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A NONEQUILIBRIUM PRODUCTION MODEL OF SWORDFISH: DATA REANALYSIS AND POSSIBLE FURTHER DIRECTIONS

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SUMMARY

The ASPIC non-equilibrium production model was fit to the swordfish biomass abundance index developed at the 1991 SCRS. Like the production model fit at the SCRS (SCRS/91/16), ASPIC was unable, without constraints, to provide reasonable estimates of all parameters from this data set. However, it was possible to obtain estimates by fixing the parameter *r* over the range from 0.5 and 2.0 (corresponding to $F_{\underline{MSY}}$ between 0.25 and 1.0). Over this range, estimates of MSY were between 13.4 and 16.4 MT, with the corresponding estimates of optimum effort between 36.34 and 10^9 hooks. For biological reasons, it seems that the estimates at the lower end of this range are probably closer to the true values for this stock.

These results are similar to those obtained from the Shepherd-Conser production model used at the 1991 SCRS meeting. Thus, it appears that ASPIC can be applied to this species with reasonable limits, and that the results are comparable to those obtained from similar approached. Other features of the ASPIC framework, such as the use of bootstrapping to obtain non-parametric confidence intervals, may prove useful in further analyses of swordfish.

RESUME

Le modèle de production ASPIC ne postulant pas de conditions d'équilibre a été ajusté à l'indice d'abondance de la biomasse de l'espadon développée à la réunion de 1991 du SCRS. Comme le modèle de production ajusté durant le SCRS (SCRS/91/16), l'ASPIC n'a pas pu, sans contraintes, fournir des estimations raisonnables de tous les paramètres à partir de ce jeu de données. Il a néanmoins été possible d'obtenir des estimations pour fixer le paramètre *r* dans la gamme de 0,5 et 2,0 (correspondant à F_{PME} entre 0,25 et 1,0). Au-delà de cette gamme, les estimations de la PME se situaient entre 13,4 et 16,4 kTM, avec les estimations correspondantes de l'effort optimum entre 36,34 x 10^9 et 46,23 x 10^9. Pour des raisons biologiques, il semble que les estimations à l'extrémité la plus faible de cette gamme soient probablement plus près des vraies valeurs pour ce stock.

Ces résultats sont semblables à ceux obtenus à partir du modèle de production de Shepherd-Conser utilisé à la réunion de 1991. Il semble donc que l'ASPIC soit appliqué à cette espèce avec des résultats raisonnables, et que les résultats sont comparables à ceux obtenus à partir de méthodes semblables. D'autres particularités du système ASPIC, telles que l'utilisation de la méthode boostrap pour obtenir des intervalles de confiance non paramétriques, peuvent s'avérer utiles pour effectuer des analyses plus poussées sur l'espadon.

RESUMEN

Se ajustó el modelo de producción de no equilibrio ASPIC al índice de abundancia de biomasa de pez espada, obtenido por el SCRS en 1991. Igual que en el caso del ajuste del modelo de producción en el SCRS (SCRS(91/16), el ASPIC, no pudo, sin cierta dificultad, dar estimaciones razonables de todos los parámetros partiendo de este conjunto de datos. Sin embargo, se pudieron obtener estimaciones fijando el parámetro *r* por encima de la escala de 0.5 a 2.0 (correspondiente a F_{rms} entre 0.25 y 1.0). Por encima de esta escala, las estimaciones del RMS se encontraban entre 13.4 y 16.4 kTM, con las correspondientes estimaciones del esfuerzo óptimo entre 36.34 x 10^9 y 46.23x10^9 anzuelos. Debido a razones biológicas, parece ser que las estimaciones en la parte inferior de esta escala, están probablemente mas cerca de los valores reales para este stock.

Estos resultados son similares a los obtenidos con el modelo de producción Sheperd-Conser, que fue aplicado en la reunión SCRS de 1991. Por tanto, parece posible aplicar el ASPIC a esta especie, con resultados razonablemente satisfactorios, y que estos resultados son comparables a los que se obtienen con métodos similares. Otras características del ASPIC, como el uso de cálculos aproximativos ("bootstrapping") para obtener intérvalos de confianza no paramétricos, podrían resultar útiles en futuros análisis sobre el pez espada.

INTRODUCTION

Production modeling can be used for assessment of fish stock for which catch-at-age data are unavailable or uncertain. It can also be used to provide another view of an assessment for which the catch-at-age data do seem sufficient. For these reasons, plus their appealing simplicity and flexibility, production models are enjoying a resurgence of use and acceptance in fishery science.

Two production models recently used for assessment of ICCAT species are the Shepherd model as modified by Conser (Conser et al. 1992) and the ASPIC model of Prager (Prager 1991, 1992; Prager and Browder 1992; Cramer and Prager 1992). The Conser–Shepherd model was applied to swordfish at the 1991 SCRS meeting. The ICCAT report (ICCAT 1992, p. 128) summarizes the results as follows:

> MSY estimates ranged from 13,100 to 14,300 MT, a level comparable to the range of catches reported for North Atlantic swordfish during 1983 to 1985. Since 1986, catches have been higher than the estimated MSY level. Declines in stock biomass estimated by the stock-production model for 1978 to 1990 were more extreme than those suggested by VPA results.

The purpose of this paper is to ascertain whether the ASPIC production model might usefully be applied to swordfish.

APPLICATION OF MODEL TO DATA

The data used were obtained from Table 6 of SCRS/91/16. As the present analysis is only exploratory, the ASPIC model was used in its simplest form: error was assumed to be in yield (rather than effort), and bootstrapping was not performed. Like the Conser-Shepherd production model fit at SCRS (SCRS/91/16), ASPIC was unable, without constraints, to provide reasonable estimates of all parameters from this data set. However, it was possible to obtain estimates by fixing the parameter r over a range of values from 0.5 to 2.0, which is equivalent to fixing F_{MSY} between 0.25 and 1.0.

The above range for F_{MSY} can be related to other mortality rates by several considerations. Stock-production models compute F as a rate in weight of fish, but the usual mortality estimates are computed in numbers. The relationship between rates expressed in numbers and in weight depends on the size structure of the population. However, since the smallest fish are not taken in swordfish fisheries, the range given above for F_{MSY} corresponds to a somewhat lower rate in numbers. The assumed rate of natural mortality M, expressed in numbers, for swordfish is 0.1 to 0.25 (ICCAT 1992, p. 128). It is likely that the true F_{MSY} is in the order of the true M, when both are expressed in the same units. If this is so, then the range of r examined is reasonable, although perhaps the higher values of r are unrealistically. Even if that is so, they still can be used to suggest the sensitivity of the MSY estimates to this assumption.

Results for model runs are presented in the tables and figures following the Discussion. Over the range of parameter values tried, estimates of MSY were between 13,400 and 15,600 MT, with the corresponding estimates of optimum effort between 36.34×10^9 and 46.23×10^9 hooks. Over this range, the estimates of MSY were relatively insensitive to the value of r.

For all three values of r, the procedure estimated a declining stock size (in biomass) over the period 1974–1991, with the biomass at the start of 1991 estimated at 75% to 92% of that required to attain MSY.

DISCUSSION

Production models tend to estimate some quantities more precisely than others. In general, levels relative to MSY are estimated more precisely than absolute levels. As specific examples, the biomass level relative to that at MSY is estimated more precisely than the absolute biomass level, and the same goes for estimates the fishing mortality rate. Likewise, benchmarks in fishing *effort rate* (an observed quantity) are more precise than those in fishing *mortality rate*, which would relate the observed catch to an absolute biomass level.

Another point of which the reader should be aware is that the biomass estimates (even relative estimates) for the first few years of a series are not very precise. This can be seen by the width of the nonparametric confidence intervals when the bootstrap is employed.

The inability to estimate all parameters, as was seen here, may indicate shortcomings in the database available for the analysis. Nonetheless, the model results were relatively insensitive to assumptions that had to be made about r, and a range of point estimates about MSY could be made. The range of solutions was quite similar to those obtained at 1991 SCRS. From this analysis, there appears no reason why ASPIC should not be applied to swordfish.

Results for the three values of r that were examined show that the estimate of MSY is relatively insensitive to the assumed value of r, but tends to decrease as the assumed value of r decreases. Based on the points given in the Introduction, one can speculate that the true value of r is probably towards the low end of the range examined, or perhaps lower. In that case the true estimate of MSY would be towards the low end of *its* range, or perhaps lower. The same is true of the estimate of the present condition of the stock: the lower assumed values of r correspond to more depressed stock levels relative to the reference level (the biomass level that can produce MSY). A data set that could define the stock dynamics without the need for an assumption on r would be extremely helpful in gaining a better understanding of this stock.

In conclusion, I note that the ASPIC model has several features, not used here, that might be useful in future analyses of swordfish:

- the ability to analyze several series of data, so that data from several fisheries could be used without prior standardization;
- when analyzing several series of data, the ability to estimate statistical weights for each series, by means of iterative reweighting;
- bootstrapping, to provide nonparametric confidence intervals on estimates and population trajectories;
- the ability to accumulate residuals in effort, rather than catch, an arrangement which theory suggest should reduce bias;
- the ability to tune the model to independent indices of abundance.

These will be discussed in more detail in an additional ICCAT Working Document.

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Table 1. Analysis with r=0.5

ASPIC on Swordfish Data from ICCAT SCRS 1991 (r=0.5)

06-09-1992 at 16:46

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.0) FIT Mode

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INPUT PARAMETERS:

Number of years analyzed:	17
Number of data series:	1
Emphasis factors:	1.000
Emphasis for (B1 > K) as residual:	1.000
Loss function:	Residuals computed in yield
Relative conv. criterion (simplex):	1.000E-08
Relative conv. criterion (restart):	3.000E-08
Relative conv. criterion (effort):	1.000E-06
Maximum estimated F allowed:	40.000
Number of bootstrap trials:	0

SUMMARY STATISTICS (Non-bootstrapped):

R-squared (CSS) for annual yield:	.1983
Value of loss function:	2.496E+00

Loss components for individual series:		N	MSE
# 0 Penalty for B1 > K	0.000E+00		
# 1 Swordfish derived effort & catch data	2.496E+00	17	1.560E-01

PARAMETER ESTIMATES:

Parameter		Starting guess	Estimate	Flag
B1	Biomass in 1974	1.200E+02	7.847E+01	1
K	Maximum stock size	1.300E+02	1.074E+02	1
r	Intrinsic rate of increase	5.000E-01	5.000E-01	0
q(i) Catchability coefficients		1.000E-02	6.879E-03	1

The following are derived from estimates of K, r, and q(i):		Formula
Maximum sustainable yield:	1.343E+01	Kr/4
Stock size at M.S.Y.:	5.371E+01	K/2
Fishing mortality at M.S.Y:	2.500E-01	r/2
Fishery-specific effort at M.S.Y.:	3.634E+01	r/2q(i)

NOTE: The quantities estimated most precisely are MSY, f(MSY), and ratios of q's.

Table 2. Analysis with r=1.0

ASPIC Analysis on Swordfish Data from ICCAT SCRS 1991

06-09-1992 at 15:09

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.0) FIT Mode

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INPUT PARAMETERS:

Number of years analyzed:	17
Number of data series:	1
Emphasis factors:	1.000
Emphasis for (B1 > K) as residual:	1.000
Loss function:	Residuals computed in yield
Relative conv. criterion (simplex):	1.000E-08
Relative conv. criterion (restart):	3.000E-08
Relative conv. criterion (effort):	1.000E-06
Maximum estimated F allowed:	40.000
Number of bootstrap trials:	0

SUMMARY STATISTICS (Non-bootstrapped):

R-squared (CSS) for annual yield:	.2456
Value of loss function:	2.290E+00

Loss components for individual series:		N	MSE
# 0 Penalty for B1 > K	4.960E-03		
# 1 Swordfish derived effort & catch data	2.285E+00	17	1.428E-01

PARAMETER ESTIMATES:

Parameter		Starting guess	Estimate	Flag
B1	Biomass in 1974	2.000E+01	6.691E+01	1
K	Maximum stock size	3.000E+01	6.236E+01	1
r	Intrinsic rate of increase	1.000E+00	1.000E+00	0
q(i) Catchability coefficients		5.000E-01	1.082E-02	1

The following are derived from estimates of K, r, and q(i):		Formula
Maximum sustainable yield:	1.559E+01	Kr/4
Stock size at M.S.Y.:	3.118E+01	K/2
Fishing mortality at M.S.Y:	5.000E-01	r/2
Fishery-specific effort at M.S.Y.:	4.623E+01	r/2q(i)

NOTE: The quantities estimated most precisely are MSY, f(MSY), and ratios of q's.

Table 3. Analysis with r=2.0

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ASPIC Analysis on Swordfish Data from ICCAT SCRS 1991 (r=2)
                                                      06-09-1992 at 16:06

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.0)          FIT Mode

Author: Michael H. Prager
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INPUT PARAMETERS:

Number of years analyzed:                                  17
Number of data series:                                      1
Emphasis factors:                1.000
Emphasis for (B1 > K) as residual:                      1.000
Loss function:                   Residuals computed in yield
Relative conv. criterion (simplex):                 1.000E-08
Relative conv. criterion (restart):                 3.000E-08
Relative conv. criterion (effort):                  1.000E-06
Maximum estimated F allowed:                           40.000
Number of bootstrap trials:                                 0

SUMMARY STATISTICS (Non-bootstrapped):

R-squared (CSS) for annual yield:                       .3388
Value of loss function:                             2.030E+00

Loss components for individual series:                   N            MSE
# 0  Penalty for B1 > K                      1.859E-02
# 1  Swordfish derived effort & catch data   2.011E+00   17      1.257E-01

PARAMETER ESTIMATES:

Parameter                         Starting guess     Estimate            Flag

B1   Biomass in 1974                  2.000E+01     3.767E+01             1
K    Maximum stock size               3.000E+01     3.287E+01             1
r    Intrinsic rate of increase       2.000E+00     2.000E+00             0

q(i) Catchability coefficients        5.000E-01     2.108E-02             1

The following are derived from estimates of K, r, and q(i):          Formula

Maximum sustainable yield:                         1.644E+01          Kr/4
Stock size at M.S.Y.:                              1.644E+01           K/2
Fishing mortality at M.S.Y:                        1.000E+00           r/2

Fishery-specific effort at M.S.Y.:                 4.744E+01       r/2q(i)

NOTE: The quantities estimated most precisely are MSY, f(MSY), and ratios of q's.
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ASPIC on Swordfish Data from ICCAT SCRS 1991 (r=0.5)

ESTIMATED POPULATION TRAJECTORY:

Obs	Year Or ID	Estim Total F mort	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Predicted Total Yield	Estimated Surplus Production	Ratio of Yield to Production	Ratio of Biomass to SSMSY
1	1974	.040	7.846E+01	8.184E+01	6.301E+00	3.290E+00	9.732E+00	.338	1.461E+00
2	1975	.172	8.490E+01	8.243E+01	8.776E+00	1.418E+01	9.583E+00	1.480	1.581E+00
3	1976	.180	8.030E+01	7.843E+01	6.587E+00	1.409E+01	1.058E+01	1.331	1.495E+00
4	1977	.119	7.679E+01	7.760E+01	6.352E+00	9.234E+00	1.077E+01	.857	1.430E+00
5	1978	.079	7.833E+01	8.032E+01	1.180E+01	6.358E+00	1.013E+01	.628	1.458E+00
6	1979	.155	8.210E+01	8.076E+01	1.186E+01	1.254E+01	1.002E+01	1.251	1.529E+00
7	1980	.255	7.959E+01	7.531E+01	1.353E+01	1.919E+01	1.123E+01	1.708	1.482E+00
8	1981	.087	7.163E+01	7.424E+01	1.113E+01	6.478E+00	1.146E+01	.565	1.334E+00
9	1982	.098	7.661E+01	7.818E+01	1.283E+01	7.662E+00	1.064E+01	.720	1.426E+00
10	1983	.191	7.959E+01	7.744E+01	1.442E+01	1.482E+01	1.080E+01	1.372	1.482E+00
11	1984	.178	7.557E+01	7.459E+01	1.252E+01	1.325E+01	1.140E+01	1.163	1.407E+00
12	1985	.196	7.372E+01	7.243E+01	1.426E+01	1.423E+01	1.180E+01	1.206	1.372E+00
13	1986	.326	7.129E+01	6.645E+01	1.828E+01	2.164E+01	1.264E+01	1.712	1.327E+00
14	1987	.400	6.229E+01	5.717E+01	1.996E+01	2.287E+01	1.334E+01	1.715	1.160E+00
15	1988	.398	5.275E+01	4.939E+01	1.914E+01	1.967E+01	1.333E+01	1.476	9.821E-01
16	1989	.369	4.641E+01	4.462E+01	1.698E+01	1.646E+01	1.304E+01	1.262	8.640E-01
17	1990	.337	4.299E+01	4.224E+01	1.542E+01	1.426E+01	1.282E+01	1.112	8.004E-01
18	1991		4.155E+01						

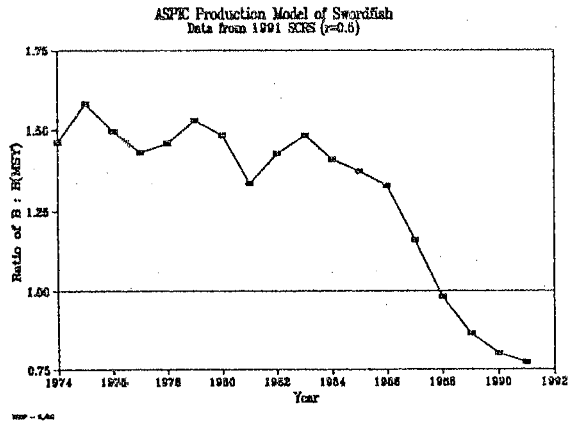

Figure 1. Results from non-equilibrium production model of swordfish in the north Atlantic: estimated scaled biomass trajectory for $r = 0.5$. The first few years of such plots are unreliable and should be ignored.

ASPIC Analysis on Swordfish Data from ICCAT SCRS 1991

ESTIMATED POPULATION TRAJECTORY:

Obs	Year Or ID	Estim Total F mort	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Predicted Total Yield	Estimated Surplus Production	Ratio of Yield to Production	Ratio of Biomass to SSMSY
1	1974	.063	6.691E+01	6.370E+01	6.301E+00	4.027E+00	-1.408E+00	-2.860	2.146E+00
2	1975	.270	6.148E+01	5.592E+01	8.776E+00	1.513E+01	5.662E+00	2.672	1.972E+00
3	1976	.282	5.202E+01	4.973E+01	6.587E+00	1.405E+01	1.005E+01	1.397	1.668E+00
4	1977	.187	4.802E+01	4.884E+01	6.352E+00	9.137E+00	1.059E+01	.863	1.540E+00
5	1978	.124	4.947E+01	5.109E+01	1.180E+01	6.358E+00	9.226E+00	.689	1.587E+00
6	1979	.244	5.234E+01	5.069E+01	1.186E+01	1.237E+01	9.479E+00	1.305	1.679E+00
7	1980	.401	4.945E+01	4.585E+01	1.353E+01	1.837E+01	1.209E+01	1.520	1.586E+00
8	1981	.137	4.317E+01	4.624E+01	1.113E+01	6.343E+00	1.192E+01	.532	1.384E+00
9	1982	.154	4.874E+01	4.998E+01	1.283E+01	7.701E+00	9.916E+00	.777	1.563E+00
10	1983	.301	5.095E+01	4.868E+01	1.442E+01	1.465E+01	1.066E+01	1.374	1.634E+00
11	1984	.279	4.697E+01	4.637E+01	1.252E+01	1.296E+01	1.189E+01	1.089	1.506E+00
12	1985	.309	4.590E+01	4.509E+01	1.426E+01	1.393E+01	1.249E+01	1.115	1.472E+00
13	1986	.512	4.446E+01	4.065E+01	1.828E+01	2.082E+01	1.409E+01	1.477	1.426E+00
14	1987	.629	3.774E+01	3.428E+01	1.996E+01	2.156E+01	1.539E+01	1.401	1.210E+00
15	1988	.626	3.157E+01	2.984E+01	1.914E+01	1.869E+01	1.555E+01	1.202	1.012E+00
16	1989	.580	2.843E+01	2.799E+01	1.698E+01	1.623E+01	1.543E+01	1.052	9.117E-01
17	1990	.531	2.762E+01	2.794E+01	1.542E+01	1.483E+01	1.542E+01	.961	8.859E-01
18	1991		2.822E+01						

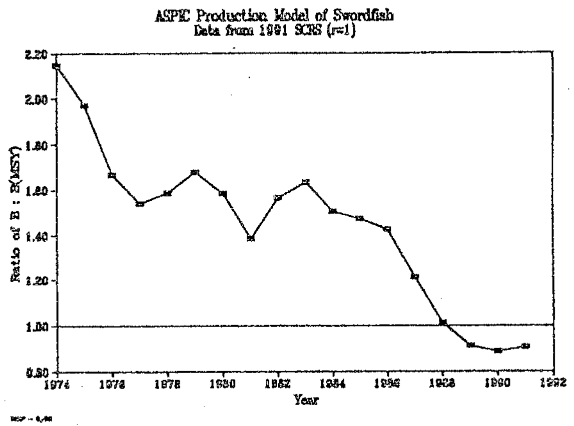

Figure 2. Results from non-equilibrium production model of swordfish in the north Atlantic: estimated scaled biomass trajectory for $r = 1.0$. The first few years of such plots are unreliable and should be ignored.

ASPIC Analysis on Swordfish Data from ICCAT SCRS 1991 (r=2)

ESTIMATED POPULATION TRAJECTORY:

Obs	Year Or ID	Estim Total F mort	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Predicted Total Yield	Estimated Surplus Production	Ratio of Yield to Production	Ratio of Biomass to SSMSY
1	1974	.123	3.767E+01	3.367E+01	6.301E+00	4.148E+00	-1.799E+00	-2.305	2.292E+00
2	1975	.527	3.173E+01	2.773E+01	8.776E+00	1.462E+01	8.492E+00	1.722	1.930E+00
3	1976	.551	2.560E+01	2.473E+01	6.587E+00	1.362E+01	1.224E+01	1.113	1.557E+00
4	1977	.365	2.422E+01	2.551E+01	6.352E+00	9.302E+00	1.140E+01	.816	1.473E+00
5	1978	.243	2.631E+01	2.763E+01	1.180E+01	6.701E+00	8.793E+00	.762	1.601E+00
6	1979	.476	2.841E+01	2.669E+01	1.186E+01	1.270E+01	1.000E+01	1.269	1.728E+00
7	1980	.781	2.571E+01	2.303E+01	1.353E+01	1.798E+01	1.370E+01	1.312	1.564E+00
8	1981	.267	2.144E+01	2.474E+01	1.113E+01	6.614E+00	1.209E+01	.547	1.304E+00
9	1982	.300	2.691E+01	2.744E+01	1.283E+01	8.239E+00	9.069E+00	.909	1.638E+00
10	1983	.586	2.774E+01	2.549E+01	1.442E+01	1.495E+01	1.139E+01	1.312	1.688E+00
11	1984	.545	2.419E+01	2.406E+01	1.252E+01	1.310E+01	1.290E+01	1.016	1.472E+00
12	1985	.602	2.398E+01	2.351E+01	1.426E+01	1.415E+01	1.339E+01	1.057	1.459E+00
13	1986	.998	2.322E+01	2.026E+01	1.828E+01	2.022E+01	1.544E+01	1.310	1.413E+00
14	1987	1.226	1.844E+01	1.628E+01	1.996E+01	1.996E+01	1.637E+01	1.219	1.122E+00
15	1988	1.220	1.484E+01	1.417E+01	1.914E+01	1.729E+01	1.612E+01	1.073	9.032E-01
16.	1989	1.130	1.367E+01	1.387E+01	1.698E+01	1.568E+01	1.604E+01	.978	8.318E-01
17	1990	1.034	1.403E+01	1.465E+01	1.542E+01	1.514E+01	1.623E+01	.933	8.535E-01
18	1991		1.512E+01						

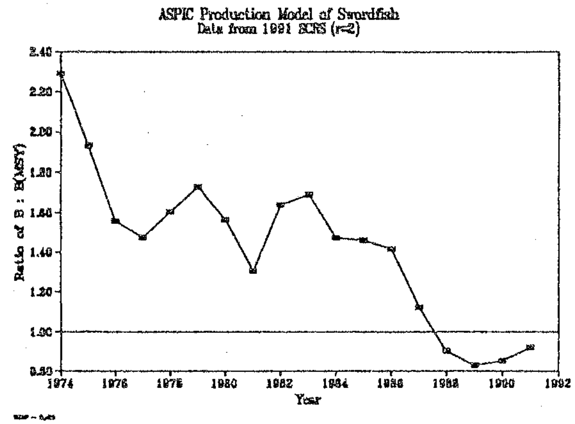

Figure 3. Results from non-equilibrium production model of swordfish in the north Atlantic: estimated scaled biomass trajectory for $r = 2.0$. The first few years of such plots are unreliable and should be ignored.