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BIOMASS AND FISHING MORTALITY PROJECTIONS OF BLUE MARLIN AND WHITE MARLIN IN THE ATLANTIC OCEAN

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SUMMARY

Blue marlin *(Makaira nigricans)* and white marlin *(Tetrapturus albidus)* total Atlantic assessments were conducted at the Third ICCAT billfish Workshop held in Miami, Florida, july, 1996, using the non-equilibrium stock-production model ASPIC. The estimated parameters from the fitted ASPIC models were used to project future total Atlantic relative biomass and relative fishing mortality trajectories under different future catch scenarios. All projections indicate that current yield levels must be reduced in order to stocks to recover to the B_{MSY} target level, One of the options tested included the effect of releasing live longline by-catch on projected biomass and fishing mortality trajectories. Based on the average reported catch from 1991 to 1995, and assuming 100% survivorship of released live by-catch, the model suggests stocks of blue marlin and white marlin for the total Atlantic could be recovered to the B_{MSY} target level in 10 years. White marlin appear to have a higher potential for recovery than blue marlin given the assumed survival of released live by-catch.

RÉSUMÉ

Lors des Troisièmes Journées d'étude de l'ICCAT sur les Istiophoridés, tenues à Miami, Floride, en juillet 1996, des évaluations du makaire bleu (*Makaira nigricans*) et du makaire blanc (*Tetrapturus albidus*) dans l'Atlantique entier ont été réalisées, en utilisant le modèle de production en condition de non-équilibre ASPIC. Les paramètres estimés des modèles ASPIC ajustés ont été utilisés pour projeter la biomasse relative future de l'Atlantique entier et les trajectoires de la mortalité par pêche relative dans le cadre de différents scénarios de prise futurs. Toutes les projections indiquent que les niveaux actuels de production doivent être réduits afin que les stocks récupèrent le niveau visé de B_{PME}. Une des options testée comprenait l'incidence de la remise à l'eau des prises accessoires vivantes de la palangre sur la biomasse projetée et les trajectoires de mortalité par pêche. Sur le fondement de la capture moyenne déclarée de 1991 à 1995, et en supposant un taux de survie de 100 % des prises accessoires remises à l'eau en vie, le modèle suggère que les stocks de makaire bleu et de makaire blanc de l'Atlantique entier pourraient récupérer le niveau visé de B_{PME} en 10 ans. Le makaire blanc semble avoir un potentiel de récupération plus élevé que le makaire bleu, étant donné la survie supposée des prises accessoires remises à l'eau en vie.

RESUMEN

En las Terceras Jornadas de Trabajo ICCAT sobre Marlines (Miami, Florida, julio de 1996) se hicieron evaluaciones de la aguja azul (*Makaira nigricans*), y aguja blanca (*Tetrapturus albidus*) en el total del Atlántico, usando el modelo de producción de no equilibrio ASPIC. Los parámetros estimados de los modelos ASPIC ajustados se usaron para proyectar la biomasa relativa del Atlántico total en el futuro y las trayectorias de la mortalidad por pesca con diferentes escenarios futuros de capturas. Todas las proyecciones indican que deben reducirse los actuales niveles de producción para que los stocks recuperen el nivel deseado de B_{RMS}. Una de las opciones ensayada incluía el efecto de liberar la captura fortuita viva del palangre sobre la biomasa proyectada y las trayectorias de mortalidad por pesca. Basándose en la captura media informada de 1991 a 1995, y suponiendo un 100% de supervivencia de la captura fortuita liberada con vida, el modelo sugiere que los stocks de aguja blanca y aguja azul de todo el Atlántico podrían recuperar el nivel deseado de B_{RMS} en 10 años. La aguja blanca parece tener un mayor potencial de recuperación que la aguja azul, dada la supuesta supervivencia de la captura fortuita liberada con vida.

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1. INTRODUCTION

Several stock assessments of blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) have been attempted over the past 18 years. Fishery data for these species is limited to catch and effort statistics, and 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). Therefore, assessments have relied on production model techniques (Conser and Beardsley, 1979; Farber and Conser, 1981; Farber 1982; Farber and Conser, 1983). More recently, billfish stock assessments conducted under the auspices of ICCAT have used the ASPIC non-equilibrium stock-production model (Prager, 1992), allowing inclusion of multiple fisheries data sets for fitting without the equilibrium assumptions for modeling the stock biomass dynamics.

An exploratory stock assessment analysis was conducted using the ASPIC approach at the Second ICCAT Billfish Workshop held in Miami in 1992 (ICCAT, 1994). This workshop refined the quality of the catch and effort series by addressing the changes in fishing strategy for the Japanese Atlantic longline fleet in the mid- to late- 1970s. This permitted using standardized CPUE indices for blue marlin and white marlin for the entire historical time series, 1960-1989, while accounting for changes in fleet effort and deployment patterns. Under a total Atlantic hypothesis, Cramer and Prager (1994) found that the blue marlin stock has been at very low levels of biomass since the late 1960s, and the most recent relative biomass ratio levels were at about 40% B_{MSY}. They concluded that the total Atlantic blue marlin stock fishing mortality rates throughout the time period are well above the optimum level, and that the stock cannot support continued harvest at present levels. Further refinements in the catch effort series allowed a similar exploratory stock assessment analysis for white marlin under at total Atlantic stock hypothesis (Farber and Jones, 1994). They found that relative biomass level have been below the optimum since 1972, and that white marlin were "at least fully exploited with a strong possibility of substantial overexploitation during the last 17 to 20 years."

The catch effort databases for blue marlin and white marlin were further updated and revised during the Third ICCAT Billfish Workshop held in Miami in 1996 (ICCAT, *in press*), and a total Atlantic assessment was conducted. As in previous assessments, the analysis indicated that stocks are over-exploited, with biomass in 1996 at about 24% and 23% of the biomass needed to produce MSY for blue marlin and white marlin, respectively.

The majority of ICCAT landings statistics for blue marlin and white marlin used in assessments to date (70-90%) come as a bycatch from the offshore longline fleet targeting tuna and swordfish. As a result of their bycatch status, uncertainties associated with Atlantic billfish databases include non-reporting of landings, failure to estimate dead discards from many of the fleets, lumping of two or more billfish species into an "unclassified" billfish category, and misidentification of some billfish species. Conversely, blue marlin and white marlin are often the target species in Atlantic recreational fisheries. However, recreational billfish statistics are complicated by uncertainties of estimating total recreational landings, since most recreationally caught Atlantic billfish released but dead discards are seldom accounted for. Recently, there have been attempts to resolve some of these problems, and it is believed that the database was significantly improved during the Third ICCAT Billfish Workshop (ICCAT, *in press*). In this paper, the estimated ASPIC model parameters for blue marlin and white marlin from the Third ICCAT Billfish Workshop assessment are used to project future levels of relative biomass and relative fishing mortality under different total Atlantic catch scenarios.

There are currently no ICCAT regulations in effect for Atlantic blue marlin or white marlin, although two ICCAT countries have billfish regulations in place (USA, Venezuela). However, the need to reduce current and future levels of fishing mortality has been recommended. One such recommendation has been to release or tag and release blue marlin and white marlin that are caught by longline vessels which appear to be alive when brought alongside the boat. This approach would potentially minimize one important source of mortality. The effects of releasing live longline bycatch on future relative biomass ratios and fishing mortality ratios is examined in this paper.

2. DATA AND METHODS

The databases and ASPIC models used in this analysis are taken from the assessment of blue marlin and white marlin stocks, under the total Atlantic stock hypothesis, conducted at the Third ICCAT Billfish Workshop (ICCAT *in press*). A detailed description of the methods used for data preparation is presented in that workshop report. Historical catches of blue marlin and white marlin in the Atlantic ocean (1960-1995) show similar trends (Figure 1). The CPUE series used in this analysis are discussed in detail in the ICCAT workshop report.

The specific parameters of the ASPIC model are *K*, the population carrying capacity, *r*, the intrinsic rate of increase, *B1R*, 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 data series. These parameters then generate yearly t estimates of absolute biomass, B_t, fishing mortality F_t, and MSY. For this analysis, catch was assumed exact and residuals (in logarithmic transform) were accumulated in effort under the assumption that errors are multiplicative with constant variance.

Using the estimated ASPIC model parameters, and management benchmarks (Table 1) from the assessment, the blue marlin and white marlin stock relative biomass and relative fishing mortality was projected forward by assigning constant levels of yield from the years 1996 to 2005. Levels assigned range from 0 catch to the 1996 estimated replacement yield. Approximate 50% and 80% confidence intervals for trajectories were constructed based on 1000 bootstrap trials. Unless actual catch in 1996 and 1997 were at or below those modeled, the projections are optimistic in terms of recovery to B_{MSY} levels by a specific date, but the results are useful as indicators of recovery potential once fishing mortality rates can be reduced.

The effect of releasing live longline bycatch on potential future relative biomass and fishing mortality was examined by first obtaining an estimated ratio of live/dead blue marlin and white marlin bycatch, from at-sea observer sampling of the Venezuelan industrial longline vessels (Jackson and Farber, 1996). This ratio was then used to adjust the average reported total Atlantic catch by longline gear for the years 1991 to 1995 (Table 2), assuming 100% survivorship of reported "live bycatch". This adjusted average value was then projected forward. Because future uncertainty is so high for most levels of yield, projections were limited to 10 years.

3. RESULTS

3.1 Blue Marlin

Scenarios were analyzed using projected catch for blue marlin (mt) of 0, 1000, 1500, 1700, 1800, 1885, and 1920 (the computed 1996 replacement yield). These values are all well below the bias corrected MSY point estimate of 4,461 mt (Table 1). The 10 year projected relative biomass (Figures 2A-2G) demonstrates not only the more rapid recovery of the stock with decreasing projected catch, but also the increase in uncertainty as the catch approaches the replacement yield.

The relative biomass (B/B_{MSY}) trajectory for 0 catch (Figure 2A) shows rapid recovery potential of blue marlin, with projected biomass reaching the optimum biomass level (1.0) within a few years. With higher levels of yield (Figures 2B-2G), the relative biomass takes longer to recover. The catch level of 1,885 projected in Figure 2F is the computed yield after adjusting for released longline bycatch (Table 2), assuming 100% survival of live released fish. Relative biomass in 1996 was estimated to be at about 24% of the biomass needed to produce MSY. The 1,920 mt replacement yield (Figure 2F) represents the estimated catch which maintains this level of relative biomass. However, the variability about this point estimate projection is very high. Projecting catch levels greater than this are expected to result in a further decline of biomass, though variability about the point estimates will decrease.

Estimated relative fishing mortality, F/F_{MSY}, for blue marlin historically has had greater fluctuations than relative biomass, with greater uncertainty (ICCAT, *in press*). Because of the large confidence intervals associated with the projected point estimate trajectory, they were excluded here. In 1995, the relative fishing mortality was well above the 1.0 reference line, at about 2.87 times the fishing mortality that produces MSY (Figure 2H). The modeled relative fishing mortality drops substantially with all projected catch levels. Like the relative biomass levels, the model projections for fishing mortality are very sensitive to small changes in assumed yield when catch approaches the replacement yield threshold. In other words, the population response can be substantial to small changes in mortality as it approaches the replacement yield threshold.

3.2 White Marlin

The levels of future projected catch for white marlin (mt) were 0, 700, 764, 800, 900, and 921 (the computed 1996 replacement yield). The replacement yield is below the bias corrected MSY point estimate of 2,177 mt (Table 1), and all projected catches thus are much lower than the MSY estimate. Like the blue marlin trajectories, the 10 year projected relative biomass trajectories (Figures 3A-3F) for white marlin demonstrate recovery of the stock with decreasing projected catch, and increases in uncertainty as the catch approaches the replacement yield.

The relative biomass (B/B_{MSY}) point estimate trajectory for 0 catch (Figure 3A) for white marlin shows a high recovery potential to the optimum biomass level (1.0) within a few years should catches be reduced to 0. However, with increasing levels of yield (Figures 3B-3F), the relative biomass recovery takes longer. The catch level of 764 mt projected in Figure 3C is the computed yield after adjusting for released longline bycatch (again assuming 100% survival, Table 2). The 921 mt replacement yield (Figure 3F) represents the level of catch which maintains the relative biomass at the most recent year in the assessment. Catches greater than this in intervening years imply further reductions in stock biomass. Relative biomass in 1996 was estimated to be at about 23% of the biomass needed to produce MSY (Table 1). As with blue marlin, there is considerable uncertainty about the replacement yield projected trajectory as indicated by the wide confidence intervals.

The relative fishing mortality projections for white marlin are similar to blue marlin, with historically high fluctuations and high uncertainty. In 1995, the relative fishing mortality was estimated to be well above the 1.0 reference line, at about 1.96 times the times fishing mortality that produces MSY (Figure 3G). Relative fishing mortality levels drop substantially with all projected catches less than the replacement yield. As with blue marlin, model projections of F for white marlin are sensitive to small changes when catch approaches this replacement yield threshold.

4. DISCUSSION

4.1 Blue Marlin

The most recent assessments (ICCAT *in press*) indicate that the total Atlantic blue marlin stock is overexploited. All projections presented in this paper are based on a lower total catch relative to the previous 12 years of reported yield. This was done to examine a reduced level of yield to allow population recovery. The most recent year that reported catch for blue marlin was below the current replacement yield was 1983, when there was a total yield of 1,896 mt In recent years (1989-1995) there have been substantially greater yields taken, with a peak of 4,503 mt in 1990. The most recent five year (1991-1995) average of 3,602 mt (Table 2) is about 1,682 mt greater than the estimated 1996 replacement yield of 1,920 mt Yields in 1996 and 1997 may well have exceed the estimated replacement yield, leading to further reduction in relative biomass,

Given that the "true" projection falls within the 80% confidence limits of the analysis, stock recovery could be possible in a decade under each of the different projections presented. However, the analysis indicates that lower catches provide the greatest recovery potential. Fishing at a level of 1,800 mt or lower results in a level of recovery that allows for the point estimate, as well as the 50% lower confidence limits, to show an upward trend over the projection horizon. Catches higher than 1,800 mt, up to the replacement yield, appear to result in upward trends for the point estimates and upper confidence limits only, implying lower odds of recovery. Figure 4A illustrates the effects of increasing yield on biomass ratios in 5 years and Figure 4B demonstrates the effects of increasing yield on the relative biomass in 10 years for these projections. From these plots, stocks could potentially be fully recovered in 5 years with a constant yield of about 1,300 mt and 10 years with a yield of about 1,900 mt, presuming no change in biomass over the past few years. It is likely that lower catches would be required to achieve these recovery trajectories if recent yields exceed replacement yields.

The effect of releasing live longline discards (assuming 100% survival) appears to have enough of an impact on the stock to result in an upward projection for the point estimates and upper confidence intervals. However, the projections are very sensitive at this level, and a slight increase in catch beyond this level may quickly decrease the potential for full recovery in 10 years (Figure 4B).

4.2 White Marlin

The total Atlantic white marlin relative biomass has been estimated at well under the level required to achieve MSY since the 1960's (ICCAT *in press*). The projections presented in this paper are based on a lower total reported catch than has been reported in the last 36 years. The most recent five year average (1991-1995) of catch has been about 1,342 mt, (Table 2), about 421 mt greater than the computed 1996 replacement yield. It is likely that catches in 1996 and 1997 will have exceeded replacement yield levels.

White marlin stock recovery is possible within a decade under each of the different projections presented, given that the catch is maintained below the replacement yield. Catches at or slightly above the replacement yield could also lead to recovery, but the odds of this are relatively low. As expected, this analysis suggests that the lower the catch is compared to the estimated replacement yield, the greater the potential for recovery. For example, fishing at a level of 800 mt or lower results in a level of recovery that allows for the point estimate, as well as the 50% lower confidence limits, to show an upward trend in about 5 years. Catches higher than that, up to the replacement yield, appear to result in upward trends for the point estimates and upper confidence limits only. Figure 5A illustrates the effects of increasing yield on white marlin relative biomass ratios in 5 years and Figure 5B demonstrate the effects of increasing yield on the relative biomass in 10 years. These plots suggest that that stocks could potentially be fully recovered in 5 years with a constant yield of about 600 mt and 10 years with a yield of about 900 mt if the relative biomass levels have not decreased over the past few years.

The potential positive effect of releasing live longline discards (assuming 100% survival) on population recovery of white marlin appears to be more pronounced compared to blue marlin. The adjusted average 5 year yield of 764 mt (Table 2) is substantially below the computed 1996 replacement yield. Catches assumed at this level results in a relatively quick recovery (Figure 3C), with both point estimates and upper and lower 50% confidence limits illustrating an upward trajectory. This level of fishing is much less sensitive than the blue marlin adjusted limits for the 10 year (year 2006) projected biomass ratio (Figure 5B). Hence, there is a greater potential for full recovery of white marlin in 10 years given that the assumptions of releasing live bycatch are met.

5. CONCLUSIONS

As with previous assessments, there were still uncertainties in the 1996 stock assessment for blue marlin and white marlin accomplished at the Third ICCAT Billfish Workshop. These uncertainties have been outlined in detail in the reports from that workshop. Nevertheless, from this study it is apparent that present levels of catches or fishing mortality must be decreased if stocks are to recover. The idea of mitigating mortality by releasing living longline by-catch has merit, particularly for white marlin. If this is accomplished with a minimum of post release mortality, this study suggests a strong potential for stock recovery.

6. LITERATURE CITED

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Table 1. Estimated management benchmarks from the ASPIC production model analysis of total Atlantic blue marlin and white marlin.

	Blue Marlin	White Marlin
Maximum Sustainable Yield, MSY: (approximate 80%CI)	4,461 mt (4,096-4,787)	2,177 mt (2,102-2,228)
Observed Yield in 1995	3,926 mt	1,406 mt
Replacement Yield in 1996	1,920 mt	921 mt
Relative Biomass, B_{1996}/B_{MSY} (approximate 80%CI)	0.236 (0.134-0.432)	0.226 (0.132-0.381)
Relative Fishing Mortality, F_{1995}/F_{MSY} (approximate 80%CI)	2.87 (1.45-3.41)	1.96 (1.33-2.91)

Table 2. Blue marlin and white marlin reported catches for 1991 to 1995. Average of 5 year longline catch was multiplied by % mortality and added to recreational catch to estimate adjusted total Atlantic catch given release of longline bycatch.

Year	Combined Longline North Atlantic	Combined Longline South Atlantic	Combined Longline Total Atlantic	Combined Recreational
Blue Marlin				
1991	1406	2755	4161	55
1992	1004	1850	2854	82
1993	1124	1938	3062	111
1994	1163	2439	3602	156
1995	1339	2496	3835	91
		Average	3502.8	99
			% Mortality from longline bycatch (Jackson and Farber, 1996) =	0.51
			Unadjusted Average Catch	3601.8
			Adjusted Average Catch	**1885.428**
White Marlin				
1991	266	1319	1585	35
1992	500	798	1298	21
1993	413	889	1302	28
1994	451	899	1350	46
1995	422	609	1031	15
		Average	1313.2	29
			% Mortality from longline bycatch (Jackson and Farber, 1996) =	0.56
			Unadjusted Average Catch	1342.2
			Adjusted Average Catch	**764.392**

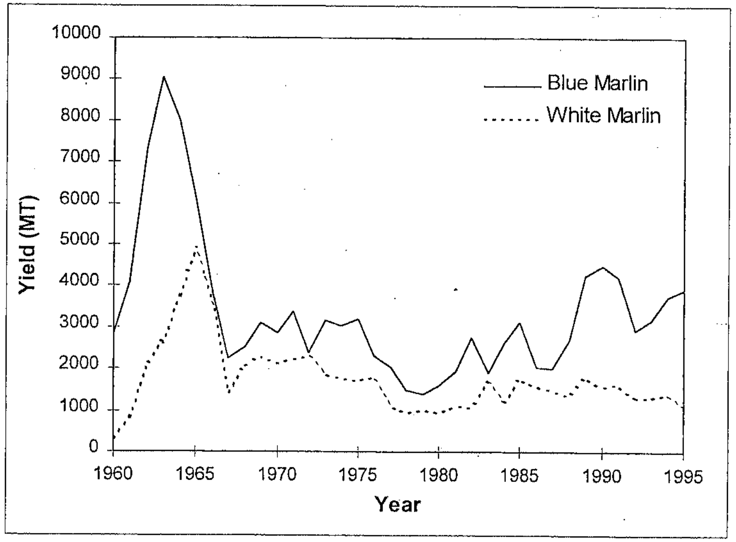

Figure 1. Historical total catch (mt) of total Atlantic blue marlin and white marlin.

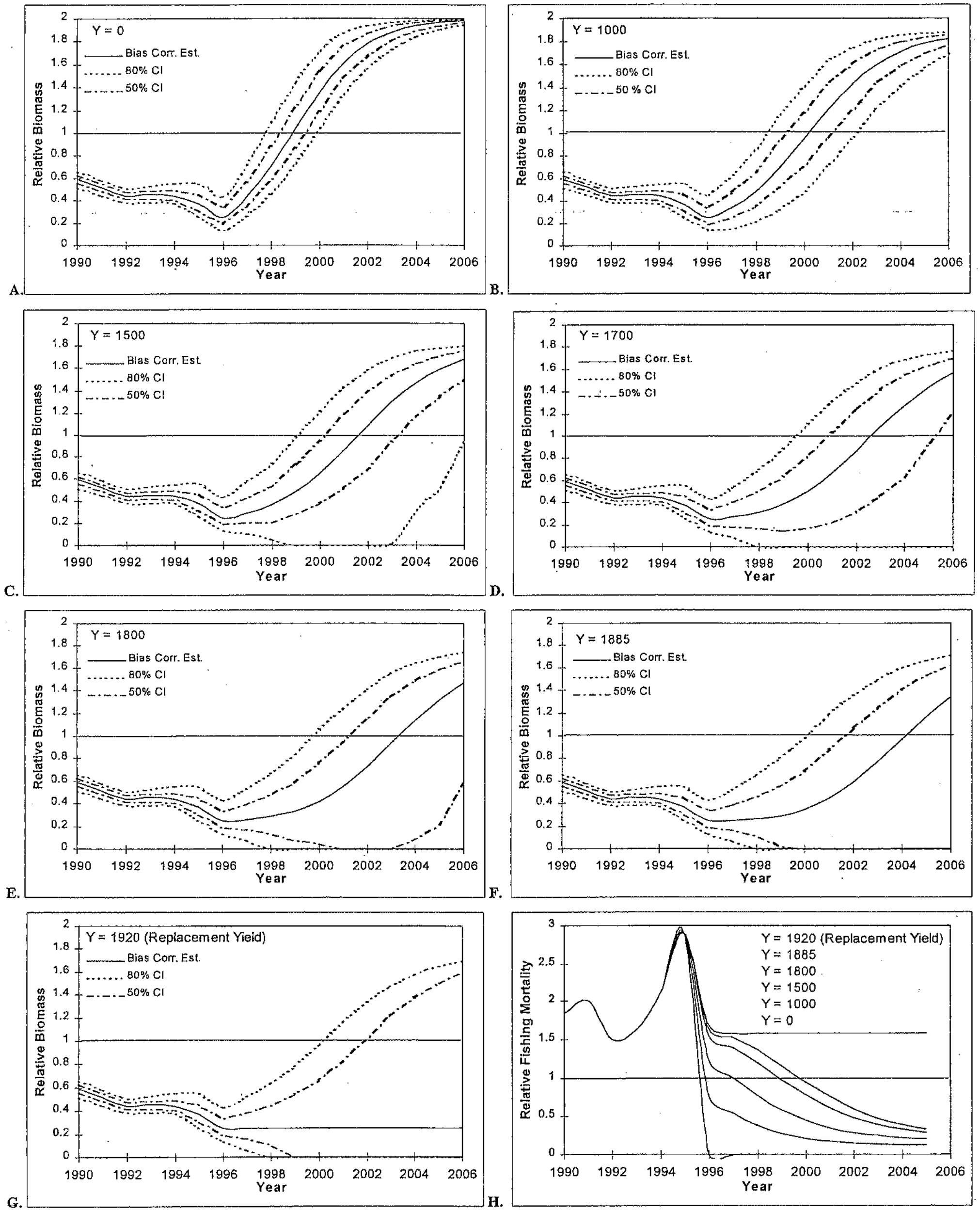

Figure 2. Ten year relative biomass (2A-2G) and relative fishing mortality (2H) trajectory projections for blue marlin in the Atlantic Ocean. Also plotted are 50% and 80% approximate confidence intervals.

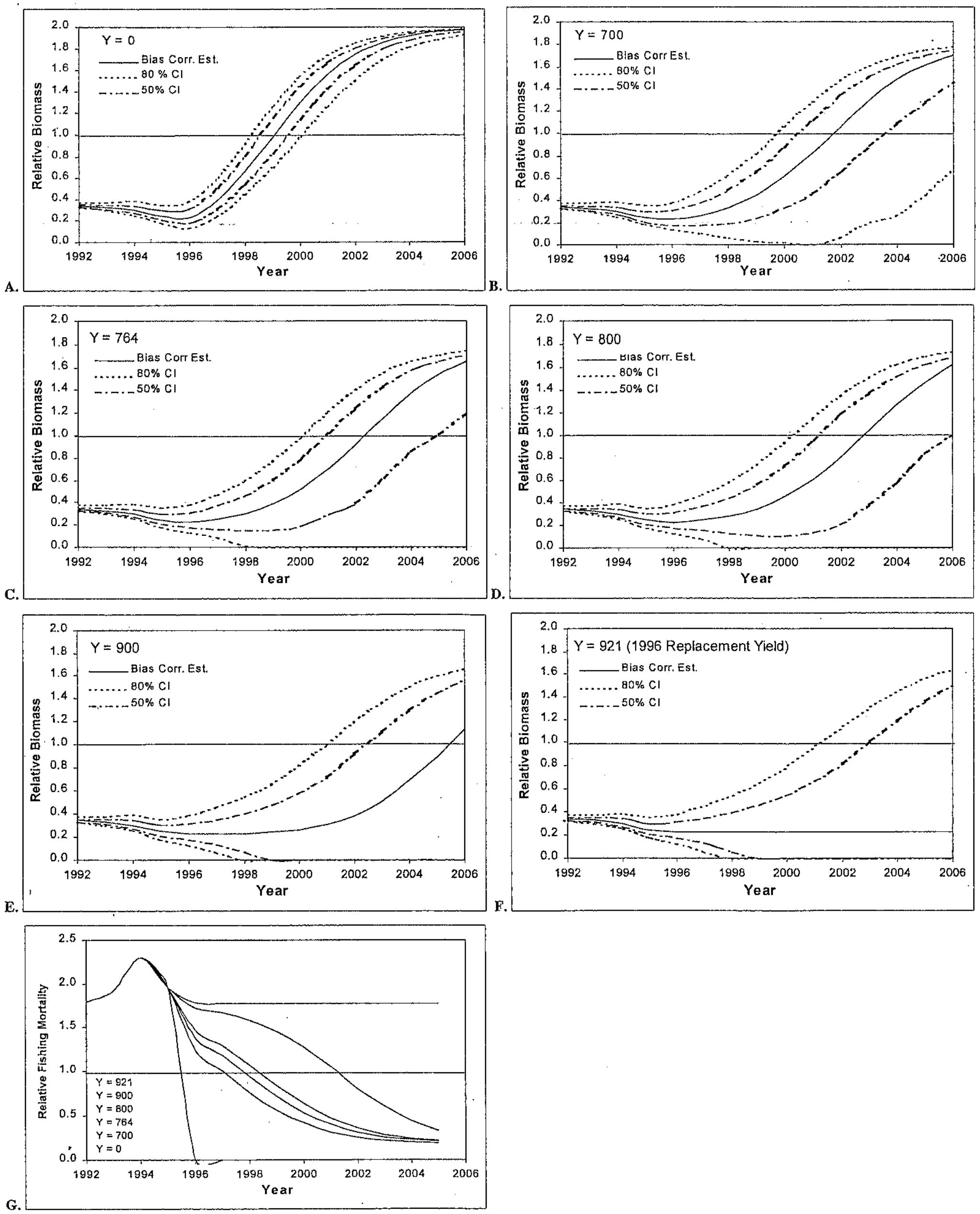

Figure 3. Ten year relative biomass (3A-2F) and relative fishing mortality (3G) trajectory projections for white marlin in the Atlantic Ocean. Also plotted are 50% and 80% approximate confidence intervals.

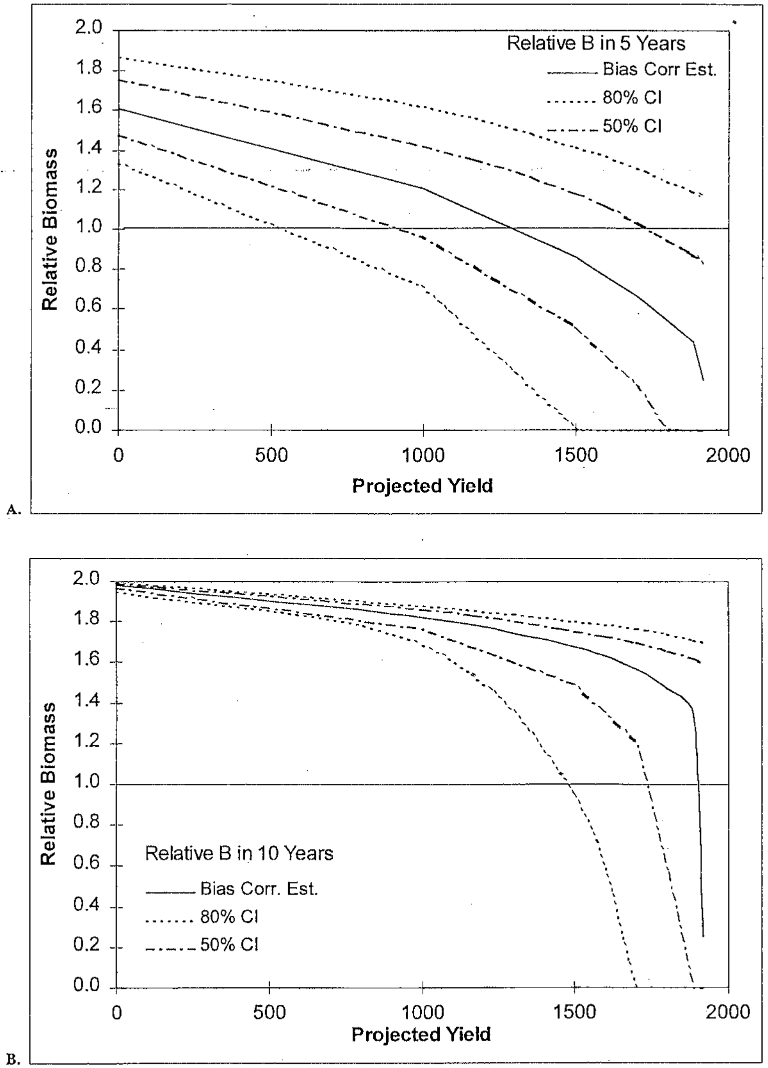

Figure 4. Blue marlin relative biomass levels in 5 years (4A) and 10 years (4B) under various levels of catch.

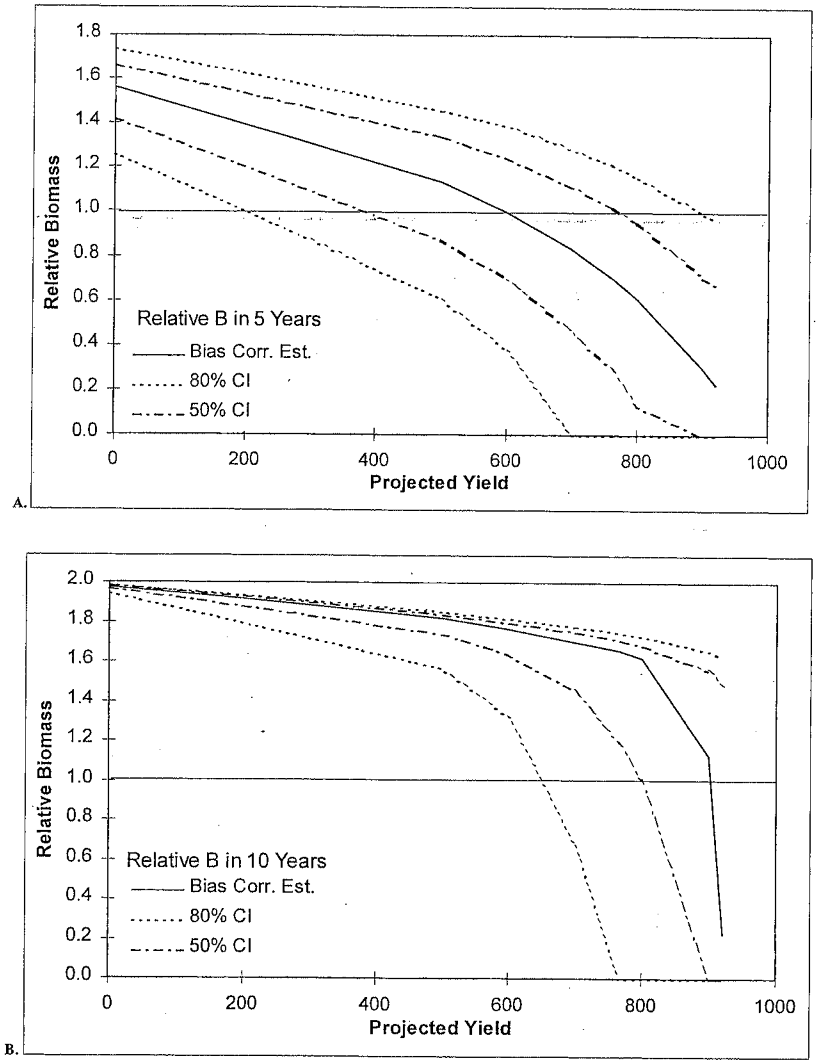

Figure 5. White marlin relative biomass levels in 5 years (5A) and 10 years (5B) under various levels of catch.