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Evaluation of Possible Limit Reference Points for Greenland halibut in NAFO Subareas 2+3, Including an Approach based on Escapement Considerations

By

D. Rivard
Department of Fisheries and Oceans, Fisheries Research Branch
200 Kent street, Ottawa, Ontario, Canada K1A 0E6

and

J. Casey
The Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory,
Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

Abstract.

When analytical assessments are available, reference points can be defined in terms of biomass or fishing mortality. For Greenland halibut in NAFO Subareas 2+3, there exists little information on the absolute estimate of biomass. However, historic data from research surveys and on the historic catch level do exist, together with estimates of total mortality calculated from the surveys. The authors discuss various ways to utilize these data in the determination of limit reference points for this resource, using *equilibrium* yield and biomass per-recruit calculations.

The population dynamics of this stock are rather complex, smaller individuals being found in shallower depths and larger (mature) individuals being found at greater depths where they contribute to the spawning pool. Superimposed on this general pattern of distribution and migration is a fishery mostly associated with the shelf and slope waters, where immature individuals are found. The authors suggest that a Precautionary Approach Framework should recognize the particular characteristic of population dynamics for this stock by setting up limit reference points allowing "sufficient" escapement through the immature age-groups.

On a more general note, the authors consider that there are three basic steps in the determination of a Precautionary Approach framework: 1) selection of possible reference points in terms of biomass and fishing mortality, 2) identification of actual limits and thresholds that will be used in of the framework (usually selected from the first step, and 3) identification of decision rules to be applied in the context of the specific stock. While each of the steps are important, they must evolve and be taken together as the end goal is an integrated framework which will be used to evaluate various management

actions. The frameworks are simply tools enabling managers to evaluate the performance of the "system" in relation to the management objectives (either explicit, or implicit from past actions). At the end, the management objectives themselves will "drive" the solutions (expressed in decision rules and management actions required) and the authors argue that from a practical standpoint, the fishery trajectories that meet a certain set of management objectives will likely be very similar under any framework. Nevertheless, until such an effect is demonstrated, more than one framework should be put forward for testing when there are diverging views on the basis for a Precautionary Approach framework (e.g. escapement-based vs. NAFO Precautionary Approach framework).

Introduction.

Under the precautionary approach two types of reference points are defined: Limit reference points and Target reference points. These may be defined in terms of biomass or fishing mortality. For the Greenland halibut resource in NAFO Sub-areas 2+3, there exists little information on the current status of either of these. However, historic data from research surveys and on the historic catch level do exist. This paper presents an attempt to utilize these data to propose limit reference points for this resource using equilibrium yield and biomass per-recruit calculations. We will also explore the possibility of using indices of biomass as a substitute to absolute biomass estimates in the definition of a Precautionary Approach Framework. Finally, we explore the use of escapement considerations as a criteria in the selection of limit reference points applicable to the biomass.

Methodology

The age-based yield-per-recruit model of Beverton and Holt (1957) describes the expected yield and biomass expected from a single recruit under equilibrium conditions for a range of values of overall fishing mortality. For each age group, the model requires input vectors of fishing mortality, natural mortality, mean weight in the stock, mean weight in the catch and maturity proportion. The survivors from age group (a) to age group (a+1) is calculated simply as $N_{a+1} = N_a * \exp(-Z_a)$
where

N = number in the stock at age and
Z = the total instantaneous mortality rate.

If the Z from age of recruitment to age (a) is summed (cumZa), exp(-cumZa) gives the probability of a single recruit surviving to age a. The calculations also allow the derivation of Spawning Stock Biomass (SSB) per recruit and other related quantities (see table 1).

Substituting average recruitment from survey estimates for a single recruit gives an estimate of long-term equilibrium stock biomass, spawning stock biomass and yield which should not be taken as absolute but must be interpreted in terms of "survey units".

Data

Total mortality (Z) estimates were obtained using a catch curve analysis based on the catch at age data for the period 1975-1988 presented in Table 4 of Bowering et al (1996). The catch curve is presented in Figure 1. The estimate gives Z=0.66 over ages 7-17. For comparison an estimate of average Z from survey abundance indices in Table 13 of Bowering et al. (1996)

was calculated. Z was estimated by age group and these estimates were averaged over the period 1978-1994. The resulting average exploitation pattern is given in Figure 2, which is dome-shaped with full exploitation on age 8. The estimate of average total mortality from the 2J3KL survey data using ages 7+/6+ for the time period 1978-1994 is Z=0.68, which is consistent with the catch curve analysis (Z=0.66).

The input PR was derived as follows. The PR from survey data was normalized to an average Z on ages 7-14 of 0.67. A nominal value for natural mortality (M) was then subtracted from the Z at age values to give fishing mortality (F) at age. Since the Survey PR pattern showed unusual values at age 15, Z on ages 15-17 were manually adjusted to the age 14 value.

Mean weights at age in the stock and the catch were averages for the period 1986-1988 from Table 5 in Bowering et al (1996). Maturity at age was taken as knife edge at age 10 and average recruitment was taken as average survey abundance at age 5 over the period 1978-1994 from Table 13 in Bowering et at (1996). This implies that yield and biomass estimates are not absolute but are relative. The input values are listed in Table 1a.

Results

Yield-per-recruit and spawner-per-recruit considerations

The yield-per recruit analysis was performed for a range of F multipliers from 0 to 2 representing F on age group 8 ranging from 0 to 1.75. Note that the oldest age group (17) was not treated as a plus-group so that it is assumed that no fish survive beyond age 17. The results are given in Table 2. The stock characteristics for the current or Status quo F (0.87 on age 8) appear under the F-multiplier of 1.0 in Table 2.

The data indicate that at average levels of F, the probability of fish reaching the age of full maturity (age 10) is only about 3%, with spawning stock biomass at 3% of the unexploited level (USSB). Yield of mature fish represents 12% of the total yield and represents only 12% of the SSB. If we consider the SSB as a proportion of the total stock, at average levels of F, SSB represents 14% of the total stock biomass (SB). The probability of reaching age 10 increases to 11% if fishing mortality is halved. SSB at this level of F represents 17% of the unexploited SSB.

In addition to the probability of surviving to maturity, also of concern is what level of SSB as a proportion of unexploited SSB would provide an acceptable level of risk, bearing in mind that the bigger the SSB, the greater likelihood of increased recruitment if conditions are favorable. A fishing mortality (F) on age 8 of about 0.3, which is about the $F_{0.1}$ level, implies and SSB at about 25%-35% of the unexploited SSB. At this level of F, SSB represents about 47%-54% of the SB, and the yield/biomass ratio is between 10% and 13% (i.e. only about 10%-13% of the total stock biomass would be harvested annually, representing a reduction in overall yield of about 4%-12% compared to the yield at average F).

It is noted that Mace and Sissenwine (1993) advocated SSB levels corresponding to 20%-30% of the unexploited level as possible limit reference points. Similarly, Mace (1994) recommended using 20% of the unexploited level as a default biomass limit for stocks with at least average resilience, and 30% for stocks with low or unknown resilience.

Precautionary Approach Framework.

For the illustrative Precautionary Approach Frameworks presented here, the recruitment from the Canadian surveys (Brodie, 1998) has been used to determine the average recruitment which has been used to derive reference points consistent with the "survey units". The estimates of total mortality (Z) provided by Brodie (1998) were used to derive estimates of fishing mortality (Table 1b), assuming a constant natural mortality rate of 0.2. These estimates of fishing mortality and the biomass estimates from the Canadian surveys (Brodie, 1998) were used to illustrate the historical trajectories (Figure 3). In addition, the probabilities of reaching age-at-maturity and various measurements of the Stock Spawning Biomass (SSB) were used as a basis to evaluate the impact of various reference points on escapement to mature age-groups.

F-based Framework

The recent trajectory of fishing mortality estimates suggests that values of fishing mortality exceeding 0.6 were accompanied with a rapid decline of the total biomass. For reference purposes, the $F_{0.1}$ reference point and an estimate of F_{max} (taken as being twice $F_{0.1}$) are also represented in Figure 3. For illustrative purposes, $F_{0.1}$ will be used here as a target reference point and F_{max} as a limit approximating the danger fishing mortality levels to avoid (i.e. higher than 0.6). If $F_{0.1}$ is used as a target, than the biomass should by default stabilize around a value of biomass corresponding to "B at $F_{0.1}$" on Figure 4. Similarly, if F_{max} is used as a limit, the "B-at-F_{lim}" in Figure 4 will become by default an implicit limit in the biomass plane. It should be clear that target and limit fishing mortality levels implicitly define corresponding reference points in the biomass plane.

Escapement-based Framework

A key issue for Greenland halibut Canadian survey is that while it covers the shelf area and slope area relatively well, it does not cover the entire depth distribution of the stock. In particular, because larger Greenland halibut tend to be found at greater depths, it is expected that the spawning component of the stock will be misrepresented in the survey results. In fact, spawner-recruit scatter plots reveal no clear relationship and high recruitment values at low biomass estimates suggest that the spawning pool must come from elsewhere (i.e. beyond the area surveyed).

If an objective of a precautionary approach is to protect spawning stock, a strategy could be to ensure a minimum escapement through the immature phase of the life history, i.e. on these age-groups where fishing is often concentrated. The calculations performed from the yield-per-recruit and spawner-per-recruit analyses (Table 1) use the average recruitment from the Canadian survey to derive estimates of yield, stock biomass and spawning biomass in terms of an "average survey recruitment index". Such calculations could serve as a basis for evaluating the probability of reaching maturity or for calculating various measurements of escapement (e.g. the SSB/SB ratio, the SSB/Spawning Potential ratio, etc.).

For example, Figure 4 indicates that under an $F_{0.1}$ strategy, the spawning stock biomass is about 35% of the spawning potential; that value decreases to 9% when fishing mortality approaches F_{lim} (or F_{max} in this case). A framework recognizing F_{lim} and B-at- F_{lim} in a PA framework as per Figure 4 would effectively set a minimum escapement through the shelf-dominated phase at about 110,000 survey biomass units, of which 33% would be mature. The idea is to leave a sufficient number of fish to go through the immature stages so as to contribute to the spawning component of the stock.

NAFO Precautionary Approach Framework.

The NAFO framework (see Serchuk *et al.*, 1997) requires reference points for B_{lim}, B_{tr} and F_{lim}. Following guidelines of ICES in absence of obvious concerns with specific biomass levels, the lowest biomass observed will be used for B_{lim}. In absence of an analytical assessment, we do not have an absolute estimate of biomass for this stock and thus we suggest deriving the limits on a scale that is consistent with that of the available measurements, i.e. the survey biomass estimate for fish larger that 35cm.

The target biomass was determined from an estimate of B_{msy} defined as half the virgin biomass, i.e. the biomass expected from an average recruitment if no fishing takes place. As the average recruitment used in these calculations is from the survey, the resulting Bmsy is on a scale compatible with the survey biomass. The MSY estimate was taken as the average of the catches since the mid-sixties. The production model being implicit to these calculations is illustrated in Figure 5. Finally, Flim was taken as twice $F_{0.1}$, a proxy for F_{max} (see discussion on F-based Framework above). The resulting framework, which would be consistent with the NAFO PA Framework, appears in Figure 6.

Discussion

The above frameworks have been developed for illustrative purposes only, to serve as a basis in the discussions of possible Precautionary Approach Framework applicable for Greenland halibut in 2+3KLMNO.

There are three basic steps in the determination of a Precautionary Approach framework: 1) selection of possible reference points in terms of biomass and fishing mortality, 2) identification of actual limits and thresholds that will be used in of the framework (usually selected from the first step, and 3) identification of decision rules to be applied in the context of the specific stock. While each of the steps are important, they must evolve and be taken together as the end goal is an integrated framework which will allow an evaluation of various management actions. Ultimately, this evaluation will have to be related to the management objectives (e.g. compromise between sustainability of fisheries and maximum possible catches, etc.). The frameworks are simply tools enabling managers to evaluate the performance of the "system" in relation to the management objectives (either explicit, or implicit from past actions).

Given a set of very soft limits or thresholds from a conservation standpoint, the decision rules and associated management actions may have to be more stringent to achieve certain objectives. However, given a set of very conservative limits or thresholds, the decision rules and associated management actions would have to be less stringent to achieve the same objectives. Two widely different sets of limits or thresholds may thus lead, in absolute terms, to similar trajectories for the catches as the decision rules and management actions would be selected to meet the desired management objectives. The conclusion is that it is the whole framework that counts, together with the specification of management objectives (a task which has to be undertaken by the managers). Consequently, we should not spent too much time refining each step individually but instead operate so as to develop a well-balanced overall framework that will allow an evaluation of various decision rules. In case of diverging views on the basis for the framework (e.g. escapement-based vs NAFO Precautionary Approach framework), more than one framework could be put forward for testing.

When developing a Precautionary Approach framework for Greenland halibut in 2+3KLMNO, other aspects of the life history of the species should be taken into consideration. For instance, there is an apparent differential natural mortality rate between the males and the females starting about at the age of first maturity for males. This particularity complicates the calculation of certain reference points. In recent years, some analyses have assumed a constant mortality rate for all ages and both sexes (M=0.15 to 0.2), while others have assumed a differential mortality rate between males and females (M=0.15 for all ages for females; for males, M=0.15 from ages 3 to 6 and M=1.05 thereafter). In additon, in the absence of a virtual population analysis, there are some questions on the partial selection pattern that best describes the fishery (e.g. the degree to which there is a dome in the partial selection). As these aspects of life history and fishing patterns could have a major impact on the calculation of reference points, they must be addressed before a Precautionary Approach framework could be finalized for this stock.

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Table 1a. Input values for yield-per-recruit and spawners-per-recruit analyses.

	F	M	Stock Wt at age (kg)	Maturity ogive
Age				
5	0.054	0.2	0.359	0
6	0.232	0.2	0.581	0
7	0.628	0.2	0.817	0
8	0.873	0.2	1.141	0
9	0.606	0.2	1.610	0
10	0.421	0.2	2.155	1
11	0.353	0.2	2.906	1
12	0.406	0.2	3.805	1
13	0.327	0.2	4.890	1
14	0.146	0.2	5.924	1
15	0.146	0.2	7.318	1
16	0.146	0.2	8.949	1
17	0.146	0.2	10.461	1

Table 1b. Data used in the illustrative Precautionary Approach frameworks.

Year	B >35cm	F	Yield (t)
1978	224029	0.887	39070
1979	165091	0.311	34104
1980	189528	0.321	32867
1981	195654	-0.213	30754
1982	216145	0.108	26278
1983	221243	0.360	27861
1984	238888	0.477	26711
1985	176937	0.123	20347
1986	205061	0.548	17976
1987	138243	0.666	32442
1988	106168	0.619	19215
1989	120827	0.899	20034
1990	102740	1.784	47454
1991	49073	1.366	65008
1992	27612	1.205	63193
1993	26211	1.082	62455
1994	17141	0.993	51029
1995	21000	0.404	15272
1996	42643	0.073	18840
1997	63588		19858

Table 2. Results of yield-per-recruit and spawner-per-recruit analyses for Greenland halibut in SA2+3KLMNO.

F Multiplier	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Probability(%) to reach age 10	0.37	0.29	0.23	0.18	0.14	0.11	0.09	0.07	0.05	0.04	0.03
SB (t)	443946	337876	262913	209497	171081	143167	122651	107382	95864	87046	80192
SSB (t)	325455	227680	159944	112844	79964	56918	40697	29232	21091	15286	11128
SSB/SB (%)	73%	67%	61%	54%	47%	40%	33%	27%	22%	18%	14%
SSB (% USSB)	100%	70%	49%	35%	25%	17%	13%	9%	6%	5%	3%
Yield (t)	0	10392	16541	20071	22001	22965	23357	23420	23300	23087	22832
Yield ages 5-9	0	5058	8965	11973	14279	16037	17370	18373	19118	19665	20058
Yield age 10+	0	5334	7576	8098	7722	6927	5987	5047	4182	3422	2775
Yield/SB	0%	3%	6%	10%	13%	16%	19%	22%	24%	27%	28%
Yield age 10+/SSB	0%	2%	5%	7%	10%	12%	15%	17%	20%	22%	25%
yield 10+/yield	0%	51%	46%	40%	35%	30%	26%	22%	18%	15%	12%
F(age 8)	0.00	0.09	0.17	0.26	0.35	0.44	0.52	0.61	0.70	0.79	0.87
Relative SB	5.54	4.21	3.28	2.61	2.13	1.79	1.53	1.34	1.20	1.09	1.00
Relative SSB	29.25	20.46	14.37	10.14	7.19	5.11	3.66	2.63	1.90	1.37	1.00
Relative yield	0.00	0.46	0.72	0.88	0.96	1.01	1.02	1.03	1.02	1.01	1.00
Recruits/SSB	0.13	0.19	0.27	0.38	0.54	0.76	1.07	1.48	2.06	2.84	3.90
No caught (5-9)	0	5026	9114	12451	15188	17444	19312	20868	22173	23274	24209
No Caught (10+)	0	1430	2084	2285	2233	2052	1815	1565	1325	1106	915
NAT deaths(5-9)	27416	25786	24371	23138	22057	21105	20264	19515	18847	18246	17704
NAT deaths(10+)	12734	9072	6488	4658	3356	2428	1762	1284	938	688	506
Total CN	0	6456	11198	14737	17422	19496	21127	22433	23497	24380	25124
Rel CN	0.00	0.26	0.45	0.59	0.69	0.78	0.84	0.89	0.94	0.97	1.00
REL CN 5-9	0.00	0.21	0.38	0.51	0.63	0.72	0.80	0.86	0.92	0.96	1.00
Rel CN 10+	0.00	1.56	2.28	2.50	2.44	2.24	1.98	1.71	1.45	1.21	1.00
CN 10+/5-9	0.00	0.28	0.23	0.18	0.15	0.12	0.09	0.07	0.06	0.05	0.04
CN/UNEX SN	0.00	0.03	0.05	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.11
Total M deaths	40150	34858	30859	27795	25413	23533	22026	20799	19785	18934	18210
CN/M	0.00	0.19	0.36	0.53	0.69	0.83	0.96	1.08	1.19	1.29	1.38
Deaths 10+	12734										
Stock 10+											
Deaths 10+/stock 10+											
Z 10+											

F Multiplier	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
Probability(%) to reach age 10	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00
SB (t)	74779	70435	66891	63954	61482	59373	57547	55949	54533	53266
SSB (t)	8136	5974	4404	3260	2422	1806	1351	1014	764	576
SSB/SB (%)	11%	8%	7%	5%	4%	3%	2%	2%	1%	1%
SSB (% USSB)	3%	2%	1%	1%	1%	1%	0%	0%	0%	0%
Yield (t)	22567	22306	22059	21829	21617	21422	21244	21081	20930	20792
Yield ages 5-9	20333	20517	20632	20695	20717	20710	20681	20636	20580	20516
Yield age 10+	2234	1789	1427	1134	900	712	563	444	350	276
Yield/SB	30%	32%	33%	34%	35%	36%	37%	38%	38%	39%
Yield age 10+/SSB	27%	30%	32%	35%	37%	39%	42%	44%	46%	48%
yield 10+/yield	10%	8%	6%	5%	4%	3%	3%	2%	2%	1%
F(age 8)	0.96	1.05	1.13	1.22	1.31	1.40	1.48	1.57	1.66	1.75
Relative SB	0.93	0.88	0.83	0.80	0.77	0.74	0.72	0.70	0.68	0.66
Relative SSB	0.73	0.54	0.40	0.29	0.22	0.16	0.12	0.09	0.07	0.05
Relative yield	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.92	0.91
Recruits/SSB	5.33	7.26	9.85	13.30	17.91	24.02	32.10	42.77	56.80	75.23
No caught (5-9)	25010	25701	26302	26829	27295	27709	28080	28416	28722	29002
No Caught (10+)	751	612	496	401	323	259	208	166	133	106
NAT deaths(5-9)	17214	16767	16358	15982	15636	15315	15018	14740	14480	14236
NAT deaths(10+)	373	276	205	152	114	85	64	48	36	27
Total CN	25761	26313	26799	27230	27617	27968	28288	28582	28854	29107
Rel CN	1.03	1.05	1.07	1.08	1.10	1.11	1.13	1.14	1.15	1.16
REL CN 5-9	1.03	1.06	1.09	1.11	1.13	1.14	1.16	1.17	1.19	1.20
Rel CN 10+	0.82	0.67	0.54	0.44	0.35	0.28	0.23	0.18	0.14	0.12
CN 10+/5-9	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
CN/UNEX SN	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13
Total M deaths	17587	17043	16563	16135	15750	15400	15081	14788	14516	14263
CN/M	1.46	1.54	1.62	1.69	1.75	1.82	1.88	1.93	1.99	2.04

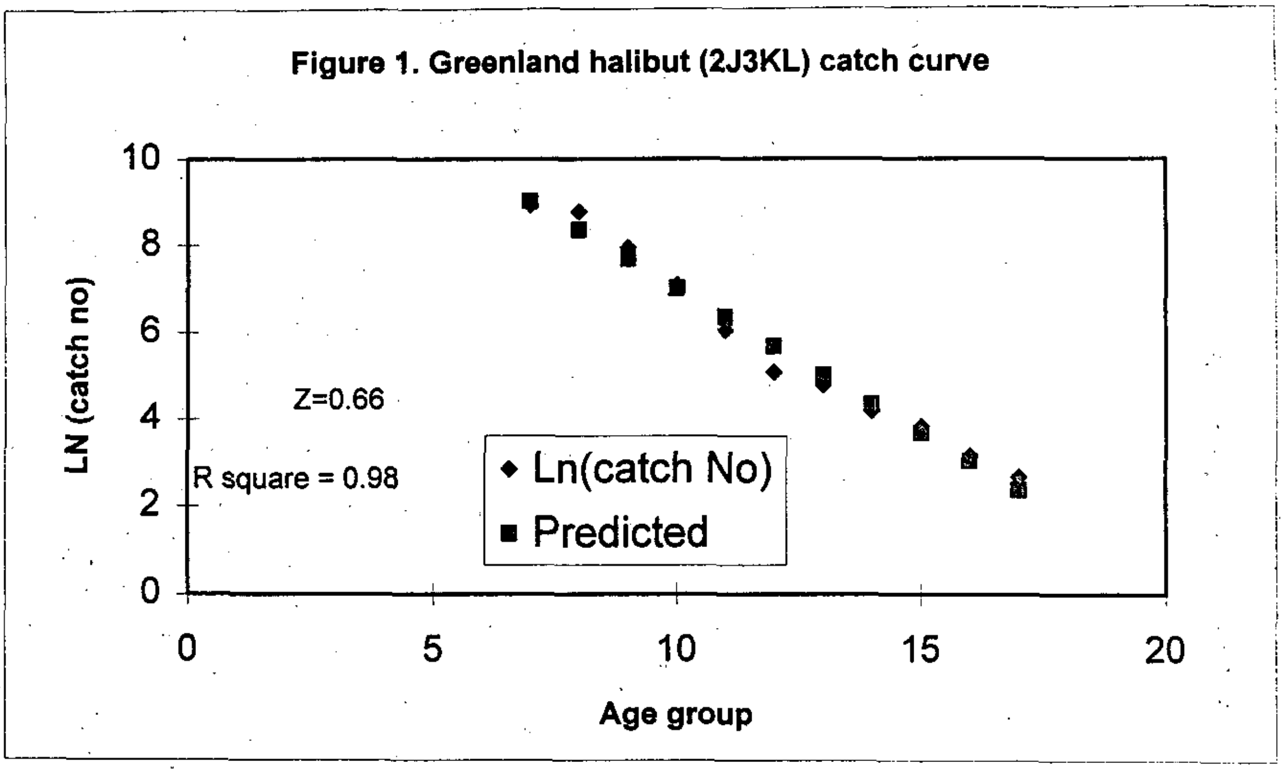

Figure 1. Greenland halibut (2J3KL) catch curve
LN (catch no)
Z=0.66
R square = 0.98
Ln(catch No)
Predicted
Age group
10
8
6
4
2
0
0
5
10
15
20

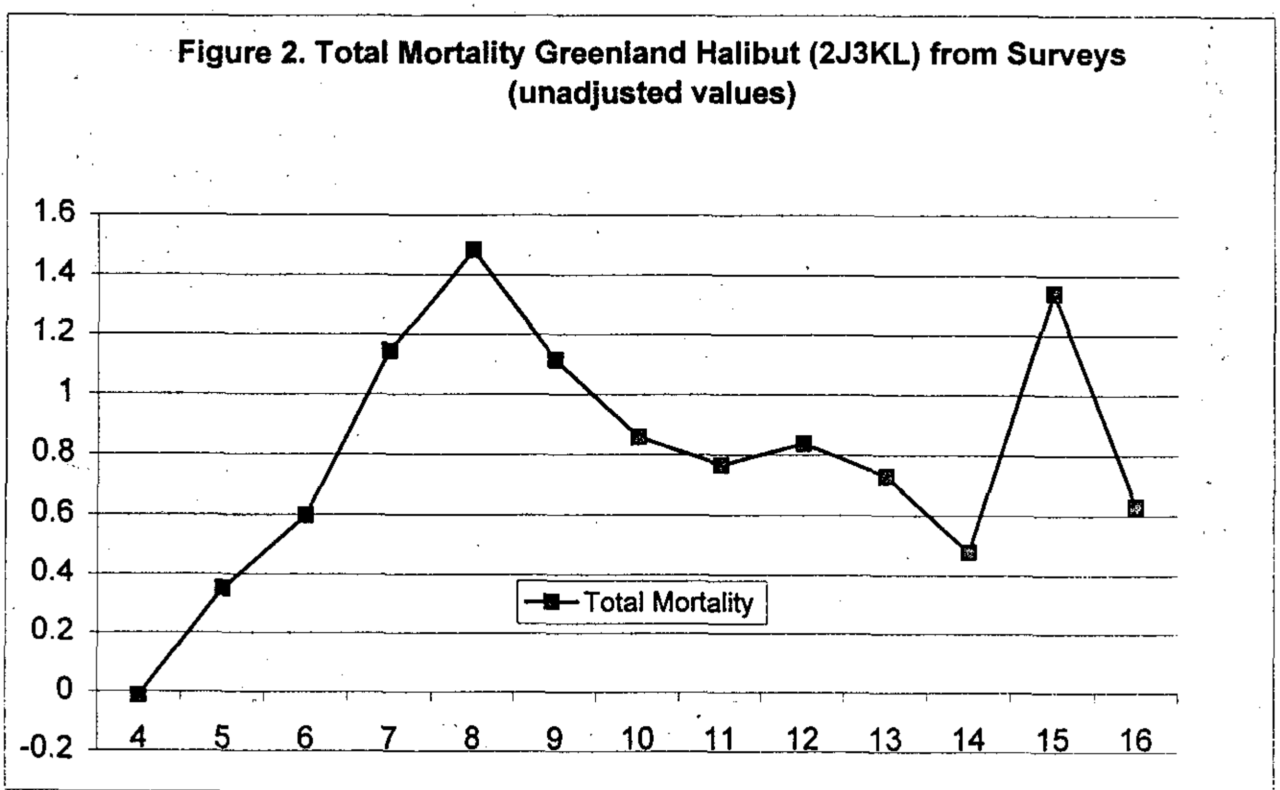

Figure 2. Total Mortality Greenland Halibut (2J3KL) from Surveys (unadjusted values)
Total Mortality
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 3. Greenland Halibut 2+3 - F-based Framework

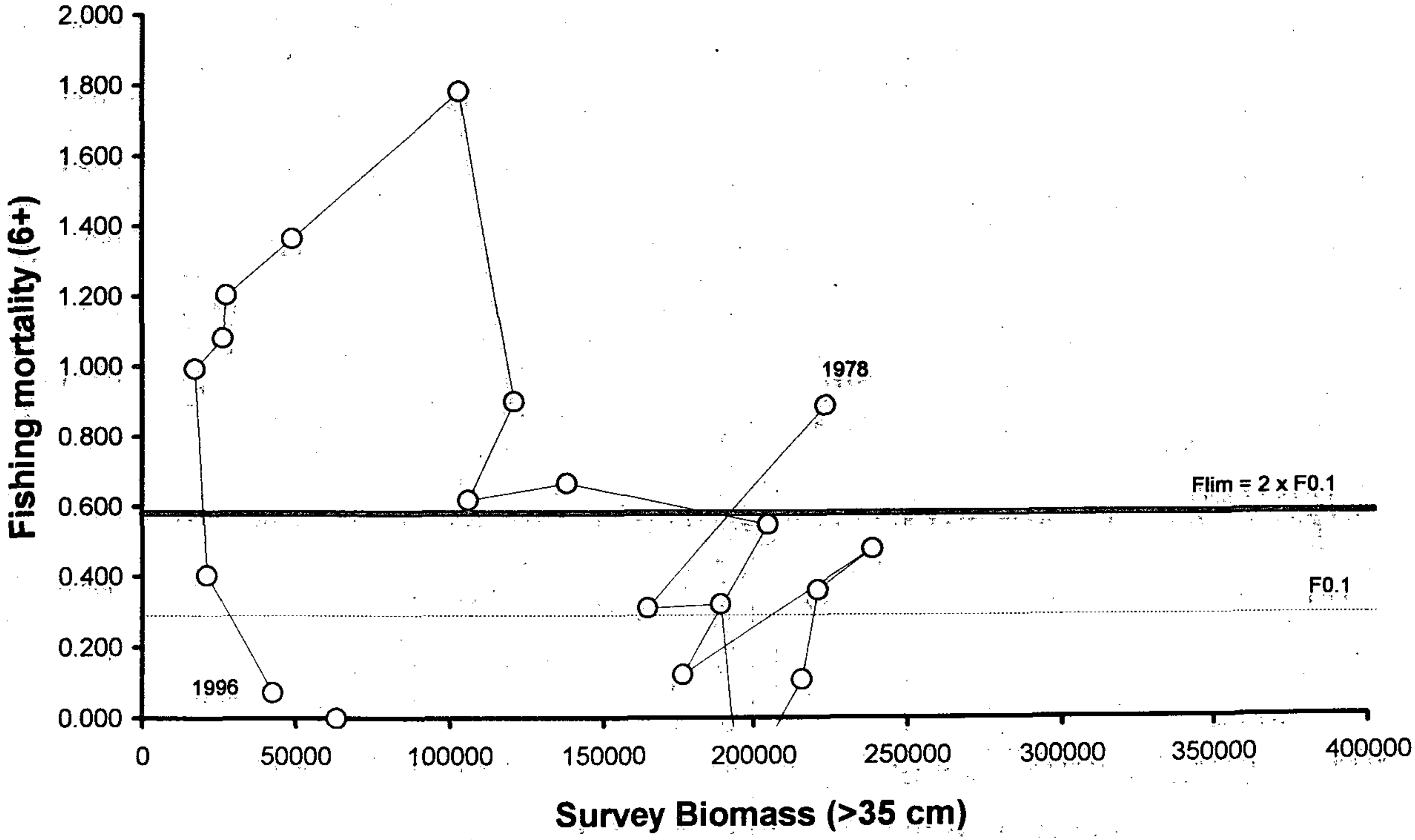

Figure 4. Greenland Halibut 2+3 - Escapement-based Framework

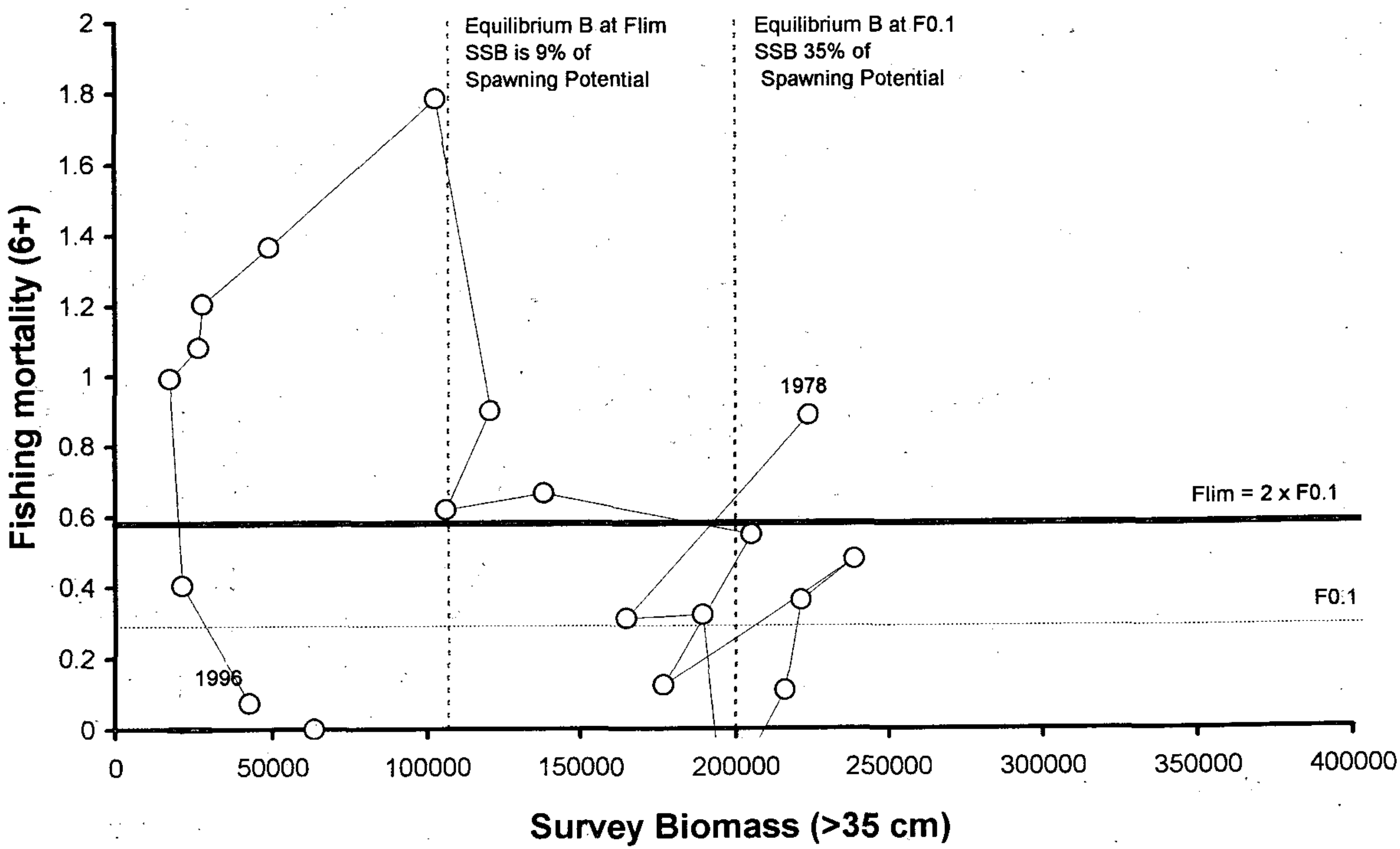

Figure 5. Greenland Halibut 2+3 - Illustrative Production Model

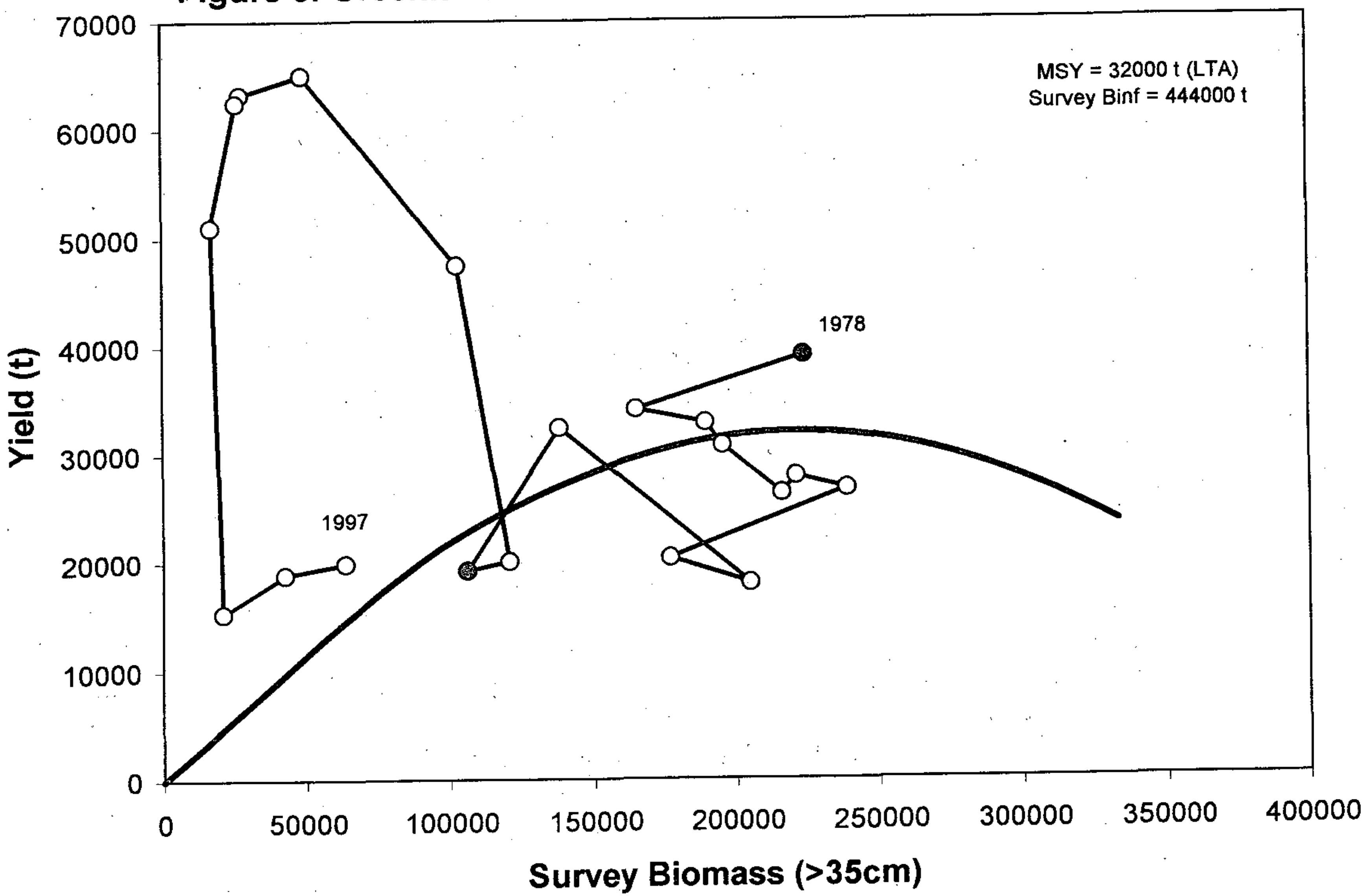

Figure 6. Greenland Halibut 2+3 - Bloss-based Framework