Annex 7

REPORT OF THE BILLFISH WORKING GROUP WORKSHOP

International Scientific Committee for Tuna and Tuna-like Species
in the North Pacific Ocean

19-26 May 2009
Busan, Korea, USA

1.0 INTRODUCTION

An intercessional workshop of the Billfish Working Group (BILLWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) was convened in Busan, Korea, 19-26 May 2009. The goal of this workshop was to conduct a stock assessment of North Pacific swordfish with objectives of: 1) reviewing swordfish stock assessment models, 2) developing base case assessment models and performing sensitivity runs, and 3) determining the status of the swordfish stock and formulating conservation advice. Besides this focus, matters related to the future work plan for the working group were included on the agenda for this workshop.

Dr. Kwang Soo Lim, President of the National Fisheries Research and Development Institute (NFRDI), provided the welcoming remarks. Gerard DiNardo, Chairman of the BILLWG, welcomed participants from Chinese Taipei, Japan, Korea, and the United States of America (USA) (Appendix 1). Rapporteuring duties were assigned to Jon Brodziak, Dean Courtney, Gakushi Ishimura, Minoru Kanaiwa, Ai Kimoto, Kevin Piner, Gary Sakagawa, Nan-Jay Su, Chi-Lu Sun, Lyn Wagatsuma, and Kotaro Yokawa. Wagatsuma served as the lead rapporteur with overall responsibility of assembling the workshop report. Working papers were distributed and numbered (Appendix 2), and the meeting agenda adopted (Appendix 3). All authors who submitted working paper agreed to have their papers posted on the ISC website where they will be available to the public.

2.0 FEBRUARY 2009 ISC BILLWG WORKSHOP

2.1 Summary

An intercessional workshop of the ISC BILLWG was convened in Honolulu, Hawaii, USA, 3-10 February 2009. The objective of that workshop was to seek agreement on input data, specifications, and procedures for conducting a swordfish stock assessment in May 2009. Specifically, the workshop sought agreement on: 1) historical and updated fishery statistics, 2) stock structure scenarios, 3) standardized swordfish catch per unit effort (CPUE) time series for abundance indices, and 4) the stock assessment model structure(s) and input parameters.

Revisions were made to fishery statistics for swordfish, including catch tables, CPUE time series for billfishes, and biological information for swordfish. Potential biological reference points for billfishes in general were also discussed.

After careful review of available genetics, CPUE, and catch distributional data presented at the ISC BILLWG special session on stock structure held in November 2008, the WG agreed that the stock structure of swordfish in the North Pacific Ocean may be more complex than a simple single-stock hypothesis. Analyses indicated a possibility of two stocks with little or no mixing between them across a boundary line. Therefore, the WG agreed that for the upcoming swordfish stock assessment in May, the BILLWG would use two scenarios to depict the possible stock structure. Stock Scenario-1 would assume a single-stock in the entire North Pacific, north of the equator (Figure 1), and Stock Scenario-2 would assume two stocks; one in the western North Pacific and separated from another stock in the eastern North Pacific by a diagonal boundary from Baja, California (30ºN x 110ºW) to approximately 170ºW at the equator (Figure 2). The boundary follows a step-wise pattern as outlined in Ichinokawa and Brodziak (ISC/08/BILLWG-SS/04). The southern boundary of the western stock (Sub-Area 1) is the equator and the southern boundary for the eastern stock (Sub-Area 2) is 20ºS. Catch associated with each of the stock scenarios are depicted in Figures 3-5.

Stock Scenario - 1

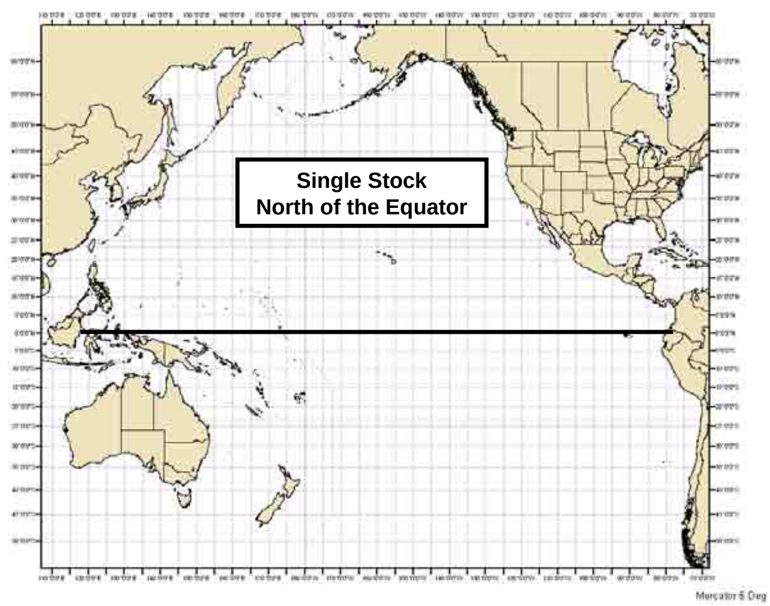


Figure 1. Stock Scenario-1, a single North Pacific stock north of the equator.

While the BILLWG will be conducting the stock assessment using these two scenarios, the WG agreed that the stock status and conservation advice would be based largely on Stock Scenario-2 results owing to the fact that most of the available data on stock structure supports the two-stock hypothesis. Results from Stock Scenario-1 will be used as a bridge for comparisons with previous results from stock assessments that have assumed a single swordfish stock in the North Pacific Ocean.

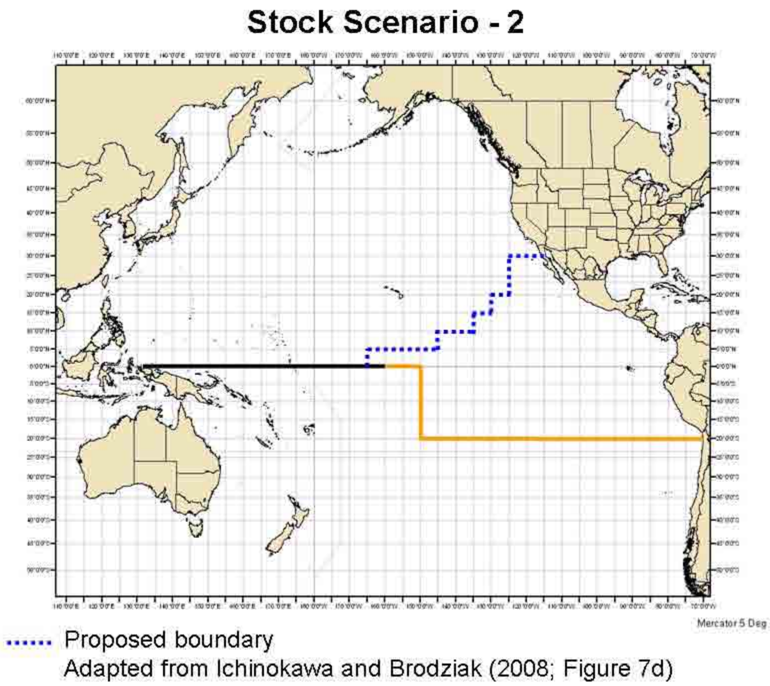


Figure 2. Stock Scenario-2, two North Pacific stocks with boundaries according to ISC/08/BILLWG-SS/04.

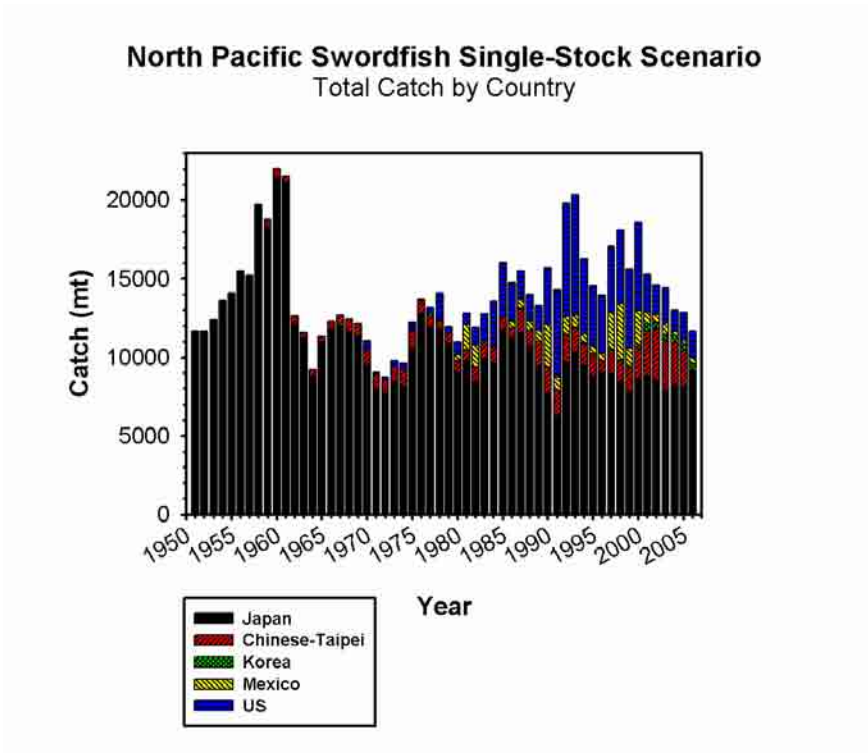


Figure 3. Total swordfish catch by country under Stock Scenario-1, a single North Pacific stock.

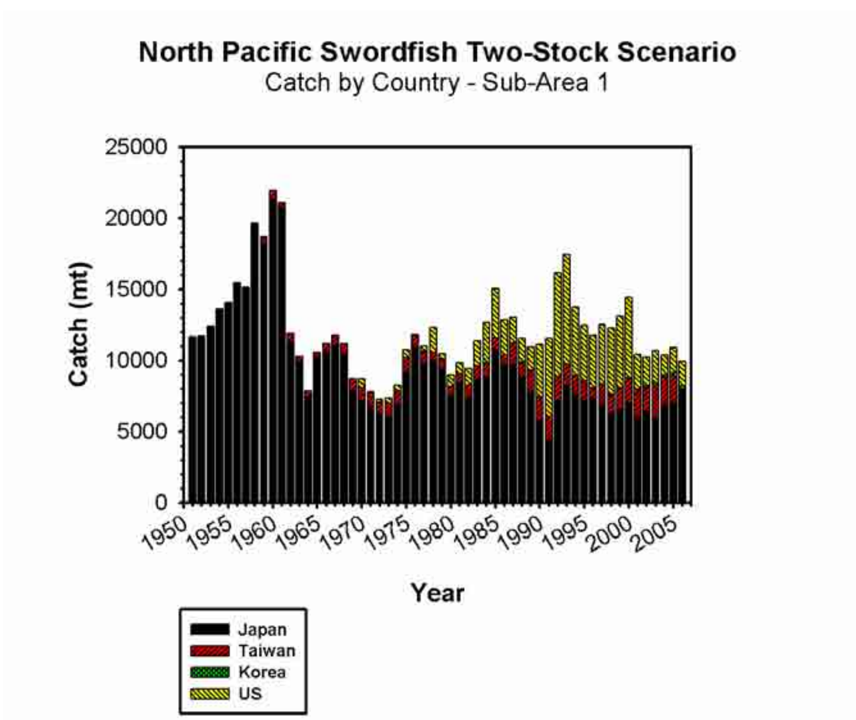


Figure 4. Total Sub-Area 1 swordfish catch by country under Stock Scenario-2, two North Pacific stocks.

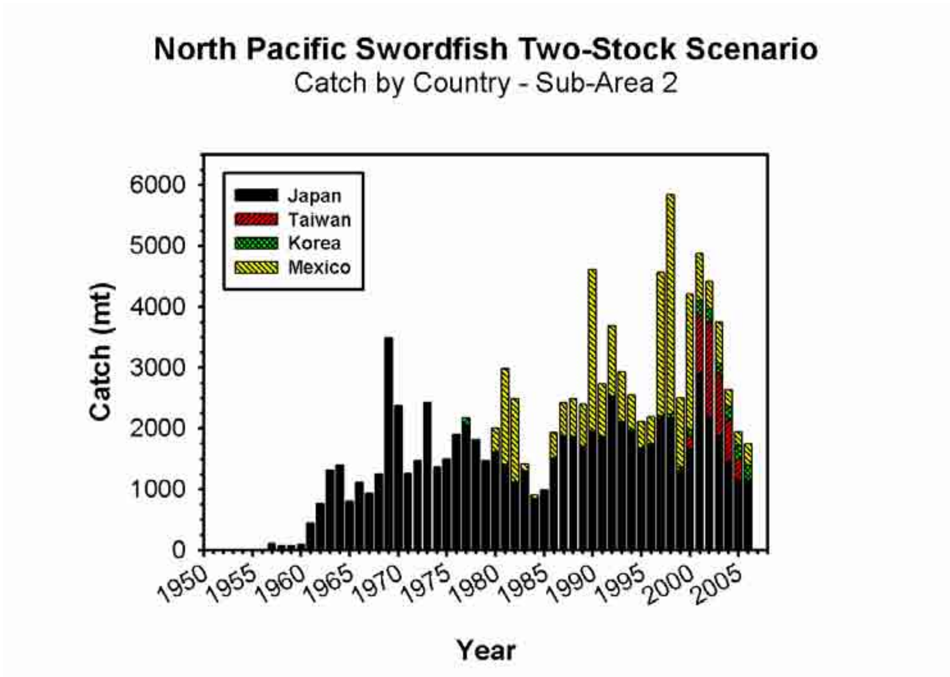
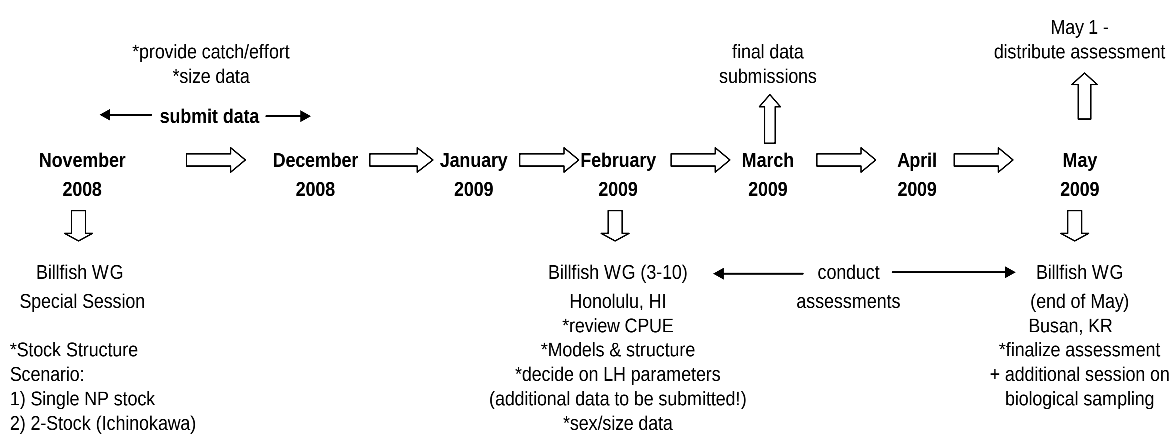


Figure 5. Total Sub-Area 2 swordfish catch by country under Stock Scenario-2, two North Pacific stocks.

The participants reviewed estimates of biological parameters and swordfish life history data for information needed as inputs for the Stock Synthesis 3 (SS3) model. The review concentrated on information estimated from empirical data, as well as from studies conducted in the central North Pacific. The WG agreed that the following information would be used in the May stock assessment: Von Bertalanffy growth parameters with eye-fork length in cm, TMAX (y), and Max eye-fork length (cm) from DeMartini et al (2007) and Uchiyama and Humphreys (2007); length-weight relationship, pooled sexes (eye-fork length in cm and weight in kg) from Uchiyama et al. (1999) and Uchiyama and Humphreys (2007); maturity probability, p(L), at length with eye fork length in cm from DeMartini et al. (2000).

Life History Parameter	Female Value	Male Value	Combined Value*	Equation/Source
Central North Pacific Von Bertalanffy growth parameters (cm of eye-fork length)	K = 0.246 ± 0.019 LINF = 230.5 ± 3.94 T0 = -1.24 ± 0.167	K = 0.271 ± 0.034 LINF = 208.9 ± 5.60 T0 = -1.37 ± 0.259	K = 0.257 LINF = 219.7 T0 = -1.31	$EFL_t = EFL_\infty\left(1-e^{-k(t-t_0)}\right)$ Uchiyama and Humphreys (2007), DeMartini et al (2007)
Central North Pacific maximum observed age TMAX (y), and Max eye frok length (cm)	TMAX (y) = 12 Max (EFL) = 259	TMAX (y) = 11 Max (EFL) = 229		Uchiyama and Humphreys (2007), DeMartini et al (2007)
Central North Pacific length-weight relationship pooled sexes (cm of eye fork length, kg)	a = 1.2988x10^{-5} b = 3.0738			$W(kg) = aEFL^b$ Uchiyama and Humphreys (2007), Uchiyama et al. (1999)
Central North Pacific maturity probability (p(L) at length (cm of eye fork length)	L50 = 143.6 σ = 9.67	L50 = 102.0 σ = 7.08	L50 = 121.1 σ = 15.9	$p(EFL) = \left(1+\exp\left(\frac{-(EFL-L_{50})}{\sigma_m}\right)\right)^{-1}$ De Martini et al. (2000)

The work plan for completing the swordfish stock assessment in May 2009 was reviewed and reaffirmed by participants. The plan commenced in November 2008 and is outlined below.



2.2 Assignment Status

Progress made on assignments from the February 2009 BILLWG workshop was reviewed. The group was assigned to: 1) complete and submit data catalogues (U.S. California, Japan, Chinese Taipei, Mexico), and 2) submit spatio-temporal data requested by the Biological Research Task Force (BRTF) (all ISC member countries) by 30 March 2009. Some country's data catalogues have not yet been completed. In addition, the spatio-temporal data requested by the BRTF have not yet been received from members. The Chairman stressed the need for these assignments to be completed, especially the latter which will be required for discussions when the BRTF meets in May 2009, immediately following the conclusion of this BILLWG workshop.

At the February WG meeting, the Chairman was tasked to contact the chairmen of the other ISC WGs, as well as Robert Humphreys, to obtain information on the optimum size categories, or size bins, to be used for their species sampling plans. That information would be considered in deciding the size categories to be used in the BILLWG sampling plan in order to be compatible with plans for the other ISC WGs. The Chairman was also tasked to share his decision on this matter with members of the WG. The Chairman noted that these tasks were completed and members were kept informed.

During the WCPFC-SC4 meeting, the WCPFC-SC did not agree with the ISC findings that most of the biomass of striped marlin in the North Pacific Ocean resides north of 20°N. Instead, the WCPFC-SC suggested that catch data from the South Pacific Ocean be included in the ISC's analysis in order to determine concentration centers of striped marlin in the Pacific Ocean.

At that same meeting, however, a stock assessment conducted under the assumption of the existence of a South Pacific stock of striped marlin separate from the North Pacific stock was accepted as a valid stock assessment. This logical inconsistency in the treatment of striped marlin stock structure by the WCPFC-SC is problematic and will require discussion with the Chairman of the WCPFC-SC.

3.0 SWORDFISH ASSESSMENT MODELS

3.1 Production Model

3.1.1 Input data for a North Pacific Swordfish Stock Assessment using Bayesian Production Models presented by Dean Courtney (ISC/09/BILLWG-2/01)

ISC BILLWG scientists collaborated to compile input data for a North Pacific swordfish stock assessment. The WG recommended two stock structure scenarios for the swordfish stock assessment in the North Pacific: 1) a single North Pacific stock north of the equator (Figure 1), and 2) a two-stock scenario with a diagonal boundary from Baja, California (25ºN x 110ºW) to approximately 170ºW at the equator (Figure 2). The WG also recommended two stock assessment modeling approaches: Bayesian surplus production (BSP) and Stock Synthesis. This report summarizes input data for Bayesian production models. Catch and CPUE were compiled annually under the two stock structure scenarios. Correlations of annual standardized CPUE by stock scenario were presented. Additional input data for Stock Synthesis models were described in a separate working paper.

<u>Discussion</u>

The WG noted that the report summarized decisions on stock structure and data series that were made during previous meetings. Those decisions were based upon the best available science and should be used as the basis to assess the swordfish stock in 2009.

3.1.2 Development of Bayesian surplus production models for assessing the North Pacific swordfish population presented by Jon Brodziak (ISC/09/BILLWG-2/02)

BSP models were developed for assessing the North Pacific swordfish population. Biomass production was allowed to vary from the symmetric Schaefer curve using an estimated shape parameter. BSP models were developed for two stock scenarios: 1) a North Pacific single-stock scenario and 2) a two-stock scenario with Sub-Areas 1 and 2. Input data included nominal landings of North Pacific swordfish during 1952-2006. Relative abundance indices for swordfish consisted of standardized CPUE for Japanese, Taiwanese, and U.S. longline fisheries and the California gillnet fishery by stock area. Annual coefficients of variation for CPUE were used to weight the annual uncertainty within each time series of relative abundance indices. Lognormal prior distributions for intrinsic growth rate (r) and carrying capacity (K) were assumed to be moderately precise with coefficients of variation set at 50%. Goodness-of-fit diagnostics were developed for comparing alternative model configurations including the root-mean squared error of CPUE fits and standardized CPUE residuals. Preliminary model fits for 1952-2006 indicated that the Japanese longline CPUE was influential under each scenario because this was the longest time series of relative abundance indices. Preliminary model results also indicated that assumptions about the prior means for intrinsic growth rate and carrying capacity may also be potentially important depending on the model configuration. Overall, the goal of developing operational Bayesian surplus that could incorporate multiple abundance indices and heterogeneous observation errors was achieved. Further work will include refinement of prior assumptions and the capacity to make stochastic catch projections for harvest scenario analyses.

Discussion (20 May 2009)

The WG discussed the results of the analysis with the intent to both understand and improve the assessment. The WG noted that the model appeared to over-fit the Japanese distant water longline CPUE. Furthermore the WG discussed the importance of priors relative to data on model results. Thus, the following were recommendations and subsequent model requests given to the authors as work to be completed and presented to the WG during the meeting.

Recommendations

- Do not use Hawaiian deep-water longline CPUE in the BSP modeling. Animals are too young to represent the exploitable biomass. Also exclude California Drift gillnet CPUE as decided at the February WG meeting.

- Include the 1951 catch which is 11,678 t.

Additional Requests

- Calculate CV's for biomass estimates and biomass relative to MSY. The WG questioned whether the biomass ratios were more robust than absolute estimates. The authors noted that the ratios are more precise because of the correlation between biomass and MSY.

- Start model with priors that describe a range of the proportion of carrying capacity (also using *Recommendations* above). The WG wanted to understand how this assumption affects model results.

- Run the model with uninformative priors on all parameters. The WG wanted to understand the importance of priors on the results.

Discussion (22 May 2009)

Based on the discussion from the previous day, a plan for conducting the BSP modeling was presented. Based upon that plan, the following are recommendations from the WG for improvement of the base case model.

Recommendations

- WG recommends that equal constant CV be applied to each CPUE series to represent observation error. The WG acknowledges that this removes information on the relative uncertainty of individual points within the series; however, it is hypothesized that the within series measures of uncertainty are more likely due to changes in catchability and are therefore better attributed to process error.

- Use a 50% CV for the observation error prior of each CPUE series. A CV of 22% appeared to over-fit the data, while a 70% CV showed non-random residuals.

- Use the base case model to project forward four years (2007-2010) using a 3 year average of recent F (2004-2006).

Discussion (23 May 2009)

Results from runs that were requested by the WG were presented. General conclusions and additional requests and recommendations are as follows:

Discussion/Conclusions

- For Stock Scenario-1: The proportions of carrying capacity assumption had a moderate impact on biomass estimates, but the ratios of biomass to MSY as well as population trends appeared to be robust to this assumption.

- Fitting the model with a 50% CV prior on the observation error to CPUE had intermediate fit between a CV 22% and CV 70%. Residual patterns were acceptable with a slight trend in residuals that might reflect an increase in catchability over time.

- Under Stock Scenario-1, the use of diffuse (uninformative) priors produced model results with population trends that were largely the same as in the base case model but with smaller population biomasses and higher intrinsic growth rates. Results using diffuse priors were not presented for Stock Scenario-2. However it was indicated that the effects of including diffuse priors was similar for Sub-Area 1 but for Sub-Area 2, the model did not converge using diffuse priors. More work may be needed to characterize the effect of using uninformative priors under Stock Scenario-2.

- All models (Stock Scenario-1 and Stock Scenario-2) indicated that the North Pacific swordfish population is above MSY with fishing mortalities below F_{MSY}.

Recommendations

- Stock status and conservation advice should be based upon the two-stock scenario (Sub-Areas 1 and 2) because the best available science indicated the presence of multiple stocks in the NPO. The single-stock assessment scenario results will be used as a bridge from previous assessments and for comparisons of methods. Comparison of BSP model results and SS3 model results should be based on the sum of estimated Sub-Area 1 and 2 exploitable biomasses using BSP versus the estimated age 3+ biomass using SS3.

- The WG agreed to use the 50% CV for the base case model.

- The WG agreed that model averaging would not be used at this time to summarize model results.

Additional Requests

- Produce plots of prior distributions and posterior distributions of parameters from all base case model runs. These plots illustrate the degree to which information in the model changed both parameter estimates and uncertainty from the initial prior belief.

Discussion 24 May 2009

As requested, plots of prior distributions and subsequent posterior distributions were presented for key assessment parameters (K, r and M). Examination of those plots indicated that the posteriors in Stock Scenario-1 and Stock-Scenario 2, Sub-Area 1were informed by data as the shape of the posterior density was different from the original prior. However, the data in Stock Scenario-2, Sub-Area 2 were not as informative about key assessment parameters because the posteriors had similar shapes to the priors. The lack of information in the Sub-Area 2 data was reflected in the higher estimates of uncertainty for the biomass estimates from that BSP model.

Recommendations

- The WG agreed that results from the BSP models Sub-Areas 1 and 2 were sufficient to provide stock status and conservation advice. It was recommended that the conservation advice described in a later section of this document be based upon those results.

- The WG agreed to produce a detailed description of the stock assessment model, diagnostics, and results (Appendix 4).

3.1.3 Model-averaging to account for prior uncertainty in swordfish intrinsic growth rate and carrying capacity presented by Gakushi Ishimura (ISC/09/BILLWG-2/03)

This study developed a model averaging procedure using Bayesian information criteria (BIC) to account for uncertainties arising from the choice of prior distributions for intrinsic growth rate and carrying capacity. Existing data to conduct a stock assessment of North Pacific swordfish were limited and available abundance indices lacked significant contrast. As a result, prior information for production model parameters was limited. Preliminary results of production modeling using available North Pacific swordfish data indicated that the goodness-of-fits for given posterior distributions varied but that the weighted parameter estimations were robust. The results indicated that the posterior distributions of means for the intrinsic growth rate and carrying capacity parameters were strongly influenced by their priors.

Discussion

The WG noted that the idea of model averaging may be appropriate for characterizing the uncertainty in the development of the priors for swordfish. The WG concluded that the model averaging approach provided a useful sensitivity analysis for the stock status of swordfish in this assessment.

3.2 Stock Synthesis Model

3.2.1 Input data for a North Pacific Swordfish Stock Assessment using Stock Synthesis presented by Dean Courtney (ISC/09/BILLWG-2/04)

Time series of swordfish catch, CPUE, and length frequency from the North Pacific Ocean were compiled for input in Stock Synthesis models. Catch and CPUE were compiled by region under two structure stock scenarios. Stock Scenario-1 is a single stock north of the equator with 6 regions (1, 2, 3, 4, 5, 6) (Figure 6). Under Stock Scenario-2, there are two sub-areas (Figure 7). Sub Area-1 has 5 regions (1-1, 1-2, 1-3, 1-4, 1-5). Sub-Area 2 has one region (2-1). Length frequency data were only available for Stock Scenario-1 and plots of length frequency by year and quarter are provided.

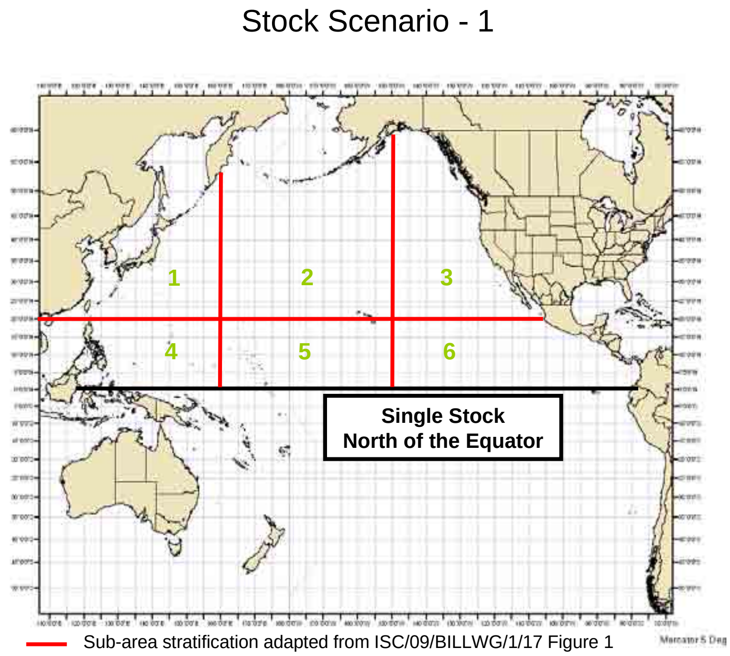


Figure 6. Additional area stratification into 6 regions for under Stock Scenario-1 (adapted from ISC/09/BILLWG-1/17; Figure1).

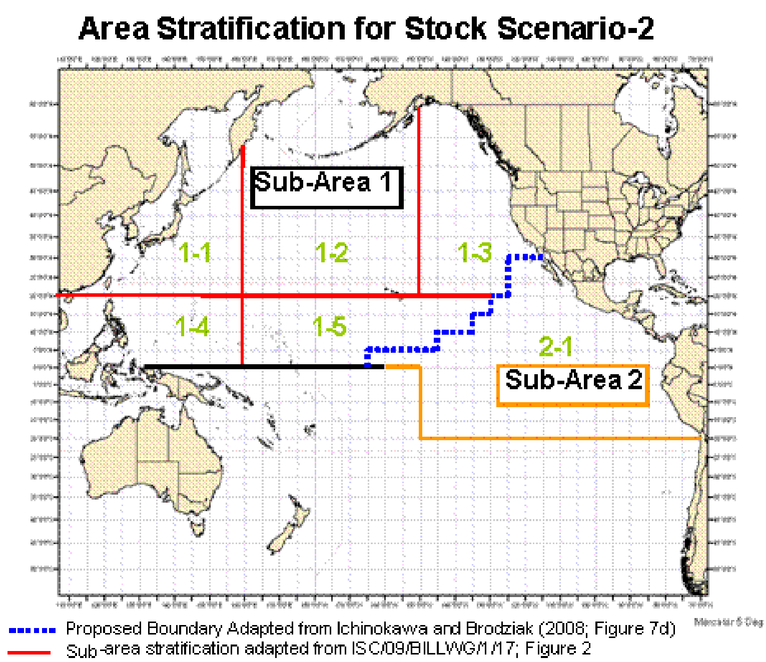


Figure 7. Additional area stratification under Stock Scenario-2 (ISC/09/BILLWG-1/17; Fig.2). Sub-Areas 2-1 and 2-2 are combined into one Sub-Area 2-1.

Discussion

The WG noted that the report summarized decisions on stock structure and data series that were made during previous meetings. Those decisions were based upon the best available science and should be used as the basis to assess the swordfish stock in 2009.

3.2.2 Preliminary Stock Synthesis Model Sensitivity Runs for a North Pacific Swordfish (Xiphias gladius) Stock Assessment presented by Dean Courtney (ISC/09/BILLWG-2/05)

Our interests at this stage of model development were first, to model the process of length based selectivity for comparison with BSP models, and second, to assess SS3 model sensitivity to a reasonable range of model parameters from the scientific literature. The stock structure assumed a single-stock north of the equator (Stock Scenario-1). Analysis of Stock Scenario-2 was not completed due to time constraints. As a result, SS3 model sensitivity was not evaluated for Stock Scenario-2. Independently estimated swordfish life history parameters from the Central North Pacific were input into Stock Synthesis as fixed parameters. The model included 10 fisheries, 5 CPUE time series, and 4 time series of length frequency. Model sensitivity was evaluated for a range of parameters. Model results were sensitive to natural mortality, effective sample size of annual CPUE time series, and the sequential removal of annual CPUE time series. The model appeared to adequately fit all CPUE time series except the Taiwanese distant water longline. Time series of model estimated mature female spawning biomass were relatively flat. The sensitivity analysis identified three issues that need further consideration. Equilibrium recruitment (R_0) was estimated at the lower bound in all runs which is a diagnostic for model non-convergence. All runs had very poor fits to length frequency modes. Selectivity did not appear to differ by sex. The sensitivity analysis also suggested reasonable alternative models to consider.

Discussion

The WG reviewed the work on the development of a SS3 model for North Pacific swordfish under the single-stock scenario. Dean Courtney presented information on initial model runs using standardized CPUE estimates for the Japanese longline, Taiwanese longline, the Hawaii shallow-set and deep-set longline fisheries, and the California gillnet fisheries. The initial model configuration did not include regional stratification. Swordfish life history data from the central North Pacific were used to set growth and maturity rates. The initial model also included two sexes with separate growth curves and natural mortality ogives. Initial fits to CPUE and length composition data included non-random residual patterns and biomass scaling problems. The WG considered this to be an indication of model misspecification.

The WG suggested that the initial model configuration could be improved by including finer-scale spatial structure to account for differences in swordfish size and fishery selectivity in the North Pacific. The use of 6 regions was agreed upon following the assessment team's suggestions. In particular, it was noted that the Japanese CPUE trends had fine-scale spatial patterns that would be better captured by modeling at a regional scale. As a result, the input catch, and length composition data for the SS3 model were reconfigured to account for the regional stratification.

Some concern was raised about the potential for missing or unreported catch from Spanish fishing fleets operating in the eastern Pacific Ocean (EPO) IATTC area in recent years. It was noted that most of this Spanish catch probably occurs south of 20°S, outside of the North Pacific swordfish stock area although the Spanish have two fishing areas: one off Chile (70%) and one near equator the (30%), according to anecdotal information. The concern about catch statistics may impact the single-stock and Sub-Area 2 stock assessment analyses. It was recommended that the IATTC provide the needed catch statistics by stock area.

The base case model was revised to account for WG suggestions. One important suggestion was to apply regional stratification to better fit the available length composition data. To divide catch totals by country into regions, it was assumed that the Taiwanese catch apportioned by numbers was the same as the apportionment by weight. This assumption was consistent with the hypothesis of separable fishery selectivity for the Japanese and Taiwanese longline fleets. Additional assumptions were also made to account for the lack of regional length composition data. In particular, it was assumed that Taiwanese and Korean longline fleets had similar catchabilities and fishery selectivities as the Japanese longline fleet on a regional basis. It was noted that the Japanese length composition data were available from 1970-2006 combined by sex and that the Hawaiian longline length frequency data were available from 1994-2006 and included information on length composition by sex. The WG noted that additional length frequency data may be gathered from the Korean observer program which began collecting swordfish lengths in 2002.

Recommendations

- Allow dome-shape selectivity for Japan offshore and distant water longline
- Add regional stratification of catch and length
- Iteratively re-weight Sigma_r and CPUE
- Add Japan driftnet length Region 1 2004, 2005 and 2006
- Add Japan harpoon length 2006 and 2007 combined into 2006

Additional Requests

- Develop single sex model to assess swordfish
- Remove California gillnet CPUE because management actions affected CPUE after 2000

Discussion (21 May 2009)

The revised base case model was also configured to model pooled sexes using the growth curve estimated by DeMartini et al (2007). In addition, the capacity to fit a dome-shaped selectivity pattern was included for the Japanese longline and driftnet fishery data. Overall, a total of 50 fishing fleets were accounted for in the revised base case model. Of these, a total of 17 fleets CPUE data were fit by iteratively reweighting the root mean-squared error of the relative abundance indices.

Several reconfigured base case runs for the single-stock scenario were reviewed by the WG. The final model reviewed by the WG had some of the following characteristics. The California gillnet CPUE series was not included as relative abundance indices. The model was configured to represent a pooled-sex population. The model includes 6 regions, each of which had a separate fishery selectivity pattern for fitting the Japanese longline CPUE. The stock-recruitment variability parameter (σ_R) was estimated to be about 0.4 which was lower than the value in previous model configurations.

Additional Requests

- Re-allocate Korea catch to regions 4 (10%), 5(60%), 6(30%)
- Remove Hawaii longline deep-set CPUE and length to be consistent with the BSP

Discussion (23 May 2009)

The WG requested that the two additional years of Hawaii shallow set CPUE be included because they wanted to see the effect of this data on the estimated recruitment pattern and also for consistency with the production model analyses.

Additional Requests

- Add 2004 and 2006 Hawaii shallow set CPUE and associated length

Discussion (24 May 2009)

The final model reviewed by the WG provided fits to some of the CPUE series but did not match the observed annual length composition data. This suggested further structural changes were needed to make the single-stock scenario model fit the observed fishery CPUE and length composition data. Overall, the base case single-stock swordfish SS3 model was improved by including regional stratification of fisheries and by iteratively reweighting CPUE indices. However, further refinements were needed to better fit the observed fishery length composition data. In particular, the inclusion of a quarterly time-step was expected to provide a better opportunity to match the length modes of this fast-growing billfish (Appendix 5).

3.3 Age-structured Population Dynamics Model

3.3.1 Stock assessment of swordfish, Xiphias gladius, in the North Pacific Ocean using an age-structured population dynamic model presented by Chi-Lu Sun (ISC/09/BILLWG-2/13)

Based on the two scenarios of spatial structure for swordfish stock in the North Pacific Ocean, an age-structured population dynamics model was fitted to catch, catch-rate, and length-frequency data for the main swordfish fisheries (Japanese, Taiwanese, and Hawaiian longline fleets) to examine the current status of the swordfish population in the North Pacific Ocean. Results indicate that the current spawning stock biomass (2006) was at a high fraction of its unfished level and that the current fishing intensity (2006) was less than F_{MSY} for different scenarios of stock structure of swordfish. Therefore, the swordfish stock in the North Pacific Ocean appears to be relatively stable at the current level of exploitation.

<u>Discussion</u>

It was noted that this assessment did not include Hawaiian longline length data which, at the time of the analysis, were not available. The model was fit for three natural mortality rates: M=0.25, 0.30, and 0.35. Management outputs included estimates of unfished spawning biomass, MSY, and relative spawning biomass and fishing mortality values (e.g., S/S_{MSY}, F/F_{MSY}). The model converged when fit to the single-stock data, or to Sub-Area 1 data, but did not converge at M=0.3 when fit to the Sub-Area 2 data. The WG found the application of an alternative size-structured model to be useful for the Sub-Area 2 stock. It was noted that the imputation of length frequencies in Sub-Area 2 from Sub-Area 1 was problematic and may have caused the lack of model fit for Sub-Area 2. Qualitatively, the model fit in Sub-Area 1 appeared similar to the initial base case for the SS3 model. In discussing this model, the WG noted that the use of a pooled-sex model in a sexually dimorphic situation tends to overestimate spawning potential when females are predominantly the larger-bodied sex. The WG requested to clarify the differences between SS3 and this model, including model assumption, model structure, and data sets. The WG also requested the work of this model should be continued with SS3.

4.0 BILLFISH CATCH AND CPUE

4.1 Size composition of the California Driftnet Fishery, 1981-Present, presented by Kevin Piner (ISC/09/BILLWG-2/06)

Drift gill net fisheries have operated off the west coast of the United States as early as the 1970's, but began targeting swordfish in 1981. With the development of the fishery the state of California and US government implemented programs to monitor catches. Information on the size composition of the fishery is available from two sources. Port samplers from California's Department of Fish and Wildlife collected size data from 1981-1990 and the National Oceanic and Atmospheric Administration's observers collected size data from 1990-2007. Both data sources show very similar size composition and can probably be considered consistent data sources. No long term trend is seen in the mean size, but within decadal variability is apparent perhaps indicating the progression of relatively strong year-classes. An equation to convert cleithrum-to-fork length to eye-to-fork length is developed and presented based upon the observer data.

Discussion

The WG suggested testing of the two sources of data for consistency; for example using the K-S test, because these data are collected during different time periods. It was also suggested to check the data from the U.S. California longline fishery, and to examine selectivity patterns as well. The longline fishery in this region is quite small and the catch of swordfish from this fishery is too small for such analysis. It was noted that the bubble plots in Figure 2 of this working paper, in the year 2004, seems to have a shift to small sizes. Checking for changes in fishing ground was suggested as a possible cause for this shift. It was also noted that the CPUE trend should be checked for the years which have less large fish catch. It was noted that some biological evidence to support this pattern on size composition should be considered for the period post 2000 because the CPUE trend increased. It was agreed that additional research is required to understand the observed pattern in size composition for incorporation into future stock assessments.

4.2 Input Data of Japanese Catch Amount of a North Pacific Swordfish Stock Assessment presented by Ai Kimoto (ISC/09/BILLWG-2/07)

Catch of swordfish from Japanese fisheries operating in the North Pacific between 1951 and 2007 was provided. The catch data are estimated by separating the aggregated data in Japanese year book, based on the logbook data. These data are available separately by stock scenario, sub-area, quarter, and gear. Swordfish catch from the offshore and distant-water longline fisheries were estimated directly from logbooks. However, the exact coverage of the fishery was not available for the coastal longline and drift net fisheries so the ratio of catch number from the logbook was used to apportion the year book catch data. Swordfish catch from the other longline, bait fishing, net fishing, and trap net fisheries were obtained by assuming the same ratio of catch number as the coastal longline, while squid driftnet and other primarily harpoon fisheries were assigned the same ratio as drift net. Drift net and other primarily harpoon catch are relatively large, but detailed data such as size samples are available only for recent years. It was noted that it is necessary to continue to accumulate the detailed data.

Discussion

It was noted that a large amount of catch is associated with the “other primarily harpoon fishery”, prior to 1970. It is possible that the large amount of reported catch may include catch from coastal longline fisheries. The WG suggested that the disposition of reported catch prior to 1970 be reevaluated. The WG recommended that these input data be used in the assessment model.

4.3 Size conversions for Striped Marlin presented by Gerard DiNardo (ISC/09/BILLWG-2/08)

Striped marlin size conversions used by Mexican scientists were presented. Data to compute the conversions were collected from the recreational fishery at Cabo San Lucas, BCS (Mexico) from 1987 to 2008. The first conversion is from lower jaw-fork length to eye-fork length using a linear model. The second conversion is from eye-fork length to weight using an exponential model. Because of the long data collection period, the regression parameters might be affected by varying environmental conditions.

Discussion

The Chairman thanked Mexico for their contribution. It was suggested that the authors provide figures of the relationships in the working paper.

4.4 CPUE time series from the California Driftnet Fishery, 1985-Present, presented by Kevin Piner (ISC/09/BILLWG-2/09)

Drift gill net fisheries targeting swordfish have operated off the west coast of the United States since the early 1980’s. Management regulations have impacted both the method and area of operation in attempts to reduce impact on non-targeted species. The fishery has been somewhat stable in operations since 1985 when ratios of swordfish to shark landings were lifted. A CPUE series was derived from 1985-2008 from logbooks recording catch and effort data. The time series show a population that has varied but with no sustained long-term trend. The index appears to be an improvement over a previous version as some of the inter-annual variability has been removed and the series was extended back in time. However, if used for stock assessment it is our recommendation that a separate q be estimated for the period after 2000.

Discussion

It was noted that no interaction terms were included in the analysis and that their inclusion could result in a better model fit. It was pointed out that the sizes or lengths of the fishing vessels may have differed over time, as well as mesh size and gear type. It was suggested that a seasonal factor be added to the standardization model, and that a year-season interaction term also be included in the model because seasonal upwelling usually occurred around this fishing ground. It was agreed that additional research is required to understand the observed pattern in the CPUE time series for incorporation into future stock assessments.\

4.5 Characteristics of spatial variations in the catch of billfish in the Pacific Ocean and factors affecting annual changes in the catch presented by Joon-Taek Yoo (ISC/09/BILLWG-2/10)

The inter-annual catches of billfish caught by the Korean tuna longline fishery in the Pacific Ocean during 1990-2008 (swordfish, sailfish, black, blue, and striped marlins and other billfishes) were presented. Also presented were the spatial distribution of billfish catch (summed over all species) and CPUE (catch/100 hooks) by 5°x5° grids. High catch-rates occurred in the Central Pacific Ocean which likely represents the main fishing ground for Korean tuna longline fisheries. The catch and catch-rate distributions for swordfish and blue marlin were shown respectively for 1997-2007. It was noted that the distribution of black marlin is very similar to that of blue marlin. Correlations between variations in the spatial distribution and the stock abundance in the EPO during El Nino years were detected. It was suggested that the correlations be compared with results from the multiple regression model (MRM) and the generalized additive model (GAM) analyses. Inter-annual changes in catch of billfish are affected by the spatial distribution of billfishes, which may be regulated by global climate changes.

Discussion

It was pointed out that a CPUE time series for this fishery was not presented and would be beneficial for future assessments. It was also noted that in earlier years there is a large amount of catch associated with other billfish category. It was agreed that effort should be made to separate this category into species. The species composition of billfish caught by the Korean fleet exhibited gradual changes, and the main species is black marlin. It was suggested that the operation pattern and fishing ground of the Korean fleet be checked because black marlin is considered a coastal species. Because blue marlin and black marlin are similar in appearance, the catch may be misidentified. It was suggested that the species composition of billfish catch from other fleets operating in the same areas (i.e., Japanese and Taiwanese longline fleets) be compared. The WG recommended that the catch of swordfish by the Korean fleet be separated for different scenarios of spatial stock structure.

4.6 The evaluation of removing hook adjacent floats for catch amount presented by Minoru Kanaiwa (ISC/09/BILLWG-2/12)

The impact of removing selected longline hooks (shallow) on total catch and catch composition was presented. Catch composition depends on the depth of the hook which is associated with a species' habitat preference. The impact of removing shallow hooks on the catch of striped marlin, blue marlin, swordfish, and yellowfin, bigeye, and albacore tunas is presented based on Japanese training vessel data. It was shown that this approach would reduce the billfish bycatch (striped and blue marlins) without significant effect on bigeye tuna catch, but would reduce the catch of swordfish, yellowfin and albacore tunas by 10-20%.

Discussion

The WG discussed the utility of the results since the analyses were conducted using Japanese Training Vessel data. Training Vessel longline gear is configured and fished differently compared to commercial longline gear, and the results (benefits) are likely not directly comparable. It was pointed out that regardless of the differences in gear configuration the behavior of fish should not change over time and benefits from this study are likely similar to that expected in the commercial fishery. Scientists at the IATTC who studied the diving depth of billfish indicated the diving depth may change by season and these studies should be expanded to assess the seasonal impact.

5.0 NORTH PACIFIC SWORDFISH STOCK STATUS AND CONSERVATION ADVICE

The assessment of swordfish stocks in the North Pacific Ocean was conducted using two hypotheses for stock structure: a single stock in the North Pacific Ocean, above the equator (Stock Scenario-1) and two stocks separated by an irregular boundary extending from Mexico to the southwest and including sections of the eastern South Pacific extending to 20°S latitude (Stock Scenario-2). Available evidence currently favors the two-stock hypothesis (Stock Scenario-2); consequently, the participants concentrated on interpreting results with this scenario although results with Stock Scenario-1 were similar. Furthermore, because analyses using the SS3 model was not completed for Stock Scenario 2, interpretation of results for stock status and conservation advice are based on information from BSP model analysis only. Analyses with the SS3 model are continuing and full results are anticipated for the 10th ISC Plenary meeting in 2010; however, preliminary results with this model provide largely similar conclusions as with the surplus production model.

Sub-Area 1—Western-Central Pacific Ocean Stock.

Results from BSP model analysis indicate that the exploitable biomass of swordfish for the Western-Central Pacific Ocean (WCPO) stock has fluctuated above the B_{MSY} level (WCPO B_{MSY}=57.3 kt ± 11.8 kt and MSY=14.4 kt ± 2.0 kt) in most years used in the analysis (1951-2006) (Figure 8). It fell below B_{MSY} for some years in the 1990's but has been above B_{MSY} in the most recent 5 years (2002-2006).

The exploitation rate for the WCPO stock has fluctuated during the period 1951-2006, but has remained below the level required for MSY (WCPO H_{MSY}=26.2% ± 6.2%) (Figure 10). The probability that the exploitation rate in 2006 exceeded the exploitation rate at MSY is low at 1%. Projecting exploitable biomass through 2010 by assuming (1) a constant 3-year (2004-2006) average exploitation rate for the fishery and (2) fishing operations largely remaining unchanged, results in exploitable biomass levels above B_{MSY} and sufficient to sustain recent levels of catch (Figure 8). In short, the WCPO stock of swordfish is healthy and well above the level required to sustain recent catches. The phase plot or Kobe diagram (Figure12) shows this conclusion.

Sub-Area 2-- Eastern Pacific Ocean Stock

Similarly, results from BSP model analysis indicate that the exploitable biomass of swordfish for the EPO stock has fluctuated above the B_{MSY} level (EPO B_{MSY}=24.8 kt ± 6.9 kt and MSY=3.1 kt ± 1.4 kt) for most years (Figure 9). The exception was for some years in the 1950s when it was below the B_{MSY}. For the most recent 5 years (2002-2006), the exploitable biomass was well above the B_{MSY}.

The exploitation rate during the period from 1951 to 2006 has remained well below the level required for (EPO H_{MSY}=12.7% ± 4.9%) (Figure 11). The probability that this rate in 2006 exceeded the exploitation rate at MSY is low at 1%. Projecting exploitable biomass forward until 2010 by assuming (1) a constant 3-year (2004-2006) average exploitation rate and (2) fishing operations to those observed in 2006, results in exploitable biomass levels above B_{MSY} which is sufficient to sustain recent levels of catch (Figure 9). The phase plot or Kobe diagram (Figure13) summarizes the information for the EPO stock of swordfish and shows that the stock is in good condition.

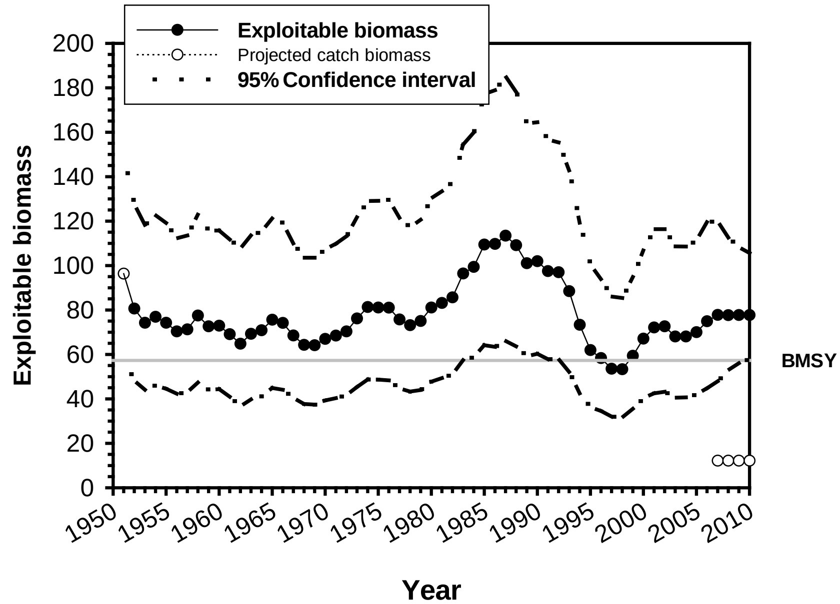


Figure 8. Exploitable biomass of swordfish in Sub-Area 1 (WCPO) relative to exploitable biomass at maximum sustainable yield (B_{MSY}) from 1951 – 2006, and projected from 2007 – 2011 assuming the average harvest rate from 2004 – 2006.

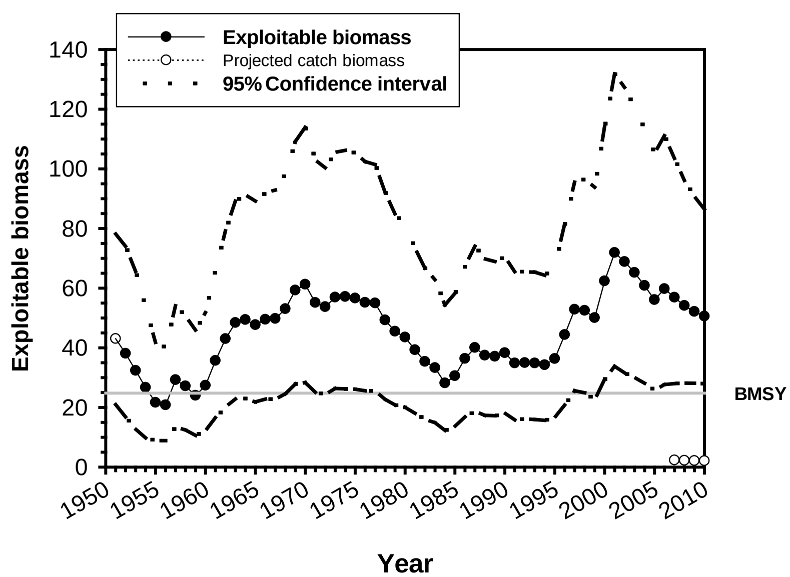


Figure 9. Exploitable biomass of swordfish in Sub-Area 2 relative to exploitable biomass at maximum sustainable yield (B_{MSY}) from 1951 – 2006, and projected from 2007 – 2011 assuming the average harvest rate from 2004 – 2006.

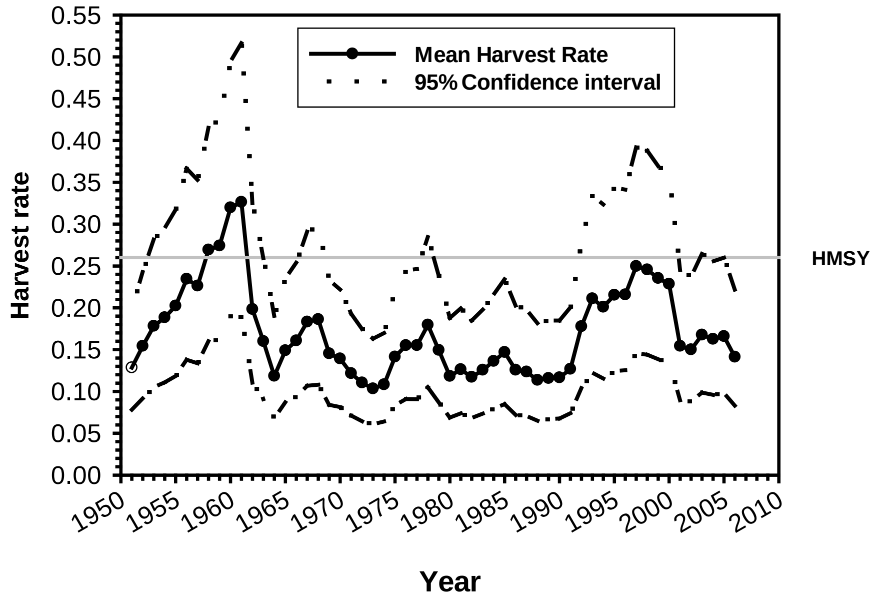


Figure 10. Harvest rate of swordfish in Sub-Area 1 relative to harvest rate at maximum sustainable yield (H_{MSY}) from 1951 – 2006.

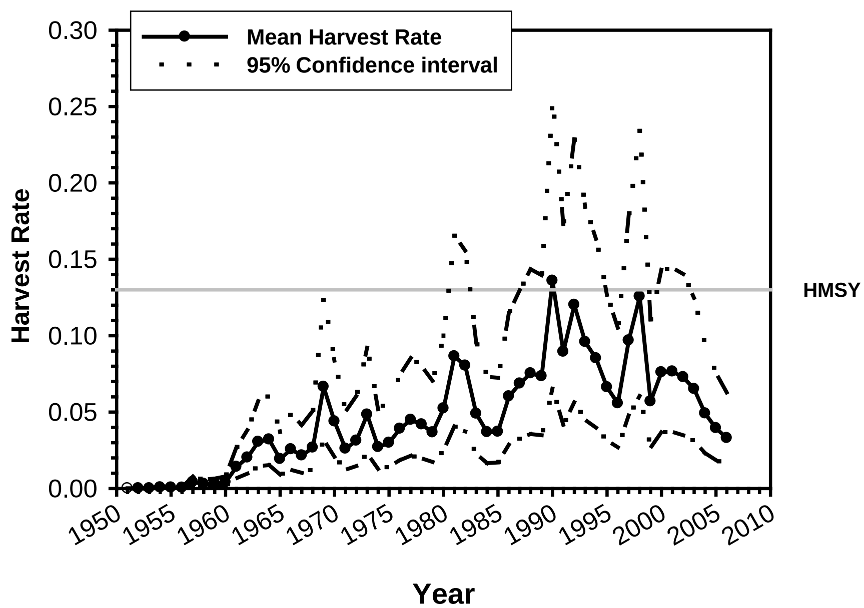


Figure 11. Harvest rate of swordfish in Sub-Area 2 relative to harvest rate at maximum sustainable yield (H_{MSY}) from 1951 – 2006.

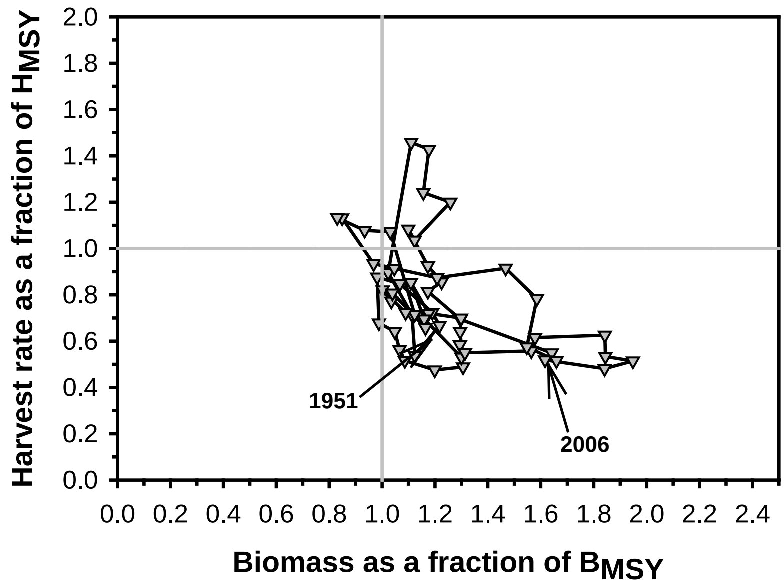


Figure 12. Sub-Area 1 biomass as a fraction of B_{MSY} and harvest rate as a fraction of H_{MSY} (1951 – 2006).

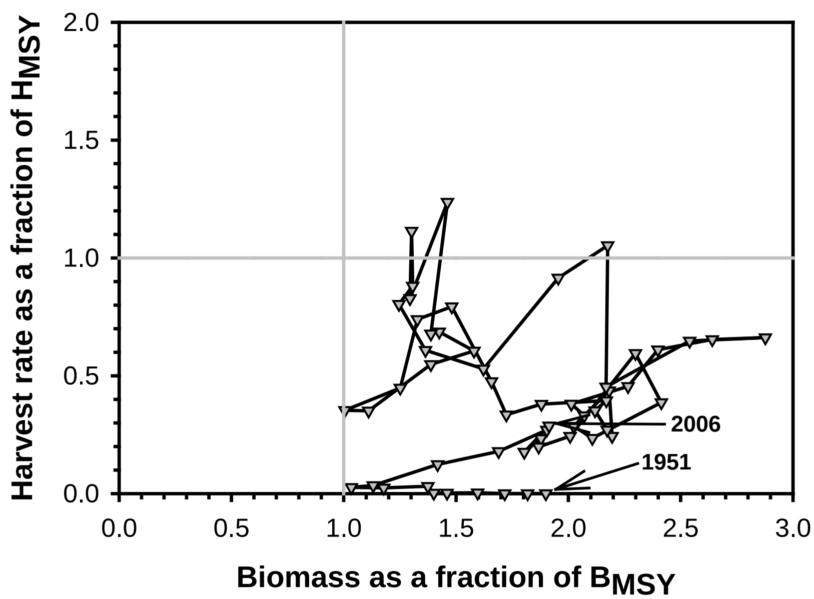


Figure 13. Sub-Area 2 biomass as a fraction of B_{MSY} and harvest rate as a fraction of H_{MSY} (1951 – 2006).

6.0 BLUE MARLIN

6.1 Analysis of the operation pattern and catch-rates of blue marlin for the Japanese and Taiwanese longline fisheries in the Pacific Ocean presented by Nan-Jay Su (ISC/09/BILLWG-2/11)

The purpose of this study was to identify changes in gear configurations and fishing locations in Japanese and Taiwanese longline fisheries over the past few decades. For Japanese longline data from 1975-2006 and Taiwanese longline data from 1995-2006, detailed gear configurations information are available and were assembled for this analysis. The number of deep and super deep operations have been increasing since 1975 for the Japanese longline fleets operating in tropical waters, while the shallow and regular configurations still dominate in temperate waters. For the Taiwanese longline fleet, deep and super deep operations dominated in the tropical waters in recent years, while the regular operations are still dominate in temperate waters. The blue marlin nominal CPUE from the Japanese longline fleet appears to be the most reliable for comparing between fleet gear setting operational characteristics. However, because the collection of hook-per-basket (HPB) data for the Taiwanese fleet is a recent event, between fleet comparisons are limited temporally.

Before 1995, spatial heterogeneity in fishing effort was observed between the two fleets. In recent years, the fishing grounds of the two fleets are similar. Overlapping fishing grounds for the Japanese and Taiwanese longline fleets are mainly located in the eastern tropical area 4 and 5 in the map. It was concluded that this region would be the most appropriate for comparing Japanese and Taiwanese longline operations.

<u>Discussion</u>

The WG discussed the seasonal difference in actual number of the “overlapping rates” between the Japanese and Taiwanese longline fisheries. It was noted that seasonal differences in spatial“overlapping” between the two fleets was not found. It was noted that there is a possibility to combine the CPUE trends for these two fleets, because the “overlapping rates” were increasing to about 40% in recent years, and the distribution of fishing effort between two fleets is moderately mixed. This increase may have occurred because of enhanced data collection in the Taiwanese fleets in recent years and a shift in target species from albacore to bigeye tuna. The WG agreed that an additional parameter in the overlapping ratio estimator may be needed to allow for differences in the number of operations fished. The WG recognized the importance of this study for the stock assessment of blue marlin. Furthermore, inclusion of Hawaiian longline data into this analysis was suggested.

6.2 Future Plans

A plan for the upcoming blue marlin assessment was discussed. Because blue marlin is considered a pan-Pacific stock, other countries besides ISC member countries will need to contribute data. To support the completion of a blue marlin assessment, holding a World Blue Marlin Symposium (WBMS) was suggested. If a WBMS is convened, the blue marlin assessment's completion date will be postponed until July 2012, instead of July 2011 as previously agreed upon.

The BILLWG agreed that the proposed WBMS is a logical step and will facilitate completion of the assessment. It was also agreed that the symposium be convened in association with the March 2011 BILLWG workshop, since many of the WG members would likely make presentations at the symposium. It was agreed that the ISC should play a major role in the development of the WBMS, and some ISC BILLWG members would likely be asked to serve on the WBMS steering committee.

The WG agreed to begin submitting data for the blue marlin assessment at the next BILLWG meeting in November 2009. Data will be collected until March 2011, at which time preliminary runs of the blue marlin assessment will begin.

7.0 BILLFISH COLLABORATIVE RESEARCH RECOMMENDATIONS

Future collaborative research for billfish was discussed and Hawaiian data will be included in the current blue marlin analysis comparing CPUE and effort between Japanese and Taiwanese fleets. Similar analysis of HPB will be preferred, and the analysis for blue marlin may apply to other billfish species.

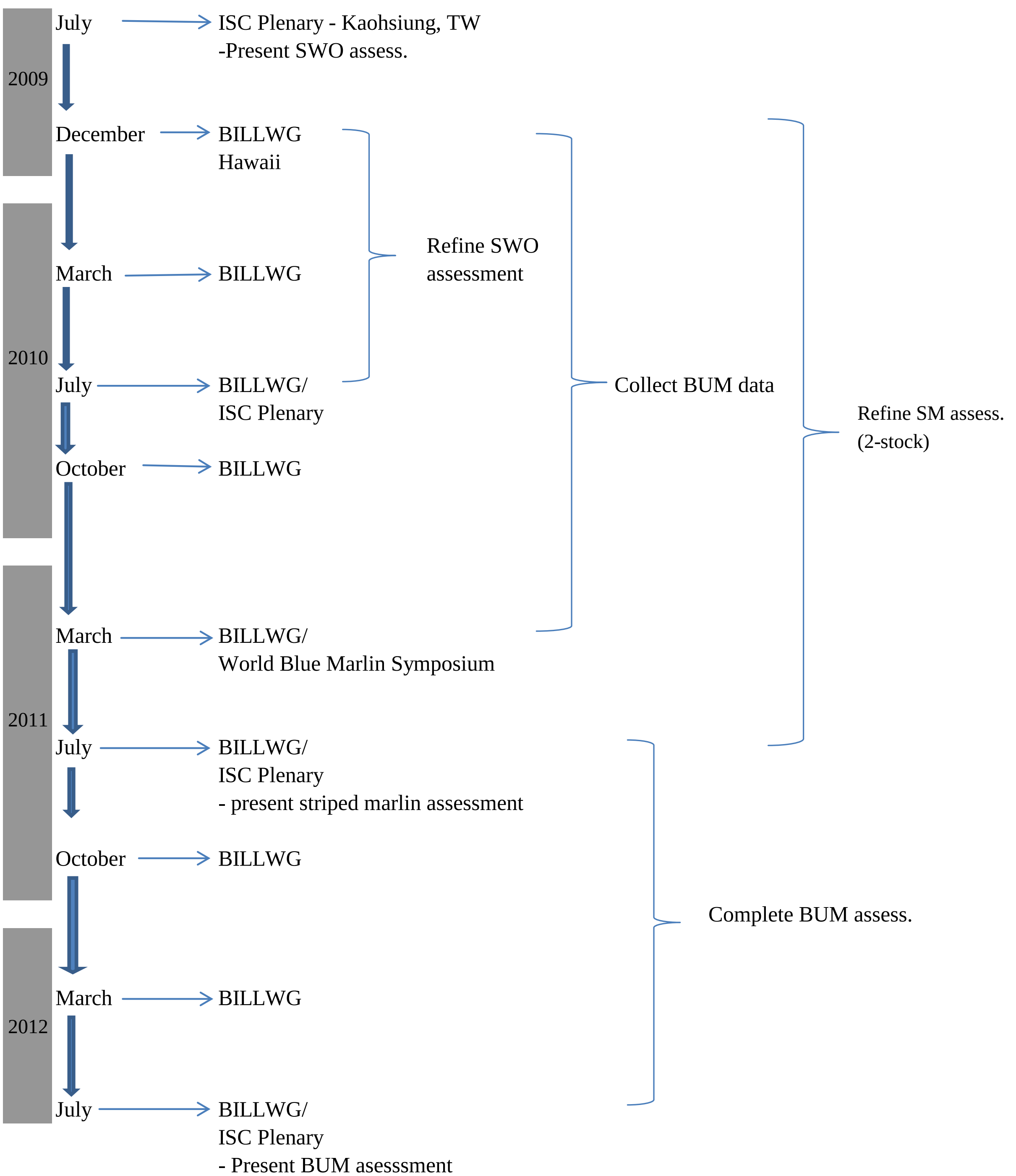
8.0 OTHER BUSINESS

8.1 Future Meetings and Timeline

Future meetings of the BILLWG were discussed, and a timeline outlined (Figure 14). It was noted that because of the intention to hold a WBMS in March 2011, the originally scheduled completion date for the blue marlin assessment of July 2011 will be postponed until July 2012. Other than collecting blue marlin data, the next three BILLWG workshops (December 2009, April 2010, and July 2010) will be used to complete the swordfish assessment using SS3, and if feasible, a two stock striped marlin assessment which is scheduled to be completed in July 2011.

The WG agreed on the next two dates for the upcoming BILLWG workshops. The next BILLWG workshop is scheduled for 2-9 December 2009 in Hawaii, USA. The goal of the meeting will be to determine if spatial structure is evident in the North Pacific striped marlin population and to determine plausible boundaries. At the same time, the BILLWG will review the progress made on the SS3 swordfish model. It was noted that at the conclusion of the December 2009 meeting, the BILLWG will not accept any swordfish or striped marlin data updates. The subsequent BILLWG workshop is tentatively scheduled for 21-28 April 2010. The location is to be determined. The exact dates of the April meeting may change to allow participation in the April 26-29, 2010 International Symposium on Climate Change Effects on Fish and Fisheries in Sendai, Japan. This work plan is subject to review and will need to be adopted at the ISC Plenary in July 2009.

Figure 14. Proposed timeline including assignments and deliverables of the BILLWG for the period Novmber 2009 to 2012.



Discussion

The WBMS was discussed. A venue will be determined somewhere in the Pacific Ocean that is easily accessible by scientists from around the world. It was stressed that the WBMS will be a scientific meeting with themes such as population dynamics, fisheries, biology/stock structure, etc. The WBMS will need to be endorsed by the ISC Plenary. The WMBS should also be announced early, and a steering committee assembled soon after the conclusion of this BILLWG workshop. Members of the steering committee should include scientists from the BILLWG, as well as scientists from the Atlantic and Indian Oceans, as well as RFOs such as ICCAT, if the symposium is to truly be a world event. It was suggested that the WBMS be convened associated with meetings such as the American Fisheries Society Annual meeting or the Tuna Conference in order to aid in logistics.

The need for refining the completed striped marlin assessment (July 2007) using a two-stock scenario was clarified. Historical catch data implies a separate western central Pacific stock from an eastern Pacific stock, and genetic evidence is limited and inconclusive. The lack of data submission from the IATTC on striped marlin in the EPO was noted. The WG agreed to document this and present it at the July 2009 ISC Plenary in order to stimulate data submission. The BILLWG will then proceed with a stock structure analysis to decide if refining the striped marlin assessment using a two-stock scenario would be plausible, or if leaving the Northern Pacific striped marlin assessment as is. The BILLWG Chairman is tasked to explore with appropriate ISC members the availability of support to conduct similar spatial structure and analysis for striped marlin as was provided for swordfish.

For billfish assessments, and especially the blue marlin assessment, the WG noted that collaboration with south Pacific scientists is important. It was noted that because of an agreement between the ISC and WCPFC, all WCPFC members can attend ISC meetings. In order to encourage information transfer among scientists from both the north and south Pacific, the Chairman is tasked to contact south Pacific scientists regarding upcoming billfish meetings that members of the BILLWG may attend.

It was also noted that a MOU between the ISC and IATTC is expected to be signed soon after the July 2009 ISC Plenary. The IATTC will then act as a participant in scientific working groups, and as an observer at the ISC Plenary meetings.

9.2 Assignments

9.2.1 BILLWG Assignments

The members of the ISC BILLWG were reminded of the ongoing assignment of completing and submitting data catalogues as soon as possible. Submission of data for the upcoming blue marlin assessment should also begin at the next BILLWG workshop in November 2009.

9.2.2 Chairman Assignments

The ISC BILLWG Chairman was tasked with a number of assignments. These tasks include:

- At the WBMS (March 2011), present the BILLWG's plan to do a blue marlin assessment, as well as the issues associated with it (biology, catch, CPUE, etc.)

- Contact south Pacific scientists regarding upcoming billfish meetings, and whether members of the BILLWG are invited to participate.

- Document lack of information submitted to the BILLWG on striped marlin in the EPO from the IATTC. Present at the July 2009 ISC Plenary.

- To explore with appropriate ISC members the availability of support to conduct similar spatial structure and analysis for striped marlin as was provided for swordfish.

9.3 Billfish Economic Studies

What the BILLWG would like to see regarding billfish economic studies was discussed. The WG recommended that economic studies should be linked to biological reference points. Imbedding economic information when evaluating management strategies would help in fishery management decisions tremendously.

The WG noted that economic studies are very important, in that economic incentives drive fishermen's actions. It would be a good idea for other WGs to incorporate economic studies in relation to biological reference points. The BILLWG endorsed the inclusion of economics studies in assessments.

10.0 ADJOURNMENT

The ISC BILLWG intercessional workshop was adjourned at 12:01pm on May 26, 2009. The Chairman expressed his appreciation to all participants for their contributions and cooperation in completing a successful meeting. On behalf of the BILLWG the Chairman thanked the hosts (NFRDI), especially Dr. Joon-Taek Yoo, for their commitment which was paramount to the success of the workhop.

11.0 REFERENCES

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Table 1. Striped marlin catches (in metric tons) by fisheries, 1952-2005. Blank indicates no effort. - indicates data not available. 0 indicates less than 1 metric ton. Provisional estimates in ( ).

	Japan							Chinese Taipei[1]												Costa Rica[1]	Korea			Mexico			United States					
Year	Distant-water and Offshore Longline	Coastal Longline	Other Longline	Small Mesh Gillnet	Large Mesh Gillnet	Other[2]	Total	Distant-water Longline	High-seas Drift Gillnet	Offshore Longline	Offshore Gillnet	Offshore Others	Coastal Harpoon	Coastal Setnet	Coastal Gillnet & Other net	Coastal Longline	Coastal others	Other	Total	Sport	Longline	High-seas Drift Gillnet	Total	Longline	Sport[1]	Total	Longline	Troll	Handline	Sport[1]	Total	Grand Total
1951	2,494	-	673	-	0	1,281	4,447																									4,447
1952	2,901	-	722	-	0	1,564	5,187												-		-		0			0				23	23	5,210
1953	2,138	-	47	-	0	954	3,139												-		-		0			0				5	5	3,144
1954	3,068	-	52	-	0	1,088	4,207												-		-		0			0				16	16	4,223
1955	3,082	-	28	-	0	1,038	4,148												-		-		0			0				5	5	4,153
1956	3,729	-	59	-	0	1,996	5,785												-		-		0			0				34	34	5,819
1957	3,189	-	119	-	0	2,459	5,767												-		-		0			0				42	42	5,809
1958	4,106	-	277	-	3	2,914	7,300			543								387	930		-		0			0				59	59	8,289
1959	4,152	-	156	-	2	3,191	7,501			391								354	745		-		0			0				65	65	8,311
1960	3,862	-	101	-	4	1,937	5,904			398								350	748		-		0			0				30	30	6,682
1961	4,420	-	169	-	2	1,797	6,388			306								342	648		-		0			0				24	24	7,060
1962	5,739	-	110	-	8	1,912	7,769			332								211	543		-		0			0				5	5	8,317
1963	6,135	-	62	-	17	1,910	8,124			560								199	759		-		0			0				68	68	8,951
1964	14,304	-	42	-	2	2,344	16,692			392								175	567		-		0			0				58	58	17,317
1965	11,602	-	19	0	1	2,794	14,416			355								157	512		-		0			0				23	23	14,951
1966	8,419	-	112	0	2	1,570	10,103			370								180	550		-		0			0				36	36	10,689
1967	11,698	-	127	0	3	1,551	13,379	2		385								204	591		-		0			0				49	49	14,019
1968	15,913	-	230	0	0	1,043	17,186	1		332								208	541		-		0			0				51	51	17,778
1969	8,544	600	3	0	3	2,668	11,818	2		571								192	765		-		0			0				30	30	12,613
1970	12,996	690	181	0	3	1,032	14,902	0		495								189	684		-		0			0				18	18	15,604
1971	10,965	667	259	0	10	2,042	13,943	0		449								135	584		0		0			0				17	17	14,544
1972	7,006	837	145	0	243	993	9,224	9		380								126	515		0		0			0				21	21	9,760
1973	6,357	632	118	0	3,265	702	11,074	1		568								139	708		0		0			0				9	9	11,791
1974	6,700	327	49	0	3,112	775	10,963	24		650								118	792		0		0			0				55	55	11,810
1975	5,281	286	38	0	6,534	686	12,825	64		732								96	892		0		0			0				27	27	13,744
1976	5,136	244	34	0	3,561	585	9,560	32		347								140	519		0		0			0				31	31	10,110
1977	3,019	256	15	0	4,424	547	8,261	17		524								219	760		43		43			0				41	41	9,105
1978	3,957	243	27	0	5,593	546	10,366	0		618								78	696		28		28			0				37	37	11,127
1979	5,561	366	21	0	2,532	526	9,006	26		432								122	580		-		0			0				36	36	9,622
1980	6,378	607	5	0	3,467	536	10,993	61		223								132	416		37		37			0				33	33	11,479
1981	4,106	259	12	0	3,866	542	8,785	17		491								95	603		-		0			0				60	60	9,448
1982	5,383	270	13	0	2,351	656	8,673	7		397								138	542		39		39			0				41	41	9,295
1983	3,722	320	10	22	1,845	827	6,746	0		555								214	769		19		19			0				39	39	7,573
1984	3,506	386	9	76	2,257	719	6,953	0		965								330	1,295		23		23			0				36	36	8,307
1985	3,897	711	24	40	2,323	733	7,728	0		513								181	694		16		16			0		18		42	60	8,498
1986	6,402	901	33	48	3,536	577	11,497	0		179								148	327		61		61	-		0		19		19	38	11,923
1987	7,538	1,187	6	32	1,856	513	11,132	31		383								151	565		1		1	-		0	272	30	1	28	331	12,029
1988	6,271	752	7	54	2,157	668	9,909	7		457								169	633		11		11	-		0	504	54		30	588	11,141
1989	4,740	1,081	13	102	1,562	537	8,035	8		184								157	349		26		26	-		0	612	24	0	52	688	9,098
1990	2,368	1,125	3	19	1,926	545	5,986	2		137								256	395		315		315	-	181	181	538	27	0	23	588	7,465
1991	2,845	1,197	3	27	1,302	507	5,881	36		254								286	576	106	141		141	-	75	75	663	41	0	12	716	7,495
1992	2,955	1,247	10	35	1,169	303	5,719	1		219								197	417	281	318		318	-	142	142	459	38	1	25	523	7,400
1993	3,476	1,723	1	-	828	708	6,736	5		221								142	368	438	388		388	-	159	159	471	68	1	11	551	8,640
1994	2,911	1,284	1	-	1,443	383	6,022	1		137								196	334	521	1,045		1,045	-	179	179	326	35	0	17	378	8,479
1995	3,494	1,840	3	-	970	283	6,590	27		83								82	192	153	307		307	-	190	190	543	52	0	14	609	8,041
1996	1,951	1,836	4	-	703	152	4,646	26		162	8	6	30	3	-	-	-		235	122	429		429	-	237	237	418	54	1	20	493	6,162
1997	2,120	1,400	3	-	813	163	4,499	59		290	9	-	33	3	-	2	-		396	138	1,017		1,017	-	193	193	352	38	1	21	412	6,655
1998	1,784	1,975	2	-	1,092	304	5,157	90		205	15	-	19	6	1	9	-		345	144	635		635	-	345	345	378	26	0	23	427	7,053
1999	1,608	1,551	4	-	1,126	184	4,473	66		128	7	-	26	5	1	3	-		236	166	433		433	-	266	266	364	28	1	12	405	5,979
2000	1,152	1,109	8	-	1,062	297	3,628	153		161	17	1	29	6	1	1	-		369	97	537		537	-	312	312	200	14	1	10	225	5,168
2001	985	1,326	11	-	1,077	237	3,636	121		129	16	-	30	5	-	-	-		301	151	254		254	-	237	237	351	42	2		395	4,974
2002	764	796	5	-	1,264	290	3,119	251		226	14	-	6	8	1	-	-		506	76	188		188	-	305	305	226	30	0		256	4,450
2003	1,013	842	3	-	1,064	203	3,124	241		91	26	-	11	5	1	-	-		375	79	206		206	-	322	322	552	29	0		581	4,687
2004	699	1,000	2	-	1,339	92	3,130	261		95	8	1	7	5	2	-	1		380	(19)	75		75	-	-	0	376	34	1		411	(4,015)
2005	(562)	(668)	(1)	-	(1,214)	(98)	(2,543)	176		76	1	-	5	9	9	-	8		284	-	141		141	-	-	0	493	20	0		513	(3,481)
2006	(642)	(538)	(1)	-	(1,190)	(95)	(2,466)														56		56				609	21	0		630	(3,152)
2007	313						(313)														28		28				265	13	0		278	(619)
2008																																

[1] Estimated from catch in number of fish

[2] Contrains bait fishing, net fishing, trapnet, trolling, harpoon, etc.

Table 2. Swordfish catches (in metric tons) by fisheries, 1952-2005. Blank indicates no effort. - indicates data not available. 0 indicates less than 1 metric ton. Provisional estimates in ( ).

	Japan								Chinese Taipei[5]											Korea			Mexico	ited States[6]						
																								Hawaii	California					
Year	Distant-water and Offshore Longline[2]	Coastal Longline	Driftnet	Harpoon[3]	Other Bait Fishing	Trapnet	Other[4]	Total	Distant-water Longline	Offshore Longline	Offshore Gillnet	Offshore Others	Coastal Harpoon	Coastal Setnet	Coastal Gillnet & other net	Coastal Longline	Coastal Others	Other	Total	Longline	High-seas Drift Gillnet	Total	All Gears	Longline	Longline	Gill Net	Harpoon	Unknown[7]	Total	Grand Total
1951	7,246	115	10	4,131	88	78	10	11,678																						11,678
1952	8,890	152	0	2,569	6	68	6	11,691	-	-									-	-			-	-	-	-	-	-	-	11,691
1953	10,796	77	0	1,407	20	21	87	12,408	-	-									-	-			-	-	-	-	-	-	-	12,408
1954	12,563	96	0	813	104	18	17	13,610	-	-									-	-			-	-	-	-	-	-	-	13,610
1955	13,064	29	0	821	119	37	41	14,111	-	-									-	-			-	-	-	-	-	-	-	14,111
1956	14,596	10	0	775	66	31	7	15,486	-	-									-	-			-	-	-	-	-	-	-	15,486
1957	14,268	37	0	858	59	18	11	15,251	-	-									-	-			-	-	-	-	-	-	-	15,251
1958	18,525	42	0	1,069	46	31	21	19,734	-	-									-	-			-	-	-	-	-	-	-	19,734
1959	17,236	66	0	891	34	31	10	18,267	-	427								91	518	-			-	-	-	-	-	-	-	18,785
1960	20,058	51	1	1,191	23	67	7	21,400	-	520								127	647	-			-	-	-	-	-	-	-	22,047
1961	19,715	51	2	1,335	19	15	11	21,147	-	318								73	391	-			-	-	-	-	-	-	-	21,538
1962	10,607	78	0	1,371	26	15	18	12,115	-	494								62	556	-			-	-	-	-	-	-	-	12,671
1963	10,322	98	0	747	43	17	16	11,244	-	343								18	361	-			-	-	-	-	-	-	-	11,605
1964	7,669	91	4	1,006	40	16	26	8,852	-	358								10	368	-			-	-	-	-	-	-	-	9,220
1965	8,742	119	0	1,908	26	14	182	10,991	-	331								27	358	-			-	-	-	-	-	-	-	11,349
1966	9,866	113	0	1,728	41	11	4	11,763	-	489								31	520	-			-	-	-	-	-	-	-	12,283
1967	10,883	184	0	891	33	12	5	12,008	-	646								35	681	-			-	-	-	-	-	-	-	12,689
1968	9,810	236	0	1,539	41	14	9	11,649	-	763								12	775	-			-	-	-	-	-	-	-	12,424
1969	9,416	296	0	1,557	42	11	14	11,336	0	843								7	850	-			-	-	-	-	-	-	-	12,186
1970	7,324	427	0	1,748	36	9	3	9,547	-	904								5	909	-			-	5	-	-	612	10	627	11,083
1971	7,037	350	1	473	17	37	31	7,946	-	992								3	995	0			-	1	-	-	99	3	103	9,044
1972	6,796	531	55	282	20	1	2	7,687	-	862								11	873	0			2	0	-	-	171	4	175	8,737
1973	7,123	414	720	121	27	23	2	8,430	-	860								119	979	0			4	0	-	-	399	4	403	9,816
1974	5,983	654	1,304	190	27	16	2	8,176	1	880								136	1,017	0			6	0	-	-	406	22	428	9,627
1975	7,031	620	2,672	205	58	18	2	10,606	29	899								153	1,081	0			-	0	-	-	557	13	570	12,257
1976	8,054	750	3,488	313	170	14	12	12,801	23	613								194	830	0			-	0	-	-	42	13	55	13,686
1977	8,383	880	2,344	201	71	7	2	11,888	36	542								141	719	219			-	17	-	-	318	19	354	12,961
1978	8,001	1,031	2,475	130	110	22	1	11,770	-	546								12	558	68			-	9	-	-	1,699	13	1,721	14,049
1979	8,602	1,038	983	161	45	15	4	10,848	7	661								33	701	-			7	7	-	-	329	57	393	11,949
1980	6,005	849	1,746	398	29	15	1	9,043	10	603								76	689	64			380	5	-	160	566	62	793	10,905
1981	7,039	727	1,848	129	58	9	3	9,813	2	656								25	683	-			1,575	3	0	473	271	2	749	12,820
1982	6,064	874	1,257	195	58	7	1	8,456	1	855								49	905	48			1,365	5	0	945	156	10	1,116	11,842
1983	7,692	999	1,033	166	30	9	2	9,931	0	783								166	949	11			120	5	0	1,693	58	7	1,763	12,763
1984	7,177	1,177	1,053	117	98	13	0	9,635	-	733								264	997	48			47	3	12	2,647	104	75	2,841	13,520
1985	9,335	999	1,133	191	69	10	0	11,737	-	566								259	825	24			18	2	0	2,990	305	104	3,401	15,981
1986	8,721	1,037	1,264	123	47	9	0	11,201	-	456								211	667	9			422	2	0	2,069	291	109	2,471	14,761
1987	9,495	860	1,051	87	45	11	0	11,549	3	1,328								190	1,521	44			550	24	0	1,529	235	31	1,819	15,439
1988	8,574	678	1,234	173	19	8	0	10,686	-	777								263	1,040	27			613	24	0	1,376	198	64	1,662	14,001
1989	6,690	752	1,596	362	21	10	0	9,431	50	1,491								38	1,579	40			690	218	0	1,243	62	56	1,579	13,279
1990	5,833	690	1,074	128	13	4	0	7,742	143	1,309								154	1,606	61			2,650	2,436	0	1,131	64	43	3,674	15,672
1991	4,809	807	498	153	20	5	0	6,292	40	1,390								180	1,610	5			861	4,508	27	944	20	44	5,543	14,306
1992	7,234	1,181	887	381	16	6	0	9,705	21	1,473								243	1,737	8			1,160	5,700	62	1,356	75	47	7,240	19,842
1993	8,298	1,394	292	309	43	4	1	10,341	54	1,174								310	1,538	15			812	5,909	27	1,412	168	161	7,677	20,368
1994	7,366	1,357	421	308	37	4	0	9,493	-	1,155								219	1,374	66			581	3,176	631	792	157	24	4,780	16,228
1995	6,422	1,387	561	423	34	7	0	8,834	50	1,135								225	1,410	10			437	2,713	268	771	97	29	3,878	14,559
1996	6,916	1,067	428	597	45	4	0	9,057	9	701	2	-	19	10	-	-	-		741	15		15	439	2,502	346	761	81	15	3,705	13,957
1997	7,002	1,214	365	346	62	5	0	8,994	15	1,358	1	1	27	8	-	24	-		1,434	100		100	2,365	2,881	512	708	84	11	4,196	17,089
1998	6,233	1,190	471	476	68	2	0	8,440	20	1,178	8	-	17	15	1	-	-		1,239	153		153	3,603	3,263	418	931	48	19	4,679	18,114
1999	5,557	1,049	724	416	47	5	0	7,798	70	1,385	4	-	51	5	1	-	-		1,516	132		132	1,136	3,100	1,229	606	81	27	5,043	15,625
2000	6,180	1,121	808	497	49	5	0	8,660	325	1,531	5	-	74	5	1	1	-		1,942	202		202	2,216	2,949	1,885	646	90	9	5,579	18,599
2001	6,932	908	732	230	30	15	0	8,847	1,039	1,691	17	-	64	8	1	1	-		2,821	438		438	780	220	1,749	375	52	5	2,401	15,287
2002	6,230	965	1,164	201	29	11	0	8,600	1,633	1,557	7	1	1	16	1	1	-		3,217	439		439	465	204	1,320	302	90	3	1,919	14,640
2003	5,376	1,063	1,198	149	28	4	0	7,818	1,084	2,196	3	-	-	8	-	-	-		3,291	381		381	671	147	1,812	216	107	0	2,282	14,443
2004	5,395	1,509	1,062	229	30	4	0	8,229	884	1,828	5	-	-	7	1	-	3		2,728	410		410	270	213	898	169	62	37	1,379	13,016
2005	(5,359)	(1,294)	(956)	(187)	(337)	(3)	(0)	(8,136)	437	1,813	1	-	-	5	2	-	18		2,276	434		434	235	1,475		220	76	0	1,771	(12,852)
2006	(6,261)	(1,505)	(796)	(244)	(342)	(5)	(1)	(9,154)												477		477	347	1,175		444	71	2	1,692	(11,670)
2007	6,499							(6,499)												452		452	383	1,444		484	58	0	1,986	(9,320)
2008																							(84)							(84)

[1] Catch data are currently unavailable for Republic of Korea, Philippines, and some other countries catching swordfish in the North Pacific.

[2] Catches by gear for 1952-1970 were estimated roughly using FAO statistics and other data. Catches for 1971-2002 are more reliably estimated.

[3] Contrains trolling and harpoon but majority of catch obtained by harpoon.

[4] For 1952-1970 "Other" refers to catches by net fishing and various unspecified gears.

[5] Offshore longline category includes some catches from harpoon and other fisheries but does not include catches unloaded in foreign ports.

[6] Estimated round weight of retained catch. Does not include discards.

[7] Unknown includes pole and line, purse seine, troll and troll/handline, half ring, and unspecified gears.

(shaded) only one vessel fished so combined with Hawaii longline

Appendix 1

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Appendix 2

Working Papers and Background Papers

WORKING PAPERS

ISC/09/BILLWG-2/01	Input data for a North Pacific Swordfish Stock Assessment using Bayesian Production Models. Dean Courtney and Lyn Wagatsuma. (Dean.Courtney@noaa.gov)
ISC/09/BILLWG-2/02	Development of Bayesian surplus production models for assessing the North Pacific swordfish population. Jon Brodziak and Gakushi Ishimura. (Jon.Brodziak@noaa.gov)
ISC/09/BILLWG-2/03	Model-averaging to account prior uncertainty in swordfish intrinsic growth rate and carrying capacity. Gakushi Ishimura and Jon Brodziak. (gakugaku@sgp.hokudai.ac.jp)
ISC/09/BILLWG-2/04	Input data for a North Pacific Swordfish Stock Assessment using Stock Synthesis. Dean Courtney and Eric Fletcher. (Dean.Courtney@noaa.gov)
ISC/09/BILLWG-2/05	Preliminary Stock Synthesis Model Sensitivity Runs for a North Pacific Swordfish (*Xiphias gladius*) Stock Assessment. Dean Courtney and Kevin Piner. (Dean.Courtney@noaa.gov)
ISC/09/BILLWG-2/06	Size composition of the California Driftnet Fishery, 1981-Present. Kevin Piner. (Kevin.Piner@noaa.gov)
ISC/09/BILLWG-2/07	Input Data of Japanese Catch Amount of a North Pacific Swordfish Stock Assessment. Ai Kimoto and Kotaro Yokawa. (aikimoto@affrc.go.jp)
ISC/09/BILLWG-2/08	Size Conversions for Striped Marlin. Alexander Klett and Luis Fleischer. (aklettt@yahoo.com)
ISC/09/BILLWG-2/09	CPUE time series from the California Driftnet Fishery, 1985-Present. Kevin Piner and Amy Betcher. (Kevin.Piner@noaa.gov)
ISC/09/BILLWG-2/10	Characteristics of spatial variations in the catch of billfish in the Pacific Ocean and factors affecting annual changes in

	the catch. Joon-Taek Yoo, Doo-Hae An, Dae-Yeon Moon, Seon-Jae Hwang, Hyun-su Jo, and Dae Soo Chang. (yoojt@nfrdi.jo.kr)
ISC/09/BILLWG-2/11	Analysis of the operation pattern and catch-rates of blue marlin for the Japanese and Taiwanese longline fisheries in the Pacific Ocean. Nan-Jay Su, Chi-Lu Sun, Kotaro Yokawa, Gerard DiNardo, Minoru Kanaiwa, and Su-Zan Yeh. (d93241011@ntu.edu.tw)
ISC/09/BILLWG-2/12	The evaluation of removing hook adjacent to floats for catch amount. Minoru Kanaiwa, Keith Bigelow, and Kotaro Yokawa. (m3kanaiw@bioindustry.nodai.ac.jp)
ISC/09/BILLWG-2/13	Stock assessment of swordfish, *Xiphias gladius,* in the North Pacific Ocean using an age-structured population dynamic model. Chi-Lu Sun, Nan-Jay Su, and Su-Zan Yeh. (chilu@ntu.edu)

BACKGROUND PAPERS

ISC/08/BILLWG-SS/05	Review and Bibliography of Recent Swordfish Stock Assessment Methods and Available Data for the North Pacific Ocean. Dean Courtney, Gakushi Ishimura, and Lyn Wagatsuma. (Dean.Courtney@noaa.gov)
	Revised review table of vital rates and life history parameters for striped marlin, swordfish, and blue marlin in the North Pacific Ocean (February 2007). PIFSC, Honolulu, Hawaii, Unpublished Pers. Comm.

Appendix 3

Agenda

BILLFISH WORKING GROUP (BILLWG)

International Scientific Committee for Tuna and Tuna-like Species
in the North Pacific Ocean

INTERCESSIONAL WORKSHOP ANNOUNCEMENT

Meeting Site: National Fisheries Research & Development Institute
152-1, Haeanro, Gijang-Up, Gijang-Gun
Busan, 619-705, Korea

Meeting Dates: May 19-26, 2009

Accommodations: Novotel Ambassador Busan (www.novotelbusan.com)
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The Novotel Ambassador Busan will provide free transportation to and from the meeting site. Access to all hotel amenities (gym, pool, etc.) is included in the room charges.

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May 19 (Tuesday), 0930-1000 – Registration

May 19 (Tuesday), 1000-1600

1. Opening of Billfish Working Group (BILLWG) Workshop
    a. Welcoming Remarks
    b. Introductions

2. Adoption of Agenda, Assignment of Rapporteurs and Numbering of Working Papers

3. Computing Facilities
    a. Access

4. Summary of the February 2009 ISC Billfish Workshop and Status of Work Assignments

5. Swordfish Production Model
    a. Input data summary
    b. Model structure, base case and sensitivity runs
    c. Model results

May 20 (Wednesday), 0930-1600

6. Swordfish Stock Synthesis Model
    a. Input data summary
    b. Model structure, base case and sensitivity runs
    c. Model results

May 21 (Thursday), 0930-1600

7. Additional Model Runs and Sensitivity Analyses

8. Catch and CPUE Trends

May 21 (Thursday), 1600-1800

9. Blue Marlin Steering Committee Meeting

May 22 (Friday), 0930-1600

10. Billfish Economic Analyses

11. Additional Model Runs and Sensitivity Analyses

12. North Pacific Swordfish Conservation Advice
    a. Projection strategy
    b. Possible reference points

May 23 (Saturday), 0930-1200

13. Blue Marlin
    a. Japan-Taiwan collaboration study

14. Billfish Collaborative Research Recommendations
    a. Identify specific projects

15. Biological Research Task Force

16. Future Meetings

May 23 (Saturday), 1330 – 1600

17. Additional Model Runs and Sensitivity Analyses (if necessary)

May 24 (Sunday), No Meeting – Complete Report and Circulate

May 25 (Monday) – WG Reviews Report

May 26 (Tuesday), 0900-1200

18. Finalize Report

19. Adjournment

Appendix 4

Bayesian Surplus Production Model

This Appendix describes the base production models for the North Pacific swordfish stock assessment used for the single-stock and two-stock scenarios. Model structure, data inputs, and output results are described including goodness-of-fit diagnostics and biomass and harvest rate trends under each stock structure scenario. These results represented the Billfish Working Group consensus on model structure, data inputs, and output results for the North Pacific swordfish stock assessment conducted in 2009.

Input Fishery Data

The fishery-dependent catch data for assessing North Pacific swordfish were taken from the most recent document summarizing the available data for both stock structure scenarios (Courtney and Wagatsuma 2009). Commercial swordfish catch biomass data were available for 1951-2006 under each stock scenario.

Estimates of standardized commercial fishery CPUE were also collected from Courtney and Wagatsuma (2009) for each stock scenario. The standardized CPUE time series for the single-stock scenario included Japanese longline CPUE (1951-2006, n=56), Taiwanese longline CPUE (1995-2006, n=12), and Hawaii shallow-set longline CPUE (1995-2000 and 2004-2006, n=9).

Under the two-stock scenario, the available standardized CPUE time series differed by Sub-Area. The standardized CPUE time series for Sub-Area 1 included Japanese longline CPUE (1951-2006, n=56), Taiwanese longline CPUE (1995-2006, n=12), and Hawaii shallow-set longline CPUE (1995-2000 and 2004-2006, n=9). The standardized CPUE time series for Sub-Area 2 included Japanese longline CPUE (1955-2006, n=52) and Taiwanese longline CPUE (1995-2006, n=12).

Production Model Structure

The base case swordfish production models were Bayesian-state space models with explicit process and observation error terms (see Meyer and Millar, 1999; Brodziak and Ishimura 2009). The unobserved biomass states were estimated from the observed relative abundance indices (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.

The process dynamics were based on a power function production model with an annual time step. In this 3-parameter production model, current biomass (B_T) depended on the previous year's biomass, catch (C_{T-1}), the intrinsic growth rate (R), carrying capacity (K), and a production shape parameter (M) for $T = 2,\ldots, N$ via

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

The shape parameter $M > 0$ determined where surplus production peaked as biomass varied in proportion to carrying capacity. If $0 < M < 1$, surplus production peaked when biomass was below ½ of K (i.e., a right-skew production curve). If $M > 1$, then biomass production was higher when biomass was above ½ of K (i.e., a left-skewed production curve). If $M = 1$, the production model was identical to a discrete-time Schaefer production model in which maximum surplus production occurred when biomass was equal to ½ of K. The values of biomass and harvest rate that maximized surplus production represented potential biological reference points for North Pacific swordfish. For the discrete-time power function model, the biomass that maximized surplus production (B_{MSY}) was

$$(2) \qquad B_{MSY} = K \cdot (M+1)^{\frac{-1}{M}}$$

The corresponding harvest rate that maximized surplus production (H_{MSY}) was

$$(3) \qquad H_{MSY} = R\left(1 - \frac{1}{M+1}\right)$$

and the maximum surplus production (MSY) was

$$(4) \qquad MSY = R\left(1 - \frac{1}{M+1}\right) \cdot K\,(M+1)^{\frac{-1}{M}}$$

The power function model was reparameterized in terms of the proportion of carrying capacity ($P = B/K$) to improve the efficiency of the Markov Chain Monte Carlo algorithm used to estimate parameters. Based on this parameterization, the process dynamics for the power function model were

$$(5) \qquad P_T = P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}^M\right) - \frac{C_{T-1}}{K}$$

The process dynamics were subject to natural variation as a result of fluctuations in life history parameters, trophic interactions, environmental conditions and other factors. The process error represented the joint effect of a large number of random multiplicative events which combined to form a multiplicative lognormal process under the Central Limit Theorem. In particular, the process error terms were assumed to be independent and lognormally distributed random variables $\eta_T = e^{U_T}$ where the U_T were normal random variables with mean 0 and variance σ^2.

The state equations defined the stochastic process dynamics by relating the unobserved biomass states to the observed catches and the population dynamics parameters. Given the lognormal process error assumption, the state equations for the initial time period
$T = 1$ and subsequent periods $T > 1$ were

$$(6) \qquad \begin{aligned} P_1 &= \eta_1 \\ P_T &= \left(P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}^{M}\right) - \frac{C_{T-1}}{K} \right) \cdot \eta_T \end{aligned}$$

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

Observation Error Model Structure

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 biomass with catchability coefficient Q

$$(7) \qquad I_T = QB_T = QKP_T$$

The observed CPUE dynamics were also subject to sampling variation which was assumed to be lognormally distributed. The observation errors were $\nu_T = e^{V_T}$ where the V_T were iid normal random variables with zero mean and variance τ^2. Given the lognormal observation errors, the observation equations for $T = 1,\ldots, N$ were

$$(8) \qquad I_T = QKP_T \cdot \nu_T$$

This was the observation error likelihood function $p(I_T|\theta)$ for each year T.

Prior Distributions

Prior distributions were employed to quantify existing knowledge of the likely value of each model parameter. The model parameters included the carrying capacity, intrinsic growth rate, shape parameter, catchability, the process and observation error variances, and the initial biomass as a proportion of carrying capacity. Unobserved biomass states were the proportions of carrying capacity, P_T, for $T > 1$, conditioned on the previous proportion. Auxiliary information was used to specify the prior distributions when it was available.

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 set to achieve a CV of 50%

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

The mean carrying capacity value differed between stock structure scenarios. Under the single-stock scenario, the mean K parameter was set to be 150 kt. For the two-stock scenario, the mean K for Sub-Area 1 was set to be 150 kt while the mean K for Sub-Area 2 was set to be 75 kt. These mean values were chosen to reflect the biomass likely needed to support the observed fishery catches under each scenario. The sensitivity of production model results to uncertainty in the prior mean of K was investigated in Ishimura and Brodziak (2009).

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 of 50%

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

The mean R parameter was set to be μ_R=0.5 for each stock scenario. This mean value was consistent with the range of prior means of (0.40, 0.43) estimated for North and South Atlantic swordfish, respectively, using demographic data (McAllister et al. 2000). Setting the prior mean of R = 0.5 with a CV of 50% allowed enough flexibility for the production model to discern the more probable range of R given the observed catch and CPUE data. The sensitivity of production model results to uncertainty in the prior mean of K was investigated in Ishimura and Brodziak (2009).

Prior for Production Shape Parameter

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

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

The values of the scale and shape parameters were equal with $\lambda = k = 2$. This choice set the mean of $p(M)$ to be $\mu_M = 1$, which corresponded to the value of M under the Schaefer production model. This choice also implied that the CV of the shape parameter prior was 71%. Thus, the shape parameter prior was centered on the symmetric Schaefer model as the default with adequate flexibility to estimate a non-symmetric production function if needed.

Prior for Catchability

The prior for catchability $p(Q)$ was chosen to be a diffuse inverse-gamma distribution with scale parameter λ and shape parameter k.

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

The scale and shape parameters were equal with $\lambda = k = 0.001$. This choice of parameters implied that $1/Q$ had a mean of 1 and a variance of 1000. Thus, the prior for catchability was approximately $p(Q) \propto Q^{-1}$. Since $1/Q$ is unbounded at $Q = 0$, an additional numerical constraint that Q lie within the interval [0.0001, 10] was imposed.

Priors for Error Variances

Under both stock structure scenarios, the priors for the process error variance $p(\sigma^2)$ and observation error variance $p(\tau^2)$ were inverse-gamma distributions, a natural choice for dispersion priors (Congdon, 2001). For the process error variance prior, the scale parameter was $\lambda = 4$ and the shape parameter was $k = 0.1$. This choice set the CV for process error to be 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 set the observation error CV to be 50%. Given these prior assumptions, the initial observation error variance was assumed to be roughly 3-fold greater than the process error variance.

Priors for Proportions of Carrying Capacity

Under both stock structure scenarios, the mean proportion of carrying capacity for the initial time period (1951 for both scenarios) was set to 0.9 based on an assumption that the swordfish population was lightly exploited following a cessation of fishing during World War II. For subsequent years, the prior distributions for the proportion of carrying capacity, $p(P_T)$, were determined by the lognormal distributions for process error specified in the process dynamics.

Posterior Distribution

The joint posterior distribution was calculated to make inferences about model parameters. From Bayes' theorem, the posterior distribution given catch and CPUE data D, $p(\theta|D)$, was proportional to the product of the priors and the likelihood of the CPUE data.

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

There was no closed form expression to calculate parameter estimates from the posterior distribution.

Parameter estimation for the swordfish production model was based on simulating a large number of independent samples from the posterior distribution. Markov Chain Monte Carlo (MCMC) simulation (Gilks et al., 1996) was applied to numerically generate a sequence of samples from the posterior distribution. The WINBUGS software (Spiegelhalter et al., 2003) was used to set the initial conditions, perform the MCMC calculations, and summarize the results.

MCMC simulations were conducted in an identical manner for each of the swordfish stock structure scenarios models described below. Three chains of 60,000 samples were simulated in each model run. The first 10,000 samples of each chain were excluded from the estimation process. This burn-in period removed any dependence of the MCMC samples on the initial conditions. Next, each chain was thinned by 2 to remove autocorrelation. As a result, 75,000 samples from the posterior were used for summarizing model results. Convergence of the MCMC simulations to the posterior distribution was checked using the Brooks-Gelman-Rubin (BGR) convergence diagnostic (Brooks and Gelman, 1998) and by monitoring the MCMC error. The BGR diagnostic was monitored for several key model parameters (intrinsic growth rate, carrying capacity, production function shape parameter, catchability coefficients) to verify convergence.

Goodness-of-Fit Criteria

Model residuals were used to measure the goodness of fit of the alternative production models. 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 when comparing models with the same number of parameters.

Results: Convergence to Posterior Distribution

The BGR diagnostic was monitored for the intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients under both stock structure scenarios. In all cases, estimated BGR values were approximately unity which was consistent with the convergence in distribution of the MCMC samples to the posterior distribution. Similarly, the MCMC errors were relatively small, on the order of 0.4-2.5%, of the estimated standard deviation of parameter estimates. This observation was also consistent with convergence to the posterior. Last, density plots of the posterior distributions of the intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients were smooth and unimodal under both stock structure scenarios. This empirical check was also consistent with a convergent sequence of MCMC samples. Overall, it appeared that the MCMC samples generated from the Bayesian production model numerically converged to the posterior distribution.

Results: Single-Stock Scenario Model Fits to CPUE

Results of the fits to standardized CPUE under the single-stock scenario indicated that the Japanese longline CPUE had the lowest RMSE while the Hawaii shallow-set longline CPUE had the poorest fit (Table 4.1). Predicted Japanese CPUE appeared to randomly fluctuate about the observed CPUE time series (Figure 4.1.1). Examination of the log-scale residuals indicated that there was a moderate but significant increasing trend with time (P=0.02). The residuals were normally distributed (P=0.54) and had constant variance (P=0.52). The fit to the observed Taiwanese longline CPUE had a pattern of consecutive negative residuals that appeared non-random (Figure 4.1.2). However, there was no significant trend in residuals (P=0.13) and the log-scale residuals were normally distributed (P=0.16) with constant variance (P=0.09). Similarly, the fits to the Hawaii shallow-set longline CPUE had a negative then positive pattern of residuals (Figure 4.1.3) but no trends in residuals were detected during 1995-2000 (P=0.21) or during 2004-2006 (P=0.23). The log-scale residuals were normally distributed during 1995-2000 (P=0.48) with constant variance (P=0.06) but were not normally distributed (P<0.01) and did have constant variance (P<0.01) during 2004-2006. Overall, under the single-stock scenario, the fits to the CPUE time series appeared adequate although there was a lack of conformance to model error assumptions in a few cases.

Results: Two-Stock Scenario Model Fits to CPUE

Under the two-stock scenario, results of the fits to standardized CPUE indicated that the Japanese longline CPUE had the lowest RMSE while the Hawaii shallow-set longline CPUE had the highest RMSE (Table 4.1). Predicted Japanese CPUE fluctuated around the observed CPUE time series (Figure 4.2.1). The log-scale residuals had no time trend (P=0.35), were normally distributed (P=0.22), and had constant variance (P=0.70). The Taiwanese longline CPUE fit had a pattern of consecutive negative residuals in the late-1990s (Figure 4.2.2). There was a detectable time trend in the residuals (P=0.05), the log-scale residuals were normally distributed (P=0.21), and had constant variance (P=0.15). Fits to the Hawaii shallow-set longline CPUE appeared to have an increasing trend in residuals (Figure 4.2.3). There was a significant increasing trend during 1995-2000 (P=0.02) and during 2004-2006 (P=0.02). The log-scale residuals were normally distributed during 1995-2000 (P=0.48) but were not normally distributed during 2004-2006 (P<0.01). The log-scale residuals did not have constant variance during 1995-2000 (P=0.04) or during 2004-2006 (P<0.01). Overall, some of the fits to the CPUE time series in subarea 1 appeared non-random and in particular, the Taiwanese and Hawaii shallow-set long CPUE fits exhibited increasing trends in their residual patterns.

For Sub-Area 2 under the two-stock scenario, the model fits to standardized CPUE indicated that the Japanese longline CPUE had a lower RMSE than the fit to the Taiwanese CPUE (Table 4.1). The fit to the Japanese longline CPUE (Figure 4.3.1) exhibited some large negative residuals in the 1950s but otherwise appeared to fluctuate randomly about the observed CPUE. The residuals had no time trend (P=0.24) but the log-scale residuals were not normally distributed (P<0.01) and the variance was not constant (P=0.04). In contrast, there was no apparent pattern in the fit to the Taiwanese longline CPUE (Figure 4.3.2). In this case, the residuals had no detectable trend (P=0.72), the log-scale residuals were normally distributed (P=0.89), but the variance was not constant (P=0.03). Overall, in subarea 2 there was a good fit to the Taiwanese longline CPUE and some lack of fit to the Japanese longline CPUE in the 1950s.

Results: Model Parameters and Reference Points

Estimates of production model parameters varied between the stock structure scenarios (Table 4.2). Under the single-stock scenario, the intrinsic growth rate was estimated to be R=0.68. In contrast, under the two-stock scenario the estimates of R were 0.58 and 0.40 for Sub-Areas 1 and 2, or 15% and 41% below the single-stock estimate. The estimate of K under the single-stock scenario (K=113.6 kt) was about 33% less than the sum of the estimates of K under the two-stock scenario (K_1+K_2=170.5 kt). The estimate of the production model shape parameter for the single-stock scenario was M=1.25 indicating a left-skewed production curve. In comparison, the estimate of M_1 for Sub-Area 1 was approximately 1.02 indicating a symmetric biomass production curve while the M_2 estimate for subarea 2 was M_2=0.66 indicating a right-skewed production curve. Overall, estimates of production model parameters R, K, and M differed between the stock scenarios.

Estimates of biological reference points also differed between the stock scenarios (Table 4.2). The mean estimate of B_{MSY} under the single-stock scenario was B_{MSY}=58.4. This was about 29% below the sum of the estimates of B_{MSY} under the two-stock scenario. The mean estimate of H_{MSY} under the single-stock scenario was H_{MSY}=0.34. In comparison, the estimates of H_{MSY} under the two-stock scenario were 0.26 and 0.13 for subareas 1 and 2, or 24% and 62% less than the single-stock estimate. In contrast, the mean estimate of MSY under the single-stock scenario was MSY=19.1 kt which was only 9% higher than the sum of the MSY estimates under the two-stock scenario. Overall, the results indicated that the North Pacific swordfish population would be considered to be a smaller (lower K) and more productive stock (higher R) under the single-stock scenario than as a combination of two sub-stocks under the two-stock scenario.

In contrast to the estimates of production model parameters and biological reference points, there was no practical difference in the estimates of stock status in 2006 between the two stock scenarios (Table 4.2). In particular, the mean estimates of B_{2006} were greater than B_{MSY} under both stock scenarios and subareas and the associated probabilities of B_{2006} exceeding B_{MSY} were 1 except for Sub-Area 1 where that probability was 0.93. Similarly, mean estimates of exploitation rate in 2006 were below H_{MSY} for both stock scenarios and subareas and the corresponding probabilities that H_{2006} exceeded H_{MSY} were no greater than 0.01. This indicated that the choice of stock scenario had no practical impact on the status of the North Pacific swordfish population with respect to MSY-based reference points.

Results: Estimates of Exploitable Biomass and Exploitation Rate

Under the single-stock scenario, exploitable biomass fluctuated above B_{MSY} during the 1950s to 2000s (Table 4.3.1, Figure 4.4.1). Biomass increased in the late-1980s, subsequently declined in the late-1990s, and then increased in the 2000s. Exploitation rates were below H_{MSY} in the early-1950s, increased to a peak of about 33% around 1960 and subsequently declined to roughly 50%

of H_{MSY} during 1965-1990 (Figure 4.4.1). Exploitation rates increased in the early-1990s to fluctuate around 70% of H_{MSY} and subsequently declined in the early-2000s to roughly 50% of H_{MSY}. Under the single-stock scenario, exploitable biomass remained above B_{MSY} and exploitation rates remained below H_{MSY} throughout the assessment time horizon.

Exploitable biomass of the swordfish stock in Sub-Area 1 under the two-stock scenario also fluctuated above B_{MSY} for most of the assessment time horizon (Table 4.3.2, Figure 4.4.2). Biomass increased during the 1980s and has since declined to roughly 25% above B_{MSY}. Exploitation rates in Sub-Area 1 increased from low values in the 1950s to a peak of about 33% around 1960 and then declined to fluctuate about 50% of H_{MSY} from the mid-1960s to the late-1980s. Exploitation rates increased to fluctuate below H_{MSY} during the 1990s and then declined in the 2000s to about 67% of H_{MSY}. Overall, exploitable biomass in Sub-Area 1 remained at or above B_{MSY} while exploitation rates remained at or below H_{MSY} throughout the assessment time horizon.

Exploitable biomass in Sub-Area 2 under the two-stock scenario fluctuated at or above B_{MSY} throughout the assessment time horizon (Table 4.3.3, Figure 4.4.3). Biomass increased to a peak around 2000 and has since declined in the 2000s, albeit to 2-fold higher than B_{MSY}. Exploitation rates in Sub-Area 2 remained at or below H_{MSY} throughout the assessment time horizon (Figure 4.4.3). Overall, the stock in Sub-Area 2 does not appear to have been depleted or experienced overfishing under this model scenario.

Results: Two-Stock Scenario Projections at Recent Average Fishing Mortality

Stochastic projections were conducted to characterize the potential distributions of exploitable and catch biomass of swordfish for Sub-Areas 1 and 2 during 2007-2010. These projections assumed status quo fishing effort by subarea. The stochastic harvest rates were random iid samples from a normal distribution with mean equal to the 2004-2006 three-year average harvest rate and variance equal to the empirical variability in harvest rate by Sub-Area. The initial conditions for the projections were set by the estimated posterior distribution of exploitable swordfish biomass by Sub-Area in 2006.

In Sub-Area 1, swordfish exploitable biomass was projected to fluctuate around 77 kt during 2007-2010 if fishing effort remained stable (Figure 4.5.1). The mean projected catch biomass in 2007 was 12.2 kt with a 95% CI of 7.2 to 19.3 kt. In comparison, the projected catch in 2010 averaged 12.2 kt with a 95% CI of 8.6 to 17.1 kt. Overall, the projections indicated that exploitable biomass and catch of swordfish in Sub-Area 1 were likely sustainable if current levels of fishing effort were maintained during 2007-2010.

Projections for Sub-Area 2 indicated that swordfish exploitable biomass would likely decline from 57 kt in 2007 to 51 kt in 2010 as the stock was fished down to slightly below its carrying capacity by 2010. The mean projected catch biomass of swordfish in subarea 1 in 2007 was 2.3 kt with a 95% CI of 1.0 to 4.6 kt. In comparison, the mean projected in 2010 was 2.0 kt with a 95% CI of 0.9 to 3.8 kt. Overall, the projections indicated that there would likely be a moderate decline in swordfish exploitable biomass and catch biomass in subarea 2 if current levels of fishing effort were maintained during 2007-2010. This decline was the result of high stock biomass in excess of carrying capacity in Sub-Area 2 and the application of a relatively low annual harvest rate of 4% or roughly $0.3*F_{MSY}$.

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Table 4.1. Root mean-squared errors of model fits to CPUE time series under the single-stock and two-stock scenarios.

Stock Scenario	Japanese Longline	Taiwanese Longline	Hawaii Longline Shallow-Set 1	Hawaii Longline Shallow-Set 2
Single-Stock Scenario	0.153	0.291	0.219	0.225
Two-Stock Scenario Subarea 1	0.151	0.318	0.280	0.236
Two-Stock Scenario Subarea 2	0.228	0.295	-	-

Table 4.2. Mean estimates of intrinsic growth rate (R), carrying capacity (K), production model shape parameter (M), 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} under the single-stock and two-stock scenarios.

Stock Scenario	Mean R	Mean K	Mean M	Mean B_{MSY}	Mean H_{MSY}	Mean MSY	Mean B_{2006}	$Pr(B_{2006}>B_{MSY})$	Mean H_{2006}	$Pr(H_{2006}>H_{MSY})$
Single-Stock Scenario	0.68	113.6	1.25	58.4	0.34	19.1	97.9	1.00	0.13	0.00
Two-Stock Scenario Subarea 1	0.58	115.9	1.02	57.3	0.26	14.4	74.9	0.93	0.14	0.00
Two-Stock Scenario Subarea 2	0.40	54.6	0.66	24.8	0.13	3.1	59.7	1.00	0.03	0.01

Table 4.3.1. Estimates of mean exploitable biomass (kt) and mean exploitation rate of North Pacific swordfish under the single-stock scenario during 1951-2006.

	Exploitable Biomass			Exploitation Rate		
Year	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
1951	97.9	57.4	156.0	0.13	0.07	0.20
1952	84.5	48.7	136.6	0.15	0.09	0.24
1953	79.0	45.7	128.3	0.17	0.10	0.27
1954	82.8	48.1	134.5	0.18	0.10	0.28
1955	78.6	45.3	128.5	0.19	0.11	0.31
1956	74.1	42.9	120.6	0.22	0.13	0.36
1957	75.9	44.0	123.5	0.22	0.12	0.35
1958	79.6	46.6	128.8	0.27	0.15	0.42
1959	73.2	42.1	119.6	0.28	0.16	0.45
1960	74.7	43.3	121.9	0.32	0.18	0.51
1961	72.8	41.2	120.8	0.32	0.18	0.52
1962	71.0	38.6	119.2	0.19	0.11	0.33
1963	77.0	43.2	127.8	0.16	0.09	0.27
1964	78.8	44.8	129.2	0.13	0.07	0.21
1965	81.5	47.1	132.8	0.15	0.09	0.24
1966	81.0	46.8	131.4	0.16	0.09	0.26
1967	76.6	44.0	124.6	0.18	0.10	0.29
1968	74.7	42.5	121.4	0.18	0.10	0.29
1969	77.5	44.6	126.7	0.17	0.10	0.27
1970	81.8	47.1	133.2	0.15	0.08	0.24
1971	82.8	47.5	134.7	0.12	0.07	0.19
1972	85.2	49.4	138.5	0.11	0.06	0.18
1973	90.4	52.9	145.7	0.12	0.07	0.19
1974	90.0	52.4	145.0	0.11	0.07	0.18
1975	85.5	49.5	138.0	0.15	0.09	0.25
1976	85.2	49.4	138.0	0.17	0.10	0.28
1977	81.5	46.7	132.7	0.17	0.10	0.28
1978	76.9	44.0	125.8	0.20	0.11	0.32
1979	75.1	42.6	123.2	0.17	0.10	0.28
1980	78.9	44.9	129.1	0.15	0.08	0.24
1981	78.1	44.9	126.9	0.18	0.10	0.29
1982	78.1	44.7	127.7	0.16	0.09	0.27
1983	86.5	49.8	140.3	0.16	0.09	0.26
1984	87.7	50.4	143.3	0.17	0.09	0.27
1985	97.9	56.0	160.0	0.18	0.10	0.29
1986	101.8	57.2	168.1	0.16	0.09	0.26
1987	107.3	60.0	177.3	0.16	0.09	0.26
1988	100.0	56.0	165.9	0.15	0.08	0.25
1989	96.0	54.3	158.1	0.15	0.08	0.25
1990	97.1	55.3	159.1	0.17	0.10	0.28
1991	89.3	50.8	146.5	0.17	0.10	0.28
1992	89.5	51.8	146.0	0.24	0.14	0.38
1993	82.1	46.4	134.9	0.27	0.15	0.44
1994	72.1	40.2	119.7	0.24	0.14	0.41
1995	66.4	37.7	108.8	0.24	0.13	0.39
1996	69.0	39.4	113.0	0.22	0.12	0.35
1997	68.3	39.5	110.8	0.27	0.15	0.43
1998	68.4	39.5	111.0	0.28	0.16	0.46
1999	76.7	43.9	125.8	0.22	0.12	0.36
2000	96.8	55.3	158.2	0.21	0.12	0.34
2001	109.9	60.9	182.4	0.15	0.08	0.25
2002	102.8	58.0	169.2	0.15	0.09	0.25
2003	92.6	52.9	151.6	0.17	0.10	0.27
2004	89.9	51.7	146.6	0.16	0.09	0.25
2005	88.5	51.1	143.8	0.16	0.09	0.25
2006	98.0	56.7	159.1	0.13	0.07	0.21

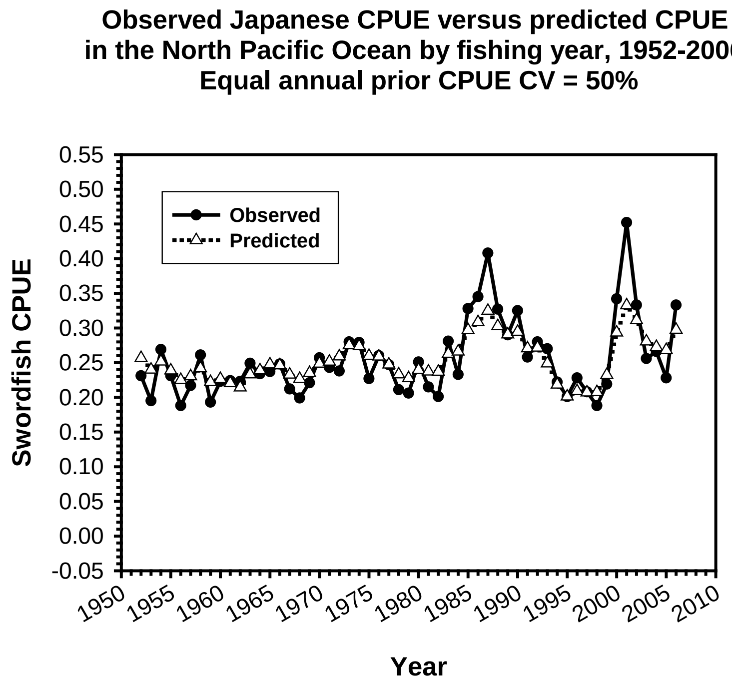
Table 4.3.2. Estimates of mean exploitable biomass (kt) and mean exploitation rate of North Pacific swordfish in Sub-Area 1 under the two-stock scenario during 1951-2006.

	Exploitable Biomass			Exploitation Rate		
Year	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
1951	96.3	58.9	149.3	0.13	0.08	0.20
1952	80.6	48.2	127.7	0.15	0.09	0.24
1953	74.2	44.1	118.3	0.18	0.10	0.28
1954	76.9	46.1	122.6	0.19	0.11	0.30
1955	74.2	44.5	119.1	0.20	0.12	0.32
1956	70.3	42.2	112.2	0.23	0.14	0.37
1957	71.3	42.9	113.5	0.23	0.13	0.35
1958	77.5	47.4	122.9	0.27	0.16	0.42
1959	72.6	44.0	115.8	0.27	0.16	0.43
1960	72.9	44.4	115.7	0.32	0.19	0.49
1961	69.1	40.9	111.7	0.33	0.19	0.52
1962	64.8	36.6	107.7	0.20	0.11	0.33
1963	69.2	39.7	113.5	0.16	0.09	0.26
1964	70.8	41.1	115.3	0.12	0.07	0.19
1965	75.6	44.9	121.2	0.15	0.09	0.23
1966	74.1	44.0	119.2	0.16	0.09	0.25
1967	68.5	40.4	110.0	0.18	0.11	0.29
1968	64.2	37.7	103.5	0.19	0.11	0.30
1969	64.1	37.4	103.5	0.15	0.08	0.23
1970	67.0	39.3	107.3	0.14	0.08	0.22
1971	68.4	40.3	109.8	0.12	0.07	0.19
1972	70.3	41.6	113.2	0.11	0.06	0.17
1973	76.2	45.4	121.7	0.10	0.06	0.16
1974	81.3	48.7	129.0	0.11	0.06	0.17
1975	81.1	48.6	129.1	0.14	0.08	0.22
1976	81.0	48.3	129.6	0.16	0.09	0.24
1977	75.7	44.6	121.5	0.16	0.09	0.25
1978	73.1	43.2	117.1	0.18	0.11	0.28
1979	75.0	44.0	120.6	0.15	0.09	0.24
1980	81.1	47.8	130.3	0.12	0.07	0.19
1981	83.1	49.4	133.4	0.13	0.07	0.20
1982	85.6	50.9	137.6	0.12	0.07	0.18
1983	96.4	57.4	154.4	0.13	0.07	0.20
1984	99.4	58.7	159.8	0.14	0.08	0.22
1985	109.4	64.1	177.2	0.15	0.08	0.23
1986	109.7	63.3	178.9	0.13	0.07	0.20
1987	113.4	66.1	185.2	0.12	0.07	0.20
1988	109.1	63.6	178.2	0.11	0.06	0.18
1989	101.0	59.1	163.9	0.12	0.07	0.18
1990	101.9	60.2	164.5	0.12	0.07	0.18
1991	97.4	57.8	156.6	0.13	0.07	0.20
1992	96.9	57.9	155.4	0.18	0.10	0.28
1993	88.4	52.2	142.8	0.21	0.12	0.33
1994	73.3	42.5	119.3	0.20	0.12	0.32
1995	61.9	36.3	100.5	0.22	0.12	0.34
1996	58.3	34.5	93.9	0.22	0.13	0.34
1997	53.5	32.0	86.0	0.25	0.15	0.39
1998	53.3	31.7	85.4	0.25	0.14	0.39
1999	59.4	35.5	94.9	0.24	0.14	0.37
2000	67.1	40.3	106.8	0.23	0.13	0.36
2001	72.1	42.5	116.3	0.15	0.09	0.25
2002	72.6	43.2	116.4	0.15	0.09	0.24
2003	68.1	40.5	108.6	0.17	0.10	0.26
2004	68.0	40.7	108.5	0.16	0.10	0.26
2005	70.0	42.0	111.3	0.17	0.10	0.26
2006	74.9	44.8	119.5	0.14	0.08	0.22

Table 4.3.3. Estimates of mean exploitable biomass (kt) and mean exploitation rate of North Pacific swordfish in Sub-Area 2 under the two-stock scenario during 1951-2006.

	Exploitable Biomass			Exploitation Rate		
Year	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
1951	43.0	20.9	78.1	0.00	0.00	0.00
1952	38.1	16.8	74.0	0.00	0.00	0.00
1953	32.3	12.7	65.6	0.00	0.00	0.00
1954	26.7	9.7	53.4	0.00	0.00	0.00
1955	21.6	8.9	41.8	0.00	0.00	0.00
1956	20.8	8.8	40.1	0.00	0.00	0.00
1957	29.2	13.5	54.1	0.00	0.00	0.01
1958	27.1	12.4	50.7	0.00	0.00	0.01
1959	24.0	10.6	46.0	0.00	0.00	0.01
1960	27.3	12.2	51.8	0.00	0.00	0.01
1961	35.7	16.5	66.0	0.01	0.01	0.03
1962	43.0	20.1	79.2	0.02	0.01	0.04
1963	48.4	22.8	89.2	0.03	0.01	0.06
1964	49.4	23.0	91.2	0.03	0.02	0.06
1965	47.7	21.8	89.1	0.02	0.01	0.04
1966	49.5	22.8	91.9	0.03	0.01	0.05
1967	49.8	22.7	92.9	0.02	0.01	0.04
1968	53.0	24.6	98.4	0.03	0.01	0.05
1969	59.3	27.8	109.1	0.07	0.03	0.13
1970	61.2	28.3	113.9	0.04	0.02	0.08
1971	55.1	25.1	102.9	0.03	0.01	0.05
1972	53.7	24.3	100.3	0.03	0.01	0.06
1973	56.9	26.3	105.5	0.05	0.02	0.09
1974	57.1	26.2	106.2	0.03	0.01	0.05
1975	56.6	26.1	105.3	0.03	0.01	0.06
1976	55.2	25.6	102.4	0.04	0.02	0.07
1977	54.9	25.5	101.4	0.04	0.02	0.09
1978	49.3	22.7	92.2	0.04	0.02	0.08
1979	45.5	20.8	84.9	0.04	0.02	0.07
1980	43.5	20.0	81.0	0.05	0.02	0.10
1981	39.3	18.0	73.4	0.09	0.04	0.17
1982	35.4	16.0	66.7	0.08	0.04	0.16
1983	33.3	14.8	62.8	0.05	0.02	0.10
1984	28.2	12.3	54.3	0.04	0.02	0.07
1985	30.6	13.7	58.2	0.04	0.02	0.07
1986	36.3	16.8	67.4	0.06	0.03	0.11
1987	40.0	18.7	74.1	0.07	0.03	0.13
1988	37.4	17.3	69.8	0.08	0.04	0.14
1989	37.1	17.2	68.9	0.07	0.03	0.14
1990	38.3	18.1	70.6	0.14	0.07	0.26
1991	34.8	15.8	65.5	0.09	0.04	0.17
1992	35.0	16.2	65.5	0.12	0.06	0.23
1993	34.8	15.9	65.3	0.10	0.04	0.18
1994	34.2	15.6	64.3	0.09	0.04	0.16
1995	36.3	16.7	67.4	0.07	0.03	0.13
1996	44.3	20.8	81.5	0.06	0.03	0.11
1997	52.8	25.6	95.5	0.10	0.05	0.18
1998	52.5	24.9	96.5	0.13	0.06	0.24
1999	50.0	22.6	93.8	0.06	0.03	0.11
2000	62.3	29.3	114.0	0.08	0.04	0.14
2001	71.9	33.8	131.8	0.08	0.04	0.14
2002	68.8	31.5	127.3	0.07	0.03	0.14
2003	65.2	30.0	120.5	0.07	0.03	0.12
2004	60.8	28.1	113.3	0.05	0.02	0.09
2005	56.1	25.7	105.2	0.04	0.02	0.08
2006	59.7	27.7	111.1	0.03	0.02	0.06

Figure 4.1.1. Time series of observed and predicted Japanese longline CPUE of swordfish along with standardized log-scale residuals of the model fit under the single-stock scenario during 1952-2006.



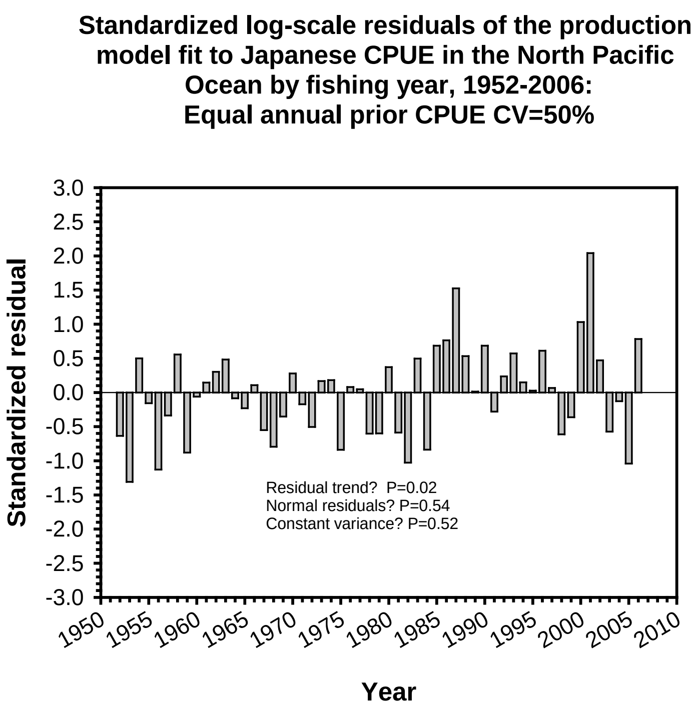
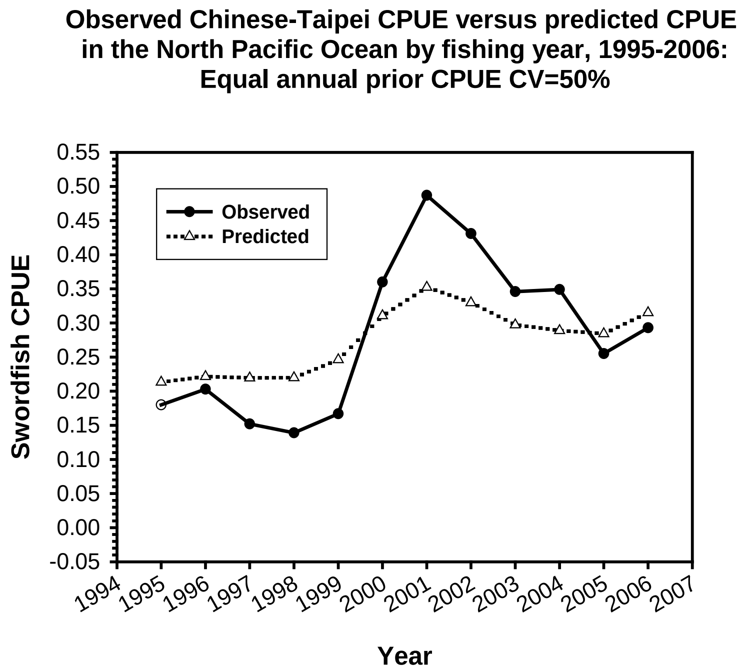


Figure 4.1.2. Time series of observed and predicted Taiwanese longline CPUE of swordfish along with standardized log-scale residuals of the model fit under the single-stock scenario during 1995-2006.



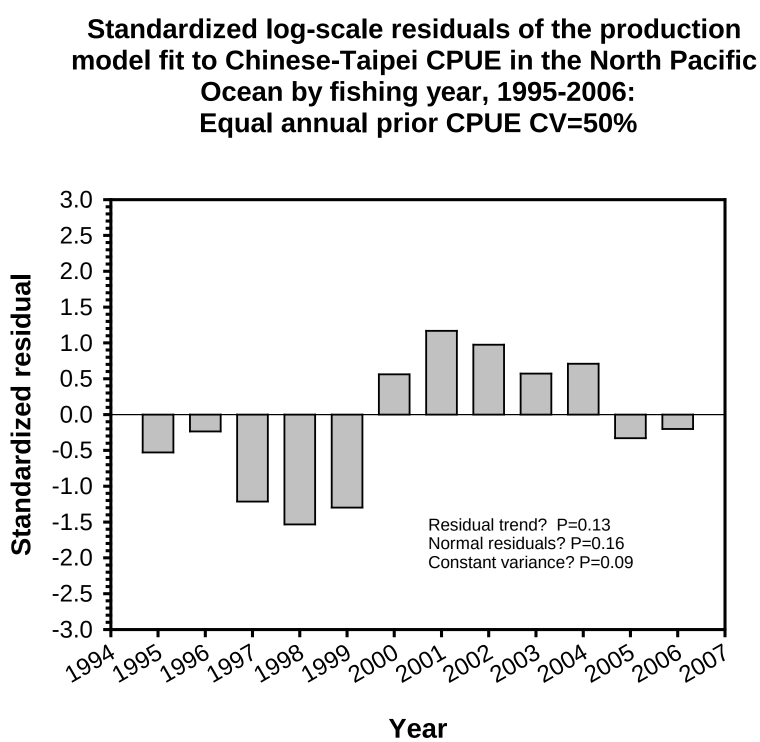
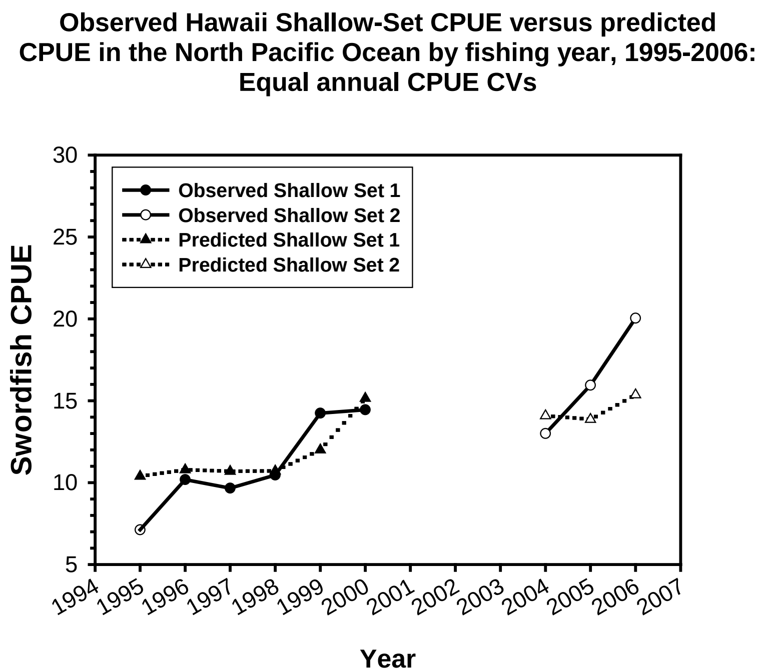


Figure 4.1.3. Time series of observed and predicted Hawaii shallow-set longline CPUE of swordfish along with standardized log-scale residuals of the model fit under the single-stock scenario during 1995-2000 and 2004-2006.



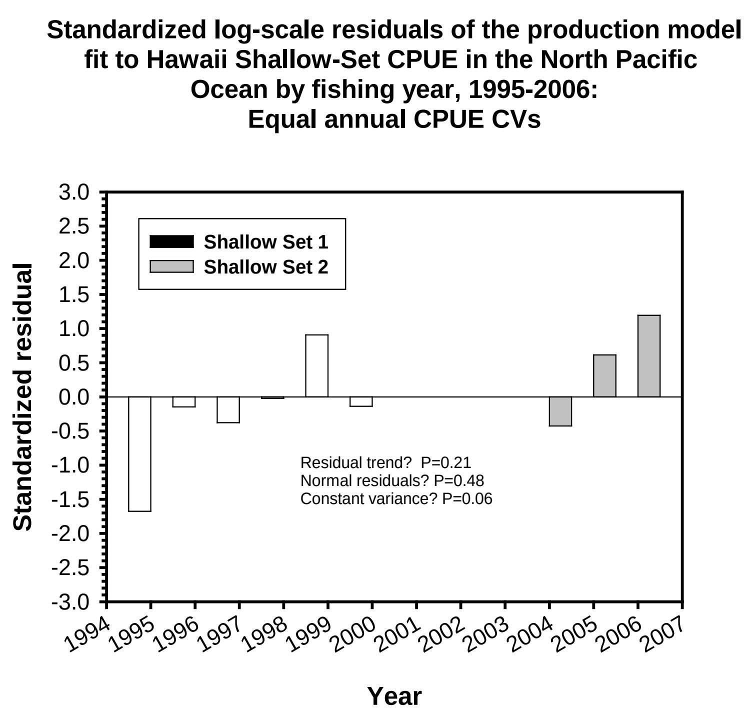
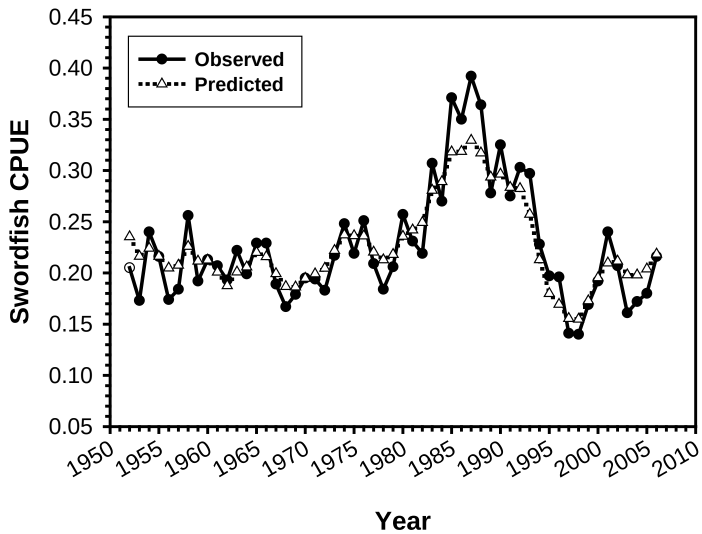


Figure 4.2.1. Time series of observed and predicted Japanese longline CPUE of swordfish in Sub-Area 1 along with standardized log-scale residuals of the model fit under the two-stock scenario during 1952-2006.

Observed Japanese CPUE versus predicted CPUE in the North Pacific Sub-Area 1 by fishing year, 1952-2006



Standardized log-scale residuals of the production model fit to Japanese CPUE in the North Pacific Sub-Area 1 by fishing year, 1952-2006

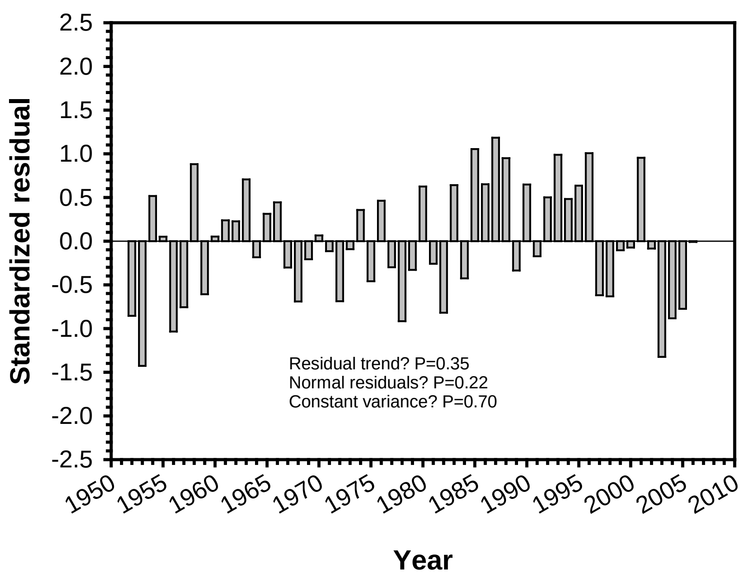
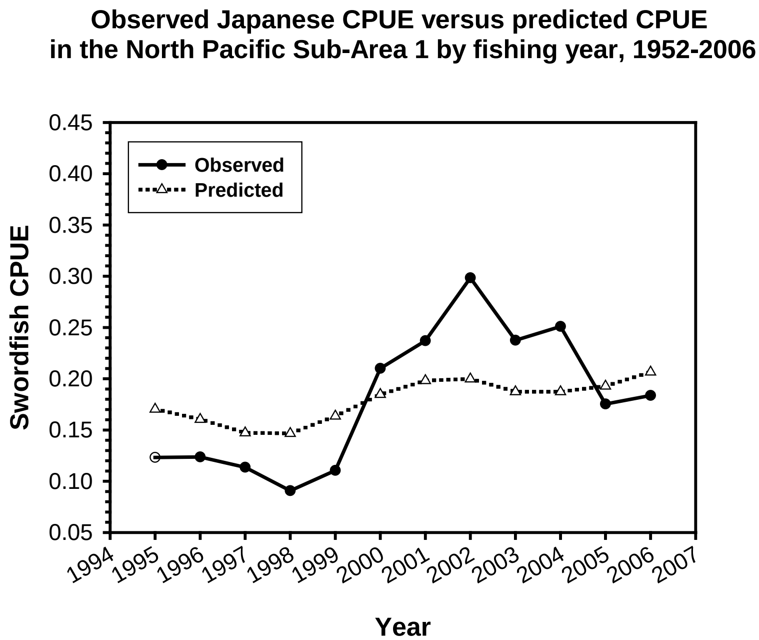


Figure 4.2.2. Time series of observed and predicted Taiwanese longline CPUE of swordfish in Sub-Area 1 along with standardized log-scale residuals of the model fit under the two-stock scenario during 1995-2006.



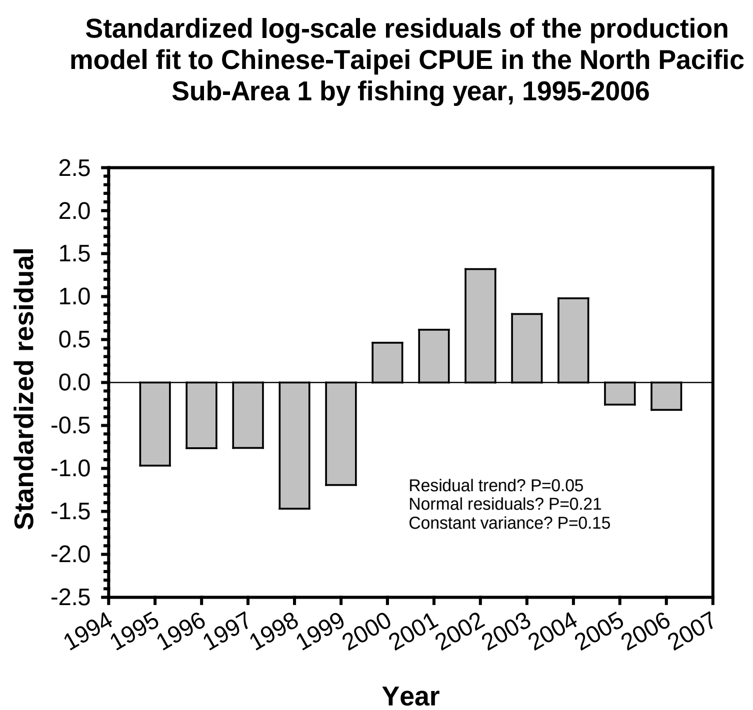
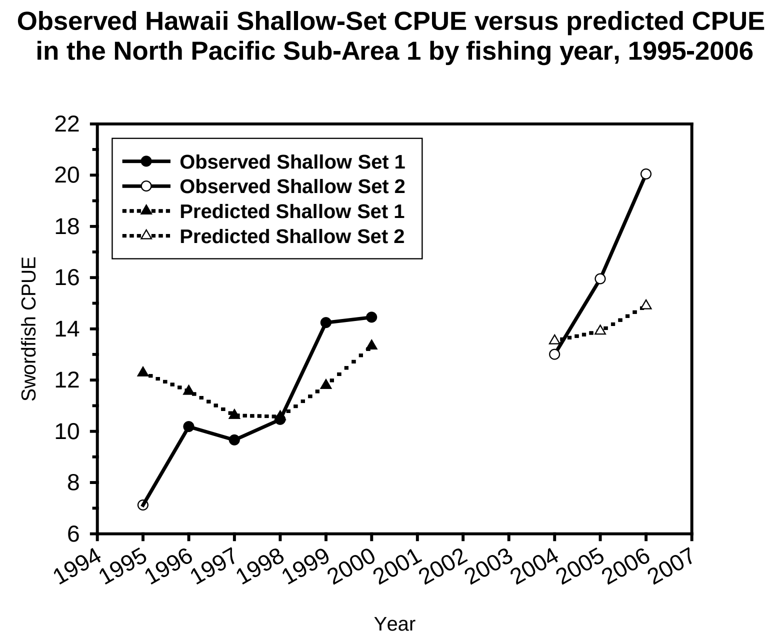


Figure 4.2.3. Time series of observed and predicted Hawaii shallow-set longline CPUE of swordfish in Sub-Area 1 along with standardized log-scale residuals of the model fit under the two-stock scenario during 1995-2000 and 2004-2006.



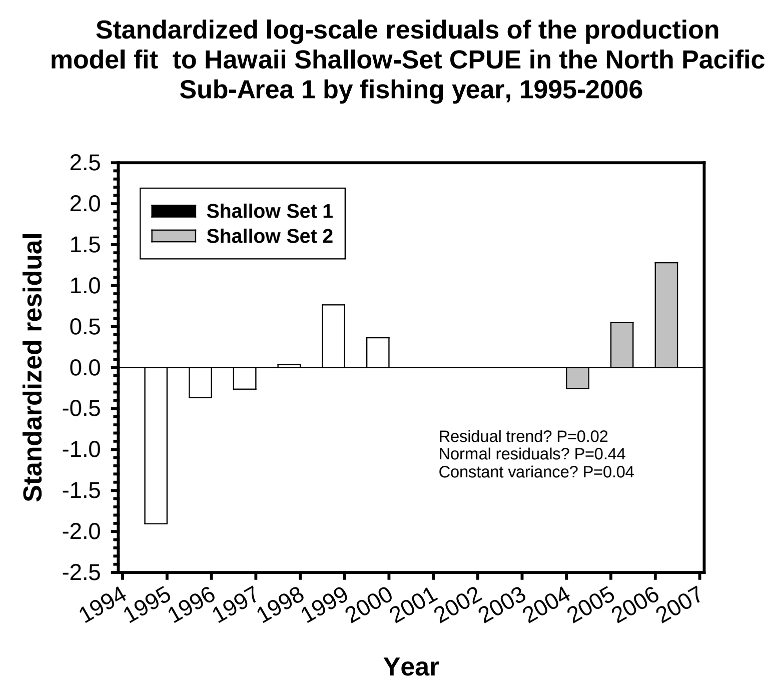
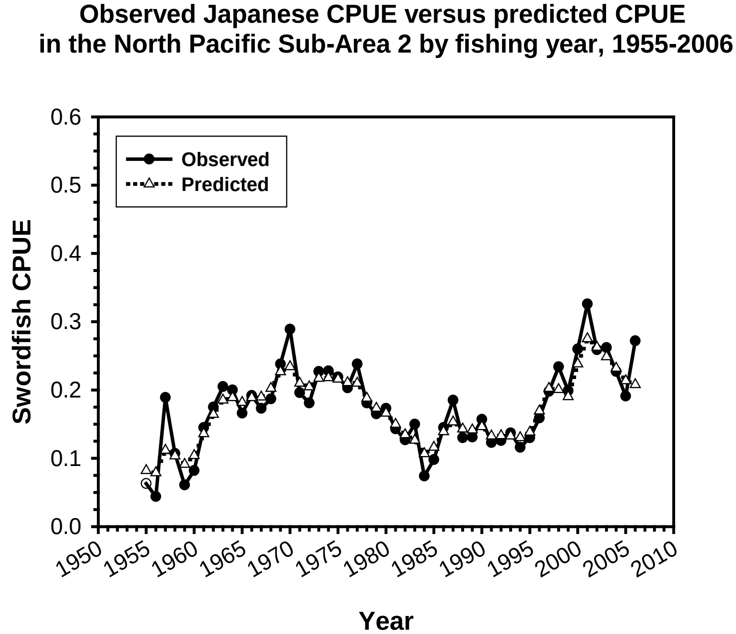


Figure 4.3.1. Time series of observed and predicted Japanese longline CPUE of swordfish in Sub-Area 2 along with standardized log-scale residuals of the model fit under the two-stock scenario during 1955-2006.



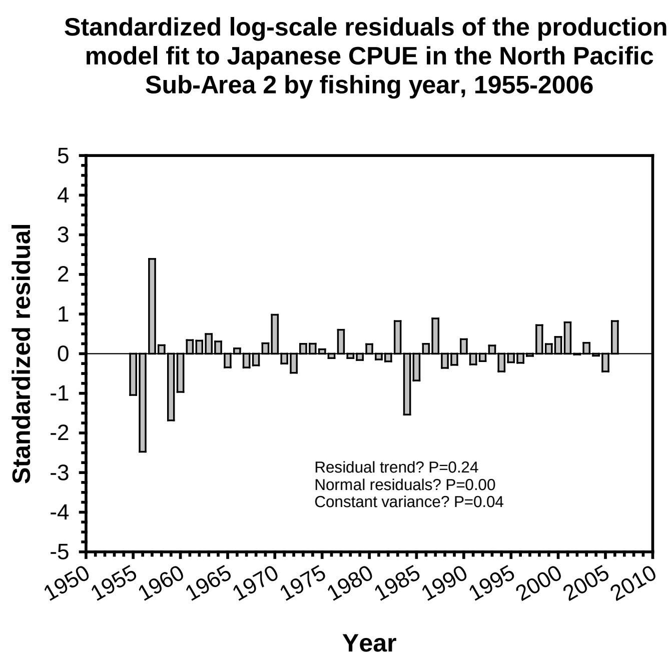
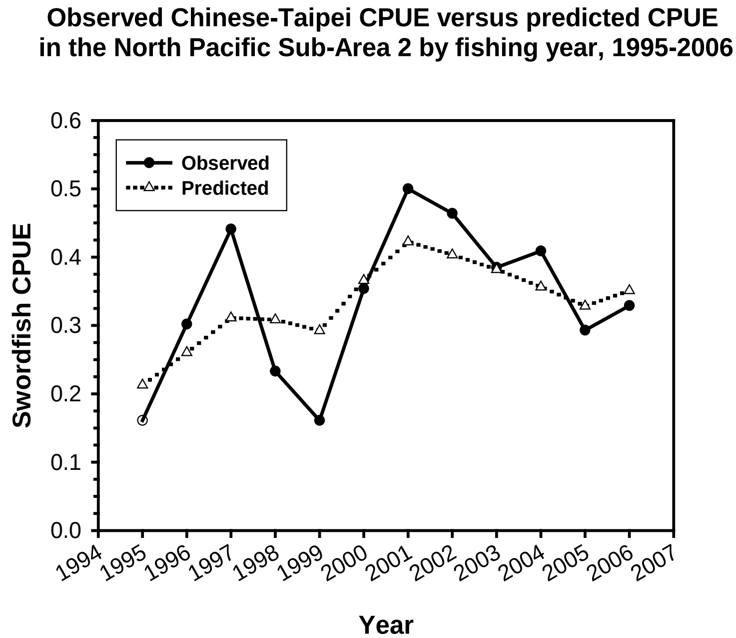


Figure 4.3.2. Time series of observed and predicted Taiwanese longline CPUE of swordfish in Sub-Area 2 along with standardized log-scale residuals of the model fit under the two-stock scenario during 1995-2006.



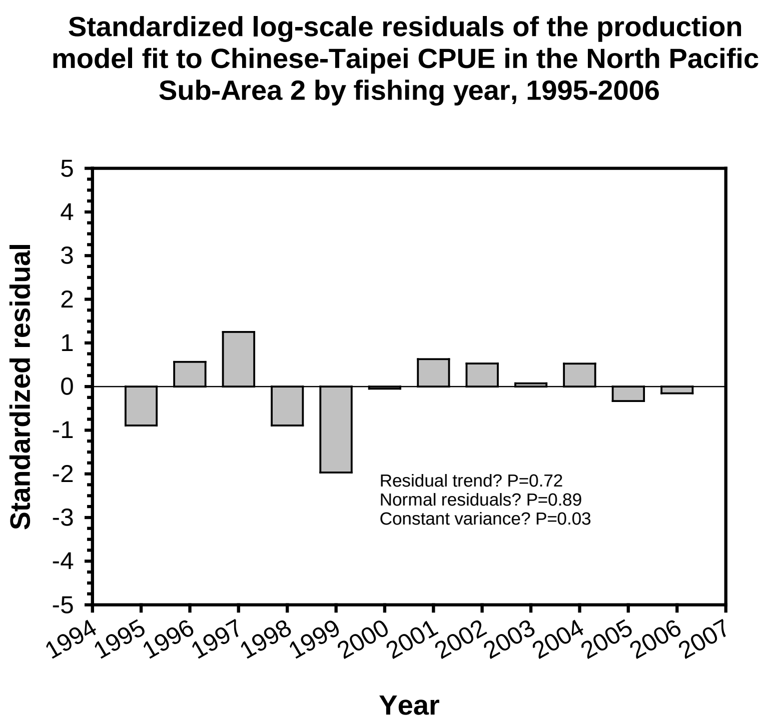
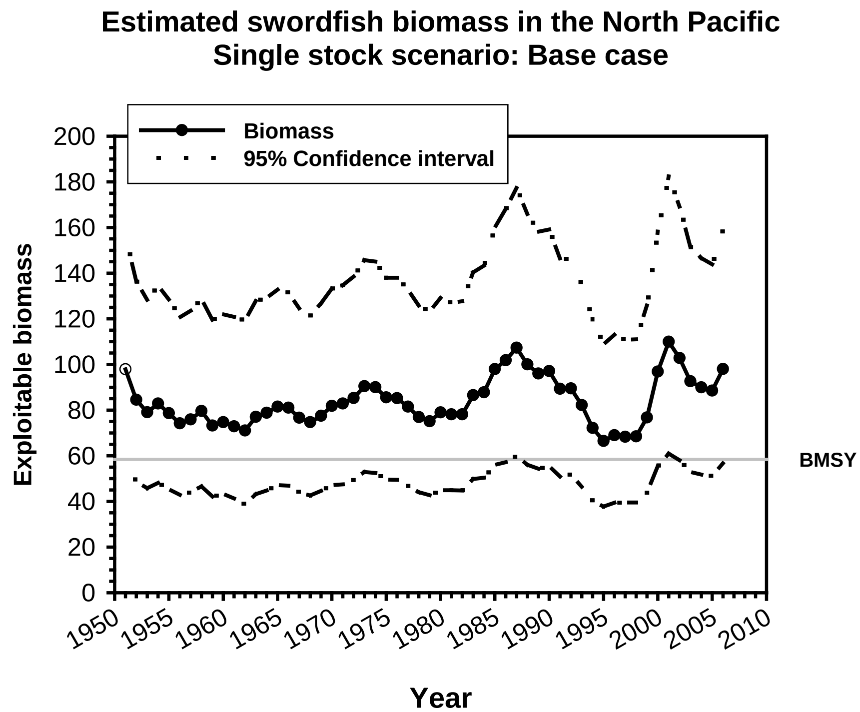


Figure 4.4.1. Trends in exploitable biomass and exploitation rate of North Pacific swordfish under the single-stock scenario, 1951-2006.



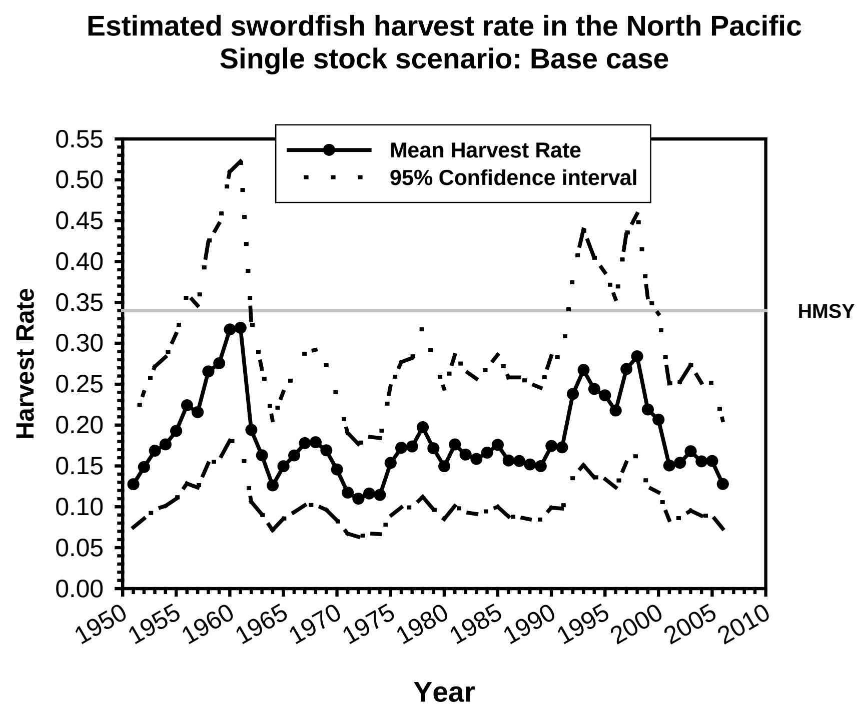
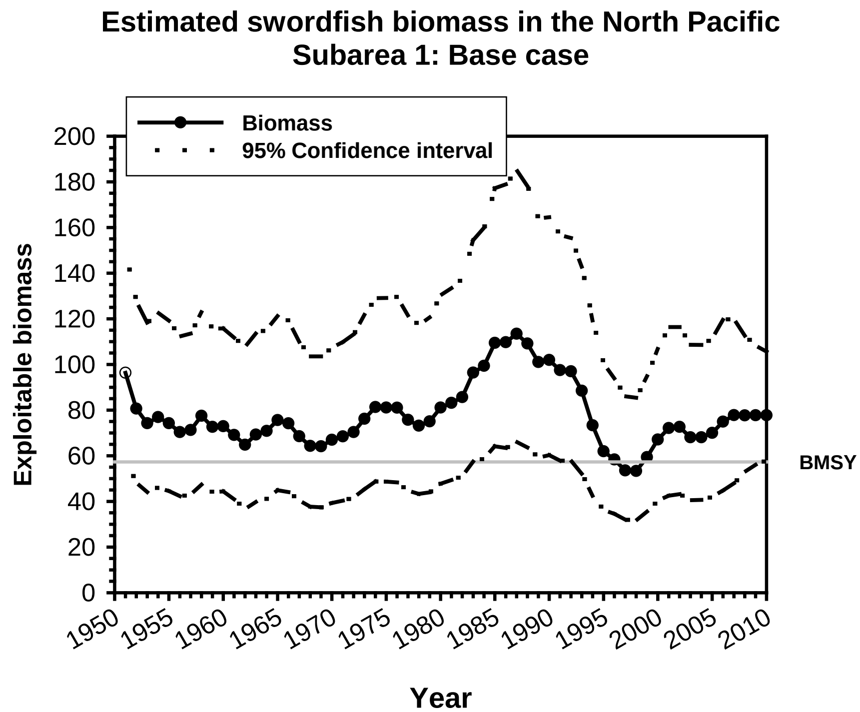


Figure 4.4.2. Trends in exploitable biomass and exploitation rate of North Pacific swordfish in Sub-Area 1 under the two-stock scenario, 1951-2006.



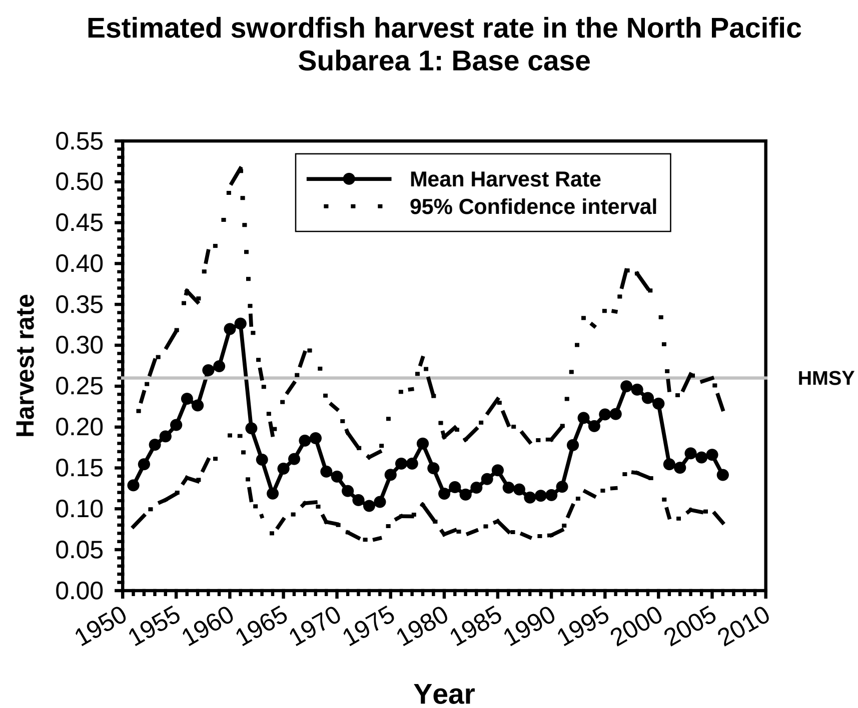
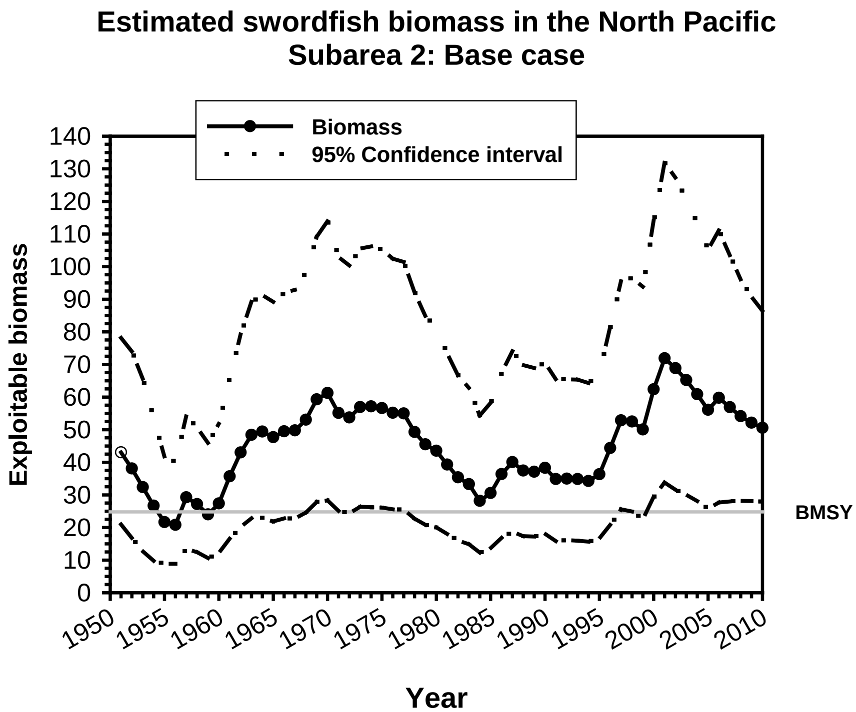


Figure 4.4.3. Trends in exploitable biomass and exploitation rate of North Pacific swordfish in Sub-Area 2 under the two-stock scenario, 1951-2006.



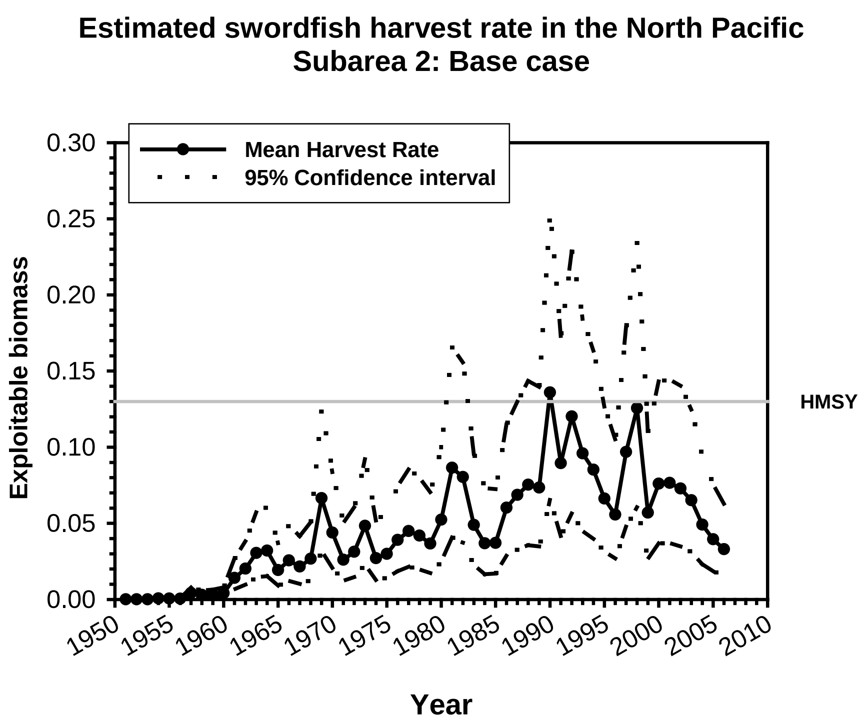


Figure 4.5.1. Stochastic projections of swordfish exploitable biomass and catch biomass in Sub-Area 1 during 2007-2010 assuming fishing effort has an iid stationary distribution.

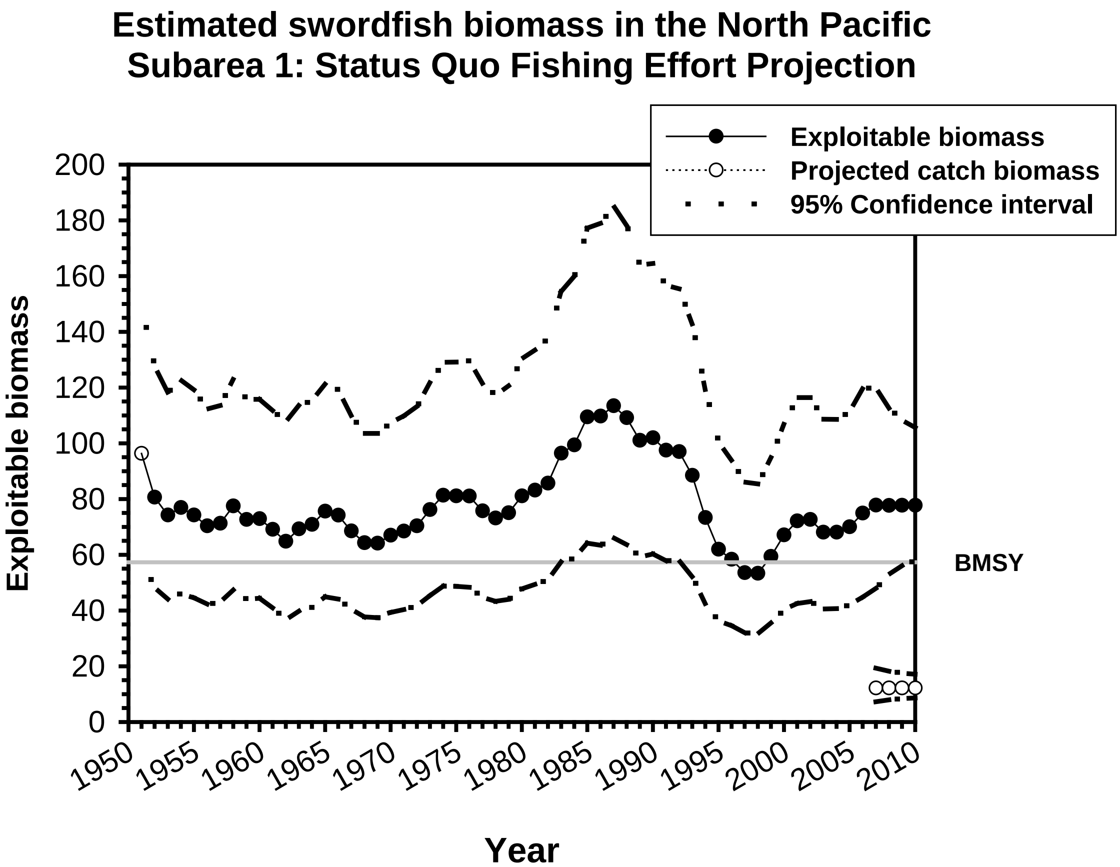
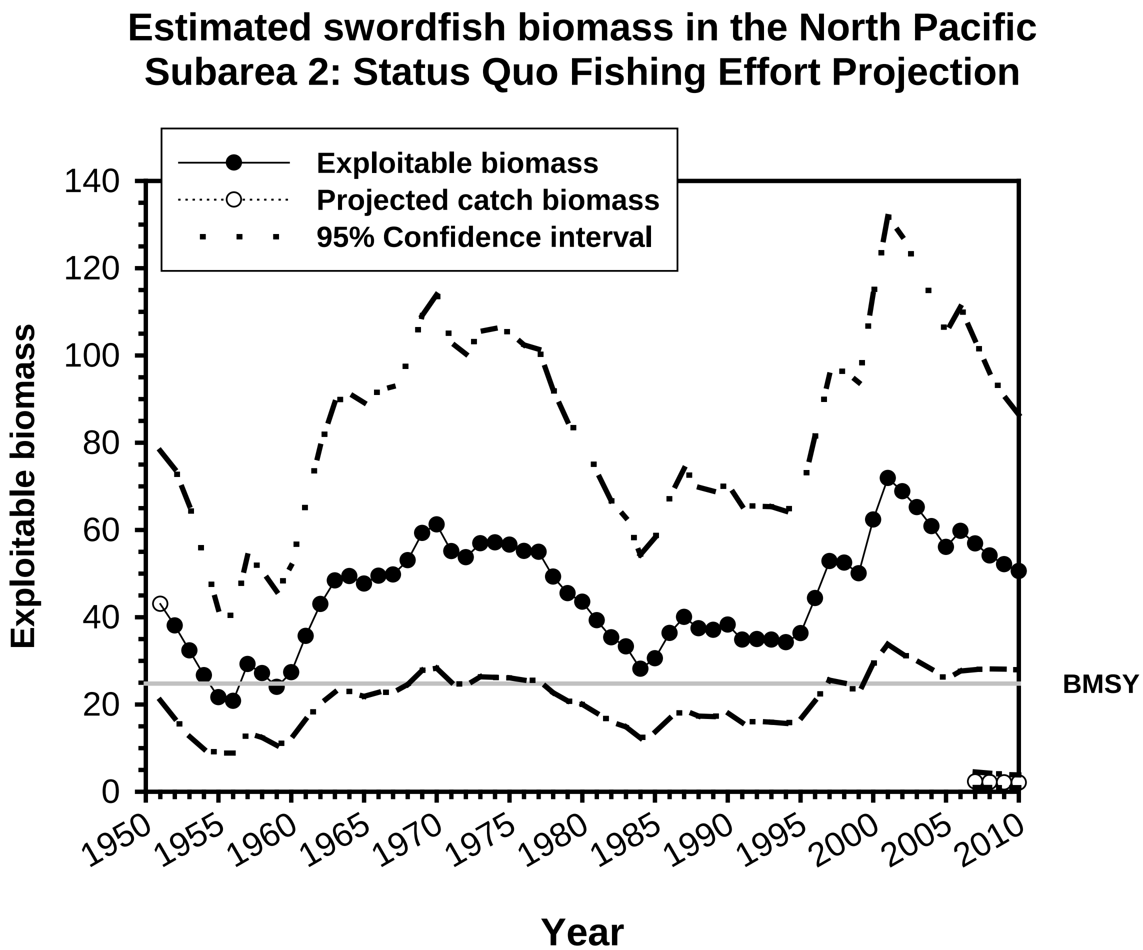


Figure 4.5.2. Stochastic projections of swordfish exploitable biomass and catch biomass in Sub-Area 2 during 2007-2010 assuming fishing effort has an iid stationary distribution.



Appendix 5

SS3 Sensitivity Analysis

Preliminary Stock Synthesis 3 (SS3) model sensitivity runs were presented for a North Pacific swordfish stock assessment under a single-stock scenario. Changes were made to the SS3 model as a result of BILLWG review (Table 5.1). The resulting input data was regionally stratified, included thirty three time series of catch (F1 – F33), three time series of CPUE (S1, S8, S15), and ten time series of length (F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30) (Table 5.2, Figure 5.2). SS3 model parameterization was modified as a result of BILLWG review (Table II.3).

Results of SS3 model changes are presented here as an additional sensitivity analysis. Parameter estimates are provided for virgin spawning biomass (S_0 Virgin mt), spawning biomass under estimated equilibrium initial fishing mortality (S_0 Init_F_F1 mt), ending spawning biomass (S_2006), the ratio of ending to virgin spawning biomass (S_2006/S_0 Virgin), estimated equilibrium initial fishing mortality Init_F_F1 (Table II.4, Panel A.). Individual likelihood component fits to CPUE data are provided (Total, S1, S8, and S15) (Table II.4, Panel B.). Individual likelihood component fits to length data are provided (Total, F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30) (Table 5.4, Panel C.).

Analysis of the regionally stratified SS3 model for north Pacific swordfish is ongoing and will be presented separately for review at a future BILLWG meeting. The regionally stratified model described in this appendix will serve as the new base case. Anticipated changes to the base case prior to the next BILLWG review include examination of model sensitivity to individual length data components, evaluation of a quarterly time step, the addition of time blocks, and application to the two stock scenarios.

Table 5.1. Changes made to the SS3 base case model as a result of BILLWG review.

- Single-sex (sex combined).

- Allow dome-shape selectivity for Japan offshore+distant water longline.

- Add regional stratification of catch and length (Figure 1).

- Iteratively re-weight Sigma_r and CPUE.

- Data Corrections:
  - Remove California gillnet CPUE and length.
  - Remove Hawaii longline deep-set CPUE and length.
  - Add Japan driftnet length Region 1 2004, 2005, 2006.
  - Add Japan harpoon length 2006 and 2007 combined into 2006.
  - Add 2004 and 2006 Hawaii shallow set CPUE and associated length.
  - Re-allocate Korea Catch to Regions 4 (10%), 5 (60%), 6(30%).

Table 5.2. The regionally stratified SS3 model included thirty three time series of catch (F1 – F33), three time series of CPUE (S1, S8, S15), and ten time series of length (F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30).

Code	Country	Fleet	Catch	Length	Selectivity	CPUE
F1	**Japan**	Offshore+Distant Water R1	y	y	Estimate-Dome	
F2	**Japan**	Offshore+Distant Water R2	y	y	Estimate-Dome	
F3	**Japan**	Offshore+Distant Water R3	y	y	Estimate-Dome	
F4	**Japan**	Offshore+Distant Water R4	y	y	Estimate-Dome	
F5	**Japan**	Offshore+Distant Water R5	y	y	Estimate-Dome	
F6	**Japan**	Offshore+Distant Water R6	y	y	Estimate-Dome	
F7	**Japan**	Japan Driftnet R1	y	y	Estimate-Dome	
F8	**Japan**	Japan Driftnet R2	y		F7	
F9	**Japan**	Japan Driftnet R3	y		F7	
F10	**Japan**	Japan Driftnet R4	y		F7	
F11	**Japan**	Japan Driftnet R5	y		F7	
F12	**Japan**	Japan other (Harpoon) R1	y	y	Estimate-Asymptotic	
F13	**Japan**	Japan All Other Gears R1	y		F1	
F14	**Japan**	Japan All Other Gears R2	y		F2	
F15	**Japan**	Japan All Other Gears R3	y		F3	
F16	**Japan**	Japan All Other Gears R4	y		F4	
F17	**Japan**	Japan All Other Gears R5	y		F5	
F18	**Japan**	Japan All Other Gears R6	y		F6	
F19	**Chinese Taipei**	Distant Water R1	y		F1	
F20	**Chinese Taipei**	Distant Water R2	y		F2	
F21	**Chinese Taipei**	Distant Water R3	y		F3	
F22	**Chinese Taipei**	Distant Water R4	y		F4	
F23	**Chinese Taipei**	Distant Water R5	y		F5	
F24	**Chinese Taipei**	Distant Water R6	y		F6	
F25	**Chinese Taipei**	All Other Gears	y		F4	
F26	**Korea**	Longline R4	y		F4	
F27	**Korea**	Longline R5	y		F5	
F28	**Korea**	Longline R6	y		F6	
F29	**US Hawaii**	Longline	y	y	Estimate-Dome	
F30	**US California**	Gillnet	y	y	Estimate-Dome	
F31	**US California**	Longline	y		F30	
F32	**US California**	Other Gear+Unknown	y		F30	
F33	**Mexico**	All Gears	y		F30	
S1	**Japan**	Offshore+Distant Water All Regions			Mirror F2	y
S8	**Chinese Taipei**	Distant Water All Regions			Mirror F6	y
S15	**US Hawaii**	Longline Shallow-Set			F29	y

Table 5.3. Changes made to SS3 base case model as a result of BILLWG review.

Model Component	Changes to Base Case
Nat. Mort. (M)	Linked to Life History (Central North Pacific)
Steepness (h)	0.9
sigma_r	0.4
Sexual Dimorphism	Sex-Combined
Effective Sample Size	Iteratively Re-weighted (Sigma_r and CPUE)
Initial Equilibrium Catch	Estimated (Japan Distant Water Longline R1)
Catch	Regionally Stratified Catch by Country and Fleet (F1 – F33)
CPUE	Single North Pacific Index for Each Country and Fleet (S1, S8, S15)
Length	Regionally Stratified Length by Country and Fleet (F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30)

Table 5.4. Additional SS3 model sensitivity analysis results.

A. Parameter estimates of virgin spawning biomass (S_0 Virgin mt), spawning biomass under estimated equilibrium initial fishing mortality (S_0 Init_F_F1 mt), ending spawning biomass (S_2006), the ratio of ending to virgin spawning biomass (S_2006/S_0 Virgin), estimated equilibrium initial fishing mortality Init_F_F1.

S_0 Virgin (mt)	s.e	S_0 Init_F_F1 (mt)	s.e	S_2006	s.e	S_2006/S_0(Virgin)	Init_F_F1	s.e	R_0 (Virgin)	s.e
87,199	4,416	67,672	4,338	43,400	5,091	49.77%	0.07	0.00	1,632	82.6

B. Individual likelihood component fits to CPUE data (Total, S1, S8, and S15).

Total	S1	S8	S15
-65.4	-56.7	-5.9	-2.8

C. Individual likelihood component fits to length data (Total, F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30).

Total	F1	F2	F3	F4	F5	F6	F7	F12	F29	F30
800.1	225.5	175.1	14.4	61.6	71.9	77.5	6.7	2.5	40.1	124.7

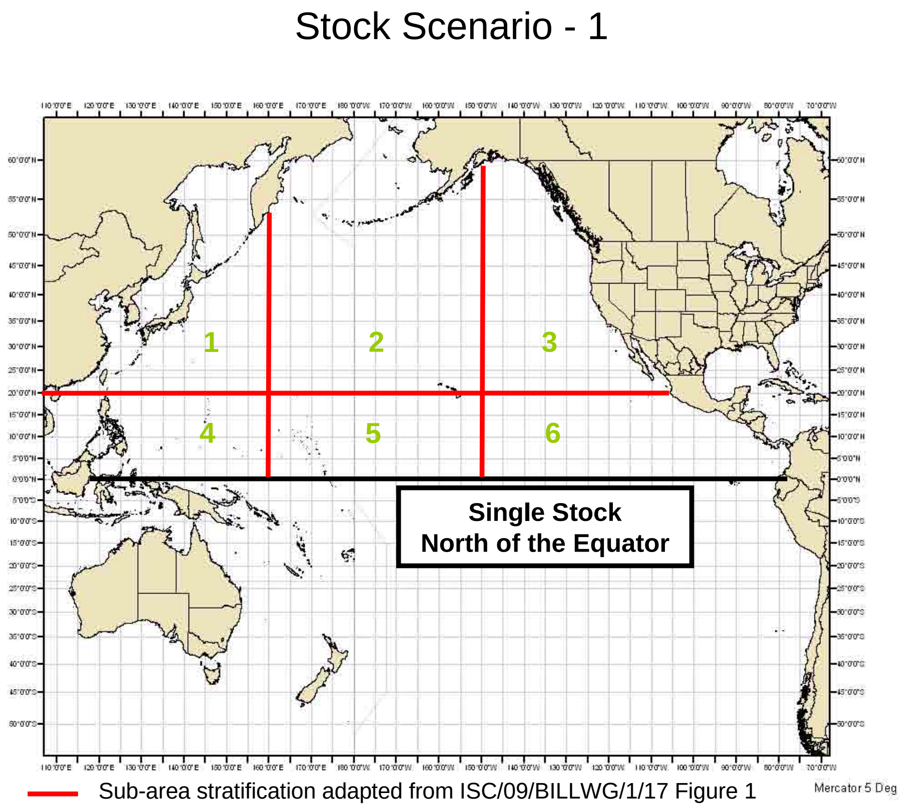


Figure 5.1. Regional stratification (6 regions) under Stock Scenario – 1 (adapted from Sun et al. 2009, Figure 1).