

**A BOOTSTRAPPED NONEQUILIBRIUM PRODUCTION MODEL OF SWORDFISH, BASED ON  
LATEST DATA**

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**SUMMARY**

A new time series of estimated swordfish abundance was analyzed with the ASPIC non-equilibrium production model. In contrast to analyses performed in 1991, it was possible to estimate all model parameters without postulating additional constraints. This indicates that the new data set, which includes additional data from 1962-1973, can define the stock dynamics better than last year's data set. The results of the bootstrapped analysis were in general agreement with previous analyses, with the median estimate of MSY being 9.840 MT per year. The median estimate of stock abundance at the start of 1991 was 64 percent of  $B_{MSY}$  (the stock biomass at which MSY can be attained), indicating an over-exploited resource by that criterion. The model estimated a decline in stock biomass since the 1960's, a decline that has accelerated in the last few years. Solely as an example, and not advocating any particular management measure, a projection was performed under the scenario that yield for the years 1991 through 1994 would be held to 7,800 MT (about 80 percent of the median estimate of MSY). Under the model assumptions and the stated scenario on yield, the median estimate of biomass at the start of 1995 was 71 percent of the optimum level.

**RESUME**

Une nouvelle série temporelle d'abondance estimée de l'espadon a été analysée avec le modèle de production ASPIC ne postulant pas de conditions d'équilibre. Par contraste avec les analyses effectuées en 1991, il a été possible d'estimer tous les paramètres du modèle sans postuler de contraintes supplémentaires. Ceci indique que le nouveau jeu de données, qui comprend les données supplémentaires de la période 1962-73, peut mieux définir les dynamiques du stock que le jeu de données de l'an dernier. Les résultats d'analyses itératives étaient en accord général avec les analyses antérieures, avec l'estimation médiane de la PME s'élevant à 9.840 TM par an. L'estimation médiane de l'abondance du stock au début de 1991 s'élevait à 64% de  $B_{PME}$  (la biomasse du stock à laquelle on peut atteindre la PME), en indiquant une ressource surexploitée par ce critère. Le modèle a estimé un déclin de la biomasse du stock depuis les années soixante, déclin qui a été accéléré ces dernières années. Uniquement comme exemple, et en n'appuyant aucune mesure de gestion particulière, une projection a été effectuée sous le scénario que

le rendement des années 1991 à 1994 s'élèverait à 7.800 TM (environ 80% de l'estimation médiane de la PME). Sous les hypothèses du modèle et le scénario sur le rendement mentionné, l'estimation médiane de la biomasse au début de 1995 était de 71% du niveau optimum.

**RESUMEN**

Se analizó una nueva serie temporal de abundancia estimada de pez espada, por medio del modelo de producción de no equilibrio ASPIC. En contraste con los análisis realizados en 1991, fue posible estimar todos los parámetros del modelo sin supuestos de limitaciones adicionales. Esto indica que el nuevo conjunto de datos, que incluye datos adicionales del período 1962-1973, es capaz de definir la dinámica del stock mejor que el conjunto de datos del año pasado. Los resultados del análisis aproximado ("bootstrapped") concordaban, en general, con análisis anteriores, siendo la estimación de la mediana del RMS 9.840 t por año. La estimación de la mediana de la abundancia del stock a principios de 1991 era el 64% de  $B_{RMS}$  (biomasa del stock a la cual se puede alcanzar el RMS), lo que, aplicando dicho criterio, indicaba un recurso sobreexplotado. El modelo estimaba un descenso en la biomasa del stock a partir de los años 60, descenso que se ha acelerado en los últimos años. Como simple ejemplo, y sin ánimo de proponer medida alguna de ordenación, se hizo una proyección bajo el supuesto que la producción en los años 1991 hasta finales de 1994, se mantendría en 7.800 t (alrededor del 80% de la estimación de la mediana del RMS). Con los supuestos del modelo y con la producción antes mencionada, la estimación de la mediana de la biomasa a principios de 1995 era el 71% del nivel óptimo.

## INTRODUCTION

Recent production-model analyses of North Atlantic swordfish have been unable to estimate a full suite of parameters, necessitating additional assumptions in the form of constraints on certain parameters (LCCAT 1992; Prager 1992b). When such extra constraints are needed, the case for performing interval estimation is somewhat weakened, as the additional uncertainty due to these extra assumptions is difficult—although not impossible—to incorporate. With the availability of a new, extended data set on swordfish (Hoey et al. 1992), it is of interest to again apply a production model to this stock. The new data set (Table 1) extends the time series back to 1962 (vs. 1974 for the previous data set), thus making possible improved estimation results and elimination of the need for additional constraints.

## MODEL AND APPLICATION

The model used for this analysis was the ASPIC model (Prager 1991, 1992a), a nonequilibrium stock-production model. ASPIC is based on the logistic form of production model, as discussed by Schaefer (1954), but without the equilibrium assumption that has been regarded with increasing disfavor (Hilborn and Walters 1992). As previously applied (e.g., by Prager and Browder 1992), ASPIC used a continuous-time, analytical solution of the biomass change (differential) equation to arrive at an expression estimating yield and year-end biomass, based on starting biomass and the observed effort in each year.

The form of the ASPIC model used for the present analysis is slightly different. The original form computes for each year an estimated yield, conditional on the observed effort, and minimizes the sum of squared residuals of the logarithm of yield. The present form, using the same equations, computes for each year an estimated effort conditional on the observed yield. The quantity minimized is the sum of squared residuals of the logarithm of effort.

The revised procedure has two advantages. The first is theoretical: yield is usually known far more precisely than effort, and it is preferable on statistical grounds to minimize residuals in the quantity observed with less precision. The second advantage is practical: the new procedure makes it possible to accommodate missing observations of effort easily. This feature can also be used for making projections based on TAC management during the estimation process.

The data set of Hoey et al. (1992) (Table 1) was analyzed by this revised ASPIC model in a bootstrapped analysis with 500 trials. This made it possible to obtain confidence bands and median values for model estimates and projections. The bootstrap is accomplished by resampling, with replacement, the residuals of the initial fit. It has been reported that for regression models this procedure provides a less biased estimate of variability than does the use of parametric methods (Freedman and Peters 1984).

## RESULTS

The model fits the data well, capturing the major dynamics in fishing effort (Fig. 1). No additional constraints (such as fixing  $r$ ) were necessary for optimization, indicating that the new data set (Hoey et al. 1992), which includes additional data from 1962–1973, can define the stock dynamics better, under the model assumptions, than the previous data set.

The bootstrapped analysis provided relatively compact distributions (Fig. 2) and confidence intervals (Table 2) on estimated management benchmarks, namely MSY and  $f_{MSY}$  (optimum effort at MSY). From the bootstrapped analysis, an estimated median biomass trajectory over time and 90% confidence intervals are obtained (Fig. 3). This trajectory estimates a decline in stock biomass since the 1960's, a decline that has accelerated in the last few years (Fig. 3) to reduce the stock to below MSY level.

Solely as an example, and not advocating any particular management measure, a projection was performed under the scenario that yield for the years 1991 through 1994 would be held to 7,800 MT (about 80% of the median estimate of MSY). Under the model assumptions and the stated scenario on yield, the median estimate of biomass at the start of 1995 was 71% of the optimum level (Fig. 3).

## DISCUSSION

Production models can do much more than estimate MSY. The present application illustrates that many types of information can be obtained. Management benchmarks (MSY,  $f_{MSY}$ , and so on) can be estimated along with nonparametric confidence intervals (Table 2) and, more informatively, probability distributions (Fig. 2). The relative biomass trajectory (Fig. 3) provides information about the position of the stock through time in relation to the important benchmark  $B_{MSY}$ , the biomass at which MSY can be attained. (This is sometimes known as the "optimum biomass.") Absolute biomass trajectories can also be estimated, but they are less precise, and therefore may be less useful from a management perspective.

Results from this analysis seem consistent with the observed data on the stock. For example, the declining stock size is consistent with a pattern of exploitation at an rate exceeding  $f_{MSY}$ . (When the stock is above or below MSY level, the equilibrium levels of effort and yield are below  $f_{MSY}$  and MSY.) The accelerated decline in stock biomass estimated in the late 1980's coincides with increased in effort and yield rates, rates that are also above the estimated benchmarks (Table 1).

The projection results illustrate how surplus-production models can be used to examine management scenarios. Results are presented here graphically as nonparametric intervals (Fig. 3); however, they can also be given as probability distributions (similar to those in Fig. 2) that would show the estimated probability of attaining a given stock size given a certain management measure. Thus the production model can be used as the basis for a risk-based analysis of fish stocks. The inclusion of all relevant information is desirable in any analysis that will be used as the basis of management. The ASPIC framework can incorporate some fishery-independent information in the form of survey indices, if they are available, and it is possible to incorporate other forms of information into production models (e.g., Freon 1986; Die and Restrepo 1990; Hilborn 1990). At the same time, if several models can be used for parallel analyses of the same stock, we have more than one view of the subject, and that would be a very desirable achievement.

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| Year | Yield (MT) | Effort |
|------|------------|--------|
| 1962 | 5342       | 6.02   |
| 1963 | 10189      | 7.79   |
| 1964 | 11258      | 22.41  |
| 1965 | 8652       | 23.07  |
| 1966 | 9338       | 28.72  |
| 1967 | 9084       | 26.5   |
| 1968 | 9137       | 36.7   |
| 1969 | 9138       | 39.53  |
| 1970 | 9425       | 35.59  |
| 1971 | 5198       | —      |
| 1972 | 4727       | —      |
| 1973 | 6001       | —      |
| 1974 | 6301       | 19.81  |
| 1975 | 8776       | 23.72  |
| 1976 | 6587       | 21.82  |
| 1977 | 6352       | 18.69  |
| 1978 | 11797      | 21.12  |
| 1979 | 11859      | 41.55  |
| 1980 | 13527      | 37.4   |
| 1981 | 11126      | 40.99  |
| 1982 | 12832      | 41.29  |
| 1983 | 14423      | 55.38  |
| 1984 | 12516      | 49.89  |
| 1985 | 14255      | 60.39  |
| 1986 | 18278      | 82.66  |
| 1987 | 19959      | 102.08 |
| 1988 | 19137      | 99.79  |
| 1989 | 16984      | 92.49  |
| 1990 | 15424      | 86.78  |

Table 1. Yield (catch in MT) and effort data used in a bootstrapped production model analysis of swordfish in the North Atlantic. Yield data were taken from the final column of Table 1 of Hoey et al. (1992); effort was derived from the CPUE index of Hoey et al. (1992) by the relationship  $\hat{f} = \frac{Y}{U}$ , where  $\hat{f}$  is the estimated effort,  $Y$  the tabulated yield (in MT), and  $U$  the CPUE index of Hoey et al. (1992). Symbol — indicates that no data were available.

Table 2. Summary results of bootstrapped nonequilibrium (dynamic) production model of swordfish in the North Atlantic. The 500 bootstrap trials were used to compute nonparametric approximate 90% confidence intervals. Relevant observed data have been included for comparison to estimated benchmarks.

| Item estimated or observed  | Lower confidence bound | Median or observed value | Upper confidence bound |
|---|------------------------|--------------------------|------------------------|
| MSY, maximum sustainable yield  | 5,134                  | 9,840                    | 13,410                 |
| $Y_{90}$ , observed yield in 1990   | —                      | 15,420                   | —                      |
| Mean observed yield, 1988-90  | —                      | 17,180                   | —                      |
| $f_{MSY}$ , optimum effort at $B_{MSY}$   | 24.6                   | 45.9                     | 62.9                   |
| $f_{90}$ , observed standardized effort in 1990   | —                      | 86.8                     | —                      |
| Mean observed effort, 1988-90   | —                      | 93.0                     | —                      |
| $B_{91} : B_{MSY}$ , estimated ratio of biomass in 1991 to level at which MSY can be attained | 0.44                   | 0.64                     | 1.0                    |

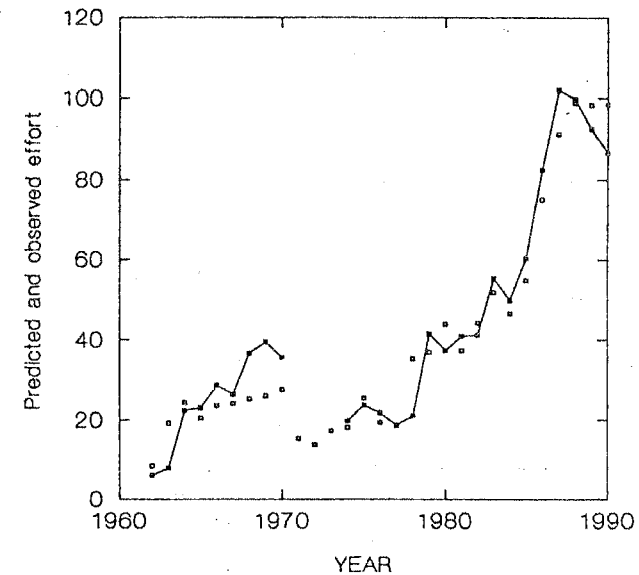


Figure 1. Predicted (open squares) and observed (solid squares) fishing effort for swordfish in the North Atlantic. Predictions are estimated values from nonequilibrium production model (ASPIC) analysis with residuals accumulated in the logarithm of effort. No observed effort data were available for 1971-1973.

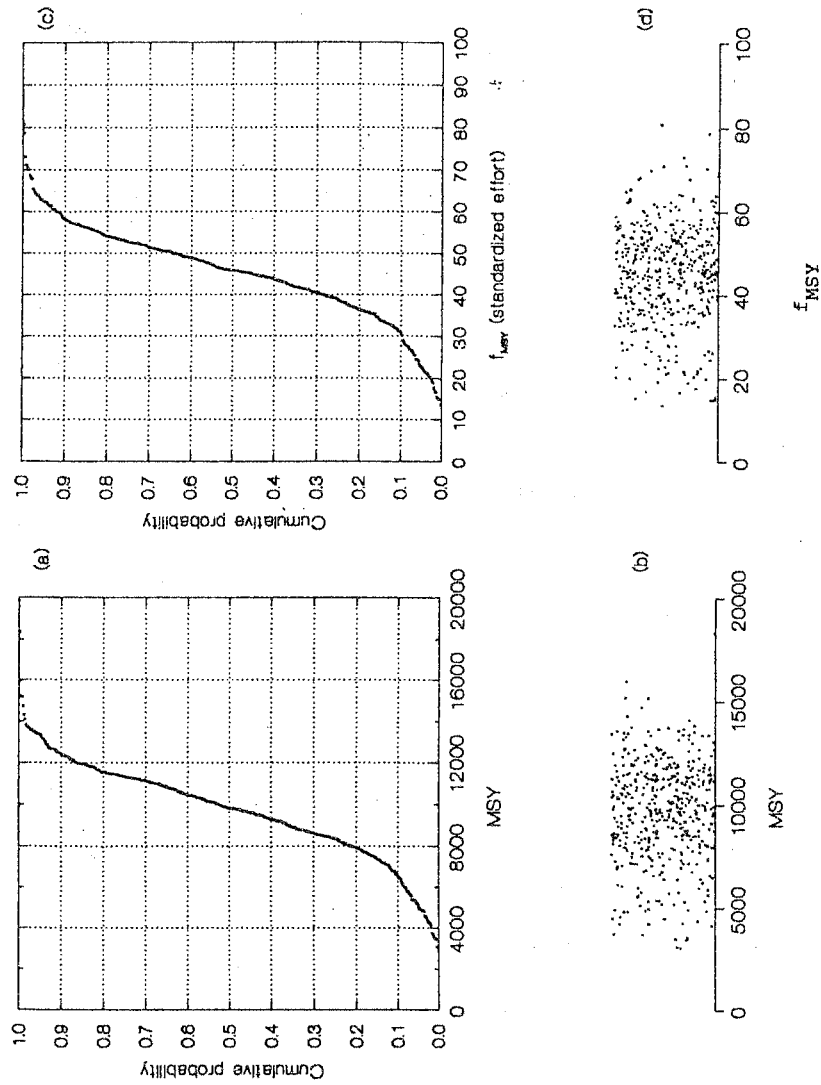


Figure 2. Nonparametric distributions of maximum sustainable yield (MSY) and standardized optimum effort ( $f_{MSY}$ ) for swordfish in the North Atlantic. Results are from a bootstrapped dynamic production model analysis with 500 trials. Panel (a), cumulative probability distribution of MSY. Panel (b), distribution (density) of estimates of MSY. Panel (c), cumulative probability distribution of  $f_{MSY}$ ; panel (d) distribution (density) of estimates of  $f_{MSY}$ .

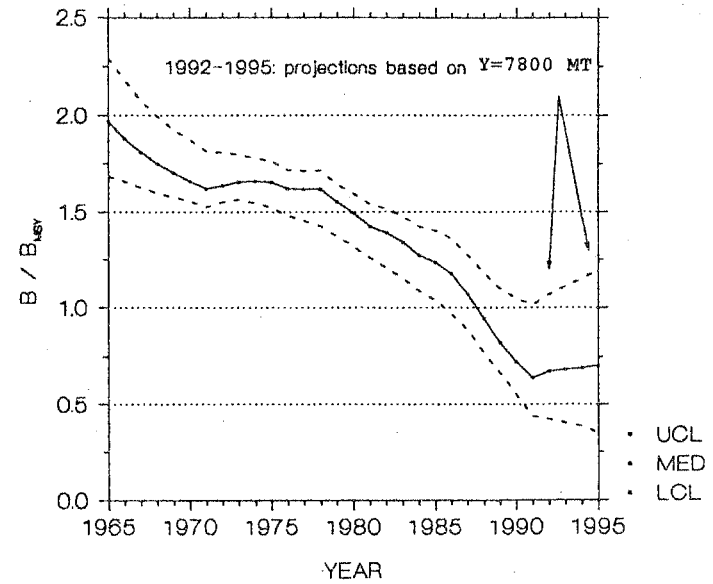


Figure 3. Nonparametric 90% confidence band (with median) of estimated start-of-year stock biomass (MT) of swordfish in the North Atlantic. Results are from a bootstrapped dynamic production model with 500 trials. To increase precision, plotted biomass estimates were normalized to corresponding estimates of  $B_{MSY}$ , thus providing a consistent reference point. Each point represents the median (or respective percentile) for that year from all bootstrap trials. They are joined to produce a synthetic median (or percentile) trajectory.