Stock assessment of Icelandic summer-spawning herring

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Abstract

This is the first Coleraine assessment of Icelandic herring, using input data starting in 1987 and ending in 2008, to exclude the ongoing period of *Ichthyophonus* infection. Point estimates of interest include spawning biomass $B_{2009} = 563$ thousand t, depletion level $B_{2009}/B_0 = 0.22$, and current surplus production 92 thousand t. The 95% confidence interval of these and other quantities is presented, based on MCMC analysis.

Contents

1 Introduction

1.1 Coleraine assessment

During a recent TAC meeting at Hafro, it was decided to assess the Icelandic summer-spawning herring stock using the Coleraine statistical catch-at-age model (Hilborn et al. 2003), in addition to the VPA and state-space models that have been used in previous herring assessments. The main objectives are to (1) provide a model run that can be compared with the other models to confront model uncertainty, and (2) evaluate the general usefulness of Coleraine as a software platform to assess Hafro stocks.

1.2 Biology, fishery, data

The biology, fishery, and available data for the Icelandic summer-spawning herring are described in other working documents. The ongoing *Ichthyophonus* infection is of central importance, as it undermines common assumptions used stock assessment models, such as constant natural mortality rate M. Instead of explicitly modelling the consequences of the *Ichthyophonus* infection, the assessment data are limited to the years up to and including 2008, before the infection had a major effect on the stock.

Early assessment data are also truncated, starting the model in 1987 to make the results directly comparable with the VPA and state-space model runs. Furthermore, age 2 is excluded from the acoustic survey data. These decisions, to exclude all data from 1975 to 1986, and to exclude age 2 from the survey data, are discussed and examined in other working documents.

2 Data

The main data used in this assessment (Table 1) are annual landings (Fig. 1), annual biomass index from the acoustic survey (Fig. 2), commercial catch at age (Fig. 3), and survey catch at age (Fig. 4).

Table 1. Data overview.

Data	Years	How many
Landings	1987–2008	22
Commercial catch at age	1987–2008	22
Survey catch at age	1987–1993, 1995-2008	21
Survey biomass index	1987–1993, 1995-2008	21

2.1 Landings

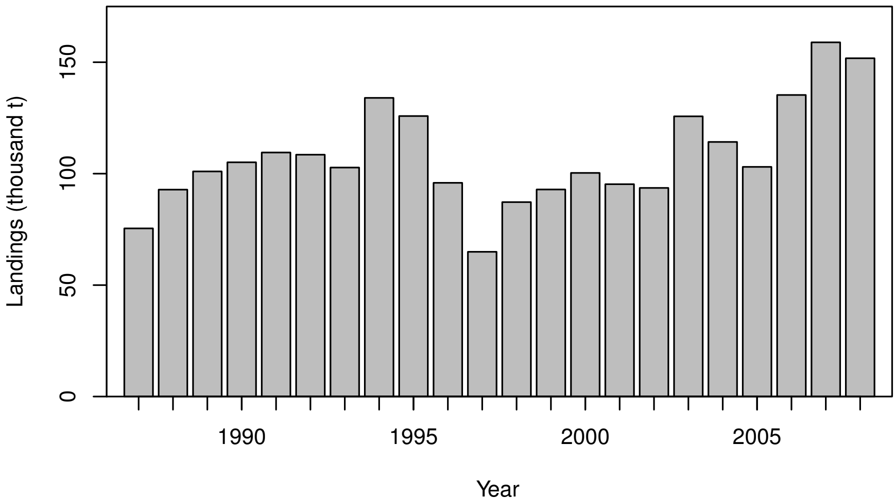

Figure 1. Landings.

2.2 Survey biomass index

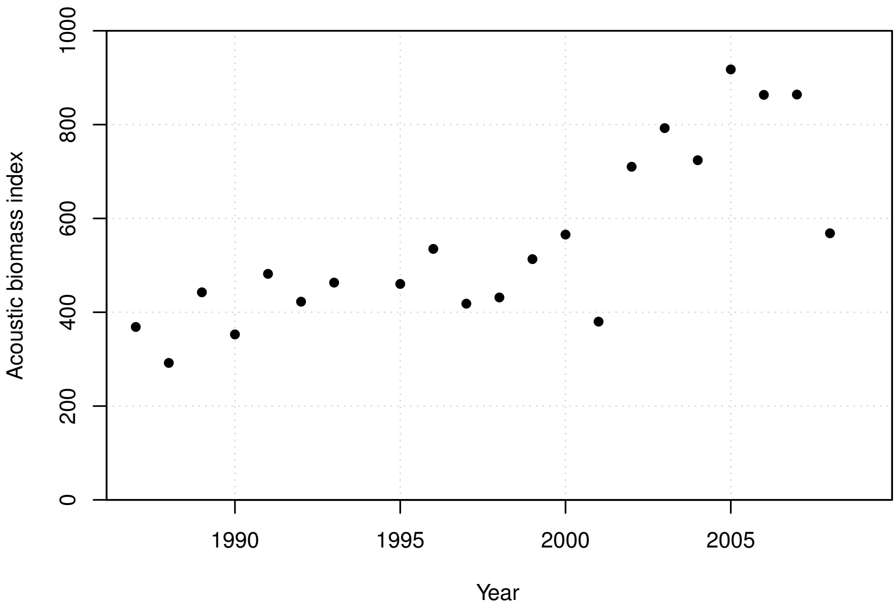

Figure 2. Survey biomass index.

2.3 Commercial catch at age

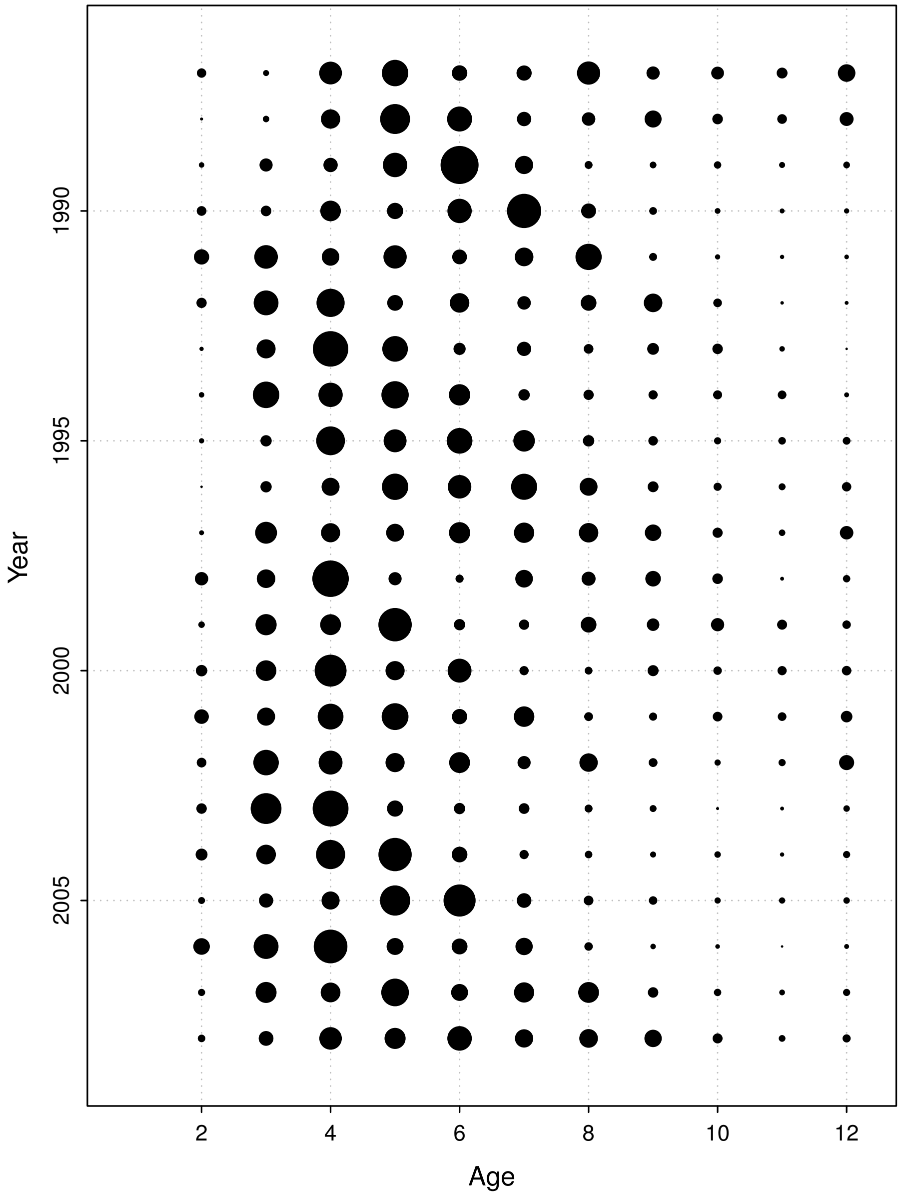

Figure 3. Commercial catch at age. Circles show relative frequency within a year.

2.4 Survey catch at age

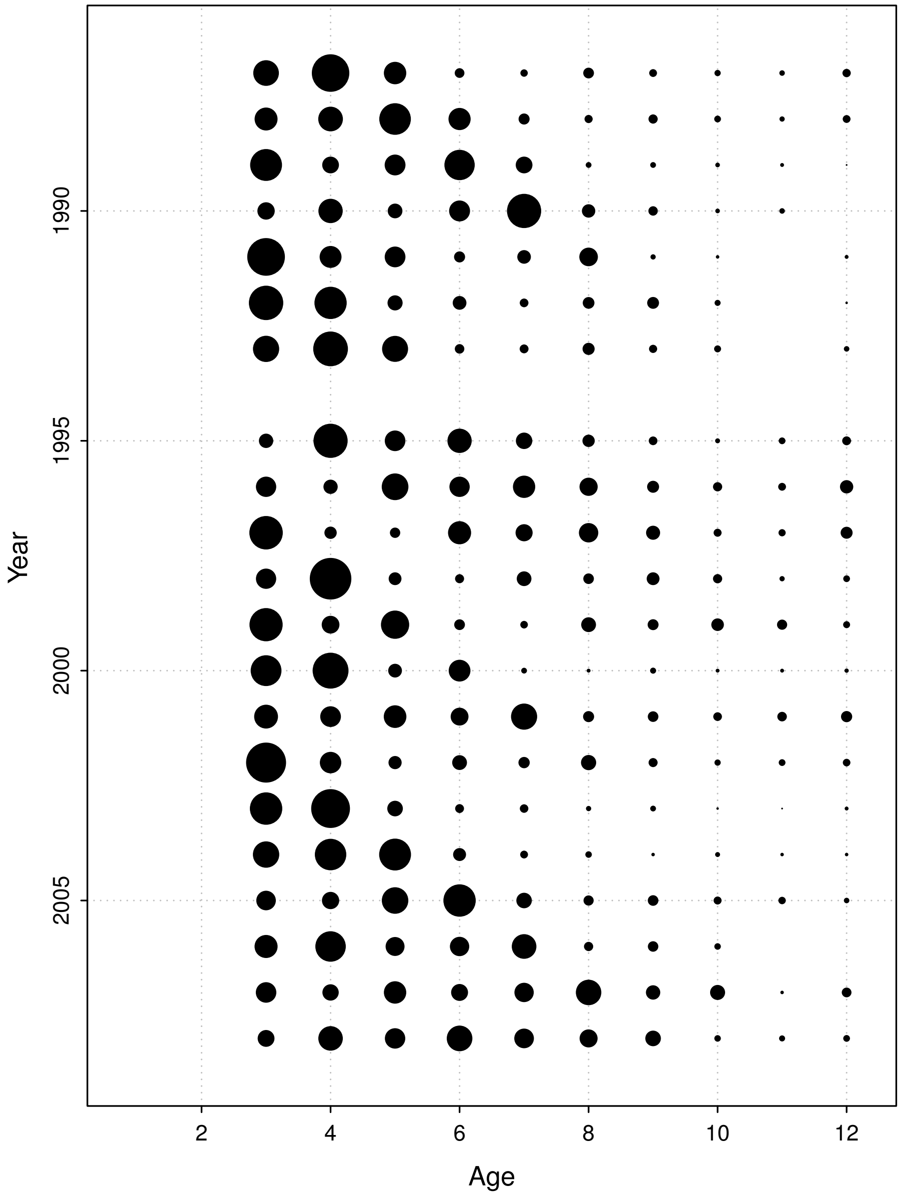

Figure 4. Survey catch at age. Circles show relative frequency within a year.

3 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 (ADMB Project 2008), supporting maximum likelihood or Bayesian estimation, using the delta method and/or Bayesian MCMC to analyze the uncertainty.

Optional software for working with Coleraine include an Excel spreadsheet interface and two R packages, 'scape' and 'scapeMCMC', for plotting and diagnosing model fits and MCMC output (Magnusson 2005). Several variations of simple age-based Coleraine models have been described and analyzed in detail by Magnusson and Hilborn (2007), while diverse examples of sex- and gear-specific age- and length-based model output can be found in Magnusson (2005).

The model used in this assessment is a simple age-based Coleraine model. Natural mortality rate is assumed to be $M=0.1$, age 12 is a plus group, and recruitment is estimated as annual deviates from a Beverton-Holt line with steepness $h=0.9$ and variability $\sigma_R=0.6$. Selectivity is constant between years and landings are assumed to be known without error. All parameters are assigned wide bounds that are used as flat priors in the Bayesian uncertainty analysis, where 1 000 draws were saved out of 1 000 000 MCMC iterations.

3.1 Dynamics

The population dynamics are governed by the equation:

$$N_{t+1,a+1} \;=\; N_{t,a}\, e^{-M}(1-{}_C S_a u_t) \tag{1}$$

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 harvest rate. The oldest age group, age A, is treated as a plus group:

$$N_{t+1,A} \;=\; N_{t,A-1}\, e^{-M}(1-{}_C S_{A-1} u_t) \;+\; N_{t,A}\, e^{-M}(1-{}_C S_A u_t) \tag{2}$$

Selectivity is asymptotic, shaped like a normal curve on the left:

$$S_a \;=\; \begin{cases} \exp\left(\dfrac{-(a-S_{\text{full}})^2}{\exp(S_{\text{left}})}\right), & a \le S_{\text{full}} \\ 1, & a > S_{\text{full}} \end{cases} \tag{3}$$

where S_{full} is the age at full selectivity and S_{left} describes the left-hand slope of the curve. Harvest rate is defined as the fraction removed from the vulnerable biomass in the middle of the fishing year,

$$u_t \;=\; Y_t\,/V_t \tag{4}$$

where Y is catch, vulnerable biomass is

$$V_t \;=\; \sum_a ({}_C S_a\, N_{t,a}\, w_{t,a})e^{-M/2} \tag{5}$$

and w is body weight.

The population size at the start of the first year is

$$
\begin{aligned}
N_{1,1} &= R_0 R_{\text{init}} \times \exp({}_R\varepsilon_{1,1} - \sigma_R^2/2) \\
N_{1,a} &= R_0\, R_{\text{init}}\, e^{-(a-1)M} \prod_{i=1}^{a-1} (1 - {}_C S_i u_{\text{init}}) \times \exp({}_R\varepsilon_{1,a} - \sigma_R^2/2) \\
N_{1,A} &= R_0\, R_{\text{init}}\, e^{-(A-1)M} \prod_{i=1}^{A-1} (1 - {}_C S_i u_{\text{init}}) \;/\; [1 - e^{-M} (1 - {}_C S_A u_{\text{init}})] \times R_{\text{plus}}
\end{aligned}
\tag{6}
$$

for one-year-olds, intermediate ages, and the plus group, where R_0 is the average virgin recruitment. Recruitment is stochastic around a Beverton-Holt stock-recruitment function, reparametrized according to Francis (1992):

$$
N_{t+1,1} = \frac{4hR_0(B_t/B_0)}{1-h+(5h-1)(B_t/B_0)} \times \exp({}_R\varepsilon_{t,1} - \sigma_R^2/2) \tag{7}
$$

where $B_t = \sum_a N_{t,a} \Phi_{t,a} w_{t,a}$ is spawning biomass,

$$
B_0 = \sum_{a=1}^{A-1} R_0 e^{-(a-1)M} \Phi_a w_{1,a} + R_0\, e^{-(A-1)M} \Phi_A w_{1,A} / (1 - e^{-M}) \tag{8}
$$

is average virgin spawning biomass, h is steepness of the stock-recruitment curve, and Φ is maturity at age.

3.2 Parameters

A total of 6 parameters are estimated (Table 2), in addition to 40 recruitment deviates. Ages 3–12 are are fully selected in the survey.

Table 2. Estimated parameters.

Parameter	Meaning
R_0	Average virgin recruitment
R_{init}	Initial population scaler
u_{init}	Initial harvest rate
${}_C S_{\text{full}}$	Age at full selectivity in the commercial fishery
${}_C S_{\text{left}}$	Left slope of commercial selectivity curve
q	Survey catchability coefficient

3.3 Estimation

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

$$
f = -\log L_I - \log L_C - \log L_S - \log L_R \tag{9}
$$

The survey biomass index likelihood component is lognormal:

$$
-\log L_I = \sum_t \frac{(\log I_t - \log \hat{I}_t)^2}{2\sigma_I^2} \tag{10}
$$

where I and $\hat{I}$ are observed and fitted abundance indices,

$$\hat{I}_t = qV_t \tag{11}$$

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,

$$-\log L_C = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_CP_{t,a} - {}_C\hat{P}_{t,a})^2}{2\left[{}_CP_{t,a}(1 - {}_CP_{t,a}) + 0.1/A\right]{}_Cn_t^{-1}}\right) + 0.01\right] \tag{12}$$

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

$$-\log L_S = -\sum_t \sum_a \log\left[\exp\left(\frac{({}_SP_{t,a} - {}_S\hat{P}_{t,a})^2}{2\left[{}_SP_{t,a}(1 - {}_SP_{t,a}) + 0.1/A\right]{}_Sn_t^{-1}}\right) + 0.01\right] \tag{13}$$

where P and $\hat{P}$ are observed and fitted catch at age,

$$\hat{P}_{t,a} = \frac{S_a N_{t,a}}{\sum_a S_a N_{t,a}} \tag{14}$$

and n_t is the year-specific effective sample size.

Recruitment deviates are penalized under the assumption of lognormality:

$$-\log L_R = \sum_{a=2}^{A-1} \frac{{}_R\varepsilon_{1,a}^2}{2\sigma_R^2} + \sum_{t=2}^{t_{\max}-1} \frac{{}_R\varepsilon_{t,1}^2}{2\sigma_R^2} \tag{15}$$

The magnitude of the observation noise (σ_I, ${}_Cn_t$, ${}_Sn_t$) is estimated iteratively as

$$\hat{\sigma}_I = \sqrt{\frac{\sum(\log I_t - \log \hat{I}_t)^2}{T-1}} \tag{16}$$

for the abundance index, where T is the number of abundance index datapoints, and

$$\hat{n}_t = \frac{\sum_a \hat{P}_{t,a}(1 - \hat{P}_{t,a})}{\sum_a (P_{t,a} - \hat{P}_{t,a})^2} \tag{17}$$

for commercial and survey catch at age (McAllister and Ianelli 1997).

3.4 Reference points

Depletion level is defined as the current biomass relative to the average virgin biomass, B_{2009}/B_0. MSY is the long-term average yield at a fixed harvest rate u_{MSY}, B_{2009}/B_{MSY} is the current biomass relative to the average biomass at u_{MSY}, and surplus production is defined as the last year's catch, plus the resulting change in vulnerable biomass. See Magnusson and Hilborn (2007) for a detailed description and analysis of these reference points.

4 Results

4.1 Key quantities

Table 3. Estimated key quantities with 95% confidence intervals.

Quantity	2.5%	Estimate	97.5%
Parameters			
R_0	696	955	1361
R_{init}	0.47	0.80	1.45
u_{init}	0.31	0.37	0.52
${}_CS_{\text{full}}$	4.58	4.79	4.97
${}_CS_{\text{left}}$	0.72	0.96	1.12
q	0.95×10^{-3}	1.08×10^{-3}	1.21×10^{-3}
Reference points			
B_{2009}	388	562	833
V_{2009}	377	545	806
u_{2008}	0.18	0.25	0.33
u_{MSY}	0.23	0.24	0.24
Depletion	0.15	0.22	0.34
MSY	90	123	175
B_{2009}/B_{MSY}	0.68	1.04	1.58
Surplus	60	92	151

Table 4. Estimates of observation noise.

Quantity	Estimate
σ_I	0.23
${}_Cn$	108
${}_Sn$	72

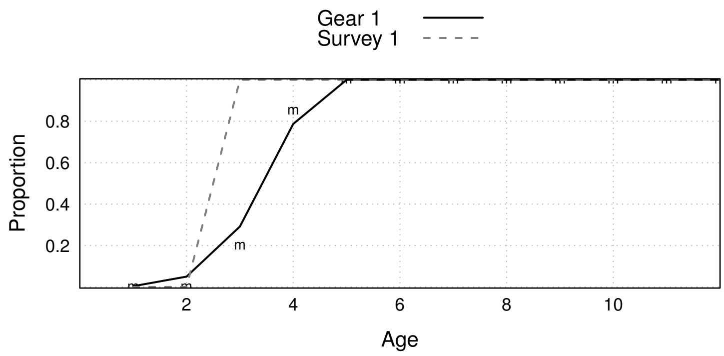

Figure 5. Selectivity and maturity (m).

4.2 Fit to data

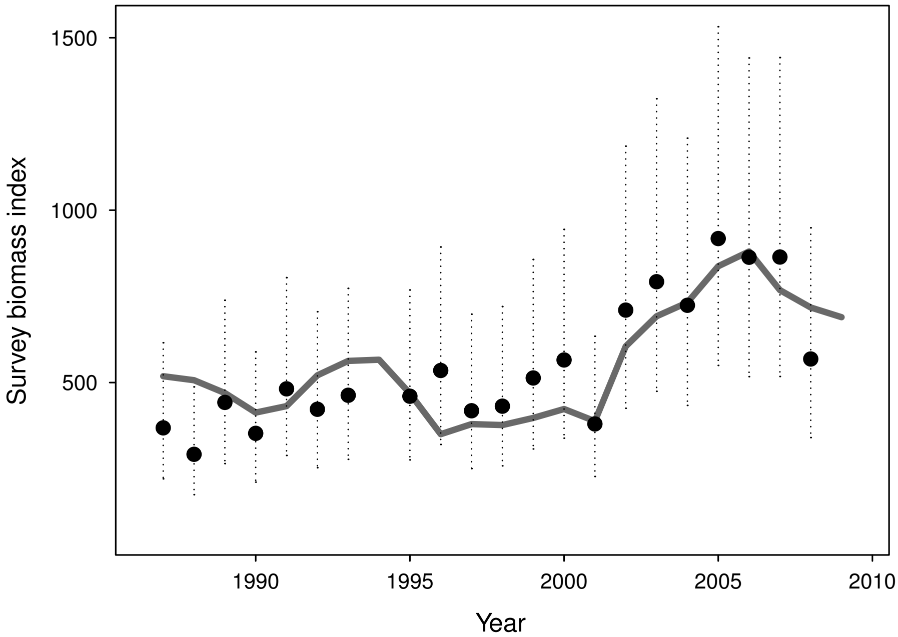

Figure 6. Model fit (line) to survey biomass index, shown with 95% error bars.

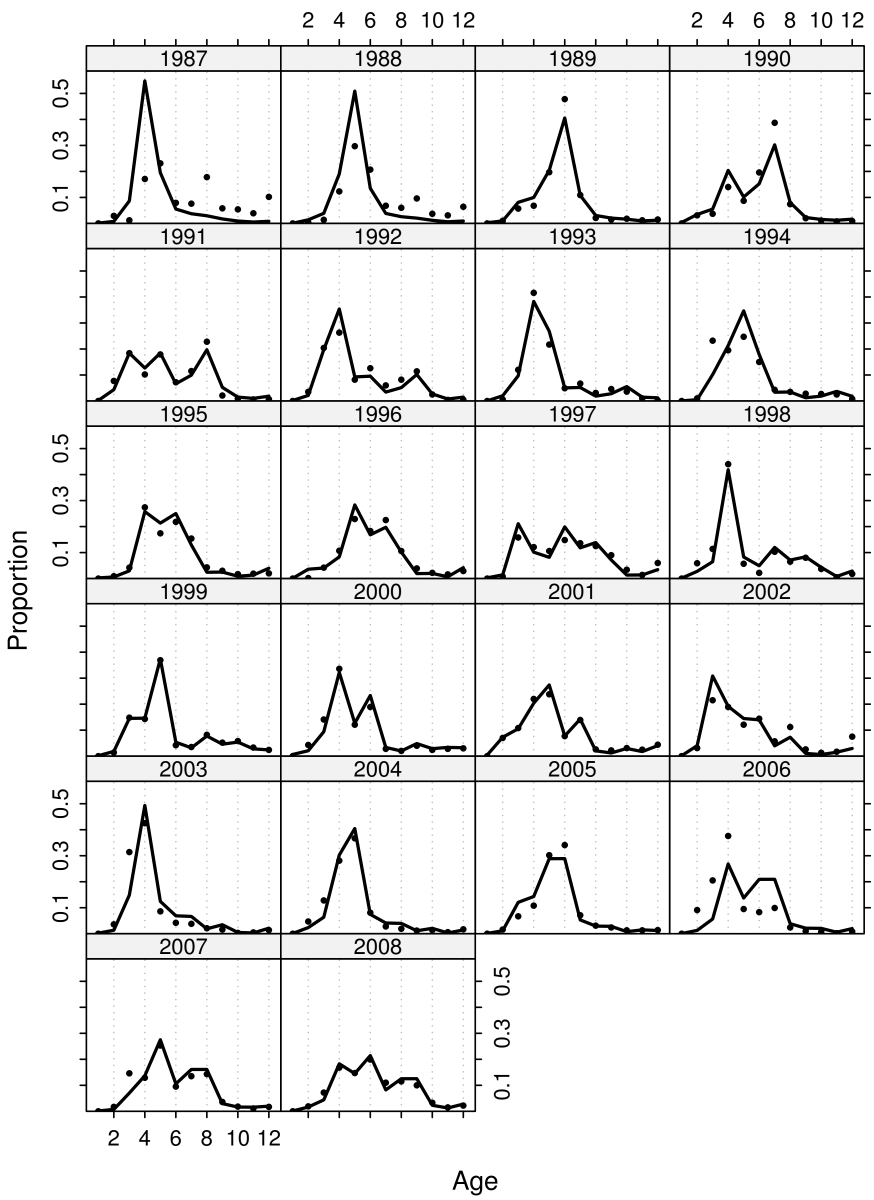

Figure 7. Model fit (line) to observed commercial catch at age (dots).

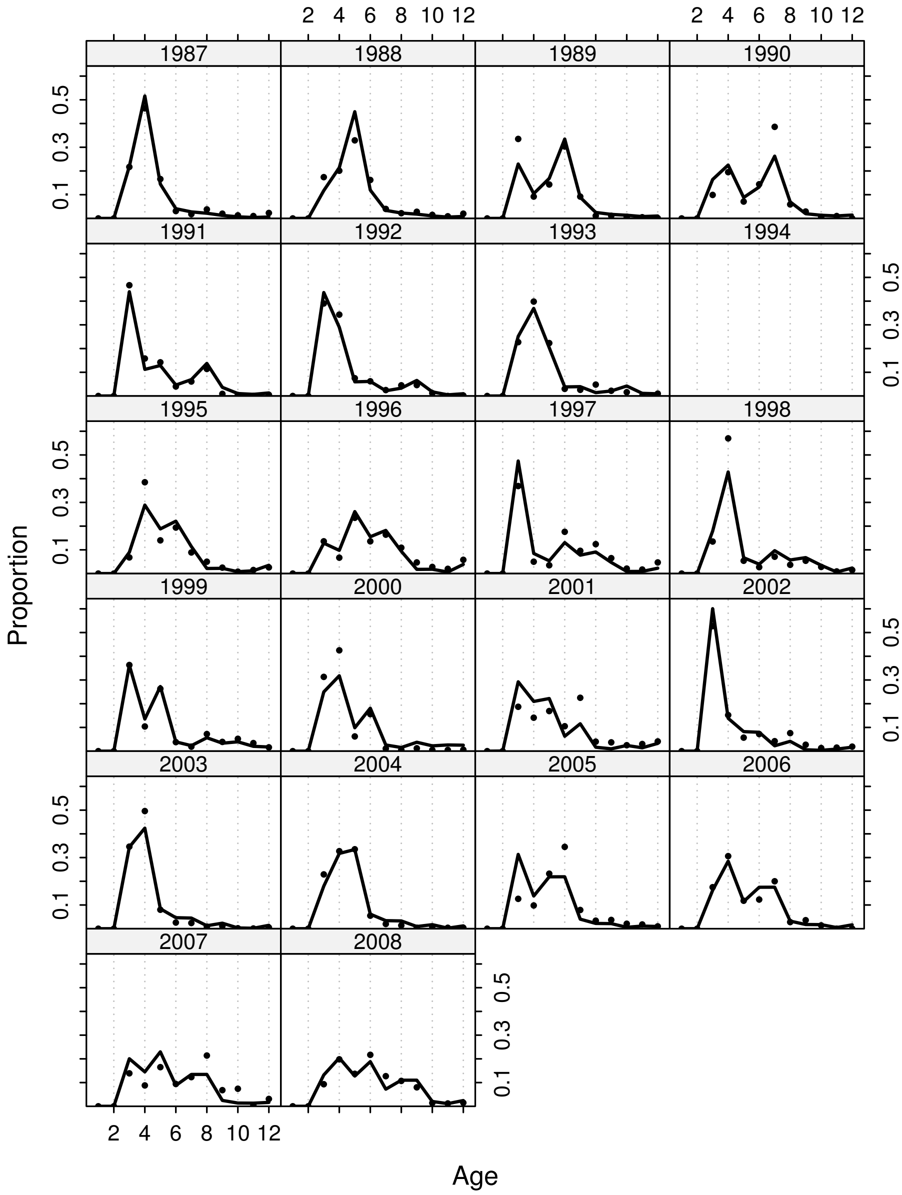

Figure 8. Model fit (line) to observed survey catch at age (dots).

4.3 Uncertainty

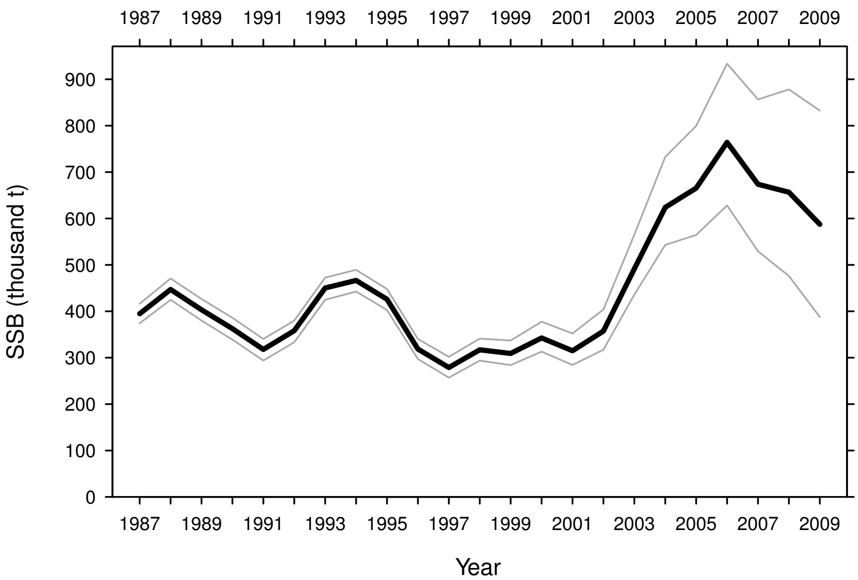

Figure 9. Spawning biomass with 95% confidence intervals.

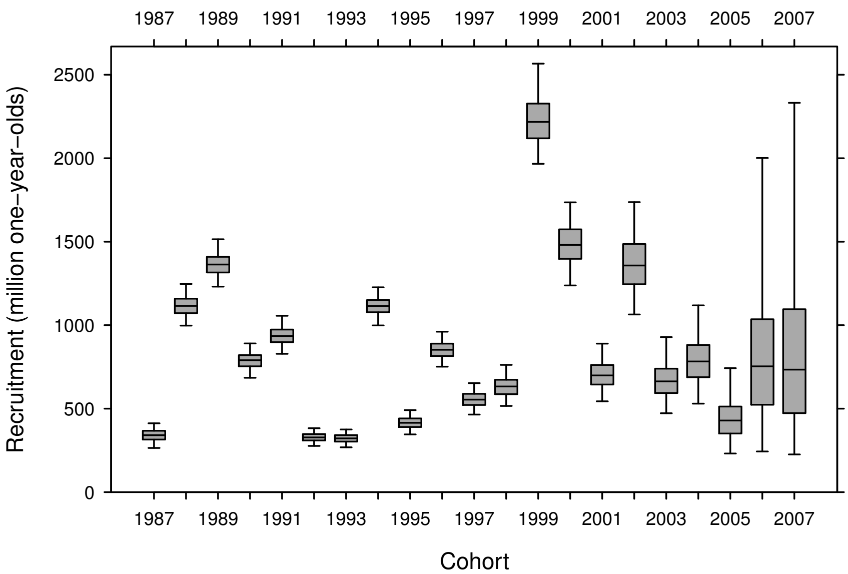

Figure 10. Recruitment with 50% and 95% confidence intervals.

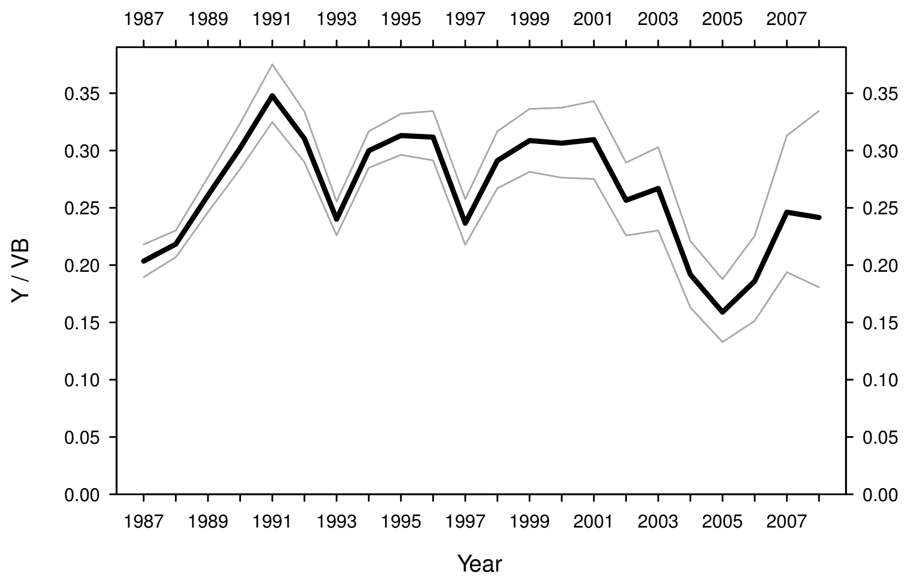

Figure 11. Harvest rate with 95% confidence intervals.

4.4 Retrospective analysis

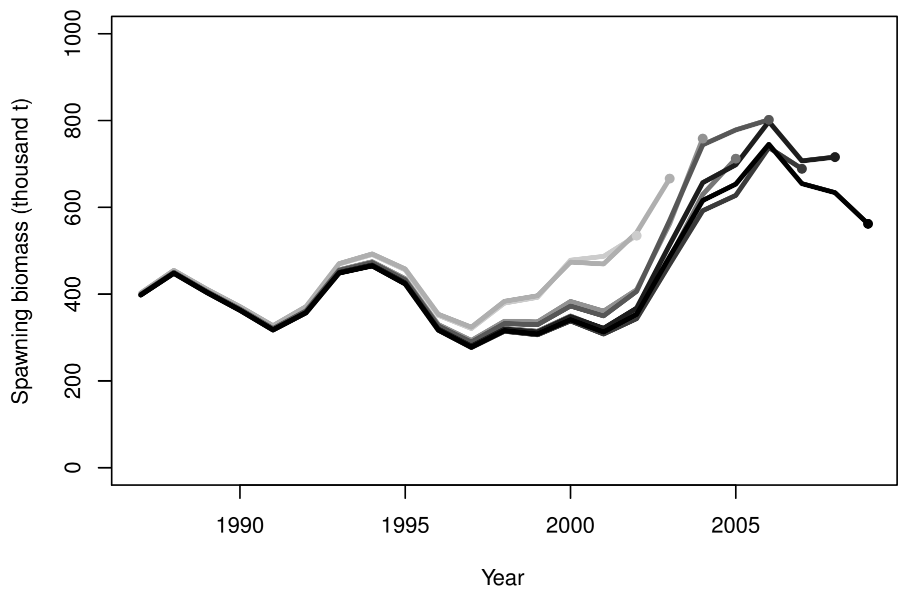

Figure 12. Retrospective analysis.

5 Discussion

Asta Gudmundsdottir has compared the results presented above to the VPA (main assessment model) and state-space (Gudmundur Gudmundsson) model runs. Despite considerably different statistical approaches and assumptions, the three models showed rather similar results overall. Thus, model uncertainty appears to somewhat less than the authors expected. Clearly, the main concern for current management of the Icelandic herring fishery is the ongoing *Ichthyophonus* infection.

Coleraine has been used in previous Icelandic cod (ICES 2001, ICES 2002, ICES 2003) and silver smelt (ICES 2010) assessments. The scientific contribution of this herring assessment is both providing a comparison model run to check model uncertainty against the VPA and state-space models, and also an exploration of uncertainty and reference points.

One of the benefits of a statistical catch-at-age model, compared to VPA, is a framework to evaluate uncertainty about estimated and derived quantities in a statistically sound and straightforward way. Coleraine, like other AD Model Builder applications, has built-in capability to evaluate uncertainty, using either the delta method or MCMC. The MCMC option, used in this herring assessment, takes more computational work than the delta method, but is more robust to non-Gaussian error structure.

Reference points were explored briefly in this assessment (Table 3). Further exploration would be worthwhile, under the assumption that the herring population will return to previous stock dynamics after recovering from the *Ichthyophonus* infection. The reference points describe the stock status before the infection, and lead to questions about sustainable harvest levels. It is worth noting that the uncertainty about the reference point u_{MSY} (optimal long-term harvest rate) is not properly analyzed in this simple assessment, where u_{MSY} is defined as a function of M, h, ${}_{C}S_{\text{full}}$, ${}_{C}S_{\text{left}}$, and body growth, but most of these quantities were fixed. More ambitious approaches to harvest control rule evaluation are likely to be discussed in the benchmark working group.

6 References

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