

EXPLORATORY STOCK-PRODUCTION MODEL ANALYSIS OF BLUE MARLIN AND WHITE MARLIN IN THE SOUTH ATLANTIC OCEAN

Christopher D. Jones¹ and Mark I. Farber¹

SUMMARY

Blue marlin (Makaira nigricans) and white marlin (Tetrapturus albidus) catch and effort data were analyzed using a non-equilibrium stock-production model (ASPIC) under a south Atlantic stock hypothesis. The south Atlantic database for blue marlin consisted of Japanese longline fishery catch and effort statistics and combined Taiwanese and Brazilian longline catches, indexed by Brazilian effort statistics. The south Atlantic white marlin database consisted of separate catch and effort series for the Japanese, Taiwanese and Brazilian longline fisheries. Due to difficulties in finding minima during the model's search routine, it was necessary to fix the initial biomass ratio (BIR) parameter for blue marlin and the initial biomass ratio (BIR) and intrinsic rate of increase (r) for white marlin in order to achieve a solution in model runs. The analysis suggests that both the blue and white marlin stocks are heavily overexploited in the south Atlantic and these results are consistent with past assessments.

RÉSUMÉ

Les données de prise et d'effort du makaire bleu (Makaira nigricans) et du makaire blanc (Tetrapturus albidus) ont été analysées avec un modèle de production du stock en état de non-équilibre (ASPIC) dans l'hypothèse d'un stock Atlantique Sud. La base de données sur le makaire bleu de l'Atlantique Sud comprenait les statistiques de prise et d'effort de la pêcherie palangrière japonaise, ainsi que les données de captures combinées des palangriers taiwanais et brésiliens, indexées avec les statistiques d'effort du Brésil. La base de données sur le makaire blanc de l'Atlantique Sud comprenait les séries séparées de prise et d'effort des pêcheries palangrières japonaises, taiwanaises et brésiliennes. Vu la difficulté pour trouver une valeur minimale lors de la recherche du modèle, on a dû fixer un paramètre de ratio initial de biomasse pour le makaire bleu ainsi qu'un paramètre de ratio initial de biomasse et un taux intrinsèque d'augmentation pour le makaire blanc afin de trouver une solution aux passages du modèle. L'analyse suggère que les stocks de makaire bleu et de makaire blanc sont tous les deux fortement surexploités dans l'Atlantique Sud. Ces résultats correspondent aux évaluations antérieures.

RESUMEN

Se analizaron los datos de captura y esfuerzo de la aguja azul (Makaira nigricans) y aguja blanca (Tetrapturus albidus) utilizando un modelo de producción para situación de no equilibrio (ASPIC) bajo una hipótesis de stock del Atlántico sur. La base de datos del Atlántico sur para aguja azul comprendía estadísticas de captura y esfuerzo de la pesquería de palangre de Japón y capturas de palangre combinadas de Taiwan y Brasil, contrastadas con las estadísticas de esfuerzo de Brasil. La base de datos de aguja blanca del Atlántico sur consistía en series separadas de captura y esfuerzo para las pesquería de palangre de Japón, Taiwan y Brasil. Debido a dificultades para encontrar mínimos de tiempo en la rutina de búsqueda del modelo, se hizo necesario fijar el parámetro del ratio de la biomasa inicial (BIR) para la aguja azul y el ratio de la biomasa inicial (BIT) y tasa intrínseca de crecimiento (r) para la aguja blanca con el fin de alcanzar una solución en los ensayos del modelo. El análisis sugiere que los stocks de aguja azul y de aguja blanca están fuertemente sobreexplotados en el Atlántico sur, siendo estos resultados coherentes con las evaluaciones anteriores.

¹ U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, Florida 33149

1. INTRODUCTION

Numerous stock assessments of Atlantic blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) have been attempted historically 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 blue marlin and white marlin in the Atlantic Ocean following the billfish stock assessment workshop held in Hawaii in 1977 (NMFS 1978). They followed the recommendation of that 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.

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. Relatively uncertain results were found for the hypothesized south Atlantic stock. However, despite the uncertainties, they concluded that the hypothesized south Atlantic stock appeared "to have been overexploited in the early 1970s."

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) did not assess the status of marlins under a south Atlantic hypothesis due to the negligible proportion of the catch being represented by the Japanese longline fishery, which had been used to index abundance. Farber and Conser (1983) updated the marlin assessments of Farber (1982) using the catch and effort data through 1980 and followed the same methodology as previous assessments. They found that the production model did not fit the data well for blue marlin or white marlin for the south Atlantic database, and therefore concluded that little information on the status of the "hypothesized south Atlantic stock can be inferred from the production model results."

The Second ICCAT Billfish Workshop held in Miami in 1992 (ICCAT, 1994) addressed the changes in fishing strategy for the Japanese Atlantic longline fleet in the mid- to late- 1970s. The marlin CPUEs from the Japanese Atlantic longline fishery were standardized using a General Linear Model (SAS, 1991) and the Honma (1974) method. This permitted standardized CPUE indices for blue marlin and white marlin to be presented for the entire historical time series, 1960-1989, while accounting for changes in fleet effort and deployment patterns. An exploratory stock assessment analysis using the ASPIC non-equilibrium stock-production model (Prager, 1992) for blue marlin in the Atlantic was presented at that Workshop (Cramer and Prager, 1994). This technique allows inclusion of multiple fisheries data for fitting and does not require equilibrium assumptions for modeling the stock biomass dynamics. They found that stock biomass point estimates were less than one half of B_{MSY} throughout the late 1980s based on the south Atlantic database. They concluded that under a south Atlantic hypothesis, the blue marlin stock biomass had "been steadily declining throughout the period studied" (1964-1989), with the last few years exhibiting an accelerated decline. A similar exploratory stock assessment analysis for white marlin in the Atlantic was presented by Farber and Jones (1994). They found that the approximated 80% upper confidence bound was less than one half of B_{MSY} since 1971 based on the south Atlantic database. They noted that during the mid-1970s, the Japanese longline catches of white marlin in the south Atlantic were extremely low. Therefore, it was questionable if the CPUEs for those years (used to calculate effort) were representative of the total south Atlantic longline catch. Their conclusion was that white marlin were "at least fully exploited with a strong possibility of substantial over-exploitation during the last 17 to 20 years."

As noted in previous assessments, marlin longline catches are a by-catch of tuna- and swordfish-directed longline fisheries. Hence, the billfish databases had historically been plagued by a continued multitude of problems, including non-reporting of landings, lumping of two or more billfish species into an "unclassified" billfish category, and likely misidentification of the species. Both blue marlin and 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. These problems, though certainly not remedied, are being addressed in recent years, and it is believed that the database has been significantly improved.

Knowledge of the life history, ecology, and biology or catch at size of the species are still not available at this time to attempt yield per recruit (YPR) or virtual population analysis (VPA). Hence, lumped biomass production models remain the best available tool to explore stock-production estimates from the marlin databases revised during that Workshop. The present analysis takes advantage of the revised blue marlin and white marlin databases developed during the Third ICCAT Billfish Workshop held in Miami in 1996.

2. DATA AND METHODS

Assessments for the north Atlantic and Total Atlantic stock hypothesis were conducted at the Third ICCAT Billfish Workshop (1996). The workshop concluded that all available biological data for blue marlin and white marlin were most consistent with a total Atlantic hypothesis. In addition, the working group concluded that the north/south separation was arbitrary for these species. However, assessments for blue marlin and white marlin under the two stock structure hypothesis were also recommended by the working group in order to be prudent. Separate one and two stock structure assessments have historically been performed because many of the uncertainties in life history, population dynamics, and stock delineation remain for these two species. Though the catch data is the same as that presented at the third billfish workshop, model fitting and handling of abundance indices differs for the south Atlantic hypothesis compared to that provided in the report of the third ICCAT workshop report (1996) for the north and total Atlantic assessments². For example, no composite indices of abundance were used in this analysis.

The updated database of catch and effort observations were obtained from data presented at the Third ICCAT Billfish Workshop. A more detailed description of the methods used for data preparation is presented in that workshop report. Historical catch series (in biomass) were updated from the Second ICCAT Billfish Workshop assessment. Historical catches of blue marlin and white marlin in the south Atlantic (1960-1995) show similar trends (Figures 1 and 2).

The CPUE series used in this analysis is expressed in numbers per unit effort. The implications of using an abundance based CPUE in a lumped biomass dynamics models is discussed in greater detail in the ICCAT workshop report². For the blue marlin and white marlin data series, indices of abundance were developed for the Japanese, Taiwanese, and Brazilian longline fisheries (Figures 3 and 4). In all series, the indices were scaled to the mean of the overlapping time-series. For the blue marlin fishery, a single adjusted Japanese CPUE was used to index overall abundance for the years 1960-1970 (the only available series for that period). For the years 1971 to 1995, the Japanese and Brazilian CPUE series was used to index overall abundance. The Taiwanese index was dropped from the analysis due to the model's failure to converge when this series was added as a separate index.

For the white marlin analysis, the Japanese longline index was only available for the years 1960 to 1967. The Japanese and Taiwanese series were included, for the years 1968-1970. Japanese, Taiwanese, and Brazilian CPUE were used for 1971 to 1994; and in 1995, Japanese and Brazilian was used. Incorporating the Taiwanese index did not result in model failure in the case of white marlin, as in the case of blue marlin.

The ASPIC model fits catch and effort series to estimate fishery specific parameters for the stock. These are K , the population carrying capacity, r , the intrinsic rate of increase, BIR , the ratio of biomass at the beginning of the first year in the time-series to the biomass at MSY, and individual q_j (catchability coefficient) estimates for each individual j data series. These parameters then generate yearly t estimates of absolute biomass, B_t , fishing mortality F_t , and MSY. For this analysis, we regarded catch as exact and residuals (in logarithmic transform) were accumulated effort under the assumption that errors are multiplicative with constant variance.

After numerous attempts to estimate all parameters for the ASPIC model, the model either failed to converge, exhibited extreme trends in residuals, or gave highly unrealistic estimates of management benchmarks. Due to difficulties in finding minima during the model's search routine, the BIR was fixed at a value of 2 in both the blue marlin and white marlin analysis. This implies that the population of both blue marlin and white marlin was at carrying capacity prior to the start of the time series in 1960. This assumption was considered appropriate in the absence of any known substantial fisheries for these species in the mid-1950s. In both cases, there were additional problems with estimates of the intrinsic rate of population increase (r). Freely estimating this parameter resulted in unrealistic and extreme values or difficulties in finding minima during the model's search routine. The estimate of r was therefore assigned a minimum bound of 0.2 for the blue marlin, and fixed at 0.4 for the white marlin analysis. These values resulted in more meaningful estimates of management benchmarks, given the catch and effort series reported for the south Atlantic stock assumption.

Approximate 80% bootstrapped confidence limits for management benchmarks and trajectories for both analyses are based on 199 trials.

² Report of the Third ICCAT Billfish Workshop. Miami, Florida - July 11 to 20, 1996. 19 pp.

3. RESULTS

3.1. Blue Marlin

The observed and predicted effort series for Japan and Brazil are based on the ratio of Yield/CPUE (Figures 5A-5B). The predicted effort series for Japan (Figure 5A) overestimates the observed levels in the early 1960s and terminal year (1995) and underestimated the observed levels in the late 1980s and early 1990s. However, most of the series are in good agreement, with the model tracking well in the late 1960s through the late 1980s. For the Brazilian data series (Figure 5B), the model failed to capture the magnitude of the jump during 1991. However, most of the series are in good agreement with the additional exception of 1995, where the model overestimated the observed effort for that year.

The computed ordinary and bias corrected point estimates of MSY for blue marlin were 1,209 MT and 1,174 MT, respectively, with an 80% confidence interval of 1,193 and 1,224 MT (Table 1). The relative biomass (B/B_{MSY}) trajectory (Figure 6A) shows levels just below 1.0 in the late 1960s through the late 1970s, followed by an increase through 1980s to just above 1.0, and a precipitous drop in the late 1980s through the end of the time-series. Biomass in 1996 was estimated to be about 35% of the biomass needed to produce MSY. Relative fishing mortality, F/F_{MSY} (Figure 6B), fluctuates somewhat above and below the 1.0 reference line from 1960 through the late 1980s, and then substantially increases in the 1990's. This increase in relative fishing mortality is accompanied with a large increase in uncertainty, as confidence limits plotted in Figure 6B demonstrate. However, these limits remain well above the 1.0 reference line, with the 1995 point estimate of relative fishing mortality is about 8 times fishing mortality that produces MSY.

3.2. White Marlin

Fitted models of observed and predicted effort series for Japan, Brazil, and Taiwan are presented in Figures 7A-7C. The predicted effort series for Japan (Figure 7A) failed to capture the magnitude of the dynamics of observed effort in the 1960s. Nevertheless, there is a general agreement in the direction of the effort trajectory. The observed levels of effort in the 1970s through the mid-1980s are in good agreement, but estimated levels of effort are underestimated in the late 1980s through the end of the time series. For the Brazilian data series (Figure 7B), the model failed to capture the magnitude of the increase in effort in 1991, as was the case for the blue marlin series. However, there is excellent model agreement for most of the time-series, with the additional exception of 1995. As was the case for blue marlin, the model overestimated the observed level of effort. The Taiwanese series (Figure 7C) tracked well over most of the time-series, with the exception of the late 1960s and early 1970s, where levels were underestimated due to the extremely high values of observed effort, and the last two years of the series, where effort levels were overestimated.

The computed point estimate of MSY (Table 1) for white marlin was 1,000 MT. Because there were two model parameters fixed for this assessment, there was little variability in the bootstrapped trials, and no bias correction adjustments for point estimates or confidence limits for point estimates resulted. The relative biomass trajectory for white marlin (Figure 8A) shows low levels throughout the entire time-series, with a substantial decrease in the 1990s. For the terminal year (1995), the B/B_{MSY} level is at about 8% of the level relative to biomass needed to produce MSY. Relative fishing mortality (Figure 8B) remains above the 1.0 reference line from 1963 through 1980, drops below the level for a short time in the early 1980's, and substantially increases through the 1990's. Although variation associated with the overall point estimates of MSY was very small, there was very high variability associated with the trajectory in the last few years of the time series, as confidence limits plotted in Figure 8B demonstrate. Nevertheless, these limits remain well above the 1.0 reference line, with the point estimate of relative fishing mortality at about 5 times the level needed to produce MSY.

4. DISCUSSION

4.1. Blue Marlin

The estimates of management benchmarks from this analysis differ little from what was presented in Cramer and Prager (1994). We found a maximum sustainable yield estimate of 1,209 MT (1,193-1,244 MT). Cramer and Prager (1994), based on an unweighted model, estimated an MSY of 1,278 MT in an analysis including the Taiwanese CPUE series and 1,185 MT where the Taiwanese series was omitted. The overall shape of the biomass and fishing mortality trajectories between these two assessments are also very similar, though our analysis gave a more optimistic picture of the relative biomass throughout most of the time-series. This was due in part to the higher assumed intrinsic rate of population increase of our model, $r = 0.2$, compared to Cramer and Prager's (1994) estimate of $r = 0.15$. However, a trial analysis fixing $r = 0.15$ yielded similar overall results to our initial approach. The similarities in estimated quantities between ours and Cramer and Prager (1994) are interesting, given the revisions in the indices of abundance and differences in assumptions. Like Cramer and Prager (1994), our estimates of MSY for the south Atlantic were lower than that of Farber and Conser's (1983) estimate of 2,074-2,353 MT, as well as Conser and Beardsley's (1978) estimates of 2,516-2,871 MT.

Though it was necessary in this analysis to fix the *BIR* and constrain the minimum *r*, the results appear consistent with the nature of the catch and CPUE series collected in the south Atlantic Ocean (Figures 1 & 3). To examine the effects of fixing parameters on estimates of MSY for blue marlin, contours were assembled using 80 realizations of different *r* and *BIK* values (Appendix 1). Negative correlations occurred between indices of abundance in the Cramer and Prager (1994) south Atlantic analysis of blue marlin data. In this analysis, indices of abundance have been revised and there are currently no negative correlations between available indices, unlike those provided during the 1992 ICCAT Billfish Workshop. Nevertheless, problems persist with the Taiwanese longline indices which currently prevent incorporation into the model.

4.2. White Marlin

The results of the white marlin assessment in the south Atlantic showed somewhat fewer similarities to that presented in earlier assessments. We computed a lower point estimate of MSY (1,000 MT) than previous studies. Farber and Jones (1994) computed 1,789 MT (739-2,282 MT); Kikawa and Homna (1978) estimated 2,008 to 2,347 MT, and Conser and Beardsley (1979) estimated 1,792 to 2,251 MT. Given the nature of the recent catch levels (Figure 2), our results appear consistent. However, it was necessary for us to make critical assumptions about the intrinsic rate of growth of the stock. The *r* parameter was fixed to facilitate model convergence. To examine the effects of fixing parameters on estimates of MSY for white marlin, contours were assembled using 80 realizations of different *r* and *BIK* values (Appendix 1). Our estimate of 0.4 was reasonable, based on the estimate of 0.34 in Farber and Jones (1994). The overall shape of the biomass and fishing mortality trajectories between these two assessments are similar, with the exception of the first few years, where we had fixed our *BIR* at 2.0. After about 1970, the biomass trajectories presented here and in Farber and Jones (1994) are very similar both in shape and magnitude. One of the important differences between these two assessments is the nature of the variability. Because we fixed 2 out of the 6 estimated parameters, the variability about the estimates and trajectories is very small. It is interesting to note that although variability is essentially non-existent for most of the F/F_{MSY} series, there is substantial uncertainty in this ratio in the final two years of the assessment.

5. CONCLUSIONS

At this point in time, there are still important problems in the analysis of the blue marlin and white marlin under a separate south Atlantic Ocean stock hypothesis. From this, and previous work, a reasonable conclusion is that the south Atlantic stock remains overexploited. However, fixing *r* and *BIR* estimates to calculate surplus production imply assessment results are unreliable, but should be examined in a sensitivity analysis. More importantly, it should be noted that the Working Group at the Third Billfish Workshop concluded that the total Atlantic hypothesis was most appropriate for blue marlin and white marlin. Nevertheless, it should be noted that these results are consistent with previous south Atlantic blue marlin and white marlin assessments in terms of both shape of biomass trajectories and estimated management benchmarks.

6. LITERATURE CITED

- CONSER, R.J. and G.L. Beardsley. 1979. An assessment of the status of stocks of blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) in the Atlantic Ocean. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. VIII(2):461-489.
- CRAMER, J.L. and M.H. Prager. 1994. Refinements in exploratory surplus-production analyses of Atlantic blue marlin. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. XLI:565-571.
- FARBER, M.I. 1982. An assessment of the status of stocks of blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) in the Atlantic Ocean through 1979. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. XVII(2):395-414.
- FARBER, M.I. and R.J. Conser. 1981. An assessment of the status of stocks of blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) in the Atlantic Ocean. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. XV(2):387-406.
- FARBER, M.I. and R.J. Conser. 1983. An update on the status of stocks of blue marlin and white marlin in the Atlantic Ocean. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. XVIII(3):674-692.

- FARBER, M.I. and C.D. Jones. 1992. An exploratory stock-production model analysis of white marlin (*Tetrapturus albidus*) in the Atlantic Ocean. Inter. Comm. Conserv. Atl. Tunas, *Coll. Vol. Sci. Pap.* XLI:572-587.
- HONMA, M. 1974. Estimation of overall effective fishing intensity of tuna longline fishery. Bull. 10, Far Seas Fisheries Research Lab. Shimizu 424, Japan, p. 63-86.
- ICCAT. 1981. Report of the ICCAT inter-sessional workshop on billfish. Inter. Comm. Conserv. Atl. Tunas, *Coll. Vol. Sci. Pap.* XVI, 375pp.
- ICCAT. 1994. Report of the Second ICCAT Billfish Workshop. Inter. Comm. Conserv. Atl. Tunas, *Coll. Vol. Sci. Pap.* XLI. 587pp.
- NMFS. 1988. Report of the Billfish Stock Assessment Workshop - Atlantic Session. Dec. 1977, Honolulu, HI. NOAA/NMFS, SEFC, Miami, FL 33149. 47pp.
- PRAGER, M.H. 1992. ASPIC - A surplus-production model incorporating covariates. Inter. Comm. Conserv. Atl. Tunas, *Coll. Vol. Sci. Pap.* XXXVII:218-229.
- SAS. 1991. SAS® System for Linear Models, Third Edition, SAS Institute, Inc., Cary, NC. 329pp.

Table 1. Estimated management parameters and benchmarks from the ASPIC production model analysis of South Atlantic blue marlin and white marlin. See text for further details.

Management Parameter	Ordinary Estimate	Bias Corrected Estimate	Approximate 80% Lower C.I.	Approximate 80% Upper C.I.
Blue Marlin				
MSY	1,209	1,174	1,193	1,224
B_{MSY}	12,090	12,480	11,870	12,860
F_{MSY}	.1	.095	.1	.1
$F_{0.1}$.09	.085	.09	.09
$Y_{0.1}$	1,197	1,162	1,181	1,212
White Marlin				
MSY	1000	1000	1000	1000
B_{MSY}	4999	4999	4998	4999
F_{MSY}	.2	.2	.2	.2
$F_{0.1}$.18	.18	.18	.18
$Y_{0.1}$	990	990	990	990

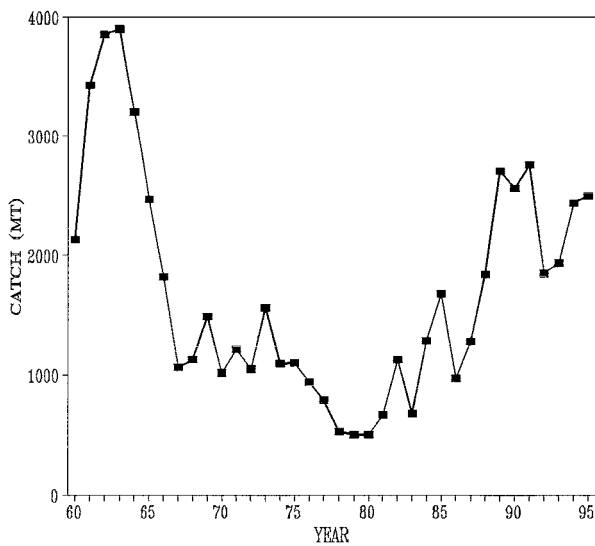


Fig. 1. Historical annual catch (mt) of south Atlantic blue marlin

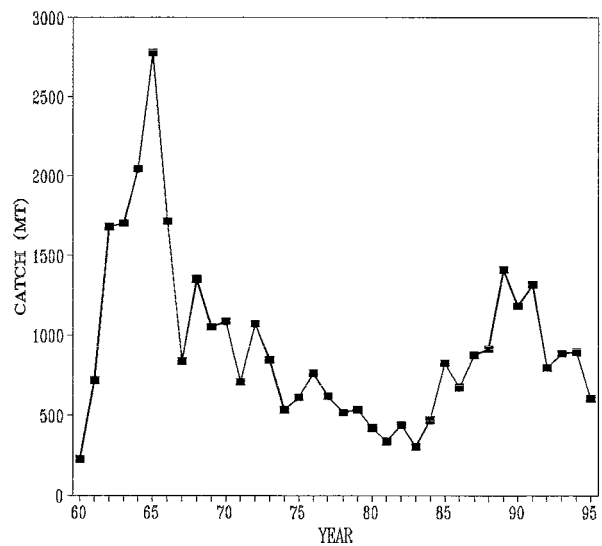


Fig. 2. Historical total catch (mt) of South Atlantic white marlin.

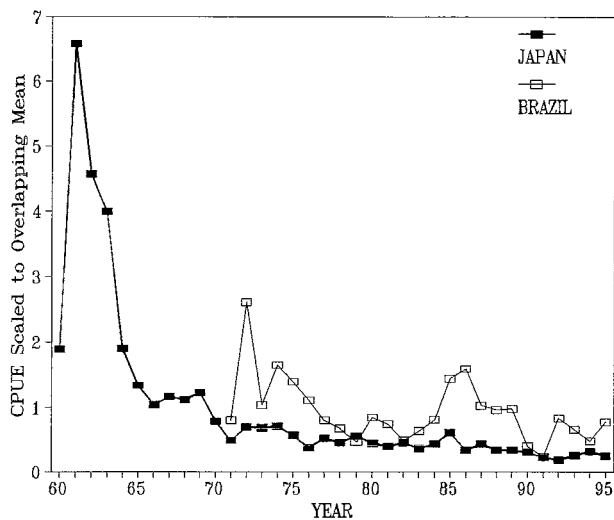


Fig. 3. Available blue marlin CPUE series used for this analysis.

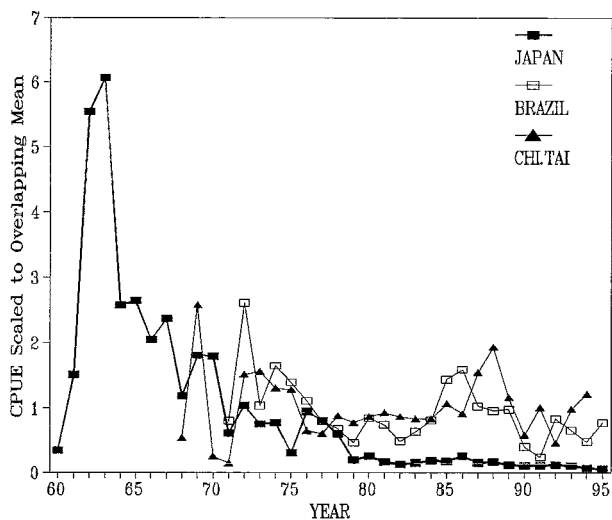


Fig. 4. Available white marlin CPUE Series used for this analysis.

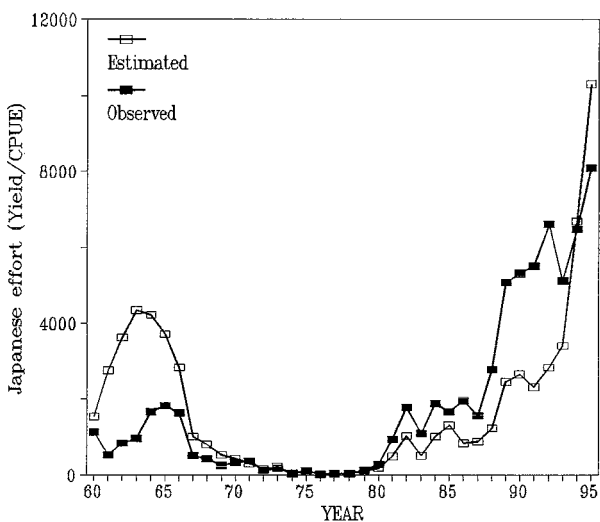


Fig. 5a. Observed and predicted Japanese effort (Yield/CPUE) series for south Atlantic blue marlin used in this analysis.

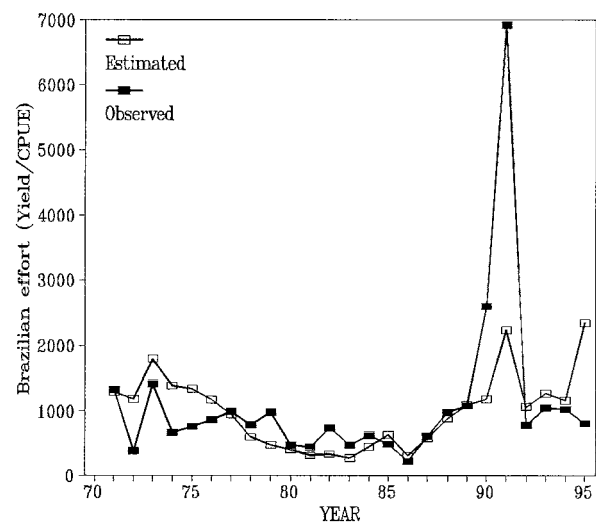


Fig. 5b. Observed and predicted Brazilian effort (Yield/CPUE) series for south Atlantic blue marlin used in this analysis.

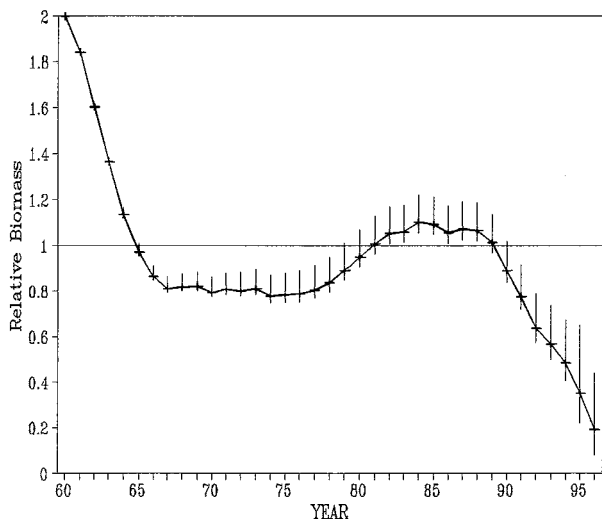


Fig. 6a. Bootstrapped annual relative biomass for blue marlin from the fitted ASPIC models. Confidence intervals are based on 199 trials.

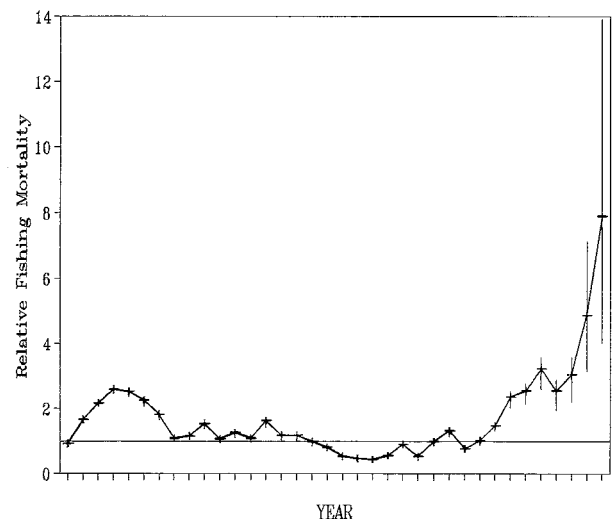
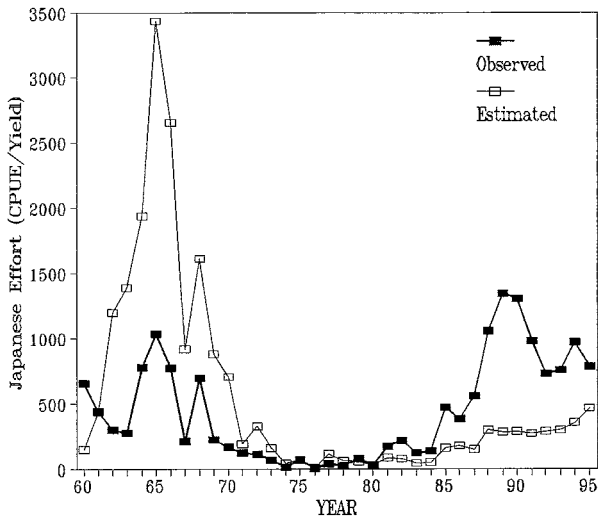
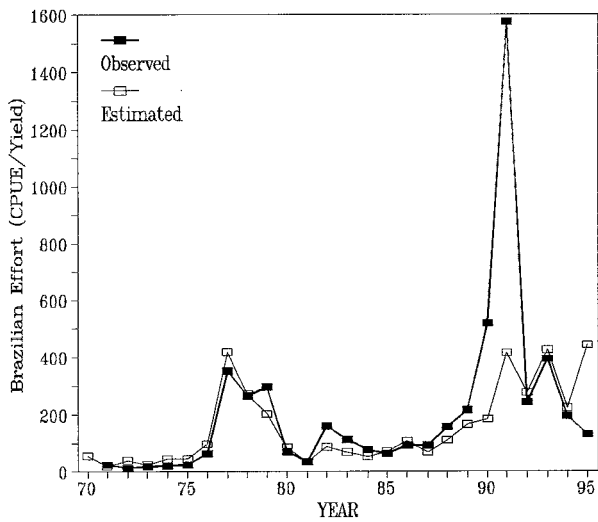


Fig. 6a. Bootstrapped annual relative fishing mortality for blue marlin from the fitted ASPIC models. Confidence intervals are based on 199 trials.

(A) Japanese effort



(B) Brazilian Effort



(C) Chi-Tai Effort

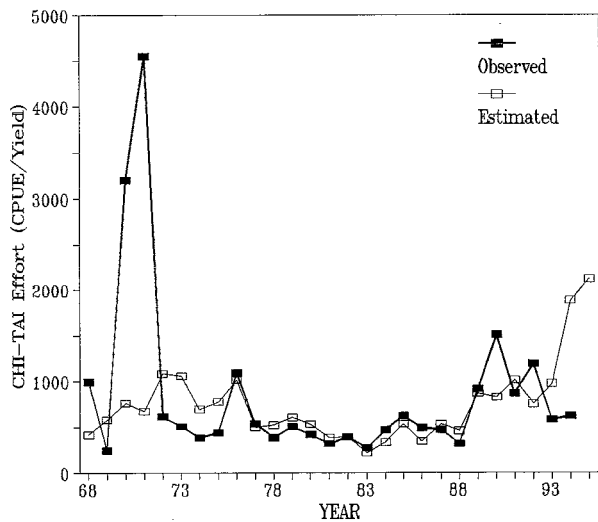


Fig. 7. Observed and predicted effort series for South Atlantic white marlin used in this analysis. Figure 7A is the Japanese effort (Yield/CPUE); Figure 7B the Brazilian effort (Yield/CPUE); and Figure 7C is the Chi-Tai effort (Yield/CPUE).

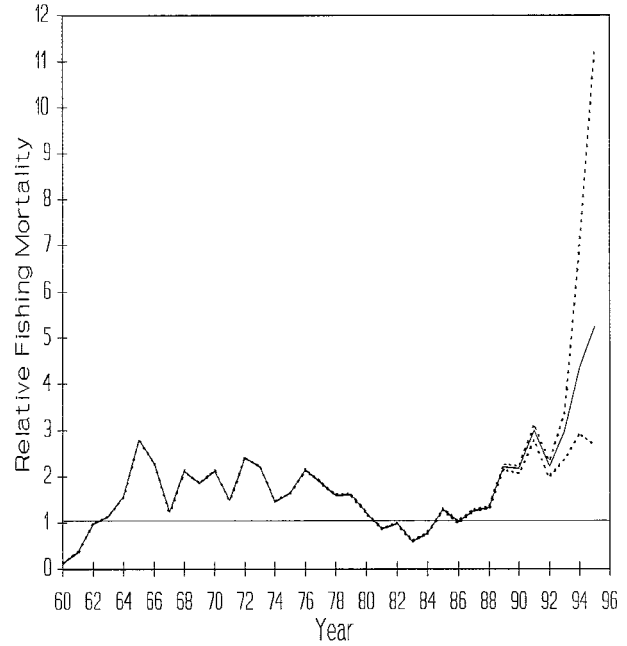
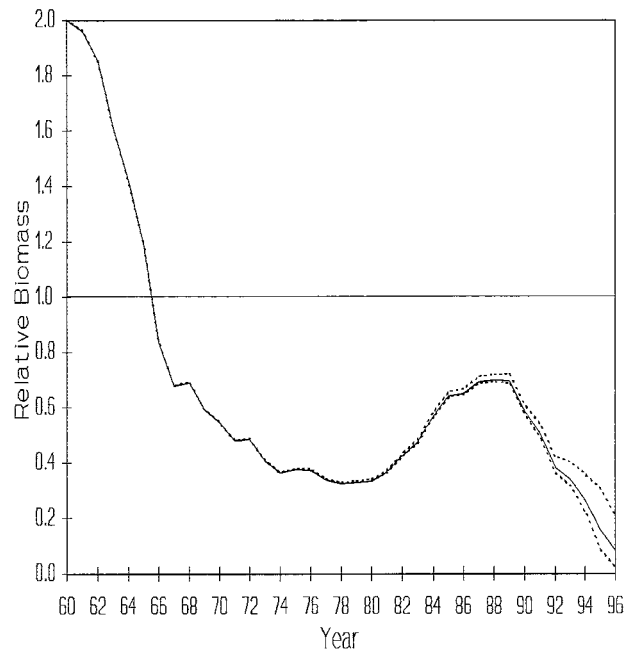


Fig. 8. Bootstrapped annual relative biomass (8A) and annual relative fishing mortality (8B) for white marlin from the fitted ASPIC models. Confidence intervals are based on 199 trials.

Appendix 1.

The analysis of South Atlantic blue marlin and white marlin required fixing the stocks intrinsic rate of increase, r , and the initial biomass ratio, $B1R$. To examine the effects of changes in these fixed parameters, maximum sustainable yield (MSY) contours were constructed for blue marlin (A) and white marlin (B). These contours were assembled using 80 realizations of different r and $B1R$ values. The dots indicate the position on the parameter surface where the analyses were conducted. Contour instability is a result of the low number of overall realizations, and can be smoothed with additional simulations.

