A Test of the Robustness ff ASPIC-Based Stock Assessments Using Simulated Atlantic Blue Marlin Data

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ABSTRACT

A simulation model constructed around the life history characteristics of Atlantic blue marlin *(Makaira nigricans)* was applied to generate several time series of catch histories for hypothetical fisheries using alternative assumptions about natural mortality and the stock-recruitment relation. Maximum sustainable yield (MSY), the biomass at MSY (B_{MSY}), the fishing mortality rate at MSY (F_{MSY}) and related parameters were computed for each of the simulated populations. The time series of simulated catches and indices of abundance were employed in simulated stock assessments using surplus the surplus production method solved by the computer program ASPIC, which was the method most recently applied by ICCAT for the species. The resulting estimates of MSY and B_{MSY} were highly correlated with the known true values from the simulations, but tended to be a somewhat higher. The production model estimates of F_{MSY} were also highly correlated with but were slightly lower than the true values. Estimates of the ratios of fishing mortality to F_{MSY} and stock biomass to B_{MSY} in the terminal year of the simulated assessment were slightly lower than the known values from the simulation. These results suggest that the surplus production model might produce results that are slightly optimistic with respect to fishing mortality rates and slightly pessimistic with respect to the status of the biomass of the stock in the most recent year of an assessment. However, the error is small for reasonable combinations of natural mortality and initial slopes of the stock-recruitment curve. These results suggest that the major sources of uncertainty in the stock assessment lie with the underlying catch and effort data and not with the use of the surplus-production model itself.

KEY WORDS: Blue marlin, simulation models, stock assessment, surplus production models

INTRODUCTION

Like many other stocks, catch data for Atlantic blue marlin cannot be classified by age or sex. Consequently, it is not possible to apply age-structured assessment methods to evaluate the status of the stocks and recent assessments have been limited to the application of the dynamic logistic surplus production model described by Prager (1994) as implemented in the computer program ASPIC (Prager 1995). The structural dissimilarity between strongly age-structured populations and the simple surplus-production model has led to uncertainty in the application of this model to such species. However, past studies have shown that surplus production models can provide a useful and often accurate and precise characterization of stock status (Ludwig and Walters 1985, Punt 1992). Recently, Prager et al. (1996) used simulation methods to study the robustness of surplus production model results for a strongly age structured stock in the context of changing gear selectivities through time. Their results suggested that for stocks similar to swordfish, the presence of strong age structure and moderate changes and selectivity should not proscribe the application of simple production models. Nonetheless, concern has been raised about the form of the production model in ASPIC with respect to billfish assessments. The current study applies methods similar to those of Prager et al. (1996) to evaluate the robustness of the ASPIC estimates using a population simulation model based on the sexual dimorphic growth characteristics of blue marlin over a wide range of assumptions about natural mortality and the steepness of the initial slope of the stock-recruitment relationship.

METHODS

Each simulation was started with the population at the stable age distribution for the mortality structure specified by the combination of natural mortality and fishing mortality for the first year of the simulation. Annual recruitments were deterministically calculated from the annual population fecundity using the stock-recruitment relationship. The total annual fishing mortality rates (F) for each simulation were taken from a spline fit of the annual estimates obtained for blue marlin during the last ICCAT assessment for the species (Anon. 1998). Fishing selectivities were asymptotic with age and held constant across all simulations. The age-structured population model employed in this analysis is described in Goodyear (1989). It is implemented monthly with separate sexes and includes consideration of the variability of size at age. The number of explicit ages considered was 100 to minimize any possible effects of artificially truncating the age structure. Post-recruitment natural mortalities were constant for both sexes and all ages within each simulation, but varied with the assumption of natural mortality for the analysis being performed.

Size at age for Atlantic blue marlin shows strong sexual dimorphism (Wilson et al. 1991), consequently the growth of each sex was modeled independently. Mean sizes at age were taken from Prince et al. (1991) for the first year of life, and from Wilson (1984) for fish at age 1 and beyond. This led to the combined growth model of Figure 1. Within year growth after age 1 was assumed constant. The coefficient of variation of size at age was assumed to be 0.10 for both sexes based on experience with other species. Morphometrics were taken from Prager et al. (1995), Data relating to reproduction in Atlantic blue marlin are available from Erdman (1968), Cyr (1987) and de Sylva and Breder (1997). De Sylva and Breder (1997) report that female blue marlin reach maturity at 120 kg (perhaps smaller) and are capable of spawning up to 4 times per reproductive year, which in the north Atlantic extends from July through August. Erdman (1968) also concluded that the spawning season was July through August, but found smaller mature females. This author set the minimum spawning size for females at about 45 kg. Fecundity in many fish species increases as a power function of length of the fish, often with a coefficient greater than that of the length-weight equation. The data available from the literature are too sparse to characterize the underlying relation between blue marlin length and fecundity, so fecundity is modeled here as a constant multiple of body weight for blue marlin above 45 kg. It is likely that this assumption overestimates the reproductive importance newly maturing females and may diminish the magnitude the generation time in the simulated population. It is assumed that the abundance of males is not limiting. This analysis assumes that the stock recruitment relation follows the Beverton-Holt model, R= P/(αP+ß) where R = recruitment in numbers of survivors at 3 months of age, P = parental fecundity, and ß = 1 / initial slope of the stock recruitment curve.

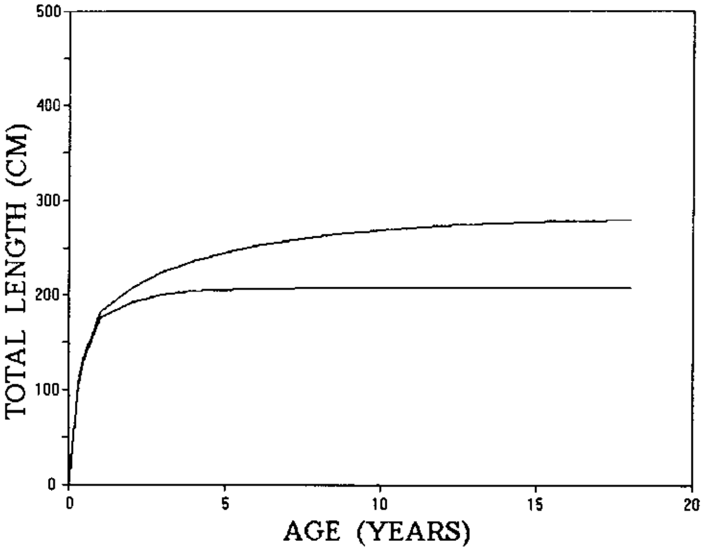

Figure 1. Mean size at age for male (lower curve) and female (upper curve) blue marlin used in this study.

For all simulations, maximum excess recruitment (MER) was arbitrarily set at 1E6. Maximum excess recruitment in this context is equivalent to Ricker's recruitment at MSY from his Appendix III (Ricker 1975, page 347). The distinction is made because his equations presume that exploitation precedes reproduction . In the multiple age analog, actual recruitment at MSY depends on the joint behavior of both the harvested biomass and the reproductive yield of the recruits in which harvested fish may also have contributed to reproduction during their lifespan. The yield per recruit (YPR) is a function of natural mortality, growth and the selectivity of the fishery by size or age. The procedure used to evaluate MSY for the simulated population follows Goodyear (1996). Catch in weight was determined from the selectivity curves by age and the fishing mortality rate for the year, and an index of the weight of the stock was calculated from the average stock biomass during the year. The annual catch and stock index values were saved for later analysis with the surplus production model. Each simulation provided a time series of 41 years. In addition, fishing mortality was set to 0 after 1995 and the simulation was carried forward for another 20 years to evaluate the recovery profile.

Separate simulations were done for initial stock-recruitment slopes of 5, 10, 15, and 50. For each assumed stock-recruitment relationship, simulations were performed for natural mortality rates of 0.05, 0.10, 0.15, 0.20, and 0.25. This combination of parameters resulted in 20 simulations that covered a wide range of the strength of the density-dependent mortality and age structure in the stock. No error was added to the catch or index of abundance to simulate sampling error. As a consequence, the current analysis only addresses the structural differences between the surplus production model and the underlying population.

Data from each simulation were formatted according to the ASPIC input file specification and then analyzed with this program. The resulting ASPIC estimates of the intrinsic growth rate (r), and MSY, B_{MSY}, and F_{MSY} were retained for comparison to the underlying values known from the simulations. Also, the ratios of fishing mortality to F_{MSY} (F_{RATIO}) and the ratios of stock biomass to Bmsy (B_{RATIO}) for each year were also saved for comparison to the known values from the simulations. Additionally, production model estimates of the 20 year population recovery trajectory for each case were determined assuming no fishing mortality.

RESULTS

No difficulties were encountered in the ASPIC fits to the simulated data except for the analyses where natural mortality was set to 0.05. At this low level of natural mortality, and with initial stock recruitment slopes 5, 10 and 15, model convergence required setting initial starting parameter estimates near their true values. Also, the performance indicators generated by ASPIC indicated these three cases fit more poorly than the rest. Inspection of the results indicate that some parameter estimates for the cases with natural mortality at 0.05 are outliers and have been omitted from some of the analyses. The management parameters MSY, B_{MSY}, and F_{MSY} and their values estimated by ASPIC for each of the 20 simulations are presented in Table 1, along with the production model estimates of the intrinsic growth rate (r).

The fitted intrinsic growth rate was a joint function of the initial slope of the stock recruitment curve ($1/\beta$) and natural mortality and increased with increases in both values ($p < 0.0001$). Over the range of values considered in this study both factors contributed about equally to the fitted values for the intrinsic growth rate. ASPIC estimates of MSY were highly correlated with the known true values from the simulations, but averaged about 72% higher (Figure 2.). Similarly, ASPIC estimates of B_{MSY} were highly correlated with but averaged 26% larger than the known true values from the simulation (Figure 3). In contrast, ASPIC estimates of F_{MSY}, which were also highly correlated with the true values, averaged 24% lower than the true values of F_{MSY} (Figure 4). The degree of divergence between true and fitted values of MSY and F_{MSY} decreased significantly ($p < 0.01$) as the natural mortality rate increased from 0.05 to 0.25.

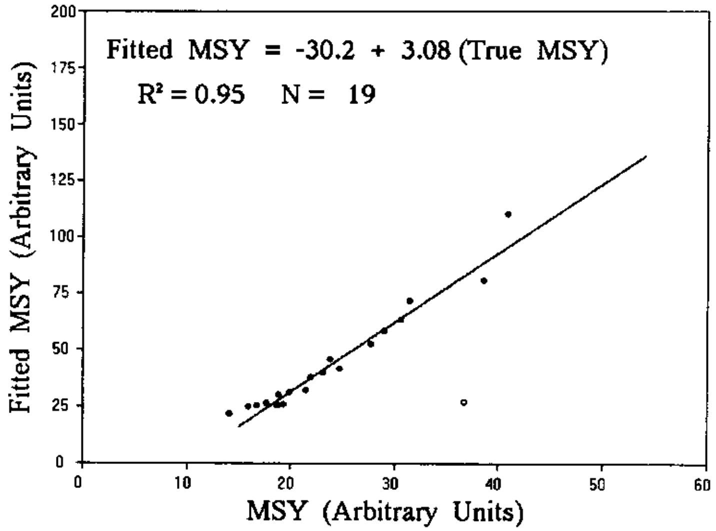

Figure 2. Relationship between ASPIC estimates of MSY and their true values.

Table 1. Slope at the origin of the SR curve,(slope) natural mortality (M), and actual and surplus production model fitted values of the intrinsic growth rate (r), MSY, B_{MSY}, and F_{MSY} for the 20 populations simulations performed in this analysis.

Slope	M	MSY	B_{MSY}	F_{MSY}	r	MSY	B_{MSY}	F_{MSY}
5	0.05	4.71E+07	1.15E+09	0.041	0.108	1.07E+08	2.00E+09	0.054
5	0.10	3.56E+07	5.27E+08	0.068	0.127	6.89E+07	1.08E+09	0.064
5	0.15	2.80E+07	2.78E+08	0.101	0.239	3.78E+07	3.17E+08	0.119
5	0.20	2.39E+07	1.84E+08	0.130	0.346	3.71E+07	2.14E+08	0.173
5	0.25	2.11E+07	1.32E+08	0.159	0.430	3.29E+07	1.53E+08	0.215
10	0.05	5.51E+07	8.91E+08	0.062	0.101	4.03E+07	8.01E+08	0.050
10	0.10	4.15E+07	4.14E+08	0.100	0.284	7.84E+07	5.52E+08	0.142
10	0.15	3.29E+07	2.18E+08	0.151	0.448	5.72E+07	2.55E+08	0.224
10	0.20	2.82E+07	1.44E+08	0.195	0.544	4.53E+07	1.67E+08	0.272
10	0.25	2.50E+07	1.03E+08	0.242	0.625	3.77E+07	1.21E+08	0.313
15	0.05	5.79E+07	7.82E+08	0.074	0.310	1.21E+08	7.82E+08	0.155
15	0.10	4.35E+07	3.64E+08	0.119	0.416	8.70E+07	4.19E+08	0.208
15	0.15	3.47E+07	1.92E+08	0.181	0.537	6.02E+07	2.24E+08	0.269
15	0.20	2.98E+07	1.27E+08	0.236	0.609	4.65E+07	1.53E+08	0.304
15	0.25	2.66E+07	9.04E+07	0.294	0.795	3.98E+07	1.00E+08	0.398
50	0.05	6.13E+07	5.82E+08	0.105	0.403	1.66E+08	8.21E+08	0.202
50	0.10	4.59E+07	2.70E+08	0.170	0.580	9.53E+07	3.29E+08	0.290
50	0.15	3.71E+07	1.39E+08	0.266	0.679	6.19E+07	1.82E+08	0.339
50	0.20	3.22E+07	8.99E+07	0.358	0.816	4.81E+07	1.18E+08	0.408
50	0.25	2.89E+07	6.29E+07	0.460	0.888	3.86E+07	8.70E+07	0.444

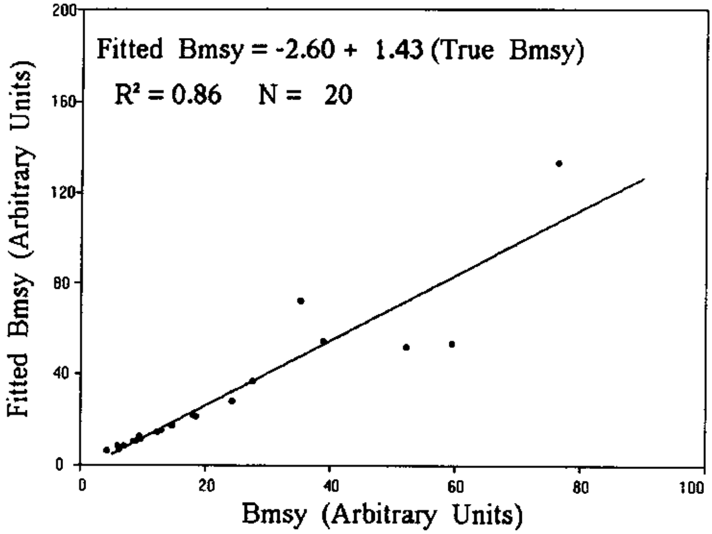

Figure 3. Relationship between ASPIC estimates of Bmsy and their true values

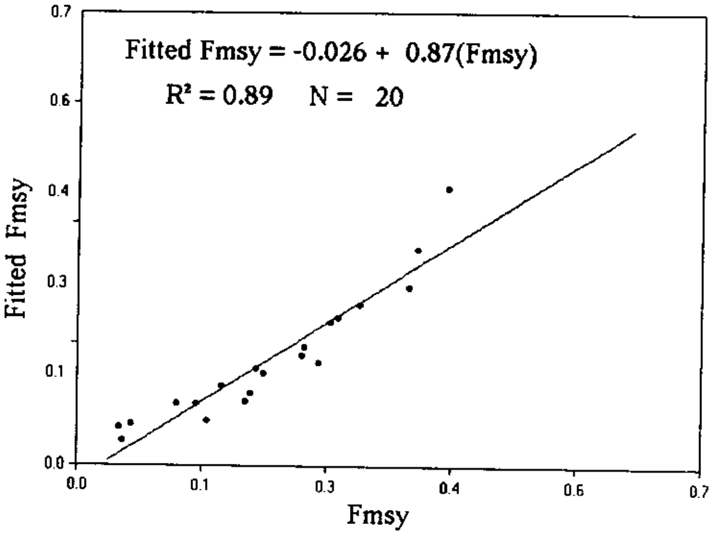

Figure 4. Relationship between ASPIC estimates of F_{MSY} and their true values

ASPIC estimates of stock biomass were highly correlated with the simulated biomass ($P < 0.001$). Over the whole range of available data the fitted biomass estimates averaged slightly less than the true values. However, when limited to the the lower ranges of abundance there was almost a one to one relationship between simulated and fitted values. The annual simulated and fitted ratios of biomass to B_{MSY} were strongly correlated near the origin ($P < 0.001$), but became much less so as the simulated B_{RATIO} values increased above 2.5. ASPIC estimates from the three poorest fits ($M = 0.05$, slopes 5 - 15) distorted the relationship between the fitted and true B_{RATIO} values in the terminal year. With these three cases omitted, there was a very strong relationship between the fitted and observed B_{RATIO} values in the terminal year of the assessment (Figure 5). The fitted values were, however, 72% of the true values from simulations ASPIC estimates of the annual fishing mortality rates were also correlated with their values from the simulated populations, but averaged about 12% higher than the true values. The fitted ratios of fishing mortality to the fishing mortality at MSY were highly correlated with the true values, but were somewhat lower especially for higher values of F ($P < 0.001$). However, for those years where the F_{RATIO} was less than 1.0, there was no apparent difference between the means of the fitted and the simulated F_{RATIO} values. Since the fishing mortalities used in the simulations increased with time, this tendency resulted in the ASPIC estimates of the F_{RATIO} values in the terminal year of the analysis being at the upper end of the range evaluated. They were highly correlated with ($P < 0.001$) but averaged about 13 percent below the known values from the simulations.

The recovery trajectories predicted by the surplus production model typically increased from any particular level of B/B_{MSY} much faster than its age-structured counterpart. This tendency would seem to support the notion that the surplus production model recovery projections are unrealistically optimistic. However, the surplus production model estimates of B_{RATIO} in the terminal year of an assessment tended to be lower than the actual values known from the simulations. As a consequence, the surplus production model predictions of the time required for the population to recover to B_{MSY} were often similar to the values calculated for the age structured simulation. Examples are shown in Figures 7 and 8. Considering all the cases simulated, about half the production model projections of time to recovery to B_{MSY} were shorter than the age structured model projections and about half were longer.

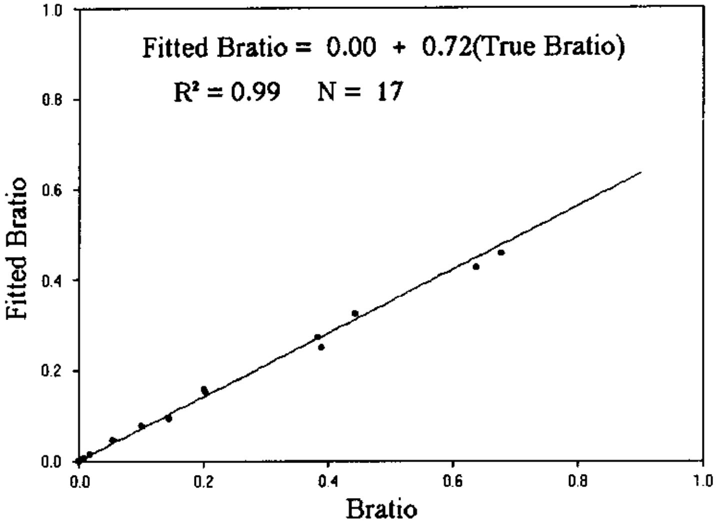

Figure 5. Relationship between ASPIC estimates of the ratios (B_{RATIO}) of biomass to the biomass at MSY and their true values in the terminal years of the analyses.

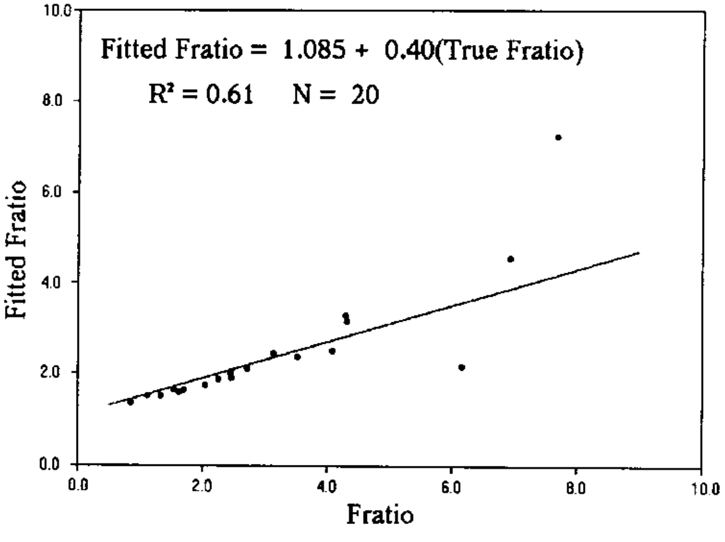

Figure 6. Relationship between ASPIC estimates of the ratios (Fratio) of F to the fishing mortality at MSY and their true values in the terminal years of the analyses.

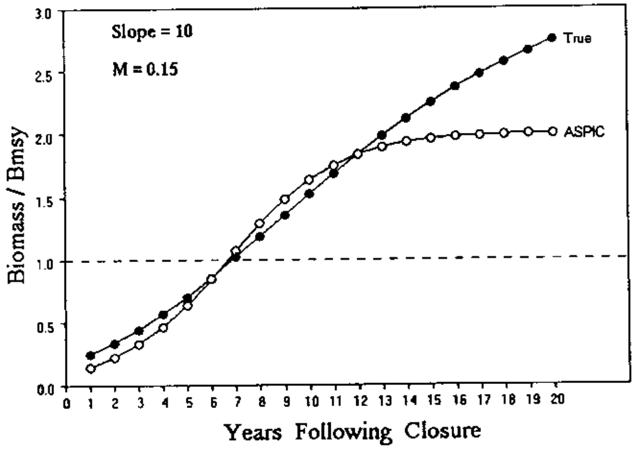

Figure 7. Surplus production model projections and stock recovery trajectories after a simulated closure of the fishery beginning the year following the terminal year of the stock assessment analysis. The surplus production model projections are based on the parameter estimates from ASPIC and its estimate of the condition of the stock in a terminal year of the assessment.

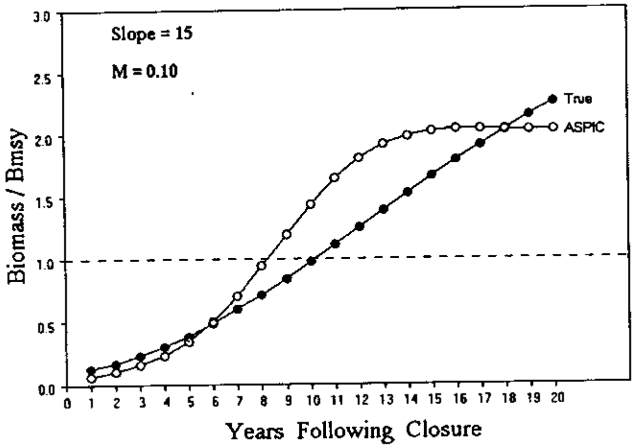

Figure 8. Surplus production model projections and stock recovery trajectories after a simulated closure of the fishery beginning the year following the terminal year of the stock assessment analysis. The surplus production model projections are based on the parameter estimates from ASPIC and its estimate of the condition of the stock in a terminal year of the assessment.

DISCUSSION

Life history data on blue marlin are sparse, creating great uncertainty in the likely values for natural mortality and the form and possible intensity of the density-dependent stock-recruitment relationship. The parameter range for the slopes of the stock-recruitment curve and for natural mortality examined in this study cover a wide range of possible life history strategies, from long-lived species with a relatively low compensatory capacity in the case of a natural mortality rate 0.05 and initial slope at the origin for the stock recruitment curve of 5.0, to a relatively short-lived species with a strong capacity to compensate for fishing mortality for the case of natural mortality of 0.25 and an initial SR slope of 50.

Natural mortality is a notoriously difficult parameter to separate from total mortality. However, there are three data sets that can be examined to estimate total mortality for the species using Hoenig's (1983) method, corrected for sample size. The oldest Pacific female blue marlin reported by Hill et al. (1989) was 27 in a sample size of 48. Assuming an age of full recruitment to total adult mortality of 2 years, one obtains an estimate of total mortality (Z) of 0.18. In a separate study, Wilson et al. (1991) found the oldest Pacific blue marlin female to be 21 years of age out of a sample size of 18 females. Again, Hoenig's (1983) method estimates Z = 0.19. Some of this mortality is from fishing, so if these data are accurate, M must be lower than 0.18. If fishing mortality is in the range of 0.03-0.04 then M would be about 0.15, which seems an upper bound on the probable level. Wilson *et al.* (1991) also sampled Atlantic blue marlin. The oldest female was 17 out of a sample size of 104 females. This produces an estimate of total mortality equal to 0.36. Surplus production model estimates of fishing mortality from the last blue marlin assessment averaged about 0.45 for the years preceding the 1981-1984 collections included in Wilson et al. (1991) study. Since this value is greater than the total mortality value derived from the Wilson et al. (1991) study it seems likely that most of the mortality in the stock is due to fishing. Given this information, natural mortality in blue marlin is probably somewhere in the range 0.05 to 0.15.

The magnitude of the initial slope of the stock recruitment curve controls the compensatory capacity of the population. Like most other stocks this value is unknown for blue marlin. Experience with many stocks has shown important population and declines or collapses when the spawning potential ratio (SPR) has fallen below about 20% (Clark 1991, Gabriel 1985, Gabriel et al. 1989, Goodyear 1993, Mace and Sissenwine 1993). This is the threshold level of SPR below which the population will tend towards extinction for an initial slope of the spawner recruit curve of 5.0. Thus, evidence from many other species suggests initial slopes of about this level. Further Mace and Sissenwine (1993) noted that replacement SPR was negatively correlated with both the maximum average body weight and body weight at 50% maturity. This observation suggests a lower than average SR slope at the origin for blue marlin, since the species is at the upper end of the scale of the size of fish at maturity. However, results of the current analysis indicate only a small potential bias in the fishing mortality rates estimated by ASPIC. Population persistence at the estimated levels of fishing mortality requires an initial slope greater than 5. The available data appear to argue for an initial SR slope in the range of 10 to15. The simulation results for an initial SR slope of 15 and a natural mortality of 0.10 and an initial SR slope of 10 and natural mortality of 0.15 seem most consistent with available information. It is perhaps noteworthy that the projected time for the populations to recover to B_{MSY} levels within this range of initial SR slopes and natural mortality rates is ten years or less.

These results suggest that the most recent blue marlin assessment which fitted a surplus production model with ASPIC might have been slightly optimistic with respect to fishing mortality rates and slightly pessimistic with respect to the status of the stock in the most recent year of the assessment. However, the potential bias is small for reasonable combinations of natural mortality and initial slopes of the stock recruitment curve. The greatest source of potential error in the current assessment is undoubtedly associated with uncertainties in the catch and cpue data to which the surplus production model was fit, and not with the use of the production model itself. However, because the fitted values of MSY were higher than the actual values, these analyses raise the concern that fishery removals at the level of MSY estimated by the surplus production model will not actually be sustainable. All of the simulations conducted here began in a near pristine state, that in many cases was at biomass levels greatly in excess of B_{MSY}. Additional analyses are warranted to determine whether or not these initial conditions play a role in the level of bias in the estimates of MSY and B_{MSY}. Also, analyses to determine the effect of random error on the robustness of ASPIC estimates would provide additional insight about the robustness of the current and future assessments using this model.

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