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AN EXPLORATORY STOCK-PRODUCTION MODEL ANALYSIS OF WHITE MARLIN (*Tetrapturus albidus*) IN THE ATLANTIC OCEAN[1]

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SUMMARY

White marlin catch and effort data were analyzed using a non-equilibrium stock-production model (ASPIC) following significant refinements in data preparation. We explored the use of this model under two current stock structure hypotheses: (1) separate North Atlantic and South Atlantic stocks, and (2) a total Atlantic-wide stock. The North Atlantic database consisted of Japanese, Taiwanese, as well as other longline fisheries, and Venezuelan and U.S. recreational fisheries. The South Atlantic database consisted of Japanese, Taiwanese and Brazilian longline fisheries. Both databases also included yields from other fisheries. We used a revised version of the model that minimized error in effort (rather than error in yield) and applied an iterative re-weighting scheme. This generated estimates of annual relative biomass and fishing mortality levels. Bootstrapping techniques estimated approximate confidence intervals for MSY, fishing mortality at MSY, and relative biomass. Results indicate that relative biomass trajectories exhibited a downward trend below MSY under both stock structure hypotheses. This is consistent with previous assessments and suggests that the white marlin stock(s) are at least fully exploited and likely overexploited. However, sensitivity analyses need to be conducted to determine how the model behaves under differing assumptions and to clarify conclusions that can be drawn from these results.

RESUME

Les données de capture et d'effort du makaire blanc ont été analysées au moyen d'un modèle de production ne postulant pas de conditions d'équilibre (ASPIC) après avoir apporté aux données des améliorations significatives lors de leur préparation. Nous avons examiné l'utilisation de ce modèle selon deux hypothèses actuelles de structure du stock: (1) des stocks distincts pour l'Atlantique nord et sud, et (2) un stock unique pour l'ensemble de l'Atlantique. La base de données nord-atlantique comprenait les pêcheries japonaise, taiwanaise, et autres pêcheries palangrières, et les pêcheries sportives du Venezuela et des Etats-Unis. La base de données sud-atlantique comprenait les pêcheries palangrières japonaise, taiwanaise, et brésilienne. Les deux bases comprenaient également la production d'autres pêcheries. Nous avons utilisé une version révisée du modèle qui minimisait l'erreur de l'effort (plutôt que celle de la production), et qui appliquait un schéma itératif de re-pondération. Ceci a donné des estimations de la biomasse relative annuelle et du niveau de mortalité par pêche. Les techniques de "bootstrap" ont estimé les intervalles approximatifs de confiance pour la PME, la mortalité par pêche au niveau de la PME, et la biomasse relative. Les résultats indiquent que les trajectoires de la biomasse relative montraient une tendance décroissante en-dessous de la PME selon les deux hypothèses de structure du stock. Ceci est cohérent avec les évaluations antérieures et suggère que le(s) stock(s) de makaire blanc sont au moins pleinement exploités, sinon surexploités. Néanmoins, il faut effectuer des analyses de sensibilité pour déterminer la façon dont le modèle se comporte selon différentes hypothèses, et pour éclaircir les conclusions qui peuvent être tirées de ces résultats.

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RESUMEN

Se analizaron los datos de captura y esfuerzo de la aguja blanca por medio del modelo de producción de no equilibrio ASPIC, tras un importante afinamiento en la preparación de los datos. Se investigó el uso de este modelo bajos dos hipótesis actuales de estructura del stock: (1) stocks separados al norte y sur del Atlántico y (2) un sólo stock en todo el Atlántico. La base de datos del Atlántico norte estaba compuesta por pesquerías de Japón, Taiwan y otras pesquerías palangreras y por pesquerías de recreo de Venezuela y Estados Unidos. La base de datos del Atlántico sur se componía de pesquerías de palangre de Japón, Taiwan y Brasil. Ambas bases incluían también rendimientos de otras pesquerías. Se usó una versión revisada del modelo que minimizaba el error en el esfuerzo (en vez del error en el rendimiento) y aplicaba un esquema de ponderación iterativa. Esto generó estimaciones de los niveles de la biomasa anual relativa y de mortalidad por pesca. Las técnicas de proceso iterativo de reajuste (bootstrap), estimaban los intervalos de confianza aproximados de RMS, la mortalidad por pesca con RMS y la biomasa relativa. Los resultados indican que las trayectorias de la biomasa relativa presentaban una tendencia al descenso, por debajo del RMS, con ambas hipótesis de estructura del stock. Este hecho concuerda con evaluaciones anteriores y sugiere que el stock (o stocks) de aguja blanca está siendo explotado por lo menos al máximo y, probablemente, sobreexplotado. Sin embargo, es necesario llevar a cabo análisis de sensibilidad con el fin de determinar el comportamiento del modelo bajo diferentes supuestos y esclarecer qué tipo de conclusiones se pueden extraer de estos resultados.

1. INTRODUCTION

Numerous stock assessments of Atlantic white marlin (*Tetrapturus albidus*) have been attempted over the past 15 years using production model techniques (Conser and Beardsley 1979; Farber and Conser 1981; Farber 1982; Farber and Conser 1983). Conser and Beardsley (1979) first assessed the status of stocks of white marlin in the Atlantic Ocean following the billfish stock assessment workshop held in Hawaii in 1977[3]. They reviewed earlier working documents presented in 1977 to the Standing Committee on Research and Statistics (SCRS) at the International Commission for the Conservation of Atlantic Tunas - ICCAT (Kikawa and Honma 1978; Otto et al. 1978). Applying production models with equilibrium assumptions, both had similar estimates for MSY of about 1,800 mt for white marlin in the North Atlantic. They followed the recommendation of the 1977 workshop and analyzed the data under two stock structure hypotheses: (1) separate North Atlantic and South Atlantic stocks, and (2) a single total Atlantic-wide stock. Estimates of MSY ranged from 1,877 to 2,042 mt for the North Atlantic, from 2,008 to 2,347 mt for the South Atlantic, and from 3,171 to 3,520 mt for the total Atlantic under varying hypotheses concerning the shape parameter m and number of significant year-classes in the catch. In 1979, the SCRS report (ICCAT 1980) concluded that it was not clear as to "whether the apparent over-fishing of the North Atlantic stock of white marlin is growth overfishing or recruitment overfishing."

Farber and Conser (1981) followed basically the same methodology as Conser and Beardsley (1979) and applied an equilibrium assumption model to the data. The data were compiled primarily from the ICCAT Statistical Bulletins, with several additional refinements to the database. Under the separate stocks hypothesis for the North Atlantic, "the models fit the data fairly well." They concluded that if the most recent (i.e., 1977-1978) indices were reliable, "the North Atlantic stock of white marlin may be seriously overfished." Relatively uncertain results were found for the South Atlantic and for the total Atlantic stock hypothesis. However, despite the uncertainties, they concluded that the South Atlantic stock appeared "to have been overexploited in the early 1970's" and the total Atlantic stock was "at least fully exploited since 1970 and probably overexploited during 1977 and 1978." Estimates of MSY ranged from 1,729 to 2,423 mt for the North Atlantic, from 1,792 to 2,251 mt for the South Atlantic, and from 2,709 to 4,836 mt for the total Atlantic.

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[3] Report of the Billfish Stock Assessment Workshop - Atlantic Session. Dec. 1977, Honolulu, HI. NOAA/NMFS, SEFC, Miami, FL 33149. Also SCRS/78/7, 47 p.

During the First ICCAT Inter-Sessional Billfish Workshop (ICCAT 1981), billfish catch statistics, by country, were reviewed, corrected, and re-estimated in June, 1981, for the period 1957-1979. Farber (1982) followed the methodology of Conser and Beardsley (1979) and Farber and Conser (1981) and attempted to assess the status of marlin stocks based on these revised data. However, production model analysis could not be used due to the lack of correspondence between CPUE and fishing effort. Concern was expressed that the Japanese longline fishery, used in the past to index abundance for Atlantic marlins, represented a decreasingly smaller percentage of the total catch - down to roughly 10% in 1979, compared to 95% over the period 1960-1964. It was concluded that it could not "be determined if exploitation levels were above optimum", but "that high levels of effort and yield had been followed by declining yields", with a "decline in CPUE over time."

Farber and Conser (1983) updated the white marlin assessment of Farber (1982) using the catch and effort data through 1980. The same methodology as previously outlined was followed with the same hypotheses. The production model did not fit the data well under either stock structure hypothesis. Equilibrium model estimates of MSY ranged from 2,092 to 3,776 mt for the North Atlantic, from 2,579 to 2,672 mt for the South Atlantic, and from 6,230 to 6,286 mt for the total Atlantic.

One of the major problems hindering improved stock assessment for white marlin was thought to result from changes in fishing strategy for the Japanese Atlantic longline fleet in the mid- to late- 1970's. This problem was addressed at the Second ICCAT Billfish Workshop held in Miami in 1992 (ICCAT, in press) by Nakano et al. (SCRS/92/63). They standardized white marlin CPUEs from the Japanese Atlantic longline fishery using a General Linear Model - GLM (SAS 1991) and the Honma (1974) method. This permitted standardized CPUE indices for white marlin to be presented for the entire historical time series, 1960-1989, (Uozumi and Nakano, SCRS/92/65) while accounting for changes in fleet effort and deployment patterns. Additional workshop documents by Farber et al. (SCRS/92/62) and Gaertner and Alio (SCRS/92/74) provided white marlin CPUE indices for the U.S. and Venezuelan recreational fisheries, respectively. White marlin longline fisheries off the Brazilian coast were analyzed by Antero-Silva et al. (SCRS/92/51), with the actual nominal catch and effort series made available to the Workshop Working Group by the Brazilian scientist[4] in attendance.

An exploratory stock assessment analysis using a non-equilibrium stock-production model (ASPIC) for blue marlin (*Makaira nigricans*) and white marlin fisheries in the North Atlantic was presented at the Workshop (Cramer and Prager, SCRS/92/69). They found the white marlin estimates of MSY in the North Atlantic highly variable and unrealistically high. Their tentative conclusion was that the white marlin stock in the North Atlantic is heavily overexploited at some unknown degree.

Because white marlin longline catches are a bycatch of tuna- and swordfish-directed longline fisheries, the databases have been plagued by a continued multitude of problems. These include non-reporting of landings, lumping of two or more billfish species into an "unclassified" billfish category, likely misidentification of the species, and deficiencies in size data. White marlin are often the target species in recreational (i.e., sport or trolling) fisheries where they would generally not be processed commercially. This makes estimation of the total recreational catch (the actual landings plus dead discards from fish released) extremely difficult.

The present analysis takes advantage of the significantly revised white marlin database developed during the 1992 Workshop. Appropriate data (such as catch-at-age) and sufficient knowledge of the life history, ecology, and biology of the species are still not available at this time to attempt yield per recruit (YPR) or virtual population analysis (VPA). Improvements in production modeling techniques, which allow inclusion of multiple fisheries data for fitting and which do not require equilibrium assumptions for modeling the stock biomass dynamics, provide a methodology for reassessing the stock status of white marlin using recently updated information on fleet-specific catch and effort. We used ASPIC (Prager 1992) to explore stock-production estimates from the most recent white marlin data available.

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2. DATA AND METHODS

This exploratory analysis uses a non-equilibrium approach termed ASPIC – A Stock-Production model Incorporating Covariates (Prager 1992) to fit a logistic production model to yearly yield (catch in weight, mt) and effort, f, data. This model extends classical stock-production modeling by allowing simultaneous analysis of multiple data series, which may be different in kind. The latest version of ASPIC allows for minimizing error in effort under the assumption that catch is known without error[5]. Catch statistics are generally more reliable than those of effort particularly for a commercial fishery where a relationship exists between catch and monetary income. Therefore, this approach is more realistic and is considered to be a more appropriate statistical model. Additionally, we used the Iteratively Reweighting Fit (IRF) mode available for this version that repeatedly adjusts data series weights and provides an asymptotically maximum likelihood result. A bootstrapping technique provides estimates of the variability of parameter values estimated by the model, and was used to provide approximate confidence limits for relative biomass trajectories conditional on the model assumptions. The detailed theory and mechanics of ASPIC are fully described in Prager (1991, 1992).

We initially investigated the use of available standardized CPUE series (Figs. 1a,b,c) to derive estimates of f by calculating f= catch (number of fish, #)/CPUE. For the Japanese, Taiwanese, and Brazilian longline and the U.S. recreational data series, the CPUEs were standardized using GLMs, with units in number of white marlin caught per unit of effort – hooks for the longline data and hours trolling for the U.S. data. Appropriate data sets were developed to explore ASPIC results under the two stock structure hypotheses noted previously for the 30-year period 1961-1990. This methodology proved invalid, with the model either not converging to any solution or the fit being extremely poor with unreasonable parameter estimates.

A plot of the ratio of yearly catch (mt)/catch(#) for both the North Atlantic and South Atlantic data gave insight into why this approach was failing. This ratio represents the average weight of individual fish in the catch, w, for white marlin and was based on ICCAT Task I (mt) statistics (Appendix 1) and Task II (#) statistics (ICCAT, in press). These w's exhibited great variability and for many years were unrealistically high indicating inconsistency between Task I and Task II statistics for white marlin. We chose an alternative method of estimating f based on catch in weight which we assumed was a more reliable statistic than the catch in number. Equating f to the ratio of catch (mt)/CPUE (#/unit effort) is valid under the assumption that the average weight of white marlin is constant over the time period being considered. The values of f for all longline fisheries were derived using the CPUE series from the Japanese fleet.

The historical Japanese longline data series was considered to represent two distinct fisheries: the earlier 1961-1979 period using regular longline techniques, and the more recent 1980-1990 period using deep longline techniques. The differences between methods are detailed in Uozumi and Nakano (SCRS/92/65) and basically refer to the gear configuration and deployment which corresponded to changes in target species and spatial changes in effort. The annual catch (mt) from all longline fisheries was combined and divided by the standardized CPUE series from the Japanese longline fishery. This ratio generated f which was used as input data to the model along with the total annual catch (mt) (Appendix 1). The general relationship between the annual standardized CPUEs from the Japanese longline fishery and the combined yields (mt) from all fisheries is graphically demonstrated in Figures 2a,b,c. Large fluctuations are evident in these CPUE series from 1961 through 1965. Therefore, the North Atlantic final model began with 1966 longline data and included the U.S. recreational (rod and reel) fishery for 1973-1990 and from the Venezuelan recreational fishery for 1966-1990. For the U.S. data series, yearly standardized CPUE indices and a smoothed time-series of average weights[6], w, were used to estimate annual yield (mt) per unit effort, YPUE, for 1973-1990 (YPUE= w*CPUE). No CPUE data were available for the U.S. recreational fishery prior to 1973. The estimated effort series was produced from

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[5] The latest version is 3.05, September 14, 1992, and will be available from the author at some future time. It is still considered exploratory at this time. The earlier version of ASPIC used by Cramer and Prager (1992) only allowed calculations based on minimizing error in catch under the assumption of effort being known without error.

[6] Obtained from the National Marine Fisheries Service (NMFS), Southeast Fisheries Science Center (SEFSC), Miami, Florida, tagging database.

f= yield (mt)/YPUE. For the Venezuelan data, standardized fishing effort (number of trips) was directly available from Gaertner and Alio (SCRS/92/74).

For the South Atlantic analysis, the procedure used for the North Atlantic database was followed to generate multiple data series for the longline fisheries beginning with 1961 data and included a separate Brazilian longline CPUE series for the period 1971 to 1990. For the total Atlantic analysis, all annual yields (mt) are the arithmetic sums of the North Atlantic and South Atlantic data series. The annual catch (mt) from all longline fisheries Atlantic-wide for 1966-1990, excluding the Brazilian longline fishery, was combined and divided by the standardized CPUE series from the Japanese longline fishery. The Venezuelan, U.S., and Brazilian data are as described above.

3. RESULTS

We analyzed the data using the ASPIC model under the two stock structure hypotheses of separate North Atlantic and South Atlantic white marlin stocks, and a total Atlantic-wide stock. Results are presented separately under each of these hypotheses. The parameters estimated for this study were:

B_1 Biomass (mt) at the beginning of the first year;
K Biological carrying capacity; i.e., maximum stock size (mt);
r Biological yearly intrinsic rate of increase of the stock; and
q(i) Catchability coefficients for each of the individual i data series.

The derived quantities of most interest were:

MSY Maximum sustainable yield (mt) per year (= Kr/4);
B_{MSY} Stock biomass (mt) at MSY (= K/2); and
F_{MSY} Fishing mortality rate at MSY (= r/2).

Production models tend to estimate relative levels of biomass and fishing mortality rates better than absolute levels (Prager 1991). For this reason graphical results are presented in terms of ratios relative to MSY estimates: annual median biomass ratios, B/B_{MSY} (Figs. 3a,b,c), and fishing mortality ratios, F/F_{MSY} (Figs. 4a,b,c). Nonparametric 80% confidence intervals about the median relative biomass estimates are incorporated in Figures 3a,b,c. The distribution of MSY estimates generated by the bootstrap demonstrate the precision of the model (Figs. 5a,b,c). These values are very different from those of Farber and Conser (1983). This discrepancy is discussed later. Plots of annual observed (actually calculated) effort, f, and estimated effort are presented for the combined longline fisheries, as described in Data and Methods (Figs. 6a,b,c).

3.1 North Atlantic

The model generated point estimates of MSY = 593 mt, B_{MSY} = 5,545 mt, and F_{MSY} = 0.107 (Table 1a). The fifth and ninety-fifth percentile bootstrapped MSY values give approximate 90% nonparametric confidence limits. For 999 replications these bounds correspond to 388 mt and 921 mt, respectively, with a median value of 651 mt (Fig. 5a). The approximate 90% interval on B_{MSY} ranges from 3,853 mt to 11,690 mt, with a median of 5,634 mt. A plot of the annual median relative biomass generated by bootstrapping indicates a declining stock over the period 1966-1991 (Fig. 3a). The estimated relative biomass was less than 1.0 for all years after 1974, and was estimated at the start of 1991 to be 57% of that biomass that could produce MSY, i.e., B_{1991}/B_{MSY} = 0.57 (Appendix 2). The estimated total annual fishing mortality, F, shows considerable annual variability (Appendix 2 and Fig. 4a). Results of the model fit show the ratio of F/F_{MSY} was greater than 1.0 over the period 1969-1988 except during 1978-1980 when it was slightly below 1.0, and was estimated to be decreasing (and below 1.0) during 1989-1990.

Effort residuals were generally balanced with no apparent trends and without extreme magnitudes. A plot of estimated versus observed effort shows that the model (predicted values) was responsive to the input (observed) values (Fig. 6a).

3.2 South Atlantic

The model generated point estimates of MSY = 1,789 mt, B_{MSY} = 10,870 mt, and F_{MSY} = 0.165 (Table 1b). The approximate 90% nonparametric confidence bounds on MSY, generated from 199 bootstraps, correspond to 739 mt and 2,282 mt, respectively, with a median value of 1,887 mt (Fig. 5b). The approximate 90% interval on B_{MSY} ranges from 5,512 mt to 14,950 mt, with a median of 10,730 mt. The median relative biomass was less than 1.0 for the entire time series and exhibits a declining trend to low levels (Fig. 3b). From this model fit, the estimated biomass at the start of 1991 was 3% of that which could produce MSY (Appendix 3). Estimates of relative fishing mortality F/F_{MSY} were greater than 1.0, exhibiting variability without trend over the period 1962-1982, and then increased sharply from 1.0 to very high levels (> 8.0) over the period 1983-1990 (Fig. 4b).

Effort residuals were reasonably balanced with no apparent trends and without extreme magnitudes. A plot of estimated versus observed effort shows that the model was responsive in tracking effort (Fig. 6b).

3.3 Total Atlantic

The model generated point estimates of MSY = 1,644 mt, B_{MSY} = 4,368 mt, and F_{MSY} = 0.753 (Table 1c). The approximate 90% nonparametric confidence bounds on MSY, generated from 199 bootstraps, correspond to 1,502 mt and 1,741 mt, respectively, with a median value of 1,666 mt (Fig. 5c). The approximate 90% interval on B_{MSY} ranges from 3,883 mt to 5,875 mt, with a median of 4,407 mt. A plot of the annual median relative biomass indicates a declining stock over the period 1966-1977, followed by an increase through the mid-1980s, and then decreasing again through 1991 (Fig. 3c). The median relative biomass was less than 1.0 for all years after 1972, with the estimated biomass at the start of 1991 at 25% of that which could produce MSY (Appendix 4). The estimates of relative fishing mortality F/F_{MSY} were greater than 1.0 for all years after 1969, with variability and periods of both increasing and decreasing trend (Fig. 4c).

Effort residuals were reasonably balanced with no apparent trends and without extreme magnitudes. A plot of estimated versus observed effort shows that the model was responsive in tracking effort (Fig. 6c).

4. DISCUSSION

Assessments of Atlantic white marlin in the early 1980s generally showed a precipitous decline in the stock(s) biomass from the early 1960s through 1980 and indicated that white marlin were at least fully exploited in the best case and overexploited in the worst case. Analyses were based on the two stock structure hypotheses detailed earlier. Significant uncertainties were expressed due to shortcomings in the available database and lack of knowledge concerning the life history and biology of the species. These assessments used the Japanese longline CPUE series to estimate effective fishing effort and then applied an equilibrium production model (Fox 1975) to generate point estimates of MSY and F_{MSY} under several hypotheses. Those production models historically have not fit white marlin data very well.

White marlin CPUE trends were recently examined at the 1992 ICCAT Billfish Workshop (ICCAT, in press). The Working Group "recommended that updated assessment analyses of white marlin be conducted in the near future." This exploratory analysis follows that recommendation and the subsequent revision of the billfish database. It is a continuation of previous white marlin stock assessments under the same stock structure hypotheses. The primary differences are that this analysis includes an additional 10 years of data and it uses a more flexible model (ASPIC). This model is especially useful because it does not assume equilibrium, it allows direct incorporation of multiple data series, and it allows for missing effort in some years to be estimated while the model minimizes the error in effort. These characteristics allow a more extensive use of the Atlantic-wide white marlin database and are particularly important because the Japanese longline white marlin bycatch during the last two decades represents a progressively smaller percentage of the total longline catch. Nevertheless, the general results from ASPIC, in conjunction with multiple CPUE series exhibiting year-to-year declines to very low levels (Fig. 2a,b,c), are very similar to stock assessment results reported previously that suggested overexploitation.

It must be emphasized that more definitive conclusions cannot be reached until sensitivity analyses, recommended at the 1992 Billfish Workshop (ICCAT, in press), are explored. Results were not robust due to extreme sensitivity in years included in the model and the starting weights used for the individual data series that were iteratively re-weighted. Further, Prager (1991) found that ASPIC model results are imprecise for the first 3 to 5 years of the data series. Therefore, implications should not be drawn based on the first few years of results from ASPIC. Additionally, the 1992 Billfish Working Group noted concerns about the accuracy of landings data and whether this assumption was adequately fulfilled. Therefore, the implications of systematic errors in annual landings need to be evaluated in terms of their effect on the behavior of the model. Sensitivity analyses should be conducted to generate confidence intervals under various assumptions; e.g., catches were under- or over-reported by 25%, 50%, or even 100%.

The point estimates for MSY (Table 1) generated from ASPIC are lower than a prior production model assessment of white marlin done under various hypotheses (Farber and Conser 1983). The MSY estimates from that study were: North Atlantic – 2,092 - 3,776 mt; South Atlantic – 2,579 - 2,672 mt; and total Atlantic – 6,230 - 6,286 mt. Results of the present analysis, using the revised and expanded databases, seem to be in better agreement with the observed patterns of CPUE and catch (mt) over the past 15 to 20 years (Figs. 2a,b,c). White marlin have been harvested at levels well below the MSY estimates of Farber and Conser (1983).

The present study incorporated data beginning in 1961 for the South Atlantic database and 1966 for the North Atlantic and total Atlantic databases. The North and total Atlantic models did not converge to a solution when previous years were included. This may be due to extreme fluctuation of the Japanese longline CPUE series during the 1961 to 1965 period (Fig. 1a and 1c). The South Atlantic model did converge when the early Japanese longline CPUE series was included (Fig. 1b). This may be due to the Japanese South Atlantic longline data simply increasing rapidly and then decreasing rapidly over the period 1961-1965 without exhibiting the high variability present in the North and total Atlantic CPUE data. The assessments for the North Atlantic and total Atlantic appear conservative because they exclude the period of very high CPUEs that exhibited rapid decline by the later 1960s.

4.1 North Atlantic

The estimated results in the relative biomass trajectories indicates that under the separate North/South hypothesis, the white marlin stock in the North Atlantic appears to be below MSY levels which could produce since 1974 (Fig. 3a). The associated estimates of relative fishing mortality indicate fishing has been generally above the MSY rate from 1969 through 1988, except when it was slightly below during the period 1978-1980 (Fig. 4a). The decreasing F/F_{MSY} during 1988-1990 (Fig. 4a) reflects the apparent upturn in relative biomass estimates during recent years (Fig. 3a).

We feel the apparent effort outlier in 1983 (Fig. 2a, 2c, and 6a) was due to the longline catch reported by Cuba in 1983 which appears questionable (Appendix 1). The reported value was the highest in the 30-year time series, and was more than 3-times the reported catch in 1982 or 1984. In 1983, that value dominated the total longline catch (plus minor catches from "other and unclassified" gears not including rod and reel), which in turn was divided by the low 1984 Japanese CPUE to give the observed effort.

4.2 South Atlantic

The estimated trajectory of relative biomass in the South Atlantic was similar to the North Atlantic and indicates that the white marlin stock in the South Atlantic appears to be below the level which could produce MSY since 1961 (Fig. 3b). The upper 80% confidence bound is below $B/B_{MSY}= 1.0$ after 1965.

The associated relative fishing mortality trend indicates fishing has been above the MSY level from 1962 through 1982, and then again from 1985 through 1990 (Fig. 4b). The increasing F/F_{MSY} during recent years (Fig. 4b) may be reflecting the apparent downturn in relative biomass estimates during recent years (Fig. 3b).

The Japanese longline catch in 1974 and 1975 were reported to be 9 mt and 14 mt, respectively (Appendix 1). Those yields were very low when compared to the total longline catch for the South Atlantic. This would make the Japanese longline CPUEs for those years (used to calculate effort) questionable as being representative of the total longline catch. In 1976, the Japanese reported catch was at an all-time low of 3 mt. The associated CPUE was an order of magnitude lower than any other year during the period 1974 to 1979. The effort calculated for 1986 was an extreme outlier and was not included with the input data series.

4.3 Total Atlantic

The estimated trajectory of relative biomass indicates that under the total Atlantic hypothesis, the white marlin stock in the North Atlantic appears to be below MSY levels since 1972 (Fig. 3c). The associated relative fishing mortality trend indicates fishing has been above the level which could produce MSY since 1969, and has exhibited a variable but increasing trend over the period 1984 through 1990 (Fig. 4c). The general pattern for B/B_{MSY} was very similar to that generated from the North Atlantic database. The observed effort represents a composite of the North and South Atlantic, with the trend being more similar to the North Atlantic through the mid-1980s and then the South Atlantic through 1989 (Fig. 6c).

5. CONCLUSIONS

The current assessment represents substantial progress in analyzing the status of the white marlin stock(s) in the Atlantic Ocean. The application of the non-equilibrium model ASPIC permits the incorporation of all available data, giving a more complete representation of the stock(s) than previous assessments which relied exclusively on the Japanese longline database. This is particularly important because the Japanese longline database represents an increasingly smaller percentage of the white marlin landings during the most recent years. The trends described here are similar to those described in past assessments and indicate that Atlantic white marlin are at least fully exploited with a strong possibility of substantial overexploitation during the last 17 to 20 years. The results justify continued concern about the status of the Atlantic white marlin stock(s). However, further sensitivity analyses need to be performed to give insight into how the results vary under differing assumptions and to clarify conclusions that can be drawn from these findings.

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Table 1. Results of the ASPIC production model analysis using the (a) North Atlantic, (b) South Atlantic, and (c) total Atlantic databases. The median estimates are obtained from a bootstrap procedure with: (a) 999 replications, and (b and c) 199 replications. The "Nonparametric standard error" is the range between the 31st and 69th percentiles; a range that would be one standard deviation of a normal population. The "Nonparametric coefficient of variation" is the nonparametric standard error divided by the median.

(a) North Atlantic

Quantity	Ordinary Estimate	Bootstrap Median	Nonparam. Std. Error	Nonparam. Coeff. Var.
MSY (mt)	593	651	119.5	18.35%
B_{MSY} (mt)	5,545	5,634	1,605	28.48%
F_{MSY}	0.1069	0.1170	0.0468	40.03%

(b) South Atlantic

Quantity	Ordinary Estimate	Bootstrap Median	Nonparam. Std. Error	Nonparam. Coeff. Var.
MSY (mt)	1,789	1,887	299.1	15.85%
B_{MSY} (mt)	10,870	10,730	1,222	11.39%
F_{MSY}	0.1646	0.1721	0.0226	13.15%

(c) Total Atlantic

Quantity	Ordinary Estimate	Bootstrap Median	Nonparam. Std. Error	Nonparam. Coeff. Var.
MSY (mt)	1,644	1,666	40.83	2.45%
B_{MSY} (mt)	4,368	4,407	351.4	7.97%
F_{MSY}	0.3764	0.3762	0.0324	8.62%

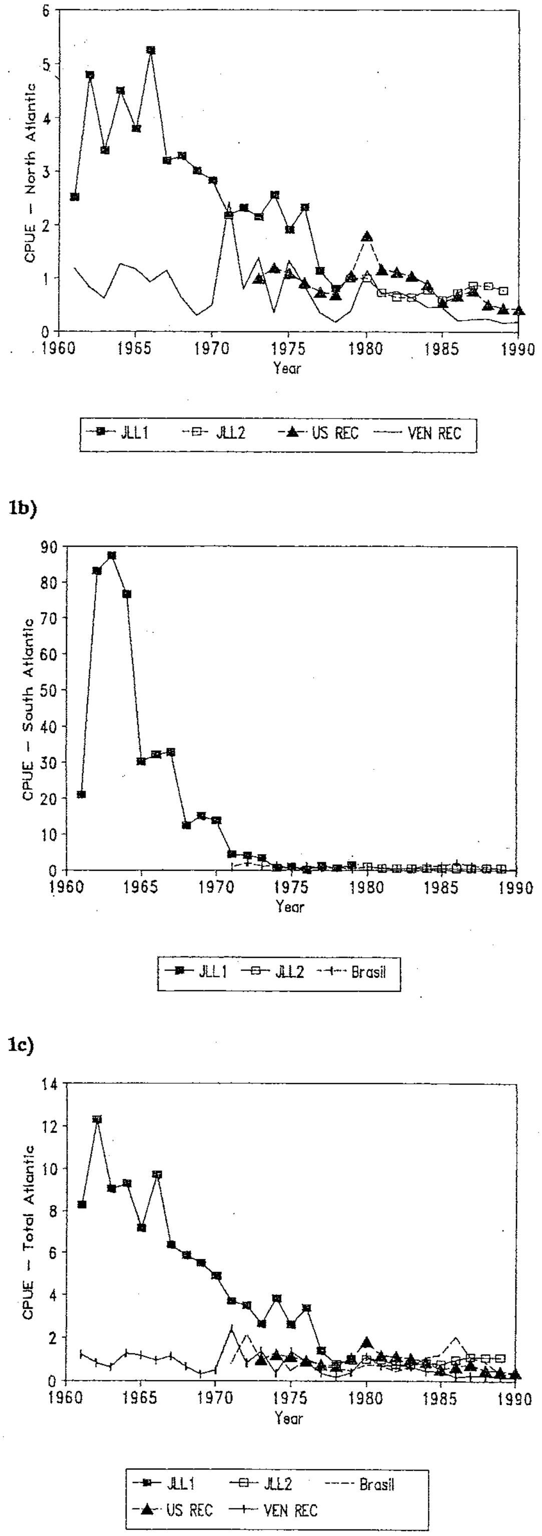

Figure 1 Historical standardized CPUE series for white marlin fisheries: (a) North Atlantic — Japanese longline 1961-1979 (JLL1) and 1980-1989 (JLL2), U.S. recreational (rod and reel) 1973-1990, Venezuelan recreational 1961-1990; (b) South Atlantic fisheries — JLL1, JLL2, and Brazilian longline 1971-1990; and (c) total Atlantic — JLL1, JLL2, Brazil, U.S., and Venezuela.

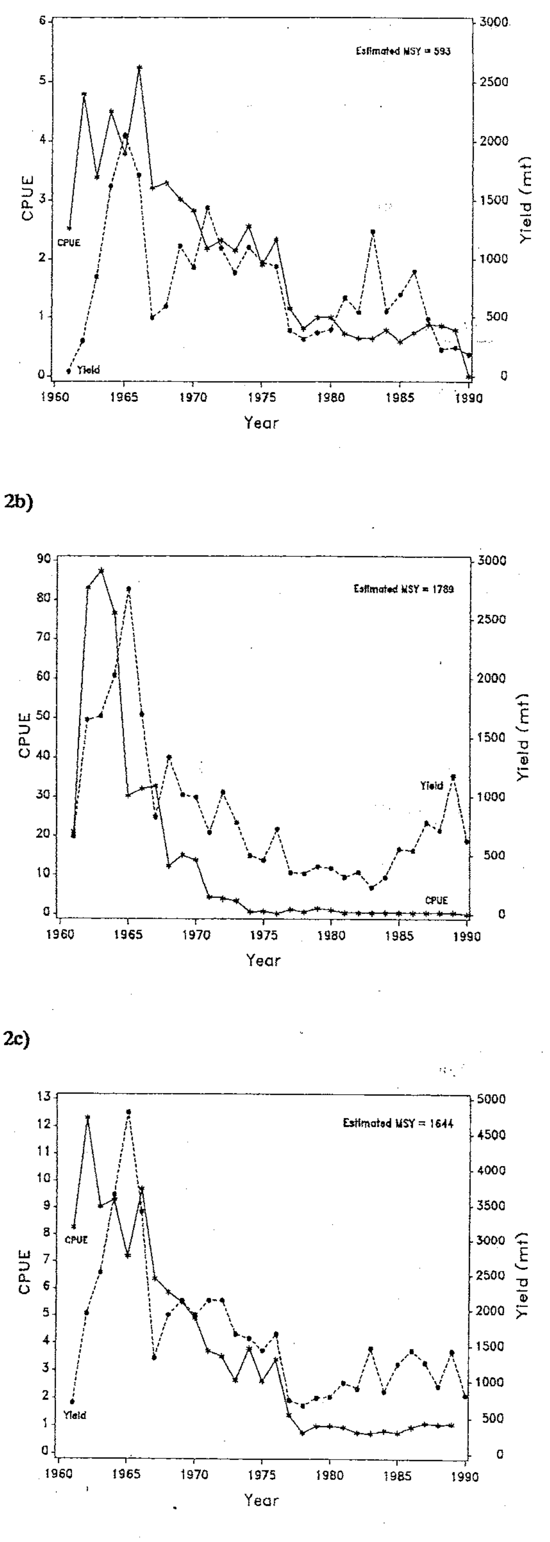

Figure 2 Japanese longline standardized CPUE series and total yield (mt) for all white marlin fisheries from the (a) North Atlantic, (b) South Atlantic, and (c) total Atlantic.

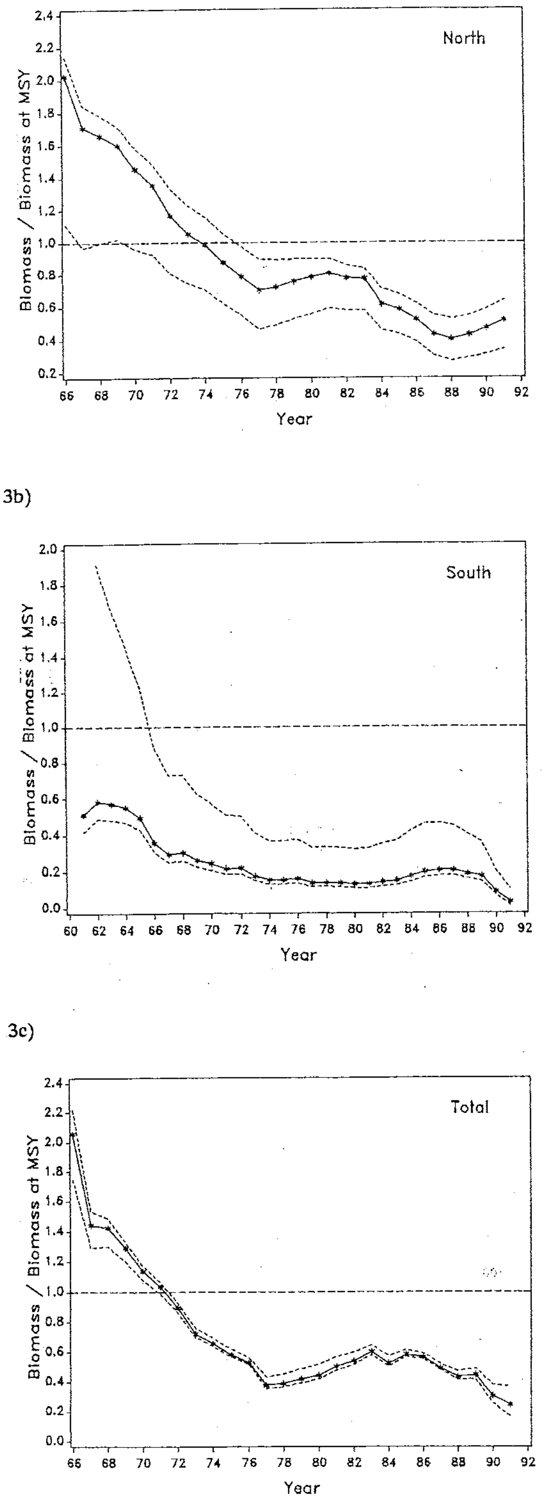

Figure 3. Bootstrapped median relative biomass trajectories with approximate nonparametric 80% confidence intervals for white marlin fisheries from the (a) North Atlantic, (b) South Atlantic, and (c) total Atlantic. Results are imprecise for the first 3 to 5 years of the time-series.

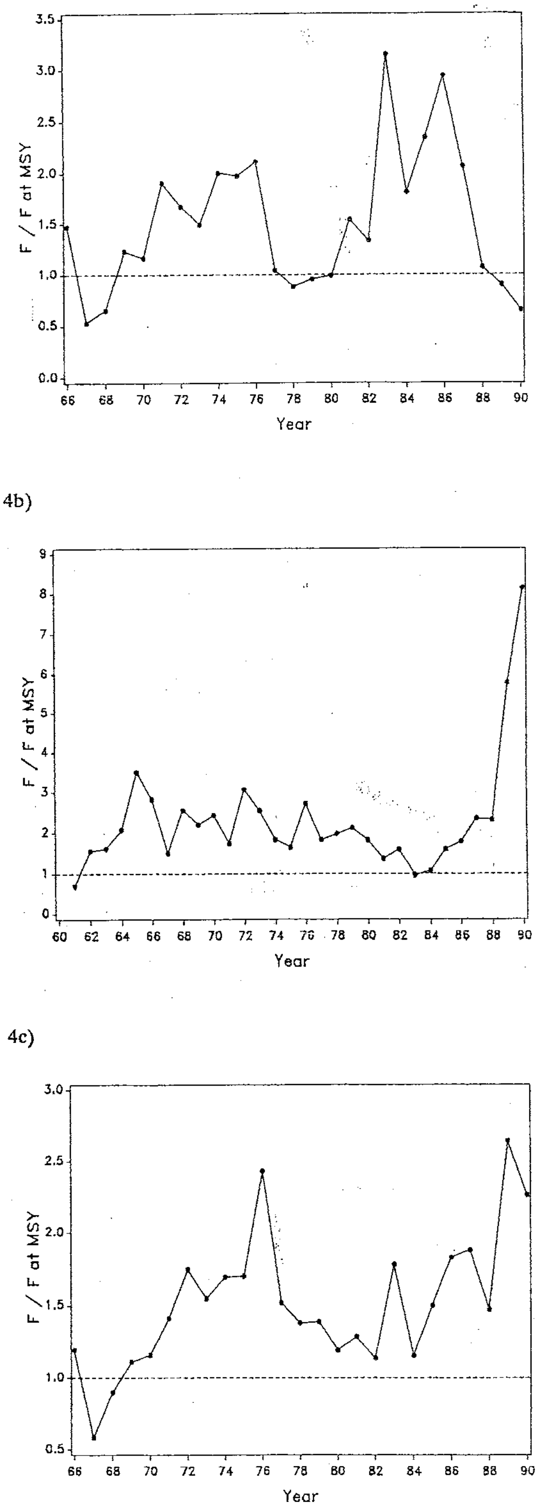

Figure 4. Relative fishing mortality trajectories for white marlin fisheries from the (a) North Atlantic, (b) South Atlantic, and (c) total Atlantic.

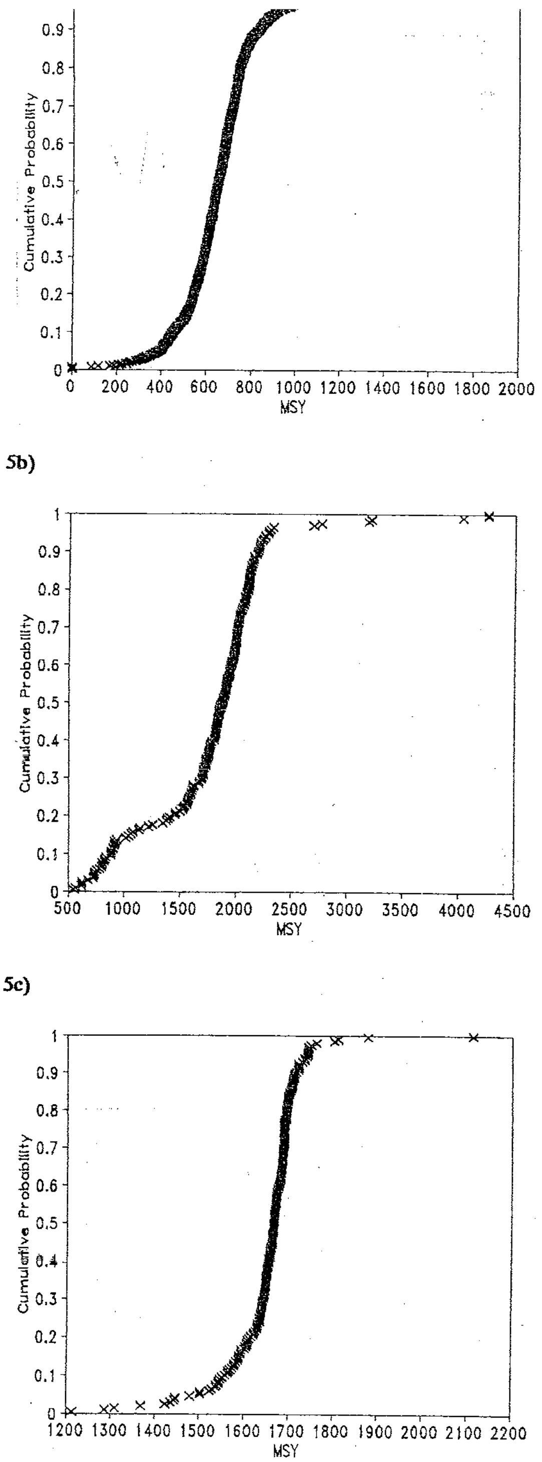

Figure 5. Distribution of estimates of MSY from bootstrap trials for white marlin fisheries: (a) North Atlantic — 999 replications with 5th, 50th (median), and 95th percentiles corresponding to 388mt, 651mt, and 921mt, respectively; (b) South Atlantic — 199 replications with 5th, 50th (median), and 95th percentiles corresponding to 739mt, 1,887mt, and 2,282mt, respectively; and (c) total Atlantic — 199 replications with 5th, 50th (median), and 95th percentiles corresponding to 1,502mt, 1,666mt, and 1,741mt .

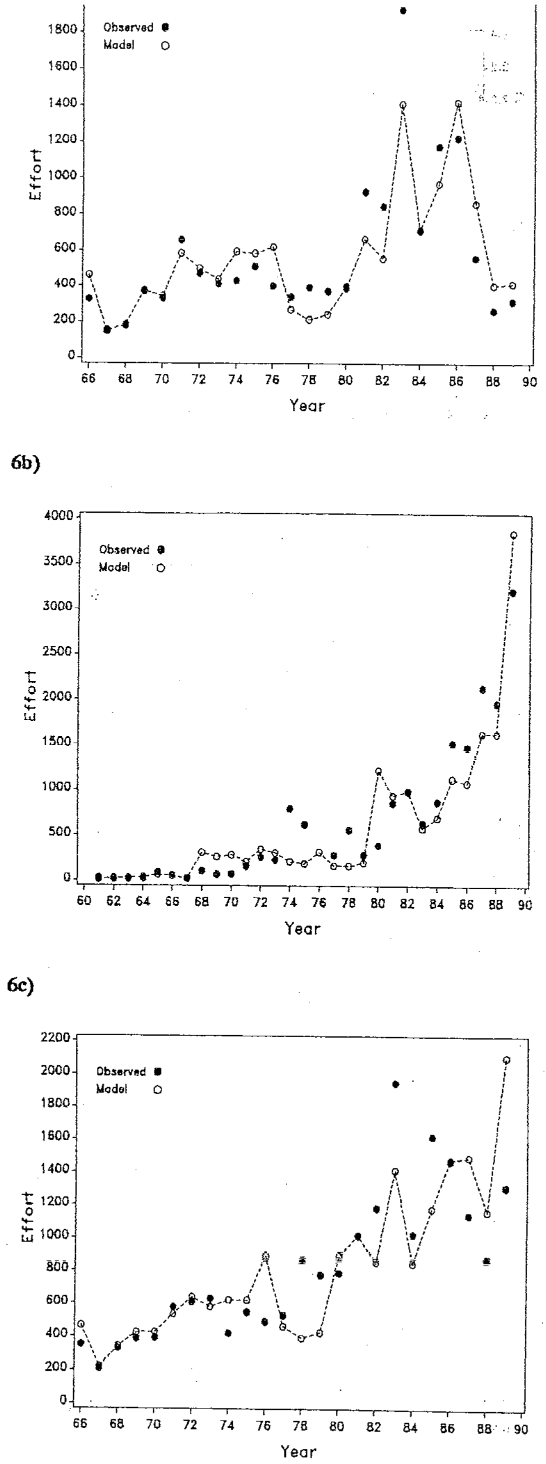

Figure 6. Plots of annual observed (actually calculated) effort, , and estimated effort from the ASPIC model for combined longline white marlin fisheries from the (a) North Atlantic, (b) South Atlantic, and (c) total Atlantic. Observed effort was calculated from the ratio of the total longline catch (mt) to the standardized Japanese longline CPUE series (number of fish per hooks). The period 1980-1990 included minor catches from "other and unclassified" gears, excluding rod and reel.

Appendix 1. White marlin catch (mt) from ICCAT Task I statistics.

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
TOTAL	830	2064	2614	3735	4906	3512	1426	2047	2254	2097	2258	2341	1784	1754	1576	1817	979	941	1015	958	1132	1092	1677	1077	1447	1617	1453	1085	1632	1042
NORTH ATLAN	108	381	914	1694	2127	1798	588	692	1212	1048	1547	1208	995	1218	1088	1052	501	428	481	508	780	653	1382	702	842	928	583	302	267	210
-LONGLINE	41	302	848	1620	2048	1711	497	594	1114	932	1440	1099	886	1103	977	938	390	317	370	396	669	543	1236	549	693	893	484	202	245	187
CANADA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
CHITAIW	0	1	4	3	2	32	47	58	132	97	178	244	120	248	84	142	44	79	62	105	174	130	203	52	100	319	153	-1	4	15
CUBA	0	0	35	45	69	118	127	103	58	61	45	34	112	256	294	68	67	43	68	70	189	205	728	241	296	225	30	13	21	-2
JAPAN	30	271	754	1493	1913	1417	174	273	451	419	915	339	328	381	404	540	80	27	42	99	118	84	27	52	45	56	60	68	73	15
KOREA	0	0	0	1	1	51	44	52	204	340	219	213	106	90	71	64	71	33	16	12	48	12	28	8	79	42	3	1	24	75
PANAMA	0	0	0	0	0	0	0	0	0	-2	-2	10	48	14	10	17	20	8	1	0	0	0	0	0	0	0	0	0	0	0
ESPANA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	14	0	0	0	13	4
USA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	39	11	103	89	82	72	40
USSR	0	0	0	0	0	0	1	1	1	0	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VENEZUEL	11	30	55	78	63	93	104	107	268	15	82	258	170	114	113	107	108	127	181	110	140	112	230	148	148	148	148	38	38	38
-ROD & REEL	67	79	66	74	79	87	91	98	98	116	107	109	109	115	111	114	111	111	111	112	111	110	145	150	148	34	97	75	21	22
USA	60	74	64	70	76	76	81	87	76	104	95	99	104	108	107	109	109	109	109	109	109	109	141	143	141	31	91	72	16	17
VENEZUEL	7	5	2	4	3	11	10	11	22	12	12	10	5	7	4	5	2	2	2	3	2	1	4	7	7	3	6	3	5	5
-OTHER & UNC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	1	3	1	1	2	25	1	1
BERMUDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	1	1	-1	1	1	1	1	1
ESPANA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0
USA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	-2	1	-1	0	0
SOUTH ATLANT	722	1683	1700	2041	2779	1714	838	1355	1042	1049	711	1133	789	536	488	765	478	513	534	450	352	439	295	375	605	689	870	783	1365	832
-LONGLINE	722	1683	1700	2041	2779	1714	838	1355	1042	1049	711	1133	789	536	488	740	475	511	530	447	352	439	295	375	601	663	864	694	1276	743
ARGENTIN	0	0	0	0	0	0	3	14	0	-2	20	100	57	-1	2	2	2	-2	0	0	0	0	0	0	0	0	0	0	0	0
BRASIL	60	34	17	17	17	17	9	21	24	54	15	94	10	36	31	41	126	165	129	58	36	82	66	60	49	146	86	67	181	204
CHITAIW	0	5	10	3	2	29	134	327	436	469	260	469	412	279	255	377	119	197	155	145	136	220	87	66	134	196	613	514	979	372
CUBA	0	0	9	17	33	23	67	15	7	8	4	6	21	48	55	38	57	127	205	212	116	45	112	153	216	192	62	24	22	-2
JAPAN	662	1644	1664	2002	2718	1585	494	815	392	284	65	101	27	9	14	3	26	14	15	7	25	27	17	24	81	73	74	76	73	54
KOREA	0	0	0	2	7	58	125	157	177	230	341	332	165	139	109	220	111	5	24	25	37	60	13	18	121	56	29	12	20	112
PANAMA	0	0	0	0	0	0	0	0	0	-2	-2	16	75	22	16	59	31	1	2	0	0	0	0	0	0	0	0	0	0	0
URUGUAY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	54	0	0	0	1	1	1
USSR	0	0	0	0	2	2	6	6	6	4	6	15	22	3	6	0	3	2	0	0	1	0	0	0	0	0	0	0	0	0
-OTHER & UNC	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	25	3	2	4	3	-1	-1	-1	-1	4	26	6	89	89	89
ARGENTIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0
BRASIL	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	25	3	2	4	3	-1	-1	-1	-1	-1	-1	0	1	1	1
GHANA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	6	88	88	88
UNCL REGION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-LONGLINE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-OTHER & UNC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

-1 CATCH: < -.5 MT

Appendix 2. **Analysis of white marlin data from the North Atlantic. The ASPIC model (vers. 3.05) minimized error in effort while assuming catch (mt) was known without error. Iterative re-weighting fitting procedure generated annual values of estimated fishing mortality (F), biomass estimates, observed yield, and estimated relative biomass indices (B/BMSY).**

North Atlantic

Year	Estimated Total F mort	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Ratio of Biomass to BMSY
1966	0.158	12340	11350	1798	2.2260
1967	0.057	10480	10260	588	1.8900
1968	0.070	10060	9822	692	1.8140
1969	0.132	9604	9149	1212	1.7320
1970	0.125	8733	8414	1048	1.5750
1971	0.204	8119	7577	1547	1.4640
1972	0.179	7084	6750	1208	1.2780
1973	0.160	6440	6228	995	1.1610
1974	0.214	6029	5704	1218	1.0870
1975	0.211	5403	5145	1088	0.9744
1976	0.226	4904	4660	1052	0.8845
1977	0.112	4430	4465	501	0.7989
1978	0.094	4499	4573	428	0.8114
1979	0.102	4646	4695	481	0.8379
1980	0.106	4744	4781	508	0.8556
1981	0.165	4818	4715	780	0.8689
1982	0.143	4617	4578	653	0.8327
1983	0.337	4539	4105	1382	0.8187
1984	0.194	3709	3617	702	0.6690
1985	0.251	3529	3353	842	0.6364
1986	0.315	3187	2946	928	0.5747
1987	0.221	2721	2644	583	0.4907
1988	0.115	2569	2632	302	0.4633
1989	0.096	2696	2785	267	0.4862
1990	0.070	2875	3004	210	0.5185
1991		3133			

Appendix 3. **Analysis of white marlin data from the South Atlantic. The ASPIC model (vers. 3.05) minimized error in effort while assuming catch (mt) was known without error. Iterative re-weighting fitting procedure generated annual values of estimated fishing mortality (F), biomass estimates, observed yield, and estimated relative biomass indices (B/BMSY).**

South Atlantic

Year	Estimated Total F mort	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Ratio of Biomass to BMSY
1961	0.115	5881	6252	722	0.5411
1962	0.258	6625	6534	1683	0.6096
1963	0.268	6447	6334	1700	0.5932
1964	0.346	6225	5902	2041	0.5727
1965	0.583	5599	4770	2779	0.5151
1966	0.466	4043	3674	1714	0.3720
1967	0.248	3334	3385	838	0.3067
1968	0.423	3437	3202	1355	0.3162
1969	0.363	2981	2868	1042	0.2742
1970	0.402	2758	2608	1049	0.2538
1971	0.288	2465	2470	711	0.2268
1972	0.509	2475	2228	1133	0.2277
1973	0.418	2000	1886	789	0.1840
1974	0.301	1778	1779	536	0.1636
1975	0.270	1780	1809	488	0.1638
1976	0.447	1838	1712	765	0.1691
1977	0.299	1592	1597	478	0.1465
1978	0.323	1601	1587	513	0.1473
1979	0.346	1573	1541	534	0.1447
1980	0.297	1510	1517	450	0.1389
1981	0.221	1525	1591	352	0.1403
1982	0.259	1658	1696	439	0.1526
1983	0.158	1734	1865	295	0.1596
1984	0.176	2001	2127	375	0.1841
1985	0.264	2257	2292	605	0.2077
1986	0.296	2327	2325	689	0.2141
1987	0.393	2322	2212	870	0.2137
1988	0.389	2106	2014	783	0.1938
1989	0.971	1925	1406	1365	0.1771
1990	1.336	992.4	622.9	832	0.0913
1991		359.4			

Appendix 4. **Analysis of white marlin data from the Total Atlantic. The ASPIC model (vers. 3.05) minimized error in effort while assuming catch (mt) was known without error. Iterative re-weighting fitting procedure generated annual values of estimated fishing mortality (F), biomass estimates, observed yield, and estimated relative biomass indices (B/BMSY).**

Total Atlantic

Year	Estim Total F mort	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Ratio of Biomass to BMSY
1966	0.450	9528	7804	3512	2.1820
1967	0.220	6584	6490	1426	1.5070
1968	0.338	6413	6055	2047	1.4680
1969	0.419	5762	5377	2254	1.3190
1970	0.436	5061	4806	2097	1.1590
1971	0.531	4590	4256	2258	1.0510
1972	0.657	3972	3562	2341	0.9095
1973	0.582	3215	3064	1784	0.7362
1974	0.638	2928	2750	1754	0.6704
1975	0.640	2592	2464	1576	0.5935
1976	0.914	2347	1989	1817	0.5374
1977	0.572	1684	1713	979	0.3855
1978	0.519	1741	1812	941	0.3986
1979	0.522	1881	1943	1015	0.4306
1980	0.449	2003	2131	958	0.4586
1981	0.484	2257	2337	1132	0.5168
1982	0.428	2414	2549	1092	0.5526
1983	0.670	2680	2504	1677	0.6136
1984	0.435	2347	2478	1077	0.5373
1985	0.565	2606	2563	1447	0.5966
1986	0.688	2522	2351	1617	0.5774
1987	0.707	2198	2056	1453	0.5031
1988	0.554	1928	1957	1085	0.4413
1989	0.993	1985	1643	1632	0.4546
1990	0.851	1355	1224	1042	0.3103
1991		1105			