DFO Atlantic Fisheries
Research Document 95/40

MPO Pêches de l'Atlantique
Document de recherche 95/40

Analysis of past replacement levels in the southern Gulf cod stock

by

Peter Shelton[1] and Alan Sinclair[2]

[1]Science Branch, Department of Fisheries and Oceans
PO Box 5667, St John's,Newfoundland
Canada, A1C 5X1

[2]Department of Fisheries and Oceans
Gulf Fisheries Centre, PO Box 5030
Moncton, New Brunswick
Canada E1C 9B

ABSTRACT

Recruitment values estimated for the southern Gulf cod stock are compared with the amount of recruitment required to replace the spawner biomass at prevailing values of fishing mortality and weights at age. The value of a recruit in terms of spawner biomass produced for the 1989-93 period, ignoring the direct effects of fishing, was half of what it was in the 1974-78 period. Thus, even before taking into account fishing mortality, recruitment had to be much higher in the 1989-93 period than in the 1974-78 period for the stock to grow. Unfortunately recruitment was low and fishing mortality high over the latter period, exacerbating the the situation. Incorporating targets and thresholds which are responsive to spawner stock replacement is a challenge in the development of future management procedures for the southern Gulf cod stock and other cod stocks in the northwest Atlantic.

RÉSUMÉ

On compare les valeurs de recrutement du stock de morue du sud du Golfe au recrutement nécessaire pour remplacer la biomasse de reproducteurs d'après les valeurs dominantes de mortalité par pêche et de poids selon l'âge. En ce qui concerne la biomasse de reproducteurs pour la période 1989-1993, la valeur d'une recrue, si l'on ne tient pas compte des effets directs de la pêche, correspondait à la moitié de ce qu'elle était durant la période 1974-1978. Par conséquent, même avant de prendre en considération la mortalité par pêche, le recrutement se devait d'être beaucoup plus élevé de 1989 à 1993 que durant la période 1974-1978 pour que le stock s'accroisse. Or, malheureusement, le recrutement a été faible et la mortalité par pêche forte entre 1989 et 1993, ce qui a aggravé la situation. L'intégration de seuils et de cibles correspondant au remplacement du stock de reproducteurs est un problème à résoudre dans l'élaboration de modalités de gestion futures du stock de morue du sud du Golfe et d'autres stocks de morue de l'Atlantique nord-ouest.

Introduction

The southern Gulf (NAFO Div. 4TVn) cod stock declined to low biomass levels in the mid-1970s but began to recover in the the late 1970s as a consequence of the strong 1974 and 1975 year-classes. Although the 1976-78 year classes were average, the 1979 and 1980 year classes were strong and the stock continued to increase up until the mid-1980s. This increase might have been greater, however the 1979 and 1980 year-classes were associated with low body growth rates. The stock declined rapidly in the latter half of the 1980s into the 1990s as recruitment returned to lower levels and fishing mortality increased. The TAC was reduced sharply in 1993 and in 1994 the fishery was closed.

Comparison of recruitment values to the amount required to replace the spawner stock biomass provides insight into the causes of stock declines (e.g. Shelton and Morgan, 1993a, 1993b, 1994a, 1994b) and might provide useful reference points in future management procedures (e.g. Sissenwine and Shepherd, 1987, Gabriel et al. 1989, Mace and Sissenwine 1993, Shelton and Morgan 1994b). In this analysis ADAPT estimates of numbers and fishing mortality at age, together with beginning of year weights at age from samples of the commercial catch (Sinclair et al. 1994) are used to compare past levels of recruitment in the southern Gulf cod stock relative to that required for replacement.

Methods

A detailed description of methods can be found in Gabriel et al. (1989) and Shelton and Morgan (1994b). A brief description of the calculations following Shelton and Morgan (1994b) is given below.

As a cohort ages, it makes annual contributions to the spawner biomass over its lifetime. The cumulative contribution to spawner biomass, S' , is given by

$$S' = \sum_{i=r}^{I} (N_i w_i p_i)$$

where

$$N_{i+1} = N_i e^{-(F_i + M)}$$

and where

S' = the cumulative contribution to spawning biomass by a cohort over its lifespan
N_i = the number alive in a cohort at age i ($N_i = R$ when $i=r$)
w_i = the weight of an individual fish at age i
p_i = the proportion mature at age i
r = the age at recruitment
I = terminal age class (alternatively a 'plus' age class could be used)
F_i = the annual instantaneous fishing mortality rate on age i
M = the annual instantaneous natural mortality rate

Spawner biomass in year j is given by

$$S_j = \sum_{i=r}^{I} (N_{i,j} w_{i,j} p_{i,j})$$

The amount of recruitment required to replace the spawner stock in year j that gave rise to the cohort, R^*_j, can be computed as

$$R^*_j = \frac{S_j}{\sum_{i=r}^{I} (\gamma_i w_i p_i)}$$

where

$$\gamma_i = 1 \quad \text{for } i=r$$

and

$$\gamma_i = \prod_{k=r+1}^{i} (e^{-(F_{k-1}+M)}) \quad \text{for } i>r$$

The subscript i tracks the cohort as it ages. Following a cohort over its lifespan does not provide a heuristic any simpler than a full age structured population model (e.g. Leslie matrix model). It also has the inconvenience that only the middle part of the data set can be used (complete cohorts). It has become common practice to calculate replacement or related quantities such as spawner per recruit (SPR) using average values for weights, maturities and partial recruitments (or fishing mortalities) at age (e.g. Sissenwine and Shepherd 1987, Gabriel et al. 1989 and Mace and Sissenwine 1993). In other words F_i, w_i and p_i are averaged for age i across several cohorts. This is particularly convenient in stock-recruit plots, where replacement calculated using averages is a straight line through the origin. However, using averages over several years can be misleading when there are trends in values. To account for strong trends in values, the period over which the averaging is carried out can be shortened, or indeed annual values can be calculated (i.e. annual replacement, Shelton and Morgan 1994b) so that F_i, w_i and p_i are age specific values in a particular year. Both annual values and average values were calculated for the southern Gulf cod stock and the results are reported below. Annual proportions mature at age were not available for this study so that knife-edge maturity was assumed at age 6, i.e. no age 5s mature but all age 6s mature.

In addition to calculating average replacement recruitment, average spawner per recruit (*SPR*) and *SPR* as a percentage of the *SPR* at F=0 (%*SPR*) are also considered to be useful references (Mace and Sissenwine 1993). *SPR* can be calculated by simply dividing the spawner stock biomass by the associated replacement value. *SPR* and %*SPR* are calculated at a variety of F values for the southern Gulf cod in this research document.

Results

In Fig.1 Annual replacement and recruitment are plotted for the 1971 to 1993 period (annual fishing mortality and weights at age). Recruitment was above annual replacement between 1973 and 1980. Recruitment fell to low levels relative to that required for replacement in the late 1980s. In Figs. 2 and 3 average weights and fishing mortalities for the period 1989 to 1993 were used. It is clear that the majority of the recruitment values (14 out of 20) are below average replacement and that all are below average replacement from 1981 onwards.

It is of interest to examine the causes for the stock falling below replacement in recent years in more detail. The direct effect of the spawning stock can be removed (indirect effects as a consequence of a stock-recruit relationship remain) by plotting recruit per spawner and replacement per spawner (Fig. 4). From this it can be seen that, as a consequence of changes in fishing mortalities and weights at age, the replacement per spawner level increased steadily from 1977 to 1992 after which there was a major reduction in TAC followed by a moratorium in 1994. The direct effects of fishing mortality can be removed by carrying out the replacement calculation at F=0 (Fig. 5). Indirect effects of fishing of course persist, for example recruitment overfishing. Even at zero fishing mortality it is evident that in recent years recruitment levels have been at values close to or slightly below replacement, i.e. at the level at which the population would continue to decline even in the absence of fishing.

The target fishing mortality for cod stocks in the Northwest Atlantic was generally *F*=0.2, assumed to be approximately equivalent to *F*0.1. Average replacement for the 1989-93 period calculated using a fully recruited *F*=0.2 (Figs. 6 and 7) suggests that this would have allowed recruitment to have been above average replacement up until 1983, however, all subsequent values are below replacement. The scatter plot (Fig. 7) indicates that this level of fishing mortality is more conservative than *F*med, or equivalently *F*rep - the level of fishing mortality at which, on average, spawner stock size is approximately constant. Using the average weights and partial recruitment values at age for the 1989-93 period gives *F*0.1= 0.385 and *F*med = 0.25.

In the mid-1970s average weights at age were higher than in the last 5 years and fishing mortality values were somewhat lower and declining. If average weights and partial recruit at age for the 1974-78 period are used the outcome at *F*=0.2 is quite different. Recruitment is calculated to be above average replacement for the 1974-78 period up until 1985 and even afterwards values are either just above, on, or just below the replacement line (Figs. 8 and 9). Using average weights and partial recruit at age for the 1974-78 period gives *F*0.1 = 0.24 and *F*med = 0.48.

SPR and %SPR for different levels of F are shown in Table 1. Calculations were performed for both the 1989-93 averages and the 1974-78 averages.

Table 1. Average SPR and %SPR calculated at different F values for the 1989-93 and 1974-78 periods.

F	*SPR* (kg)	*%SPR*
1989-93 average values		
F=0	4.44140	100
5 year average *F*=0.98	1.31598	29.6298464
F=0.2	2.89912	65.2749133
Fmed=0.25	2.66589	60.0236412
*F*0.1=0.385	2.19952	49.5231233
1974-78 average values		
F=0	9.73453	100
5 year average *F*=0.64	2.07116	21.2764253
F=0.2	5.00205	51.3846072
Fmed=0.48	2.65762	27.3009585
*F*0.1=0.24	4.48472	46.0702263

Discussion

Although it is tautological to say that a population declined because recruitment was insufficient to replace the spawner stock at prevailing rates of mortality, body growth and maturity, the tautology leads to a set of heuristics which provide insight into the causes for decline. *SPR* provides an estimate of the value of an individual recruit in terms of subsequent spawner biomass and the replacement calculation indicates the number of recruits needed, given the *SPR*, to replace the spawner stock biomass.

The value of a recruit in terms of spawner biomass produced for the 1989-93 period in the absence of fishing was half of what it was in the 1974-78 period (Table 1, *SPR* at F=0). Thus, even before taking into account the effect of fishing mortality, recruitment had to be much higher in the 1989-93 period than in the 1974-78 period to meet replacement. Unfortunately, recruitment was high in the 1974-78 period when the amount required for replacement was low, and low in the 1989-93 period when the amount required for replacement was high (Fig. 5). This situation was exacerbated by the comparatively high levels of fishing mortality in the late-1980s (Figs. 1 and 4).

It is of interest to note that whereas the F=0.2 target was conservative relative to the mid to late 1970s, this level of fishing mortality was close to the *Fmed* reference level for the late 1980s - early 1990s (Table 1) and recruitment after 1983 would have been below replacement even at this level of F (Figs. 6 and 7).

Different perspectives on the stock are given by yield per recruit analysis and by replacement-*SPR* analysis. Whereas yield per recruit analysis suggests that the target of *F*0.1 should be taken at a higher level of F in the late 1980s-early 1990s than in the mid to late 1970s, replacement-*SPR* analysis suggests that replacement in the latter period could only have been achieved by lowering the F.

Levels of %SPR between 20-35% are commonly used to define overfishing by U.S Fisheries Management Councils. The target of F=0.2 is well above this level for the recent period (Table 1), even though recruitment was falling below replacement (Figs. 6 and 7).

Clearly yield-per-recruit and %SPR analysis may suggest levels of fishing mortality which exceed the level of fishing mortality at which replacement is achieved. Although brief periods below replacement are normal and of no concern for a population fluctuating at high levels of abundance, prolonged periods below replacement precipitated by high levels of fishing mortality combined with low weights at age are disastrous for a stock at low levels of abundance. Incorporating targets and thresholds which are responsive to replacement is a challenge in the development of future management procedures for stocks such as the southern Gulf cod.

References

Gabriel, W.L., M.P. Sissenwine and W.J. Overholtz. 1989. Analysis of spawning stock biomass per recruit: an example for Georges Bank Haddock. N. Am. J. Fish. Man. 9:383-391.

Mace, P.M. and M.P. Sissenwine. 1993. How much spawning per recruit is enough? In Risk evaluation and biological reference points for fisheries management. S.J. Smith, J.J. Hunt and D. Rivard (eds.) Can. Spec. Publ. Fish. Aquat. Sci. 120:101-118.

Shelton, P.A, and M.J. Morgan. 1993a. An analysis of NAFO Division 2J3KL cod spawner biomass and recruitment. NAFO SCR Doc. 93/37, 14p.

Shelton, P.A, and M.J. Morgan. 1993b. Assessing the risk of failing to achieve replacement recruitment. ICES C.M. 1993/D:54, 20p.

Shelton, P.A. and M.J. Morgan. 1994a. NAFO Divs. 3NO cod stock - spawner stock biomass and recruitment required for replacement. NAFO SCR Doc. 94/1, 10p.

Shelton, P.A. and M.J. Morgan. 1994b. An analysis of of spawner biomass and recruitment of cod (*Gadus morhua*) in Divisions 2J and 3KL. NAFO Sci. Coun. Studies, 21: 67:82.

Sinclair, A., G. Chouinard, D. Swain, R.J. Hébert, G. Nielson, M. Hanson, L. Currie and T. Hurlbut. 1994. Assessment of the fishery for southern Gulf of St Lawrence cod: May 1994. DFO Atl. Fish. Res. Doc. 94/77, 116p.

Sissenwine, M.P. and J.G. Shepherd. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aquat. Sci. 44:913-918.

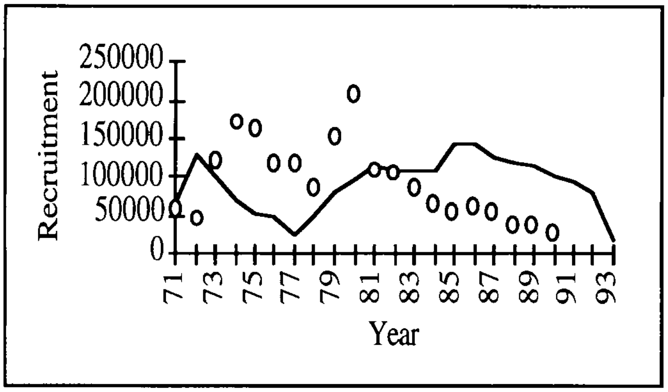

Fig. 1. Annual replacement (line) and recruitment (circles) for the period 1971 to 1993. Annual replacement is calculated using the year-specific values for weights and fishing mortality at age.

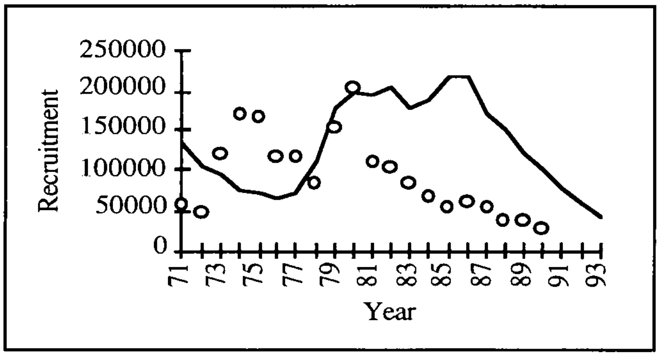

Fig. 2. Average replacement (line) and recruitment (circles) for the period 1971 to 1993. Average replacement was calculated by averaging year-specific values of weights and fishing mortality at age for the 5 year period.

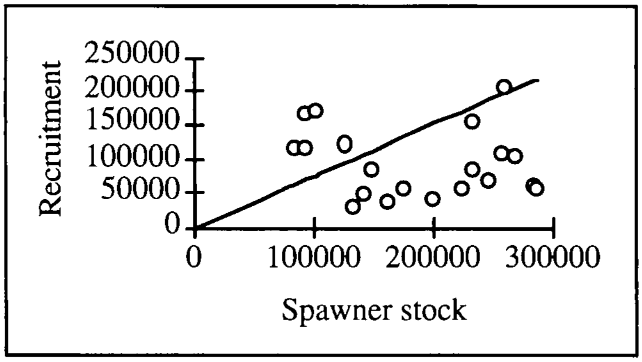

Fig. 3. The equivalent stock-recruit scatter plot and replacement line calculated by averaging weights and mortalities at age for the 1989-93 period.

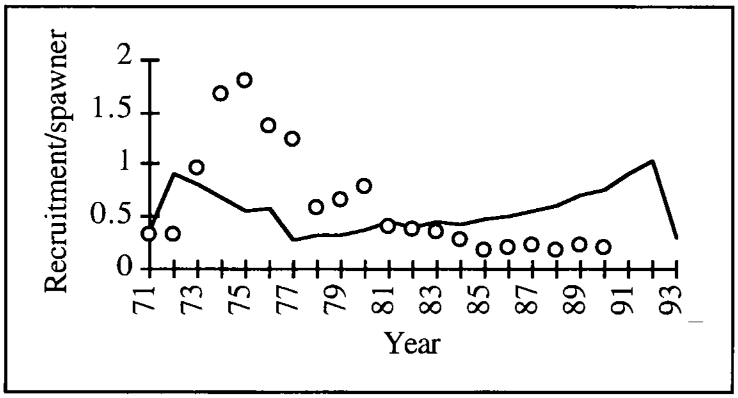

Fig. 4. Annual replacement (line) and recruitment (circles) per spawner. In this plot the direct effect of spawner stock size is removed. Indirect effects on recruitment through a S-R relationship remain.

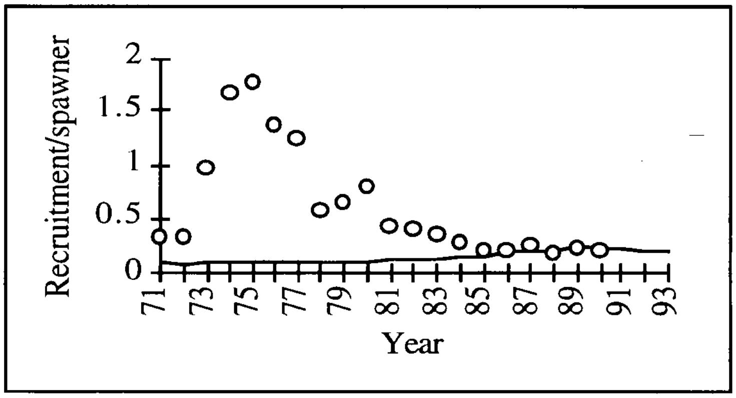

Fig. 5. Annual replacement (line) and recruitment per spawner (circles) at F=0. In this plot the direct effects of fishing mortality and spawner stock size are removed in calculating the replacement level.

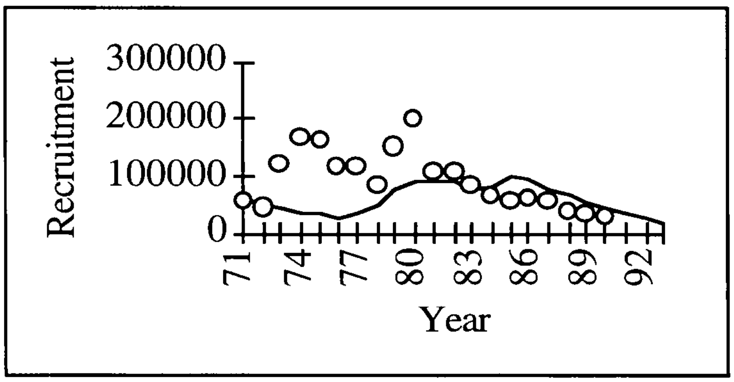

Fig. 6. Average replacement (line) and recruitment (circles) for the 1989-93 period calculated at a fully recruited F=0.2.

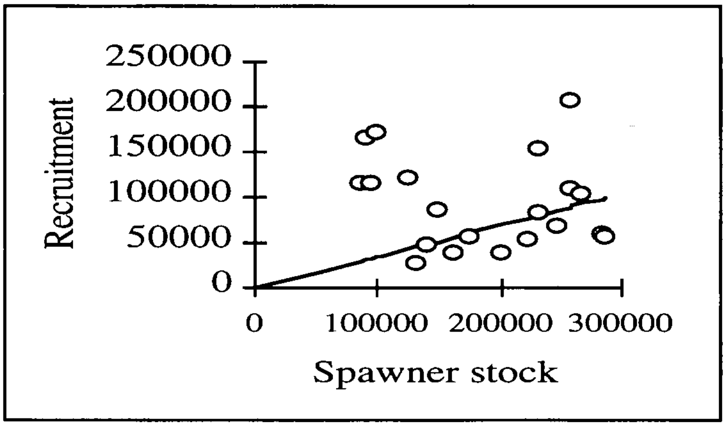

Fig. 7. The equivalent S-R scatter plot and replacement line for Fig. 6.

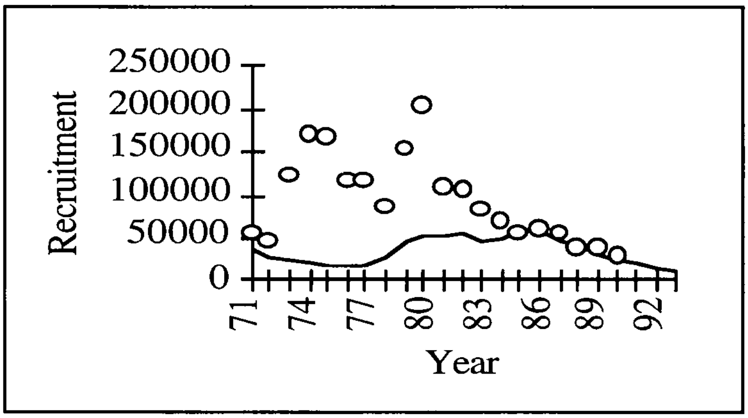

Fig. 8. Average replacement (line) and recruitment (circles) for the 1974-78 period calculated at a fully recruited F=0.2.

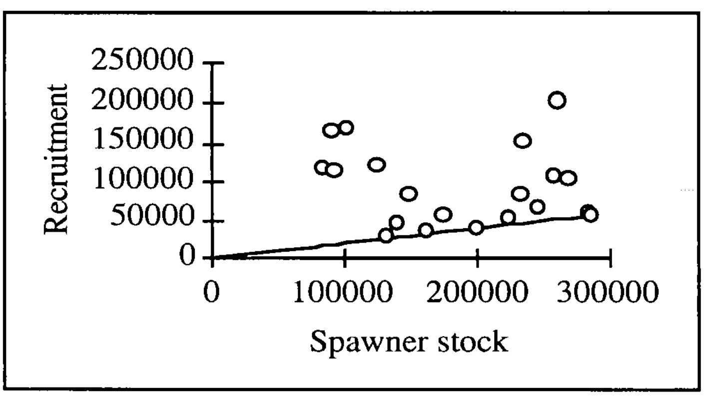

Fig. 9. The equivalent S-R scatter plot and replacement line for Fig. 7.