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Analysis of replacement in eight Northwest Atlantic cod stocks

by

Peter A. Shelton

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

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ABSTRACT

The relationship between ADAPT estimates of recruitment and the amount required for replacement is examined for eight northwest Atlantic cod stocks. Comparison among stocks shows that in six cases recruitment fell below replacement and remained below at approximately the same time (early 1980s). In five of the stocks recruitment fell to a level close to or below replacement calculated at zero fishing mortality. For most of the stocks replacement per spawner and spawner per recruit (*SPR*) showed very similar temporal changes. SPR at F=0 declined by a half or a third in four of the stocks as a result of declining weights at age (and to some extent changes in maturity at age in one of the stocks) over the 1980s. The conclusion is drawn that decreases in recruitment and growth in at least four of the eight stocks over the 1980s played a major role in the decline of these stocks. It seems unlikely that these events can be attributed entirely to fishing.

RÉSUMÉ

On examine la relation entre les estimations de recrutement d'après la méthode ADAPT et la quantité nécessaire au remplacement dans huit stocks de morue de l'Atlantique nord-ouest. Les comparaisons entre stocks révèlent que dans six des cas le recrutement est tombé et est demeuré sous la valeur de remplacement à peu près à la même période (début des années 1980). Dans cinq des stocks considérés, le recrutement est descendu à un niveau égal ou inférieur à celui du remplacement calculé selon une mortalité par pêche de zéro. Pour la plupart des stocks, les valeurs de remplacement par reproducteur et de biomasse du stock reproducteur par recrue (BSR/R) dénotaient des changements temporels très similaires. La valeur BSR/R à F=0 a diminué de moitié ou d'un tiers dans quatre des stocks, en raison d'une baisse des poids selon l'âge (et, dans une certaine mesure, de changements dans la maturité selon l'âge en ce qui concerne un des stocks) au cours des années 1980. On en conclut que la baisse du recrutement et de la croissance dans au moins quatre des huit stocks considérés durant les années 1980 a joué un rôle déterminant dans le recul de ces stocks. Il est peu probable que ces phénomènes soient attribuables entièrement à la pêche.

Introduction

Application of the ADAPT framework (Gavaris 1988) to the assessment of eight cod stocks in the Northwest Atlantic (Bishop et al. 1993, Davis et al. 1993, Bishop et al. 1994, Fréchet et al. 1994, Sinclair et al. 1994, Mohn and MacEachern 1994, Gavaris et al. 1994 and Hunt et al. 1994) provides fishing mortality and population estimates that can be compared among stocks. For all stocks fishing mortality increased over the 1980s into the 1990s and concurrently population size declined. In six of the eight stocks the decline has been judged so severe, that no directed commercial fishery is currently taking place.

A population declines in terms of biomass when, on average, year-classes born to the population produce insufficient spawner biomass to equal that of their parents. Failure to replace the spawner biomass can be a consequence of (i) insufficient numbers of recruits; (ii) low post-recruit survival as a result of fishing or some other source of mortality; (iii) low weights-at-age, or (iv) low proportions mature-at-age, in any combination. Although brief periods below replacement are normal and of no concern for a population fluctuating at high levels of abundance, prolonged periods below replacement leading to severe stock decline are of obvious concern.

While high fishing mortality is undoubtedly the major cause of the declines in the eight cod stocks in the northwest Atlantic, it is important not to neglect the possible influences of factors that are not a direct consequence of fishing. Such factors may have retarded or accelerated the declines and may be important in determining the rate of recovery.

The relationship between ADAPT estimates of recruitment and the amount required for replacement has been examined for three of the northwest Atlantic cod stocks in previous studies (Shelton and Morgan 1993a, 1993b, 1994a, 1994b, Shelton and Sinclair 1995). In this paper these studies are extended to eight stocks. Comparison among stocks shows that in six cases recruitment fell below replacement and remained below at approximately the same time (early 1980s). In five of the stocks recruitment fell to a level close to or below replacement calculated at zero fishing mortality. For most of the stocks replacement per spawner and spawner per recruit (SPR) showed very similar temporal changes.

The conclusion is drawn that deceases in recruitment and growth occurring in at least four of the eight stocks over the 1980s played a major role in the decline of these stocks. It is suggested that these changes are not a direct consequence of fishing mortality in the context of the ADAPT recreation of the population dynamics of these stocks.

Methods

Recruitment to age i in year t, $N_{i,t}$, was obtained from the ADAPT estimates of numbers at the beginning of year t for the earliest age given in each of the stock assessment reports cited in the introduction. i=3 at recruitment for all stocks except for the 4VsW, 4X and 5Zjm stocks where i=1 at recruitment.

Spawner biomass in year t was calculated from

$$S_t = \sum_{i=r}^{l} (N_{i,t} w_{i,t} p_{i,t})$$

where

S_t = beginning of year spawner biomass in year t
$N_{i,t}$ = number alive at age i at the beginning of year t
$w_{i,t}$ = weight at age i at the beginning of year t
$p_{i,t}$ = the proportion mature at age i at the beginning of year t
r = age at recruitment (r =1 or r =3)
I = terminal year in the ADAPT estimate (I =ranges from 9 to 15 for the different stocks considered).

Estimates of $p_{i,t}$ are only available for the 2J3KL (Shelton and Morgan 1994b) and 3NO (Shelton and Morgan 1994a) stocks. These estimates are from the fit of a generalized linear model with a logit link function to numbers of mature fish at age in DFO groundfish survey samples. Model estimates are for the fall in year t-1 when fish are age i-1. For the remaining stocks, the knife-edge age at maturity assumed in the assessments is used (range of first maturity from 3 to 7).

ADAPT assessments routinely include estimates of beginning of year weights at age $w_{i,t}$. These are estimated from the geometric mean of of average annual weights at age in the commercial catch, as described in Rivard (1982, p14). Weights at age are inferred from sample estimates of length at age by applying a year-invariant length-weight relationship.

The amount of recruitment required to replace the spawner stock in year t, Rep_t was calculated from

$$Rep_t = \frac{S_t}{\sum_{i=r}^{I} (\gamma_{i,t} w_{i,t} p_{i,t})}$$

where

$$\gamma_{i,t} = 1 \quad \text{for } i = r$$

and

$$\gamma_{i,t} = \prod_{k=r+1}^{i} (e^{-(F_{k-1,t}+M)}) \qquad \text{for } i > r.$$

$F_{i,t}$ is the ADAPT estimate of fishing mortality at age i in year t. M is the natural mortality rate, assumed to be equal to 0.2 in all cases, consistent with the assumption made in the assessments.

Replacement at F=0 is calculated as above but with all $F_{i,t}$ = 0;

Replacement per spawner = Rep_t / S_t

Spawner per recruit (SPR) = S_t / Rep_t

Results and Discussion

Recruitment (points) and the amount of recruitment required for replacement (line) (both in units of millions of recruits) are plotted against year in Fig. 1. In these plots the replacement level is influenced by the spawner biomass, annual values of weights-at-age and fishing mortality at age. For 2J3KL and 3NO stocks, annual values of maturity-at-age also play a role. In both of these stocks there is some evidence that proportions mature-at-age increased in late 1970s to a high around 1980 and then subsequently declined during the 1980s with some evidence of an increase again in the late 1980s-1990s (Shelton and Morgan 1994a, 1994b). In the six stocks for which data are available, the dip in the replacement level in about 1977 corresponds to the low spawner biomass at around that time. The subsequent increase in the amount of recruitment required for replacement reflects the increasing spawner biomass, decreasing weights-at-age and increasing fishing mortality that occurred. Concomitant with this increase in the amount of recruitment required for replacement was a decline in the amount of recruitment occurring in all stocks except the 5Zjm stock. The decline in the amount of recruitment required for replacement in most stocks in the 1990s reflects lower spawner biomass, decreased fishing mortality, and, in some cases, increased weights-at-age (and maturity-at-age in the 2J3KL and 3NO stocks) in recent years.

By setting fishing mortality to zero in the calculation of the replacement level, the effects of changes in spawner biomass and weights-at-age (as well as proportion mature-at-age for the 2J3KL and 3NO stocks) alone can be seen (Fig. 2). With the exception of the southernmost two stocks, it is apparent that recruitment was at a low level at the time (mid-80s) when the amount of recruitment required for replacement at F=0 was at or close to the highest level recorded. This was followed by an increase (varying in magnitude among stocks) in recruitment between 1985 and 1990 coinciding with a decline in the amount of recruitment required for replacement. In most of the stocks recruitment was at or near the lowest for the period under consideration by 1990 (4X is an exception).

By retaining F=0 and dividing through by the spawner biomass, only the effects of change in weight-at-age and, in the case of the 2J3KL and 3NO stocks, change in proportion mature at age remain as variables in the calculation of the amount of recruitment per spawner required for replacement (Fig. 3, units are fractions of a recruit per kg spawner biomass). In four of the stocks (2J3KL, 3NO, 3Pn4Rs and 4VsW) the replacement per spawner level declined over the mid to late 1970s to reach a low level in 1980 as a result of increasing weights-at-age. With the exception of the southernmost two stocks, all stocks showed generally increasing replacement per spawner from 1980 throughout the remainder of the 1980s as a result of decreasing weights-at-age. In several of the stocks there is a levelling off or dip in the replacement per spawner in the early 1990s as a result of a slight increase in the weights-at-age (and in 2J3Kl and 3NO, proportion mature-at-age).

The effect of changes in weights-at-age can perhaps be more easily recognised in a plot of spawner biomass per recruit (*SPR*, units of kg spawner biomass per recruit, Fig. 4). The peak in *SPR* around 1980 is a factor of about 2 or 3 higher than the subsequent trough in the 2J3KL, 3Pn4RS, 4TVn and 4VsW stocks (note, absolute values are not comparable between stocks with different ages at recruitment).

Conclusions

Within the assumptions of the ADAPT assessments and the calculations of replacement performed here, there are dramatic changes in the number of recruits required to replace the spawner biomass, or, conversely, the amount of spawner biomass obtained from an individual recruit These changes cannot be attributed directly to changes in fishing mortality, as demonstrated by setting $F=0$. Further, these changes are synchronous, hinging around 1980, in several of the stocks.

It is possible that accounting for annual changes in proportion mature-at-age for stocks in addition to 2J3KL and 3NO may alter this interpretation to some extent. Accounting for annual changes in the length-weight relationship may also have an effect. An analysis of the indirect effects of fishing mortality, for example on the commercial weight at age, would be of additional interest.

In retrospect, the sequence of events can be seen to have been most unfortunate. Extension of jurisdiction coincided with good recruitment and increasing weights at age. After 1980, while fishing mortality continued to increase, weights-at-age and recruitment fell and biomass declined. Slightly elevated recruitment in the mid-1980s in several stocks coincided with low weights-at-age and high levels of fishing mortality and did not ameliorate the decline to any significant extent. It seems unlikely that these events, parallelled in several of the stocks, can be attributed entirely to fishing.

References

Bishop, C.A., E.F. Murphy, M.B. Davis, J.W. Baird and G.A. Rose. 1993. An assessment of the cod stock in NAFO Divisions 2J+3KL. NAFO SCR Doc., No. 86, Serial No. N2271, 51p.

Bishop, C.A., E.F. Murphy and M.B. Davis. 1994. An assessment of the cod stock in NAFO Subdivision 3Ps. DFO Atl. Fish. Res. Doc. 94/33, 33p.

Davis, M.B., D. Stansbury, E.G. Murphy and C.A. Bishop, 1993. An assessment of the cod stock in NAFO Divisions 3NO. NAFO SCR Doc. No. 90, 38p.

Fréchet, A., Y. Gagnon, P. Schwab, D. D'Amours, J.D. Dutil, Y. Lambert, L. Bourassa and C. Rollet. 1994. Revue de l'état du stock de morue du nord du Golfe du Saint-Laurent, (3Pn,4RS) en 1993. DFO Atl. Fish. Res. Doc. 94/29, 50p.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. CAFSAC Res. Doc. 88/29, 12p.

Gavaris, S., D. Clark and P. Perley. 1994. Assessment of cod in Division 4X. DFO Atl. Fish. Res. Doc. 94/36, 29p.

Hunt, J.J. and M-I. Buzeta. 1994. Biological update of Georges Bank cod in Unit Areas 5Zj,m fo 1978-93. DFO Atl. Fish. Res. Doc. 94/30, 33p.

Mohn, R. and W.J. MacEachern. 1994. Assessment of 4VsW cod in 1993. DFO Atl. Fish. Res. Doc. 94/40, 37p.

Rivard, D. 1982. APL Programs for Stock Assessment. Can. Tech. Rep. Fish. Aquat. Sci. 1091, 146p.

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.

Shelton, P.A and A. Sinclair, A.F. 1995. Analysis of replacement levels in the southern Gulf cod stock. DFO Atl. Fish. Res. Doc. 95/40, 10p.

Sinclair, A., G. Chouinard, D. Swain, R. Hébert, G. Nielsen, 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.

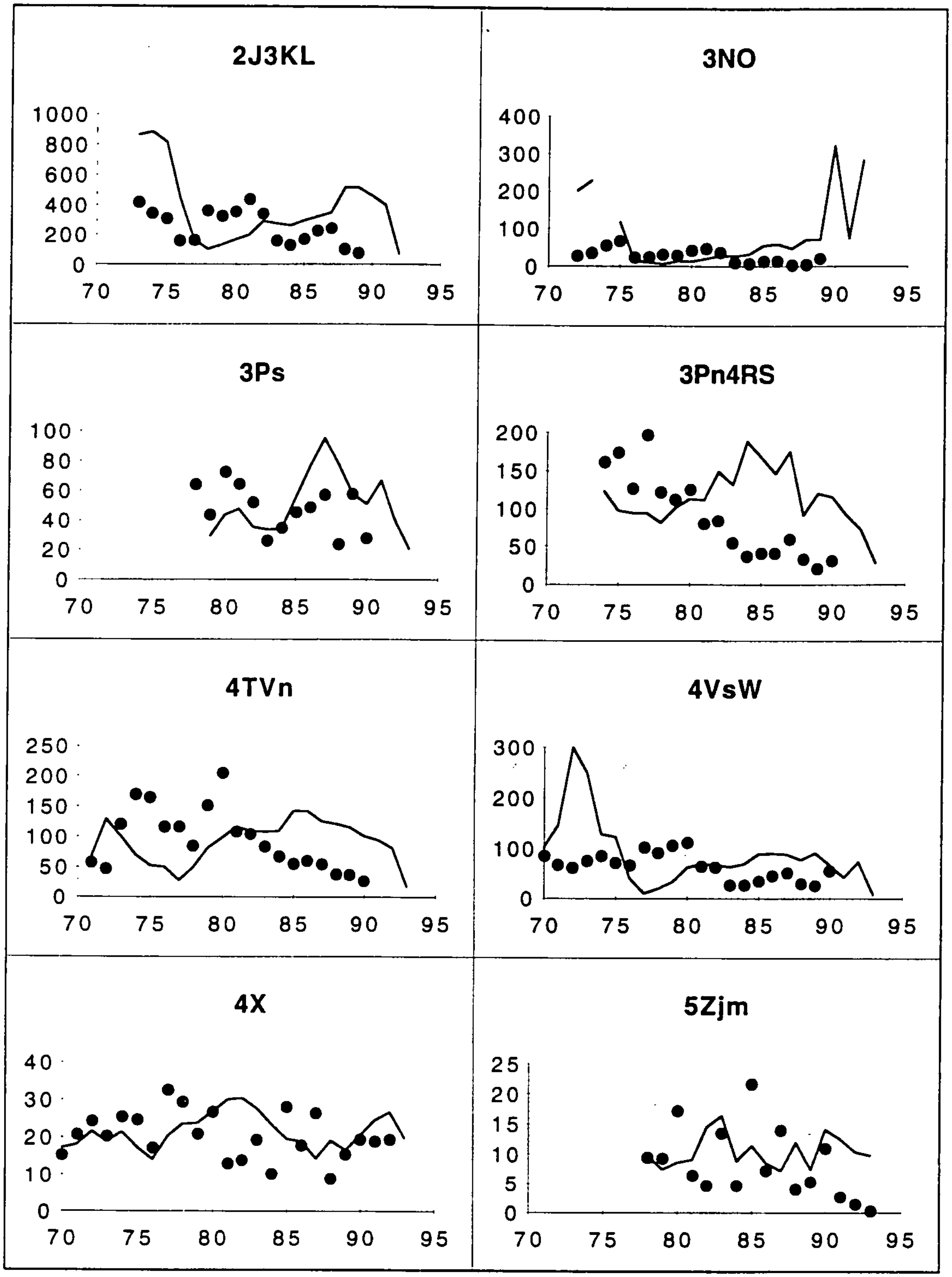

Fig. 1. Recruitment (points) and the amount of recruitment required for replacement (line) in units of millions of recruits plotted against year for eight cod stocks. ADAPT estimates of the annual fishing mortality at age are used in the calculations.

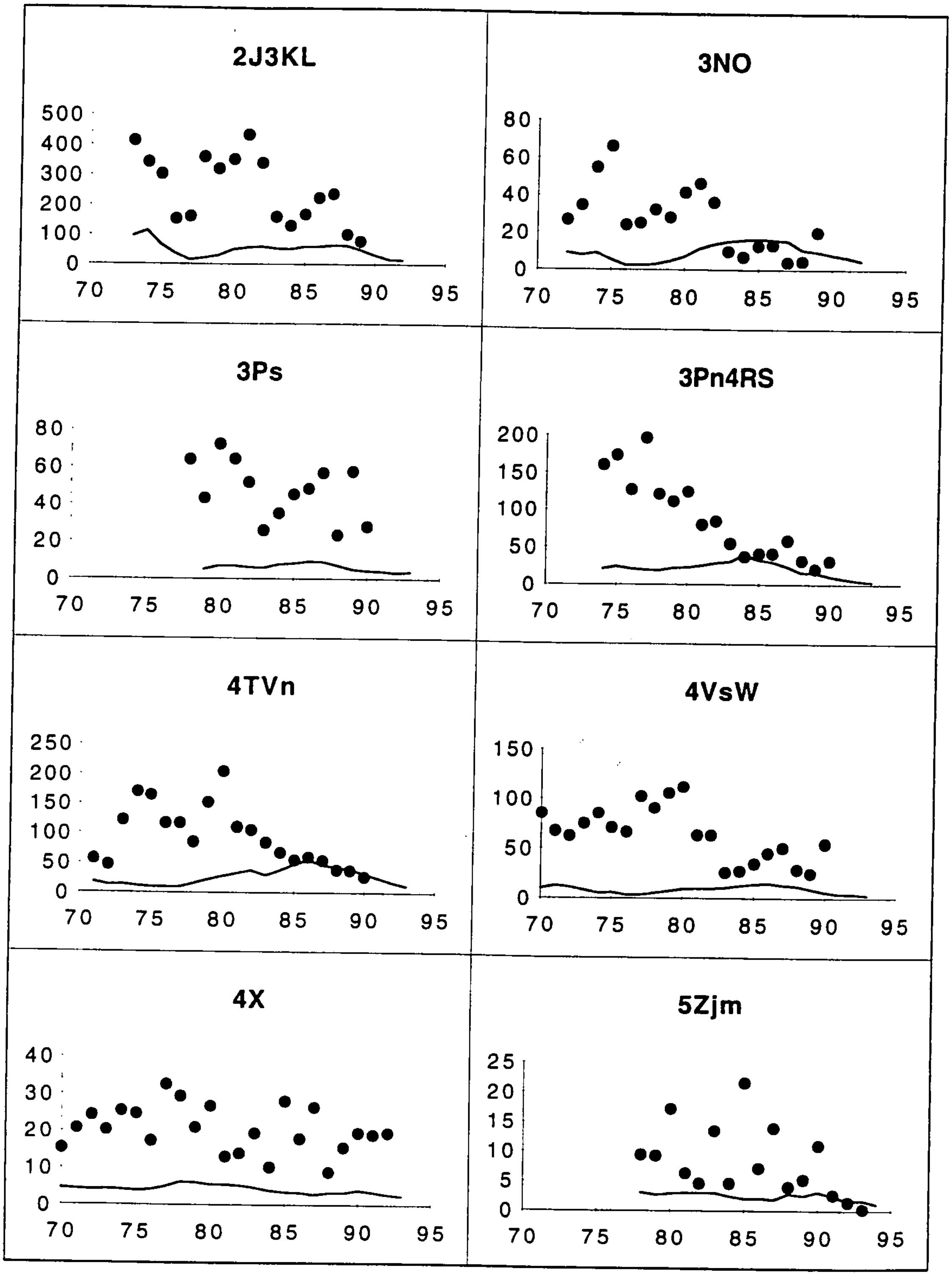

Fig. 2. Recruitment (points) and the amount of recruitment required for replacement (line) in units of millions of recruits calculated at F=0, plotted against year for eight cod stocks.

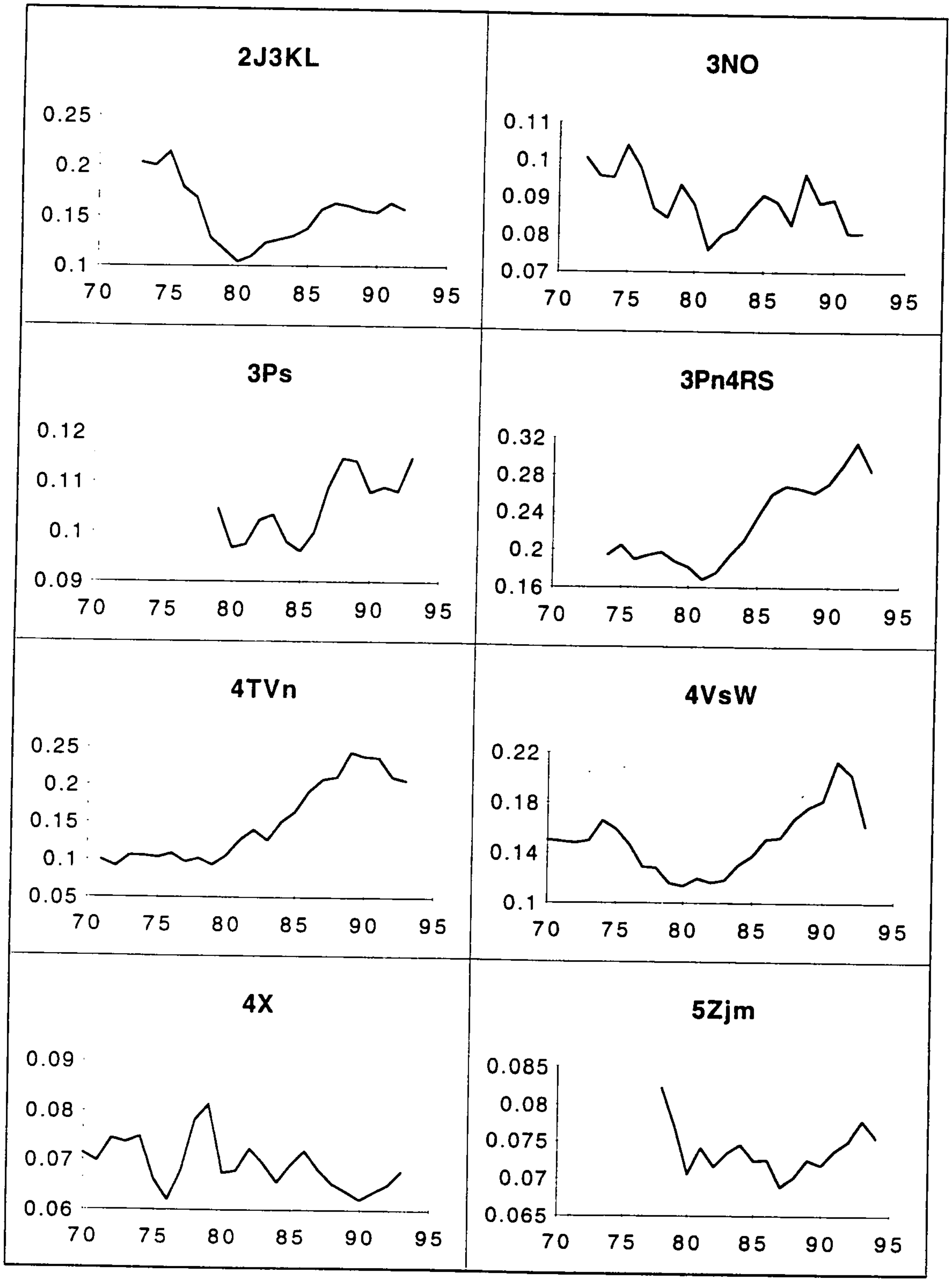

Fig. 3. Replacement per spawner (units of fractions of a recruit per kg spawner biomass) calculated at F=0, plotted against year for eight cod stocks.

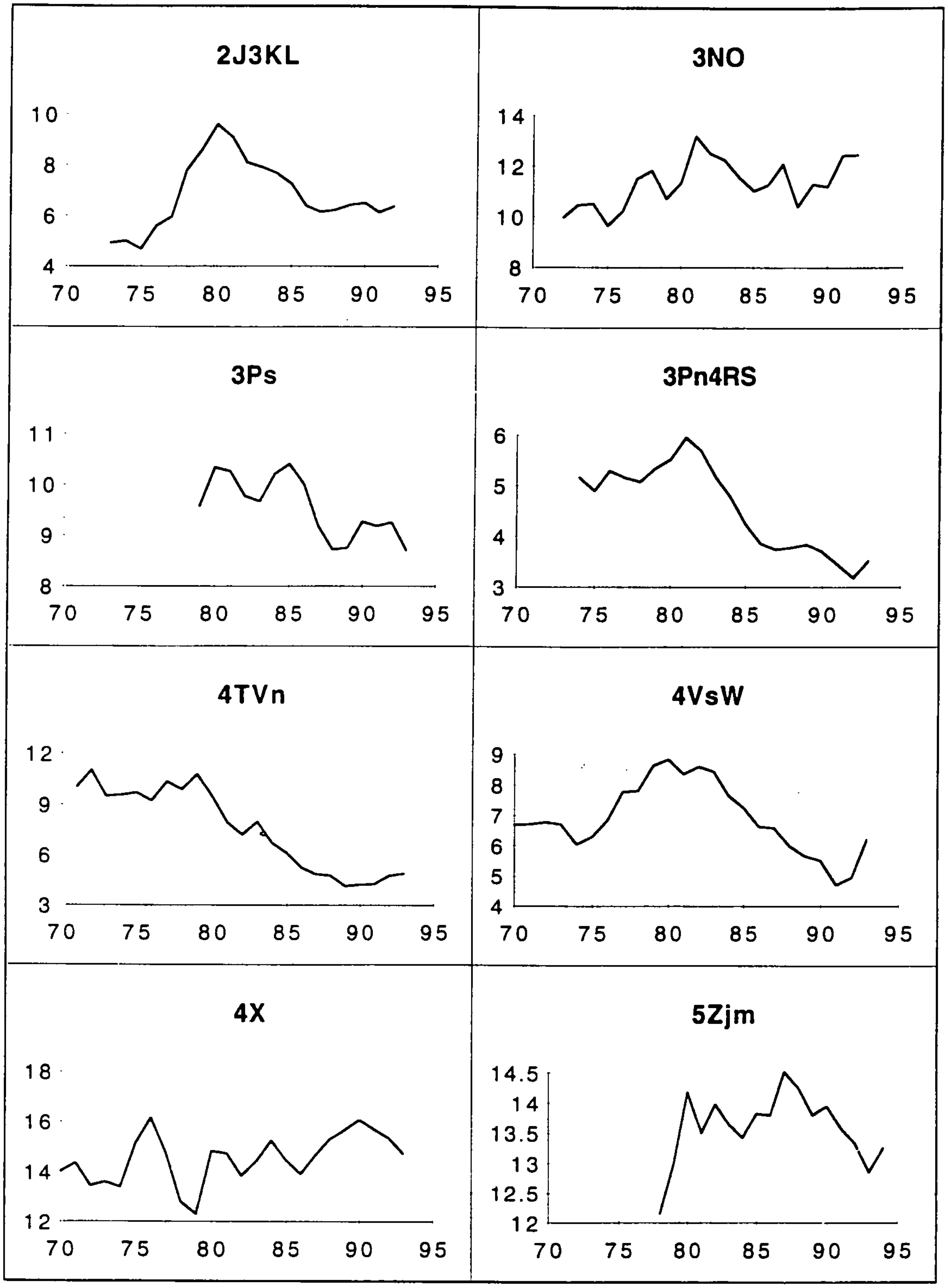

Fig. 4. Spawner per recruit (units of kg spawner biomass per recruit) calculated at F=0, plotted against year for eight cod stocks.