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# Maximum Sustainable Yield-Based Reference Points for North Pacific Striped Marlin, *Tetrapturus audax*

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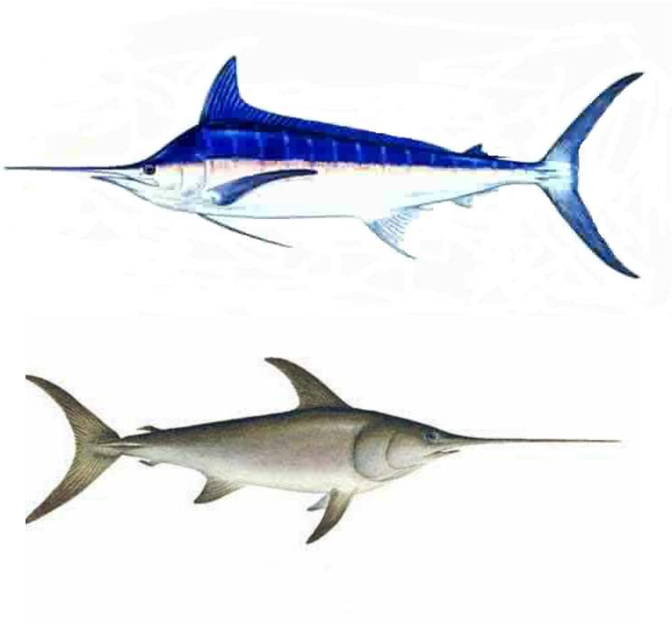

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# Maximum Sustainable Yield-Based Reference Points for North Pacific Striped Marlin, *Tetrapturus audax*

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At the July 2007 Billfish Working Group Meeting, the Working Group (WG) reviewed preliminary calculations of yield- (YPR) and spawning biomass per recruit (SPR, $F_{\%MSP}$, where %MSP refers to specified fraction of unfished spawning potential) biological reference points for North Pacific striped marlin (Brodziak 2007). The input data for these calculations included quarterly values of weight at age, maturity probability at age, and fishery selectivity at age taken from the stock assessment (Piner et al. 2007, ISC 2007). Fishery selectivities were taken from both the base case assessment model (Model 1, steepness h=0.7) and alternative assessment model (Model 2, steepness h=1) to characterize the effect of model-based uncertainty about steepness on the reference points. Differences in the YPR reference points between Model 1 and Model 2 were moderate, roughly 5% for $F_{0.1}$ and about 25% for $F_{MAX}$. Differences in SPR reference points ($F_{5\%}$ to $F_{50\%}$) between Model 1 and Model 2 were also relatively small, ranging from 4%-7%. Although estimates of YPR and SPR reference points for striped marlin were similar, equilibrium yields were higher under Model 2 than Model 1 due to differences in recent recruitment estimates from the two models. After discussing the relative merits of the biological reference points, the WG concluded that *"If $F_{20\%}$ were an appropriate reference point, then the stock is experiencing excessive fishing mortality"*. However, the WG also concluded that further analyses would be needed to select an appropriate reference point for North Pacific striped marlin given uncertainty about the most appropriate value of steepness and other factors.

In this working paper, we address the question "What are appropriate maximum sustainable yield (MSY)-based reference points for North Pacific striped marlin?". To do this, we apply a standard age-structured production model to calculate external estimates of MSY-based reference points using stock-recruitment estimates from the most recent assessment and a model-averaging approach developed by Brodziak and Legault (2005). Under this approach, two alternative structural models for striped marlin stock-recruitment dynamics were fit under various assumptions about error terms. These were the compensatory Beverton-Holt (BH) relationship, as was used in the stock assessment, and the overcompensatory Ricker (RK) relationship in which recruitment was reduced at high spawning biomasses. Annual error terms for fitting the annual stock-recruitment estimates from the stock assessment model were either a multiplicative lognormal distribution with mean unity and constant variance or an additive normal distribution with zero mean and constant variance. In this case, the lognormal provided a positively skewed distribution for recruitment deviations while the normal provided a symmetric distribution.

The annual error terms were either independent and identically distributed (iid) uncorrelated random variables or autocorrelated random variables with a lag of 1 year. In this case, the correlated errors provided an explicit model for temporal dependence in annual recruitment deviations as might be observed if recruitment was subject to low frequency environmental forcing. In contrast, the uncorrelated errors presumed temporal dependence was negligible among years. Under the lognormal error assumption, there were four alternative models for fitting a striped marlin stock-recruitment data set: BH with uncorrelated errors denoted as BHLNU, BH with correlated errors denoted as BHLNC, RK with uncorrelated errors denoted as RKLNU, and RK with correlated errors denoted as RKLNC. Similarly, there were four alternative models assuming a normal error distribution: : BH with uncorrelated errors denoted as BHNU, BH with correlated errors denoted as BHNC, RK with uncorrelated errors denoted as RKNU, and RK with correlated errors denoted as RKNC. The models fitted with the lognormal and normal error terms were treated separately for model-averaging analyses because the differences between predicted and observed stock-recruitment estimates were scaled differently under the lognormal and normal likelihood assumptions. Thus, there were two separate model fitting and model-averaging analyses applied to each set of stock-recruitment estimates.

Estimates of spawning biomass and recruitment were taken from the two stock assessment scenarios (Piner et al. 2007, ISC 2007); these were Model 1 with steepness h=0.7 and Model 2 with steepness h=1 (Table 1). The stock-recruitment estimates during 1965-2004 (n=40) were used for fitting parameters of the age-structured production model. The initial cutoff of 1965 was selected to match when recruitment deviations were freely estimated in Model 2. The ending cutoff of 2004 was selected to match the most recent period for which there was relatively complete catch information. Stock-recruitment estimates from a third scenario (Model 3) that assumed an intermediate value of steepness (h=0.85) relative to the two assessment scenarios were also included in the model fitting and model evaluation process (Table 3). As a result, there were three sets of stock-recruitment estimates for evluating MSY-based reference points along the primary axis of assessment uncertainty which was the stock-recruitment steepness parameter.

The age-structured production model was fit to the three sets of stock-recruitment estimates. Striped marlin weights and maturity probabilities at age were taken from the most recent assessment (Table 2). In this case, population age structure was approximated with a total of 21 age classes representing age classes 0.5, 1.5, ..., 19.5 and a plus group consisting of fish age-20 and older. Fishery selectivities at age were approximated using the length-specific selectivities estimated for the Japanese distant water longline (DWLL) fleets in regions 1 through 5, the Japanese drift net fleet selectivity (DNET), and the estimated Hawaii-based longline (HWLL) fleet selectivities in regions 3 and 4. For each model scenario, estimates of selectivity by 5 cm length bins from 78.5 cm to 213.5 cm were calculated as the catch-weighted average of fleet-specific length selectivities using the proportion of catch numbers by fleet during 1994-2003. The proportions for the DWLL 1-5 were 0.26, 0.03, 0.07, 0.07, 0.06, the proportion for the DNET was 0.28, and the proportions for HWLL 3 and 4 were 0.13 and 0.10, respectively. Age-specific selectivities were approximated using the catch-weighted average selectivity from the 5-cm length bin closest to the predicted mean length at age.

There were a total of four age-structured production models fit to each combination of error distribution (lognormal or normal) and set of stock-recruitment estimates (n=3); this gave a total of 4x6=24 alternative models. Model parameters were estimated using the likelihood-based approach of Brodziak and Legault (2005) as implemented in the NOAA Fisheries Toolbox Module SRFIT version 6.3 (available at http://nft.nefsc.noaa.gov/). Values of $S_{MAX}$ under models 1, 2, and 3 were the estimated spawning biomasses in 1952; these were: 60.232 kt, 28.624 kt, and 39.718 kt, respectively. Broad uninformative uniform priors were set for each model parameter (Brodziak and Legault 2005, eqn 12, note $\pi_\varphi \sim U[-1,1]$). After the posterior mode was estimated for each model, Markov chain Monte Carlo simulation was applied to generate two chains of length 600,000 from the posterior distribution. Each chain was thinned by 100 to eliminate autocorrelation. Last, the first 1000 thinned iterates were excluded to remove dependence on initial conditions; this left 5000 iterates for numerical inference using the first chain. The thinned iterates from the second chain were used to assess convergence to the posterior distribution. For each combination of error distribution and model scenario, the likelihood of the four alternative models was assessed by applying the Schwarz criterion (a.k.a., BIC) to approximate the Bayes factor for each posterior draw and averaging the resulting model probabilities. Here each of the four models was assigned an equal prior weight of ¼. In particular, given the difference in BIC values between the ith and the best-fitting model ($\Delta_{i,k}$) at the kth iterate, the posterior probability that model $M_i$ was the true model given the available data D was approximated as

$$\Pr\left(M_i \mid D\right) \approx \frac{1}{5000}\sum_{k=1}^{5000}\frac{\exp\left(-0.5\Delta_{i,k}\right)}{\sum_{j=1}^{4}\exp\left(-0.5\Delta_{j,k}\right)} \tag{0.1}$$

Given the posterior model probabilities, model-averaged expected values of derived parameters, such as the spawning biomass that produced MSY ($S_{MSY}$), were computed as the weighted average of the four conditional model expectations as

$$E\left[S_{MSY} \mid D\right] = \sum_{i=1}^{4}\Pr\left(M_i \mid D\right)\cdot E\left[S_{MSY} \mid M_i, D\right] \tag{0.2}$$

Similarly, model-averaged variances of derived parameters such as SMSY were computed from the four conditional model variance estimates and expected values as

(0.3)

$$Var\left[S_{MSY} \mid D\right] = \sum_{i=1}^{4}\Pr\left(M_i \mid D\right)\cdot\left\{Var\left[S_{MSY} \mid M_i,\, D\right] + \left(E\left[S_{MSY} \mid D\right] - E\left[S_{MSY} \mid M_i,\, D\right]\right)^2\right\}$$

Model-averaged results indicated that the Beverton-Holt model was well-supported for each of the sets of stock-recruitment estimates (Table 3). In contrast, there was very little support for the Ricker model suggesting that overcompensatory recruitment dynamics were unlikely for North Pacific striped marlin. The calculated model probabilities showed that the uncorrelated error assumption was more likely than the autocorrelated error assumption across scenarios with the exception of the normal errors and steepness h=1 scenario (Table 3). Comparing the model-averaged MSY-based reference points across steepness scenarios showed that the low steepness h=0.7 scenario had a higher value of $S_{MSY}$ and lower values of $F_{MSY}$ and MSY than the higher steepness scenarios as would be expected from a stock with less reslient stock-recruitment dynamics. Model-averaged estimates of $F_{MSY}$ corresponded to roughly 45%, 23%, and 25% of unfished spawning potential under model scenarios 1, 2, and 3, respectively.

Model-averaged residuals indicated that each of the stock-recruitment scenarios had nonrandom patterns in the standardized residuals during 1965-1975 (Figures 1.1-1.3). Subsequent to 1975, the residual patterns of model 1 under lognormal and normal distributions appeared to have random errors (Figure 1.1). In contrast, the corresponding residual patterns of models 2 and 3 under lognormal or normal distributions did not conform to the assumption of random errors. Overall, the low steepness scenario produced the best-fitting age-structured production models.

Kobi plots of the time trajectories of the relative fishing mortality rate (F/FMSY) and the relative biomass (S/SMSY) showed a consistent pattern for each set of stock-recruitment estimates. Under steepness scenario 1, the model-averaged estimates of relative fishing mortality and biomass showed that the striped marlin stock began to experience overfishing in the 1960s and became overfished in the late-1970s regardless of the assumed error distribution (Figures 2.1 and 2.2). Under steepness scenario 2, estimates of relative fishing mortality and biomass fluctuated during the 1950s-1970s (Figures 2.3 and 2.4). Fishing mortality generally increased and biomass decreased in the 1980s-1990s and the stock was experiencing overfishing and was overfished in the most recent period, 2001-2003 (Figures 2.3 and 2.4). Estimates of relative fishing mortality and biomass exhibited a similar pattern under steepness scenario 3. In the 1950s-1970s, fishing mortality and biomass fluctuated until the late-1980s when fishing mortality increased and biomass decreased (Figures 2.5 and 2.6). As a result, the stock was also experiencing overfishing and was overfished in the most recent period under model 3 regardless of the assumed error distribution (Figures 2.5 and 2.6).

Model-averaged estimates of MSY-based reference points indicated that North Pacific striped marlin in currently experiencing overfishing regardless of the steepness scenario assumed. Under the scenarios 1, 2, and 3 the average relative fishing mortality rates during 2001-2003 were: 3.9 to 4.5*$F_{MSY}$ (model 1), 1.9*$F_{MSY}$ (model 2), and 1.9 to 2.1*$F_{MSY}$ (model 3). Model averaged estimates of relative biomass during 2001-2003 indicated that North Pacific striped marlin biomass was well below $S_{MSY}$ and ranged from 29%-34% of $S_{MSY}$ under model 1 to 60%-64% of $S_{MSY}$ under model 2. If the MSY-based reference points are interpreted as limits instead of targets (see, for example, Mace 2001), then the stock would likely be determined to be overfished in the most recent period as well. Overall, the current status determination of North Pacific striped marlin using MSY-based reference points was robust to model assumptions about the form of stock-recruitment curve used to fit the age-structured production model and was also robust to the steepness scenario assumed in the stock assessment model.

## References

Brodziak, J. 2007. Preliminary calculations of yield and spawning biomass per recruit biological reference points for striped marlin. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/MARWG-SWORWG-2/Working Paper 3.

Brodziak, J., and C. Legault. 2005. Model averaging to estimate rebuilding targets for overfished stocks. Can. J. Fish. Aquat. Sci. 62:544-562.

International Scientific Committee for Tuna and Tuna-like species in the North Pacific Ocean.2007. Report of the Marlin and Swordfish Working Group Joint Workshop. Intercessional Workshop, March 19-26, 2007, Institute of Oceanography, National Taiwan University, Taipei, Taiwan, 50 p.

Mace, P. 2001. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries, 2:2-32.

Piner, K., R. Conser, G. Dinardo, and J. Brodziak. 2007. Stock synthesis 2 sensitivity runs for striped marlin assessment WG 2007. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/MARWG-SWORWG-1/Working Paper 2.

Table 1. Stock-recruitment estimates used for MSY-based reference point calculations by two assessment scenarios (Models 1 and 2) and an intermediate steepness scenario (Model 3).

| | Model 1: Steepness h=0.7 | | Model 2: Steepness h=1 | | Model 3: Steepness h=0.85 | |
|---|---|---|---|---|---|---|
| Year | Spawning biomass (kt) | Recruitment millions of age-0 fish) | Spawning biomass (kt) | Recruitment millions of age-0 fish) | Spawning biomass (kt) | Recruitment millions of age-0 fish) |
| 1965 | 28.809 | 2.517 | 7.859 | 5.934 | 13.583 | 4.679 |
| 1966 | 22.501 | 4.043 | 5.695 | 2.441 | 9.844 | 2.803 |
| 1967 | 22.153 | 2.244 | 6.435 | 2.945 | 10.198 | 2.667 |
| 1968 | 20.614 | 1.498 | 7.468 | 1.465 | 10.369 | 1.436 |
| 1969 | 19.148 | 1.844 | 14.879 | 1.949 | 15.097 | 1.855 |
| 1970 | 26.434 | 1.657 | 30.273 | 1.719 | 27.461 | 1.652 |
| 1971 | 35.374 | 1.239 | 39.867 | 1.301 | 36.172 | 1.241 |
| 1972 | 37.692 | 0.976 | 42.431 | 1.017 | 38.323 | 0.980 |
| 1973 | 37.679 | 0.974 | 42.504 | 1.019 | 38.299 | 0.970 |
| 1974 | 33.728 | 0.560 | 38.320 | 0.562 | 34.249 | 0.569 |
| 1975 | 28.759 | 1.051 | 32.980 | 1.088 | 29.165 | 1.041 |
| 1976 | 21.996 | 0.794 | 24.709 | 0.801 | 22.214 | 0.805 |
| 1977 | 17.239 | 2.135 | 19.308 | 2.177 | 17.361 | 2.115 |
| 1978 | 13.700 | 0.728 | 14.807 | 0.729 | 13.741 | 0.751 |
| 1979 | 12.178 | 1.542 | 12.922 | 1.591 | 12.207 | 1.525 |
| 1980 | 10.801 | 0.476 | 11.347 | 0.466 | 10.828 | 0.506 |
| 1981 | 10.710 | 1.340 | 11.089 | 1.378 | 10.693 | 1.321 |
| 1982 | 12.315 | 1.042 | 12.625 | 1.045 | 12.275 | 1.062 |
| 1983 | 11.967 | 1.574 | 12.239 | 1.609 | 11.949 | 1.552 |
| 1984 | 11.947 | 0.341 | 12.349 | 0.318 | 11.967 | 0.362 |
| 1985 | 11.660 | 1.175 | 12.120 | 1.199 | 11.729 | 1.165 |
| 1986 | 11.730 | 1.348 | 12.243 | 1.364 | 11.798 | 1.343 |
| 1987 | 11.646 | 0.520 | 12.013 | 0.518 | 11.686 | 0.531 |
| 1988 | 10.360 | 0.813 | 10.734 | 0.824 | 10.379 | 0.810 |
| 1989 | 7.558 | 1.047 | 7.883 | 1.062 | 7.588 | 1.048 |
| 1990 | 7.540 | 1.048 | 7.869 | 1.062 | 7.547 | 1.049 |
| 1991 | 8.528 | 0.899 | 8.875 | 0.910 | 8.533 | 0.897 |
| 1992 | 7.809 | 0.610 | 8.144 | 0.619 | 7.834 | 0.617 |
| 1993 | 7.677 | 1.090 | 8.012 | 1.109 | 7.703 | 1.088 |
| 1994 | 7.575 | 0.818 | 7.926 | 0.838 | 7.597 | 0.822 |
| 1995 | 7.404 | 0.608 | 7.775 | 0.620 | 7.424 | 0.618 |
| 1996 | 5.927 | 1.049 | 6.298 | 1.087 | 5.954 | 1.055 |
| 1997 | 5.467 | 0.533 | 5.842 | 0.555 | 5.504 | 0.547 |
| 1998 | 5.337 | 0.362 | 5.741 | 0.376 | 5.382 | 0.381 |
| 1999 | 4.491 | 0.819 | 4.924 | 0.882 | 4.564 | 0.854 |
| 2000 | 4.440 | 0.301 | 4.851 | 0.323 | 4.543 | 0.331 |
| 2001 | 4.800 | 0.539 | 5.256 | 0.598 | 4.950 | 0.592 |
| 2002 | 4.001 | 0.498 | 4.472 | 0.587 | 4.227 | 0.586 |
| 2003 | 3.659 | 0.317 | 4.170 | 0.398 | 3.980 | 0.448 |
| 2004 | 3.574 | 0.413 | 4.197 | 0.877 | 4.034 | 0.783 |

Table 2. Weight-at-age, maturity-at-age and fishery selectivity estimates under two assessment scenarios (Models 1 and 2) and an intermediate steepness scenario (Model 3) used to calculate MSY-based reference points.

| Age (yr) | Weight (kg) at Age | Fraction Mature at Age | Fishery Selectivity at Age Model 1 h=0.7 | Fishery Selectivity at Age Model 2 h=1 | Fishery Selectivity at Age Model 3 h=0.85 |
|---|---|---|---|---|---|
| 0.5 | 0.389 | 0 | 0.000 | 0.000 | 0.000 |
| 1.5 | 7.251 | 0 | 0.063 | 0.062 | 0.061 |
| 2.5 | 14.374 | 0 | 0.295 | 0.293 | 0.291 |
| 3.5 | 21.089 | 0 | 0.406 | 0.405 | 0.405 |
| 4.5 | 27.090 | 0 | 0.597 | 0.597 | 0.597 |
| 5.5 | 32.278 | 0 | 0.728 | 0.726 | 0.728 |
| 6.5 | 36.666 | 1 | 0.785 | 0.782 | 0.785 |
| 7.5 | 40.320 | 1 | 0.833 | 0.830 | 0.833 |
| 8.5 | 43.328 | 1 | 0.875 | 0.872 | 0.875 |
| 9.5 | 45.786 | 1 | 0.915 | 0.913 | 0.915 |
| 10.5 | 47.780 | 1 | 0.956 | 0.955 | 0.956 |
| 11.5 | 49.392 | 1 | 0.956 | 0.955 | 0.956 |
| 12.5 | 50.689 | 1 | 0.956 | 0.955 | 0.956 |
| 13.5 | 51.730 | 1 | 1.000 | 1.000 | 1.000 |
| 14.5 | 52.564 | 1 | 1.000 | 1.000 | 1.000 |
| 15.5 | 53.231 | 1 | 1.000 | 1.000 | 1.000 |
| 16.5 | 53.763 | 1 | 1.000 | 1.000 | 1.000 |
| 17.5 | 54.188 | 1 | 1.000 | 1.000 | 1.000 |
| 18.5 | 54.526 | 1 | 1.000 | 1.000 | 1.000 |
| 19.5 | 54.796 | 1 | 1.000 | 1.000 | 1.000 |
| 20.5 | 55.011 | 1 | 1.000 | 1.000 | 1.000 |

Table 3. Posterior model probabilities and model-averaged estimates of spawning biomass to produce MSY ($S_{MSY}$, kt), fishing mortality rate to produce MSY ($F_{MSY}$, $yr^{-1}$), and MSY (kt) along with model-averaged standard deviations (σ) for lognormal and normal error distributions under three scenarios of stock-recruitment estimates.

**Lognormal Error Distribution**

| | Model Probabilities | | | | Model-Averaged MSY-Based Reference Points | | |
|---|---|---|---|---|---|---|---|
| Steepness Scenario | BHLNU | BHLNC | RKLNU | RKLNC | SMSY ($\sigma_{SMSY}$) | FMSY ($\sigma_{FMSY}$) | MSY ($\sigma_{MSY}$) |
| Model 1 h=0.7 | 0.83 | 0.17 | 0 | 0 | 14.5 (6.5) | 0.16 (0.03) | 4.2 (1.3) |
| Model 2 h=1 | 0.68 | 0.32 | 0 | <0.01 | 7.8 (4.3) | 0.33 (0.14) | 5.8 (1.5) |
| Model 3 h=0.85 | 0.81 | 0.19 | 0 | 0 | 8.8 (3.1) | 0.31 (0.10) | 6.4 (0.8) |

**Normal Error Distribution**

| | Model Probabilities | | | | Model-Averaged MSY-Based Reference Points | | |
|---|---|---|---|---|---|---|---|
| Steepness Scenario | BHNU | BHNC | RKNU | RKNC | SMSY ($\sigma_{SMSY}$) | FMSY ($\sigma_{FMSY}$) | MSY ($\sigma_{MSY}$) |
| Model 1 h=0.7 | 0.55 | 0.44 | 0 | <0.01 | 12.3 (5.8) | 0.18 (0.07) | 4.1 (1.2) |
| Model 2 h=1 | 0.48 | 0.52 | 0 | 0 | 7.2 (6.4) | 0.34 (0.19) | 6.0 (3.9) |
| Model 3 h=0.85 | 0.63 | 0.37 | 0 | <0.01 | 7.8 (3.5) | 0.34 (0.14) | 6.2 (1.2) |

Figure 1.1. Model-averaged standardized recruitment residuals from the fitted age-structured production for model 1 assuming lognormal or normal error distributions.

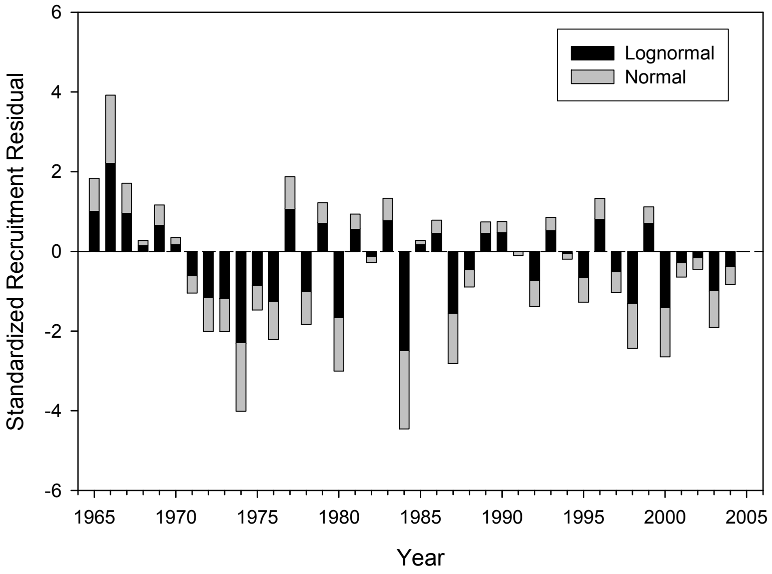

Figure 1.2. Model-averaged standardized recruitment residuals from the fitted age-structured production for model 2 assuming lognormal or normal error distributions.

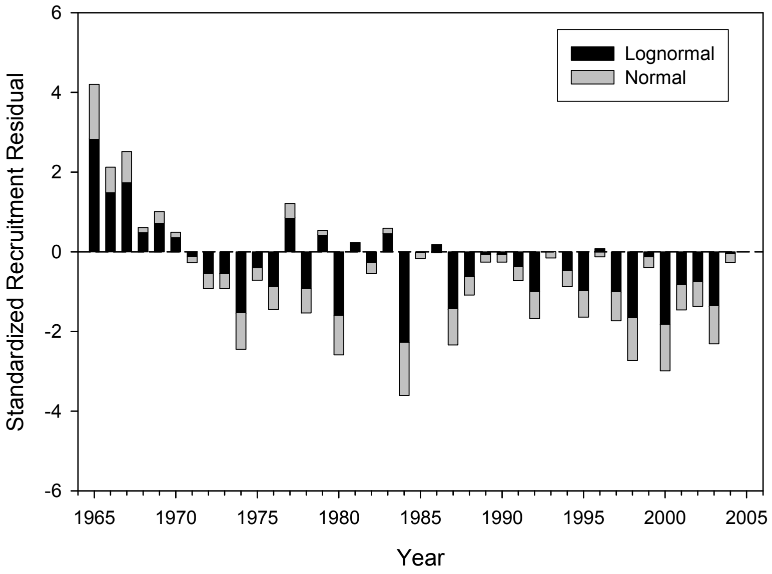

Figure 1.3. Model-averaged standardized recruitment residuals from the fitted age-structured production for model 3 assuming lognormal or normal error distributions.

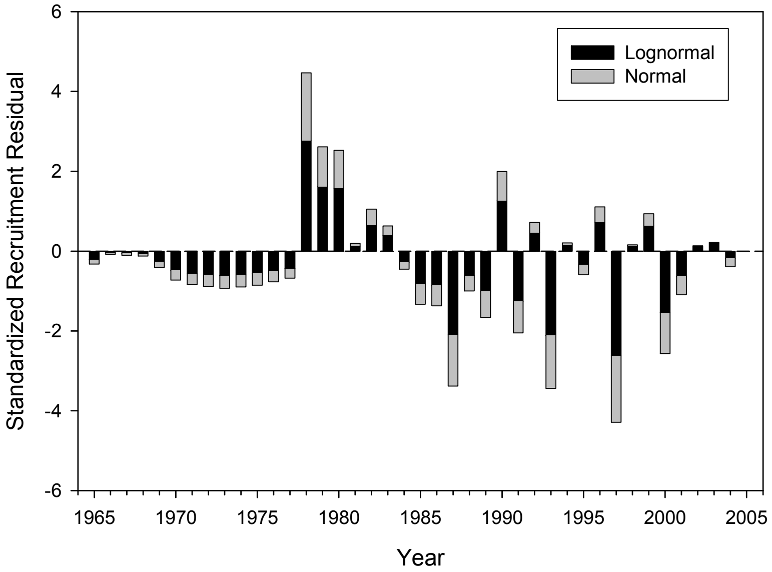

Figure 2.1. Kobi plot of the trajectory of relative fishing mortality and relative biomass using model-averaged estimates of $F_{MSY}$ and $S_{MSY}$ from model scenario 1 assuming a lognormal error distribution.

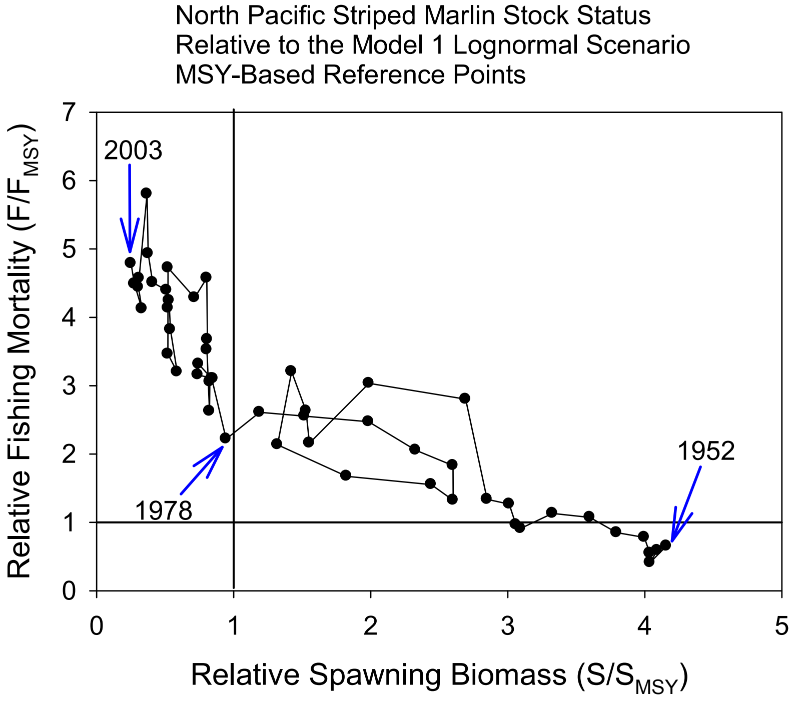

Figure 2.2. Kobi plot of the trajectory of relative fishing mortality and relative biomass using model-averaged estimates of $F_{MSY}$ and $S_{MSY}$ from model scenario 1 assuming a normal error distribution.

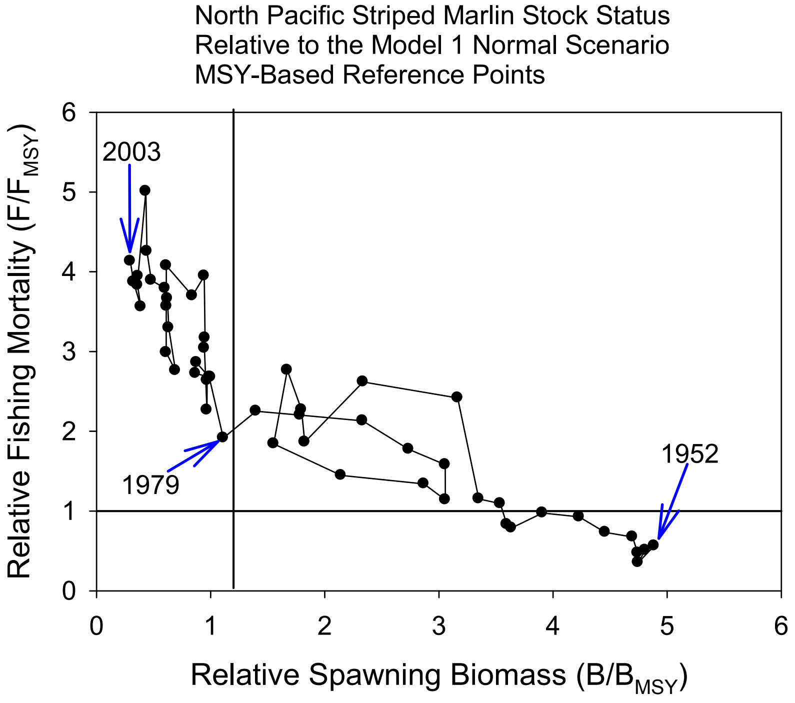

Figure 2.3. Kobi plot of the trajectory of relative fishing mortality and relative biomass using model-averaged estimates of $F_{MSY}$ and $S_{MSY}$ from model scenario 2 assuming a lognormal error distribution.

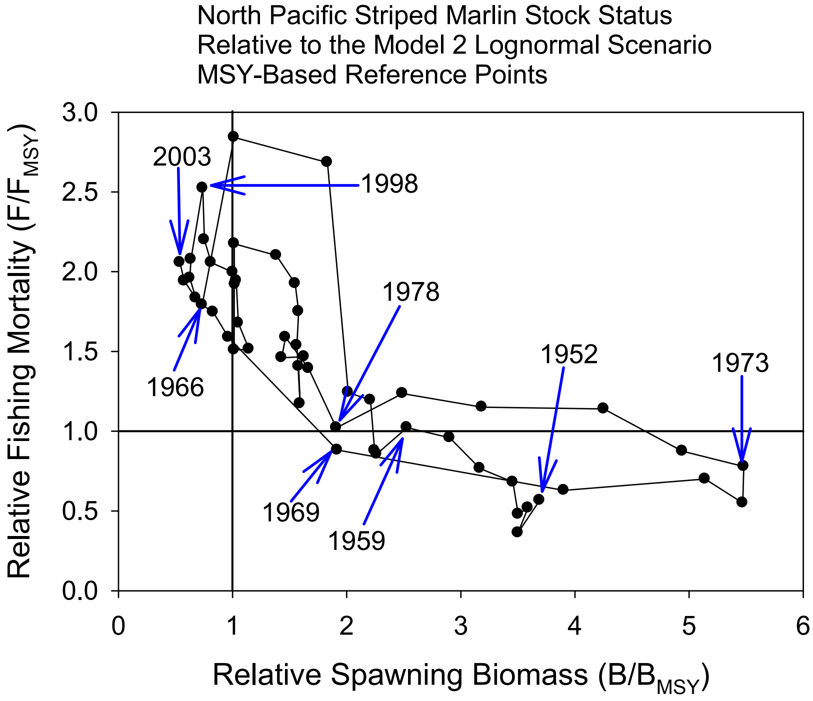

Figure 2.4. Kobi plot of the trajectory of relative fishing mortality and relative biomass using model-averaged estimates of $F_{MSY}$ and $S_{MSY}$ from model scenario 2 assuming a normal error distribution.

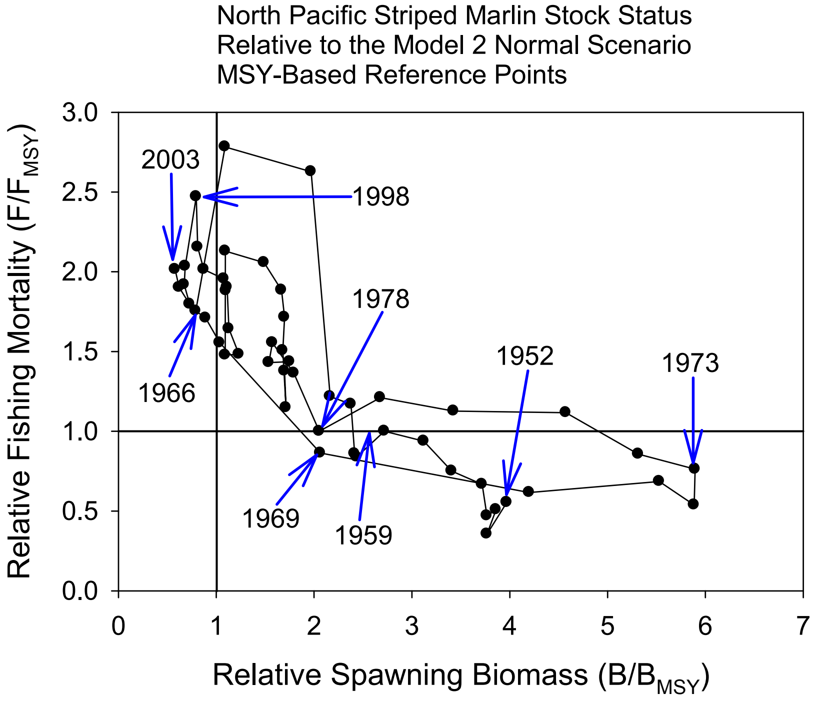

Figure 2.5. Kobi plot of the trajectory of relative fishing mortality and relative biomass using model-averaged estimates of $F_{MSY}$ and $S_{MSY}$ from model scenario 3 assuming a lognormal error distribution.

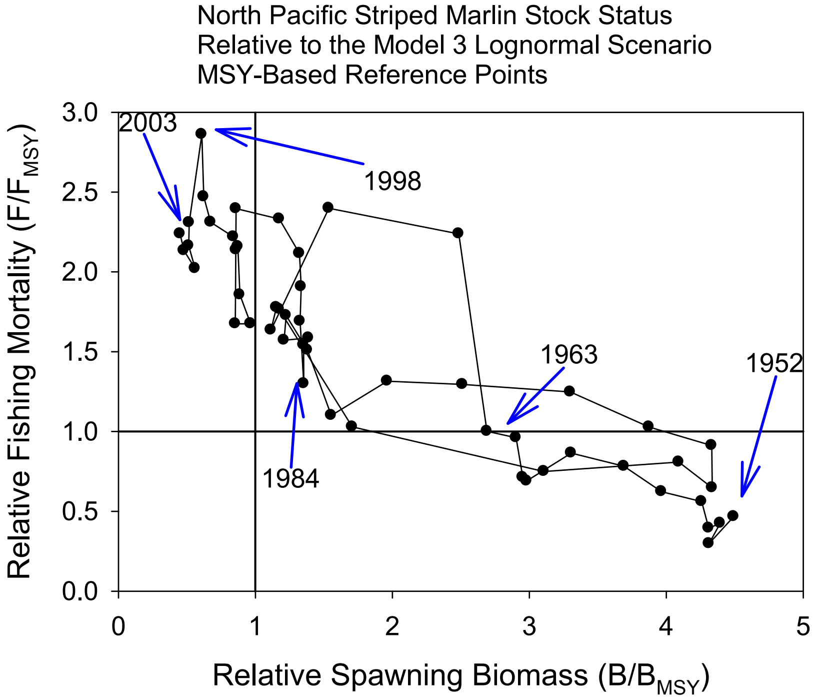

Figure 2.6. Kobi plot of the trajectory of relative fishing mortality and relative biomass using model-averaged estimates of $F_{MSY}$ and $S_{MSY}$ from model scenario 3 assuming a normal error distribution.