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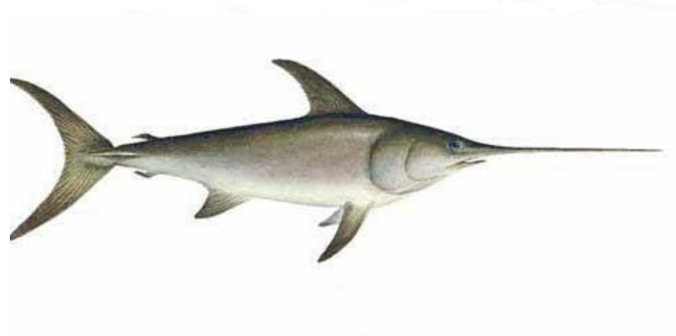
Age Structured Stock Assessment of North Pacific Swordfish (*Xiphias gladius*) with Stock Synthesis under a Single Stock Scenario

Dean Courtney
NOAA/NMFS PIFSC
2570 Dole St., Honolulu, HI 96822-2396

Kevin Piner
NOAA/NMFS PIFSC
2570 Dole St., Honolulu, HI 96822-2396



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Dean Courtney and Kevin Piner

NOAA Fisheries, Pacific Islands Fisheries Science Center,
2570 Dole St., Honolulu, HI 96822

Abstract

This report summarizes Stock Synthesis (SS) model runs for a North Pacific Swordfish (*Xiphias gladius*) stock assessment under a single stock scenario (one stock in the Pacific Ocean north of the equator). The base model (Model-1) followed recommendations from a preliminary review of the assessment model by the ISC BILLWG. Model-1 results were compared to those from a Bayesian production model fit to the same data. Sensitivity analyses runs were conducted to assess model fit to length composition data and to the independently estimated growth parameters form the Central North Pacific. Additional runs were conducted to test for global convergence. Model-1 appeared to adequately estimate selectivity for the major fisheries and to fit CPUE series well enough to scale the absolute abundance estimates. Model-1 appeared to adequately fit length compositions from the major fisheries. Model-1 estimated ending year 2006 spawning biomass above spawning biomass at maximum sustainable yield (MSY) and 2006 fishing mortality (F) below F at MSY. Model results from SS indicated slightly lower biomass and slightly higher harvest rates (often outside 95% Bayesian credible intervals) than a Bayesian production model run on the same data. SS deviated from BSP after 1983 coincident with a change in time-varying selectivity estimated for the Japan Offshore + Distant Water Longline fleet. Our results were consistent with previous age-structured assessments of North Pacific swordfish in that the available CPUE time series were relatively flat and uninformative and as a result, model estimates were highly sensitive to key parameters. Model-1 results from SS were sensitive to the weight given to length frequency data, to the parameterization of length based selectivity, and to the estimation of growth parameters within the model. Previous analyses indicated that model fits from SS were also sensitive to natural mortality, steepness of the stock recruit relationship, effective sample size of CPUE time series, and the sequential removal of CPUE time series. Our results differed from previous age-structured assessments of North Pacific swordfish in that the estimated ending year female spawning stock biomass from Model-1 was at a lower fraction of unfished spawning stock biomass than in previous assessments. Our intent at this stage of model development was to provide a bridge from a single stock scenario to a two stock scenario. Results from the two stock scenario are presented separately.

1. Introduction

This report summarizes Stock Synthesis (SS) model runs for a North Pacific Swordfish (*Xiphias gladius*) stock assessment under a single stock scenario (Figure 1). Model results were compared to those from a Bayesian production model fit to the same data (Brodziak and Ishimura 2009, BILL-WG 2009b). Sensitivity analyses runs were conducted to assess model fit to length composition data and to the independently estimated growth parameters. Additional runs were conducted to test for global convergence. Our intent at this stage of model development was to provide a bridge from a single stock scenario to a two stock scenario. Results from the two stock scenario are presented in a separate document (Courtney and Piner 2009b).

2. Methods

2.1 Stock Structure

The stock structure assumed for this assessment was a single stock north of the equator (Figure 1). Catch, CPUE, and length data were incorporated into the assessment model using a regional stratification modified from Sun et al. (2009) (BILL-WG 2009a, BILL-WG 2009b). This resulted in a single-stock with 6 regional strata (Figure 2). The SS model structure was not spatially explicit; instead, SS modeled each fishery relative to the global population. An assumption was that all fisheries within a region sampled the same subset of the total stock so that they had the same apparent selectivity relative to the total stock. Another assumption was that movement between areas was sufficiently high so that the effects of catch in one region were instantaneously diffused among all other regions. Homogeneity in recruitment across regions was also assumed.

2.2 Biological Parameters

For this analysis, independently estimated swordfish life history parameters from the Central North Pacific were input into Stock Synthesis as fixed parameters (Table 1). Length-at-age growth parameters (cm of eye-fork length), maximum age (TMAX y), and maximum eye fork length (cm) were taken from DeMartini et al. (2007), and Uchiyama and Humphreys (2007). Length-weight relationship for pooled sexes (cm of eye fork length, kg) were taken from Uchiyama et al. (1999), and Uchiyama and Humphreys (2007). Maturity probability at length p(L) in cm of eye fork length was taken from DeMartini et al. (2000). Combined values for von Bertalanffy growth parameters and maturity probability were not available from DeMartini et al. (2000). As a result, combined values for von Bertalanffy growth parameters and maturity probability were estimated here by fitting length-at-age growth models and maturity-at-length models to the sex-combined data in Excel and minimizing the sum of squared differences between observed and expected values (Table 1).

Estimates of natural mortality were linked to life history of swordfish from the Central North Pacific Ocean (Brodziak 2009, BILLWG 2009a) (Tables 2 and 3). Natural mortality estimates were obtained by taking the average of 4 age-independent estimates of M and 1 age-dependent estimate of M from (Brodziak 2009). Age-independent estimates of M followed methods from Hoenig (1983), Alverson and Carney (1975), Pauly (1980), and Beverton-Holt invariant 2 (Jensen 1996). Age-dependent estimates of M followed methods from the Lorenzen (1996) tropical system estimator. Separate estimates were made for female and male swordfish. Estimates for females and males combined were obtained as the average of male and female natural mortality rates at a quarterly time step.

Life history data were compiled separately for females (Table 4), males (Table 5) and females and males combined (Table 6). However, for this assessment, a single sex model was implemented because sexually specific length data were limited. Sex ratio data for Japan distant water longline fisheries were only available from training vessels which did not fish in the same location as the commercial fishery. As a result, the BILL-WG recommended not incorporating Japan distant water longline fisheries sex ratios in this assessment. Sexually specific length composition data were only available for US Hawaii Longline (Brodziak and Courtney 2009, Courtney et al. 2009, Courtney and Fletcher 2009). Sexually specific length frequency data were limited and preliminary analysis indicated that the stock synthesis model was not sensitive to the addition of the limited sexually specific length frequency data available from US Hawaii Longline (Courtney and Piner 2009a). As a result BILL-WG recommended that a single sex model was more parsimonious (BILL-WG 2009b). Preliminary fits to length frequency were poor (BILL-WG 2009b), and Pacific swordfish growth rates during the first year are very high (DeMartini et al. 2007). As a result, a quarterly time step was implemented in an effort to improve model fits to length frequency data.

2.3 Catch, Length, and CPUE

Data included 27 fisheries, 10 time series of length frequency, and 3 CPUE time series (Tables 7-9). Catch and CPUE data were the same as compiled for a Bayesian production model (Courtney and Wagatsuma 2009) (Figure 3). Length data were compiled separately for Stock Synthesis (Courtney and Flecther 2009).

Catch for Japan (all fleets) was available by region at a quarterly time step (Jan-March, April-June, July-September, and October-December) (Table 7). Annual catch for Chinese Taipei and Korea was apportioned to quarters in the same ratios as Japan Offshore + Distant Water Longline catch in the same region (Table 7). Catch for U.S. Hawaii longline was available at a quarterly time step (Table 7). Annual catches for US California Gillnet, US California Longline, and US California Other + Unknown were assigned to quarter four (Q4) which was consistent with the seasonal timing of swordfish catch (Ito and Childers 2008). Annual catches for Mexico were also assigned to Q4. The Mexico swordfish longline fleet operated in Mexican waters from September-October to February, and swordfish catches declined after that period and were very scarce in the summer months of July and August (Fleischer et al. 2009). The seasonal timing of Mexico catch appeared to differ from that of Japan Offshore + Distant Water Longline in Region 6 which had 41% of recent (1990-1997) catch (mt) in Q2 (F6, Table 7).

Regionally stratified length frequency data were available for 10 combinations of fleets and regions (F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30) (Table 8). However, because of limited sample size, quarterly length frequency data were only incorporated for Japan Offshore + Distant Water Longline (F1, F2, F4), US Hawaii Longline (F29), and US California Gillnet (F30) (Table 8). Annual length frequency data were incorporated for

Japan Offshore + Distant Water Longline (F3, F5, and F6), Japan Driftnet (F7), Japan Other, Primarily Harpoon (F12) and assigned to the quarter with most catch (Table 8).

Standardized time-series of CPUE were available for three fleets (S1, S8, and S15) (Table 9). Japan Offshore + Distant Water Longline CPUE was assigned to Q1 based on the proportion of Japan Offshore + Distant Water Longline catch (mt) from 1990 - 2007 in Q1 (50%), Q2 (21%), Q3 (10%), Q4 (19%) (Table 7). Chinese Taipei Distant Water Longline CPUE was assigned to Q2 based on the proportion of Japan Offshore + Distant Water Longline catch (mt) in region 6 by quarter from 1990 – 2007 (Table 7). Hawaii longline shallow-set CPUE was assigned Q2 based on the proportion of Hawaii longline catch (mt) by quarter from 1990 - 2007 (Table 7).

Length based selectivity for Japan Offshore + Distant Water Longline CPUE (S1) was assumed to be the same as (mirror) the Japan Offshore + Distant Water Longline fleet in region 1 (F1), the region with the highest catch (Tables 7 and 9). Length based selectivity for Chinese Taipei Distant Water Longline CPUE (S8) was assumed to be the same as (mirror) the Japan Offshore + Distant Water Longline fleet in region 6 (F6) (Tables 7 and 9). Length based selectivity for US Hawaii longline shallow-set CPUE (S15) was assumed to be the same as (mirror) US Hawaii longline shallow-set (F29) (Table 9).

2.4 Model Structure

The assessment was conducted with Stock Synthesis (SS) V3.02E-SAFE, 04/07/09, using Otter Research ADMB 7.0.13 by Richard Methot (NOAA) and available from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/SS.html) (Methot 2000).

The base model (Model-1) structure was similar to a previous striped marlin assessment conducted by the ISC BILLWG with Stock Synthesis 2 (SS2) (Piner et al. 2007a), and preliminary model sensitivity runs for a North Pacific swordfish stock assessment in SS (Courtney and Piner 2009a).

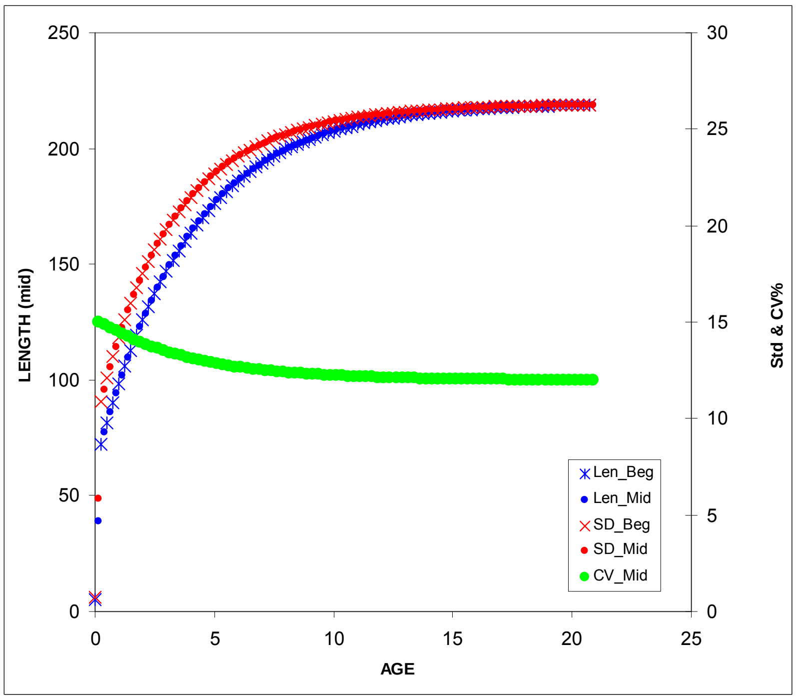
As a result of BILL-WG review (BILLWG 2009b), the population was assumed to be in equilibrium prior to 1951 with an estimated equilibrium exploitation level approximated by average Japan Distant Water Longline Catch (1951 – 1955) of 10,512 (mt) (Table 10). Beverton-Holt spawner-recruit steepness (h) was fixed at 0.9 with an assumed standard error of the process error in recruitment (σ_r) fixed at 0.6 and iteratively re-weighted once (Table 10). Natural mortality (M) was linked to life history (Table 10).

Recruitment occurred on January 1, no recruitment occurred in other quarters. Main recruitment deviations were estimated from 1970 – 2006. The central tendency was bias corrected for process error in recruitment from 1960 – 1970 using a linear interpolation of σ_r beginning at 0 in 1960 and ending at the full value of σ_r in 1970. In order to avoid potential bias in the magnitude of main recruitment deviations near the beginning of the time series, early recruitment deviations were estimated from 1951 – 1970. The estimated standard deviation of each early recruitment deviation should be equal to σ_r

except for the last few which are influenced by length data which began in 1970. However, as a result of estimating early recruitment deviations, reported depletion levels during the early period (prior to 1970) may be biased and should be treated with caution when interpreted relative to the status of the stock.

The population model had 49 length bins (5 cm) from 20 – 260+ (cm). The fishery length data had 45 length bins (5 cm) from 40 to 260+ (cm). The population had 20 annual ages from 0 to 20+.

There were no age data. Fishery length frequency data were used to estimate selectivity patterns which controlled the size (and age) distribution of fishery removals. The assumed CV for combined values of von Bertalanffy length at age was set to 0.15 for young fish and 0.12 for old fish.



CPUE indices were treated as survey indices and were assumed to be linearly proportional to available biomass, with constant catchability (q) assumed to occur halfway through the assigned quarter of the survey (Table 9). Catch was assumed to be known without error and removed by estimating continuous fishing mortality (F) for each set of fleets with the same selectivity by region.

2.5 Length Based Selectivity

Length based selectivity was estimated for fleets with length frequency data (F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30) (Table 8). We assumed that length based selectivity for fleets without length frequency data was the same as (mirrored) fleets with length frequency data within the same region. For Chinese Taipei Distant Water Longline and

Korea Longline, we assumed that the selectivity patterns were the same as (mirrored) those of Japan Offshore + Distant Water Longline in their respective regions (Table 8). For US California Longline and US California Other Gear + Unknown, we assumed that selectivity patterns mirrored US California Gillnet (the only fleet in Region 3 with sufficient length data to estimate selectivity) (Table 8). For Mexico All Gears, we assumed that selectivity patterns also mirrored US California Gillnet based upon the proximity of Mexico longline catch (primarily off Baja California, Mexico) and the similar timing of Mexico longline and California Gillnet catch (assigned Q4) (Table 8) (Ito and Childers 2008).

Selectivity patterns for CPUE time series (S1, S8, S15) mirrored their respective fleet in the region with the highest proportion of catch (Tables 7 and 9).

All selectivity models were two parameter asymptotic logistic equations except for Japan Offshore + Distant Water Longline Region 1 (F1) which had a 6 parameter dome-shaped double normal model, and Japan Other, Primarily Harpoon (F12) which had a modified 3 parameter asymptotic double normal model. The rational for dome-shaped selectivity for Fleet 1 was a relatively larger mode in length of swordfish captured in the same region by the Japan Other, Primarily Harpoon (F12) (e.g., see Figure 28). Including dome-shaped selectivity for Fleet 1 resulted in a better fit to the Japan Offshore + Distant Water longline length frequency data in region 1. The rational for including a modified 3 parameter asymptotic double normal model for F12 was to force a maximum selectivity of 1, which allowed interpretation of resulting fishing mortality for Fleet 12 to match those of the other fleets. Models run without a three parameter selectivity model for F12 were very sensitive to the selectivity pattern estimated for fleet 12, and resulted in maximum selectivity below 1. This may have resulted from not setting parameter bounds correctly to bound within the larger size range of this stock. Selectivity parameters for the two parameter asymptotic logistic equation were estimated with a diffuse lognormal prior (Stdev = 999). Selectivity parameters for the double normal model were estimated with a diffuse symmetric beta prior (0.05).

Length based selectivity was allowed to vary over two time periods (blocks) for Japan Offshore + Distant Water Longline (1951 – 1983, 1984 – 2006) corresponding to a change in target species during the years 1984 – 1990 (Ishimura et al. 2008) (Table 11). Length based selectivity was allowed to vary over two time periods (blocks) for US Hawaii Longline (1995 – 2003, 2004 – 2006) and US California Gillnet (1980 – 1999, 2000 – 2006) corresponding to management actions that may have affected length based selectivity (Ito and Childers 2008, Piner and Betcher 2009) (Table 11).

2.6 Effective Sample Size

Input standard errors for Japan Offshore + Distant Water Longline CPUE (S1) and Chinese Taipei Distant Water Longline CPUE (S8) were estimated from annual standard errors of GLM standardized CPUE (Courtney and Wagatsuma 2009). Input standard errors for US Hawaii Longline CPUE (S15) were estimated from annual standard errors of the ratio of GAM standardized catch to effort (Courtney and Wagatsuma 2009).

Input standard errors for CPUE were iteratively re-weighted once to match the initial Stock Synthesis model estimate of Root Mean Squared Error (R.M.S.E.) for each CPUE time series (McAllister and Ianelli 1997, Piner et al. 2007a) (Table 12).

Fishery length frequency sample size was input as the square root of the number of fish measured. The square root transformed very large input sample sizes to a scale that approximated the R.M.S.E. effective mean sample size (Table 12). Minimum sample size for length frequency data in the Stock Synthesis model was set at n = 100, for both annual and quarterly data, based on an ad-hoc review of the available length frequency data. If less than 100 fish were measured for length, then the length data were excluded from the model.

2.7 Evaluation of Stock Status

Maximum sustainable yield (MSY), female spawning biomass (S) at MSY (S_MSY), and fishing mortality (F) at MSY (F_MSY) were calculated relative to the selectivity regime in "zero state," defined here as the time blocks which included the ending year 2006, and relative to the fixed value of steepness and an assumed 50:50 sex ratio. Model estimated time-series of female spawning biomass (S in metric tons, mt = 1,000 kg), recruitment (R in 1,000s of fish), total biomass (B mt), and age 2+ total biomass (B_2+ mt) were tabulated on an annual basis. Total annual exploitation rate was calculated as (Catch mt)/(B_2+ mt) for comparison to exploitable biomass estimated from Bayesian production models. Age 2+ total biomass was used as a simple measure of the exploitable biomass because age 2 fish (125.8 cm EFL) were approximately 50% fully selected (with near knife edge selectivity) in the major fisheries (Japan Offshore + Distant Water Longline in regions 1 and 2; e.g., see Figure 7).

MSY is commonly considered an upper bound for catch rather than a target. Empirical evidence has shown that populations are often exploited at levels higher than MSY before MSY can be estimated with precision (Hilborn and Walters 1992). Alternative biological reference points (BRPs) including spawning stock or egg production on a per-recruit basis have been recommended as a means to preserve reproductive potential of a population (Quinn and Deriso 1999), but were not considered here.

2.8 Sensitivity Analysis

The base model (Model-1) was compared to sensitivity runs conducted to assess Model-1 sensitivity to length composition data.

Base (Model-1)	Input standard errors iteratively re-weighted once to equal model estimated R.M.S.E. for all (three) CPUE time series: Japan Offshore + Distant Water (0.08+S1), Chinese Taipei (0.21+S8), and US Hawaii Longline (0.14+S15)
Sensitivity-1	Priors turned off for all parameter estimates
Sensitivity-2	Input sample size (input N) iteratively re-weighted once for all length frequency time series to equal model estimated mean effective sample (VarAdj* input N). This increased the weight of length frequency data in the likelihood by reducing the standard error se=s/N

Sensitivity-3	Input sample size (input N) down-weighted for all length frequency time series (0.01* input N). This reduced the weight of length frequency data in the likelihood by increasing the standard error se=s/N Input standard errors iteratively re-weighted once to equal model estimated R.M.S.E for only two of the CPUE time series: Chinese Taipei (0.21+S8) and US Hawaii Longline (0.14+S15)
Sensitivity-4	Model-1 with sigma r = 0.4
Sensitivity-5	Model-1 with bias correction for sigma r turned off
Initial F-1	Model-1 with initial F turned off
Initial F-2	Model-1 with initial F estimated from initial catch = 0.25* 10,512 mt (average catch from Japan Offshore + Distant Water Longline R1 and R2 during the years 1951 – 1955)
Initial F-3	Model-1 with initial F estimated from initial catch = 0.50* 10,512 mt (average catch from Japan Offshore + Distant Water Longline R1 and R2 during the years 1951 – 1955)
Initial F-4	Model-1 with initial F estimated from initial catch = 0.75* 10,512 mt (average catch from Japan Offshore + Distant Water Longline R1 and R2 during the years 1951 – 1955)
Selectivity-1	Asymptotic selectivity for all fleets
Selectivity-2	Block added to selectivity of Japan Offshore + Distant Water during the years 1999 – 2006
Selectivity-3	Dome-shape selectivity for all fleets
Growth-1	Estimated growth coefficients t_0, and K (combined sex)
Growth-2	Estimated growth coefficients t_0, K, and Linf (combined sex)
Growth-3	Estimated growth coefficients t_0, K, and Linf (combined sex), and Block added to estimated growth coefficients during the years 1999 – 2006
Growth-4	Estimated growth coefficients t_0, and K (two sex)
Growth-5	Estimated growth coefficients t_0, K, and Linf (two sex)
Growth-6	Estimated growth coefficients t_0, K, and Linf (two sex), and Block added to estimated growth coefficients during the years 1999 – 2006

Model results for sensitivity run 3 were used to compare SS model results to those obtained from a production model fit to the same data (Brodziak and Ishimura 2009, BILL-WG 2009b). Sensitivity-3 was the same as Model-1 except that fishery length frequency sample size was down-weighted by 1/100 (Table 12). The value 1/100 was sufficient to reduce the influence of length composition data on the likelihood fit to CPUE while allowing length based selectivity to be estimated for each fleet.

2.9 Convergence Criteria and Diagnostics

The model was assumed to have converged if the standard error of the parameter estimates could be derived from the inverse of the negative hessian matrix. Convergence diagnostics were also evaluated. Excessive CV's on estimated quantities were indicative of a non-converged model. The correlation matrix was examined for non-informative parameters. Individual likelihood components were compared for fits to CPUE data (Total, S1, S8, and S15), length data (Total, F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30), total recruitment, total objective function, and the total number of parameters estimated. Parameters estimated at a bound were a diagnostic for possible problems with data or the assumed model structure. Fits to CPUE and patterns in Pearson's residuals of fits to length frequency time series were examined as diagnostics for problems with data or the assumed model structure.

In order to test for global convergence, the initial parameter estimates from the base model (Model-1) were varied randomly by 5-10% and the initial phases of the estimated parameters were changed for 20 runs.

3. Model Results

Model results were evaluated with Microsoft Excel subroutines available for SS from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/SS.html) and with R statistical package plotting subroutines designed specifically for SS (r4ss Google Code, http://code.google.com/p/r4ss/).

3.1 Convergence Diagnostics

Model-1 took 2 hrs to run. SS model execution could be improved with no loss of accuracy by combining the catch of all fisheries that share the same selectivity pattern (Table 8). Similarly, SS model execution could be improved with no loss of accuracy by assigning CPUE directly to a fishing fleet with length data rather than modeling CPUE as a mirrored fleet (Tables 8 and 9).

All convergence diagnostics were met except that Model-1 length at maximum selectivity for Japan Other, Primarily Harpoon (F12) was estimated at an upper bound (260 cm TL) and may be an indication that the data or model structure needs further examination. In particular, earlier model runs were very sensitive to length based selectivity estimated for (F12) with runs resulting in maximum logistic selectivity less than 1. Since length frequency for F12 was only available for one year (combined 2006 + 2007), selectivity for F12 was re-parameterized as a three parameter double normal to force maximum selectivity to 1.

3.2 Model Fits

Fits to Japan Offshore + Distant Water Longline CPUE showed non-random blocks of positive and negative residuals prior to 1960 and following the 1980s (Figure 4.1). Down-weighting length compositions in Sensitivity-3 resulted in a better fit to all survey data relative to Model-1 (Figures 4 – 6). Down-weighting length compositions in Sensitivity-3 had little effect on estimated selectivity or fits to frequency length data relative to the base case (not shown).

The incorporation of a quarterly time step for catch and length resulted in an improved fit to Japan Offshore + Distant Water Longline length frequency time series (Figure 12) relative to preliminary assessment runs (Courtney and Piner 2009a). Fits to U.S. Hawaii Longline (Figure 15), and U.S. California Gillnet length frequency (Figure 16) were marginally improved relative to preliminary assessment model runs by the incorporation of quarterly data (Courtney and Piner 2009a). However, length frequency residuals showed non-random blocks of positive and negative residuals (Figures 12.1 and 16) as well as trends in residuals (Figures 12.2 and 15).

The addition of time blocks for length based selectivity resulted in substantially different selectivity for Japan Offshore + Distant Water Longline in regions 1 and 6 (R1 and R6) between the years 1951 – 1983 and 1984 – 2006, but not in regions 2, 4, or 5 (R2, R4, and R5) (Figure 7). Selectivity for Japan Offshore + Distant Water Longline R1 was relatively more dome-shaped prior to 1983 (Figure 7.1) consistent with a fleet that captured swordfish incidentally prior to 1983 and as a target species after 1990 (Ishimura et al. 2008).

The addition of time blocks for length based selectivity resulted in steeper selectivity for U.S. Hawaii Longline and U.S. California Gillnet in recent years (Figures 10 and 11). Estimated selectivity for both US Hawaii Longline and U.S. California Gillnet also increased for smaller swordfish in more recent years (Figures 10 and 11). Including time blocks for length based selectivity did not result in an improved fit to U.S. Hawaii Longline CPUE (Figure 6) relative to preliminary assessment model runs (Courtney and Piner 2009a).

3.3 Estimated Time Series

Model-1 estimated time series of total biomass, age 2+ biomass, and female spawning biomass exhibited a period of decline from 1951 – 1960 and then were relatively flat (Table 13, Figures 17 - 19). The large drop in initial equilibrium biomass suggests that the large initial assumed catch (10,512 mt) may not be appropriate (Figure 17 – 19). Sensitivity analysis results indicated that the estimation of initial F had no effect on ending year S_2006/S_MSY or F_Avg (1995-2006)/F_MSY (Figure 27). However, the estimation of large initial F may influence reported depletion levels in early years.

Model-1 estimated Age-0 recruitment variability was consistent with the availability of length frequency data which began in 1970 (Figure 20). Estimation of main recruitment deviations began in 1970 and ended in 2006, consistent with the availability of length frequency data (1970 – 2006). Model estimation of early recruitment 1951 – 1970 moved from the central tendency about 10 years prior to 1970 as length frequency data from older fish available starting in 1970 began to influence the estimates. There was limited data at low population size to estimate the spawner-recruit relationship (Figure 21).

As a result of estimating early recruitment deviations, reported depletion levels during the early period (prior to 1970) may be biased and should be treated with caution when interpreted relative to the status of the stock.

3.4 Stock Status

Model-1 estimated female spawning biomass was above MSY for all years from 1951-2006 (Table 13, Figures 22 and 23). Model-1 estimated fishing mortality (F) was below F_MSY for all years except 1958 to 1962, 1985, 1992, and 1993 (Table 14, Figures 22 and 24). Model-1 ending female spawning biomass (S_2006) as a proportion of unfished female spawning biomass (S_0) was 30% (Table 17). Model-1 annual fishing mortality

(F - summed over all fleets and quarters) averaged from 1995-2006 (F_Avg) was 0.63 (Table 18). Model-1 average fishing mortality (F_avg) from 1995-2006 was below estimated F at MSY (F_MSY = 0.79) (Table 18). Average fishing mortality (F_avg) from 1995-2006 was higher than male and female natural mortality (M) which ranged from 0.40 at age 0.25 to 0.35 at older ages (Table 6).

3.5 Stock Status estimated with SS relative to BSP

Time-series of age 2+ biomass estimated with Model-1 were slightly lower than (often outside the 95% Bayesian credible intervals) time-series of exploitable biomass estimated with Bayesian surplus production (BSP) models run on the same data (Table 13, Figure 25). Time-series of exploitable biomass and harvest rate estimated with Sensitivity-3 model were consistent with (inside the 95% Bayesian credible intervals) BSP, but deviated from BSP beginning in 1983 (Figures 25 and 26). The deviation in model estimates of exploitable biomass and harvest rate between Sensitivity-3 and BSP was coincident with the change in estimated selectivity for the Japan Offshore and Distant Water Longline fleet in regions 1 and 6 after 1983 (Figure 7.1, 7.6) (Ishimura et al. 2008).

As a result of estimating early recruitment deviations in SS, reported depletion levels from SS during the early period (prior to 1970) may be biased and should be treated with caution when interpreted relative to the status of the stock. Similarly, the assumed equilibrium catch of 10,512 mt in SS prior to 1951 may also have influenced depletion levels estimated by SS during early years.

The time-series of estimated fishing mortality (F) from Sensitivity-3 was above F_MSY for all years except 1958, 1960, 1961, and 1993 - 2000 (Figure 24). Sensitivity-3 resulted in increased uncertainty for estimated parameters such as spawning biomass (Figure 23). This is a mathematical result of se = stdev/sqrt(N). Sensitivity-3 reduced the N associated with the data.

3.6. Sensitivity Analysis Results

3.6.1 Sensitivity Runs

Model results for sensitivity runs 1, 4 and 5 were nearly identical to Model-1 indicating that the effect of including uninformative priors, setting sigma_r = 0.4 and removing bias correction of sigma_r had little influence on Model-1 parameter estimates (Tables 15 – 18, Figure 27).

Sensitivity runs 2 and 3 had a large effect on model results indicating that Model-1 was still sensitive to the weight given to length frequency data even after improving the fit to the length frequency data by adding a quarterly time step and time blocks for selectivity (Tables 15 – 18, Figure 27). Sensitivity run-3 was used to compare SS results directly to production model results fit to the same data.

3.6.2 Initial F Runs

The estimation of initial F had no effect on ending year S_2006/S_MSY or F_Avg (1995-2006)/F_MSY (Tables 15 – 18, Figure 27).

3.6.3 Selectivity Runs

Model results for selectivity runs 1 and 2 were similar to Model-1 indicating that Model-1 was not sensitive to the estimation of dome-shaped selectivity for Fleet 1 (Selectivity-1) or the estimation of selectivity in time blocks during the years 1999 – 2006 for Fleets 1-6 (Selectivity-2) (Tables 15 – 18, Figure 27). Selectivity run 3 had a large effect on model results indicating that Model-1 was sensitive to the estimation of dome-shaped selectivity for all fleets and therefore that the parameterization of length based selectivity would require further exploration before implementation of dome-shaped selectivity for all fleets (Tables 15 – 18, Figure 27).

Dome-shaped vs. asymptotic selectivity were examined because Japan Driftnet 2004 – 2006 and Japan Other (Primarily Harpoon) 2006+2007 in region 1 captured larger fish than all of the other fleets in all regions (Figure 28 Panel C.). However, patterns in Pearson's residuals also revealed that observed length frequencies of large fish were underestimated in Model-1 after 1983 in Japan Offshore + Distant Water Longline in Region 1 suggesting that dome-shape selectivity may not be appropriate for Fleet 1 (Figure 12.1).

A 1999 – 2006 time block for selectivity was examined because Japan Offshore + Distant Water Longline length frequency data have been available since 1999 from extensive port sampling, and the number of port sample data increased substantially at that time. Prior to 1999, sales slip data, along with limited on board length sampling, were the major source for size data from the subtropical and temperate area of the northwest and north-central Pacific (Regions 1 and 2). For this assessment, more than half the length data for the period before 1999 was obtained from sales slip data and the processed weight of sales slip data was converted into eye-fork length using a conversion factor obtained in the period of 1999 – 2003 by port sampling. However, length-processed weight relationship may change by quarter/region. For this reason, the reliability of size information from Japan Offshore + Distant Water Longline before 1999 is lower than for the period 1999 – 2006.

3.6.4 Growth Runs

Growth runs 1-6 had a large effect on model results. In all runs, fits to length frequency and CPUE were improved (Tables 15 and 16, Figure 27). These results indicate that Model-1 was sensitive to the estimation of growth parameters within the model, and therefore that the model might benefit from further exploration of the length data and/or growth parameters.

Fixing length at age growth parameters in SS Model-1 to the independently estimated growth curve assumed that the independently estimated growth curve represented the true population (Figure 29). However, the independent data used to estimate growth were presumably collected from size-selective fisheries, and therefore might be biased toward faster growing fish. Growth runs 1-6 estimated length at age for the von Bertalanffy growth (VBG) curve within SS while taking into account the size-selectivity of the fisheries (Table 19, Figure 30). Then, SS estimated size-selectivity of fisheries relative to size at age predicted from the internally estimated growth curve. All estimated growth curves were lower (indicating slower growth) than the independently estimated growth curve from the Central North Pacific for ages 2 – 14 (Figure 30). Estimated Linf for combined sex and female model runs were consistent with independently estimated Linf from the Central North Pacific (Table 19, Figure 30). However, SS internal estimates of growth also depend on the assumed CV of length at age (15% for young fish to 12% for old fish), recruitment timing, and natural mortality and as a result may not be directly comparable to those estimated independently for the Central North Pacific (VBG, Table 1).

Estimated growth parameters for combined sex and male models differed between the periods 1970 – 1998 and 1999 – 2006 (Figure 30 Panel C.). This result indicates that Model-1 may be sensitive to the length frequencies provided for Japan Offshore + Distant Water Longline prior to 1999 from the length-processed weight relationship.

3.7. Test for Global Convergence

The initial parameter estimates from the base model were varied randomly by 5-10% and the initial phases of the estimated parameters were changed for 20 runs to test global convergence (Table 20). These changes to model structure should cause the model to travel down a different path to convergence and locate a better solution if one exists. Results indicated that Model-1 successfully converged to almost the identical solution in 17 of the 20 runs (Figure 31) from widely different initial starting conditions (Figure 32).

We do note that there appeared to be two minima very near the global solution that were separated by 0.21 likelihood units. We suspect that a boundary condition may have been reached, but an initial attempt to determine the cause of the two minima was unsuccessful. The model dynamics at these two minima were nearly identical and did not change the view of stock condition or future productivity.

4. Conclusions

Model-1 appeared to adequately estimate selectivity for the major fisheries and to fit CPUE series well enough to scale the absolute abundance estimates (Figures 4 – 11). Model-1 appeared to adequately fit length compositions from the major fisheries, however, trends in Pearson's residuals were evident for Hawaii Shallow Set Longline and U.S. California Gillnet (Figures 12 – 16). Model-1 estimated ending year 2006 spawning biomass was above spawning biomass at maximum sustainable yield (MSY) and 2006 fishing mortality (F) was below F at MSY (Figure 22).

Model-1 results from SS indicated slightly lower biomass and slightly higher harvest rates (often outside 95% Bayesian credible intervals) than Bayesian surplus production model run on the same data (Figures 23 – 26). SS deviated from BSP after 1983 coincident with a change in time-varying selectivity estimated for Japan Offshore + Distant Water Longline fleet (Figures 7.1, 25, and 26).

As a result of estimating early recruitment deviations in SS, reported depletion levels from SS during the early period (prior to 1970) may be biased and should be treated with caution when interpreted relative to the status of the stock. Similarly, the assumed equilibrium catch of 10,512 mt in SS prior to 1951 may also have influenced depletion levels estimated by SS during early years.

Results from SS were consistent with previous age-structured assessments of North Pacific swordfish in that the available CPUE time series were relatively flat and uninformative and as a result, model estimates were highly sensitive to key parameters (Bigelow and Kleiber 2004, Kleiber and Yokawa 2004, and Wang et al. 2007). Model-1 results from SS were sensitive to the weight given to length frequency data, to the parameterization of length based selectivity, and to the estimation of growth parameters within the model (Tables 15 – 18, Figure 27). Previous analyses indicated that model fits from SS were also sensitive to natural mortality, steepness of the stock recruit relationship, effective sample size of CPUE time series, and the sequential removal of CPUE time series (Courtney and Piner 2009a).

MSY from this assessment, 15,529 mt, was slightly higher than that (13,151 mt) estimated by Wang et al. (2007). Estimated ending year female spawning stock biomass from Model-1 as a fraction of spawning stock biomass at MSY (1.4) was lower than that found by Kleiber and Yokawa (2004) (2.1) and Wang et al. (2007) (2.3). Unfished spawning biomass estimated here with SS (54,184 mt) was less than half that (110,547 mt) estimated by Wang et al. (2007). The lower spawning biomass estimated with SS may have resulted from the lower natural mortality rate (0.25) assumed by Wang et al. (2007). Additionally Wang et al. (2007) included length compositions and sex ratios of fish captured in research cruises which were not included in this assessment. Finally, standardized catch rates (CPUE) were re-estimated for input into this assessment and differed from those used in previous assessments (Kleiber and Yokawa 2004, and Wang et al. 2007).

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Table 1. Central North Pacific swordfish life history parameters estimated independently.

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	$\boxed{EFL_t = EFL_\infty \left(1 - e^{-k(t-t_0)}\right)}$ 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 = 1.2988×10^{-5} b = 3.0738			$\boxed{W(kg) = aEFL^b}$ 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	$\boxed{p(EFL) = \left(1 + \exp\left(\frac{-(EFL - L_{50})}{\sigma_m}\right)\right)^{-1}}$ De Martini et al. (2000)

* Combined values for Von Bertalanffy growth parameters and maturity probability were obtained by fitting the respective models to combined data in Excel and minimizing the squared differences between observed and expected values.

Table 2. Estimates of female swordfish natural mortality rates at age linked to life history of Central North Pacific swordfish (adapted from Brodziak 2009).

Age (yrqtr)	Female Weight (kg)	Hoenig 1983	Alverson and Carney (1975)	Pauly (1980)	Beverton-Holt invariant 2 (Jensen 1996)	Lorenzen (1996) tropical system estimator	Mean
0.25	6.3	0.35	0.36	0.35	0.37	0.49	0.38
0.5	9.3	0.35	0.36	0.35	0.37	0.45	0.38
0.75	12.9	0.35	0.36	0.35	0.37	0.42	0.37
1	17.0	0.35	0.36	0.35	0.37	0.40	0.37
1.25	21.6	0.35	0.36	0.35	0.37	0.38	0.36
1.5	26.6	0.35	0.36	0.35	0.37	0.36	0.36
1.75	32.0	0.35	0.36	0.35	0.37	0.35	0.36
2	37.7	0.35	0.36	0.35	0.37	0.34	0.35
2.25	43.7	0.35	0.36	0.35	0.37	0.33	0.35
2.5	49.8	0.35	0.36	0.35	0.37	0.32	0.35
2.75	56.1	0.35	0.36	0.35	0.37	0.31	0.35
3	62.5	0.35	0.36	0.35	0.37	0.30	0.35
3.25	69.0	0.35	0.36	0.35	0.37	0.30	0.35
3.5	75.4	0.35	0.36	0.35	0.37	0.29	0.34
3.75	81.9	0.35	0.36	0.35	0.37	0.29	0.34
4	88.2	0.35	0.36	0.35	0.37	0.28	0.34
4.25	94.5	0.35	0.36	0.35	0.37	0.28	0.34
4.5	100.7	0.35	0.36	0.35	0.37	0.27	0.34
4.75	106.8	0.35	0.36	0.35	0.37	0.27	0.34
5	112.7	0.35	0.36	0.35	0.37	0.27	0.34
5.25	118.5	0.35	0.36	0.35	0.37	0.26	0.34
5.5	124.1	0.35	0.36	0.35	0.37	0.26	0.34
5.75	129.5	0.35	0.36	0.35	0.37	0.26	0.34
6	134.8	0.35	0.36	0.35	0.37	0.26	0.34
6.25	139.9	0.35	0.36	0.35	0.37	0.26	0.34
6.5	144.7	0.35	0.36	0.35	0.37	0.25	0.34
6.75	149.4	0.35	0.36	0.35	0.37	0.25	0.34
7	153.9	0.35	0.36	0.35	0.37	0.25	0.34
7.25	158.3	0.35	0.36	0.35	0.37	0.25	0.34
7.5	162.4	0.35	0.36	0.35	0.37	0.25	0.34
7.75	166.4	0.35	0.36	0.35	0.37	0.25	0.34
8	170.1	0.35	0.36	0.35	0.37	0.25	0.34
8.25	173.8	0.35	0.36	0.35	0.37	0.24	0.33
8.5	177.2	0.35	0.36	0.35	0.37	0.24	0.33
8.75	180.5	0.35	0.36	0.35	0.37	0.24	0.33
9	183.6	0.35	0.36	0.35	0.37	0.24	0.33
9.25	186.5	0.35	0.36	0.35	0.37	0.24	0.33
9.5	189.4	0.35	0.36	0.35	0.37	0.24	0.33
9.75	192.0	0.35	0.36	0.35	0.37	0.24	0.33
10	194.6	0.35	0.36	0.35	0.37	0.24	0.33
10.25	197.0	0.35	0.36	0.35	0.37	0.24	0.33
10.5	199.3	0.35	0.36	0.35	0.37	0.24	0.33
10.75	201.4	0.35	0.36	0.35	0.37	0.24	0.33
11	203.5	0.35	0.36	0.35	0.37	0.24	0.33
11.25	205.4	0.35	0.36	0.35	0.37	0.24	0.33
11.5	207.2	0.35	0.36	0.35	0.37	0.24	0.33
11.75	209.0	0.35	0.36	0.35	0.37	0.24	0.33
12	210.6	0.35	0.36	0.35	0.37	0.23	0.33
12.25	212.2	0.35	0.36	0.35	0.37	0.23	0.33
12.5	213.6	0.35	0.36	0.35	0.37	0.23	0.33
12.75	215.0	0.35	0.36	0.35	0.37	0.23	0.33
13	216.3	0.35	0.36	0.35	0.37	0.23	0.33
13.25	217.6	0.35	0.36	0.35	0.37	0.23	0.33
13.5	218.7	0.35	0.36	0.35	0.37	0.23	0.33
13.75	219.8	0.35	0.36	0.35	0.37	0.23	0.33
14	220.9	0.35	0.36	0.35	0.37	0.23	0.33
14.25	221.8	0.35	0.36	0.35	0.37	0.23	0.33
14.5	222.8	0.35	0.36	0.35	0.37	0.23	0.33
14.75	223.6	0.35	0.36	0.35	0.37	0.23	0.33
15	224.4	0.35	0.36	0.35	0.37	0.23	0.33

Table 3. Estimates of male swordfish natural mortality rates at age linked to life history of Central North Pacific swordfish (adapted from Brodziak 2009).

Age (yrqtr)	Male Weight (kg)	Hoenig 1983	Alverson and Carney (1975)	Pauly (1980)	Beverton-Holt invariant 2 (Jensen 1996)	Lorenzen (1996) tropical system estimator	Mean
0.25	7.3	0.38	0.39	0.38	0.41	0.48	0.41
0.5	10.3	0.38	0.39	0.38	0.41	0.44	0.40
0.75	13.8	0.38	0.39	0.38	0.41	0.42	0.40
1	17.7	0.38	0.39	0.38	0.41	0.39	0.39
1.25	21.9	0.38	0.39	0.38	0.41	0.38	0.39
1.5	26.5	0.38	0.39	0.38	0.41	0.36	0.38
1.75	31.3	0.38	0.39	0.38	0.41	0.35	0.38
2	36.3	0.38	0.39	0.38	0.41	0.34	0.38
2.25	41.4	0.38	0.39	0.38	0.41	0.33	0.38
2.5	46.6	0.38	0.39	0.38	0.41	0.32	0.38
2.75	51.9	0.38	0.39	0.38	0.41	0.32	0.38
3	57.1	0.38	0.39	0.38	0.41	0.31	0.37
3.25	62.4	0.38	0.39	0.38	0.41	0.30	0.37
3.5	67.5	0.38	0.39	0.38	0.41	0.30	0.37
3.75	72.6	0.38	0.39	0.38	0.41	0.29	0.37
4	77.6	0.38	0.39	0.38	0.41	0.29	0.37
4.25	82.5	0.38	0.39	0.38	0.41	0.29	0.37
4.5	87.2	0.38	0.39	0.38	0.41	0.28	0.37
4.75	91.7	0.38	0.39	0.38	0.41	0.28	0.37
5	96.2	0.38	0.39	0.38	0.41	0.28	0.37
5.25	100.4	0.38	0.39	0.38	0.41	0.27	0.37
5.5	104.5	0.38	0.39	0.38	0.41	0.27	0.37
5.75	108.4	0.38	0.39	0.38	0.41	0.27	0.37
6	112.2	0.38	0.39	0.38	0.41	0.27	0.37
6.25	115.8	0.38	0.39	0.38	0.41	0.27	0.37
6.5	119.2	0.38	0.39	0.38	0.41	0.26	0.36
6.75	122.4	0.38	0.39	0.38	0.41	0.26	0.36
7	125.5	0.38	0.39	0.38	0.41	0.26	0.36
7.25	128.5	0.38	0.39	0.38	0.41	0.26	0.36
7.5	131.3	0.38	0.39	0.38	0.41	0.26	0.36
7.75	133.9	0.38	0.39	0.38	0.41	0.26	0.36
8	136.4	0.38	0.39	0.38	0.41	0.26	0.36
8.25	138.8	0.38	0.39	0.38	0.41	0.26	0.36
8.5	141.0	0.38	0.39	0.38	0.41	0.26	0.36
8.75	143.1	0.38	0.39	0.38	0.41	0.25	0.36
9	145.1	0.38	0.39	0.38	0.41	0.25	0.36
9.25	147.0	0.38	0.39	0.38	0.41	0.25	0.36
9.5	148.8	0.38	0.39	0.38	0.41	0.25	0.36
9.75	150.4	0.38	0.39	0.38	0.41	0.25	0.36
10	152.0	0.38	0.39	0.38	0.41	0.25	0.36
10.25	153.5	0.38	0.39	0.38	0.41	0.25	0.36
10.5	154.9	0.38	0.39	0.38	0.41	0.25	0.36
10.75	156.2	0.38	0.39	0.38	0.41	0.25	0.36
11	157.4	0.38	0.39	0.38	0.41	0.25	0.36
11.25	158.6	0.38	0.39	0.38	0.41	0.25	0.36
11.5	159.6	0.38	0.39	0.38	0.41	0.25	0.36
11.75	160.6	0.38	0.39	0.38	0.41	0.25	0.36
12	161.6	0.38	0.39	0.38	0.41	0.25	0.36
12.25	162.5	0.38	0.39	0.38	0.41	0.25	0.36
12.5	163.3	0.38	0.39	0.38	0.41	0.25	0.36
12.75	164.1	0.38	0.39	0.38	0.41	0.25	0.36
13	164.9	0.38	0.39	0.38	0.41	0.25	0.36
13.25	165.5	0.38	0.39	0.38	0.41	0.25	0.36
13.5	166.2	0.38	0.39	0.38	0.41	0.25	0.36
13.75	166.8	0.38	0.39	0.38	0.41	0.25	0.36
14	167.4	0.38	0.39	0.38	0.41	0.25	0.36
14.25	167.9	0.38	0.39	0.38	0.41	0.25	0.36
14.5	168.4	0.38	0.39	0.38	0.41	0.25	0.36
14.75	168.9	0.38	0.39	0.38	0.41	0.25	0.36
15	169.3	0.38	0.39	0.38	0.41	0.25	0.36

Table 4. Central North Pacific female swordfish life history.

Age Class (yrqtr)	Female Length (cm)	Female Weight (kg)	Female Fraction Mature	Female Natural Mortality (Life History Mean Table 2)
0.25	71	6.3	0.00	0.38
0.5	80	9.3	0.00	0.38
0.75	89	12.9	0.00	0.37
1	98	17.0	0.01	0.37
1.25	106	21.6	0.02	0.36
1.5	113	26.6	0.04	0.36
1.75	120	32.0	0.08	0.36
2	127	37.7	0.15	0.35
2.25	133	43.7	0.25	0.35
2.5	139	49.8	0.37	0.35
2.75	144	56.1	0.51	0.35
3	149	62.5	0.64	0.35
3.25	154	69.0	0.75	0.35
3.5	159	75.4	0.83	0.34
3.75	163	81.9	0.88	0.34
4	167	88.2	0.92	0.34
4.25	171	94.5	0.94	0.34
4.5	174	100.7	0.96	0.34
4.75	178	106.8	0.97	0.34
5	181	112.7	0.98	0.34
5.25	184	118.5	0.98	0.34
5.5	187	124.1	0.99	0.34
5.75	189	129.5	0.99	0.34
6	192	134.8	0.99	0.34
6.25	194	139.9	0.99	0.34
6.5	196	144.7	1.00	0.34
6.75	198	149.4	1.00	0.34
7	200	153.9	1.00	0.34
7.25	202	158.3	1.00	0.34
7.5	204	162.4	1.00	0.34
7.75	205	166.4	1.00	0.34
8	207	170.1	1.00	0.34
8.25	208	173.8	1.00	0.33
8.5	210	177.2	1.00	0.33
8.75	211	180.5	1.00	0.33
9	212	183.6	1.00	0.33
9.25	213	186.5	1.00	0.33
9.5	214	189.4	1.00	0.33
9.75	215	192.0	1.00	0.33
10	216	194.6	1.00	0.33
10.25	217	197.0	1.00	0.33
10.5	218	199.3	1.00	0.33
10.75	218	201.4	1.00	0.33
11	219	203.5	1.00	0.33
11.25	220	205.4	1.00	0.33
11.5	220	207.2	1.00	0.33
11.75	221	209.0	1.00	0.33
12	222	210.6	1.00	0.33
12.25	222	212.2	1.00	0.33
12.5	223	213.6	1.00	0.33
12.75	223	215.0	1.00	0.33
13	224	216.3	1.00	0.33
13.25	224	217.6	1.00	0.33
13.5	224	218.7	1.00	0.33
13.75	225	219.8	1.00	0.33
14	225	220.9	1.00	0.33
14.25	225	221.8	1.00	0.33
14.5	226	222.8	1.00	0.33
14.75	226	223.6	1.00	0.33
15	226	224.4	1.00	0.33

Table 5. Central North Pacific male swordfish life history.

Age Class (yrqtr)	Male Length (cm)	Male Weight (kg)	Male Fraction Mature	Male Natural Mortality (Life History Mean Table 3)
0.25	74	7.3	0.02	0.41
0.5	83	10.3	0.06	0.40
0.75	91	13.8	0.18	0.40
1	99	17.7	0.40	0.39
1.25	106	21.9	0.64	0.39
1.5	113	26.5	0.82	0.38
1.75	119	31.3	0.92	0.38
2	125	36.3	0.96	0.38
2.25	131	41.4	0.98	0.38
2.5	136	46.6	0.99	0.38
2.75	141	51.9	1.00	0.38
3	145	57.1	1.00	0.37
3.25	149	62.4	1.00	0.37
3.5	153	67.5	1.00	0.37
3.75	157	72.6	1.00	0.37
4	160	77.6	1.00	0.37
4.25	163	82.5	1.00	0.37
4.5	166	87.2	1.00	0.37
4.75	169	91.7	1.00	0.37
5	172	96.2	1.00	0.37
5.25	174	100.4	1.00	0.37
5.5	176	104.5	1.00	0.37
5.75	179	108.4	1.00	0.37
6	181	112.2	1.00	0.37
6.25	182	115.8	1.00	0.37
6.5	184	119.2	1.00	0.36
6.75	186	122.4	1.00	0.36
7	187	125.5	1.00	0.36
7.25	189	128.5	1.00	0.36
7.5	190	131.3	1.00	0.36
7.75	191	133.9	1.00	0.36
8	192	136.4	1.00	0.36
8.25	193	138.8	1.00	0.36
8.5	195	141.0	1.00	0.36
8.75	195	143.1	1.00	0.36
9	196	145.1	1.00	0.36
9.25	197	147.0	1.00	0.36
9.5	198	148.8	1.00	0.36
9.75	199	150.4	1.00	0.36
10	199	152.0	1.00	0.36
10.25	200	153.5	1.00	0.36
10.5	201	154.9	1.00	0.36
10.75	201	156.2	1.00	0.36
11	202	157.4	1.00	0.36
11.25	202	158.6	1.00	0.36
11.5	203	159.6	1.00	0.36
11.75	203	160.6	1.00	0.36
12	203	161.6	1.00	0.36
12.25	204	162.5	1.00	0.36
12.5	204	163.3	1.00	0.36
12.75	204	164.1	1.00	0.36
13	205	164.9	1.00	0.36
13.25	205	165.5	1.00	0.36
13.5	205	166.2	1.00	0.36
13.75	205	166.8	1.00	0.36
14	206	167.4	1.00	0.36
14.25	206	167.9	1.00	0.36
14.5	206	168.4	1.00	0.36
14.75	206	168.9	1.00	0.36
15	206	169.3	1.00	0.36

Table 6. Central North Pacific combined female and male swordfish life history input to Stock Synthesis.

Age Class (yrqtr)	Combined Female and Male Length (cm)	Combined Female and Male Weight (kg)	Combined Female and Male Fraction Mature	Average Female and Male Natural Mortality (Life History Mean of Tables 2 and 3)
0.25	72	6.8	0.01	0.40
0.5	82	9.8	0.03	0.39
0.75	90	13.3	0.09	0.38
1	98	17.3	0.20	0.38
1.25	106	21.8	0.33	0.37
1.5	113	26.5	0.43	0.37
1.75	120	31.6	0.50	0.37
2	126	37.0	0.56	0.37
2.25	132	42.5	0.61	0.36
2.5	137	48.2	0.68	0.36
2.75	142	54.0	0.75	0.36
3	147	59.8	0.82	0.36
3.25	152	65.7	0.87	0.36
3.5	156	71.5	0.91	0.36
3.75	160	77.2	0.94	0.36
4	164	82.9	0.96	0.36
4.25	167	88.5	0.97	0.36
4.5	170	94.0	0.98	0.35
4.75	173	99.3	0.99	0.35
5	176	104.4	0.99	0.35
5.25	179	109.5	0.99	0.35
5.5	182	114.3	0.99	0.35
5.75	184	119.0	1.00	0.35
6	186	123.5	1.00	0.35
6.25	188	127.8	1.00	0.35
6.5	190	132.0	1.00	0.35
6.75	192	135.9	1.00	0.35
7	194	139.7	1.00	0.35
7.25	195	143.4	1.00	0.35
7.5	197	146.8	1.00	0.35
7.75	198	150.1	1.00	0.35
8	200	153.3	1.00	0.35
8.25	201	156.3	1.00	0.35
8.5	202	159.1	1.00	0.35
8.75	203	161.8	1.00	0.35
9	204	164.3	1.00	0.35
9.25	205	166.8	1.00	0.35
9.5	206	169.1	1.00	0.35
9.75	207	171.2	1.00	0.35
10	208	173.3	1.00	0.35
10.25	208	175.2	1.00	0.35
10.5	209	177.1	1.00	0.35
10.75	210	178.8	1.00	0.35
11	210	180.4	1.00	0.35
11.25	211	182.0	1.00	0.35
11.5	211	183.4	1.00	0.35
11.75	212	184.8	1.00	0.35
12	212	186.1	1.00	0.35
12.25	213	187.3	1.00	0.35
12.5	213	188.5	1.00	0.35
12.75	214	189.6	1.00	0.35
13	214	190.6	1.00	0.35
13.25	214	191.6	1.00	0.35
13.5	215	192.5	1.00	0.35
13.75	215	193.3	1.00	0.35
14	215	194.1	1.00	0.35
14.25	216	194.9	1.00	0.35
14.5	216	195.6	1.00	0.35
14.75	216	196.2	1.00	0.35
15	216	196.9	1.00	0.35

Table 7. Time series of catch (27) by country, fleet, and region (R).

Fleet Code	Country	Fleet(Region)	Annual Catch[1]	Years[2]	Percent of total catch (mt) by Fleet(Region) 1951-1983	1990-1997	Quarterly Resolution	Percent of Annual Fleet/region catch (mt) by quarter 1990-1997 Q1	Q2	Q3	Q4
F1	**Japan**	Offshore+Distant Water L. (R1)	Y	1951 – 2006	41.80%	16.75%	Y	49.29%	21.21%	10.05%	19.45%
F2	**Japan**	Offshore+Distant Water L. (R2)	Y	1951 – 2006	27.09%	16.59%	Y	32.31%	22.96%	9.42%	35.31%
F3	**Japan**	Offshore+Distant Water L. (R3)	Y	1960 – 2006	2.86%	0.76%	Y	62.33%	2.05%	6.67%	28.95%
F4	**Japan**	Offshore+Distant Water L. (R4)	Y	1951 – 2006	0.89%	0.64%	Y	18.77%	43.15%	27.16%	10.91%
F5	**Japan**	Offshore+Distant Water L. (R5)	Y	1951 – 2006	1.37%	1.56%	Y	37.47%	38.25%	14.24%	10.05%
F6	**Japan**	Offshore+Distant Water L. (R6)	Y	1954 – 2006	3.50%	3.69%	Y	21.70%	41.04%	24.54%	12.72%
F7	**Japan**	Driftnet (R1)	Y	1972 – 2006	3.55%	4.15%	Y	33.94%	12.49%	22.29%	31.28%
F8	**Japan**	Driftnet (R2)	Y	1973 – 1993	1.04%	0.47%	Y	74.50%	23.82%	0.92%	0.75%
F12[3]	**Japan**	Other, Primarily Harpoon (R1)	Y	1951 – 2006	6.32%	1.78%	Y	33.41%	12.31%	22.79%	31.49%
F13	**Japan**	All Other Gears (R1)	Y	1951 – 2006	2.75%	6.47%	Y	38.98%	14.30%	8.75%	37.96%
F14	**Japan**	All Other Gears (R2)	Y	1951 – 1993	0.93%	0.15%	Y	76.61%	22.01%	0.73%	0.65%
F16[3]	**Japan**	All Other Gears (R4)	Y	1951 – 2006	0.73%	1.67%	Y	25.62%	31.19%	25.31%	17.88%
F19[3]	**Chinese Taipei**	Distant Water Longline (R1)	Y	1995 – 2006	0.00%	0.77%	Mirror F1	-	-	-	-
F20	**Chinese Taipei**	Distant Water Longline (R2)	Y	1995 – 2006	0.00%	1.33%	Mirror F2	-	-	-	-
F21	**Chinese Taipei**	Distant Water Longline (R3)	Y	2003 – 2006	0.00%	0.02%	Mirror F3	-	-	-	-
F22	**Chinese Taipei**	Distant Water Longline (R4)	Y	2001 – 2006	0.00%	0.03%	Mirror F4	-	-	-	-
F23	**Chinese Taipei**	Distant Water Longline (R5)	Y	2000 – 2006	0.00%	0.14%	Mirror F5	-	-	-	-
F24	**Chinese Taipei**	Distant Water Longline (R6)	Y	2000 – 2006	0.00%	0.39%	Mirror F6	-	-	-	-
F25	**Chinese Taipei**	All Other Gears (Assume R4)	Y	1959 – 2006	4.14%	10.10%	Mirror F4	-	-	-	-
F26	**Korea**	Longline (R4)	Y	1976 – 2006	0.01%	0.13%	Mirror F4	-	-	-	-
F27	**Korea**	Longline (R5)	Y	1976 – 2006	0.06%	0.80%	Mirror F5	-	-	-	-
F28	**Korea**	Longline (R6)	Y	1976 – 2006	0.03%	0.40%	Mirror F6	-	-	-	-
F29	**US Hawaii**	Longline (Stratified by Depth)	Y	1976 – 2006	0.01%	15.53%	Y	36.04%	39.44%	11.18%	13.35%
F30	**US California**	Gillnet	Y	1984 – 2006	0.00%	3.95%	Assign Q4	-	-	-	100.00%
F31	**US California**	Longline	Y	1980 – 2006	0.76%	4.33%	Assign Q4	-	-	-	100.00%
F32	**US California**	Other Gear + Unknown	Y	1970 – 2006	1.37%	0.69%	Assign Q4	-	-	-	100.00%
F33	**Mexico**	All Gears	Y	1980 – 2006	0.80%	6.71%	Assign Q4	-	-	-	100.00%

[1] Courtney and Wagatsuma (2009, Table 1)
[2] First year with catch greater than 10 mt to last year with catch.
[3] Six Fleets (Regions) had total catch < 10 mt: F9 Japan Driftnet (R3), 8 mt; F10 Japan Driftnet (R4), 6 mt; F11 Japan Driftnet (R5), 1 mt; F15 Japan All Other Gears (R3), 1 mt; F17 Japan All Other Gears (R5), 0 mt; F18 Japan All Other Gears (R6), 0 mt.

Table 8. Time series of length frequency (10) by country, fleet, and region.

Fleet Code	Country	Fleet(Region)	Annual Length[1]	Years[2]	Quarterly Resolution	Length Selectivity
F1	**Japan**	Offshore+Distant Water L. (R1)	Y	1970 – 2006	Y	Dome
F2	**Japan**	Offshore+Distant Water L. (R2)	Y	1970 – 1972, 1974 – 2006	Y	Logistic
F3	**Japan**	Offshore+Distant Water L. (R3)	Y	1972, 1987, 1988, 1992, 2005	Assign Q1	Logistic
F4	**Japan**	Offshore+Distant Water L. (R4)	Y	1976 – 1979, 1981, 1983 – 2003, 2005, 2006	Y	Logistic
F5	**Japan**	Offshore+Distant Water L. (R5)	Y	1970 – 1972, 1974, 1978, 1983 – 1997, 1999 – 2002,	Assign Q2	Logistic
F6	**Japan**	Offshore+Distant Water L. (R6)	Y	1970 – 1972, 1974, 1986, 1989 – 1993, 1996 – 2002, 2004, 2006	Assign Q2	Logistic
F7	**Japan**	Driftnet (R1)	Y	2004 – 2006	Assign Q1	Logistic
F8	**Japan**	Driftnet (R2)	N	-	Mirror F7	Mirror F7
F12	**Japan**	Other, Primarily Harpoon (R1)	Y	2006+2007	Assign Q1	Modified Dome
F13	**Japan**	All Other Gears (R1)	N	-	Mirror F1	Mirror F1
F14	**Japan**	All Other Gears (R2)	N	-	Mirror F2	Mirror F2
F16	**Japan**	All Other Gears (R4)	N	-	Mirror F4	Mirror F4
F19	**Chinese Taipei**	Distant Water Longline (R1)	N	-	mirror F1	mirror F1
F20	**Chinese Taipei**	Distant Water Longline (R2)	N	-	mirror F2	mirror F2
F21	**Chinese Taipei**	Distant Water Longline (R3)	N	-	mirror F3	mirror F3
F22	**Chinese Taipei**	Distant Water Longline (R4)	N	-	mirror F4	mirror F4
F23	**Chinese Taipei**	Distant Water Longline (R5)	N	-	mirror F5	mirror F5
F24	**Chinese Taipei**	Distant Water Longline (R6)	N	-	mirror F6	mirror F6
F25	**Chinese Taipei**	All Other Gears (Assume R4)	N	-	mirror F4	mirror F4
F26	**Korea**	Longline (R4)	N	-	mirror F4	mirror F4
F29	**US Hawaii**	Longline (Stratified by Depth)	Y	1994 – 2001, 2004 – 2006	Y	Logistic
F30	**US California**	Gillnet	Y	1981 – 2006	Y	Logistic
F31	**US California**	Longline	N	-	mirror F30	mirror F30
F32	**US California**	Other Gear + Unknown	N	-	mirror F30	mirror F30
F33	**Mexico**	All Gears	N	-	mirror F30	mirror F30

[1] Courtney and Fletcher (2009)
[2] Years with annual or quarterly length frequency sample size greater than 100 fish.

Table 9. Time series of CPUE (3) by country and fleet (S1, S8, S15).

Survey Code	Country	Fleet	Annual CPUE[1\]	Years	Quarterly Resolution	Length Selectivity
S1	Japan	Offshore + Distant Water (All Regions)	Y	1952 – 2006	Assign Q1	Mirror F1
S8[2]	Chinese Taipei	Distant Water (All Regions)	Y	1995 – 2006	Assign Q2	Mirror F6
S15[2]	US	Hawaii Longline Shallow-Set	Y	1995 – 2000, 2004 - 2006	Assign Q2	Mirror F29

[1] Courtney and Wagatsuma (2009, Table 4)
[2] Several exploratory CPUE time series were not fit in the likelihood: Japan Offshore + Distant Water R1 – R6 (S2 – S7), Chinese Taipei Distant Water R1 – R6 (S9 – S14), US Hawaii Longline Deep Set (S16), US California Gillnet (S17).

Table 10. Base case model (Model-1) resulting from ISC BILLWG review (BILLWG 2009b).

Model Component	Changes to Base Case
Nat. Mort. (M)	Linked to Life History (Central North Pacific)
Steepness (h)	0.9
sigma_r	Iteratively re-weighted once from 0.6
Sexual Dimorphism	Sex-Combined
Effective Sample Size	Iteratively re-weighted for CPUE from input standard error
Initial Equilibrium Catch	Estimated from initial catch = 10,512 mt (average catch from Japan Offshore + Distant Water Longline R1 and R2 during the years 1951 – 1955)
Catch	Regionally Stratified Catch by Country, Fleet, and Region (F1 – F33)
CPUE	Single North Pacific Index for Each Country, Fleet, and Region (S1, S8, S15)
Length	Regionally Stratified Length by Country, Fleet, and Region (F1, F2, F3, F4, F5, F6, F7, F12, F29, and F30)

Table 11. Time blocks for length based selectivity for three fleets.

Fleet Code	Country	Fleet(Region)	Component	Block 1	Block 2
F1 – F6	Japan[1]	Offshore + Distant Water Regions R1 – R6	Length Selectivity	1951 – 1983	1984 – 2006
F29	US Hawaii[2]	Longline Shallow-Set	Length Selectivity	1995 – 2003	2004 – 2006
F30	US California[3]	Gillnet	Length Selectivity	1980 – 1999	2000 – 2006

[1] Ishimura et al. 2008.
[2] Ito and Childers 2008.
[3] Piner and Betcher 2009

Table 12. Root mean squared error (R.M.S.E.), input standard error (SE), effective sample size (Mean Eff. n), mean input sample size (sqrt(n)), variance adjustments (Var Adj), and sample size adjustments (n_Adj) applied to each model.

Likelihood Component			N	Model Estimate (R.M.S.E)	Input SE	+Var Adj Model-1	+Var Adj Sensitivity -2	+Var Adj Sensitivity -3
Sigma r			36	0.520	0.6	-0.080	-0.080	-0.080

CPUE	Country	Fleet	N	Model Estimate (R.M.S.E)	Mean Input SE	+Var Adj Model-1	+Var Adj Sensitivity -2	+Var Adj Sensitivity -3
S1	**Japan**	Offshore + Distant Water (All Regions)	55	0.206	0.131	0.075	0.075	0.000
S8	**Chinese Taipei**	Distant Water (All Regions)	12	0.556	0.346	0.211	0.211	0.211
S15	**US Hawaii**	Longline Shallow-Set	9	0.289	0.153	0.136	0.136	0.136

Length Frequency	Country	Fleet (Region)	N	Model Estimate Mean Eff. n	Mean Input Sqrt(n)	*n_Adj Model-1	*n_Adj Sensitivity -2	*n_Adj Sensitivity -3
F1	**Japan**	Offshore + Distant Water (R1)	133	222.2	61.8	1	3.60	0.01
F2	**Japan**	Offshore + Distant Water (R2)	115	265.4	57.3	1	4.63	0.01
F3	**Japan**	Offshore + Distant Water (R3)	5	117.5	16.3	1	7.20	0.01
F4	**Japan**	Offshore + Distant Water (R4)	78	123.3	16.0	1	7.69	0.01
F5	**Japan**	Offshore + Distant Water (R5)	25	124.4	17.2	1	7.25	0.01
F6	**Japan**	Offshore + Distant Water (R6)	19	93.8	15.3	1	6.12	0.01
F7	**Japan**	Driftnet (R1)	3	415.5	36.9	1	11.25	0.01
F12	**Japan**	Other, Primarily Harpoon (R1)	1	219.6	22.3	1	9.84	0.01
F29	**US Hawaii**	Longline (Stratified by Depth)	33	196.4	31.9	1	6.15	0.01
F30	**US California**	Gillnet	48	143.6	25.6	1	5.62	0.01

Table 13. Stock Synthesis Model-1 estimated time-series of female spawning biomass (S), recruitment (R), total biomass (B), and age 2+ biomass (B_2+); Along with Bayesian surplus production (BSP) estimates of mean exploitable biomass (BSP Biomass) and 95% confidence intervals (BSP MCMC 2.5%, 97.5%)[1].

Year	SS S (mt)	s.e.	SS R (1,000s)	s.e.	SS B (mt)	SS B_2+ (mt)	BSP[1] MCMC 2.5%	BSP[1] Mean Biomass	BSP[1] MCMC 97.5%
Unfished	54,184	1,072	873	17					
1951	30,657	1,048	684	194	79,884	68,945	57,370	97,870	156,000
1952	30,275	1,097	737	209	77,228	68,729	48,650	84,460	136,600
1953	29,161	1,547	756	216	73,908	64,765	45,740	78,990	128,300
1954	27,254	2,135	725	208	69,775	60,455	48,060	82,810	134,500
1955	24,826	2,476	781	222	64,558	55,601	45,290	78,590	128,500
1956	22,640	2,583	882	247	60,419	50,809	42,910	74,120	120,600
1957	20,578	2,577	872	248	57,349	46,517	44,030	75,860	123,500
1958	19,477	2,529	889	251	55,673	44,970	46,570	79,580	128,800
1959	17,228	2,483	1,018	282	50,804	40,014	42,080	73,200	119,600
1960	15,905	2,434	1,010	278	49,161	36,870	43,260	74,670	121,900
1961	14,133	2,323	934	258	45,695	33,602	41,210	72,820	120,800
1962	13,003	2,245	826	230	42,529	31,428	38,630	70,980	119,200
1963	14,897	2,285	760	212	46,178	36,135	43,190	76,980	127,800
1964	16,789	2,317	743	206	49,100	39,863	44,770	78,770	129,200
1965	18,832	2,339	717	199	52,893	43,767	47,140	81,460	132,800
1966	19,500	2,281	723	200	53,701	44,914	46,840	81,010	131,400
1967	19,322	2,162	824	217	53,017	44,161	43,980	76,620	124,600
1968	18,849	1,994	802	203	52,862	42,796	42,530	74,650	121,400
1969	18,884	1,798	727	158	53,400	43,617	44,620	77,480	126,700
1970	19,156	1,604	571	143	53,371	44,495	47,120	81,820	133,200
1971	19,436	1,473	576	125	52,088	45,088	47,460	82,820	134,700
1972	19,606	1,510	191	72	51,312	44,257	49,380	85,220	138,500
1973	18,727	1,547	1,460	179	45,489	43,068	52,870	90,430	145,700
1974	17,373	1,532	786	177	52,202	34,394	52,360	89,970	145,000
1975	19,245	1,521	514	128	57,292	47,671	49,530	85,500	138,000
1976	20,588	1,520	616	103	55,747	49,443	49,420	85,200	138,000
1977	19,683	1,463	571	90	51,659	44,121	46,730	81,460	132,700
1978	17,693	1,333	595	89	46,902	39,917	43,980	76,860	125,800
1979	15,233	1,193	709	97	41,859	34,580	42,630	75,060	123,200
1980	14,090	1,060	708	97	40,624	31,986	44,860	78,920	129,100
1981	14,064	945	650	88	41,609	32,917	44,880	78,110	126,900
1982	13,849	844	497	76	40,845	32,864	44,710	78,070	127,700
1983	13,786	755	1,003	83	38,909	32,798	49,790	86,510	140,300
1984	13,199	684	1,188	88	41,333	29,036	50,370	87,720	143,300
1985	14,234	663	569	70	48,267	33,760	55,980	97,930	160,000
1986	15,759	682	852	64	47,543	40,584	57,170	101,800	168,100
1987	16,481	712	661	61	48,361	37,925	59,990	107,300	177,300
1988	16,010	732	1,059	73	46,107	37,986	55,960	100,000	165,900
1989	16,024	752	902	74	49,325	36,307	54,280	95,950	158,100
1990	17,445	779	643	66	53,265	42,138	55,330	97,070	159,100
1991	18,058	788	1,166	76	51,799	43,832	50,840	89,280	146,500
1992	18,660	783	1,381	90	56,095	41,737	51,840	89,480	146,000
1993	18,480	788	827	82	60,165	43,309	46,420	82,130	134,900
1994	19,494	843	831	76	59,113	49,016	40,220	72,140	119,700
1995	20,813	900	955	81	59,262	49,049	37,690	66,430	108,800
1996	21,525	919	984	76	61,069	49,314	39,410	68,950	113,000
1997	22,338	909	285	51	63,881	51,772	39,450	68,260	110,800
1998	21,394	882	1,428	80	55,530	51,959	39,530	68,410	111,000
1999	18,949	855	1,180	90	56,852	39,292	43,880	76,720	125,800
2000	19,850	894	493	70	62,513	48,015	55,340	96,810	158,200
2001	20,689	990	618	68	58,000	51,938	60,920	109,900	182,400
2002	20,350	1,084	656	74	53,798	46,175	57,950	102,800	169,200
2003	18,428	1,147	749	96	49,483	41,401	52,850	92,600	151,600
2004	16,549	1,248	842	114	46,800	37,600	51,700	89,930	146,600
2005	16,138	1,500	410	74	47,606	37,286	51,140	88,480	143,800
2006	16,081	1,937	323	79	44,140	39,109	56,660	97,950	159,100

[1] (Brodziak and Ishimura 2009, BILL-WG 2009b).

Table 14. Stock Synthesis Model-1 estimated time series of annual fishing mortality (F) (the sum of quarterly fishing mortality for all fleets), and total exploitation (Catch mt)/(B_2+ mt); Along with Bayesian surplus production (BSP) estimates of mean exploitable biomass harvest rates (BSP Mean Harvest Rate) and 95% confidence intervals (BSP MCMC 2.5%, 97.5%)[1].

Year	SS F	s.e.	SS C/B_2+	BSP[1] MCMC 2.5%	BSP[1] Mean Harvest Rate	BSP[1] MCMC 97.5%
1951	0.62	0.082	0.17	0.07484	0.1273	0.2036
1952	0.50	0.053	0.17	0.08557	0.1484	0.2403
1953	0.43	0.036	0.19	0.09668	0.1684	0.2713
1954	0.45	0.043	0.23	0.1012	0.1761	0.2832
1955	0.47	0.051	0.25	0.1098	0.1926	0.3116
1956	0.56	0.068	0.30	0.1284	0.224	0.3608
1957	0.64	0.083	0.33	0.1235	0.2155	0.3463
1958	0.90	0.128	0.44	0.1532	0.2654	0.4237
1959	0.91	0.142	0.47	0.1571	0.2754	0.4464
1960	1.27	0.234	0.60	0.1808	0.3167	0.5097
1961	1.47	0.323	0.64	0.1784	0.3188	0.5226
1962	1.10	0.292	0.40	0.1063	0.1938	0.328
1963	0.66	0.130	0.32	0.09081	0.1628	0.2687
1964	0.57	0.113	0.23	0.07135	0.126	0.2059
1965	0.76	0.153	0.26	0.08545	0.1493	0.2407
1966	0.72	0.122	0.27	0.09345	0.1625	0.2622
1967	0.58	0.072	0.29	0.1019	0.1777	0.2885
1968	0.68	0.098	0.29	0.1024	0.1787	0.2921
1969	0.68	0.096	0.28	0.09617	0.1688	0.2731
1970	0.68	0.098	0.25	0.0832	0.1454	0.2352
1971	0.36	0.031	0.20	0.06713	0.1172	0.1906
1972	0.33	0.026	0.20	0.06309	0.1098	0.1769
1973	0.38	0.033	0.23	0.06735	0.116	0.1857
1974	0.39	0.034	0.28	0.0664	0.1144	0.1839
1975	0.50	0.047	0.26	0.08885	0.1534	0.2475
1976	0.58	0.058	0.28	0.09919	0.172	0.2769
1977	0.56	0.047	0.30	0.0993	0.1736	0.282
1978	0.69	0.062	0.35	0.1122	0.1972	0.321
1979	0.59	0.045	0.35	0.09696	0.1713	0.2803
1980	0.70	0.061	0.34	0.08496	0.1494	0.2445
1981	0.76	0.065	0.39	0.101	0.1761	0.2856
1982	0.70	0.052	0.36	0.09315	0.1636	0.2659
1983	0.73	0.047	0.39	0.09103	0.1584	0.2566
1984	0.79	0.054	0.47	0.09466	0.166	0.2694
1985	0.86	0.055	0.47	0.1	0.1756	0.2859
1986	0.73	0.045	0.36	0.08786	0.1565	0.2583
1987	0.70	0.042	0.41	0.08732	0.1558	0.2581
1988	0.67	0.041	0.37	0.08453	0.1515	0.2507
1989	0.67	0.039	0.37	0.08423	0.1495	0.2454
1990	0.73	0.046	0.37	0.09892	0.1742	0.2843
1991	0.60	0.032	0.33	0.09766	0.1725	0.2815
1992	0.84	0.045	0.48	0.136	0.2379	0.3829
1993	0.85	0.048	0.47	0.1511	0.2672	0.4391
1994	0.66	0.037	0.33	0.1362	0.244	0.4051
1995	0.59	0.035	0.30	0.1339	0.2361	0.3866
1996	0.58	0.039	0.28	0.1236	0.2175	0.3541
1997	0.64	0.033	0.33	0.1543	0.2683	0.4332
1998	0.80	0.044	0.35	0.1632	0.2839	0.4583
1999	0.71	0.039	0.40	0.1242	0.2189	0.3561
2000	0.73	0.042	0.39	0.1175	0.2064	0.3361
2001	0.54	0.027	0.29	0.08383	0.1503	0.2509
2002	0.56	0.032	0.32	0.08654	0.1536	0.2527
2003	0.59	0.040	0.35	0.09525	0.1677	0.2733
2004	0.59	0.049	0.35	0.0888	0.1554	0.2518
2005	0.57	0.061	0.34	0.08939	0.1558	0.2513
2006	0.68	0.099	0.37	0.07335	0.1277	0.206

[1] (Brodziak and Ishimura 2009, BILL-WG 2009b).

Table 15. Stock Synthesis model results for individual likelihood component fits to CPUE data (Total, S1, S8, and S15) total recruitment, and total objective function, along with the total number of estimated parameters.

	Total (S)	S1	S8	S15	Total Recruitment	Total Obj Fun	# Parameters
Model-1	**-63**	**-53**	**-6**	**-4**	**-15**	**1,764**	**111**
Sensitivity-1	-63	-53	-6	-4	-15	1,763	111
Sensitivity-2	-28	-37	-3	12	-8	8,830	111
Sensitivity-3	-118	-100	-8	-10	-21	-66	111
Sensitivity-4	-66	-55	-6	-5	-21	1,755	111
Sensitivity-5	-68	-57	-6	-5	10	1,779	111
Initial F-1	-58	-49	-6	-4	-15	1,771	110
Initial F-2	-59	-50	-6	-4	-15	1,770	111
Initial F-3	-60	-51	-6	-4	-15	1,768	111
Initial F-4	-62	-52	-6	-4	-15	1,766	111
Selectivity-1	-56	-49	-5	-2	-11	1,797	103
Selectivity-2	-64	-53	-5	-5	-15	1,745	125
Selectivity-3	-65	-54	-6	-5	-16	1,678	159
Growth-1	-71	-60	-6	-5	-4	1,600	113
Growth-2	-71	-60	-6	-5	-4	1,601	114
Growth-3	-78	-65	-5	-7	-5	1,582	117
Growth-4	-71	-60	-6	-5	-7	1,631	115
Growth-5	-69	-59	-5	-4	-11	1,542	117
Growth-6	-79	-66	-5	-7	-12	1,521	123

Table 16. Stock Synthesis model results for 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
Model-1	**1,840**	**718**	**514**	**14**	**175**	**62**	**54**	**6**	**1**	**108**	**187**
Sensitivity-1	1,839	718	514	14	175	62	54	6	1	108	187
Sensitivity-2	8,860	2,644	2,303	101	1,290	443	327	64	14	638	1,035
Sensitivity-3	73	20	17	1	14	4	4	0	0	5	8
Sensitivity-4	1,840	722	513	14	174	61	54	6	1	108	187
Sensitivity-5	1,836	723	510	14	172	61	53	6	1	108	187
Initial F-1	1,842	717	516	15	176	62	54	6	1	108	186
Initial F-2	1,842	717	516	15	176	62	54	6	1	108	187
Initial F-3	1,841	717	515	14	176	62	54	6	1	108	187
Initial F-4	1,840	718	515	14	175	62	54	6	1	108	187
Selectivity-1	1,863	745	511	14	171	63	54	6	1	109	188
Selectivity-2	1,823	711	505	14	174	62	54	6	1	110	186
Selectivity-3	1,755	703	475	16	164	59	49	5	1	108	177
Growth-1	1,674	647	439	14	166	59	53	6	2	104	183
Growth-2	1,674	647	440	14	165	59	53	6	1	104	183
Growth-3	1,665	642	437	15	164	60	53	7	2	105	180
Growth-4	1,709	678	434	15	174	61	55	8	3	95	185
Growth-5	1,620	606	409	15	169	59	54	6	2	120	180
Growth-6	1,611	602	406	15	168	60	53	7	2	119	179

Table 17. Sensitivity analysis results for unfished female spawning biomass (S_0), total biomass in 1951 (B_1951) and the ratios of ending year to female spawning biomass at MSY (S_2006/S_MSY), unfished female spawning biomass (S_2006/S_0), unfished recruitment (R_2006/R_0), total biomass in 1951 (B_2006/B_1951), and age 2+ biomass in 1951 (B_2+ 2006/B_2+ 1951).

	S_0 (Unfished mt)	B_1951 (mt)	S_2006/ S_MSY	S_2006/ S_0	R_2006/ R_0	B_2006/ B_1951	(B_2+ 2006)/ (B_2+ 1951)
Model-1	**54,184**	**79,884**	**1.47**	**30%**	**37%**	**55%**	**57%**
Sensitivity-1	54,177	79,857	1.47	30%	37%	55%	57%
Sensitivity-2	49,821	71,420	**0.86**	17%	15%	33%	34%
Sensitivity-3	63,931	99,136	1.76	35%	80%	63%	60%
Sensitivity-4	52,266	75,468	1.64	33%	45%	63%	65%
Sensitivity-5	48,280	66,451	1.88	38%	48%	76%	78%
Initial F-1	54,266	128,349	1.49	30%	37%	35%	34%
Initial F-2	54,249	119,180	1.49	30%	37%	37%	36%
Initial F-3	54,224	105,048	1.48	30%	37%	42%	42%
Initial F-4	54,203	92,797	1.48	30%	37%	48%	48%
Selectivity-1	51,434	77,488	1.31	26%	33%	48%	49%
Selectivity-2	55,150	82,029	1.62	33%	53%	61%	51%
Selectivity-3	67,760	109,819	2.29	44%	42%	73%	65%
Growth-1	79,676	146,402	3.49	65%	52%	84%	93%
Growth-2	78,950	144,525	3.46	65%	52%	84%	93%
Growth-3	90,245	172,066	3.77	78%	65%	103%	99%
Growth-4	109,935	170,167	3.10	62%	58%	82%	90%
Growth-5	159,314	273,494	3.67	67%	45%	77%	84%
Growth-6	208,846	369,711	3.93	76%	93%	99%	97%

Table 18. Stock Synthesis model estimates of maximum sustainable yield (MSY), fishing mortality at MSY (F_MSY), initial fishing mortality for fleet 1 (Init_F_F1), maximum F during the years 1951 – 2006, average F during the years 1951 - 2006, average F during the years 1995 – 2006 (F_Avg (1995-2006)), and the ratio F_Avg (1995-2006) to F_MSY.

	MSY	F_MSY	s.e	Init_F_F1	s.e	F_Max 1951-2006	F_Avg 1951- 2006	F_Avg 1995-2006	F_Avg (1995-2006) / F_MSY
Model-1	**15,529**	**0.79**	**0.036**	**0.81**	**0.040**	**1.47**	**0.67**	**0.63**	**0.80**
Sensitivity-1		0.80	0.033	0.81	0.040	1.49	0.67	0.63	0.80
Sensitivity-2		0.81	0.015	0.83	0.030	1.69	0.80	0.79	0.98
Sensitivity-3		0.68	0.104	0.83	0.160	1.09	0.50	0.64	0.94
Sensitivity-4		0.80	0.035	0.84	0.042	1.62	0.69	0.62	0.78
Sensitivity-5		0.80	0.035	0.92	0.049	2.08	0.77	0.61	0.76
Initial F-1		0.79	0.035	0.00	_	1.22	0.62	0.63	0.79
Initial F-2		0.79	0.035	0.11	0.005	1.26	0.62	0.63	0.80
Initial F-3		0.79	0.035	0.31	0.014	1.32	0.64	0.63	0.80
Initial F-4		0.79	0.035	0.52	0.025	1.39	0.65	0.63	0.80
Selectivity-1		0.80	0.038	0.69	0.027	1.65	0.73	0.68	0.85
Selectivity-2		0.83	0.046	0.80	0.039	1.31	0.62	0.61	0.73
Selectivity-3		0.73	0.022	0.64	0.044	0.83	0.42	0.38	0.52
Growth-1		1.38	0.095	0.43	0.038	0.35	0.18	0.15	0.11
Growth-2		1.35	0.094	0.44	0.068	0.36	0.18	0.15	0.11
Growth-3		1.40	0.116	0.38	0.076	0.30	0.15	0.13	0.09
Growth-4		0.83	0.045	0.36	0.032	0.43	0.23	0.20	0.24
Growth-5		1.00	0.070	0.22	0.064	0.21	0.12	0.11	0.11
Growth-6		1.02	0.085	0.16	0.045	0.18	0.09	0.08	0.08

Table 19. Von Bertalanffy growth parameters estimated independently from the Central North Pacific (VBG, Table 1), for Model-1, and estimated within SS for sensitivity analyses runs (Growth 1-6).

			K	t_0	L_inf
VBG	Combined Sex		0.26	-1.31	219.66
Model -1	Combined Sex		0.26	-1.31	219.66
Growth-1	Combined Sex		0.15	-2.38	226.59
Growth-2	Combined Sex		0.15	-2.39	227.45
Growth-3	Combined Sex	1951-1998	0.13	-2.70	234.42
Growth-3	Combined Sex	1999-2006	0.20	-2.08	210.32

			K	t_0	L_inf
VBG	Female		0.25	-1.24	230.50
VBG	Male		0.271	-1.37	208.9
Growth-4	Female		0.18	-1.89	233.75
Growth-4	Male		0.20	-1.03	211.03
Growth-5	Female		0.18	-1.86	234.15
Growth-5	Male		0.22	-2.34	181.88
Growth-6	Female	1951-1998	0.17	-2.01	233.93
Growth-6	Male	1951-1998	0.20	-2.56	182.09
Growth-6	Female	1999-2006	0.15	-2.73	242.15
Growth-6	Male	1999-2006	0.33	-1.12	184.72

Table 20. Results of the test for convergence.

	Ending Total Likelihood	ln R0	R0	Phase 1 Likelihood	Phase Estimated R0	Phase Estimated Recruitment Deviation
run1	1779	6.8	858.4	4849.4	2	1
run2	1764	6.8	873.1	3646.5	1	2
run3	1764	6.8	873.1	6195.1	1	2
run4	1764	6.8	873.1	7620.7	1	4
run5	1763	6.8	872.5	5512.8	1	1
run6	1764	6.8	873.1	6779.1	1	4
run7	1763	6.8	872.5	5776.6	1	4
run8	1763	6.8	872.5	3671.8	1	1
run9	1764	6.8	873.1	4903.8	2	3
run10	1763	6.8	872.5	5300.0	1	2
run11	1766	6.8	858.4	7987.5	2	3
run12	1763	6.8	872.5	4512.4	1	3
run13	1763	6.8	872.5	7256.7	2	3
run14	1764	6.8	873.1	3660.3	1	1
run15	1763	6.8	872.5	7844.7	2	2
run16	1764	6.8	873.1	3984.4	1	1
run17	1763	6.8	872.5	6432.9	1	2
run18	1764	6.8	873.1	4172.2	1	3
run19	1798	6.7	834.9	6266.5	1	1
run20	1764	6.8	873.1	9830.3	3	3
base	1764	6.8	873.1	5647.8	1	3

Figures

Stock Scenario - 1

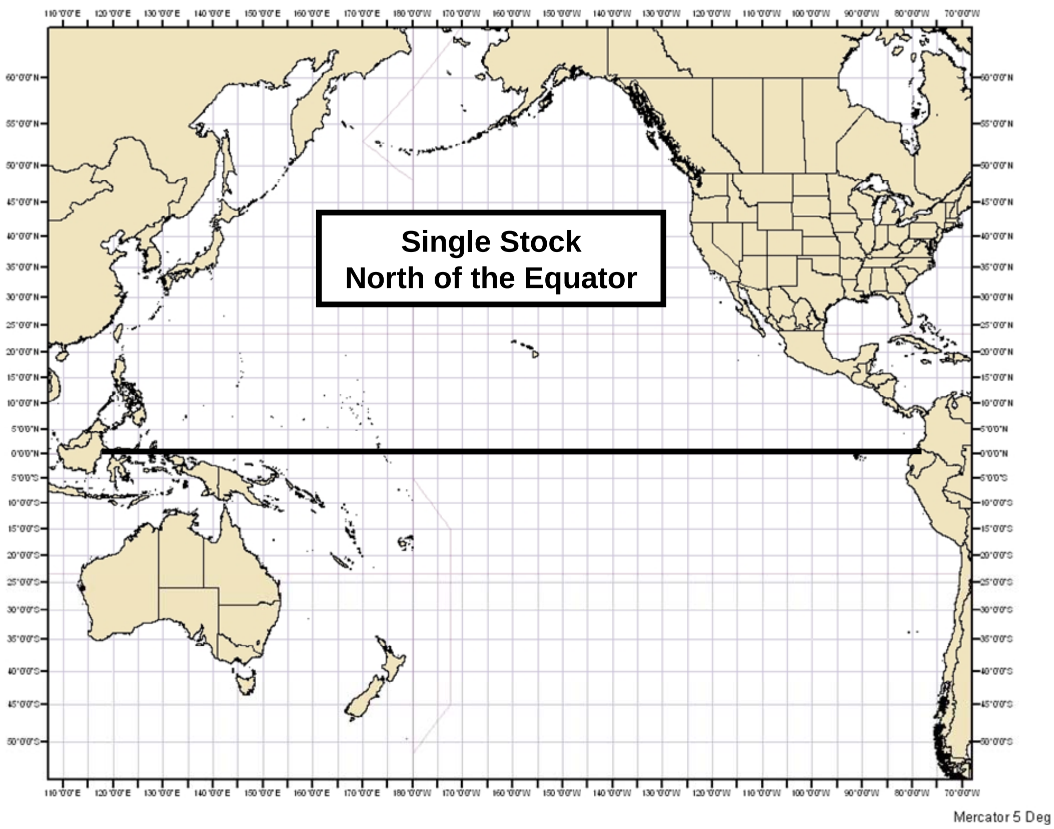

Figure 1. Stock Scenario-1, a single North Pacific stock north of the equator (BILLWG 2009a, BILLWG 2009b).

Stock Scenario - 1

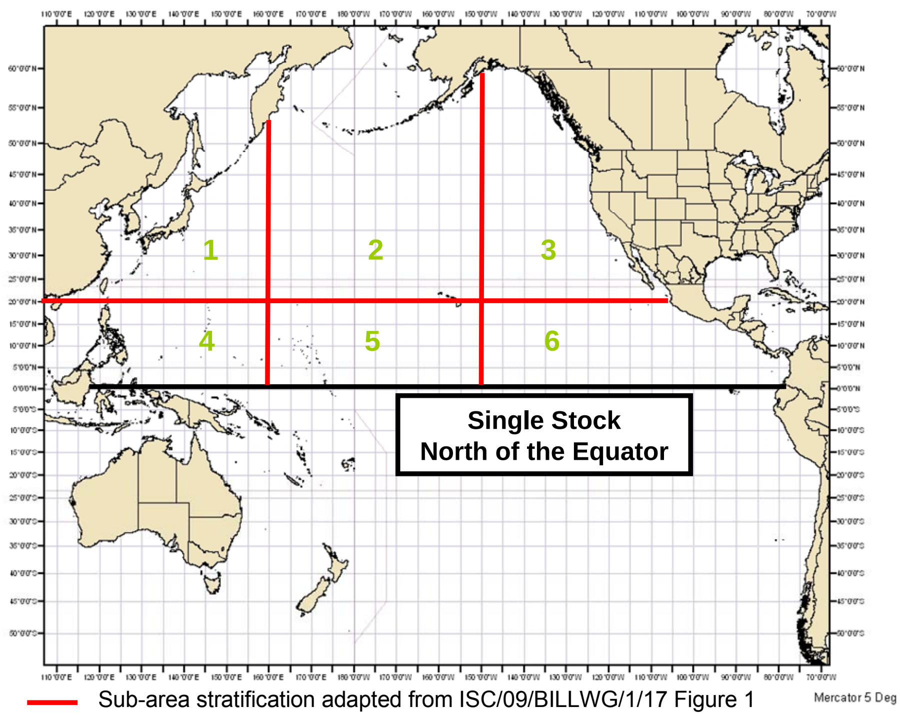

Figure 2. Regional stratification (6 regions) under Stock Scenario – 1 (BILL-WG 2009a, BILL-WG 2009b).

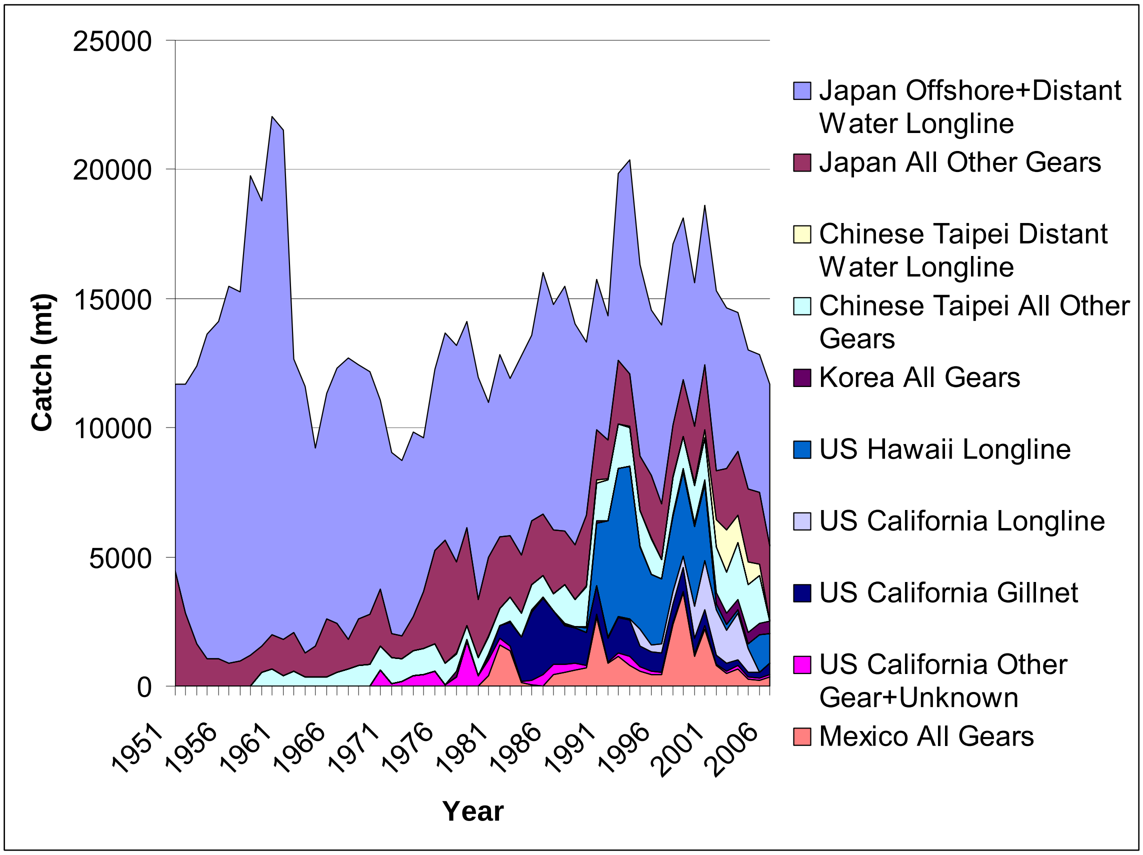

Figure 3. Annual catch of swordfish (mt) in the North Pacific by fleet (Courtney and Wagatsuma 2009).

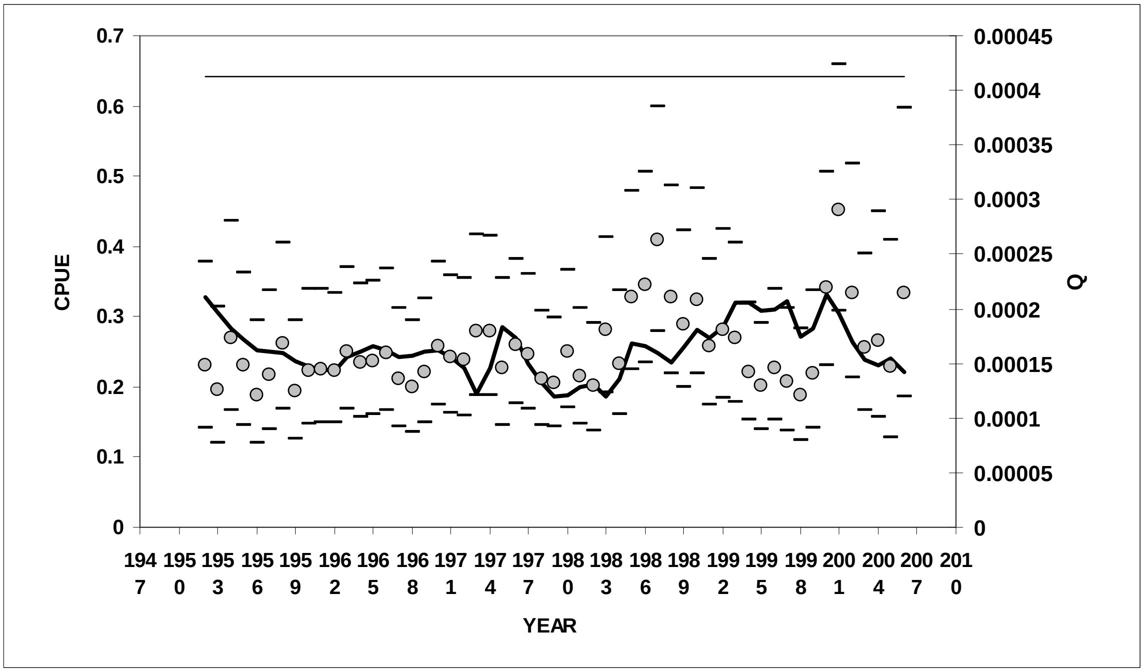

Figure 4.1. Model-1 fit to standardized CPUE time series from Japan Offshore+Distant Water Longline from all regions combined (S1). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

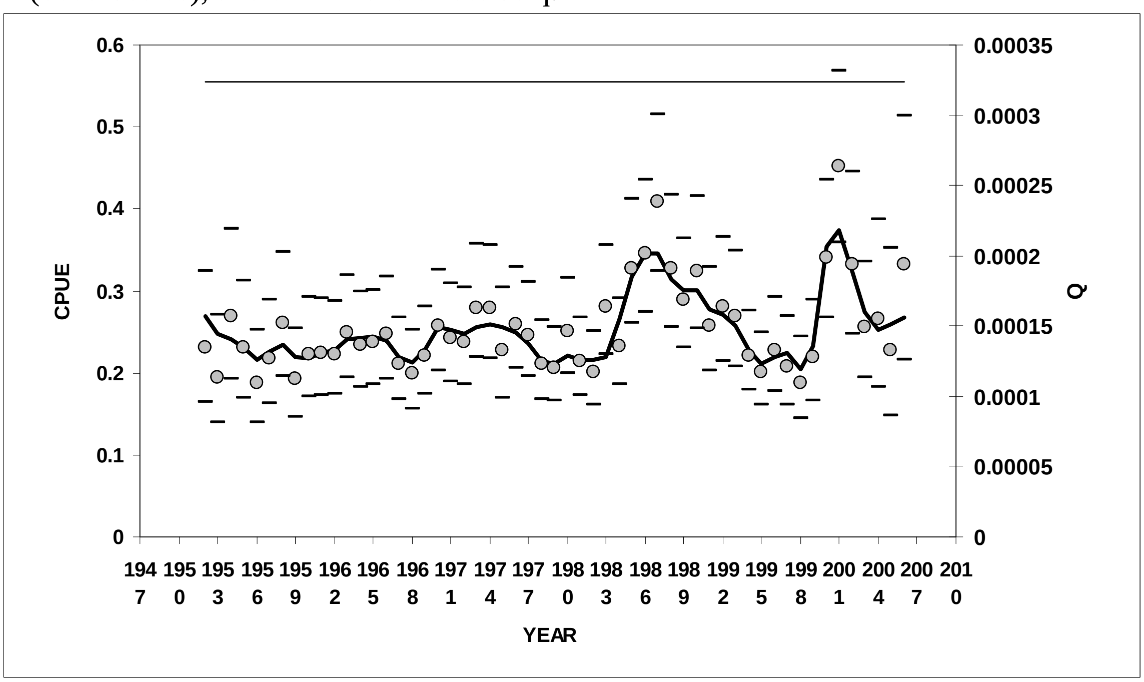

Figure 4.2. Sensitivity-3 fit to standardized CPUE time series from Japan Offshore+Distant Water Longline from all regions combined (S1). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

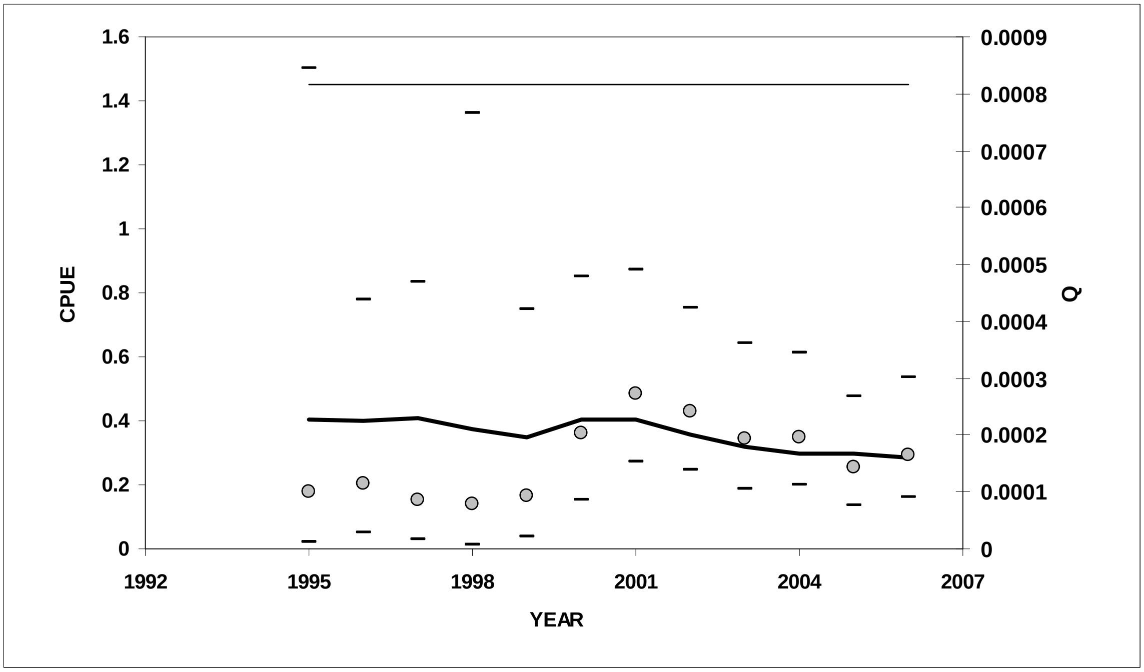

Figure 5.1. Model-1 fit to standardized CPUE time series from Chinese Taipei Distant Water Longline from all regions combined (S8). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

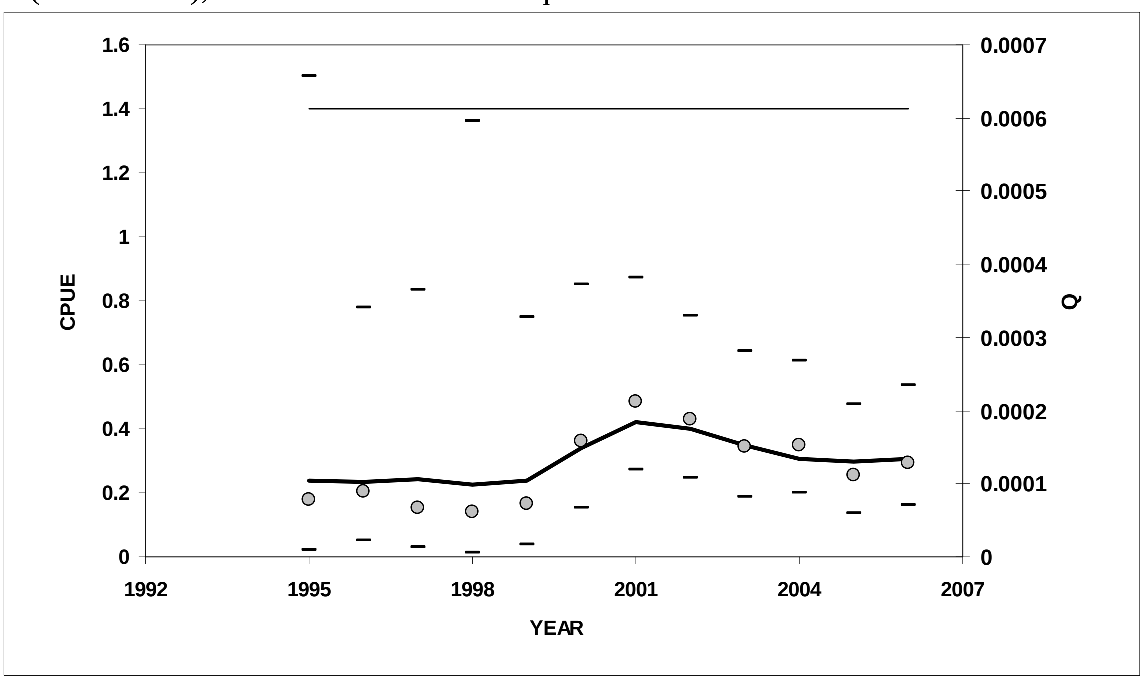

Figure 5.2. Sensitivity-3 fit to standardized CPUE time series from Chinese Taipei Distant Water Longline from all regions combined (S8). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

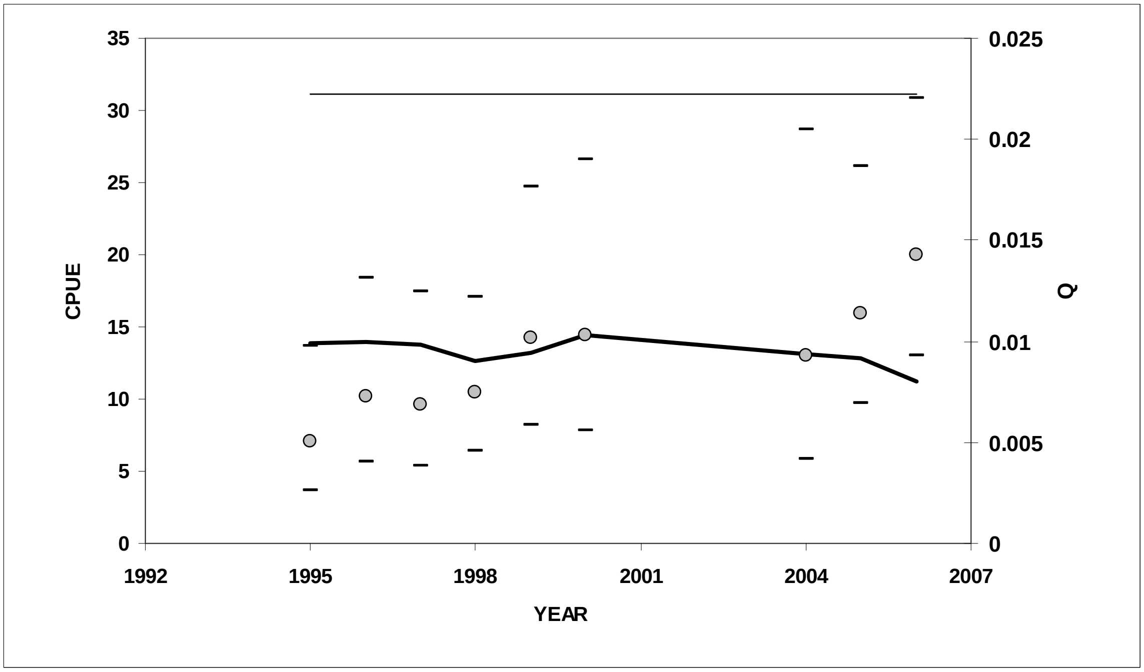

Figure 6.1. Model-1 fit to standardized CPUE time series from US Hawaii Longline Shallow-Set (S15). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

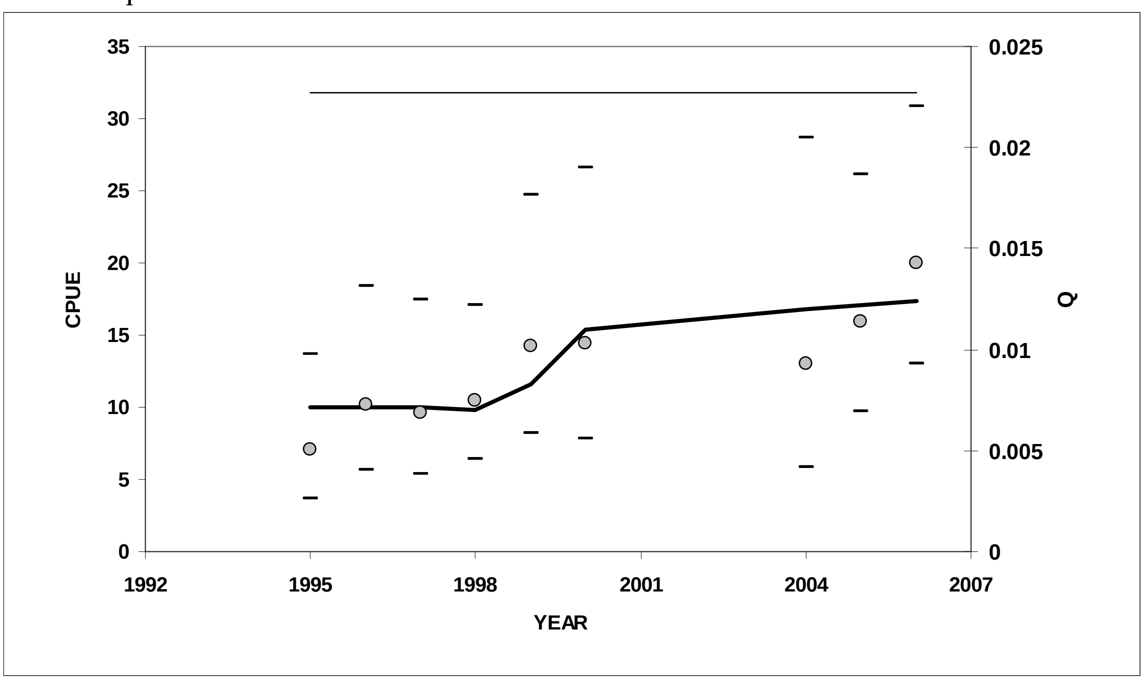

Figure 6.2. Sensitivity-3 fit to standardized CPUE time series from US Hawaii Longline Shallow-Set (S15). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

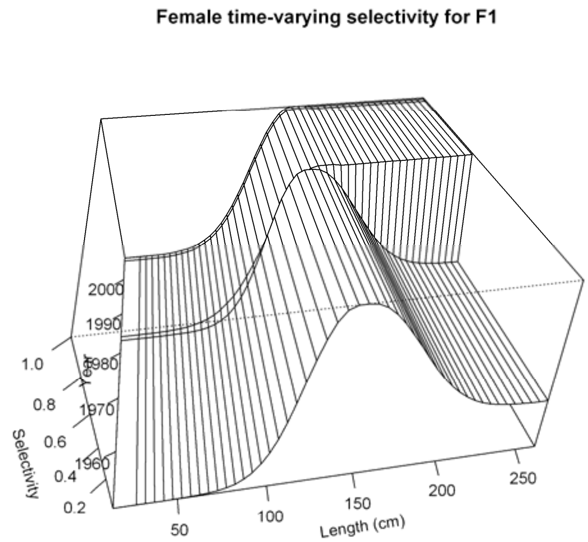

Figure 7.1. Model-1 length selectivity (F1) Japan Offshore + Distant Water Longline in Region-1 (R1) (Female = Male; 1951 – 1983, 1984 – 2006).

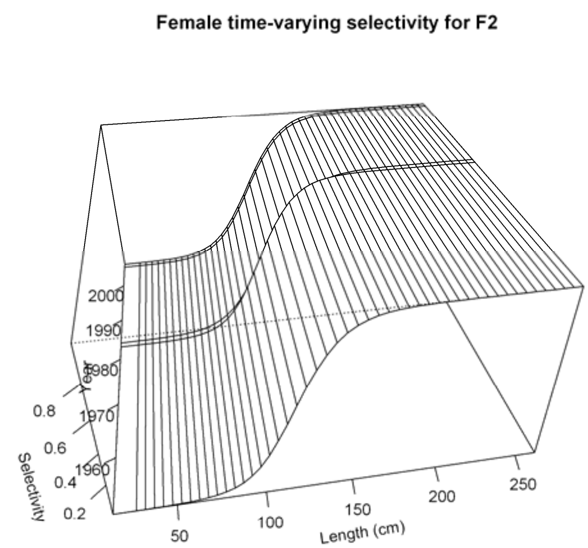

Figure 7.2. Model-1 length selectivity (F2) Japan Offshore + Distant Water Longline in Region-2 (R2) (Female = Male; 1951 – 1983, 1984 – 2006).

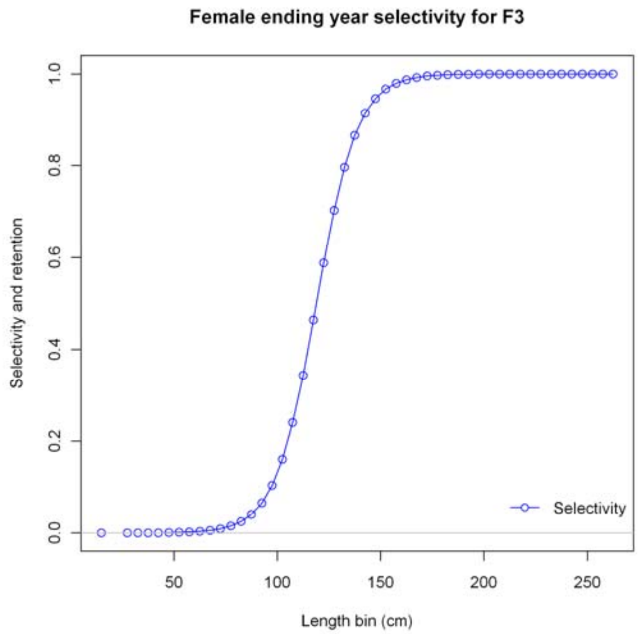

Figure 7.3. Model-1 length selectivity (F3) Japan Offshore + Distant Water Longline in Region-3 (R3) (Female = Male; 1951 – 2006).

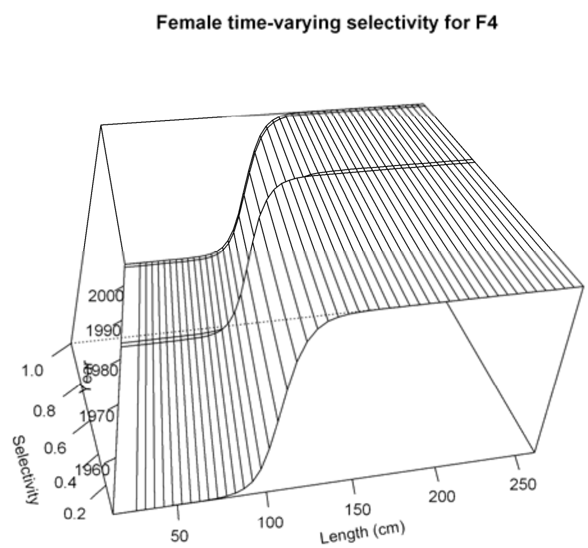

Figure 7.4. Model-1 length selectivity (F4) Japan Offshore + Distant Water Longline in Region-4 (R4) (Female = Male; 1951 – 1983, 1984 – 2006).

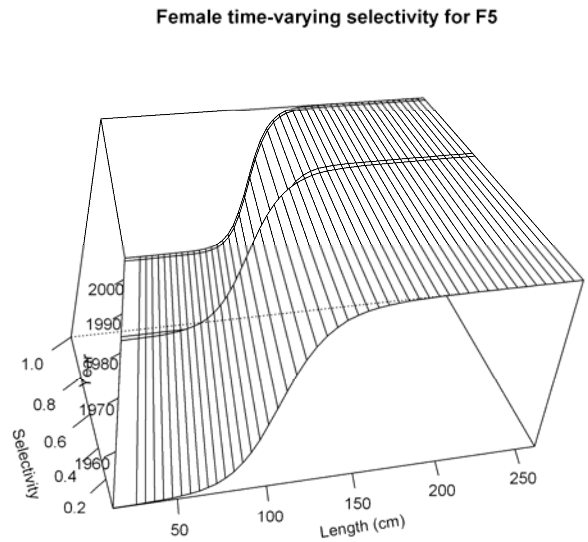

Figure 7.5. Model-1 length selectivity (F5) Japan Offshore + Distant Water Longline in Region-5 (R5) (Female = Male; 1951 – 1983, 1984 – 2006).

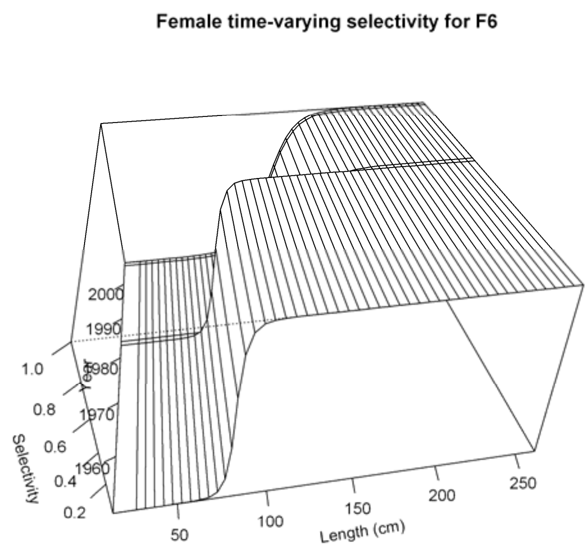

Figure 7.6. Model-1 length selectivity (F6) Japan Offshore + Distant Water Longline in Region-6 (R6) (Female = Male; 1951 – 1983, 1984 – 2006).

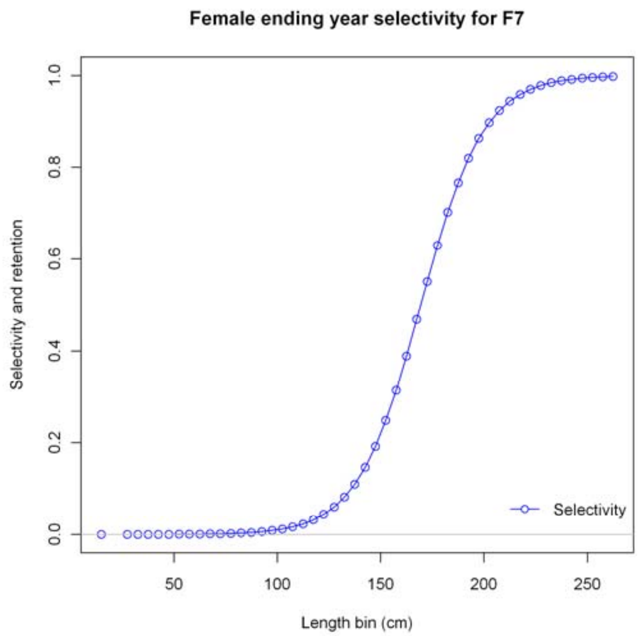

Figure 8. Model-1 length selectivity (F7) Japan Driftnet in Region -1 (R1) (Females=Males; 2004 – 2006).

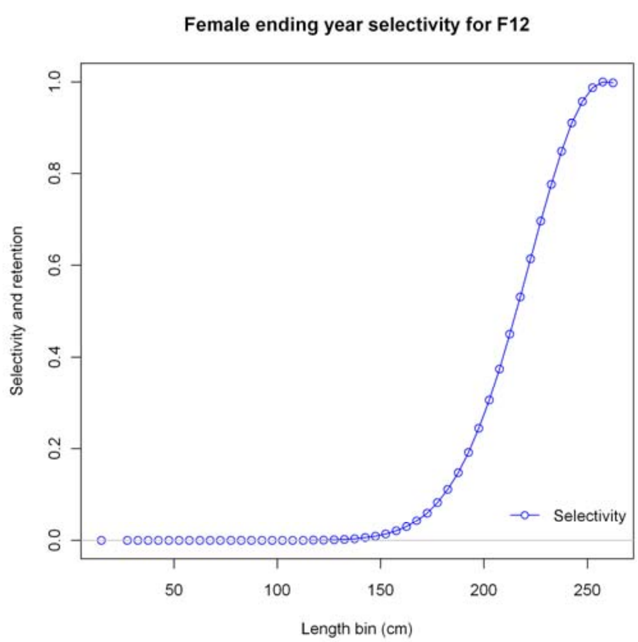

Figure 9. Model-1 length selectivity (F12) Japan Other Primarily Harpoon in Region -1 (R1) (Females=Males; 2006).

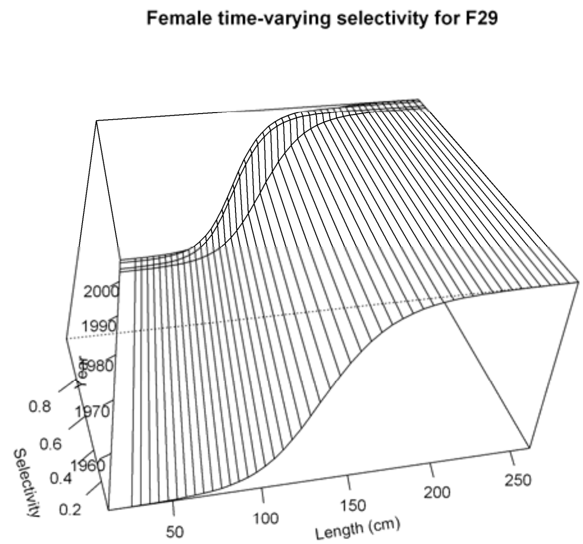

Figure 10. Model-1 length selectivity (F29) US Hawaii Longline Shallow Set (Females=Males; 1995 – 2003, 2004 – 2006).

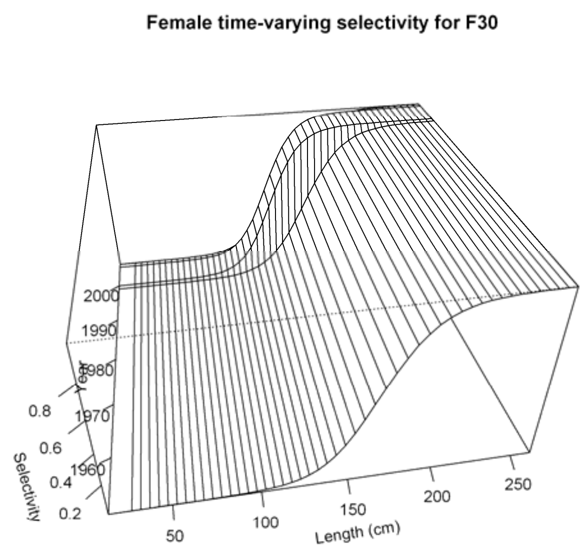

Figure 11. Model-1 length selectivity (F30) US California Gillnet (Females=Males; 1980 – 1999, 2000 – 2006).

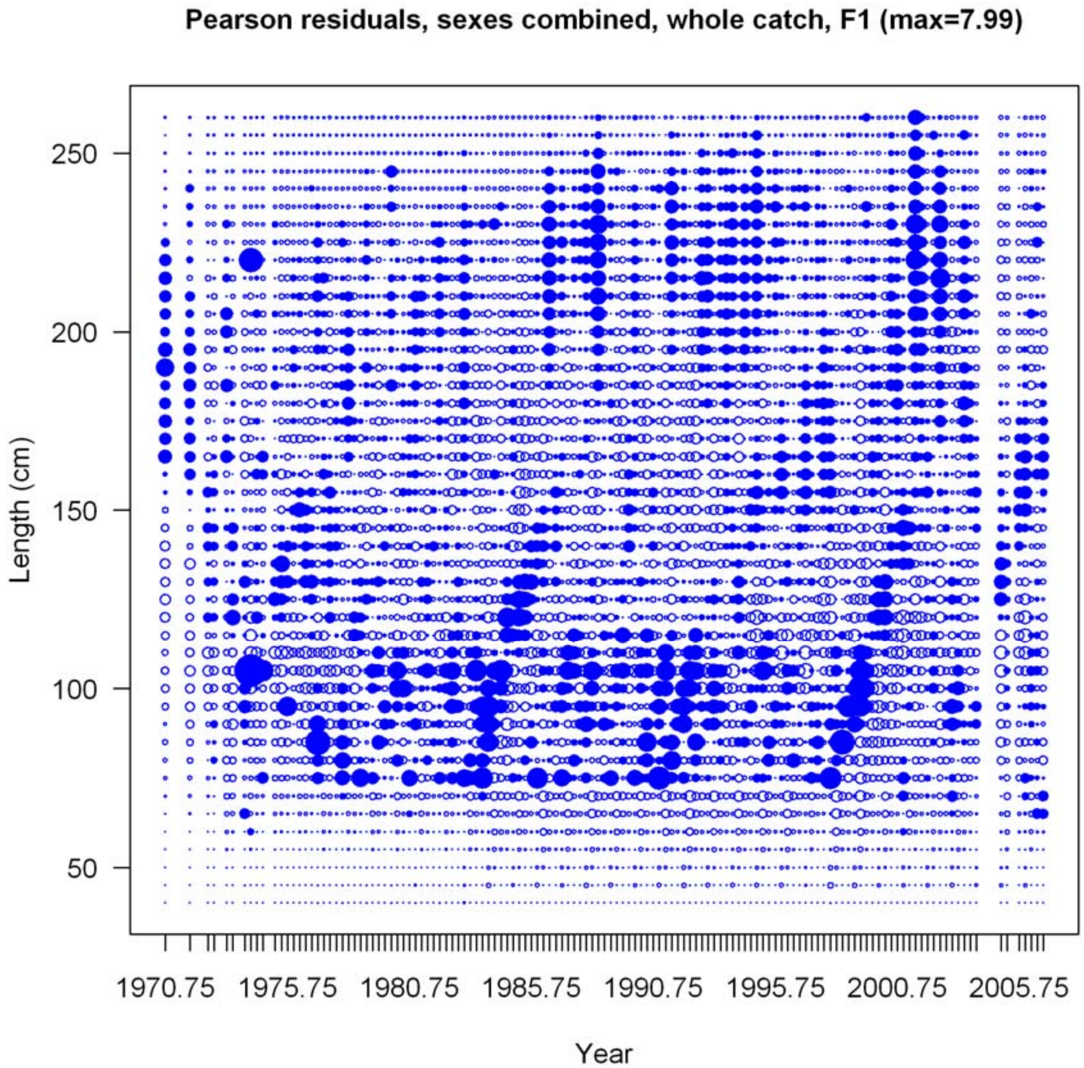

Figure 12.1. Model-1 length frequency fit for Japan Offshore + Distant Water Longline (F1) Region-1 (R1). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

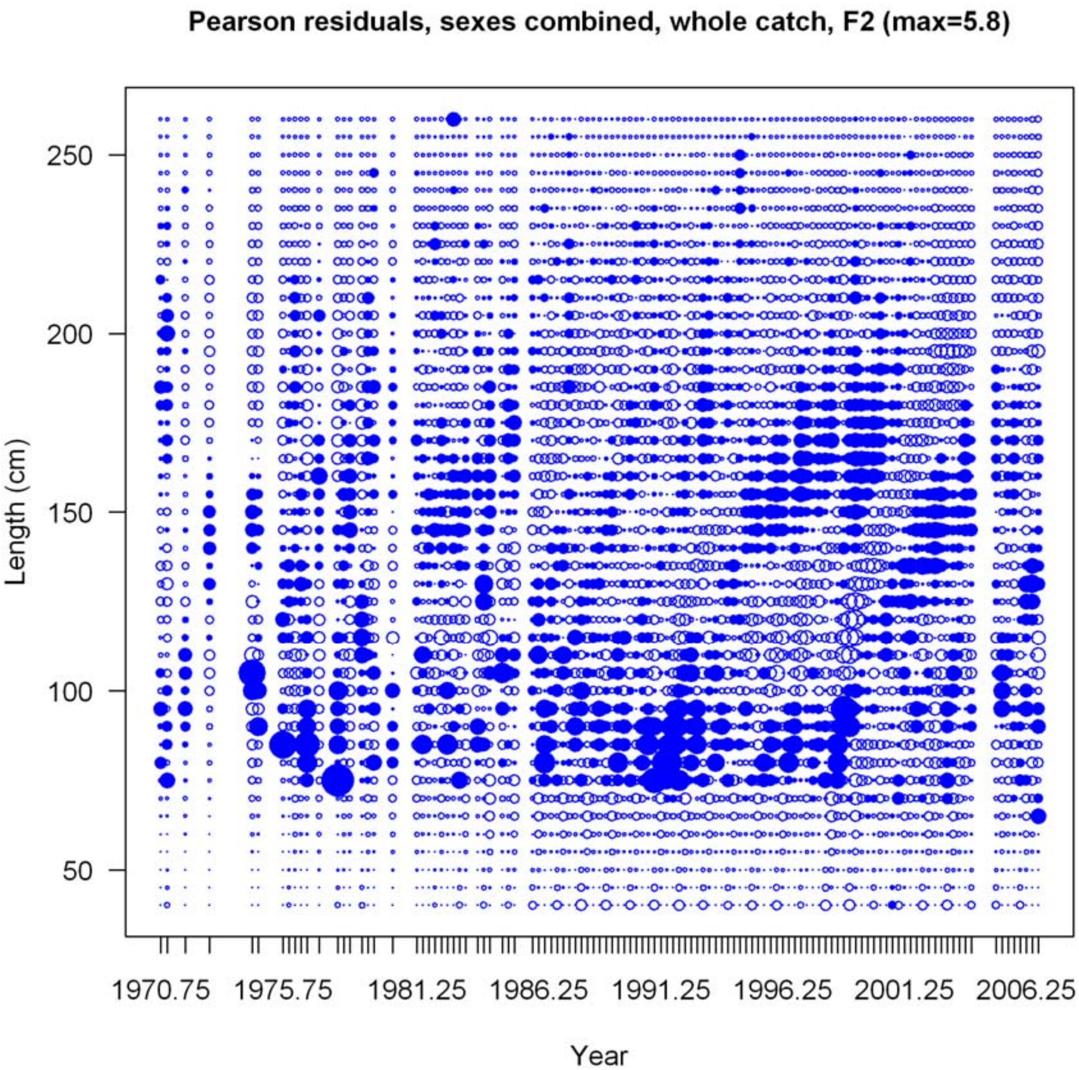

Figure 12.2. Model-1 length frequency fit for Japan Offshore + Distant Water Longline (F2) Region-2 (R2). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

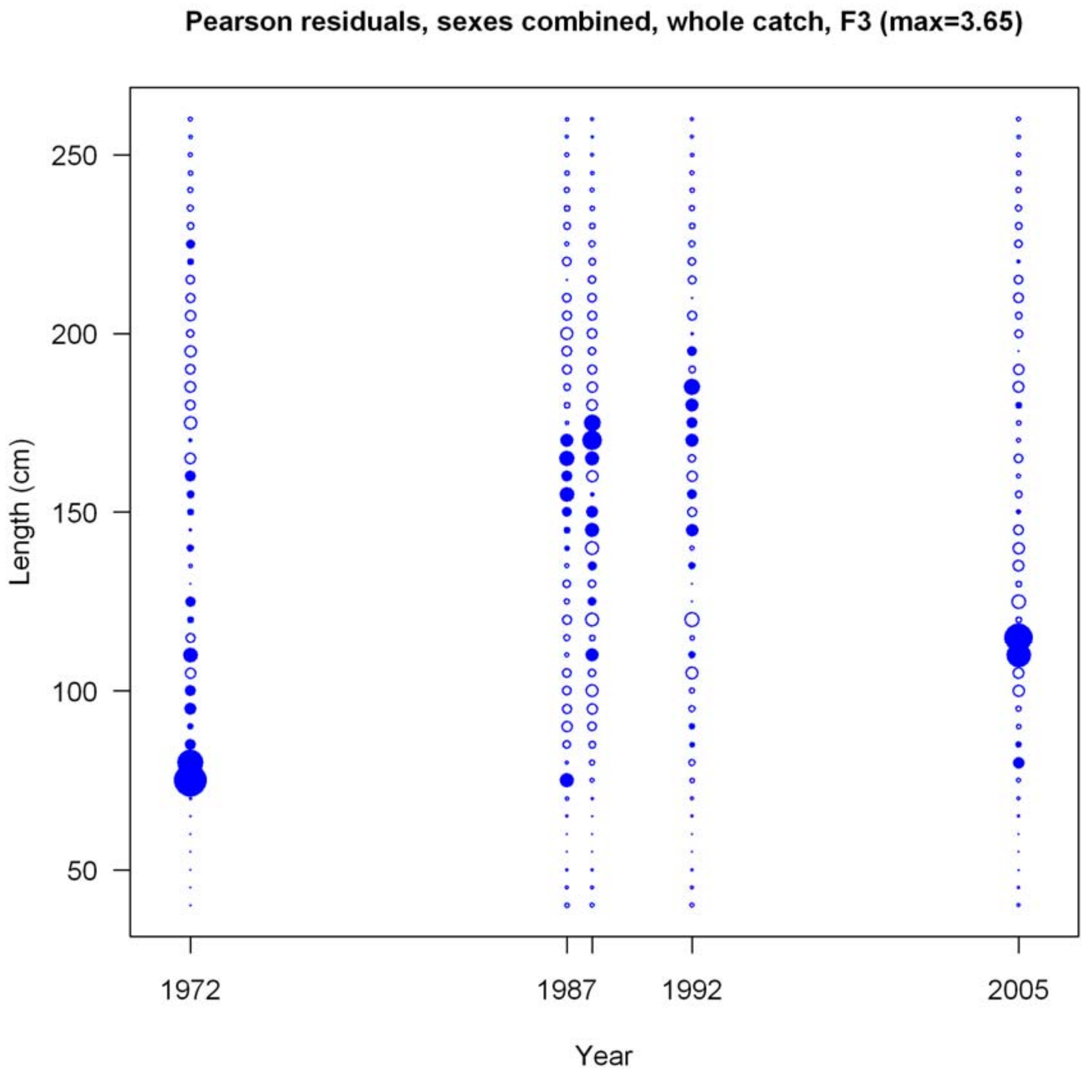

Figure 12.3. Model-1 length frequency fit for Japan Offshore + Distant Water Longline (F3) Region-3 (R3). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

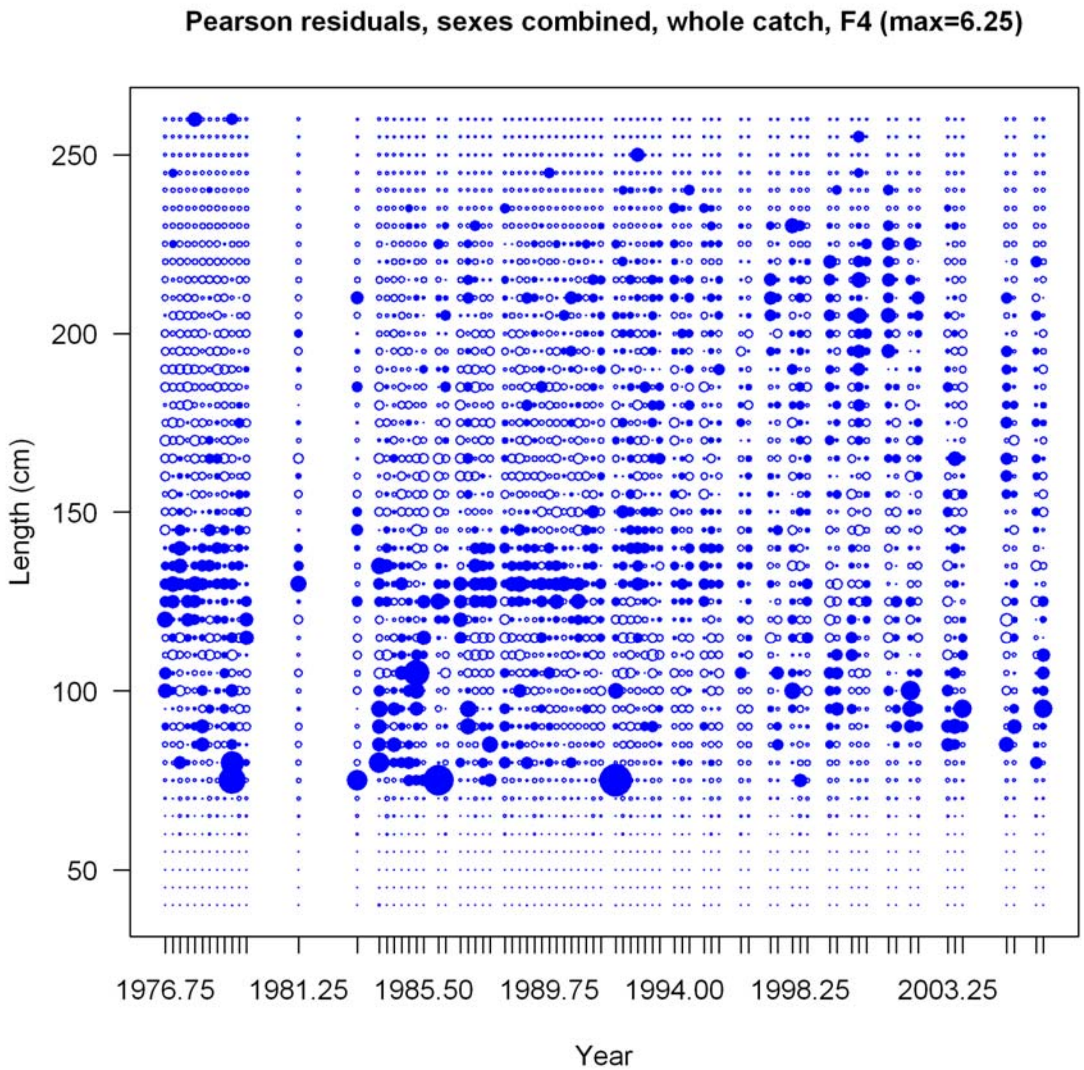

Figure 12.4. Model-1 length frequency fit for Japan Offshore + Distant Water Longline (F4) Region-4 (R4). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

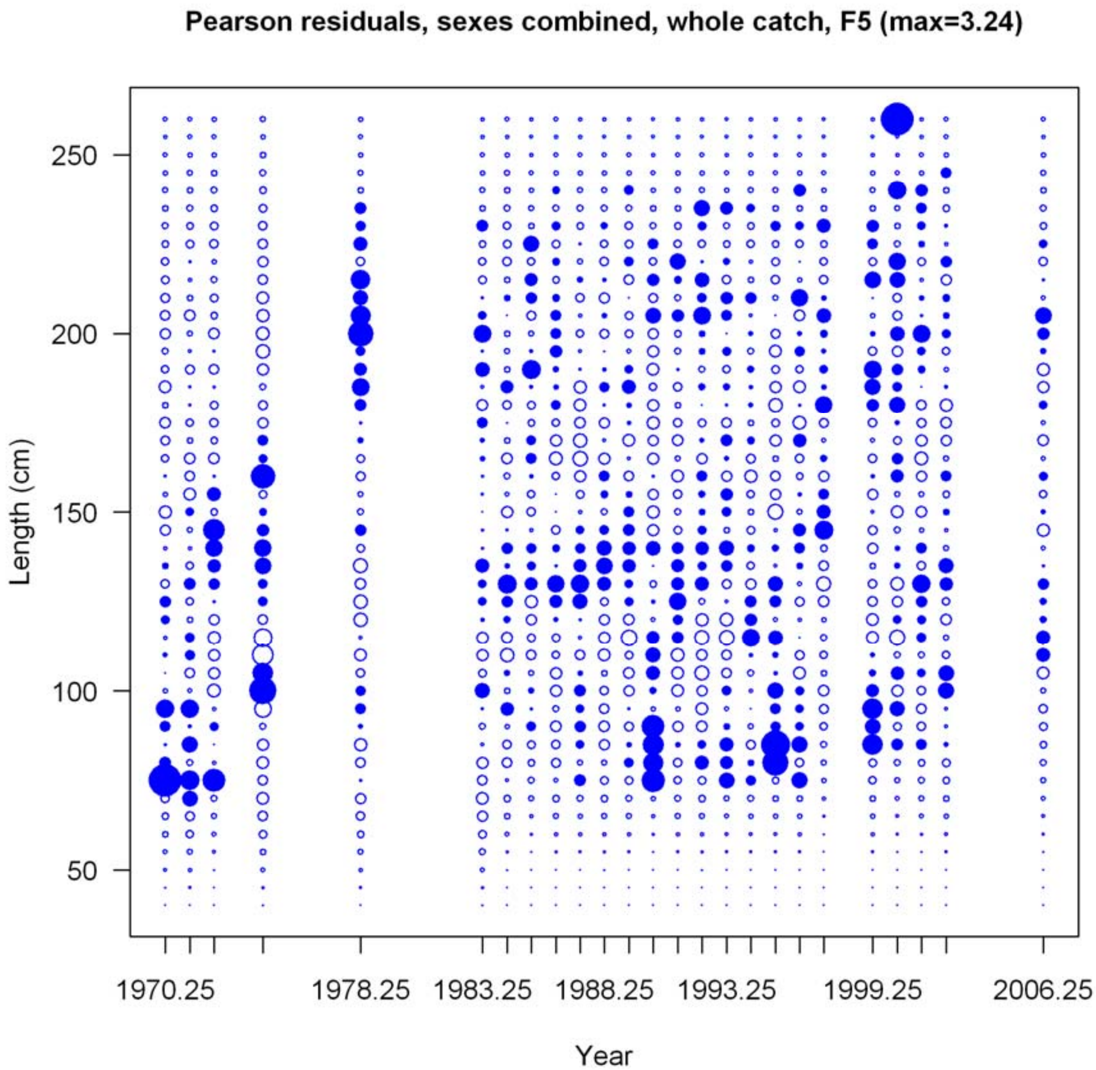

Figure 12.5. Model-1 length frequency fit for Japan Offshore + Distant Water Longline (F5) Region-5 (R5). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

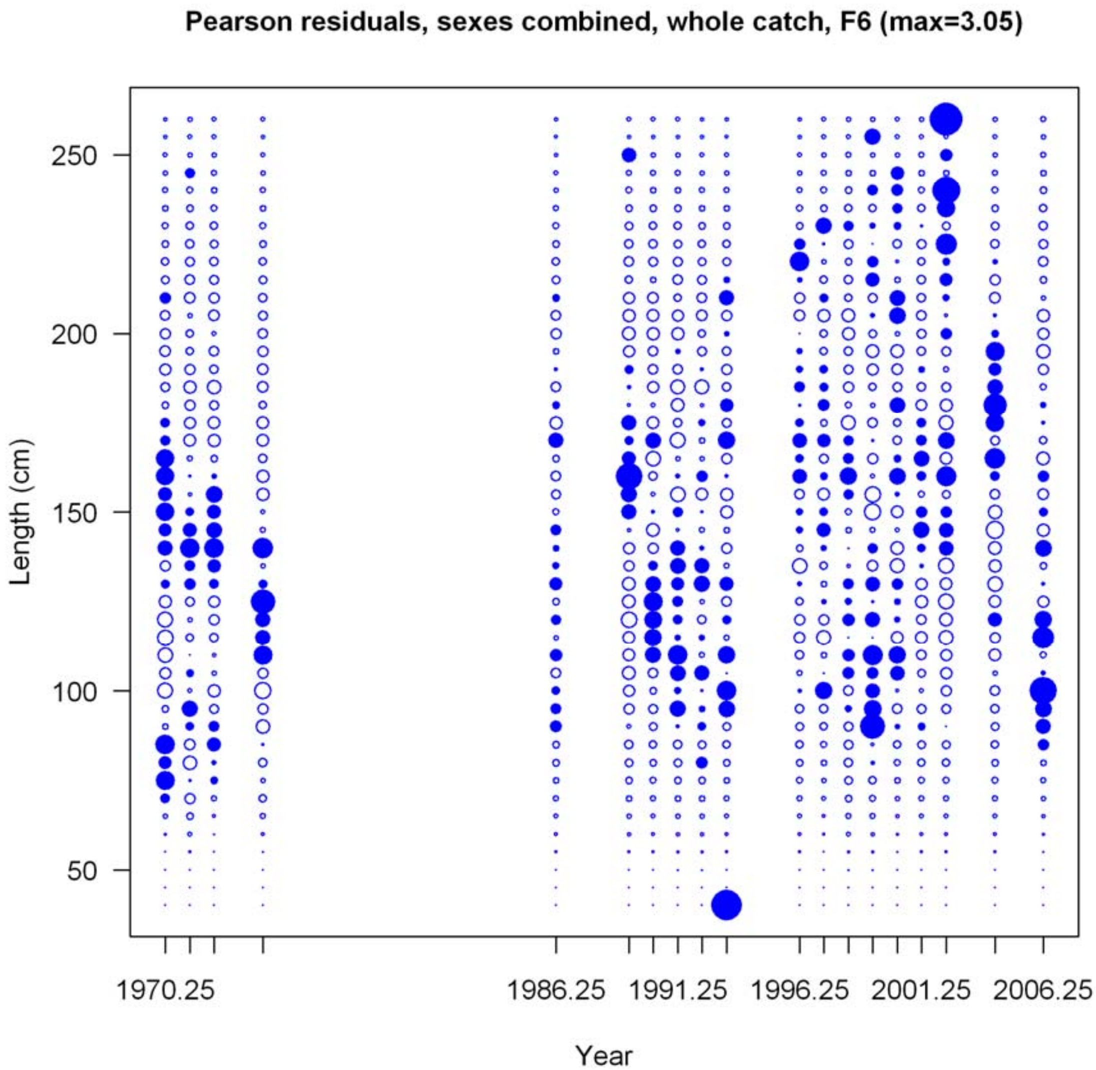

Figure 12.6. Model-1 length frequency fit for Japan Offshore + Distant Water Longline (F6) Region-6 (R6). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

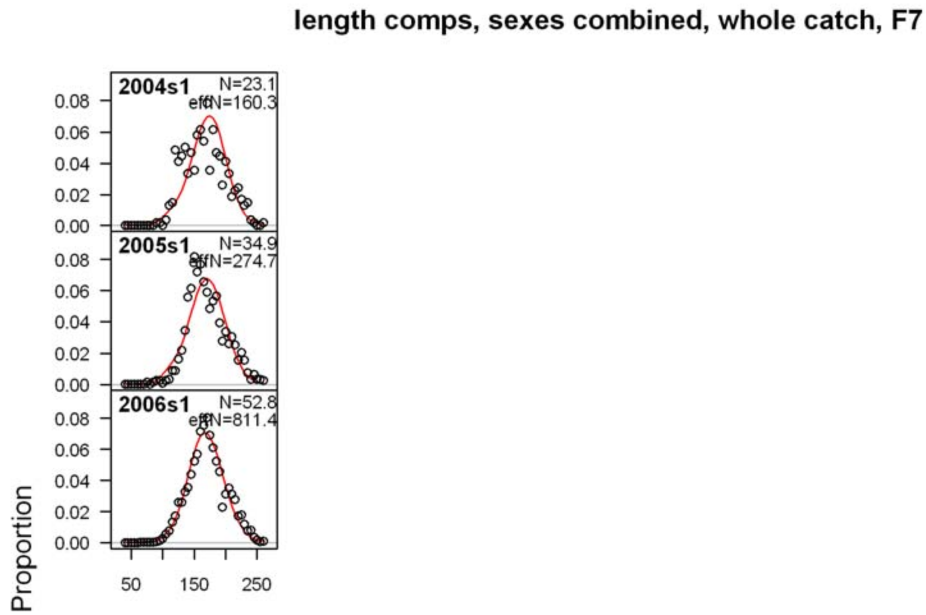

Figure 13. Model-1 length frequency fits from Japan Driftnet (F7) in Region-1 (R1) (Females=Males; 2004 – 2006).

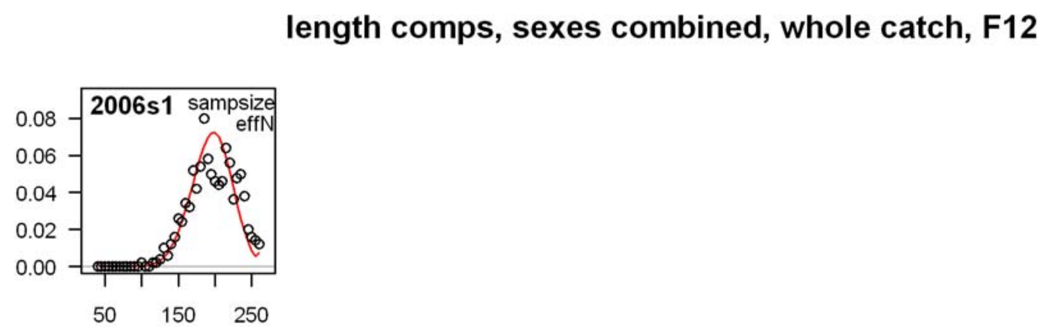

Figure 14. Model-1 length frequency fit from Japan Other Primarily Harpoon (F12) in Region-1 (R1) (Females=Males; 2006).

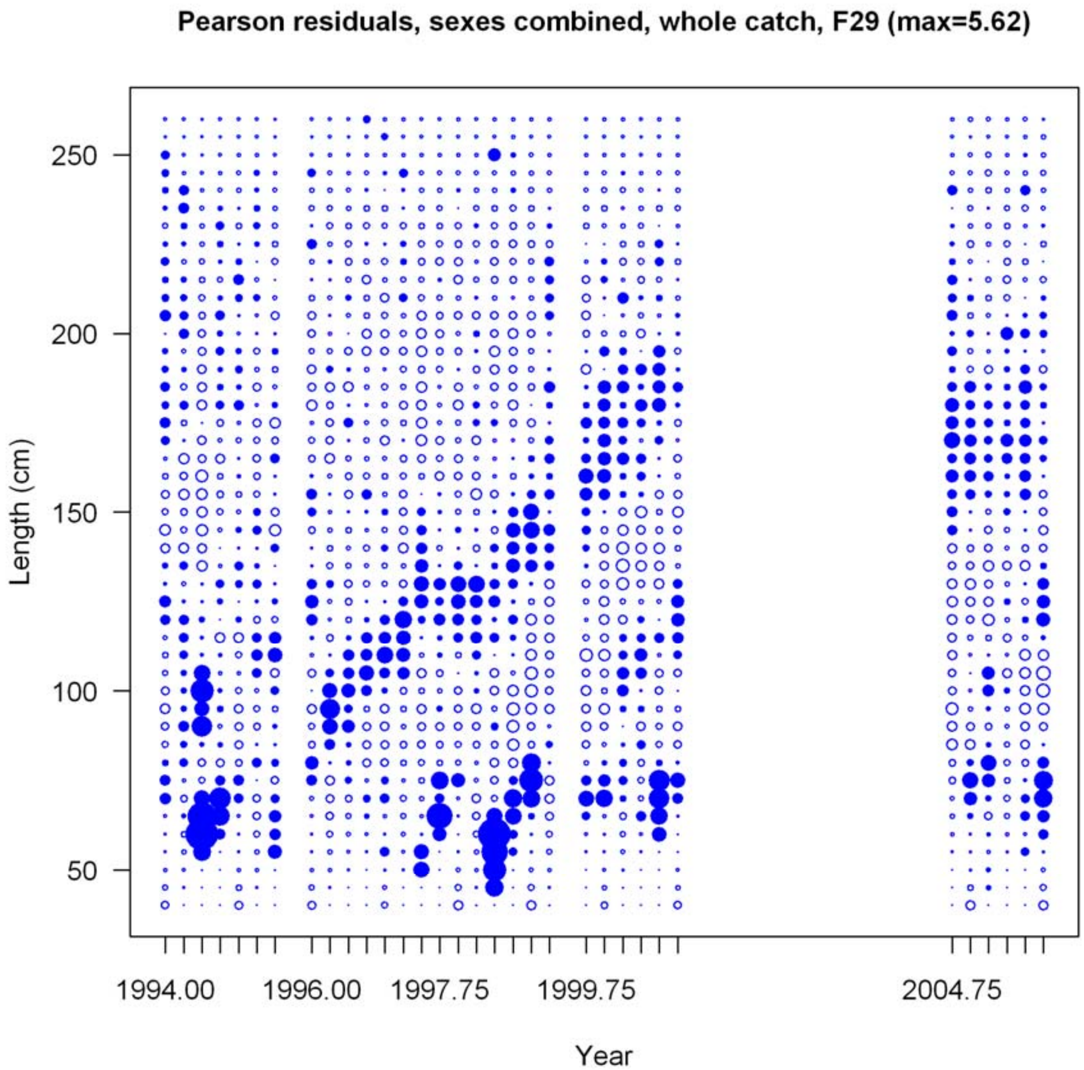

Figure 15. Model-1 length frequency fit for US Hawaii Longline Shallow Set (F29). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

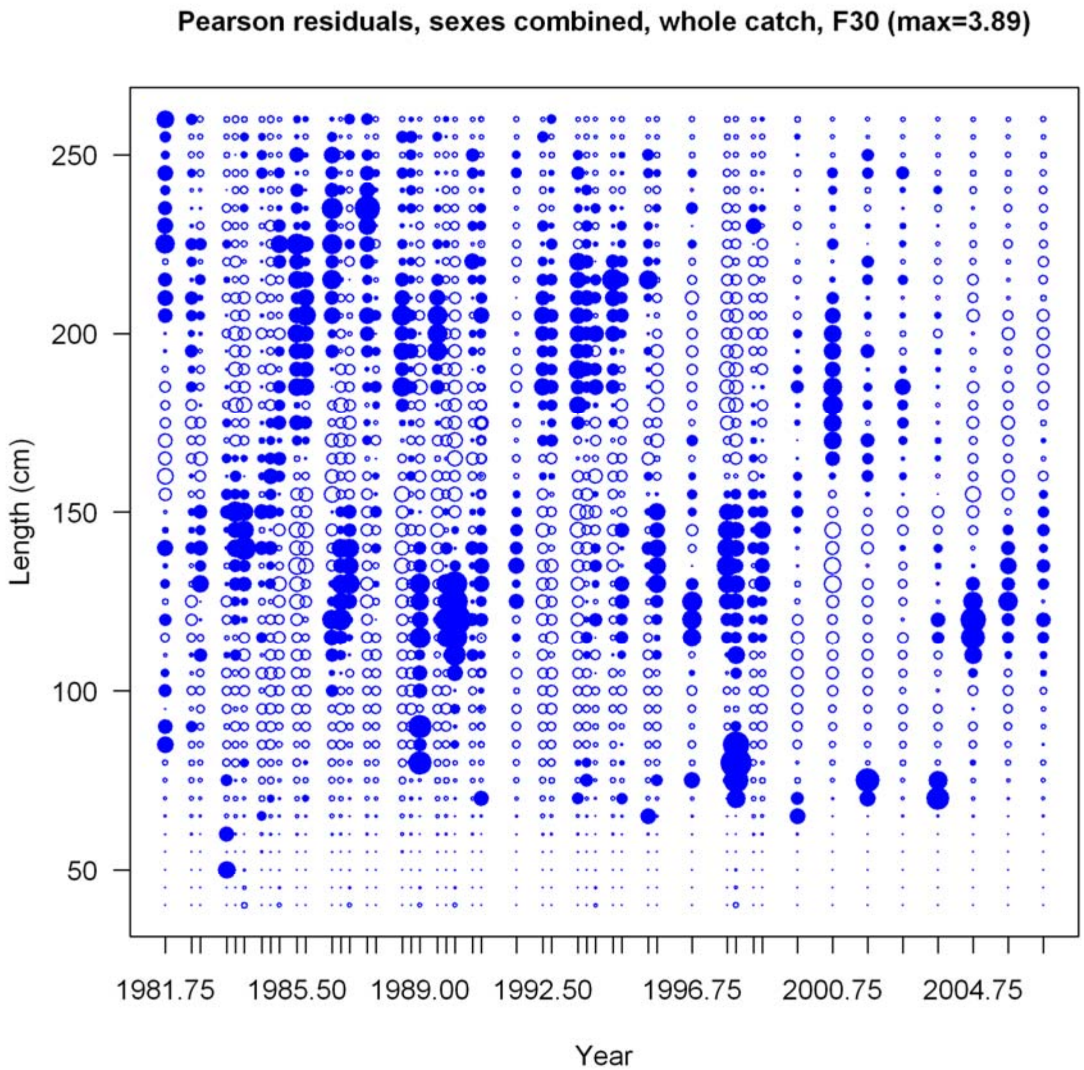

Figure 16. Model-1 length frequency fit for U.S. California Gillnet (F30). Circle width represents the Pearson residuals (observed-predicted)/sqrt(var(predicted)). Closed circles represent fewer predicted than observed.

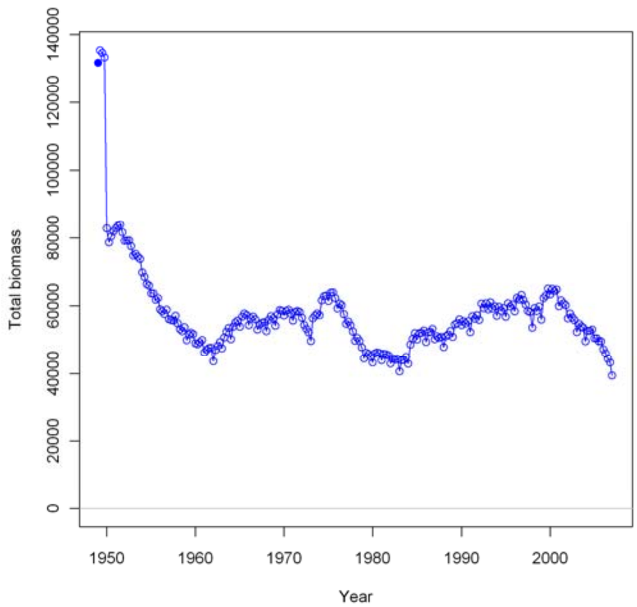

Figure 17. Model-1 estimated total biomass (mt).

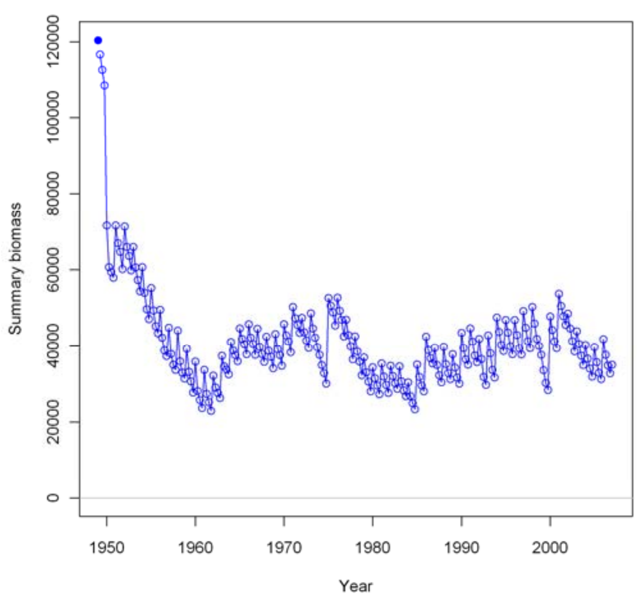

Figure 18. Model-1 estimated summary biomass (Age 2+ mt).

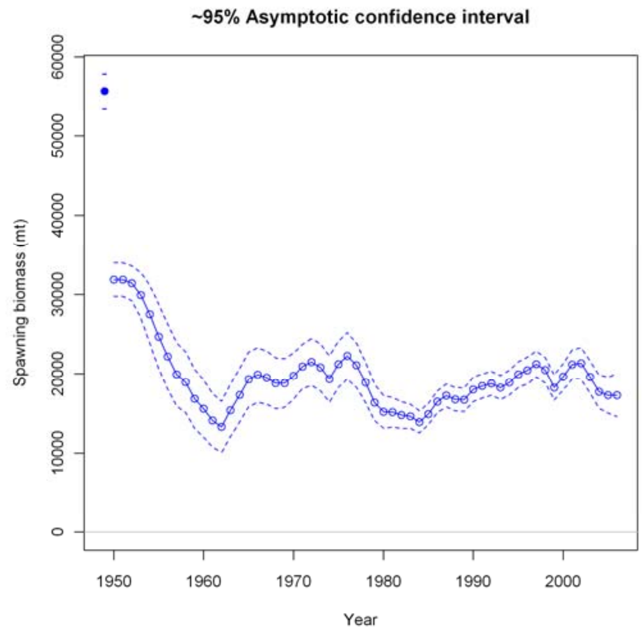

Figure 19. Model-1 estimated mature female spawning biomass (mt) and 95% confidence interval calculated as +-2 * (model estimated se from inverse Hessian matrix).

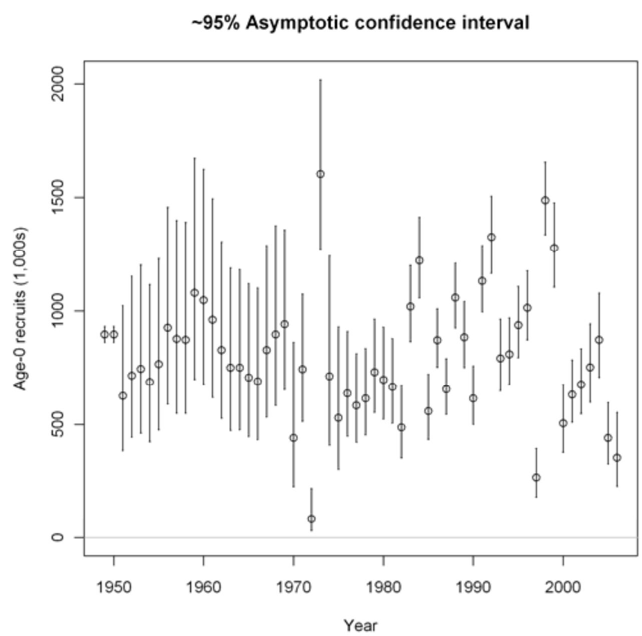

Figure 20. Model-1 estimated age-0 recruitment (1,000s) and 95% confidence interval calculated as +-2 * (model estimated se from inverse Hessian matrix).

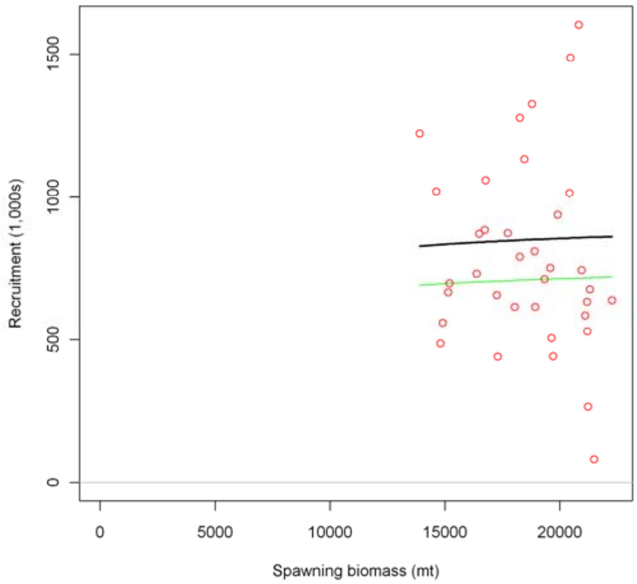

Figure 21. Model-1 estimated Beverton-Holt spawner-recruit relationship for a fixed steepness (h = 0.9). Bold line is not biased adjusted.

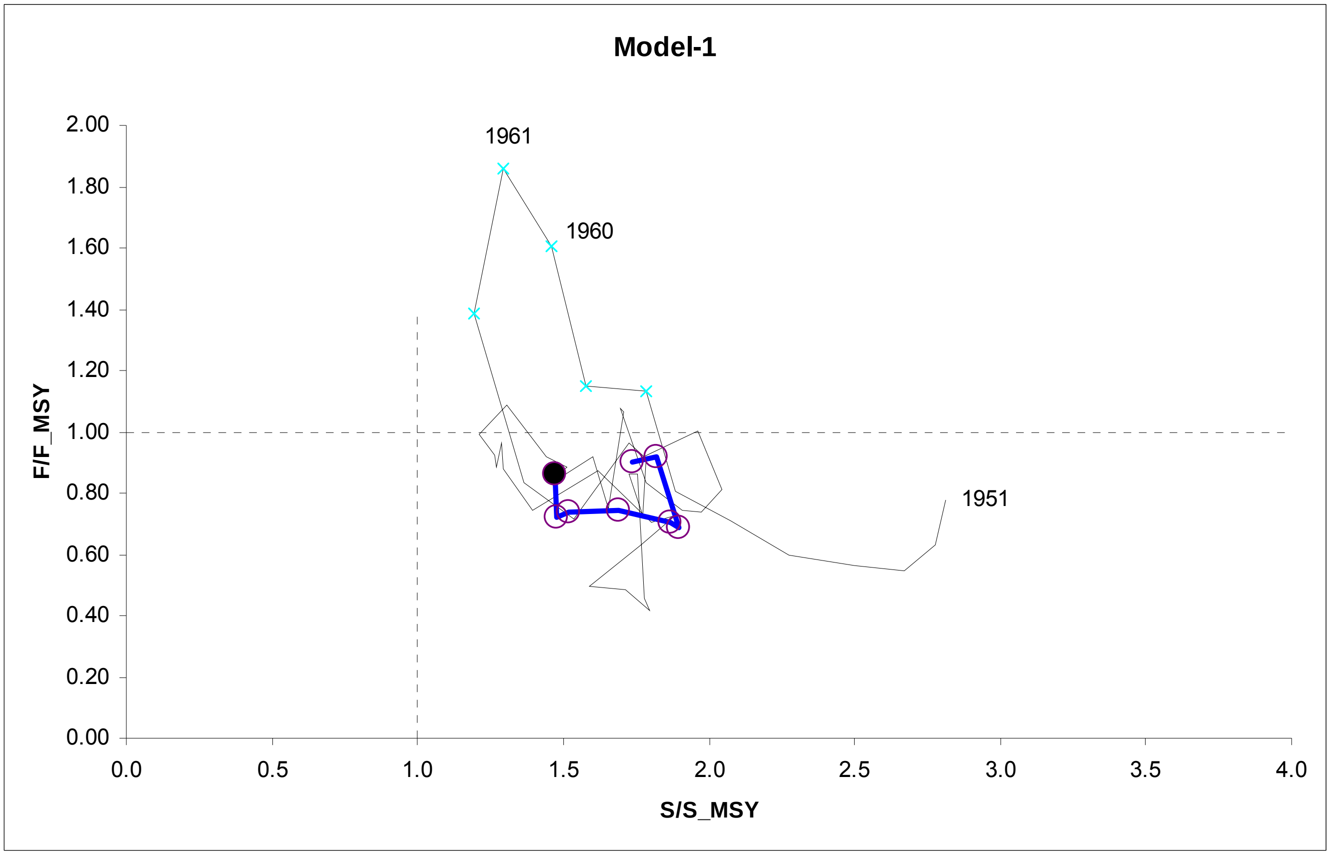

Figure 22. Model-1 “Kobe” plots of female spawning biomass (S) relative to female spawning biomass at MSY (S_MSY) and fishing mortality (F) relative to fishing mortality at MSY (F_MSY); Bold line represents years 1999 – 2006; Solid circle represents year 2006.

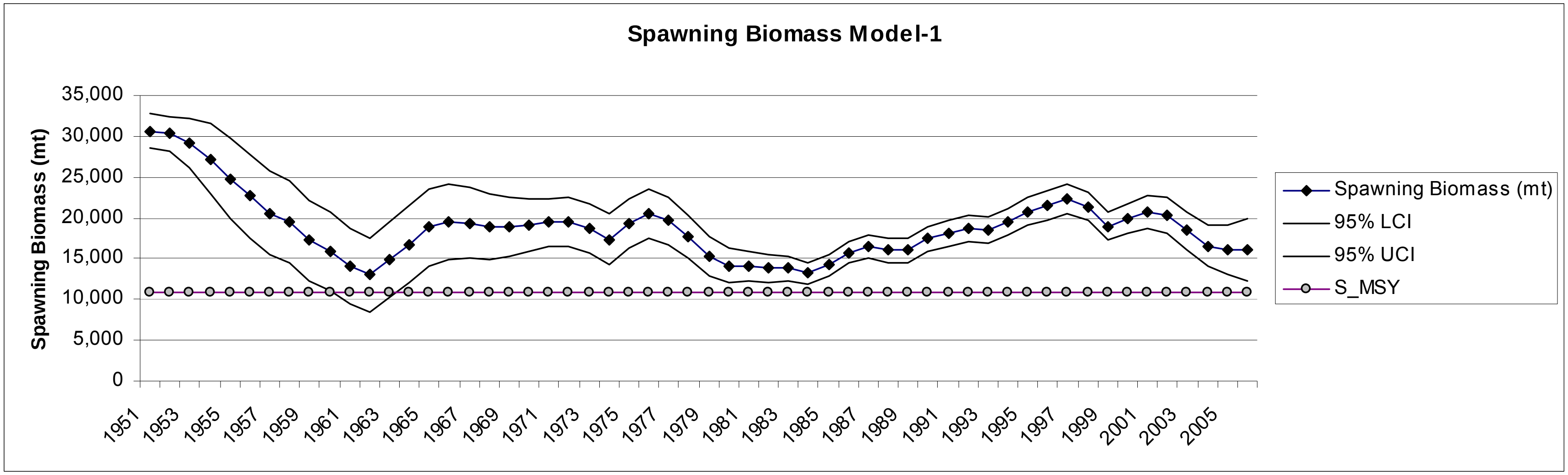

Figure 23.1. Model-1 estimated female spawning biomass (S) along with female spawning biomass at MSY (S_MSY).

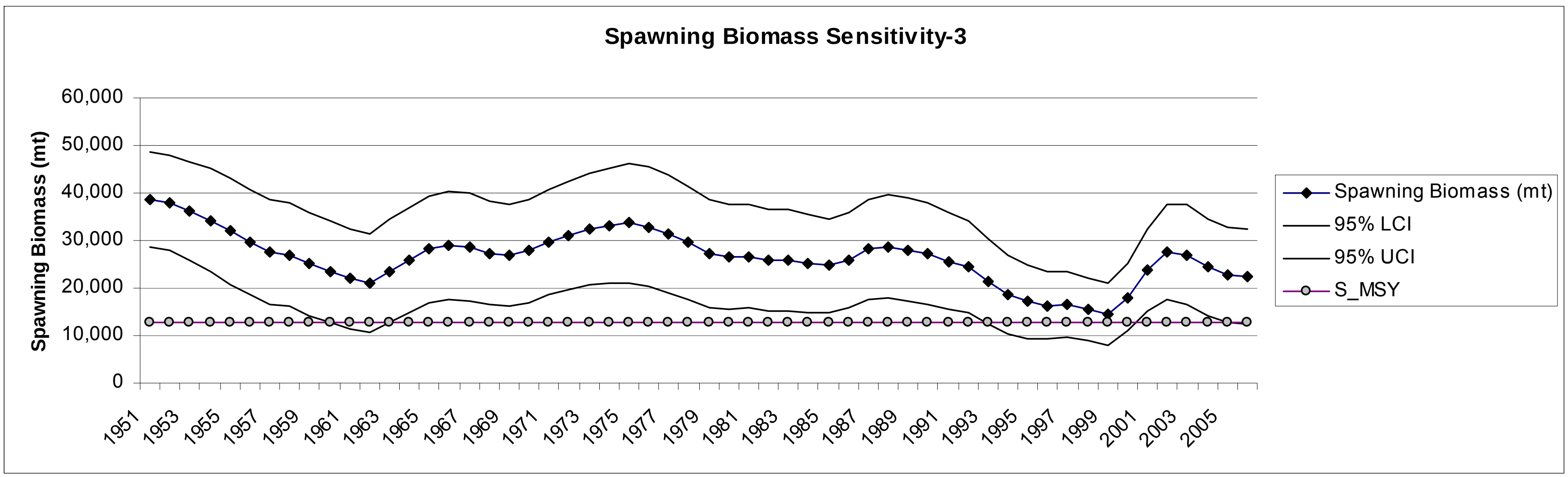

Figure 23.2. Sensitivity-3 model estimated female spawning biomass (S) along with female spawning biomass at MSY (S_MSY).

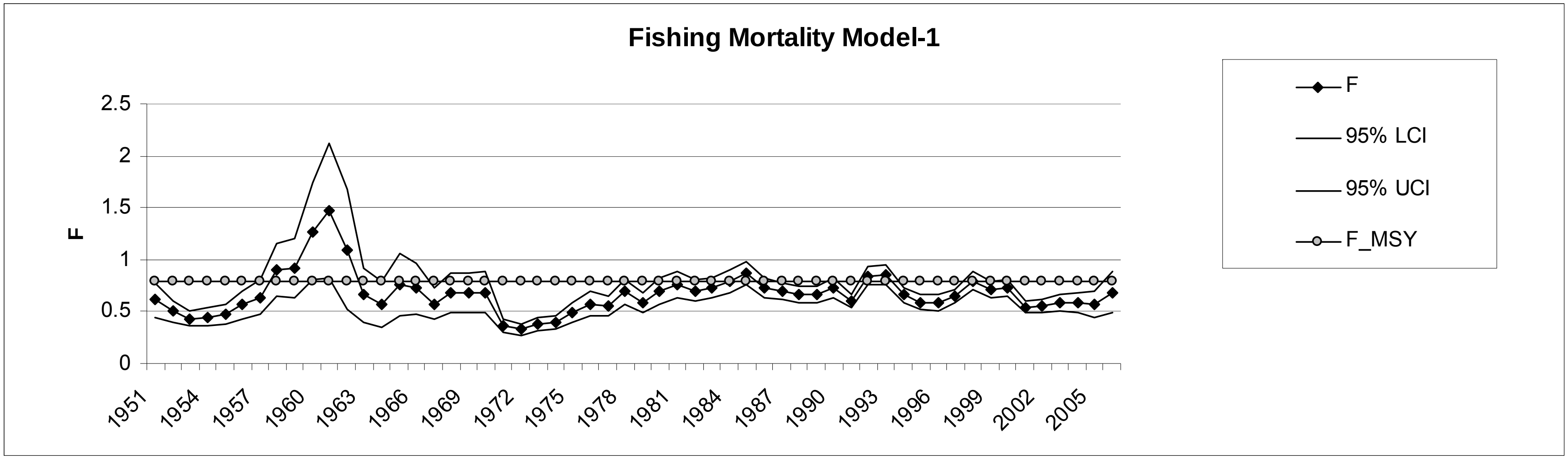

Figure 24.1. Model-1 estimated fishing mortality (F) along with fishing mortality at MSY (F_MSY).

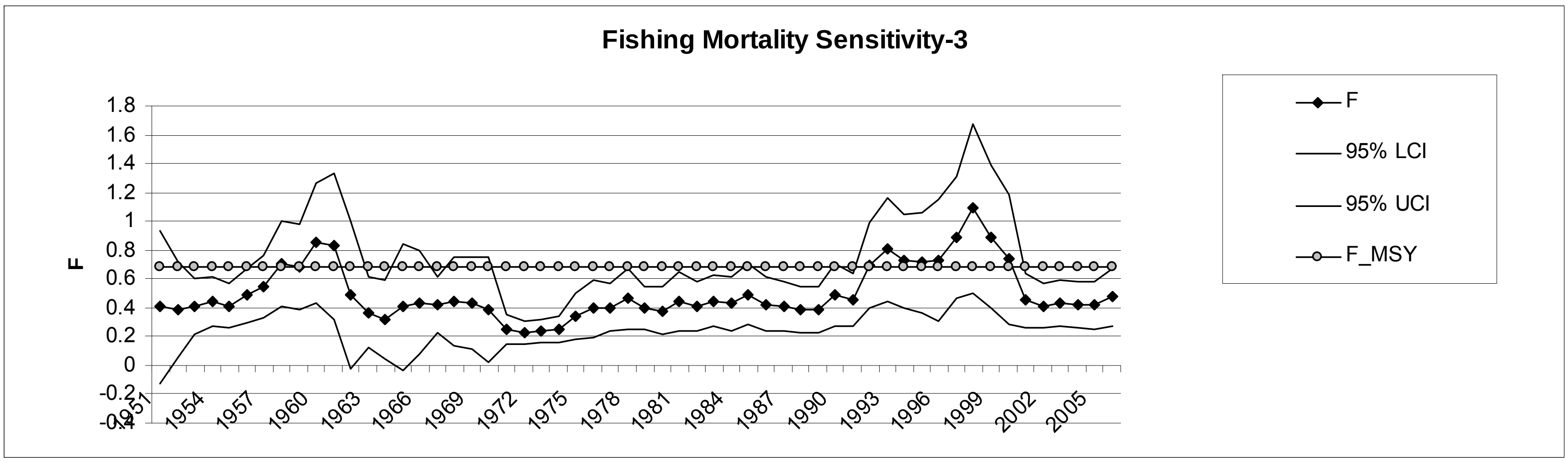

Figure 24.2. Sensitivity-3 model estimated fishing mortality (F) along with fishing mortality at MSY (F_MSY).

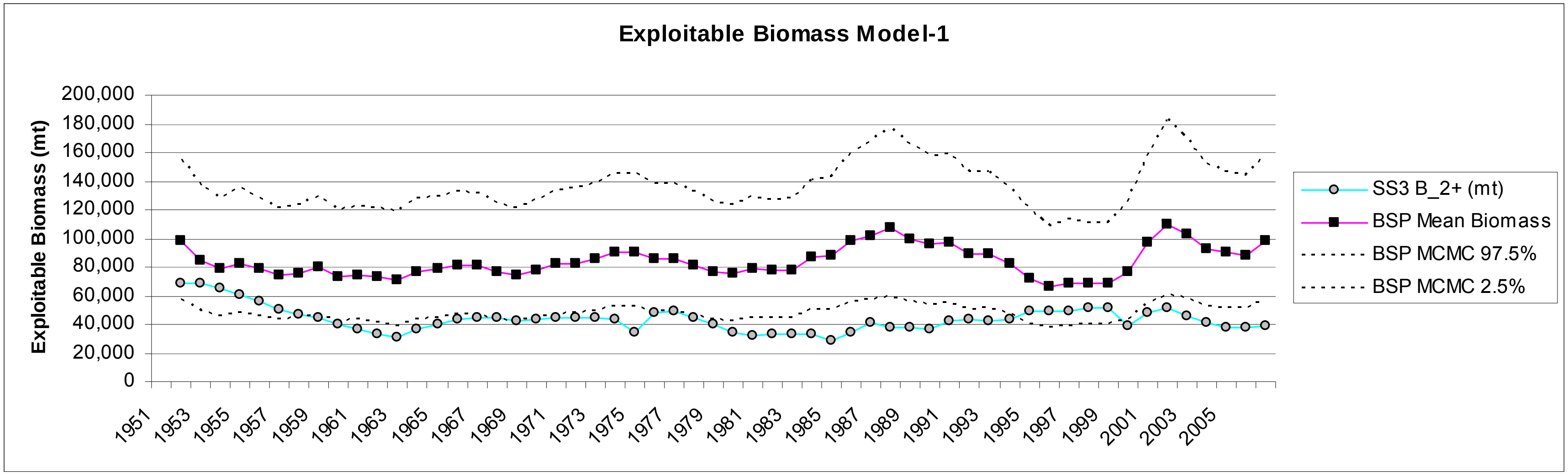

Figure 25.1. Stock Synthesis Model-1 estimated time-series of age 2+ biomass (B_2+) along with Bayesian surplus production (BSP) estimates of mean exploitable biomass (BSP Mean Biomass) and 95% confidence intervals (BSP MCMC 2.5%, 97.5%) reproduced from (Brodziak and Ishimura 2009, BILL-WG 2009b).

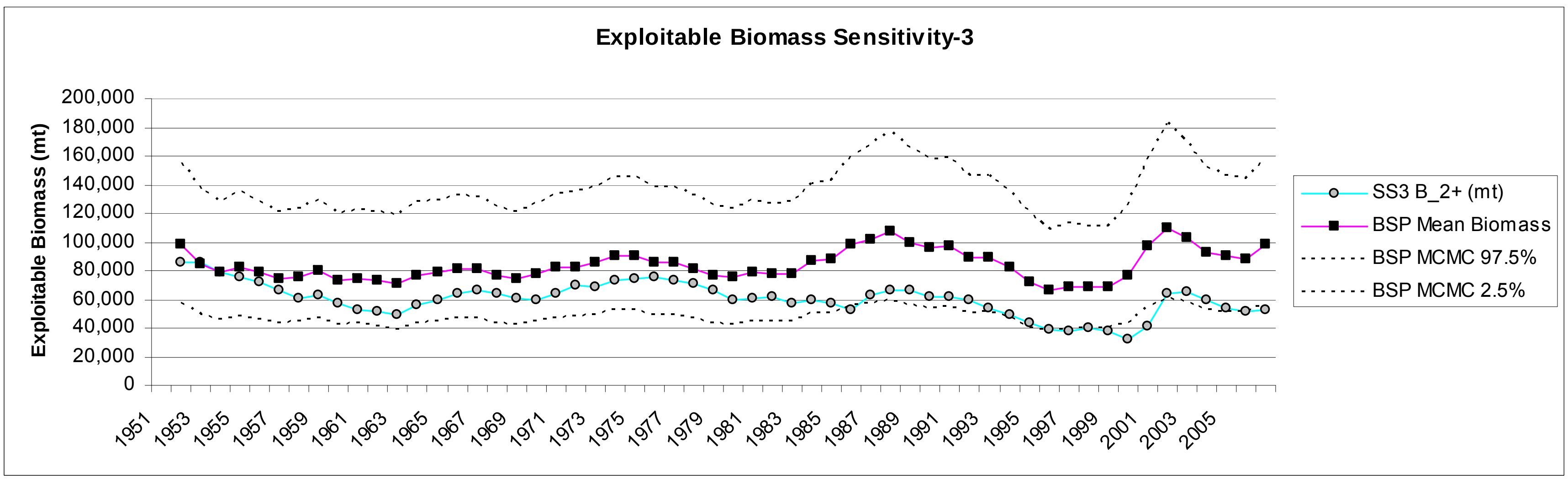

Figure 25.2. Stock Synthesis Sensitivity-3 model estimated time-series of age 2+ biomass (B_2+) along with Bayesian surplus production (BSP) estimates of mean exploitable biomass (BSP Mean Biomass) and 95% confidence intervals (BSP MCMC 2.5%, 97.5%) reproduced from (Brodziak and Ishimura 2009, BILL-WG 2009b)

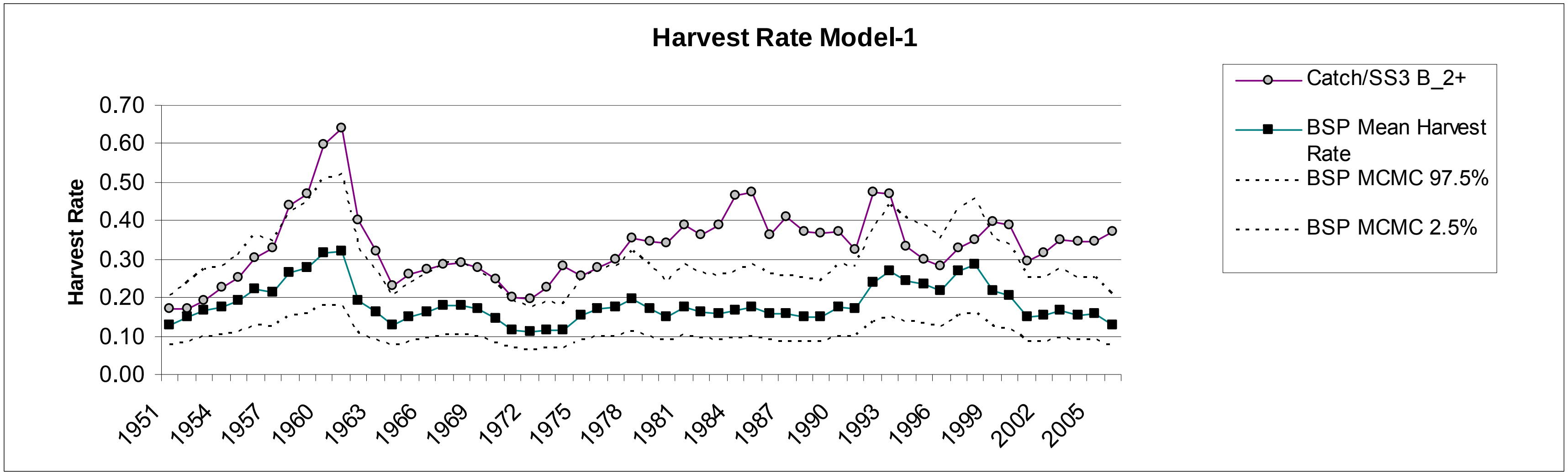

Figure 26.1. Stock Synthesis Model-1 estimated time series of total exploitation (Catch mt)/(SS3 B_2+ mt) along with Bayesian surplus production (BSP) estimates of mean exploitable biomass harvest rates (BSP Mean Harvest Rate) and 95% confidence intervals (BSP MCMC 2.5%, 97.5%) reproduced from (Brodziak and Ishimura 2009, BILL-WG 2009b).

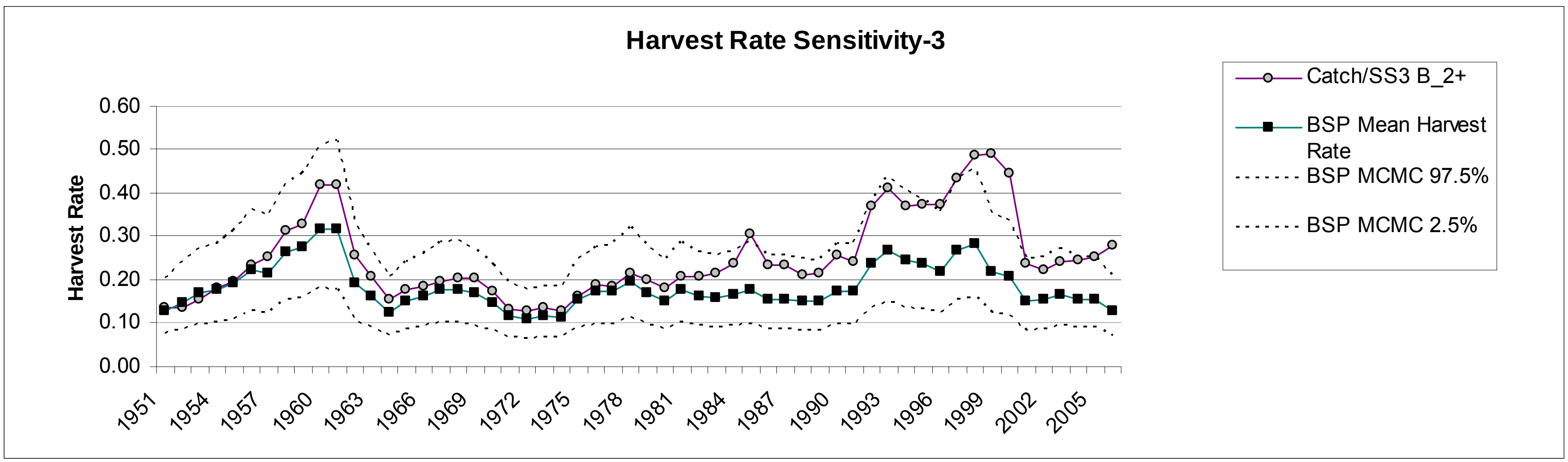

Figure 26.2. Stock Synthesis Sensitivity-3 model estimated time series of total exploitation (Catch mt)/(SS3 B_2+ mt) along with Bayesian surplus production (BSP) estimates of mean exploitable biomass harvest rates (BSP Mean Harvest Rate) and 95% confidence intervals (BSP MCMC 2.5%, 97.5%) reproduced from (Brodziak and Ishimura 2009, BILL-WG 2009b).

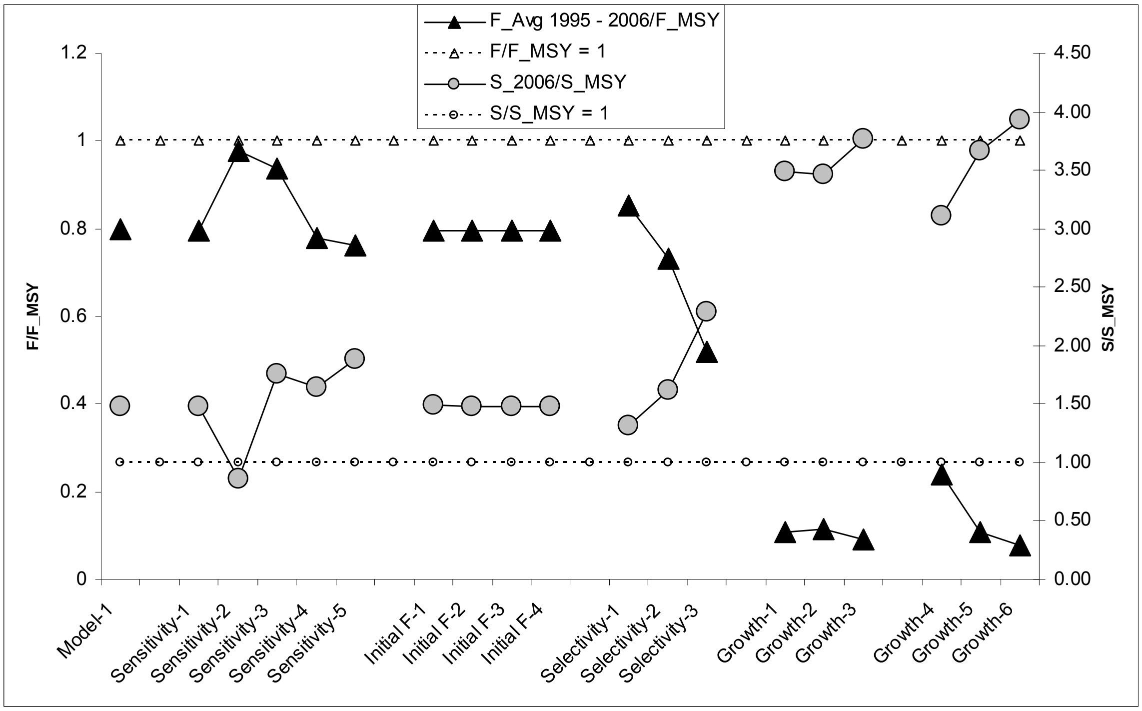

Figure 27.1. Sensitivity results for average fishing mortality (F_Avg) during the years 1995 -2006 relative to fishing mortality at MSY (F_MSY) and female spawning biomass in 2006 (S_2006) relative to female spawning biomass at MSY (S_MSY).

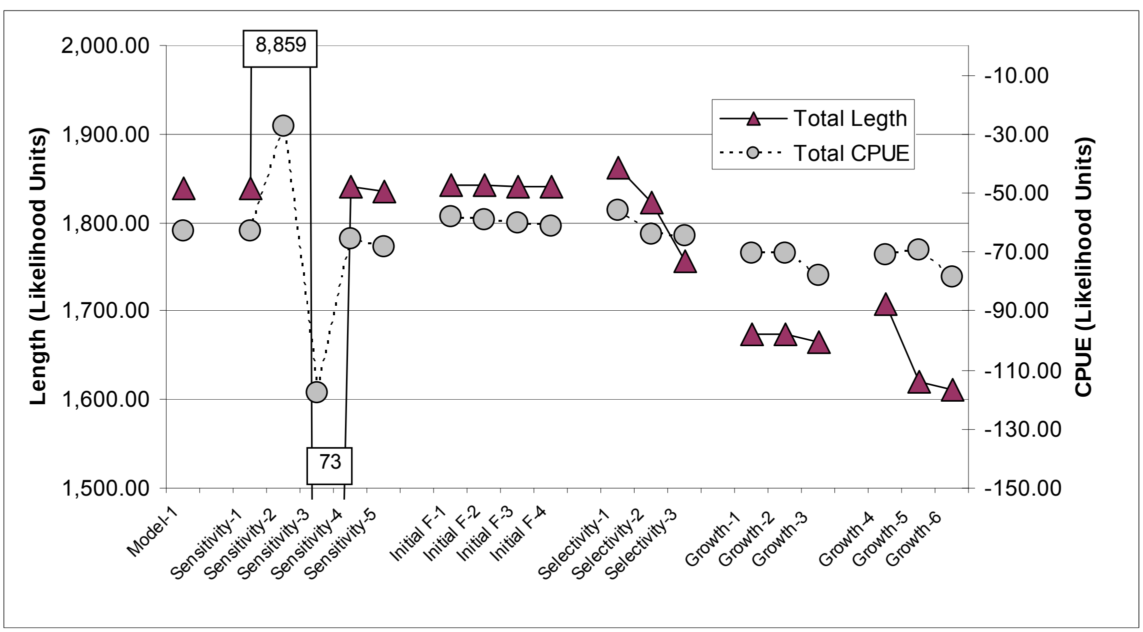

Figure 27.2. Sensitivity results for objective function likelihood fits to CPUE and Length.

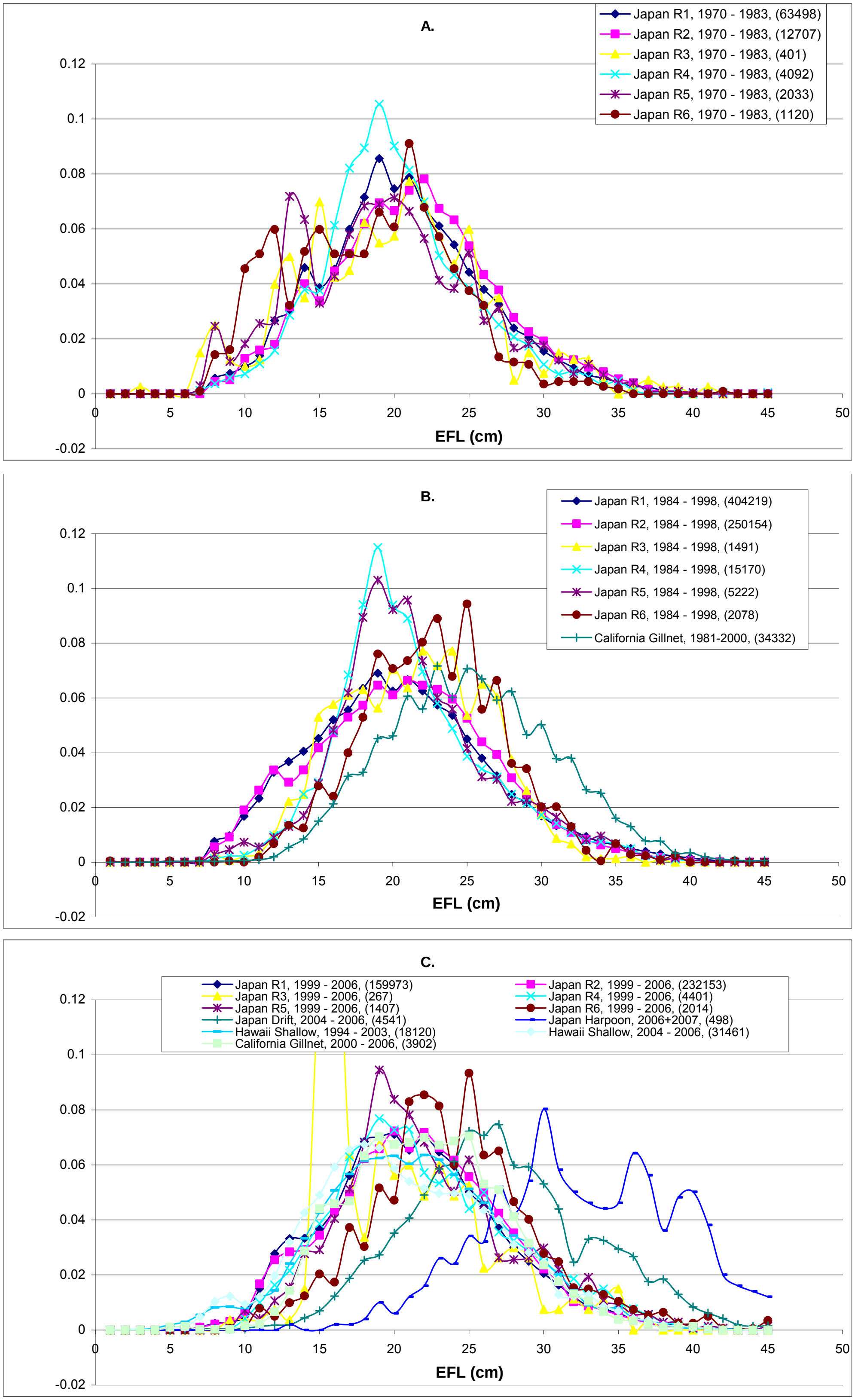

Figure 28. Length frequency by fleet, years (and sample size).

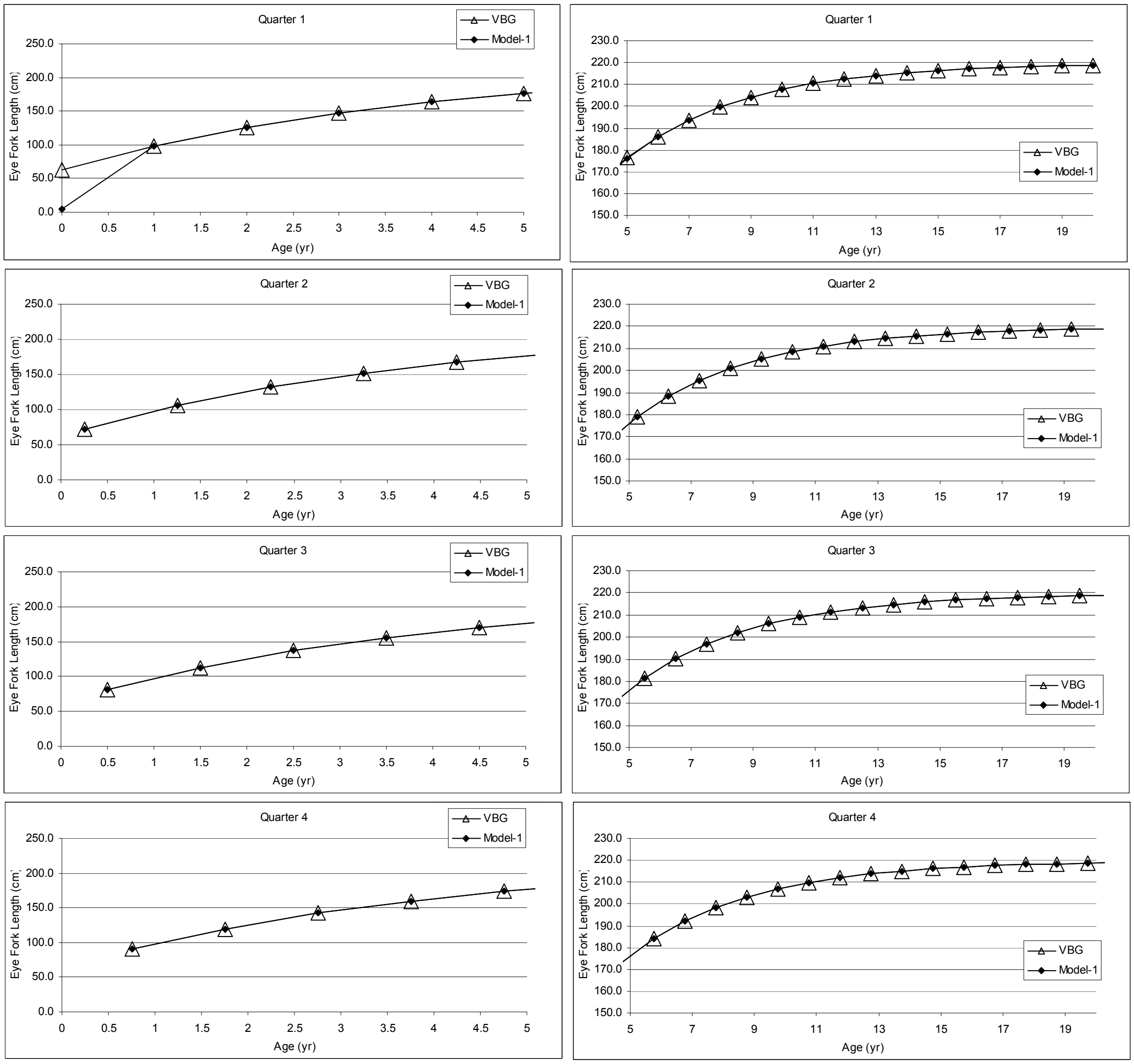

Figure 29. Length at age for Model-1 ages 0 to 5 (left panel) and ages 5 to 20 (right panel) compared to the Central North Pacific independently estimated values (VBG, Table 1).

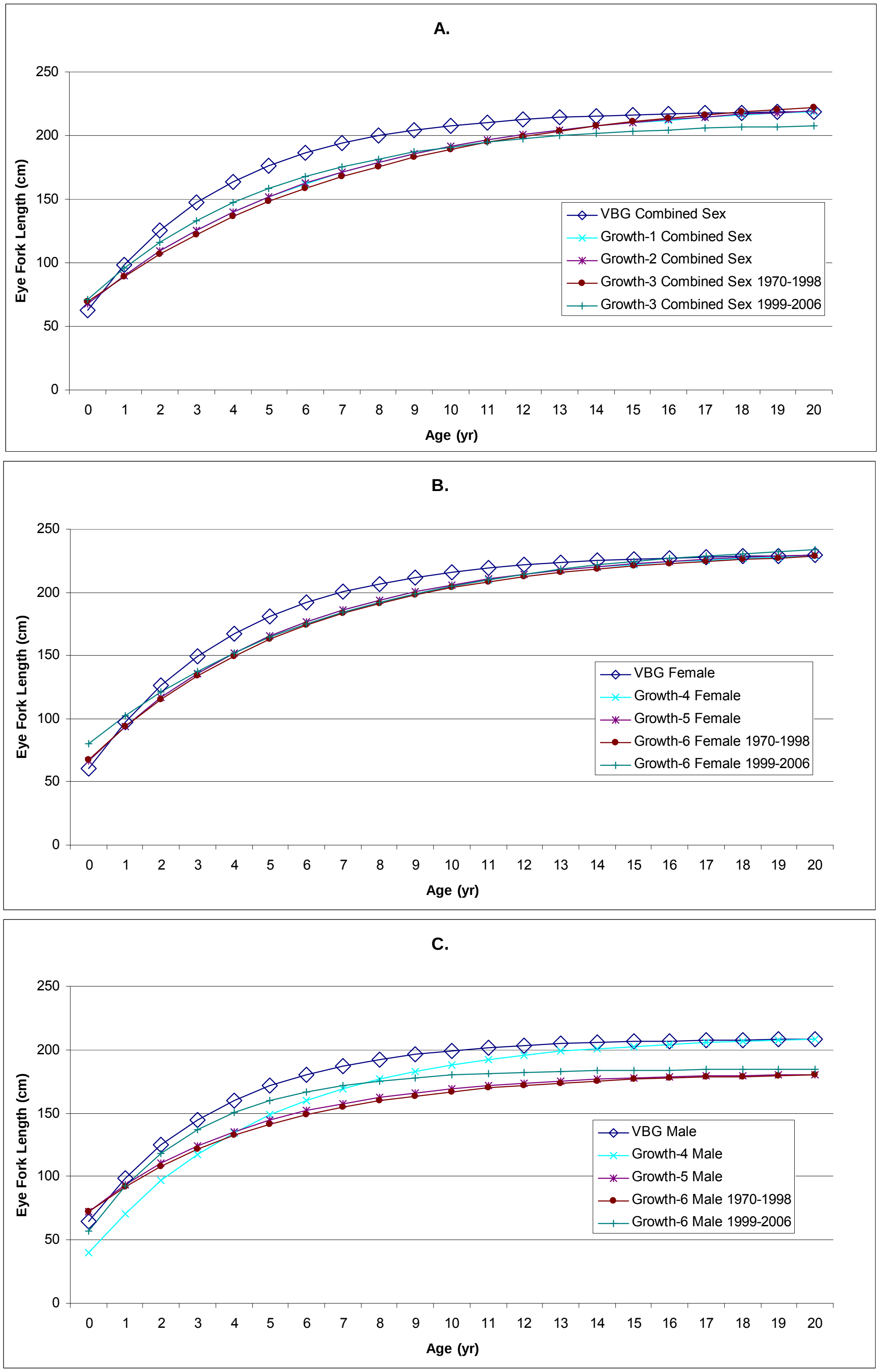

Figure 30. Length at age from sensitivity analyses (Growth 1-6) compared the Central North Pacific independently estimated values (VBG, Table 1); Panel A is combined sex, Panel B is female, and Panel C is male.

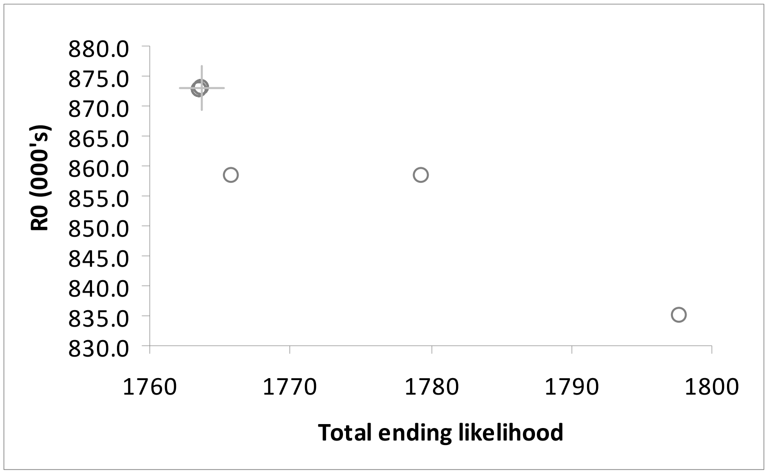

Figure 31. Plot of test of global convergence. Opened circles are the model runs with initial values changed 5-10% and phases of parameterization changed. The single crosshair is the value from the base model depicted in the document.

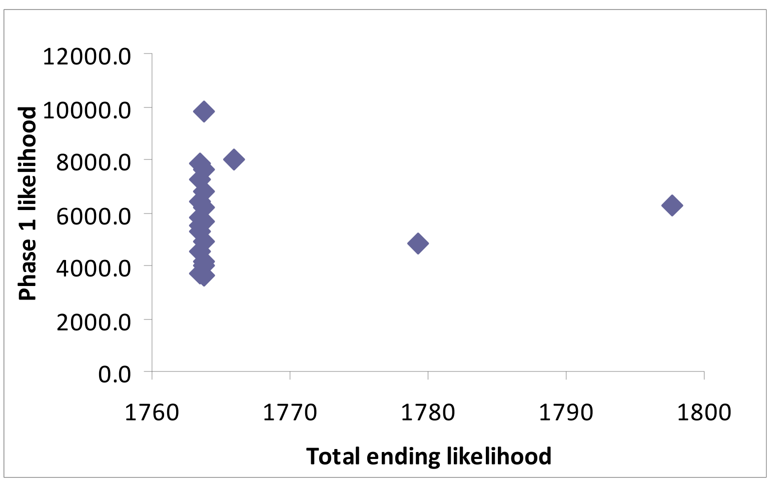

Figure 32. Plot from the global convergence test illustrating the effects of changing initial parameter values by 5-10%. Phase 1 likelihoods ranged from 3,000-10,000 likelihood units. Ending likelihoods centered near 1,673 with some outliers.