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Re-examining Target Spawning Biomass for the Cod Stock in NAFO Divisions 2J+3KL

by

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In 1977, a rebuilding strategy was recommended for the depressed 2J3KL cod stock, aimed at restoring the spawning stock biomass to between 1.2 and 1.8 million metric tons (mmt) by 1985. The strategy was based on assuming "average" recruitment and a fishing mortality of 0.15 (NAFO SCR 1977). The estimated spawning stock biomass in 1984 was only 0.5 mmt (NAFO SCR 1985). Possible reasons that might contribute to the failure to rebuild include the following:

1) Not enough time was allowed;

2) The effect of depressed stock size on recruitment was ignored;

3) Fishing mortality was higher than planned;

4) The target was unrealistically high;

5) Pure bad luck produced unexpectedly poor year-classes.

Recently we have developed a new method of projecting recruitments from past stock-recruit data (Rice and Evans submitted to J. Cons.). We shall use this method to help re-examine the 1977 strategy, evaluate the suggested reasons for failure to rebuild, and examine different rebuilding strategies and targets possible today.

METHODS

Before we could use the historical stock-recruit data, we needed to reconsider how assessments were done. Assessment methods current in 1977 assumed that all of the age 14+ fish in a year were age 13 fish the previous year (ICNAF 77/VI/26). If F for age 14+ is correct, this method will estimate the numbers of 14+ fish correctly but must overestimate the numbers from about age 10 to 13. This overestimation seriously distorted estimates of fishable biomass, so subsequent assessments assumed that there were no 14+ fish. If F for age 13 is correct, this method estimates numbers up to age 13 correctly but estimates no 14+ fish. Neither of these extremes is acceptable for determining the spawning stock for stock-recruit data, because old fish form a larger fraction of the spawning stock biomass than they do of the fishable biomass. This is especially important because the proportion of older fish in the stocks for which stock-recruit data are available is much higher than in the currently rebuilding stock. The distortions can be large: for the 2J3KL cod stock in 1962, the "correct" (1985) method of estimating age 10-13 numbers gives an estimate of $150x10^6$ fish whereas the 1977 method estimates $280x10^6$; the "correct" (1977) method for 14+ fish estimates $72x10^6$ whereas the 1985 method asserts there are none.

One way to estimate the numbers of age 14 and older fish is to accept the age 13 numbers from the 1985 assessment and apply the age 13 mortality to all older ages in the same year. We still need a boundary condition for 14+ fish in the first year of the assessment: we make one up by assuming that they are the same as in the second year. This is the method we have chosen, although others are possible - for example making 14+ a single age class and doing the VPA allowing for the fact that both age 13 and age 14+ fish contribute to age 14+ in the next year.

We projected the population dynamics of the 2J3KL cod stock forward from 1977 using a straightforward model of recruitment and mortality. The vectors of weights (beginning of year) and partial recruitments to the fishery and the spawning stock are given in Table 1. The order of events within a year is: become a year older; compute spawning stock biomass; project recruitment (for 4 years hence); suffer fishing and natural mortality (at rates that are constant over the year). The weight of harvest will be slightly underestimated by this method, this entails a small and easy correction. Projections were repeated 200 times with different random number seeds to give an idea of the variability to be expected in the stock size 10 or 20 years ahead.

Of the many methods of projecting recruitment discussed by Rice and Evans, we used two. Both methods assume that every recruitment observed in the future will be one of those observed in the past. One assumes that there is no effect of stock on recruitment - all historically observed recruitments are equally probable regardless of stock size; the other assumes that the probability of selecting a particular historical recruitment is proportional to a decreasing function of its distance from the current stock size. We used the function $f(d) = (1+(d/D)^2)^{-1}$ where typically D = 0.15 mmt, or about a quarter of the observed range in spawning stock biomass. A recruitment for which d = 0 is then twice as likely to be chosen as a recruitment for which d = D.

RESULTS

We must first point out a result, not of our projection methods, but of looking at how assessment methods have changed. Changing the way that 14+ fish are treated in the cohort analysis decreased the estimated numbers of older fish. That means historic stocks producing good recruitments actually had substantially lower spawning stock biomasses than were assumed in the informal 1977 projections. A corresponding change is required in the target biomasses. Correctly calculating numbers of age 7^+ fish converts the desired target spawning stock biomass to .85 - 1.3 mmt. Part of the failure to attain an estimated biomass between 1.2 and 1.8 mmt is due to improvements in the methods used in estimating stock sizes. However, the stock has not rebuilt to the revised lower target range, and that failure still requires explanation. All of our subsequent discussion refers to the target as it would have been set using the assessment method we propose.

If there is no stock-recruit relation (all recruitments observed prior to 1977 are equally probable), and the fishing mortality (F) had been 0.2, then the 1977 spawning stock would have been expected to rebuild to beyond the target range by 1985, and to grow slowly thereafter.

If there is a stock-recruit relation and F = 0.16 then the stock would rebuild to the target range in 10 years or slightly less. For F = 0.2 the stock would reach the target range in around 10 years. Under both fishing mortalities, biomass would continue to grow for at least another decade.

With F = 0.35, the actual estimated value for 1977-84, we would expect the revised target to be reached only if there is no stock-recruit relation. If we take into account the effect of low stock size on recruitment, we do not expect the stock to rebuild. Projected biomass with a stock-recruit relation and F = 0.35 corresponds well to estimates of current spawning stock size.

The pattern of annual yield should be different for the three fishing mortalities, starting higher but not changing for F = 0.35, growing yearly with lower values for F. After 20 years cumulative yield is the same for all F's, and annual yield is lowest for F = 0.35, highest for F = 0.16. The initial advantage of higher catch with greater F has almost disappeared within 10 years, and the cost of capture are presumably higher.

This is all using the stock and recruitment data available in 1977, i.e. the 1962 to 1971 year-classes. If it had been possible to use stock-recruit data from the 1972 to 1980 year-classes as well (information we have now, but which was unavailable when the target was set), the results are basically unchanged.

Projecting ahead from the 1985 assessment, using all available data, if F = 0.16 the stock should reach the upper end of the target range in 10 years; if F = 0.2 the lower end will be attained. Under both F's the target is surpassed within 20 years. Annual harvest at the two lower F's is indistinguishable after 10 years, and grows slightly more with a lower F thereafter. With F = 0.35 the spawning stock does not grow. Annual harvest is already lower after 10 years and cumulative harvest is substantially lower after 20 years at the higher F.

DISCUSSION

When we use our projection method, and assume F = 0.16, starting numbers at age from the 1976 vector of the cohort analysis, and no stock-recruitment relationship, our assumptions are consistent with those used in the 1977 NAFO SCR. After correcting the error in estimating numbers of older fish, we come to the same conclusions as the committee did at that time; the spawning stock biomass should have rebuilt to around 1.0 mmt within 10 years. Why isn't it there? The reason cannot be just a higher fishing mortality. Just changing F to 0.35 would have produced a spawning stock biomass of around 0.87 mmt by 1985, substantially higher than recent estimates for the stock. Figure 1 and our projections both strongly imply that there is a stock recruit relation in this stock. The 1977 projections erred in not taking account of the relation.

The 1977 projection started at a stock size much smaller than those for which stock and recruitment data were available. It might have been more reasonable at the time to project as if the data were stock and recruit-per-unit-stock; that is, selecting a value of recruitment-per-unit-stock and multiplying by the stock size to project recruitment using that method much lower recruitments would have been projects early in the rebuilding process. The recruitments observed for 1972-80 were in fact much larger than previously, per unit stock size: if anything, we would argue that the stock has been unusually fortunate in its recruitments during the 1970's, even though recruitments were much smaller than were assumed when the rebuilding projections were done.

Looking either at the 1962-71 or 1962-80 stock-recruit data (Fig. 1), it is clear that no curve of standard shape, like Ricker or Beverton-Holt, would fit it well: raw data methods are more appropriate.

Our methods are constrained to go on repeating the recruitments that have been observed. The data in Fig. 1 strongly suggest that stock sizes larger than those recorded will produce recruitments larger than those recorded. These are not incorporated in our projections. Hence we may be underestimating both the rebuilding potential at higher stock sizes, and the desirability of achieving such higher stocks. It seems reasonable to recommend that the stock be allowed to rebuild to a spawning stock biomass of at least 1.3 mmt (as measured by the assessment method we propose. This would correspond to a stock of at least 1.8 mmt, as estimated by the methods used when setting the target in 1977. The projected harvests under the different fishing mortalities also indicate that lower F's, leading to larger spawning stocks, would produce better catches per unit effort, and overall greater yields after periods as short as 10 years.

REFERENCES

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Table 1. Starting vectors for projections.

Age	Weights	Partial recruitment		Numbers at age	
		Spawning	Fishing	1977	1985
0	-	0.0	0.0	-	-
1	-	0.0	0.0	-	-
2	-	0.0	0.0	-	-
3	-	0.0	0.0	-	-
4	0.55	0.0	0.31	2346	3460
5	0.88	0.0	0.50	885	2338
6	1.23	0.0	0.73	491	2060
7	1.66	1.0	0.88	315	669
8	2.12	1.0	1.0	259	385
9	2.64	1.0	1.0	172	471
10	3.18	1.0	1.0	69	225
11	3.76	1.0	1.0	29	134
12	4.15	1.0	1.0	16	21
13	6.06	1.0	1.0	6	6
14	6.5	1.0	1.0	4	1
15	7.0	1.0	1.0	2	1
16	7.5	1.0	1.0	1	0
17	8.0	1.0	1.0	1	0
18	8.5	1.0	1.0	0	0
19	9.0	1.0	1.0	0	0

Table 2. Results of projections with various parameter values. Biomasses are millions of metric tons ±1SD.

Years of S-R data	Starting # at age from	Projection length	Fishing mortality	Spawning stock biomasses	Annual yield	Cumulative yield
10-yrs No S-R function	1977	10	.16	1.7±.3	.29±.05	1.7±.3
			.20	1.4±.3	.29±.05	1.9±.3
			.35	.87±.21	.37±.07	2.5±.4
		20	.16	2.1±.4	.35±.05	5.1±.6
			.20	1.8±.3	.37±.04	5.6±±.7
			.35	.96±.21	.39±.07	6.3±.8
10-yrs + SR function	1977	10	.16	1.0±.3	.18±.04	1.2±.3
			.20	.89±.26	.19±.05	1.3±.3
			.35	.53±.19	.22±.06	1.7±.4
		20	.16	2.0±.5	.36±.08	4.1±.9
			.20	1.5±.4	.34±.09	4.0±.9
			.35	.56±.18	.23±.07	3.9±.8
19 yrs + SR function	1977	10	.16	.99±.14	.18±.02	1.1±.1
			.20	.86±.14	.19±.03	1.3±.1
			.35	.50±.10	.21±.03	1.6±.2
		20	.16	1.9±.4	.34±.06	3.8±.5
			.20	1.4±.3	.31±.06	3.8±.5
			.35	.52±.10	.22±.03	3.7±.3
	1985	10	.16	1.2±.2	.23±.03	1.7±.2
			.20	0.97±.19	.23±.04	1.9±.2
			.35	.51±.11	.21±.38	2.2±.2
		20	.16	2.4±.3	.41±.05	5.1±.5
			.20	1.8±.3	.40±.06	5.1±.7
			.35	.53±.1	.22±.41	4.4±.4

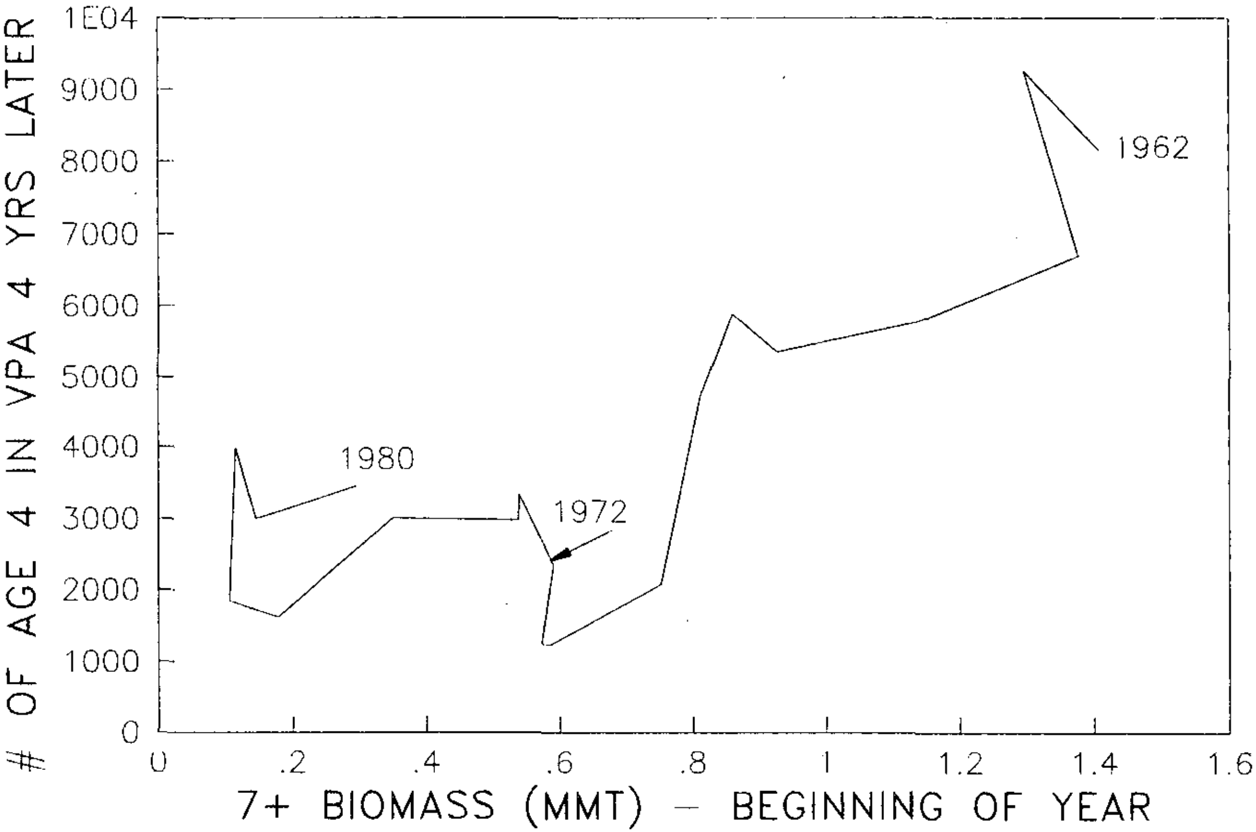

Fig 1. Plot of stock and recruit data used in projections. Recruit numbers from cohort analysis (NAFO SCR 1985); stock biomass calculations described in text. Projections with 10 years of S-R data used 1962 to 1971; 19 years added 1972 to 1980.