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A Declining Cod Stock in the Gulf of St. Lawrence: How Can We Learn From the Past?

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Abstract

A number of factors have contributed to the current decline of the biomass of the Northern Gulf of St. Lawrence cod stock (Subdiv. 3Pn and Div. 4RS). Some of these are overruns of total allowable catches, declining weights-at-age, poor recruitment, misreporting and discards. Based on the formulation used in the most recent assessment, a series of simulations allows one to investigate the role of events and to place them in perspective.

Introduction

A number of events can contribute to the biomass level of a fish stock, the 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-1970s. Many of these fish stocks have experienced changes in biomass levels since then. This makes it possible to partition the importance for "events" that have been measured (or expected to have occurred) for a given stock, in order to put them into perspective with current levels.

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

Events investigated can be categorized into either fishery independent (recruitment, weights-at-age, etc.) or fishery dependent (total allowable catch (TAC) overruns, misreporting, discards, etc.). This means that some events can be changed with management decisions while others have less direct effects. A number of events were investigated independently at three levels; at what was considered reasonable minimum and maximum values and at average conditions. Events for which a good estimate was available (e.g. overruns of TAC), stock status was estimated under the presence or absence of the event. Considering what this stock has experienced in the past, a priority list of events allowed the stock assessment process to focus more attention on particular events.

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

Materials and Methods

The influence of the following parameters were investigated:

- perceived status of the stock;
- recruitment variations;
- target fishing mortality;
- changes in averge weights-at-age;
- fishing limited by TAC;
- discards;
- misreporting.

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

Perceived status of the stock

Analytical stock assessments have been done annually since 1981 and they provide an insight to changes in perception of stock status. In order to describe graphically the historical perception of stock status, Fig. 1 and 2 were based on results from past assessments (Gavaris and Bishop, MS 1981 and MS 1982; Gascon, MS 1983 and MS 1984; Gascon and Fréchet, MS 1985, Fréchet, MS 1986, MS 1987 and MS 1988; Fréchet and Schwab, MS 1989 and MS 1990).

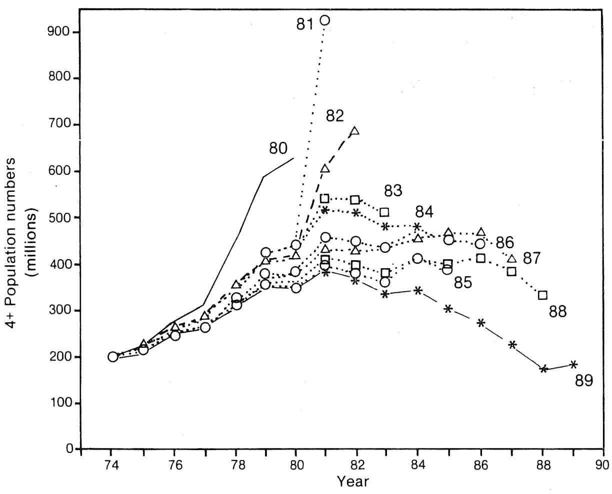

Fig. 1. Historical perception of the Subdiv. 3Pn+Div. 4RS cod stock population numbers.

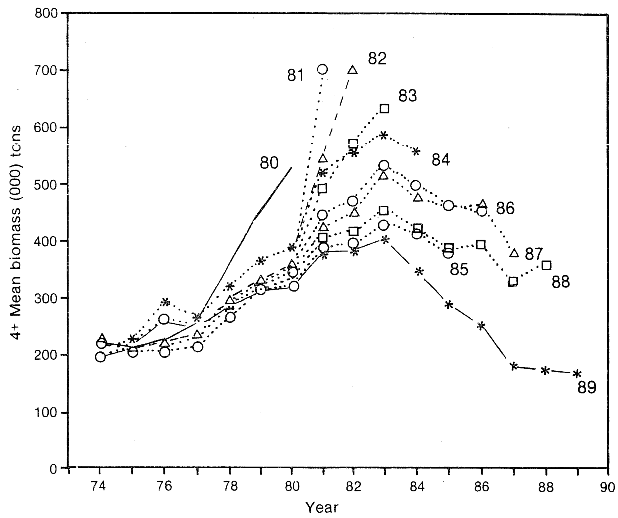

Fig. 2. Historical perception of the Subdiv. 3Pn+Div. 4RS cod stock mean biomass.

Recruitment variations

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

Input parameters were:

1. Population numbers-at-age for 1974; this was the first year of the sequential population analysis and was fully converged.

Age	Population numbers ('000)
4	57,832
5	37,863
6	48,588
7	18,748
8	21,049
9	9,268
10	4,632
11	1,717
12	695
13	609
14	308
15	158

2. Average partial recruitment.

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

Age	4	5	6	7	8	9	10	11	12	13	14	15
PR	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, MS 1990).

Year	F	Year	F
1974	0.428	1982	0.605
1975	0.365	1983	0.358
1976	0.505	1984	0.528
1977	0.548	1985	0.498
1978	0.423	1986	0.648
1979	0.585	1987	0.805
1980	0.518	1988	0.320
1981	0.400	1989	0.349

4. Recruitment options.

   The following options were considered at varying levels of recruitment.

Current estimates:	(see Fréchet, MS 1990)
Geometric mean:	90,000 fish at age 4
Maximum observed:	161,000 fish at age 4
Minimum observed:	34,000 fish at age 4 (This year-class strength was poorly estimated since it was a recent year-class; the 1984 year-class.)

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

Input parameters were the same as population numbers for 1974, partial recruitment was as in the earlier section on recruitment variations. Yearly incoming recruitment at age 4 was as derived from the latest stock assessment (Fréchet, MS 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:

1. Commercial sampling was done every year and weights-at-age were 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:

$$\overline{B}_{i,t} = W_{i+0.5,t+0.5} \quad N_{i,t}(1-e^{-z_{i,t}}) \;/\; Z_{i,t} \quad \ldots (1)$$

where $\overline{B}_{i,t}$ = mean biomass for age i in year t
$W_{i+0.5,t+0.5}$ = Mid-year average weights-at-age
$Z_{i,t}$ = Total mortality (natural and fishing), and
$N_{i,t}$ = Population numbers for age i in year t.

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 scenarios. Catches frequently exceeded the TAC between 1977 and 1984 and were thus adjusted by the difference (in percent) 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 overrun (i.e. using landing values only in years when the TAC was overrun)
4. TAC not reached (i.e. using landing values only in years when the TAC was not overrun)

Discards of small fish

No accurate estimates of discards were available for this stock, but discards were believed to have been more important during the winter otter trawl fishery, especially during the years of high abundance (1981–84). Some levels of discards may have occurred from the trap fishery when catches were high (1978–85). As these simulations are based on very subjective estimates of the levels of discards, they must not be considered as indications of the actual levels of discards. These simulations should merely be interpreted in terms of expected trends on the population size rather than their effect on current stock size. Some fishermen alleged that discards of small fish (under 46 cm) in the winter fisheries were as high as what was landed. These would have been mostly age 4 and 5 fish. Accordingly, the simulations were done using discard levels of age 4 and 5 fish equivalent to those landed during the first 3 months of the year. Twenty-five percent would have been caught at age 4 and 75% at age 5. The catch-at-age was thus modified for each year t using the following relationships:

$$C_{4,t} = 0.25 * \Sigma(\text{Jan to Mar}) \text{ Catch} \;/\; W_{4.5,t+0.5} \quad \ldots (2)$$

and

$$C_{5,t} = 0.75 * \Sigma(\text{Jan to Mar}) \text{ Catch} \;/\; W_{5.5,t+0.5} \quad \ldots (3)$$

TABLE 1. Average weights-at-age used for the simulations.

	Weights-at-age		
Age	Maximum[a]	Average[b]	Minimum[c]
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

[a] Average weights-at-age observed in 1983.
[b] Average of the average weights-at-age for the period 1974–89.
[c] Average weights-at-age observed in 1987.

TABLE 2. Annual landings and TAC for the Subdiv. 3Pn and Div. 4RS cod stock.

Year	Catch (tons)	TAC (tons)	Difference (%)
1974	66,436	—	—
1975	60,233	—	—
1976	76,981	—	—
1977	73,566	55,000	+33.8
1978	78,506	55,000	+42.7
1979	82,777	75,000	+10.4
1980	97,579	75,000	+30.1
1981	97,911	75,000	+30.5
1982	104,939	93,300	+12.5
1983	106,080	100,000	+ 6.1
1984	103,643	100,000	+ 3.6
1985	88,289	100,000	−11.7
1986	82,816	92,100	−10.1
1987	65,594	80,300	−18.3
1988	47,624[a]	73,900	−35.6
1989	46,668[a]	76,540	−39.0

[a] Preliminary

where $C_{4,t}$ = catch-at-age 4 in year t, and

$W_{4.5,t+0.5}$ = Mid-year average weights-at-age 4.

Results are presented in Table 3.

Misreporting

As in the case of discarding, there was no documented evidence, but there was widespread allegations that misreporting took place in some years. The same caviats, mentioned in the above section of discards, apply here (i.e. their impact on stock trend rather than the actual stock size). It is generally considered that misreporting during the winter fisheries occurred widely during the 1984–87 fishing seasons. A trip landing of 10,000 lb. would have been reported as 5,000 lb. (i.e. a 50% difference). Simulations were thus done by doubling the winter fishery landings for those years and applying them to the catch-at-age for the first quarter) for all age-groups (Table 4). The landing figures used were as follows:

Year	Twice the reported first quarter landings (t)
1984	51,150
1985	52,982
1986	62,138
1987	42,690

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) were due to two factors, a doubling in standardized catch rates from the mobile gear fleet and appearance of strong incoming year-classes. In assessments conducted in subsequent years, a gradual decrease in the estimated abundance of the population occurred. This was due to the gradual convergence of the virtual population analysis (VPA), where a jump in the catch-per-unit effort (CPUE) had taken place and less confidence was being placed in the doubling of the mobile gear catch rates. In the 1988 and 1989 fisheries, more confidence was given to the research survey biomass estimates. These had been 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 were the lowest in the 12-year time series and thus should not be disregarded any more.

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			
	1984	1985	1986	1987
4	763	1,929	774	93
5	2,784	11,949	4,053	5,229
6	7,365	9,583	11,315	7,680
7	10,477	8,470	10,627	10,832
8	3,601	4,488	4,446	5,999
9	2,658	1,515	4,208	2,443
10	1,058	1,016	1,253	1,020
11	338	329	1,419	729
12	305	40	208	146
13	105	5	129	156
14	15	0	17	18
15	18	3	1	14

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 (tons)	Estimated removals[a]			
		Average weights-at-age		In numbers	
		Age 4 (kg)	Age 5 (kg)	Age 4	Age 5
1974	29,707	0.64	0.99	11,640	22,505
1975	30,420	0.72	1.00	10,562	22,815
1976	34,451	0.76	1.13	11,331	22,865
1977	23,536	0.65	1.02	9,052	17,305
1978	32,222	0.75	0.96	10,740	25,173
1979	26,291	0.65	0.93	10,011	21,202
1980	24,170	0.62	0.93	9,746	19,491
1981	27,694	0.79	0.98	8,764	21,194
1982	24,082	0.85	1.11	7,083	16,272
1983	25,700	0.93	1.30	6,909	14,827
1984	25,575	0.79	1.03	8,093	18,623
1985	26,491	0.79	0.98	8,383	20,273
1986	31,069	0.73	0.98	10,640	23,777
1987	21,345	0.60	0.77	8,894	20,791
1988	8,352	0.73	0.88	2,860	7,118
1989	15,864	0.69	0.94	5,683	12,514

[a] These removals were added to the reported catches for these ages.

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

An attempt to establish a stock/recruitment relationship from the most recent assessment resulted in a negative relationship (Fig. 3). Although all statistics were significant (significant slope; $R^2 = 0.66$), this relationship was thought to be spurious since all points to the right (corresponding to a low recruitment) were from the non-converged part of the matrix. At 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 the average incoming recruitment and the minimum observed recruitment (Fig. 4). Stock status in the early-1980s was half way between the geometric mean recruitment and the maximum observed recruitment. All lines started at the same level in 1974, this is because the various scenarios were done by projections. The various stock levels were thus

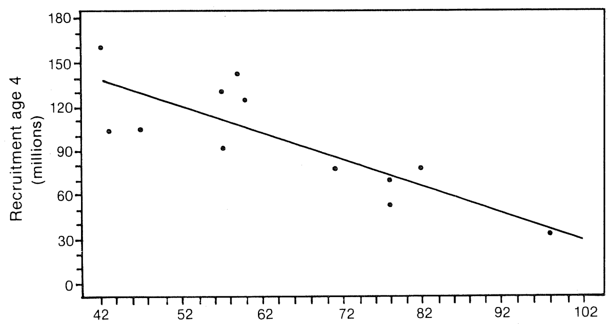

Fig. 3. Stock recruitment relationship for the Subdiv. 3Pn+Div. 4RS cod stock.

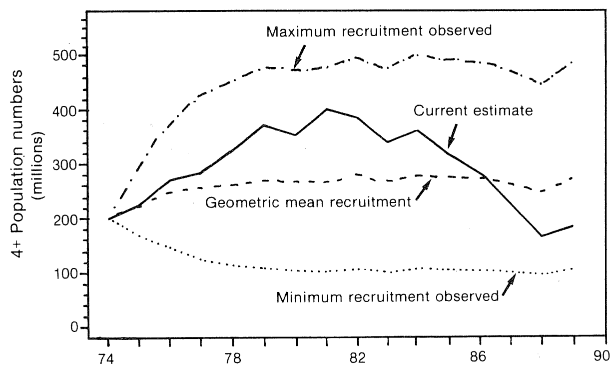

Fig. 4. Evolution of the Subdiv. 3Pn+Div. 4RS cod stock since 1974 under various incoming recruitment (age 4) strength.

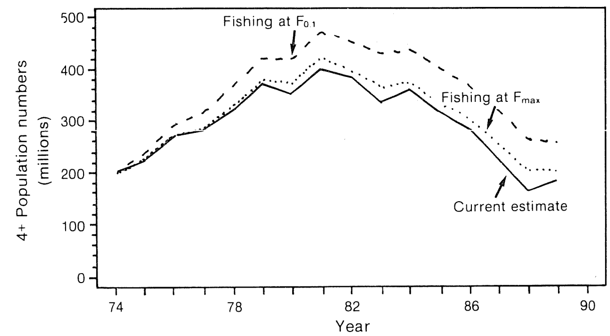

Fig. 5. Trend of 4+ population numbers since 1974 if fishing was prosecuted at the $F_{0.1}$ and F_{max} levels.

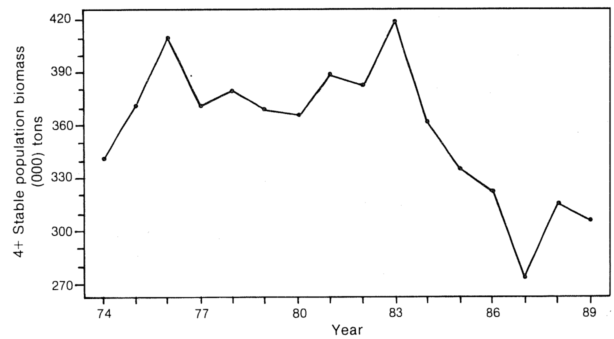

Fig. 6. Trend in 4+ population biomass with observed average weights-at-age and a stable population structure.

increasing with time as new recruiting age-classes were being introduced to 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 were closer to F_{max}. The second simulation was intended to describe the path in which the stock would have been progressing 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 have been present in 1989 if the fishery was prosecuted at the $F_{0.1}$ level. Since 1974, current estimates are slightly less than if the F_{max} catch level had occurred.

The first reference to a decline of average weights-at-age for this stock occurrred in the assessment of the 1985 fishery (Fréchet, MS 1986). A few years later a working group was commissioned by Canadian Atlantic Fishery Advisory Committee to look into what could be the underlying factors. Those that have been identified for certain cod stocks are stock dependence and water temperature. The simulations performed here were done to reflect, relative to the current stock biomass, what levels could be expected under the three scenarios of average weights-at-age (maximum, average, minimum). Figure 6 shows the bounds in biomass that could have been observed with the observed weights-at-age given that the population numbers were stable. The biomass would have reached a peak in 1983 and a minimum value in 1987. The average weights-at-age for those 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 its lowest.

TACs were first imposed on this stock in 1977 and have seldom been restrictive (Table 2). The impact of these overruns was simulated and are shown in Fig. 8. Under the three scenarios (TAC respected, TAC not overrun, TAC not reached), a series of calibrations were done using the ADAPT workspace. These indicate that marginal impact on the current stock size can be expected.

Finally, simulations including the effect of discards and misreporting indicate a trend for a more rapid decline, if misreporting had occurred for only a few years (Fig. 9). A more optimistic view of the resource would result if these practices had occurred throughout the time period 1974–89 as in the case of the simulation on discards. Recent discussions with fishermen suggest much higher levels of discards and misreporting than those used in this study. This is why these simulations should be interpreted only in terms of their impact on stock trend rather than their actual level. Table 5 summarizes the importance of the studied variables on the current status of this stock.

Discussion

Out of the various simulations that can be done, the most important factor is the decision on what "standard" one should be comparing the results to. This is the perceived status of the stock. With this as the standard, 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, and in some years (1980–83) it was more than twice the current estimate (which is now converged). One implication this has on 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 (Myers *et al.*, 1990).

The stock recruitment relationship for this stock was not attempted previously because the number of years in the cohort analysis was too low. The attempt in this study was not encouraging, since it suggests a negative relationship (this would mean that the absence of a stock would produce 211 million fish at

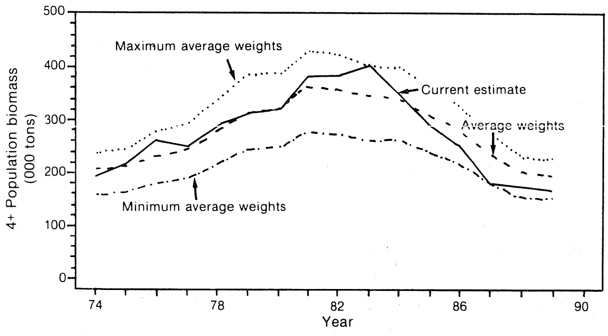

Fig. 7. Evolution of the Subdiv. 3Pn+Div. 4RS cod stock since 1974 under various average weights-at-age.

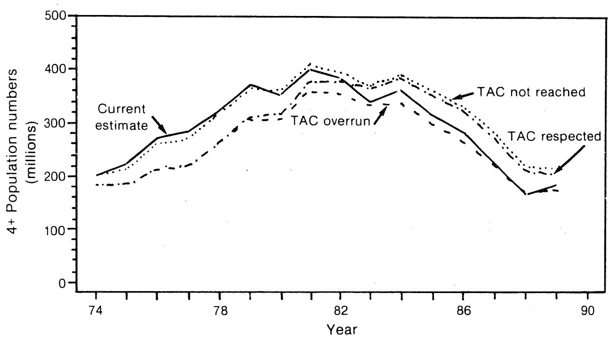

Fig. 8. Evolution of the Subdiv. 3Pn+Div. 4RS cod stock since 1974 under various scenarios concerning limitations of the fishery by the TACs.

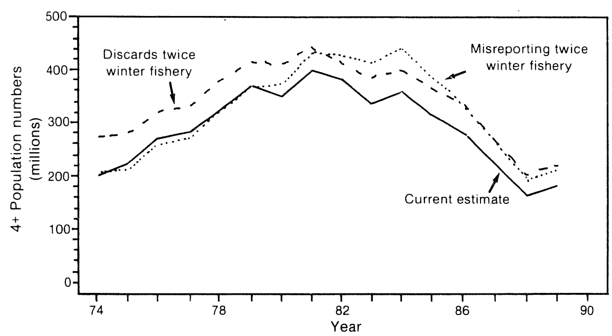

Fig. 9. Trend in 4+ population numbers with given levels of discards and misreporting.

TABLE 5. Summary of the various simulations on current stock size.

Event	Observed effect Maximum	Average	Minimum
Perception of the stock	++++++[a]		
Recruitment	+++++	++	---
Target fishing mortality $F_{0.1}$	+++		
F_{max}	+		
Average weights-at-age	++	+	–
TAC overrun		0	
respected		+	
not reached		+	
Misreporting		+	
Discards		+	

[a] Its effect can be either positive or negative.

age 4). Most of this inconsistency would be caused by the fact that the peak in adult (age 7+) population numbers (1982-85) is compared to very recent poor recruitment (last 4 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 useful consideration when attempting to simulate the effect of recruitment while a fishery takes place.

Table 5 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 present at age 4 is the determining factor of the stock abundance. The alternation of strong and weak year-classes should produce an average population size. However, if the strongest year-classes had been observed, this would generate a population of nearly 500 million individuals. These results are generated under the assumption that such optimal conditions may occur in reality. In fact, they are unlikely to occur for as many years as there are year-classes in the exploited stock (roughly ten). This stock, at its highest observed abundance (1981) was 20% lower than this maximum value. Concurrently, the population estimate for 1989 (185 million at 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 its peak biomass in 1983, if minimum observed weights-at-age had 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 its 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 have been 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 the fact that these projections were being done at the $F_{0.1}$ level, current stock status still showed 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). Only age 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 occurred 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 (1984-87). A higher rate of decline in population size is observed since 1984 but more fish are generated in the four preceding years.

It is apparent that for assessment purposes, the most important factors to determine are those not directly related to the fisheries. The incoming recruitment, average weights-at-age are crucial to the stock status. Since no density dependence is evident for this stock under the observed stock levels, it may be presumed that recruitment has been independent of the fishery. There are some indications that growth may be density dependent. 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 occurred 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.

Acknowledgements

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