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Update of the Production Model Assessment of the Eastern Pacific Swordfish Stock (*Xiphias gladius*) in 2010

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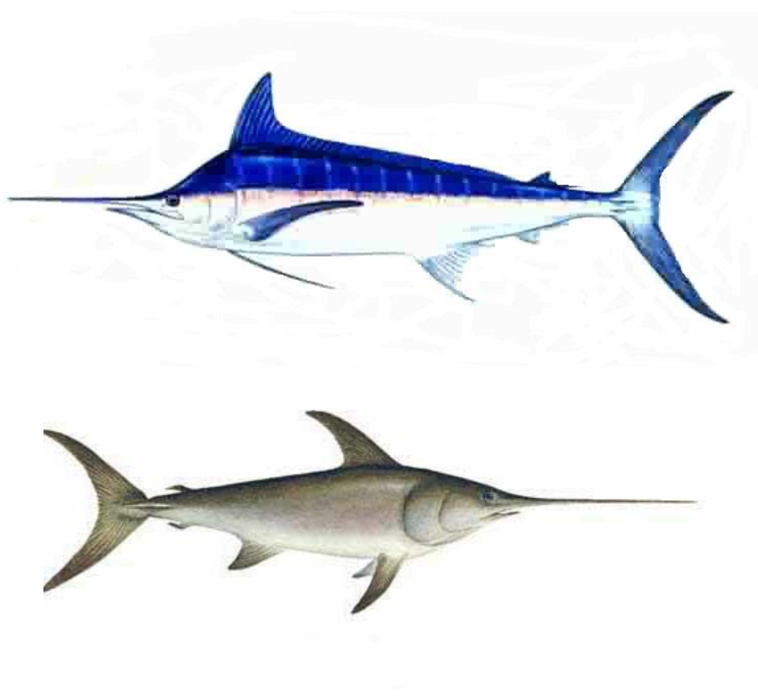

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Abstract

This document updates results of the stock assessment of the Eastern Pacific swordfish stock (a.k.a., Subarea 2) conducted in 2009 by the Billfish Working Group of the International Scientific Committee for Tunas and Tuna-Like Species (ISC). The update consisted of running the Bayesian surplus production model for the Eastern Pacific swordfish stock with new catch data that included revised estimates of swordfish catches of Japan, Chinese Taipei, Korea, and Spain in Subarea 2.

As in the 2009 assessment, biomass production was modeled using a 3-parameter production model that allowed production to vary from a symmetric Schaefer curve. Input fishery data included nominal catches of Eastern Pacific swordfish during 1951-2006. Relative abundance indices for swordfish consisted of standardized catch-per-unit effort (CPUE) for Japanese and Chinese-Taipei longline fisheries in Subarea 2. Lognormal prior distributions for intrinsic growth rate and carrying capacity were assumed to be moderately informative with coefficients of variation set at 50%. Goodness-of-fit diagnostics included the root-mean squared error of CPUE fits and the standardized CPUE residuals. Production model results indicated that it was highly likely that current estimates of exploitable biomass of Eastern

Pacific swordfish were above the biomass to maximize surplus production, B_{MSY}. Results also indicated that it was highly likely that current estimates of swordfish exploitation rates were below the harvest rate to maximize surplus production, H_{MSY}. These updated results are consistent with the results of the previous stock assessment of Eastern Pacific swordfish conducted in 2009. Stochastic projections of swordfish biomass and catch assuming recent levels of variability about swordfish fishing effort and mortality indicated that exploitable biomass was likely sufficient to support current catches through 2010.

Introduction

This assessment update applied a Bayesian statistical framework to estimate parameters of the base case production model used to assess the Eastern Pacific swordfish stock (Figure 1) with revised catch estimates for Subarea 2 updated in March 2010. The Bayesian production model provided direct estimates of parameter uncertainty that were straightforward to interpret and were appropriate for risk analyses. The production model included both process error for fitting biomass production dynamics and observation error for fitting the standardized CPUE from Japanese and Chinese-Taipei longline fishing fleets.

Material and Methods

Fishery Data

Fishery catch data for assessing Eastern Pacific swordfish were taken from the most recent summary of available fishery-dependent data (ISC Billfish Working Group 2009). Commercial catch catches of swordfish by Japanese, Chinese Taipei, Korea, and Spain fleets in Subarea 2 were updated from the 2009 assessment; this led to an increase of about 82% in the reported swordfish catch biomass in Subarea 2 (Table 1) compared to the 2009 assessment (Brodziak and Ishimura 2009).

Estimates of standardized commercial fishery CPUE of swordfish were collected from Courtney and Wagatsuma (2009) for the Eastern Pacific swordfish stock. The standardized CPUE time series for Subarea 2 in the Eastern Pacific included standardized Japanese longline CPUE (1955-2006, n=52) and standardized Chinese-Taipei longline CPUE (1995-2006, n=12). These time series of standardized CPUE were the same as those used in the 2009 assessment and provided indices of relative swordfish abundance in Subarea 2 through time.

Production Model

The production model for Eastern Pacific swordfish was formulated as a Bayesian state-space model with observation and process error terms (e.g., Meyer and Millar 1999; Brodziak 2007). The time series of exploitable biomass comprised the unobserved state variables which were estimated from the observed relative abundance indices (e.g., CPUE) and catches using an observation error likelihood function and prior distributions for model parameters (θ). The observation error likelihood measured the discrepancy between observed and predicted CPUE and the prior distributions represented the relative degree of belief about the probable values of model parameters.

The process dynamics represented the fluctuations in exploitable swordfish biomass due to density-dependent population processes and fishery harvests. The production dynamics of biomass were based on a power function model with an annual time step. Under this 3-parameter model, current amount of exploitable biomass (B_T) depended on the previous biomass (B_{T-1}), catch (C_{T-1}), intrinsic growth rate (R), carrying capacity (K), and a production shape parameter (S) for T = 2,…, N.

(1) $$B_T = B_{T-1} + R \cdot B_{T-1}\left(1 - \left(\frac{B_{T-1}}{K}\right)^S\right) - C_{T-1}$$

The production model shape parameter determined where surplus production peaked as biomass varied as a fraction of carrying capacity. If the shape parameter was less than unity (0 < S < 1) then surplus production peaked when biomass was below ½ of K (i.e., a right-skewed production curve). If the shape parameter was greater than unity (S > 1), then surplus production was highest when biomass was above ½ of K (i.e., a left-skewed production curve). If the shape parameter was identically unity (S = 1), then the production model was identical to a discrete-time Schaefer production model where maximum surplus production occurred when biomass was equal to ½ of S. Thus, the shape of the biomass production curve could be symmetric, right- or left-skewed depending on the estimated value of S.

The power function model was rewritten in terms of the proportion of swordfish carrying capacity (*P* = *B*/*K*) to improve the efficiency of the Markov Chain Monte Carlo algorithm used to estimate parameters (i.e., Meyer and Millar 1999). Given this parameterization, the process dynamics for the power function model were

(2) $$P_T = P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}^S\right) - \frac{C_{T-1}}{K}$$

Biological Reference Points

The values of exploitable biomass and harvest rate that maximize biomass production were relevant as biological reference points for maximum sustainable yield (MSY). For the 3-parameter production model, the exploitable biomass that produced MSY (B_{MSY}) was a function of carrying capacity and the production shape parameter

(3) $$B_{MSY} = K \cdot (S+1)^{\frac{-1}{S}}$$

The corresponding harvest rate that produced MSY (H_{MSY}) was a function of the intrinsic growth rate and the production shape parameter

(4) $$H_{MSY} = R\left(1 - \frac{1}{S+1}\right)$$

The associated value of maximum sustainable yield (MSY) was a function of carrying capacity, intrinsic growth rate, and the production shape parameter

(5) $$MSY = R\left(1-\frac{1}{S+1}\right)\cdot K\left(S+1\right)^{\frac{-1}{S}}$$

Thus, the production model produced direct estimates of biological reference points for swordfish that are commonly used for determining stock status.

Observation Error Model

The observation error model related the observed fishery CPUE to the exploitable biomass of the swordfish stock under each scenario. It was assumed that each CPUE index (*I*) was proportional to exploitable biomass multiplied by a fleet-specific catchability coefficient *Q*

(6) $$I_T = QB_T = QKP_T$$

The observed CPUE values were subject to sampling variation which was assumed to have a multiplicative lognormal distribution. As a result, the observation errors were distributed as $v_T = e^{V_T}$ where the V_T values were independent and identically distributed normal random variables with zero mean and variance τ^2. Given the lognormal observation errors, the observation equations for each annual time period indexed by T = 1,..., N were

(7) $$I_T = QKP_T \cdot v_T$$

This was the general form of the observation error likelihood function $p(I_T|\theta)$ for the Japanese and Chinese-Taipei fishing fleets through time.

Process Error Model

The process error model related the dynamics of exploitable biomass to natural variability due to demographic and environmental processes affecting the Eastern Pacific swordfish stock. The deterministic dynamics of the production model were subject to natural variation as a result of fluctuations in life history parameters, trophic interactions, environmental conditions and other factors.

As a result, the annual process error represented the joint effects of a large number of random multiplicative events which combined to form a multiplicative lognormal process under the Central Limit Theorem. As a result, the process error terms were assumed to be independent and lognormally distributed random variables $\eta_T = e^{U_T}$ where the U_T values were normal random variables with mean 0 and variance σ^2. Given the process errors, the state equations related the unobserved biomass states to the observed catches and the estimated population dynamics parameters. Assuming multiplicative lognormal process errors, the state equations for the initial time period (T = 1) and subsequent periods (T > 1) were

(8)

$$\begin{aligned} P_1 &= \eta_1 \\ P_T &= \left(P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}^S\right) - \frac{C_{T-1}}{K} \right) \cdot \eta_T \quad for\ T > 1 \end{aligned}$$

These coupled equations set the conditional prior distribution for the proportion of carrying capacity, $p(P_T)$, in each time period T, conditioned on the proportion in the previous period.

Prior Distributions

The prior distributions provided a means to quantify existing knowledge, or the lack thereof, of the likely value of each model parameter under the Bayesian paradigm. For the production model, the model parameters consisted of the carrying capacity, the intrinsic growth rate, the shape parameter, the catchability coefficients, the process and observation error variances, and the annual biomasses as a proportion of carrying capacity. Auxiliary information was incorporated into the formulation of the prior distributions when it was available. The same prior distributions that were used in the 2009 assessment for the swordfish stock in Subarea 2 were used in this 2010 update.

Prior for Carrying Capacity

The prior distribution for the carrying capacity $p(K)$ was a lognormal distribution with mean (μ_K) and variance (σ_K^2) parameters.

(9) $$p(K) = \frac{1}{\sqrt{2\pi}K\sigma_K}\exp\left(-\frac{(\log K - \mu_K)^2}{2\sigma_K^2}\right)$$

The variance parameter was set to achieve a coefficient of variation (CV) for K of 50%. That is, $CV[K] = \left(\exp\left(\sigma_K^2\right) - 1\right)^{\frac{1}{2}}$ = 0.5. The mean carrying capacity for subarea 2 was set to be μ_K = 75,000 mt. This mean value was chosen to reflect the magnitude of exploitable biomass likely needed to support the observed fishery catches (Table 1).

Prior for Intrinsic Growth Rate

The prior distribution for intrinsic growth rate $p(R)$ was a lognormal distribution with mean (μ_R) and variance (σ_R^2) parameters set to achieve a CV for R of 50%

(10) $$p(R) = \frac{1}{\sqrt{2\pi}R\sigma_R}\exp\left(-\frac{(\log R - \mu_R)^2}{2\sigma_R^2}\right)$$

The mean R parameter was set to be μ_R=0.5. This mean value was slightly higher than the range of prior means of (0.40, 0.43) estimated for North and South Atlantic swordfish, respectively, based on an analysis of life history parameters (McAllister et al. 2000). The primary difference between the Atlantic and Pacific swordfish life history parameters was the value of annual natural mortality. McAllister et al. (2000) assumed a constant natural mortality rate of M=0.2 for Atlantic swordfish while the Pacific swordfish natural mortality rate was estimated to be M ≈ 0.35 (Brodziak 2009), roughly 75% higher than the Atlantic swordfish value. Setting the prior mean to be $\mu_R = 0.5$ with a CV of 50% allowed sufficient flexibility to estimate the probable value of R given the observed catch and CPUE data.

Prior for Production Shape Parameter

The prior distribution for the production function shape parameter $p(S)$ was a gamma distribution with scale parameter λ and shape parameter k:

$$\textbf{(11)} \qquad p(S) = \frac{\lambda^k S^{k-1} \exp(-\lambda S)}{\Gamma(k)}$$

The values of the scale and shape parameters were set to $\lambda = k = 2$. This choice of parameters set the mean of $p(S)$ to be $\mu_S = 1$, which corresponded to the value of S for the Schaefer production model. This choice also implied that the CV of the shape parameter prior was 71%. In effect, the prior for the shape parameter was centered on the symmetric Schaefer model and had sufficient flexibility to estimate a nonsymmetrical production function if needed.

Priors for Catchability

The prior distributions for the catchability coefficients $p(Q)$ of the Japanese and Chinese-Taipei fleets were chosen to be identical inverse-gamma distributions with scale parameter λ and shape parameter k.

$$\textbf{(12)} \qquad p(Q) = \frac{\lambda^k Q^{-(k+1)}}{\Gamma(k)} \exp\left(\frac{-\lambda}{Q}\right)$$

The scale and shape parameters were set to be $\lambda = k = 0.001$. This choice of parameters implied that $1/Q$ has a mean of 1 and a variance of 1000 and produced a relatively uninformative prior. Since $1/Q$ is unbounded at $Q = 0$, an additional numerical constraint that Q be no smaller than 10^{-4} was imposed for the Markov Chain Monte Carlo (MCMC) sampling.

Priors for Error Variances

Priors for the process error variance $p(\sigma^2)$ and observation error variance $p(\tau^2)$ were chosen to be diffuse inverse-gamma distributions. The choice of an inverse gamma distribution implied that the associated prior for error precision ($\pi = 1/\sigma^2$) was effectively $p(\pi) \propto \pi^{-1}$ which is the Jeffrey's prior for the precision parameter (Congdon 2001). As a result of this choice, inferences based on the gamma assumption were not affected by changing the scale of the variance parameter. For the process error variance prior, the scale parameter was set to $\lambda = 4$ and the shape parameter was $k = 0.1$. This choice of parameters produced an expected value of approximately $E[\sigma^2] = 0.025$ with a CV of 16%. Similarly, for the observation error variance prior, the scale parameter was set to $\lambda = 2$ and the shape parameter was $k = 0.446$. This choice of parameters produced an expected value of approximately $E[\tau^2] = 0.223$ with a CV of 50%. Given these priors, the initial observation error variance was roughly 3-fold greater than the process error variance. The fitted posterior means of the process and observation errors estimated from the MCMC sampling also depended on the model fits to the observed data.

Priors for Proportions of Carrying Capacity

Prior distributions for the time series of the proportion of biomass to carrying capacity, $p(P_T)$, were lognormal distributions as specified in the process dynamics. The mean proportion of carrying capacity for the initial year of 1951 was set to 0.9. This corresponded to an assumption that the Eastern Pacific swordfish stock was lightly exploited and had exploitable biomass near its carrying capacity following a period of limited directed fishing during World War II.

Posterior Distribution

Samples from the joint posterior distribution of the swordfish production model were needed to make inferences about the probable values of the model parameters. Given the catch and the CPUE data (*D)*, the posterior distribution $p(\theta|D)$ was proportional to the product of the prior distributions and the likelihood of the CPUE data via Bayes' theorem

$$\textbf{(13)} \quad p(\theta|D) \propto p(K)\,p(R)\,p(S)\,p(Q)\,p(\sigma^2)\,p(\tau^2)\prod_{T=1}^{N} p(P_T)\prod_{T=1}^{N} p(I_T|\theta)$$

Inferences about this nonlinear multi-parameter model were based on generating a large number of independent samples from the posterior distribution. In this case, Markov Chain Monte Carlo simulation using the Gibbs sampler was applied to numerically generate a sequence of samples from the posterior distribution (Gilks et al. 1996).

Markov Chain Monte Carlo simulations were conducted with the WINBUGS software (Spiegelhalter et al. 2003) which was used to set the initial conditions, perform the MCMC calculations, and summarize the results. Three independent MCMC chains of 130,000 samples with different initial conditions were simulated. A burn-in period of 30,000 samples was removed from each chain to reduce any dependence of the MCMC samples on initial conditions. Next, each chain was thinned by 10 to reduce autocorrelation and every tenth sample was used for inference. As a result, a total of 30,000 samples from the posterior were available for summarizing model results.

Convergence of the MCMC simulations to the posterior distribution was checked using the Geweke diagnostic (Geweke 1992), Gelman and Rubin diagnostic (Gelman and Rubin 1992), and the Heidelberger and Welch stationarity and half-interval test (Heidelberger and Welch 1992) as implemented in the CODA software package (Best et al. 1996; Plummer et al. 2006) in the R Language (R Development Core Team 2009). Convergence diagnostics for several key model parameters (intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients) were monitored to verify convergence of the MCMC chains to the posterior distribution. In addition, Monte

Carlo errors, which measured the variation of the mean of each parameter due to the MCMC simulation, were calculated and compared to the posterior standard deviation of the key model parameters. In this case, relatively small Monte Carlo errors on the order of a few percent of the posterior standard deviation provided an empirical check that parameter variability due to the MCMC simulations was relatively low.

Goodness-of-Fit Criteria

Model residuals were used to measure the goodness of fit to the CPUE series. Residuals for the CPUE series were the log-scale observation errors ε_{T}.

(14) $$\varepsilon_T = \ln\left(I_T\right) - \ln\left(QKP_T\right)$$

Non-random patterns in the residuals indicated that the observed CPUE did not conform to one or more model assumptions. The root mean-squared error (RMSE) of the CPUE fit provided another diagnostic of the model goodness of fit with lower RMSE indicating a better fit to an individual CPUE series.

Stochastic Projections at Recent Average Fishing Mortality

Stochastic projections were conducted to illustrate the possible changes in exploitable biomass and catch if swordfish fishing effort during 2007-2010 was similar to the recent average effort pattern. The projections assumed that status quo fishing effort in Subarea 2 for swordfish would continue during 2007-2010. Stochastic harvest rates were simulated to project the probable distributions of exploitable swordfish biomass and catch. Harvest rates were assumed to be random independent and identically distributed samples from a normal distribution with mean equal to the three-year average (2004-2006) harvest rate in Subarea 2 and variance equal to the observed variability in mean harvest rate during 2004-2006. The initial conditions for the projections were based on the MCMC samples from the estimated posterior distribution of exploitable swordfish biomass in Subarea 2 during 2006.

Results

Convergence to Posterior Distribution

Convergence diagnostics were compiled to see if there were any problems with convergence of the MCMC simulations. The Geweke (1992) Z-score diagnostic was applied to the intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients and indicated no significant departures from the hypothesis of equality of mean parameter estimates of subsets within each chain. The Gelman and Rubin (1992) potential scale reduction factor was also calculated for these key parameters and the estimated reduction factors were equal to 1.00, which was consistent with the convergence in distribution of the MCMC samples to the joint posterior distribution. Similarly, the Heidelberger and Welch stationarity and half-interval tests could not reject the hypothesis that the MCMC chains were stationary at the 5% confidence level for any of the parameters. Examination of the Monte Carlo errors, a measure of the variability in each estimate due to simulation, indicated that these errors were relatively small and ranged from 0.5% to 1.8% of the estimated posterior standard deviation for the key parameters, consistent with convergence to the posterior distribution. Last, visual inspection of density plots of the posterior distributions of the intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients indicated that these densities were smooth and unimodal for all parameters as expected for a convergent sequence of MCMC samples. Overall, each of the convergence diagnostics indicated that the MCMC samples generated from the production model numerically converged to the posterior distribution.

Model Fits to CPUE

Root mean-squared errors of the model fits to standardized CPUE indicated that the fit to the Japanese longline CPUE ($RMSE_J$ = 0.225) was better than the fit to the Taiwanese CPUE ($RMSE_T$ = 0.292). The model fit to the Japanese longline CPUE in this 2010 assessment update was very similar to the fit in the 2009 assessment (Figure 2.1). The Japanese longline CPUE exhibited some large negative residuals in the 1950s but otherwise predicted CPUE appeared to fluctuate randomly about the observed CPUE. Standardized residuals had no time trend (Figure 2.2, P=0.24) but the log-scale residuals were not normally distributed (P<0.01) and the variance was not constant (P=0.04).

The model fit to the Chinese-Taipei longline CPUE in this 2010 assessment update was also very similar to the fit in the 2009 assessment (Figure 3.1). In contrast to the Japanese CPUE, there was no systematic pattern in the fit to the Chinese-Taipei longline CPUE (Figure 3.2). For this fleet, the residuals had no detectable trend (P=0.72), the log-scale residuals were normally distributed (P=0.90), but the variance was not constant (P=0.03). Overall, the model fits to the Eastern Pacific swordfish CPUE indicated that there was a good fit to the Taiwanese longline CPUE and a minor lack of fit to the Japanese longline CPUE during the 1950s.

Posterior Estimates of Model Parameters and Reference Points

Parameter estimates from this 2010 update were generally similar to those from the 2009 assessment. Model parameter estimates that scaled with biomass exhibited the largest differences between this 2010 assessment update and the 2009 assessment (Table 2). The estimates of mean carrying capacity (K), biomass to maximize surplus production (B_{MSY}), maximum sustainable yield (MSY), and exploitable biomass in 2006 (B_{2006}) from the 2010 assessment were all greater than those from the 2009 assessment. Thus, the effect of the roughly 80% increase in reported catches used in this 2010 update was to increase parameter estimates that scaled with exploitable biomass. The estimated production model shape parameter (S) in this 2010 update also differed from the value estimated in the 2009 assessment (Table 2). In this case, neither the 2010 estimate nor the 2009 estimate was significantly different from the value of 1 and both had CVs in excess of 80%. This indicated that the shape parameter was not well-determined from the available data. In contrast, model parameters that scaled with intrinsic growth rate in this 2010 update did not differ substantially from those in the 2009 assessment (Table 2). In particular, the mean intrinsic growth rate R and the harvest rate to produce MSY (H_{MSY}) were similar. Similarly, the probabilities that exploitable biomass exceeded B_{MSY} and that harvest rate was less than H_{MSY} in 2006 were virtually identical in this 2010 update and in the 2009 assessment (Table 2).

<u>Posterior Estimates of Exploitable Biomass and Exploitation Rate</u>

Exploitable biomass of Eastern Pacific swordfish has fluctuated at or above B_{MSY} throughout the assessment time horizon (Table 3, Figure 4). Biomass increased to a peak around 2000 and has since declined in the 2000s, albeit to a level roughly 2-fold higher than B_{MSY}. Trends in exploitable biomass from this 2010 update are very similar to those from the 2009 assessment (Figure 4).

The harvest rate of swordfish in Subarea 2 has fluctuated at or below H_{MSY} throughout most of the assessment time horizon (Table 3, Figure 5). Exploitation rates increased from near zero in the 1950s to exceed H_{MSY} in the early-1990s. Exploitation rates have remained below H_{MSY} since 1998 (Figure 5) coincident with increases in exploitable biomass. Trends in exploitation rates from this 2010 update are very similar to those from the 2009 assessment (Figure 5).

Relative biomasses (B/B_{MSY}) have fluctuated above unity and relative harvest rates (H/H_{MSY}) have fluctuated below unity in Subarea 2 for most of the assessment time series (Figure 6). The trends in relative biomass and relative harvest rate from this 2010 update very similar to those from the 2009 assessment are (Figure 6). Overall, the Eastern Pacific swordfish stock does not appear to have been depleted or experienced overfishing during most of the assessment time horizon of 1951-2006. Further, stochastic projections of swordfish biomass and catch in Subarea 2 assuming recent levels of variability about swordfish fishing effort and mortality indicated that exploitable biomass was likely sufficient to support current catches through 2010.

References

Best, N., Cowles, M., and Vines, K. 1996. CODA: Convergence diagnostics and output analysis software for Gibbs sampling output, Version 0.30. MRC Biostatistics Unit, Institute of Public Health, Cambridge, UK.

Brodziak, J. 2007. An investigation of alternative production models to assess the Hawaiian bottomfish complex. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Ser., NOAA, Honolulu, HI 96822-2326. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-07-01, 71 p.

Brodziak, J. 2009. Potential natural mortality rates of North Pacific swordfish. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/Billfish WG, ISC/09/BILLWG-1/13, 20 p.

Brodziak, J. and Ishimura, G. 2009. Development of Bayesian surplus production models for assessing the North Pacific swordfish population. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/Billfish WG, ISC/09/BILLWG-2/02, 29 p.

Congdon, P. 2001. Bayesian statistical modeling. Wiley, New York, 531 p.

Courtney, D., and Wagatsuma, L. 2009. Input data for a North Pacific swordfish stock assessment using Bayesian production models. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/Billfish WG, ISC/09/BILLWG-2/01.

Gelman, A., and Rubin, D. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7:457-511.

Geweke, J. 1992. Evaluating the accuracy of sampling-based approaches to calculating posterior moments. In Bernardo, J., Berger, J., Dawid, A., and Smith, A. [Eds.] Bayesian statistics, Vol. 4, Clarendon Press, Oxford, U.K., pp. 169-194.

Gilks, W., Richardson, S., and Spiegelhalter, D. [Eds.] 1996. Markov Chain Monte Carlo in Practice. Chapman and Hall, London. 486 p.

Heidelberger, P., and Welch, P. 1992. Simulation run length control in the presence of an initial transient. Operations Research 31:1109-1144.

ISC Billfish Working Group. 2009. Report of the billfish working group workshop, International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean. 30 November to 4 December 2009. Honolulu, Hawaii, USA. ISC/09/BILLWG-3/Report.

McAllister, M., Babcock, E. Pikitch, E. and Prager, M. 2000. Application of a non-equilibrium generalized production model to South and North Atlantic swordfish: Combining Bayesian and demographic methods for parameter estimation. Col. Vol. Sci. Pap. ICCAT, 51(5):1523-1550.

Meyer, R., and Millar, R.1999. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56:1078–1086.

Plummer, M., Best, N., Cowles, K., and Vines, K. 2006. "CODA: Convergence diagnosis and output analysis for MCMC", R News 6(1), 7-11, available at http://CRAN.R-project.org/doc/Rnews/Rnews_2006-1.pdf.

R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Spiegelhalter, D., Thomas, A., Best, N., and Lunn, D. 2003. WinBUGS User Manual. Available at: http://www.mrc.bsu.carn.ac.uk/bugs/winbugs/manual14.pdf

Table 1. Time series of catch biomass of Eastern Pacific swordfish used in the 2009 assessment and used in the current 2010 assessment update along with the annual percentage change in catch biomass.

Year	Original Swordfish Catch Biomass (thousand mt) in Subarea2 from Courtney and Wagatsuma (2009)	Updated Swordfish Catch Biomass (thousand mt) in Subarea2 from Courtney (4-Mar-2010, Pers. Comm.)	Percentage Change in Total Swordfish Catch Biomass in Subarea2
1951	0.001	0.001	0%
1952	0.001	0.001	0%
1953	0.002	0.002	0%
1954	0.015	0.015	0%
1955	0.010	0.012	13%
1956	0.008	0.011	41%
1957	0.106	0.168	58%
1958	0.071	0.138	94%
1959	0.068	0.098	45%
1960	0.097	0.138	42%
1961	0.443	0.645	46%
1962	0.768	1.066	39%
1963	1.306	2.228	71%
1964	1.397	2.372	70%
1965	0.807	1.304	62%
1966	1.115	2.059	85%
1967	0.943	1.461	55%
1968	1.246	1.873	50%
1969	3.487	7.286	109%
1970	2.368	4.243	79%
1971	1.257	1.804	44%
1972	1.472	2.196	49%
1973	2.424	3.634	50%
1974	1.359	2.054	51%
1975	1.491	2.359	58%
1976	1.900	3.278	72%
1977	2.178	3.806	75%
1978	1.815	3.642	101%
1979	1.466	2.796	91%
1980	2.004	3.859	93%

Table 1. continued.

Year	Original Swordfish Catch Biomass (thousand mt) in Subarea2 from Courtney and Wagatsuma (2009)	Updated Swordfish Catch Biomass (thousand mt) in Subarea2 from Courtney (4-Mar-2010, Pers. Comm.)	Percentage Change in Total Swordfish Catch Biomass in Subarea2
1981	2.985	4.707	58%
1982	2.486	3.640	46%
1983	1.419	2.885	103%
1984	0.897	1.825	103%
1985	0.988	1.936	96%
1986	1.934	3.652	89%
1987	2.429	4.625	90%
1988	2.484	4.927	98%
1989	2.397	4.028	68%
1990	4.611	7.449	62%
1991	2.731	5.772	111%
1992	3.694	7.493	103%
1993	2.929	5.690	94%
1994	2.553	5.106	100%
1995	2.114	4.343	105%
1996	2.186	4.287	96%
1997	4.561	7.310	60%
1998	5.847	9.008	54%
1999	2.495	4.377	75%
2000	4.201	7.119	69%
2001	4.877	9.008	85%
2002	4.423	7.925	79%
2003	3.742	7.327	96%
2004	2.629	6.746	157%
2005	1.947	4.405	126%
2006	1.724	3.924	128%
Average	1.909	3.465	0.713
Stdev	1.421	2.571	0.332
Total	106.910	194.061	82%
Minimum	0.001	0.001	0
Maximum	5.847	9.008	1.566

Table 2. Estimates of the mean value of intrinsic growth rate (R), carrying capacity (K), production model shape parameter (S), biomass to produce maximum sustainable yield (B_{MSY}), exploitation rate to produce maximum sustainable yield (H_{MSY}), maximum sustainable yield (MSY), exploitable biomass in 2006 (B_{2006}), probability that B_{2006} exceeds B_{MSY}, exploitation rate in 2006, and probability that H_{2006} exceeds H_{MSY} for the Eastern Pacific Subarea 2 with the current base case model using the updated March 2010 swordfish catch biomass (1st row) compared with the previous base case model using the ISC 9 July 2009 catch biomass (2nd row). Estimated coefficients of variation (%) of model parameters are listed below the parameter estimates in parentheses.

Stock Scenario	Mean R	Mean K	Mean S	Mean B_{MSY}	Mean H_{MSY}	Mean MSY	Mean B_{2006}	$Pr(B_{2006}>B_{MSY})$	Mean H_{2006}	$Pr(H_{2006}>H_{MSY})$
Eastern Pacific Subarea 2 with Updated March 2010 Swordfish Catch Biomass	0.40 (44%)	69.2 (26%)	0.96 (87%)	33.0 (25%)	0.16 (36%)	5.0 (38%)	69.5 (35%)	0.99	0.06 (36%)	0.02
Eastern Pacific Subarea 2 with ISC 9 July 2009 Swordfish Catch Biomass	0.40 (45%)	54.6 (28%)	0.66 (81%)	24.8 (28%)	0.13 (38%)	3.1 (45%)	59.7 (36%)	1.00	0.03 (37%)	0.01

Table 3. Estimates of the mean value of exploitable biomass, exploitation rate, relative biomass, and relative exploitation rate of Eastern Pacific swordfish along with 95% credibility intervals, 1951-2006.

	Exploitable Biomass (B)			Exploitation Rate (H)			Relative Biomass (B/B_{MSY})			Relative Explotation (H/H_{MSY})		
Year	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
1951	55.5	27.6	99.8	0.00	0.00	0.00	1.69	1.01	2.65	0.00	0.00	0.00
1952	49.8	20.7	99.2	0.00	0.00	0.00	1.52	0.74	2.77	0.00	0.00	0.00
1953	42.7	11.0	97.6	0.00	0.00	0.00	1.30	0.33	2.85	0.00	0.00	0.00
1954	34.6	8.4	91.7	0.00	0.00	0.00	1.06	0.27	2.85	0.00	0.00	0.01
1955	24.7	8.9	47.7	0.00	0.00	0.00	0.76	0.30	1.33	0.00	0.00	0.01
1956	23.7	9.9	45.3	0.00	0.00	0.00	0.73	0.34	1.27	0.00	0.00	0.01
1957	34.8	15.6	62.8	0.01	0.00	0.01	1.07	0.53	1.83	0.04	0.02	0.09
1958	31.9	14.6	58.4	0.00	0.00	0.01	0.98	0.50	1.66	0.04	0.01	0.08
1959	27.7	12.3	51.8	0.00	0.00	0.01	0.85	0.43	1.46	0.03	0.01	0.06
1960	31.7	14.4	58.6	0.00	0.00	0.01	0.97	0.50	1.66	0.04	0.01	0.08
1961	42.2	19.9	76.2	0.02	0.01	0.03	1.30	0.68	2.19	0.12	0.05	0.27
1962	51.3	24.4	91.8	0.02	0.01	0.04	1.58	0.84	2.64	0.17	0.07	0.37
1963	58.1	27.9	103.6	0.04	0.02	0.08	1.79	0.96	3.00	0.31	0.13	0.67
1964	58.9	27.9	106.3	0.05	0.02	0.09	1.81	0.97	3.03	0.33	0.13	0.71
1965	56.2	26.2	102.5	0.03	0.01	0.05	1.72	0.92	2.90	0.19	0.08	0.41
1966	58.5	27.6	105.3	0.04	0.02	0.07	1.80	0.97	3.02	0.29	0.12	0.61
1967	58.4	27.3	106.4	0.03	0.01	0.05	1.79	0.96	3.04	0.20	0.08	0.44
1968	62.5	29.4	113.0	0.03	0.02	0.06	1.92	1.04	3.24	0.24	0.10	0.52
1969	71.1	34.2	127.8	0.11	0.06	0.21	2.19	1.20	3.67	0.83	0.35	1.76
1970	72.1	33.3	131.4	0.07	0.03	0.13	2.22	1.17	3.77	0.48	0.20	1.02
1971	64.1	29.1	118.0	0.03	0.02	0.06	1.97	1.04	3.35	0.23	0.10	0.49
1972	62.9	29.1	115.1	0.04	0.02	0.08	1.93	1.03	3.28	0.28	0.12	0.60
1973	67.3	31.6	122.2	0.06	0.03	0.11	2.07	1.12	3.48	0.44	0.18	0.94
1974	67.4	31.7	122.0	0.03	0.02	0.06	2.07	1.11	3.51	0.25	0.10	0.53
1975	67.0	31.6	120.7	0.04	0.02	0.07	2.06	1.11	3.47	0.29	0.12	0.61
1976	65.3	30.8	117.4	0.06	0.03	0.11	2.01	1.08	3.37	0.41	0.17	0.86
1977	65.4	31.1	117.7	0.07	0.03	0.12	2.01	1.08	3.38	0.47	0.19	1.02
1978	58.0	27.2	105.6	0.07	0.03	0.13	1.78	0.95	2.99	0.51	0.21	1.08
1979	53.4	24.9	96.8	0.06	0.03	0.11	1.64	0.87	2.75	0.43	0.17	0.91
1980	51.3	24.2	92.9	0.08	0.04	0.16	1.58	0.83	2.67	0.61	0.25	1.30
1981	46.0	21.3	83.7	0.12	0.06	0.22	1.41	0.74	2.40	0.83	0.34	1.77
1982	41.3	19.1	75.7	0.10	0.05	0.19	1.27	0.66	2.16	0.72	0.29	1.54
1983	39.2	17.8	72.0	0.08	0.04	0.16	1.20	0.62	2.03	0.60	0.24	1.29
1984	32.4	14.4	61.2	0.06	0.03	0.13	0.99	0.51	1.71	0.46	0.18	1.00
1985	35.5	16.3	65.7	0.06	0.03	0.12	1.09	0.57	1.84	0.44	0.18	0.96
1986	43.1	20.3	78.2	0.10	0.05	0.18	1.33	0.70	2.23	0.69	0.28	1.48
1987	47.8	22.8	86.0	0.11	0.05	0.20	1.47	0.78	2.49	0.79	0.32	1.69
1988	44.2	20.7	80.0	0.13	0.06	0.24	1.36	0.72	2.28	0.90	0.37	1.93
1989	43.4	20.4	78.9	0.10	0.05	0.20	1.33	0.71	2.26	0.75	0.31	1.59
1990	45.6	22.1	82.0	0.18	0.09	0.34	1.40	0.76	2.35	1.32	0.55	2.76
1991	41.4	19.6	75.4	0.16	0.08	0.29	1.27	0.68	2.16	1.13	0.47	2.37
1992	41.3	19.8	74.6	0.20	0.10	0.38	1.27	0.69	2.14	1.47	0.61	3.07
1993	40.5	18.8	74.4	0.16	0.08	0.30	1.24	0.66	2.11	1.14	0.47	2.42
1994	39.7	18.5	72.8	0.15	0.07	0.28	1.22	0.65	2.07	1.04	0.43	2.21
1995	42.1	19.7	75.9	0.12	0.06	0.22	1.29	0.69	2.17	0.84	0.35	1.76
1996	51.9	24.8	93.1	0.09	0.05	0.17	1.59	0.87	2.66	0.67	0.28	1.40
1997	62.4	30.7	109.9	0.13	0.07	0.24	1.92	1.06	3.18	0.94	0.40	1.97
1998	61.5	29.6	109.7	0.16	0.08	0.30	1.89	1.03	3.18	1.18	0.51	2.44
1999	57.9	26.7	106.3	0.09	0.04	0.16	1.77	0.96	3.02	0.61	0.26	1.27
2000	73.3	34.8	131.4	0.11	0.05	0.20	2.25	1.23	3.79	0.78	0.34	1.61
2001	85.0	40.0	152.2	0.12	0.06	0.23	2.62	1.40	4.40	0.85	0.37	1.76
2002	80.2	36.9	144.5	0.11	0.05	0.22	2.47	1.29	4.19	0.79	0.35	1.63
2003	76.1	35.6	137.3	0.11	0.05	0.21	2.34	1.25	3.95	0.77	0.34	1.59
2004	71.0	33.1	128.8	0.11	0.05	0.20	2.18	1.17	3.70	0.76	0.33	1.59
2005	64.4	29.9	117.2	0.08	0.04	0.15	1.98	1.07	3.32	0.55	0.24	1.15
2006	69.5	33.0	125.3	0.06	0.03	0.12	2.14	1.17	3.59	0.46	0.19	0.96
Average 1951-2006	52.6	24.3	96.4	0.07	0.03	0.13	1.61	0.85	2.76	0.51	0.21	1.08
Average 1997-2006	68.4	32.2	123.0	0.11	0.05	0.21	2.10	1.13	3.54	0.79	0.34	1.64
Current 2004-2006	68.3	32.0	123.8	0.08	0.04	0.16	2.10	1.14	3.54	0.59	0.25	1.23

Figure 1. The 2009 stock assessment of the North Pacific swordfish population conducted by the ISC Billfish Working Group included a Western and Central Pacific stock (subarea 1) and an Eastern Pacific stock (subarea 2). The Eastern Pacific stock is the focus of this 2010 assessment update.

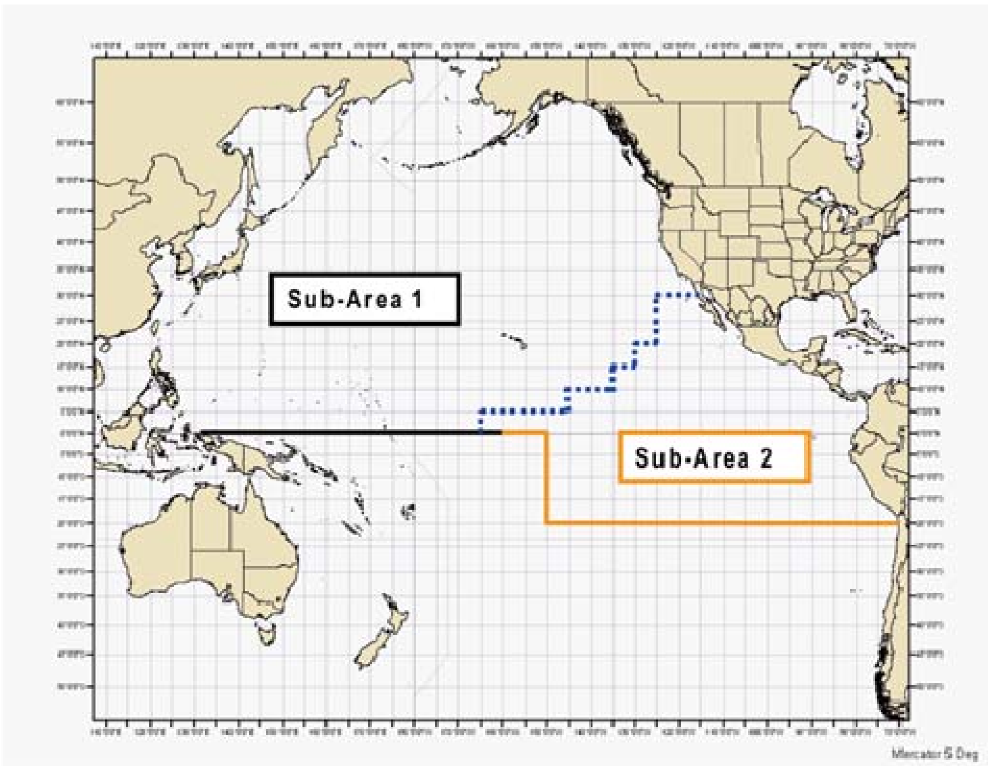
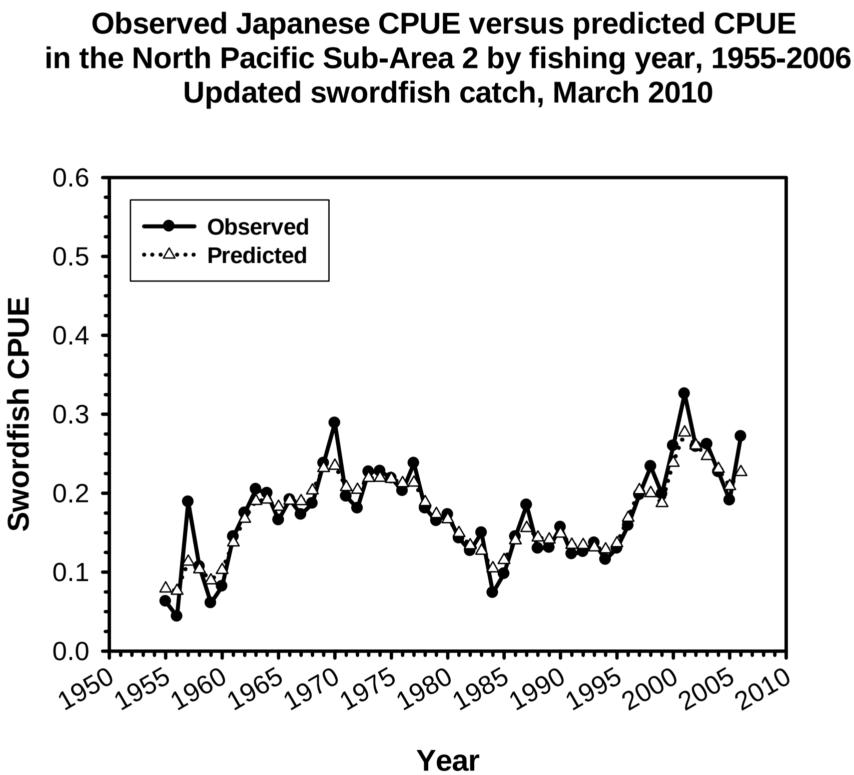


Figure 2.1. Comparison of production model fits to Japanese CPUE in this 2010 assessment (top panel) and in the 2009 assessment (bottom panel).



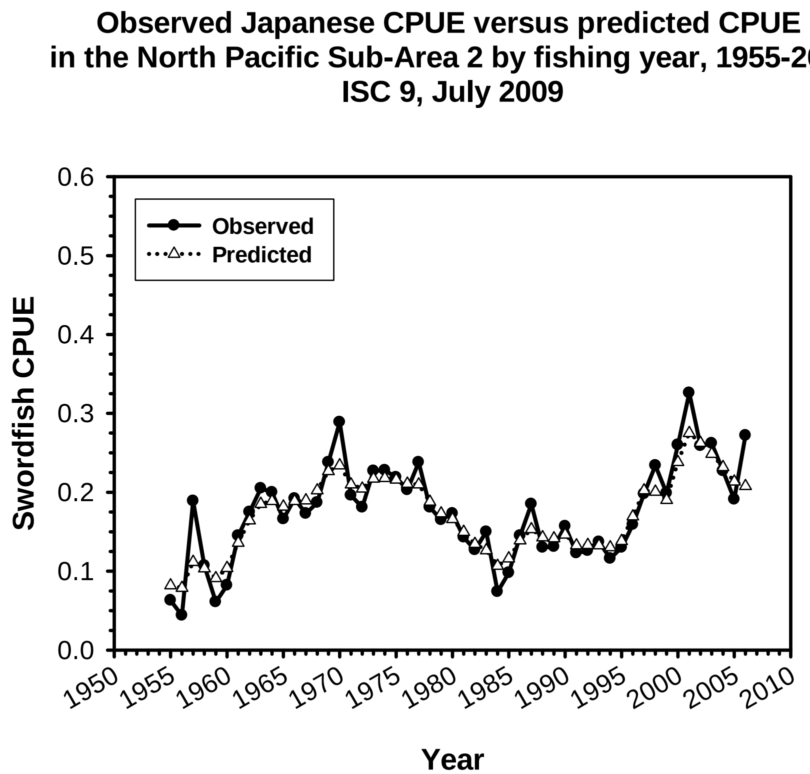
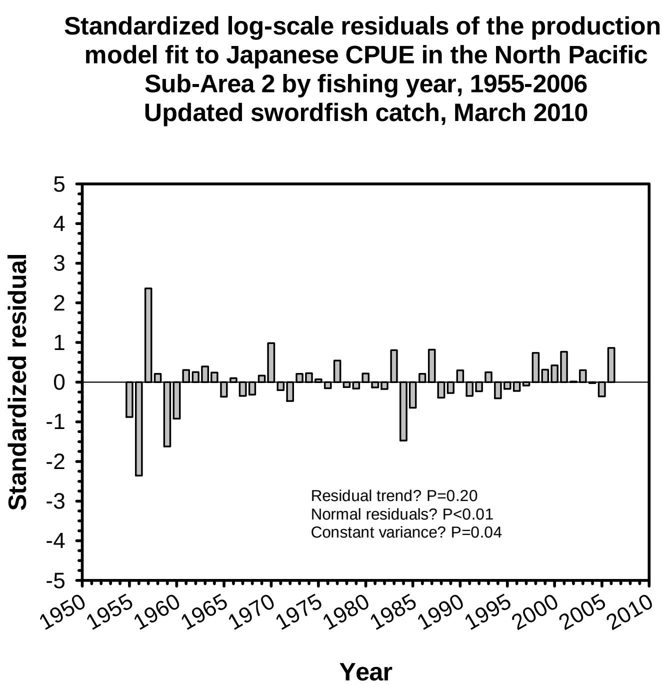


Figure 2.2. Comparison of standardized log-scale residuals of the production model fit to Japanese CPUE in this 2010 assessment (top panel) and in the 2009 assessment (bottom panel).



Standardized log-scale residuals of the production model fit to Japanese CPUE in the North Pacific Sub-Area 2 by fishing year, 1955-2006
ISC 9, July 2009

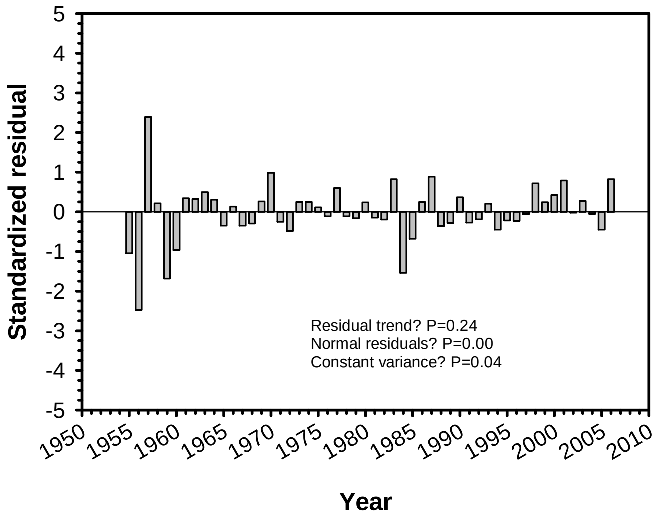
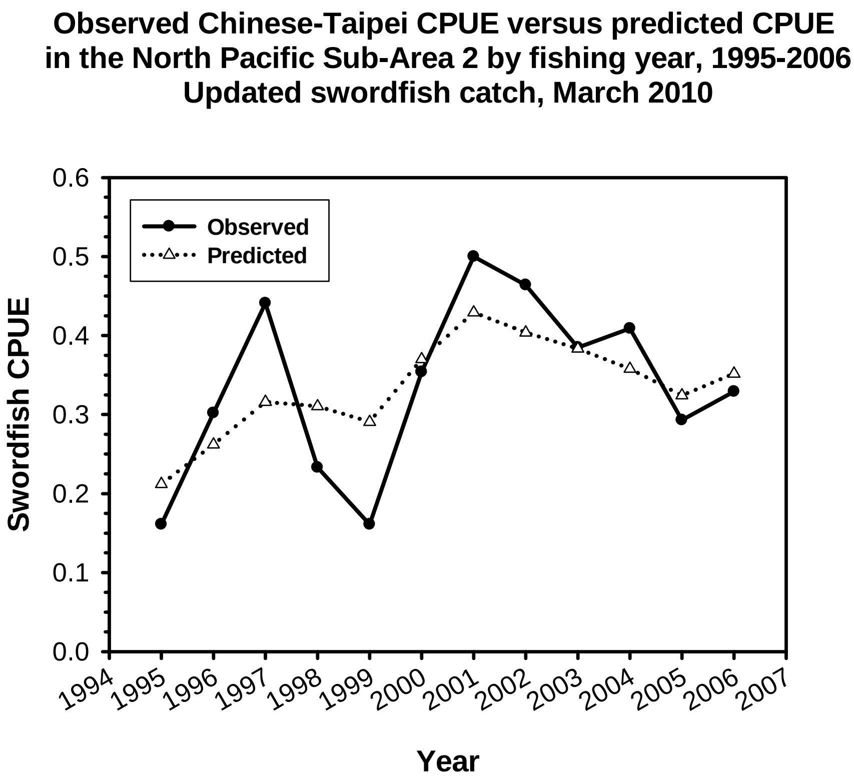


Figure 3.1. Comparison of production model fits to Chinese-Taipei CPUE in this 2010 assessment (top panel) and in the 2009 assessment (bottom panel).



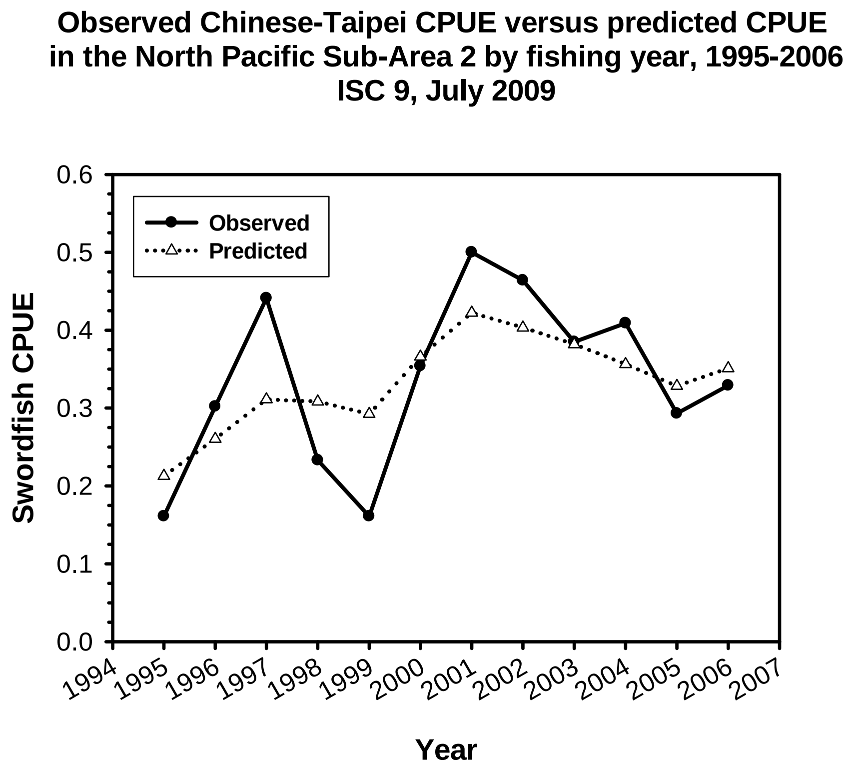
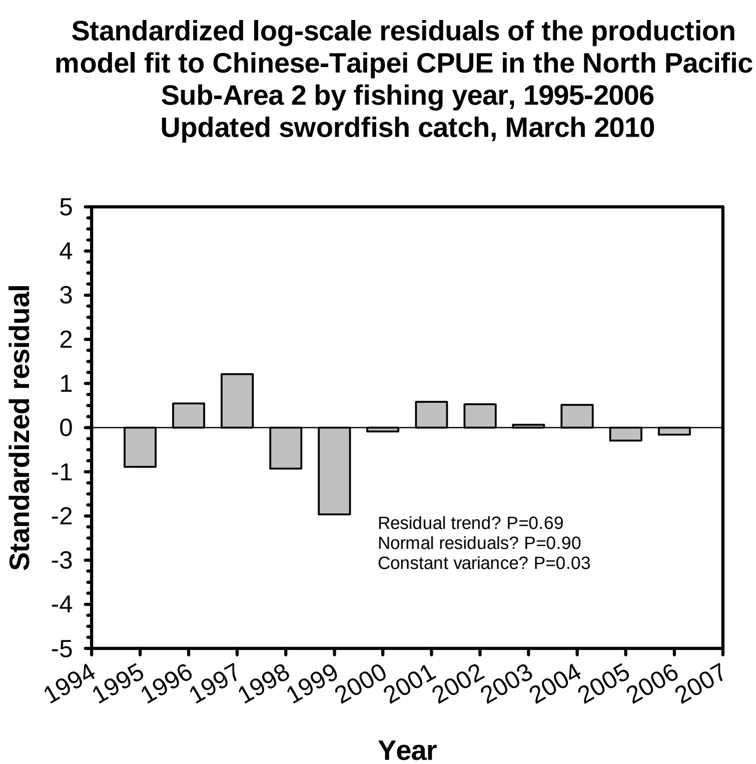


Figure 3.2. Comparison of standardized log-scale residuals of the production model fit to Chinese-Taipei CPUE in this 2010 assessment (top panel) and in the 2009 assessment (bottom panel).



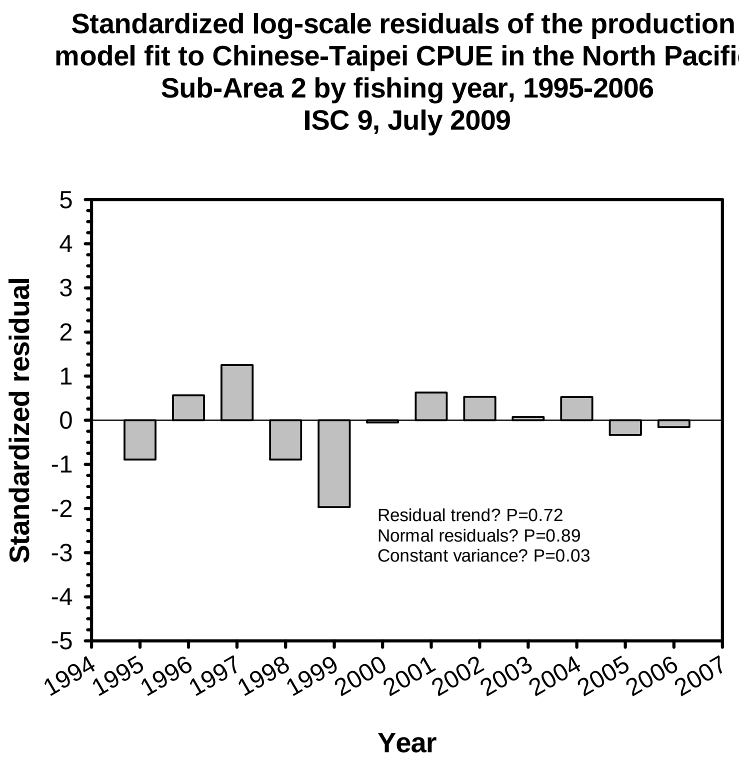
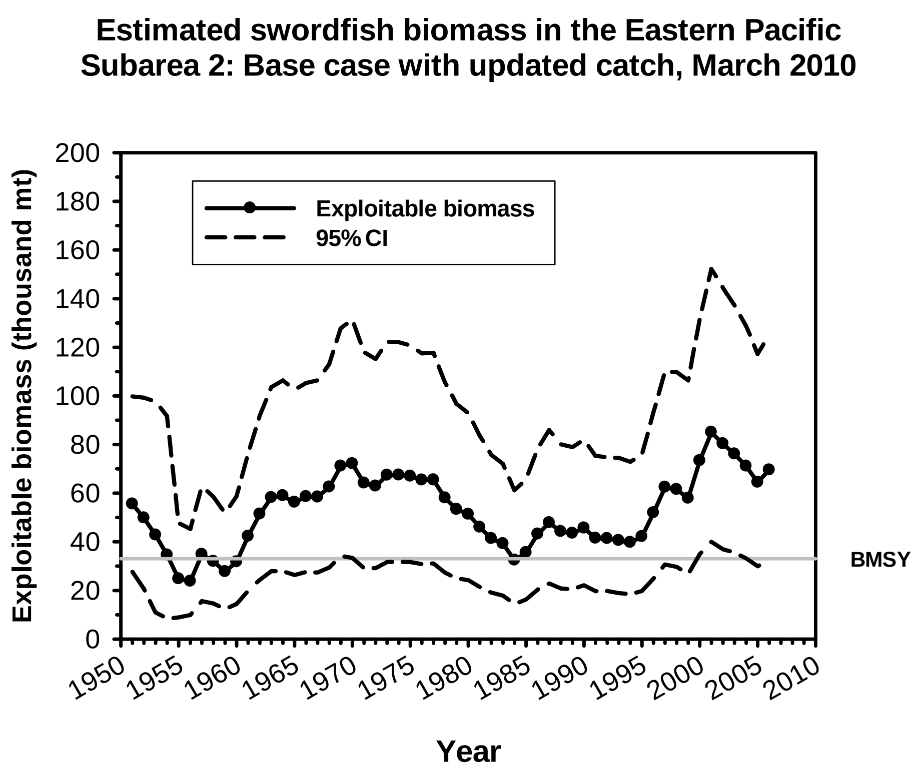


Figure 4. Comparison of trends in exploitable biomass estimates from this 2010 update (top panel) and from the 2009 assessment (bottom panel) of Eastern Pacific swordfish.



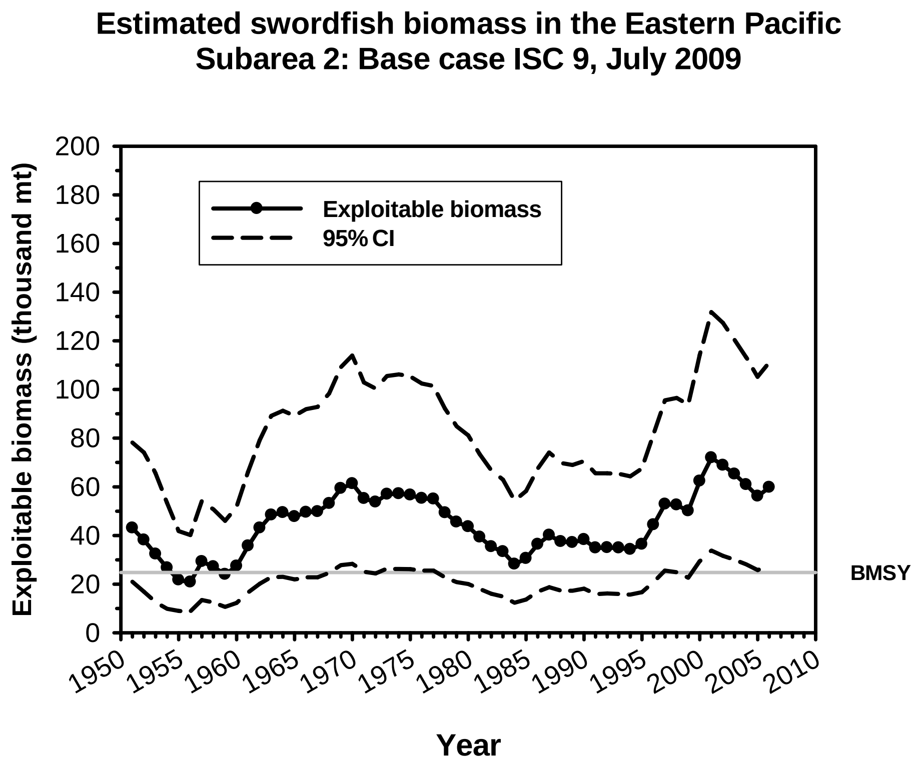
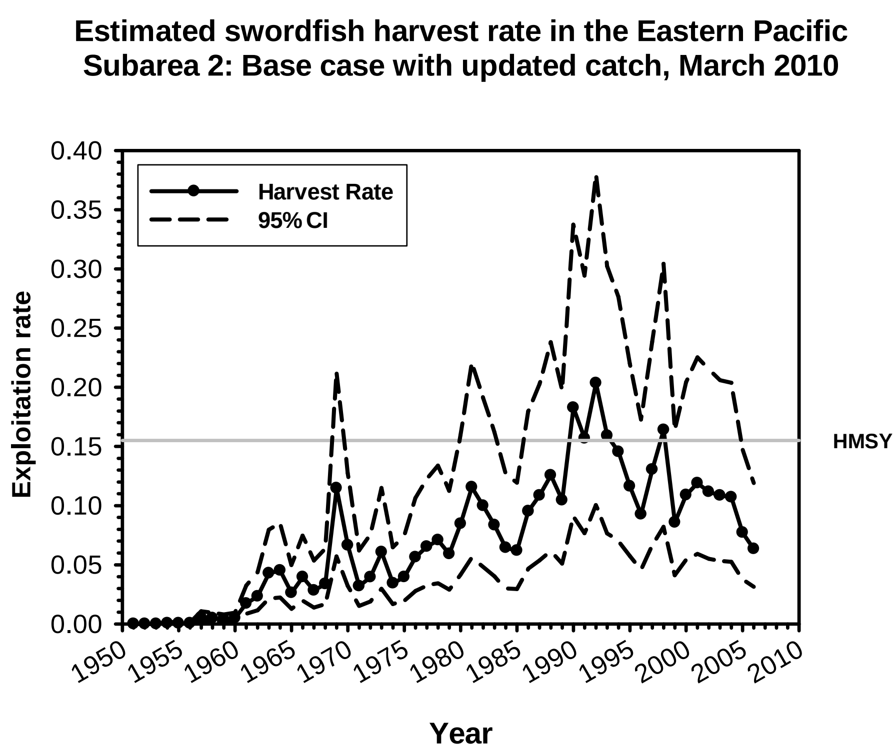


Figure 5. Comparison of trends in harvest rate estimates from this 2010 update (top panel) and from the 2009 assessment (bottom panel) of Eastern Pacific swordfish.



Estimated swordfish harvest rate in the Eastern Pacific Subarea 2: Base case ISC 9, July 2009

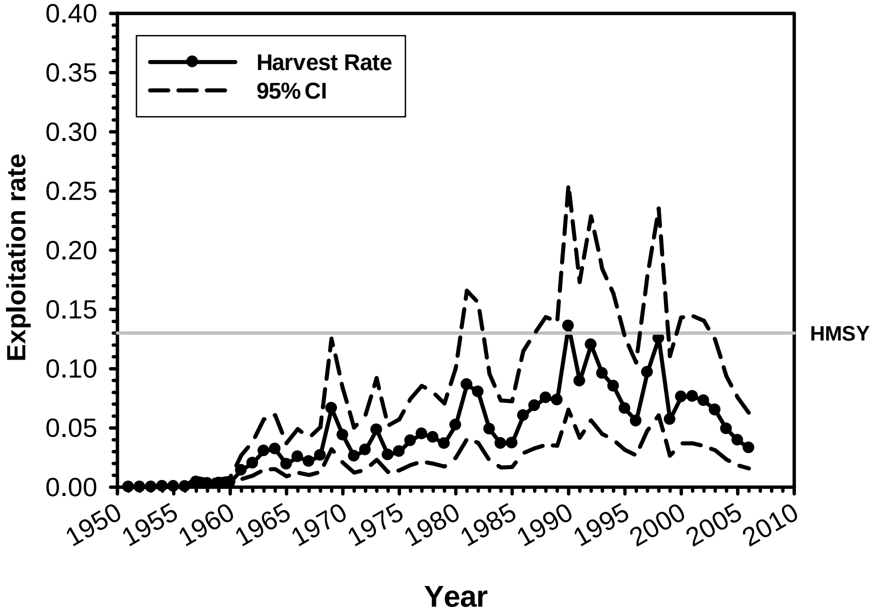
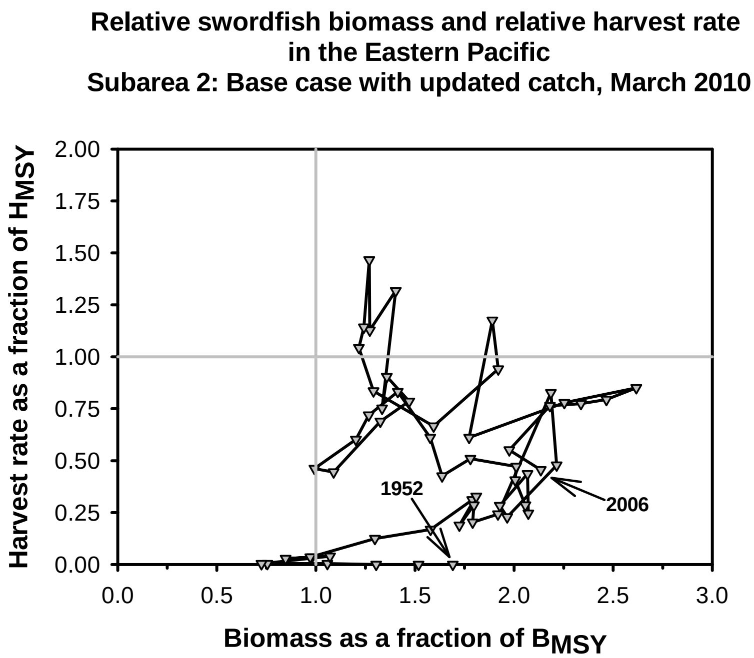


Figure 6. Comparison of trends in relative biomass and harvest rate from this 2010 update (top panel) and from the 2009 assessment (bottom panel) of Eastern Pacific swordfish.



Relative swordfish biomass and relative harvest rate in the Eastern Pacific Subarea 2: Base case ISC 9, July 2009

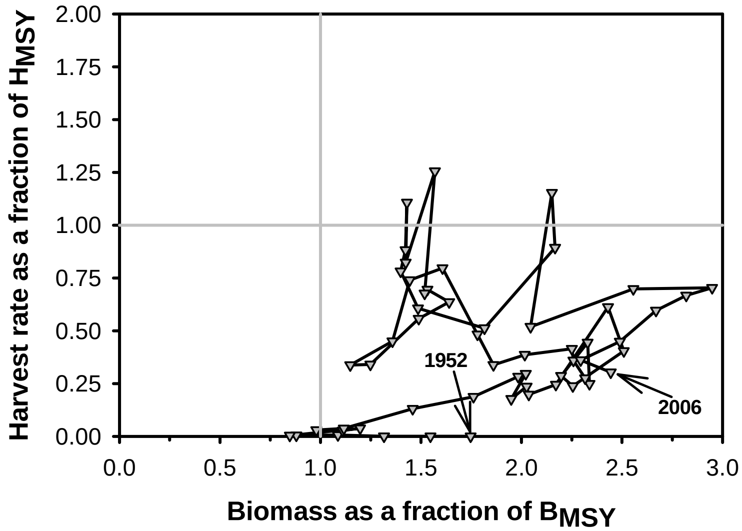
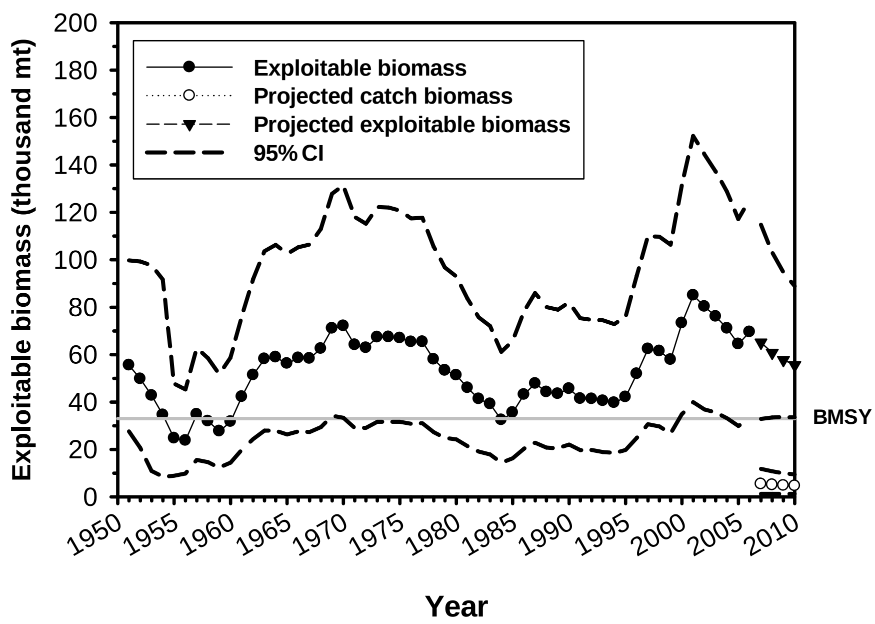


Figure 7. Comparison of stochastic projections from this 2010 update (top panel) and from the 2009 assessment (bottom panel) of Eastern Pacific swordfish assuming recent average fishing effort.

Projected swordfish biomass and catch in the Eastern Pacific Subarea 2: Base case with updated catch, March 2010



Projected swordfish biomass and catch in the Eastern Pacific Subarea 2: Base case ISC 9, July 2009