Northwest Atlantic Fisheries Organization

Serial No. N5687 **NAFO SCR Doc. 09/48**

SC WG ON GREENLAND HALIBUT ASSESSMENT METHODS – JUNE 2009

A Stock Production Model Incorporating Covariates (ASPIC) for Greenland halibut (*Reinhardtius hippoglossoides*) including sensitivity and retrospective analyses.

D. Maddock Parsons & B. Healey

Abstract

A stock production model (ASPIC) was applied to age-aggregated biomass indices covering the same time period and from surveys used in the XSA assessment accepted by Scientific Council in recent years. Results were sensitive to the starting estimates for several parameters, and resulted in two very different estimates of relative biomass and fishing mortality. Retrospective patterns were also problematic for the two resulting solutions. When standardized CPUE series (from Canadian, Russian and Portuguese fisheries) were included in the model with the catch and survey indices, model diagnostics and fit were poor and results were considered unacceptable. Using only the CPUE series and catch information resulted in model fits and results similar to those using biomass indices and catch alone. Sensitivity analyses for the model including only CPUE and catch also indicated two possible solutions. Retrospective patterns for the CPUE/catch runs were severe and were not considered acceptable.

Methods

Surplus production model (ASPIC)

A non-equilibrium surplus production model incorporating covariates (ASPIC; Prager, 1994, 1995, 2005) was applied to nominal catch and survey biomass indices (see Tables 1 and 2). The Schaefer production model used assumes logistic population growth, in which the change in stock biomass over time (dB_t/dt) is a quadratic function of biomass (B):

$$dB_t/dt = rB_t - (r/K)B^2_t$$

where r is the intrinsic rate of population growth, and K is carrying capacity. For a fished stock, the rate of change is also a function of catch biomass (C):

$$dB_t/dt = rB_t - (r/K)B_t^2 - C_t$$

Biological reference points can be calculated from the production model parameters:

$$MSY = K\,r / 4; \quad B_{msy} = K / 2; \quad F_{msy} = r / 2$$

Initial biomass (expressed as the ratio: $B1/K$), K, MSY, and catchability coefficients for each biomass index (q_i) were estimated using non-linear least squares.

Because of differences in catchability among the various indices, relative biomass and fishing mortality estimates (with respect to MSY) were considered instead of absolute values which are thought to be estimated with less precision. Fishing mortality refers to yield (catch) /biomass ratio.

The last assessment of Greenland halibut that applied ASPIC (Darby *et. al.* 2004) used version 5.05 of the software. The nominal catch series and biomass indices from Canadian and EU surveys (see Tables 1 and 2) were explored from two time periods (1960-2003 and 1975-2003). A new version of ASPIC (version 5.33) was available for the current investigation, and to compare versions, indices similar to those from Darby *et. al.* (2004) were used in the new version and results compared. This comparison run used indices from the same surveys and time periods as those used in Darby *et. al.* (2004) formulation 2. Survey series were not identical, however; in the current investigations the EU 3M survey revised data were used (González Troncoso and Casas, 2005) and the Canadian 2J3K Engel series was used in place of the 2J3K Campelen equivalent series (1978-1994).

Survey biomass indices and catch series were updated to include data to 2007 and ASPIC (version 5.33) was run with the updated information using the same input indices as the comparison run (labeled “Rerun updated to 2007” in the plots and figures). Two additional runs omitted the Canadian Fall Engel series and used two time series of catch: Run 1 used catch from 1960-2007 and Run 2 used catch from 1975-2007. Run 2 is most similar to the last accepted XSA analysis (Healey and Mahé, 2008), with the caveat that the XSA is fitted to age disaggregated mean number per tow indices and ASPIC is fitted to biomass indices.

The model requires starting estimates for several parameters and Prager (2005) suggests testing the sensitivity of the model to those. Initial values for MSY, B1/K and the random number seed were varied and results examined. Retrospective analyses for various model runs were also conducted by dropping the terminal year of data from each series and running the model again, removing a total of five years in succession from the catch and survey data series.

Standardized CPUE series that were modeled using depth and year interactions (Rademeyer, pers. comm.), were available for input into the stock production model. (see Table 8). These CPUE series were used as input to ASPIC with the nominal catch series (1975-2007) alone and also as additional tuning series to those included in the accepted XSA model (i.e. Run 2).

Results

In order to evaluate potential differences in results and model fit from ASPIC version 5.05 and 5.33, the previous ASPIC analysis (labeled “SCR 04/55” in plots and figures) was compared with a run in the newest available version of the program (“SCR 04/55 rerun v5.33”). Even with the slight differences in the series used (revised EU 3M survey data and Engel data (1978-1994) for the Canadian Fall 2J3K survey were used in the v5.33 comparison run), parameter estimates and model diagnostics were not appreciably different between the two versions of ASPIC (Table 3). Estimates of relative biomass and fishing mortality were also alike (Fig. 1). All further analyses were produced using version 5.33 of ASPIC.

The rerun of SCR 04/55 (formulation 2) updated to include data to 2007 gave similar parameter estimates and model fit (Table 3) as the model run repeating the SCR 04/55 formulation 2 in ASPIC version 5.33. Differences in relative biomass and fishing mortality (SCR 04/55 rerun v5.33 compared to SCR 04/55 1960-2007 in Figure 2). Differences in the early part of the time period are likely due to estimation difficulties given that the data series used do not precede 1978 and only catch is available to compute biomass and fishing mortality. The trend in relative biomass and fishing mortality in the most recent years (2000-2007) was quite different in the updated rerun, and indicated lower relative fishing mortality and higher relative biomass than those resulting from data series ending in 2003. These results are consistent with the retrospective patterns in the XSA assessment (Healey and Mahé, 2008).

Further analyses were then conducted dropping out the Canadian Fall Engel data series to more closely approximate the 2008 XSA formulation. Two different time series of catch and survey indices were considered: Run 1 used catch from 1960-2007 and Run 2 used catch from 1975 onwards. Run 2 most closely matched the model set up used in the last accepted XSA model (Healey and Mahé, 2008), with catch and survey indices from the same periods. Runs 1 and 2 had nearly identical parameter estimates and model fit diagnostics (Table 3), but the population trajectories were somewhat dissimilar prior to 1990. Post 1990, both runs had nearly identical results for relative biomass and fishing mortality. Compared to the rerun of the 2004 ASPIC analysis of Darby et al., estimates of B_{msy}, carrying capacity (K), and estimated yield at equilibrium (“*Ye*” in Table 3) were higher and model fit diagnostics were slightly better. Figures 3- 5 show the observed and predicted biomass indices and also residuals for Runs 1 and 2. For both model runs, there were patterns in the residuals from all series, most of which are not severe.

Sensitivity analyses for both Run 1 (Table 4) and Run 2 (Table 5) were conducted by varying starting values for several parameters, as suggested by Prager (2005). Both model runs were sensitive to the starting values for K, MSY, and the random number seed (required by ASPIC to generate random number sequences used in fitting). Two sets of solutions were obtained for both data sets, each of which are hereafter referred to as Solution A and Solution B (see Tables 4 and 5, Figures 6 and 7). Both solution sets A and B had parameter estimates and model fit that were nearly identical for both Run 1 and Run 2. Runs that produced Solution B had slightly higher mean squared error (MSE), higher total objective function, and lower R^2 value for each series in both Run 1 and Run 2, suggesting worse model fit. Given the catch history and survey trends for this stock, Solution A was considered to be the more reasonable representation, while relative fishing mortality and relative biomass trends (Figs. 6 and 7) for Solution B were not considered realistic. Prager (2005) states that substantially different results indicate a local minimum in one solution. Increasing the number of restarts (a suggested way to resolve the problem) did not remove this sensitivity. Results that are not repeatable (within a few percent) when the random number seed is varied indicate a fitting failure and results should not be considered valid estimates (Prager, 2005).

Retrospective patterns were evident in both Run 1 and Run 2 (Solution A; Tables 6 and 7, Figs. 8 and 9). The initial conditions that resulted in Solution B were then examined for retrospective trends and patterns are also evident (Figure 10).

Standardized commercial CPUE series from Canada (Divs. 2HJ3K), Spain (Divs. 3MNO) and Portugal (Divs. 3LMNO) were modeled using depth and year interactions (Rademeyer, pers comm; see Table 8). These series, and others used in other model setups, were scaled to the series mean and plotted in Figure 11.

When the CPUE series were added to the ASPIC model setup for Run 2 as additional tuning indices, there were very poor or negative correlations between indices (Table 9). Model fit indicators were also poor.

CPUE indices used on their own to condition catch (1975-2007) in ASPIC produced parameter estimates and population trajectory similar to those of Run 2 (Table 10 and Figure 12). From 1998 onward, though, relative biomass was estimated to increase more quickly (and relative F declined more quickly) in the CPUE/catch run than in Run 2. This model setup was also sensitive to starting estimates; 2 solutions resulted when the starting estimate of MSY was varied (Table 10 and Figure 13). Severe retrospective patterns were seen in both solutions. The retrospective pattern for the CPUE/catch run (solution A) is plotted in Figure 14.

Conclusions

Given that there were model fit issues within all of the datasets considered, with sensitivity to starting estimates of some parameters and the random number seed, as well as retrospective patterns with all model specifications, ASPIC does not appear to model the data well. Parameter estimates (including biomass, fishing mortality, MSY) resulting from these runs, are therefore, considered unreliable.

References

DARBY, C.D., B. P. HEALEY, AND J.-C. MAHÉ. 2004. Greenland halibut (*Reinhardtius hippoglossoides*) in Subarea 2 + Divisions 3KLMNO: an assessment of stock status based upon XSA, ADAPT and ASPIC analyses with stochastic projections of potential stock dynamics. NAFO SCR Doc. 04/55. Ser. No. N5008.

GONZÁLEZ TRONCOSO, D. and CASAS, J.M. 2005. Calculation of the Calibration Factors from the Comparative Experience between the R/V Cornide de Saavedra and the R/V Vizconde de Eza in Flemish Cap in 2003 and 2004. SCR Doc. 05/29. Ser. No. N5115.

PRAGER, M. H. 2005. Users manual for ASPIC: a stock-production model incorporating covariates (ver. 5) and auxillary programs. *Beaufort Lab. Doc*., No. BL-2004-01.

HEALEY, B. P., and J.-C. MAHÉ. 2008. An assessment of Greenland halibut (*Reinhardtius hippoglossoides*) in NAFO Subarea 2 and Divisions 3KLMNO. NAFO SCR Doc. 08/48. Ser. No. 5550.

Table 1. Input series to ASPIC runs for Greenland halibut.

	SCR 04/55	Rerun SCR 04/55	Rerun updated to 2007	Run 1	Run 2
ASPIC version	5.05	5.33	5.33	5.33	5.33
Catch data	1960-2003	1960-2003	1960-2007	1960-2007	1975-2007
Canadian 2J3K Fall Engel	1978-1994 (Campelen equivalent)	1978-1994 (Engel)	1978-1994 (Engel)		
Canadian 2J3K Fall (Campelen)	1995-2003	1995-2003	1995-2007	1995-2007	1995-2007
EU 3M	1995-2003 unrevised	1995-2003 revised	1995-2007 revised	1995-2007 revised	1995-2007 revised
Canadian Spring 3LNO	1996-2003	1996-2003	1996-2007	1996-2007	1996-2007

Table 2. Input series to ASPIC version 5.33. Note that the ASPIC run in SCR 04/55 used unrevised EU survey data and 2J3K Campelen equivalent data in place of the 2J3K Engel series below. Run 1 used catch 1960-2007 while Run 2 used catch 1975-2007.

		Canadian Surveys			
	Landings (000 t)	2J3K Campelen	2J3K Engel	3LNO Campelen	EU 3M
1960	0.66				
1961	0.74				
1962	0.59				
1963	1.62				
1964	4.25				
1965	10.07				
1966	19.28				
1967	26.53				
1968	32.39				
1969	37.24				
1970	36.23				
1971	24.83				
1972	27.68				
1973	29.11				
1974	27.59				
1975	28.81				
1976	24.61				
1977	32.05				
1978	39.07		184.32		
1979	34.10		133.32		
1980	32.87		145.23		
1981	30.75		154.76		
1982	26.28		175.18		
1983	27.86		176.48		
1984	26.71		193.06		
1985	20.35		141.51		
1986	17.98		184.09		
1987	32.44		127.31		
1988	19.22		103.80		
1989	20.03		111.38		
1990	47.45		97.66		
1991	65.01		47.28		
1992	63.19		29.33		
1993	62.46		46.04		
1994	51.03		33.00		
1995	15.27	★			13.52
1996	18.84	21.58		1.53	14.42
1997	19.86	24.80		2.46	20.01
1998	19.95	23.83		4.56	30.13
1999	24.23	32.48		2.81	26.37
2000	34.18	23.89		3.04	21.08
2001	38.23	22.69		1.46	17.25
2002	34.06	14.07		0.72	15.05
2003	35.15	15.30		1.45	7.73
2004	25.49	17.45		1.12	15.28
2005	23.26	20.30		1.67	14.55
2006	23.53	25.73		★	14.56
2007	22.75	29.12		3.03	16.22

★ omitted from the time series due to incomplete coverage.

Table 3. ASPIC Parameter estimates and model diagnostics for Greenland Halibut datasets considered.

	SCR 04/55 ASPIC v5.05	Rerun SCR 04/55 v5.33	Rerun updated to 2007 (v5.33)	Run 1(1960-2007)	Run 2 (1975-2007)
Bmsy	124.80	107.00	103.90	136.50	136.30
Fmsy	0.27	0.34	0.35	0.24	0.24
MSY	33.49	35.97	36.60	32.70	32.45
K	249.50	214.00	207.80	273.00	272.60
B/Bmsy	0.23	0.21	0.57	0.60	0.60
F/Fmsy	3.52	3.40	1.14	1.19	1.19
Y(Fmsy)	7.85	7.73	21.03	19.58	19.62
Ye	13.86	13.79	29.98	27.43	27.38
B1/K	1.00	0.87	0.21	1.00	1.01
q (FC/Engel)	0.16	0.79	0.81		
q (FC/EU 3M)				0.20	0.20
q (2J3K Fall)	0.34	0.44	0.40	0.27	0.26
q (EU 3M)	0.18	0.36	0.31		
q (Spring 3LNO)	0.03	0.04	0.04	0.02	0.02
R2 FC/Engel	0.36	0.37	0.38		
R2 FC/EU 3M				0.36	0.36
R2 2J3K Fall	0.67	0.68	0.51	0.37	0.37
R2 EU 3M	0.59	0.61	0.27		
R2 Spring 3LNO	0.27	0.24	0.09	0.11	0.11
Tot Obj Function	4.13	5.42	6.90	3.72	3.72
MSE	0.11	0.15	0.15	0.12	0.12
restarts	5	6	317	11	18

Note: The ASPIC run in SCR 04/55 used unrevised data for the EU survey and for the Canadian Fall survey (Engel trawl unconverted). All other runs used revised EU data and Campelen converted data.

Table 4. ASPIC Run 1 model sensitivity to starting estimates of B1/K, K, and MSY and to the random number seed.

var	Run 1	B1/K 0.5	B1/K 0.75	K 100	K 200	K 300	MSY 20*	MSY 40	MSY 50*	random 1845273	random 5706844*
Bmsy	136.50	136.40	136.50	136.50	136.50	136.50	65.37	136.50	65.36	136.50	65.53
Fmsy	0.24	0.24	0.24	0.24	0.24	0.24	0.79	0.24	0.79	0.24	0.79
MSY	32.70	32.71	32.71	32.70	32.70	32.70	51.72	32.70	51.72	32.70	51.72
K	273.00	272.90	272.90	272.90	272.90	272.90	130.70	272.90	130.70	272.90	131.10
B/Bmsy	0.60	0.60	0.60	0.60	0.60	0.60	1.74	0.60	1.74	0.60	1.74
F/Fmsy	1.19	1.19	1.19	1.19	1.19	1.19	0.25	1.19	0.25	1.19	0.25
Y(Fmsy)	19.58	19.58	19.58	19.58	19.58	19.58	90.16	19.58	90.15	19.58	90.14
Ye	27.43	27.44	27.44	27.44	27.44	27.44	23.16	27.44	23.18	27.44	23.17
B1/K	1.00	0.49	0.75	0.80	0.98	1.00	0.46	0.94	1.00	0.80	0.90
q (FC/EU 3M)	0.20	0.20	0.20	0.20	0.20	0.20	0.16	0.20	0.16	0.20	0.16
q (2J3K Fall)	0.27	0.27	0.27	0.27	0.27	0.27	0.20	0.27	0.20	0.27	0.20
q (Spring 3LNO)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
R2 FC/EU 3M	0.36	0.36	0.36	0.36	0.36	0.36	0.17	0.36	0.17	0.36	0.17
R2 2J3K Fall	0.37	0.37	0.37	0.37	0.37	0.37	0.21	0.37	0.21	0.37	0.21
R2 Spring 3LNO	0.11	0.11	0.11	0.11	0.11	0.11	0.07	0.11	0.07	0.11	0.07
Tot Obj Function	3.72	3.73	3.73	3.73	3.73	3.73	4.12	3.73	4.12	3.73	4.12
MSE	0.12	0.12	0.12	0.12	0.12	0.12	0.14	0.12	0.14	0.12	0.14
restarts	11	5	4	5	4	6	6	4	4	4	5

Note: Run 1 had starting estimates for B1/K=1, K=250 and MSY=35, and the random number seed was 3941285.
* Results are sensitive to starting values and yield two solutions: Solution A results from most starting values while solution B is shown in the shaded columns.

Table 5. ASPIC Run 2 model sensitivity to starting estimates of B1/K, K, and MSY and to the random number seed.

var	Run 2	B1/K0.5	B1/K0.75	K100*	K200	K300	MSY20	MSY40	MSY50*	random 142872	random 4298333	random 5000000*	random 5706844*
Bmsy	136.30	136.30	136.40	65.53	136.40	136.30	136.40	136.40	65.53	136.30	136.40	65.53	65.54
Fmsy	0.24	0.24	0.24	0.79	0.24	0.24	0.24	0.24	0.79	0.24	0.24	0.79	0.79
MSY	32.45	32.45	32.45	51.72	32.45	32.45	32.45	32.45	51.72	32.45	32.44	51.72	51.72
K	272.60	272.60	272.70	131.10	272.70	272.70	272.70	272.70	131.10	272.70	272.80	131.10	131.20
B/Bmsy	0.60	0.60	0.60	1.74	0.60	0.60	0.60	0.60	1.74	0.60	0.60	1.74	1.74
F/Fmsy	1.19	1.19	1.19	0.25	1.19	1.19	1.19	1.19	0.25	1.19	1.19	0.25	0.25
Y(Fmsy)	19.62	19.62	19.62	90.15	19.62	19.62	19.62	19.62	90.15	19.62	19.62	90.15	90.14
Ye	27.38	27.38	27.37	23.17	27.37	27.38	27.37	27.37	23.17	27.38	27.37	23.17	23.17
B1/K	1.01	1.01	1.01	0.61	1.01	1.01	1.01	1.01	0.91	1.01	1.01	0.71	0.97
q (FC/EU 3M)	0.20	0.20	0.20	0.16	0.20	0.20	0.20	0.20	0.16	0.20	0.20	0.16	0.16
q (2J3K Fall)	0.26	0.26	0.26	0.20	0.26	0.26	0.26	0.26	0.20	0.26	0.26	0.20	0.20
q (Spring 3LNO)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
R2 FC/EU 3M	0.36	0.36	0.36	0.17	0.36	0.36	0.36	0.36	0.17	0.36	0.36	0.17	0.17
R2 2J3K Fall	0.37	0.37	0.37	0.21	0.37	0.37	0.37	0.37	0.21	0.37	0.37	0.21	0.21
R2 Spring 3LNO	0.11	0.11	0.11	0.07	0.11	0.11	0.11	0.11	0.07	0.11	0.11	0.07	0.07
Tot Obj Function	3.72	3.72	3.72	4.12	3.72	3.72	3.72	3.72	4.12	3.72	3.72	4.12	4.12
MSE	0.12	0.12	0.12	0.14	0.12	0.12	0.12	0.12	0.14	0.12	0.12	0.14	0.14
restarts	18	42	37	10	63	26	10	40	4	5	15	11	7

Note: The Run 2 had starting estimates for B1/K=1, K=250 and MSY=35, and the random number seed was 3941285.
* Results are sensitive to starting values and yield two solutions: Solution A results from most starting values while solution B is shown in the shaded columns.

Table 6. Parameter estimates and model diagnostics for a five-year retrospective analysis of Run 1.

var	Run 1 1960-2007	1960-2006	1960-2005	1960-2004	1960-2003	1960-2002
Bmsy	136.50	159.60	168.50	168.20	147.00	108.20
Fmsy	0.24	0.19	18.03	0.18	0.21	0.33
MSY	32.70	31.01	30.38	30.18	31.39	35.66
K	273.00	319.20	337.00	336.40	294.00	216.50
B/Bmsy	0.60	0.46	0.40	0.31	0.23	0.20
F/Fmsy	1.19	1.62	1.86	2.50	3.79	3.54
Y(Fmsy)	19.58	14.39	12.20	9.46	7.37	0.28
Ye	27.43	22.11	19.51	15.95	13.01	12.74
B1/K	1.00	0.92	0.89	1.00	0.97	1.00
q (FC/EU 3M)	0.20	0.18	0.18	0.19	0.24	0.42
q (2J3K Fall)	0.27	0.23	0.22	0.25	0.31	0.51
q (Spring 3LNO)	0.02	0.02	0.02	0.02	0.03	0.04
R2 FC/EU 3M	0.36	0.43	0.44	0.47	0.60	0.58
R2 2J3K Fall	0.37	0.35	0.58	0.66	0.69	0.66
R2 Spring 3LNO	0.11	0.20	0.24	0.29	0.30	0.36
Tot Obj Function	3.72	3.19	2.94	2.59	2.08	1.40
MSE	0.12	0.12	0.12	0.12	0.11	0.09
restarts	11	15	4	79	4	28

Table 7. Parameter estimates and model diagnostics for a five-year retrospective analysis of Run 2.

var	Run 2 (1975-2007)	1975-2006	1975-2005	1975-2004	1975-2003	1975-2002
Bmsy	136.30	158.30	165.50	164.00	144.90	108.10
Fmsy	0.24	0.19	0.18	0.18	0.21	0.33
MSY	32.45	30.52	29.84	29.69	31.09	35.63
K	272.60	316.70	330.90	328.00	289.80	216.30
B/Bmsy	0.60	0.48	0.41	0.32	0.24	0.20
F/Fmsy	1.19	1.61	1.84	2.47	3.77	0.28
Y(Fmsy)	19.62	14.49	12.33	9.56	7.41	7.08
Ye	27.38	22.11	19.56	16.05	13.06	12.75
B1/K	1.01	1.01	1.01	1.01	1.00	1.00
q (FC/EU 3M)	0.20	0.18	0.18	0.19	0.24	0.42
q (2J3K Fall)	0.26	0.23	0.22	0.24	0.31	0.51
q (Spring 3LNO)	0.02	0.02	0.02	0.02	0.03	0.04
R2 FC/EU 3M	0.36	0.43	0.44	0.47	0.60	0.58
R2 2J3K Fall	0.37	0.35	0.58	0.66	0.60	0.66
R2 Spring 3LNO	0.11	0.20	0.24	0.29	0.60	0.36
Tot Obj Function	3.72	3.18	2.93	2.58	0.30	1.40
MSE	0.12	0.12	0.12	0.12	0.11	0.09
restarts	18	19	19	10	66	15

Table 8. Commercial catch per unit effort series standardized and modeled to remove the effects of depth and year.

	Model 5 (Depth*Year interaction)		
	Canada 2HJ3K	Spain 3MNO	Portugal 3LMNO
1992		0.9856	
1993		0.8733	
1994		0.7671	
1995		0.9496	
1996		1.0032	
1997		1.0060	
1998	0.8155	0.8243	1.0000
1999	0.8171	0.6262	1.1801
2000	1.3473	1.0000	1.0938
2001	1.5574	0.8424	0.8489
2002	1.3583	1.1073	0.8633
2003	1.0000	0.8256	0.8372
2004	0.9989	0.6517	0.5141
2005	1.1214	0.7563	0.9681
2006	2.5716	0.9733	1.1235
2007	2.6470	2.0088	1.4436
2008	2.7869	1.7906	

Table 9. Correlation among input series (Number of pairwise observations below) for survey indices and commercial CPUE series.

		1	2	3	4	5	6
1	Spain CPUE+Catch (Kt)	1.000					
		16					
2	Cdn 2J3K Fall (Camp)	0.248	1.000				
		12	12				
3	Cdn Spring 3LNO	0.182	0.666	1.000			
		11	11	11			
4	EU 3M	-0.067	0.594	0.796	1.000		
		16	12	11	20		
5	Canadian comm CPUE	0.753	0.320	0.019	-0.311	1.000	
		10	10	9	10	10	
6	Portugal comm CPUE	0.656	0.766	0.603	0.289	0.558	1.000
		10	10	9	10	10	10

Table 10. Parameter estimates and model diagnostics from representative runs (one from each solution group) of ASPIC with commercial CPUE series and catch only.

	Comm CPUE +catch only	
	Solution A	Solution B
Bmsy	112.8	230.4
Fmsy	0.313	0.2648
MSY	35.3	61.01
K	225.5	460.8
B/Bmsy	0.981	0.5472
F/Fmsy	0.6944	0.7499
Y(Fmsy)	34.63	33.39
Ye	35.29	48.5
B1/K	0.09508	0.1432
q (FC/EU 3M)	0.01215	0.01277
q (2J3K Fall)	0.01594	0.01666
q (Spring 3LNO)	0.01163	0.01212
R2 FC/EU 3M	0.479	0.234
R2 2J3K Fall	0.336	0.511
R2 Spring 3LNO	0.47	0.552
Tot Obj Function	2.74062456	2.31874124
MSE	0.09135	0.0729
restarts	10	411

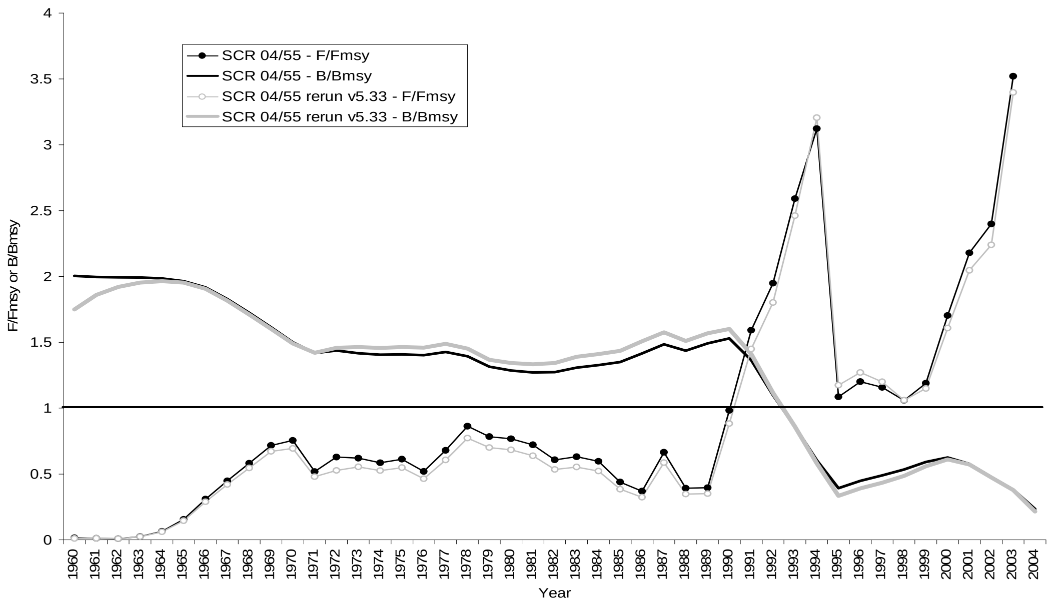

Figure 1. Relative biomass and fishing mortality from SCR 04/55 (ASPIC version 5.05) compared with the same formulation (but with revised EU survey and unconverted Engel data) in ASPIC version 5.33 (rerun SCR 04/55).

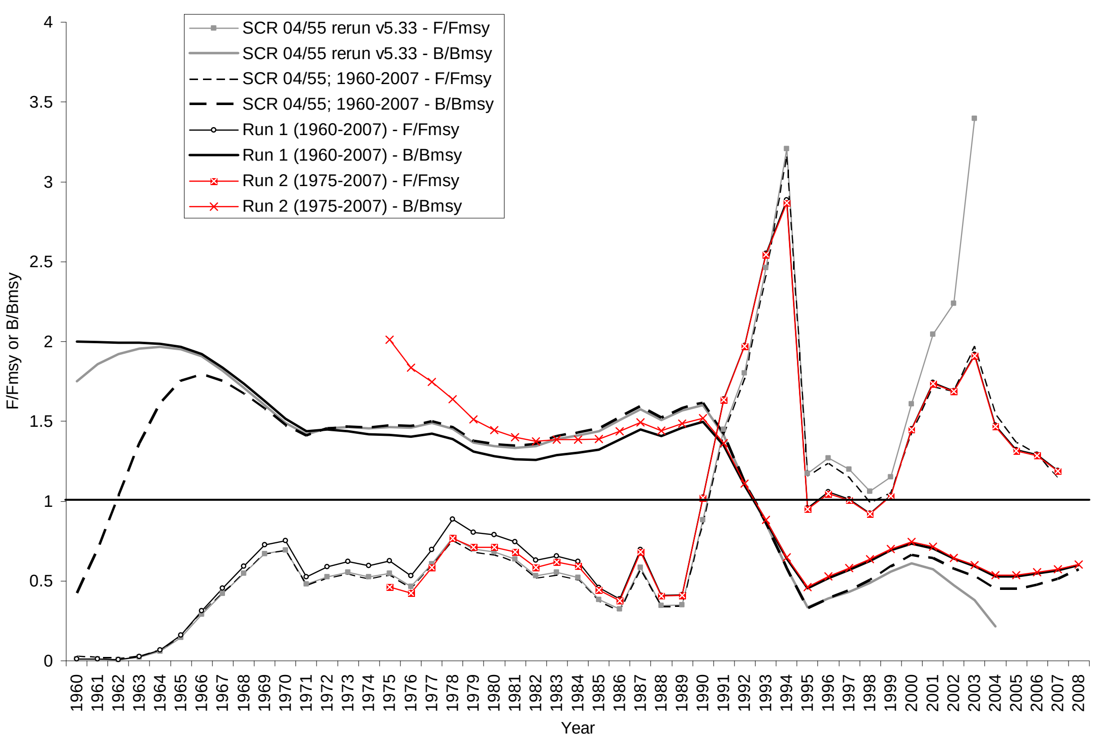

Figure 2. Relative biomass and fishing mortality from ASPIC (V5.33) comparative runs: SCR 04/55, updated rerun (2007 data), Run 1 (1960-2007) and Run 2 (1975-2007).

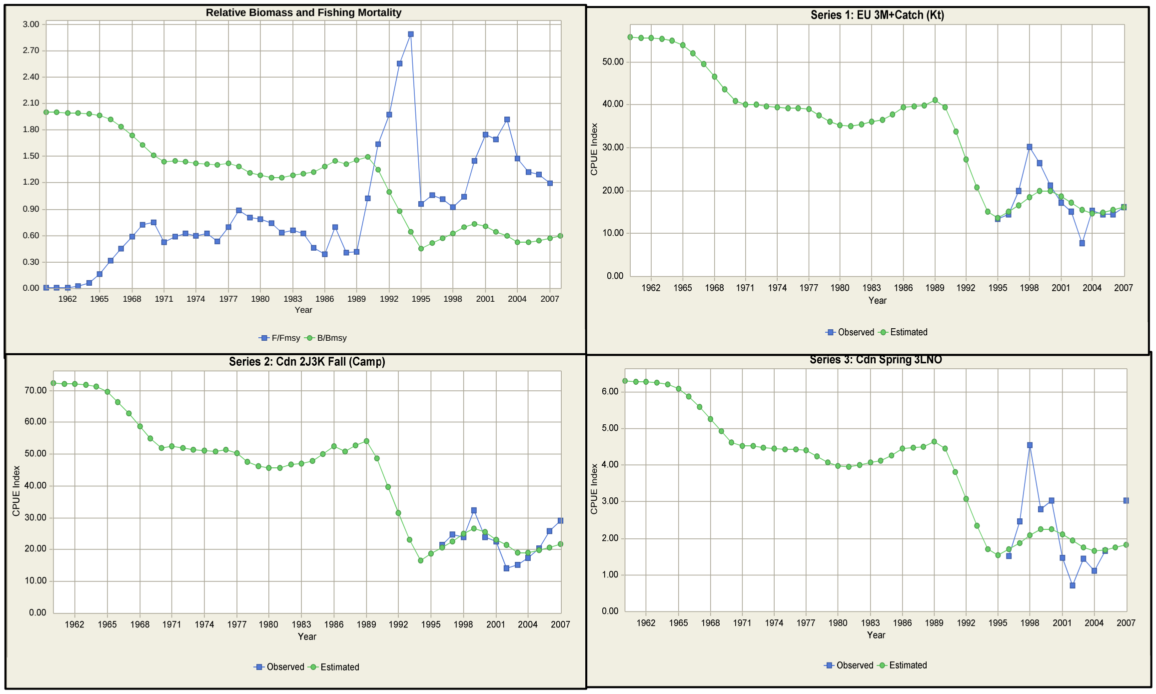

Figure 3. Relative biomass and fishing mortality (upper left panel), and observed and predicted biomass indices from ASPIC model Run 1.

Figure 4. Relative biomass and fishing mortality (upper left panel), and observed and predicted biomass indices from ASPIC model Run 2.

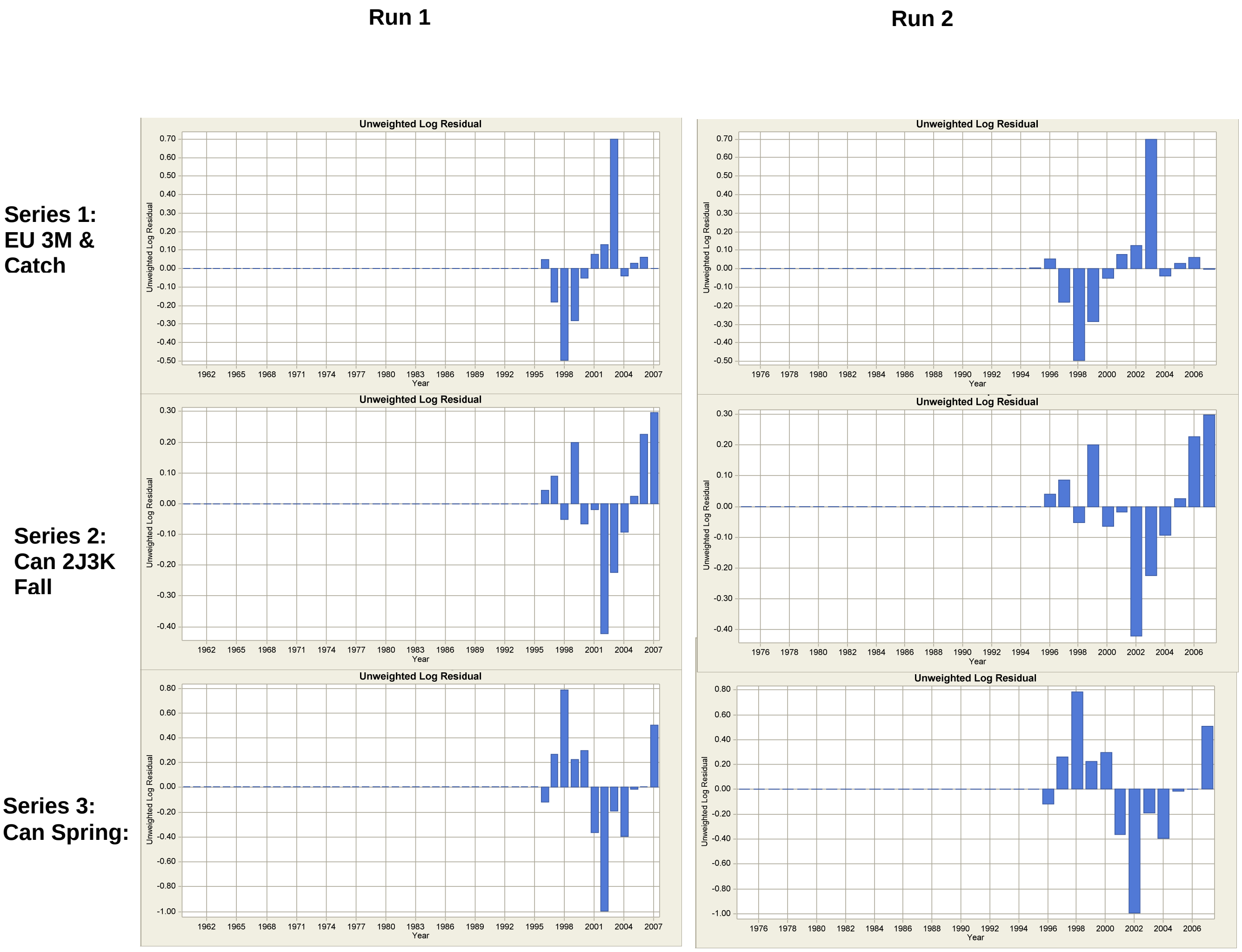

Figure 5. Log residuals for the 3 series in the ASPIC model Runs 1 and 2 for Greenland halibut.

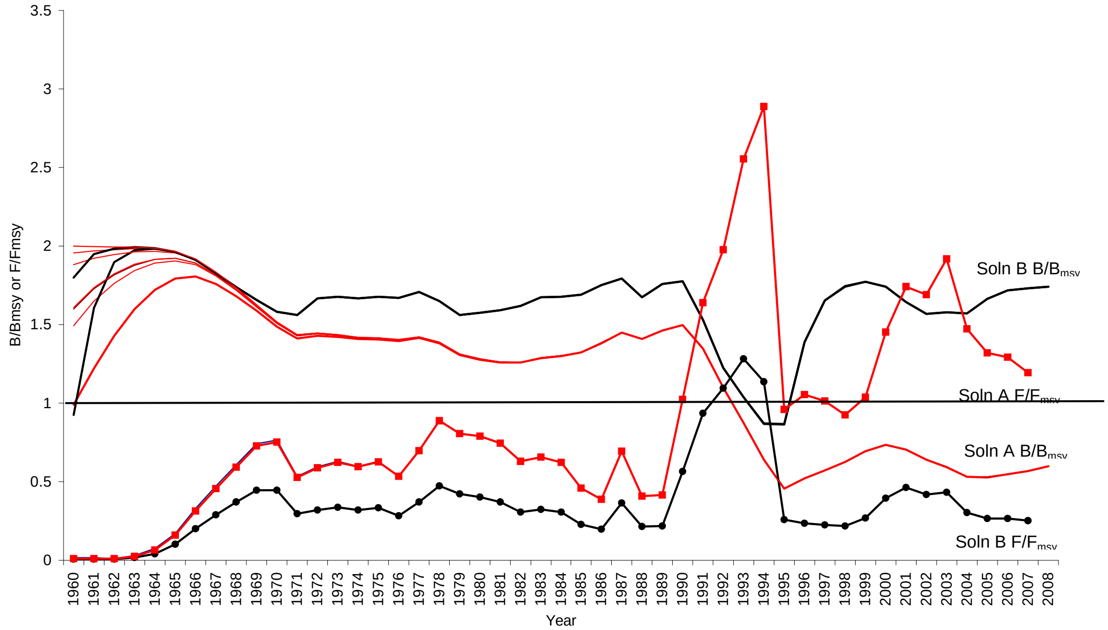

Figure 6. ASPIC model Run 1 sensitivity to changing starting estimates for B1/K, MSY, K and the random number seed. (See Table 4 for parameter starting estimates that yield solution A and B)

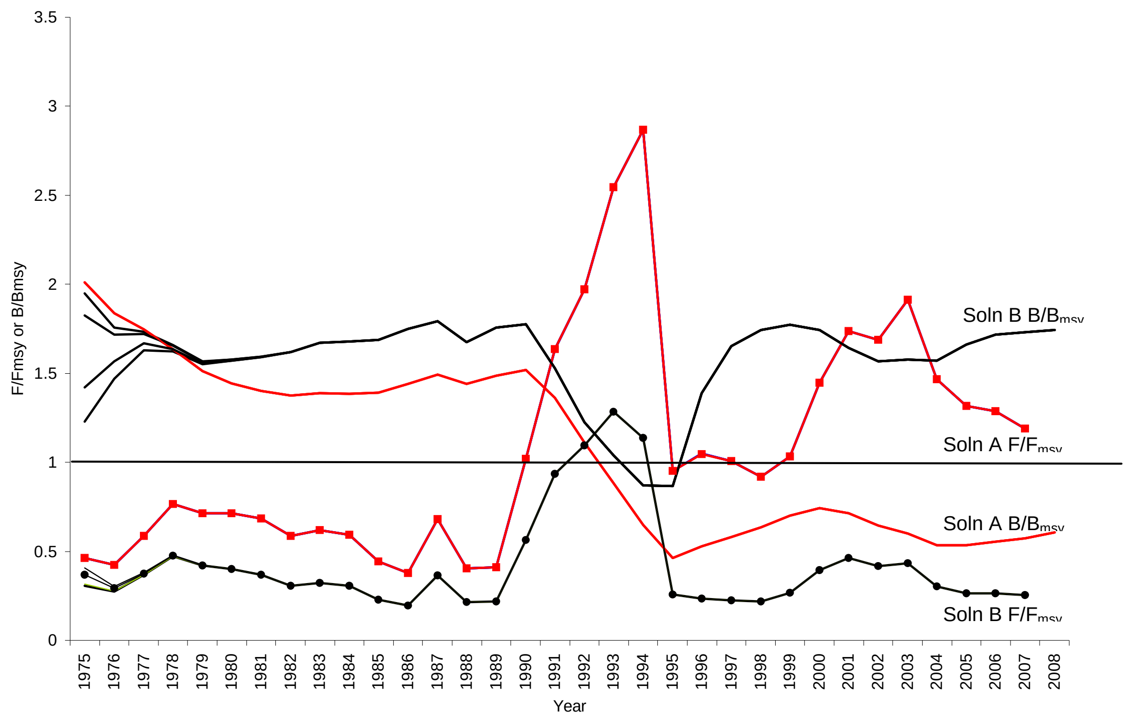

Figure 7. ASPIC model Run 2 sensitivity to changing starting estimates for B1/K, MSY, K and the random number seed. (See Table 5 for parameter starting estimates that yield solution A and B)

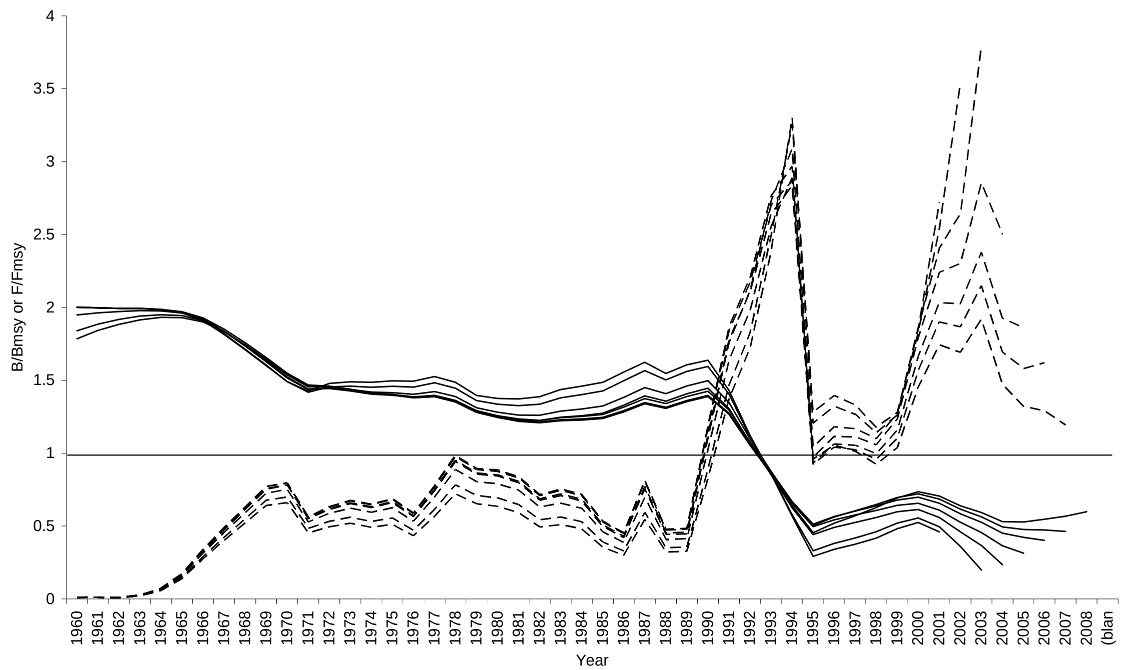

Figure 8. Relative biomass and fishing mortality for a five year retrospective view of ASPIC for Greenland halibut Run 1. Solid lines represents B/B_{msy}; dashed lines are F/F_{msy}.

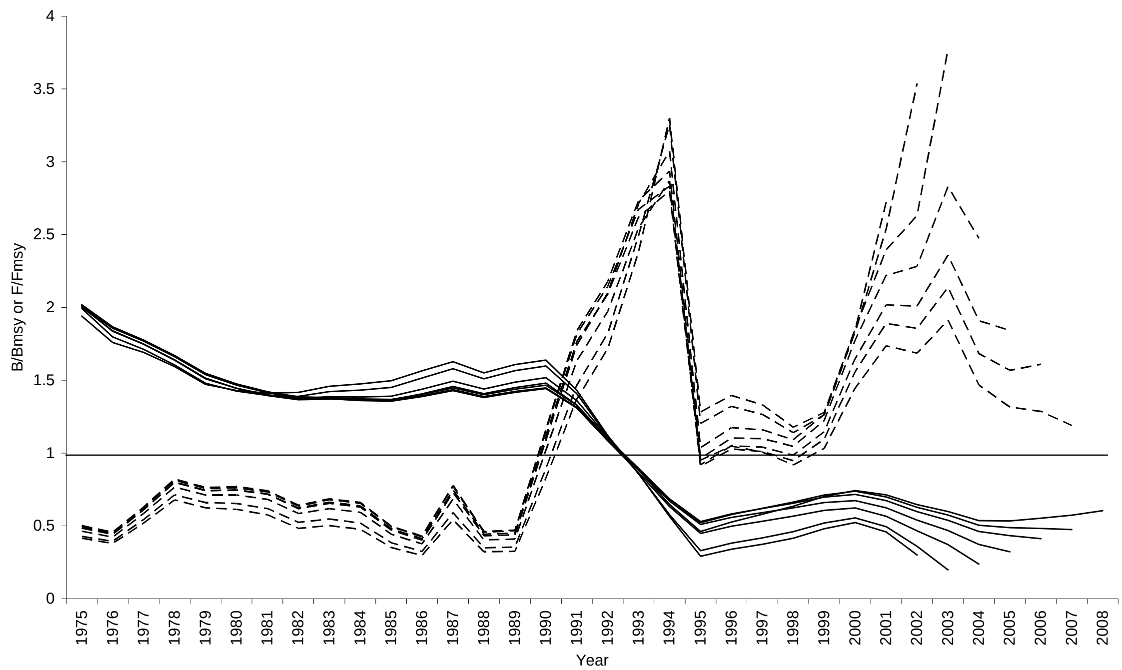

Figure 9. Relative biomass and fishing mortality for a five year retrospective view of ASPIC for Greenland halibut Run 2. Solid lines represents B/B_{msy}; dashed lines are F/F_{msy}.

Figure 10. Relative biomass and fishing mortality for a five year retrospective view of ASPIC for Greenland halibut from a sensitivity run of Run 2 with random number changed to 5706844 (solution B). Solid lines represents B/B_{msy}; dashed lines are F/F_{msy}.

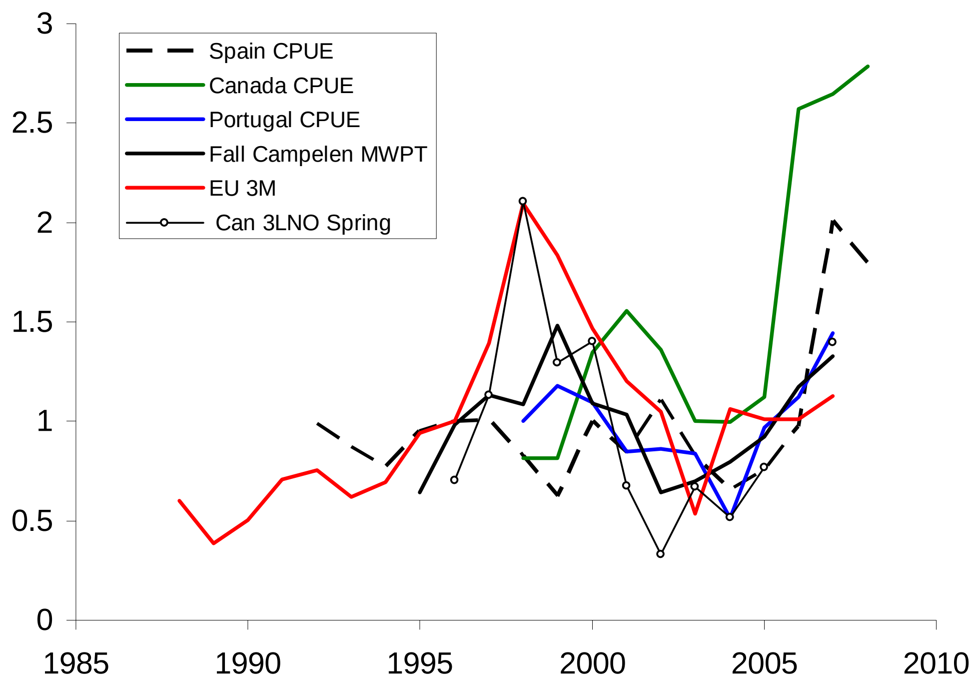

Figure 11. Survey indices scaled to each series mean, and commercial CPUE series that have been modeled for effects of depth and year (see Table 8, Rademeyer pers. comm.).

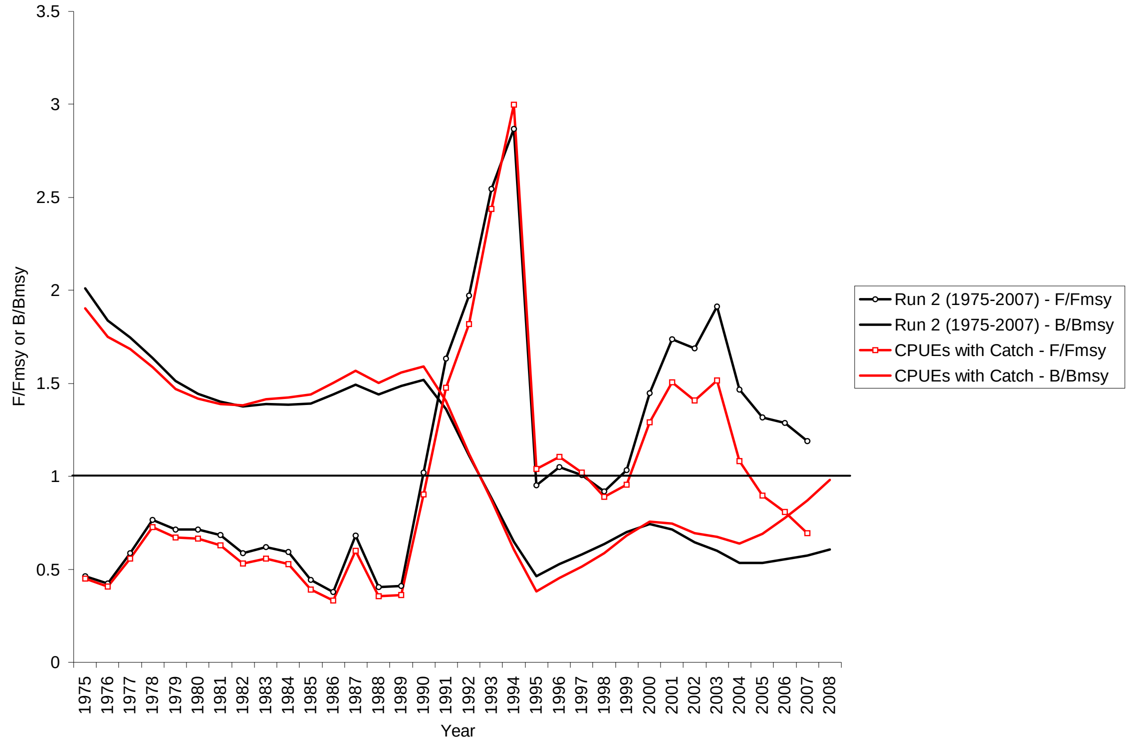

Figure 12. Relative biomass and fishing mortality from ASPIC Run 2 (survey indices and catch) compared to a run with only commercial CPUEs and catch (starting estimates the same as run2).

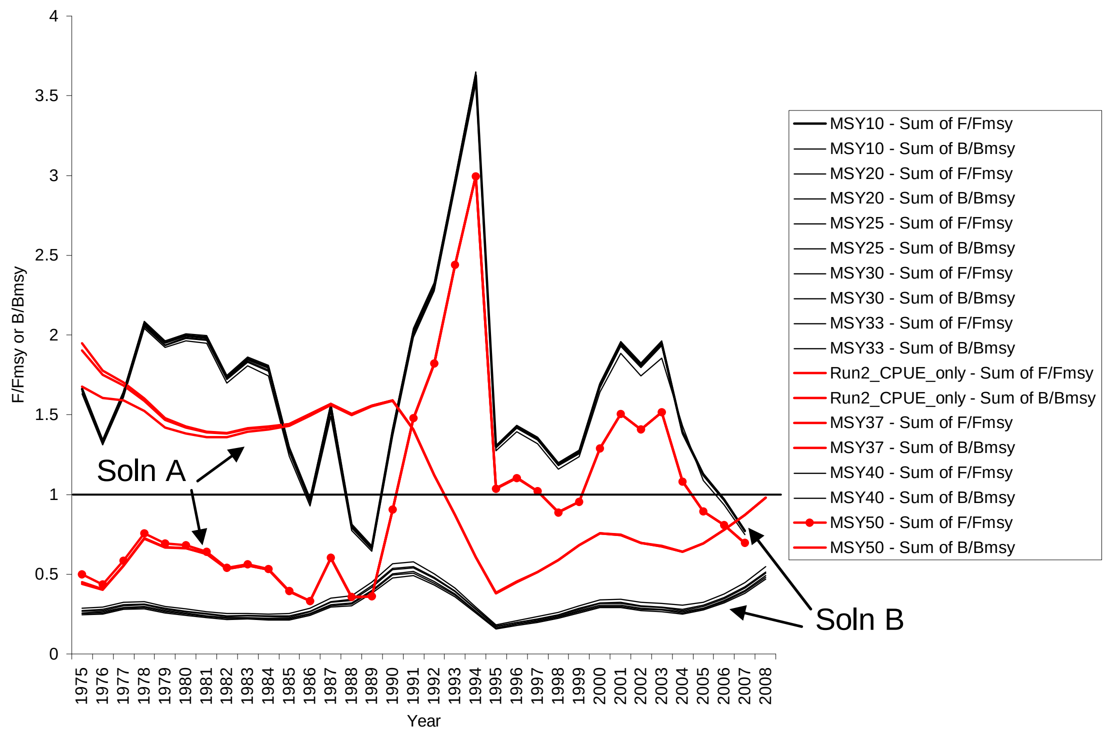

Figure 13. Relative biomass and fishing mortality from ASPIC sensitivity runs for the CPUEs + catch only run changing the starting estimates for MSY.

Figure 14. Relative biomass and fishing mortality for a five year retrospective view of ASPIC for Greenland halibut from the commercial CPUE + catch run.