

# **THE USE OF SURPLUS PRODUCTION MODELS AND LENGTH FREQUENCY DATA IN STOCK ASSESSMENTS: EXPLORATIONS USING GREENLAND HALIBUT OBSERVATIONS**

June H. C. Masters  
Caribbean Regional Fisheries Mechanism  
3rd Floor Corea's Building, Halifax Street  
St. Vincent and the Grenadines

Supervisor  
Einar Hjorleifsson ([einarhj@hafro.is](mailto:einarhj@hafro.is))  
Marine Research Institute, Iceland

## **ABSTRACT**

Production models and length-frequency based methods can be used in situations where data are limited. The West Nordic stock of Greenland halibut (where limited data are available) was assessed using three different fittings (equilibrium, linear and nonlinear) with a surplus production model and length based methods for estimating  $Z$ . The data analysed were: CPUE indices from (1) the Icelandic bottom trawl fleet 1985-2006, (2) the Icelandic fall survey 1996 – 2006, and (3) the Greenlandic fall survey 1998 – 2006 (2001 missing), along with total landings from the fishery and length frequency data sampled from the commercial fishery. The three fittings of the surplus production model produced  $r$ 's ( $\sim 0.4$ ) and  $q$ 's ( $\sim 0.005$ ) that were similar but  $K$ 's and  $MSY$ 's that were different. The regression method returned the highest  $MSY$  of 44,459 t and the nonlinear fitting the least of 28,000 – 30,000 t estimated by the Excel and ASPIC model. Indications are that total fishing mortality is increasing while average biomass, surplus production and total yield is decreasing. The relative biomass ( $B/B_{MSY}$ ) trend is predicted to have steadily declined. Using length at age data the growth parameters for the species were estimated to be  $L_{\infty} = 100$ ,  $K = 0.937$  and  $t_0 = -1.347$ , and mortality estimates from the length frequency (0.1 – 0.2) are lower than those predicted by the surplus production model (0.3 – 0.4). In terms of the overall outlook for the fishery; at the current rate of fishing mortality, catches will decline since the biomass is predicted to decline and there is a high probability of stock collapse if this trend continues. All indications are that fishing mortality needs to be reduced. Based on the results of forward projection, if fishing mortality is reduced by approximately 60% of the present fishing mortality. This translates to a catch of 8100 tonnes in 2007, with increases in catches in consecutive years as the stock starts to rebound.

## TABLE OF CONTENTS

<b>1</b>	<b>INTRODUCTION .....</b>	<b>5</b>
<b>2</b>	<b>RATIONALE .....</b>	<b>6</b>
<b>3</b>	<b>BACKGROUND .....</b>	<b>6</b>
3.1	THE GREENLAND HALIBUT FISHERIES AND STOCK PERCEPTION .....	6
3.2	THE SURPLUS PRODUCTION MODEL.....	7
3.2.1	<i>Fitting surplus production models to observed data .....</i>	<i>9</i>
3.3	THE USE OF LENGTH FREQUENCY DISTRIBUTION IN STOCK ASSESSMENTS.....	11
3.3.1	<i>Estimation of population parameters from length frequency distribution .....</i>	<i>11</i>
<b>4</b>	<b>METHODOLOGY .....</b>	<b>12</b>
4.1	SUMMARY OF DATA USED .....	12
4.2	METHODOLOGY FOR SURPLUS PRODUCTION MODEL .....	12
4.3	LENGTH FREQUENCY MODELS.....	13
<b>5</b>	<b>RESULTS.....</b>	<b>14</b>
5.1	RESULTS FROM SURPLUS PRODUCTION MODELS .....	14
5.1.1	<i>Estimates of parameters and management reference points determined by equilibrium, linear and nonlinear methods of fitting SPM.....</i>	<i>14</i>
5.1.2	<i>Model predictions from equilibrium, linear and nonlinear methods of fitting .....</i>	<i>14</i>
5.1.3	<i>Projections for future trends in biomass based on time series fitting in ASPIC v 5.16 computer programme.....</i>	<i>15</i>
5.2	RESULTS FROM LENGTH FREQUENCY MODELING .....	15
5.2.1	<i>Estimates of growth parameters and the Von Bertalanffy growth curve of Greenland halibut .....</i>	<i>15</i>
5.2.2	<i>Estimates of total mortality (Z) from length frequency data of Greenland halibut.....</i>	<i>15</i>
<b>6</b>	<b>DISCUSSION .....</b>	<b>16</b>
6.1	SURPLUS PRODUCTION MODEL.....	16
6.2	LENGTH FREQUENCY METHOD .....	18
<b>7</b>	<b>CONCLUSIONS .....</b>	<b>19</b>
	<b>APPENDICES .....</b>	<b>44</b>
	APPENDIX 1: .....	44
	APPENDIX 2: ASPIC OUTPUT FILE .....	45

## LIST OF FIGURES

FIGURE 1: GENERAL DISTRIBUTION OF GREENLAND HALIBUT (FISHBASE 2000). (DISTRIBUTION AREA OUTLINED IN RED) .....	24
FIGURE 2: FISHING AREAS OF THE WEST NORDIC STOCK OF GREENLAND HALIBUT (THE 500M AND 1000 M DEPTH CONTOURS ARE SHOWN) (ANON. 2007A).....	24
FIGURE 3: DEVELOPMENT OF THE WEST NORDIC STOCK GREENLAND HALIBUT FISHERY (ANON. 2007B) .....	25
FIGURE 4: RELATIONSHIP BETWEEN CPUE AND EFFORT FOR WEST NORDIC STOCK GREENLAND HALIBUT USING THE SCHAEFER EQUILIBRIUM ASSUMPTION MODEL. ....	28
FIGURE 5: THE SCHAEFER EQUILIBRIUM YIELD PARABOLA AND YIELD VS EFFORT DATA POINTS FOR THE ICELANDIC BOTTOM TRAWL FLEET TARGETTING GREENLAND HALIBUT. ....	29
FIGURE 6: OBSERVED VERSUS PREDICTED CATCH-PER-UNIT EFFORT IN THE ICELANDIC BOTTOM TRAWL FLEET TARGETTING GREENLAND HALIBUT 1985 - 2006, AFTER ADJUSTING INITIAL REGRESSION PARAMETERS USING TIME SERIES FITTING.....	29
FIGURE 7: OBSERVED VERSUS PREDICTED CATCH-PER-UNIT EFFORT FOR THREE CPUE SERIES FROM THE GREENLAND HALIBUT 1985 - 2006, AFTER ADJUSTING INITIAL REGRESSION PARAMETERS USING TIME SERIES FITTING. ....	30
FIGURE 8: TREND OF OBSERVED AND ESTIMATED CPUE FROM ICELANDIC BOTTOM TRAWL FLEET TARGETTING GREENLAND HALIBUT.....	30
FIGURE 9: TREND OF OBSERVED AND ESTIMATED CPUE FROM ICELANDIC FALL SURVEY TARGETTING GREENLAND HALIBUT .....	31
FIGURE 10: TREND OF OBSERVED AND ESTIMATED CPUE FROM GREENLAND FALL SURVEY TARGETTING GREENLAND HALIBUT .....	31
FIGURE 11: TREND OF SURPLUS PRODUCTION AND OBSERVED YIELD (CATCH) FOR THE GREENLAND HALIBUT 1961 TO 2007 FROM ASPIC FITTING. ....	33
FIGURE 12: TREND OF RELATIVE BIOMASS AND RELATIVE FISHING MORTALITY OF GREENLAND HALIBUT IN ICELANDIC WATERS AS PREDICTED BY ASPIC 1961-2006. ....	34
FIGURE 13: BOOTSTRAP ESTIMATED CONFIDENCE LIMITS RESULTS FOR BIOMASS OVER THE PERIOD 1961 TO 2006. ....	36
FIGURE 14: A-D: EXPECTED PATH OF PROJECTED RELATIVE BIOMASS IF STOCK IS FISHED AT DIFFERENT FISHING MORTALITIES. A) $F_{2007-2021} = 1.00$ $F_{2006} = 2.56$ FMSY . B) $F_{2007-2021} = 0.50$ $F_{2006} = 1.28$ FMSY . C) $F_{2007-2021} = 0.39$ $F_{2006} = 1.00$ FMSY . D) $F_{2007-2021} = 0.25$ $F_{2006} = 0.64$ FMSY .....	38
FIGURE 15: PROJECTION OF MOST LIKELY ANNUAL CATCH UNDER DIFFERENT FISHING MORTALITY SCENARIOS.....	39
FIGURE 16: NUMBER OF FISH MEASURED PER LENGTH CATEGORY OVER THE PERIOD 1976 – 2007. ....	39
FIGURE 17: THE FITTED VON BERTALANFFY GROWTH CURVE FOR THE GREENLAND HALIBUT PRODUCED FROM GROWTH PARAMETERS, $L_{\infty} = 100$ , $K = 0.937$ AND $T_0 = -1.347$ ESTIMATED FROM LENGTH AT AGE DATA. ....	41
FIGURE 18: LINEARIZED CATCH CURVES FOR PSEUDO-COHORTS, CONSISTING OF THE AVERAGED STANDARDIZED FIVE YEAR LENGTH FREQUENCIES: 1978-1982, 1983-1987, 1988-1992, 1993-1997, 1998-2002, 2003-2007, ESTIMATED FROM THE LINEARIZED CATCH CURVES WHERE $L_{\infty} = 100$ , $K = 0.0937$ AND $T_0 = -1.34$ .....	42

## LIST OF TABLES

TABLE 1: CPUE INDICES FROM (1) ICELANDIC BOTTOM TRAWL FLEET 1985-2006, (2) ICELANDIC FALL SURVEY 1996 – 2006, (3) GREENLANDIC FALL SURVEY 1998 – 2006 (2001 MISSING) AND TOTAL CATCH FROM THE FISHERY 1961-2007.....	26
TABLE 2: PARAMETER ESTIMATES AND MANAGEMENT REFERENCE POINTS DETERMINED FROM THE THREE ALTERNATIVE FITTINGS OF THE ICELANDIC GREENLAND HALIBUT DATA. ....	28
TABLE 3: STOCK PERFORMANCE AS DETERMINED FROM NONEQUILIBRIUM TIME SERIES FITTING IN ASPIC v 5.16 COMPUTER PROGRAMME.....	32
TABLE 4: PARAMETER ESTIMATES AND MANAGEMENT REFERENCE POINTS DETERMINED FROM NONEQUILIBRIUM TIME SERIES FITTING IN ASPIC v 5.16 COMPUTER PROGRAMME.....	35
TABLE 5: GROWTH PARAMETERS AND MEAN LENGTH AT AGE AS DETERMINED BY USING AGE AT LENGTH DATA (MRI APPENDIX 1) AND ELEFAN 1 (FISAT).....	40
TABLE 6: PARAMETER ESTIMATES AND ESTIMATES OF Z AND F (M=0.15) OF PSEUDO-COHORTS MADE FROM AVERAGE OF 5 YEARS DATA 1978-2007.....	43
TABLE 7: TEST OF SENSITIVITY OF Z TO DIFFERENT VALUES OF $L_{\infty}$ AND K. ....	43

## 1 INTRODUCTION

In situations of limited data, fishery scientists often look to production models, which require less data and are appropriate for limited datasets, for stock assessment. Production models have the advantage of producing an estimate of maximum sustainable catch (MSC) or maximum sustainable yield (MSY) where only total landings and an index of abundance (such as catch per unit of effort CPUE) are available. They also allow for a quick check on overfishing if the MSC is assumed to occur at one-half of the virgin stock level (Natural Resources Consultants, Inc. 2002). The same rationale accounts for the use of length frequency data collected from the commercial fisheries (which are often cheaply and easily collected). Length frequency data together with the Von Bertalanffy growth equation can provide estimates of population parameters for fish stock assessment.

The information available for the Greenland halibut (*Reinhardtius hippoglossoides*) in east Greenland, Iceland, and Faroese waters can be considered limited, and the fishery not well known:

“The current definition of the Greenland halibut in east Greenland, Iceland, and Faroe waters as one stock, specified by ICES (1976) was "based on a strong probability that the spawning grounds [for Greenland halibut in these waters] are the same". A summary of the current state of knowledge on Greenland halibut in the above-mentioned waters shows that key information on the life cycle is lacking (Woll 2000). Information on the spawning location and spawning time of the stock is very limited. It is hypothesised, based on information from one scientific bottom trawl cruise in 1977, that the major spawning grounds are located on the continental slopes west of Iceland at depths around and below 1000 m (Magnusson 1977, Sigurdsson 1977, Sigurdsson and Magnusson 1980)”.

Source: ANON. 2004

Data available for analysis are CPUE indices from three sources: (1) the Icelandic bottom trawl fleet 1985-2006, (2) the Icelandic fall survey 1996 – 2006, and (3) the Greenlandic fall survey 1998 – 2006 (2001 missing), along with total landings from the fishery from 1961-2006. Length frequency data 1976 – 2007 are also available. Otoliths have been sampled from the Icelandic fishery and limited length at age data are available.

Though limited, these data can be analysed by a production model and length frequency methods.

The aim of this paper therefore is twofold:

- (1) To analyse the data available for the Greenland halibut using a production model and length frequency methods.
- (2) And to use these analyses to demonstrate the use of these methods

## 2 RATIONALE

The Caribbean region has many small island developing states where resources are usually limited, especially for non-tangible items such as the collecting information or data. However, most of the countries of the Caribbean are surrounded by a marine environment with resources that they must manage scientifically according to global standards. The usual accepted process of fisheries management is that the management process should be advised from a number of sources one of which is stock assessment. To conduct stock assessment, information/data must be collected and sometimes this can be a costly matter. But inadequate or inappropriate theory or data will cause stock assessments to be inaccurate. Given the concern for limited resources, perhaps fishery scientists of the Caribbean region will have to depend on length frequency data, and production models for stock assessments. Ideally, three principal types of data could be collected, broken down by stock: (1) total catches in weight for each commercial group, fleet and period, (2) size and species frequencies within fleet commercial groups, based on sampling and (3) total effort by fleet and by period (for example number of fishing days/month, then production models could be used for stock assessment).

The Caribbean should therefore learn to maximise the use of length-frequency methods and production models as this could alleviate some of the burden of the cost of data collection. Perhaps even more importantly, stock assessments need to become a commonplace tool for fishery managers at all levels, and also stake holders in the fishery. Grasping the concepts and principles of the stock assessment process can seem a daunting task, but it is not impossible. Fishery managers with concerns about biomass estimates and harvest rates should have a basic understanding of the concepts involved in the process. Since the data available for the Greenland halibut is similar in type to that available in the Caribbean, its analysis using production models and length frequency methods should provide insight into how the methods are used and also add to the knowledge base for Greenland halibut.

## 3 BACKGROUND

### 3.1 The Greenland halibut fisheries and stock perception

The Greenland halibut (*Reinhardtius hippoglossoides*) is an epibenthic species (Coad and Reist 2004) with adults preferring bottom temperatures of  $-0.5 - 6.0^{\circ}\text{C}$  and generally distributed circumglobal in arctic and temperate waters of the northern hemisphere (Scott and Scott 1988) (Figure 1). The species has a continuous distribution in the northwest Atlantic from Smith Sound, between Greenland and Canada, southward throughout Baffin Bay and Davis Strait to the northeast coast of the U.S.A. and eastward along east Greenland to Iceland and further to the Faroe Islands (Bowering and Brodie 1995, Smidt 1969, Gundersen *et al.* 2004). Based on evidence that there are two major spawning stocks in the northwestern Atlantic; the Canadian-Greenland stock complex and the West Nordic stock in east Greenland, Iceland and the Faroe Islands (ANON. 1999, ICES 1999), the fishery is managed as these two stocks. The data for this analysis comes from the West Nordic stock in east Greenland, Iceland and the Faroe Islands.

Based on the distribution of catches in the West Nordic stock fishery 1991-2006, (Figure 2) (ANON. 2007a) the highest aggregation of commercial-sized Greenland halibut are found just south of the Greenland-Iceland ridge, at depths between 500 and 1000 meters. Other areas of commercial-sized Greenland halibut are along the north and east coast of Iceland (at depths between 500 and 700 meters), in waters off the Faroe Islands, as well as along the continental slope off east Greenland (Boje and Hjørleifsson 2000).

The fishery for Greenland halibut in the waters of Iceland commenced in the early 1960s (Duffy 2007). The development of the fishery can be seen in Figure 3 (ANON. 2007b) and was as follows:

1961 – 1973: Exploited by foreign vessels (Icelandic Ministry of Fisheries 2007)

1974 - 1990: Exploited mainly in Icelandic waters by Icelandic vessels using bottom trawl: 200 mile EEZ declared, fisheries in EEZ reserved for nationals (ICES 2006, ICES 2007).

1991-1998: Exploitation of the stock in east Greenland and Faroese waters increased. Iceland's exploitation falls due to quota restrictions (Hjørleifsson 2008, personal communication Feb. 2008).

1999 – 2006: Icelandic catches have decreased by 60% while landings by other nations have increased considerably (Icelandic Ministry of Fisheries 2007).

By 1967 the yield reached 30,000 t, remaining between 20,000 t and 30,000 t for most of the next 8 years. Up to the 1990s, the fisheries for Greenland halibut took place principally in Icelandic waters. The annual average catch in east Greenland (15,000 t) and Faroese waters (1,000 t) per year, contributed less than 10% of the total annual yield of the stock. In 1992 - 1993 significant fisheries developed in both east Greenland and Faroese waters with the annual yield increasing to approximately 74,000 t in east Greenland and 3,000 t in Faroese waters over the last 10 years (1997 – 2006). The yield in Icelandic waters has declined, in part due to national quota restrictions (ANON. 2007a, ANON. 2007b, Hjørleifsson 2008, personal communication Feb. 2008).

### **3.2 The surplus production model**

The main objective of fish stock assessment of exploited stocks is to estimate the exploitation rate and predict what will happen in terms of future yields, biomass levels (sustainability) and value of the catch, if the level of fishing effort remains the same or if it is changed in one way or another (Sparre and Venema 1998). Sparre and Venema (1998) discuss two types of models. Firstly, analytical models: usually those requiring the age composition of catches to be known. For example, Beverton and Holt Yield Per Recruit Analysis and Thompson and Bell Yield and Biomass Prediction, as developed by Baronov (1914), Thompson and Bell (1934) and Beverton and Holt (1956). Secondly, holistic models: which usually consider a fish stock as a homogeneous biomass and do not take into account the length or age structure of the stock, for example the Swept Area Method and the Surplus Production Model.

Russell (1931) wrote a simple algebraic expression which describes what induces a gain or loss in a population of fish where the stock is being fished and emigration and immigration are irrelevant. He summarised stock biomass dynamics as:

$$(1) \quad B_{t+1} = B_t + A_t + G_t - M_t - C_t \quad B$$

Where:

$B_{t+1}$ : is the stock biomass in year  $t+1$

$B_t$ : is the stock biomass in year  $t$

$A_t$ : is the sum of the initial weights of all individuals recruited to the stock each year

$G_t$ : is the sum of the growth in biomass of individuals already recruited to the stock

$M_t$ : is the sum of the weights of all fish which die of natural causes during the year

$C_t$ : is the sum of weights of all fish caught

Russell's formulation set the foundation for mathematical methods by which estimates of how many fish are in a particular stock (abundance or biomass) could be determined. Since in most cases only the catch is known, Russell's equation (Equation 1) needs to be simplified, requiring certain assumptions to be made. In the holistic framework the following simplification is made: The gain terms, recruitment and growth is generally referred to as production. Surplus production ( $P_t$ ) is defined as the difference between production term (recruitment and growth) and natural mortality. Russell's equation can thus be simplified to the following form:

$$(2) \quad B_{t+1} = B_t + P_t - C_t \quad B$$

which simply means that the biomass in the next time period is equal to the biomass in the previous time period plus surplus production minus the catch. It is generally assumed that the surplus production is a function of the biomass at any given time, i.e.:

$$(3) \quad B_{t+1} = B_t + f(B_t) - C_t \quad B$$

where  $B_t$  is the stock biomass at the beginning of year  $t$ ,  $f(B_t)$  is the production function of the biomass in year  $t$ , and  $C_t$  is the catches in year  $t$ .  $f(B_t)$  is thus a function which describes the population dynamic: birth, gain in weight and natural mortality, as a function of the biomass; i.e. the agglomeration of the  $R$ ,  $G$  and  $M$  terms in Russell's original formulation.

Common forms of the production model in use today include the original Schaefer (1954) form, the modified Fox (1970) form and the modified Pella and Tomlinson (1969) form. These models differ in the assumption made about the response of the production as a function of biomass. In this paper we will use the Schaefer (1954) form, often referred to as the logistic model, in which the production term is described as:

$$(4) \quad f(B_t) = rB_t(1-B_t/K) \quad f$$

where  $r$  is the intrinsic growth rate and  $K$  is the carrying capacity, or the maximum biomass that the environment can support. The Schaefer (1954) form of the basic equation of the production model is thus:

$$(5) \quad B_{t+1} = B_t + rB_t(1-B_t/K) - C_t \quad B$$



Recognising that catch is a product of fishing mortality (F) and biomass the equation can be written as:

(6)

$$B_{t+1} = B_t + rB_t(1-B_t/K) - F_t B_t$$

B

This equation is usually referred to as the biological model, where the population trajectory is simply a function of the initial biomass, the intrinsic growth rate (r), the carrying capacity (K) and the fishing mortality (F).

Direct measures of biomass are rarely available in marine populations. Indices of stock size such as catch rate (CPUE: catch per unit of effort) are however frequently collected. It is often assumed that these indices are proportional to the stock size, i.e.:

(7)

$$PUE_t = C_t/E_t = U_t = qB_t$$

C

Here q stands for catchability, which acts as a simple scaling factor. The CPUE data can either be from the commercial fishery or based on survey abundance information. Equations 6 and 7 form the basis of a stock production model, where observations of catch and stock indices are used to estimate catchability (q), the intrinsic rate of growth (r) and the carrying capacity (K). Additionally, the biomass at the start of the time series available ( $B_1$ ) needs to be estimated. These estimated parameters are then used to calculate fishery performance indicators of maximum sustainable yield (MSY), biomass at MSY ( $B_{(MSY)}$ ) and fishing mortality at MSY ( $F_{(MSY)}$ ) as follows:

$$MSY = rK/4$$

$$B_{MSY} = K/2$$

$$F_{MSY} = r/2q$$

$$E_{MSY} = r/2$$

### 3.2.1 Fitting surplus production models to observed data

There are three methods used to estimate the parameters of the biomass dynamic model when only an index of abundance (CPUE, index of abundance from surveys etc.) is available: (1) the assumption of equilibrium conditions, (2) transformation of the equations into linear forms, and (3) time series fitting. All three methods use the assumption that the relationship between CPUE and effort is linear.

#### (1) The assumption of equilibrium conditions

In equilibrium conditions it is assumed that the biomass does not change between two consecutive time periods, i.e.:

$$(8) B_{t+1} = B_t$$

The removal in the form of annual yield is thus equivalent to the production, i.e.:

$$(9) C_t = rB_t(1-B_t/K)$$

Since  $C = qEB$ , and  $CPUE = C/E$  and  $B = CPUE/q$ , equation 9 can be rewritten as:

$$(10) C = r(CPUE/q) [1-(CPUE/q)/K]$$

which can be simplified to:

$$(11) \quad \text{CPUE}_t = a - b E_t$$

which is just a simple linear model. The parameters  $a$  and  $b$  can then be estimated by minimising the sums of squares:

$$(12) \quad \min SS = \sum_{t=0}^t (U_t - \hat{U}_t)^2 = \sum_{t=0}^t (U_t - a - bE_t)^2$$

Having obtained estimates of  $a$  and  $b$ , the maximum sustainable yield and the equivalent effort can then be obtained from:

$$(13) \quad \text{MSY} = (a/2)^2/b$$

$$(14) \quad E_{\text{MSY}} = a/(2b)$$

The equilibrium assumption was made to simplify the process of fitting surplus production models to data in the days prior to computers. The assumption that populations are in equilibrium at all exploitation levels is however in almost all cases incorrect. The model ignores the difference in standing crop between the two different biomass levels and the time it takes the system to respond to changed conditions and this makes the model incorrect and the method is explicitly warned against in the literature (Pitcher and Hart 1982, Hilborn and Walters 1992). It's use when fitting the Greenland halibut data is just for demonstrative purpose.

(2) Linear regression (transformation of the equations into linear forms)

By substituting the  $B_t$  term in equation 6 with  $U_t/q$  (from equation 7) Schnute (1977) showed that the Schaefer surplus production equation can be transformed into a multiple linear form:

$$(15) \quad \ln (U_{t+1}/U_t) = r - r/kq (U_{t+1} + U_t/2) - q E_{t+1} + E_t/2$$

where  $U_t$  = observed CPUE,  $k$  = carrying capacity,  $q$  = catchability,  $r$  = intrinsic growth rate,  $E_t$  = effort.

Equation (15) conforms to the multiple linear regression model:

$$(16) \quad Y = b_0 + b_1 X_1 + b_2 X_2$$

Where  $X_1 = U_t$  and  $X_2 = E_t$ , where the parameters  $b_0$ ,  $b_1$  and  $b_2$  can be fitted by minimising:

$$(17) \quad \begin{aligned} \min SS &= \sum_{t=0}^t \ln U_{t+1}/U_t - \ln U_{t+1}/U_t \\ &= \sum_{t=0}^t \ln U_{t+1}/U_t - \left[ b_0 + b_1 (U_{t+1} + U_t)/2 + b_2 (E_{t+1} + E_t)/2 \right]^2 \end{aligned}$$

Although regression methods are easily applied to solve fisheries models, it has been demonstrated that they can give very biased answers (Uhler 1979). They can also produce obviously wrong answers, such as negative values of  $r$  or  $q$ , which are biologically impossible.

(3) Time series fitting with objective function

The method that is at present considered best, and which is also the most transparent, for estimating production model parameters is the nonlinear time-series fitting

method. Here the parameters  $q$ ,  $r$ ,  $K$  and the biomass in the first year are ( $B_1$ ) in equations 5 and 7 are estimated directly by minimising:

$$(18) \quad \min SS = \sum_{t=0}^T \ln U_t - \ln \hat{U}_t^2$$

### 3.3 The use of length frequency distribution in stock assessments

#### 3.3.1 Estimation of population parameters from length frequency distribution

Estimates of population parameters (growth ( $K$ ) and mortality, i.e. natural mortality ( $M$ ), fishing mortality ( $F$ ) and total mortality ( $Z$ )) are fundamental in fisheries because stock assessment and management rely on these parameters (Wang and Ellis 2005). For example information about growth, maturity, and mortality of individual fish stocks is used to estimate how many fish can be caught without impacting the future recruitment of young fish (Witherell and Ianelli 1997). In stock assessment growth means, the determination of the body size of a fish as a function of age. The mathematical model for individual growth by von Bertalanffy (1934), has been shown to conform to the observed growth of most fish species (Sparre and Venema 1998).

The mathematical model expresses the length,  $L$ , as a function of the age of the fish,  $t$ :

$$(19) \quad L(t) = L_{\infty} * [1 - \exp(-K*(t-t_0))]$$

Where fish cannot be aged or aging techniques are expensive length-frequency-based methods are often used to determine the ages of fish and thus growth parameters which in turn can be used to estimate total mortality ( $Z$ ). The mortality model used is usually a linearised catch curve based on length composition data, where the inverse Von Bertalanffy growth equation is used to convert length into age.

Length measurements from commercial fisheries are susceptible to bias due to a number of different systematic errors in the sampling process and gear selection (the technical aspects of the gear and the way it is operated (Gulland and Rosenberg 1992)). Systematic errors in sampling occur where the catch is sampled after smaller or larger fish have been discarded, sampling occurs after the catch has been sorted by size or nonrandom sample selection on the part of the data collectors. Estimation of mortality relies on the distribution of the lengths, which is determined by the age distribution. It stands to reason, therefore, that if an inappropriate age-length distribution is generated this could lead to biases in parameter estimates.

## 4 METHODOLOGY

### 4.1 Summary of data used

CPUE indices from (1) the Icelandic bottom trawl fleet 1985-2006, (2) the Icelandic fall survey 1996 – 2006, and (3) the Greenlandic fall survey 1998 – 2006 (2001 missing) along with total landings from the fishery were obtained from ANON. (2007a) and ANON. (2007b). In the case of the Icelandic bottom trawl commercial fleet, the CPUE indices were taken from all hauls with Greenland halibut exceeding 50% of the total catch. Indices from the Icelandic fall survey were calculated from trawl surveys of 300 stations on the continental shelf within the Icelandic EEZ. The surveys were conducted in October of each year and are fixed station stratified random surveys. The Greenlandic fall surveys are carried out late June/early July on the east Greenland main commercial fishing grounds. The data on length was obtained from the electronic database at the Marine Research Institute, Iceland.

### 4.2 Methodology for surplus production model

Modeling was done in Excel and the non-equilibrium surplus production model incorporating covariates (ASPIC) (Prager 2005).

The data were fitted to:

- (1) Schaefer production model using equilibrium assumptions (only the longest time series was used; the Icelandic bottom trawl fleet 1985-2006).
- (2) Schaefer (logistic) surplus-production non-equilibrium model using regression analysis (only the longest time series was used; Icelandic bottom trawl fleet 1985-2006).
- (3) The non-equilibrium surplus production model incorporating covariates (ASPIC) (Prager 2005).
- (4) Time series fitting using non-linear least squares minimisation modeled in Excel.

The results from the different types of fitting were compared to demonstrate both the process of the method and the pitfalls of the production model. For the equilibrium model effort was regressed against CPUE to find  $a$  and  $b$ . The log-transformed observed and predicted catch-per-effort values CPUE ( $u_t$ ) were then minimised using the least-squares method and the routine available in Excel Solver: minimise  $(\ln(\hat{U}_t) - \ln(U_t))^2$ . The maximum sustainable yield (MSY) and effort needed to achieve MSY  $E_{(MSY)}$  were estimated using the Schaefer (1954) model, where  $MSY = rK/4$  and  $E_{(MSY)} = r/2q$ .

For ASPIC, the initial guesses of the parameter  $r$ , was 0.3 and  $K$  was assumed to be equal to an initial starting value  $B_0 = 400$ , and given the observed yield ( $Y_t$ ) per year, a series of expected biomass ( $B_t$ 's) for each year was developed. The outputs of the model are trajectories of absolute biomass ( $B$ ), relative biomass ( $B/B_{(MSY)}$ ) and relative fishing mortality ( $F/F_{(MSY)}$ ). ASPIC also allows for forward projections. The estimated bootstrapped parameters were used in the PROJECTION mode to determine bias corrected trajectories 2007-2022.

### 4.3 Length frequency models

The von Bertalanffy parameters ( $K$ ,  $L_{\infty}$  and  $t_0$ ) were estimated using two alternative methods:

- (1) Direct estimates, using age estimates based on annual ring structures in otolith. The estimates were obtained by minimising the sums of squares of the predicted and observed length at age, the algorithm being setup in an Excel spreadsheet.
- (2) Modal progression analysis of length frequency distribution through time. ELEFAN I program (Pauly and David 1981) in FISAT version 1.2.2. (Gayanilo *et al.* 2005) was used to determine  $K$  and  $L_{\infty}$ . The method used by the programme is to clarify the position of the modes by smoothing. This program calculates a 5-point running average and then compares the observed frequency with this average, values much above the average indicating a mode. After various adjustments to correct for various sources of bias etc., it gives a set of numbers, the peaks, expressed in a standard form that can be used in the following stages of the ELEFAN program.

Once the von Bertalanffy parameters have been estimated the total mortality is estimated by converting length to age by using the inverse von Bertalanffy growth equation:

$$(20) \quad t(L) = t_0 - 1/K * \ln(1 - L/L_{\infty}).$$

To take into account that a length distribution contains data where the time unit within each length interval is not constant we divide the catch with the time duration that it takes the fish to pass through the length interval.

To give:

$$(21) \quad \frac{C_{L_1, L_2}}{\Delta t_{L_1, L_2}}$$

Pseudo cohorts, consisting of the averaged standardised five year length frequency for the periods 1978-1982, 1983-1987, 1988-1992, 1993-1997, 1998-2002, 2003-2007 were used in the analysis. The assumption is that the recruitment has been relatively stable over the time period used in the analysis. To estimate  $Z$  we take the logarithm of the catches per time unit and estimate the slope  $(t(L_1+L_2)/2)$  against  $\ln(N/dt)$ . The formula in full is:

$$(22) \quad \ln \left( \frac{C_{L_1, L_2}}{\Delta t_{L_1, L_2}} \right) = a - Z t_{0.5(L_1+L_2)}$$

The portion of the plot corresponding to points 10 to 23 was used to determine the slope which was equivalent to  $Z$ .

## 5 RESULTS

### 5.1 Results from surplus production models

#### 5.1.1 *Estimates of parameters and management reference points determined by equilibrium, linear and nonlinear methods of fitting SPM*

Input data used for the three alternative fits of the surplus production model are listed in Table 1 and the estimated parameters and management reference points in Table 2. The three methods used produced  $r$ 's ( $\sim 0.4$ ) and  $q$ 's ( $\sim 0.005$ ) that were similar but  $K$ 's and  $MSY$ 's that were different. The regression method returned the highest  $MSY$  of 44,459 t approximately one third more than the 28,000 – 30,000 t estimated by the Excel and ASPIC models.

Figure 4 shows the regression of CPUE on effort for the determination of the  $a$  and  $b$  parameters of the Schaefer equilibrium assumption model. The  $a$  parameter (the intercept) = 1.081 and the  $b$  parameter (slope) = -0.007. The regression indicates that 56% of the variation of the CPUE is explained by the effort. Figure 5 shows the expected equilibrium catches vs. the observed catches. The figure shows that the parabolic relationship between effort and catch ( $c = aE - bE^2$ ) is not well described by the data.

The non-equilibrium fittings generally indicated that biomass of the Greenland halibut is declining, although the model does not fully respond to short term fluctuations in the CPUE measurements (Figure 6 – linear fit, Figure 7 - nonlinear fit (Excel), Figure 8 e.g., - nonlinear fit (ASPIC))

#### 5.1.2 *Model predictions from equilibrium, linear and nonlinear methods of fitting*

Schaefer form using equilibrium assumptions: since equilibrium conditions are most likely violated, inferences based on those results should not be made. They are only shown here for demonstrative purposes. The parabolic relationship between effort and catch ( $c = aE - bE^2$ ) is not well described by the data (Figure 5).

The fittings by linear regression give a maximum sustainable yield of 44,459 t that can be harvested by the standardised effort of 36,896.

Time series fittings in Excel and ASPIC gave similar results. ASPIC results (Table 3 and Figure 11) show that total fishing mortality is increasing while average biomass, surplus production and total yield is decreasing. The relative biomass ( $B/B_{MSY}$ ) trend is predicted to have steadily declined (with only two short periods of increasing relative biomass (1977 – 1979 and 1999 – 2000)) and that of the relative fishing mortality ( $F/F_{MSY}$ ) trend (Figure 12) to have increased. Relative fishing mortality is predicted to have increased gradually over the three periods of increase: (1) 1961 – 1966 average  $F/F_{MSY} = 0.083$ , (2) 1967 – 1986 average  $F/F_{MSY} = 0.582$ , and (3) 1987 – 2002 average  $F/F_{MSY} = 1.665$ , (4) 2003 – 2006 average  $F/F_{MSY} = 2.489$ .

Uncertainty in the point estimates of the model results (ASPIC fit), was assessed using the distribution obtained from 1,000 bootstrap estimates. Bootstrapping developed arrays of different parameter values that are used to characterise the

uncertainty inherent the model fitting exercise. Table 4 describes the uncertainty in the production model point estimates. Of note is the large uncertainty in the K estimate,  $K = 298.400$  (213.4 - 472.20) 80% confidence limits (Figure 13). The uncertainty is also positively skewed, reflecting the lognormal distribution of the residuals of the CPUE data.

### 5.1.3 *Projections for future trends in biomass based on time series fitting in ASPIC v 5.16 computer programme*

ASPIC projections over a 15 year period indicate that if the present exploitation levels are maintained over the next 15 years then relative biomass could decrease to the point of a stock crash (Figure 14a). Fishing the stock at half of the current fishing mortality would promote an increase in the relative biomass but perhaps not enough to get the relative biomass levels up to  $B/B_{(MSY)} = 1$  (Figure 14b). If fishing mortality was reduced by 60% of its current level there is a more than 50% likelihood that the stock will be below  $B_{(MSY)}$  after 15 years (Figure 14c). However, if the fishing mortality applied to the fishery for the next 15 years were set at one quarter of the present level then the model predicts that relative biomass could increase and get to  $B/B_{(MSY)} = 1$ , within 10 years (Figure 14d). In terms of possible yield from the fishery over the 15 year period, the model predicts that yields obtained at the higher fishing mortalities would decrease over time but at lower fishing mortalities would increase over time (Figure 15).

## 5.2 Results from length frequency modeling

### 5.2.1 *Estimates of growth parameters and the Von Bertalanffy growth curve of Greenland halibut*

The length frequency data was entered into FiSAT (Gayanilo *et al* 2005) and analysed using ELEFAN 1 (Pauly and David 1981). Estimates were  $L_{\infty} = 110.25$  and  $K = 0.14$  (Table 5). However, the score functions for the value (which corresponds to the r square value) was low (0.12) indicating that the estimates are very imprecise. The reason is that the length frequency data do not show clear modes (Figure 16), a prerequisite for using model progression analysis to estimate the von Bertalanffy parameters.

Using length at age data the growth parameters for the species were estimated to be  $L_{\infty} = 100$ ,  $K = 0.937$  and  $t_0 = -1.347$  (Table 5).  $L_{\infty}$  had to be assumed to be 100 as the model could not predict all three parameters simultaneously. Figure 17 shows the fit of the Von Bertalanffy growth curve. The Von Bertalanffy growth curve produced by this set of growth parameters shows that K approaches  $L_{\infty}$  slowly and it is possible that the growth rate does not differ greatly with age.

### 5.2.2 *Estimates of total mortality (Z) from length frequency data of Greenland halibut*

The linearised catch curves for pseudo-cohorts, consisting of the averaged standardised five year length frequencies: 1978-1982, 1983-1987, 1988-1992, 1993-1997, 1998-2002, 2003-2007, where  $L_{\infty} = 100$ ,  $K = 0.0937$  and  $t_0 = -1.34$ , are shown in Figure 18.  $Z$  = slope of descending best straight portion of the curve. Points 10 to

23 for each pseudo – cohort were used for the regression analysis. Estimated  $Z$  &  $F$  seem to have been stable over the analysed time period (Table 6)  $Z = \sim 0.3$  and  $F = \sim 0.2$ .

Length based  $Z$  calculation are sensitivity to the value of  $K$  and  $L_{\infty}$ . Sensitivity tests using a range of  $L_{\infty}$   $K$  and  $t_0$  (Table 7) were carried out.  $Z$  was found to be relatively stable over a reasonable range of values.

## 6 DISCUSSION

### 6.1 Surplus production model

All three fittings of the surplus production model explored have provided us with answers (estimates for parameters and an  $MSY$ ). However these answers must be interpreted in the light of the limitations of the model and input data being used, and the consequences of assumption violations. Firstly, it has been established that the equilibrium assumption applied to the Greenland halibut stock is incorrect and thus this method should not be used for the assessment of this stock. Other model assumptions that might prove problematic to the assessment are: (1) no changes in gear or vessel efficiency have taken place, (2) catch and effort statistics are accurate. However, perhaps the most important assumption to the reliability of the model is the assumption made concerning catch-per-unit-effort (CPUE).

Recall that we have no direct estimate of biomass, and to determine biomass we have assumed that the catch rate  $C$  is proportional to the stock size and to fishing effort. In the context of parameter estimation for biomass dynamic models, the CPUE data used must have historical variation in stock size and fishing pressure to estimate the parameters of the model with any reliability (Hilborn and Walters 1992). Thus the results produced by such stock assessment are influenced by the amount of information that was embedded in the CPUE data that was used. To answer the question of the amount of information embedded in the CPUE data presented for the Greenland halibut, the data was examined for the regular problems of the “one way trip”, and the form of the relationship between CPUE and abundance.

Commercial fisheries usually develop with consistently increasing fishing effort and declining catch per effort. This type of time series is referred to as the “one way trip” (Hilborn and Walters 1992).

Ideally, we are looking for strong contrast between CPUE and effort. Indications are that there is not a great amount of contrast in the data. This means, therefore, that  $r$  and  $q$  can be reasonably estimated but the  $K$  estimate will not be expected to be reliable. We also need to examine the relationship between CPUE and biomass. Recall that the core assumption of the model is that CPUE is an index of abundance, and that CPUE is directly linked to biomass (abundance) by a constant catchability factor  $q$ . If efficiency has changed in the fishery with time then the CPUE signal could be misleading.

The CPUE trends for the Icelandic bottom trawl fleet CPUE series (Figure 8) was not adequately reflected by the model. The modeled CPUE for this period shows a steady



continuous decline in CPUE, at a slower rate than the observed CPUE, and is not responsive to short term changes.

For the shorter time series of the Icelandic fall survey (Figure 9) the modeled CPUE and observed CPUE were better reflected. The modeled CPUE overall reflected the observed CPUE, however it should always be kept in mind that the information embedded in the data might not be enough to answer the questions that are asked of it. This could be an indication that model was not robust enough to analyse this data.

Managers will be interested in the size or biomass of the exploited stock ( $K$ ), the biomass at MSY ( $B_{(MSY)}$ ), the maximum sustainable yield (MSY) and the effort needed to take MSY ( $E_{(MSY)}$ ). Bootstrap analysis of the point estimate of these potential management outputs was done, as few of these are of value without some idea of the uncertainty around their values (Haddon 2001). Bootstrapping is able to counter some of the effects of observation error and provide bounds for the derived parameters and are valuable tools for interpreting the results of the model. The bootstrapped estimate of the confidence limit for the biomass indicates that at 80% confidence limits, biomass could have been anywhere between 473,175 and 214,083 t, that is 58.3% more or 40% less than the point estimate of 298,809 t. At the 80% confidence limit the boundaries around MSY,  $B_{(MSY)}$  and  $F_{(MSY)}$  are also wide. Hilborn and Walters (1992) found that unrealistic results from surplus production models are generally not due to model failure, but rather to errors in the data. Perhaps the CPUE data for the Greenland halibut needs to be reviewed. The effort used in the analysis was the derived effort, and this could have also had some impact on the results as it increases uncertainty in estimates of effort. The reporting of one reference point in relation to another such as  $F/F_{(MSY)}$  allows for the reporting of one figure which immediately tells the manager where the fishing effort stands in relationship to  $F_{(MSY)}$ . This is a scaling of the point estimates and it makes the reporting process simpler.

In terms of the overall outlook for the fishery: at the current rate of fishing mortality catches will decline since the biomass is predicted to decline. There is a high probability of stock collapse if this trend continues. According to the forward projections done in ASPIC reducing fishing mortality by half of the current level would result in some rebounding of the stock, albeit at a great temporary sacrifice in terms of catches. Advice concerning this fishery for a manager would depend on the objectives for the fishery with regards to the stock. If the objective is that there should be high probability (>90%) that the stock is above  $B_{(MSY)}$  in 15 years time, the advice would be to reduce the fishing mortality by three quarters of the present level. This translates to a catch of 5400 t in 2007, with increases in catches in consecutive years as the stock starts to rebound. If the objective is to fish at  $F_{(MSY)}$  irrespective of the status of the stock, the advice is to reduce fishing mortality by approximately 60% of the present fishing mortality. This translates to a catch of 8100 t in 2007, with increases in catches in consecutive years as the stock starts to rebound. It should, however, be pointed out to the manager that under this scenario, there is more than 50% likelihood that the stock will be below  $B_{(MSY)}$  after 15 years.

## 6.2 Length frequency method

The principle of converting length to age is to separate a length frequency into cohorts and thus into age groups by the assumption that a peak can be detected among the smallest fish (corresponding to the youngest well-recruited age group), which moves up month by month until after a year a new peak becomes apparent, and the first peak is indistinguishable among the larger fish (Gulland and Rosenberg 1992). It is recommended, therefore, that if a plot of the length frequency data shows no obvious modes, it is probably not worth proceeding further to analyse these data for growth estimates fish (Gulland and Rosenberg 1992). A plot of the length frequency of Greenland halibut (Figure 16) showed no distinct modes in the data, nonetheless the data was analysed with FiSAT to demonstrate the error of ignoring the fact that the data had no modes. Analysis using ELEFAN 1 (Pauly and David 1981) to scan for a K value returns a result with a low r square value (0.152), which renders the result useless. The von Bertalanffy plot produced shows that the programme was unable to distinguish where the modes in the larger size categories were. The Greenland halibut length frequency data can be said to have “no signal” meaning there was no signal about time available in an implicit form in the data (Gulland and Rosenberg 1992). Finding no signal in length frequency data collected from commercial fisheries is not an uncommon occurrence, as commercial dictates and gear selectivity often result in particular sizes or year classes being caught by a commercial fishery. In the case that growth parameters are to be determined solely from length frequency data, close attention must be paid to the sampling scheme for such data to ensure the collection of statistically adequate information, i.e. data that takes full account of the variability in the sizes (and ages) of fish caught at different times and places and with different gears (Gulland and Rosenberg 1992).

For the purpose of stock assessment length frequency data, when being used to determine growth, should be supplemented by even limited age reading (such as in an Age Length Key) (Sparre and Venema 1998), and in the case of Greenland halibut an Age Length Key was available. The model estimates were  $K = 0.0937$ ,  $t_0 = -1.3468$ , and  $L_\infty = 100$ , which were then used in developing the model for estimation of total mortality, from which fishing mortality can be calculated (as  $Z = F+M$ ) if the natural mortality is known.

Given that the surplus production model predicted that the fishing mortality has been increasing it would be of interest to compare the results on mortality from the two models. Mortality estimates from the length frequency (0.1 – 0.2 Table 6) are lower than those predicted by the surplus production model (0.3 – 0.4 Table 3). The length frequency model seems to indicate that the fishing mortality has been relatively stable over the period while the surplus model indicates that fishing mortality has been increasing over the period.

## 7 CONCLUSIONS

The production model has several assumptions that are not always easy to test, the most important being that the CPUE index is directly related to population size. In the assessment of the Greenland halibut the CPUE was not adequately reflected by the model, and in addition the CPUE was found to be uninformative. Confidence limits around  $K$ ,  $MSY$ ,  $B_{(MSY)}$  and  $F_{(MSY)}$  are wide. The results of the assessment, though in need of fine tuning, are not unrealistic. However, better methods for estimating parameters could be used for this model. Use of the Bayesian methods is assumed to improve the estimates of  $r$  and  $K$  in the model (Natural Resources Consultants, Inc. 2002) and perhaps could be used in further assessments of this data.

The length frequency data for the Greenland halibut was not useful in determining age classes. Since the data is already being collected perhaps consideration could be given to a collection system according to a careful statistical design, which would collect more informed data, and a full statistical analysis in order to determine the optimum design of such a system.

## LIST OF REFERENCES

- ANON. 1999. Northwest Atlantic Fisheries Organization, Scientific Council Reports 1999.
- ANON. 2004. ICES Report of the North-Western Working Group, ICES CM 2004/ACFM
- ANON. 2007a. ICES Report of the North-Western Working Group, 24 April 3 May 2007. ICES CM 2007/ACFM:17
- ANON. 2007b. State of the main stocks in Icelandic waters 2006/2007. Prospects for the quota year 2007/2008. Fjölrit nr. 129. Marine Research Institute, Reykjavik. Iceland.
- Baranov, F. I. 1914. The capture of fish by gillnets. *Mater.Poznaniyu Russ.Rybolov.* 3(6):56-99 (Partially translated from Russian by W.E. Ricker).
- Bertalanffy, L. von, 1934. Untersuchungen über die Gesetzmäßigkeiten des Wachstums. 1. Allgemeine Grundlagen der Theorie. *Roux'Arch.Entwicklungsmech.Org.*, 131:613-653.
- Beverton, R. J. H. and Holt, S. J. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. *Rapp.P.-v.Réun.CIEM*, 140:67-83.
- Boje, J. and Hjörleifsson, E. 2000. Nursery grounds for the West Nordic Greenland halibut stock – where are they? ICES 2000 Annual Science Conference CM 2000/N:03 [Feb. 18. 2008]  
<http://www.ices.dk/products/CMdocs/2000/N/N0300.pdf>
- Bowering, W. R. and Brodie, W. B. 1995. Greenland halibut (*Reinhardtius hippoglossoides*): a review of the dynamics of its distribution and fisheries off eastern Canada and Greenland. In *Deep-water fisheries of the North Atlantic slope* (A. G. Hopper, ed.), p. 113-160. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Coad, B.W. and Reist, J.D. 2004. Annotated list of the arctic marine fishes of Canada. Can. MS Rep. *Fish Aquat. Sci.* 2674:iv:+112 p.
- Duffy, J. E. (ed) 2007. Fisheries and aquaculture in the Central North Atlantic (Iceland and Greenland). International Arctic Science Committee (other articles) [Feb.28,2008]  
[http://www.eoearth.org/article/Fisheries\\_and\\_aquaculture\\_in\\_the\\_Central\\_North\\_Atlantic\\_\(Iceland\\_and\\_Greenland\)](http://www.eoearth.org/article/Fisheries_and_aquaculture_in_the_Central_North_Atlantic_(Iceland_and_Greenland)).
- Froese, R. and Pauly, D. (Editors). 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines. 344 p.  
<http://filaman.ifm-geomar.de/Summary/SpeciesSummary.php?id=516>.

Fox, W.W. 1970. An exponential yield model for optimizing exploited fish populations. *Transactions of the American Fish Society*, **99**, pp. 80–88.

Gayanilo, Jr. F. C., Sparre, P. and Pauly, D. 2005. *The FAO-ICLARM Stock Assessment Tools (FISAT) User's Guide*. FAO Computerized Information Series (Fisheries) 6, 186p. Rome,

Gulland, J. A. and Rosenberg, A. A. 1992. A review of length-based approaches to assessing fish stocks. FAO Fisheries Technical Paper. No. 323. Rome, FAO. 100p.

Gundersen, A., Simonsen, C., Jørgensen, O., Fossen, I., Lyberth, B. and Boje, J. 2004. Sexual maturity and spawning of Greenland halibut, *R. hippoglossoides*, in West Greenland waters. ICES Annual Science Conference, Vigo 2004, Theme Session K: Life history, dynamics and Exploitation of living marine resources: Advances in knowledge and Methodology, ICES CM 2004 / K: 72. February 13 2008  
<http://www.ices.dk/products/CMdocs/2004/K/K7204.pdf>.

Haddon M. 2001. Modelling and quantitative methods in fisheries, 402 pp. Chapman and Hall/CRC, Boca Raton.

Hilborn, R. and Walters, C. J. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York. 570 p.

Icelandic Ministry of Fisheries, 2007. Marine stocks, Greenland halibut [Feb. 28, 200]  
<http://www.fisheries.is/stocks/ghalibut.htm>.

ICES, 1999. Report of the ICES Advisory Committee on Fishery Management. ICES Cooperative Research Report No. 236. International Council for the Exploration of the Sea.

ICES, 2006. Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2006. ICES Advice. Books 1 - 10. 2, 94 pp. [Feb. 28, 2008]  
<http://www.ices.dk/products/icesadvice/2006PDF/ICES%20Advice%202006%20Book%202.pdf>.

ICES, 2007. ICES Advice 2007 Book 2, Iceland and East Greenland [Feb. 28, 2008]  
<http://www.ices.dk/committe/acom/comwork/report/2007/may/Iceland%20and%20Greenland.pdf>.

Magnusson, J. V. 1977. Notes on eggs and larvae of Greenland halibut at Iceland. ICES CM 1977/F:47.

Natural Resources Consultants, Inc. 2002. Review of 2002 Stock Assessment for Large Coastal Sharks. NOAA's National Marine Fisheries Service, USA.  
<http://www.nmfs.noaa.gov/sfa/hms/Alverson.htm>.

- Pauly, D. and David, N. 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequencies data. *Meeresforsch.*, 28(4):205-211.
- Pella, J. J. and Tomlinson, P. K. 1969. *A generalized stock production model. Bulletin of the Inter-American Tropical Tuna Commission*, . **13** (1969), pp. 421–458.
- Pitcher, T. J. and Hart, P. J. B. 1982. *Fisheries Ecology*. Croom Helm, London.
- Prager, M.H. 2005. User's Manual for ASPIC: Stock Production Model Incorporating Covariates (ver. 5.16) and Auxiliary Programs. *National Marine Fisheries Service. Population Dynamic Team*. CCFHR/NOCAA-North Carolina, USA.
- Russell, E. S. 1931. "Some theoretical considerations on the 'overfishing' problem" *Journal du Conseil Permanent International pour l'Exploration de la Mer*, **6**: 3-20.
- Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. *Bulletin of the Inter-American tropical tuna commission* **1**, 25-56.
- Schnute, J. 1977. Improved estimates from the Schaefer production model: theoretical considerations. *Journal of the Fisheries Research Board of Canada*, **34**, pp. 583–603.
- Scott, W.B. and Scott, M.G. 1988. Atlantic fishes of Canada. *Can. Bull. Fish. Aquat. Sci.* 219: 731 p.
- Sparre, P. and Venema, S. C. 1998. Introduction to tropical fish stock assessment-Part 1: Manual. FAO fisheries technical paper 306/1 Rev. 2. Food and Agriculture Organization of the United Nations. Rome. [ Nov. 25, 2007]  
<http://www.fao.org/docrep/w5449e/w5449e00.htm>
- Sigurdsson, A. 1977. "On the spawning grounds of Greenland halibut in Icelandic waters." ICES E.M. 1977/F:28.
- Sigurdsson, A. and Magnusson, J. V. 1980. "On the nursery grounds of the Greenland halibut spawning in Icelandic waters." ICES C.M.(1980/G:45): 8 pp.
- Smidt, E. L. B. 1969. The Greenland halibut, *Reinhardtius hippoglossoides* (Walb.), biology and exploitation in Greenland waters. *Medd. Danm. Fisk.-Havunders.* 6(4):79-148.
- Thompson, W. F. and Bell, F.H. 1934. Biological statistics of the Pacific halibut fishery. 2. Effect of changes in intensity upon total yield and yield per unit of gear. *Rep.Int.Fish. (Pacific Halibut) Comm.*, (8):49 p.
- Uhler, R. 1979. Least squares regression estimates of the Schaefer production model: some Monte Carlo simulation results. *Can. J. Fish. Aquat. Sci.* 37:1248-1294.

Wang, Y-G. and Ellis, N. 2005. Maximum likelihood estimation of mortality and growth with individual variability from multiple length-frequency data. Fish. Bull. 103:380–391 (2005). [ Nov. 25, 2007] <http://fishbull.noaa.gov/1032/wang.pdf>.

Witherell, D. and Ianelli, J. 1997. A guide to stock assessment of Bering Sea and Aleutian Islands. Groundfish North Pacific Fishery Management Council. Anchorage, Alaska 99501. [ Nov. 25, 2007] [http://www.fakr.noaa.gov/npfmc/summary\\_reports/bsstock.htm](http://www.fakr.noaa.gov/npfmc/summary_reports/bsstock.htm).

Woll, A. K. (Editor) 2000. Greenland halibut in East Greenland waters. Recruitment studies and mapping of nursery grounds. Nordic project 1998-1999. Tema Nord, Fiskeri: 2000:585.

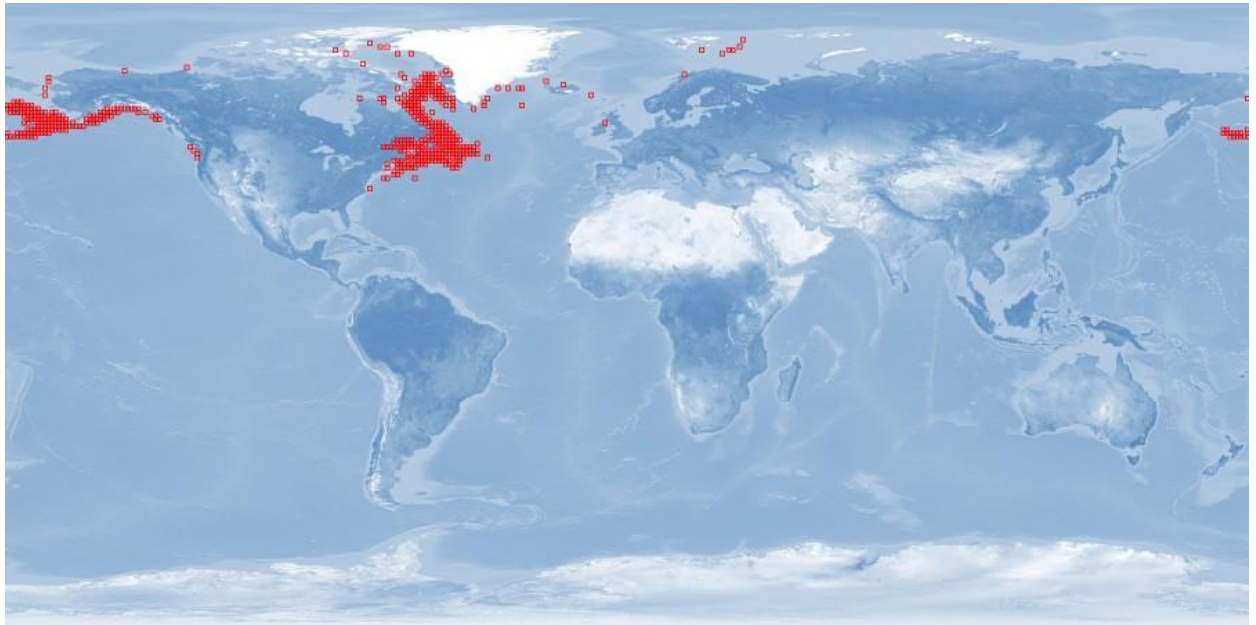
**FIGURES AND TABLES**

Figure 1: General distribution of Greenland halibut (FishBase 2000). (Distribution area outlined in red)

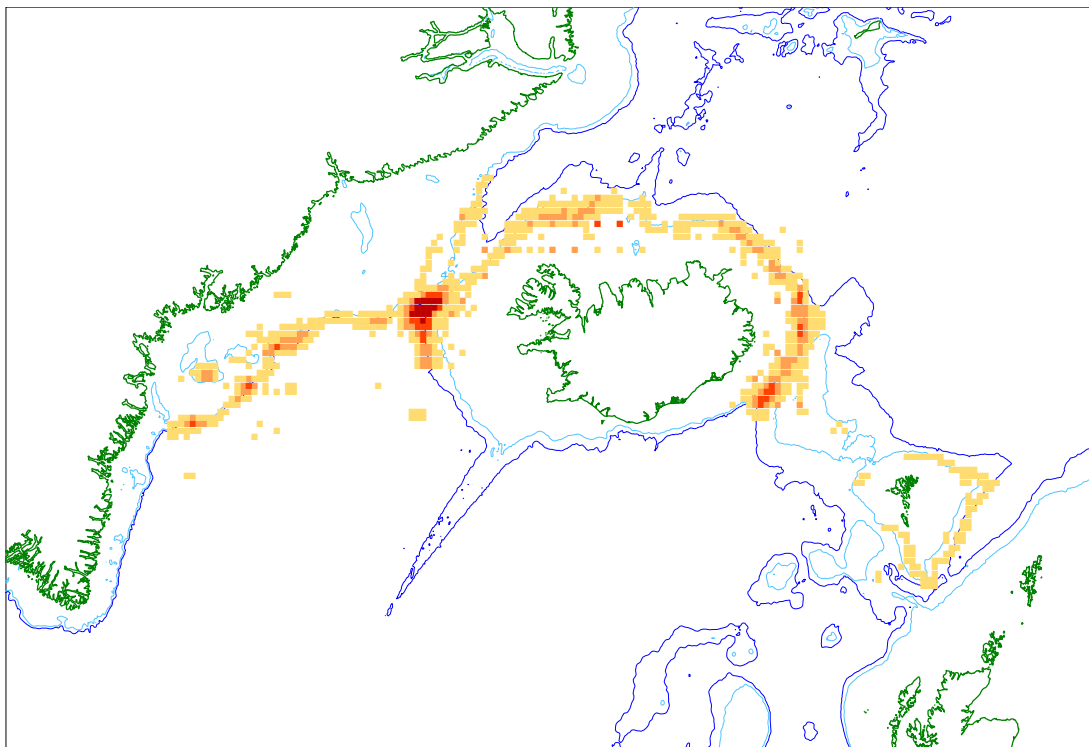


Figure 2: Fishing areas of the West Nordic stock of Greenland halibut (the 500m and 1000 m depth contours are shown) (ANON. 2007a).



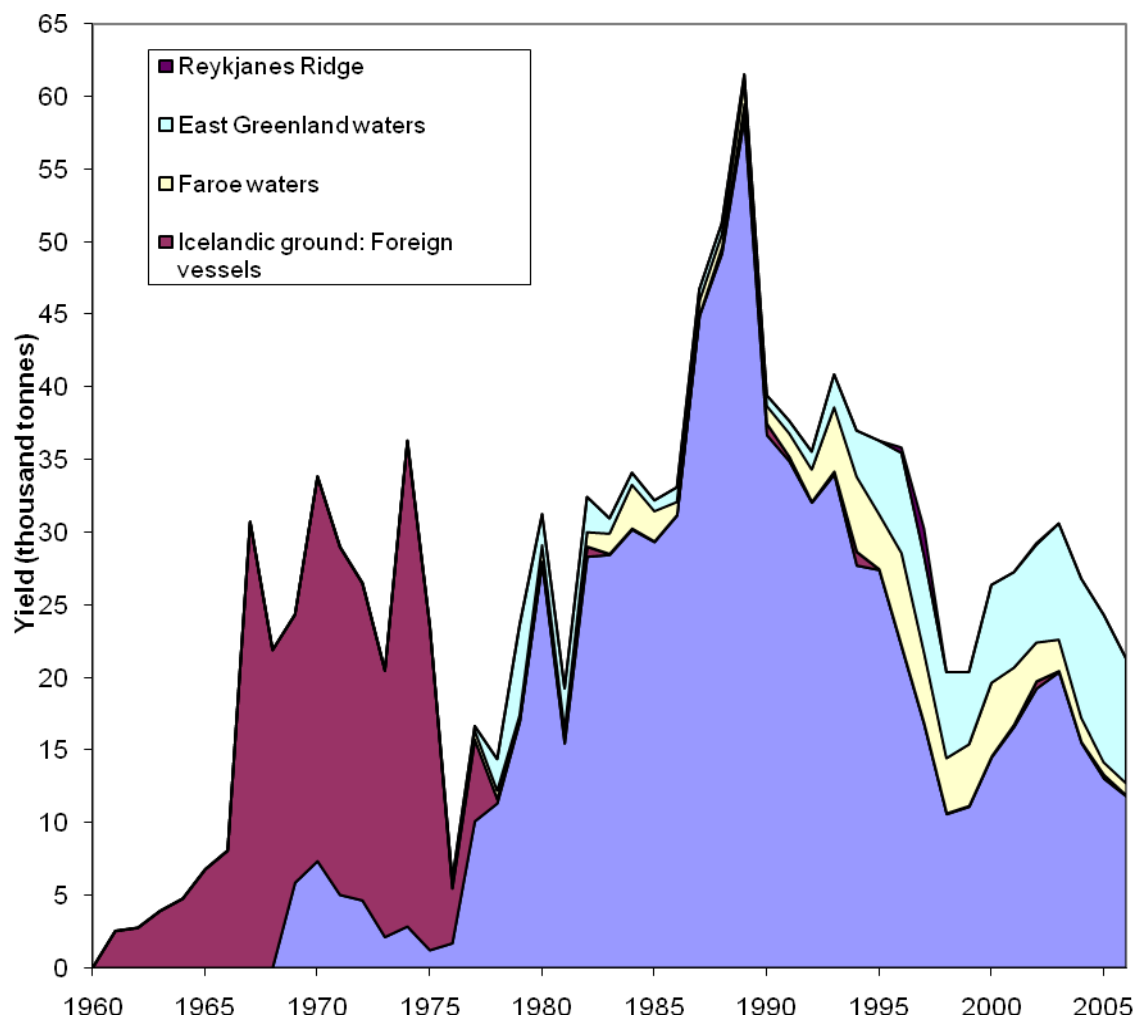


Figure 3: Development of the West Nordic stock Greenland halibut fishery (ANON. 2007b)

Table 1: CPUE indices from (1) Icelandic bottom trawl fleet 1985-2006, (2) Icelandic fall survey 1996 – 2006, (3) Greenlandic fall survey 1998 – 2006 (2001 missing) and total catch from the fishery 1961-2007.

Year	Catch	CPUE1: Icelandic bottom trawl fleet	Derived Effort Icelandic bottom trawl fleet	CPUE2: Icelandic fall survey	Derived effort Icelandic fall survey	CPUE3: Greenlandic fall survey	Derrived effort Greenlandic fall survey
1961	2.513						
1962	2.73						
1963	3.901						
1964	4.74						
1965	6.755						
1966	8.052						
1967	30.699						
1968	21.872						
1969	24.321						
1970	33.823						
1971	28.973						
1972	26.472						
1973	20.463						
1974	36.28						
1975	23.494						
1976	6.044						
1977	16.643						
1978	14.359						
1979	23.616						
1980	31.252						
1981	19.239						
1982	32.441						
1983	30.888						
1984	34.024						
1985	29.197	1	29.197				

Table 1: Contd.

Year	Catch	CPUE1: Icelandic bottom trawl fleet	Derived Effort Icelandic bottom trawl fleet	CPUE2: Icelandic fall survey	Derived effort Icelandic fall survey	CPUE3: Greenlandic fall survey	Derrived effort Greenlandic fall survey
1986	31.027	1.011	30.689				
1987	44.659	1.074	41.582				
1988	49.379	1.08	45.721				
1989	59.049	1.034	57.107				
1990	37.308	0.705	52.919				
1991	36.288	0.682	53.208				
1992	33.154	0.597	55.534				
1993	36.383	0.472	77.082				
1994	31.733	0.386	82.209				
1995	32.468	0.307	105.758				
1996	29.356	0.261	112.475	0.344	85.337		
1997	25.35	0.278	91.187	0.42	60.357		
1998	16.535	0.438	37.751	0.42	39.369	0.48	34.448
1999	16.514	0.5	33.028	0.524	31.515	0.394	41.914
2000	21.565	0.574	37.569	0.396	54.457	0.474	45.496
2001	23.971	0.591	40.560	0.557	43.036		
2002	26.464	0.489	54.118	0.472	56.068	0.589	44.930
2003	28.432	0.324	87.753	0.244	116.524	0.356	79.865
2004	25.331	0.222	114.104	0.16	158.319	0.254	99.728
2005	23.2	0.239	97.071	0.223	104.036	0.355	65.352
2006	21	0.239	87.866	0.185	113.513	0.381	55.118

Table 2: Parameter estimates and management reference points determined from the three alternative fittings of the Icelandic Greenland halibut data.

	Schaefer form using equilibrium assumptions	Schaefer form using transformation of the equations into linear forms non-equilibrium assumption	Schaefer form using series/objective function fitting in Excell non-equilibrium assumptions:	ASPIC v 5.16 computer programme nonequilibrium surplus-production model.
Total Objective Function		0.7	TSS: 2.588, LL: -1.196	2.381
q1 (80% C.L.)		0.0049	0.0048	0.0055
q2 (80% C.L.)			0.0047	0.0053
q3 (80% C.L.)			0.0061	0.0068
R		0.443	0.34	0.40
K(mt)		401,780.	336,830.	298,400
$B_{(2006)} / B_{MSY}$			0.26	0.285
$B_{(2007)} / B_{MSY}$			0.21	0.233
$F_{(2006)} / F_{MSY}$			1.96	2.754
$F_{MSY}$	68.26		0.17	0.198
$B_{MSY}$			168,415.	149,200.
MSY(mt)	36,896.	44,459.	28,223.	29,520. (80% C.L. = 24,320., 32,940)
Ye/MSY				
Equilibrium yield available in 2007				12,170.

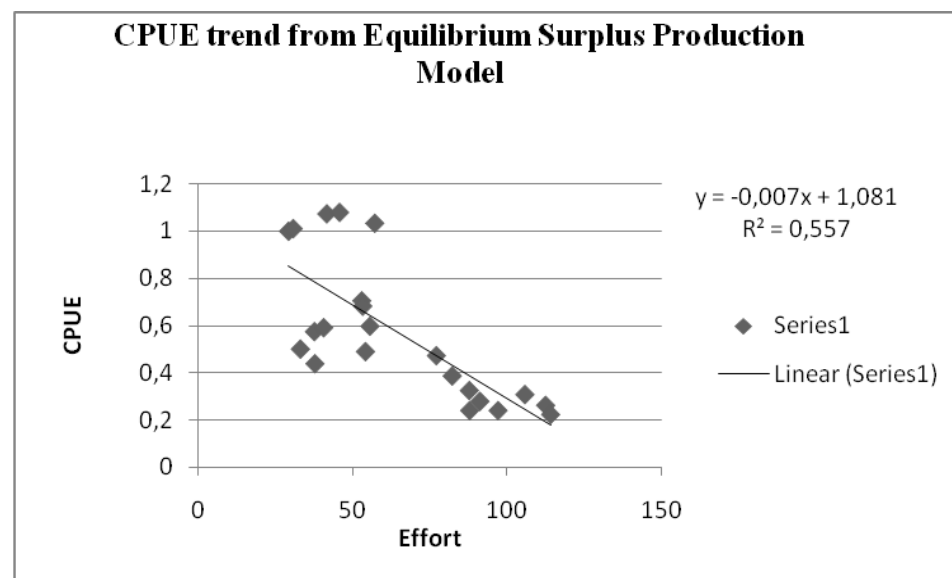


Figure 4: Relationship between CPUE and effort for West Nordic stock Greenland halibut using the Schaefer equilibrium assumption model.

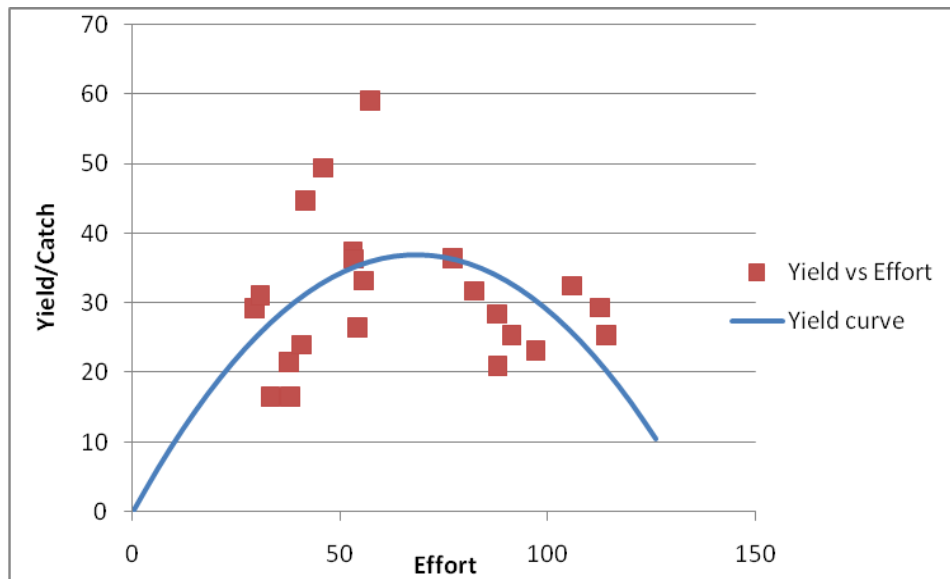


Figure 5: The Schaffer equilibrium yield parabola and yield vs effort data points for the Icelandic bottom trawl fleet targetting Greenland halibut.

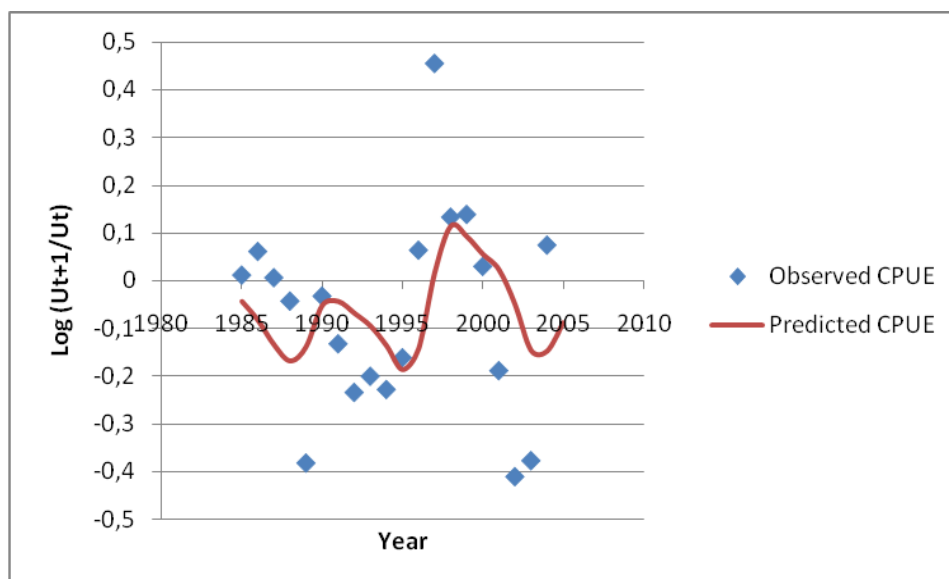


Figure 6: Observed versus predicted catch-per-unit effort in the Icelandic bottom trawl fleet targetting Greenland halibut 1985 - 2006, after adjusting initial regression parameters using time series fitting.

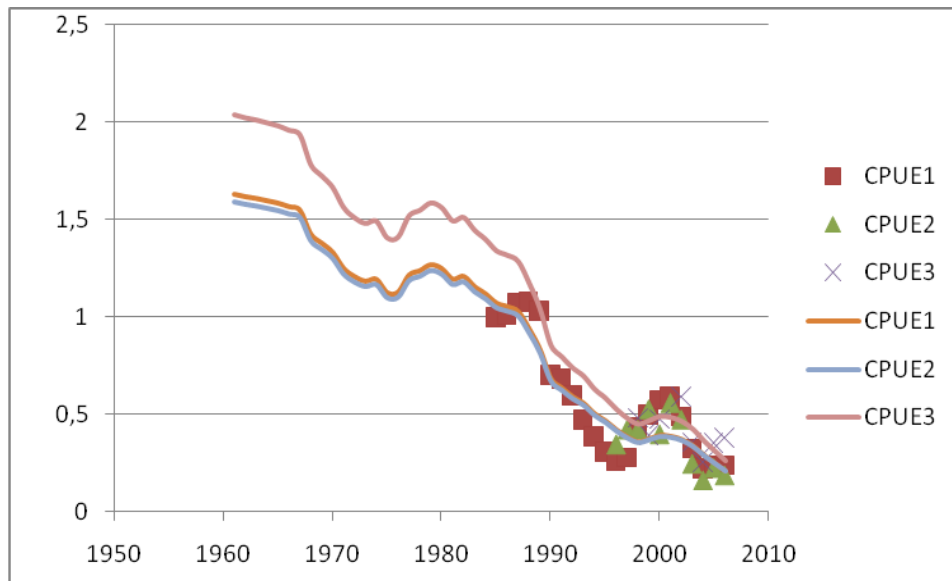


Figure 7: Observed versus predicted catch-per-unit effort for three CPUE series from the Greenland halibut 1985 - 2006, after adjusting initial regression parameters using time series fitting.

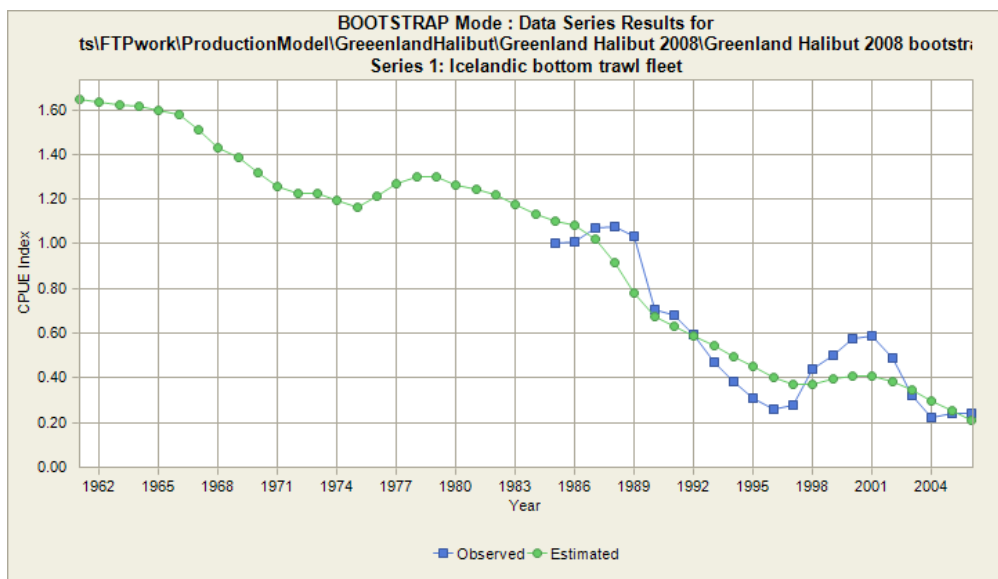


Figure 8: Trend of observed and estimated CPUE from Icelandic bottom trawl fleet targeting Greenland halibut

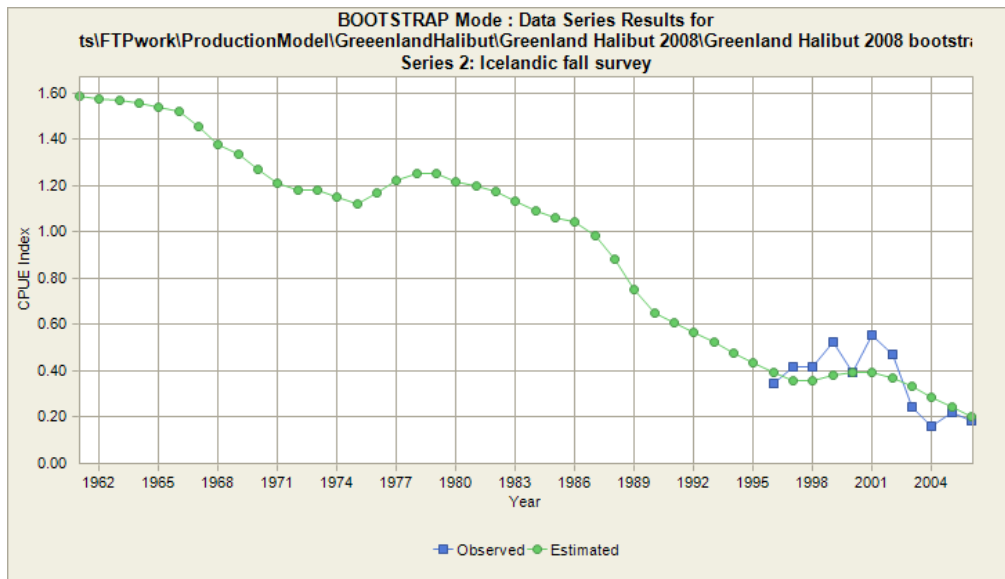


Figure 9: Trend of observed and estimated CPUE from Icelandic fall survey targeting Greenland halibut

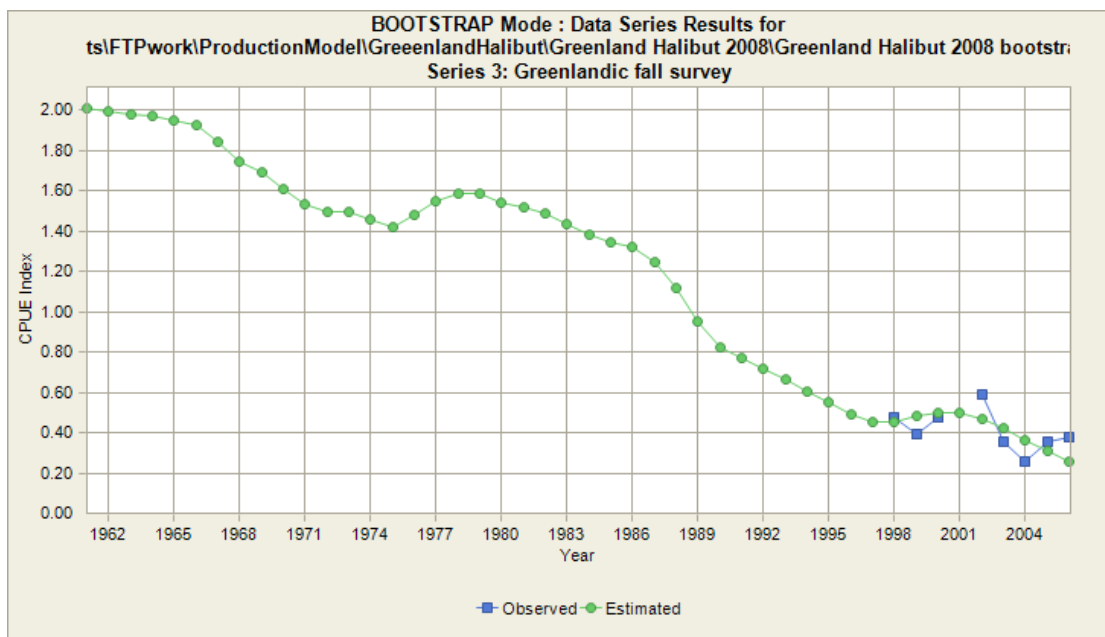


Figure 10: Trend of observed and estimated CPUE from Greenland fall survey targeting Greenland halibut

Table 3: Stock performance as determined from nonequilibrium time series fitting in ASPIC v 5.16 computer programme

year	Estimated total F	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	F/F <sub>(MSY)</sub>	B/B <sub>(MSY)</sub>
1961	0.008	298.4	297.3	2.513	2.513	0.4363	0.0427	2
1962	0.009	296.3	295.5	2.73	2.73	1.145	0.0467	1.986
1963	0.013	294.7	293.6	3.901	3.901	1.851	0.067	1.975
1964	0.016	292.7	291.5	4.74	4.74	2.641	0.082	1.962
1965	0.023	290.6	288.9	6.755	6.755	3.63	0.118	1.948
1966	0.028	287.4	285.7	8.052	8.052	4.8	0.142	1.927
1967	0.113	284.2	272.7	30.7	30.7	9.245	0.569	1.905
1968	0.085	262.7	258.4	21.87	21.87	13.7	0.428	1.761
1969	0.097	254.6	250.1	24.32	24.32	16	0.491	1.706
1970	0.142	246.2	238.3	33.82	33.82	18.96	0.717	1.651
1971	0.127	231.4	227.4	28.97	28.97	21.41	0.644	1.551
1972	0.119	223.8	221.7	26.47	26.47	22.54	0.603	1.5
1973	0.093	219.9	221	20.46	20.46	22.68	0.468	1.474
1974	0.168	222.1	215.4	36.28	36.28	23.69	0.851	1.489
1975	0.112	209.5	210.1	23.49	23.49	24.61	0.565	1.404
1976	0.028	210.6	219.4	6.044	6.044	22.96	0.139	1.412
1977	0.072	227.5	229.8	16.64	16.64	20.91	0.366	1.525
1978	0.061	231.8	234.7	14.36	14.36	19.83	0.309	1.554
1979	0.1	237.3	235.2	23.62	23.62	19.71	0.507	1.59
1980	0.137	233.4	228.1	31.25	31.25	21.26	0.692	1.564
1981	0.086	223.4	224.8	19.24	19.24	21.94	0.433	1.497
1982	0.147	226.1	220.9	32.44	32.44	22.69	0.742	1.515
1983	0.145	216.3	212.8	30.89	30.89	24.16	0.734	1.45
1984	0.166	209.6	205	34.02	34.02	25.38	0.839	1.405
1985	0.146	200.9	199.4	29.2	29.2	26.18	0.74	1.347
1986	0.159	197.9	195.6	31.03	31.03	26.66	0.801	1.327
1987	0.242	193.6	184.7	44.66	44.66	27.82	1.222	1.297
1988	0.297	176.7	166	49.38	49.38	29.1	1.503	1.185
1989	0.42	156.4	140.6	59.05	59.05	29.33	2.122	1.049



Table 3. contd.

Year	Estimated total F	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	F/F <sub>(MSY)</sub>	B/B <sub>(MSY)</sub>
1990	0.305	126.7	122.2	37.31	37.31	28.55	1.543	0.850
1991	0.319	118	113.6	36.29	36.29	27.83	1.614	0.791
1992	0.312	109.5	106.4	33.15	33.15	27.09	1.575	0.734
1993	0.371	103.4	98.08	36.38	36.38	26.05	1.874	0.693
1994	0.354	93.11	89.53	31.73	31.73	24.8	1.791	0.624
1995	0.398	86.18	81.49	32.47	32.47	23.44	2.013	0.578
1996	0.401	77.14	73.28	29.36	29.36	21.87	2.024	0.517
1997	0.377	69.66	67.23	25.35	25.35	20.61	1.905	0.467
1998	0.247	64.93	66.94	16.54	16.54	20.55	1.248	0.435
1999	0.231	68.94	71.45	16.51	16.51	21.5	1.168	0.462
2000	0.291	73.93	74.18	21.57	21.57	22.06	1.469	0.496
2001	0.327	74.43	73.37	23.97	23.97	21.9	1.651	0.499
2002	0.38	72.36	69.61	26.46	26.46	21.12	1.921	0.485
2003	0.456	67.01	62.39	28.43	28.43	19.52	2.303	0.449
2004	0.469	58.1	54.05	25.33	25.33	17.51	2.368	0.390
2005	0.501	50.28	46.27	23.2	23.2	15.47	2.534	0.337
2006	0.545	42.55	38.52	21	21	13.27	2.754	0.285
2007		34.82						0.233

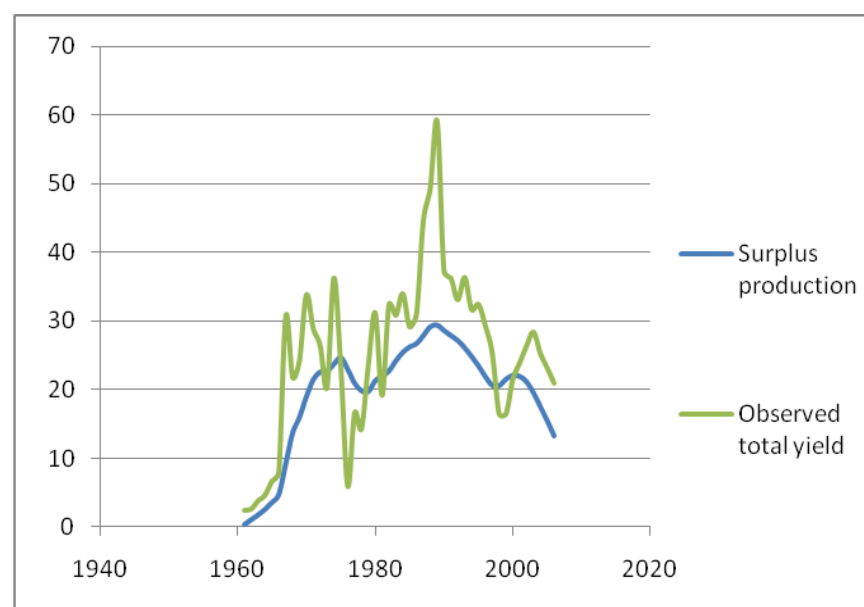


Figure 11: Trend of surplus production and observed yield (catch) for the Greenland halibut 1961 to 2007 from ASPIC fitting.

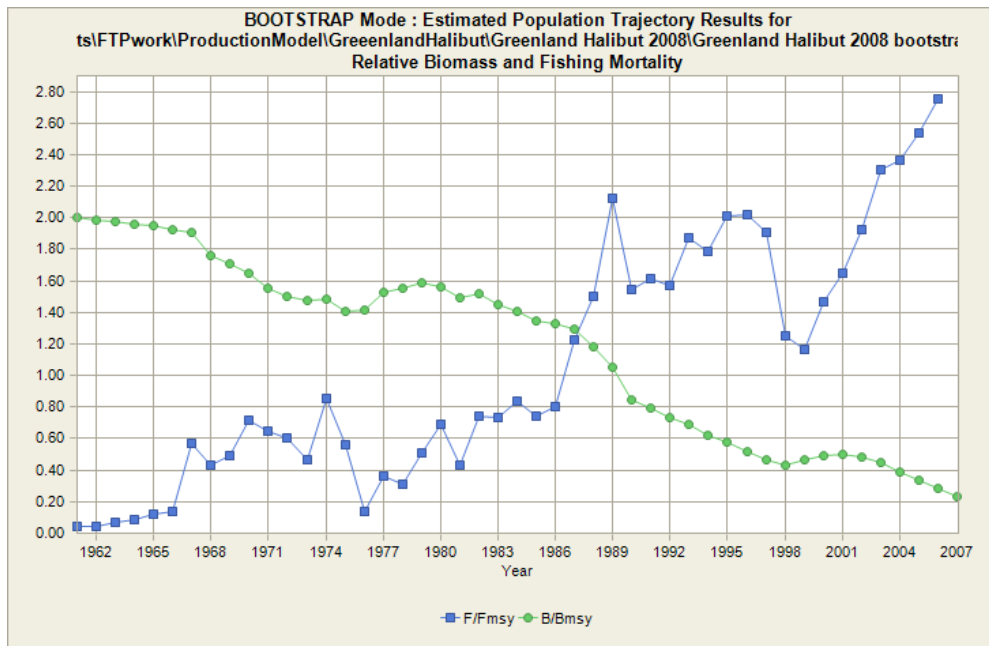


Figure 12: Trend of relative biomass and relative fishing mortality of Greenland halibut in Icelandic waters as predicted by ASPIC 1961-2006.

Table 4: Parameter estimates and management reference points determined from nonequilibrium time series fitting in ASPIC v 5.16 computer programme

				Bias-corrected approximate confidence limits					
Parameter name	Point Estimate	Estimated Bias in Point Estimate	Estimated relative bias	80% Lower	80% Upper	50% Lower	50% Upper	Interquartile Range	Relative Interquartile Range
B1/K	1.000	0.000	0.000	1.000	1.000	1.000	1.000	0.000	0.000
K	298.400	29.540	0.099	213.400	472.200	248.700	370.900	122.200	0.410
q(1)	0.006	0.000	0.021	0.003	0.008	0.004	0.007	0.003	0.453
q(2)	0.005	0.000	0.030	0.003	0.008	0.004	0.007	0.003	0.483
q(3)	0.007	0.000	0.029	0.004	0.010	0.005	0.009	0.003	0.469
MSY	29.520	-0.607	-0.021	24.320	32.940	27.220	31.400	4.176	0.141
Ye(2007)	12.170	-0.335	-0.028	9.982	15.560	11.270	14.000	2.733	0.224
Y. $@F_{(MSY)}$	6.892	-0.147	-0.021	5.429	9.055	6.208	8.013	1.805	0.262
B $_{(MSY)}$	149.200	14.770	0.099	106.700	236.100	124.300	185.400	61.100	0.410
F $_{(MSY)}$	0.198	0.005	0.023	0.103	0.309	0.147	0.253	0.106	0.535
B./B $_{(MSY)}$	0.233	0.003	0.012	0.176	0.314	0.204	0.272	0.068	0.292
F./F $_{(MSY)}$	2.754	0.158	0.058	2.196	3.329	2.449	3.013	0.564	0.205
Ye./MSY	0.412	0.002	0.004	0.321	0.530	0.366	0.470	0.104	0.252

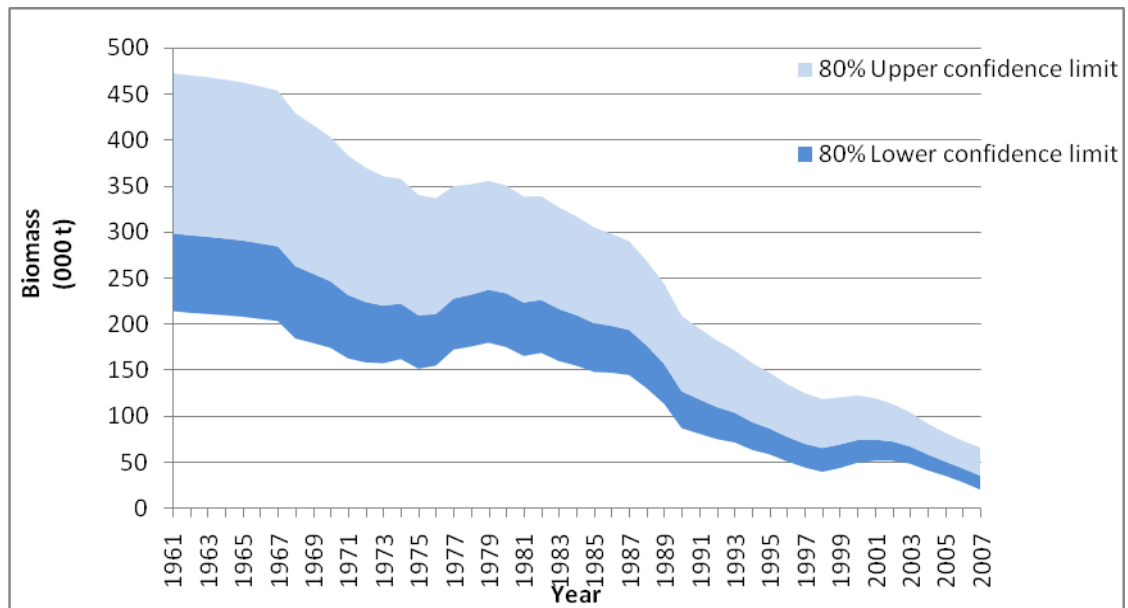
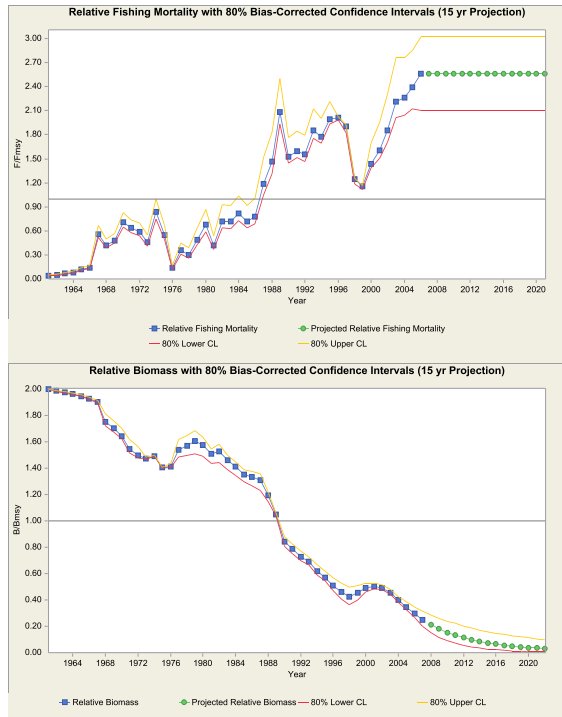
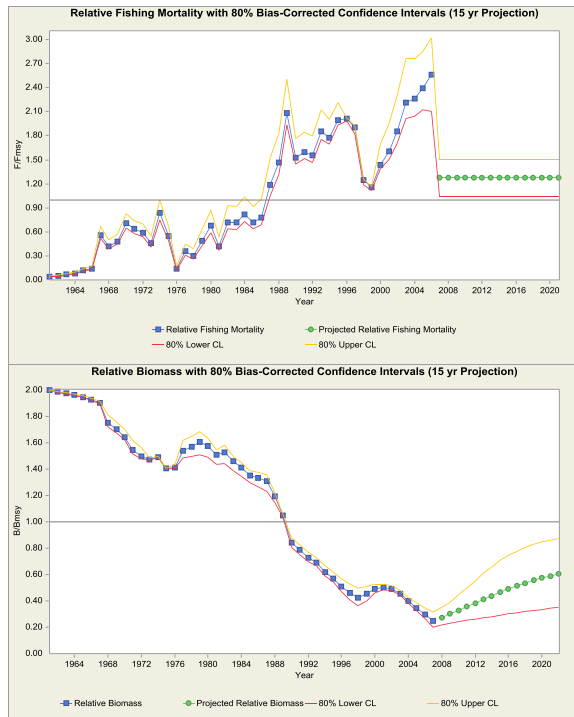


Figure 13: Bootstrap estimated confidence limits results for biomass over the period 1961 to 2006.

A



B



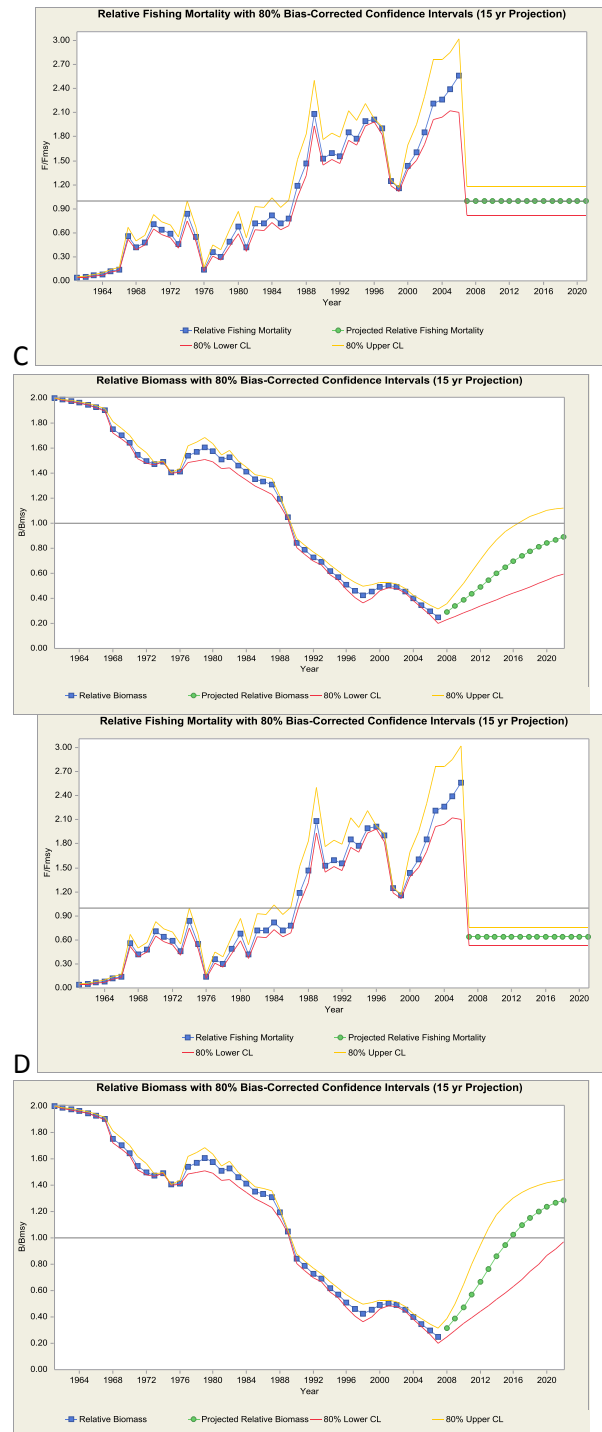


Figure 14: a-d: Expected path of projected relative biomass if stock is fished at different fishing mortalities. A)  $F_{2007-2021} = 1.00$   $F_{2006} = 2.56$  FMSY . B)  $F_{2007-2021} = 0.50$   $F_{2006} = 1.28$  FMSY . C)  $F_{2007-2021} = 0.39$   $F_{2006} = 1.00$  FMSY . D)  $F_{2007-2021} = 0.25$   $F_{2006} = 0.64$  FMSY .

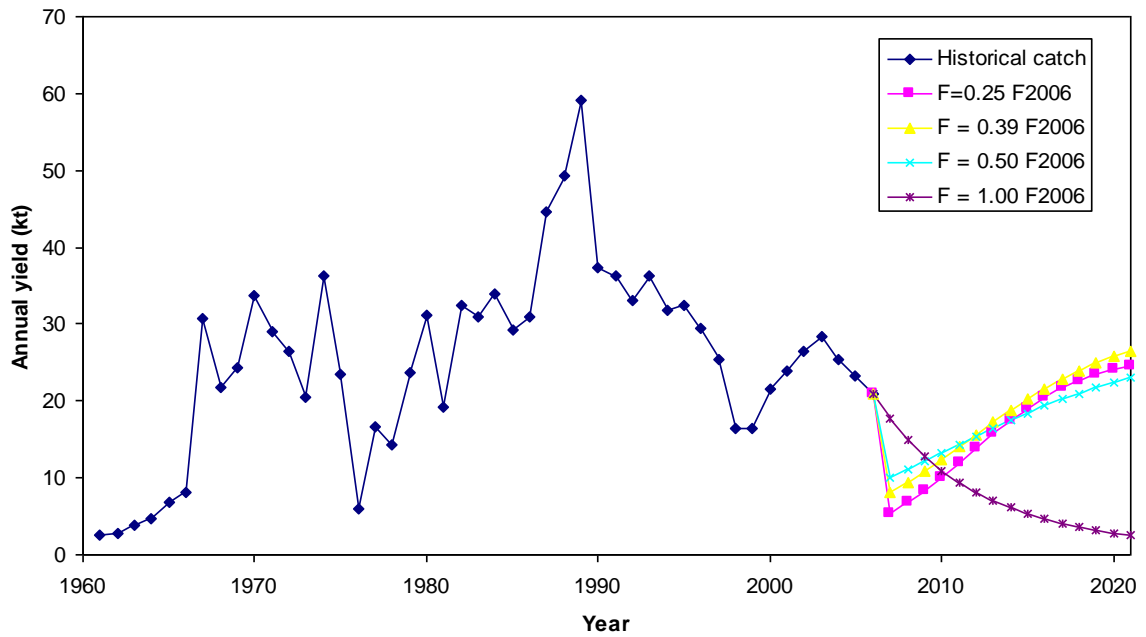


Figure 15: Projection of most likely annual catch under different fishing mortality scenarios.

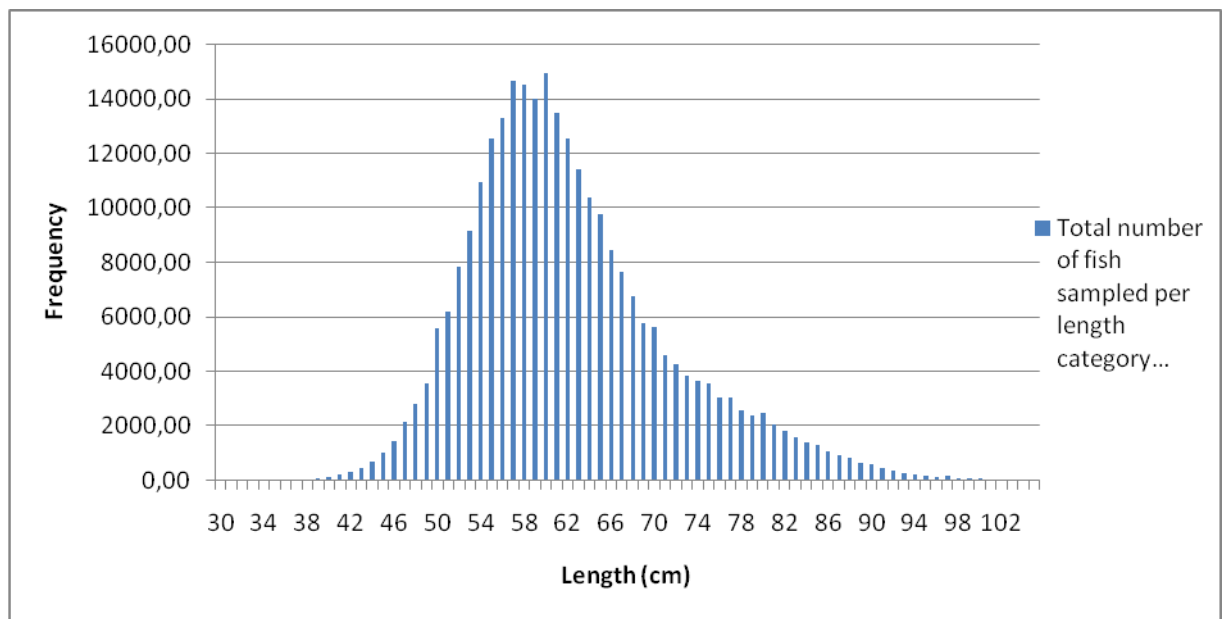


Figure 16: Number of fish measured per length category over the period 1976 – 2007.

Table 5: Growth parameters and mean length at age as determined by using age at length data (MRI Appendix 1) and ELEFAN 1 (FiSAT)

Parameters	ELEFAN 1		Age Length Key	
$L_{\infty}$	110.25		$L_{\infty}$	100
K	0.14		K	0.09371
$t_0$	Assumed = 0		$t_0$	-1.3468
Ages	Mean length		Ages	Mean length
1	14.403		1	19.742
2	26.925		2	26.922
3	37.811		3	33.459
4	47.274		4	39.412
5	55.501		5	44.832
6	62.654		6	49.767
7	68.872		7	54.261
8	74.278		8	58.352
9	78.977		9	62.078
10	83.063		10	65.470
11	86.614		11	68.559
12	89.702		12	71.372
13	92.387		13	73.932
14	94.720		14	76.265
15	96.749		15	78.388
16	98.513		16	80.321
17	100.046		17	82.082
18	101.379		18	83.685
19	102.538		19	85.144
20	103.546		20	86.473
21	104.422		21	87.683
22	105.183		22	88.785



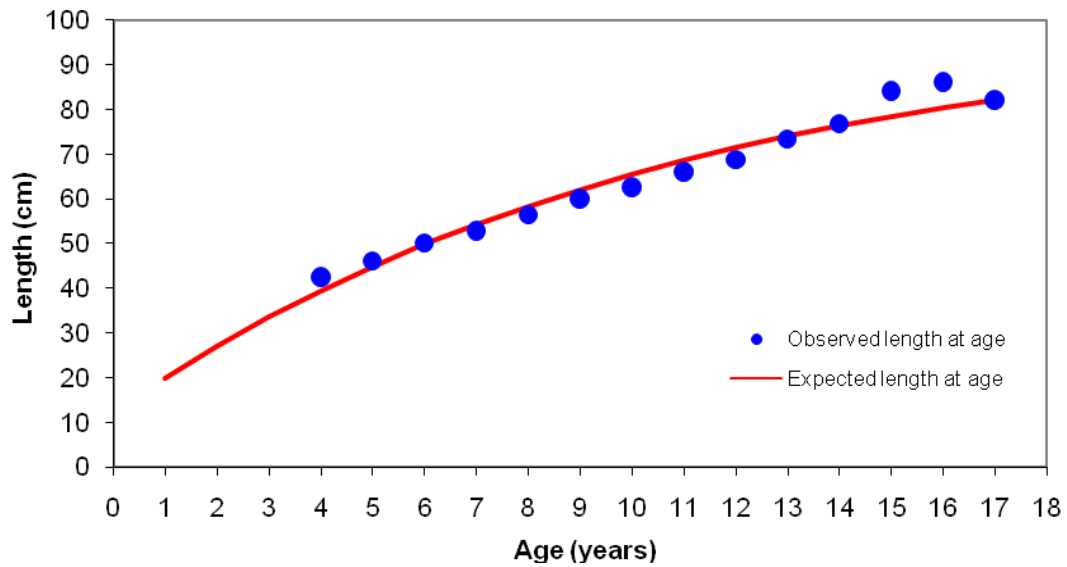
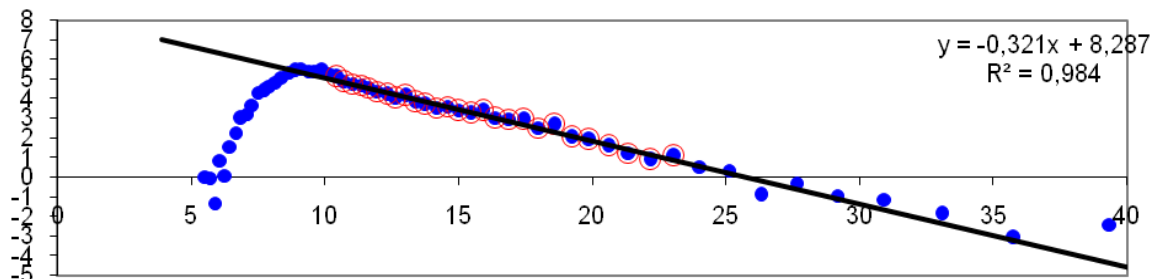
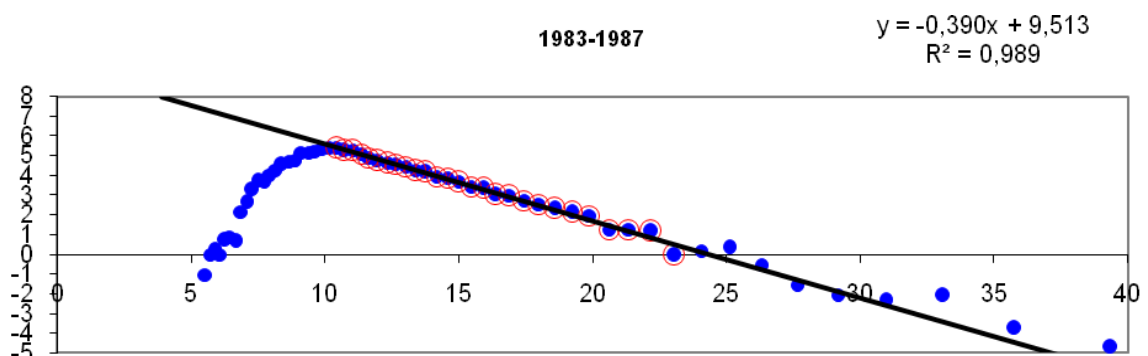


Figure 17: The fitted Von Bertalanffy growth curve for the Greenland halibut produced from growth parameters,  $L_{\infty} = 100$ ,  $K = 0.937$  and  $t_0 = -1.347$  estimated from length at age data.

1978-1982



1983-1987



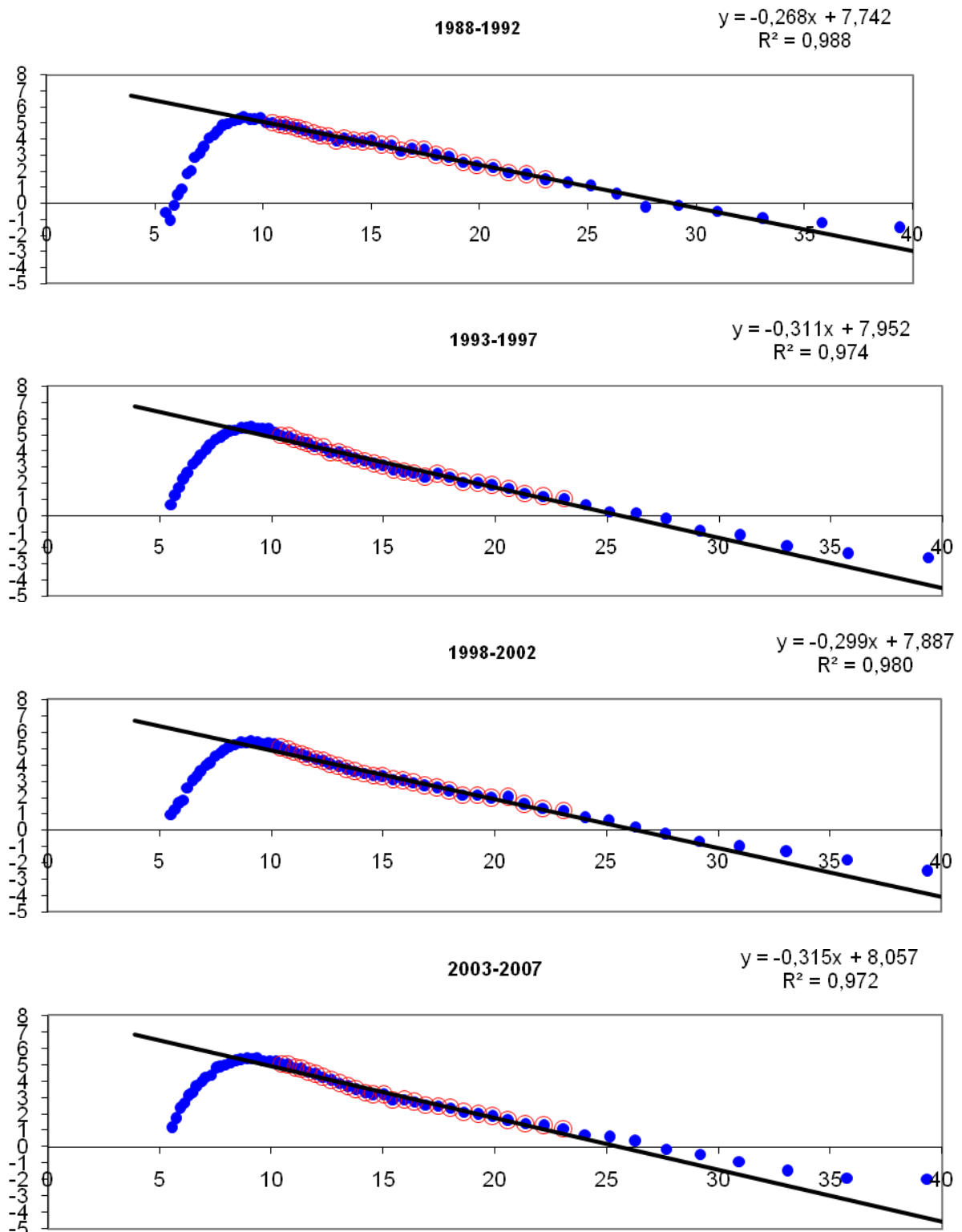


Figure 18: Linearized catch curves for pseudo-cohorts, consisting of the averaged standardized five year length frequencies: 1978-1982, 1983-1987, 1988-1992, 1993-1997, 1998-2002, 2003-2007, estimated from the linearized catch curves where  $L_{\infty} = 100$ ,  $K = 0.0937$  and  $t_0 = -1.34$ .

Table 6: Parameter estimates and Estimates of Z and F (M=0.15) of pseudo-cohorts made from average of 5 years data 1978-2007.

Parameter estimates				Estimates of Z and F (M=0.15) of pseudo-cohorts made from average of 5 years data 1978-2007.					
$L_{\infty}$	K	$t_0$	Z = total mortality F = Fishing mortality	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007
100	0.0937	-1.347	Z	0.321	0.39	0.268	0.311	0.299	0.315
			F	0.171	0.24	0.118	0.161	0.149	0.165

Table 7: Test of sensitivity of Z to different values of  $L_{\infty}$  and K.

Parameter estimates				Estimates of Z and F (M=0.15) of pseudo-cohorts made from average of 5 years data 1978-2007.					
$L_{\infty}$	K	$t_0$	Z = total mortality F = Fishing mortality	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007
96	0.1048	-0.997	Z	0.16	0.191	0.135	0.159	0.152	0.161
			F	0.01	0.041	-0.015	0.009	0.002	0.011
98	0.0990	-1.175	Z	0.154	0.185	0.129	0.153	0.147	0.155
			F	0.004	0.035	-0.021	0.003	-0.003	0.005
100	0.0937	-1.347	Z	0.321	0.39	0.268	0.311	0.299	0.315
			F	0.171	0.24	0.118	0.161	0.149	0.165
106	0.0807	-1.823	Z	0.332	0.408	0.273	0.323	0.309	0.327
			F	0.182	0.258	0.123	0.173	0.159	0.177
110	0.7386	-2.111	Z	0.336	0.416	0.275	0.325	0.314	0.333
			F	0.186	0.266	0.125	0.175	0.164	0.183

## APPENDICES

### Appendix 1:

Length at age for Greenland halibut, from using age estimates based on annual ring structures in otolith. Readings were done at the Marine Research Institute Iceland.

Age	Obs(L)	Obs(W)
1		
2		
3		
4	42,40	758,00
5	46,00	950,00
6	50,10	1213,00
7	52,80	1413,00
8	56,40	1703,00
9	60,00	2028,00
10	62,50	2279,00
11	65,90	2643,00
12	68,70	2992,00
13	73,30	3568,00
14	76,70	4068,00
15	84,00	5302,00
16	86,10	5686,00
17	82,00	4887,00

## Appendix 2: ASPIC output file

Greenland Halibut 2008 Page 1  
Monday, 14 Jan 2008 at 15:10:48  
ASPIC -- A Surplus-Production Model Including Covariates (Ver. 5.16)  
BOT program mode  
Author: Michael H. Prager; NOAA Center for Coastal Fisheries and Habitat Research LOGISTIC model mode  
101 Pivers Island Road; Beaufort, North Carolina 28516 USA YLD conditioning  
Mike.Prager@noaa.gov SSE optimization  
Reference: Prager, M. H. 1994. A suite of extensions to a nonequilibrium ASPIC User's Manual is available  
surplus-production model. Fishery Bulletin 92: 374-389. gratis from the author.  
CONTROL PARAMETERS (FROM INPUT FILE) Input file: c:\my  
documents\ftpwork\productionmodel\greenlandhalibut\gr

---

Operation of ASPIC: Fit logistic (Schaefer) model by direct optimization with bootstrap.  
Number of years analyzed: 46 Number of bootstrap trials: 1000  
Number of data series: 3 Bounds on MSY (min, max): 5.000E+00 1.000E+02  
Objective function: Least squares Bounds on K (min, max): 3.000E+01 5.000E+03  
Relative conv. criterion (simplex): 1.000E-08 Monte Carlo search mode, trials: 0 50000  
Relative conv. criterion (restart): 3.000E-08 Random number seed: 4120359  
Relative conv. criterion (effort): 1.000E-04 Identical convergences required in fitting: 5  
Maximum F allowed in fitting: 4.000  
PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) error code 0

---

Normal convergence  
CORRELATION AMONG INPUT SERIES EXPRESSED AS CPUE (NUMBER OF PAIRWISE OBSERVATIONS BELOW)

---

1 Icelandic bottom trawl fleet		1.000				
		22				
2 Icelandic fall survey		0.822	1.000			
		11	11			
3 Greenlandic fall survey		0.744	0.739	1.000		
		8	8	8		
		1	2	3		

---

GOODNESS-OF-FIT AND WEIGHTING (NON-BOOTSTRAPPED ANALYSIS)

---

Loss component number and title	Weighted SSE	Weighted N	Current MSE	Inv. var. weight	R-squared weight	in CPUE
Loss(-1) SSE in yield	0.000E+00					
Loss(0) Penalty for B1 > K	0.000E+00	1	N/A	1.000E+00	N/A	
Loss(1) Icelandic bottom trawl fleet	1.145E+00	22	5.727E-02	1.000E+00	1.155E+00	0.852
Loss(2) Icelandic fall survey	8.156E-01	11	9.062E-02	1.000E+00	7.300E-01	0.509
Loss(3) Greenlandic fall survey	4.203E-01	8	7.004E-02	1.000E+00	9.445E-01	0.220
<hr/>						
TOTAL OBJECTIVE FUNCTION, MSE, RMSE:			2.38120619E+00	6.614E-02	2.572E-01	
Estimated contrast index (ideal = 1.0):	0.8833		C* = (Bmax-Bmin)/K			
Estimated nearness index (ideal = 1.0):	1.0000		N* = 1 -  min(B-Bmsy) /K			

## MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	User/pgm guess	2nd guess	Estimated	User guess
B1/K Starting relative biomass (in 1961)	1.000E+00	1.000E+00	8.481E-01	0	1
MSY Maximum sustainable yield	2.952E+01	3.000E+01	2.147E+01	1	1
K Maximum population size	2.984E+02	2.000E+02	1.288E+02	1	1
phi Shape of production curve (Bmsy/K)	0.5000	0.5000	----	0	1
----- Catchability Coefficients by Data Series -----					
q(1) Icelandic bottom trawl fleet	5.533E-03	4.000E-04	3.800E-02	1	1
q(2) Icelandic fall survey	5.334E-03	4.000E-04	3.800E-02	1	1
q(3) Greenlandic fall survey	6.758E-03	4.000E-04	3.800E-02	1	1

## MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	Logistic formula	General formula
MSY Maximum sustainable yield	2.952E+01	----	----
Bmsy Stock biomass giving MSY	1.492E+02	K/2	$K \cdot n^{**}(1/(1-n))$
Fmsy Fishing mortality rate at MSY	1.979E-01	MSY/Bmsy	MSY/Bmsy
n Exponent in production function	2.0000	----	----
g Fletcher's gamma	4.000E+00	----	$[n^{**}(n/(n-1))]/[n-1]$
B./Bmsy Ratio: B(2007)/Bmsy	2.334E-01	----	----
F./Fmsy Ratio: F(2006)/Fmsy	2.754E+00	----	----
Fmsy/F. Ratio: Fmsy/F(2006)	3.631E-01	----	----
Y.(Fmsy) Approx. yield available at Fmsy in 2007	6.892E+00	MSY*B./Bmsy	MSY*B./Bmsy
...as proportion of MSY	2.334E-01	----	----
Ye. Equilibrium yield available in 2007	1.217E+01	$4 \cdot MSY \cdot (B/K - (B/K)^{**}2)$	$g \cdot MSY \cdot (B/K - (B/K)^{**}n)$
...as proportion of MSY	4.124E-01	----	----
----- Fishing effort rate at MSY in units of each CE or CC series -----			
fmsy(1) Icelandic bottom trawl fleet	3.577E+01	Fmsy/q( 1)	Fmsy/q( 1)

Greenland Halibut 2008

## ESTIMATED POPULATION TRAJECTORY (NON-BOOTSTRAPPED)

Obs	Year or ID	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to Fmsy	Ratio of biomass to Bmsy
1	1961	0.008	2.984E+02	2.973E+02	2.513E+00	2.513E+00	4.363E-01	4.272E-02	2.000E+00
2	1962	0.009	2.963E+02	2.955E+02	2.730E+00	2.730E+00	1.145E+00	4.669E-02	1.986E+00
3	1963	0.013	2.947E+02	2.936E+02	3.901E+00	3.901E+00	1.851E+00	6.713E-02	1.975E+00
4	1964	0.016	2.927E+02	2.915E+02	4.740E+00	4.740E+00	2.641E+00	8.215E-02	1.962E+00
5	1965	0.023	2.906E+02	2.889E+02	6.755E+00	6.755E+00	3.630E+00	1.181E-01	1.948E+00
6	1966	0.028	2.874E+02	2.857E+02	8.052E+00	8.052E+00	4.800E+00	1.424E-01	1.927E+00
7	1967	0.113	2.842E+02	2.727E+02	3.070E+01	3.070E+01	9.245E+00	5.689E-01	1.905E+00
8	1968	0.085	2.627E+02	2.584E+02	2.187E+01	2.187E+01	1.370E+01	4.277E-01	1.761E+00
9	1969	0.097	2.546E+02	2.501E+02	2.432E+01	2.432E+01	1.600E+01	4.913E-01	1.706E+00
10	1970	0.142	2.462E+02	2.383E+02	3.382E+01	3.382E+01	1.896E+01	7.171E-01	1.651E+00
11	1971	0.127	2.314E+02	2.274E+02	2.897E+01	2.897E+01	2.141E+01	6.439E-01	1.551E+00
12	1972	0.119	2.238E+02	2.217E+02	2.647E+01	2.647E+01	2.254E+01	6.032E-01	1.500E+00
13	1973	0.093	2.199E+02	2.210E+02	2.046E+01	2.046E+01	2.268E+01	4.678E-01	1.474E+00
14	1974	0.168	2.221E+02	2.154E+02	3.628E+01	3.628E+01	2.369E+01	8.510E-01	1.489E+00
15	1975	0.112	2.095E+02	2.101E+02	2.349E+01	2.349E+01	2.461E+01	5.651E-01	1.404E+00
16	1976	0.028	2.106E+02	2.194E+02	6.044E+00	6.044E+00	2.296E+01	1.392E-01	1.412E+00
17	1977	0.072	2.275E+02	2.298E+02	1.664E+01	1.664E+01	2.091E+01	3.660E-01	1.525E+00
18	1978	0.061	2.318E+02	2.347E+02	1.436E+01	1.436E+01	1.983E+01	3.092E-01	1.554E+00
19	1979	0.100	2.373E+02	2.352E+02	2.362E+01	2.362E+01	1.971E+01	5.074E-01	1.590E+00
20	1980	0.137	2.334E+02	2.281E+02	3.125E+01	3.125E+01	2.126E+01	6.924E-01	1.564E+00
21	1981	0.086	2.234E+02	2.248E+02	1.924E+01	1.924E+01	2.194E+01	4.325E-01	1.497E+00
22	1982	0.147	2.261E+02	2.209E+02	3.244E+01	3.244E+01	2.269E+01	7.420E-01	1.515E+00
23	1983	0.145	2.163E+02	2.128E+02	3.089E+01	3.089E+01	2.416E+01	7.335E-01	1.450E+00
24	1984	0.166	2.096E+02	2.050E+02	3.402E+01	3.402E+01	2.538E+01	8.385E-01	1.405E+00
25	1985	0.146	2.009E+02	1.994E+02	2.920E+01	2.920E+01	2.618E+01	7.400E-01	1.347E+00
26	1986	0.159	1.979E+02	1.956E+02	3.103E+01	3.103E+01	2.666E+01	8.014E-01	1.327E+00
27	1987	0.242	1.936E+02	1.847E+02	4.466E+01	4.466E+01	2.782E+01	1.222E+00	1.297E+00
28	1988	0.297	1.767E+02	1.660E+02	4.938E+01	4.938E+01	2.910E+01	1.503E+00	1.185E+00
29	1989	0.420	1.564E+02	1.406E+02	5.905E+01	5.905E+01	2.933E+01	2.122E+00	1.049E+00
30	1990	0.305	1.267E+02	1.222E+02	3.731E+01	3.731E+01	2.855E+01	1.543E+00	8.495E-01
31	1991	0.319	1.180E+02	1.136E+02	3.629E+01	3.629E+01	2.783E+01	1.614E+00	7.907E-01
32	1992	0.312	1.095E+02	1.064E+02	3.315E+01	3.315E+01	2.709E+01	1.575E+00	7.341E-01
33	1993	0.371	1.034E+02	9.808E+01	3.638E+01	3.638E+01	2.605E+01	1.874E+00	6.934E-01
34	1994	0.354	9.311E+01	8.953E+01	3.173E+01	3.173E+01	2.480E+01	1.791E+00	6.241E-01
35	1995	0.398	8.618E+01	8.149E+01	3.247E+01	3.247E+01	2.344E+01	2.013E+00	5.777E-01
36	1996	0.401	7.714E+01	7.328E+01	2.936E+01	2.936E+01	2.187E+01	2.024E+00	5.171E-01
37	1997	0.377	6.966E+01	6.723E+01	2.535E+01	2.535E+01	2.061E+01	1.905E+00	4.670E-01
38	1998	0.247	6.493E+01	6.694E+01	1.654E+01	1.654E+01	2.055E+01	1.248E+00	4.352E-01
39	1999	0.231	6.894E+01	7.145E+01	1.651E+01	1.651E+01	2.150E+01	1.168E+00	4.621E-01
40	2000	0.291	7.393E+01	7.418E+01	2.157E+01	2.157E+01	2.206E+01	1.469E+00	4.956E-01
41	2001	0.327	7.443E+01	7.337E+01	2.397E+01	2.397E+01	2.190E+01	1.651E+00	4.989E-01
42	2002	0.380	7.236E+01	6.961E+01	2.646E+01	2.646E+01	2.112E+01	1.921E+00	4.850E-01
43	2003	0.456	6.701E+01	6.239E+01	2.843E+01	2.843E+01	1.952E+01	2.303E+00	4.492E-01
44	2004	0.469	5.810E+01	5.405E+01	2.533E+01	2.533E+01	1.751E+01	2.368E+00	3.895E-01
45	2005	0.501	5.028E+01	4.627E+01	2.320E+01	2.320E+01	1.547E+01	2.534E+00	3.371E-01
46	2006	0.545	4.255E+01	3.852E+01	2.100E+01	2.100E+01	1.327E+01	2.754E+00	2.852E-01
47	2007		3.482E+01				2.334E-01		

## RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED)

Icelandic bottom trawl fleet

Data type CC: CPUE-catch series

Series weight: 1.000

Obs	Year	Observed CPUE	Estimated CPUE	Estim F	Observed yield	Model yield	Resid in log scale	Statist weight
1	1961	*	1.645E+00	0.0085	2.513E+00	2.513E+00	0.00000	1.000E+00
2	1962	*	1.635E+00	0.0092	2.730E+00	2.730E+00	0.00000	1.000E+00
3	1963	*	1.624E+00	0.0133	3.901E+00	3.901E+00	0.00000	1.000E+00
4	1964	*	1.613E+00	0.0163	4.740E+00	4.740E+00	0.00000	1.000E+00
5	1965	*	1.598E+00	0.0234	6.755E+00	6.755E+00	0.00000	1.000E+00
6	1966	*	1.581E+00	0.0282	8.052E+00	8.052E+00	0.00000	1.000E+00
7	1967	*	1.509E+00	0.1126	3.070E+01	3.070E+01	0.00000	1.000E+00
8	1968	*	1.430E+00	0.0846	2.187E+01	2.187E+01	0.00000	1.000E+00
9	1969	*	1.384E+00	0.0972	2.432E+01	2.432E+01	0.00000	1.000E+00
10	1970	*	1.319E+00	0.1419	3.382E+01	3.382E+01	0.00000	1.000E+00
11	1971	*	1.258E+00	0.1274	2.897E+01	2.897E+01	0.00000	1.000E+00
12	1972	*	1.227E+00	0.1194	2.647E+01	2.647E+01	0.00000	1.000E+00
13	1973	*	1.223E+00	0.0926	2.046E+01	2.046E+01	0.00000	1.000E+00
14	1974	*	1.192E+00	0.1684	3.628E+01	3.628E+01	0.00000	1.000E+00
15	1975	*	1.162E+00	0.1118	2.349E+01	2.349E+01	0.00000	1.000E+00
16	1976	*	1.214E+00	0.0276	6.044E+00	6.044E+00	0.00000	1.000E+00
17	1977	*	1.271E+00	0.0724	1.664E+01	1.664E+01	0.00000	1.000E+00
18	1978	*	1.298E+00	0.0612	1.436E+01	1.436E+01	0.00000	1.000E+00
19	1979	*	1.301E+00	0.1004	2.362E+01	2.362E+01	0.00000	1.000E+00
20	1980	*	1.262E+00	0.1370	3.125E+01	3.125E+01	0.00000	1.000E+00
21	1981	*	1.244E+00	0.0856	1.924E+01	1.924E+01	0.00000	1.000E+00
22	1982	*	1.222E+00	0.1468	3.244E+01	3.244E+01	0.00000	1.000E+00
23	1983	*	1.177E+00	0.1452	3.089E+01	3.089E+01	0.00000	1.000E+00
24	1984	*	1.134E+00	0.1659	3.402E+01	3.402E+01	0.00000	1.000E+00
25	1985	1.000E+00	1.103E+00	0.1465	2.920E+01	2.920E+01	0.09802	1.000E+00
26	1986	1.011E+00	1.082E+00	0.1586	3.103E+01	3.103E+01	0.06823	1.000E+00
27	1987	1.074E+00	1.022E+00	0.2418	4.466E+01	4.466E+01	-0.04992	1.000E+00
28	1988	1.080E+00	9.185E-01	0.2975	4.938E+01	4.938E+01	-0.16202	1.000E+00
29	1989	1.034E+00	7.779E-01	0.4200	5.905E+01	5.905E+01	-0.28457	1.000E+00
30	1990	7.050E-01	6.760E-01	0.3054	3.731E+01	3.731E+01	-0.04207	1.000E+00
31	1991	6.820E-01	6.284E-01	0.3195	3.629E+01	3.629E+01	-0.08184	1.000E+00
32	1992	5.970E-01	5.886E-01	0.3117	3.315E+01	3.315E+01	-0.01423	1.000E+00
33	1993	4.720E-01	5.426E-01	0.3710	3.638E+01	3.638E+01	0.13943	1.000E+00
34	1994	3.860E-01	4.953E-01	0.3544	3.173E+01	3.173E+01	0.24941	1.000E+00
35	1995	3.070E-01	4.509E-01	0.3984	3.247E+01	3.247E+01	0.38436	1.000E+00
36	1996	2.610E-01	4.054E-01	0.4006	2.936E+01	2.936E+01	0.44044	1.000E+00
37	1997	2.780E-01	3.720E-01	0.3771	2.535E+01	2.535E+01	0.29119	1.000E+00
38	1998	4.380E-01	3.704E-01	0.2470	1.654E+01	1.654E+01	-0.16771	1.000E+00
39	1999	5.000E-01	3.953E-01	0.2311	1.651E+01	1.651E+01	-0.23499	1.000E+00
40	2000	5.740E-01	4.104E-01	0.2907	2.157E+01	2.157E+01	-0.33541	1.000E+00
41	2001	5.910E-01	4.059E-01	0.3267	2.397E+01	2.397E+01	-0.37562	1.000E+00
42	2002	4.890E-01	3.851E-01	0.3802	2.646E+01	2.646E+01	-0.23879	1.000E+00
43	2003	3.240E-01	3.452E-01	0.4557	2.843E+01	2.843E+01	0.06333	1.000E+00
44	2004	2.220E-01	2.990E-01	0.4687	2.533E+01	2.533E+01	0.29792	1.000E+00
45	2005	2.390E-01	2.560E-01	0.5014	2.320E+01	2.320E+01	0.06866	1.000E+00
46	2006	2.390E-01	2.131E-01	0.5451	2.100E+01	2.100E+01	-0.11450	1.000E+00

\* Asterisk indicates missing value(s).



## RESULTS FOR DATA SERIES # 2 (NON-BOOTSTRAPPED)

Icelandic fall survey

Data type II: Abundance index (annual average)

Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed index	Model index	Resid in log index	Statist weight
1	1961	0.000E+00	0.000E+00	-- *		1.585E+00	0.00000	1.000E+00
2	1962	0.000E+00	0.000E+00	-- *		1.576E+00	0.00000	1.000E+00
3	1963	0.000E+00	0.000E+00	-- *		1.566E+00	0.00000	1.000E+00
4	1964	0.000E+00	0.000E+00	-- *		1.555E+00	0.00000	1.000E+00
5	1965	0.000E+00	0.000E+00	-- *		1.541E+00	0.00000	1.000E+00
6	1966	0.000E+00	0.000E+00	-- *		1.524E+00	0.00000	1.000E+00
7	1967	0.000E+00	0.000E+00	-- *		1.454E+00	0.00000	1.000E+00
8	1968	0.000E+00	0.000E+00	-- *		1.378E+00	0.00000	1.000E+00
9	1969	0.000E+00	0.000E+00	-- *		1.334E+00	0.00000	1.000E+00
10	1970	0.000E+00	0.000E+00	-- *		1.271E+00	0.00000	1.000E+00
11	1971	0.000E+00	0.000E+00	-- *		1.213E+00	0.00000	1.000E+00
12	1972	0.000E+00	0.000E+00	-- *		1.183E+00	0.00000	1.000E+00
13	1973	0.000E+00	0.000E+00	-- *		1.179E+00	0.00000	1.000E+00
14	1974	0.000E+00	0.000E+00	-- *		1.149E+00	0.00000	1.000E+00
15	1975	0.000E+00	0.000E+00	-- *		1.120E+00	0.00000	1.000E+00
16	1976	0.000E+00	0.000E+00	-- *		1.170E+00	0.00000	1.000E+00
17	1977	0.000E+00	0.000E+00	-- *		1.225E+00	0.00000	1.000E+00
18	1978	0.000E+00	0.000E+00	-- *		1.252E+00	0.00000	1.000E+00
19	1979	0.000E+00	0.000E+00	-- *		1.254E+00	0.00000	1.000E+00
20	1980	0.000E+00	0.000E+00	-- *		1.216E+00	0.00000	1.000E+00
21	1981	0.000E+00	0.000E+00	-- *		1.199E+00	0.00000	1.000E+00
22	1982	0.000E+00	0.000E+00	-- *		1.178E+00	0.00000	1.000E+00
23	1983	0.000E+00	0.000E+00	-- *		1.135E+00	0.00000	1.000E+00
24	1984	0.000E+00	0.000E+00	-- *		1.094E+00	0.00000	1.000E+00
25	1985	0.000E+00	0.000E+00	-- *		1.063E+00	0.00000	1.000E+00
26	1986	0.000E+00	0.000E+00	-- *		1.043E+00	0.00000	1.000E+00
27	1987	0.000E+00	0.000E+00	-- *		9.849E-01	0.00000	1.000E+00
28	1988	0.000E+00	0.000E+00	-- *		8.854E-01	0.00000	1.000E+00
29	1989	0.000E+00	0.000E+00	-- *		7.499E-01	0.00000	1.000E+00
30	1990	0.000E+00	0.000E+00	-- *		6.516E-01	0.00000	1.000E+00
31	1991	0.000E+00	0.000E+00	-- *		6.058E-01	0.00000	1.000E+00
32	1992	0.000E+00	0.000E+00	-- *		5.674E-01	0.00000	1.000E+00
33	1993	0.000E+00	0.000E+00	-- *		5.231E-01	0.00000	1.000E+00
34	1994	0.000E+00	0.000E+00	-- *		4.775E-01	0.00000	1.000E+00
35	1995	0.000E+00	0.000E+00	-- *		4.347E-01	0.00000	1.000E+00
36	1996	1.000E+00	1.000E+00	--	3.440E-01	3.908E-01	-0.12767	1.000E+00
37	1997	1.000E+00	1.000E+00	--	4.200E-01	3.586E-01	0.15810	1.000E+00
38	1998	1.000E+00	1.000E+00	--	4.200E-01	3.570E-01	0.16239	1.000E+00
39	1999	1.000E+00	1.000E+00	--	5.240E-01	3.811E-01	0.31852	1.000E+00
40	2000	1.000E+00	1.000E+00	--	3.960E-01	3.957E-01	0.00084	1.000E+00
41	2001	1.000E+00	1.000E+00	--	5.570E-01	3.913E-01	0.35302	1.000E+00
42	2002	1.000E+00	1.000E+00	--	4.720E-01	3.713E-01	0.24006	1.000E+00
43	2003	1.000E+00	1.000E+00	--	2.440E-01	3.328E-01	-0.31025	1.000E+00
44	2004	1.000E+00	1.000E+00	--	1.600E-01	2.883E-01	-0.58878	1.000E+00
45	2005	1.000E+00	1.000E+00	--	2.230E-01	2.468E-01	-0.10130	1.000E+00
46	2006	1.000E+00	1.000E+00	--	1.850E-01	2.055E-01	-0.10496	1.000E+00

\* Asterisk indicates missing value(s).

## RESULTS FOR DATA SERIES # 3 (NON-BOOTSTRAPPED)

Greenlandic fall survey

Data type II: Abundance index (annual average)

Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed index	Model index	Resid in log index	Statist weight
1	1961	0.000E+00	0.000E+00	-- *		2.009E+00	0.00000	1.000E+00
2	1962	0.000E+00	0.000E+00	-- *		1.997E+00	0.00000	1.000E+00
3	1963	0.000E+00	0.000E+00	-- *		1.984E+00	0.00000	1.000E+00
4	1964	0.000E+00	0.000E+00	-- *		1.970E+00	0.00000	1.000E+00
5	1965	0.000E+00	0.000E+00	-- *		1.952E+00	0.00000	1.000E+00
6	1966	0.000E+00	0.000E+00	-- *		1.931E+00	0.00000	1.000E+00
7	1967	0.000E+00	0.000E+00	-- *		1.843E+00	0.00000	1.000E+00
8	1968	0.000E+00	0.000E+00	-- *		1.746E+00	0.00000	1.000E+00
9	1969	0.000E+00	0.000E+00	-- *		1.690E+00	0.00000	1.000E+00
10	1970	0.000E+00	0.000E+00	-- *		1.611E+00	0.00000	1.000E+00
11	1971	0.000E+00	0.000E+00	-- *		1.537E+00	0.00000	1.000E+00
12	1972	0.000E+00	0.000E+00	-- *		1.498E+00	0.00000	1.000E+00
13	1973	0.000E+00	0.000E+00	-- *		1.494E+00	0.00000	1.000E+00
14	1974	0.000E+00	0.000E+00	-- *		1.456E+00	0.00000	1.000E+00
15	1975	0.000E+00	0.000E+00	-- *		1.420E+00	0.00000	1.000E+00
16	1976	0.000E+00	0.000E+00	-- *		1.482E+00	0.00000	1.000E+00
17	1977	0.000E+00	0.000E+00	-- *		1.553E+00	0.00000	1.000E+00
18	1978	0.000E+00	0.000E+00	-- *		1.586E+00	0.00000	1.000E+00
19	1979	0.000E+00	0.000E+00	-- *		1.589E+00	0.00000	1.000E+00
20	1980	0.000E+00	0.000E+00	-- *		1.541E+00	0.00000	1.000E+00
21	1981	0.000E+00	0.000E+00	-- *		1.519E+00	0.00000	1.000E+00
22	1982	0.000E+00	0.000E+00	-- *		1.493E+00	0.00000	1.000E+00
23	1983	0.000E+00	0.000E+00	-- *		1.438E+00	0.00000	1.000E+00
24	1984	0.000E+00	0.000E+00	-- *		1.386E+00	0.00000	1.000E+00
25	1985	0.000E+00	0.000E+00	-- *		1.347E+00	0.00000	1.000E+00
26	1986	0.000E+00	0.000E+00	-- *		1.322E+00	0.00000	1.000E+00
27	1987	0.000E+00	0.000E+00	-- *		1.248E+00	0.00000	1.000E+00
28	1988	0.000E+00	0.000E+00	-- *		1.122E+00	0.00000	1.000E+00
29	1989	0.000E+00	0.000E+00	-- *		9.502E-01	0.00000	1.000E+00
30	1990	0.000E+00	0.000E+00	-- *		8.256E-01	0.00000	1.000E+00
31	1991	0.000E+00	0.000E+00	-- *		7.675E-01	0.00000	1.000E+00
32	1992	0.000E+00	0.000E+00	-- *		7.189E-01	0.00000	1.000E+00
33	1993	0.000E+00	0.000E+00	-- *		6.628E-01	0.00000	1.000E+00
34	1994	0.000E+00	0.000E+00	-- *		6.050E-01	0.00000	1.000E+00
35	1995	0.000E+00	0.000E+00	-- *		5.507E-01	0.00000	1.000E+00
36	1996	0.000E+00	0.000E+00	-- *		4.952E-01	0.00000	1.000E+00
37	1997	0.000E+00	0.000E+00	-- *		4.543E-01	0.00000	1.000E+00
38	1998	1.000E+00	1.000E+00	--	4.800E-01	4.524E-01	0.05927	1.000E+00
39	1999	1.000E+00	1.000E+00	--	3.940E-01	4.828E-01	-0.20327	1.000E+00
40	2000	1.000E+00	1.000E+00	--	4.740E-01	5.013E-01	-0.05602	1.000E+00
41	2001	0.000E+00	0.000E+00	-- *		4.958E-01	0.00000	1.000E+00
42	2002	1.000E+00	1.000E+00	--	5.890E-01	4.704E-01	0.22485	1.000E+00
43	2003	1.000E+00	1.000E+00	--	3.560E-01	4.216E-01	-0.16915	1.000E+00
44	2004	1.000E+00	1.000E+00	--	2.540E-01	3.653E-01	-0.36328	1.000E+00
45	2005	1.000E+00	1.000E+00	--	3.550E-01	3.127E-01	0.12699	1.000E+00
46	2006	1.000E+00	1.000E+00	--	3.810E-01	2.603E-01	0.38083	1.000E+00

\* Asterisk indicates missing value(s).

## ESTIMATES FROM BOOTSTRAPPED ANALYSIS

Param name	Estimated			Bias-corrected approximate confidence limits				Inter-		Relative range	IQ range
	Point estimate	bias in pt estimate	relative bias	80% lower	80% upper	50% lower	50% upper	quartile	Relative		
B1/K	1.000E+00	-3.083E-10	0.00%	1.000E+00	1.000E+00	1.000E+00	1.000E+00	5.267E-11	0.000		
K	2.984E+02	2.954E+01	9.90%	2.134E+02	4.722E+02	2.487E+02	3.709E+02	1.222E+02	0.410		
q(1)	5.533E-03	1.158E-04	2.09%	3.395E-03	8.248E-03	4.343E-03	6.848E-03	2.505E-03	0.453		
q(2)	5.334E-03	1.572E-04	2.95%	3.202E-03	8.212E-03	4.127E-03	6.700E-03	2.574E-03	0.483		
q(3)	6.758E-03	1.944E-04	2.88%	4.101E-03	1.022E-02	5.347E-03	8.516E-03	3.169E-03	0.469		
MSY	2.952E+01	-6.068E-01	-2.06%	2.432E+01	3.294E+01	2.722E+01	3.140E+01	4.176E+00	0.141		
Ye(2007)	1.217E+01	-3.352E-01	-2.75%	9.982E+00	1.556E+01	1.127E+01	1.400E+01	2.733E+00	0.224		
Y.@Fmsy	6.892E+00	-1.474E-01	-2.14%	5.429E+00	9.055E+00	6.208E+00	8.013E+00	1.805E+00	0.262		
Bmsy	1.492E+02	1.477E+01	9.90%	1.067E+02	2.361E+02	1.243E+02	1.854E+02	6.110E+01	0.410		
Fmsy	1.979E-01	4.553E-03	2.30%	1.030E-01	3.089E-01	1.469E-01	2.527E-01	1.058E-01	0.535		
fmsy(1)	3.577E+01	-8.284E-01	-2.32%	3.110E+01	3.978E+01	3.390E+01	3.803E+01	4.133E+00	0.116		
fmsy(2)	3.711E+01	-7.862E-01	-2.12%	3.217E+01	4.264E+01	3.488E+01	4.021E+01	5.336E+00	0.144		
fmsy(3)	2.929E+01	-6.241E-01	-2.13%	2.445E+01	3.442E+01	2.709E+01	3.227E+01	5.186E+00	0.177		
B./Bmsy	2.334E-01	2.762E-03	1.18%	1.761E-01	3.142E-01	2.040E-01	2.720E-01	6.807E-02	0.292		
F./Fmsy	2.754E+00	1.583E-01	5.75%	2.196E+00	3.329E+00	2.449E+00	3.013E+00	5.640E-01	0.205		
Ye./MSY	4.124E-01	1.503E-03	0.36%	3.213E-01	5.297E-01	3.663E-01	4.701E-01	1.037E-01	0.252		
q2/q1	9.640E-01	3.762E-03	0.39%	8.516E-01	1.095E+00	9.016E-01	1.039E+00	1.370E-01	0.142		
q3/q1	1.221E+00	1.017E-02	0.83%	1.055E+00	1.406E+00	1.124E+00	1.322E+00	1.977E-01	0.162		

## INFORMATION FOR REPAST (Prager, Porch, Shertzer, &amp; Caddy. 2003. NAJFM 23: 349-361)

Unitless limit reference point in F (Fmsy/F.):	0.3631
CV of above (from bootstrap distribution):	0.1715

## NOTES ON BOOTSTRAPPED ESTIMATES:

- Bootstrap results were computed from 1000 trials.
- Results are conditional on bounds set on MSY and K in the input file.
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The default 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.
- Bias estimates are typically of high variance and therefore may be misleading.

Trials replaced for lack of convergence:	0	Trials replaced for MSY out of bounds:	4
Trials replaced for q out-of-bounds:	0		
Trials replaced for K out-of-bounds:	0	Residual-adjustment factor:	1.0672

Elapsed time: 0 hours, 4 minutes, 59 seconds.