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A Declining Cod Stock (3Pn, 4RS), How Can We Learn From the Past?

by

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INTRODUCTION

A number of events can contribute to the biomass level of a fish stock, most obvious of these being recruitment and fishing pressure. For most Canadian Atlantic groundfish stocks, reliable information on historical stock status are available since the early seventies. Many of these fish stocks have experienced changes in biomass levels since. This makes it possible to partition, for a given stock the importance of "events" that have been measured (or expected to have occured) in order to put into perspective current biomass levels.

The Northern Gulf of St. Lawrence cod stock (3Pn, 4RS) has shown an increase in stock size from 1974 to 1983 and has declined since to a level comparable to the situation in 1974 (Fréchet and Schwab, 1990). Two major fleets exploit this ressource, an important winter fishery, mostly prosecuted by otter trawlers, and a summer inshore fishery by fixed gears. Landings from this second sector have declined from a historical peak of 51,478 t in 1980 to a historical low of 13,816 t in 1989.

Events investigated can be categorized as fishery independent (recruitment, weights at age, etc.) or dependent on the fishery (TAC overruns, misreporting, discards etc.). This means that some events can be changed with management decisions while others cannot. A number of events were investigated independently under three levels, a reasonably minimum and maximum value as well as average condition. Events for which a good estimate is available (i.e. overruns of TAC), stock status was estimated under presence or absence of the event. Considering what this stock has experienced in the past a priorisation of these events allows the stock assessment process to focus more attention on particular events.

This approach is somewhat different than previous studies since simulations of sensitivity in the production of various groundfish stocks (Rivard, 1988), were done using arbitrary levels in the magnitude of imput parameters because these studies were aimed at explaining inter-stock variability. Other were more directed towards model misspecification (Sinclair et. al., 1990) or effects of errors on catch projections (Rivard and Foy, 1987).

MATERIAL AND METHODS

The influence of the following parameters were investigated:

- perception of the stock
- recruitment variations
- target fishing mortality
- changes in average weights at age
- fishing limited by TAC
- discards
- misreporting

The basic data used in the latest assessment of the 3Pn, 4RS cod stock (Fréchet, 1990) was used for simulations using the ADPAT and FISH (Rivard, 1982) software.

Perception of the stock.

Analytical stock assessments have been done yearly since 1981 and provide an insight to what level the perception of stock status have evolved. In order to describe graphicaly the historical perception of stock status, figures 1 and 2 were based on past assessments (Gavaris and Bishop, 1981,1982. Gascon, 1983 1984. Gascon and Fréchet, 1985. Fréchet, 1986, 1987, 1988. Fréchet and Schwab, 1989, 1990).

Recruitment variations.

In order to examine the influence of the relative strength of incoming year classes (at age 4) to the stock status, a series of long term projections were done.

Input parameters were:

1- Population numbers at age for 1974 this is the first year of the sequential polulation analysis and is fully converged.

Age	Population numbers ('000)
4	57832
5	37863
6	48588
7	18748
8	21049
9	9268
10	4632
11	1717
12	695
13	609
14	308
15	158

2- Average partial recruitment.

The average partial recruitment was derived from the fishing mortality matrix (Fréchet, 1990).

AGE	4	5	6	7	8	9	10	11	12	13	14	15
P.R.	0.08	0.3	0.6	0.9	1	1	1	1	1	1	1	1

3- Fishing mortality from the most recent assessment (Fréchet, 1990).

YEAR	F	YEAR	F
74	0.428	82	0.605
75	0.365	83	0.358
76	0.505	84	0.528
77	0.548	85	0.498
78	0.423	86	0.648
79	0.585	87	0.805
80	0.518	88	0.320
81	0.400	89	0.349

4- Recruitment options.

The following options were considered in varying recruitment.

Current estimates:	(see Fréchet, 1990).
Geometric mean:	90 million fish at age 4.
Maximum observed:	161 million fish at age 4.
Minimum observed:	34 million fish at age 4 [1].

[1] This year class strength poorly estimated since it is a recent year class (1984 year class).

Fishing at the target level $F_{0.1}$ and F_{max}.

Input parameters were the same population numbers for 1974, partial recruitment as the previous section on recruitment variations. Yearly incoming recruitment at age 4 was as derived from the latest *stock assessment* (Fréchet, 1990). Projections from 1974 were done using fishing mortalities of 0.2 ($F_{0.1}$) and 0.4 (F_{max}) for all years.

Changes in average weights at age.

Input parameters were:

Commercial sampling is done every year and weights at age are available since 1974. In order to determine the year when the observed weights at age were the highest and the lowest, an average population at age was derived (average population numbers at age for the period 1974 to 1989) and the observed weights at age were applied. New mean biomass values were thus calculated using the current population estimates and the various average weights at age using the equation:

$$\bar{B}_{i,t} = W_{i+.5,t+.5} \quad N_{i,t} \; (1\text{-}e^{-Zi,t}) \; / \; Z_{i,t} \qquad (1)$$

The average weights at age options are shown in Table 1.

Fishing limited by TAC

The catch at age for a particular year was adjusted to investigate various catch senarios. Catches exeeded frequently the TAC between 1977 and 1984 and were thus adjusted by the factor on table 2 to examine the impact of these overruns.

The TAC scenario options were:

1- Observed catch levels.
2- TAC adhered to.
3- TAC not overruned. (i.e. using landing values only in years when the TAC was overruned)
4- TAC not reached. (i.e. using landing values only in years when the TAC was not overruned).

Discards of small fish

1- No accurate estimates of discards are available for this stock but it is believed to have been more important during the winter otter trawl fishery, especially during the years of high abundance (1981 to 1984). Some discards may have occured from the trap fishery when catches were high (1978 to 1985). Some fishermen alledged that discard of small fish (under 18 inches, 46 cm) in the winter fisheries was as high as what was landed. These would have been mostly ages 4 and 5 fish. Simulations were done considering that as many fish at ages 4 and 5 were discarded than were landed during the first three months of the year. Twenty five percent would have been caught at age 4 and 75 percent at age 5. The catch at age was thus modified for each year $_t$:

$$C_{4't} = 0.25^{*} \; \Sigma(\text{Jan to March}) \text{ Catch } / \; AW_{4,t} \qquad (2)$$

and

$$C_{5't} = 0.75^{*} \; \Sigma(\text{Jan to March}) \text{ Catch } / \; AW_{5,t} \qquad (3)$$

Results are presented in table 3.

Misreporting

As in the case of discarding, there is no documented evidence but widespread allegations that misreporting took place in some years. It is generally considered that misreporting during the winter fisheries occured widely during the 1984 to 1987 fishing season. A 10,000 pound trip would have been reported as 5,000 pounds (50% difference). Simulations were thus done by doubling the winter fishery landings for those years and applying it to the catch at age (first quarter) for all age groups (table 4).

Year	Twice the reported first quarter landings. (t)
1984	51150
1985	52982
1986	62138
1987	42690

RESULTS

From Fig. 1 and 2, it appears that the perception of the stock size has changed substantially since the first assessment of this stock in 1981 (1980 fishery). Most of the large increases in the population estimates from the 1980, 1981 and 1982 fisheries (corresponding to the 1981, 1982 and 1983 assessments) are due to two factors, a doubling in standardised catch rates from the mobile gear fleet and apperance of strong incoming year classes. In assessments conducted in following years, a gradual decrease in the estimated abundance of the population occured. This is due to the gradual convergence of the VPA where the jump in the CPUE took place and less confidence being placed in the doubling of the mobile gear catch rates. In the 1988 and 1989 fisheries, more confidence has been given to the research survey biomass estimates. These were discarded as a calibration tool in the past mostly because of large variations in the estimates. As more years were added to the time series it became apparent that this index could be used as a calibration tool. In the most recent assessment of this stock, data available from the surveys indicate that the biomass estimates from the four most recent surveys are the lowest in the 12 year time series and thus should not be disregarded any more.

The current perception is that population numbers have doubled since 1974 to reach a peak in 1981 and have declined since to a level lower than in 1974 for 1989. Roughly the same picture arrises in respect to the total biomass of this stock except that the peak biomass occurs in 1983.

An attempt to establish a stock/recruitment relationship from the most recent assessment resulted in a negative relationship. Although all statistics are significant, (significant slope, R^2=0.66) this relationship is thought to be spurious since all points to the right (corresponding to a low recruitment) are from the non converged part of the matrix. At the most one may conclude that there is no stock recruitment relationship.

Under three incoming recruitment scenarios (maximum, average and minimum), the current estimate lies half way between average incoming recruitment and minimum observed recruitment.

Stock status in the early 80's lied half way between the geometric mean recruitment and the maximum observed recruitment. All lines start at the same level in 1974, this is because the various scenarios were done by projections. The various stock levels are thus increasing with time as new recruiting age classes are being introduced in the population.

It has frequently been discussed in various research documents that the historical exploitation rates for this stock were higher than the target $F_{0.1}$ and closer to F_{max}. The second simulation was intended to describe the path on which the stock would have been if the target level of $F_{0.1}$ or even F_{max} had been adhered to (Fig. 5). Results indicate that 40% more fish would be present in 1989 if the fishery was prosecuted at the $F_{0.1}$ level. Current estimates are slightly less than if the F_{max} catch level had occured since 1974.

The first reference to a generalised decline of average weights at age for Atlantic cod stocks occured in the assessment of the 1985, 3Pn,4RS cod fishery (Fréchet, 1986). A few years later a working group was commissioned by CAFSAC to look into what could be the underlying factors. Those that have been identified to date are stock dependance and water temperature. The simultaions performed were done to reflect, relative to the current stock biomass, what levels could be expected under the three scenarios (maximum, average, minimum). Fig. 6 shows the bounds in biomass that could have been observed with the observed weights at age given stable population numbers. The biomass would have reached a peak in 1983 and a minimum value in 1987. The average weights at age for these years were thus considered as maximum and minimum, respectively. From this, trends in total population biomass were calculated (Fig. 7). Results indicate that as the stock had reached the maximum biomass in 1983, the stock had reached its growth potential and that in 1987, with a low biomass estimate, growth was at it's lowest.

TAC's were first imposed on this stock in 1977 and have seldom been restrictive. The impact of these overruns was simulated in Fig. 8. Under the three scenarios (TAC respected, TAC not overruned, TAC not reached), a series of calibrations using the ADAPT workspace were done. These indicate that marginal impact on the current stock size can be expected.

Finaly, simulations including the effect of discards and misreporting show a marginal impact on the current stock status.The population numbers in 1990 would have been 20% under the discard scenario and 16% higher under the misreporting scenario. The impact of these events to the current stock size are in the same bracket as those of overriding the TAC's (Fig. 9).

Table 5 sumarises the importance of the studied variables on the current status of this stock.

DISCUSSION

Out of the various simulation that can be done, the most important factor is to what "standard" one is comparing results. This is the perception of the stock status. From this any inferences on recruitment or other parameters are relative. The historical perception of the stock status shows that the estimate from the latest year was consistently overestimated, in some years (1980 to 1983) more than twice the current estimate (which is now converged). One implication for the assessment of this stock is that such large changes in stock status have not been observed in the converged part of the analysis. This may be due to the relative stability in recruitment for this stock.

The stock recruitment relationship for this stock was not attempted previously because the number of years in the cohort analysis was to low. This attempt was not encouraging since it suggests a significant *negative* relationship (this would mean that the absence of a stock would produce 211 million fish at age 4!!). Most of this inconsistency would be caused by the fact that the peak in mature population numbers (1982 to 1985) is compared to very recent recruitment (last four years). These incoming year classes are poorly estimated since they are in the unconverged part of the analysis. Despite this, strong year classes were produced when abundance was low. From this, no stock recruitment relationship is concluded. This is a usefull consideration when attempting to simulate the effect of recruitment while a fishery takes place.

Table 1 suggests that two factors are crucial for the abundance estimate, the first being the assessment itself. A variety of estimates of stock status can be derived by these models by altering the values of the terminal fishing mortality (F_t). Second is the level of recruitment. It is obvious that the amount of fish introduced at age 4 is the determining factor of the stock abundance. The alternation of strong and weak year classes should produce average population size. However, if the strongest year classes would have been observed, this would generate a population near 500 million individuals. These results are generated under the assumption that such optimal conditions may occur in reality. In fact, it is unlikely to occur for as many years as there are year classes in the exploited stock (roughly ten). This stock, at it's highest observed abundance (1981) was 20 % lower than this maximum value. Concurrently, the population estimate for 1989 (185 million age 4+) is relatively slightly higher than if historical low recruitment values were used (100 million).

The third important variable to explain the contrast of various stock sizes is growth. When the stock was at it's peak biomass in 1983, if minimum observed weights at age would have been present, the biomass would have been 35 % lower. It is interesting to note that the average weights at age were maximum when the stock was at it's highest biomass and minimum in the recent time period (with the lowest biomass estimates).

The fourth important variable is the target level of exploitation. If the fishery had been prosecuted at the $F_{0.1}$ level, the abundance of this stock in 1989 would be 40 % higher. It is apparent from the simulation at F_{max} (0.4) that the observed levels of fishing mortalities were in excess. It is important to note that despite these projections being done at the $F_{0.1}$ level, current stock status would still show an important decline since 1981. This is mostly due to the lower than average recruitment observed.

All other simulations are closely related to the fishery (catch levels and TAC, discards, misreporting) and have marginal effects on current stock status. Only 4+ population numbers and biomass have been examined, a larger effect would have been perceived if exploitable numbers and biomass had been used.

A larger population is generated by the SPA when discards are at a high level for all years. Since this level of discarding may have occured in the past and that the observed catch at age did not show any detrimental effect, a larger population must be generated in order to sustain these levels of discards. A slightly different situation occurs when misreporting occurs only in a few years (1984 to 1987). A higher rate of decline in population size is observed since 1984 but more fish are generated in the four preceeding years.

It is apparent that for assessment purposes, the most important factors to monitor are those not directly related to the fisheries (those that can be modified). The incoming recruitment, average weights at age are crucial to the stock status. Since no density dependance is evident for this stock under the observed stock levels it may be presumed that recruitment has been independant from the fishery. There are some indications that growth may be density dependant. Despite all insights these simulations can give on considerations of the current stock status, it must be stressed that these factors were examined independently. Many of these events occured simultaneously and their effects on stock status may be multiplicative. For example, small year classes for a number of years in a row with declining weights at age, accompanied with overruns of the TAC would give disastrous results.

ACKNOWLEDGMENTS

I would like to thank Louise Savard, Dominique Gascon and Philippe Schwab for their revision of the document.

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Table 1: Average weights at age used for the simulations.

Age	Weights at age (kg) Maximum [1]	Average [2]	Minimum [3]
4	0.93	0.73	0.60
5	1.30	1.00	0.77
6	1.60	1.37	1.01
7	1.90	1.76	1.31
8	2.18	2.18	1.58
9	2.45	2.64	2.09
10	3.47	3.12	2.65
11	4.52	3.69	2.73
12	4.37	4.33	3.05
13	6.66	4.94	3.28
14	5.94	5.68	4.22
15	6.68	6.84	5.48

1 Average weights at age observed in 1983.
2 Average of the average weights at age for the period 1974 to 1989.
3 Average weights at age observed in 1987.

Table 2. Yearly landings and TAC for the 3Pn, 4RS cod stock.

Year	Catch	TAC	Difference (%)
74	66436	-	-
75	60233	-	-
76	76981	-	-
77	73566	55000	+ 33.8
78	78506	55000	+ 42.7
79	82777	75000	+ 10.4
80	97579	75000	+ 30.1
81	97911	75000	+ 30.5
82	104939	93300	+ 12.5
83	106080	100000	+ 6.1
84	103643	100000	+ 3.6
85	88289	100000	- 11.7
86	82816	92100	- 10.1
87	65594	80300	- 18.3
88	47624 [1]	73900	- 35.6
89	46668 [1]	76540	- 39.0

1 Preliminary.

Table 3: Estimated removals of cod of ages 4 and 5 if discarding was as large as the winter fishery (January to March).

Year	Landings winter fishery (t)	Average weights at age 4	5 (kg)	Estimated removals [1] 4	5 ('000)
74	29707	0.64	0.99	11640	22505
75	30420	0.72	1.00	10562	22815
76	34451	0.76	1.13	11331	22865
77	23536	0.65	1.02	9052	17305
78	32222	0.75	0.96	10740	25173
79	26291	0.65	0.93	10011	21202
80	24170	0.62	0.93	9746	19491
81	27694	0.79	0.98	8764	21194
82	24082	0.85	1.11	7083	16272
83	25700	0.93	1.30	6909	14827
84	25575	0.79	1.03	8093	18623
85	26491	0.79	0.98	8383	20273
86	31069	0.73	0.98	10640	23777
87	21345	0.60	0.77	8894	20791
88	8352	0.73	0.88	2860	7118
89	15684	0.69	0.94	5683	12514

1 These removals were added to the reported catches for these ages.

Table 4. Modified catch at age matrix used in simulation of the effect of misreporting on stock status.

Age	Twice the first quarter catch at age ('000) 1984	1985	1986	1987
4	763	1929	774	93
5	2784	11949	4053	5229
6	7365	9583	11315	7680
7	10477	8470	10627	10832
8	3601	4488	4446	5999
9	2658	1515	4208	2443
10	1058	1016	1253	1020
11	338	329	1419	729
12	305	40	208	146
13	105	5	129	156
14	15	0	17	18
15	18	3	1	14

Table 5: Summary of the various simulations on current stock size.

Event	Effect	"Observed" Max.	Average	Min.
Perception of the stock	++++++ (1)			
Recruitment		+++++	++	---
Target fishing mortality $F_{0.1}$	+++			
F_{max}	+			
Average weights at age		++	+	-
TAC overrun	0			
respected	+			
not reached	+			
Misreporting	+			
Discards	+			

1 It's effect can be either positive or negative.

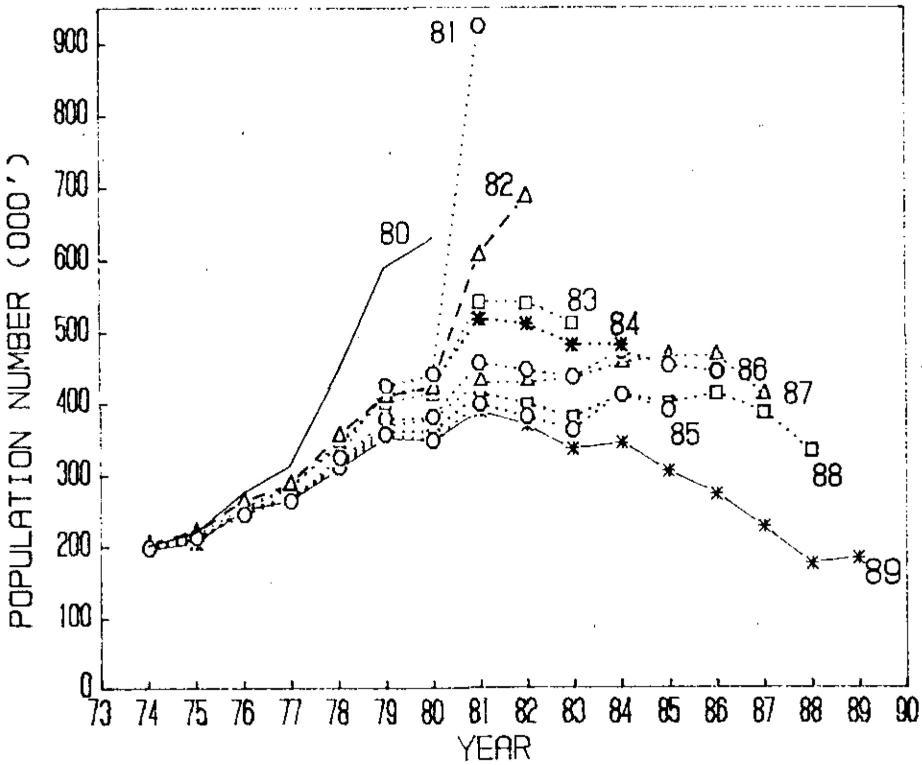

Figure 1. Historical perception of the 3Pn, 4RS cod stock population numbers.

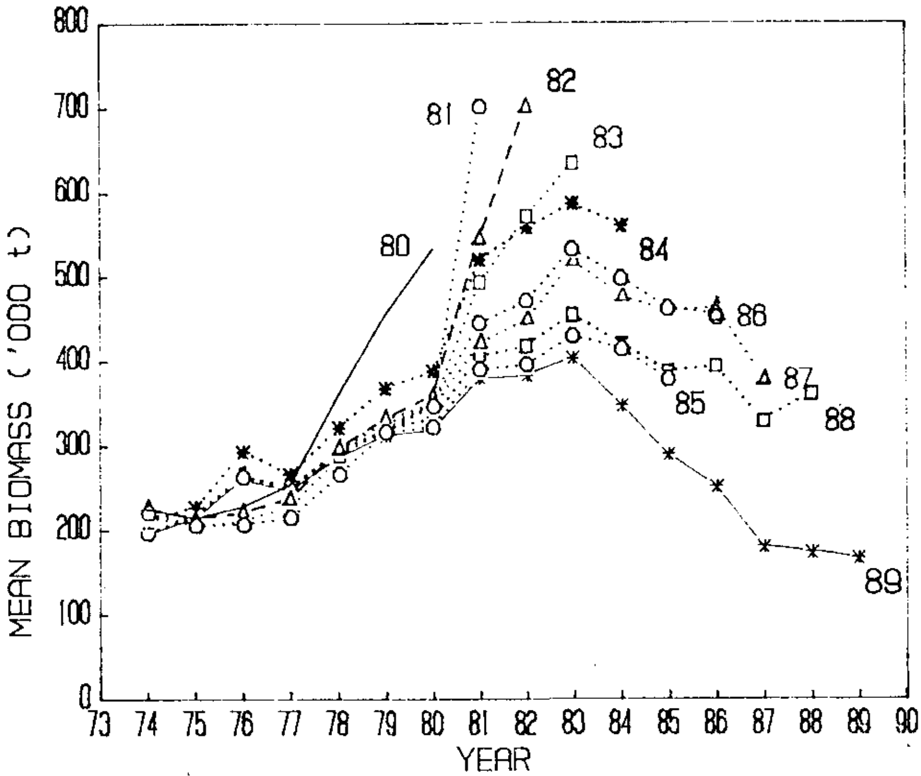

Figure 2. Historical perception of the 3Pn, 4RS cod stock 4+ mean biomass.

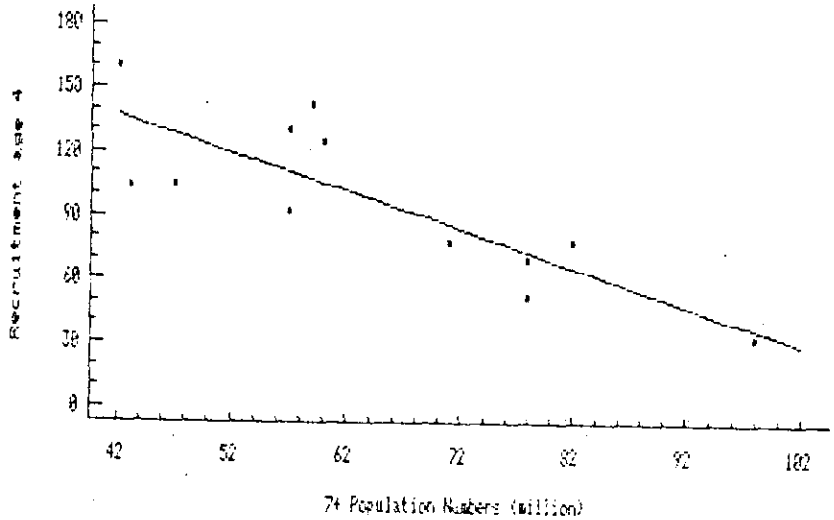

Figure 3. Stock recruitment relationship for the 3Pn, 4RS cod stock.

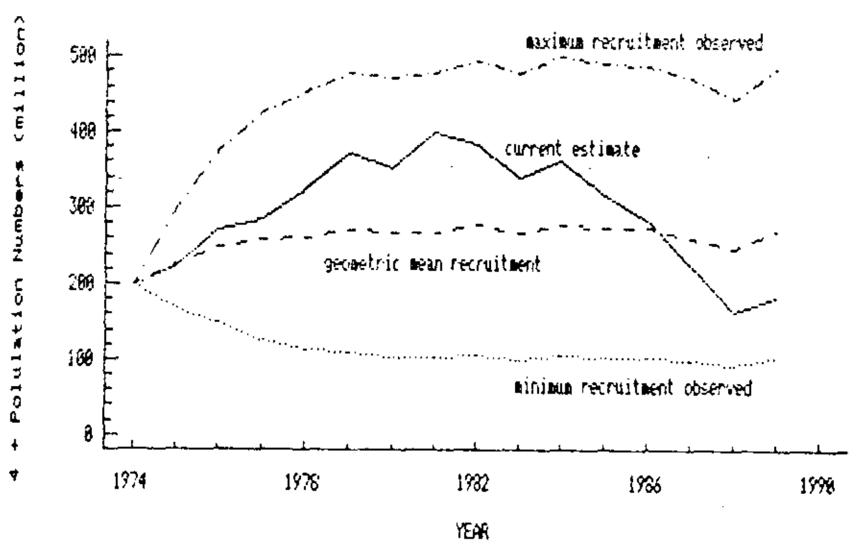

Figure 4. Evolution of the 3Pn, 4RS cod stock since 1974 under various incoming recruitment (age 4) strength.

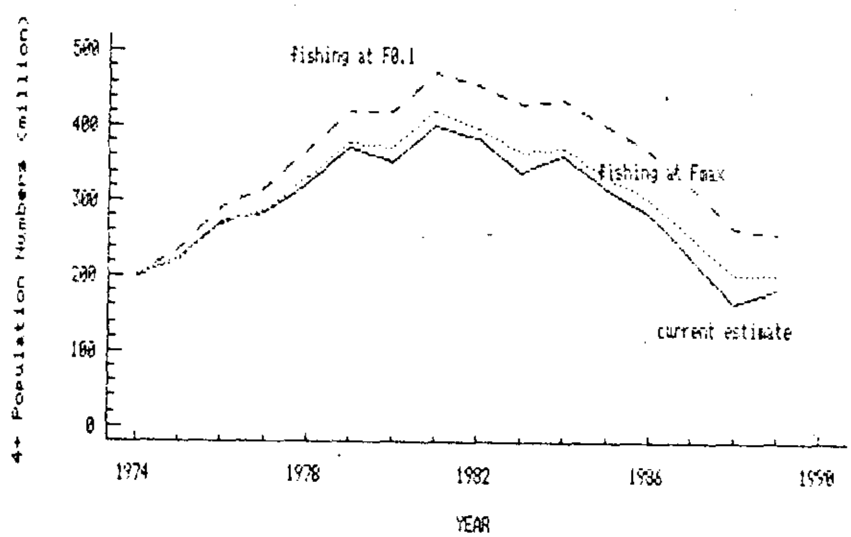

Figure 5. Trend of 4+ population numbers since 1974 if fishing was prosecuted at the $F_{0.1}$ and F_{max} levels.

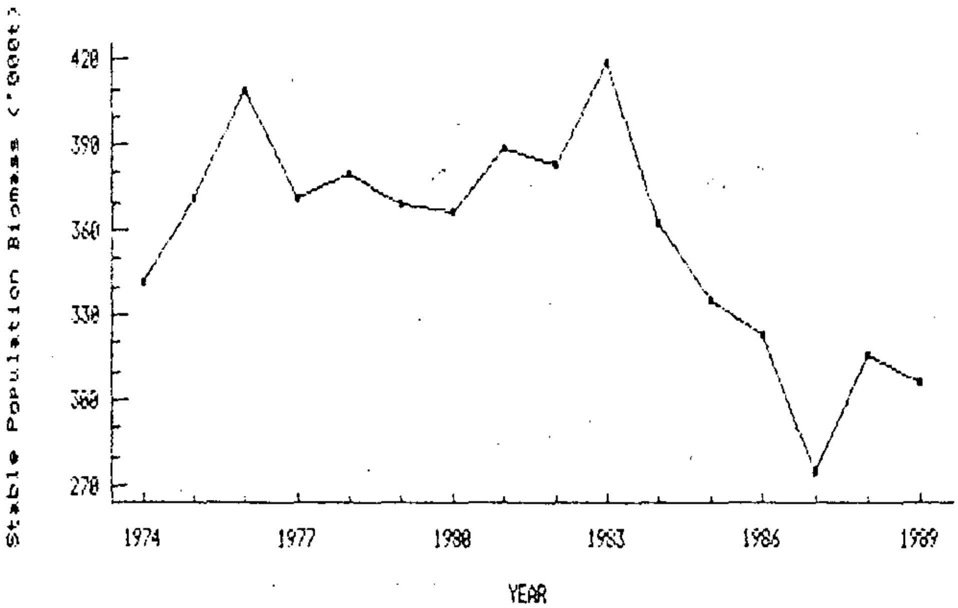

Figure 6. Trend in 4+ population biomass with observed average weights at age and a stable population structure.

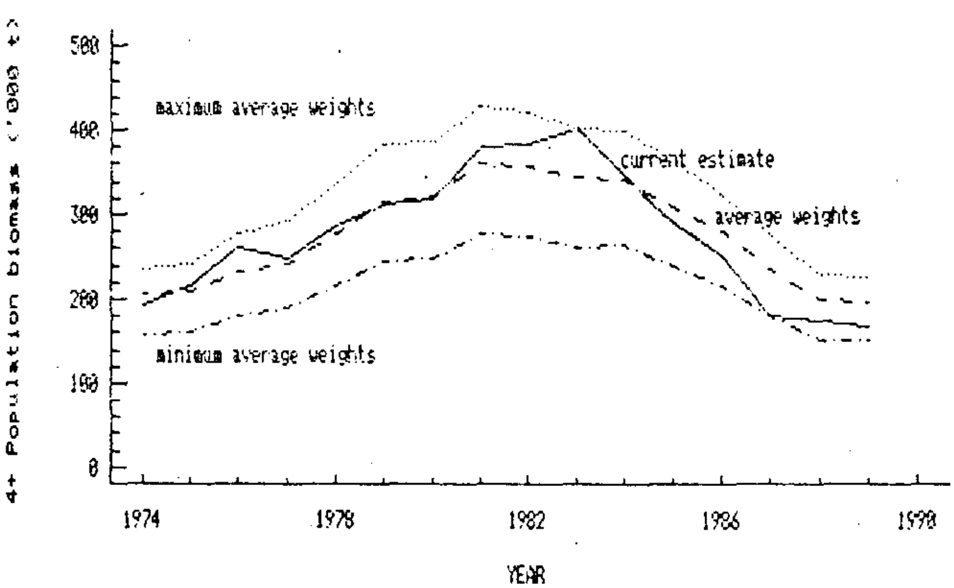

Figure 7. Evolution of the 3Pn, 4RS cod stock since 1974 under various average weights at age.

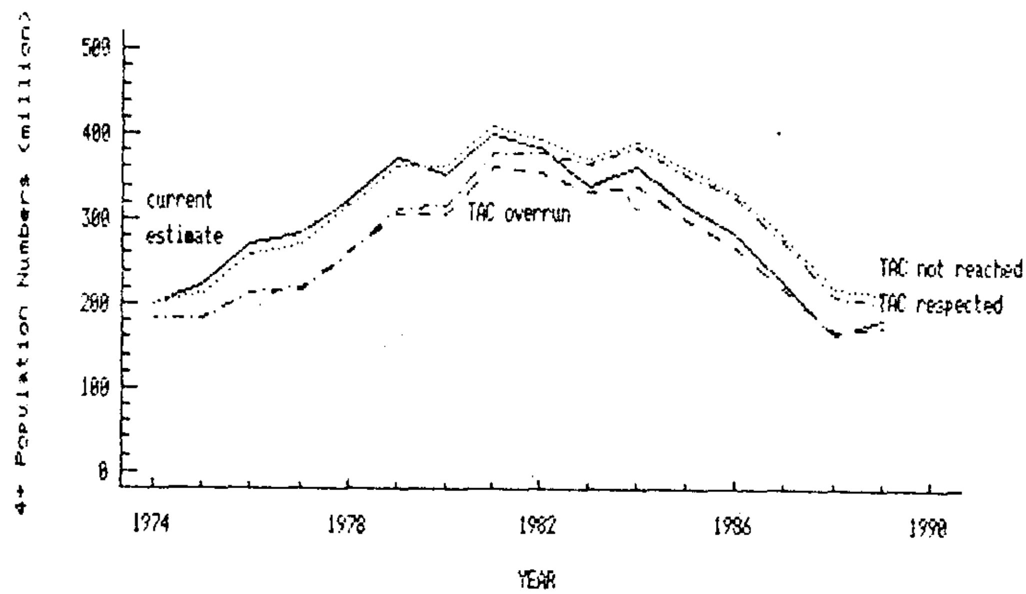

Figure 8. Evolution of the 3Pn, 4RS cod stock since 1974 under various scenarios concerning limitations of the fishery by the TAC's.

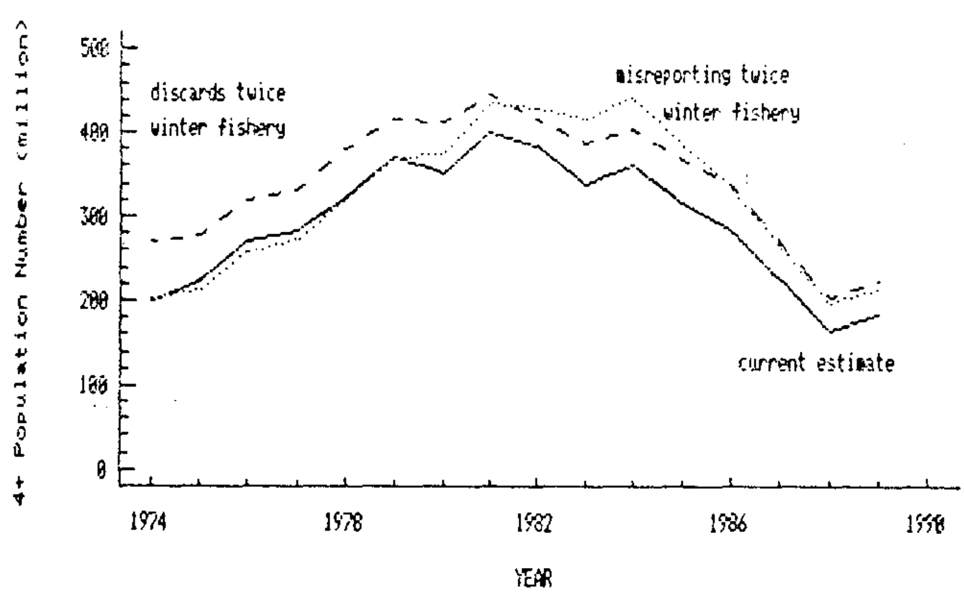

Figure 9. Trends in 4+ population numbers with given levels of discards and misreporting.