ICES IBPHALI REPORT 2015

ICES ADVISORY COMMITTEE

ICES CM 2015\ACOM:54

Report of the Inter Benchmark Process on Greenland Halibut in ICES areas I and II (IBPHALI)

August 2015

By correspondence

ICES
CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l’Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2015. Report of the Inter Benchmark Process on Greenland Halibut in ICES areas I and II (IBPHALI), August 2015, By correspondence. ICES CM 2015\ACOM:54. 41 pp.

Contents

Executive Summary

The Inter Benchmark Process on Greenland Halibut in ICES areas I and II (IBPHALI) was set up to follow up the benchmark process for this stock which was started by The Benchmark Workshop on Greenland Halibut Stocks (WKBUT) in 2013 (ICES, 2013) and continued at The Data Compilation Workshop on Northeast Arctic Greenland Halibut and Assessment Methods (DCWKNGHD) in 2014 (ICES, 2014a). The work took place by correspondence in May-August 2015. A Gadget model (age-length-structured, tuned only on length data) is used for assessment of this stock, without use of age data since there still are disagreements on age reading methodology. The model was set up for the period 1992–2014.

The Gadget model produced a population rising from around 180 million individuals and 300 thousand tonnes in 1992 to around of 340 million individuals and 550 thousand tonnes in the late 1990s/early 2000s, followed by a slight decline in numbers and roughly constant biomass up to 2005. The population then increased to around 428 million individuals and 736 thousand tonnes by 2012, with a flattening off and then very slight decline in the most recent year(s). The decline in numbers occurs early and is steeper than the very slight decline in biomass. This, combined with no recent strong recruitment, indicates that the number of smaller fish in the 45+ cm category is declining, and it can be expected that the overall biomass will follow this decline in coming years.

From the medium-term projections it can be seen that fishing at either the previous advised level or the current level reduce the stock over the medium term, but in moderate manner. In either case one can expect the stock to remain above the proposed B_{lim} (c. 500 000 tonnes biomass of 45+ cm fish) for over 10 years, allowing time for new recruits to enter the fishery and spawning stock. However under the increased fishing pressure scenarios the rate of decline is steeper, and even under a 50% increase in fishing pressure the stock is projected to fall more than half way to the proposed B_{lim} within 5 years. Given the sporadic nature of recruitment and the relatively short time period of the model, constructing a SSB-recruitment relationship has not been possible.

Biomass (production) models will not accurately track the year-to-year stock development as would be required from an assessment model. However, such models can potentially give information on overall trends in biomass. Since the tuning data requirement is lighter than for more complex models, production models can often be run much further back in time, in this case back to the start of the large-scale fishery in the early 1960s. This gives the possibility to examine the overall trends over the course of the whole fishery. Two such models are under development, and one of them was reviewed by the group.

1 Introduction

The Inter Benchmark Process on Greenland Halibut in ICES areas I and II (IBPHALI) chaired by Bjarte Bogstad (Norway), with invited external expert Joanne Morgan (Canada) worked by correspondence in May–August 2015 to provide an assessment for this stock that could be used as a basis for management advice for 2016. The process was set up following The Benchmark Workshop on Greenland Halibut Stocks (WKBUT) in 2013 (ICES, 2013) and The Data Compilation Workshop on Northeast Arctic Greenland Halibut and Assessment Methods (DCWKNGHD) in 2014 (ICES, 2014a) held in Murmansk 10–12 November 2014, as it then became clear that ongoing modelling work for this stock would not be finished in time for use as basis for stock assessment at the AFWG meeting in April 2015. It was thus decided to delay the provision of advice for this stock for 2016 until September 2015 so that new methodology could be provided, and the client for the advice agreed to this. Six web meetings with the external expert were held (26 May, 18 and 24 June and 4, 20 and 27 August 2015).

2 Input data

A data compilation workshop (ICES, 2014a) was conducted in Murmansk in November 2014 and information on both fisheries dependent data and survey data can be found in the workshop report. Also the updated stock annex lists available data, and shows which data are used in the analytical assessment with Gadget (see also Section 3.1 and Annex 1 Stock Annex).

The DCWKNGHD workshop recommended further work on standardization of the Russian CPUE series (GLM). Updated work on the Russian CPUE series is presented in Kovalev and Tretyakov (Kovalev and Tretyakov, WD 3).

DCWKNGHD also recommend further work to derive survey indices for Greenland halibut based on the Joint Ecosystem Survey in the Barents Sea. This was addressed by Hallfredsson and Vollen (Hallfredsson and Vollen , 2015; Hallfredsson and Vollen, WD 1) who developed two indices based on the Ecosystem Survey and precursory Juvenile Greenland halibut survey. A juvenile index (EcoJuv) is based the coverage of these surveys in the nursery area of NEA Greenland halibut, and the other index (EcoSouth) is based on the remaining survey area of the Ecosystem Survey. These new indices are among the tuning series in the analytical assessment presented here.

Figure 2.1 shows the EcoJuv index, Figure 2.2 shows the EcoJuv abundance index split into age groups, and Figure 2.3 shows the EcoSouth index.

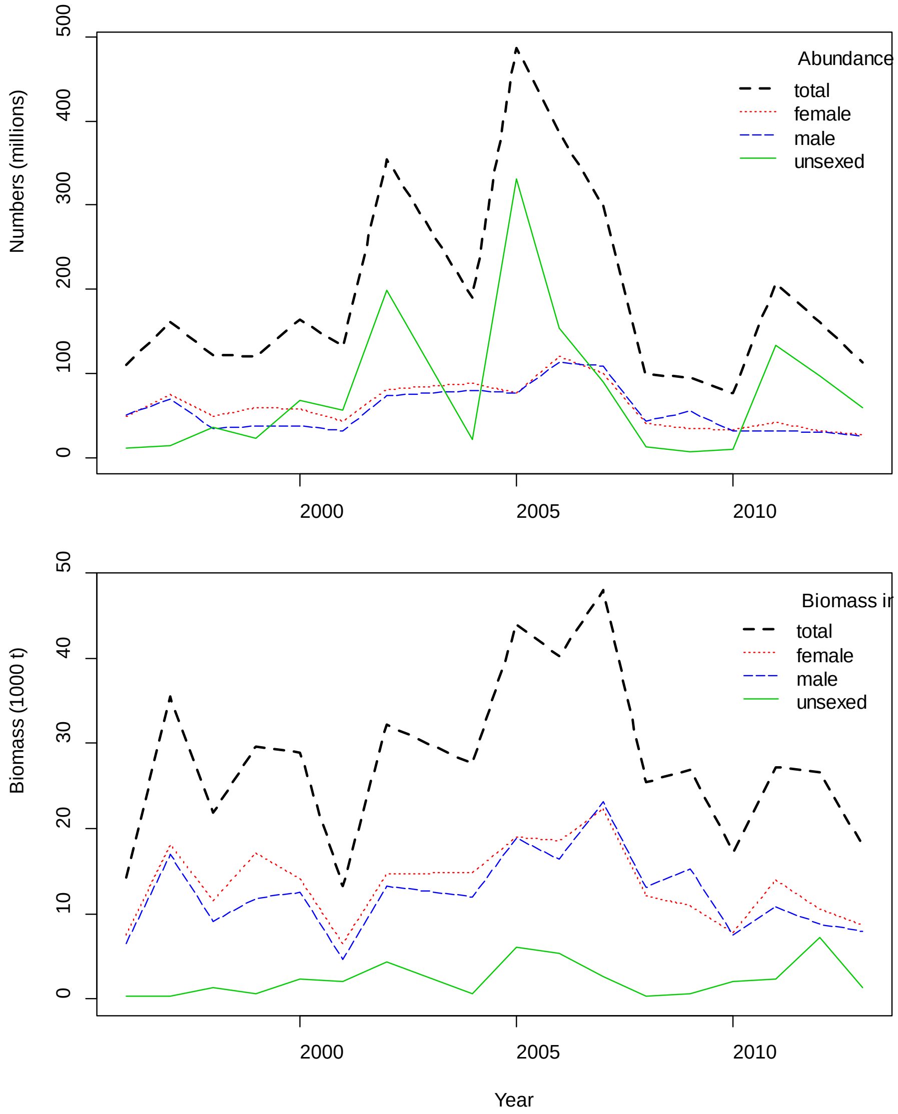

Figure 2.1. EcoJuv index- Swept area abundance and biomass indices by sex and total (Hallfredsson and Vollen, WD1).

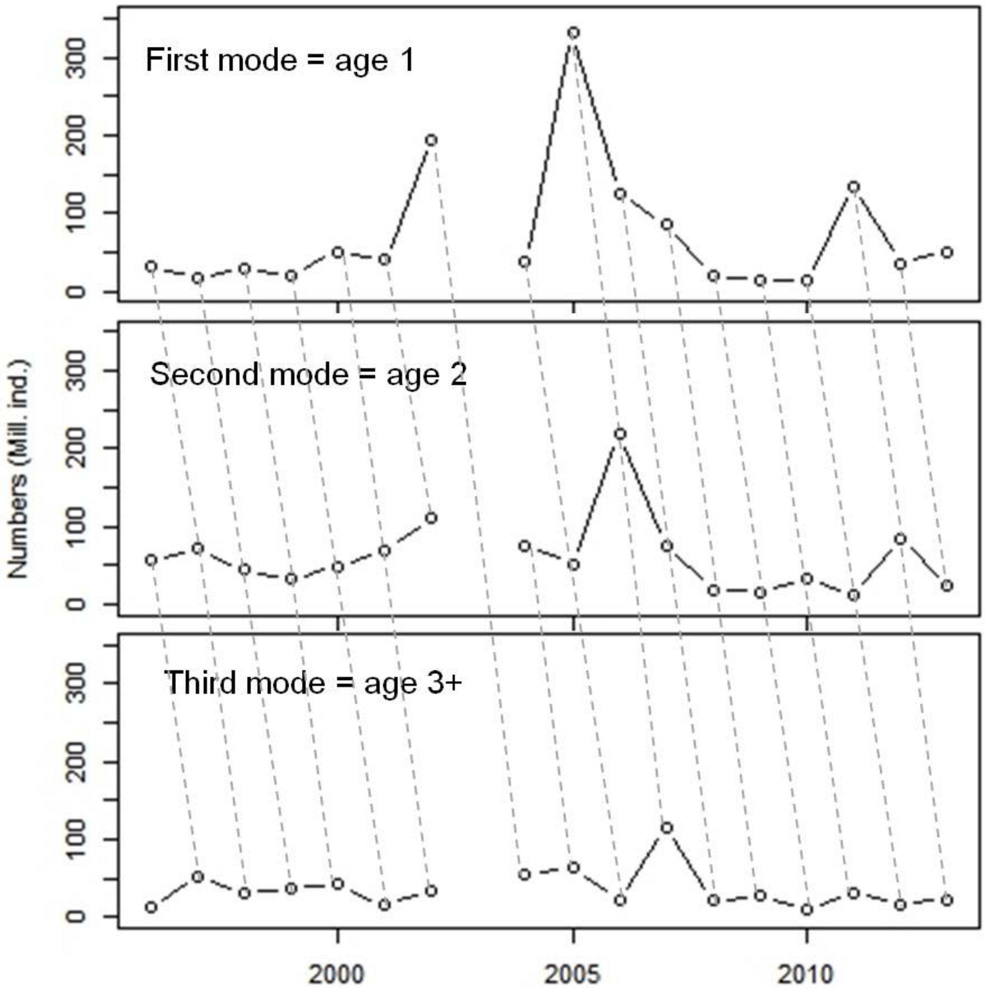

Figure 2.2. Juvenile Greenland halibut numbers by year and length modes as defined by mixture distribution analysis. Each panel represents numbers in an age group. Each dot gives fitted numbers of observations within a gamma distribution for the given mode and year (Hallfredsson and Vollen, WD 1).

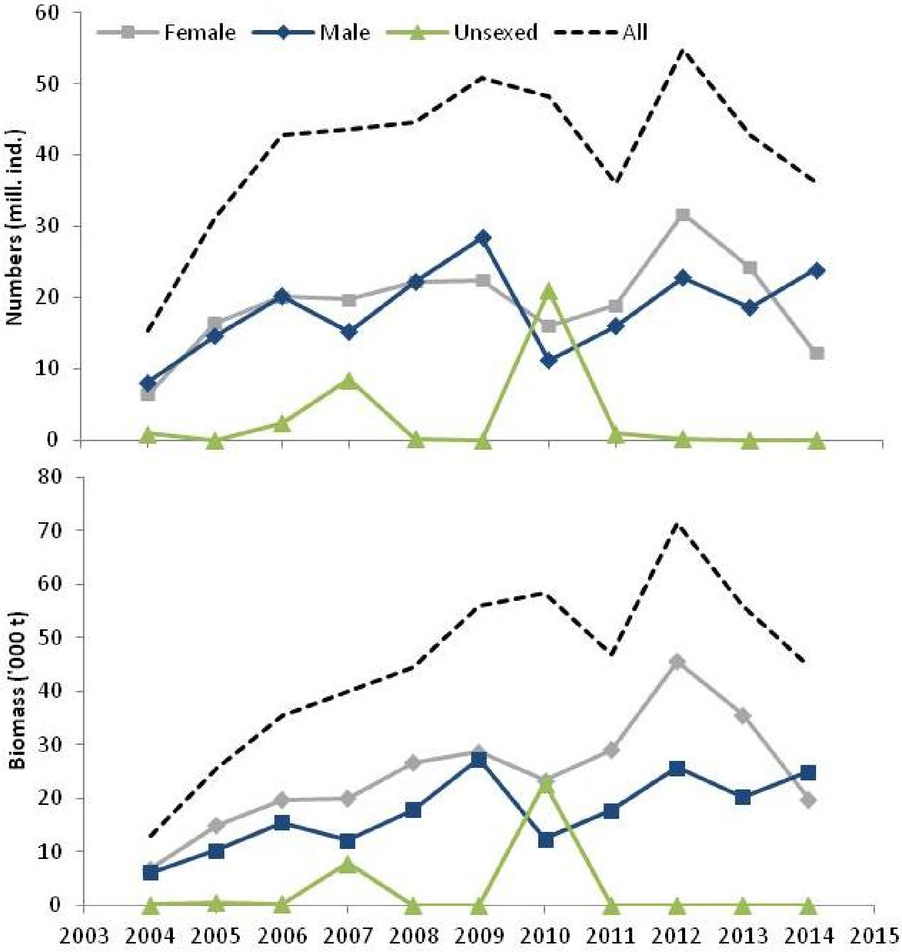

Figure 2.3. The EcoSouth index based on the Joint Ecosystem Survey in the Barents Sea (Hallfredsson and Vollen, 2015).

3 Modeling approaches

The GHL stock is challenging to model for a number of reasons. Sporadic recruitment and late maturity make production models more suited to estimating long term trends than as assessment models; conflicting signals from various partial surveys make trends-based methodologies problematic; lack of an agreed age-reading methodology precludes age-based models. An age-reading workshop (ICES, 2011) was held, and determined that the previous method for reading otoliths was not accurate; however no agreement was reached on an alternate methodology. Until such agreement is reached one cannot base an assessment methodology on age data.

Two approaches have therefore been developed. Production models have been developed to investigate long–term stock developments, and an age-length structured Gadget model, tuned only on length data, has been developed for assessments and medium term forecasts.

3.1 Gadget

The Gadget model for this stock is described in more detail in Howell, WD 2. In particular many of the diagnostics conducted during the benchmark are presented in the WD rather than in the main report.

3.1.1 Model settings

The model runs from 1992 to 2014, with monthly time steps. Note that due to the presence of initial conditions, the first few years should be considered as a lead-in period to the model. The Greenland Halibut is modelled with a single-species model, with maturation modelled explicitly. In the current version the maturation is simply set, this flexibility has been included to allow for future work. Mature males and females are treated separately. Immature fish is split into male and female components to allow for differences in maturation. The fish in the model is divided into one cm length categories.

3.1.2 Biological processes

The Greenland Halibut is considered to have Von Bertanlanffy growth, with separate parameters estimated for males and females. Length-weight relationships are based on data from the Norwegian Slope survey and are fixed through time for all years, with no annual variations. Separate parameters are used for female and male (Females: a=1.4E-6 and b=3.47. Males: a=5.7E-6 and b=3.12). Predation is not explicitly modelled and natural mortality is set to 0.1 for all components of the stock.

Recruitment is handled as a number of recruits to be estimated per year, no attempt at closure of the life cycle is attempted. A single variable governing length of recruitment is estimated, assumed to be constant over all years. In reality, spawning occurs over several months, peaking in December. In the model, recruitment to the immature stock is assumed to occur at 1 January, with fish being assigned an age of one year. A sex split of 50–50 is assumed in recruits.

Maturation is modelled using logistic functions and takes place once per year. Males and females have different parameters. It should be noted that the process modelled in an L50 (length at 50% maturation)-type approach is that of becoming mature, not the proportion mature in the population at a given time. The L50 estimated here would thus be different (higher) than L50 for proportion mature if a more sophisticated maturation function were to be employed.

The model was run from 1992–2014 as this was the time span with quarterly catch data split by sex available. It would be extremely valuable to extend the time span back to the early 1980s in order to cover the period of low stock size, and thus give better estimates for limit reference points.

3.1.3 Model structure:

- Time period: 1992–2014, monthly time steps
- 1 cm length classes (1–115cm) and 1 year age classes (1–30+)
- Two sexes, split into mature and immature
- Logistic maturity estimated for each sex
- Von Bertanlanffy growth estimated separately for males and females
- L-W relationship fixed based on data from the Norwegian slope (Females: a=1.4E-6 and b=3.47. Males: a=5.7E-6 and b=3.12)
- Natural mortality set to 0.1 for all fish
- Initial size of recruits fixed at 8.5 cm (necessary to fix this in the absence of age data)
- Recruitment modelled as annual numbers, no relationship to SSB
- Four aggregated fleets, each with sex-specific selectivity (logistic for gill fleets, asymmetric dome shaped for trawl)
    - Norwegian Trawl (bottom trawl, purse seine, Danish seine)
    - Russian Trawl (bottom trawl, purse seine, Danish seine)
    - Norwegian Gillfleet (gillnet and longline)
    - Russian Gillfleet (gillnet and longline)

3.1.4 Tuning Data

Data used for tuning are:

- Quarterly length distribution of the landings from commercial fishing fleets (by sex)
- Quarterly catch in tonnes for each fleet (by sex)
- Length disaggregated survey indices from the four surveys (by sex except for the Russian survey)
- Overall survey index (by biomass) for four surveys, Norwegian autumn survey (EggaNor), Russian autumn survey, EcoSouth and EcoJuv (by sex except for the Russian survey)
- Estimated maturity ogives (maturity at length in the population) for 1992–2014 (by sex)

Note that in order to avoid the problem of modelled fish not covered by any fleet (and therefore not tuned to any data) the gillfleets have been assumed to have logistic (flat topped) selectivity.

3.1.5 Estimated parameters:

L50 and slope for the maturation (male and female separately), two growth parameters per sex, two maturation parameters per sex, one annual recruitment parameter per year, two parameters for s.d. of length of recruits, parameters governing commercial selectivity (two per sex per gillfleet and three per sex per trawlfleet), one effort parameter per year for each fleet, three parameters per survey per sex governing selectivity, initial population numbers for male and female fish by age, initial population s.d. of lengths by sex and age.

3.1.6 Results

The 45+ cm numbers and biomass as well as the exploitation rate from the assessment model and the modeled recruitment at age 1 is shown in Table 3.1 and Figure 3.1–3.3. The Gadget model has produced a population rising from around 180 million individuals and 260 thousand tonnes in 1992 to around of 340 million individuals and 530 thousand tonnes in the late 1990s/early 2000s, followed by a slight decline in numbers and roughly constant biomass up to 2005. The population then increased to around 428 million individuals and 736 thousand tonnes by 2012, with a flattening off and then very slight decline in the most recent year(s). The decline in numbers occurs early and is steeper than the very slight decline in biomass. This, combined with no recent strong recruitment, indicates that the number of smaller fish in the 45+ cm category is declining, and it can be expected that the overall biomass will follow this decline in coming years.

Concerning the recruitment, it should be noted that age 1 is the age for recruitment to the stock, NOT the age for recruitment to the fishery, which is the quantity normally used to describe recruitment. But since age 1 recruitment is the quantity estimated by the model and the age of recruitment to the fishery can't be defined due to disagreement on age reading, we use age 1 as the recruitment age for this stock. Even if there had been agreement on age reading methodology, the strong sexual dimorphism in growth would make it very difficult to define an appropriate recruitment age. Sporadic recruitment at age 1 is supported empirically by the juvenile data (Figure 2.2) and also reflected in recruitment pulses going through all available survey series, which in turn facilitates length based approach.

Harvest rates in year y have been computed as catch in year y divided by fishable (in this case 45+ cm) stock biomass at the start of the year. This is different from an instantaneous F, but the difference is marginal for the low values involved here. The results are presented in Table 3.1. The values are low, mostly in the range 0.02–0.035, but there has been an increasing trend since 2009. As a long-lived species, one would not expect this stock to sustain high harvest rates, and the model does not extend far enough back in time to capture the period of unregulated heaviest fishing.

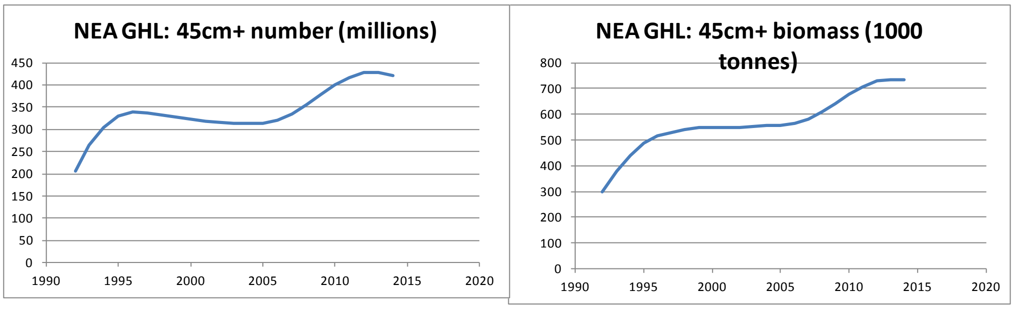

Figure 3.1. 45+ cm numbers (left) and biomass (right)

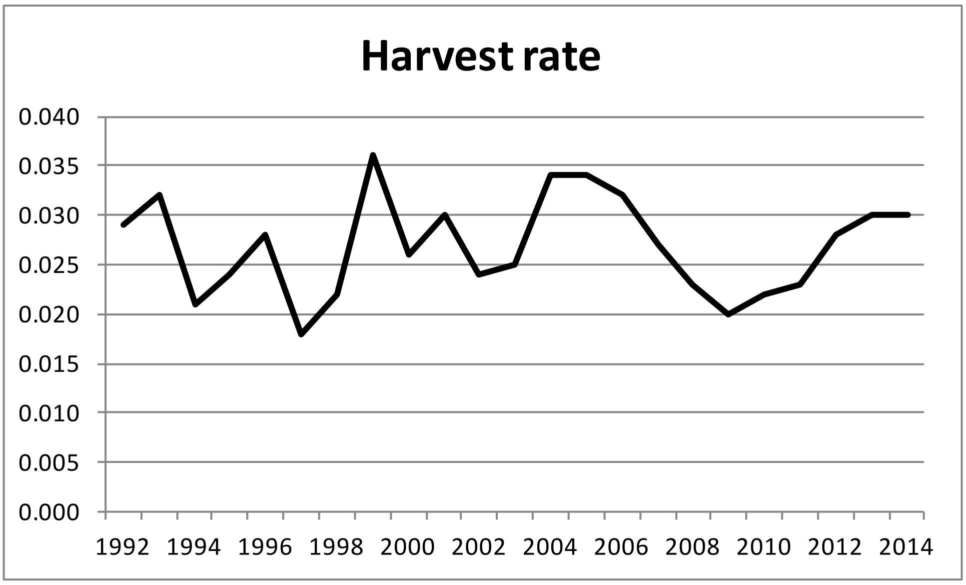

Figure 3.2. Estimated exploitation rates (below) for the Gadget model 1992–2014

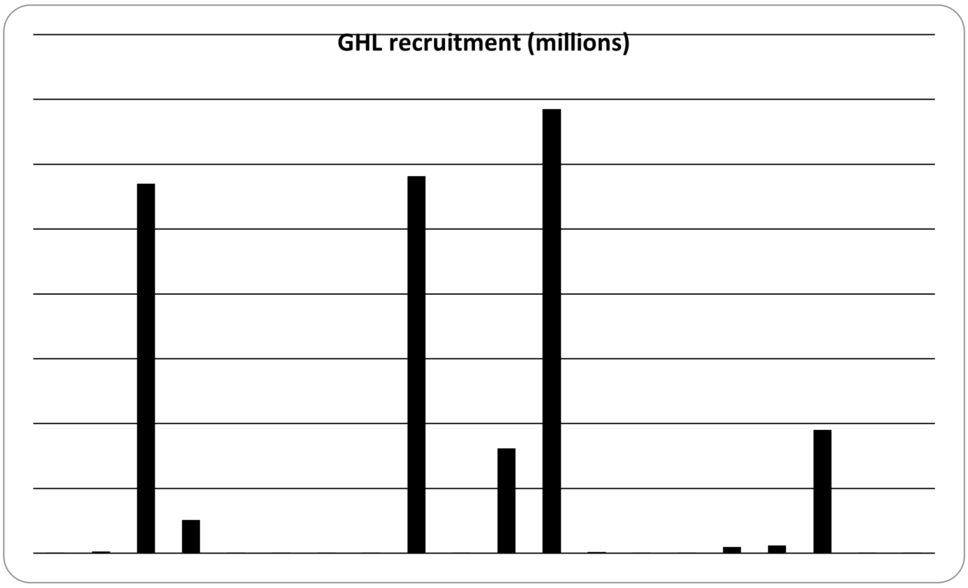

Figure 3.3. Greenland halibut recruitment (millions age 1).

Table 3.1 Recruitment at age 1, 45+ cm biomass, catch in tonnes and harvest rate by year

Year	Recruitment	Biomass	Catch	Harvest
	Million age 1	45cm+	tonnes	rate
1992	-	300444	8602	0.029
1993	1	377815	11933	0.032
1994	3	439104	9226	0.021
1995	570	487292	11734	0.024
1996	51	515856	14347	0.028
1997	1	530290	9410	0.018
1998	1	542043	11893	0.022
1999	1	546636	19517	0.036
2000	1	547237	14437	0.026
2001	582	549461	16307	0.03
2002	1	550507	13161	0.024
2003	162	553607	13578	0.025
2004	685	556405	18899	0.034
2005	1	556644	18834	0.034
2006	1	564575	17904	0.032
2007	1	582071	15453	0.027
2008	10	609407	13792	0.023
2009	12	643230	12990	0.02
2010	190	678384	15229	0.022
2011	1	707166	16606	0.023
2012	1	727990	20288	0.028
2013	-	735908	22167	0.03
2014	-	733870	22244	0.03

3.1.7 Reference points

Given that the GHL stock is driven by sporadic recruitment events, long-term average values (F_{MSY} or B_{MSY}) have little relevance to practical fisheries management (c.f. the *Sebastes mentella* stock in the same area, ICES, 2014b). Rather, fishing pressure should be based on the current state of the stock, recent recruitment history and a biomass limit reference point which we should endeavor to remain above. Since reference points should come from the same model as the assessment (in order to ensure consistency), the Gadget model has been used to evaluate a limit reference point.

Given the sporadic nature of recruitment and the relatively short time period of the model, constructing a SSB-recruitment relationship has not been possible. We therefore take the "B_{loss}" route to arriving at a reference point. Figures 3.1–3.3 show the 45+ cm biomass, the exploitation rate and the estimated recruitment. There is evidence of good recruitment in 1995, when the biomass was around 500 000 tonnes. Note that we are currently around 50% above this level. This could be taken as a precautionary reference point, "B_{loss} with good recruitment". This is likely to be precautionary, and a "real" B_{lim} is likely to be rather lower. This is because the stock is rising at this point, and there is evidence in the estimated initial population in the Gadget model that there was a previous good recruitment event from a lower, although unknown, stock size. See WD 2 for more details.

We therefore **recommend using the 1995 biomass (c. 500 000 tonnes 45+ cm biomass) as a precautionary reference point** to use in the current advice. There is good confidence that this is precautionary, possibly overly so, given that there was a previous good recruitment from a lower stock size. We also **recommend further work extending the model back to the early 1980s to investigate behavior at lower stock sizes.**

3.1.8 Medium-term projections

Medium term (5 year) projections have been conducted using the assessment. A period of 5 years was chosen in order to ensure that the 45+ cm biomass was not influenced by new recruits, rather the model is required to only track the future development of existing year classes. In all of these runs fishing pressure in 2015 is assumed to be an average of that in 2013 and 2014 (when the harvest rate was approximately 0.03). In the subsequent years this average is multiplied by a scaling factor (ranging from 0 to 3). Results are presented in Figures 3.4a–d and Table 3.2. As can be seen, the recent poor recruitment suggests a very slight downward trend in biomass, even in the absence of a fishery. The previous advice (which has not been followed) or the current fishing pressure both result in a slow downward trend. Higher fishing pressures, which give harvest rates above anything seen in the stock over the past two decades, result in the stock being depleted rather rapidly. Note that in all cases it is not clear how long the stock must be maintained to allow future recruitment of juveniles to enter the fishery.

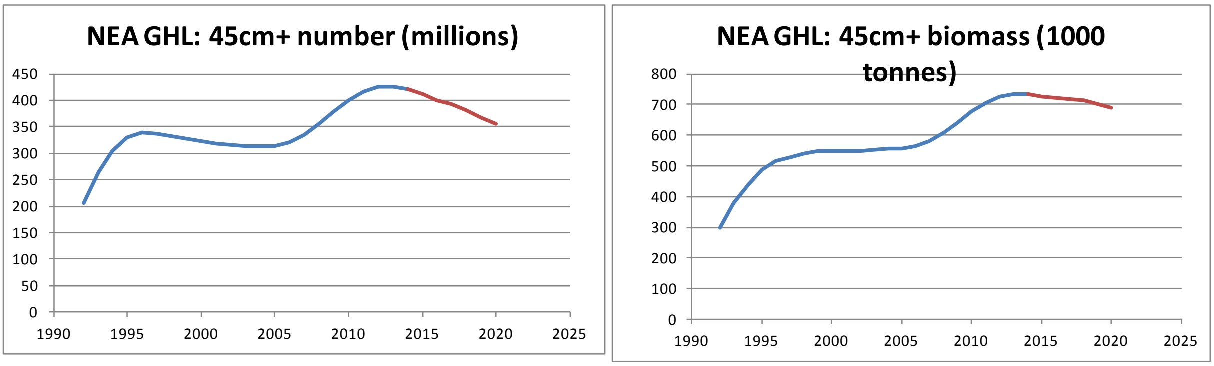

Figure 3.4a. Forecast 45+ cm stock under a no fishing scenario. Historic in blue, projected in red.

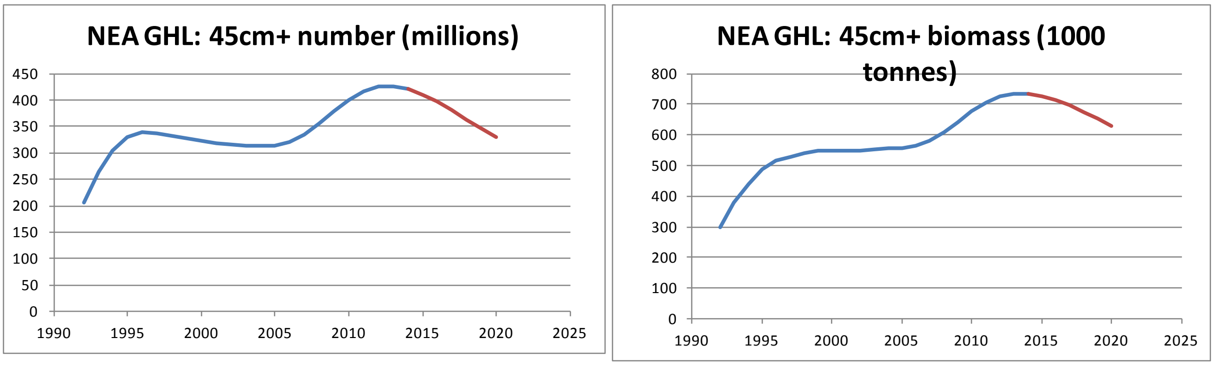

Figure 3.4b. Forecast 45+ cm stock under "previously advised fishing intensity" scenario, fishing at 0.75x present levels. Historic in blue, projected in red.

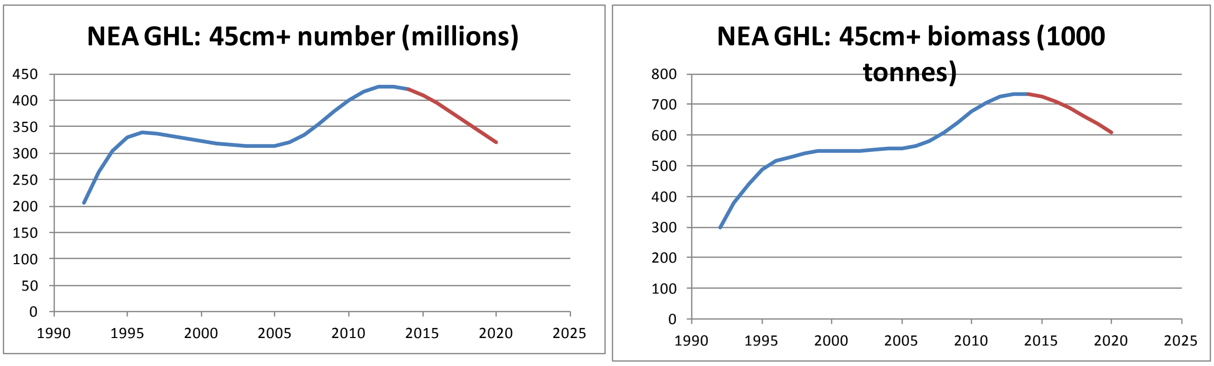

Figure 3.4c. Forecast 45+ cm stock under "current fishing intensity" scenario. Historic in blue, projected in red.

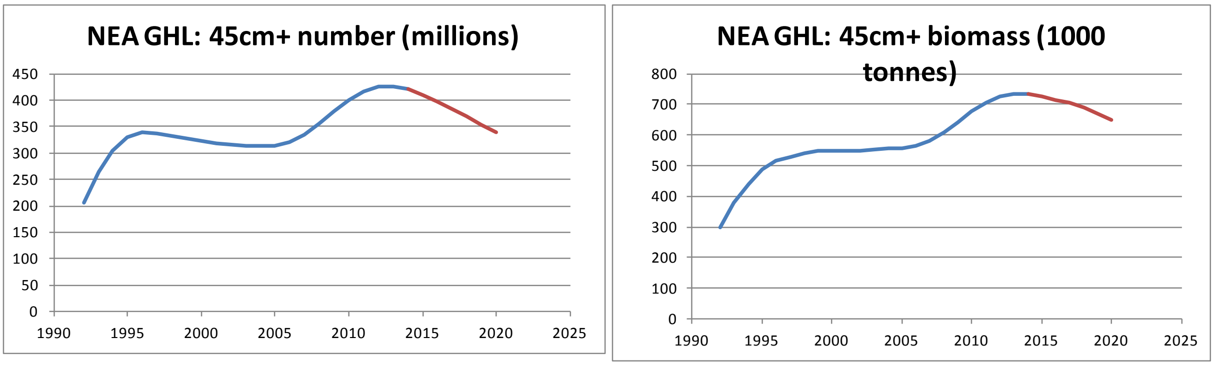

Figure 3.4d. Forecast 45+ cm stock under "× 0.5 fishing intensity" scenario. Historic in blue, projected in red.

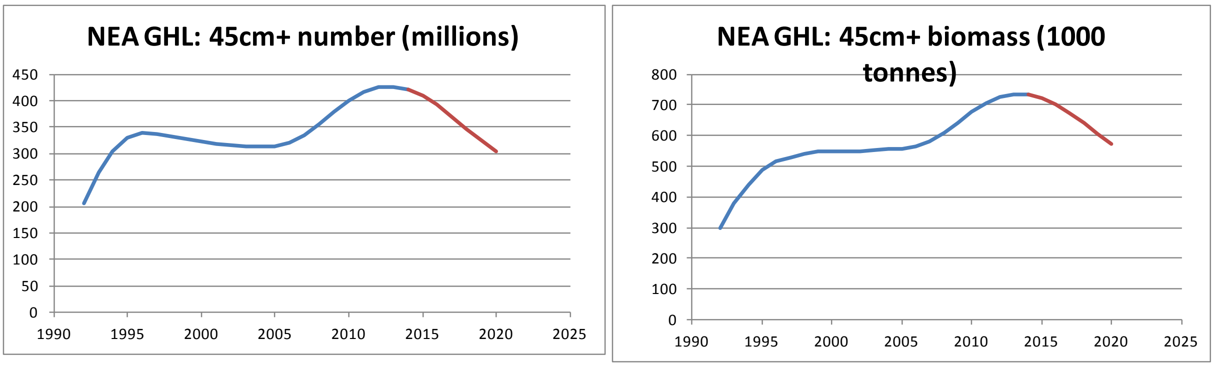

Figure 3.4e. Forecast 45+ cm stock under "× 1.5 fishing intensity" scenario. Historic in blue, projected in red.

Table 3.2. 5 year forecasts, showing expected 45+ cm biomass on 1st January 2020 and average yield 2016–2019 for different harvest rates.

Scenario (multiplier on current fishery)	Harvest rate (2016-2019)	Biomass 1st January 2020 (kt)	Average catch (2016-2019) (kt)
× 0	0	691	0
× 0.5	0.015	650	10.7
× 0.75 (approximately previous advice)	0.02	630	15.8
×1	0.03	610	20.7
×1.5	0.045	574	30.0
×2	0.06	540	38.7
×3	0.09	478	54.1

3.2 Production models

As mentioned in the introduction, this stock is characterised by occasional years of good recruitment separated by multiple years of poor recruitment. The stock is relatively late maturing. Both of these violate the central assumption in production models that (in this case fishable) biomass is year t+1 is a function of the biomass in year t. Instead, in reality, the biomass will be a function of the existing biomass and the recruitment history. Consequently biomass models will not accurately track the year-to-year stock development as would be required from an assessment model. However, such models can potentially give information on overall trends in biomass. Since the tuning data requirement is lighter than for more complex models, production models can often be run much further back in time, in this case back to the start of the large-scale fishery in the early 1960s. This gives the possibility to examine the overall trends over the course of the whole fishery.

3.2.1 PINRO production model

The stochastic version of a Schaefer production model developed for the Barents Sea Greenland halibut stock was presented during the ICES Benchmark Workshop on Greenland Halibut Stocks (ICES, 2013). One of the conclusions of the presented working document (WD 14 WKBUT) was that despite high uncertainty this version of the model provides an analytical alternative to the previous methods of assessment of the Greenland halibut stock.

During the discussion of the production model at the WKBUT workshop, there were comments regarding the correctness of using catch-per-unit-effort index for the entire period of observations in view of the fact that there was a significant renewal of the fishing fleet during the second half of the period. Attention was also paid to the fact that the stock dynamics, described by the existing abundance indices, can vary significantly.

Additional test calculations were therefore carried out and their results were reviewed in order to obtain a more complete picture of the possibility of using the Schaefer production model to assess the Barents Sea Greenland halibut stock (Kovalev and Tretyakov, WD 3).

It was assumed that the size of biomass was equal to the environmental carrying capacity (B1 = K) at the beginning of fishing in 1964. The catch statistics and the abundance indices, obtained during the scientific surveys, are taken from the data used during the meeting of the Arctic Fisheries Working Group (ICES, 2015) and the Benchmark Workshop on Greenland Halibut Stocks (ICES, 2013) and are similar to the data used in the model "Gadget" (Table 3.3). The calculation procedure of the standardized catch-per-unit-effort (CPUE) of the Russian fishing fleet is described in WD 3. Generalized linear model (GLM) method was used in standardization of the catch rate.

Table 3.3. Catch (thousand tonnes) and indices (standardized units) of the Greenland halibut abundance in the Barents Sea in 1964–2014 (CPUE – standardized catch-per-unit-effort of the Russian fleet, *NO-GH-Btr-Q3* - Norwegian survey indices, *RU-Btr-Q4* - abundance index from the Russian survey, *Eco-NoRu-Q3 (Btr)* - abundance indices from the ecosystem survey)

Year	Catch, ktons	CPUE	NO-GH-Btr-Q3	RU-Btr-Q4	Eco-NoRu-Q3 (Btr)
1964	40.39	0.55	-	-	-
1965	34.75	0.39	-	-	-
1966	26.32	0.35	-	-	-
1967	24.27	0.40	-	-	-
1968	26.17	0.44	-	-	-
1969	43.79	0.46	-	-	-
1970	89.48	0.36	-	-	-
1971	79.03	0.25	-	-	-
1972	43.06	0.21	-	-	-
1973	29.94	0.25	-	-	-
1974	37.76	0.27	-	-	-
1975	38.17	0.22	-	-	-
1976	36.07	0.17	-	-	-
1977	28.83	0.13	-	-	-
1978	24.62	0.15	-	-	-
1979	17.31	0.18	-	-	-
1980	13.28	0.18	-	-	-
1981	15.02	0.29	-	-	-
1982	16.79	0.30	-	-	-
1983	22.15	0.26	-	-	-
1984	21.88	0.27	-	113.7	-
1985	19.95	0.33	-	128.4	-
1986	22.88	0.28	-	83.7	-
1987	19.11	0.25	-	48.7	-
1988	19.59	0.23	-	49.0	-
1989	20.14	0.21	-	76.1	-
1990	23.18	0.16	-	60.3	-
1991	33.32	0.14	-	97.9	-
1992	8.60	-	-	100.2	-
1993	11.93	-	-	86.0	-
1994	9.23	-	67.15	69.2	-
1995	11.73	-	80.89	71.6	-
1996	14.35	0.82	82.92	86.8	-
1997	9.41	0.96	78.97	75.6	-
1998	11.89	0.99	83.06	102.4	-
1999	19.52	1.16	104.17	91.5	-
2000	14.30	1.12	80.08	121.9	-
2001	16.37	1.45	93.51	161.6	-
2002	13.29	0.99	96.28	84.2	-
2003	13.45	1.04	109.76	95.8	-
2004	18.90	0.61	104.24	132.6	12.84
2005	18.83	0.66	87.03	111.2	25.09

2006	17.90	0.59	81.77	184.8	35.16
2007	15.45	0.59	88.25	213.3	40.06
2008	13.79	0.59	84.78	239.4	44.48
2009	12.99	1.09	107.9	256.4	56.04
2010	15.23	1.29	-	321.9	58.48
2011	16.61	2.03	84.98	433.3	46.79
2012	20.29	1.48	-	318.5	71.36
2013	22.17	1.34	63.13	-	55.90
2014	22.24	1.67	-	209.3	44.67

Note that there are conflicting trends in the signals from these different indices. The indices all cover different fractions of the stock, both geographically and in terms of maturity. The standardized catch-per-unit-effort of the Russian fishing fleet shows a slow decline in the first part of the period and grows after 1996 when the catch was substantially reduced (Figure 3.4). It should be noted that the stock growth according to the CPUE index increase since the 1990s is less rapid than the growth observed in the indices of the Russian and ecosystem surveys. Since 2005, these two surveys show a rapid increase in the indices. The Norwegian survey data in this period contradicts the rest of the observations to an even greater extent and indicates rather stabilization of the stock at a certain level than its rapid growth. Such a substantial discrepancy in signals may cause difficulties for the interpretation while using any model. For a production model in particular, the flexibility of which is negligible in comparison with the cohort methods, it can create even greater difficulties.

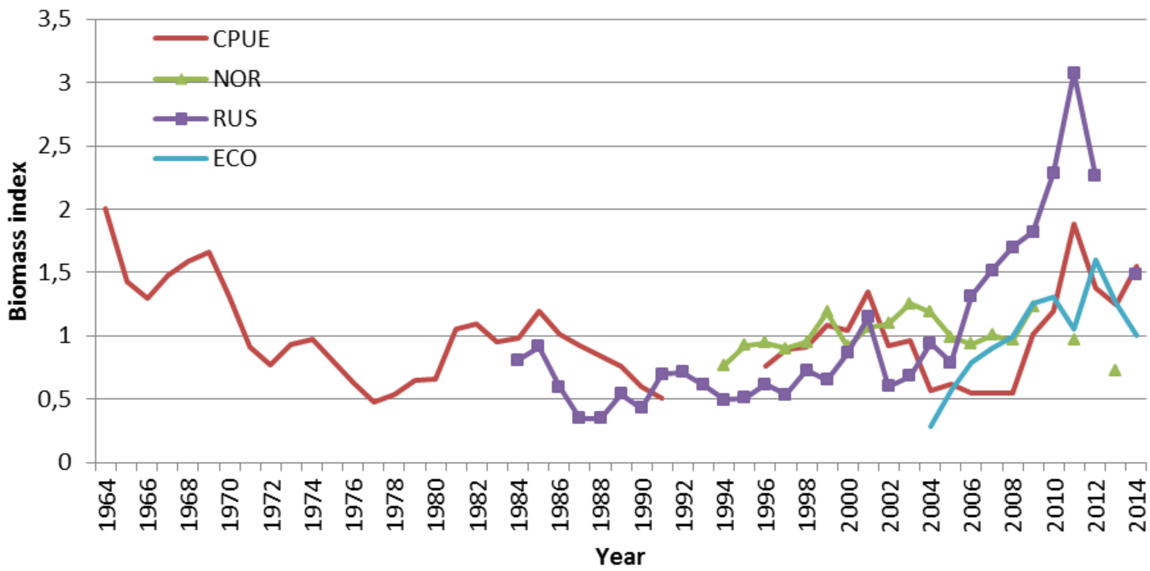

Figure 3.4. Dynamics of indices of the Barents Sea Greenland halibut stock in 1964–2014 (indices are taken divided by corresponding mean to put them in comparable scale; CPUE series divided by two: 1964–1991 and after 1996). In addition to the standardized CPUE three survey indices are shown; the Russian autumn survey (RUS), the Norwegian autumn survey (NOR) and the EcoSouth index (ECO).

Some calculations were carried out in order to test the possible effect of the above mentioned contradictions in the index signals on the stock assessment performed in the production model. Results obtained by fitting model to various data sets were very different (Kovalev and Tretyakov, WD 3). Similar experiments were conducted for the

Gadget model (Howell, WD 2) where the differences between choosing different tuning series, although present, were much less.

The applicability of a production model to carry out the evaluation of the Barents Sea Greenland halibut stock is therefore questionable. One of the major constraints is impossibility of describing by the model the observed nature of the variability of the year-classes abundance, the fluctuation of which is very large and the effects of this on the stock biomass is not captured by production models.

At the same time the production model has some value as a diagnostic tool for the analysis of the available catch data and the abundance indices. It can also be used for "crude" approximate estimation of such parameters as the environmental carrying capacity or the stock biomass prior to its exploitation, and of the potential catch levels. The results obtained during fitting the model to the data of the standardized catch-per-unit-effort (CPUE) of the Russian fishing fleet for the period 1964–1991 can be used, for example, as such estimates.

3.2.2 VNIRO production model

Another production model developed by VNIRO (Mikhaylov, 2015) is under development. On 27 August a suggestion for additional report text about this model was presented by some group members. IBPHali had at that stage already finished its work and the reviewer had provided her evaluation of the draft report. The group was therefore not in the position to review and comment on the suggested text and the majority of the group supported by the reviewers decided not to include this text in the report. A minority within the group disagreed with this decision and a text explaining the substance of the disagreement is included as Annex 4 to this report.

4 Management advice

The defining characteristic of the Greenland halibut stock in Subareas I and II is one of occasional sporadic good years of recruitment combined with a long lag before these recruits mature or enter the fishery. Consequently management needs to consider the overall state of the stock and the recent recruitment history, rather than simply rely on a long-term average F_{MSY}. The precautionary goal needs to be protecting the stock until new recruits can enter both the fishery and the spawning stock.

From the medium-term projections (Section 3.1.8) it can be seen that fishing at either the previous advised level or the current level reduce the stock over the medium term, but in moderate manner. In either case one can expect the stock to remain above the proposed Blim (c. 500 000 tonnes) for over 10 years, allowing time for new recruits to enter the fishery and spawning stock. However under the increased fishing pressure scenarios the rate of decline is steeper, and even under a 50% increase in fishing pressure the stock is projected to fall more than half way to the proposed Blim within 5 years. We therefore recommend that the harvest rate should not be allowed to rise above the current level.

It is worth noting that (as shown in Figure 4.1) periods of fishing above the present level have existed in the past, and were associated with rapid decline in the stock. In Figure 4.1 note that there was an open access fishery prior to 1992; and it is likely that the declines in catches reflect a decline in the stock. This would also suggest that increases above current level would not be precautionary.

Given the relatively slow trend in the stock at fishing levels at or below current levels, we recommend that a two year period is appropriate for advice for this stock. One of the key surveys (EggaNor) is run on a biannual basis and new data will be available for an assessment in 2017, and this time frame will provide scope to work on extending the Gadget back to 1982 in order to better model the behavior at lower stock levels.

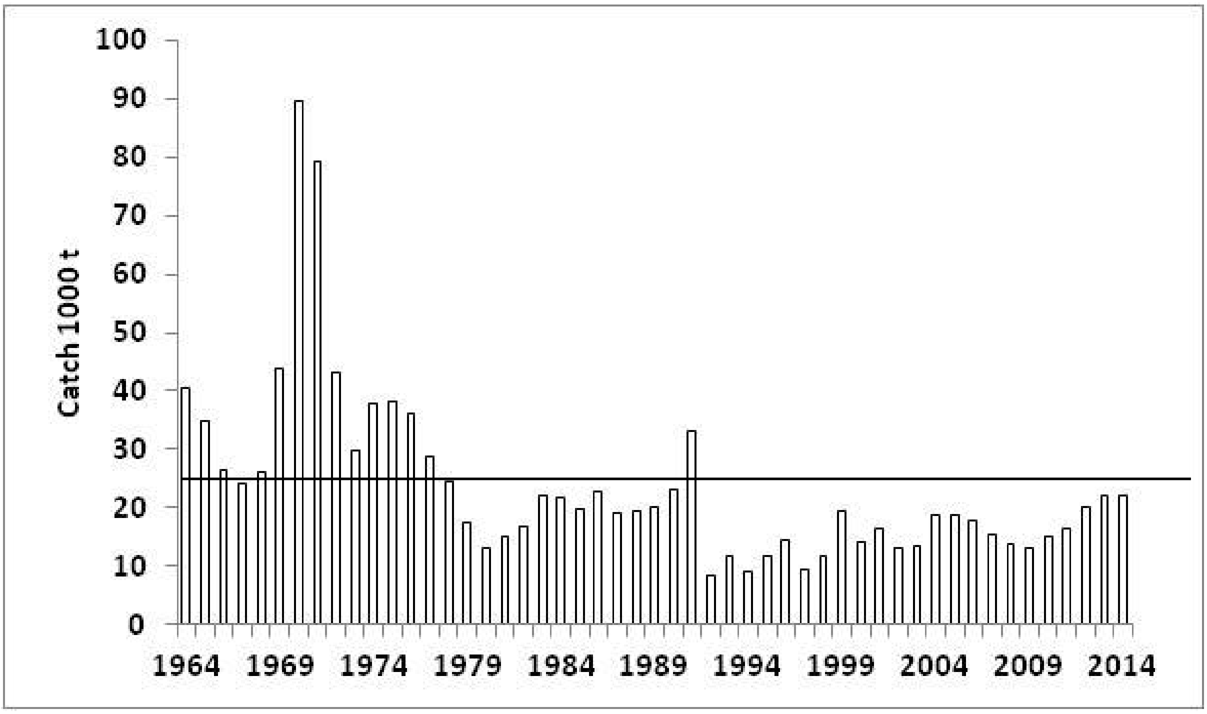

Figure 4.1. Historical catches, with current (2013–2014) catch level marked with a line.

5 Further work

In order to improve the setting of limit reference points, there should be work to try and extend the Gadget model back to the early 1980s. This would enable the behavior of the stock at lower stock sizes to be modeled. Also, harvest control rules should be investigated and work on biomass models should continue.

Work should continue on trying to obtain an agreed ageing methodology for this stock. As described in WD 2, the lack of age data in the model has had limited impact on the assessed biomass, but does negatively impact on modeling recruitment (and hence the ability to produce forecasts). There could be a new ageing workshop in 2016 or 2017. Age data for the youngest age groups (< 4–5) would be very useful for recruitment modelling, and for these age groups there is good agreement between different age reading methodologies.

At present both males and females have natural mortality fixed at 0.1 for all years and ages. It is unlikely that the data exists to support modeling time-varying trends in M, however there is scope to attempt to improve the handling of M within the model. In particular it would seem reasonable that males, which mature sooner and smaller, may have higher mortality than females. It would also seem reasonable that the youngest age classes have a higher mortality rate. Both of these issues should be investigated further.

The Russian survey index should be split by sex, and other potential tuning series (Joint winter survey, juveniles in Northern Kara Sea) should be examined.

Use of female SSB in determining reference points should be investigated.

Work on quality control of input data needs to continue, including the newly derived EcoJuv and EcoSouth indices.

Continuation of good coverage of the nursery area by the Joint Ecosystem Survey should be promoted, and more data from the northern Kara Sea would be valuable.

6 Report by external reviewer

Reviewer Report - Joanne Morgan

This inter-benchmark aimed at developing an analytical model to form the basis of the advice. Both a production model and GADGET were examined with most of the work being focussed on GADGET. Several data series were examined and a 'new' index of juvenile abundance was derived. The derivation of reference points was also discussed.

The process was very interactive and thorough. Most of the points that I raised during the process have already been addressed if it was possible to do so at the present time. Both the GADGET model and the data were examined in detail.

It was concluded that the applicability of the production model is questionable. Contradictory signals in the tuning indices have a large impact on the results of the model. Highly variable, sporadic recruitment that seems to be a feature of this stock, likely complicates the use of a production model estimating a single productivity rate.

I agree with the conclusion that the basis of the advice be the GADGET model that was developed during IBPHALI. The setting of reference points for this stock is complicated by the relatively short time series in the model and the apparent episodic/sporadic recruitment. Within the time frame of the model the lowest 45+ cm biomass that gave good recruitment was about 500 000 t and I agree with setting this as the biological reference point B_{lim}. The model (and survey data) shows that there have been no recent large year classes. This means that the stock is likely to decline in the medium term even with no fishing. This fact supports a precautionary approach to advice that will limit the speed and extent of stock decline to ensure that the stock remains above B_{lim}. Medium term projections indicate that current levels of fishing are a reasonable approach. (Note that scenarios will be slightly different than at the time of writing this report as the projections need to be redone with the same assumed fishing level in 2015). At this point it seems reasonable to provide advice for 2016 and 2017 while further work is conducted on the modelling and data.

There are several areas that could be improved in future.

- The inclusion of ageing data could help the model. There may be another workshop on ageing Greenland halibut in 2016 or 2017 and this workshop may finally result in an agreed method of ageing this species.
- There may be data to allow the model to extend the model back to the 1980s. This should be pursued as it will be of great benefit to determining reference points.
- There are juveniles in the Kara Sea. This needs to be explored further if more data become available to either include this area in the juvenile index or at least to determine if the proportion of juveniles in the area changes over time.

The uncertainty in any stock/recruit relationship means that projections should be based on 45+ cm biomass and that they should not extend more than 4–5 years. This avoids the need to estimate recruitment as it works with the fish 'already in the system'. An improved understanding of recruitment processes would be very helpful. At the moment maturity data seem limited. If there is an opportunity to extend these data it may help to better understand the relationship between SSB and recruitment.

7 References and Working Documents

7.1 References

Hallfredsson, E.H. and Vollen T. 2015. Two abundance indices for Greenland halibut based on the Joint Ecosystem Survey in the Barents Sea and previous surveys in the nursery area. ICES AFWG, WD 20, April 2015.

ICES. 2011. Report of the Workshop on Age Reading of Greenland Halibut (WKARGH), Copenhagen 14-17 February 2011. ICES C.M. 2011/ACOM:41

ICES. 2013 Report of the Benchmark Workshop on Greenland Halibut Stocks (WKBUT), 26—29 November 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:44 367 pp.

ICES. 2014a. Report of the Data Compilation Workshop on Northeast Arctic Greenland Halibut and Assessment Methods (DCWKNGHD), 10–12 November 2014, Murmansk, Russia. ICES CM 2014/ACOM:65. 56 pp.

ICES. 2014b. Report on the Workshop on Redfish Management Plan Evaluation (WKREDMP), Copenhagen 20-25 January 2014. ICES C. M. 2014/ACOM:52, 269 pp.

ICES. 2015. Report of the Arctic Fisheries Working Group, Hamburg, 23-29 April 2015. ICES C.M. 2015/ACOM:05, 590 pp.

Mikhaylov, A. 2015. MSY estimation for Greenland halibut. ICES. AFGW, WD 18, April 2015.

7.2 Working documents

WD 1. Hallfredsson, E. and Vollen, T.2015. Juvenile index for Barents Sea Greenland halibut

WD 2. Howell, D. Gadget stock assessment of Greenland halibut.

WD 3. Kovalev, Y. and Tretyakov, I. Results of the Schaefer production model run to be used for assessment of the Barents Sea Greenland halibut.

Annex 1. Stock Annex

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	North-East Arctic Greenland Halibut
Working Group:	Arctic Fisheries Working Group
Date:	01.09.2015

A. General

A.1 Stock definition

Greenland halibut (*Reinhardtius hippoglossoides,* Walbaum) is distributed in the Arctic and boreal waters in the North Atlantic and in the North Pacific (Shuntov, 1965; Fedorov 1971; Godø and Haug 1989; Bowering and Brodie 1995; Bowering and Nedreaas 2000). In the northeastern Atlantic the distribution is more or less continuous along the continental slope from the Faeroe Islands and Shetland to north of Spitsbergen (Whitehead *et al*. 1986; Godø and Haug 1989), with the highest concentrations from 500 to 800 m depth between Norway and Bear Island, which is also regarded as the main spawning area (Nizovtsev, 1968; Godø and Haug 1987; Albert *et al*. 2001b). Peak spawning occurs in December in the main spawning area, but also in nearby localities during summer (Albert *et al*. 2001b). Atlantic currents transport eggs and larvae northwards and the juveniles are distributed around Svalbard and in the northeastern Barents Sea, to the waters around Franz Josef Land and Novaja Zemlya area and into the Kara Sea (Borkin,1983; Nizovtsev, 1983; Godø and Haug 1987; Godø and Haug 1989; Albert *et al*. 2001a, Ådlandsvik *et al*. 2009, Smirnov 2009, Hallfredsson and Vollen 2015a,b). As they grow older they gradually move southwards and eventually may alternate between the spawning area and feeding areas in the central-western Barents Sea (Nizovtsev, 1989).

The Northeast arctic Greenland halibut stock is a pragmatically defined management unit. The degree of exchange with other stocks is not fully resolved but later and still ongoing studies indicate that it may be more pronounced than previously thought (Knudsen *et al*. 2007, Albert and Vollen 2015, Westgaard *et al*. (submitted)). Potential routes of exchange may be drift of larvae towards Greenland and migration of adults between the Barents Sea and the Iceland-Faeroe Islands area. Revision of stock structure is regarded as a relevant issue for a future Benchmark.

A.2 Fishery

Before the mid-1960s the fishery for Greenland halibut was mainly a coastal long line fishery off the coasts of eastern Finnmark and Vesterålen in Norway. The annual catch of the coastal fishery was about 3000 t. In recent years this fishery has landed 3000—6000 t although now gillnets are also used in the fishery. In 1964 dense Greenland halibut concentrations were found by Soviet trawlers in the slope area to the west of the Bear Island (Nizovtsev, 1989). Following the introduction of international trawlers in the fishery in the mid-1960s, the total landings increased to about 80,000 t in the early 1970s. The total Greenland halibut landings decreased steadily to about 20 000 t during the early 1980s. This level was maintained until 1991, when the catch increased sharply to 33 000 t. From 1992—2009 total landings varied between 9000—19 000 t with a peak in 1999. Since then landings have increased steadily from 13 000 t in 2009 to 22 000 t in

2014. From 1980 to 1989 around 90% of the total landings of Greenland halibut were by trawlers. Regulations enforced in 1992 reduced landings by trawlers from 20 000 to about 6 000 t. Since 1992 the total landings have been approximately equally divided between longline/gillnet and trawl fisheries.

From 1992—2009 the fishery was regulated by allowing only the long line and gillnet fisheries by vessels smaller than 28 m to be directed for Greenland halibut. This fishery was also regulated by seasonal closure. Target trawl fishery was prohibited and trawl catches limited to bycatch only. From 1992 to autumn 1994 bycatch in each haul was not to exceed 10% by weight. In autumn 1994 this was changed to 5% bycatch of Greenland halibut onboard at any time. In autumn 1996 it was changed to 5% bycatch in each haul, and in January 1999 this percentage was increased to 10%. In August 1999 it was adjusted further to 10% in each haul but only 5% of the landed catch. In 2001 the bycatch regulations changed again to 12% in each haul and 7% of the landed catch.

The 38th JRNFC's Session in 2009 decided to cancel the ban against targeted Greenland halibut fishery and established the TAC at 15 000 t for next three years (2010—2012). The TAC was allocated between Norway, Russia and other countries with shares of 51, 45 and 4% respectively. The 40th JRNFC's Session in 2011 decided to increase TAC for 2012 up to 18 000 t, and the TAC for 2013—2015 has been 19 000 t each year.

Minimum size regulation for Greenland halibut is 45 cm, and starting in 2012 it became mandatory to use sorting grids during target Greenland halibut trawl fishery.

During fishing for other species, it is permitted to have an intermixture of Greenland halibut of up to 7% by weight on board at the end of fishing operations and in the catch landed.

Norwegian regulations (quota figures are for 2015)

The annual catch (including bycatch) for each trawler and conventional vessel above 28 m is limited to 57 t pr. vessel.

The Norwegian conventional fleet, vessels smaller than 28 m, are allowed to conduct a targeted fishery with longlines and gillnets in a limited area in approximately one month each year. For these vessels the TAC is set to 22.5, 26.3 and 30 t, dependent of size of the vessel.

A.3 Ecosystem aspects

Greenland halibut is a large fish predator that occurs over a wide range of depths (from 20 to 2200 m) and temperatures (from -1.5 to 10°C) (Shuntov, 1965; Nizovtsev, 1989; Boje and Hareide, 1993) with the continental slope between the Barents Sea and the Norwegian Sea as its most important area, but it is also found in wider range of the northern Kara Sea, Barents Sea and Norwegian Sea at different life stages.

Food composition of the Greenland halibut in the Barents Sea includes more than 40 prey species (Nizovtsev 1989; Dolgov and Smirnov 2001, Hovde *et al.*, 2002; Vollen *et al.*, 2004). Investigations over a wide area of the continental slope up to Novaya Zemlya show that the main food source of Greenland halibut consists of fish, mostly capelin (*Mallotus villosus villosus*), polar cod (*Boreogadus saida*) and herring (*Clupea harengus*), and cephalopods and shrimp (*Pandalus borealis*). During the 1990s an important component of the diet was waste products from fisheries for other species (heads, guts etc.). Ontogenetic shift in prey preference was clear with decreasing proportion of small prey (shrimps and small capelin) and increasing proportion of larger fish with increasing predator length. The largest Greenland halibut (length more than 65—70 cm) had a rather big portion of cod and haddock in the diet.

Given a Greenland halibut stock of nearly 100 000 tonnes, the total food consumption of the NEA stock was estimated to be about 280 000 tonnes (Dolgov and Smirnov, 2001). The biomass of commercial species consumed (shrimp, capelin, herring, polar cod, cod, haddock, redfish (*Sebastes sp*.), long rough dab (*Hippoglossoides platessoides*) did not exceed 5000—10 000 tonnes per species. The effect of Greenland halibut as predator on other commercial species in the Barents Sea may thus be minor.

According to Russian data (Dolgov and Smirnov, 2001), among the variety of fish, seabirds and marine mammals investigated, Greenland halibut were found in the diet of three species - Greenland shark (*Somniosus microcephalus*), cod (*Gadus morhua morhua*) and Greenland halibut itself. Additionally, killer whale (*Orcinus orca*), grey seal (*Halichoerus grypus*) and narwhal (*Monodon monoceros*) are potential predators. However, the presence of Greenland halibut in the diet of the above species was minor. Predators fed mainly on juvenile Greenland halibut up to 30—40 cm long.

The mean annual percentage of Greenland halibut in cod diet in 1984—1999 constituted 0.01—0.35% by weight (0.05% in average) (Dolgov and Smirnov, 2001). Cannibalism was highest in 1960s (up to 1.2% in frequency of occurrence) according to Russian stomach content data. During the 1980s frequency of occurrence of juveniles in the stomachs did not exceed 0.1 %. During the 1990s, the portion of juveniles (by weight) was at the level of 0.6—1.3%. Low levels of consumption of juveniles are related to the distribution pattern of juvenile Greenland halibut. Young Greenland halibut occur mostly in the north-eastern Barents Sea (Spitsbergen archipelago and further east to Franz Josef Land and Northern Kara Sea) where the presence of adult Greenland halibut and other main predators appear minimal in most years. Therefore, the observed variability in recruitment may be driven mainly by environmental factors. However in some years predation might affect recruitment, and the resent northward extension in distribution of potential predators such as cod, and high abundance of cod, is a concern in that respect. Predation on eggs and larvae is unknown, and a future research topic.

B. Data

B.1 Commercial catch

Norwegian commercial landings in tonnes by quarter, area and gear are derived from the sales notes statistics of the Directorate of Fisheries. Data from 21 sub areas are aggregated by quarter on 4 main areas for the gears gill net, long line, bottom trawl and shrimp trawl. For bottom trawl the quarterly area distribution of the landings is adjusted by logbook data from The Directorate of Fisheries and the total bottom trawl landings by quarter and area is adjusted so that the total annual landings for all gears is the same as the official total landings reported to ICES. No discards are reported or accounted for in the catch statistics.

The sampling strategy is to have length samples from all major gears in each area and quarter. There are at present no defined criteria on how to allocate samples to unsampled landings, but the following general process has been applied: First look for samples from a similar area in the same quarter. If there are no samples available in similar areas, search for samples from other gears with the most similar selectivity in the same area or similar areas. The last option is to search in neighbouring quarters, first from the same gear in the same area, and then from similar areas and similar gears. ALKs from research surveys (commercial bottom trawl or shrimp trawl) are also used to fill gaps in age sampling data.

Russian catch based on daily reports from the vessels are combined in the statistics of the All-Russian Research Institute of Fisheries and Oceanography (VNIRO, Moscow). Data are provided separately by ICES areas, quarter and gear (trawl and longline).

Norway and Russia, on average, have accounted for about 90—95% of the Greenland halibut landings during more recent years. Data on landings in tonnes from other countries are either reported directly to the Working group, taken from ICES official statistics (by ICES area) or from reports to Norwegian authorities.

The analytical GADGET assessment, which was run for 1992—present, uses landings from ICES area I, IIa and IIb. For the assessment, the Norwegian landings are split on year, quarter, gear (fleet.trawl=bottom trawl, shrimp trawl, purse seine and Danish seine; fleet.gil=gillnet, longline, handline and other gears) and sex. Russian landings data by year, fleet and quarter are split on sex according to same-year proportions in Norwegian landings. Finally, landings from other nations were added to the Norwegian fleet.trawl and split on quarter and sex accordingly.

Length distributions from Norwegian landings are split on year, gear (fleet.trawl and fleet.gil) and sex. 1 cm length categories are used from 1—113 cm, with a plus group for larger fish. Length categories smaller than 20 cm are set to zero.

B.2 Biological

Parameters of the length-weight relationship in the fisheries (W=a*L^b) was calculated yearly from all available samples. Not split on sex.

A fixed natural mortality of 0.1 is used both in the assessment and the forecast.

At present in the analytical assessment ogives are calculated based on data from all EggaNor surveys since 2000. The L50 for males of 42 cm is similar to what has been found in previous studies (Smirnov 2011, Hallfredsson *et al*. 2011), while L50 of 62 cm is slightly higher than previously calculated due to adjustment as suggested in Núñez *et al.* (2015).

B.3 Surveys

The results from the following research vessel survey series have been evaluated by the Working Group and/or in the benchmark process (2013—2015).

1) Norwegian Greenland halibut slope survey *(NO-GH-Btr-Q3)* in August, from 1994, split on sex since 1996. Biennial since 2009. The survey covers the continental slope from 68 to 80°N, in depths of 400—1500 m north of 70.30°N, and 400—1000 m south of this latitude. The survey covers the main spawning areas and a commercially sized bottom trawl is used.
2) Joint Russian-Norwegian ecosystem bottom trawl survey in the Barents Sea in autumn (*Eco-NoRu-Q3 (Btr)*), from 2004. Survey covers depths of less than 100 m and mainly down to 500 m. Its precursor was the Norwegian bottom trawl survey in August in the Barents Sea and Svalbard, from 1984.
3) The Norwegian juvenile Greenland halibut survey north and east of Svalbard in autumn, from 1996. From 2000 this survey was conducted as a joint survey between Norway and Russia. From 2004 it was part of the Joint Rus-

sian-Norwegian ecosystem bottom trawl survey in the Barents Sea in autumn (*Eco-NoRu-Q3 (Btr)*). During later years, parts of the Kara Sea have occasionally been included in the survey.

4) Russian bottom trawl survey in the Barents Sea from 1984 in fishing depths of 100–900 m (*RU-Btr-Q4*). This series has been revised substantially since the 1998 assessment in order to make the years more comparable with respect to area coverage and gear type.

5) Norwegian (from 2000 Joint) Barents Sea bottom trawl survey in winter (*BS-NoRu-Q1 (Btr)*) from 1989. Survey covers depths of less than 100 m and down to 500 m.

6) International pelagic 0-group surveys in the Barents Sea since 1970. Year class strengths are currently available for the period 1980—2014. It should be noted that the survey, which now is executed within the frame of the Ecosystem survey, has not been considered optimal for Greenland halibut. Further work is needed to evaluate the value of the series regarding recruitment.

7) Spanish bottom trawl survey in the slope of Svalbard area, from 73.5°—81°N and depths 500—1500 (*SP-Svalbard-Q4)*. The survey was run in autumn in 1997—2005, 2008, 2010 and 2012—2014, and in spring in 2008, 2009 and 2011. In Basterretxea *et al.* 2013 (ICES AFWG WD13 2013, ANNEX III: Spanish Survey standardization) an attempt was made to standardize survey indexes for Greenland halibut in earlier Spanish surveys (1997—2005) with resent surveys (2008—2012). The conclusion was that it is considered not possible to obtain a reliable standardization of the surveys. As the survey in autumn is run biennially, the Spanish index is available for years 2008, 2010, 2012 and 2014.

8) Polish Greenland halibut bottom trawl survey in the Svalbard-Bears Island area (73.5°—76.5°N) at depths 500—1200 m in October 2006, April 2007, April 2008, June 2009 and March 2011.

Four indices go into the current assessment:

- EggaNor – based on the Norwegian Greenland halibut slope survey *(NO-GH-Btr-Q3)* (1996—present).

- EcoJuv - a juvenile index based on data from the northern/eastern areas of the Joint Ecosystem survey (*Eco-NoRu-Q3 (Btr)*) (2004—present) and the precursory Norwegian juvenile Greenland halibut survey north and east of Svalbard (1996—2002).

- EcoSouth - an index for the Barents Sea south of 76.5°N, based on data from the Joint Ecosystem survey (*Eco-NoRu-Q3 (Btr)*)(2004—present).

- Russian - Russian bottom trawl survey in the Barents Sea from (*RU-Btr-Q4*) (1992—present)

Future work should consider including other survey indices in the analytical assessment. At present, trends in these surveys will be evaluated qualitatively by the working group.

The GADGET assessment is presently run back to 1992, and no data prior to that are used. This can preferably be extended further back in time in future work. The EggaNor index split by sex is only available since 1996.

The split of the Joint Ecosystem survey into two indices was described by Hallfredsson and Vollen, 2015a and 2015b). In the northern and eastern survey area mainly juveniles and immature fish < 40 cm are found, whereas larger immature and mature fish (> 40 cm) are found south of 76.5°N and west of Svalbard. Thus the juvenile index (Eco Juv) was based on areas north of 76.5°N, excluding areas west of Svalbard. The EcoSouth index is based on the remaining area of the Joint Ecosystem Survey.

Length distributions were split on year and sex. One cm length categories were used from 1—113 cm, with a plus group for larger fish, and length categories smaller than 10 cm were set to zero.

The coverage of the northern, and particularly eastern, part of the juvenile area has been very variable, partly due to ice conditions. Thus, areas south of Frantz Josef Land and in the northern Kara Sea are not included in the juvenile index (EcoJuv) even though considerable amounts of juveniles have been observed in this area (Smirnov 2011, Hallfredsson and Vollen 2015b). It therefore needs to be assumed that trends in the EcoJuv index, which is based on the western part of the juvenile area only, are representative for the whole area.

B.4 Commercial CPUE

Several cpue series are available from Russian and Norwegian fisheries (ICES, 2014). Nedreaas (2014) reviewed the cpue series which previously have been used in stock assessment. His main conclusion was that many of the cpue indices conflicted in the signals and could thus not all reflect the underlying stock trends. Because of limitations due to effort, area, time, regulations and technological differences one should be very careful when using the trawl cpue. If used in assessment tuning, any long-term commercial trawl cpue series must be well described how it has been derived with regards to all the mentioned limitations and pitfalls. The Norwegian standardized cpue survey with rented trawlers during (1992) 1994—2005, is probably the only series sufficiently standardized for an abundance estimation purpose, but even this has many shortcomings compared with the scientific swept-area surveys along the slope since 1994. The experimental cpue series, or commercial cpue series when limited in area and time, should hence be avoided used as tuning series in stock assessments as long as better scientific research surveys are available. This applies both to Russian and Norwegian cpue series in the time period after 1992 when regulations were implemented. The scientific swept-area surveys are better stratified and cover a much larger area (by latitude and depth) than the experimental cpue series.

Different cpue series exist from the time period before regulations were introduced in 1992, and the ICES DCWKNGHD workshop concluded that these potentially give useful information on stock development until 1991 (ICES, 2014). The Russian CPUE series has been standardized (Kovalev and Tretyakov 2015).

B.5 Other relevant data

None

C. Historical stock development

Model used: Gadget (see ICES, 2015 and Howell *et al.*, 2015).

Time period: 1992—2014, monthly time steps

Model structure:

- 1 cm length classes (1—114+ cm) and 1 year age classes (1—30+)
- Two sexes, split into mature and immature
- Logistic maturity estimated for each sex
- Von Bertanlanffy growth estimated separately for males and females
- L-W relationship fixed based on data from the Norwegian slope (Females: a=1.4E-6 and b=3.47. Males: a=5.7E-6 and b=3.12)
- Natural mortality set to 0.1 for all fish
- Initial size of recruits fixed at 8.5 cm (necessary to fix this in the absence of age data)
- Recruitment modelled as annual numbers, no relationship to SSB
- Four aggregated fleets, each with sex-specific selectivity (logistic for gill fleets, asymmetric dome shaped for trawl)
    - Norwegian Trawl (bottom trawl, purse seine, Danish seine)
    - Russian Trawl (bottom trawl, purse seine, Danish seine)
    - Norwegian Gillfleet (gillnet and longline)
    - Russian Gillfleet (gillnet and longline)
- Four surveys (as described above), all with asymmetric dome shaped selectivity
    - EggaNor (split by sex)
    - EcoJuv (split by sex)
    - EcoSouth (split by sex)
    - Russian (sex aggregated) (can be split by sex in future work)

Note that in order to avoid the problem of modelled fish not covered by any fleet (and therefore not tuned to any data) the gillfleets have been assumed to have logistic (flat topped) selectivity.

Estimated parameters:

l50 and slope for the maturation (male and female separately), two growth parameters per sex, two maturation parameters per sex, one annual recruitment parameter per year, two parameters for s.d. of length of recruits, parameters governing commercial selectivity (two per sex per gillfleet and three per sex per trawlfleet), one effort parameter per year for each fleet, three parameters per survey per sex governing selectivity, initial population numbers for male and female fish by age, initial population s.d. of lengths by sex and age

Data used for tuning are:

- Quarterly length distribution of the landings from commercial fishing fleets (by sex)
- Quarterly catch in tonnes for each fleet (by sex)
- Length disaggregated survey indices from the four surveys (by sex except for the Russian survey)
- Overall survey index (by biomass) for the four surveys (by sex except for the Russian survey)
- Estimated maturity ogives (maturity at length in the population) for 1992—2014 (by sex)

Note that no age data is used in tuning the model. Although age readings are available for some years there is no agreement on which age-reading methodology should be used, and these data are thus not suitable for inclusion in an assessment model.

Concerning the recruitment it should be noted that age 1 is the age for recruitment to the stock, NOT the age for recruitment to the fishery, which is the quantity normally used to describe recruitment. But since age 1 recruitment is the quantity estimated by the model and the age of recruitment to the fishery can't be defined due to disagreement on age reading, we use age 1 as the recruitment age for this stock. Even if there had been agreement on age reading methodology, the strong sexual dimorphism in growth would make it very difficult to define an appropriate recruitment age.

D. Short-term projection

Not done/incorporated into medium term projections.

E. Medium-term projections

Five year projections conducted using the Gadget assessment model under the following assumptions:

- split between fleets and between quarters assumed to remain unchanged from the average of the previous two years;
- fishing intensity in the current year assumed to be the average of the intensity in previous two years
- fishing intensity in the following four years assumed to be a multiplier of the two most recent years average levels.
- Results are presented for 1. January the following year

F. Long-term projections

Not done

G. Biological reference points

The last observed year with good recruitment occurred in 1995 at 487 000 tonnes fishable (45+ cm) biomass. There is evidence that an earlier good recruitment event occurred in the 1980s from a lower biomass, but the exact biomass level is unknown as this is before the model period. The precautionary reference point is therefore taken at

487 000 tonnes. Using 45+ cm biomass (rather than total or female SSB) avoids uncertainty around maturation sizes and the different distributions of males and females, and relates directly to the fishable stock.

Other issues

Lack of agreement on age reading methodology precludes using age-based data for the assessment.

I References

Albert, O.T., E.M. Nilssen, K.H. Nedreaas & A.C. Gundersen 2001a. Distribution and abundance of juvenile Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*) in relation to survey coverage and physical environment. *ICES Journal of Marine Science* 58(5): 1053-1062.

Albert, O.T., E.M. Nilssen, A. Stene, A.C. Gundersen & K.H. Nedreaas 2001b. Maturity classes and spawning behaviour of Greenland halibut (*Reinhardtius hippoglossoides*). *Fisheries Research* 51: 217-228.

Albert, O. T., and Vollen, T. 2015. A major nursery area around the Svalbard archipelago provides recruits for the stocks in both Greenland halibut management areas in the Northeast Atlantic. ICES Journal of Marine Science 72(3):872-879.

Boje, J., & N.R. Hareide 1993. Trial deepwater longline fishery in Davis Strait, May-June 1992. NAFO SCR Doc. 93/53, Serial No. N2236, 6 pp.

Borkin, I.V. 1983. Results from research on ichthyophauna in the Frantz-Josef Land area and north of Svalbard. In: Research into biology, morphology and physiology of marine organisms. USSR Academy of Science Publishers, Apatity, pp. 34-42 (in Russian).

Bowering, W.R. & W.B. Brodie 1995. Greenland halibut (*Reinhardtius hippoglossoides*). A review of the dynamics of its distribution and fisheries off eastern Canada and Greenland. -Pp. 113-160 in: Hopper, A.G. (ed.). *Deep-Water Fisheries of the North Atlantic Oceanic Slope*. Kluwer Academic Publishers, Boston, USA.

Bowering, W.R. & K.H. Nedreaas 2000. A comparison of Greenland halibut (*Reinhardtius hippoglossoides,* Walbaum) fisheries and distribution in the Northwest and Northeast Atlantic. *Sarsia* 85: 61-76.

Fedorov, K.Y. 1971. Zoogeographic characteristics of the Greenland halibut (*Reinhardtius hippoglossoides*, Walbaum). *Journal of Ichthyology* 11: 971-976.

Dolgov, A.V. and Smirnov, O.V. 2001. The role of Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), in the ecosystem of the Barents Sea. Deep-sea Fisheries: Symp./NAFO/ICES/CSIRO (12-14 Sept. 2001): Abstracts. Paper 1.10

Godø, O.R. & T. Haug 1987. Migration and recruitment to the commercial stock of Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), in the Svalbard area. *FiskeridirektoratetsSkrifterSerieHavundersøkelser* 18: 311-328.

Godø, O.R. & T. Haug 1989. A review of the natural history, fisheries and management of Greenland halibut (*Reinhardtius hippoglossoides*) in the eastern Norwegian and Barents Seas. *Journal du Conseil. Conseil international pour l'Exploration de la Mer* 46: 62-75.

Hallfredsson, E.H. and Vollen T. 2015a. Two abundance indices for Greenland halibut based on the Joint Ecosystem Survey in the Barents Sea and previous surveys in the nursery area. ICES AFWG, WD 20, April 2015.

Hallfredsson, E.H. and Vollen T. 2015b. Juvenile index for Barents Sea Greenland halibut. WD 1 ICES IBPHali 2015.

Hallfredsson E. H., Pavlenko A., Jørgensen T. and Smirnov O., 2011. Technical measurements in Greenland halibut fisheries in the Barents Sea. Appendix 3 in: Report of the Sixth Meeting of the Russian-Norwegian Working Group on Technical Regulations for Joint Fish Stocks in the Barents and Norwegian Seas. 29 - 30 August 2011, MURMANSK

Hovde, S. C., Albert, O. T., and Nilssen, E. M. 2002. Spatial, seasonal and ontogenetic variation in diet of Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*). ICES Journal of Marine Science, 59: 421–437.

Howell D., Hallfredsson E. H., Vollen T. and Fotland Å., 2015. Gadget stock assessment of Greenland halibut (*Reinharditius hippogossoides*). WD2, IBPHALI 2015.

ICES. 2014. Report of the Data Compilation Workshop on Northeast Arctic Greenland Halibut and Assessment Methods (DCWKNGHD), 10–12 November 2014, Murmansk, Russia. ICES CM 2014/ACOM:65. 56 pp.

ICES. 2015. Report of the Inter Benchmark Process on Greenland Halibut in ICES areas I and II (IBPHALI, by correspondence). ICES C.M. 2015/ACOM:xx.

Knutsen, H., Jorde, P. E., Albert, O. T., Hoelzel, A. R., and Stenseth, N. C. 2007. Population genetic structure in the North Atlantic Greenland halibut (*Reinhardtius hippoglossoides*): influenced by oceanic current systems? Canadian Journal of Fisheries and Aquatic Sciences, 64: 857-866.

Kovalev, Y., and Tretyakov, I. 2015. Results of the Schaefer production model run to be used for assessment of the Barents Sea Greenland halibut. WD3, IBPHALI 2015.

Nedreaas, K. 2014. Review of historic commercial catch-per-unit-effort (CPUE) series previously used in stock evaluation of Greenland halibut (*Reinhardtius hippoglossoides*) in ICES Subareas I and II. Are such CPUE series appropriate to use in future Greenland halibut stock assessments? WD1, ICES DCWKNGHD 2014 (included in report).

Nizovtsev, G.P. 1968. Distribution and age-length characteristics of Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) catches in the Barents Sea in 1966. *Trudy PINRO*,23: 402-413. (in Russian).

Nizovtsev, G.P. 1983. Distribution of young Greenland halibut in the Barents Sea and in the eastern Norwegian Sea. *Rybnoye khozyaistvo*, 12:26-28 (in Russian).

Nizovtsev, G.P. 1989. Recommendations on rational exploitation of Greenland halibut stocks in the Barents and Norwegian seas. *USSR Ministry of Fisheries, PINRO, Murmansk*, 93 pp. (in Russian).

Núñez, L. A., Hallfredsson, E. H., and Falk-Petersen, I.-B. 2015. Different maturity scales affect estimations of fecundity, TEP and spawning stock size of Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum, 1792). Marine Biology Research: 1-10. Published online: 23 Jun 2015. DOI: 10.1080/17451000.2015.1031797

Shuntov, V.P. 1965. Distribution of Greenland halibut and arrowtooth flounder in the northern Pacific.*Trudy VNIRO*, 58: 155-164 (in Russian).

Smirnov, O.V. 2009. New data on Greenland halibut (*Reinhardtius hippoglossoides*, Walbaum 1792) distribution in the northern Eurasian seas. WD 4 ICES AFWG, San-Sebastian,Spain, April 2009.

Smirnov O., 2011. Some thoughts about Greenland halibut minimum legal size. Presentation at the meeting between Russian and Norwegian scientists in Murmansk, Russia, 14-18 March 2011.

Vollen, T., Albert, OT., Nilssen, EM. 2004. Diet composition and feeding behaviour of juvenile Greenland halibut (*Reinhardtius hippoglossoides*) in the Svalbard area. Journal of Sea Research, 51 (3-4): 251-259.

Westgaard J-I., Saha A., Kent M., Hellerud Hansen H., Knutsen H., Hauser L, Cadrin S., Albert O. T. and Johansen T., submitted. SNP markers from RAD sequences reveal genetic patterns relevant to management in Greenland halibut (*Reinhardtius hippoglossoides*). Canadian Journal of Fisheries and Aquatic Science.

Whitehead, P.J.P., M.-L. Bauchot, J.-C. Hureau, J. Nielsen & E. Tortonese 1986. *Fishes of the North-eastern Atlantic and the Mediterranean.* UNESCO, Paris, France, 1473 pp.

Ådlandsvik, B., Gundersen, A. C., Nedreaas, K. H., Stene, A., and Albert, O. T. 2004. Modelling the advection and diffusion of eggs and larvae of Greenland halibut (*Reinhardtius hippoglossoides*) in the north-east Arctic. FISHERIES OCEANOGRAPHY, 13: 403-415

Annex 2. 2015 IBPHALI Terms of Reference

2014/2/ACOM39 The Inter-Benchmark Protocol of Greenland halibut in Subareas I and II, chaired by Bjarte Bogstad, Norway, and with Joanne Morgan, Canada as external reviewer will be established and will meet by correspondence from May to August 2015 to:

a) Approve an assessment model and model configuration.

b) Approve reference points and harvest rate for use over the next few years.

c) Describe the resulting data analysis procedure and assessment methodology in the stock annex;

d) Review and agree on the resulting stock annex

IBPHali will report by end of August 2015 for the attention of the ACOM and AFWG.

Supporting information

Priority	High. Will improve basis for advice for ghl-arct.
Scientific justification	AFWG recommend this stock be benchmarked over summer 2015 by IBP. This stock was benchmarked in 2013. WKBUT suggested that the final approval of the assessment model (Gadget or production model presented at benchmark) and choice of tuning series should be conducted by correspondence following the proposed data workshop meeting. The Data Workshop (DCWKNGHD) took place in autumn 2014 and in addition a meeting involving Russian and Norwegian scientists took place outside of ICES during spring 2015. During AFWG April 2015 further analysis was ongoing to have modeling approach in process and ready for review.
Resource requirements	-
Participants	Scientists and stakeholders involved with this stock/fishery
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	ACOM
Linkages to other committees or groups	AFWG
Linkages to other organizations	-

Annex 3. List of participants

NAME	ADDRESS	EMAIL
Bjarte Bogstad ICES Chair	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	bjarte.bogstad@imr.no
Oleg Bulatov	Russian Federal Research Institute of Fisheries and Oceanography (VNIRO) 17 Verkhne Krasnoselskaya, 107140 Moscow Russian Federation	obulatov@vniro.ru
Elvar Halldor Hallfredsson	Institute of Marine Research PO Box 6404 9294 Tromsø Norway	elvarh@imr.no
Daniel Howell	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	daniel.howell@imr.no
Yuri A. Kovalev	Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	kovalev@pinro.ru
Andrey Mikhailov	Russian Federal Research Institute of Fisheries and Oceanography (VNIRO) 17 Verkhne Krasnoselskaya, 107140 Moscow Russian Federation	mikhailov1984@gmail.com
Joanne Morgan (external reviewer)	Fisheries and Oceans Canada P.O. Box 5667 St. John's, Newfoundland A1C 5X1 Canada	Joanne.Morgan@dfo-mpo.gc.ca
Oleg V. Smirnov	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	smirnov@pinro.ru
Ivan Tretyakov	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	tretyakov@pinro.ru

Name	Address	Email
Dmitry Vasilyev	Russian Federal Research Institute of Fisheries and Oceanography (VNIRO) 17 Verkhne Krasnoselskaya, 107140 Moscow Russian Federation	dvasilyev@vniro.ru
Tone Vollen	Institute of Marine Research PO Box 6404 9294 Tromsø Norway	tone.vollen@imr.no
Mette Bertelsen ICES Secretariat	International Council for the Exploration of the Sea H.C. Andersens Blvd. 44—46 1553 Copenhagen V Denmark	mette@ices.dk

Annex 4. Special opinion/minority statement

With respect to ToR (b) "Approve reference points and harvest rate use over the next few years" we consider it to be necessary to mention that the recommendations on reference points and harvest rate seems to be in conflict with the results of the calculations presented to the Group: current stock biomass exceeds BMSY (B>BMSY) for all types of specifications of the PINRO production model; similarly, the results of the GADGET model show that the current biomass exceeds Blim which interpreted as BMSY. It should be noted that according to the GADGET model the current biomass of the stock exceeds the capacity of the environment, estimated by production model of PINRO. Specialists from VNIRO evaluated reference points based on data from the GADGET. The output from GADGET was used as input to the production model described in AFWG WD18 where the reference points were among parameters estimated in the model.

We would like to outline that current biomass of the stock significantly exceeds BMSY from point of view of all models which were considered at the group (see table below), however current and recommended value of fishing mortality is less than the smallest estimate of FMSY.

It seems that GADGET scenario corresponding to twice the current level of fishing mortality (see Table 4.2) and suggesting average catch equal to 38.7 kt. looks much more scientifically based and quite precautionary since it suggests still SSB=540 kt. in 2020.

	CPUE data 1984–2014 (AFWG WD18)	GADGET data 1992–2014	PINRO model fitted to the CPUE for the period 1964–1991(IBPHali WD3)	PINRO model fitted to the Russian and the ecosystem survey (IBPHali WD3)	PINRO model fitted to the Russian and the ecosystem survey with estimate initial biomass (IBPHali WD3)
MSY (kt)	70.85	38.70	23.7	30.57	51.6
B_{MSY}(kt)	524.443	418.126	269.0	166.75	478.57
F_{MSY}	0.135	0.0925	0.088	0.18	0.11

O.Bulatov

A.Mikhaylov

D.Vasilyev