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APPLICATION OF TESTS OF A STOCK-PRODUCTION MODEL ON AGE-STRUCTURED SIMULATED DATA: A SWORDFISH-LIKE STOCK

Prager, M.H., C.P. Goodyear, G.P. Scott

National Marine Fisheries Service, Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida 33149, U.S.A.

SUMMARY

A common question stock-production models is how well they treat data from fisheries whose selectivity has changed over time or fisheries on stocks with strong age structure. An age-structured populations and fishery similar to north Atlantic swordfish was simulated, including a changing selectivity vector over time. A lumped-biomass dynamic stock-production model was then fit to simple, non-age-structured data from the simulated fishery. Estimates were compared to the "true" MSY computed from biological and fishery parameters. The change in selectivity in the simulated fishery produced only a small (< 10%) decrease in MSY over time. The production-model estimates of MSY were close to the "true" value. Fits were also made to nine other simulated trajectories; the results were not always as accurate as the first example, but were generally qualitatively correct in their estimates of stock status. Finally, it was found that two proposed reliability statistics can provide useful information about the quality of a production-model fit to a particular set of data. The results demonstrate that presence of strong age structure and moderate changes in selectivity do not negate the applicability of production models.

RESUME

L'une des questions que l'on se pose habituellement sur les modèles de production est : "comment peuvent-ils traiter correctement des données qui proviennent de pêcheries dont la sélectivité a changé au fil des années ou de pêcheries qui visent des stocks ayant une forte structure par âge ?". Nous avons simulé une population structurée par âge et une pêcherie semblable à celle de l'espadon de l'Atlantique Nord, avec un vecteur de sélectivité variable dans le temps. Nous avons ensuite ajusté un modèle dynamique de production de stock de biomasse regroupée à des données simples, non structurées par âge, de la pêcherie simulée. Les estimations ont été comparées à la "vraie" PME calculée à partir des paramètres biologiques et de ceux de la pêcherie. Le changement de sélectivité dans la pêcherie simulée n'a produit qu'une petite diminution (< 10%) dans la PME au fil des années. Les estimations du modèle de production de la PME étaient proches de la "vraie" valeur. Nous avons également effectué des ajustements sur 9 autres trajectoires simulées : les résultats n'étaient pas toujours aussi précis que dans le premier exemple, mais ils étaient généralement qualitativement correctes dans leurs estimations de la situation du stock. Finalement, nous avons trouvé que deux statistiques crédibles qui sont proposées peuvent fournir des informations utiles sur la qualité d'un modèle de production ajusté à un ensemble particulier de données. Nos résultats démontrent que la présence d'une forte structure par âge et de changements modérés dans la sélectivité ne remettent pas en question l'applicabilité des modèles de production.

RESUMEN

Una pregunta común acerca de los modelos de producción de stock es con qué bondad tratan los datos de pesquerías cuya selectividad ha cambiado a lo largo del tiempo o pesquerías sobre stocks con una fuerte estructura por edad. Simulamos un población estructurada por edad y una pesquería similar a la del pez espada del Atlántico norte, incluyendo un vector de selectividad variable a lo largo del tiempo. Se ajustó después un modelo dinámico de producción de stock de biomasa agrupada a datos sencillo, no estructurados por edad, de la pesquería simulada. Las estimaciones se compararon con el RMS "real" calculado a partir de parámetros biológicos y de pesquería. El cambio en la selectividad en la pesquería estimada produjo sólo un pequeño descenso (< 10%) del RMS a lo largo del tiempo. Las estimaciones del modelo de producción del RMS estaban próximas a los valores "reales". También se hicieron ajustes a otras 9 trayectorias simuladas; los resultados no siempre fueron tan precisos con en el primer ejemplo, pero en general fueron cualitativamente correctos en sus estimaciones del status del stock. Finalmente, encontramos que dos estadísticas de fiabilidad propuestas pueden facilitar información util acerca de la calidad de un modelo de producción ajustado a un conjunto de datos particular. Nuestros resultados demuestran que la presencia de una fuerte estructura por edad y cambios moderados en la selectividad no niegan la aplicabilidad de modelos de producción.

Introduction

Production models are attractive tools for assessments in which the age composition of the catch is uncertain or unknown. Nonetheless, a recurring concern is how estimates from production models might perform in the presence of factors not directly accounted for by the model; for example, changes in the selectivity of the fishing gear over time. The theoretical MSY that can be taken from an age-structured population depends on its patterns of growth, fecundity, and recruitment; its natural mortality rate; and the selectivity (pattern of F at age) of the fishery. Large changes in the selectivity vector can cause large changes in the MSY attainable (Goodyear 1994); the degree of change in MSY in any specific case will depend on that stock's biology and the corresponding change in selectivity. A broader concern is how well production models work on stocks with many age classes (we call such stocks "strongly age-structured"). Both questions have been raised in connection with the use of production models in the assessment of swordfish, *Xiphias gladius*, in the North Atlantic Ocean (ICCAT 1993).

In this paper, we examine these issues with a simulation approach. We fit a dynamic production model to data from a simulated fishery similar to the fishery for swordfish in the North Atlantic. Although the simulated population was age-structured, only lumped-biomass data were used to fit the model. We believe that this is one of the first simulation studies to exercise production models on age-structured data.

Methods

Simulation of Data

A base population trajectory of 30 years' length was generated with the LSIM simulator (Goodyear 1989), and possessed the following characteristics, based on those of swordfish in the North Atlantic Ocean:

Natural mortality rate: 0.2 yr^{-1}

Growth: sexually dimorphic, using the sex-specific growth equations of Ehrhardt (1992). The CV of length at age was set to 10% for each sex; however, because the simulator allows the age structure of a cohort to be changed by fishing, the realized CVs varied.

Fecundity: computed as a function of length L of the individual as $P \times B$, where the probability of maturity P for a given length (Arocha et al. 1993) is

$$P = \frac{1}{1 + \exp(-0.06778(L - 189))},$$

and the batch fecundity B for a given length (Arocha and Lee 1994) is

$$B = 70016 \exp(0.18L).$$

Yield and fishing mortality: simulated yields (Fig. 1) were within 5% of the catch history of North Atlantic swordfish from 1962–1991, as given in ICCAT (1993), p. 217. This was achieved by generating a slowly increasing trend in F for 20 yr, then a more rapidly increasing F. We used $F_1 = M/2$ (subscripts represent year); $F_{20} = M$; and $F_{30} = 4M$. Then the F series was adjusted slightly to give yields close to ICCAT (1993).

Initial conditions: pre-simulation recruitment was assumed to be the ratio of mean yield to mean yield per recruit for the first 9 yr of the yield series. The initial age distribution was the steady-state age distribution corresponding to the pre-simulation recruitment level and the F vector in the first year.

Recruitment: followed a Ricker recruitment model without error. Parameter β was the value that produced the pre-simulation recruitment from the equilibrium pre-simulation population fecundity. The parameter α was then made large enough to allow the observed yield series.

Selectivity: simulated selectivity (vulnerability) varied in two stanzas. Years 1–20 simulated the change from fishery mainly using harpoon to one mainly using longline. Years 21–30 simulated expansion of the longline fishery to areas where smaller fish were increasingly vulnerable. The year-30 selectivity pattern was given by the logistic function of Kimura and Scott (1993),

$$V(L) = 1 / [1 + \exp(8.75 - 0.062L)],$$

which implies 50% vulnerability V at about 141 cm LJFL. Year-1 selectivity was given by a similar curve with 50% vulnerability at 175 cm. The year-20 selectivity was set midway between these two. Other years' selectivities were interpolated linearly between those of years 1 and 20 or years 20 and 30 (Fig 2).

Additional Trajectories

In addition to this "base" simulation, nine other population trajectories were generated with identical biological and selectivity characteristics, but with widely varying initial conditions and trajectories of F by year. This was done to examine performance of the production model more generally.

Fitting

Data used for fitting were the yield (total simulated catch in biomass) and a simulated abundance index (Fig. 1). The abundance index was computed by dividing the yield by the corresponding fishing mortality rate.

The simulated assessment was done with the ASPIC computer program (Prager 1994a), which implements a dynamic logistic surplus–production model (Prager 1994b). Estimation was conditional on catch (rather than effort). Besides the usual point estimates, bias-corrected estimates and 80% confidence intervals were computed (as in Prager 1994) through bootstrapping with 401 realizations.

Production-model estimates can be sensitive to the value of initial biomass, which can be estimated, often imprecisely. To reveal any such sensitivity, two sets of estimates were made for each trajectory: one with all parameters estimated freely, the second with a penalty term added to the objective function (Prager 1994b) to avoid solutions in which the estimated initial biomass is substantially greater than the estimate of K.

Reliability Statistics

The reliability of estimates from production models depends on many factors, the most notable of which is the amount of contrast (change) in the data series. Several statistics have been used as a guide to the reliability of results. Despite the frequent observation that goodness of fit is seldom an appropriate measure of a model's utility, most such measures have been based on goodness of fit. We propose two new statistics, neither based on goodness of fit, for this purpose. We emphasize that research on the utility of these statistics is only beginning.

The *nearness index* measures how closely the modeled stock has approached B_{MSY}, the biomass level from which MSY can be taken as an equilibrium yield. The *coverage index* measures how widely the stock biomass has varied between $B = 0$ and $B = K$. These indices would ideally be known for the underlying stock; however, because the true characteristics of the stock are unknown (except in simulation studies like this one), estimated values are used instead.

The estimated nearness index has a range from 0 (least reliable) to 1 (most reliable). It is defined

$$\hat{N} = 1 - \frac{|\hat{B}_{\mathrm{MSY}} - \hat{B}^*|}{\hat{B}_{\mathrm{MSY}}},$$

where B^* is the smaller of (i) K or (ii) the estimated stock biomass closest to B_{MSY}. If the biomass is estimated to have crossed B_{MSY}, the index is defined to equal 1.

The estimated coverage index has a range from 0 (least reliable) to 2 (most reliable). It is defined

$$\hat{C} = \frac{\hat{B}^{+} - \hat{B}^{-}}{\hat{B}_{MSY}},$$

where B^{+} is the smaller of (i) K or (ii) the largest value of estimated stock biomass in the time series, and B^{-} is the smallest value of estimated stock biomass in the time series.

We estimated N and C for each trajectory. This was done to gain insight into the possible utility of these statistics.

Results

The biological characteristics and changes in selectivity used in this study resulted in relatively small changes in management benchmarks. Maximum sustainable yield (MSY) decreased from 13,210 MT in simulation year 1 to 12,360 mt in year 30, a decrease of 6.4%. Over the same period, B_{MSY}, the stock biomass at which MSY can be taken, decreased by 7.2%, from 69,460 mt to 64,480 mt; and F_{MSY}, the fishing mortality rate that obtains MSY from B_{MSY}, increased very slightly from 0.190 yr^{-1} to 0.192 yr^{-1} (in biomass units).

In analyzing all ten trajectories, point estimates and bias-corrected (BC) estimates were made. Time did not allow comparing point and BC estimates for every trajectory, but we examined many of them. The point and BC estimates were most often within a few percent of one another, with the BC estimates usually being closer to the true values. Both estimates are presented here for the base trajectory; only bias-corrected results are presented for other trajectories.

In describing the closeness of model estimates to the true characteristics of the simulation, we use quotation marks around the word "true." This is done to emphasize that the population in question is simulated and is not a biological population.

Base Trajectory

Estimates of MSY from the base trajectory were quite close to the true value (Table 1). Use of the penalty term to constrain B_1 produced a slightly worse estimate; however, the bias correction reduced that difference, and the two bias-corrected estimates were only negligibly different from the population's "true" MSY in year 30. The constrained estimate had a slightly narrower 80% approximate confidence interval on MSY.

Estimates of relative biomass for the base trajectory began rather optimistic and remained so through about the first half of the data series, then approached the true values more closely, and became less optimistic throughout the remainder of the series (Fig. 3). The first few years of biomass estimates from production models re best disregarded (Prager 1994b), but nonetheless, the estimated trajectory is optimistic, lagging the true decline below $B = B_{MSY}$ by about one year.

Estimates of relative fishing mortality rate were also slightly optimistic (Fig. 4), although the approximate 80% confidence intervals encompassed the true values for about the last half of the time series.

Estimated reliability indices were high for the base trajectory, suggesting relatively reliable results.

Trajectory 2

In this trajectory, the "true" biomass was always above B_{MSY}. Estimated reliability indices were lower than in the base trajectory (Table 2), suggesting less reliable results. Estimates of stock status and MSY were overly optimistic (Table 2, Fig. 5). The model correctly identified the stock as underexploited, but exaggerated the degree of additional exploitation possible. Results using the penalty term were slightly better (Table 2, Fig. 6), but still markedly overoptimistic.

Trajectory 3

In this trajectory, the "true" biomass varied from below to above B_{MSY} as the F declined from a very high to a moderate level. The nearness index was high, and the coverage index was moderate (Table 2). MSY was estimated well, as was the stock status in the last year (Table 2, Fig. 7). The unconstrained estimate of B_1 was well below K, so using a penalty term made no difference to the estimates.

Trajectory 4

This trajectory represented a case with little contrast: F was high throughout, and the biomass level was low and becoming lower. Both nearness and coverage indices were low to moderate. The model correctly identified the stock as overexploited and with a low and declining biomass, but it was moderately overpessimistic about stock status (Table 2, Fig. 8).

Trajectory 5

Trajectory 5 represented a slightly overexploited stock with some trend towards recovery in the final years. The model correctly portrayed the stock as recovered (Fig. 9,Table 2). The model slightly underestimated MSY and slightly overestimated the increase in F required to reach F_{MSY}.

Trajectory 6

In Trajectory 6 was the very end of what has been called a "one-way trip." An extremely high F pertained throughout (Fig 10), and the stock biomass was depleted in year 1 and became more depleted each year. We were unable to obtain any estimates from the production model, because the solution algorithm did not converge. This indicates insufficient information in the data stream to estimate the desired benchmarks.

Trajectory 7

This trajectory represents the opposite of Trajectory 6: here, the stock is near virgin levels and exploited at a very low level (Fig. 11). Estimation without a constraint on B_1 did not converge. When the penalty term was used to constrain B_1, convergence was achieved. The model correctly identified the stock as very lightly exploited; the estimate of MSY was about 45% too low (Table 2), although it was estimated to be substantially above the largest recorded catch. The 80% confidence intervals on MSY were particularly wide for this trajectory, 4,669 mt to 24,570 mt. Relative stock size and relative F in year 30 were both overestimated.

Trajectory 8

The stock in Trajectory 8 is near carrying capacity in year 1 and is subjected to a strong pulse of fishing mortality that ends by year 15. The model estimated the patterns of biomass and fish mortality rate quite well (Fig. 12, Table 2). Although MSY was underestimated by about 14%, the model correctly identified the stock as substantially over B_{MSY} and being fished at substantially below F_{MSY}.

Trajectory 9

In this trajectory, F changes erratically, with a declining trend. The stock responds with a modest recovery by the end of the trajectory. The model estimated the relative F trends fairly well, especially in the most recent years, although it was a bit pessimistic about F throughout. Estimates of relative biomass were also pessimistic throughout, and the model markedly underestimated the recovery in the final 10 yr. Conversely, the model overestimated MSY by about 43%, and the estimated 80% confidence interval (16,060 mt to 19,360 mt) does not include the "true" value.

Trajectory 10

Here, F oscillates about F_{MSY}, with a slight increasing trend, while the stock responds with a slight decline. The model estimated all three benchmarks quite well (Fig. 13, Table 2).

Discussion

The results of this study provide insight into several questions: the effects of moderate selectivity changes on MSY estimates; the applicability of production models to strongly age-structured stocks; the effects of constraints on estimates of starting biomass; and the potential usefulness of several statistics to provide an indicator of reliability of production-model estimates.

As noted above, the selectivity changes in this study resulted in relatively small changes in the MSY obtainable from the stock, in the biomass that can support MSY, and in the F at which MSY can be taken. Perhaps for that reason, nothing in the results that suggests that selectivity changes of the magnitude simulated might invalidate the use of a production model or cause problems in estimation. Similarly, we found nothing to indicate that production models cannot or should not be used on strongly age-structured stocks. To the contrary, in most cases, the model produced useful assessment results.

In this study, recruitment followed a Ricker curve exactly. Further research would be helpful in understanding how recruitment variability would affect the results of assessments based on production models. However, it is worth noting that a previous work (Prager 1994c) used a production model to successfully recover population trends of an age-structured population with random recruitment.

In this simulation study, we based the CPUE index on the exact catch and the exact fishing effort (in biomass units). The statistical model used for fitting assumes that any error in the CPUE index is lognormal. Examining error in the input data was beyond the scope of this study, but could be done in future research. Based on the general theory of nonlinear regression, we expect that error in the data should cause mainly an increase in variance of the model's parameter estimates.

We did not reach any strong impressions about the use of a penalty term to constrain the starting biomass. In two cases (trajectories 1 and 2), using the penalty term influenced the estimates slightly. In another case (Trajectory 7), obtaining estimates—although very imprecise and inaccurate ones—was possible only through the use of the penalty term.

The nearness and coverage indices (N and C) proposed here may prove useful as general indicators of reliability of production model results. In Table 2, trajectories for which the estimated MSY is within 15% of the "true" value are shaded. Most such cases have $\hat{N} = 1$; i.e., the population is estimated to have crossed the MSY level. (Conversely, all trajectories with $\hat{N} = 1$ have errors smaller than 15% in estimating MSY.) Of the shaded trajectories, 3 of the 4 lowest percentage errors are associated with high (>1.0) values of the coverage index. The precise way in which these indices can be useful is still not certain, and further research and experience are undoubtedly needed. Nonetheless, consideration of these indices may help the analyst to judge the reliability of a production model analysis and to describe it in a concise way.

In several cases, the estimated confidence intervals in this simulation study did not encompass the "true" underlying values of MSY, B_{30}/B_{MSY}, or F_{30}/F_{MSY}. It would be valuable to make a thorough examination of all such confidence intervals from this study, including comparisons to the "true" values. For lack of time, we were unable to accomplish that, but hope to do it in the near future. (Prager 1994b) discussed several reasons why estimated confidence intervals for fisheries models are likely to be optimistic. We reassert that in general, it is probably appropriate to consider such intervals as minimum estimates of variability.

In conclusion, the results of this study suggest that production models can be quite valuable in assessment of even strongly age-structured populations with moderate changes in selectivity. In every case except for Trajectory 9, the model used here correctly indicated whether the population was overexploited or underexploited. The quantitative estimates of the degree of departure from the optimum state were not always very accurate, but the estimates would lead to qualitatively correct management decisions about increasing or decreasing fishing effort. For stocks that were near or had passed through B_{MSY}, the model was also able to make reasonably accurate estimates of MSY. For other stocks, it is reasonable to suppose that, if management decisions were made in accordance with the model results and additional data were collected in succeeding years, estimates of MSY would improve as the stock approached its optimum level.

Literature Cited

Arocha, F., D.W. Lee, and J.R. Grubich. 1993. Observations on sex ratio, maturity stages, and fecundity of swordfish, *Xiphias gladius*, in the Northwest Atlantic Ocean. ICCAT Working Document SCRS/93/106.

Arocha, F., and D.W. Lee. 1994. The spawning of swordfish from the northwest Atlantic. ICCAT Working Document SCRS/94/121.

Ehrhardt, N. E. 1992. Age and growth of swordfish, *Xiphias gladius*, in the northwestern Atlantic. Bull. Mar. Sci. 50: 292–301.

Goodyear, C.P. 1989. LSIM: A length-based fish population simulation model. NOAA Tech. Memo. NMFS-SEFC-219. 55 pp.

Goodyear, C.P. 1994. Variability of fishing mortality by age: consequences for MSY. ICCAT Working Document SCRS/94/61.

ICCAT, 1993. Report for biennial period 1992–1993, Part I (1992), English version. ICCAT, Madrid.

Kimura, D., and G.P. Scott. 1993. Length-based separable sequential population analysis as applied to swordfish (*Xiphias gladius*). ICCAT Working Document SCRS/93/51.

Prager, M.H. 1994a. User's manual for ASPIC: A stock-production model incorporating covariates, program version 3.5x. NMFS S.E. Fisheries Science Center, Miami Laboratory Document MIA-92/93-55, 3rd ed.

Prager, M. H. 1994b. A suite of extensions to a non-equilibrium surplus-production model. Fishery Bulletin (U.S.) 92:374–389.

Prager, M. H. 1994c. Use of a surplus-production model to analyze the standard ICCAT age-structured simulated data sets. ICCAT Working Document SCRS/94/60.

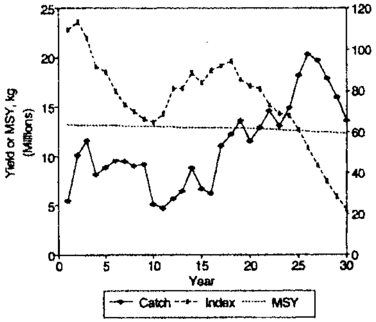

Figure 1. Simulated catch, CPUE, and MSY used in the base age-structured simulation of a swordfish-like stock. MSY is computed from recruitment and growth curves and varies by year because of selectivity changes in the fishery.

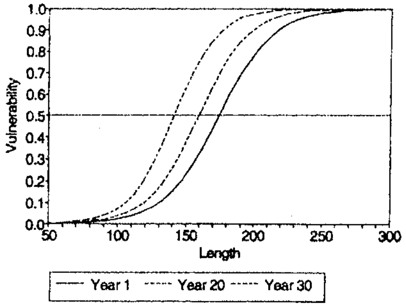

Figure 2. Selectivity (relative F-at-age) curves used in the all simulations of the swordfish-like stock.

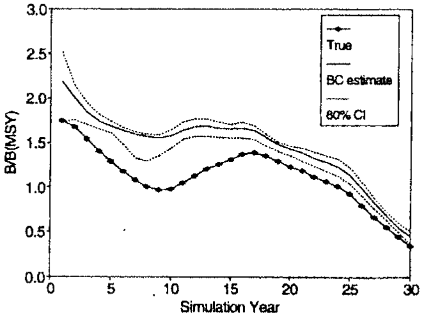

Figure 3. Results of base assessment of a simulated swordfish-like stock. True and estimated ratios of B/B_{MSY} with approximate 80% nonparametric confidence interval.

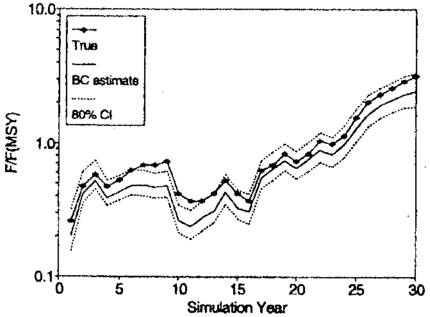

Figure 4. Results of base assessment of simulated stock. "True" and estimated ratio of F/F_{MSY} with approximate 80% nonparametric confidence interval.

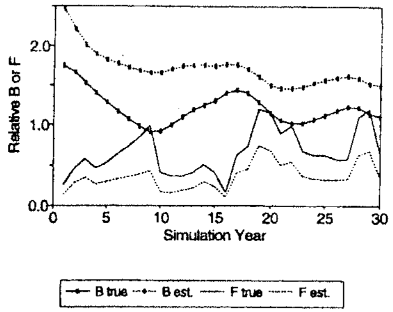

Figure 5. Results from simulated Trajectory 2, with all parameters freely estimated.

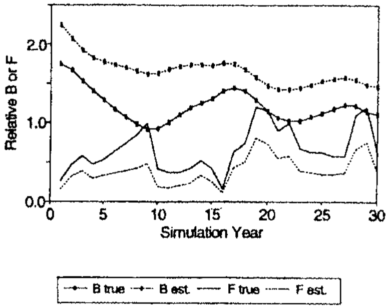

Figure 6. Results from simulated Trajectory 2, with penalty term added to constrain starting biomass.

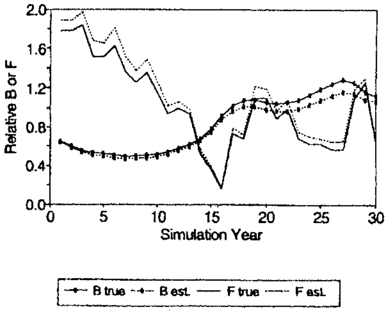

Figure 7. Results from simulated Trajectory 3.

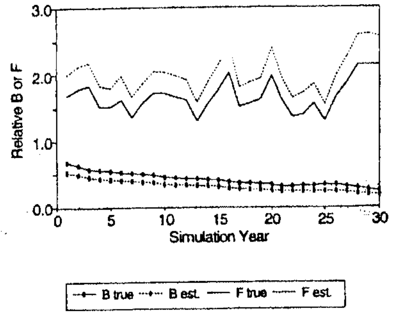

Figure 8. Results from simulated Trajectory 4.

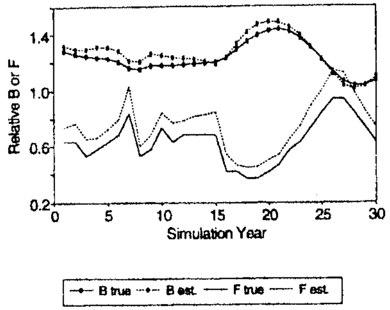

Figure 9. Results from simulated Trajectory 5.

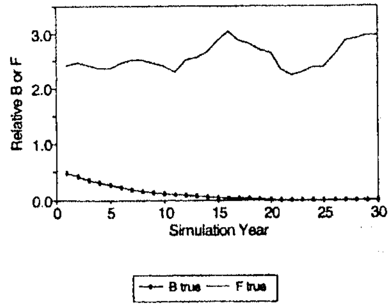

Figure 10. Simulated Trajectory 6. No estimates were obtained due to lack of convergence.

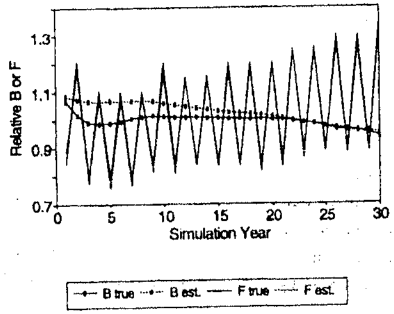

Figure 14. Results from simulated Trajectory 10.

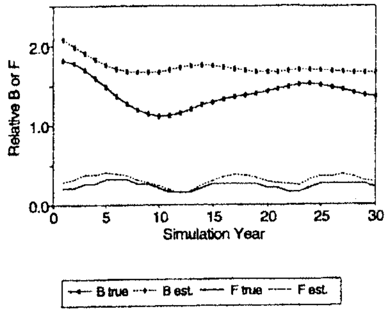

Figure 11. Results from simulated Trajectory 7, with penalty term added to constrain starting biomass.

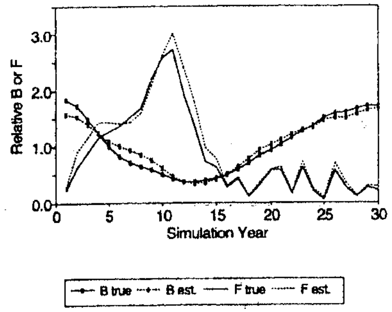

Figure 12. Results from simulated Trajectory 8

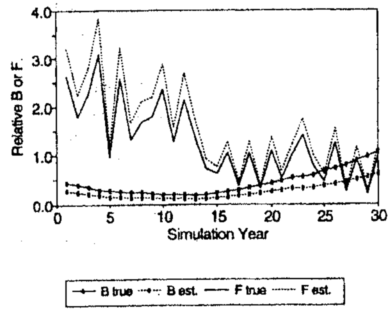

Figure 13. Results from simulated Trajectory 9.

Table 1. MSY estimates from fitting a production model to an age-structured simulated data set with biological parameters and catch trajectory similar to those of North Atlantic swordfish. The true MSY computed by age-structured methods ranged from 1.32 × 10^7 in the first year to 1.236 × 10^7 in the last year.

Type of estimate	Estimates with all parameters freely estimated	Estimates with parameter B_1 constrained to $\le K$
Estimates of MSY (true values decline from 1.32 × 10^7 in first year to 1.24 × 10^7 in last year)		
Point estimate	1.232 × 10^7	1.179 × 10^7
Bias-corrected estimate	1.240 × 10^7	1.237 × 10^7
80% confidence interval	9.86 × 10^6–1.46 × 10^7	1.01 × 10^7–1.48 × 10^7
Estimates of B_{30}/B_{MSY} [a]		
True value	0.348	0.348
Bias-corrected estimate	0.445	0.444
80% confidence interval	0.373–0.508	0.373–0.495
Estimates of F_{30}/F_{MSY}		
True value	3.2	3.2
Bias-corrected estimate	2.5	2.5
80% confidence interval	1.9–3.3	1.9–3.3

[a] Biomass ratios are estimated mid-year values.

Table 2. Management benchmarks and proposed reliability statistics from analyzing 10 simulated age-structured 30-yr trajectories with a dynamic production model (ASPIC). If using a penalty term to constrain the initial biomass gave different estimates, results are designated "P" (e.g., Trajectory 1P). Comparisons of MSY are to the "true" year-30 value of 1.236 × 10^7 kg/yr. By this criterion, an estimate corresponding to the "true" year-1 MSY (1.321 × 10^7 kg/yr) would have a positive error of 6.9%. Shaded rows mark results in which estimated MSY is within ±15% of the "true" value.

Trajectory no.	Brief description of trajectory dynamics (also see Figs. 3 through 14).	MSY		F/F_{MSY}, year 30		B/B_{MSY}, year 30		Nearness index (estimated)	Coverage index (estimated)
		Estimated	Percent error	True	Estimated	True	Estimated		
1	Base run; similar to North Atlantic swordfish	1.240 × 10^7	0.3	3.18	2.45	0.35	0.45	1.00	1.50
1P	(same)	1.237 × 10^7	0.1	3.18	2.48	0.35	0.44	1.00	1.51
2	F varies between low level and approximately F_{MSY}	1.635 × 10^7	32.3	0.63	0.35	1.11	1.52	0.53	0.53
2P	(same)	1.539 × 10^7	24.5	0.63	0.38	1.11	1.48	0.62	0.62
3	F starts high and declines to below MSY level	1.262 × 10^7	2.1	0.63	0.66	1.13	1.08	1.00	0.71
4	Relatively constant high F	1.413 × 10^7	14.3	2.14	2.56	0.24	0.19	0.54	0.36
5	Relatively constant low F	1.057 × 10^7	−14.5	0.63	0.73	1.07	1.03	1.00	0.49
6	Relatively constant, very high F	No convergence; no estimates could be obtained							
7	Varying F always very low	No convergence; no estimates could be obtained							
7P	(same)	6.804 × 10^6	−45.0	0.21	0.28	1.36	1.67	0.46	0.46
8	F starts low; increases to very high level in year 11; declines to low levels by year 16; remains low	1.065 × 10^7	−13.8	0.21	0.27	1.70	1.63	1.00	1.32
9	Varying F high for first 13 years; low for other years	1.757 × 10^7	42.2	0.99	1.20	1.05	0.57	0.61	0.51
10	F oscillates near F_{MSY}	1.250 × 10^7	1.1	1.36	1.32	0.94	0.96	1.00	0.15