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Surplus Production Analysis of Shrimp in the Denmark Strait

by

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Abstract

A nonequilibrium surplus production model (ASPIC) of landings, effort, and survey indices of shrimp in the northern area of the Denmark Strait suggests that a maximum sustainable yield (MSY) of 8,400 t can be produced by a stock biomass of 23,300 t (B_{MSY}) at a fishing mortality of 0.36 (F_{MSY}). The model indicates that biomass was near the stock=s carrying capacity at the beginning of the fishery (1978), decreased to less than B_{MSY} as landings exceeded sustainable levels in the late 1980s and early 1990s, then increased to above B_{MSY} in the late 1990s when landings were relatively low. Precautionary management targets can be derived from conditional probability distributions of MSY and F_{MSY} (e.g., a long-term target catch of 7,800 t would have a 90% chance of being less than MSY), and risk of management decisions can be assessed with stochastic projection, which incorporates uncertainty in production model parameters and current biomass (e.g., the recommended target catch for 1998 has a very low probability of exceeding F_{MSY} or decreasing the stock to below B_{MSY}).

Introduction

A fishery for shrimp (*Pandalus borealis*) in the Denmark Strait began in 1978 and developed to an international fishery yielding up to 12,500 t annually (Skúladóttir 1997). The fishery traditionally operated north of 65° N, but began exploiting more southerly areas in 1993. Coastal states request fishery management advice for the Denmark Strait shrimp stock from NAFO (NAFO 1997). NAFO has endorsed a >precautionary approach= to fishery management which is based on maintaining B_{MSY} (the level of stock biomass which will produce maximum sustainable yield, MSY), while limiting fishing mortality to below the level which produces MSY (F_{MSY}) (Serchuk et al. 1997).

Surplus production models can provide guidance on MSY, B_{MSY}, and F_{MSY} where information on age structure is unavailable or unreliable, and provide a valuable perspective for stock assessment. Skúladóttir (1985, 1990) modeled the exponential relationship of yield and catch-per-unit-effort (CPUE) (Fox 1970) from 1980 to 1989 and reported that fishing effort on the Denmark Strait shrimp stock was exceeding sustainable levels and annual catches should be reduced to less than 10,000 t. A preliminary analysis was developed at the November 1997 meeting of the NAFO Scientific Council to apply a nonequilibrium production model (ASPIC, Prager 1994, 1995) to CPUE and survey indices from the Denmark Strait fishery (Cadrin 1997). The present investigation was performed to revise estimates of MSY, B_{MSY}, and F_{MSY}, and derive precautionary management targets.

Methods

A surplus production model incorporating covariates (ASPIC; Prager 1994, 1995) was applied to the shrimp fishery in the northern area of the Denmark Strait (north of 65°N) using landings, effort (Skúladóttir 1997), and the Greenland survey index of stock abundance (Carlsson 1996). The model assumes logistic population growth, in which the change in stock biomass over time (dB/dt) is a quadratic function of biomass (B):

$$dB_t/dt = rB_t - (r/K)B_t^2 \quad (1)$$

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

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

MSY, B_{MSY}, and F_{MSY} can be calculated from the production model parameters:

$$MSY = Kr/4 \quad (3)$$
$$B_{MSY} = K/2 \quad (4)$$
$$F_{MSY} = r/2 \quad (5)$$

Initial biomass (expressed as a ratio to B_{MSY}: $B1R$), r, MSY, commercial catchability (q_1) and survey catchability (q_2) were estimated using nonlinear least squares of lognormally distributed observation errors in effort and survey indices. Total landings and unstandardized effort were reported by Skúladóttir (1997). Landings and effort for 1997 in the northern area were derived from statistics reported through October (3,750 t and 23,100 hr) expanded by a factor of 1.2 to approximate a full year of fishing (4,500 t and 27,700 hr). Mean number per tow from the Greenland survey (Carlsson 1996) was used as an independent biomass index. The Norway survey, 1985-1989 (NAFO 1990), was negatively correlated with CPUE and could not be used as a tuning index. Total model error included a penalty function for estimates of $B1R$ greater than 2 (initial biomass exceeding the carrying capacity, Prager 1994). The CPUE and survey indices were iteratively reweighted based on initial mean square errors (MSE). Observation errors were randomly resampled for 500 bootstrap simulations to assess model precision. The recommended catch for 1998 (5,000 t) was used to project the model one year using all 500 bootstrap solutions and provide a conditional probability distribution of 1999 biomass. Several alternative analyses were conducted to assess the sensitivity of results to the penalty function, iterative reweighting, and including catch and effort from the southern area (south of 65° N).

Results

Annual landings of shrimp in the Denmark Strait increased from an annual average of 6,200 t in the early 1980s to a peak of 12,500 t in 1988, and gradually decreased to 3,400 t in 1996 (Figure 1). Survey indices and CPUE generally declined in the 1980s and increased in the 1990s (Figure 2), but correlation between CPUE and the survey series was weak (r=0.1). The model fit the data well: most of the variance in CPUE and the survey index was explained by the production model (R^2= 0.86, and 0.54), and there were no apparent patterns in model residuals (Appendix A).

The production model indicated that an MSY of 8,400 t can be produced by the Denmark Strait shrimp stock when biomass is approximately 23,300 t (Figure 3). F_{MSY} was estimated to be 0.36. The model suggests that biomass was near the stock=s carrying capacity (47,000 t) in the late 1970s, decreased to 17,000 in the early 1990s, then grew to 32,400 t in 1998, which is 140% of B_{MSY}. Annual estimates of F averaged 0.19 in the early 1980s, increased to 0.54 by 1990, then decreased to 0.15 in 1997, which is 40% of F_{MSY}. Sensitivity analysis showed that results were very similar with no penalty function for $B1R$>2 (Table 2), but equal weighting produced a slightly greater MSY estimate. Including catch and effort from the southern area (south of 65° N) substantially increased estimates of MSY and F_{MSY}, and decreased the estimate of B_{MSY}, but decreased goodness of fit.

Bootstrap estimates suggest that MSY was precisely estimated (relative interquartile range, IQR, of bootstrap estimates was 6%), and other parameters were estimated with moderate precision (IQRs were 8% to 31%). Stochastic projection of 5,000 t catch in 1998, which was recommended by the NAFO Scientific Council, suggests that biomass will slightly increase to 34,200 t with an 80% bootstrap confidence limit of 30,800 to 41,000 t, which is well above B_{MSY} (23,300 t) (Figure 4). The projection also indicates that a 5,000 t catch will slightly decrease F to 0.15 in 1998 with an 80% confidence limit of 0.12 to 0.17, which is well below F_{MSY} (0.36) (Figure 5).

Discussion

This analysis provides guidance on stock status and management advice for the shrimp stock in the northern area of the Denmark Strait. Limit reference points can be defined directly from model results: according to the precautionary approach, the fishery should be managed to limit catch to less than 8,400 t, maintain a stock biomass of at least 23,300 t, and limit F to less than 0.36. Precautionary targets can be derived from conditional bootstrap distributions of MSY and F_{MSY}: a long-term target catch of 7,800 t would have a 90% probability of being less than MSY, and a long-term target F of 0.27 would have a 90% chance of being less than F_{MSY}. These limits and targets apply to a healthy stock, which has a biomass greater than B_{MSY}. If the stock should decrease to less than B_{MSY}, more restrictive catch and F targets should be advised to rebuild the stock to at least B_{MSY}.

These results apply to the northern area of the Denmark Strait stock. Recent landings from south of 65°N are apparently from a previously unexploited resource which is not accurately represented by CPUE or survey catches in the northern area. Including catch and effort from the southern area in these analyses produces unrealistically high values of r (Table 2).

Estimates of MSY and effort at MSY (f_{MSY}) were less than those reported by Skúladóttir (1990) and $CPUE_{MSY}$ was greater (Table 1). The lower MSY estimate from ASPIC, as compared to previous estimates by Skúladóttir (1990) may result from several aspects of this revised analysis: more years of data providing more contrast in production observations, assuming logistic growth rather than Gompertz growth (Fox 1970), allowing for non-equilibrium conditions, or tuning biomass estimates with the survey index.

The increase in biomass estimates since 1992 suggests that the stock can sustain the recent levels of catch. However, the increase in CPUE may result from qualitative changes in effort in the northern area or technological improvements in fishing power, and stock biomass may not have increased as substantially as the survey abundance index suggests. If relative changes in CPUE and survey indices do not reflect changes in stock biomass, model results may be misleading. Modifications to this analysis should be explored to improve input data (e.g., effort standardization and development of survey biomass indices).

Acknowledgments

This analysis was initiated with the cooperation of the participants of the November 1997 Scientific Council meeting.

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Table 1. Comparison of production model estimates from Fox models (Skúladóttir 1990) and ASPIC of the shrimp fishery in the northern area of the Denmark Strait.

Estimate	ASPIC	Fox Model #1 2-y mean CPUE	Fox Model #2 3-y mean CPUE
MSY (t)	8,400	11,200	10,000
f_{MSY} (hr)	68,100	112,900	101,300
$CPUE_{MSY}$ (kg/hr)	123	99	99
$2/3f_{MSY}$ (hr)	45,400	75,300	67,500
$CPUE@2/3f_{MSY}$ (kg/hr)	164	130	138
$Yield@2/3f_{MSY}$ (t)	7,500	10,200	9,300

Table 2. Results from alternative ASPIC analyses of the shrimp fishery in the Denmark Strait.

Model Settings	*			
B1R>2 Penalty?	Y	N	Y	Y
Reweighted?	Y	Y	N	Y
Data from South?	N	N	N	Y
Results				
B1R	2.155	3.620	2.069	2.004
R	0.720	0.703	0.920	2.197
K	46,580	47,700	38,330	18,840
MSY	8,382	8,379	8,821	10,350
B_{MSY}	23,290	23,850	19,170	9,422
F_{MSY}	0.360	0.351	0.460	1.099
Diagnostics				
MSE CPUE	0.026	0.024	0.026	0.032
MSE survey	0.027	0.025	0.054	0.032
R^2 CPUE	0.855	0.873	0.827	0.766
R^2 survey	0.542	0.531	0.712	0.613

* analysis reported in Appendix A and described in text.

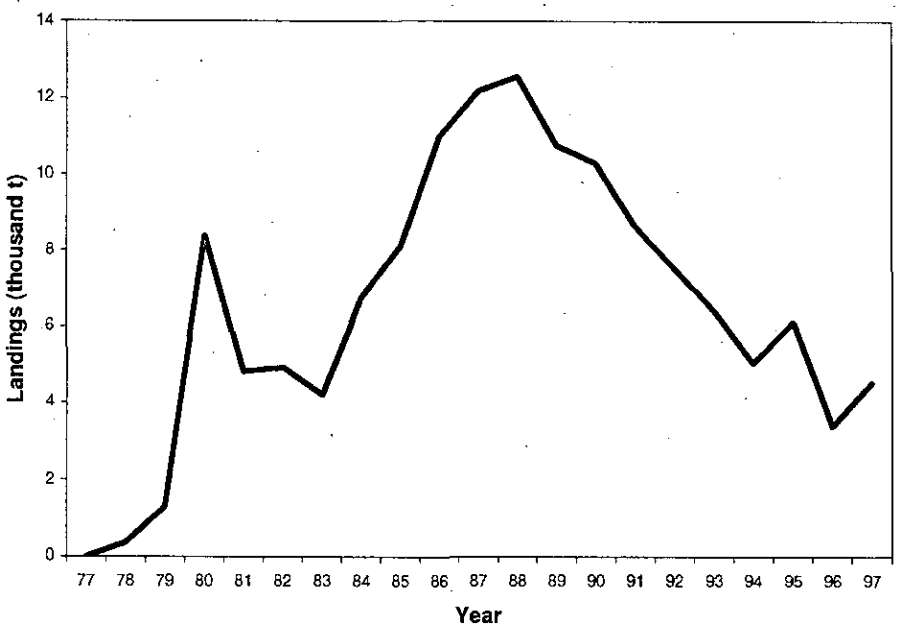

Figure 1. Landings of shrimp from the northern area of the Denmark Strait, 1978-1997 (1997 landings are preliminary).

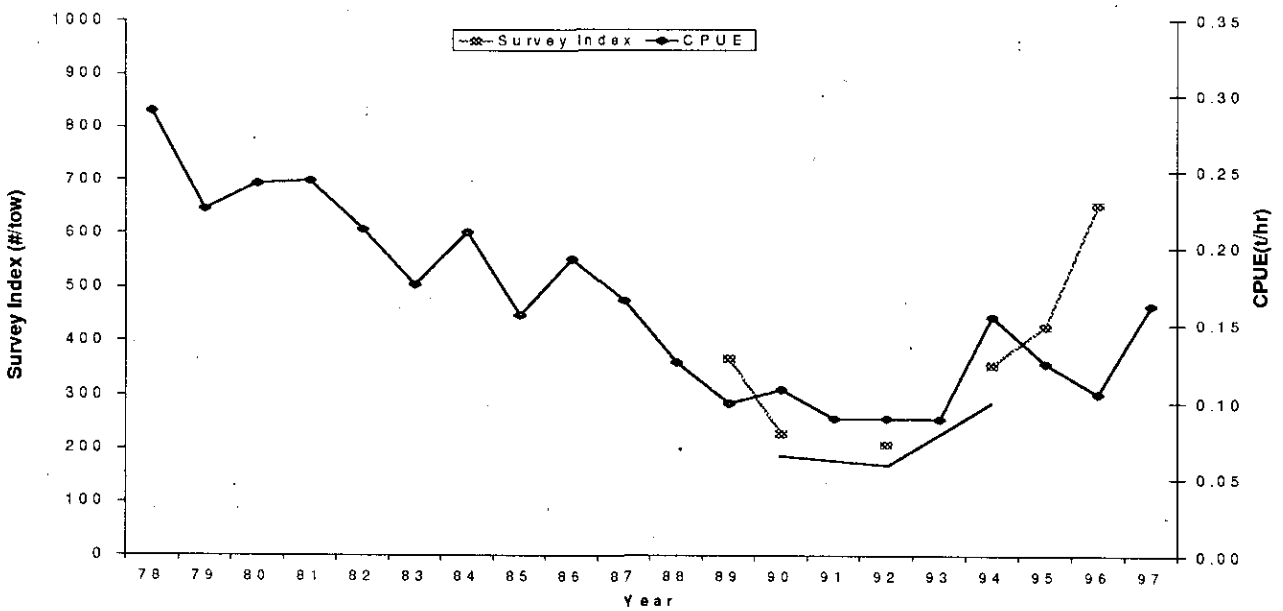

Figure 2. Catch-per-unit effort of survey indices of abundance of shrimp in the northern area of the Denmark Strait.

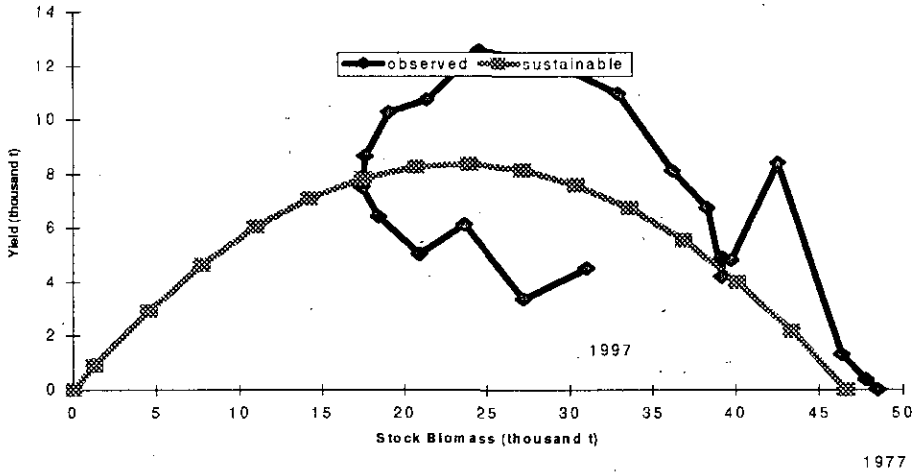

Figure 3. Yield of shrimp in the northern are of the Denmark Strait as a function of estimated biomass.

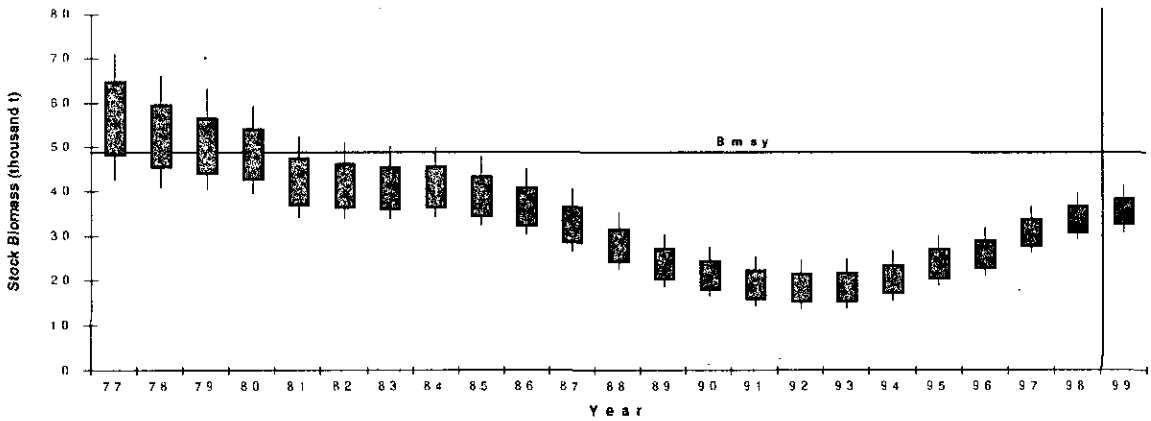

Figure 4. Bootstrap distributions (80% confidence limits and interquartile ranges) of estimated stock biomass of shrimp in the northern area of the Denmark Strait 1978-1998 and projected 1999 biomass based on 5,000 t of catch in 1998

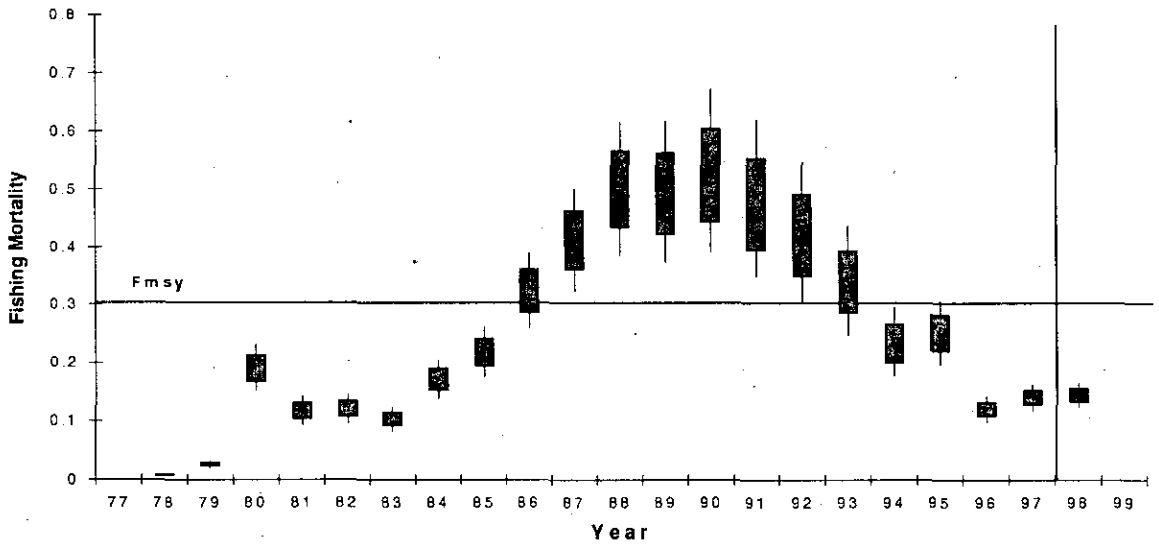

Figure 5. Bootstrap distributions (80% confidence limits and interquartile ranges) of estimated fishing mortality of shrimp in the northern area of the Denmark Strait 1978-1998 and projected 1998 fishing mortality based on 5,000 t of catch in 1998.

Appendix A: Surplus production results for Denmark Strait shrimp - yield and biomass are in thousand t.

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.65) IRF Mode

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CONTROL PARAMETERS USED (FROM INPUT FILE)

Number of years analyzed:	21	Number of bootstrap trials:	0
Number of data series:	2	Lower bound on MSY:	1.000E+00
Objective function computed:	in EFFORT	Upper bound on MSY:	5.000E+01
Relative conv. criterion (simplex):	1.000E-06	Lower bound on r:	1.000E-01
Relative conv. criterion (restart):	3.000E-08	Upper bound on r:	1.000E+01
Relative conv. criterion (effort):	1.000E-04	Random number seed:	1964286
Maximum F allowed in fitting:	5.000	Monte Carlo search trials:	50000

ITERATIVE REWEIGHTING PHASE

Iter	Angle	Loss	Revised weights...	
User	--	--	1.00E+00	1.00E+00
Start	--	--	1.00E+00	1.00E+00
1	19.62	6.787E-01	1.14E+00	5.40E-01
2	8.67	6.209E-01	1.19E+00	3.58E-01
3	2.51	5.846E-01	1.21E+00	3.06E-01
4	0.60	5.726E-01	1.21E+00	2.93E-01

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) code 0

Normal convergence.

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

1 effort (thousand hr)	1.000 20	
2 Greenland Survey	0.128 6	1.000 6
	1	2

GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS

Loss component number and title		Weighted SSE	N	Weighted MSE	Current weight	Suggested weight	R-squared in CPUE
Loss(-1)	SSE in yield	0.000E+00					
Loss(0)	Penalty for B1R > 2	3.009E-03	1	N/A	1.000E+00	N/A	
Loss(1)	effort (thousand hr)	4.621E-01	20	2.567E-02	1.208E+00	1.212E+00	0.855
Loss(2)	Greenland Survey	1.074E-01	6	2.686E-02	3.057E-01	2.932E-01	0.542

TOTAL OBJECTIVE FUNCTION: 5.72556691E-01

NOTE: B1-ratio constraint term contributing to loss. Sensitivity analysis advised.

Number of restarts required for convergence: 4
Est. B-ratio coverage index (0 worst, 2 best): 1.2571
Est. B-ratio nearness index (0 worst, 1 best): 1.0000

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	Starting guess	Estimated	User guess
B1R	Starting biomass ratio, year 1977	2.113E+00	2.000E+00	1	1
MSY	Maximum sustainable yield	8.382E+00	1.000E+01	1	1
r	Intrinsic rate of increase	7.189E-01	9.000E-01	1	1
.....	Catchability coefficients by fishery:				
q(1)	effort (thousand hr)	5.263E-03	1.000E-02	1	1
q(2)	Greenland Survey	1.615E+01	2.000E+01	1	1

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	Formula		
MSY	Maximum sustainable yield	8.382E+00	Kr/4		
K	Maximum stock biomass	4.664E+01			
Bmsy	Stock biomass at MSY	2.332E+01	K/2		
Fmsy	Fishing mortality at MSY	3.595E-01	r/2		
F(0.1)	Management benchmark	3.235E-01	0.9*Fmsy		
Y(0.1)	Equilibrium yield at F(0.1)	8.298E+00	0.99*MSY		
B-ratio	Ratio of B(1998) to Bmsy	1.393E+00			
F-ratio	Ratio of F(1997) to Fmsy	4.025E-01			
Y-ratio	Proportion of MSY avail in 1998	8.456E-01	2*Br-Br^2	Ye(1998) =	7.088E+00
.....	Fishing effort at MSY in units of each fishery:				
fmsy(1)	effort (thousand hr)	6.830E+01	r/2q(1)	f(0.1) =	6.147E+01

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	1977	0.000	4.926E+01	4.848E+01	0.000E+00	0.000E+00	-1.384E+00	0.000E+00	2.113E+00
2	1978	0.008	4.788E+01	4.779E+01	3.634E-01	3.634E-01	-5.376E-01	2.116E-02	2.053E+00
3	1979	0.010	4.698E+01	4.669E+01	4.853E-01	4.853E-01	-3.730E-02	2.892E-02	2.015E+00
4	1980	0.195	4.646E+01	4.303E+01	8.405E+00	8.405E+00	2.348E+00	5.434E-01	1.992E+00
5	1981	0.120	4.040E+01	4.001E+01	4.792E+00	4.792E+00	4.086E+00	3.332E-01	1.733E+00
6	1982	0.124	3.969E+01	3.941E+01	4.900E+00	4.900E+00	4.389E+00	3.459E-01	1.702E+00
7	1983	0.106	3.918E+01	3.932E+01	4.175E+00	4.175E+00	4.432E+00	2.954E-01	1.680E+00
8	1984	0.175	3.944E+01	3.841E+01	6.731E+00	6.731E+00	4.867E+00	4.875E-01	1.691E+00
9	1985	0.223	3.757E+01	3.629E+01	8.110E+00	8.110E+00	5.781E+00	6.217E-01	1.611E+00
10	1986	0.332	3.525E+01	3.301E+01	1.096E+01	1.096E+01	6.914E+00	9.240E-01	1.512E+00
11	1987	0.422	3.120E+01	2.884E+01	1.218E+01	1.218E+01	7.889E+00	1.175E+00	1.338E+00
12	1988	0.510	2.691E+01	2.460E+01	1.256E+01	1.256E+01	8.334E+00	1.420E+00	1.154E+00
13	1989	0.502	2.268E+01	2.138E+01	1.074E+01	1.074E+01	8.317E+00	1.398E+00	9.728E-01
14	1990	0.538	2.026E+01	1.910E+01	1.028E+01	1.028E+01	8.102E+00	1.497E+00	8.688E-01
15	1991	0.490	1.809E+01	1.768E+01	8.656E+00	8.656E+00	7.892E+00	1.362E+00	7.756E-01
16	1992	0.429	1.732E+01	1.750E+01	7.514E+00	7.514E+00	7.861E+00	1.194E+00	7.429E-01
17	1993	0.346	1.767E+01	1.851E+01	6.401E+00	6.401E+00	8.022E+00	9.623E-01	7.577E-01
18	1994	0.240	1.929E+01	2.096E+01	5.027E+00	5.027E+00	8.283E+00	6.671E-01	8.272E-01
19	1995	0.257	2.255E+01	2.373E+01	6.109E+00	6.109E+00	8.373E+00	7.163E-01	9.669E-01
20	1996	0.124	2.481E+01	2.727E+01	3.378E+00	3.378E+00	8.112E+00	3.446E-01	1.064E+00
21	1997	0.145	2.954E+01	3.111E+01	4.500E+00	4.500E+00	7.436E+00	4.025E-01	1.267E+00
22	1998		3.248E+01						1.393E+00

RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) effort (thousand hr)

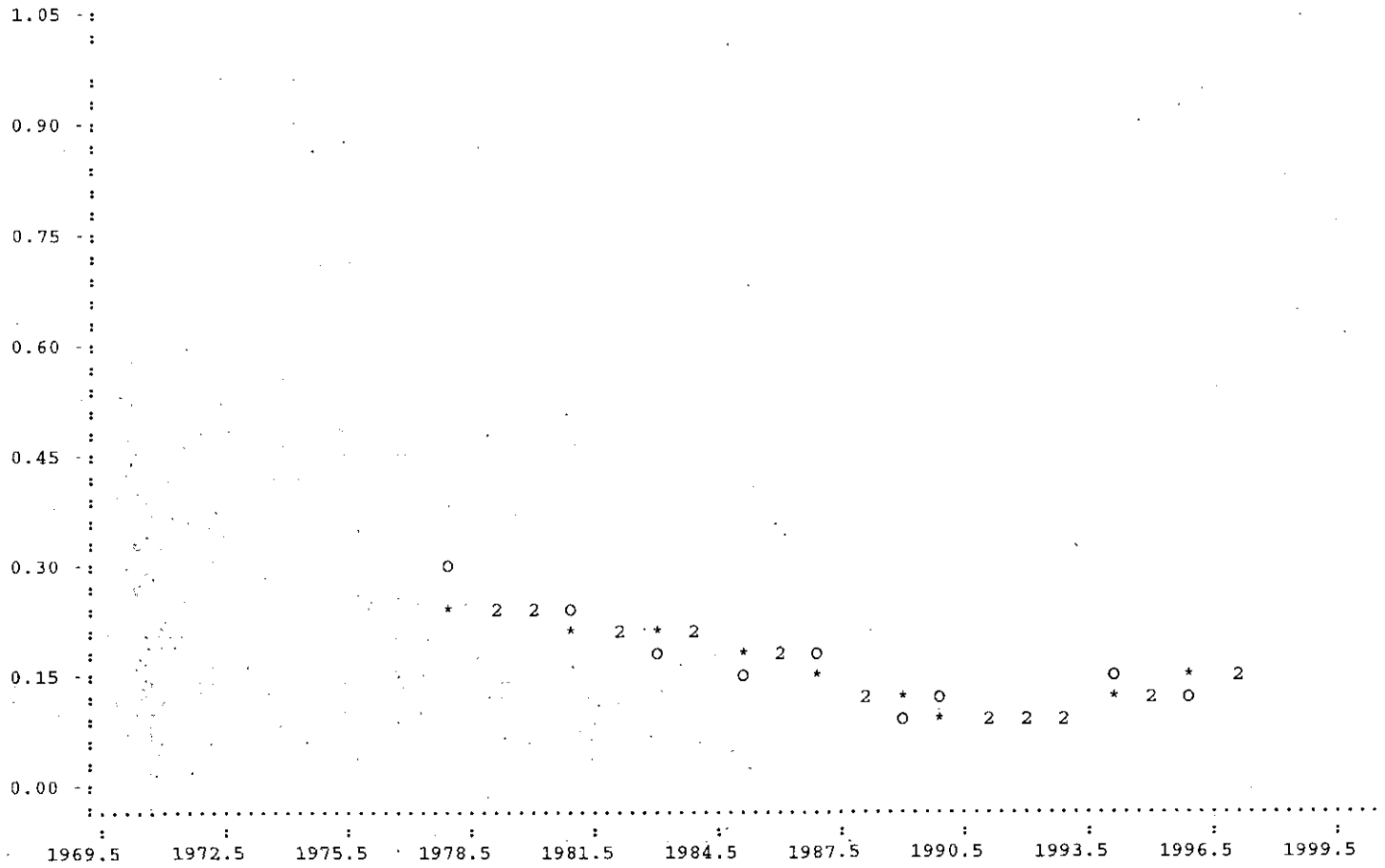
Data type CE: Effort-catch series Series weight: 1.208

Obs	Year	Observed effort	Estimated effort	Estim F	Observed yield	Model yield	Resid in log effort	Resid in yield
1	1977	*	0.000E+00	0.0000	0.000E+00	0.000E+00	0.00000	0.000E+00
2	1978	1.250E+00	1.445E+00	0.0076	3.634E-01	3.634E-01	-0.14495	0.000E+00
3	1979	2.148E+00	1.975E+00	0.0104	4.853E-01	4.853E-01	0.08387	0.000E+00
4	1980	3.459E+01	3.712E+01	0.1953	8.405E+00	8.405E+00	-0.07053	0.000E+00
5	1981	1.959E+01	2.276E+01	0.1198	4.792E+00	4.792E+00	-0.15000	0.000E+00
6	1982	2.307E+01	2.362E+01	0.1243	4.900E+00	4.900E+00	-0.02366	0.000E+00
7	1983	2.367E+01	2.018E+01	0.1062	4.175E+00	4.175E+00	0.15971	0.000E+00
8	1984	3.197E+01	3.330E+01	0.1752	6.731E+00	6.731E+00	-0.04060	0.000E+00
9	1985	5.174E+01	4.246E+01	0.2235	8.110E+00	8.110E+00	0.19753	0.000E+00
10	1986	5.681E+01	6.311E+01	0.3322	1.096E+01	1.096E+01	-0.10527	0.000E+00
11	1987	7.326E+01	8.024E+01	0.4223	1.218E+01	1.218E+01	-0.09103	0.000E+00
12	1988	9.956E+01	9.697E+01	0.5104	1.256E+01	1.256E+01	0.02631	0.000E+00
13	1989	1.079E+02	9.546E+01	0.5024	1.074E+01	1.074E+01	0.12252	0.000E+00
14	1990	9.470E+01	1.022E+02	0.5380	1.028E+01	1.028E+01	-0.07649	0.000E+00
15	1991	9.610E+01	9.301E+01	0.4895	8.656E+00	8.656E+00	0.03270	0.000E+00
16	1992	8.365E+01	8.158E+01	0.4293	7.514E+00	7.514E+00	0.02507	0.000E+00
17	1993	7.155E+01	6.573E+01	0.3459	6.401E+00	6.401E+00	0.08492	0.000E+00
18	1994	3.236E+01	4.556E+01	0.2398	5.027E+00	5.027E+00	-0.34213	0.000E+00
19	1995	4.886E+01	4.892E+01	0.2575	6.109E+00	6.109E+00	-0.00126	0.000E+00
20	1996	3.194E+01	2.353E+01	0.1239	3.378E+00	3.378E+00	0.30540	0.000E+00
21	1997	2.770E+01	2.749E+01	0.1447	4.500E+00	4.500E+00	0.00763	0.000E+00

* Asterisk indicates missing value(s).

UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 1

Year	Residual	-1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1
1977	0.0000	|
1978	-0.1450	======|
1979	0.0839	|===
1980	-0.0705	===|
1981	-0.1500	======|
1982	-0.0237	=|
1983	0.1597	|======
1984	-0.0406	==|
1985	0.1975	|========
1986	-0.1053	====|
1987	-0.0910	====|
1988	0.0263	|=
1989	0.1225	|=====
1990	-0.0765	===|
1991	0.0327	|=
1992	0.0251	|=
1993	0.0849	|===
1994	-0.3421	==========|
1995	-0.0013	|
1996	0.3054	|==========
1997	0.0076	|


1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
1969.5
1972.5
1975.5
1978.5
1981.5
1984.5
1987.5
1990.5
1993.5
1996.5
1999.5

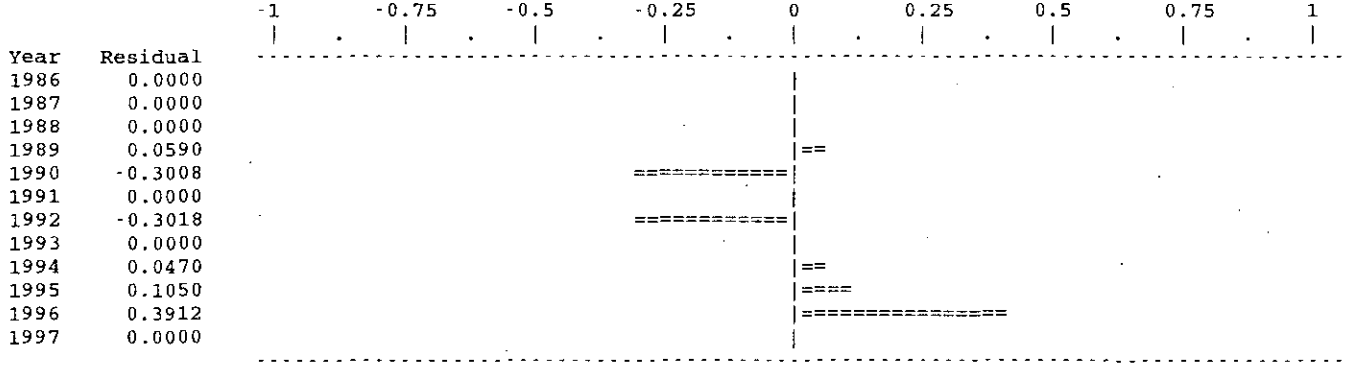
RESULTS FOR DATA SERIES # 2 (NON-BOOTSTRAPPED) Greenland Survey

Data type I1: Year-average biomass index Series weight: 0.306

Obs	Year	Observed effort	Estimated effort	Estim F	Observed index	Model index	Resid in log index	Resid in index
1	1977	0.000E+00	0.000E+00	0.0	*	7.830E+02	0.00000	0.0
2	1978	0.000E+00	0.000E+00	0.0	*	7.717E+02	0.00000	0.0
3	1979	0.000E+00	0.000E+00	0.0	*	7.539E+02	0.00000	0.0
4	1980	0.000E+00	0.000E+00	0.0	*	6.948E+02	0.00000	0.0
5	1981	0.000E+00	0.000E+00	0.0	*	6.461E+02	0.00000	0.0
6	1982	0.000E+00	0.000E+00	0.0	*	6.365E+02	0.00000	0.0
7	1983	0.000E+00	0.000E+00	0.0	*	6.350E+02	0.00000	0.0
8	1984	0.000E+00	0.000E+00	0.0	*	6.203E+02	0.00000	0.0
9	1985	0.000E+00	0.000E+00	0.0	*	5.860E+02	0.00000	0.0
10	1986	0.000E+00	0.000E+00	0.0	*	5.331E+02	0.00000	0.0
11	1987	0.000E+00	0.000E+00	0.0	*	4.657E+02	0.00000	0.0
12	1988	0.000E+00	0.000E+00	0.0	*	3.973E+02	0.00000	0.0
13	1989	1.000E+00	1.000E+00	0.0	3.663E+02	3.453E+02	0.05904	2.100E+01
14	1990	1.000E+00	1.000E+00	0.0	2.283E+02	3.084E+02	-0.30081	-8.012E+01
15	1991	0.000E+00	0.000E+00	0.0	*	2.856E+02	0.00000	0.0
16	1992	1.000E+00	1.000E+00	0.0	2.090E+02	2.826E+02	-0.30184	-7.364E+01
17	1993	0.000E+00	0.000E+00	0.0	*	2.988E+02	0.00000	0.0
18	1994	1.000E+00	1.000E+00	0.0	3.548E+02	3.385E+02	0.04696	1.628E+01
19	1995	1.000E+00	1.000E+00	0.0	4.256E+02	3.832E+02	0.10498	4.242E+01
20	1996	1.000E+00	1.000E+00	0.0	6.513E+02	4.404E+02	0.39121	2.109E+02
21	1997	0.000E+00	0.000E+00	0.0	*	5.023E+02	0.00000	0.0

* Asterisk indicates missing value(s).

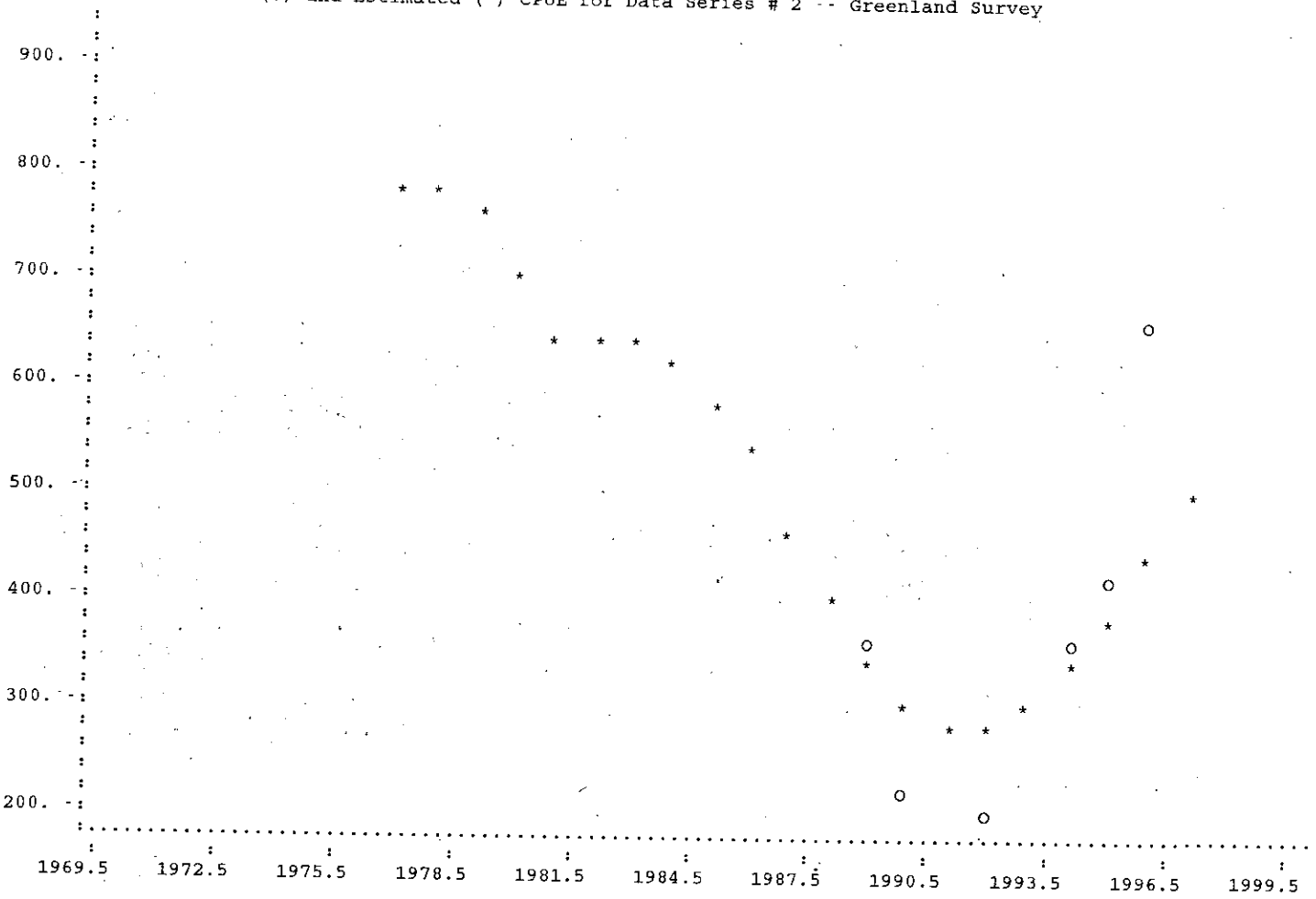
UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 2



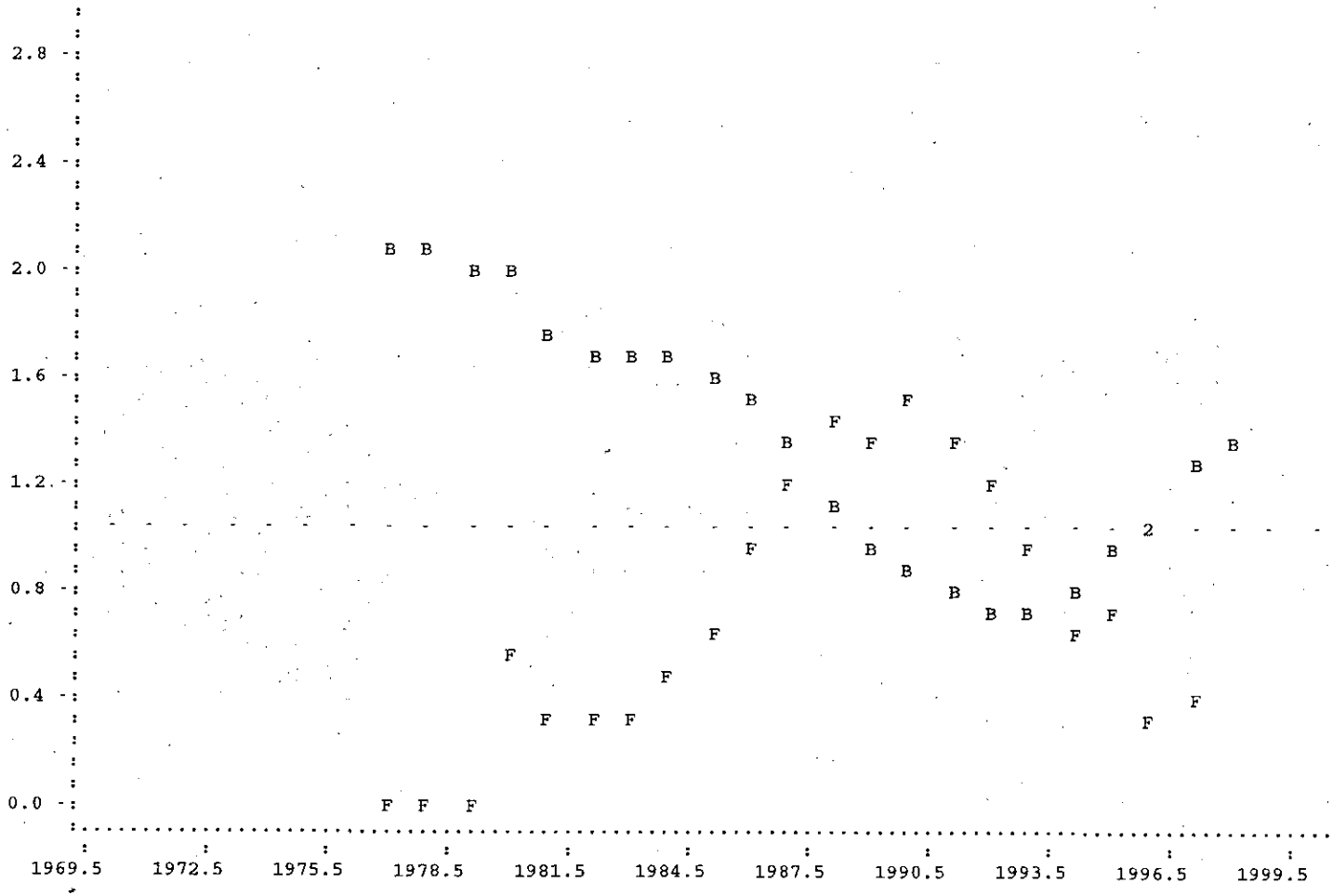
Observed (O) and Estimated (*) CPUE for Data Series # 1 -- effort (thousand hr)

Denmark Strait Shrimp, Northern Area -- ASPIC 3.6 -- Two Indices

Observed (O) and Estimated (*) CPUE for Data Series # 2 -- Greenland Survey



Time Plot of Estimated F-Ratio and B-Ratio



RESULTS OF BOOTSTRAPPED ANALYSIS

Param name	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
Biratio	2.213E+00	2.114E+00	-4.46%	2.092E+00	2.375E+00	2.160E+00	2.340E+00	1.808E-01	0.082
K	4.745E+01	4.659E+01	-1.83%	3.993E+01	5.843E+01	4.297E+01	5.327E+01	1.030E+01	0.217
r	7.035E-01	7.197E-01	2.30%	5.345E-01	8.688E-01	6.042E-01	7.929E-01	1.887E-01	0.268
q(1)	5.105E-03	5.284E-03	3.51%	4.007E-03	6.273E-03	4.463E-03	5.767E-03	1.304E-03	0.255
q(2)	1.558E+01	1.621E+01	4.02%	1.091E+01	2.015E+01	1.295E+01	1.778E+01	4.835E+00	0.310
MSY	8.330E+00	8.382E+00	0.62%	7.832E+00	8.729E+00	8.077E+00	8.544E+00	4.670E-01	0.056
Ye(1998)	7.092E+00	7.102E+00	0.14%	6.477E+00	7.528E+00	6.817E+00	7.351E+00	5.340E-01	0.075
Bmsy	2.373E+01	2.329E+01	-1.83%	1.996E+01	2.922E+01	2.149E+01	2.664E+01	5.148E+00	0.217
Fmsy	3.518E-01	3.599E-01	2.30%	2.673E-01	4.344E-01	3.021E-01	3.965E-01	9.435E-02	0.268
fmsy(1)	6.901E+01	6.810E+01	-1.33%	6.335E+01	7.492E+01	6.615E+01	7.207E+01	5.912E+00	0.086
fmsy(2)	2.235E-02	2.220E-02	-0.66%	1.834E-02	2.689E-02	2.002E-02	2.463E-02	4.612E-03	0.206
F(0.1)	3.166E-01	3.239E-01	2.07%	2.405E-01	3.910E-01	2.719E-01	3.568E-01	8.491E-02	0.268
Y(0.1)	8.247E+00	8.298E+00	0.62%	7.753E+00	8.642E+00	7.996E+00	8.458E+00	4.624E-01	0.056
B-ratio	1.388E+00	1.391E+00	0.17%	1.237E+00	1.506E+00	1.305E+00	1.451E+00	1.468E-01	0.106
F-ratio	4.054E-01	4.035E-01	-0.47%	3.558E-01	4.863E-01	3.808E-01	4.500E-01	6.915E-02	0.171
Y-ratio	8.491E-01	8.473E-01	-0.21%	7.436E-01	9.438E-01	7.963E-01	9.073E-01	1.110E-01	0.131
f0.1(1)	6.211E+01	6.129E+01	-1.19%	5.701E+01	6.743E+01	5.954E+01	6.486E+01	5.321E+00	0.086
f0.1(2)	2.011E-02	1.998E-02	-0.60%	1.651E-02	2.420E-02	1.802E-02	2.217E-02	4.151E-03	0.206
q2/q1	3.075E+03	3.067E+03	-0.25%	2.576E+03	3.650E+03	2.795E+03	3.390E+03	5.943E+02	0.193

NOTES ON BOOTSTRAPPED ESTIMATES:

- The bootstrapped results shown were computed from 500 trials.
- These results are conditional on the constraints placed upon MSY and r in the input file (ASPIC.INP).
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.
- The bias corrections used here are based on medians. This is an accepted statistical procedure, but may estimate nonzero bias for unbiased, skewed estimators.

Trials replaced for lack of convergence: 0
Trials replaced for MSY out-of-bounds: 0
Trials replaced for r out-of-bounds: 0
Residual-adjustment factor: 1.1127

USER CONTROL INFORMATION (FROM INPUT FILE)

Name of biomass (BIO) file	denstshr.bio
Name of output file (this file)	denstshr.prj
Number of years of projections	1

Year	Input data	User data type
1998	5.000E+00	TAC

TRAJECTORY OF ABSOLUTE BIOMASS (BOOTSTRAPPED)

Year	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
1977	5.476E+01	4.924E+01	-10.08%	4.260E+01	7.099E+01	4.842E+01	6.474E+01	1.632E+01	0.298
1978	5.188E+01	4.784E+01	-7.79%	4.085E+01	6.598E+01	4.561E+01	5.960E+01	1.399E+01	0.270
1979	4.975E+01	4.694E+01	-5.65%	4.034E+01	6.315E+01	4.419E+01	5.657E+01	1.239E+01	0.249
1980	4.769E+01	4.584E+01	-3.87%	3.958E+01	5.923E+01	4.277E+01	5.397E+01	1.119E+01	0.235
1981	4.157E+01	4.004E+01	-3.67%	3.411E+01	5.229E+01	3.703E+01	4.726E+01	1.023E+01	0.246
1982	4.069E+01	3.946E+01	-3.01%	3.399E+01	5.102E+01	3.647E+01	4.608E+01	9.613E+00	0.236
1983	4.007E+01	3.902E+01	-2.62%	3.380E+01	5.008E+01	3.616E+01	4.524E+01	9.081E+00	0.227
1984	4.018E+01	3.933E+01	-2.12%	3.423E+01	4.990E+01	3.655E+01	4.538E+01	8.826E+00	0.220
1985	3.823E+01	3.749E+01	-1.94%	3.238E+01	4.768E+01	3.464E+01	4.310E+01	8.460E+00	0.221
1986	3.582E+01	3.518E+01	-1.80%	3.029E+01	4.492E+01	3.246E+01	4.065E+01	8.192E+00	0.229
1987	3.176E+01	3.114E+01	-1.98%	2.653E+01	4.026E+01	2.855E+01	3.627E+01	7.721E+00	0.243
1988	2.743E+01	2.685E+01	-2.13%	2.258E+01	3.523E+01	2.443E+01	3.146E+01	7.029E+00	0.256
1989	2.325E+01	2.263E+01	-2.68%	1.860E+01	3.014E+01	2.039E+01	2.697E+01	6.581E+00	0.283
1990	2.081E+01	2.020E+01	-2.94%	1.644E+01	2.749E+01	1.807E+01	2.436E+01	6.283E+00	0.302
1991	1.870E+01	1.802E+01	-3.60%	1.428E+01	2.517E+01	1.593E+01	2.203E+01	6.098E+00	0.326
1992	1.784E+01	1.725E+01	-3.30%	1.359E+01	2.450E+01	1.524E+01	2.147E+01	6.229E+00	0.349
1993	1.831E+01	1.758E+01	-3.98%	1.383E+01	2.480E+01	1.530E+01	2.155E+01	6.255E+00	0.342
1994	1.990E+01	1.919E+01	-3.56%	1.540E+01	2.667E+01	1.717E+01	2.341E+01	6.231E+00	0.313
1995	2.321E+01	2.244E+01	-3.31%	1.876E+01	2.987E+01	2.051E+01	2.676E+01	6.252E+00	0.269
1996	2.556E+01	2.471E+01	-3.33%	2.115E+01	3.178E+01	2.283E+01	2.875E+01	5.920E+00	0.232
1997	3.032E+01	2.945E+01	-2.86%	2.616E+01	3.631E+01	2.771E+01	3.345E+01	5.734E+00	0.189
1998	3.330E+01	3.240E+01	-2.72%	2.931E+01	3.929E+01	3.083E+01	3.654E+01	5.706E+00	0.171
1999	3.518E+01	3.420E+01	-2.79%	3.084E+01	4.095E+01	3.262E+01	3.808E+01	5.461E+00	0.155

NOTE: Printed BC confidence intervals are always approximate.
At least 500 trials are recommended when estimating confidence intervals.

TRAJECTORY OF ABSOLUTE FISHING MORTALITY RATE (BOOTSTRAPPED)

Year	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
1977	0.000E+00	0.000E+00	0.00%	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000
1978	7.058E-03	7.611E-03	7.83%	5.621E-03	8.875E-03	6.260E-03	8.068E-03	1.809E-03	0.256
1979	2.636E-02	2.774E-02	5.25%	2.060E-02	3.214E-02	2.315E-02	2.943E-02	6.285E-03	0.238
1980	1.896E-01	1.975E-01	4.13%	1.517E-01	2.310E-01	1.677E-01	2.132E-01	4.558E-02	0.240
1981	1.165E-01	1.206E-01	3.58%	9.287E-02	1.409E-01	1.030E-01	1.309E-01	2.790E-02	0.240
1982	1.213E-01	1.250E-01	3.06%	9.689E-02	1.445E-01	1.073E-01	1.350E-01	2.769E-02	0.228
1983	1.038E-01	1.065E-01	2.67%	8.340E-02	1.226E-01	9.214E-02	1.148E-01	2.270E-02	0.219
1984	1.719E-01	1.757E-01	2.18%	1.382E-01	2.027E-01	1.528E-01	1.902E-01	3.741E-02	0.218
1985	2.196E-01	2.239E-01	1.98%	1.754E-01	2.599E-01	1.943E-01	2.427E-01	4.840E-02	0.220
1986	3.262E-01	3.328E-01	2.02%	2.584E-01	3.892E-01	2.863E-01	3.623E-01	7.595E-02	0.233
1987	4.141E-01	4.231E-01	2.18%	3.240E-01	5.006E-01	3.618E-01	4.634E-01	1.016E-01	0.245
1988	4.983E-01	5.115E-01	2.66%	3.852E-01	6.164E-01	4.346E-01	5.672E-01	1.326E-01	0.266
1989	4.875E-01	5.037E-01	3.33%	3.741E-01	6.188E-01	4.220E-01	5.630E-01	1.409E-01	0.289
1990	5.196E-01	5.397E-01	3.87%	3.922E-01	6.737E-01	4.437E-01	6.060E-01	1.623E-01	0.312
1991	4.717E-01	4.915E-01	4.18%	3.491E-01	6.207E-01	3.952E-01	5.542E-01	1.590E-01	0.337
1992	4.165E-01	4.313E-01	3.56%	3.037E-01	5.465E-01	3.490E-01	4.918E-01	1.427E-01	0.343
1993	3.335E-01	3.476E-01	4.24%	2.482E-01	4.365E-01	2.853E-01	3.940E-01	1.087E-01	0.326
1994	2.325E-01	2.410E-01	3.65%	1.785E-01	2.959E-01	2.004E-01	2.668E-01	6.641E-02	0.286
1995	2.498E-01	2.586E-01	3.52%	1.982E-01	3.058E-01	2.206E-01	2.820E-01	6.141E-02	0.246
1996	1.202E-01	1.243E-01	3.38%	9.883E-02	1.420E-01	1.085E-01	1.331E-01	2.461E-02	0.205
1997	1.411E-01	1.452E-01	2.88%	1.192E-01	1.624E-01	1.293E-01	1.538E-01	2.452E-02	0.174
1998	1.454E-01	1.498E-01	3.04%	1.243E-01	1.658E-01	1.336E-01	1.572E-01	2.354E-02	0.162

NOTE: Printed BC confidence intervals are always approximate.
At least 500 trials are recommended when estimating confidence intervals.