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Assessment of the Greenland Halibut Stock Component in NAFO Subarea 0 + Div. 1A Offshore + Div.1B-1F

by

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Abstract

The paper presents the background and the input parameters from research surveys and the commercial fishery to the assessment of the Greenland halibut stock component in NAFO Subarea 0 + Div. 1A offshore + Div.1B-1F. Catches peaked at 18,000 tons in 1992 but have been stable around 10,500 tons since then. The catch composition has been stable in recent years. Survey trawlable biomass in Div. 1CD was in 1998 estimated as 70,000 tons which is an increase from the 56,000 estimated in 1997. Recruitment estimates at age 1 of the 1992-94 year-classes were lower than the presumably good 1991 year-class, but are still considered to be at or above average for the last decade. The 1995 year-class was estimated to be the best in the series. The 1996 and 1997 year-classes were estimated to be slightly below the average of the last decade. A combined standardized CPUE index from Div. 0B and Div. 1CD has been stable during 1990-98. Although the survey series from 1987-1995 not is directly comparable with the series from 1997-98 the decline in the stock observed in Subarea 1 until 1994 has stopped and the stock seems to be back at the level in the late-1980s and early-1990s.

1. TAC, description of the fishery and nominal catches

Between 1979 and 1994 a TAC has been set at 25,000 tons for SA 0+1, including Div. 1A inshore. In 1994 it was decided to make separate assessments for the inshore area in Div. 1A and SA 0 + Div. 1A offshore + Div.1B-1F. From 1995-1999 a TAC for this area was set at 11,000 tons.

In the period 1982-1989 nominal catches of Greenland halibut in SA 0 + Div. 1A offshore + Div.1B-1F fluctuated between 300 and 4,500 tons. Catches increased from 2,200 in 1989 tons to 10,500 in 1990. Catches stayed at that level in 1991 but increased again in 1992 to 18,100, the highest in the time series. Since then catches have been about 11,000 tons but they decreased to 8,898 in 1998. The increase in catches from 1989 to 1990 was mainly due to a new trawl fishery by Canada and Norway in Div. 0B, while the increase from 1991 to 1992 was due to the introduction of a trawl fishery by Russia in Div. 0B and an increase in fishing activity in SA 1.

In 1983 annual catches in Div. 0B were about 4,500 tons. Catches then dropped to a level of 1,000 tons or lower, where they remained until they increased from 907 tons in 1989 to 9,498 tons in 1990. Catches decreased in 1991 to 8,606 tons, to increase again in 1992 to 12,358 tons. Catches then decreased gradually to 4,274 tons in 1994, but increased again to about 5,500 tons in 1995 and stayed at level until 1997. In 1998 catches dropped to 4370 tons. (Table 1).

Canadian catches amounted to 3,265 tons of which 1,178 tons were taken by trawl, 1,854 tons by gillnets and 233 tons were taken on longlines. Not reported catches amounted to 1,105 tons. Less than 100 tons were taken in Cumberland sound. An exploratory trawl fishery in Div. 0A by Canada yielded 42 tons.

The catches in Subarea 1 (Div. offshore 1A Div. + 1B-1F) were below 1,600 tons during the period 1982-1990. In 1991 catches increased to 2,376 tons and were around 5,500 tons in the period 1992-1995, but decreased to around 4,500 in 1996 and they have been at that level since. In 1998 total catches in offshore Div. 1A + Div. 1B-1F were 4,528 tons, of which 4,521 tons were taken offshore, almost exclusively in Div. 1D. Longliners from Greenland and Norway caught 662 tons compared to 1,090 tons in 1997, while trawlers from Greenland, Russia, EU-Germany and Norway caught 3859 tons. Inshore catches amounted to 7 tons (Table 2).

2. Input data

2.1. Research trawl survey

GHL-survey

In 1998 a stratified random trawl survey for Greenland halibut was conducted in September-October (SCR 99/30) as the second in the survey series. The survey covered NAFO Division 1CD between the 3-nm line or the midline to Canada at depths between 400 and 1500 m. The biomass and abundance was estimated at 70,474 tons and $67.667*10^6$ which is a statistically insignificant (95% level) increase from 56,260 tons and $53.613*10^6$ specimens estimated in a similar survey in 1997. The highest densities were found at depths between 1000 and 1400 m. The increase in biomass and abundance from 1997 to 1998 was seen in all strata except the shallow stratum (401-600 m) in Div. 1CD, where the biomass is very low and in the deepest stratum in Div. 1D (1401-1500 m). The over all length distribution was dominated by a single mode around 48-50 cm similar to the length distribution observed in 1997.

Shrimp-survey

Since 1988 annual trawl surveys with a shrimp trawl have been conducted off West Greenland in July-September. The survey covers the area between 59^oN and $72^o30'N$ (Div. 1A-1F), from the 3-mile limit to the 600 m depth contour line. Estimated total trawlable biomass of Greenland halibut in the offshore areas (- Disko Bay) was about 9,000 tons in 1992 and 1993 and increased to 11,000 tons in 1994. After a drop in 1995 to 6,800 tons the total offshore biomass increased to 14,772 tons in 1996 to decline again to 9,631 tons in 1997. In 1998 the biomass was estimated at 13,111 ton. The abundance was estimated at 175 mill, which is an increase from 115 mill specimens in 1997. The catches were almost exclusively comprised of one and two year old fish. The increase in biomass and abundance was seen in all NAFO divisions except Div. 1C (SCR 99/27).

In the Disko Bay the biomass and abundance was estimated at record high 12,500 tons and 182 mill compared to 7,772 tons and 126 mill specimens in 1997.

The biomass in the nursery area (1AS and 1B) was estimated at 6478 tons compared to 4,229 tons in 1997. The abundance was estimated at 106 mill compared to 67 mill 1997. The estimate from 1998 is above the level in 1990-1991, but below the 1992-1995 level (200 mill).

Recruitment

A recruitment index was provided from the shrimp trawl survey. By means of the Petersen-method ages 1, 2 and 3+ were separated in the survey catches in the nursery area during the period 1988 to 1998. Catches were standardized as catch in number per hour as described in Bech (1995). Data were plotted by year-classes to visualize the relative year-class strength and development in relative abundance (Fig. 1).

The recruitment has been declining since the presumably large 1991 year-class, but the recruitment has been above

the level in the 1980s. The recruitment increased again with the 1995 year-class which was the largest on record. The 1996 year-class was at the low level of the 1990 year-class. With a mean catch of 185 one year old specimens per hour the 1997 year-class seems to be at an average level for the time series. The large 1995 year-class has at age 3 been reduced markedly offshore and is now at the average level for the 1990s. In Disko Bay catches of one year old fish is the largest on record (1040 specimens per hour). The 1995 year-class is still above average as age 3 in the Disko Bay.

SSB/Recruitment

The relation between the spawning stock in numbers (ages 10-18) in Div. 1CD from the joint Japan/Greenland survey and the Greenland survey and recruitment, given as the number of fish age 1 in the nursery area (Div. 1AS and Div. 1B) estimated from the Greenland shrimp trawl survey, is shown in Fig 2.

Exploratory fishery in 0A

An exploratory trawl fishery for Greenland halibut was conducted in Div. 0A. The catch was 42 tons in 10 days. The CPUE was 619 kg/hr, which is somewhat higher than in 1967 but at the same level as in 1996. The length distribution ranged from 29-86 cm with a clear mode around 50 cm, which is very similar to the results from 1997 (SCR 99/45).

2.2 Tagging

A review of the tagging experiments on Greenland halibut that have been conducted in Greenlandic waters in the period 1986-1998 was presented (SCR 99/25). In total 7244 fish have been tagged inshore and offshore and 517 recaptures were recorded from the Northwest Atlantic area. A substantial proportion of the fish tagged in the Davis Strait, Baffin Bay and the fjords in southwestern and eastern Greenland migrated up to 2500 km, primarily to the Denmark Strait between East Greenland and Iceland. But migrations from the southwestern Greenland to the Newfoundland coast were also observed. The migrations were probably prespawning and feeding migrations. The results indicated that some of the Greenland halibut in the Davis Strait and the southwest Greenland fjords originated from the spawning grounds west of Iceland.

Of the 4319 fish tagged inshore in northwest Greenland (Div. 1A) 418 were recaptured until 8 years after tagging. Of these 400 had reliable information on recapture position. No fish were captured outside the inshore areas comprised of Disko Bay, Uummannaq and Upernavik area and 90% of the fish were recaptured in the fjord where they were tagged indicating that these fish are resident. There were observed some limited migration between some of the inshore areas especially in the Disko Bay where fish have moved between the fjord Torsukattaq and Ilulisat. Further, the data indicated some seasonal migrations in and out of the fjords probably related to feeding.

2.3 Commercial fishery data.

Length and age distribution

Catch-at-age data from the offshore trawl fishery in Div. 1D were obtained from a trawler German trawler (SCS 99/9).

Catch-at-age by gear (trawl and gillnet+longlines) and for gears combined was available from SA 0 (SCR 99/49). The longline catches from SA1 (662 tons) were added to the combined gillnet-longline catch-at-age-data from 0B. Table 3 and 4 shows catch-at-age and weight-at-age, respectively. The age distributions for trawl and longline + gillnets are given in Fig.3.

Ages 7 and 8 are the most dominant year-class in the trawl fishery, age 7 being most dominant in 0B and age 8 most dominant in 1CD. The ages 10 and 11 was dominant in the gillnet catches. The increase in number of 10+ caught was due to an increase in gillnet catches and a shift in the mode from 8-9 in 1997 to 10-11 in 1998 (Table 3).

Mean weigh-at-age

Mean weight-at-age for the ages 7-12 in the commercial offshore fishery has been stable in resent years (Table 4).

Catch rates

Standardized catch rate series for the offshore trawl fishery were calculated based on observer data in SA0 (Div. 0B) for the period 1990-1998 (SCR 99/47) and for the offshore trawl fishery in SA1 (1CD) for the period 1987-1998 based on available logbook data.

Unstandardized catch rates from the trawl fishery were available from Div. 0B (SCR 99/47), from the Norwegian trawl fishery in Div. 1CD in the period 1991-1998 and form an EU(German) trawler were available for 1996-1998 (SCS 99/9). Further, unstandardized catch rates were obtained from logbooks from the trawl fishery Div. 1CD Fig.6 (Japan s: small trawlers, Japan l: one large trawler).

Further, catch rates from one offshore longliner fishing in Div. 1CD were available for the period 1994-1998.

The standardized catch rate series from 0B showed stable catch rates during the period. The catch rates for 96-98 are slightly below the average for the 1990-1998 period. (Fig. 5). The standardized catch rates in SA 1 fluctuated in the period 1987-1992 and declined in the period 1993–1995. In 1996 the catch rate increased slightly to drop again in 1997. In 1998 catch rates increased again to a level near the average for the period 1990-1998 (Fig. 5). The increase in the catch rate in SA1 in 1998 was caused by a small increase in Greenland catch rates and more pronounced increase in Norwegian catch rates (Fig. 4).

A combined catch rate for SA0 and SA1 was made based on the data from the two areas. The catch rates were stable in the period 1987-1989 (One large vessel in SA1 only and catches < 2600 tons), but dropped in 1990. From then on the catch rates haven been stable with minor fluctuations and the catch rates in 1998 are the same as in 1990 (Fig. 5, Appendix 1). Due to frequency of fleet changes in the fishery in both SA0 and SA1, the standardized indices of CPUE should however be treated with caution.

The catch rates in the longline fishery in Div. 1CD increased from 112 kg/hr in 1994 to 181 kg/hr in 1995, but have been decreasing gradually since from 110 kg/hr in 1996 to 81 kg/hr in 1997 and 52 kg/hr in 1998. The 1998 data represents, however, only 14% of the catches and there was no information from 4. quarter where the catch rates use to be highest. According to the company the catch rates increased in 4. quarter, but they could not give any figures.

3. Assessment

3.1. Yield-per-Recruit Analysis.

The level of total mortality has in 1994-1996 been estimated by means of catch-curves using data from the offshore longline fishery in Div. 1D. Z was estimated from regression on age 15-21. A relative F-at-age was derived from the catch curve analysis, where the trawl, longline and gillnet catches were weighed and scaled to the estimated stock composition. In all three years STACFIS considered that the estimation of Z was based on too limited samples and represented too small a part of the fishery and that the outcome of the catch curve analysis were too uncertain to be used in the yield per recruit analysis. No longline data were available from 1998 for catch curve analysis this year.

3.2. XSA

An XSA has been run unsuccessful several times during the 1990'ies, the latest in 1996 using a survey series covering 1987-1995 as tuning. STAFIS considered the XSA's unsuitable for an analytic assessment due to high log-catchability residuals and S.E.'s and systematic shift in the residuals by year. Further, a retrospective plot of

F_{bar} showed poor convergence. In 1999 the XSA analyses was rerun including the latest two years surveys (1997-1998, new vessel and gear) (not presented) but the outcome of the analysis has not improved.

3.3. Spawning stock/recruitment relations

A spawning stock/recruitment plot based on the 8 available observations from the joint Japan/Greenland survey and the Greenland survey is shown in Fig. 2. No further analysis of spawning stock recruitment relationships have been made due to few observations distributed on two different surveys, poor estimate of spawning stock biomass (survey trawl only take a small proportion of the mature fish, the survey covers only a restricted part of the area covered by the assessment, further, knife edge maturity ogive was applied), poor estimate of age of the recruits (the Petersen method), poor estimates of the numbers of recruits (data from Div. 1AS and 1B only, but the recruits occurs in an larger area especially when the year-class is good).

3.4. ASPIC

ASPIC was run with standardized CPUE data and a biomass index as inputs. Three CPUE series were available, one series covering Div. 0B during the period 1990-1998, one covering Div. 1CD during the period 1987-1998 and a series combining the two data sets. The biomass index was from 1CD and covered the period 1987-1995 and 1997-1998. Several runs showed that the combined CPUE series from Div. 0B+1CD fitted the total catch data best in terms of r^2 and "total objective function". Runs with biomass alone gave relatively bad fits in terms of "total objective function" and r^2 and the modeled population trajectory declining drastically over the period. Runs with the CPUE series from 0B gave unrealistic high B_{msy} and negative r^2. The run with the combined CPUE series showed, however, that sensitivity analysis should be run, because "the B1-ratio constraint term contributed to loss". Several runs with different realistic values for the constraint did not solve the problem. Further, the coverage index and nearness index was equal in all runs. Several runs with different constraints on r and MSY were tried but it did changes the outcome of the analysis. Removing the three first years from the input data gave negative r^2. To get measures of variance the run with the combined CPUE series was bootstrapped (500 resamplings). Inputs and outputs are given in Appendix 2.

The results show that estimated fishing moralities 1987-1998 have been less than the (bias-reduced) estimate of F_{msy} (0.22) except for one year (1992).

A number of essential parameters are quite imprecisely estimated (r, q, F_{msy}), and it is considered that the estimates of MSY and F_{msy} were not precise enough to be used.

4. Prognosis

Since catches peaked with 18.000 tons in 1992 they have been stable at around 10.500 tons. The age composition in the catches seems stable. Standardized catch in Div. 1CD have increased from 1997 to 1998. And both the catch rates from Div. 1CD and Div. 0B are at an average level for the period 1990-1998, and the combined catch rate has showed very little variation in the same period. An unstandardized longline CPUE index showed a decrease from 1995 to 1998.

Survey biomass showed an increasing trend between the survey in 1997 and 1998. The length distribution in the survey 1998 peaked around 48-50 cm, as seen in previous year's surveys. The recruitment increased compared to 1997 and was at a level little below average for the period 19987-1998.

5. Biological reference points

Yield-per-recruit analysis or other age-based methods are not available, for estimating biological reference points. Biomass indices and CPUE series are relative short and show little variability and are not useful for estimating reference points.

6. References

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Table 1. Greenland halibut catches (metric tons) by year and country for Subarea 0 from 1987 to 1998.

	Year											
Country	87	88	89	90	91	92	93	94[a]	95[a]	96[a]	97[a]	98[a]
CAN	-	2	-	589	256	2194	883	-	1656	2293[d]	1700	3265
EST	-	-	-	-	-	-	631	-	-	-	-	-
FRO	388	963	596	2252	2401	463	1038	-	-	-	-	-
JAP	-	-	-	113	232	337	252	600	1031	500	-	-
LAV	-	-	-	-	-	-	83	-	-	-	-	-
NOR	-	-	282	5016[f]	3959	-	373	-	-	-	-	-
RUS	-	59	29	1528	1758	9364	4229[b]	3674	261	915	-	-
TOTAL	388	1024	907	9498	8606	12358	7489	4274	5589[c]	5818[e]	5740[g]	4370[h]

[a] Provisional data.
[b] The russian catch is reported as area unknown, but has peviously been reported from 0B
[c] Including 2641 tons non-reported.
[d] Including 60 tons from Cumberland Sound and 295 tons from an exploratory fishery in 0A.
[e] Including 2110 tons non-reported
[f] Dobbel reported as 10031 tons
[g] Including 4040 tons non-reported
[h] Including 1105 tons unreported

Table 2. Greenland halibut catches (metric tons) by year and country for Subarea 1 from 1987 to 1998.

	Year											
Country	87	88	89	90	91	92	93	94[a]	95[a]	96[a]	97[a]	98[a]
GRL (excl. 1A inshore)	-	-	-	-	965	227	213	885	1405	1880	2312	2296
FRO	-	-	-	54	123	151	128	780	-	-	-	-
JPN	907	1581	1300	988	677	2902	1198	820	337	-	-	-
NOR	-	-	-	-	611	2432	2344	3119	2472	1839	1912	1339
RUS	-	-	-	-	-	-	5	-	296	254	-	543
EU	-	-	-	-	-	-	46	266	527	450	446	350
1A-F (excl. 1A inshore)	907	1581	1300	1042	2376	5712	3934	5870	5704[b]	4551[d]	4798[d]	4528

[a] Provisional data.
[b] Including 667 tons non-reported.
[c] Including 128 tons non-reported.
[d] Including 128 tons non-reported.

Table 3. Catch numbers at age

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
AGE												
5	2	1	1	4	20	53	241	252	99	164	60	76
6	31	29	36	87	318	678	651	856	488	603	425	378
7	182	190	244	592	1742	2967	2422	2460	2064	2178	1942	818
8	296	354	409	1711	2679	4311	2356	1683	1225	1840	2398	1140
9	193	245	212	1356	1418	2604	1048	950	765	785	1151	905
10	77	115	75	711	533	951	590	293	385	370	481	583
11	40	80	47	359	221	398	224	182	335	188	256	430
12	18	61	48	195	144	231	130	159	293	146	126	209
13	10	58	44	189	108	158	72	125	160	71	100	155
14	9	46	42	115	60	85	59	57	111	61	22	99
15	6	35	26	67	36	45	37	54	121	41	13	19
16	3	15	12	17	6	23	26	34	53	37	12	4
17	4	4	1	3	2	1	4	10	26	14	0	
18+	2	1	0	0	0	0	2	7	13	22	0	
TOTNUM	873	1234	1197	5406	7287	12505	7862	7122	6138	6520	6986	4816
TONS	1295	2605	2207	10640	10982	18070	11423	10144	11293	10369	10538	8898

Table 4. Catch weights at age (kg)

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
AGE												
5	0.29	0.29	0.29	0.33	0.34	0.33	0.58	0.43	0.47	0.52	0.36	0.50
6	0.51	0.51	0.51	0.54	0.54	0.56	0.72	0.62	0.64	0.68	0.55	0.72
7	0.74	0.74	0.74	0.79	0.79	0.80	0.96	0.91	0.93	0.94	0.86	0.97
8	1.08	1.08	1.08	1.10	1.12	1.13	1.26	1.26	1.33	1.38	1.27	1.25
9	1.41	1.42	1.42	1.52	1.57	1.59	1.80	1.72	1.81	1.90	1.83	1.57
10	1.97	2.05	2.00	2.11	2.27	2.28	1.43	2.19	2.40	2.48	2.37	2.24
11	2.58	2.80	2.68	2.94	3.22	3.02	3.25	2.73	2.93	3.18	3.01	3.09
12	3.52	3.88	3.73	3.90	4.24	4.02	4.10	3.43	3.65	4.04	3.84	3.84
13	4.64	5.01	4.87	4.96	5.50	5.33	5.26	4.48	4.48	5.05	4.93	4.74
14	5.79	6.16	6.20	6.26	6.82	6.76	6.17	5.75	5.67	5.95	5.70	6.04
15	6.61	7.44	7.65	7.96	8.33	7.76	7.42	6.58	6.66	7.33	6.79	6.60
16	7.99	8.88	9.36	9.90	9.89	8.58	8.04	7.36	7.74	8.64	8.00	13.45
17	9.56	9.86	9.56	11.86	9.56	11.95	9.24	9.42	10.28	9.17		
+gp		11.33					10.25	11.15	11.00	11.10		

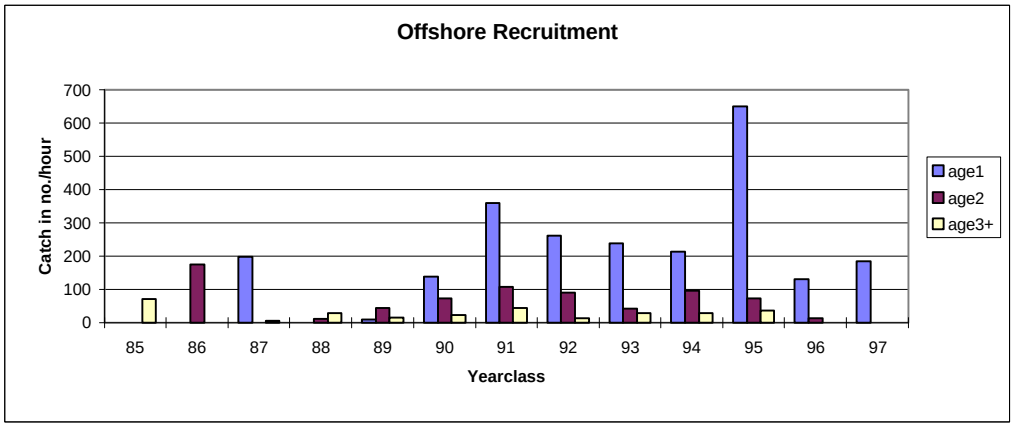


Fig. 1. Year-class strength of Greenland halibut of ages 1-3 in number per hour trawled in the offshore nursery area.

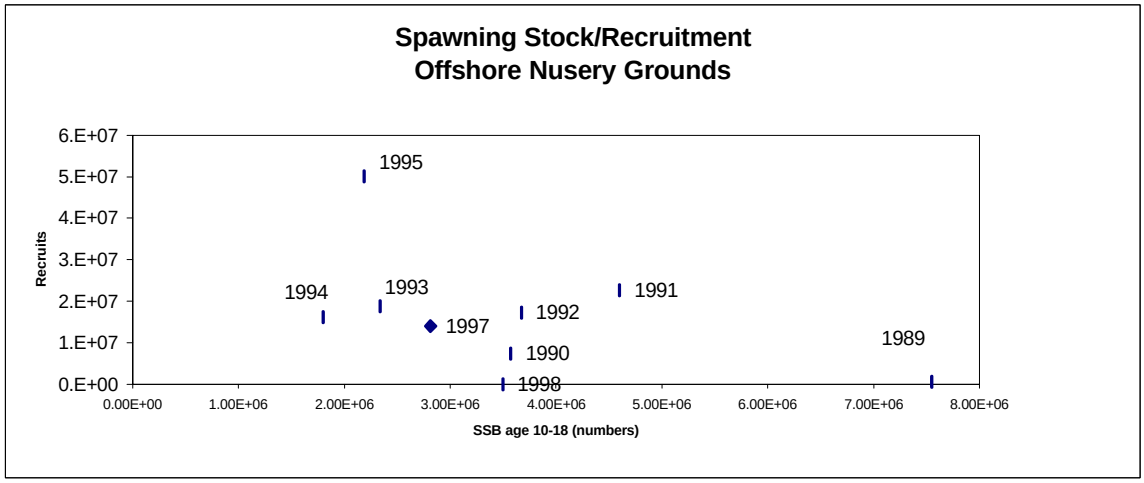
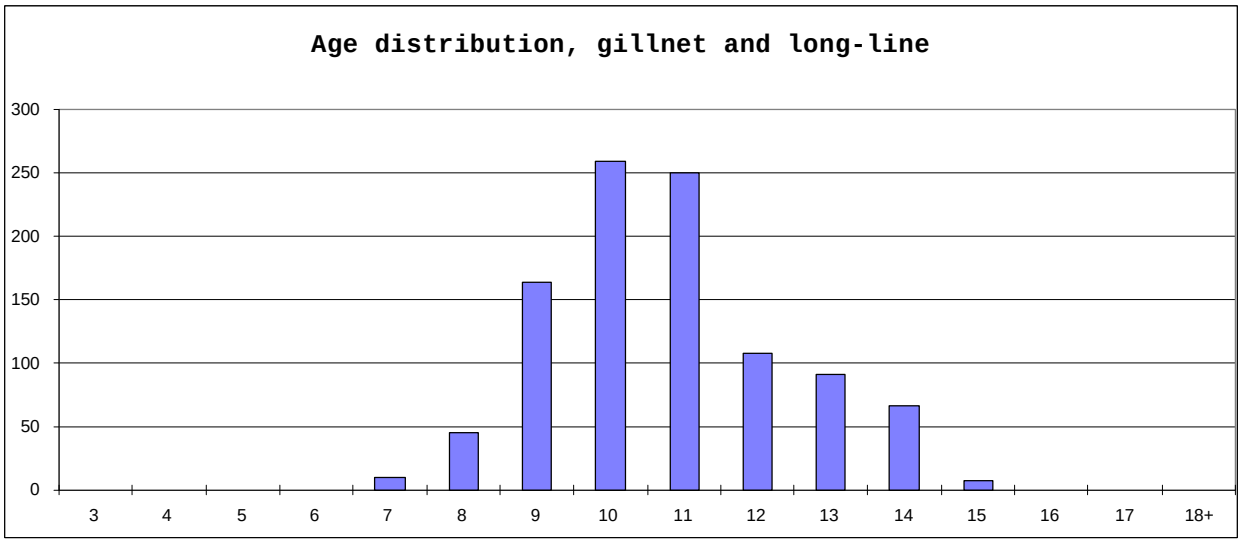


Fig.2. Spawning stock in numbers (ages 10-18 in Div.1CD from the joint Japan/Greenland survey and the Greenland survey (1997)) plotted *vs* number of fish age 1 in the nursery area (Div. 1AS-1B) the following year estimated from the Greenland shrimp trawl survey.



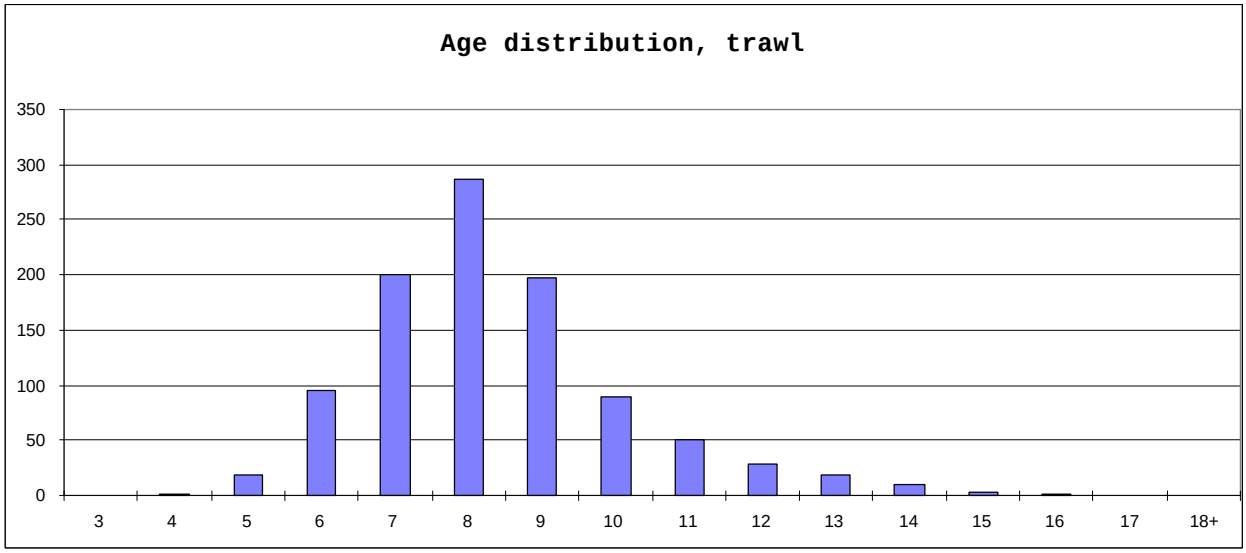


Fig. 3. Age distribution in the offshore gillnet and longline and trawl fishery in SA 0+1 in 1998 in per mill.

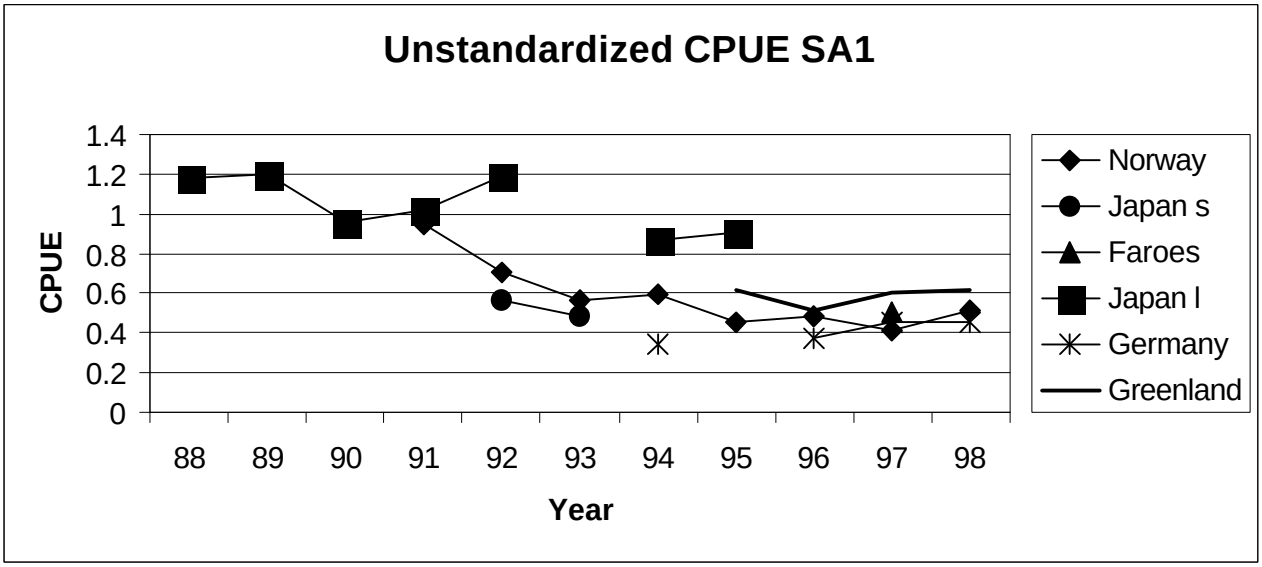


Fig. 4. Unstandardized trawl CPUE series from Div. 1CD.

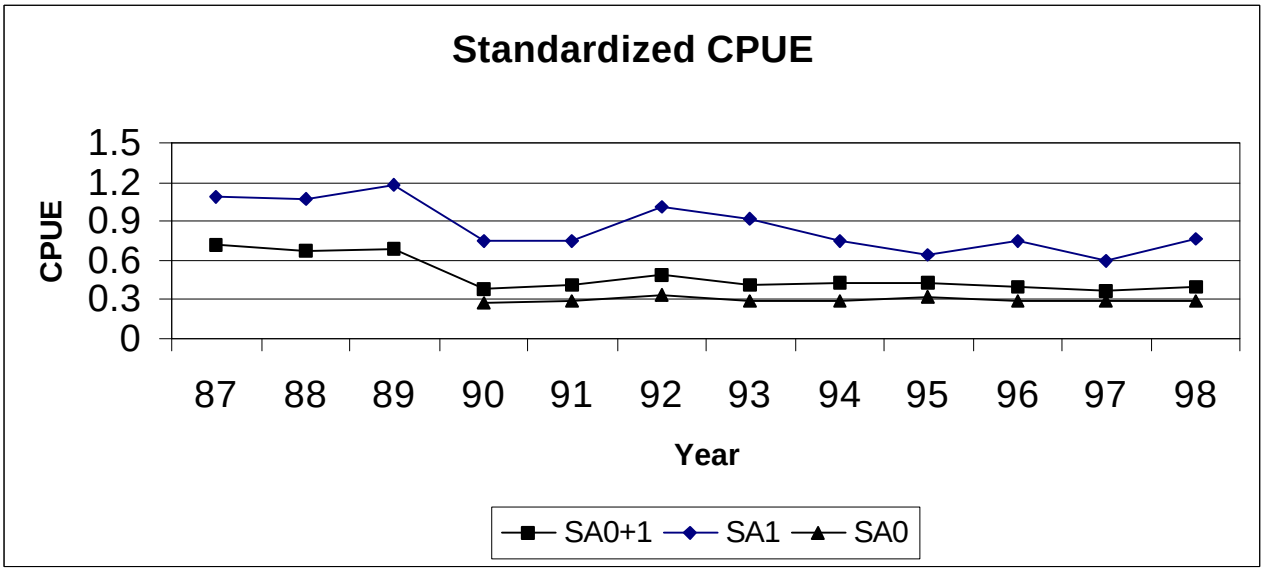


Fig. 5. Standardized trawl CPUE indices from SA1 (Div. 1CD) and SA0+1 (Div. 0B) (not corrected for retransformation) and SA0 corrected for retranformation.

Appendix 1. Combined standardized CPUE index SA0+1

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YR	12	87 88 89 90 91 92 93 94 95 96 97 98
MD	10	2 4 5 6 7 8 9 10 11 12
CGT	17	2 4 5 6 7 8 9 2126 2127 5126 5127 14124 14125 15126 15127 20126 20127

Number of observations in data set = 459

Dependent Variable: LCPH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	36	89.5268914	2.4868581	42.31	0.0001
Error	422	24.8045034	0.0587784		
Corrected Total	458	114.3313947			

R-Square	C.V.	Root MSE	LCPH Mean
0.783047	-31.67216	0.24244	-0.76548

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YR	11	35.3381065	3.2125551	54.66	0.0001
MD	9	7.4043201	0.8227022	14.00	0.0001
CGT	16	46.7844648	2.9240290	49.75	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YR	11	3.4093979	0.3099453	5.27	0.0001
MD	9	5.6906708	0.6322968	10.76	0.0001
CGT	16	46.7844648	2.9240290	49.75	0.0001

Parameter		Estimate		T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		-0.911036854	B	-10.33	0.0001	0.08816185
YR	87	0.584803165	B	2.23	0.0259	0.26165837
	88	0.522692293	B	3.07	0.0023	0.17046663
	89	0.541095566	B	3.46	0.0006	0.15621709
	90	-0.034721603	B	-0.45	0.6523	0.07700927
	91	0.024659605	B	0.32	0.7518	0.07791904
	92	0.204064203	B	2.71	0.0069	0.07521129
	93	0.036634635	B	0.48	0.6295	0.07587267
	94	0.064246459	B	0.82	0.4151	0.07875161
	95	0.062715950	B	0.74	0.4609	0.08497257
	96	-0.010236347	B	-0.13	0.8937	0.07657837
	97	-0.091540332	B	-1.24	0.2140	0.07355240
	98	0.000000000	B	.	.	.
MD	2	-1.131675539	B	-4.31	0.0001	0.26231823
	4	-0.556666581	B	-1.96	0.0507	0.28405346
	5	-0.302787940	B	-1.47	0.1417	0.20565384
	6	-0.876334871	B	-5.32	0.0001	0.16466193
	7	-0.431763120	B	-6.69	0.0001	0.06456031
MD	8	-0.329348148	B	-5.77	0.0001	0.05704522
	9	-0.371601710	B	-6.95	0.0001	0.05350555
	10	-0.369298384	B	-7.21	0.0001	0.05118960
	11	-0.204092657	B	-3.93	0.0001	0.05194667
	12	0.000000000	B	.	.	.
CGT	2	0.410346556	B	6.25	0.0001	0.06562293
	4	0.344192941	B	2.13	0.0337	0.16157831
	5	0.463185180	B	4.37	0.0001	0.10608272
	6	0.676702810	B	2.65	0.0083	0.25501935
	7	0.988931714	B	12.63	0.0001	0.07828358
	8	0.242514699	B	2.56	0.0108	0.09473587
	9	0.614155480	B	6.61	0.0001	0.09285180
	2126	0.384287155	B	4.78	0.0001	0.08038495
	2127	0.885907696	B	13.25	0.0001	0.06687932
	5126	0.741903513	B	6.40	0.0001	0.11585855

5127	0.920259354	B	15.24	0.0001	0.06039581
14124	0.320872034	B	5.28	0.0001	0.06071936
14125	0.582609803	B	3.82	0.0002	0.15250303
15126	1.103476545	B	16.19	0.0001	0.06815652
15127	1.055405245	B	11.83	0.0001	0.08918357
20126	0.019753561	B	0.47	0.6359	0.04169023
20127	0.000000000	B	.	.	.

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

Appendix 2a. Input parameters to Aspic.

```
'BOT'                   ## Mode (FIT, IRF, BOT)
'NAFO Subarea 0-1 Greenland halibut -- ASPIC 3.6x -- one Indices'   ## Title for run
'EFF'                    ## Error type ('EFF' = condition on yield)
2                        ## Verbosity (0 to 4)
500                      ## Number of bootstrap trials, <= 1000
1 50000                  ## Monte Carlo search enable (0,1,2), N trials
1d-6                     ## Convergence crit. for simplex
3d-8                     ## Convergence crit. for restarts
1.0d-4                   ## Convergence crit. for estimating effort
3.0                      ## Maximum F when estimating effort
1.0                      ## Statistical weight for B1 > K as residual
1                        ## Number of data series (fisheries)
1.0                      ## Statistical weights for fisheries
2.5                      ## B1-ratio (starting guess)
8000                     ## MSY (starting guess)
0.2                      ## r (starting guess)
1.0d-4 1.0 1.0d-4        ## q (starting guess)
1 1 1 1                  ## Flags to estimate parameters
8000 80000              ## Min and max allowable MSY
0.1  2.0                 ## Min and max allowable r
1872085                  ## Random number seed
12                       ## Number of years of data.
'Standardized CPUE SA0+1'     ## Title for first series
'CC'                          ## Type of series ('CC' = CPUE, catch)
1987    0.722  1295
1988    0.678  2605
1989    0.691  2207
1990    0.388 10640
1991    0.412 10982
1992    0.493 18070
1993    0.417 11423
1994    0.429 10144
1995    0.428 11293
1996    0.398 10366
1997    0.367 10538
1998     0.402 8898
```

Appendix 2B. Output of bootstrapped Aspic run.

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07 Jun 1999 at 15:56

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

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CONTROL PARAMETERS USED (FROM INPUT FILE)

Number of years analyzed:	12	Number of bootstrap trials:	500
Number of data series:	1	Lower bound on MSY:	1.000E+03
Objective function computed:	in EFFORT	Upper bound on MSY:	4.000E+04
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:	2.000E+00
Relative conv. criterion (effort):	1.000E-04	Random number seed:	1872085
Maximum F allowed in fitting:	3.000	Monte Carlo search trials:	50000

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) code 0

Normal convergence.

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	1.287E-02	1	N/A	1.000E+00	N/A	
Loss(1)	Standardized CPUE SA0+1	2.381E-01	12	2.381E-02	1.000E+00	1.000E+00	0.678

TOTAL OBJECTIVE FUNCTION: 2.50933819E-01

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

Number of restarts required for convergence: 15
Est. B-ratio coverage index (0 worst, 2 best): 0.6625
Est. B-ratio nearness index (0 worst, 1 best): 0.6625

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	Starting guess	Estimated	User guess
B1R	Starting biomass ratio, year 1987	2.240E+00	3.500E+00	1	1
MSY	Maximum sustainable yield	1.175E+04	8.000E+03	1	1
r	Intrinsic rate of increase	6.012E-01	2.000E-01	1	1
.....	Catchability coefficients by fishery:				
q(1)	Standardized CPUE SA0+1	7.590E-06	1.000E-04	1	1

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	Formula	
MSY	Maximum sustainable yield	1.175E+04	Kr/4	
K	Maximum stock biomass	7.816E+04		
Bmsy	Stock biomass at MSY	3.908E+04	K/2	
Fmsy	Fishing mortality at MSY	3.006E-01	r/2	
F(0.1)	Management benchmark	2.705E-01	0.9*Fmsy	
Y(0.1)	Equilibrium yield at F(0.1)	1.163E+04	0.99*MSY	
B-ratio	Ratio of B(1999) to Bmsy	1.372E+00		
F-ratio	Ratio of F(1998) to Fmsy	5.585E-01		
Y-ratio	Proportion of MSY avail in 1999	8.613E-01	2*Br-Br^2	Ye(1999) = 1.012E+04
.....	Fishing effort at MSY in units of each fishery:			
fmsy(1)	Standardized CPUE SA0+1	3.960E+04	r/2q(1)	f(0.1) = 3.564E+04

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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	1987	0.015	8.757E+04	8.453E+04	1.295E+03	1.295E+03	-4.147E+03	5.096E-02	2.241E+00
2	1988	0.033	8.213E+04	8.004E+04	2.605E+03	2.605E+03	-1.157E+03	1.083E-01	2.101E+00
3	1989	0.029	7.837E+04	7.740E+04	2.207E+03	2.207E+03	4.586E+02	9.485E-02	2.005E+00
4	1990	0.147	7.662E+04	7.246E+04	1.064E+04	1.064E+04	3.148E+03	4.884E-01	1.961E+00
5	1991	0.165	6.913E+04	6.640E+04	1.098E+04	1.098E+04	6.000E+03	5.502E-01	1.769E+00
6	1992	0.306	6.415E+04	5.896E+04	1.807E+04	1.807E+04	8.657E+03	1.020E+00	1.641E+00
7	1993	0.212	5.473E+04	5.399E+04	1.142E+04	1.142E+04	1.004E+04	7.038E-01	1.400E+00
8	1994	0.190	5.335E+04	5.337E+04	1.014E+04	1.014E+04	1.018E+04	6.323E-01	1.365E+00
9	1995	0.214	5.339E+04	5.285E+04	1.129E+04	1.129E+04	1.029E+04	7.108E-01	1.366E+00
10	1996	0.198	5.239E+04	5.240E+04	1.037E+04	1.037E+04	1.039E+04	6.581E-01	1.340E+00
11	1997	0.201	5.241E+04	5.234E+04	1.054E+04	1.054E+04	1.040E+04	6.698E-01	1.341E+00
12	1998	0.168	5.227E+04	5.300E+04	8.898E+03	8.898E+03	1.026E+04	5.585E-01	1.337E+00
13	1999		5.363E+04						1.372E+00

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RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) Standardized CPUE SA0+1

Data type CC: CPUE-catch series Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed yield	Model yield	Resid in log effort	Resid in yield
1	1987	1.794E+03	2.019E+03	0.0153	1.295E+03	1.295E+03	-0.11831	0.000E+00
2	1988	3.842E+03	4.289E+03	0.0325	2.605E+03	2.605E+03	-0.10997	0.000E+00
3	1989	3.194E+03	3.757E+03	0.0285	2.207E+03	2.207E+03	-0.16248	0.000E+00
4	1990	2.742E+04	1.935E+04	0.1468	1.064E+04	1.064E+04	0.34870	0.000E+00
5	1991	2.666E+04	2.180E+04	0.1654	1.098E+04	1.098E+04	0.20122	0.000E+00
6	1992	3.665E+04	4.039E+04	0.3065	1.807E+04	1.807E+04	-0.09700	0.000E+00
7	1993	2.739E+04	2.788E+04	0.2116	1.142E+04	1.142E+04	-0.01764	0.000E+00
8	1994	2.365E+04	2.505E+04	0.1901	1.014E+04	1.014E+04	-0.05757	0.000E+00
9	1995	2.639E+04	2.816E+04	0.2137	1.129E+04	1.129E+04	-0.06500	0.000E+00
10	1996	2.605E+04	2.607E+04	0.1978	1.037E+04	1.037E+04	-0.00094	0.000E+00
11	1997	2.871E+04	2.653E+04	0.2014	1.054E+04	1.054E+04	0.07893	0.000E+00
12	1998	2.213E+04	2.213E+04	0.1679	8.898E+03	8.898E+03	0.00038	0.000E+00

UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 1

```
                  -1       -0.75     -0.5      -0.25       0        0.25      0.5       0.75       1
                   |    .    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |
Year   Residual    ----------------------------------------------------------------------------------
1987    -0.1183                                    =====|
1988    -0.1100                                     ====|
1989    -0.1625                                    ======|
1990     0.3487                                          |==============
1991     0.2012                                          |========
1992    -0.0970                                     ====|
1993    -0.0176                                        =|
1994    -0.0576                                      ==|
1995    -0.0650                                     ===|
1996    -0.0009                                         |
1997     0.0789                                         |===
1998     0.0004                                         |
                  ----------------------------------------------------------------------------------
```

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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
B1ratio	2.435E+00	2.240E+00	-8.00%	2.298E+00	2.369E+00	2.369E+00	2.369E+00	0.000E+00	0.000
K	9.429E+04	7.816E+04	-17.10%	5.304E+04	1.993E+05	7.093E+04	1.407E+05	6.973E+04	0.740
r	4.438E-01	6.012E-01	35.46%	1.913E-01	9.653E-01	2.903E-01	7.260E-01	4.357E-01	0.982
q(1)	4.560E-06	7.590E-06	66.46%	2.426E-06	1.178E-05	3.737E-06	8.282E-06	4.545E-06	0.997
MSY	1.221E+04	1.175E+04	-3.75%	1.054E+04	1.769E+04	1.135E+04	1.428E+04	2.924E+03	0.240
Ye(1999)	1.010E+04	1.012E+04	0.17%	8.338E+03	1.044E+04	9.613E+03	1.028E+04	6.714E+02	0.066
Bmsy	4.715E+04	3.908E+04	-17.10%	2.652E+04	9.965E+04	3.546E+04	7.033E+04	3.487E+04	0.740
Fmsy	2.219E-01	3.006E-01	35.46%	9.567E-02	4.826E-01	1.452E-01	3.630E-01	2.178E-01	0.982
fmsy(1)	4.505E+04	3.960E+04	-12.09%	3.465E+04	9.542E+04	3.960E+04	6.523E+04	2.562E+04	0.569
F(0.1)	1.997E-01	2.705E-01	31.91%	8.611E-02	4.344E-01	1.307E-01	3.267E-01	1.960E-01	0.982
Y(0.1)	1.208E+04	1.163E+04	-3.71%	1.043E+04	1.751E+04	1.124E+04	1.413E+04	2.895E+03	0.240
B-ratio	1.450E+00	1.372E+00	-5.34%	1.224E+00	1.664E+00	1.310E+00	1.560E+00	2.494E-01	0.172
F-ratio	4.844E-01	5.585E-01	15.30%	2.763E-01	6.935E-01	3.891E-01	6.044E-01	2.153E-01	0.445
Y-ratio	8.107E-01	8.613E-01	6.25%	5.590E-01	9.499E-01	6.911E-01	9.058E-01	2.146E-01	0.265
f0.1(1)	4.054E+04	3.564E+04	-10.88%	3.119E+04	8.588E+04	3.564E+04	5.870E+04	2.306E+04	0.569

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: 1
Trials replaced for r out-of-bounds: 72
Residual-adjustment factor: 1.2247