Stock Annex: Greenland halibut (*Reinhardtius hippoglossoides*) in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Greenland halibut
Working Group	North Western Working Group (NWWG)
Created:	
Authors:	
Last updated:	1 December 2013 (after WKBUT)
Last updated by:	Benchmark Workshop on Greenland Halibut Stocks (WKBUT)

A. General

A.1. Stock definition

Greenland halibut in ICES Subareas 5, 6, 12 and 14 are assessed as one stock unit although precise stock associations are not known.

Available biological information and information on distribution of the fisheries suggest that Greenland halibut in 14 and 5 belong to the same entity and do mix. Historic information on tag-recapture experiments in Iceland have shown that Greenland halibut migrate around Iceland. Similar information from Greenland suggests some mix, both between West Greenland and Iceland but also between East Greenland and Iceland.

The scientific basis for the assumption on spawning grounds located west of Iceland is weak and based only on a few observed spawning fish and on distribution of eggs and larvae. 0-group surveys suggest that recruits are supplied to East Greenland and might also drift to West Greenland. Nursery grounds have not been found in the entire assessment area. Tag-recapture experiments have shown migrations of adult fish from Greenland to Iceland and also a mix within Icelandic waters, which supports a drift of larvae from west of Iceland to both Greenland and to north of Iceland. Tagging also suggest occasional migrations of adult fish from east Greenland and Iceland to Faroe Islands.

No major new information has been presented in recent years to contribute to the clarification of stock structure of Greenland halibut. However, compilation of fishery information (Section on Fisheries and Fleets) provides an overview of the geographical distribution of the fishery over time (Fig. 15.2.2-5.). Fishery in East Greenland and Iceland occurs continuously along the continental slopes at depth of 500-1000 m, which suggest that Greenland halibut in those areas belong to the same stock entity. A more detailed description of the present perception on stock structure is provided in the NWWG report 2006 (ICES 2006).

A.2. Fishery

The major fishing grounds in Icelandic waters are located west of Iceland (64º30-66ºN, 27º-29ºW), where approximately 95% of the annual trawl catch in Icelandic waters has been taken in recent years. The Icelandic trawlers moved to deeper waters around 1988, but the average depth of fishing on the western grounds has remained at approximately 900 meters since 1990. A minor fishery also occurred north of Iceland (67º-68ºN, 19º-24ºW, at approximately 500 m), and along the narrow continental slope northeast and east of Iceland (63º30-66ºN, 11º–16ºW, between 400 and 700 meter depth). The main fishing season in Division 5.a formerly occurred during the spawning season in spring, but in recent years, the fishing season has expanded and the present fishery is conducted in late winter to early summer, with the bulk of the catches taken in spring.

The trawlers (single trawlers > 1000 Hp) fishing in Division 5.b operate on relatively shallow parts of the continental slope, mainly in summer. The gillnet fishery in Division 5.b started in 1993, and since then the fishing grounds have expanded. This fishery is carried out during the whole year with a peak activity in the spring, and has been the main Greenland halibut fishery in 5.b in recent years. Since 2006, however, their catch has decreased considerable, mainly due to an allocation of effort towards monkfish and in some cases to longline fisheries for cod, ling and tusk. .

The fishing grounds in Division 14.b are found on the continental slopes from southeast Greenland to the Icelandic EEZ east of Ammasalik (61ºN-65ºN, 36º-41ºW). Trawling was formerly concentrated in a narrow belt of the continental slope at depths of 500–1000 meters in the north-easternmost area of 14.b, but since 1997 expanded to a southerly area between 61°40-62°30N, 40°00-40°30W at depths of 1000–1400 meters, where longliners are also fishing. In 2005 the fishery entered an unexploited area north of 67º N just north of the Icelandic EEZ with catches of about 1 200 t. The fishery began as an exploratory fishery in September 2005 by a Greenlandic vessel, which was followed by 3-4 foreign vessels that operated in the area through October and November. This fishery continued in 2006 and 2007, but only with total catches of approx. 250 t annually taken in July-September. The fishery in 2007 is distributed almost continuously along the continental shelf at depths of 500-1300 m from 30ºW to 41ºW, and has since 2005, when the area north of 67ºN were explored, been the most widespread fishery recorded since 1991. It should be noted that in 2006 and 2007 also the most comprehensive information (91% and 93% respectively) from the fishery is available as logbook data. The main fishing season in 14. has expanded and is in recent years from March to November with the bulk of the catches taken in the 2nd quarter. Both freezer trawlers and fresh fish trawlers operate in the area.

A.3. Ecosystem aspects

B. Data

B.1. Commercial catch

EU, Norway, The Faroe Islands and Greenland collects biological information (lengths, weights, otoliths) from commercial fisheries which is used for stock assessment. Landings data are supplied annually by the relevant nations. Data files are available from ICES.

B.2. Biological

Considerable ageing problems are still unsolved, it seems that present ageing underestimates the current age of fish more than a few years old (Albert 2007). Therefore since 2001 no age readings of otoliths were available from the main fishing areas. Otoliths are still being sampled in hope that this problem will be solved in the future.

B.3. Surveys

Three surveys are being conducted, separately in 5.a, 5.b and 14.

Icelandic survey in 5.a

An October groundfish survey in Icelandic waters, covering the distributional area of Greenland halibut within the Icelandic EEZ, was started in 1996. The survey is a fixed station stratified random survey consisting of approximately 300 stations on the continental shelf and slope down to a depth of 1300 m. 176 stations of the stations in the survey are on depths between 400 and 1500 meters. Since 2001 the fishable biomass of Greenland halibut (fish of length equal to or greater than 50 cm) has decreased significantly, but stabilized at a low level since 2004.

Faroese survey in 5.b

Since 1995, a Faroese Greenland halibut survey has been carried out on the southern and eastern slope on the Faroe Plateau at depths of 400–600 m. The survey is designed as an exploratory fishery where the skipper decides haul location; due to the design of the survey with a mix of fixed stations in combination with an exploratory part, and in addition to a shift on area coverage over time, it has been considered inappropriate as a biomass indicator at present time.

WD 20 in 2011 provides a description of the Faroese Greenland halibut survey. A brief summary is provided here. The survey was initiated in 1995. The survey vessel "Magnus Heinason" is used to the purpose; i.e. the same vessel, which conducts the groundfish surveys in Faroese waters. The trawl is a star trawl with a mesh size of 135 mm in the codend, a rock-hopper gear, and doors of the Thyborøn type. The bridles are 120 m long. A few hauls have been taken with codends having 40 mm mesh size (as in the standardized surveys). The towing speed is approximately 3 nautical miles per hour. The tow duration has normally ranged between three and six hours, most commonly three or four hours; i.e. a covered distance of 9 to 12 nautical miles. In 1995, there was a one-week trip at the beginning of July (19 hauls) whereas the other years a two-week trip (around 42 hauls) has been conducted in late May to early June (except for 24 hauls in 2003 when there was a strike and in 2010 when technical problems with the survey vessel only allowed one haul to be taken). There has been no major change in the gear or the rigging of the gear during the period. Hauls are taken continuously both day and night, and there is normally little sailing between hauls. Since the major distribution of Greenland halibut occurs along a rather narrow strip of water, which could be expected to vary slightly in depth and probably thickness from year to year, it was decided not to use fixed stations but rather to follow the distribution of Greenland halibut each year. In such a rather one-dimensional distributional area, it was decided to use long tows (several hours) so that the fishing time could be maximized. An increase in the towing duration along this relatively homogeneous area (in terms of fish density and fishing depth) meant that the exact towing and hauling positions became less important, compared with short hauls in a heterogeneous environment (as in the groundfish surveys). A drawback of this design was that the distributional area of Greenland halibut was rather poorly covered the first four years, from 1995 to 1998. From 1999 and onwards, the trawlable area was better covered, although technical difficulties prevented stations to be taken in certain areas certain years (the trawl was stuck each time). On some occasions, additional hauls were taken outside the Greenland halibut area. This was partly done to allow at least some comparison with the standardized groundfish surveys (which covers shallower waters), but mainly to sample cod stomachs (in 1997).

Greenlandic halibut survey in 14.b

Since 1998, a Greenland survey for Greenland halibut has been carried out in East Greenland waters from 60°N to 67°N at the main commercial fishing grounds at depths of 400–1500 m in late June/early July (Figure 15.5.4.). No survey took place in 2001. Total biomass in 2008 was estimated at 11 000 tons which is a 50% reduction from 2006 (Figure 15.5.5). Compared to the period 1999–2001, total biomass estimates for the period 2002–2006 is somewhat lower, and were followed by a period of even lower biomasses from 2007 to 2010. In September 2006 an extension of the Greenland survey was conducted north (67°N–72°N) of the area annually surveyed in East Greenland waters. The survey found poor concentrations of Greenland halibut; of 44 hauls Greenland halibut were only found in 18 hauls and only with one haul having a catch higher than 50 kg (30 min hauls).

The survey is documented in an annual WD at NWWG.

Calibration of surveys in 5.a and 14.b

As a part of the 2006 surveys the Icelandic and the Greenlandic research vessels "Arni Fridriksson" and "Paamiut", respectively, met in Icelandic waters in October to conduct parallel trawling experiments. A total of eleven parallel hauls were made. The original plan called for more hauls but due to problems on board Paamiut, the experiment had to be halted. Because of the small number of hauls it was impossible to get good estimates of the relative trawling efficiency of the two vessels. However the average catch of Greenland halibut standardized to number or weight per km^2 was highest for Paamiut but there was no statistical difference (95% level) in the catches between the two vessels.

Combination of survey indices for use as single index in assessment

Greenland halibut in Subareas 5, 6, 12, and 14 is surveyed by three surveys aimed at this stock: The Icelandic Autumn survey (IAGS), the Greenlandic Greenland halibut survey (EG) and the Faroe Greenland halibut survey. In many aspects the Icelandic and Greenland Survey are similar and combined they cover most of the known distribution of Greenland halibut in that management area. Apart from the northern most fishing area in the Greenland EEZ the Faroe survey covers the rest of the area. However the Faroe survey design is very different as it is not standardized.

In order to construct a combined index from the Greenland and the Iceland survey (EG and IAGS) a single stratification scheme was constructed that covers both survey areas. The main objectives in the scheme were to have a fairly large number of stations in each strata (>6) and to have the stratas small so that biomass is not being extrapolated over large unsurveyed areas. The first objective was not reached in all stratas for the EG as it has fairly few stations (40–55) whereas the IAGS has around 177 stations at depths greater than 400 m.

The combined survey index is agreed to be used as input data to the assessment model.

B.4. Commercial cpue

Haul by haul logbooks are available from 5.a, 5.b and 14.

Indices of cpue for the Icelandic trawl fleet directed at Greenland halibut for the period 1985–2008 were estimated from a GLM multiplicative model, taking into account changes in the Icelandic trawl catch due to vessel, statistical square, month, and year effects. All hauls with Greenland halibut exceeding 50% of the total catch were included in the cpue estimation. The cpue indices from the trawling fleets in Divisions 5.a, as well as in 5.b and 14.b were used to estimate the total effort for each year (y) for each of the divisions according to:

$$E_{y,div} = Y_{y,div} / CPUE_{y,div}$$

where E is the total effort and Y is the total reported landings.

Information from logbooks from the Faroese otterboard trawl fleet (>1000 hp) are available. Only hauls where Greenland halibut consisted of more than 50% of the catches and conducted on depths more than 450 meters were selected for the analyses. The standardization procedure for the logbooks was similar to that of the 5.a fleet.

For Division 14.b, logbook data were available from both Greenland and foreign fleets. In the time-series a variable proportion of all logbooks have been available for analysis (on average 40%, since 2006 more than 90%). Hauls where targeted species was Greenland halibut and where catch weight exceeds 100 kg were selected, as no information on other species caught was available. Cpue from logbooks in the years 1991–2008 were standardized in the same way as described for fleets in 5.a and so was effort.

At WKBUT in 2013 analyses of the cpue series (Thordarson WD 20, WKBUT), showed that the high cpue in the early part of the time-series was mainly due to high cpues in 2nd quarter, while this pattern is not distinct in the remaining part of the series, e.g. from mid-1990s and onwards. The reason for these seasonal spikes according to Dr Einar Hjörleifsson (IMR, Iceland) is what fisherman claimed to be fishing on spawning aggregations in spring at fishing grounds known in Iceland as 'Hampiðjutorgið'. The trawlers would search for the boundary of the Greenland current where the fish would aggregate, and consequently trawlers concentrated their effort in those spots. In reality the trawlers cued in line and did go over the spot one after another. A similar phenomenon has been seen in the redfish fishery in the Irminger Sea with were very high catch rates. WKBUT agreed that work should be accomplished to consider this phenomenon in standardization of the index for use in the assessment model at the NWWG 2014. At NWWG 2015 no progress has been made on this issue.

The CPUE index that are input to the assessment model are averaged standardised CPUE series from each of four areas around Iceland, recognizing that each areas is equally representative as population distribution area.

C. Assessment methods

C.1. Stock production model

Since 2008 assessment and management advice was derived using a stochastic version of the logistic production model and Bayesian inference (Hvingel *et al.*, 2008 WD #4).

Modelling framework

The model was built in a state–space framework (Hvingel and Kingsley, 2006; Schnute, 1994) with a set of parameters (θ) defining the dynamics of the stock. The posterior distribution for the parameters of the model, $p(\theta \mid data)$, given a joint prior distribution, $p(\theta)$, and the likelihood of the data, $p(data \mid \theta)$, was determined using Bayes' (1763) theorem:

$$p(\theta \mid data) \propto p(data \mid \theta)\, p(\theta) \qquad (1)$$

The posterior was derived by Monte-Carlo-Markov-Chain (MCMC) sampling methods using WinBUGS v.1.4.3 (Spiegelhalter *et al.*, 2004).

State equations

The equation describing the state transition from time t to t+1 was a discrete form of the logistic model of population growth including fishing mortality (e.g. Schaefer, 1954), and parameterized in terms of *MSY* (Maximum Sustainable Yield) rather than *r* (intrinsic growth rate) (cf. Fletcher, 1978):

$$B_{t+1} = B_t - C_t + 4MSY \frac{B_t}{K}\left(1 - \frac{B_t}{K}\right) \qquad (2)$$

K is the carrying capacity, or the equilibrium stock size in the absence of fishing; B_t is the stock biomass; C_t is the catch taken by the fishery.

To reduce the uncertainty introduced by the "catchabilities" (the parameters that scales biomass indices to real biomass) equation (2) was divided throughout by B_{MSY} (Hvingel and Kingsley, 2006). Finally a term for the process error was applied and the state equation took the form:

$$P_{t+1} = \left(P_t - \frac{C_t}{B_{MSY}} + \frac{2\,MSY\,P_t}{B_{MSY}}\left(1 - \frac{P_t}{2}\right)\right) \cdot \exp(\nu_t) \qquad (3)$$

where P_t is the stock biomass relative to biomass at MSY ($P_t = B_t / B_{MSY}$) in year t. This frames the range of stock biomass (*P*) on a relative scale where $P_{MSY}=1$ and $K=2$. The 'process errors', *v*, are normally, independently and identically distributed with mean 0 and variance σ_v^2 .

Observation equations

Five candidate biomass indices were available: The Icelandic survey and cpue series and the Greenland survey series are reasonably well correlated. However, for unknown reasons the Greenland cpue series showed trends conflicting with those of the other biomass indices; even if restricted to data just opposite the midline next to the Icelandic fishery and were therefore not included. The Faroese survey was also conflicting with the Icelandic indices and the Greenland survey and was therefore not included. This survey only covers areas contributing less than 4% of the catches.

The model synthesized information from input priors and two independent index series of GHL biomasses and one series of catches by the fishery. The series of GHL biomass indices were: a standardized series of annual commercial-vessel catch rates since 1985, cpuet, and one combined trawl-survey biomass index since 1996, Icet. These indices were scaled to true biomass by catchability parameters, qcpue and qSur. Lognormal observation errors, ω, κ and ε were applied, giving:

$$CPUE_t = q_{cpue} B_{MSY} P_t \exp(\omega_t)$$

$$Ice_t = q_{Ice} B_{MSY} P_t \exp(\kappa_t) \qquad (4)$$

$$Green_t = q_{Green} B_{MSY} P_t \exp(\varepsilon_t)$$

The error terms, ω, κ and ε are normally, independently and identically distributed with mean 0 and variance σ^2_{cpue}, σ^2_{Ice} and σ^2_{Green}.

Total reported catch in ICES Subareas 5, 6, 12 and 14 since 1960 is used as yield data.The fishery being without major discarding problems or variable misreporting, reported catches were therefore entered into the model as error-free.

Priors

Bayesian philosophy considers that an observer maintains a model-perhaps mental or conceptual-of reality that is subject to being modified, updated, by observations (Hvingel and Kingsley, 2006). As a quantitative version of this, Bayesian statistics considers that quantitative observations, data, can be used to update pre-existing probability distributions of the values of parameters defining a quantitative model. In such a discrete updating process, the prior distributions pre-date and are therefore independent of the study that furnishes the data on which the updating is based. The prior distribution for a parameter should incorporate all the information that is already available, but if none can be identified a low-information or "reference" prior (Kass and Wasserman, 1996) is used.

Initial stock size: We did not have any information on the size of the stock in 1985 when the stock index series start and an informative prior could not be constructed. However, we did know that the fishery din not start until 1961 and it was therefore likely that the stock was close to *K* in 1960. To provide this information to the model we made it simulate stock development from 1960 and on giving P_{1960} a normal prior with a mean of 2 (K=2) and a standard error of 0.071. As we had no observations on stock size until 1985 we ran the model for the 1960–1984 period without the process error in order not to blow up the uncertainty and avoid unrealistically large values of the P_{1985}-estimate due to the long period of 'prediction' (1960 to 1985 = 25 years).

The prior distributions for the error terms associated with the biomass indices (the observation errors) were assigned inverse gamma distributions (the gamma distribution, $G(r,\mu)$, is defined by: $\mu^r x^{r-1} e^{-\mu x}/\Gamma(r)$; $x>0$) as error standard deviations typically follow this kind of distribution. Their standard deviations were given inverse gamma distributions with 95% of their values.

The catchabilities q_{Surv} and q_{cpue} are confounded with the carrying capacity *K*. A uniform distribution was therefore not non-informative, and a prior distributions uniform on a log scale was preferred as a reference prior (cf. Gelman *et al*., 1995; Punt and Hilborn, 1997; McAllister and Kirkwood, 1998; Hvingel and Kingsley, 2006). For all these catchabilities the distributions were truncated at -10 and 1 (log scale), the range chosen large enough as not to interfere with the posteriors.

To provide the model with information on the order of magnitude of *K*, its prior was constructed as follows: Mean biomass densities recorded by the survey are some 0.5 tons/km². If we assume that the survey 'sees' around 1/3 of the biomass and that *K* is in the area of 3–4 times larger than this 1996–2007 level we end up around 5 tons/km² corresponding to 750 ktons in the total area. The prior for *K* was therefore given a normal prior with a mean of 750 ktons and standard error of 300 supposed to account for our prior uncertainty and provide a reasonable range of what *K* might be. The sensitivity of model results to changes in this prior was investigated (see later text and Table 6).

Low information or reference priors were given to MSY, and σ_v as we had little or no information on what their probability distributions might look like. MSY was given a uniform prior between 0 and 300 ktons. The upper limit was chosen high enough not to truncate the posterior distribution (Figure 4).

Convergence diagnostics

In order to check whether the sampler had converged to the target distribution a number of parallel chains with different starting points and random number seeds were analysed by the Brooks, Gelman and Rubin convergence diagnostic (Gelman and Rubin, 1992; Brooks and Gelman, 1998) A stationarity test (Heidelberger and Welch, 1983) was applied to individual chains. If evidence of non-stationarity is found iterations were discarded from the beginning of the chain until the remaining chain passed the test. Raftery and Lewis's (1992) tests for convergence to the stationary distribution and estimation of the run-lengths needed to accurately estimate quantiles were used, and finally the Geweke convergence diagnostic was applied (Geweke, 1992). This ensured that only samples from the target posterior were used for inference.

Model check

In order to check whether the model was a 'good' fit to the data, different goodness-of-fit statistics were computed. First, we calculated the simple difference between each observed data point and its trial value in each MCMC sampling step. The summary statistics of the distributions of these residuals indicated by their central tendency whether the modelled values were biased with respect to the observations.

Secondly, the overall posterior distribution was investigated for potential effects of model deficiencies by comparing each data point with its posterior predictive distribution (Posterior Predictive Checks; Gelman *et al.*, 1995; 1996). If the model fitted the observed data well, the observed data and the replicate data should look alike. The degree of similarity between the original and the replicate data points was summarized in a vector of p-values, calculated as the proportion of n simulations in which a sampling of the posterior distribution for an observed parameter exceeded its input value:

$$p.value = \frac{1}{\mathrm{n}} \sum\nolimits_{\mathrm{j}=1}^{\mathrm{N}} I((data_{\mathrm{j}}^{rep}, \theta_{\mathrm{j}}) - (data^{obs}, \theta_{\mathrm{j}})) \qquad (5)$$

where $I(x)$ is 1 if x is true, 0 if x is false. Values close to 0 or 1 in the vector *p-value* would indicate that the observed datapoint was an unlikely drawing from its posterior distribution.

Derived parameters and risk calculations

The mortality caused by fishery, F, is scaled to F_{MSY} (fishing mortality that yields MSY) for the same reasons as relative biomass was used instead of absolute. The equations added for generating posterior distributions of the F ratio were:

$$F\mathrm{ratio}_{\mathrm{t}} = \frac{F_{\mathrm{t}}}{F_{MSY}} = \frac{-\ln\left(\frac{B_{\mathrm{t}} - C_{\mathrm{t}})}{B_{\mathrm{t}}}\right)}{\frac{MSY}{B_{MSY}}} \qquad (6)$$

The risk of a parameter transgressing a reference point is the relative frequency of the MCMC sampled values (after convergence has occurred) that are smaller (or larger, depending on type) than the reference points.

C.2 Gadget model

A Gadget model approach to assess the stock was considered at WKBUT in 2013 as an alternative to the stock production model. Gadget should continue to be developed and be reviewed at an inter-benchmark. This work will likely take one to two years and the date of the inter-benchmark should be set two to three months after the work is complete in order to give participants time to review the analyses. The Gadget model should include the anticipated revised cpue, length frequencies representative of all the catch, the new combined survey index, a growth function based on Icelandic tagging data, length selectivities by sex, iterative reweighting as in the assessment of tusk in 5.a. Uncertainties on the estimates, tests of sensitivity to the natural mortality assumption, and analyses of possible reference points should be presented.

D. Short-Term Projection

E. Medium-Term Projections

F. Long-Term Projections

G. Biological Reference Points

WKBUT in 2013 approved a set of reference points as derived from this model as B_{lim}=0.3B_{MSY} , F_{lim}=1.7F_{MSY} and MSY$B_{trigger}$ as 0.5B_{MSY} based on the following considerations:

B_{lim}

The Schaefer production curve fitted by the assessment model is the estimated stock–recruitment relation of the stock. The slope of this curve is decreasing linearly (Figure. G.1) i.e. there is not a distinct "change-point" where recruitment starts to decline rapidly as the stock is reduced, which could provide a candidate for a B_{lim} reference.

A B_{lim} could instead be set in relation to the time it takes for the stock to recover from this point (cf. Cadrin, 1999). The time needed to rebuild an overfished stock from B_{lim} back to B_{MSY} depends on the stock size at B_{lim}, the rate of growth and fishing mortality.

At 30%B_{MSY} production is reduced to 50% of its maximum (Figure G.1). This is equivalent to the SSB at 50% R_{MAX} (maximum recruitment). Greenland halibut is believed to be a slow growing species i.e. with relative low r (intrinsic rate of increase) (Figure G.2 left). This means that even without fishery it would take some ten years to rebuild the stock from 30%B_{MSY} to B_{MSY} (calculated by setting r=0.21, the 75th percentile), but likely longer (Figure G.2 right).

Once fished down to low levels the stock will, due to the predicted slow recovery potential, spend proportionally longer time at low levels once a recovery plan is implemented and fishing pressure is relaxed. Longer time at low levels means higher risk of "bad things" happening which could destabilize the stock. B_{lim} therefore be set no lower than 30% B_{MSY}.

F_{lim}

An F-ratio (F/F_{MSY}) corresponding to a yield of 50%MSY (50%R_{MAX}) at a stock biomass of 30%B_{MSY} (suggested B_{lim}) may be derived from equation 3 as follows:

$$\frac{production}{B_{MSY}} = \frac{2\,MSY\,P_t}{B_{MSY}}\left(1-\frac{P_t}{2}\right),$$

at equilibrium: $C = production$ and

$$F = \frac{C}{B} = \frac{C}{B_{MSY}}\frac{B_{MSY}}{B} \Rightarrow$$

$$F = \frac{2\,MSY\,P_t}{B_{MSY}}\left(1-\frac{P_t}{2}\right)\frac{1}{P}, \quad \text{as } F_{MSY} = \frac{MSY}{B_{MSY}} \Rightarrow$$

$$\frac{F}{F_{MSY}} = Fratio = 2 - P$$

if B_{lim} is 30%B_{MSY} (P=0.3) then the corresponding F_{ratio} is 1.7 (Figure G.1). The proposed F_{lim} at 1.7F_{MSY} is the fishing mortality that will drive the stock biomass to B_{lim}.

MSYB$_{trigger}$

In order to have a safety margin between the defined B_{lim} and a MSY $B_{trigger}$, taking account of the precision of the assessment, ICES have previously used a factor of 1.4 or if error is known in assessment, then $B_{lim}e^{1.645\sigma}$, where σ denotes std variation. If σ is assumed at 0.3 then MSY $B_{trigger}$ will be estimated at approx. 0.5B_{MSY}, which is proposed as MSY $B_{trigger}$ reference point for this stock. Similar MSY $B_{trigger}$ values in this order of magnitude have been adopted for several ICES and NAFO stocks.

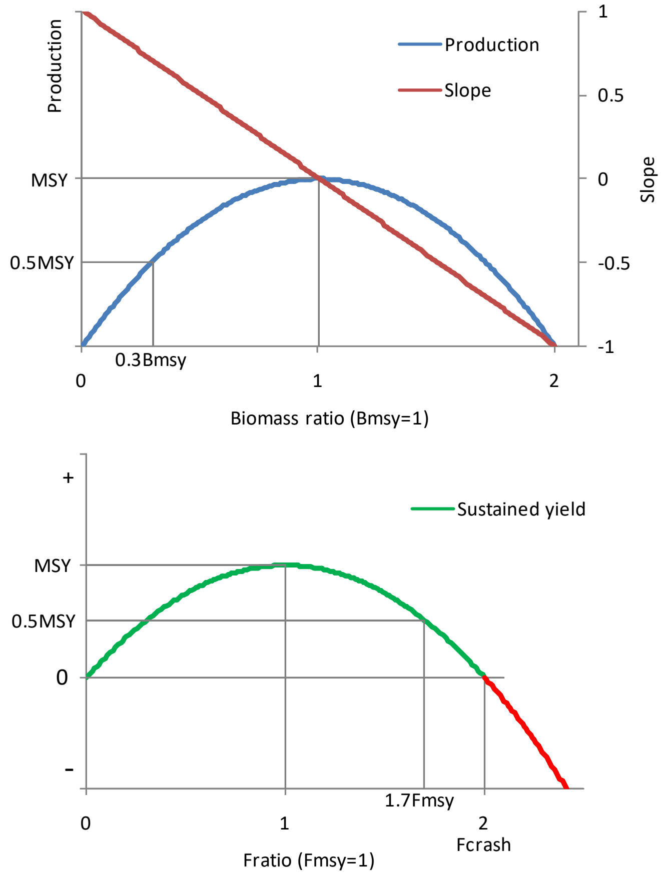

Figure G.1. The logistic production curve in relation to stock biomass (B/B_{MSY}) (*upper*) and fishing mortality (F/F_{MSY}) (*lower*). *Upper*: points of maximum sustainable yield (MSY) and corresponding stock size are shown as well as the slope (red line) of the production curve (blue line); *lower*: points of MSY and corresponding fishing mortality and F_{crash} ($F \geq F_{crash}$ do not have stable equilibriums and will drive the stock to zero).

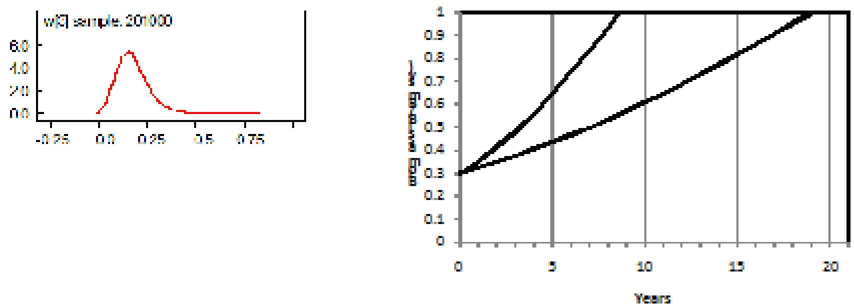

Figure G.2 *Left*: The posterior probability density distribution of *r*, the intrinsic rate of growth. Right: estimated recovery time from B$_{lim}$ (0.3B$_{MSY}$) to B$_{MSY}$ (relative biomass = 1) given *r*-values ranging within the 95% conf. lim. of the posterior (left figure) and no fishing mortality.

H. Other Issues

History of assessment methods used.

In the 1990's a VPA was conducted to assess the state of the stock. Only the Icelandic trawler fleet was available for calibration of the VPA. Due to diagnostic problems with the VPA and a strong retrospective pattern in the estimation of F and SSB this approach was rejected in 2000. Also ageing problems caused the rejection of an age based assessment model. At the same time age reading ceased in the main fishing lab dealing with assessment of the stock. This still prevents the reversion to an age based assessment. In 2001 – 2004 a stock production model was used as basis for the advice (ASPIC). In 2004 the ASPIC were not able to track the indices (Icelandic survey and CPUE) and thus rejected as an assessment approach. State of the stock in 2004-2006 was entirely based on indices from surveys and the commercial fishery. In 2007 the stock production model was presented in a Bayesian framework and accepted by the NWWG. This approach was, however, rejected by the review group based on some technicalities. The comments of the 2007 reviewers have been taken into account in the 2008 assessment that was accepted.

I. References

Annex 1 Management plan