ISC/09/BILLWG-2/05

Preliminary Stock Synthesis Model Sensitivity Runs for a North Pacific Swordfish (*Xiphias gladius*) Stock Assessment

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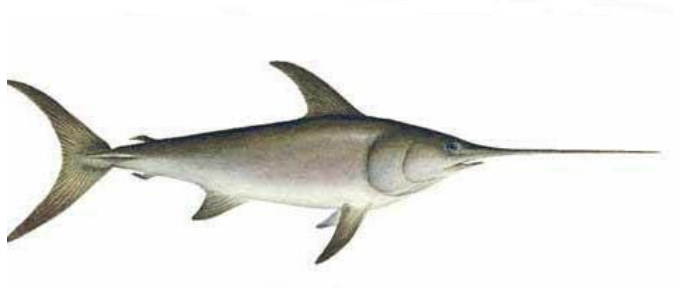

Working document submitted to the ISC Billfish Working Group Workshop, 19-26 May 2009,Busan, Korea. Document not to be cited without author's written permission.

Preliminary Stock Synthesis Model Sensitivity Runs for a North Pacific Swordfish (*Xiphias gladius*) Stock Assessment

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Abstract

This report summarizes preliminary Stock Synthesis 3 (SS3) model sensitivity runs for a North Pacific Swordfish (*Xiphias gladius*) stock assessment. Our interests at this stage of model development was first, to model the process of length based selectivity for comparison with Bayesian Production models, and second, to assess SS3 model sensitivity to a reasonable range of model parameters from the scientific literature. The stock structure assumed a single stock north of the equator (Stock Scenario-1). SS3 model sensitivity was not evaluated for Stock Scenario-2 due to time constraints. Independently estimated swordfish life history parameters from the Central North Pacific were input into Stock Synthesis as fixed parameters. The model included 10 fisheries 5 CPUE time series, and 4 time series of length frequency. A base-case was chosen and model sensitivity was evaluated for a range of parameters centered around the base case. Model results were sensitive to natural mortality, effective sample size of annual CPUE time series, and the sequential removal of annual CPUE time series. The base case model appeared to adequately estimate selectivity for the major fisheries and CPUE series except Chinese Taipei distant water longline. Time series of model estimated mature female spawning biomass were relatively flat. The sensitivity analysis identified three issues that need further consideration. Equilibrium recruitment (R_0) was estimated at the lower bound in all runs which is a diagnostic for model non-convergence. All runs had very poor fits to length frequency modes. Selectivity did not appear to differ by sex. The sensitivity analysis also suggested reasonable alternative models to consider. These issues will be addressed during ongoing development of a regionally stratified stock assessment for North Pacific swordfish with SS3 under Stock Scenario-1 to be presented separately.

1. Introduction

This report summarizes preliminary Stock Synthesis 3 (SS3) model sensitivity runs for a North Pacific Swordfish (*Xiphias gladius*) stock assessment. Our interests at this stage of model development was first, to model the process of length based selectivity for comparison with Bayesian Production models, and second, to assess SS3 model sensitivity to a reasonable range of model parameters from the scientific literature. The sensitivity runs were informed by a review of previous North Pacific swordfish assessments (Kleiber and Yokawa 2004, Bigelow and Kleiber 2004, Wang et al. 2005, Wang et al. 2007, Courtney et al. 2008). The presentation of results followed ISC BILLWG stock assessments for striped marlin (Piner et al 2007a and 2007b, MAR&SWOWG 2007a and 2007b). A single "best" model is not advocated. Instead, a range of plausible models was presented based on model sensitivity to influential parameters.

Sensitivity analysis results were presented for equilibrium (virgin) female spawning biomass (S_0), ending female spawning biomass (S_2006), and the ratio (S_2006/S_0) (Kleiber and Yokawa 2004, Wang et al. 2005, Wang et al. 2007). Sensitivity analysis results were also presented for individual CPUE and length composition likelihood components and the overall objective function. Time series of total biomass and female spawning biomass were presented for a base case. Biological reference points were not calculated for the preliminary runs (Brodziak and Legault 2005, Sun et al. 2005, Brodziak 2007, Brodziak and Piner 2008, Brodziak and Piner 2009).

2. Methods

2.1 Stock Structure

The stock structure assumed in this preliminary sensitivity analysis was a single stock north of the equator with no regional stratification (Figure 1). SS3 model sensitivity was not evaluated for Stock Scenario-2 due to time constrains.

North Pacific swordfish stock structure was considered by a special session of the ISC Billfish Working Group (WG) in November, 2008 (BILL-WG 2008), and reviewed at a regular session of the WG, February 2009 (BILL-WG 2009). The WG recommended two stock structure scenarios be considered for swordfish stock assessment in the North Pacific: 1) a single North Pacific stock north of the equator (Figure 1), and 2) a two-stock scenario with a diagonal boundary from Baja, California (25ºN x 110ºW) to approximately 170ºW at the equator (Figure 2). The boundary followed a stair step pattern modified from (Ichinokawa and Brodziak 2008). The southern boundary of Stock Scenario-2 in the Western-Central Pacific Ocean is at the equator and in the EPO the southern limit is set at 20ºS.

For Stock Synthesis, the BILL-WG recommended that catch, CPUE, and length be compiled using additional regional spatial stratification modified from Sun et al. (2009) (BILL-WG, 2009) (Figures 3 and 4). Under Stock Scenario-1, there is one area with 6 regions (1, 2, 3, 4, 5, 6). Under Stock Scenario-2, Sub Area-1 has 5 regions (1-1, 1-2, 1-3, 1-4, 1-5) and Sub Area-2 has one region (2-1). The rational for regional stratification was that the smaller spatial scale may be more homogeneous in catch, length, and CPUE, and as a result may be more likely to accurately reflect the effect of fishery removals on the population in Stock Synthesis. The downside is that some regions lack data. Analysis of regional data was not implemented in this preliminary sensitivity analysis. A regionally stratified stock assessment for North Pacific swordfish with SS3 is under development for Stock Scenario-1 and will be presented separately.

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), TMAX (y), and max 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 (p(L) at length (cm of eye fork length) was taken from DeMartini et al. (2000). Combined values for Von Bertalanffy growth parameters and maturity probability were estimated by fitting length-at-age growth models and maturity-at-length models to the sex-combined data in Excel and minimizing the 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) (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. Estimated for females and males combined were obtained as the average of males and females natural mortality rates.

Life history data were input separately for females (Table 4), males (Table 5) and females and males combined (Table 6).

2.3 BILLWG Swordfish Life History Reviews

The BILLWG reviewed available swordfish biological data for the North Pacific Ocean, including length-at-age and length at 50% maturity (BILL-WG 2009). Three swordfish growth curves were available for males and females separately from the Western North Pacific, Central North Pacific, and Eastern North Pacific. The working group concluded that length-at-age growth curves from the Central North Pacific represented the best available scientific information for North Pacific swordfish growth rates because of the relatively large sample size of larger swordfish which resulted in a clearly defined asymptote in length at age for larger sizes. The working group also noted that the length-at-age curves presented for the Eastern North Pacific lacked an asymptote in length at age for larger sizes, probably as a result of limited sample size from large swordfish, and that large swordfish were probably not being represented in the growth curve for the Eastern North Pacific. Because of the lack of cross-validation, the working group did not consider growth curves from the Western South Pacific. The working group concluded that length-at-age growth curves from the Western North Pacific should also be considered for use in stock assessment as a sensitivity analysis.

Similarly, the BILLWG concluded that size-at-age maturity schedules from the Central North Pacific represented the best available scientific information for North Pacific swordfish (BILL-WG 2009). The working group noted that size-at-age maturity schedules from the Central North Pacific and Western North Pacific were similar (BILL-WG 2009).

For this analysis, sensitivity analysis of length-at-age estimates from the Western Pacific was not implemented due to time constraints. Instead, model sensitivity to Western North Pacific life history parameters (Sun et al. 2002, Wang et al. 2003, Uchiyama and Humphreys 2007) was tested by incorporating a range of natural mortality values (0.2, 0.25, and 0.3) linked to Western North Pacific swordfish life history parameters (Sun et al. 2005, Wang et al. 2005, Wang et al. 2007).

The BILLWG reviewed the estimation of potential swordfish natural mortality rates for the North Pacific Ocean (BILL-WG 2009). Natural mortality rates (M) were estimated using seven empirical and four theoretical approaches that depended on estimates of swordfish life history parameters (Brodziak 2009). Empirical estimation of M followed Alverson and Carney (1975), Pauly (1980), Hoenig (1983), Lorenzen (1996), and Hewitt and Hoenig (2005) and was applied to Eastern and Central North Pacific swordfish life history data. Theoretical approaches developed by Peterson and Wroblewski (1984), Jensen (1996), and Chen and Watanabe (1989) were also considered. Sex-specific estimates of M were developed to account for sexual dimorphism in swordfish growth based on life history data from the Central North Pacific data along with a sensitivity analysis using data from the Eastern North Pacific. Age-dependent estimates of M were also evaluated to account for changes in survival rates as fish age. Overall, the Hoenig (1983), Alverson and Carney (1975), Pauly (1980), and Beverton-Holt invariant 2 (Jensen 1996) provided consistent estimates of constant natural mortality of female and male swordfish in the Central North Pacific with M ranging from roughly M=0.35 to M=0.41 y-1. Of the age-dependent M estimators, the Lorenzen (1996) tropical system estimator appeared to provide the most plausible results that were consistent with the central tendency of the constant M estimators. Alternative estimates of female and male swordfish natural mortality at age based on Eastern North Pacific life history parameters exhibited a greater range of values and were more variable than those based on the Central North Pacific data. The working group concluded that tying the estimation of natural mortality rates (M) to recent biological data from the Central North Pacific represented the best available scientific information on natural mortality rates for North Pacific swordfish.

2.4 Catch, CPUE, and Length

The Stock Synthesis model included 10 fisheries, 5 CPUE time series, and 4 time series of length frequency (Table 7). The Stock Synthesis model used the same catch and CPUE data as compiled for Bayesian Production models (Courtney Wagatsuma 2009) (Figure 5). Length data for Stock Synthesis were compiled separately by Courtney and Flecther (2009).

2.5 Model Structure

The assessment was conducted with Stock Synthesis 3 (SS3) available from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/SS3.html). Model structure followed a previous striped marlin assessment conducted by the ISC BILLWG with Stock Synthesis 2 (SS2, Methot 2000, Piner et al. 2007a). The SS3 model used a Beverton-Holt spawner-recruit relationship. 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). Steepness (h), the assumed standard error of the process error in recruitment (σ_r), and natural mortality (M) were fixed at a range of reasonable values for sensitivity analysis. Unfished (virgin) equilibrium recruitment (R_0) was estimated subject to estimated initial equilibrium exploitation. Main recruitment deviations were estimated from 1970 – 2006, early recruitment deviations were estimated from 1951 – 1970, and bias correction for the process error in recruitment (σ_r) was applied from 1960 – 1970. Unfished equilibrium recruitment (R_0) can be interpreted as analogous to carrying capacity in a surplus production model. Steepness (h) can be interpreted as analogous to the intrinsic rate of increase in a surplus production model.

Fishery length frequency data were used to estimate selectivity patterns which controlled the size (and age) distribution of fishery removals. The model was set up as an annual model with one season. 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 season 1 (annual year). The population model had 49 length bins (5 cm) from 20 – 260+ (cm). The 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. Effective sample sizes were iteratively re-weighted for fits to CPUE and length frequency (McAllister and Ianelli 1997, Piner et al. 2007a). Catch was assumed to be known without error and catch was removed halfway through the calendar year.

2.6 Selectivity Patterns

Length frequency data were available for 3 out of 10 Fisheries (F1, F6, F8), and one CPUE time series (S4). We assumed that the selectivity patterns of the other 7 fisheries mirrored the Japan Distant Water Longline fishery (F1). Selectivity patterns for CPUE series (S1-S5) mirrored their respective fisheries, except for Hawaii Deep-Set (S4) for which a separate length frequency data set was available. All selectivity models were two parameter asymptotic logistic equations except for Hawaii Deep-Set CPUE which had a 6 parameter dome-shaped double normal model. Logistic selectivity parameters were estimated with uninformative priors. Dome shaped double normal selectivity parameters were estimated with informative priors.

2.7 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 conducted. Excessive CV's on estimated quantities were indicative of a non-converged model. The correlation matrix was examined for non-informative parameters. Parameters estimated at a bound were a diagnostic of non-convergence.

2.8 Base-Case

A base-case was chosen for the sensitivity analysis. Natural mortality (M) was tied to Central North Pacific swordfish life history for females, males and females and males combined (Table 4 -7). Steepness (h = 0.9) and the assumed standard error of the process error in recruitment ($\sigma_r = 0.4$) were taken from (Wang et al. 2005 and Wang et al. 2007). Selectivity was estimated with sex-specfic growth curves (Table 4 -6). Raw sample sizes were assigned to CPUE and length frequency.

2.9 Sensitivity Analysis

Model sensitivity was examined in relation to influential parameters identified through previous Monte Carlo simulation and application of a sex-specific age-structured assessment method for swordfish in the North Pacific Ocean (Wang et al. 2005 and 2007). Natural mortality (M) was fixed at 0.2, 0.25, and 0.3. Steepness (h) of the Beverton-Holt stock-recruitment relationship was fixed at 0.6, 0.8, 0.9, and 0.95. The assumed standard error of the process error in recruitment (σ_r) was fixed at 0.2, 0.4, and 0.6. An additional steepness value was obtained from Atlantic swordfish ($z_m = 0.88$) (Myers et al. 1999). Additional natural mortality values (M) were obtained from the last ISC North Pacific swordfish assessment (M = 0.4, 0.5, 0.6) (Kleiber and Yokawa 2004).

A single sex (sex-combined) model was tested by setting sex specific growth information (length at age) in the model to the mean for males and females combined (Table 6), and replacing the sex-specific length frequencies for Hawaii Longline shallow-sets and deep-sets with sex-combined length frequencies (assumed sex ratios 50:50). Model sensitivity to effective sample size (root mean squared error of residuals) was tested by assigning the model estimated effective sample size sequentially, first to the process error in recruitment (σ_r), second to annual CPUE indices, and third to annual length frequency indices. Model sensitivity to initial equilibrium catch was tested by removing the estimation of equilibrium catch for one model run. Model sensitivity to each CPUE index, was tested by sequentially turning off model fits to individual CPUE index likelihoods.

3. Model Results

Model results from SS3 were evaluated with Microsoft Excel subroutines available from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/SS3.html) and with R statistical package plotting subroutines designed specifically for SS3 (r4ss Google Code, http://code.google.com/p/r4ss/).

3.1 Sensitivity

Model fits were sensitive to natural mortality, effective sample size of CPUE time series, and the sequential removal of CPUE time series (Table 8, Figure 6). Some model runs did not converge and are indicated by "NA" (Table 8). One parameter (R_0) was estimated at the lower bound and is a diagnostic of non-convergence (LO; Table 8). Model estimates of effective sample size differed substantially from raw input sample sizes (Table 9).

3.2 Model Fits

The base case had reasonable fits to CPUE time series from Japan Offshore + Distant Water Longline (S1), US Hawaii Longline Shallow-Set (S3), US Hawaii Longline Deep-Set (S4), and US California Gillnet-Updated (S5) (Figure 7).

3.3 Estimated Selectivity Patterns

The base case appeared to have reasonable selectivity estimates for Japan Offshore + Distant Water Longline (F1) , U.S. Hawaii Shallow-Set Longline (F6), U.S. California Gillnet (F8), and U.S. Hawaii Deep-Set Longline (S4) (Figure 8).

Selectivity estimates did not appear to differ by sex (Figure 8). Estimated numbers at age also did not appear to differ by sex (Figure 9). This may be a diagnostic for model mis-specification or it may reflect the limited amount of sex-specific length data.

Model fits to length frequency data were generally poor and did not fit length frequency modes that moved through the population over time (Figures 10 - 13). This may be a diagnostic for model mis-specification or it may reflect changing length frequency selectivity over time that was not accommodated in the current model.

3.4 Estimated Time Series

Natural mortality, size at age, spawning output at length, and weight at size were fixed as model input (Figures 14 – 16). Spawning output was assumed to be proportional to weight at length for females (Figures 16). Model estimated time series of total biomass were relatively flat (e.g., Figure 17). Model estimated Age-0 recruitment variability was consistent with the availability of length frequency data which began in 1970 (Figure 18). 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. 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. There was limited data at low population size to estimate the spawner-recruit relationship (Figure 19). Model estimates of mature female spawning biomass (mt) were relatively flat (e.g., Figure 20).

4. Discussion

One of our interests at this stage of model development was to model the process of length based selectivity for the major fishery and CPUE time series as a comparison for Bayesian Production models. The major fisheries were Japan Offshore+Distant Water Longline (63% of total catch mt 1951 – 2006), Japan All Other Gears (16% of total catch mt 1951 – 2006), US Hawaii Longline (12% of total catch mt 1995 – 2006), Chinese Taipei All Other Gears (10% of total catch mt 1995 – 2006), and Mexico All Gears (7% of total catch mt 1995 – 2006) (Courtney and Wagatsuma 2009) (Figure 1). The major CPUE time series were Japan Offshore+Distant Water Longline (1952 – 2006), Chinese Taipei Distant Water Longline (1995 – 2006; 3% of total catch mt 1995 – 2006), and U.S. Hawaii Longline (1995 – 2006) (Courtney and Wagatsuma 2009). Exploratory time series of CPUE were also included for US California Gillnet (1985 – 2006; 3% of total catch mt 1995 – 2006), and U.S. Hawaii Deep-set Longline (as a recruitment index) (Courtney and Wagatsuma 2009). Fits to the major CPUE indices were reasonable except for the fit to Chinese Taipei Distant Water Longline (Figure 7). The base case model appeared to adequately estimate selectivity for the major fisheries and CPUE series (Figure 8). In this respect, the model appeared to reasonably account for length based selectivity on the population and supports the use of SS3 models for north Pacific Swordfish assessment.

The model had a poor fit to the length modes as evidenced by the obvious trends in residuals (Figure 13). This may have resulted from model mis-specification of the growth curves and will be evaluated. Additionally, there may have been changes in selectivity of Japan Offshore + Distant Water Longline over time as a result of changes in target species that were not accounted for in the current model structure. Previous North Pacific swordfish assessments dealt with changing length frequency selectivity by stratifying data into day and night sets (Kleiber and Yokawa 2004, Wang et al. 2007). An alternative solution available in SS3 could be to separate the estimation of length based selectivity into shorter time periods “blocks” associated with major changes in target species.

Results from these preliminary sensitivity runs were consistent with Wang et al. (2007) except that the models of Wang et al. (2007) were sensitive to sexual dimorphism, and our models were not. Wang et al. (2007) included length data by sex from Japan. Our model did not. Wang et al. (2007) also included parameter estimates for sex ratio in 4 sub-regions of the North Pacific. Our model did not. Sex ratio data were obtained from Japan training vessels which operated in different locations than the fishery. As a result, sex ratios from Japan training vessels may not be representative of fishery removals. In this assessment, SS3 sex ratios were based on the length frequency (numbers) input separately for females and males. Hawaii longline shallow-set was the only fishery with length for males and females.

Results from these preliminary sensitivity runs were also consistent with (Kleiber and Yokawa 2004) in that the available CPUE time series were relatively flat and uninformative and as a result, model estimates were sensitive to key parameters. Our model fits improved for higher values of natural mortality (M) (Figure 6) which is also consistent with (Kleiber and Yokawa 2004).

Additional caveats are that previous ISC assessments for striped marlin with SS2 used 4 seasons with catchability (q) occurring half way through season 3 (Piner et al 2007). This preliminary sensitivity analysis had 1 season. Previous swordfish assessments stratified the data regionally (Kleiber and Yokawa 2004, Wang et al. 2007). These preliminary sensitivity runs had no spatial structure. An obvious solution is to include the BILLWG recommended regional spatial structure in the Stock Synthesis assessment (Figure 3).

Finally, likelihood components included negative values (Table 8.2). It was assumed that this resulted from the negative log of likelihoods that were greater than one (not true probabilities, 0 – 1) and that negative values for likelihood components could be interpreted analogously to positive values when interpreting the relative fit of likelihood components in the objective function (Figure 6).

5. Conclusions

The base case model appeared to adequately estimate selectivity for the major fisheries and CPUE series. The base case model fits to all CPUE indices except Chinese Taipei distant water longline appeared reasonable. Model estimates of mature female spawning biomass were relatively flat. Model results were sensitive to natural mortality, effective sample size of CPUE, and the sequential removal of CPUE time series.

The sensitivity analysis identified three issues that may need further consideration. Equilibrium recruitment (R_0) was estimated at the lower bound in all runs. All runs had very poor fits to length frequency. Selectivity did not appear to differ by sex.

The sensitivity analysis also suggests that there may be reasonable alternative models worthy of consideration. For example: Natural mortality (M = base); Steepness (h = base); Sigma_r = base; Selectivity = separate sex; Sigma_r and CPUE iteratively re-weighted with model estimated effective sample size; and CPUE time series S1,S2,S3.

SS3 analysis of a regionally stratified stock assessment for swordfish under Stock Scenario-1 (Figure 3) is ongoing and will be presented separately. The issues identified in this preliminary sensitivity analysis will be addressed in the regionally stratified assessment.

Acknowledgements

The authors thank Dr Richard Methot (NOAA Fisheries) for a helpful review of the sensitivity analysis and for the implementation of SS3 http://nft.nefsc.noaa.gov/SS3.html (NOAA Fisheries Toolbox). The authors also thank Dr Ian Stewart and Dr Ian Taylor

(NOAA Fisheries) for development of the R statistical package plotting subroutines http://code.google.com/p/r4ss/ (r4ss Google Code) used to make many of the figures in this report.

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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	$EFL_t = EFL_\infty \left(1 - e^{-k(t-t_0)}\right)$ 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			$W(kg) = aEFL^b$ Uchiyama and Humphreys (2007), Uchiyama et al. (1999)
Central North Pacific maturity probability (p(L) at length (cm of eye fork length)	L50 = 143.6 σ = 9.67	L50 = 102.0 σ = 7.08	L50 = 121.1 σ = 15.9	$p(EFL) = \left(1 + \exp\left(\frac{-(EFL - L_{50})}{\sigma_m}\right)\right)^{-1}$ De Martini et al. (2000)

* 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 et al. 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 et al. 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 input to Stock Synthesis.

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 input to Stock Synthesis.

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. Preliminary Stock Synthesis 3 model data included 10 fisheries (F1 – F10), 5 CPUE time series (S1 –S5), and 4 time series of length frequency.

Fishery			Catch Data[1]	Length Data[2]	Selectivity
F1	Japan	Offshore+Distant Water Longline	1951 – 2006	1970 – 2006 Female and Male Combined	Estimated - Logistic
F2		All Other Gears	1951 – 2006	-	Assumed same as F1
F3	Chinese Taipei	Distant Water Longline	1969 – 2006	-	Assumed same as F1
F4		All Other Gears	1959 – 2006	-	Assumed same as F1
F5	Korea	All Gears	1971 – 2006	-	Assumed same as F1
F6	US Hawaii	Longline	1970 – 2006	Shallow-Set 1994 – 2000, 2005 Female and Male Combined	Estimated - Logistic
F7	US California	Longline	1981 – 2006	-	Assumed same as F1
F8		Gillnet	1980 – 2006	1981 – 2006 Female and Male Combined	Estimated - Logistic
F9		Other Gear+Unknown	1970 – 2006	-	Assumed same as F1
F10	Mexico	All Gears	1972 – 2006	-	Assumed same as F1

CPUE Index			CPUE Data[3]	Length Data[2]	Selectivity
S1	Japan	Offshore+Distant Water Longline	1952 – 2006	-	Assumed same as F1
S2	Chinese Taipei	Distant Water Longline	1995 – 2006	-	Assumed same as F1
S3	US Hawaii	Longline Shallow-Set	1995 – 2006	-	Assumed same as F6
S4	US Hawaii	Longline Deep-Set	1995 – 2006	1994 – 2006 Female and Male Combined	Estimated – Logistic
S5	US California	Gillnet (Updated)	1985 – 2006	-	Assumed same as F8

1 Courtney and Wagatsuma (2009, Table 1)
2 Courtney and Fletcher (2009)
3 Courtney and Wagatsuma (2009, Table 4)

Table 8.1. Preliminary Stock Synthesis 3 model sensitivity analysis results.

Model Run	Specification	S_0 (Virgin mt)	s.e	S_0 (Init_F_F1 mt)	s.e	S_2006	s.e	S_2006/S_0 (Virgin)	Init_F_F1	s.e	R_0 (Virgin)	s.e
1	Base-case	76,500	0.033	52,135	264.261	38,522	1,822.12	50.36%	0.08	0.001	1,097	LO
	M (base = Linked to Life History)											
1.2	0.2	243,036	0.142	202,284	436.807	219,306	7,600.36	90.24%	0.02	0.000	1,097	LO
1.3	0.25	158,909	0.084	126,237	354.523	121,611	4,556.91	76.53%	0.04	0.000	1,097	LO
1.4	0.3	NA										
1.5	0.4	56,954	0.028	38,166	205.315	26,920	1,360.24	47.27%	0.10	0.001	1,097	LO
1.6	0.5	32,412	0.020	18,898	144.532	10,865	655.66	33.52%	0.18	0.003	1,097	LO
1.7	0.6	19,560	0.025	9,729	100.660	4,559	328.99	23.31%	0.31	0.005	1,097	LO
	h (base = 0.9)											
1.8	Estimated	NA										
1.9	0.6	NA										
1.10	0.8	76,500	0.029	52,164	263.878	35,177	1,712.64	45.98%	0.08	0.001	1,097	LO
1.11	0.95	76,500	0.034	52,124	264.398	39,732	1,863.82	51.94%	0.08	0.001	1,097	LO
	sigma_r (base = 0.4)											
1.12	0.2	NA										
1.13	0.6	76,500	0.030	52,214	263.327	31,277	1,665.03	40.89%	0.08	0.001	1,097	LO
	Selectivity (base = Sex-Separated)											
1.14	Sex-Combined	71,235	0.029	48,709	246.353	29,261	1,557.63	41.08%	0.08	0.001	1,097	LO
	Effective Sample Size (base = raw sample size)											
1.15	sigma_r	76,500	0.034	52,111	264.516	41,244	1,831.49	53.91%	0.08	0.001	1,097	LO
1.16	sigma_r, CPUE	76,500	0.035	52,268	262.981	54,267	3,024.73	70.94%	0.08	0.001	1,097	LO
1.17	sigma_r, CPUE, Length	76,500	0.019	52,390	259.437	63,253	3,256.88	82.68%	0.08	0.001	1,097	LO
	Initial Equilibrium Catch (base = estimated)											
1.18	No Initial F	76,500	0.035	76,500	0.035	38,543	1,830.44	50.38%	0.00	_	1,097	LO
	CPUE (base = S1, S2, S3, S4, S5)											
1.19	S1	76,500	0.034	52,290	263.266	51,174	3,205.50	66.89%	0.08	0.001	1,097	LO
1.20	S1 and S2	76,500	0.035	52,236	263.591	50,277	2,874.78	65.72%	0.08	0.001	1,097	LO
1.21	S1, S2, S3	76,500	0.034	52,242	263.372	51,052	2,788.04	66.73%	0.08	0.001	1,097	LO
1.22	S1, S2, S3, S4	76,500	0.033	52,135	264.425	36,007	1,748.70	47.07%	0.08	0.001	1,097	LO
1.23	S1, S2, S3, S5	76,500	0.035	52,242	263.195	52,221	2,753.95	68.26%	0.08	0.001	1,097	LO

Table 8.2. Preliminary Stock Synthesis 3 model sensitivity analysis results, continued.

Run	Specification	CPUE Total	S1	S2	S3	S4	S5	Length Total	F1	F6	F8	S4	R_0	Grand Total	# Par.
1	Base-case	11.1	-62.1	10.5	-10.0	-8.4	81.0	923.1	670.3	47.6	164.8	40.4	-28.6	905.7	80
	M (base = Linked to Life History)														
1.2	0.2	88.0	-51.1	9.6	-10.9	-11.9	152.2	1,820.4	1,408.1	107.3	258.1	46.8	-21.0	1,887.6	80
1.3	0.25	49.9	-60.8	9.9	-10.5	-10.8	122.1	1,454.5	1,108.5	82.8	220.5	42.7	-25.5	1,479.2	80
1.4	0.3	NA													
1.5	0.4	-0.4	-62.8	10.1	-9.8	-7.9	70.1	801.6	568.7	40.3	151.7	40.8	-28.4	773.0	80
1.6	0.5	-17.9	-61.4	8.9	-9.4	-6.4	50.3	594.9	389.7	28.5	130.3	46.4	-27.8	549.4	80
1.7	0.6	-34.2	-62.7	6.6	-9.0	-5.0	36.0	502.0	299.7	24.2	122.1	56.1	-24.2	443.8	80
	h (base = 0.9)														
1.8	Estimated	NA													
1.9	0.6	NA													
1.10	0.8	14.7	-57.8	10.9	-10.0	-8.2	79.8	904.4	655.5	46.1	162.3	40.4	-28.6	890.7	80
1.11	0.95	10.0	-63.4	10.4	-10.0	-8.4	81.4	929.5	675.3	48.1	165.7	40.3	-28.6	911.1	80
	sigma_r (base = 0.4)														
1.12	0.2	NA													
1.13	0.6	22.5	-43.7	10.7	-10.0	-8.1	73.5	886.0	640.5	44.9	160.4	40.3	-15.8	892.9	80
	Selectivity (base = Sex-Separated)														
1.14	Sex-Combined	21.8	-44.0	10.7	-10.0	-8.1	73.2	875.6	632.5	44.3	158.6	40.2	-15.8	881.8	80
	Effective Sample Size (base = raw sample size)														
1.15	Sigma_r	11.1	-66.7	10.1	-9.8	-8.6	86.1	936.2	681.0	48.5	166.0	40.6	-37.5	910.0	80
1.16	Sigma_r, CPUE	-87.4	-53.8	-5.3	-10.7	-8.3	-9.2	868.5	618.1	48.1	162.5	39.8	-36.5	744.9	80
1.17	S_r, CPUE, Length	-39.9	-25.8	-1.5	-8.8	-5.1	1.3	1,722.4	759.7	187.1	559.7	215.9	-22.4	1,660.6	80
	Initial Equilibrium Catch (base = estimated)														
1.2	No Initial F	15.6	-56.8	10.4	-10.0	-8.5	80.5	925.1	671.9	47.8	165.1	40.3	-28.4	912.6	79
	CPUE (base = S1, S2, S3, S4, S5)														
1.2	S1 only	-38.8	-38.8	19.3	-9.6	3.9	192.1	813.4	605.5	47.8	160.2	126.3	-26.7	747.9	80
1.20	S1 and S2	-51.9	-50.3	-1.6	-10.7	-3.5	195.3	835.6	614.9	52.9	167.8	132.1	-29.3	754.5	80
1.2	S1, S2, S3	-61.1	-48.9	-1.1	-11.1	-3.5	196.5	833.7	614.1	52.4	167.1	131.9	-29.0	743.6	80
1.2	S1, S2, S3, S4	15.1	-60.8	15.7	-10.1	6.1	70.2	880.7	672.4	46.3	162.0	126.9	-28.0	868.1	80
1.2	S1, S2, S3, S5	-69.3	-48.3	-0.4	-11.2	-9.4	197.5	874.1	614.2	53.2	168.0	38.7	-29.2	775.9	80

Table 9. Model estimates of effective sample size.

Likelihood Component	Fleet	N	Model Estimate (R.M.S.E)	Input SE	
Sigma_r		36	0.2842	0.4	
CPUE	Fleet	N	R.M.S.E.	Mean Input SE	+VarAdj
	S1	55	0.184988	0.1	0.053984
	S2	12	0.473448	0.3	0.157719
	S3	7	0.162535	0.1	0.012958
	S4	12	0.352308	0.2	0.14789
	S5	22	0.238204	0.1	0.187336
Length Composition	Fleet	N	Mean Eff. N	Mean input N Sqrt(n)	*Var_Adj
	F1	36	192.217	155	1.236186
	F2	_	_	_	1
	F3	_	_	_	1
	F4	_	_	_	1
	F5	_	_	_	1
	F6	8	287.878	60	4.765135
	F7	_	_	_	1
	F8	26	136.378	36	3.813084
	F9	_	_	_	1
	F10	_	_	_	1
	S1	_	_	_	1
	S2	_	_	_	1
	S3	_	_	_	1
	S4	13	102.557	19	5.463384
	S5	_	_	_	1

Figures

Stock Scenario - 1

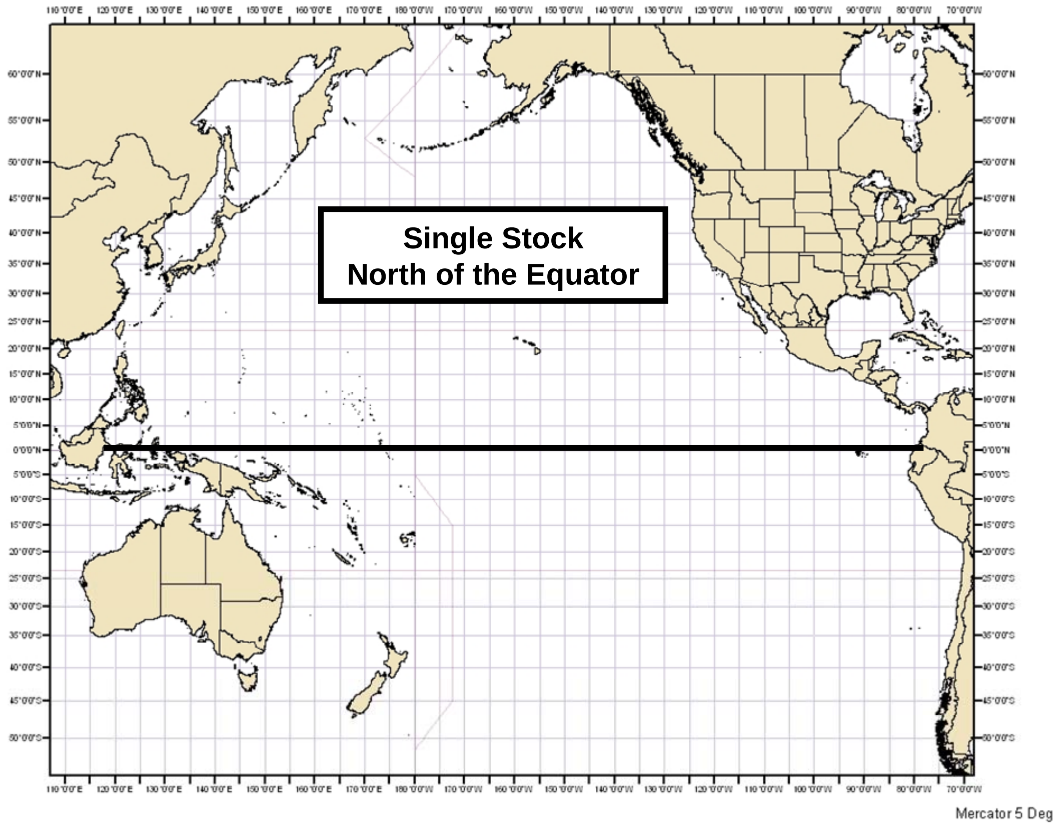

Figure 1. Stock Scenario-1, a single North Pacific stock north of the equator (the stock structure assumed for this preliminary sensitivity analysis).

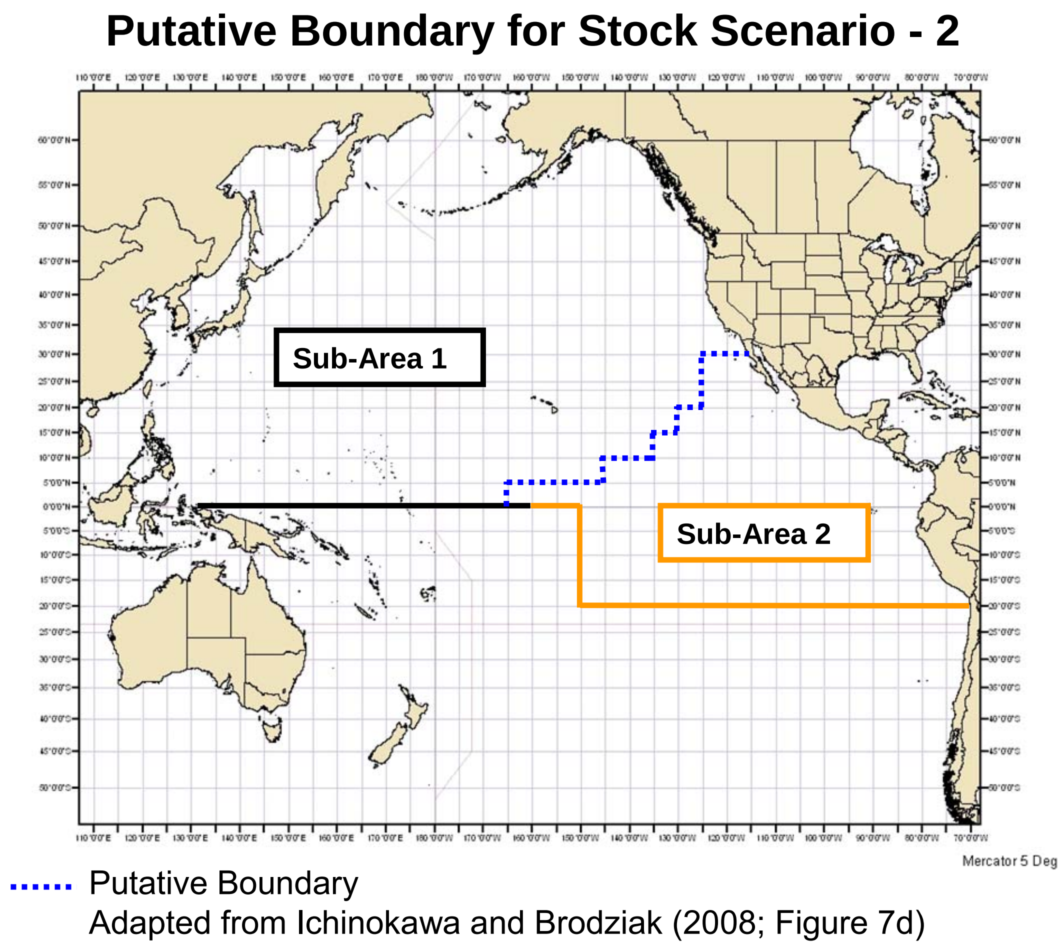

Figure 2. Putative boundary for Stock Scenario-2, two North Pacific stocks (not implemented for this preliminary sensitivity analysis).

Stock Scenario - 1

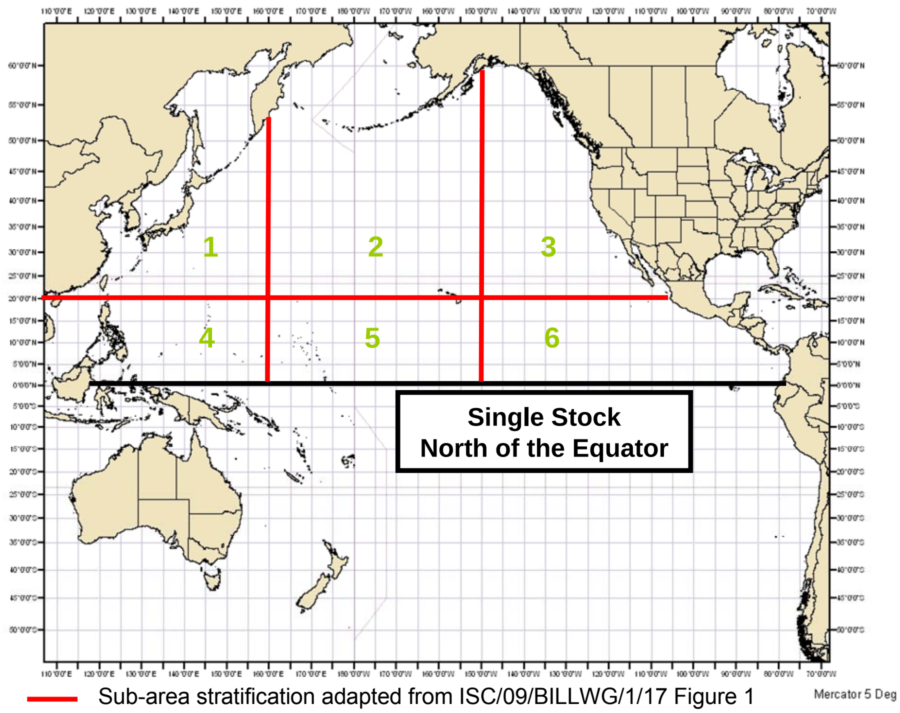

Figure 3. Regional stratification (6 regions) under Stock Scenario – 1 (adapted from Sun et al. 2009, Figure 1) (not implemented for this preliminary sensitivity analysis).

Putative Boundary for Stock Scenario - 2

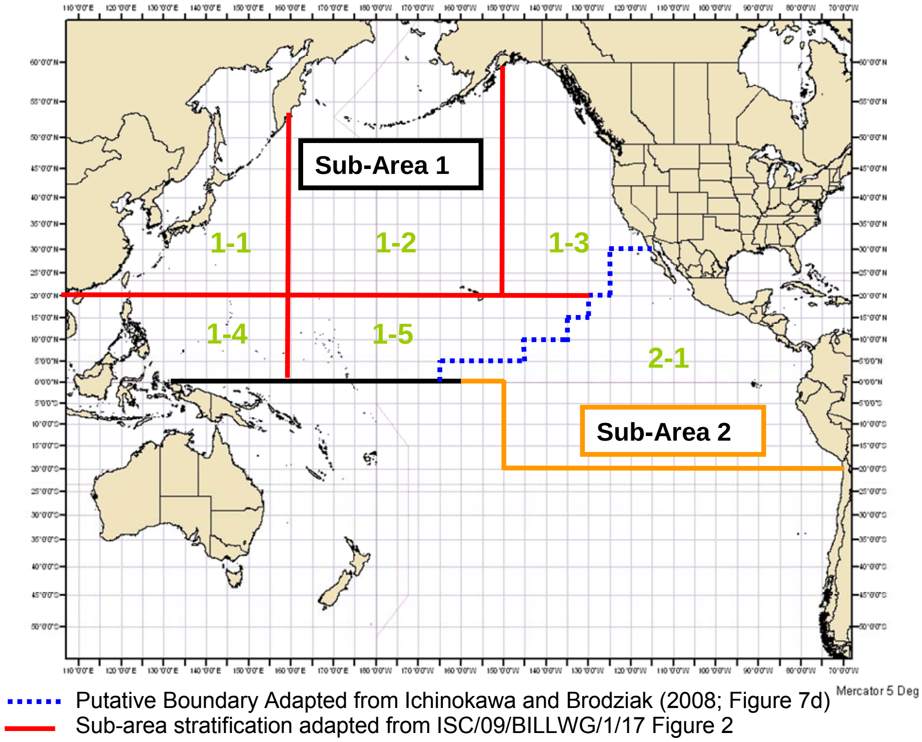

Figure 4. Regional stratification (5 regions in Sub-Area 1 and 1 region in Sub-Area 2) under Stock Scenario-2 (adapted from Sun et al. 2009, Figure 2) (not implemented for this preliminary sensitivity analysis).

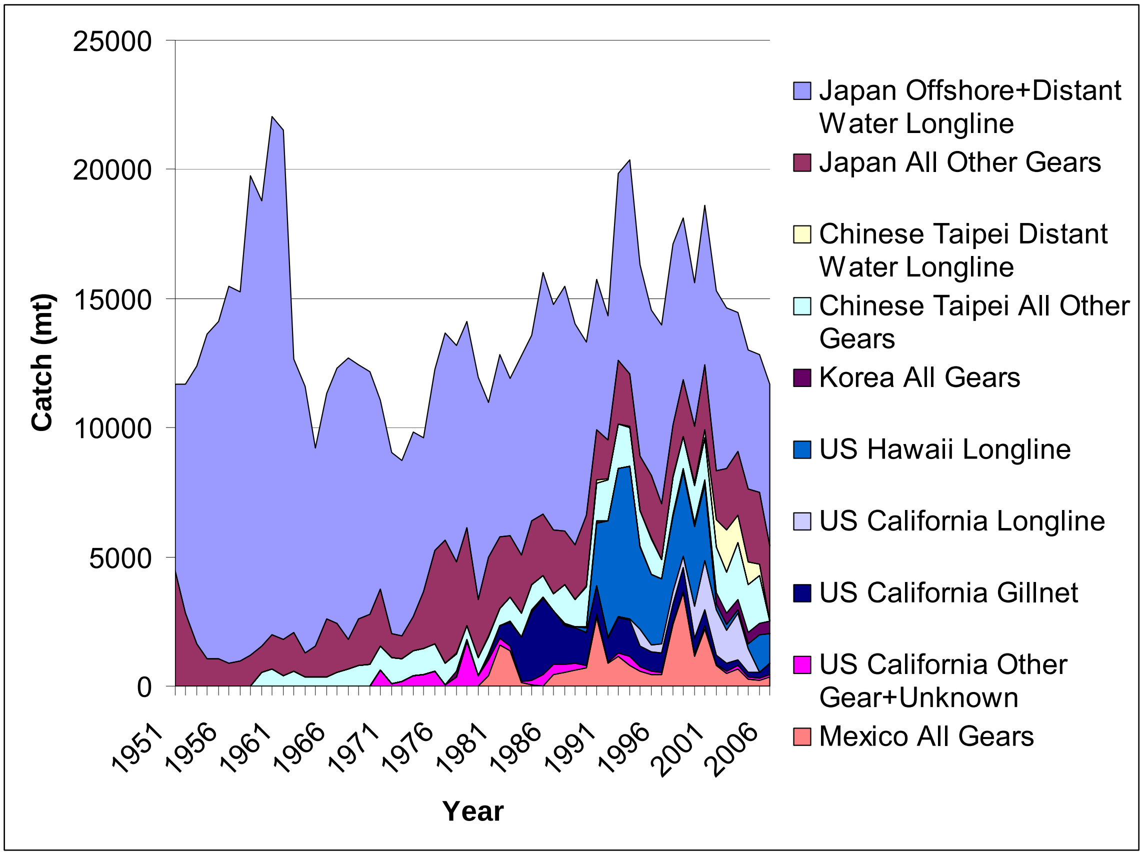

Figure 5. Annual catch of swordfish (mt) in the North Pacific by fleet (adapted from Courtney and Wagatsuma 2009).

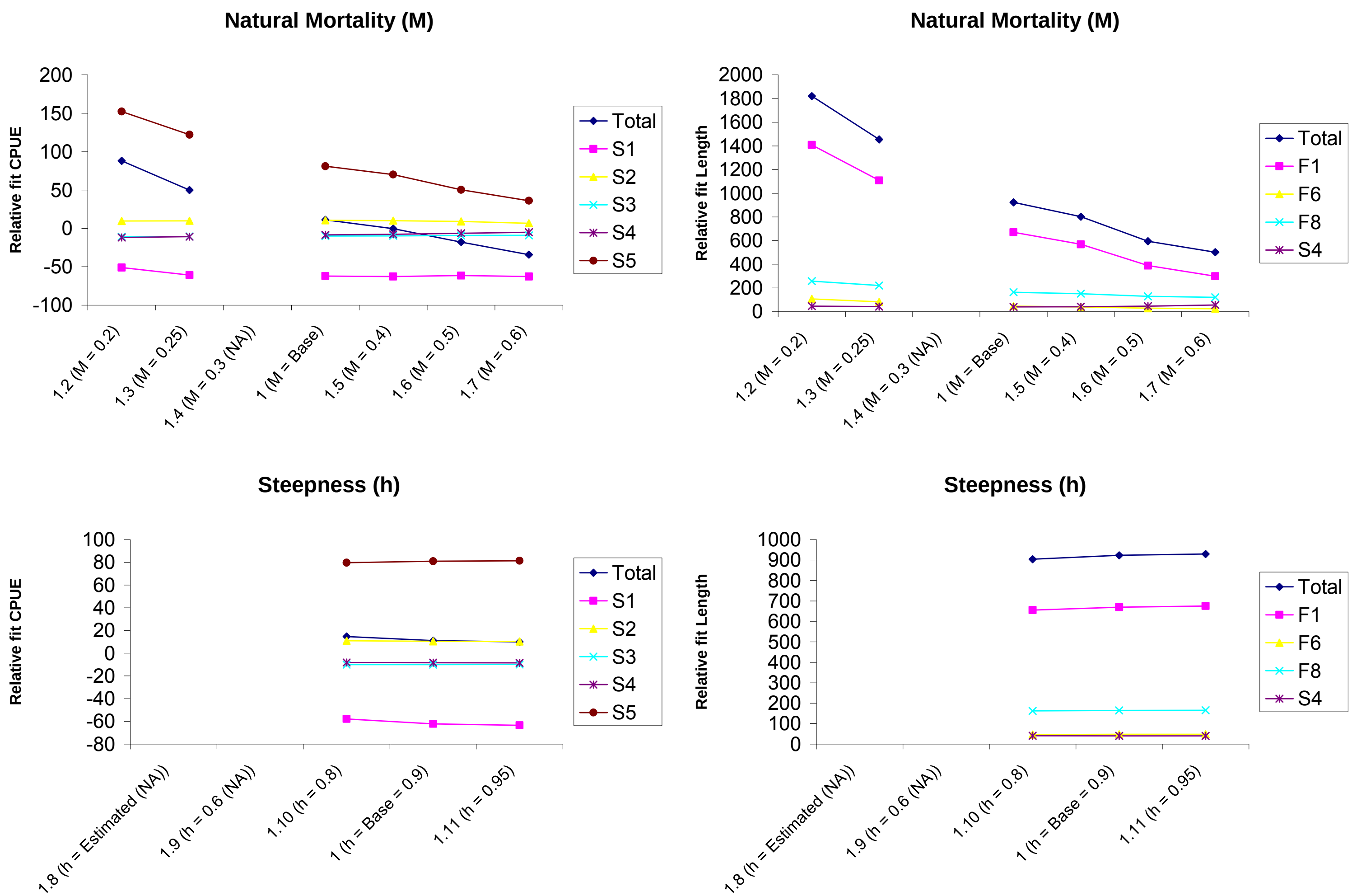

Figure 6.1. Relative fit of CPUE and length frequency likelihood components from sensitivity analysis: Natural mortality (M) and steepness (h). “NA” indicates that the model did not converge, lower values are assumed to indicate better fit.

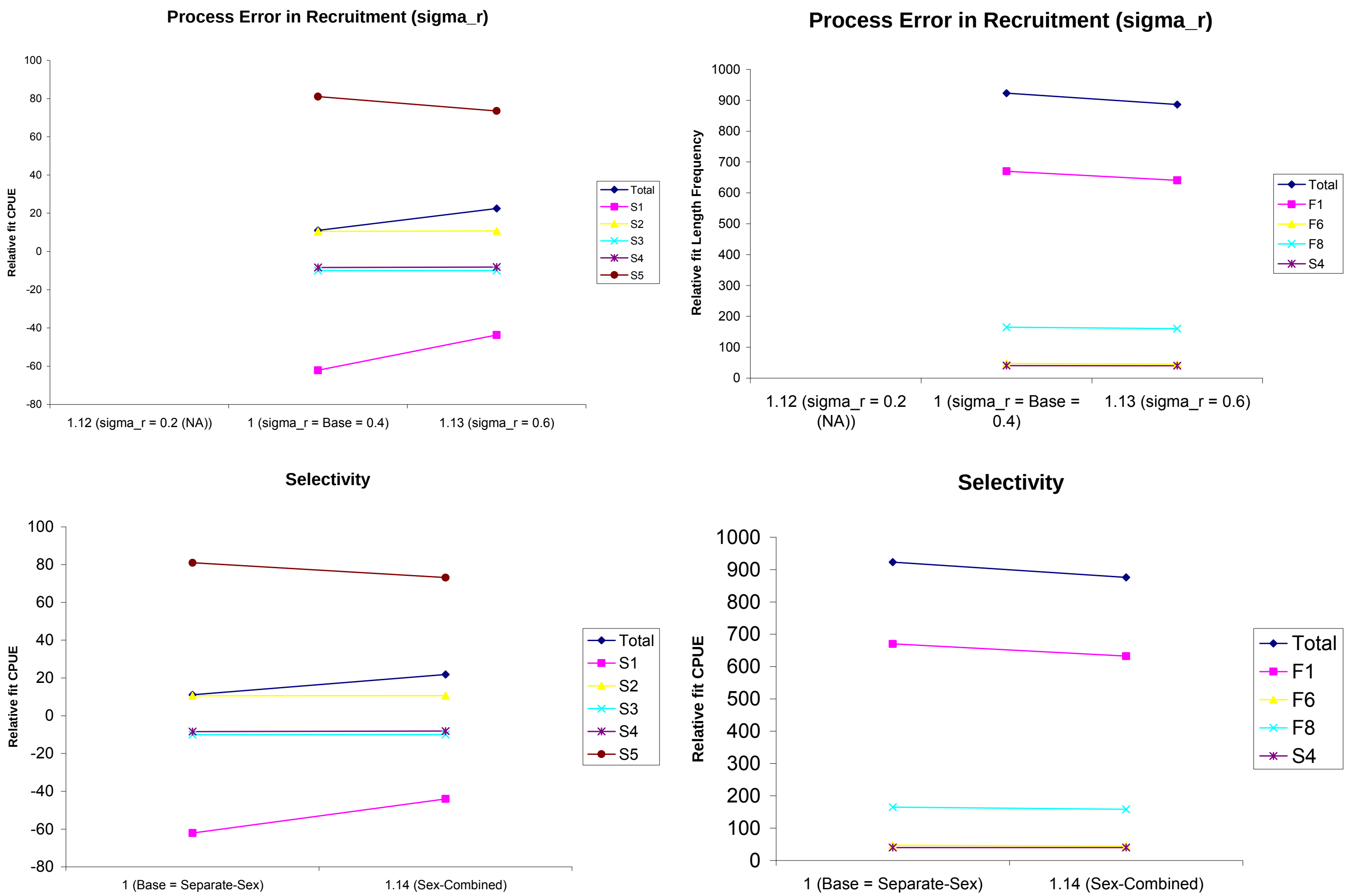

Figure 6.2. Relative fit of CPUE and length frequency likelihood components from sensitivity analysis: Process error in recruitment (sigma_r) and separate-sex versus sex-combined selectivity. “NA” indicates that the model did not converge, lower values are assumed to indicate better fit.

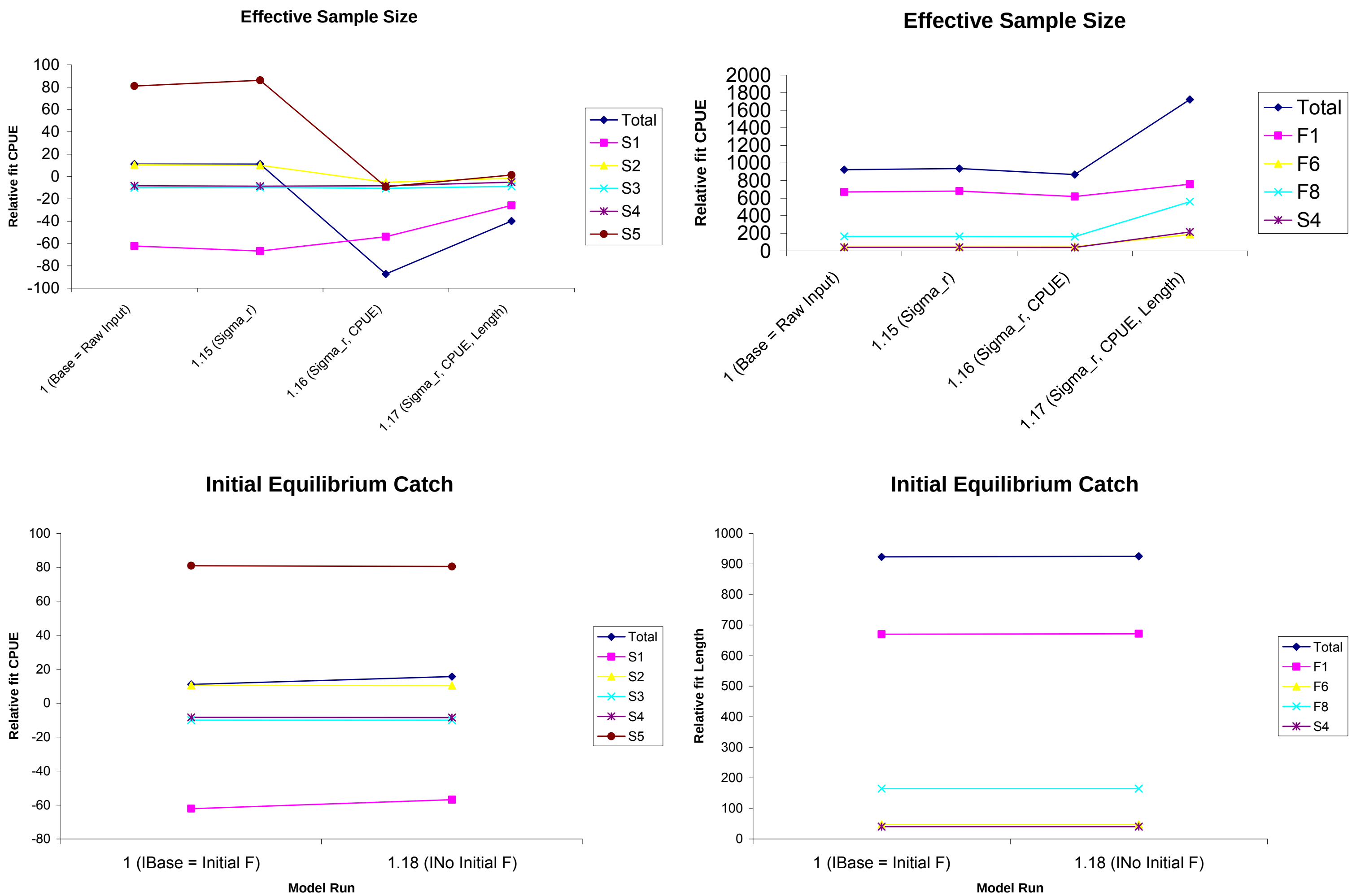

Figure 6.3. Relative fit of CPUE and length frequency likelihood components from sensitivity analysis: Effective sample size and Initial equilibrium catch. Lower values are assumed to indicate better fit.

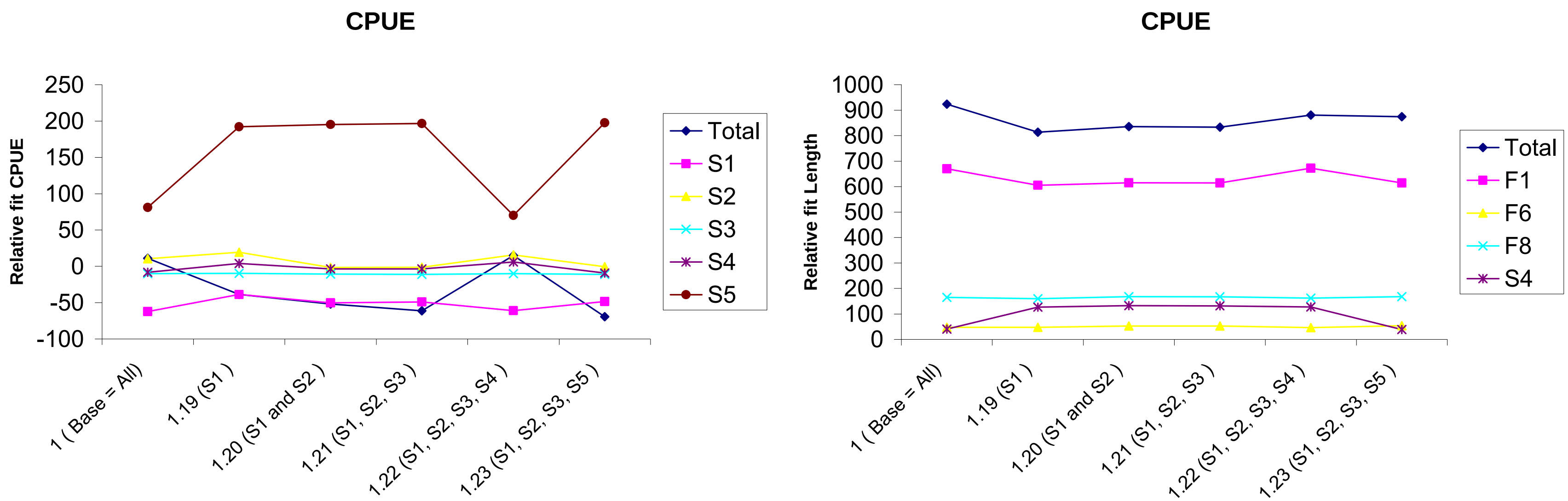

Figure 6.4. Relative fit of CPUE and length frequency likelihood components from sensitivity analysis: CPUE. Lower values are assumed to indicate better fit.

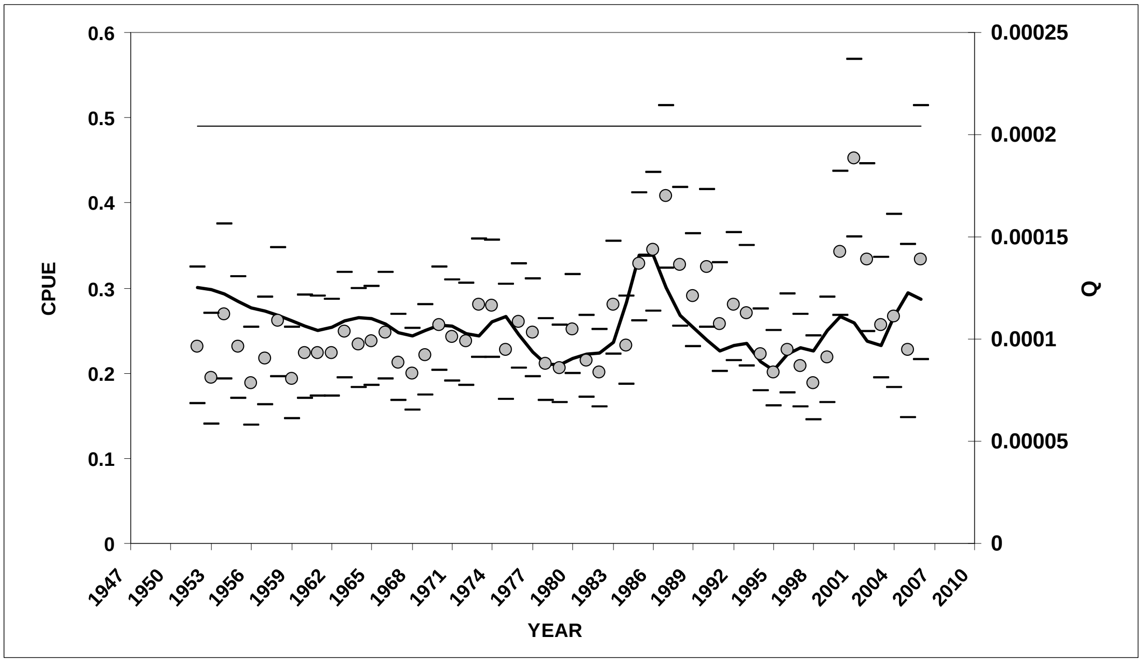

Figure 7.1. Model fit to Standardized CPUE time series (S1) Japan Offshore+Distant Water Longline. Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

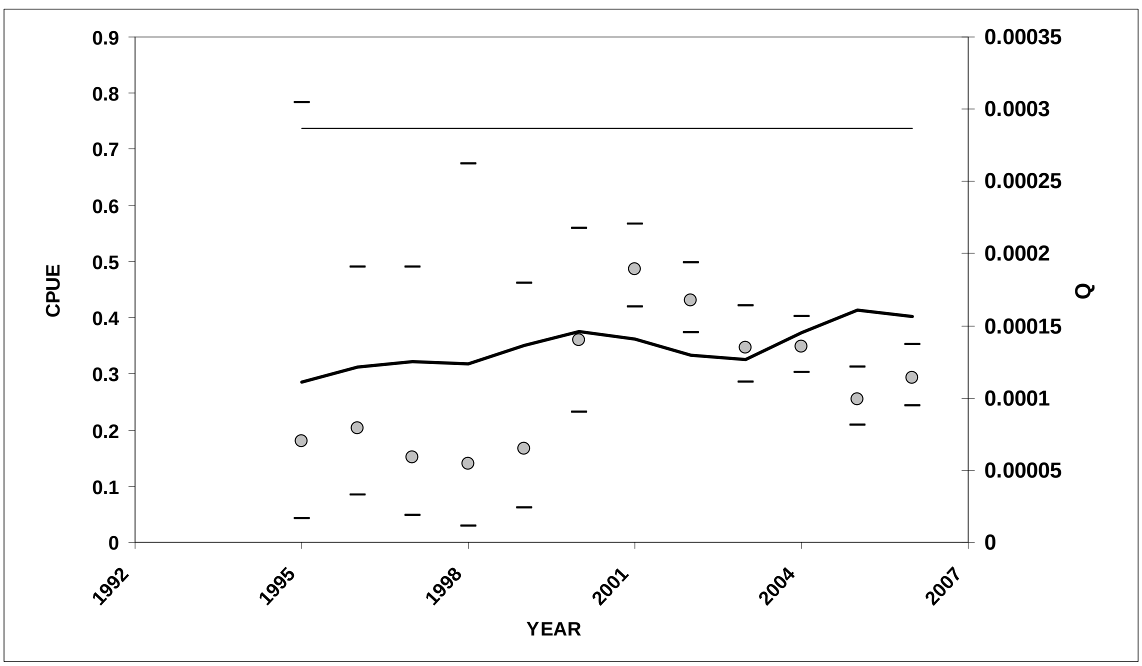

Figure 7.2 Model fit to Standardized CPUE time series (S2) Chinese Taipei Distant Water Longline. Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

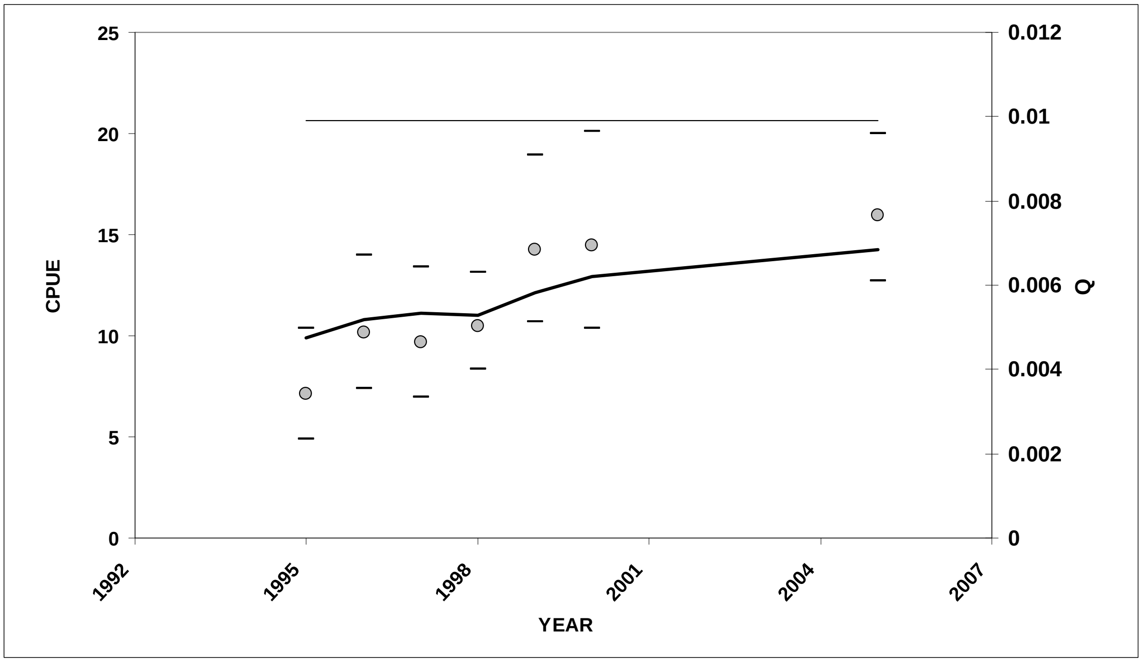

Figure 7.3. Model fit to Standardized CPUE time series (S3) US Hawaii Longline Shallow-Set. Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

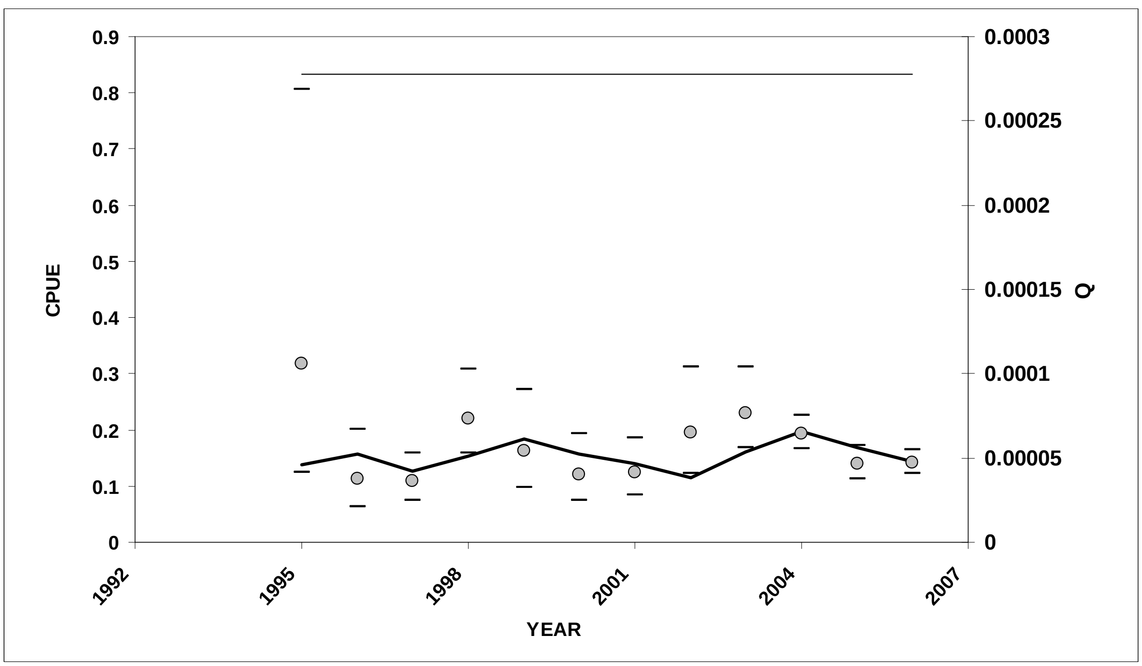

Figure 7.5. Model fit to Standardized CPUE time series (S4) US Hawaii Longline Deep-Set. Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

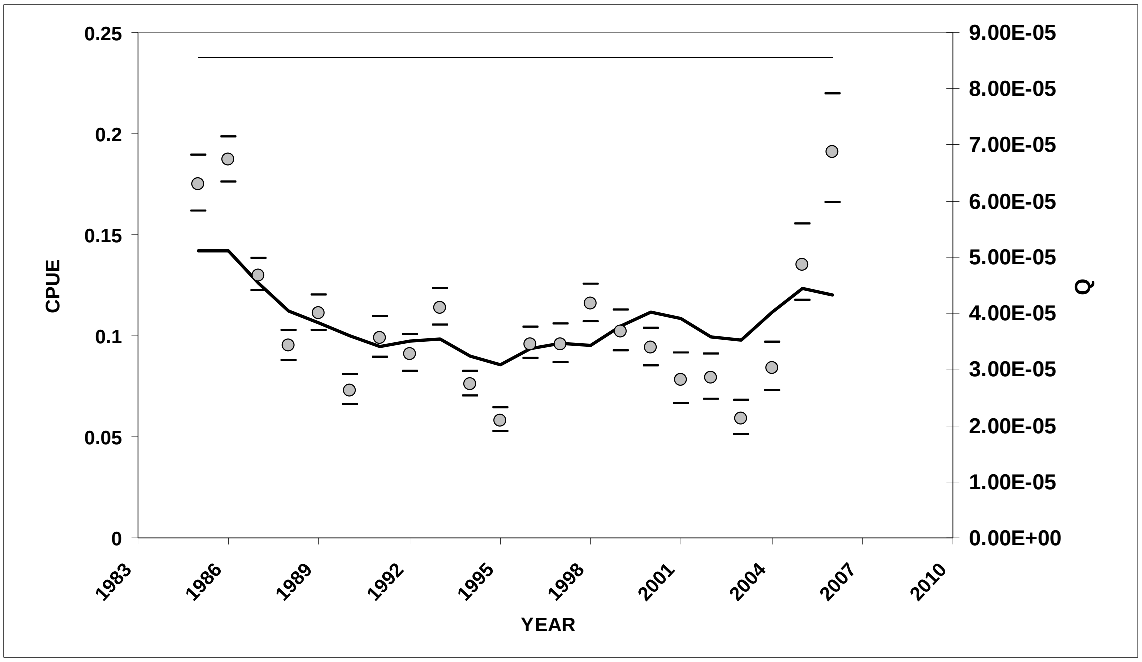

Figure 7.5. Model fit to Standardized CPUE time series (S5) US California Gillnet (Updated). Circles are observed CPUE, bold line is model estimate, dashes are +-2*(observed se), and thin line is effective q.

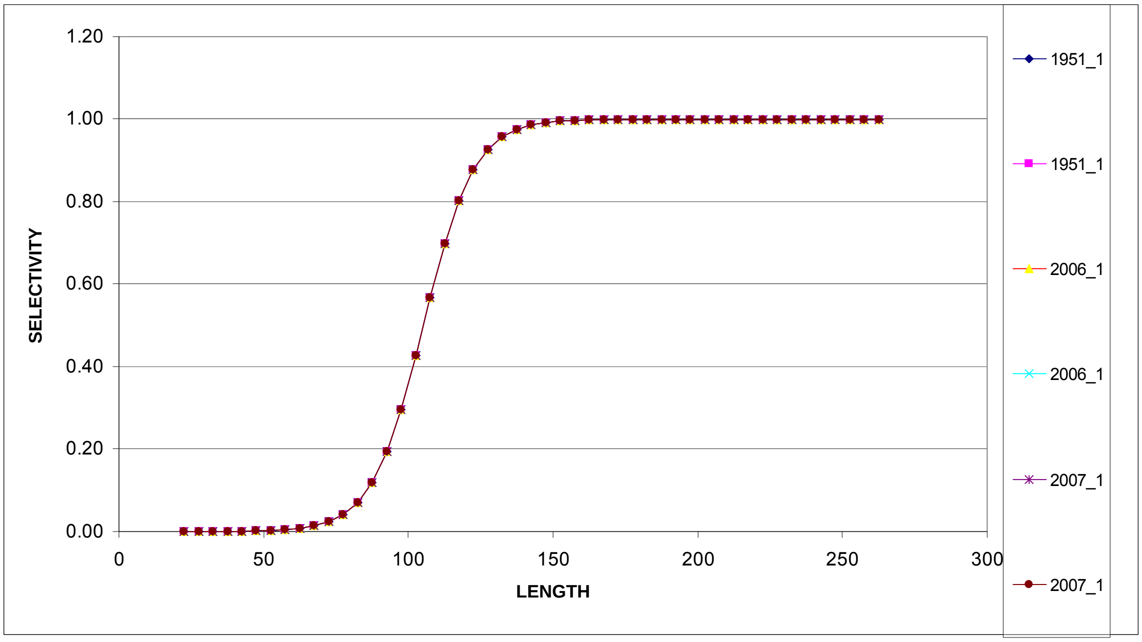

Figure 8.1. Length selectivity (F1) Japan Offshore+Distant Water Longline (1951 males, 1951 females, 2006 males, 2006 females, 2007 males, 2007 females).

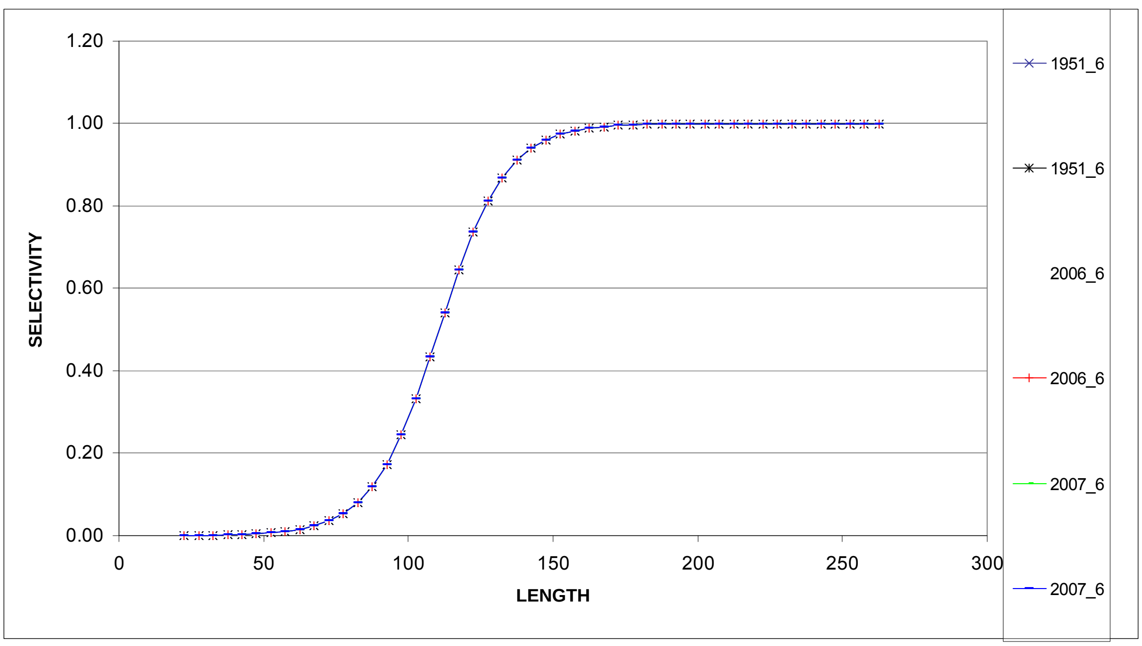

Figure 8.2. Length selectivity (F6) U.S. Hawaii Shallow-Set Longline (1951 males, 1951 females, 2006 males, 2006 females, 2007 males, 2007 females).

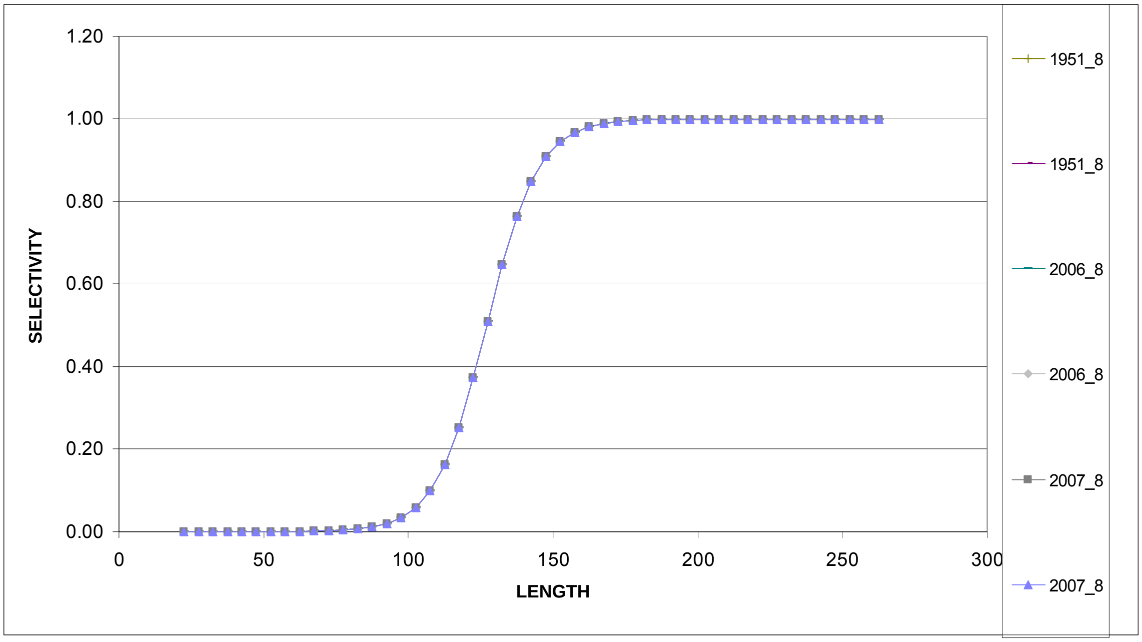

Figure 8.3. Length selectivity (F8) U.S. California Gillnet (1951 males, 1951 females, 2006 males, 2006 females, 2007 males, 2007 females).

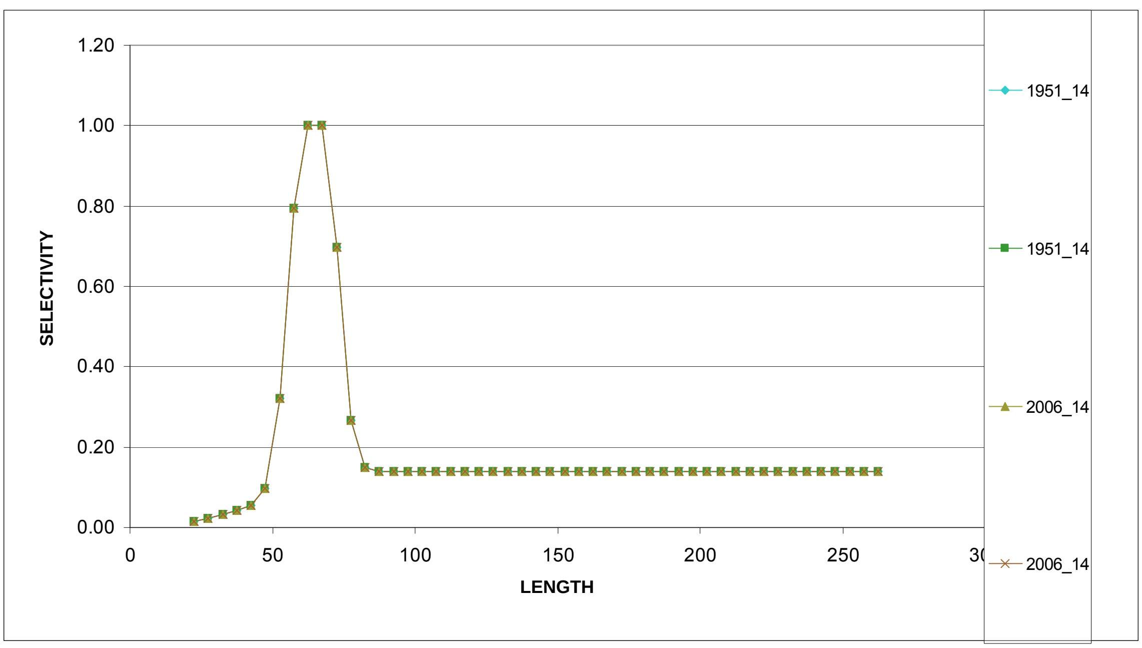

Figure 8.4. Length selectivity (S4) U.S. Hawaii Deep-Set Longline (1951 males, 1951 females, 2006 males, 2006 females, 2007 males, 2007 females).

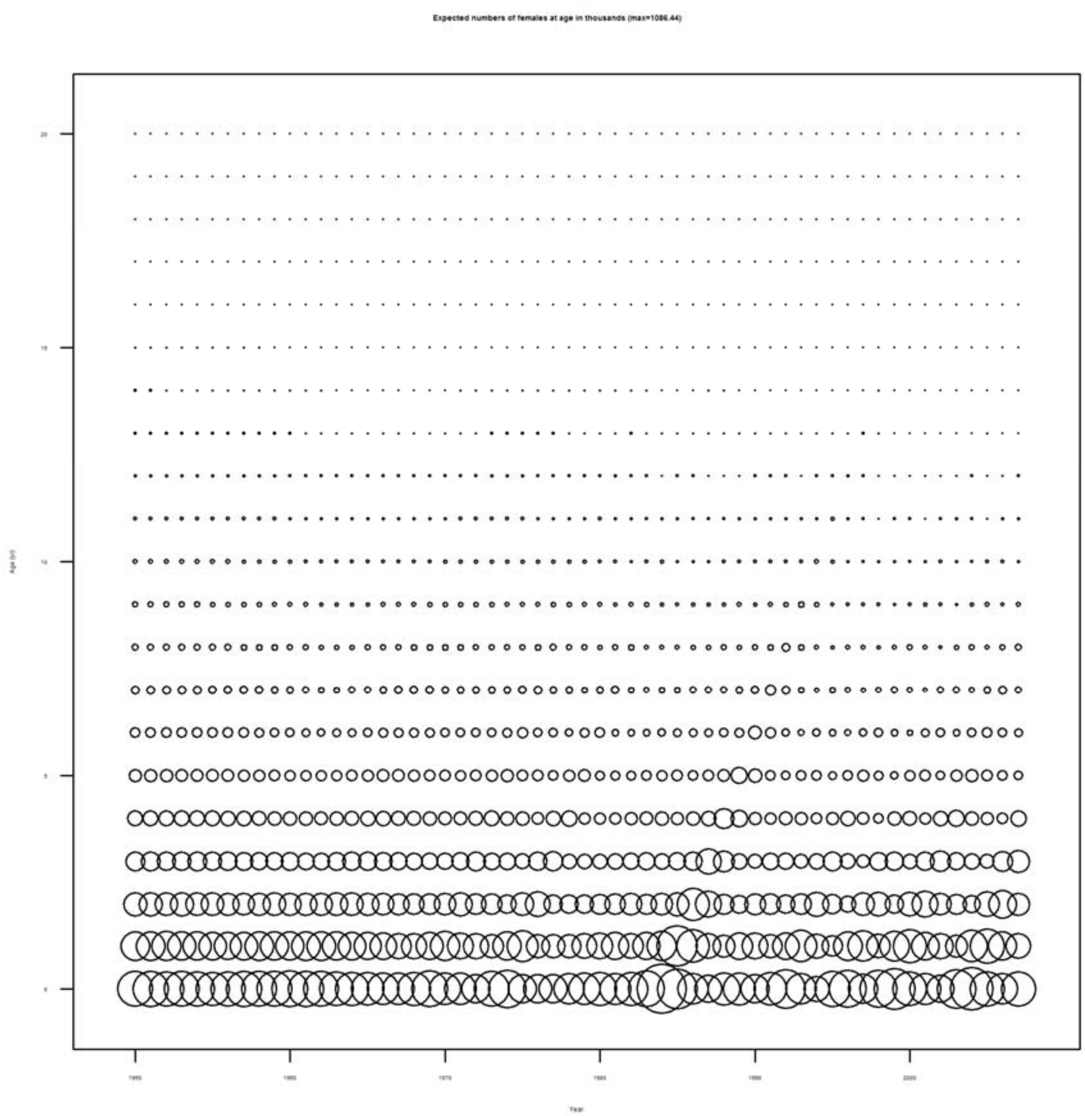

Figure 9.1. Model estimated numbers at age sex 1.

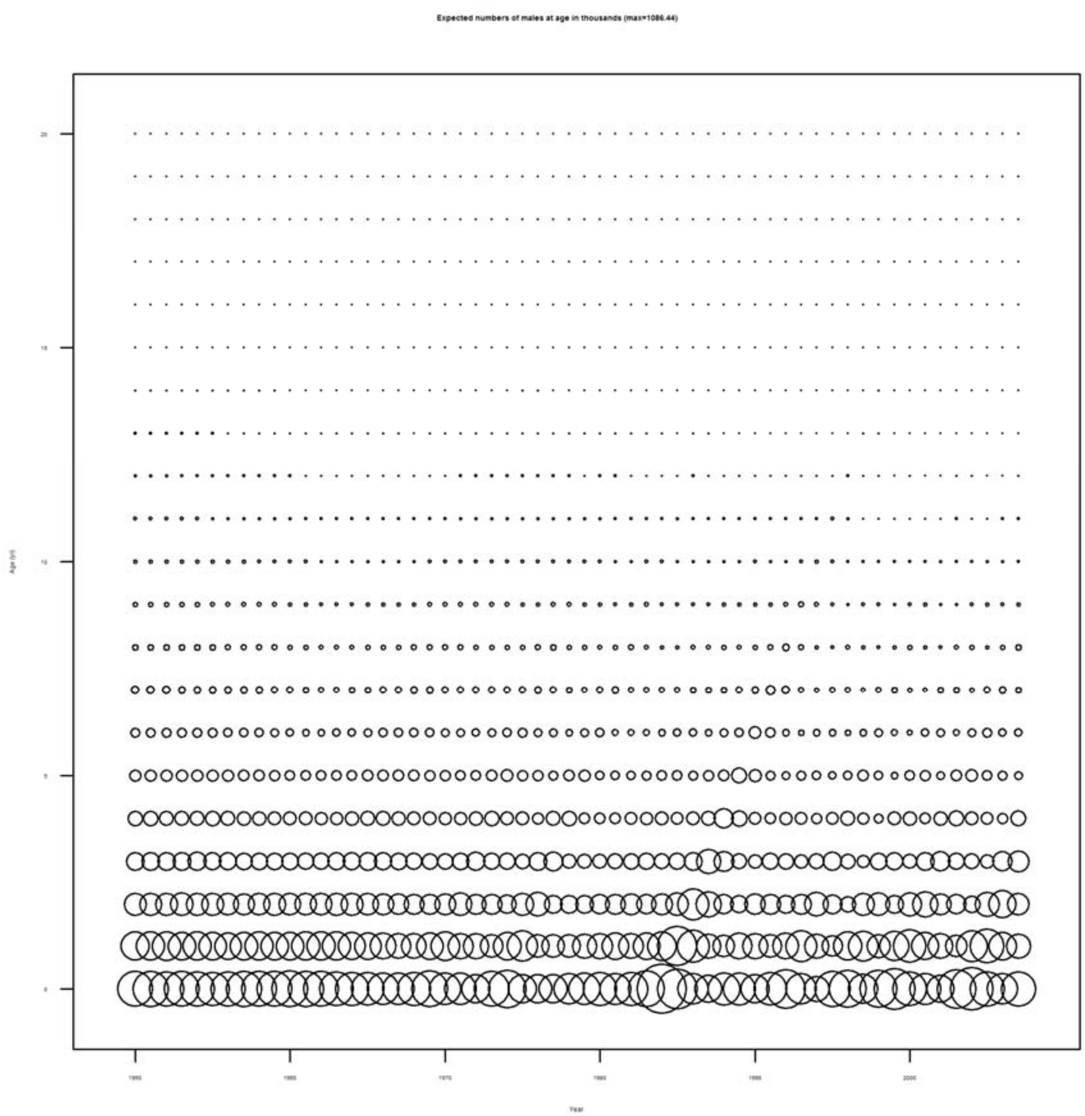

Figure 9.2. Model estimated numbers at age sex 2.

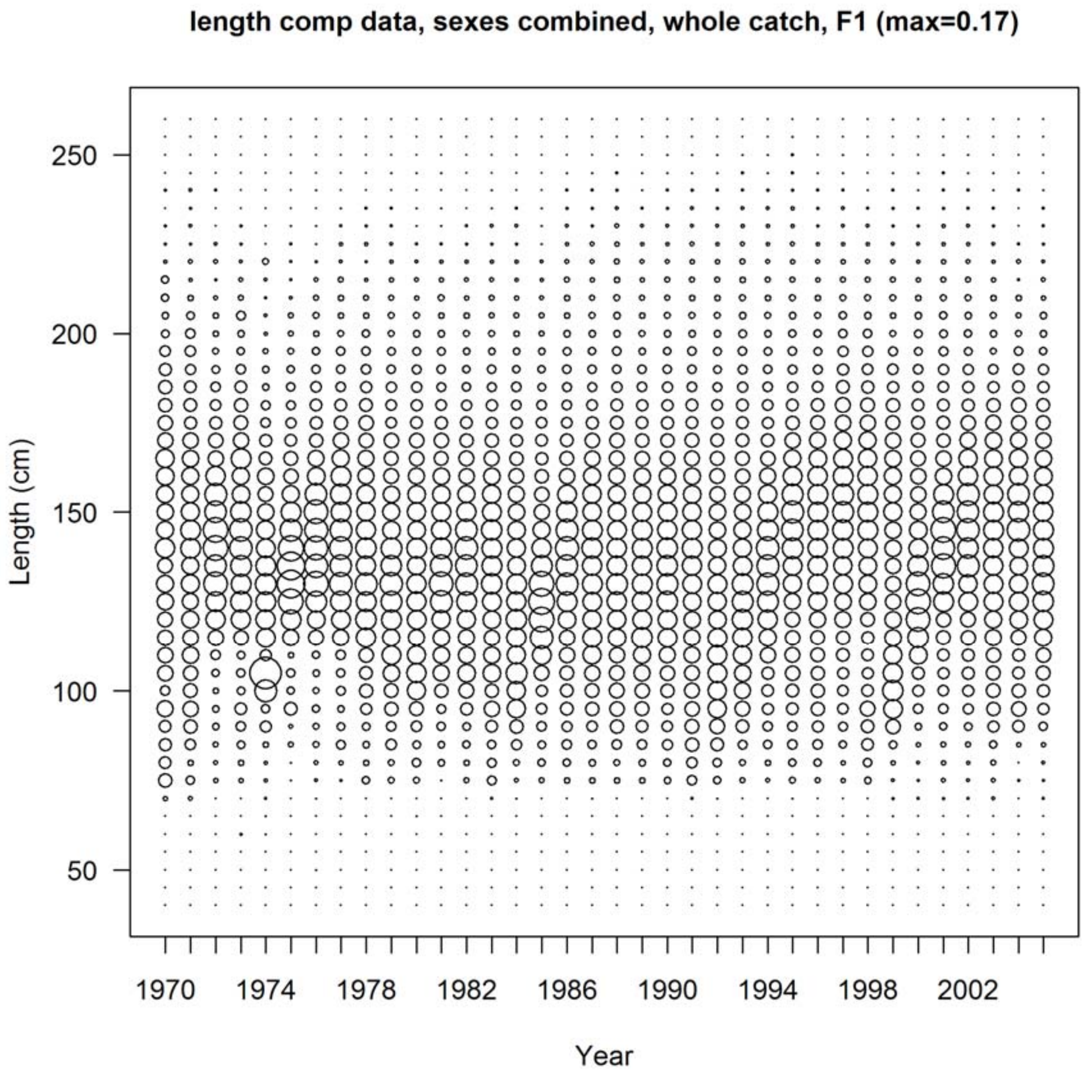

Figure 10.1. Length frequency bubble plots sex-combined (F1) Japan Offshore+Distant Water Longline.

Figure 10.2. Length frequency bubble plots (F6) U.S. Hawaii Shallow-Set Longline.

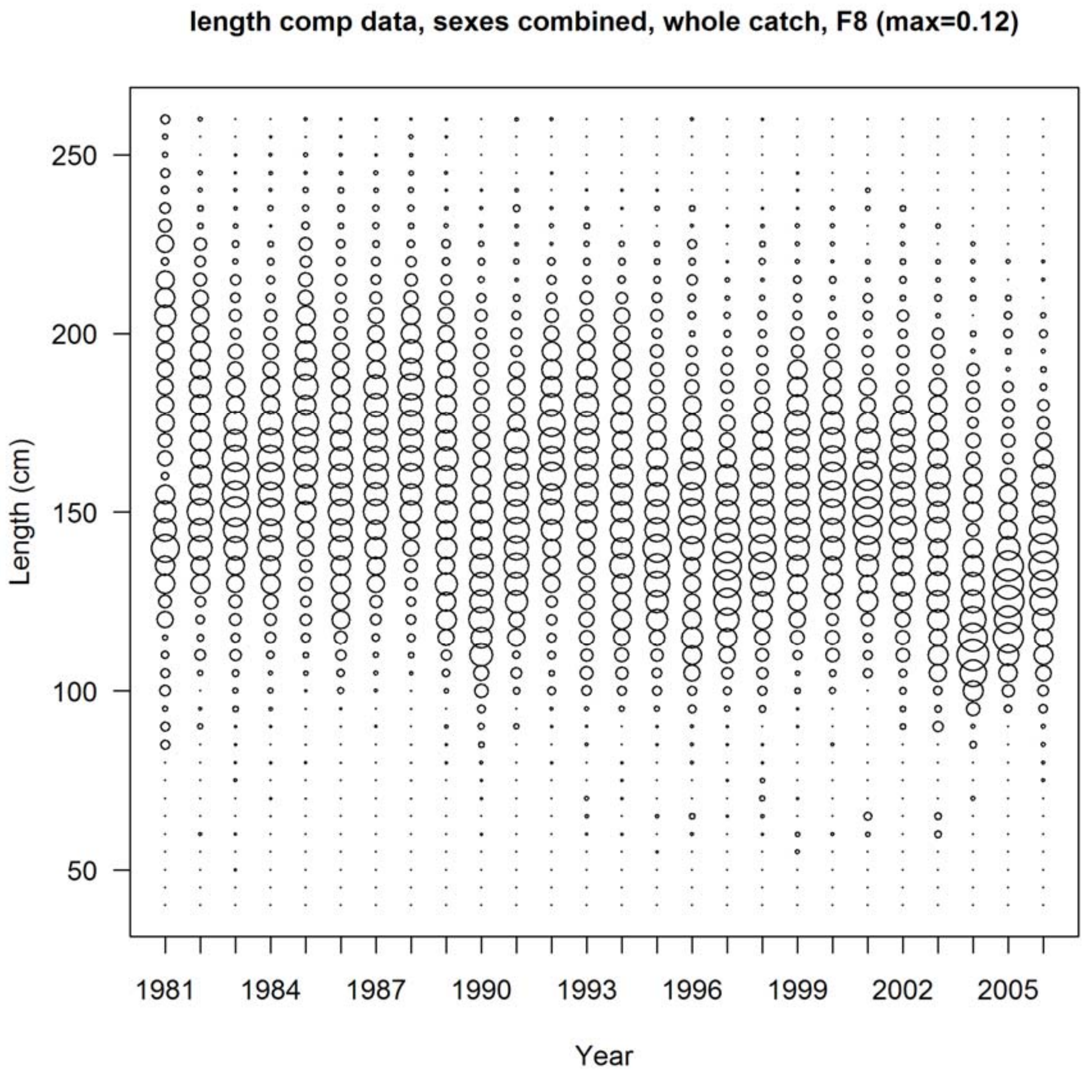

Figure 10.3. Length frequency bubble plots sex-combined (F8) U.S. California Gillnet.

Figure 10.4. Length frequency bubble plots sex-combined (S4) U.S. Hawaii Deep-Set Longline.

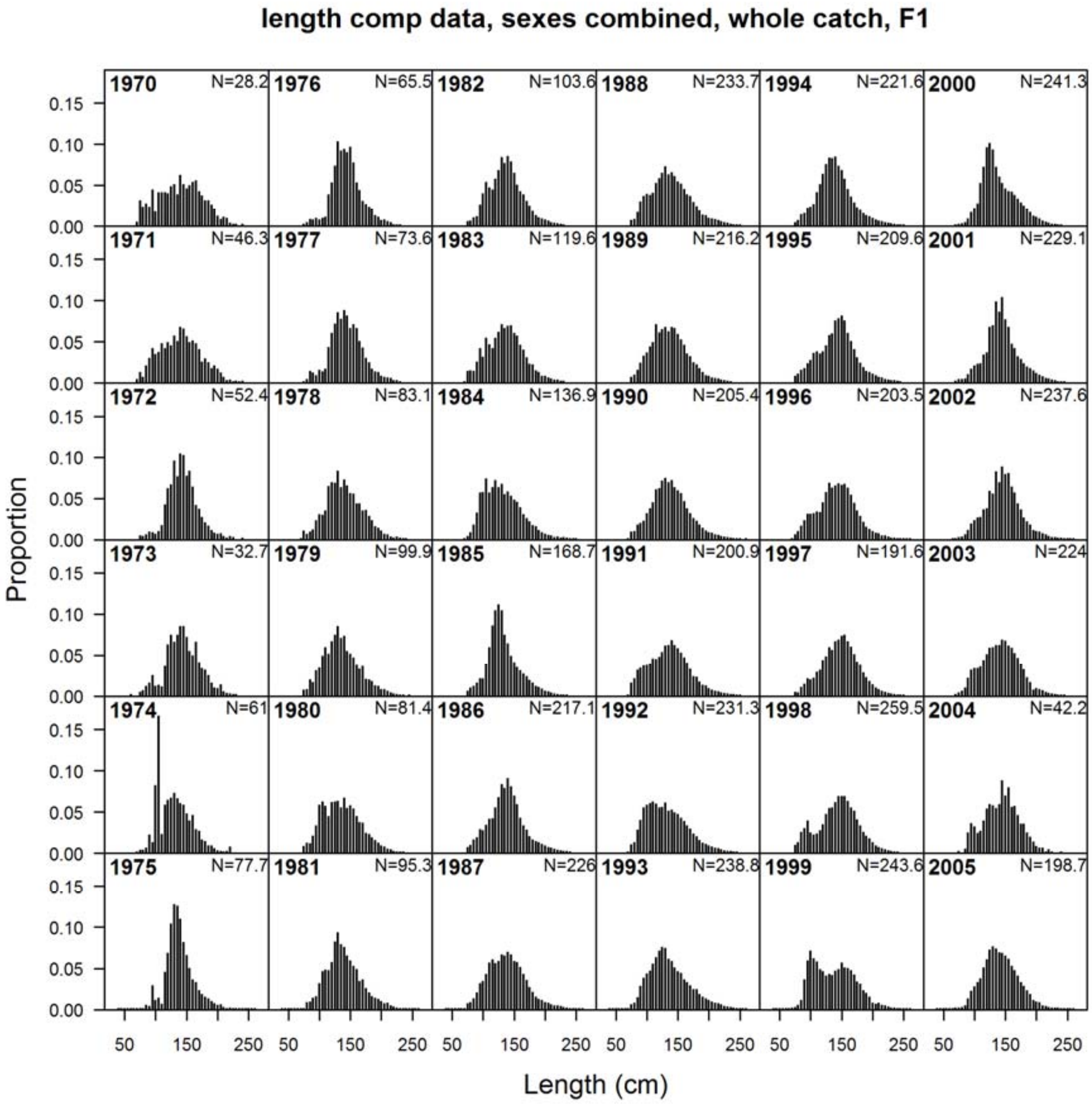

Figure 11.1. Length frequency histograms sex-combined (F1) Japan Offshore+Distant Water Longline.

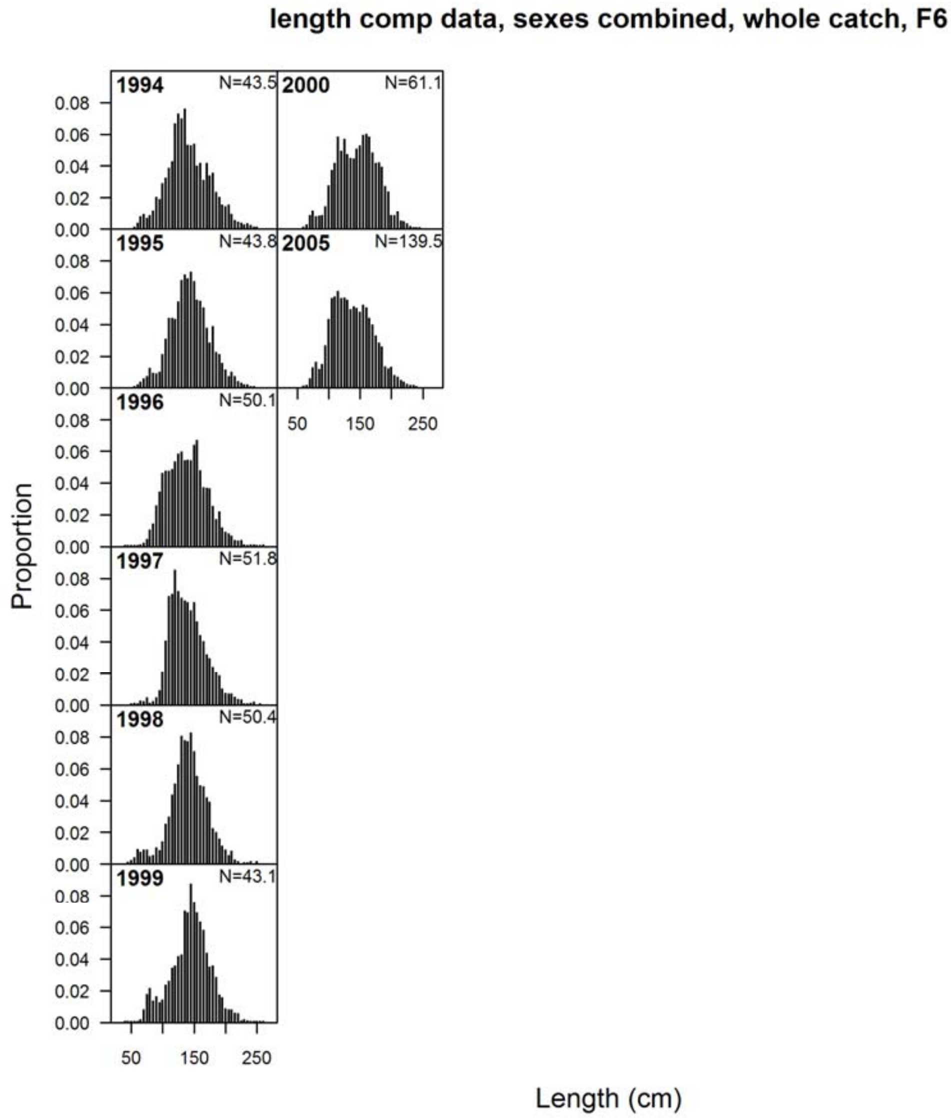

Figure 11.2. Length frequency histograms sex-combined (F6) U.S. Hawaii Shallow-Set Longline.

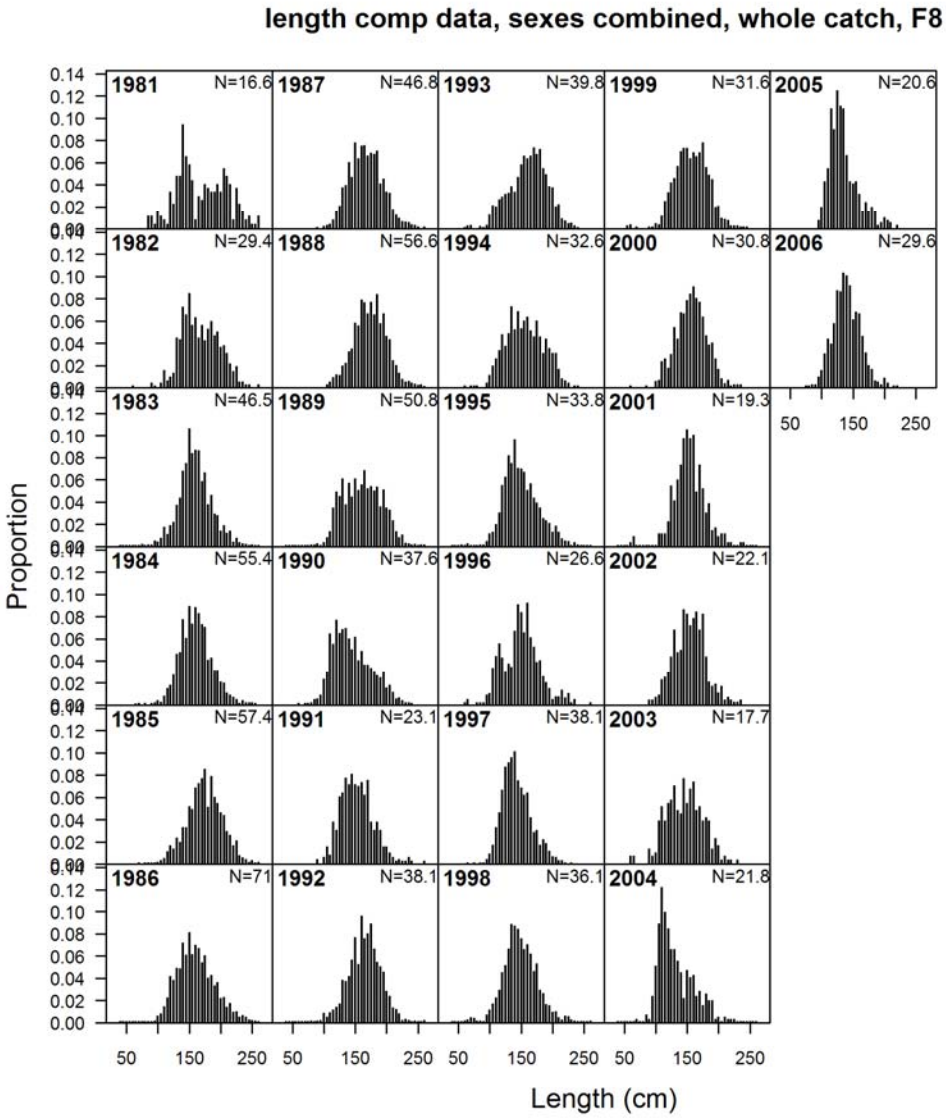

Figure 11.3. Length frequency histograms sex-combined (F8) U.S. California Gillnet.

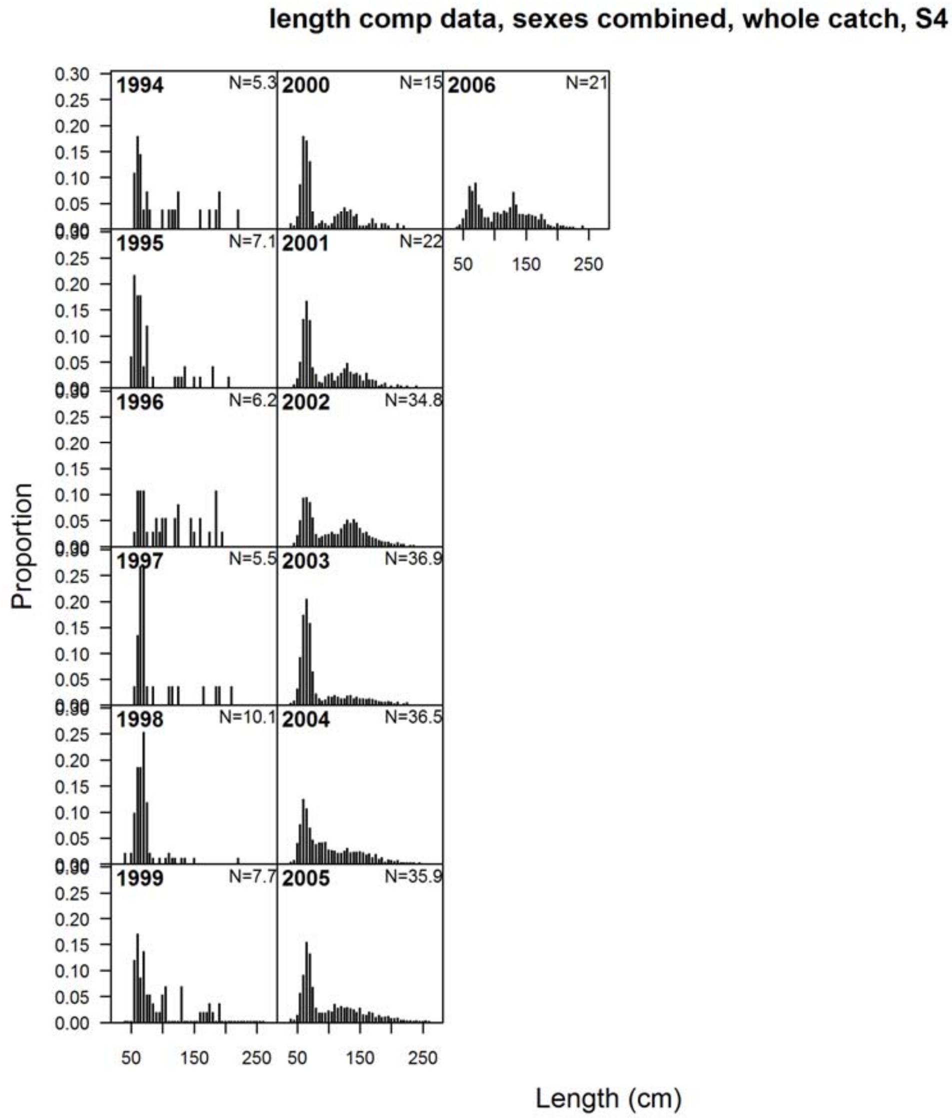

Figure 11.4. Length frequency histograms sex-combined (S4) U.S. Hawaii Deep-Set Longline.

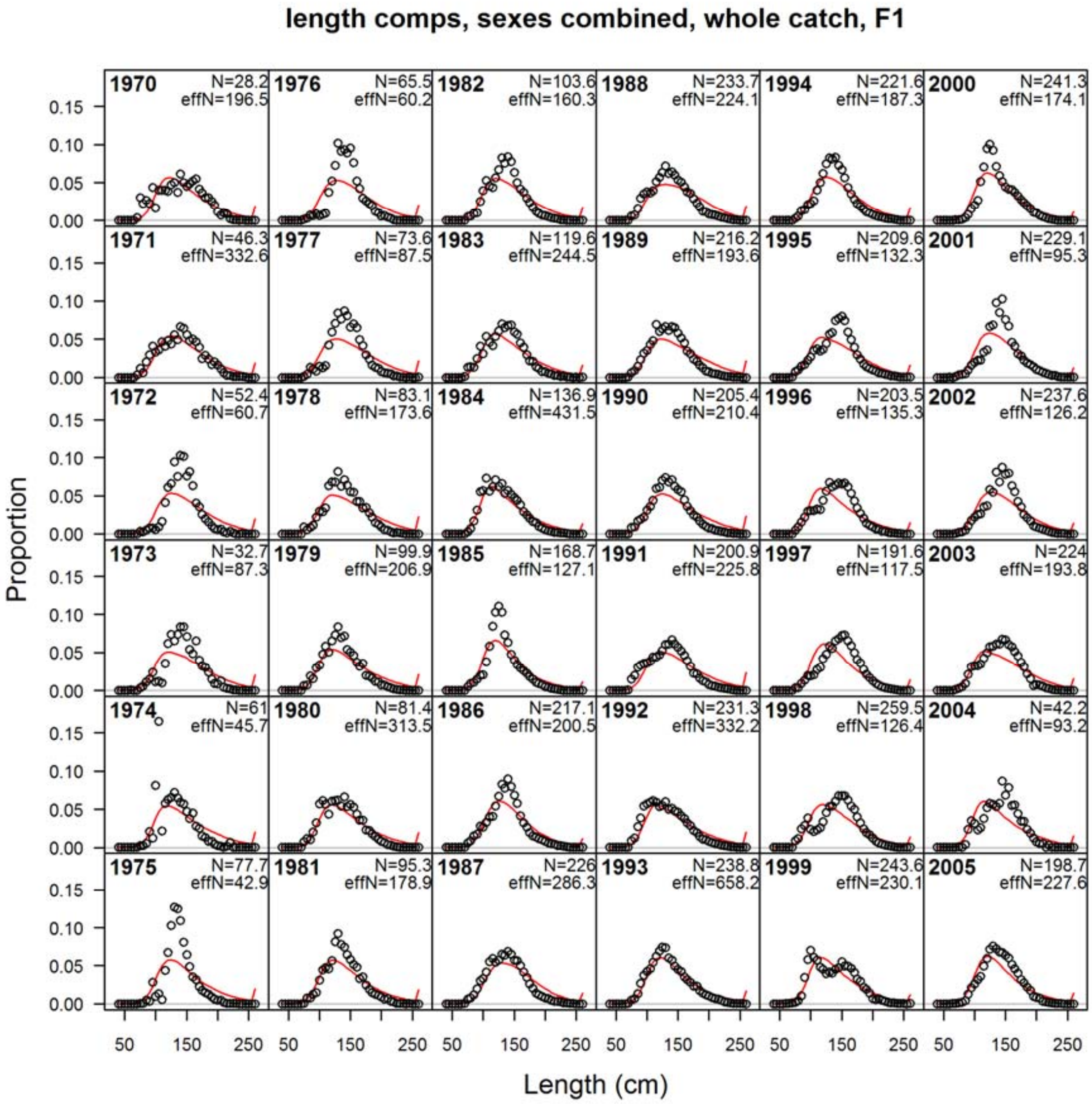

Figure 12.1. Length fit (F1) Japan Offshore+Distant Water Longline.

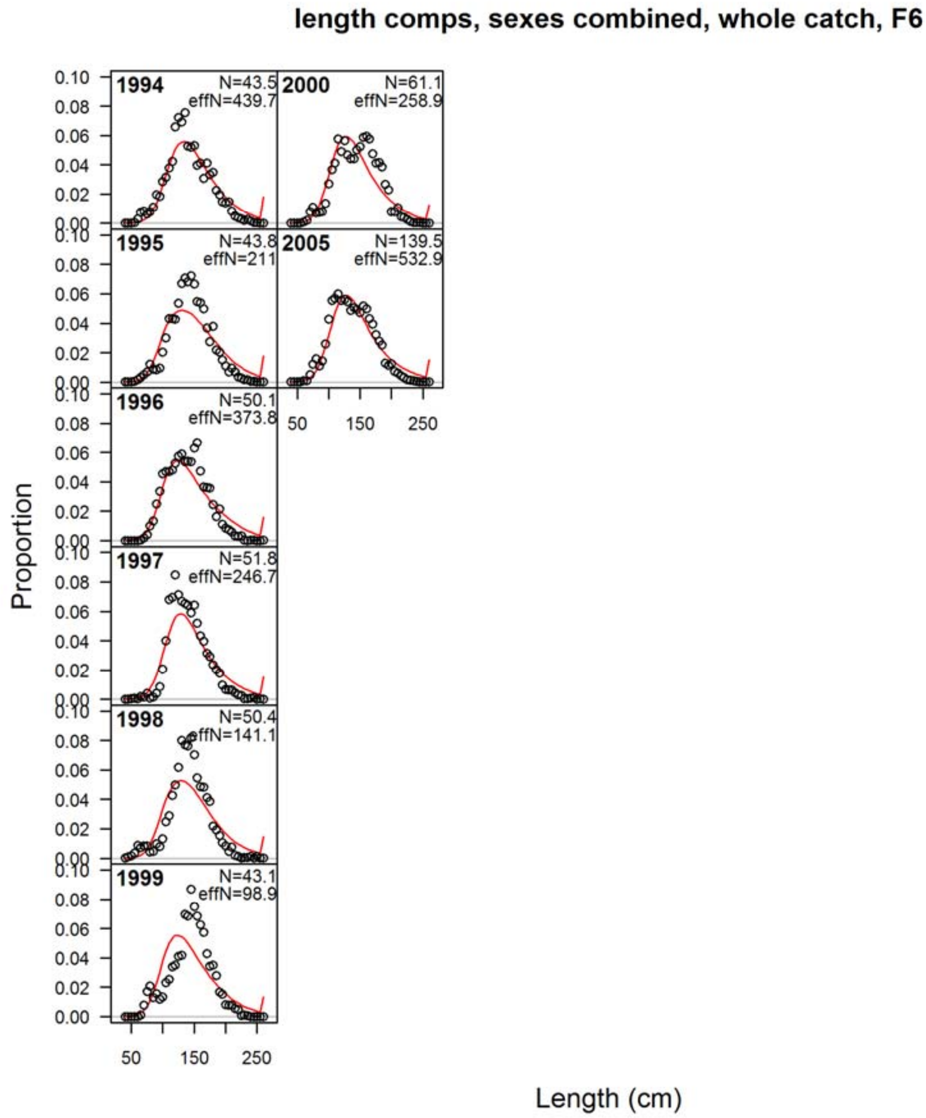

Figure 12.2. Length fit (F6) U.S. Hawaii Shallow-Set Longline.

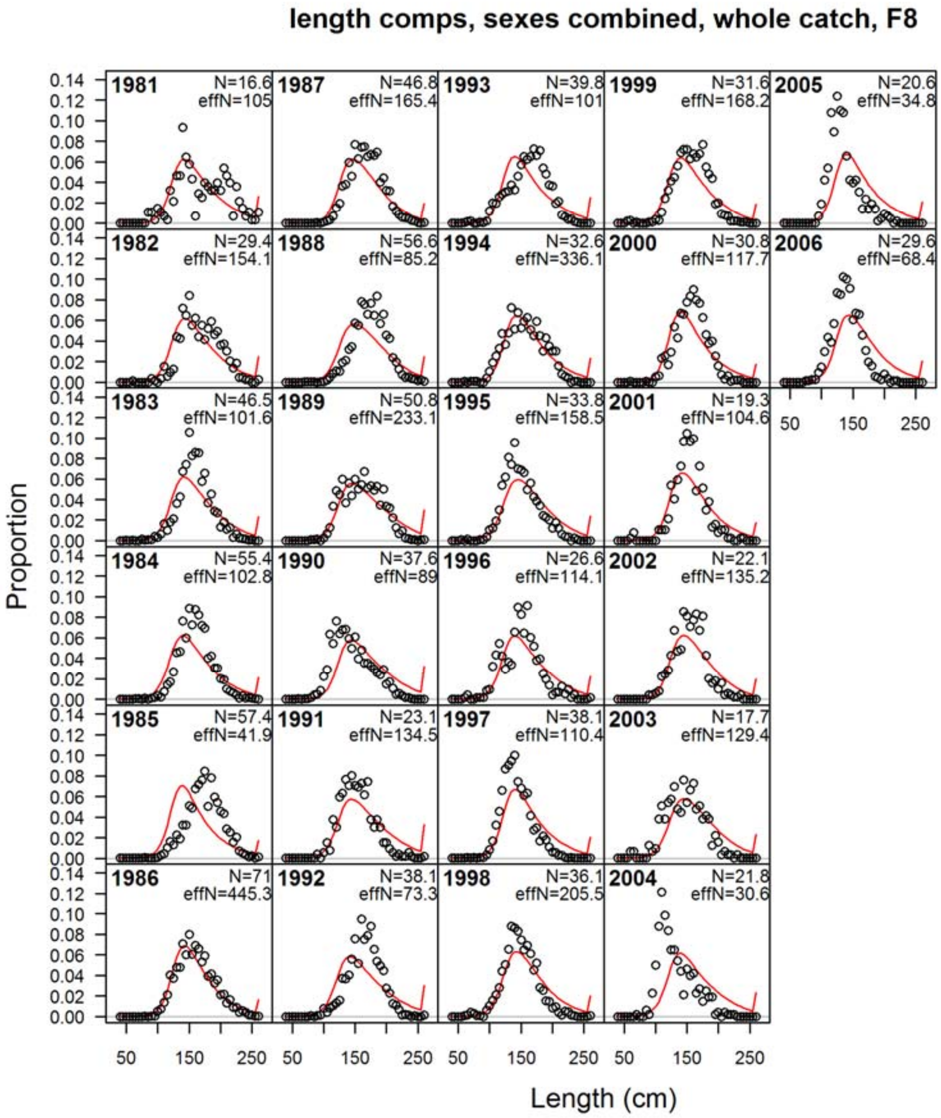

Figure 12.3. Length fit (F8) U.S. California Gillnet.

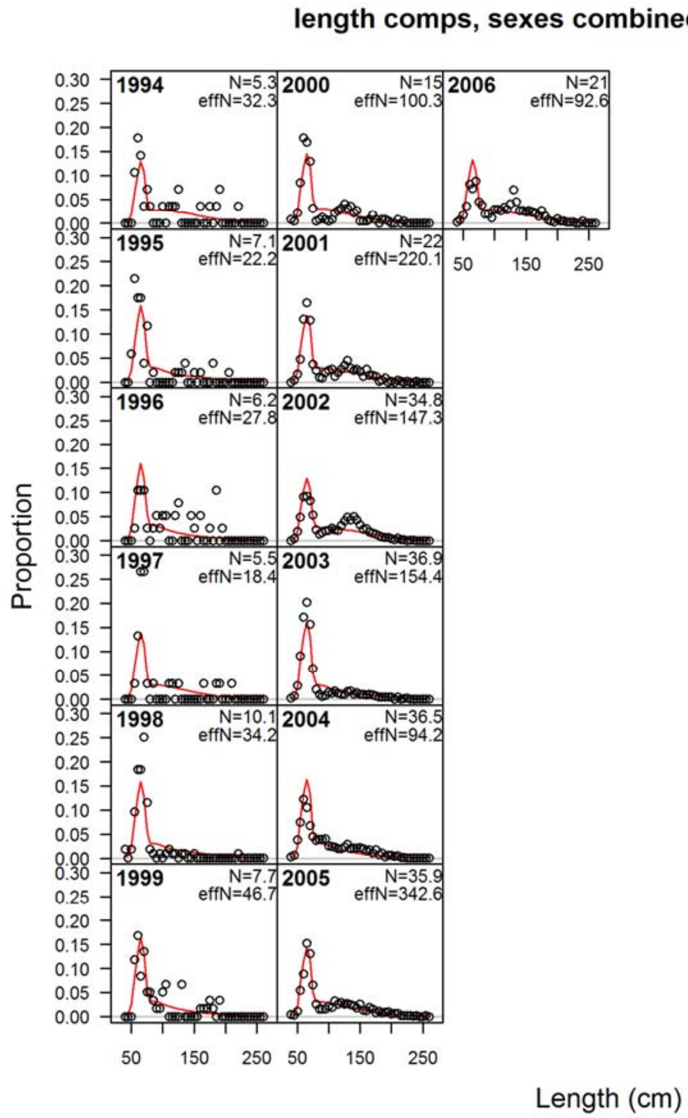

Figure 12.4. Length fit (S4) U.S. Hawaii Deep-Set Longline.

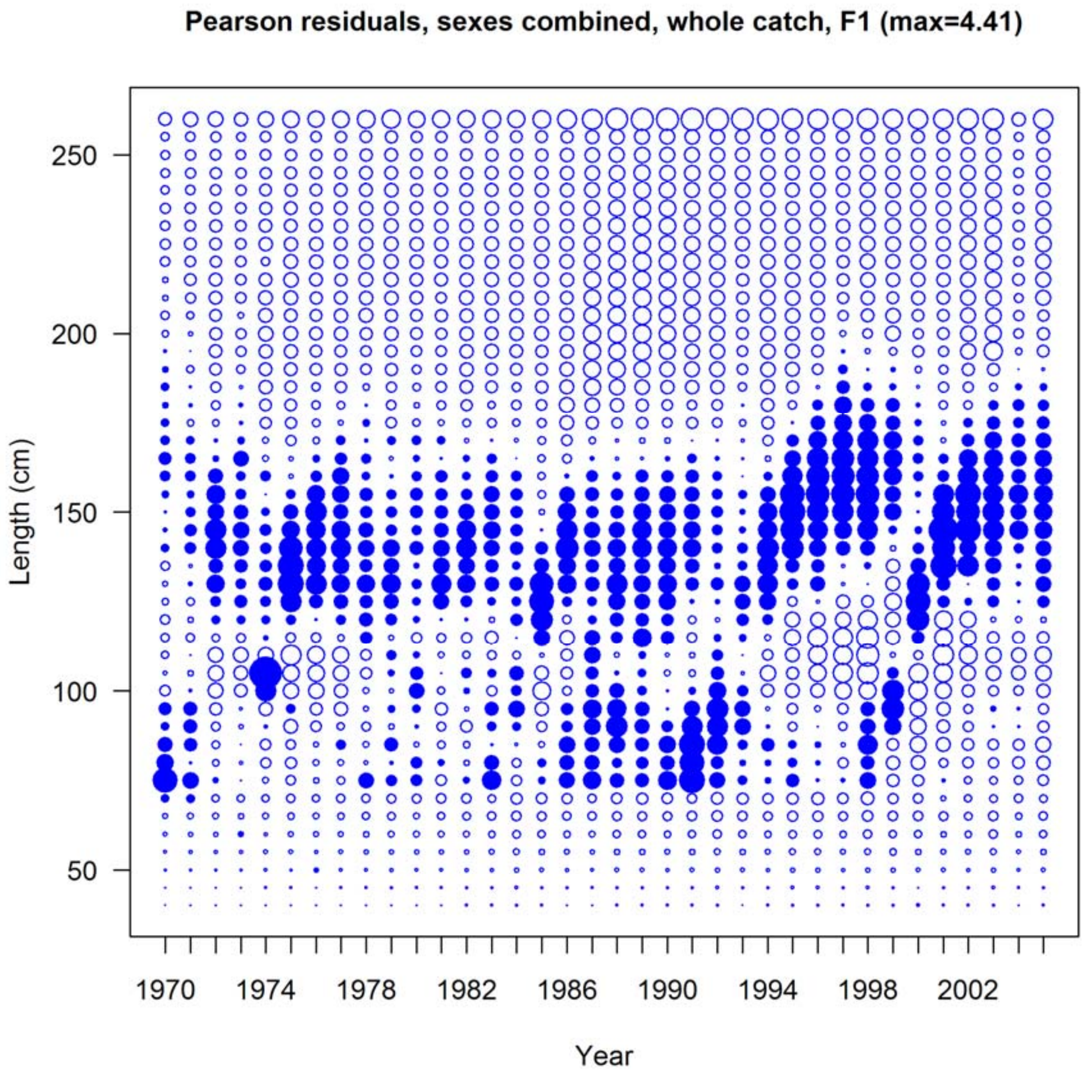

Figure 13.1. Length fit residual bubble plots (F1) Japan Offshore+Distant Water Longline.

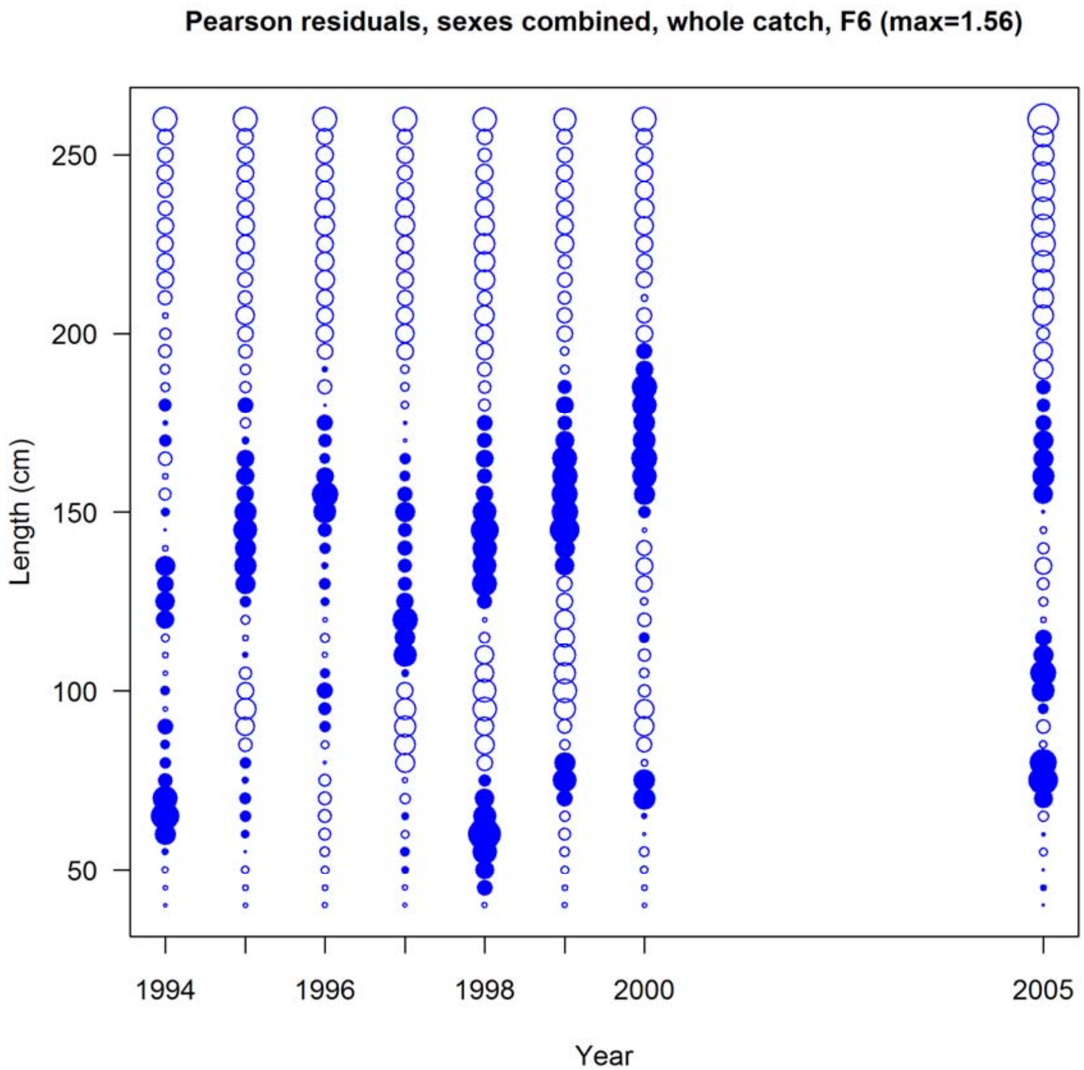

Figure 13.2. Length fit residual bubble plots (F6) U.S. Hawaii Shallow-Set Longline.

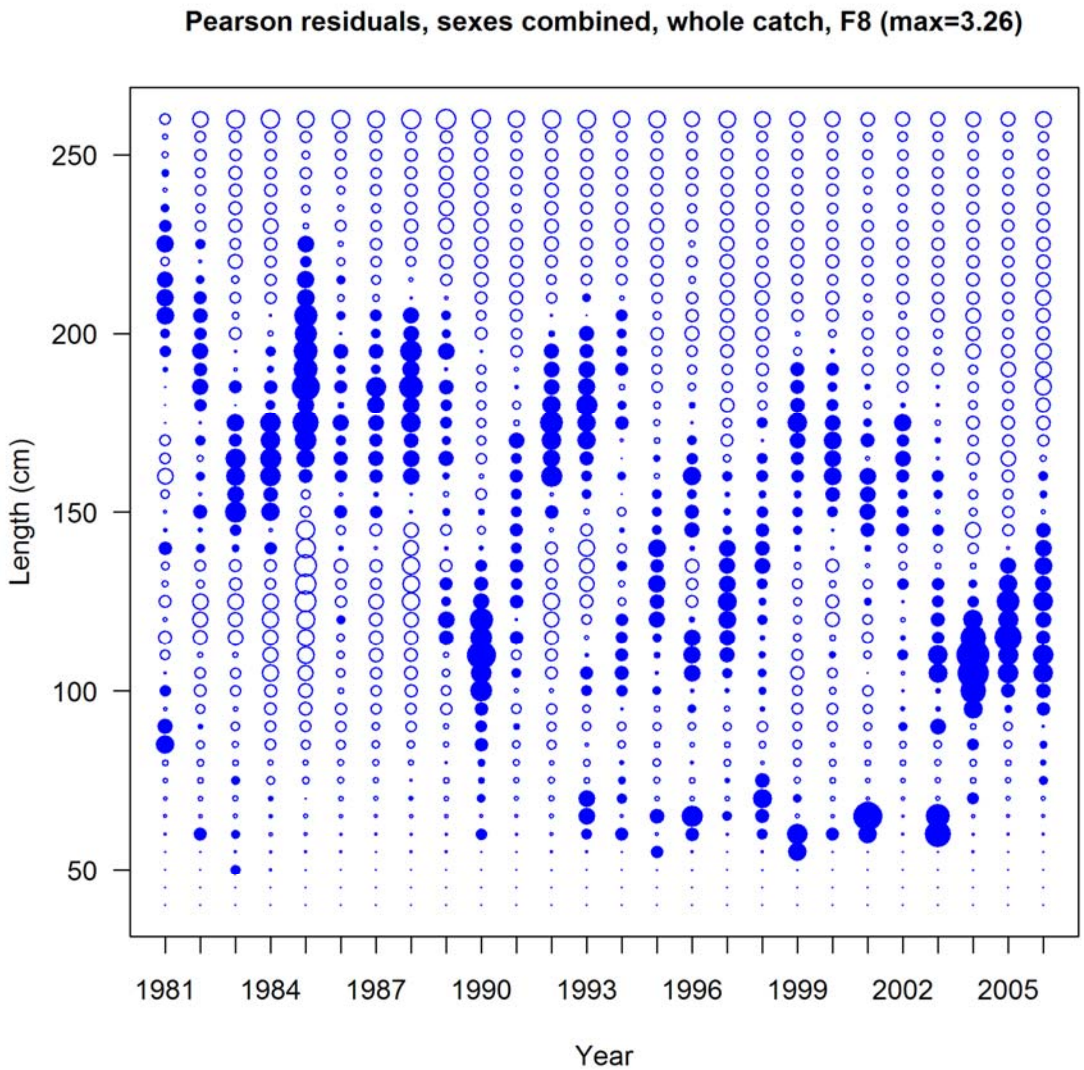

Figure 13.3. Length fit residuals bubble plots (F8) U.S. California Gillnet.

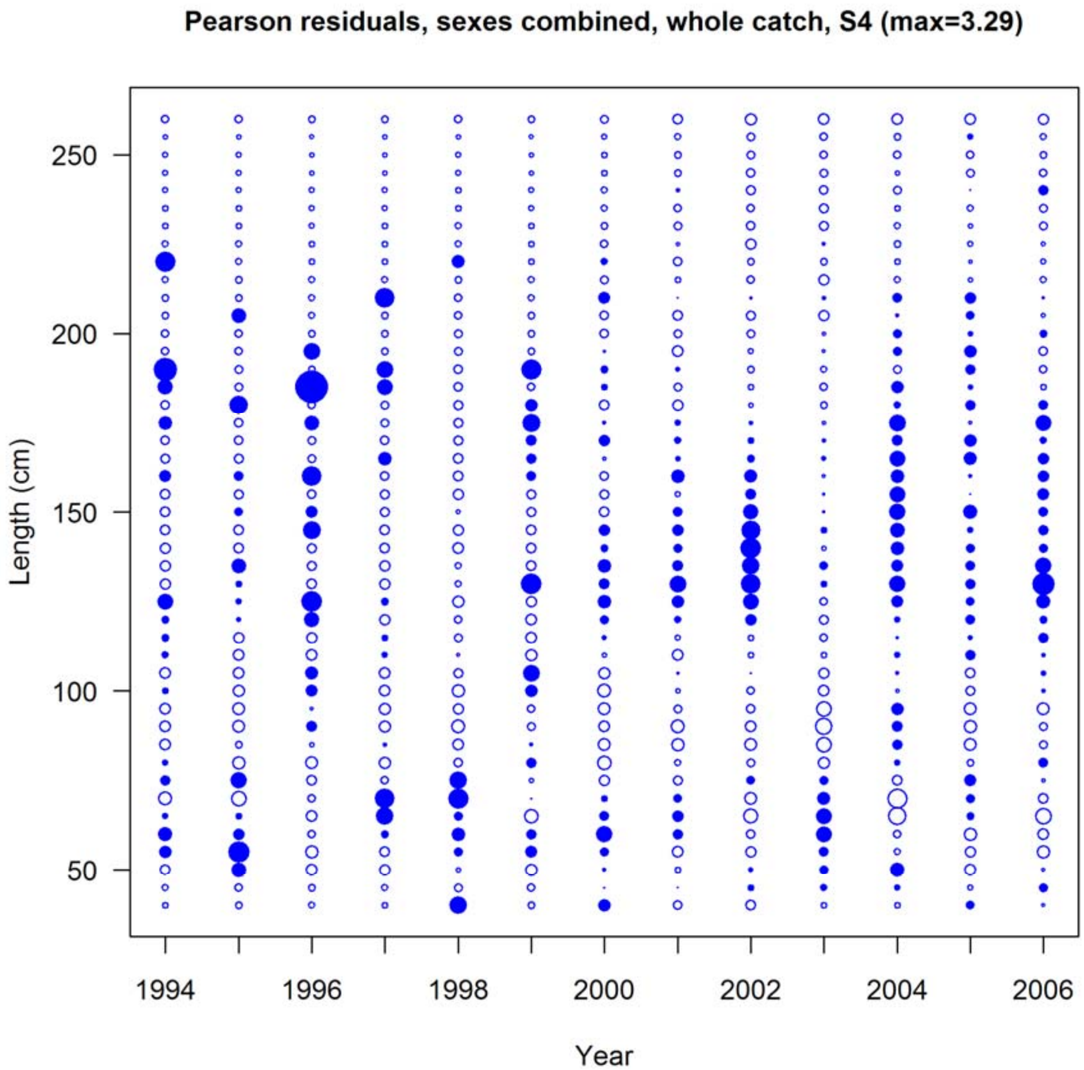

Figure 13.4. Length fit residuals bubble plots (S4) U.S. Hawaii Deep-Set Longline..

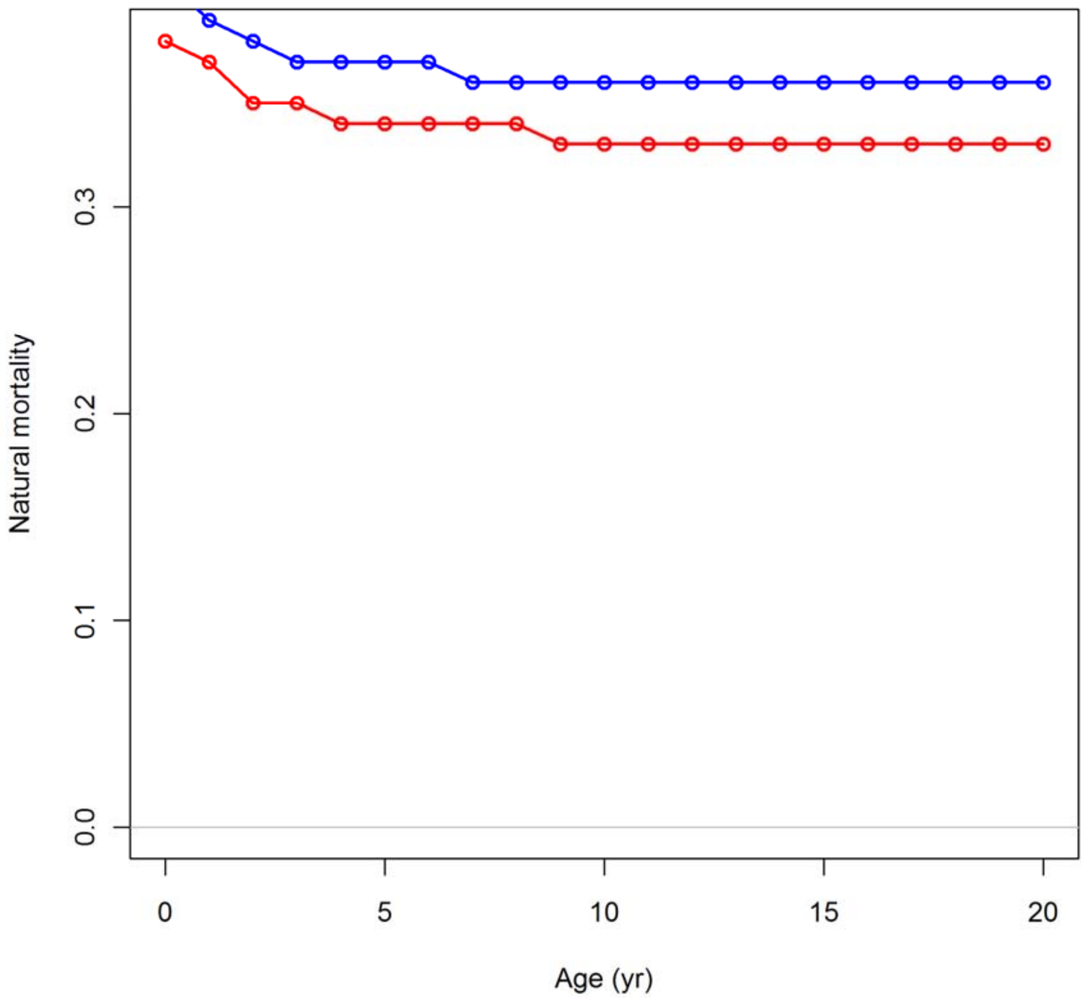

Figure 14. Natural mortality at age (red is females, blue is males).

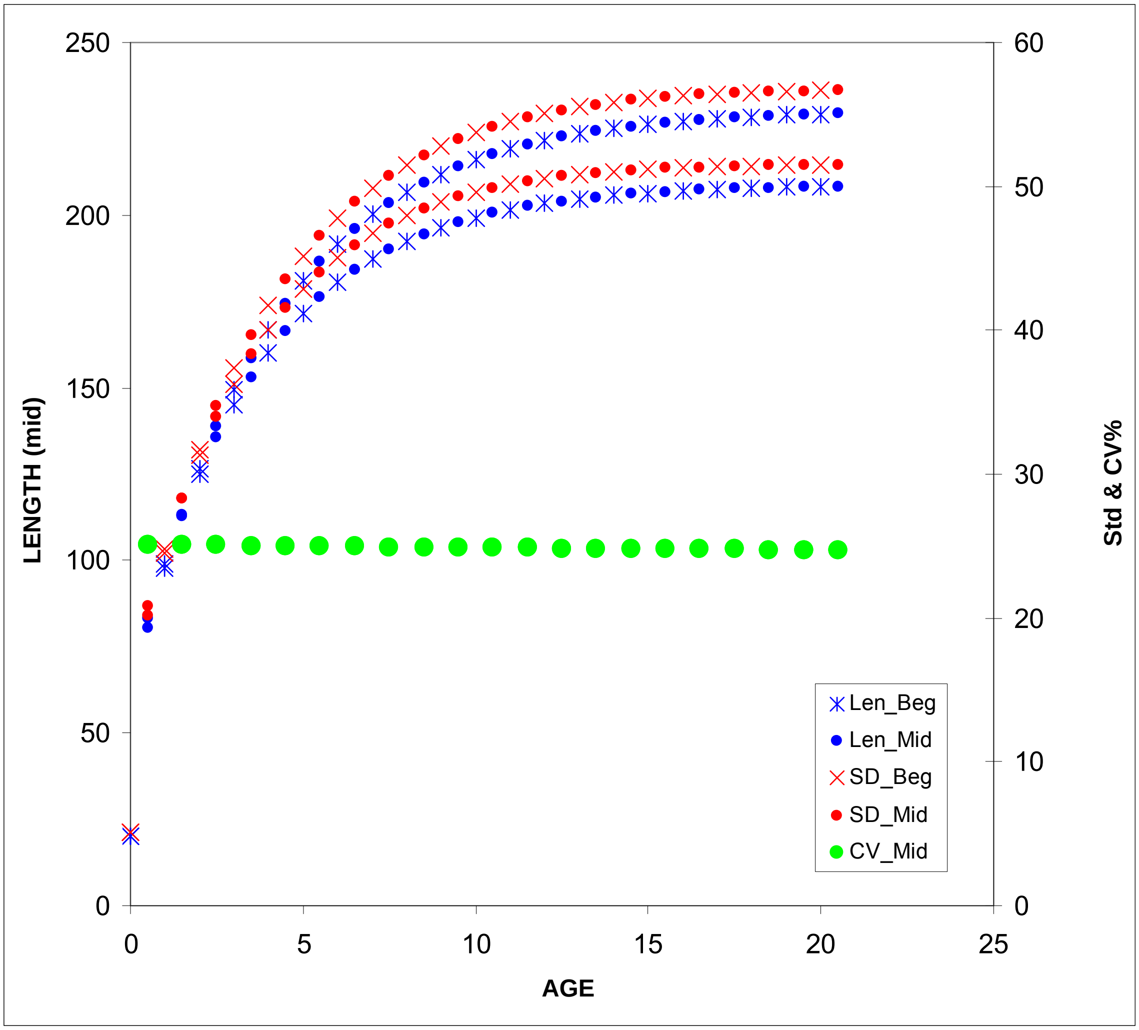

Figure 15. Length (EFL cm) at age (red is females, blue is males).

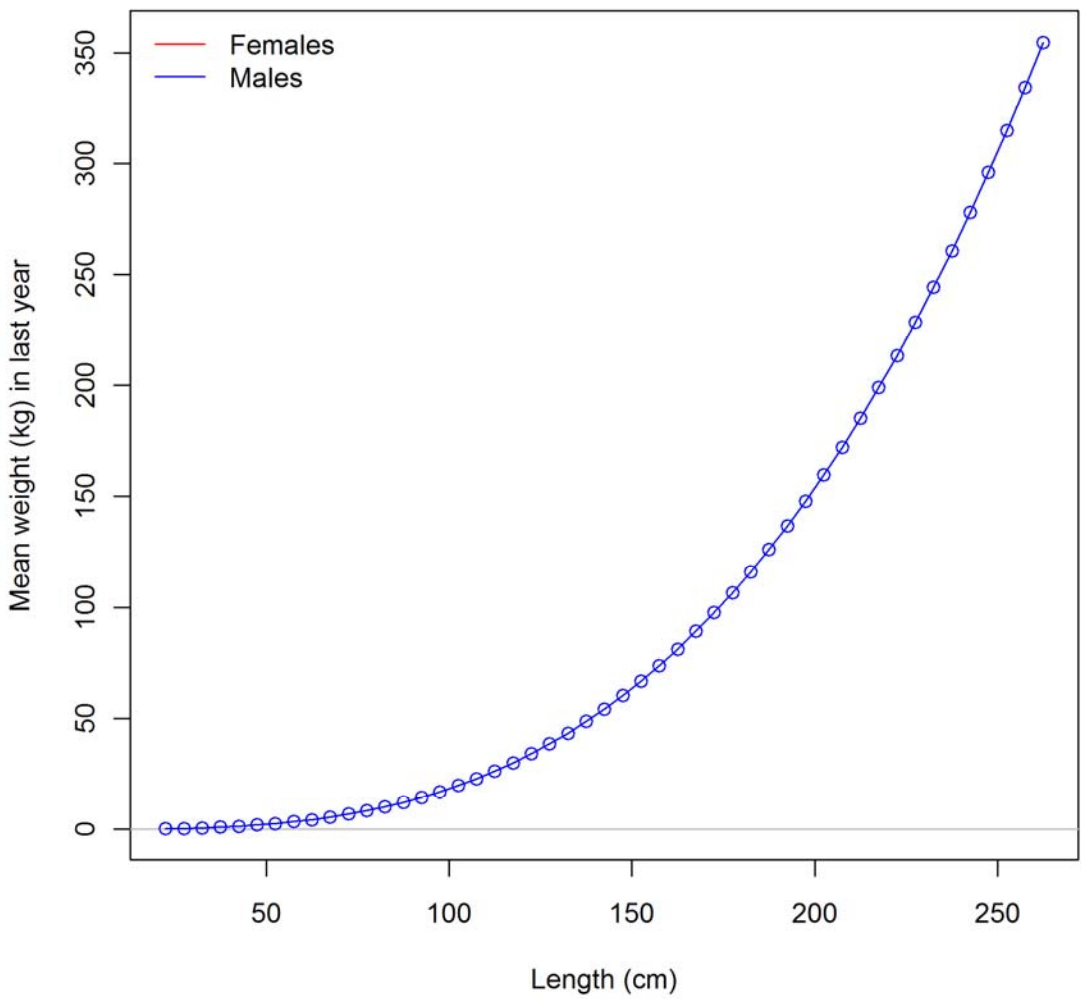

Figure 16. Mean weight (kg) at age (for males and females combined).

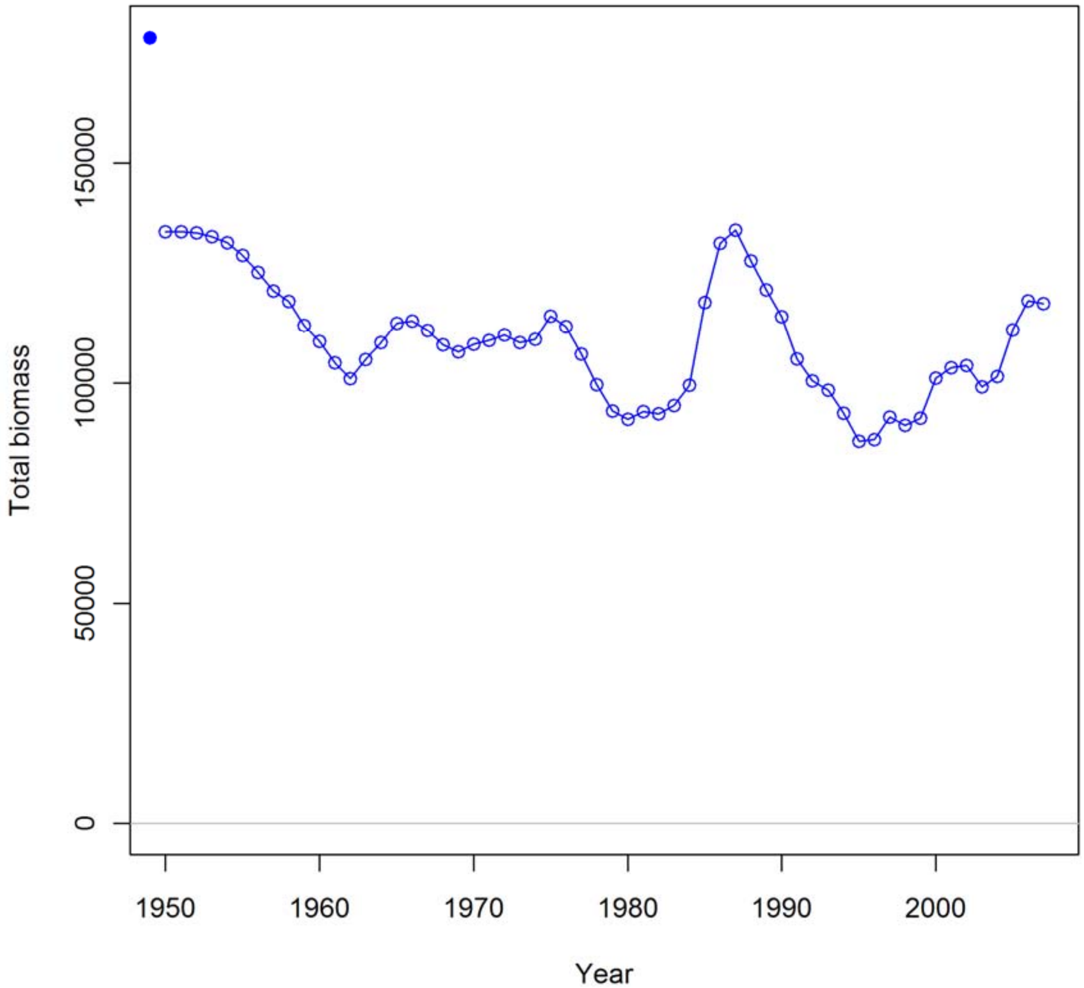

Figure 17. Model estimated total biomass (mt).

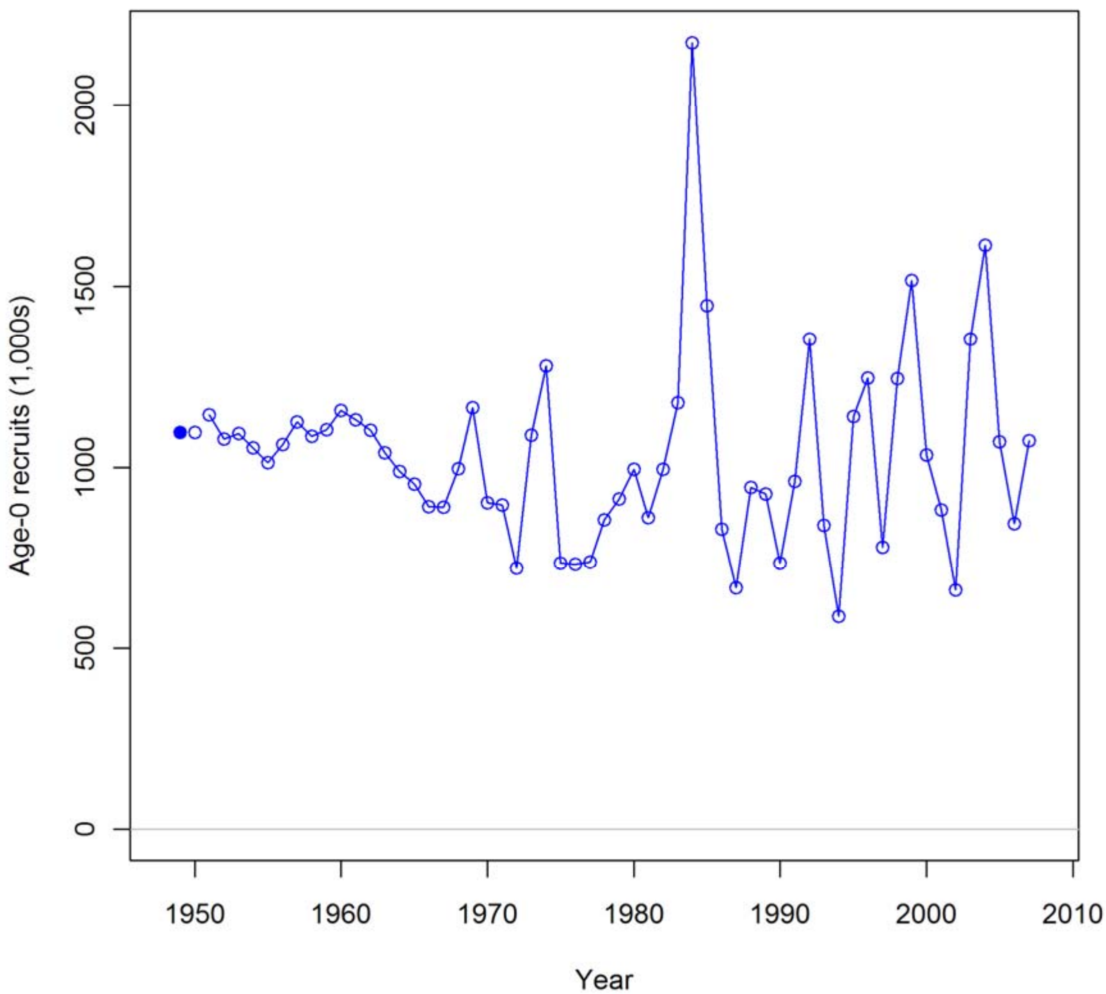

Figure 18. Model estimated age-0 recruitment (1,000s).

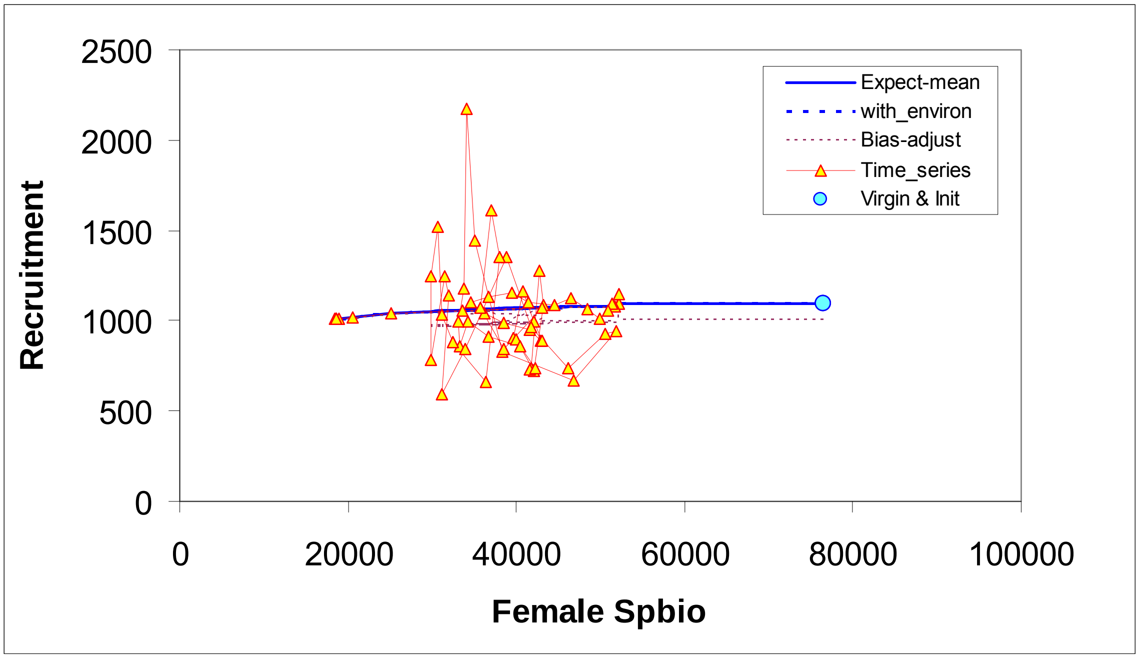

Figure 19. Model estimated Beverton-Holt spawner-recruit relationship.

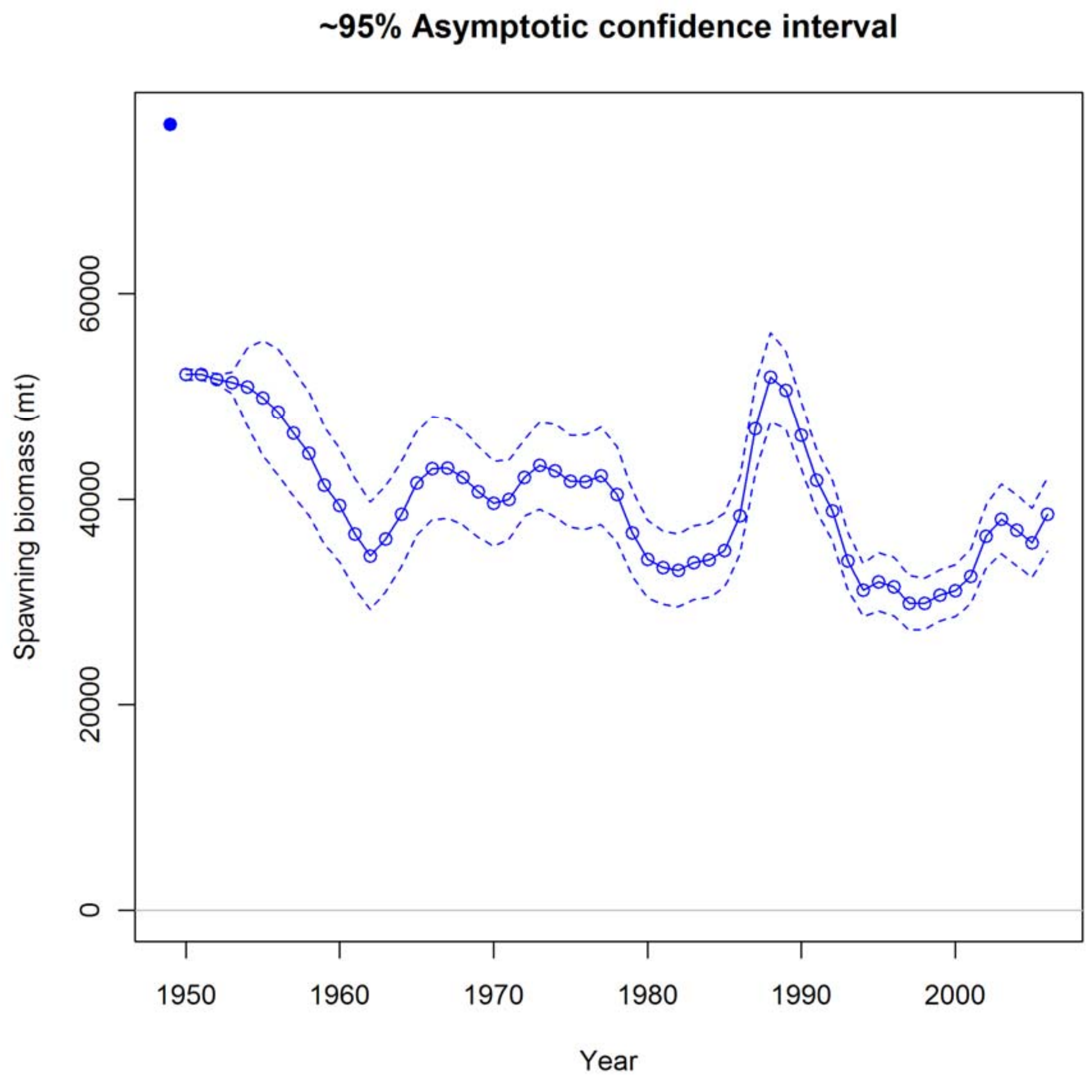

Figure 20. Model estimated mature female spawning biomass (mt) and 95% confidence interval calculated as +-2 * (model estimated se of annual spawning biomass).