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Northern cod recruitment before, during and after collapse

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Abstract

We show that clear recruitment signals are present in the research vessel and commercial catch at age data for northern cod from extension of jurisdiction to moratorium. There have been three main periods of strong recruitment, preceded and followed by brief periods of much lower recruitment. SPA provides good model fits to the first two pulses but is unable to reconcile survey and catch data with respect to the third pulse, under standard assumptions. In this research document we use a diagnostic formulation that estimates unaccounted for deaths in the early 1990s to evaluate recruitment before and during the collapse. We reconstruct a relative recruitment strength series for the post-collapse period from a number of indices using an iterative reweighting procedure. Recruitment has decreased with the decline in spawner biomass and has been particularly low since the collapse.

Résumé

Les auteurs montrent qu'il existe des signes clairs de recrutement dans les données des prises selon l'âge des navires de recherche et des prises commerciales de morue du nord depuis l'extension de la limite territoriale à la mise en œuvre du moratoire. Il y a eu 3 principales périodes de recrutement élevé, lesquelles ont été précédées et suivies de courtes périodes de recrutement marginal. L'ASP donne un bon étalonnage du modèle dans le cas des deux premières poussées, mais est incapable de réconcilier les données de relevé et les données sur les prises dans le cas de la troisième poussée lorsque les hypothèses courantes sont appliquées. Les auteurs utilisent dans le présent document de recherche une formule de diagnostic pour estimer la mortalité non comptabilisée au début des années 90 afin d'évaluer le recrutement avant et pendant l'effondrement des stocks. Ils reconstituent une série de degrés de recrutement relatif pour la période post-effondrement à l'aide de divers indices en utilisant une procédure de repondération itérative, ce qui leur a permis de déterminer que le recrutement a diminué avec le déclin de la biomasse de reproducteurs et qu'il est particulièrement faible depuis l'effondrement des stocks.

Introduction

In this working paper we show that clear recruitment signals are present in the research vessel and commercial catch at age data for northern cod from extension of jurisdiction to moratorium. There have been three main periods of strong recruitment, preceded and followed by brief periods of much lower recruitment. SPA provides good model fits to the first two pulses but is unable to reconcile survey and catch data with respect to the third pulse. There are three possible explanations: (i) the assumption that catches are reported with minimal error and that ages are assigned without error does not hold; (ii) the assumption of age-independent year-invariant instantaneous rate of natural mortality of 0.2 does not hold; or (iii) the assumption of age-dependent year-invariant survey catchability does not hold. (i) and (ii) can be grouped as "unaccounted for deaths". Shelton and Lilly (2000) have explored the magnitude of the departures from the standard assumptions that are required to remove the pattern in the northern cod SPA residuals. In this working paper we use a diagnostic formulation from Shelton and Lilly (2000) that estimates unaccounted for death in the early 1990s to evaluate recruitment before and during the collapse. With the change-over from the Engel groundfish trawl to the Campelen shrimp trawl in the fall research vessel surveys from 1995 onwards, and the sparse catch at age data from 1993 onwards, SPAs for the recent period are unreliable. We therefore reconstruct a relative recruitment strength series for the post-collapse period from a number of indices using an iterative reweighting procedure.

Methods

Simple measure of yearclass strength

A simple measure of yearclass presence was computed from survey and catch data. It was assumed that commercial catch of fish aged a in year y, $C_{a,y}$ is proportional to the number of fish aged a in year y, $N_{a,y}$ through a time-invariant age-specific proportionality constant g_a which encompasses both fishing effort and catchability by commercial gear. Similarly the mean number per tow of fish aged a in the random stratified research vessel survey index in year y, $RV_{a,y}$ was assumed to be proportional to $N_{a,y}$ through a time-invariant age-specific catchability constant q_a. While this assumption is reasonable and common for survey data, changes in the total allowable catch, the amount of fishing effort and the availability of fish in fishing areas violates the proportionality assumption in the case of the commercial catch. Nevertheless, it may provide a basic measure of the relative abundance of fish, providing the departure from these assumptions are not too severe.

The average presence of yearclasses of fish in the commercial fishery and the research vessel survey, $\overline{C}_c$ and $\overline{RV}_c$ were calculated over the lifetime of each cohort from age 2 to 13 after standardizing each $C_{a,y,c}$ and $RV_{a,y,c}$ (the catch and survey index respectively for cohort c at age a in year y) by the average value for that age, $\overline{C}_a$ and $\overline{RV}_a$. Results were plotted for yearclasses 1970 to 1990. A drawback of this approach is that younger fish are not in the data for the early cohorts and older fish are not in the data for recent cohorts.

SPA on data prior to the moratorium

The population was modeled in the SPA by

$$N_{a+1,y+1} = ((N_{a,y} e^{(-M/2)}) - C_{a,y}) e^{(-M/2)} ,$$

where $N_{a,y}$ is the number alive at the beginning of age a and the beginning of year y, $C_{a,y}$ is the catch in number of age a in year y, assumed taken in mid-year, M is the annual instantaneous rate of natural mortality, assumed to be 0.2, a = 2 to 13 and y = 1962 to 1994. Research vessel survey mean numbers per tow at age, $RV_{a,y}$ from the fall groundfish bottom trawl survey for a = 2 to 13 and y = 1978 to 1994 were used to "calibrate" the model using the ADAPT framework (Gavaris 1988). The objective function sums of squares, SS, that was minimized is

$$SS = \sum_{a,y} (\log(RV_{a,y}) - \log(q_a N_{a,y}))^2 ,$$

where q_a is a vector of catchability parameters to be estimated. The vector of survivors in the last year, $N_{a,1994}$ were also treated as parameters that must be estimated. A constraint was placed on the fishing mortality on the oldest age, $F_{13,y}$ so that

$$F_{13,y} = (F_{9,y} + F_{10,y} + F_{11,y} + F_{12,y}) / 4 ,$$

where $F_{a,y} = -\log\left(\frac{(N_{a,y} \exp^{(-M/2)} - C_{a,y})}{(N_{a,y} \exp^{(-M/2)})} \right)$.

This model was fit to the data taken from Shelton et al. (1996) and Bishop et al. (1993) to provide a base case for comparison with the results from diagnostic analyses which attempt to determine the departures required from assumptions regarding M, $C_{a,y}$ and $q_{a,y}$ to achieve a consistent interpretation of catch and survey data within the SPA.

While violations of the assumptions regarding natural mortality and catch reporting can both provide explanations for the lack of model fit, in practice it is not easy to distinguish between them without additional information. In the diagnostic analyses departures from both these assumptions were evaluated treating "missing fish" over some years and ages as catch to be estimated from the survey and remaining catch data. The missing fish model is

$$N_{a+1,y+1} = ((N_{a,y} e^{(-M/2)}) - C'_{a,y}) e^{(-M/2)} ,$$

where $C'_{a,y}$ is a matrix of parameters representing missing fish to be estimated. It is not feasible to estimate the entire matrix. Instead, through trial and error, a block of cells was chosen so as to provide the smallest departure from the assumptions required in order to allow a reasonably consistent interpretation of survey and catch data in the SPA. The remaining catch matrix remained unaltered from that used in the base model.

Analysis of post-collapse indices

The indices of recruitment for the post-collapse period that were evaluated to determine post-collapse recruitment are given in Table 1. A total of 11 surveys (maximum age = 3) were included in the analysis. Data for age 0 from the research vessel surveys in the inshore and offshore were removed. Total number of survey age indices considered in the analysis were 28. Data for the Flemming survey are from Methven et al. (1998); pelagic 0-group data are from Anderson et al. (1999); research vessel bottom trawl survey data are from Lilly et al. (1999); sentinel data are from Maddock Parsons (DFO Science, Newfoundland Region); and squid trap data are from Dalley and Dawe (DFO Science, Newfoundland Region); Demersal inshore and offshore from Dalley and Anderson (1997). An iterative reweighting multiplicative model was fitted to survey at age indices to removes survey and age effects and thereby reveal the yearclass strength signal:

$$I_{say} = q_{s,a}N_{o,y} ,$$

where I_{say} is the index for survey s at age a in year y, q is the catchability parameter for the survey index at age, and N_0 is the yearclass effect. The weighting factor is the reciprocal of the variance for each survey age index. To prevent one indices from capturing all the weight, indices were ranked by their variances and the top 1/3 of the indices were assigned the variance of lowest index in the top third. All other indices weightings were $1/\text{variance}_{sa}$. The weighting values were also standardized for each iteration to sum to 10. The values of 1/3 for a cut off and the sum of the weights equal to 10 are arbitrary.

Results and discussion

Historical recruitment

Survey and catch at age data are in close agreement regarding relative yearclass strength and indicate 3 periods of strong recruitment since the 1970 yearclass, separated by brief periods of low recruitment (Fig. 1). The SPA has no problem resolving the survey and catch information relating to the first two periods of strong recruitment, however survey data over the third period of strong recruitment (1986 and 1987 yearclasses) can only be explained by substantial unreported deaths due to fishing or natural morality (missing fish) or by a change in survey catchability (q) over the period of the early 1990s (Shelton and Lilly 2000, Fig. 2). The missing fish model required there to be substantial unreported deaths in the early 1990s. Although there is some indication that the increase in foreign fishing effort on the remaining offshore cod aggregations in the late 1980s and early 1990s, including the arrival of between 30 and 40 Spanish factory freezer trawlers expelled from Namibia, may have been responsible for a substantial portion of these deaths, there are no data at present to prove this. Reanalysis of surveillance records on the activities of foreign vessels may provide more information.

There are no substantial differences between using spawner biomass less than age 14 or spawner biomass less than age 21 (Fig. 3). Both series suggest a decrease from about 1.4 million tons of spawners in the early 1960s to less than 160,000 t at extension of jurisdiction in 1977, a recovery to a post-extension of jurisdiction peak of about 450,000 t in 1981, a period of relative stability through the 1980s and a rapid collapse thereafter. In contrast, the biomass of fish aged 10 years and older declined rapidly in the 1960s and showed no subsequent recovery. The northern cod stock therefore essentially collapsed through overfishing prior to extension of jurisdiction to 200 miles in 1977 (from nearly 3 million tons total biomass in early 1960s to about 0.5 million tons at extension of jurisdiction, (Fig. 4). Following extension of jurisdiction, the stock went through a partial recovery as a consequence of smaller catches, entry of the strong 1973-1975 year-classes and an increase in the growth rate of individual fish. However, this recovery was cut short as a consequence of rapidly increasing exploitation by the expanding Canadian trawler fleet, combined with weak 1976 and 1977 year classes and lower individual growth rates. The 1978-1982 year-classes were moderately strong but the 1983-1985 year-classes were weak. The age 2+ biomass is estimated to have peaked in 1984 and then began to decline.

Shelton and Lilly (2000) suggest that this decline became precipitous in the early 1990s as a consequence of a dramatic increase in foreign fishing effort in the stock area outside 200 miles superimposed on the high levels of domestic fishing in both the inshore and offshore. The reliability of reported catches over this period are very poor. The SPA that allows for substantial unaccounted for deaths in the early 1990s gives recruitment estimates which suggest that the 1987, and to a lesser extent the1986 yearclass were strong (Fig. 5). In terms of R/S, the recruitment rate is slightly higher than that observed in 1978 (Fig. 6) a time when the spawner biomass was also low. Although the second and third recruitment pulses therefore have some common characteristics, the third pulse co-occurred with high levels of fishing effort, particularly in the offshore. It seems likely that had the F0.1 TAC levels recommended by the Groundfish Subcommittee in 1988 and 1989 (Bishop and Shelton 1997) been adopted and foreign fishing effort curtailed, the final collapse of the northern cod stock may have been averted (Shelton 1998).

Recruitment levels in the 1970s and 1980s (with the exception of 1987) were lower than those estimated in the early to mid 1960s. Reduced levels of recruitment are consistent with the much lower spawner biomass as well as the virtual elimination of spawners age 10 and older by the time of extension of jurisdiction. Even though spawner biomass was much lower, and the older fish had been removed from the population, substantial recruitment rates were observed around the time of extension of jurisdiction, fuelling the partial recovery of the 1980s. If the SPA that assumes substantial unaccounted for deaths in the early 1990s is correct, then 1987 yearclass, and to a lesser extent the 1986 yearclass, were also the result of very high recruitment rates. The decline in recruitment with spawner biomass is fairly linear with the exception of the 1987 yearclass (Fig. 7) – showing no evidence of compensation within the time period for which estimates are available. Consequently one could surmise that spawner biomass had declined from virgin levels somewhat in excess of 1.5 million tons before the commencement of the collection of catch at age data.

Recent recruitment

A total of 11 surveys with data for cod aged 0 – 3 were evaluated in the model for obtaining a relative recruitment timeseries for the 1990s (Table 1). Reweighting was stopped after 7 iterations (Table 2). Indices with higher weights are more internally consistent and more influential in the estimation of relative yearclass strength than indices with low weightings. The sums of squares and associated significance levels for the yearclass and index effects are given in Table 3 and the and the estimates of yearclass strength parameters in Table 4. The residuals from the model fit are illustrated in Fig. 8. Estimates of yearclass strength suggest very low levels of recruitment with little year-to-year variation from 1990 to 1997, followed by a possible increase (Fig. 9). There is considerable uncertainty associated with the most recent estimates of yearclass strength because these yearclasses have only been observed in the last year or two. The relatively weak 1996 yearclass – a consistent feature of most of the indices, may be expected to have considerable negative impact on spawner biomass recovery.

Conclusion

Three pulses of stronger recruitment arose over the period 1970 to 1990. The second of these pulses fueled the partial recovery that took place after extension of jurisdiction. There is uncertainty regarding the third of these pulses. Although both the survey and the catch data indicate that the 1986 and 1987 yearclasses were stronger than those that occurred just previously or just subsequent, the SPA model cannot resolve the rate at which these yearclasses declined in the survey from the reported catch data alone. If the estimated number of missing fish are supplied to the model, then it would appear that recruitment rates in 1986 and particularly in 1987, were strong. Overall, there has been a decline of recruitment with spawner biomass. The age composition of the spawner biomass has changed substantially over the time period from the early 1960s with fish age 10 and older becoming extremely scarce over the last 20 years. Subsequent to the 1986 and 1987 yearclasses, recruitment has been extremely weak. Recovery of the northern cod stock would require a succession of relatively strong yearclasses arising as a consequence of favourable environmental conditions from a severely depleted spawner biomass.

References

Anderson, J.T., Dalley, E.L. and Davis, D.J. 1999. Year-class strength of northern cod (2J3KL) and southern Grand Bank cod (3NO) estimated from the pelagic juvenile fish survey in 1999. DFO Can. Stock. Assess. Sec. Res. Doc. 99/80.

Bishop, C.A., Murphy, E.F., Davis, M.B., Baird, J.W., and Rose, G.A.. 1993. An assessment of the cod stock in NAFO Divisions 2J+3K. NAFO SCR Doc. 93/86.

Bishop, C.A., and Shelton, P.A. 1997. A narrative of NAFO 2J3KL cod assessments from extension of jurisdiction to moratorium. Can. Tech. Rep. Fish. Aquat. Sci. 2199.

Dalley, , E.L. and Anderson, J.T. 1997. Age-dependent distribution of demersal juvenile Altlantic cod (*Gadus morhua*) in inshore/offshore northeast Newfoundland. Can. J. Fish. Aquat. Sci. (Suppl. 1):168-176.

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

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, N., Murphy, E.F., and Stansbury D.E. 1999. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO Can. Stock. Assess. Sec. Res. Doc. 99/42.

Methven, D.A., Schneider, D.C., Ings, D.W. and Davis, M.B. 1998. Results of the 1997 Flemming survey of demersal juvenile cod in the coastal zone of eastern Newfoundland. DFO Can. Stock. Assess. Sec. Res. Doc. 98/77.

Shelton, P.A. 1998. A comparison between a fixed and a variable fishing mortality control rule used to manage the cod stock off southern Labrador and the east coast of Newfoundland. Fisheries Research **37**: 275-286.

Shelton, P.A. and Lilly, G.R. 2000. Interpreting the collapse of the northern cod stock from survey and catch data. Can. J. Fish. Aquat. Sci. **57**:2230-2239.

Shelton, P.A., Stansbury, D.E., Murphy, E.F., Lilly, G.R., Brattey, J. 1996. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO Atl. Fish. Res. Doc. 96/80.

Table 1. Indices of cod abundance age 0 – 3 analysed in the multiplicative model to estimate relative yearclass strength for the recent period.

SURVEY	AGE	YCLASS 1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
fleming	0	.	.	.	9.5	9.1	19.7	13.2	6.7	21.9	.	.
	1	.	.	3.9	10.2	16.4	1.1	2.4	1.6	.	.	.
	2	.	0.3	0.2	0.9	0.2	0.5	0.7	.	.	.	.
O group inshore	0	.	.	.	.	.	18.0	16.9	3.9	7.5	9.4	54.6
O group offshore	0	.	.	.	.	.	19.9	4.8	1.4	4.0	20.9	31.9
RV inshore	1	.	.	.	.	.	.	6.0	2.0	0.4	.	.
	2	.	.	.	.	.	3.6	1.8	3.1	.	.	.
	3	.	.	.	.	1.6	1.1	1.3	.	.	.	.
RV offshore	0	.	.	.	.	.	.	.	0.0	0.0	0.2	0.2
	1	.	.	.	.	.	.	0.4	0.1	0.5	0.7	.
	2	.	.	.	.	.	1.4	0.7	0.4	1.7	.	.
	3	.	.	.	.	0.9	0.9	0.6	1.6	.	.	.
Squid trap	0	.	.	0.4	0.2	1.4	1.0	.	.	.	.	.
	1	.	22.5	43.1	57.8	35.3	.	.	.	.	.	.
	2	11.3	154	125	37.4	.	.	.	.	.	.	.
	3	89.4	79.9	20.7	.	.	.	.	.	.	.	.
Sentinel 5.5 Fixed	3	.	.	.	0.0	0.0	0.0	0.0	0.0	.	.	.
Sentinel LT Fixed	3	.	.	.	0.8	1.9	1.5	1.7	0.9	.	.	.
Sentinel 3.25	2	.	.	.	.	.	0.0	0.0	0.0	0.3	.	.
	3	.	.	.	.	5.4	6.5	5.4	6.7	.	.	.
Demersal inshore	0	.	.	.	7.3	14.4	60.0	19.0	.	.	.	.
	1	.	.	34.2	83.7	136	47.4	.	.	.	.	.
	2	.	54.1	5.2	39.9	12.9	.	.	.	.	.	.
	3	7.7	0.5	0.8	0.7	.	.	.	.	.	.	.
demersal offshore	0	.	.	.	0.0	0.0	0.1	0.1	.	.	.	.
	1	.	.	1.2	1.0	3.1	4.3	.	.	.	.	.
	2	.	7.3	7.7	6.7	2.9	.	.	.	.	.	.
	3	5.6	4.9	1.2	2.3	.	.	.	.	.	.	.

Table 2. Ranking of recruitment estimates from the iterative reweighting procedure after run 7.

10.0000

run number 7 22:32 Thursday, March 23, 2000 9

OBS	_TYPE_	_FREQ_	SUMWGT	CEIL	SURVEY	AGE	MEAN2	MEANR	WEIGHT	RANK
1	3	4	147.049	0.093308	demersal offshore	3	0.02479	-1.4301E-14	0.7288	1
2	3	3	147.049	0.093308	Squid trap	3	0.02672	-2.9606E-16	0.7288	2
3	3	6	147.049	0.093308	fleming	0	0.03374	1.07322E-15	0.7288	3
4	3	5	147.049	0.093308	Sentinel LT Fixed	3	0.04385	-4.1356E-16	0.7288	4
5	3	4	147.049	0.093308	demersal offshore	0	0.06047	1.33227E-15	0.7288	5
6	3	4	147.049	0.093308	RV offshore	2	0.07368	4.16334E-16	0.7288	6
7	3	4	147.049	0.093308	Sentinel 3.25	3	0.07707	-1.6653E-16	0.7288	7
8	3	4	147.049	0.093308	demersal offshore	1	0.08205	4.16334E-17	0.7288	8
9	3	3	147.049	0.093308	RV inshore	3	0.09331	9.25186E-16	0.7288	9
10	3	4	147.049	0.093308	RV offshore	0	0.09791	-6.6613E-16	0.6945	10
11	3	3	147.049	0.093308	RV inshore	2	0.15070	-8.1416E-16	0.4513	11
12	3	4	147.049	0.093308	Demersal inshore	0	0.24205	7.77156E-16	0.2809	12
13	3	4	147.049	0.093308	RV offshore	3	0.28866	-3.3307E-16	0.2356	13
14	3	4	147.049	0.093308	Demersal inshore	1	0.32990	-7.7716E-16	0.2061	14
15	3	4	147.049	0.093308	RV offshore	1	0.37077	-4.1633E-16	0.1834	15
16	3	4	147.049	0.093308	demersal offshore	2	0.40778	9.4369E-16	0.1668	16
17	3	6	147.049	0.093308	O group offshore	0	0.41230	-6.6613E-16	0.1649	17
18	3	6	147.049	0.093308	fleming	2	0.41316	-2.0354E-16	0.1646	18
19	3	4	147.049	0.093308	Squid trap	0	0.42445	-1.55E-15	0.1602	19
20	3	4	147.049	0.093308	Squid trap	1	0.45449	-2.2204E-16	0.1496	20
21	3	6	147.049	0.093308	O group inshore	0	0.52724	9.62193E-16	0.1290	21
22	3	4	147.049	0.093308	Demersal inshore	2	0.56333	-1.7208E-15	0.1207	22
23	3	4	147.049	0.093308	Demersal inshore	3	0.71214	-1.0339E-15	0.0955	23
24	3	4	147.049	0.093308	Sentinel 3.25	2	1.08147	-2.609E-15	0.0629	24
25	3	5	147.049	0.093308	Sentinel 5.5 Fixed	3	1.28771	1.59872E-15	0.0528	25
26	3	6	147.049	0.093308	fleming	1	1.30383	-4.0708E-16	0.0522	26
27	3	4	147.049	0.093308	Squid trap	2	1.91307	-4.4409E-16	0.0355	27
28	3	3	147.049	0.093308	RV inshore	1	1.99920	-1.0362E-15	0.0340	28
									=======	
									10.0000	

Table 3. Sums of squares and signficance levels for the yearclass and index type effects from the iteratively reweighted multiplicative model.

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                                General Linear Models Procedure
                                    Class Level Information

Class     Levels    Values

YCLASS        11    1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999

SA            28    a0 a1 a2 b0 c0 d1 d2 d3 e0 e1 e2 e3 g0 g1 g2 g3 h3 j3 k2 k3 l0 l1 l2 l3 m0
                    m1 m2 m3

                            Number of observations in data set = 120


NOTE: Due to missing values, only 119 observations can be used in this analysis.


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                                General Linear Models Procedure

Dependent Variable: LOGEST
Weight:             WEIGHT

Source                  DF           Sum of Squares           Mean Square   F Value     Pr > F

Model                   37             159.07146117            4.29922868     48.84     0.0001

Error                   81               7.13027430            0.08802808

Corrected Total        118             166.20173546

                  R-Square                     C.V.              Root MSE          LOGEST Mean

                  0.957099                 37.57191            0.29669526           0.78967307


Source                  DF                Type I SS           Mean Square   F Value     Pr > F

YCLASS                  10              20.18077250            2.01807725     22.93     0.0001
SA                      27             138.89068866            5.14409958     58.44     0.0001

Source                  DF              Type III SS           Mean Square   F Value     Pr > F

YCLASS                  10               7.55123137            0.75512314      8.58     0.0001
SA                      27             138.89068866            5.14409958     58.44     0.0001
```

Table 4. Estimates of yearclass strength effects in the iteratively reweighted multiplicative model, together with standard errors of the estimates.

General Linear Models Procedure
Least Squares Means

YCLASS	LOGEST LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0
1989	1.24449762	0.31438951	0.0002
1990	0.90132710	0.26295608	0.0010
1991	-0.05108900	0.20650788	0.8052
1992	0.25958052	0.15222833	0.0920
1993	0.69401890	0.14597515	0.0001
1994	1.06260221	0.13809253	0.0001
1995	0.79747404	0.14733363	0.0001
1996	0.38463021	0.17231087	0.0284
1997	1.26259925	0.22687159	0.0001
1998	2.41733575	0.36965650	0.0001
1999	2.92891422	0.40640840	0.0001

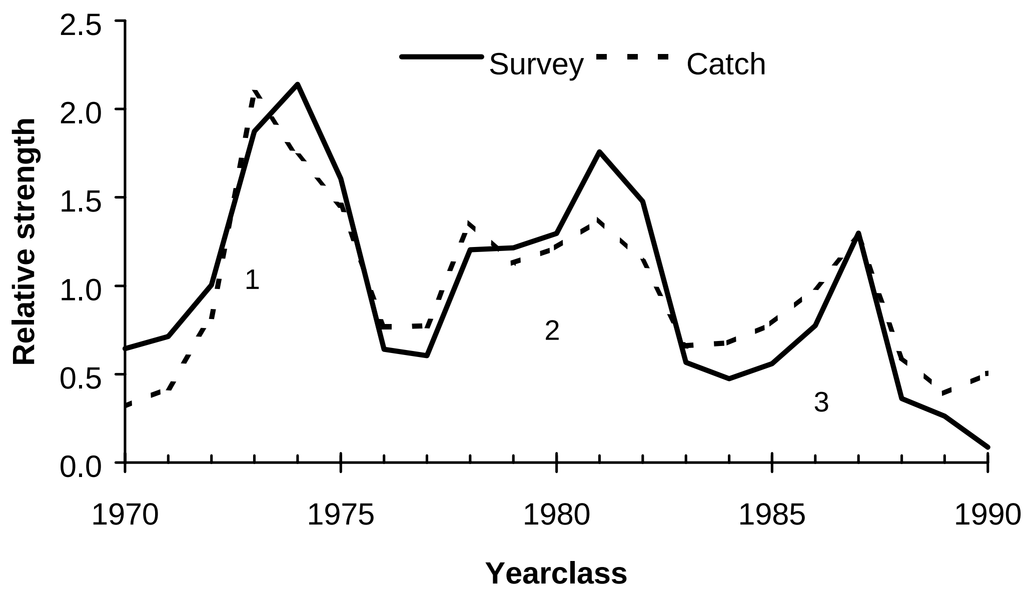

Fig. 1. A simple measure of relative yearclass strength from survey and catch data showing three pulses of strong recruitment between the 1970 and 1990 yearclasses.

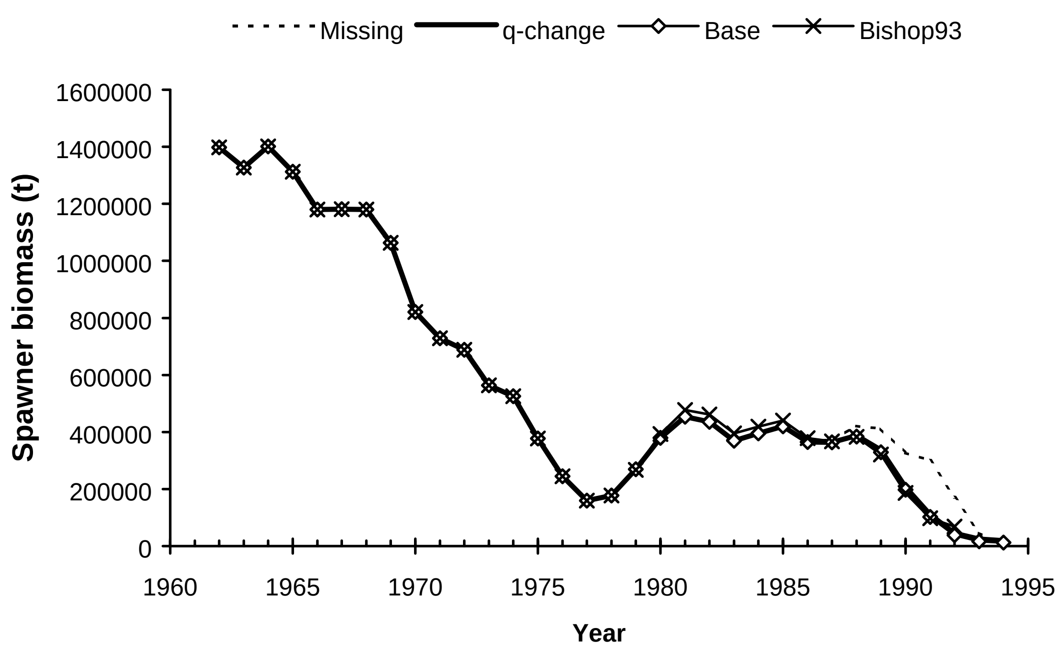

Fig. 2. Spawner biomass estimates from the last analytical assessment (Bishop et al. 1993), a base model fitted to data up to 1994, a change in *q* model and a missing fish model.

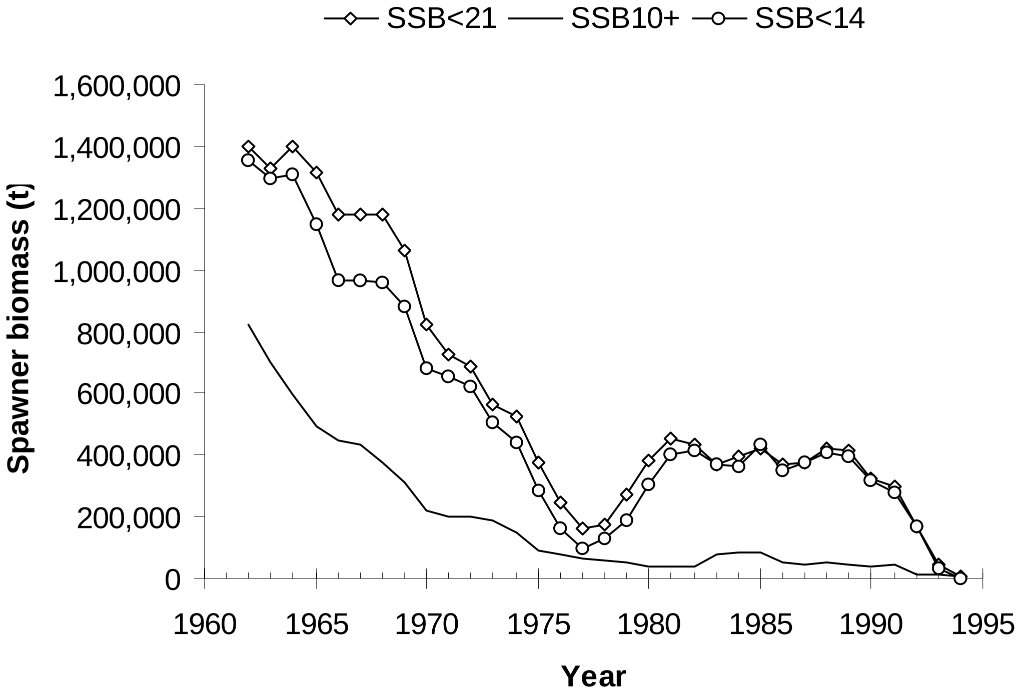

Fig. 3. Estimates of spawner biomass from the missing fish model computed to age 13 and age 20 compared with the biomass of fish aged 10 and older.

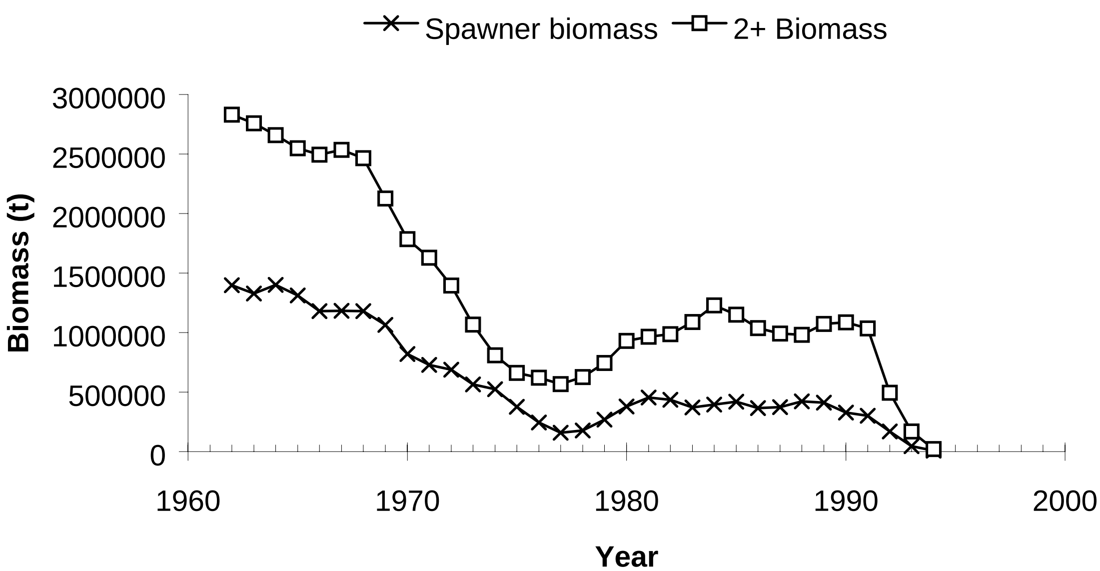

Fig. 4. Estimates spawner biomass and 2+ biomass from the missing fish model showing the decline from about 3 million tons in the early 1960s.

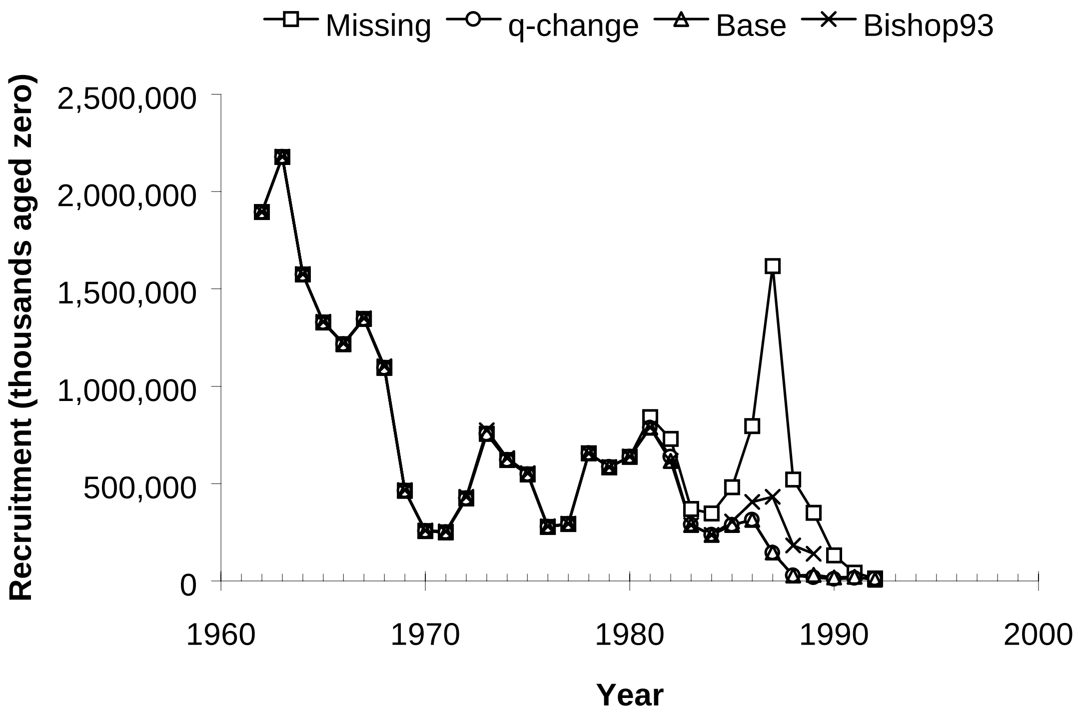

Fig. 5. Estimates of recruitment from the missing cod SPA compared to the *q*-change, base and Bishop et al. (1993) estimates.

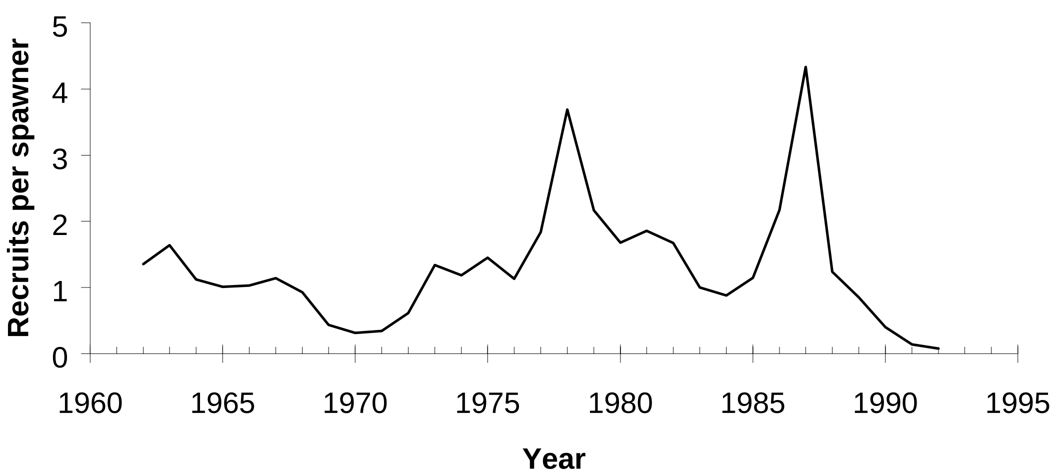

Fig. 6. Plot of recruitment in thousands of 0-year olds divided by spawner biomass in tons (R/S or recruitment rate). The two spikes are associated with the second and third recruitment pulses. The first pulse was associated with relatively high spawner biomass so does not appear as a peak.

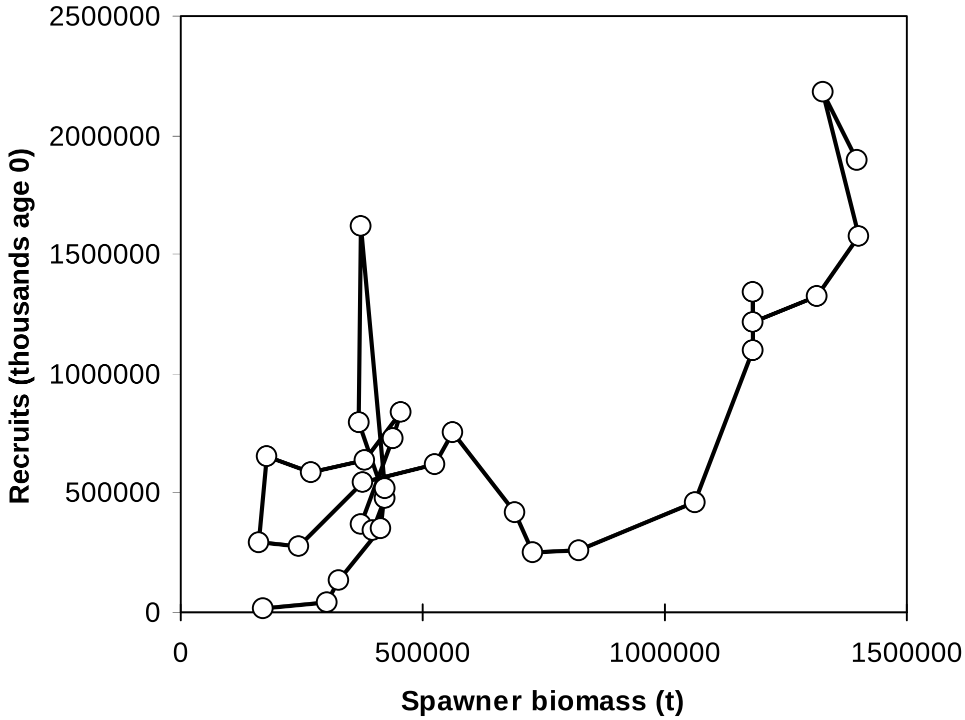

Fig. 7. Stock-recruit trajectory estimated by the missing cod SPA.

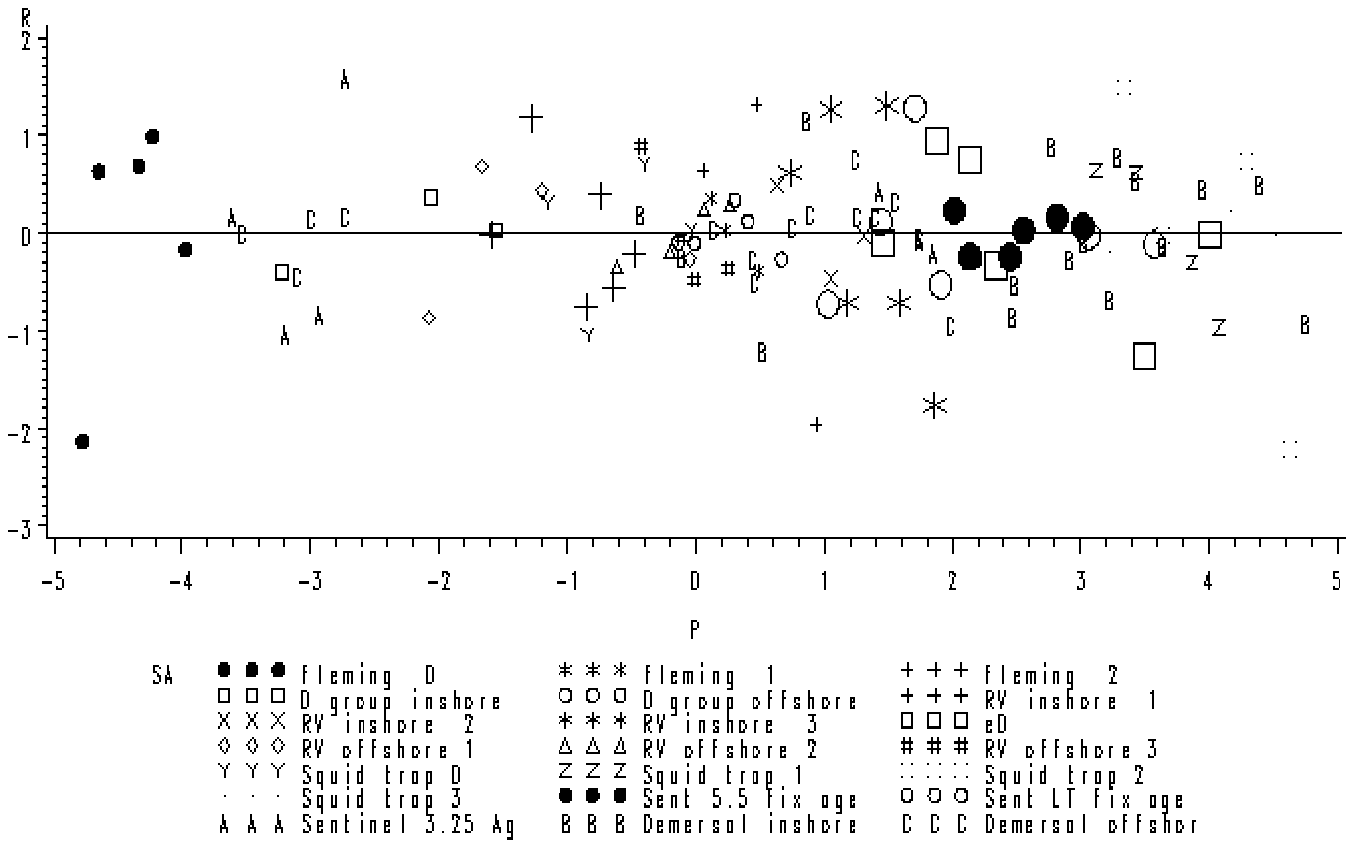

Fig. 8. Residuals from the model fit to the indices of yearclass strength.

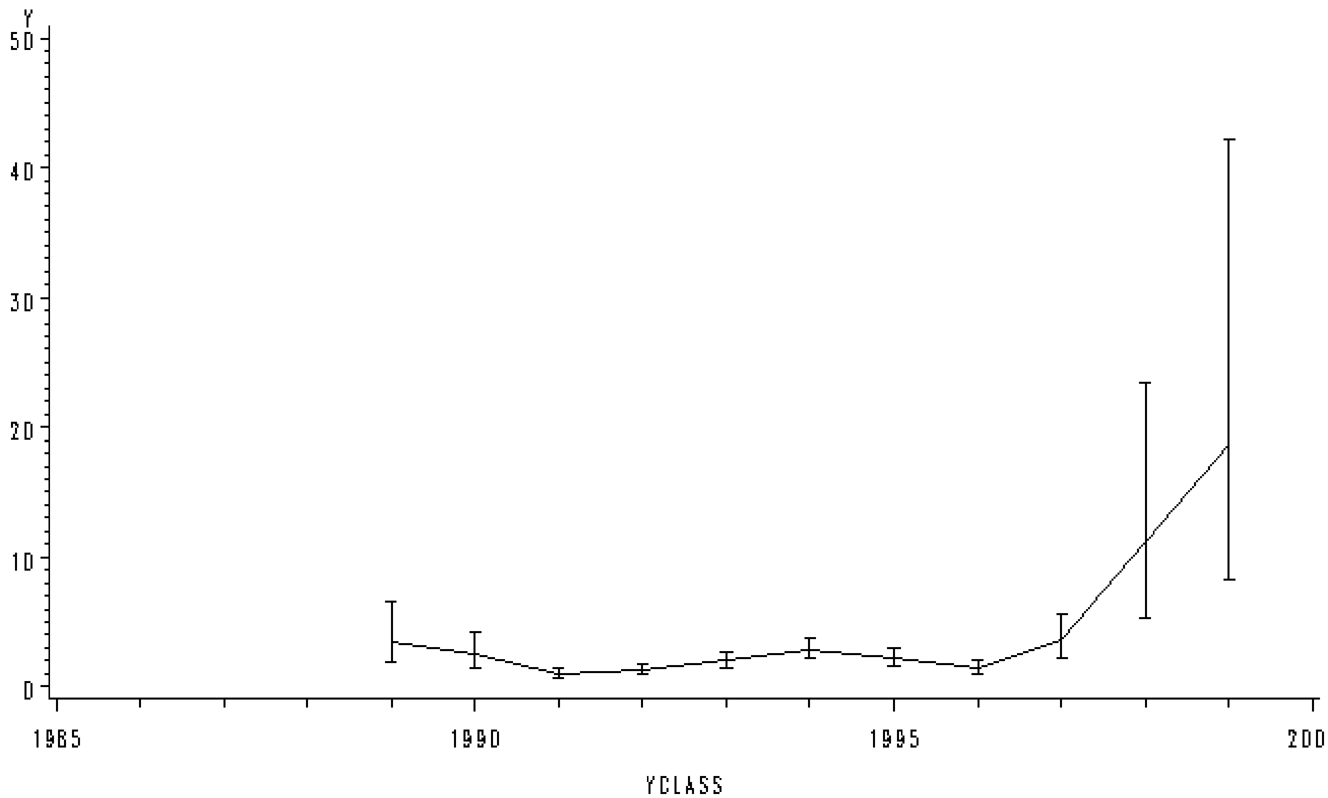

Fig. 9. Estimates of relative yearclass strength from the multiplicative model. Error bars show plus and minus one standard error of the estimate.