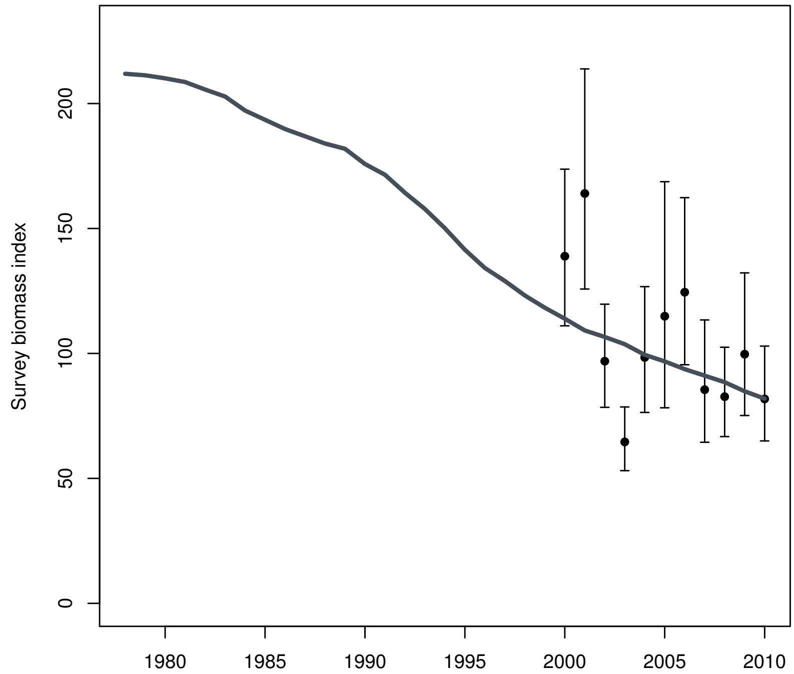

Figure 3. Model fit to autumn survey biomass index. The Schaefer and replacement yield models have the same fit.

4.2 Point estimates

Both models fit the data best when annual surplus production is zero, in the form of $r = 0$ and $\tau = 0$ (Table 2).

Table 2. Parameter estimates from the two biomass models.

Model	Parameter estimates			
Schaefer	$K = 1406$	$r = 0.000$	$q = 0.151$	$\tau = 1.54$
Replacement yield	$B_{\mathrm{init}} = 1406$	$\gamma = 0.000$	$q = 0.151$	$\tau = 1.54$

The estimated biomass in the last year, B_{2010}, is estimated as 544 thousand t, corresponding to a depletion level of $B_{2010}/B_{\mathrm{init}} = 0.39$.

4.3 Uncertainty

To quantify the uncertainty about the current biomass and depletion level, profile likelihood was applied to the replacement yield model. The Schaefer model was also analyzed in the same way, giving very similar results, but less numerically stable.

The B_{init} parameter was fixed at various arbitrary values, while estimating the γ, q and τ to maximize the likelihood. The resulting profiles indicate a high level of uncertainty for estimated quantities like current biomass (Fig. 4), depletion level (Fig. 5), and annual surplus production (Fig. 6).

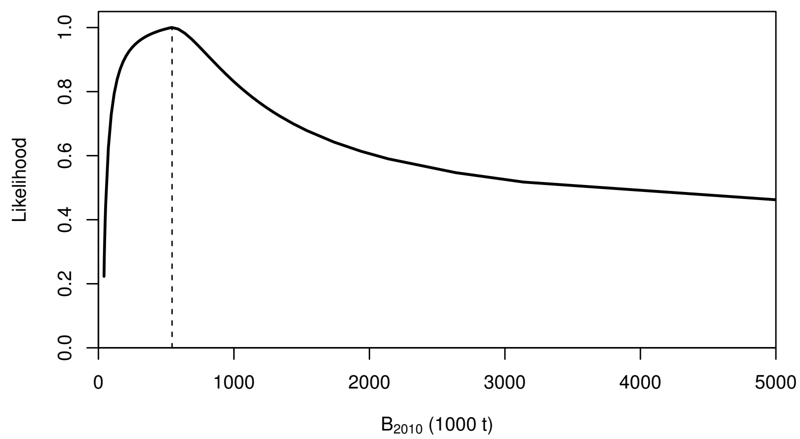

Figure 4. Profile likelihood for current biomass.

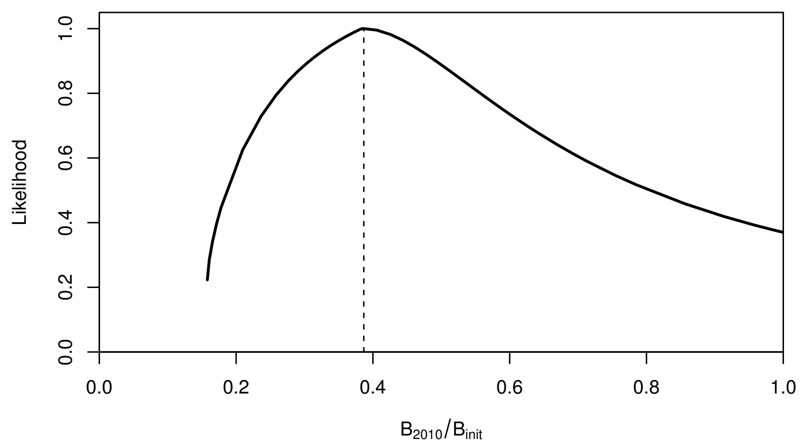

Figure 5. Profile likelihood for current depletion level.

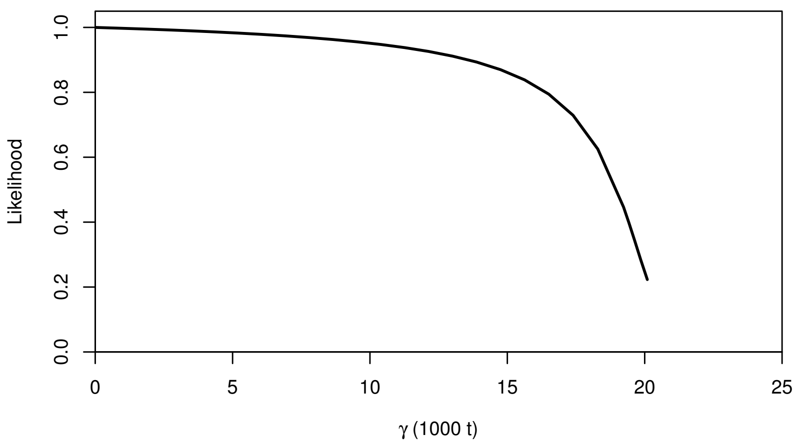

Figure 6. Profile likelihood for annual surplus production.

A 95% confidence interval covers the profile likelihood interval where $L > 0.15$, or $L > e^{-0.5\chi^2_{df=1}}$ to be exact (Hilborn and Mangel 1997). There is no upper limit in the 95% confidence intervals for B_{init} and B_{2010} (Table 3), because a flat horizontal line fits the observed biomass indices with $L = 0.37$. The most likely value of γ is zero, but higher values of γ become likely if the biomass is very small, with the most extreme case being $B_{2010} = 40, \gamma = 21$.

Table 3. 95% confidence intervals and maximum likelihood estimate of selected estimated quantities, based on profile likelihood.

Quantity	Lower	MLE	Upper
B_{init}	245	1406	∞
B_{2010}	40	544	∞
$B_{2010}/B_{\mathrm{init}}$	0.16	0.39	1.00
γ	0	0	21

5 Discussion

Both the Schaefer and replacement yield biomass models tell a similar story. The most likely parameter values describe a stock with very low productivity, which has been gradually mined down for three decades, but the biomass is still relatively large, around 40% of carrying capacity.

The uncertainty analysis highlights two possible extremes. One possibility is that the stock may be considerably larger than the MLE, but still with very low productivity. Another possibility is that the stock is considerably smaller than the MLE, with productivity that comes close to sustaining the annual removals, but in that case the depletion level could be as low as 19% of carrying capacity.

Altogether, this study puts in numbers what was already known: there is great uncertainty about the stock status of the Icelandic slope redfish, given the landings and autumn survey time series. Other data components, such as length and age distribution may provide additional information about productivity (recruitment) and stock status.

6 References

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