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Blue Marlin Stock Assessment in the Pacific Ocean[1]

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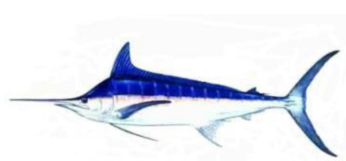

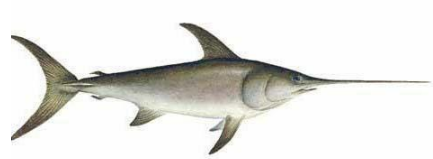

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Blue marlin (*Makaira nigricans*) stock assessment in the Pacific Ocean

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SUMMARY

We present an analysis of stock status and trends of the blue marlin stock in the Pacific Ocean conducted using a length-based age-structured dynamics model in Stock Synthesis (SS). Life-history parameters time series of catch and effort were developed by the International Scientific Committee for Tunas and Tuna-like Species in the North Pacific (ISC). We assumed a well-mixed population, sex-specific rates of natural mortality and growth, and sex-specific length-weight relationships. The model was structured with annual time steps and fitted to data compiled by quarter. Time-varying domed selectivity was assumed for all fisheries and equal probability of selection by sex. The model did not include a strong assumption that the population was at equilibrium at the start of the model period. The sex-ratio at birth was fixed at one, however age- and sex-specific natural mortality rates, size-based selectivity, and sex-specific growth rates can result in significant departures from one-to-one sex ratios in the population. The model was fitted using the method of maximum likelihood.

Likelihood profile on global scale (R_0) was used to develop and structure the model. Cubic spline selectivities were fit to size composition data for Japanese distant-water and offshore longline and Hawaii longline better than double normal functional forms which remove the influence of misfit to the height of particular size bin. Changes to data structure included separating CPUE series into two groups based on internal model consistency. Although data series are available to 1952, the preferred model starts in 1971 when more accurate catch and complete data were available than before due to misidentified marlin catch by species. Since the model is structured using separate growth curves for males and females, the spawning output for use in calculating management quantities tracks females only.

Key Results

1. Catches of Pacific blue marlin have exhibited a long-term increase since the 1970s. Catches averaged roughly 12,000 t per year during 1971-1979 and increased by 77 percent to average of roughly 21,300 t per year during 2000-2009. Reported catches in 2010 and 2011 averaged about 18,400 t.
2. Estimates of population biomass of the Pacific blue marlin stock exhibit a long-term decline. Population biomass (age-1 and older) averaged roughly 115,160 t during 1971-1979 and declined to roughly 78,700 t in 2011. Female spawning biomass (*SB*) is estimated to be

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around 57,700 t, or 44 percent of unfished *SB* during 1975-1979, and declined to roughly 25,000 t or 20 percent of unfished *SB* in 2011.

3. The current female spawning biomass (*SB*) is greater than 29 percent of SB_{MSY}, the spawning biomass to produce MSY.
4. Fishing mortality on the stock has undergone a long-term increase. Average *F* on ages two and older was roughly 0.13 during 1971-1979 and has since increased to about 0.26, which is 24 percent less than F_{MSY}. The current female spawning potential ratio (*SPR*: the spawning output at current *F* as a fraction of the spawning output of the unfished stock) was estimated to be about 0.23, which is about 28 percent above the level of *SPR* required to produce MSY.
5. Recruitment (age-0 fish) estimates exhibited a long-term fluctuation around the mean (881 thousand recruits during 1971-2010).
6. Compared to MSY-based reference points, the blue marlin stock in the Pacific Ocean currently is not being overfished and is not in an overfished state.

1. INTRODUCTION

We present an analysis of the status and trends of the single, pan-Pacific stock of blue marlin (*Makaira nigricans*, Graves and McDowell 2003). This analysis draws on improved understanding of the biology and life history of blue marlin, on a review and recompilation of available catch and effort and of size frequency data for 1971-2011, and on technical advances in programming and solving integrated stock assessment models.

Previous assessments of blue marlin in the Pacific (Hinton 2001, Kleiber *et al.* 2003) used two modeling approaches applied to the same data (1951-1997) and found that the stock was fully exploited but was not overfished and overfishing was not occurring. During the latter years of this period, the fishing mortality was less than that which would provide harvest at the level of maximum sustained yield (F_{MSY}) and the spawning-stock biomass was greater than that which would produce harvest at maximum sustained yield (MSY). These assessments noted there was uncertainty surrounding the life history and biology of blue marlin, including sex-specific growth and natural mortality (M) rates; uncertainty about the quality and completeness of available data; and uncertainty about the structure of the assessment models.

In the years since those assessments were completed, there have been considerable advances in knowledge of blue marlin biology, including improved understanding of growth of juveniles[7], sex-specific growth rates of adults (Chang *et al.* 2013), length at 50 percent- maturity (Sun *et al.* 2009), and age- and sex-specific estimates of natural mortality rates (Lee and Chang 2013). Data were reviewed for completeness and to correct for problems arising from misidentification of species reported in the catch of blue marlin, and they were recompiled for 1971-2011 for the high seas longline fisheries of Chinese Taipei, Japan, and Korea, which principally target tuna but also take the majority of the harvest of blue marlin in the Pacific, and for other fisheries, such

[7] T. Shimose. 2013. Pers. Comm. Unpublished manuscript.

as smaller-scale coastal longline, purse seine, and driftnet fisheries, in which blue marlin occasionally have been observed in the catch.

2. MATERIALS AND METHODS

2.1. Assessment model

The assessment was conducted using Stock Synthesis (Methot 2009). Stock Synthesis is a sex-specific, size-based, age-structured, integrated (fitted to many different types of data) statistical stock assessment model. The initial step in the assessment was to establish the spatial distribution of the stock of blue marlin in the Pacific Ocean for which the population dynamics model was developed. This was followed by identifying available data inputs to the assessment, including indices of relative abundance, total retained catch and dead discards, and size measurements of blue marlin. These available inputs determined, to a great degree, the structure of the assessment model, such as whether it was possible to incorporate sex-specific parameters, and the definitions of fisheries. In addition to the data, estimates of a number of population characteristics or parameters, such as natural mortality rate, growth rates, and age at first maturity, were obtained from studies of blue marlin of the Pacific Ocean. These estimates were included in the assessment as assumed or fixed parameters. Stock Synthesis was fitted to a suite of scenarios using the method of maximum likelihood. The value of the negative log-likelihood from each of the scenarios was used for evaluation and comparison of results.

2.2. Fishery data

Three types of data were used in this assessment: fishery-specific catches, length and weight measurements, and abundance indices derived from logbooks. These data were compiled for 1971-2011. Data sources and temporal coverage of the datasets are summarized in Figure 2.1. Details of these data are presented below.

2.2.1. Spatial and Temporal stratification

A single geographic area consisting of all waters of the Pacific Ocean was used for the assessment. It was assumed that there was instantaneous mixing of fish throughout the area at each quarterly time-step in the model. The assessment started in 1971. Prior to about 1971 the catches of black and blue marlin were combined in catch reports of the longline fisheries of Japan. Catch and size composition data were compiled by calendar quarter.

2.2.2. Definition of fisheries

Sixteen fisheries were defined on the basis of country, gear type, and reported unit of catch (Table 2.1). It is expected that these represent relatively homogeneous fishing units for which differences in selectivity and catchability among fisheries are greater than temporal changes of these parameters within fisheries. In the case of the Japanese distant-water-longline fishery, two fisheries were defined because of significant differences in data reporting and compilation prior to 1994 and from thence (Kanaiwa *et al.* 2013).

2.2.3. Catch and effort

Estimates of total catch by fishery by calendar quarter for 1971-2011 were compiled for fisheries F1, F2, F7, F8, and F14. Only annual catch data were available for other fisheries, so for these fisheries catch by quarter within year was estimated as one-fourth of the annual catch. (Table 2.2 and Figure 2.2). Catch was reported in original units, which was weight for all but F8 and F14 which were reported in numbers of fish.

Catch and effort data were available for F1, F2, F7, and F10, and were used to develop standardized time series of catch-per-unit-effort (CPUE), which were assumed to be proportional to population size and were used as indices of relative abundance. Operational dataset were used at a spatial resolution of 5-degree longitude by 5-degree latitude (5x5 data) for Japan longline fisheries. Monthly aggregated dataset were used at a spatial resolution of 5-degree longitude by 5-degree latitude (5x5 data) for Taiwan longline fisheries. Observer dataset with a resolution of 1-degree latitude by 1-degree longitude (1x1 data) were used for Hawaii-based longline fisheries.

Delta lognormal generalized linear models (delta-GLM) was used to standardize CPUE for the 1975-1993 Japanese longline fishery (F1) and a habitat-based standardization model (HBS) was used to standardize CPUE for the 1994-2011 Japanese longline fishery (F2) (Kanaiwa *et al.* 2013). The former method applied to data from 1975 to 1993 considers main factors including year, quarter, location, number of hooks between float, and others depending on characteristic of the fishery. The later method applied to data from 1994 to 2011 uses three model components, fishing effort distribution (gear model), blue marlin distribution (habitat-preference model), and habitat distribution (habitat model). Generalized additive models (GAMs) were used to standardize abundance indices for Taiwan longline fisheries considering main factors including year, month, location and number of hooks between float (Sun *et al.* 2013). A zero-inflated negative binomial GLM (ZINB) was used to obtain a standardized abundance index for the Hawaii longline fisheries considering main factors including year, quarter, set type, bait, and sea surface temperature, and interaction factors (Walsh *et al.* 2013).

Six standardized annual indices of relative abundance were developed for four fisheries (Table 2.3, Figure 2.3). A season was assigned to each index based on the annual quarter in which the majority of catch is recorded. As for Japan longline fisheries, two temporally separate indices were defined as years: 1975-1993 and 1994-2011 to account for changes of operation (depth of hook), hook-per-basket (HPB) distribution, targeted fish and length distribution of catch. Three indices (S4-S6) covering different time periods were separated from Taiwan longline fishery (F10) to account for the temporal effect of the fishing ground shift from the South Pacific Ocean to the whole Pacific Ocean since the 1980s and the changes in targeting species of the fishery from albacore to bigeye tuna since 2000. It is noted that very low annual catches were observed before 1978.

Visual inspection of all indices grouped by fishery type revealed conflicting trends among longline indices during the 1970s and the 1980s. The JPNEarlyLL index (S1) increased during 1975-1993, whereas TWNLL indices (S4-S5) show a flat trend for 1971-1978 and declined over 1979-1999. This slight decline was also observed in the of JPNLateLL index (S2). After that, a consistent trend among JPNLateLL index (S2) and TWNLL index (S6) were observed although there is some variation in the timing and magnitude. However, there are conflicting tends between JPNLateLL index (S2) and HWLL index (S3) where HWLL showed steeply decline. It was noted that there was a low coverage rate of observer dataset in 1994-1999. The coefficients of variation (CVs) of these indices estimated from GLM models were included to represent annual variability for each index.

2.2.4. Size frequency data

Length- and weight-frequency data were compiled by calendar quarter by fishery for 1971-2011. Length frequency data were available for seven fisheries, and weight frequency data for one (Figure 2.4.a-2.4.c). Since not all samples were known by sex, all samples were aggregated into frequency distributions. Length frequency data were compiled using 5-cm size bins from 80 to 320 cm for JPNEarlyLL (F1), JPNLateLL (F2), HWLL (F7), TWNLL (F10), and EPOPS (F14) (Figure 2.4.a) and using 10-cm bins from 80 to 320 cm for OthLL (F12) and PYFLL (F13) (Figure 2.4.b). To make consistent interpretation of population binning structure, 10-cm bins were used for F12 and F13. Weight frequency data were compiled using varying binning structure from 10 to 300 kg to account for the allometric length-weight relationship (Figure 2.4.c). The lower boundary of each bin was used to define each bin for all frequency data and each size frequency observation consisted of the actual number of blue marlin measured.

Eye fork lengths (EFL; cm) and processed weight (kg) of blue marlin for JPNLL (F1, F2, 1971-2011) and JPNGN (F4) were measured to the nearest 1 or 5 cm or nearest 1 kg at the landing ports or onboard fishing depending on the sampling resolution. The processed weight data were converted to round weight and all of size composition data were compiled by the National Research Institute of Far Seas Fisheries (NRIFSF), Japan (Kimoto and Yokawa 2013).

Eye fork lengths of fish taken by the HWLL fishery (F7, 1994-2011) were measured to the nearest 1 cm by observers on board fishing vessels (Walsh *et al.* 2013). Eye fork lengths for TWNLL fishery (F10, 2005-2010) were measured to the nearest 1 cm by crew members onboard fishing vessels and compiled by the Overseas Fisheries Development Council (OFDC) of Taiwan (Sun *et al.* 2012). Length composition data from OthLL (F12, 1992-2011) and PYFLL (F13, 1996-2011) were measured to the nearest 2 cm. Length data for the EPOPS fishery (F14, 1991-2011) were measured to the nearest 2 cm.

2.3. Biological and demographic assumptions

2.3.1. Maximum age

The maximum age bin in the model was 26 years. This bin functions as an accumulator for all older ages. To avoid potential biases associated with the approximation of dynamics in the accumulator age, the maximum age was set at an age sufficient to result near zero (≈ 0.1 percent of a cohort) fish in this age bin.

2.3.2. Growth

Growth for both female and male are rapid. It was assumed that there is little sexual dimorphism in the first year of growth based on otolith microstructure counts[7]. Sex-specific length-at-age relationships for ages greater than one year were based on meta-analyses of growth studies of dorsal spines and size frequency data (Chang *et al.* 2013). Their hierarchical model with homogeneous variance (HBHV) for females was used in the assessment because the estimate of size-at-age one (144 cm) was very close to the mean size-at-age one of Shimose[7] (146 cm, C.V. = 7 percent) and Prince *et al.* (1991). Size-at-age one from their HBHV model for males was underestimated, so the HBHV model for males was refitted with the size-at-age one constrained to the fitted value for females (Figure 2.5).

In SS the relationship between eye fork length (cm) and fractional age for the blue marlin (Figure 2.5) was parameterized as:

$$L_2 = L_\infty + (L_1 - L_\infty)e^{-K(A_2 - A_1)}$$

where L_1 and L_2 are the sizes associated with ages near the youngest A_1 and oldest A_2 ages in the data, L_∞ is the theoretical maximum length, and K is the growth coefficient. In this assessment, L_1 were 144 cm for both female and male at age 1 and L_2 were 304.178 for female and 226 cm for male at age 26. K were 0.107 and 0.211 for female and male, respectively. The L_∞ can be solved based on the length at age as:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-K(A_2 - A_1)}}$$

The growth parameters K, L_1 and L_2 were fixed in the SS model. CV on age 1 fish was assumed to be 0.14 for both female and male to account for variability in the sizes of fish observed and extra variance of disparate timing of recruitment and regional and inter-annual variability in growth. CV on age 26 year fish were assumed to be 0.15 and 0.1 for female and male, respectively. The assumption of the larger uncertainty in the length at age of old fish was consistent with ageing study that has old fish sample (Hill 1986).

2.3.3. Weight at length

Weight-at-length relationships are used to convert between length and weight. The length-weight relationships based on the same biological samples indicated that eye-fork length (EFL) and weight (W) were different between sexes (Brodziak 2013). The sex-specific length-weight relationships are:

$$W_L(\text{kg}) = 1.844 \times 10^{-5} L(\text{cm})^{2.956} \text{ for female}$$

$$W_L(\text{kg}) = 1.370 \times 10^{-5} L(\text{cm})^{2.975} \text{ for male}$$

where W_L is weight-at-length L. These weight-at-length relationships were applied as fixed parameters in the SS (Figure 2.6).

2.3.4. Sex specificity

We chose a two-sex model for the assessment, because of known differences in growth and growth rates, in expected differences in natural mortality rates, and in observed length-weight relationships. There is no data on sex of individual fish taken in the fisheries. The model did not include sex-based selectivity, and the sex-ratio at birth was fixed at 1:1. However, after birth significant differences in sex-ratio in a cohort may arise from sex-specific natural mortality rates, from size-based selectivity, and from sexually-dimorphic growth.

2.3.5. Natural mortality

Natural mortality (M) was assumed to be age- and sex-specific. Age-specific M estimates for Pacific blue marlin were derived from a meta-analysis of nine estimators based on empirical and life history methods to represent adult fish. Males were considered fully mature at age one, and females at age four. After fish are fully mature, M is assumed to be a constant. Since there was no sexual dimorphism modeled for ages zero to one[7], M was the same for females and males over this period. A Lorenzen size-mortality relationship (Lorenzen 1996) was used to calculate the relative change of M between age 0 and age 1 (adult male) and rescale M at age 1 to represent M at age 0 for both female and male (Lee and Chang 2013). Female mortality is assumed to decline linearly from age 1 to fully mature age to account for size-dependent processes and cost-of-reproduction. The M estimators relied on a range of factors (e.g. length or age at maturity, maximum age, growth rate, asymptotic length, environmental factor) based on the same biological parameters used in this assessment. Age-specific estimates of M were fixed in the SS model as 0.42 year-1 for age 0, 0.37 year-1 for age 1, 0.32 year-1 for age 2, 0.27 year-1 for age 3, and 0.22 year-1 for age above 4 for female and 0.42 year-1 for age 0, 0.37 year-1 for age above 1 for male in this assessment (Figure 2.7).

2.3.6. Recruitment and reproduction

Spawning was found by Shimose *et al.* (2009) and Sun *et al.* (2009) to occur from late spring throughout summer (May-September) based on gonadal examination for females. In the SS model, spawning was assumed to occur in the beginning of second calendar quarter, which corresponds with the beginning of spawning cycle. The maturity ogive was based on Sun *et al.* (2009) but was refit using the parameterization used in the SS3 (Figure 2.8), where the size-at-50 percent-maturity was 179.76 cm and slope of the logistic function was -0.2039. Recruitment timing was assumed in the model to occur in the second quarter (April-June) on the basis of model fit in early runs, where second quarter recruitment gave greatly improved fit to fisheries 1, 2, 7, 10, 12, and 14, all of which take age 0 fish (Table 2.4).

A standard Beverton and Holt stock recruitment model was used in this assessment. The expected annual recruitment was the function of spawning biomass with steepness (h), virgin recruitment (R0), and unfished equilibrium spawning biomass (SB_0) corresponding to R_0 and were assumed to follow a lognormal distribution with standard deviation σ_R (Methot 2005, 2012, Methot and Wetzel 2013). Annual recruitment deviations were estimated based on the information available in the data and the central tendency that penalizes the log (recruitment) deviations for deviating from zero and assumed to sum to zero over the estimated period. Log-bias adjustment factor was used to assure that the estimated log-normally distributed recruitments are mean unbiased (Methot and Taylor 2011).

Recruitment variability (σ_R: the standard deviation of log-recruitment) was fixed and iteratively rescaled in the final model to match the expected variability at 0.32. The log of R0 and annual recruitment deviates were estimated by the SS base-case model. The offset for the initial recruitment relative to virgin recruitment, R1, was assumed to be negligible and fixed at 0. The choice of estimating years with information on recruitment was based on a model run with all recruitment deviations estimated (1971-2011). The CV of the recruitment estimates was plotted and it was assumed that data, especially size compositions (but other sources as well) provide information about individual year class strengths to inform recruitment magnitude when the CV is stabilized (Figure 2.9). Thus recruitment was estimated during 1971-2010 and used the SR expectations for 2011. Early data also have some information on recruitment from early cohort before 1971 and the variability of recruitment deviances often increase as the information goes down back in time (Methot and Taylor 2011). The attempt was to select the numbers of years for which young fish can be observed for the early cohort and estimate these initial recruitment deviances in the model. Five deviations were estimated prior to the start of the model. The 5-year period was chosen because early model runs showed little information on deviates more than 5 years prior to the beginning of the data because of the fast growth before they mature around age 3. Bias adjustment was used to account for lack of information of data for estimation of all recruitment deviations. This adjustment mostly affects the estimation of uncertainty not the population trajectory.

Steepness of the stock-recruitment relationship (h) was defined as the fraction of recruitment from a virgin population (R0) when the spawning stock biomass is 20 percent of its virgin level (SB0). Studies indicated that h is poorly estimated due to little information in the data about this quantity (Magnusson and Hilborn 2007; Conn *et al*. 2010, Lee *et al*. 2012). Lee *et al*. (2012) has further concluded that steepness is estimable inside the stock assessment models when the model is correctly specified for relatively low productive stocks with good contrast in spawning stock biomass. Estimating h might be imprecise and biased without good contrast of data for blue marlin. Independent estimates of steepness incorporated biological and ecological characteristic of striped marlin in the western and central North Pacific Ocean (Brodziak 2011) was reported that mean h was 0.87±0.05. Due to the fast-growing characteristic on the early life history stages for both striped marlin and blue marlin, a fixed value at 0.87 was borrowed from striped marlin in this assessment. It was noted that estimates are subject to uncertainty and further work needs to be done to evaluate the estimate.

2.3.7. Initial conditions

A model must assume something about the period prior to the start of the estimation of dynamics. Typically, two approaches are used. The first is to start the model as far back as necessary to assume the period prior to the estimation of dynamics was in an unfished or near unfished state. The other approach is to estimate (where possible) initial conditions usually assuming equilibrium catch. The equilibrium catch is the catch taken from a fish stock when it is in equilibrium assuming that removals and natural mortality are balanced by stable recruitment and growth. This equilibrium catch was then used to estimate the initial fishing mortality rates in the assessment model. Since the model started in 1971, the assumption for the first approach is not applicable for the blue marlin. Equilibrium catch taken by Japan longline early fishery, which was responsible for the majority of the historical catch, was estimated in the model (Figure 2.2). This allowed the model to start in 1971 at a depletion level that was consistent with the data. Also, the model included estimation of five recruitment deviations prior to 1971 to allow non-equilibrium age structure at the start of the model.

2.4. Fishery dynamics

Fishery dynamics describes the ways in which a given population is harvested by commercial or recreational fisheries. Changes in fishery patterns resulted from changes in target species and fishery activity (ex. locations), effects of various types of fishing gears, and environmental changes, etc. Two processes are modeled to describe the fishery dynamics, selectivity and catchability. Selectivity is used to characterize age/length-specific pattern for the fishery and catchability is used to scale vulnerable biomass.

2.4.1. Selectivity

This assessment is structured to be sex-specific, with separate growth curves and natural mortality for males and females. Because available size data were not identified to sex, the underlying assumption of selection by sex is that fish are equally vulnerable and taken by fisheries in a well-mixed ocean.

The selectivity patterns were not constrained by particular parametric structures (Methot and Wetzel 2013) and the influence of misfits of size composition was minimized in model dynamics (Francis 2011). Flexibility in the selection can be through domed shaped and time varying patterns. Selectivity pattern is fishery-specific and is assumed to be length-based for blue marlin because it affects the size distribution of the fish taken by the gear. Age-based selectivity is also invoked that allows age 0-26 to be fully selected for by JPNEarlyLL, JPNLateLL, HWLL, TWNLL, OthLL, PYFLL and EPOPS fisheries. The JPNGN fishery was considered to select ages 1-26 based on the size distribution of the catch (Figure 2.4c). In this assessment, selectivity patterns were estimated for all fisheries with length and weight composition data and those selectivity patterns were applied to the associated CPUE indices.

JPNEarlyLL was divided into two fisheries with two temporally separate indices at the point in time (1993/1994) that size composition sampling changed, because the changes in sample procedures provided the ability to account for known changes in fishing practices. In the case of

PYFLL, two time blocks (time varying) of selection pattern estimation were used to explain a bimodal pattern that was expected to result from a change of fishing patterns (Figure 2.4b).

Different selectivity assumptions can have large influence on the expected length-frequency distribution and given the relative importance of size-frequency data in the model, on the total log-likelihood. Functional forms of double normal curves were used for all fisheries in the initial model (model 1 in section 2.7) to allow for various domed shapes, as well as for asymptotic shaped selectivity. A double normal curve is comprised of outer sides of two adjacent normal curves with separate variances for the upper and lower limbs of the distribution, and it has peaks joined by a horizontal line. A fit to this selectivity implies that a fishery selects a certain size range of fish (dome-shaped selectivity curve). The initial and final parameters of the selectivity patterns were assigned values of -999, which cause SS to ignore the first and last bins of the size frequency and allows SS to fit selectivity of small and large fish independently. The four estimated parameters describing dome-shaped selectivity (the beginning size for the plateau, the width of plateau, the ascending width, and the descending width) were estimated by the model.

A cubic spline was used for fitting to size composition data for F1 and F7, since it was not possible to obtain model solutions using the double-normal functional form due to extreme peaks in the size-composition data (model 2 in section 2.7). The parameterization of the cubic spline function estimates a starting and ending gradient and a selectivity value at each node using a smoothing function to connect the nodes (cubic spline selectivity curve). Given its flexibility, the benefit of this function is not just to increase additional process but also reduce the potential misfit of size compositions without introducing too many highly-correlated nodes. Four nodes starting at 80 cm and ending at 320 cm with a total of five parameters were estimated for F1, and three nodes starting at 80 cm and ending at 200 cm with total of four parameters were estimated for F7. This amounted to one additional parameter in the selectivity functions for F1 and F7 when in comparison to other fisheries.

Selectivity patterns of fisheries without size composition data were mirrored to (assumed equal to) the selectivity patterns of fisheries with similar operations and areas for which a selectivity pattern was estimated. Mirrored selectivity patterns were based on expert opinions of members of the working group and were as follows:

- JPNCLL (F3) and JPNOth (F6) mirrored to JPNEarlyLL (F2);
- JPNBAIT (F5) mirrored to JPNGN (F4);
- ASLL (F8) and HWOth (F9) mirrored to HWLL (F7);
- TWNOth (F11) mirrored to TWNLL (F10); and
- WCPFCPS (F15) and EPOOth (F16) mirrored to EPOPS (F14).

2.4.2. Catchability

Catchability (q) was estimated assuming that survey indices are proportional to vulnerable biomass with a scaling factor of q. It was assumed that q was constant over time for all indices.

2.5. Observation models for the data

The fitting to three data components determine the value of the log-likelihood function. They are the total catch data, the CPUE indices, and the size-frequency data. The observed total catch data are assumed to be unbiased and relatively precise and were fitted with a lognormal error distribution with standard error (SE) equal to 0.05. The small CVs were for computational convenience to avoiding having to solve the Baranov equation iteratively in the multiple fisheries assessment. An unacceptably poor fit to catch was defined as models that when fitted did not remove greater than 99 percent of the observed total catch from any fishery.

The probability distributions for the CPUE indices were assumed to be lognormal with SE in log space, which was assumed to be the equivalent of the CV (typically SD/estimate) in natural space described in each CPUE paper. A minimum average CV for indices of 0.14 was assumed for each series following the modeling of a simple smoother on the CPUE data outside the model and then estimating the residual variance. Series with average CV < 0.14 were scaled to CV = 0.14 through the addition of a constant. Series with average CV > 0.14 were input as given.

The probability distributions for the size frequency data were assumed to be multinomial with distributions of the error variance determined by the effective sample size (effN). In commercial fisheries, the sample measurements of size of fish are usually not a random sample of individual fish from the entire population, rather they are a samples of clusters (trips or sets). Effective sample size is usually lower than the actual number of fish sampled, since within cluster variance is significantly lower than the variance in the population. To obtain random sample from population, approximations of the clusters were taken from an analysis of the relationship with number of trips sampled in the HWLL fleet which found around 10 fish per trip for marlin (Piner *et al.* 2013). Thus for all longline fisheries (F1, F2, F7, F10, F12, F13), sample size was assumed to be number of fish measured/10, and it was the number of fish measured for JPNGN and EPOPS (F4, F14). The minimum quarterly sample size was fixed at 2.5 (i.e. 25 samples/10) and the maximum quarterly sample size was fixed at 50 to restrict the influence of size frequency on model fit to the CPUE indices. Most sample sizes were 50 for F1, F2, F4, F10, and F14. These samples were highly precise and exhibited little variability among samples within fisheries. In order to retain the relative among sample variability when fitting the models, a single iteration of the model was made. The effective sample sizes estimated in this tuning fit were then reduced by a scalar based on the regression (through the origin) of the tuning model run input sample sizes against the estimated effective sample sizes obtained from the tuning model run (MacCall 2003, Maunder 2011).

2.6. CPUE indices included

A key assumption of the modeling is that the values in a CPUE series are proportional to stock abundance. Those that are should be consistent and in relative agreement. If two or more abundance indices show conflicting trends, then at least one of the indices is not representative of relative abundance. All series considered for use in the assessment had strong and weak points; therefore an objective method was used to segregate the CPUE indices into two separate data sets based on a down-weighting analyses and correlation analyses. These two separate data sets presented two different population trajectories.

In the model runs for down weighting analyses, likelihood components for indices derived from the same fishery were treated as one component with respect to inclusion or exclusion from the base model, because it was considered unlikely that a fishery would be representative in one time period but not another. Each likelihood component (excluding that for catch) was sequentially down-weighted in separate model runs. CPUE indices were determined to provide consistent information if down-weighting these indices led to loss of fit in the other indices. The results indicated that the JPNEarlyLL (S1, S2) and TWNLL (S4, S5, S6) were consistent and considered as initial CPUE data set used for further diagnostics (Table 2.5). The other index including HWLL (S3) represents the different population trajectories after 1995.

Correlation analyses among time series of CPUE indices were examined. Unlike in the down weighting analyses, indices derived from the same fishery were treated as separate components. For example, two indices from two time stratifications (1975-1993, 1994-2011) for the JPNEarlyLL were analyzed. Pearson correlation coefficients (ρ) were interpreted as measuring the association among pairs of CPUE series showing similar results with down-weighting analyses (Table 2.6). There is no strong correlation ($|\rho| \geq 0.5$) among CPUE time series. For moderate correlation ($0.4 \leq |\rho| < 0.5$), there were positive correlation among JPNEarlyLL (S2) and TWNLL (S6) and negative correlation among HWLL (S3) and TWNLL (S5).

Based on the correlation and down-weighting analyses, JPNEarlyLL (S1, S2) and TWNLL (S4, S5, S6) were fitted and contributed to the total likelihood as one candidate model (CPUE subset 1). HWLL (S3) along with early index from JPNEarlyLL (S2) to inform early population dynamic was fitted as an alternative model (CPUE subset 2). The authors note that having a priori knowledge of the "best" representative index of abundance is preferable (e.g. fishery independent survey) but given that only the fishery dependent indices of relative abundance were available, a selection process such as that used was necessary.

2.7. Preferred model configuration

Based on the preliminary analyses, four models differing in CPUE series, selectivity curves, and sex-based model structure assumptions were explored. Each of these four models was evaluated based on the consistency of results and goodness of fit to data. For each model the fit to the size composition and indices of abundance, as well as an R0 profile and estimated time series of spawning biomass, were produced. The detailed descriptions of model differences are as follows:

- Model 1. Use data set 1 (subset cpue: S1, S2, S4, S5, S6) and domed shaped selectivity curves for all fisheries.
- Model 2. Use data set 1 (subset cpue: S1, S2, S4, S5, S6), cubic spline selectivity curves for F1 and F7 and domed shaped selectivity curves for others.
- Model 3. Use data set 2 (subset cpue: S1 and S3), cubic spline selectivity curves for F1 and F7 and domed shaped selectivity curves for others.
- Model 4. Use data set 1 (subset cpue: S1, S2, S4, S5, S6), one-sex model structure with one growth curve, one natural mortality schedule, one length-weight relationship, cubic spline selectivity curves for F1 and F7, and domed shaped selectivity curves for other fisheries.

The model providing the best fit to the data was Model 2.

3. RESULTS

In this section we describe model results for Model 2, the preferred model, and provide comparisons to other models in terms of model-derived quantities:

3.1. Model convergence

Convergence to a global minimum was examined by randomly perturbing the starting values of all parameters by 10 percent and by randomly assigning the estimated phase. Models were refitted to these random changes for model 2. Improved fit (relative to the model 2) would confirm that the model had not converged to the global solution. There is no evidence of substantial differences in the scaling parameter (R0) and total likelihood showing a better fit (Figure 3.1). Based on these results, it is concluded that the model is relatively stable with no evidence of lack of convergence to the global minimum.

3.2. Model fit diagnostics

The performance of the model was assessed by comparing input data with predictions for two data types: abundance indices and size compositions. Abundance indices provide direct information about stock trends and composition data inform about strong and weak year classes and the shape of selectivity curves (Francis 2011).

3.2.1. Abundance indices

The model fits to the CPUE indices by fishery are provided in Figure 3.2 and Table 3.1. The fit to the CPUE indices were summarized into two groups: (1) those in which indices contributed to the total likelihood, were influential to the dynamics with root-mean-squared-error (RMSE) < 0.3; and (2) those in which indices did not contribute to the total likelihood.

Models 1, 2 and 4 (Sec. 2.7) generally followed JPNEarlyLL and JPNLateLL (S1, S2), and TWNLL (S4, S5, S6) with RSME < 0.3. The fit to these tuning indices were generally within the 95 percent CI. Since the majority of the longline catch comes from S1, S2, and S6, these indices were considered primary indices and thought to be the most reliable source of CPUE as indices of relative abundance. These three models statistically fit S1 and S2 and TWNLL (S4, S6) well with RSME < 0.2. These indices indicate a slight upward trend from 1976-1981, show no trend from 1982-1992, exhibit a moderate negative trend from 1994-1998, and show no trend thereafter. Although not included in the likelihood of the fitted models, index HWLL (S3) was included in the model to allow comparison of the fitted and observed trends. The model did not fit S3 well, indicating that this index was not consistent with the other data included in these models.

Model 3 was fitted to S3. Since S3 was available for 1995-2011, inclusion of the early-period Japanese index (S1) provided information on relative abundance without introducing a conflicting index (Table 2.5 and 2.6). The fit to these indices were generally within 95 percent CI with RMSE < 0.3. Although not contributing to the total likelihood, the indices S2 and S6 were included in this model to compare the expectation. These indices were not consistent with model results (RMSE > 0.3).

Iteratively rescaling of the data weights for all indices resulted in minimum inputted series precision of 0.14. Although fits of models resulted in a smaller RMSE for S4 and S5 than inputted C.V., the attempt to rescale these two indices to RMSE was not done, because the fit to S1, a principal abundance index, deteriorated.

3.2.2. Size composition

The models fit the length modes in data aggregated by fishery and season fairly well given the estimated effective sample sizes (effN) (Figure 3.3 and Table 3.2). Effective sample size (EffN) is the models estimate of the statistical precision. Larger effN indicates a better fit. In general, average statistical fits for effN ≥ 30 indicate reasonably good fit to the composition information. For all fisheries in all models, precision of model predictions is greater than that of observations.

Model 1 exhibited some level of misfit to the size composition data for F1, F2, and F7, where it was not able to fit the extreme peak at particular size bins (Figure 3.3). Models 2-4 have additional process in the selectivity pattern parameterization (cubic spline) that reduced the level of misfit to the size composition data for F1 and F7 (Figure 3.3) and improved statistical fit to those data components (Table 3.2). The fit to the composition data for F2 could not be improved with a more flexible selection pattern (cubic spline) due to the seasonal patterns. Additional model run using the cubic spline for F2 in Model 2 improved the fit to the season 1 and season 2 data but degraded the fit to the season 3 and season 4, resulting in a stronger likelihood gradient in F2 than in Model 2 (results not shown).

Pearson residual plots are presented for the model fits to size composition data for Model 2 (Figure 3.4), where the filled and open circles represent observations that are higher (positive residuals) and lower (negative residuals) than the model predictions, respectively. The positive or negative residuals are determined by the difference between predictions and observations. The areas of the circles are proportional to the absolute values of the residuals.

Model 2 fitted the observations well, exhibiting no substantial residual pattern for fisheries when using the most flexible selectivity patterns. There were notable misfits for JPNLateLL (F2) due to seasonality. The greatest level of model misfit appears to be from the PYFLL (F13), which was modeled using time varying selectivity in two time blocks. However, the likelihood gradient was minimal in the Models 2-4 (Table 3.3). This suggests that the level of misfit hasn’t much influence on the population scale.

3.3. Selectivity

Estimated selectivity patterns were domed shaped in Model 1 for JPNEarlyLL (F1), JPNGN (F4), HWLL (F7), TWNLL (F10), first time period of PYFLL (F13), and EPOPS (F14); however, were asymptotic for JPNLateLL (F2), OthLL (F12), and second time period of PYFLL (F13) (Figure 3.5). Temporal variations in selectivity were captured by the time blocks employed for F13, suggesting that the selectivity of larger sizes of fish was low in 1996-2002 and high in more recent years (2003-3011). Selectivity parameters were precisely estimated, with CV < 10 percent for F1, F4, F7, F10, the first period of F13, and for F14. The least precise estimates of selectivity parameters were for fisheries F2, F12, and second period of F13, for which size-frequency data were insufficient to estimate parameters of the selectivity function.

A relatively new approach for modeling selectivity curves, using a cubic spline function over length (Figure 3.5) greatly improved the fit to size composition for F1 and F7 in Model 2 (Figure 3.3). The fitted selectivity patterns for other fisheries were consistent with the assumed domed-shaped selectivity, and the precision of parameter estimates describing the descending limb of selectivity curves improved for F2 and F12. The least precise estimates of selectivity parameters were in F7 and resulted from the seasonality of size composition, and in second time period of F13, where length data was insufficient to inform the descending shape of selectivity. Model 3 and Model 4 used the same selectivity assumptions as Model 2, and the expected selectivity patterns were consistent with the assumed shapes. The estimates of selectivities in Model 4 were generally similar to the estimates in Model 2 except for the descending shape of selectivity in F2.

The estimated selectivity patterns for most longline fisheries are decidedly domed. Whether this result reflects gear operations (such as depth, bait, etc.) or is related to the spatial distribution of the fleet relative to the size-structure of the population is not clear. Additional work to address on a finer spatial distribution of catch by size and associated fishing effort should be considered to better understand the fisheries and improve their definition in future models. A third possibility is that this reflects a bias in the size sampling process, but this is thought to be less likely. Uncertainty in the life history parameters (growth and mortality) is also influential in the degree of dome-shaped selectivity.

3.4. Catchability

Catchability coefficient (q) was estimated in the model as a single value for each index (Table 3.4). Catchability was allowed to change through time by separating the time series into two fisheries based on known changes in fishing practices of the Japan distant-water longline fisheries (F1, F2). Although CPUE indices are assumed to be proportional to vulnerable biomass with a scaling factor of q, this does not imply that the proportion of biomass taken by a fishery (q* biomass) can be fully explained by dome-shaped selectivity. In other words, higher q means higher availability to the fishery but cannot be directly interpreted as higher population biomass, since the proportion taken is determined in part by selectivity.

3.5. Biomass

Estimates of population biomass (age-1 and older) experienced a long-term decline during 1971-2011 (Table 3.5 and Figure 3.6). Since the assessment model has a quarterly time step, there are four estimates of total biomass for each year. For presentation purposes, population biomass estimates in the beginning of the year (season 1) are shown. Spawning biomass also exhibited a declining trend during 1971-2011 (Table 3.5 and Figure 3.6). Estimates of spawning biomass are in the beginning of spawning cycle (season 2). A comparison to the other candidate models is shown. All models indicated a stock at levels below their long-term average.

3.6. Recruitment

Recruitment variability (σ_R: the standard deviation of log-recruitment) was estimated at 0.32. Recruitment (age-0 fish) estimates indicated a long-term fluctuation around its mean (Table 3.5 and Figure 3.6) for all models. Recruitment was low in the early of time series (1974-1976) and several strong year classes recruited to the fisheries during 1977-1989 following by several weak year classes during 1990-2011 with fewer larger recruitment events. Recruitment prior to 1990 appeared to be from somewhat higher spawning biomasses and corresponds to generally higher levels of recruitment. The 2011 estimate was the expectations of the spawner-recruit (SR) relation.

3.7. Fishing mortality

Spawning potential ratio (SPR) is the ratio of spawning biomass per recruit given a particular fishing intensity and stock's biological characteristics divided by the spawning biomass per recruit with no fishing (Goodyear, 1993). It is a measure of residual population under fishing and a comparable measure with fishing mortality is 1-SPR. SPR has a maximum value of unity and declined toward zero as fishing intensity increases. Although SPR may not be a straightforward measure of the actual mortality, it incorporates all aspects of multi-fleet fishing intensity and the life history of the stock with no subjectivity in the weighting of each age and fishery. Estimated fishing intensity (1-SPR) is given in Figure 15 for model 1-4. During the period of informative data, exploitation has typically allowed 20-30 percent and 12-30 percent of the spawning potential for model 2 and other models, respectively. The most recent years have been closer to 18 percent, 22 percent, 10 percent, and 13 percent for Models 1-4.

4. DISCUSSION

The data after 1971 is much more reliable than the data from prior years, due in large measure to the failure to identify catch to species in the earlier years. Model 2 is based on the post-1970 data and is expected to best describe the status and trends of blue marlin in the Pacific. This model exhibited little to no conflict in the R_0 profiles. The gradients of likelihood resulting from size-composition data is minimum in Model 2, and therefore the CPUE indices were influential in driving the model in the fitting process. As a result, the fits to the indices (subset CPUE 1) and size composition were acceptable.

Model fits to the CPUE indices generally follow the Japan DWLL indices (S1, S2). While it is not possible to know if these or any other indices are proportional to relative abundance, we noted that the majority (>60 percent) of the LL catch has come from S1 and 20-50 percent of the LL catch from S2. The choice of S1 and S2 as our primary indices considered the magnitude of the catch and that fact that Japan longline fisheries are often the most reliable data source for CPUE data.

Fit to the size-composition data was generally good, especially for fisheries with the most flexible selectivity patterns and large sample sizes. The greatest level of model misfit was from three fisheries, F2, F7, and F13. F2 and F7 had seasonal variability in size-composition, and F13 had small sample sizes. The likelihood profile across R_0 for F7 and F13 did not show a strong gradient, meaning that misfit of F7 and F13 size-composition data would have little influence on model results. However, misfit for F2 indicates same level of gradient as primary index (S2). An alternative solution would be to split F2 into separate seasonal fisheries with separate selection patterns. Unfortunately, this was not an option, because the primary index (S2) was an annual estimate associated with F2 size data. Although we do not know the influence of misfit for F2, the location of population scale from the F2 composition data was generally consistent with of the other data components, which indicated a lack of conflict over scale.

Based on the results obtained from Model 2, the blue marlin biomass in the Pacific Ocean was high during 1971-1976, when total harvest of blue marlin was low. The observed decline in the biomass was explained by a lack of the larger recruitment events, and possibly an increased frequency of low recruits per spawner. During 1977-1991, the biomass was stable, although there was an increase of catch.. This could be the result of contributions of several large recruitment events, and possibly from increased frequency of higher levels of recruits per spawner. During 1991-2008, the biomass again declined, reaching a historical low level in the mid-2000s. During this period the catch was at a historical high. The observed decline in biomass may have resulted from the combination of high catch and increased frequency of below-SR expectation with loss of the larger recruitment events. A strong year class was observed in 2009 resulting in increasing biomass in recent years.

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Table 2.1. Fisheries in the assessment of blue marlin. DWLL – distant water longline; OSLL – offshore longline; COLL – coastal and other longline; GN – gillnet; HAR – harpoon

Fishery	Alpha Code	Fishing entities
F1	JPNEarlyLL	Japan DWLL
F2	JPNLateLL	Japan DWLL
F3	JPNCLL	Japan COLL
F4	JPNGN	Japan GN
F5	JPNBait	Japan bait fishing
F6	JPNOth	Japan other gears
F7	HWLL	United States (Hawaii) LL
F8	ASLL	United States (American Samoa) LL
F9	HWOth	United States (Hawaii) troll & handline
F10	TWNLL	TaiwanDWLL
F11	TWNOth	TaiwanOSLL, COLL, GN & HAR
F12	OthLL	Various flags[8] longline
F13	PYFLL	French Polynesia longline
F14	EPOPS	Various flags[9] purse seine
F15	WCPFCPS	Various flags[10] purse seine
F16	EPOOth	French Polynesia troll & handline, HAR

[8] Australia, Belize, China, Cook Islands, Costa Rica, Fiji, Indonesia, Kiribati, Korea, Marshall Islands, Mexico, Federated States of Micronesia, New Caledonia, Niue, New Zealand, Papua New Guinea, Philippines, Samoa, Senegal, Spain, Solomon Islands, Tonga, Tuvalu, Vanuatu, Vietnam

[9] Ecuador, Honduras, México, Nicaragua, Panamá, El Salvador, Spain, Venezuela, Vanuatu, USA

[10] Australia, China, Ecuador, Federated States of Micronesia, Indonesia, Kiribati, Marshall Islands, Mexico, New Zealand, Papua New Guinea, Philippines, Solomon Islands, El Salvador, Spain, Tuvalu, Vanuatu, Korea, Japan, USA

Table 2.2. Estimates of total catch (t) by fishery by calendar quarter for 1971-2011.

Yr	Seas	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
1971	1	1897.7	0.0	28.2	0.0	1.5	12.3	9.8	0.0	0.0	26.0	483.8	15.0	0.0	0.0	2.0	0.0
1971	2	1667.4	0.0	28.2	0.0	1.5	12.3	8.2	0.0	0.0	26.0	483.8	15.0	0.0	0.0	2.0	0.0
1971	3	1894.5	0.0	28.2	0.0	1.5	12.3	2.9	0.0	0.0	26.0	483.8	15.0	0.0	0.0	2.0	0.0
1971	4	1404.1	0.0	28.2	0.0	1.5	12.3	0.5	0.0	0.0	26.0	483.8	15.0	0.0	0.0	2.0	0.0
1972	1	2546.8	0.0	52.8	2.0	1.7	13.0	0.5	0.0	0.0	50.8	439.8	15.8	0.0	0.0	2.3	0.0
1972	2	2241.3	0.0	52.8	2.0	1.7	13.0	0.7	0.0	0.0	50.8	439.8	15.8	0.0	0.0	2.3	0.0
1972	3	2123.2	0.0	52.8	2.0	1.7	13.0	0.1	0.0	0.0	50.8	439.8	15.8	0.0	0.0	2.3	0.0
1972	4	1581.5	0.0	52.8	2.0	1.7	13.0	0.2	0.0	0.0	50.8	439.8	15.8	0.0	0.0	2.3	0.0
1973	1	2855.0	0.0	52.8	65.9	5.7	33.5	0.3	0.0	0.0	56.3	550.5	18.8	0.0	0.0	3.5	0.0
1973	2	2606.6	0.0	52.8	65.9	5.7	33.5	0.7	0.0	0.0	56.3	550.5	18.8	0.0	0.0	3.5	0.0
1973	3	1661.1	0.0	52.8	65.9	5.7	33.5	8.2	0.0	0.0	56.3	550.5	18.8	0.0	0.0	3.5	0.0
1973	4	2001.9	0.0	52.8	65.9	5.7	33.5	5.9	0.0	0.0	56.3	550.5	18.8	0.0	0.0	3.5	0.0
1974	1	2493.9	0.0	45.5	56.6	15.2	12.8	3.1	0.0	0.0	40.3	662.5	21.8	0.0	0.0	1.8	0.0
1974	2	2081.2	0.0	45.5	56.6	15.2	12.8	5.2	0.0	0.0	40.3	662.5	21.8	0.0	0.0	1.8	0.0
1974	3	1740.5	0.0	45.5	56.6	15.2	12.8	17.3	0.0	0.0	40.3	662.5	21.8	0.0	0.0	1.8	0.0
1974	4	1757.2	0.0	45.5	56.6	15.2	12.8	9.3	0.0	0.0	40.3	662.5	21.8	0.0	0.0	1.8	0.0
1975	1	1585.3	0.0	116.6	195.5	36.4	19.9	9.1	0.0	0.0	37.0	814.8	33.8	0.0	0.0	1.8	0.0
1975	2	1269.2	0.0	116.6	195.5	36.4	19.9	8.6	0.0	0.0	37.0	814.8	33.8	0.0	0.0	1.8	0.0
1975	3	1614.8	0.0	116.6	195.5	36.4	19.9	9.1	0.0	0.0	37.0	814.8	33.8	0.0	0.0	1.8	0.0
1975	4	1188.0	0.0	116.6	195.5	36.4	19.9	6.2	0.0	0.0	37.0	814.8	33.8	0.0	0.0	1.8	0.0
1976	1	1469.6	0.0	107.3	142.9	49.9	79.4	3.6	0.0	0.0	44.0	493.3	191.6	0.0	0.0	1.5	0.0
1976	2	1817.9	0.0	107.3	142.9	49.9	79.4	5.2	0.0	0.0	44.0	493.3	191.6	0.0	0.0	1.5	0.0
1976	3	2050.3	0.0	107.3	142.9	49.9	79.4	23.4	0.0	0.0	44.0	493.3	191.6	0.0	0.0	1.5	0.0
1976	4	1807.7	0.0	107.3	142.9	49.9	79.4	27.4	0.0	0.0	44.0	493.3	191.6	0.0	0.0	1.5	0.0
1977	1	2100.5	0.0	129.5	245.5	47.7	38.4	23.8	0.0	0.0	36.3	421.8	164.1	0.0	0.0	2.3	0.0
1977	2	2033.5	0.0	129.5	245.5	47.7	38.4	23.2	0.0	0.0	36.3	421.8	164.1	0.0	0.0	2.3	0.0
1977	3	1838.0	0.0	129.5	245.5	47.7	38.4	54.4	0.0	0.0	36.3	421.8	164.1	0.0	0.0	2.3	0.0
1977	4	1877.5	0.0	129.5	245.5	47.7	38.4	22.7	0.0	0.0	36.3	421.8	164.1	0.0	0.0	2.3	0.0
1978	1	2329.9	0.0	206.9	217.4	49.2	98.1	19.4	0.0	0.0	15.8	505.0	285.1	0.0	0.0	2.0	0.0
1978	2	2629.8	0.0	206.9	217.4	49.2	98.1	70.0	0.0	0.0	15.8	505.0	285.1	0.0	0.0	2.0	0.0
1978	3	2129.0	0.0	206.9	217.4	49.2	98.1	81.8	0.0	0.0	15.8	505.0	285.1	0.0	0.0	2.0	0.0
1978	4	1705.3	0.0	206.9	217.4	49.2	98.1	23.2	0.0	0.0	15.8	505.0	285.1	0.0	0.0	2.0	0.0
1979	1	2269.3	0.0	186.9	126.2	41.3	66.4	21.4	0.0	0.0	105.5	543.5	354.9	0.0	0.0	3.3	0.0
1979	2	2761.7	0.0	186.9	126.2	41.3	66.4	55.2	0.0	0.0	105.5	543.5	354.9	0.0	0.0	3.3	0.0
1979	3	2148.6	0.0	186.9	126.2	41.3	66.4	62.3	0.0	0.0	105.5	543.5	354.9	0.0	0.0	3.3	0.0
1979	4	2184.3	0.0	186.9	126.2	41.3	66.4	20.2	0.0	0.0	105.5	543.5	354.9	0.0	0.0	3.3	0.0
1980	1	3410.3	0.0	171.6	213.5	34.4	28.8	19.7	0.0	0.0	122.5	445.8	301.1	0.0	0.0	3.3	0.0
1980	2	2755.6	0.0	171.6	213.5	34.4	28.8	48.2	0.0	0.0	122.5	445.8	301.1	0.0	0.0	3.3	0.0
1980	3	2145.3	0.0	171.6	213.5	34.4	28.8	68.6	0.0	0.0	122.5	445.8	301.1	0.0	0.0	3.3	0.0
1980	4	2075.4	0.0	171.6	213.5	34.4	28.8	37.5	0.0	0.0	122.5	445.8	301.1	0.0	0.0	3.3	0.0
1981	1	2785.4	0.0	200.6	286.5	46.2	35.2	32.5	0.0	0.0	115.8	557.8	336.1	0.0	0.0	7.5	0.0
1981	2	3085.0	0.0	200.6	286.5	46.2	35.2	48.7	0.0	0.0	115.8	557.8	336.1	0.0	0.0	7.5	0.0
1981	3	2281.9	0.0	200.6	286.5	46.2	35.2	76.1	0.0	0.0	115.8	557.8	336.1	0.0	0.0	7.5	0.0
1981	4	1951.2	0.0	200.6	286.5	46.2	35.2	32.9	0.0	0.0	115.8	557.8	336.1	0.0	0.0	7.5	0.0
1982	1	3073.8	0.0	176.5	234.9	42.3	61.0	28.5	0.0	0.0	76.0	640.5	390.3	0.0	0.0	10.5	0.0
1982	2	3152.1	0.0	176.5	234.9	42.3	61.0	52.4	0.0	0.0	76.0	640.5	390.3	0.0	0.0	10.5	0.0
1982	3	2542.3	0.0	176.5	234.9	42.3	61.0	64.3	0.0	0.0	76.0	640.5	390.3	0.0	0.0	10.5	0.0
1982	4	2049.5	0.0	176.5	234.9	42.3	61.0	34.7	0.0	0.0	76.0	640.5	390.3	0.0	0.0	10.5	0.0
1983	1	2997.2	0.0	258.7	229.0	56.8	108.7	15.1	0.0	0.0	68.0	753.8	243.4	0.0	0.0	16.8	0.0
1983	2	2753.7	0.0	258.7	229.0	56.8	108.7	35.8	0.0	0.0	68.0	753.8	243.4	0.0	0.0	16.8	0.0
1983	3	1918.2	0.0	258.7	229.0	56.8	108.7	56.6	0.0	0.0	68.0	753.8	243.4	0.0	0.0	16.8	0.0
1983	4	2116.5	0.0	258.7	229.0	56.8	108.7	35.1	0.0	0.0	68.0	753.8	243.4	0.0	0.0	16.8	0.0
1984	1	3968.5	0.0	318.4	60.5	45.7	105.8	18.9	0.0	0.0	95.5	720.5	376.9	0.0	0.0	21.5	0.0
1984	2	3272.0	0.0	318.4	60.5	45.7	105.8	22.2	0.0	0.0	95.5	720.5	376.9	0.0	0.0	21.5	0.0
1984	3	2547.4	0.0	318.4	60.5	45.7	105.8	67.3	0.0	0.0	95.5	720.5	376.9	0.0	0.0	21.5	0.0
1984	4	2465.4	0.0	318.4	60.5	45.7	105.8	28.7	0.0	0.0	95.5	720.5	376.9	0.0	0.0	21.5	0.0
1985	1	3206.3	0.0	255.4	100.4	74.5	86.1	29.8	0.0	0.0	53.0	499.3	383.3	0.0	0.0	17.3	0.0
1985	2	2718.3	0.0	255.4	100.4	74.5	86.1	38.7	0.0	0.0	53.0	499.3	383.3	0.0	0.0	17.3	0.0
1985	3	1665.4	0.0	255.4	100.4	74.5	86.1	45.4	0.0	0.0	53.0	499.3	383.3	0.0	0.0	17.3	0.0
1985	4	1762.0	0.0	255.4	100.4	74.5	86.1	22.5	0.0	0.0	53.0	499.3	383.3	0.0	0.0	17.3	0.0
1986	1	3360.8	0.0	219.3	43.8	91.5	37.1	34.5	0.0	0.0	46.0	690.8	429.1	0.0	0.0	16.5	0.0
1986	2	3616.6	0.0	219.3	43.8	91.5	37.1	53.4	0.0	0.0	46.0	690.8	429.1	0.0	0.0	16.5	0.0
1986	3	2301.7	0.0	219.3	43.8	91.5	37.1	74.9	0.0	0.0	46.0	690.8	429.1	0.0	0.0	16.5	0.0
1986	4	2075.9	0.0	219.3	43.8	91.5	37.1	46.2	0.0	0.0	46.0	690.8	429.1	0.0	0.0	16.5	0.0
1987	1	2743.7	0.0	373.6	63.0	70.3	29.8	34.9	0.0	70.8	49.5	1403.3	1073.4	0.0	0.0	18.3	0.0
1987	2	3506.6	0.0	373.6	63.0	70.3	29.8	60.2	0.0	70.8	49.5	1403.3	1073.4	0.0	0.0	18.3	0.0
1987	3	3153.7	0.0	373.6	63.0	70.3	29.8	85.8	0.0	70.8	49.5	1403.3	1073.4	0.0	0.0	18.3	0.0
1987	4	2296.0	0.0	373.6	63.0	70.3	29.8	58.7	0.0	70.8	49.5	1403.3	1073.4	0.0	0.0	18.3	0.0
1988	1	3796.3	0.0	355.4	90.5	57.3	34.9	36.2	0.0	74.0	80.0	1024.3	898.2	0.0	0.0	17.8	0.0
1988	2	2883.9	0.0	355.4	90.5	57.3	34.9	34.6	0.0	74.0	80.0	1024.3	898.2	0.0	0.0	17.8	0.0
1988	3	1952.4	0.0	355.4	90.5	57.3	34.9	102.1	0.0	74.0	80.0	1024.3	898.2	0.0	0.0	17.8	0.0
1988	4	1475.8	0.0	355.4	90.5	57.3	34.9	91.1	0.0	74.0	80.0	1024.3	898.2	0.0	0.0	17.8	0.0
1989	1	2269.0	0.0	307.7	73.8	97.2	30.7	70.9	0.0	91.3	111.3	829.3	677.4	0.0	0.0	21.5	0.0
1989	2	2446.9	0.0	307.7	73.8	97.2	30.7	115.1	0.0	91.3	111.3	829.3	677.4	0.0	0.0	21.5	0.0
1989	3	2100.2	0.0	307.7	73.8	97.2	30.7	146.0	0.0	91.3	111.3	829.3	677.4	0.0	0.0	21.5	0.0

1989	4	1931.5	0.0	307.7	73.8	97.2	30.7	145.1	0.0	91.3	111.3	829.3	677.4	0.0	0.0	21.5	0.0
1990	1	2357.7	0.0	293.0	63.0	62.5	43.3	73.6	0.0	84.3	109.3	581.8	730.9	0.8	0.0	23.8	0.0
1990	2	2171.8	0.0	293.0	63.0	62.5	43.3	130.4	0.0	84.3	109.3	581.8	730.9	0.8	0.0	23.8	0.0
1990	3	1316.5	0.0	293.0	63.0	62.5	43.3	215.5	0.0	84.3	109.3	581.8	730.9	0.7	0.0	23.8	0.0
1990	4	1868.0	0.0	293.0	63.0	62.5	43.3	97.2	0.0	84.3	109.3	581.8	730.9	0.8	0.0	23.8	0.0
1991	1	2417.1	0.0	326.6	44.3	42.3	16.2	50.7	0.0	96.8	180.0	674.0	728.2	5.8	0.0	33.8	0.0
1991	2	2675.6	0.0	326.6	44.3	42.3	16.2	153.4	0.0	96.8	180.0	674.0	728.2	5.8	0.0	33.8	0.0
1991	3	1468.9	0.0	326.6	44.3	42.3	16.2	187.8	0.0	96.8	180.0	674.0	728.2	5.8	0.0	33.8	0.0
1991	4	1774.1	0.0	326.6	44.3	42.3	16.2	142.9	0.0	96.8	180.0	674.0	728.2	5.8	0.0	33.8	0.0
1992	1	2769.6	0.0	403.3	41.3	37.6	12.5	80.3	0.0	75.3	30.5	1095.0	981.2	20.0	0.0	35.3	0.0
1992	2	2748.5	0.0	403.3	41.3	37.6	12.5	95.7	0.0	75.3	30.5	1095.0	981.2	20.0	0.0	35.3	0.0
1992	3	1790.6	0.0	403.3	41.3	37.6	12.5	131.9	0.0	75.3	30.5	1095.0	981.2	20.0	0.0	35.3	0.0
1992	4	1599.0	0.0	403.3	41.3	37.6	12.5	59.7	0.0	75.3	30.5	1095.0	981.2	20.0	0.0	35.3	0.0
1993	1	2621.9	0.0	509.2	35.9	46.7	21.9	27.8	0.0	84.8	112.3	1110.8	959.8	53.8	31.1	35.5	0.0
1993	2	2704.8	0.0	509.2	35.9	46.7	21.9	79.3	0.0	84.8	112.3	1110.8	959.8	53.8	30.8	35.5	0.0
1993	3	2026.3	0.0	509.2	35.9	46.7	21.9	214.4	0.0	84.8	112.3	1110.8	959.8	53.8	31.0	35.5	0.0
1993	4	2111.9	0.0	509.2	35.9	46.7	21.9	145.3	0.0	84.8	112.3	1110.8	959.8	53.8	31.3	35.5	0.0
1994	1	0.0	3036.5	377.7	38.6	34.9	17.5	91.4	0.0	83.5	150.8	815.5	1017.0	42.2	15.2	35.3	0.0
1994	2	0.0	3004.1	377.7	38.6	34.9	17.5	115.8	0.0	83.5	150.8	815.5	1017.0	42.2	24.3	35.3	0.0
1994	3	0.0	2433.1	377.7	38.6	34.9	17.5	247.8	0.0	83.5	150.8	815.5	1017.0	42.2	24.0	35.3	0.0
1994	4	0.0	2660.1	377.7	38.6	34.9	17.5	69.6	0.0	83.5	150.8	815.5	1017.0	42.2	26.6	35.3	0.0
1995	1	0.0	2743.9	446.6	34.9	42.8	16.5	27.8	0.0	87.8	81.5	1192.8	1293.4	93.0	23.0	36.0	0.0
1995	2	0.0	2659.9	446.6	34.9	42.8	16.5	150.9	0.0	87.8	81.5	1192.8	1293.4	93.0	25.3	36.0	0.0
1995	3	0.0	2175.6	446.6	34.9	42.8	16.5	217.6	0.0	87.8	81.5	1192.8	1293.4	93.0	23.3	36.0	0.0
1995	4	0.0	1737.2	446.6	34.9	42.8	16.5	173.1	0.0	87.8	81.5	1192.8	1293.4	93.0	22.2	36.0	0.0
1996	1	0.0	1342.1	274.9	26.3	44.3	9.8	160.5	0.1	110.3	46.8	906.5	897.6	87.8	10.5	40.0	0.0
1996	2	0.0	1308.9	274.9	26.3	44.3	9.8	140.9	0.9	110.3	46.8	906.5	897.6	87.8	25.7	40.0	0.0
1996	3	0.0	1056.1	274.9	26.3	44.3	9.8	208.5	2.7	110.3	46.8	906.5	897.6	87.8	19.6	40.0	0.0
1996	4	0.0	951.5	274.9	26.3	44.3	9.8	110.0	3.0	110.3	46.8	906.5	897.6	87.8	26.7	40.0	0.0
1997	1	0.0	1207.9	238.0	18.7	58.3	8.4	45.2	4.4	105.5	26.0	977.5	1029.3	62.6	23.1	44.8	0.0
1997	2	0.0	1615.1	238.0	18.7	58.3	8.4	165.0	4.2	105.5	26.0	977.5	1029.3	62.6	33.1	44.8	0.0
1997	3	0.0	1679.5	238.0	18.7	58.3	8.4	279.1	5.2	105.5	26.0	977.5	1029.3	62.6	46.1	44.8	0.0
1997	4	0.0	1642.9	238.0	18.7	58.3	8.4	167.0	2.4	105.5	26.0	977.5	1029.3	62.6	50.0	44.8	0.0
1998	1	0.0	1609.2	272.7	13.5	70.6	6.6	77.8	4.4	66.0	52.3	940.5	1457.8	44.7	37.7	45.5	0.0
1998	2	0.0	1487.6	272.7	13.5	70.6	6.6	62.1	3.3	66.0	52.3	940.5	1457.8	44.7	36.8	45.5	0.0
1998	3	0.0	1257.3	272.7	13.5	70.6	6.6	176.4	7.0	66.0	52.3	940.5	1457.8	44.7	43.7	45.5	0.0
1998	4	0.0	1067.8	272.7	13.5	70.6	6.6	108.3	4.7	66.0	52.3	940.5	1457.8	44.7	44.1	45.5	0.0
1999	1	0.0	1167.4	272.9	18.9	42.6	2.7	74.9	4.6	83.0	32.8	888.0	1494.8	81.6	50.7	38.3	0.0
1999	2	0.0	989.2	272.9	18.9	42.6	2.7	81.5	4.8	83.0	32.8	888.0	1494.8	81.6	88.9	38.3	0.0
1999	3	0.0	997.0	272.9	18.9	42.6	2.7	210.2	5.6	83.0	32.8	888.0	1494.8	81.6	65.4	38.3	0.0
1999	4	0.0	934.6	272.9	18.9	42.6	2.7	91.0	6.4	83.0	32.8	888.0	1494.8	81.6	28.4	38.3	0.0
2000	1	0.0	1003.6	304.5	5.2	48.5	5.7	64.6	9.9	58.8	28.5	1997.3	1306.9	70.5	48.9	46.0	0.0
2000	2	0.0	797.1	304.5	5.2	48.5	5.7	57.6	8.5	58.8	28.5	1997.3	1306.9	70.5	38.2	46.0	0.0
2000	3	0.0	1198.4	304.5	5.2	48.5	5.7	195.0	5.1	58.8	28.5	1997.3	1306.9	70.5	49.7	46.0	0.0
2000	4	0.0	1025.0	304.5	5.2	48.5	5.7	140.3	8.5	58.8	28.5	1997.3	1306.9	70.5	17.9	46.0	0.0
2001	1	0.0	924.6	290.8	39.8	33.9	3.4	27.7	11.7	73.5	146.3	2257.5	1536.6	71.0	34.0	47.3	0.0
2001	2	0.0	991.1	290.8	39.8	33.9	3.4	118.2	25.4	73.5	146.3	2257.5	1536.6	71.0	40.0	47.3	0.0
2001	3	0.0	1091.7	290.8	39.8	33.9	3.4	274.8	21.9	73.5	146.3	2257.5	1536.6	71.0	42.3	47.3	0.0
2001	4	0.0	1054.1	290.8	39.8	33.9	3.4	120.2	43.9	73.5	146.3	2257.5	1536.6	71.0	53.4	47.3	0.0
2002	1	0.0	1098.6	215.7	26.1	37.1	4.4	75.2	86.3	57.8	123.8	2199.8	1811.8	24.5	32.8	51.3	0.0
2002	2	0.0	1036.7	215.7	26.1	37.1	4.4	125.4	71.1	57.8	123.8	2199.8	1811.8	24.5	93.2	51.3	0.0
2002	3	0.0	842.4	215.7	26.1	37.1	4.4	155.4	40.4	57.8	123.8	2199.8	1811.8	24.5	61.5	51.3	0.0
2002	4	0.0	811.7	215.7	26.1	37.1	4.4	40.9	55.6	57.8	123.8	2199.8	1811.8	24.5	49.5	51.3	0.0
2003	1	0.0	1235.8	245.3	9.1	43.8	4.2	26.4	39.9	52.5	301.8	1940.0	2514.8	77.5	31.6	53.5	0.0
2003	2	0.0	947.8	245.3	9.1	43.8	4.2	181.7	48.5	52.5	301.8	1940.0	2514.8	77.5	49.1	53.5	0.0
2003	3	0.0	712.4	245.3	9.1	43.8	4.2	130.2	44.7	52.5	301.8	1940.0	2514.8	77.5	71.7	53.5	0.0
2003	4	0.0	811.8	245.3	9.1	43.8	4.2	97.0	51.6	52.5	301.8	1940.0	2514.8	77.5	59.5	53.5	0.0
2004	1	0.0	1043.6	286.5	4.9	48.0	6.6	95.4	27.4	47.0	364.0	1643.0	2022.0	58.6	31.0	56.5	0.0
2004	2	0.0	747.1	286.5	4.9	48.0	6.6	131.9	37.6	47.0	364.0	1643.0	2022.0	58.6	52.9	56.5	0.0
2004	3	0.0	693.0	286.5	4.9	48.0	6.6	125.9	33.0	47.0	364.0	1643.0	2022.0	58.6	39.3	56.5	0.0
2004	4	0.0	911.5	286.5	4.9	48.0	6.6	55.1	37.8	47.0	364.0	1643.0	2022.0	58.6	37.7	56.5	0.0
2005	1	0.0	1111.7	246.4	9.1	48.0	4.4	55.9	14.6	46.8	376.5	1885.0	2197.9	49.2	48.4	212.0	0.0
2005	2	0.0	697.3	246.4	9.1	48.0	4.4	170.6	20.0	46.8	376.5	1885.0	2197.9	49.2	74.3	212.0	0.0
2005	3	0.0	639.7	246.4	9.1	48.0	4.4	141.3	30.7	46.8	376.5	1885.0	2197.9	49.2	56.4	212.0	0.0
2005	4	0.0	437.7	246.4	9.1	48.0	4.4	71.8	48.6	46.8	376.5	1885.0	2197.9	49.2	42.5	212.0	0.0
2006	1	0.0	589.7	246.9	7.9	34.7	4.9	43.2	38.1	40.0	419.5	1452.0	2000.0	68.4	36.5	152.8	26.3
2006	2	0.0	719.1	246.9	7.9	34.7	4.9	133.4	34.8	40.0	419.5	1452.0	2000.0	68.4	61.7	152.8	26.3
2006	3	0.0	600.2	246.9	7.9	34.7	4.9	125.8	44.4	40.0	419.5	1452.0	2000.0	68.4	39.2	152.8	26.3
2006	4	0.0	597.1	246.9	7.9	34.7	4.9	126.6	51.6	40.0	419.5	1452.0	2000.0	68.4	44.9	152.8	26.3
2007	1	0.0	786.9	276.2	18.7	39.8	7.9	50.6	56.0	32.3	317.8	1290.3	1622.8	83.8	35.0	206.0	26.5
2007	2	0.0	537.5	276.2	18.7	39.8	7.9	112.7	43.2	32.3	317.8	1290.3	1622.8	83.8	35.7	206.0	26.5
2007	3	0.0	452.4	276.2	18.7	39.8	7.9	93.4	54.4	32.3	317.8	1290.3	1622.8	83.8	17.9	206.0	26.5
2007	4	0.0	388.4	276.2	18.7	39.8	7.9	82.5	79.3	32.3	317.8	1290.3	1622.8	83.8	40.7	206.0	26.5
2008	1	0.0	510.5	287.2	7.9	49.9	11.3	42.8	47.2	45.3	227.5	1380.8	1542.5	56.4	37.7	148.0	28.5
2008	2	0.0	525.5	287.2	7.9	49.9	11.3	104.6	48.1	45.3	227.5	1380.8	1542.5	56.4	42.8	148.0	28.5
2008	3	0.0	429.6	287.2	7.9	49.9	11.3	150.1	33.7	45.3	227.5	1380.8	1542.5	56.4	25.8	148.0	28.5
2008	4	0.0	377.3	287.2	7.9	49.9	11.3	120.8	48.7	45.3	227.5	1380.8	1542.5	56.4	23.3	148.0	28.5
2009	1	0.0	550.1	273.8	14.3	39.4	7.6	66.3	64.3	45.3	334.5	1196.8	1678.2	57.4	21.1	158.8	32.8
2009	2	0.0	396.8	273.8	14.3	39.4	7.6	156.4	60.9	45.3	334.5	1196.8	1678.2	57.4	34.4	158.8	32.8
2009	3	0.0	398.2	273.8	14.3	39.4	7.6	178.9	47.3	45.3	334.5	1196.8	1678.2	57.4	56.7	158.8	32.8

2009	4	0.0	582.0	273.8	14.3	39.4	7.6	67.1	50.4	45.3	334.5	1196.8	1678.2	57.4	61.9	158.8	32.8
2010	1	0.0	704.5	365.5	23.1	55.6	7.6	37.2	39.0	37.5	372.5	1435.5	1538.7	58.1	37.3	172.0	31.5
2010	2	0.0	657.3	365.5	23.1	55.6	7.6	142.1	59.3	37.5	372.5	1435.5	1538.7	58.1	53.5	172.0	31.5
2010	3	0.0	452.4	365.5	23.1	55.6	7.6	143.7	44.9	37.5	372.5	1435.5	1538.7	58.1	51.2	172.0	31.5
2010	4	0.0	419.8	365.5	23.1	55.6	7.6	74.6	45.3	37.5	372.5	1435.5	1538.7	58.1	35.6	172.0	31.5
2011	1	0.0	599.6	239.0	24.4	58.5	9.1	44.5	23.9	48.8	332.8	1277.8	1443.7	58.1	27.2	217.5	31.5
2011	2	0.0	580.2	239.0	24.4	58.5	9.1	110.7	33.1	48.8	332.8	1277.8	1443.7	58.1	51.1	217.5	31.5
2011	3	0.0	436.9	239.0	24.4	58.5	9.1	98.0	23.6	48.8	332.8	1277.8	1443.7	58.1	43.9	217.5	31.5
2011	4	0.0	272.8	239.0	24.4	58.5	9.1	68.4	28.7	48.8	332.8	1277.8	1443.7	58.1	23.3	217.5	31.5

Table 2.3. Likelihood components considered in the population dynamics model. Fishery number is the identification numbering inside the stock assessment model. Mirrored is a term that defines which selectivity pattern is assumed to be the same as the fishery for describing removals. Time blocks indicated the number of discreet periods where selectivity was allowed to change.

Fishery	Alpha Code	Catch units	Size-frequency data	# CPUE indices	Selectivity	Time blocks
1	JPNEarlyLL	t	1971-1993	1	Domed	
2	JPNLateLL	t	1994-2011	1	Domed	
3	JPNCLL	t	none	0	mirrored	2
4	JPNGN	t	1977-1980, 1982-1986, 1988, 1989, 1993, 1998	0	Domed	
5	JPNBait	t	none	0	mirrored	4
6	JPNOth	t	none	0	mirrored	2
7	HWLL	t	1994-2011	1	Domed	
8	ASLL	1,000 numbers of fish	none	0	mirrored	7
9	HWOth	t		0	mirrored	7
10	TWNLL	t	2005-2010	3	Domed	
11	TWNOth	t		0	mirrored	10
12	OthLL	t	1992-2011	0	Domed	
13	PYFLL	t	1996-2011	0	Domed	2
14	EPOPS	1,000 numbers of fish	1991-2011	0	Domed	
15	WCPFCPS	t	none	0	mirrored	14
16	EPOOth	t	none	0	mirrored	14

Table 2.4. Results of the test of seasonality of recruitment. Column headings are total likelihood followed by the change in likelihood from season 2 for each length composition component. A negative value indicates better fit (highlighted in green), and a positive value indicates worse fit (highlighted in red).

	-Log-likelihood			
Season / Fishery	**1**	**2**	**3**	**4**
JPNEarlyLL	25.7	0.0	48.5	56.9
JPNLateLL	23.7	0.0	35.7	54.9
JPNGN	0.1	0.0	0.1	0.1
HWLL	1.2	0.0	34.8	27.0
TWNLL	3.5	0.0	1.9	3.5
OthLL	5.6	0.0	12.3	14.6
PYFLL	-0.2	0.0	-2.4	-3.7
EPOPS	0.3	0.0	3.0	2.8
Total	1078.6	1023.1	1152.6	1173.1

Table 2.5. Results of the test of consistency between CPUE indices based on downweight (DW) analyses. Column headings are the change in likelihood from the model where all the indices were fitted for each index component. The blanks indicate very little likelihood contributions (weight=0.001) to these components. A negative value indicates better fit (highlighted in green), and a positive value indicates worse fit (highlighted in red).

Indices DW	S1	S2	S3	S4	S5	S6
S1 &S2			-13.2	0.0	-0.6	6.6
S3	0.0	-11.6		0.0	-0.1	-4.0
S4, S5, S6	0.0	5.4	-5.1			

Table 2.6. Correlation matrix between CPUE indices. Lower diagonal values are correlation coefficient and upper diagonal values indicate number of overlapped years.

	S1	S2	S3	S4	S5	S6
S1 (1975-1993)		0	0	4	15	0
S2 (1994-2011)	NA		17	0	6	12
S3 (1995-2011)	NA	0.36		0	5	12
S4 (1971-1978)	0.20	NA	NA		0	0
S5 (1979-1999)	0.15	0.15	-0.48	NA		0
S6 (2000-2011)	NA	0.46	-0.27	NA	NA	

Table 3.1. Inputted mean variance by data component (input CV+VarAdj) and model estimated mean variance from model 1-4 (RMSE) where root mean squared error (RMSE) is a measure of the statistical fit to the indices of abundance. Smaller RMSE indicates better fit. The italics in parentheses indicate the indices were not fitted into the model.

Index	Number of observations	Input CV	VarAdj	Input + VarAdj	RMSE			
					Model 1	Model 2	Model 3	Model 4
S1	19	0.03	0.11	0.14	0.14	0.14	0.14	0.14
S2	18	0.02	0.12	0.14	0.16	0.16	*(0.35)*	0.17
S3	17	0.07	0.07	0.14	*(0.48)*	*(0.48)*	0.28	*(0.49)*
S4	8	0.64	0	0.64	0.06	0.09	*(0.09)*	0.07
S5	21	0.45	0	0.45	0.26	0.21	*(0.26)*	0.22
S6	12	0.14	0	0.14	0.17	0.17	*(0.34)*	0.18

Table 3.2. Inputted mean variance by data component (Mean N input) and model estimated mean variance from model 1-4 (Mean EffN) where effective sample size (EffN) is the models estimate of the statistical precision. Larger EffN indicates a better fit.

Fishery	N of observations	Mean N input	Mean EffN			
			Model 1	Model 2	Model 3	Model 4
F1	92	30.00	153.07	249.59	250.09	246.53
F2	72	30.00	125.73	122.38	123.95	127.10
F4	19	30.00	124.88	121.68	121.98	135.39
F7	59	14.50	49.98	61.35	60.10	61.11
F10	23	30.00	421.20	408.63	396.52	411.32
F12	70	26.49	85.82	85.14	84.22	82.84
F13	40	6.95	19.49	19.38	19.16	18.70
F14	82	30.00	208.37	209.53	207.47	208.16

Table 3.3. Results of the profile over fixed values of Ln(*R0*) from model 1-4. Values represent the negative log-likelihood for each component minus the minimum component negative log-likelihood across profile. Changes in likelihood across different values of R0 can be thought of as how much information there is on scaling from that likelihood component. A value of zero indicates that the data component fit best at that fixed Ln(*R0*) value. Data components designated by (F) are fleet composition data, and those by (S) are CPUE series treated as indices of relative abundance. Values are rounded to nearest integer.

Model	Ln (R0)	Composition data components								Index data components					
		F1	F2	F4	F7	F10	F12	F13	F14	S1	S2	S3	S4	S5	S6
1	6.5	5	8	0	0	0	0	1	1	0	7	0	0	2	1
	6.6	0	5	0	1	0	1	1	1	0	5	0	0	2	0
	6.7	1	2	0	2	0	1	1	0	1	3	0	0	2	0
(6.78)	6.8	8	0	0	4	0	1	0	0	1	2	0	0	1	0
	6.9	19	0	0	6	0	2	0	0	1	2	0	0	1	1
	7.0	22	3	0	8	1	3	2	2	1	0	0	0	0	0
	7.1	25	5	0	9	1	4	1	3	1	0	0	0	0	0
2	6.5	8	7	0	3	0	0	2	1	2	7	0	0	2	1
	6.6	4	4	0	3	0	0	1	1	0	6	0	0	1	1
	6.7	0	1	0	3	0	1	1	0	0	4	0	0	1	0
	6.8	0	0	0	2	0	2	0	0	1	2	0	0	1	0
(6.86)	6.9	1	1	0	1	0	3	0	1	1	1	0	0	0	0
	7.0	1	3	1	0	1	4	0	2	2	0	0	0	0	0
	7.1	1	4	1	0	1	5	1	3	2	0	0	0	0	0
3	6.5	10	4	0	1	1	0	1	2	2	0	6	0	0	0
	6.6	3	2	0	1	0	1	1	1	0	0	5	0	0	0
	6.7	0	0	0	1	0	1	0	0	0	0	4	0	0	0
(6.79)	6.8	1	1	0	1	0	2	0	0	0	0	3	0	0	0
	6.9	2	3	0	0	0	3	2	0	1	0	1	0	0	0
	7.0	2	4	0	0	0	4	3	1	1	0	0	0	0	0
	7.1	2	6	0	1	1	6	2	1	2	0	0	0	0	0
4	6.3	9	5	0	1	2	0	1	2	2	4	0	0	1	2
	6.4	4	3	0	1	2	1	0	1	0	3	0	0	0	1
	6.5	0	1	0	0	0	2	3	0	1	1	0	0	1	0
(6.60)	6.6	1	0	0	1	0	3	0	0	2	0	0	0	1	0
	6.7	6	1	0	1	1	5	0	0	3	0	0	0	1	1
	6.8	10	16	0	0	1	7	0	3	8	1	0	0	0	3
	6.9	12	43	0	0	1	9	2	4	11	3	0	0	0	4

Table 3.4. Analytical estimates of catchability for CPUE indices from model 1-4 where the italics in parentheses indicate the indices were not fitted into the model.

Index	No. of observations	Catchability (q)			
		Model 1	Model 2	Model 3	Model 4
S1	19	0.000548	0.000528	0.000560	0.000913
S2	18	0.004413	0.003776	*(0.004454)*	0.006218
S3	17	*(0.000353)*	*(0.000394)*	0.000521	*(0.000629)*
S4	8	0.000101	6.69E-05	*(7.46E-05)*	0.00013
S5	21	0.000188	0.000142	*(0.000155)*	0.000259
S6	12	0.000421	0.000363	*(0.000472)*	0.000596

Table 3.5. Estimated time-series of spawning biomass, recruitment and exploitation level (1-SPR) from model 2 along with their estimated asymptotic standard deviation.

Year	Spawning biomass (*SB* in t)	StdDev for *SB*	Recruitment (*R* in 1,000 fish)	StdDev for *R*	1-SPR	StdDev for 1-SPR
Virgin	131619.0	4546.1	956.0	33.0		
1971	67223.9	22547.0	847.4	178.4	0.44	0.06
1972	64970.3	20522.2	806.4	174.0	0.49	0.06
1973	62840.3	18694.0	798.3	157.0	0.54	0.05
1974	60704.7	16987.6	508.0	110.5	0.52	0.05
1975	59190.7	15358.7	595.6	119.9	0.52	0.05
1976	56388.6	13780.1	625.3	131.4	0.57	0.04
1977	52452.3	12294.4	1021.0	197.0	0.61	0.04
1978	48516.4	10985.1	912.0	205.5	0.64	0.04
1979	46697.3	9944.1	1063.2	220.5	0.64	0.04
1980	45429.6	9182.7	861.2	201.6	0.64	0.04
1981	45870.6	8687.2	912.5	203.4	0.65	0.04
1982	45342.1	8324.6	1163.0	240.1	0.67	0.04
1983	44657.1	8078.7	1000.8	222.5	0.64	0.04
1984	45491.1	7981.7	860.1	194.3	0.68	0.04
1985	45907.3	7909.3	842.0	184.3	0.61	0.04
1986	46419.3	7817.1	1056.0	199.9	0.67	0.04
1987	44906.3	7649.0	1055.7	210.5	0.77	0.03
1988	41604.9	7440.0	1050.2	216.5	0.73	0.04
1989	41289.3	7295.3	949.3	215.5	0.68	0.04
1990	42069.0	7126.3	1022.7	203.9	0.64	0.04
1991	43297.2	6912.0	987.1	193.2	0.65	0.03
1992	43974.2	6636.6	950.1	195.7	0.70	0.03
1993	43561.4	6289.9	907.5	176.2	0.73	0.03
1994	41676.9	5816.6	810.4	160.4	0.75	0.02
1995	38886.2	5375.5	888.8	151.8	0.78	0.02
1996	36193.8	5054.1	845.2	159.5	0.67	0.03
1997	36573.6	4853.5	994.7	150.1	0.70	0.02
1998	35785.9	4608.0	579.9	112.0	0.71	0.02
1999	36200.8	4361.9	830.6	131.6	0.70	0.02
2000	34689.8	4127.6	890.6	130.9	0.77	0.02
2001	32093.3	3816.6	809.6	127.4	0.81	0.02
2002	29092.3	3516.2	874.9	131.6	0.82	0.02
2003	25971.8	3210.3	1026.2	127.4	0.85	0.01
2004	23190.4	2951.1	785.0	115.3	0.82	0.02
2005	22730.4	2842.8	913.9	120.4	0.85	0.02
2006	21573.7	2805.5	888.6	126.7	0.82	0.02
2007	21701.0	2888.9	718.1	122.7	0.79	0.02
2008	23002.5	3035.8	689.4	127.6	0.77	0.02
2009	23486.4	3168.7	1177.4	177.6	0.78	0.03
2010	22987.6	3334.6	705.2	172.1	0.78	0.03
2011	24989.8	3716.6	824.6	41.0	0.75	0.03

FIGURES

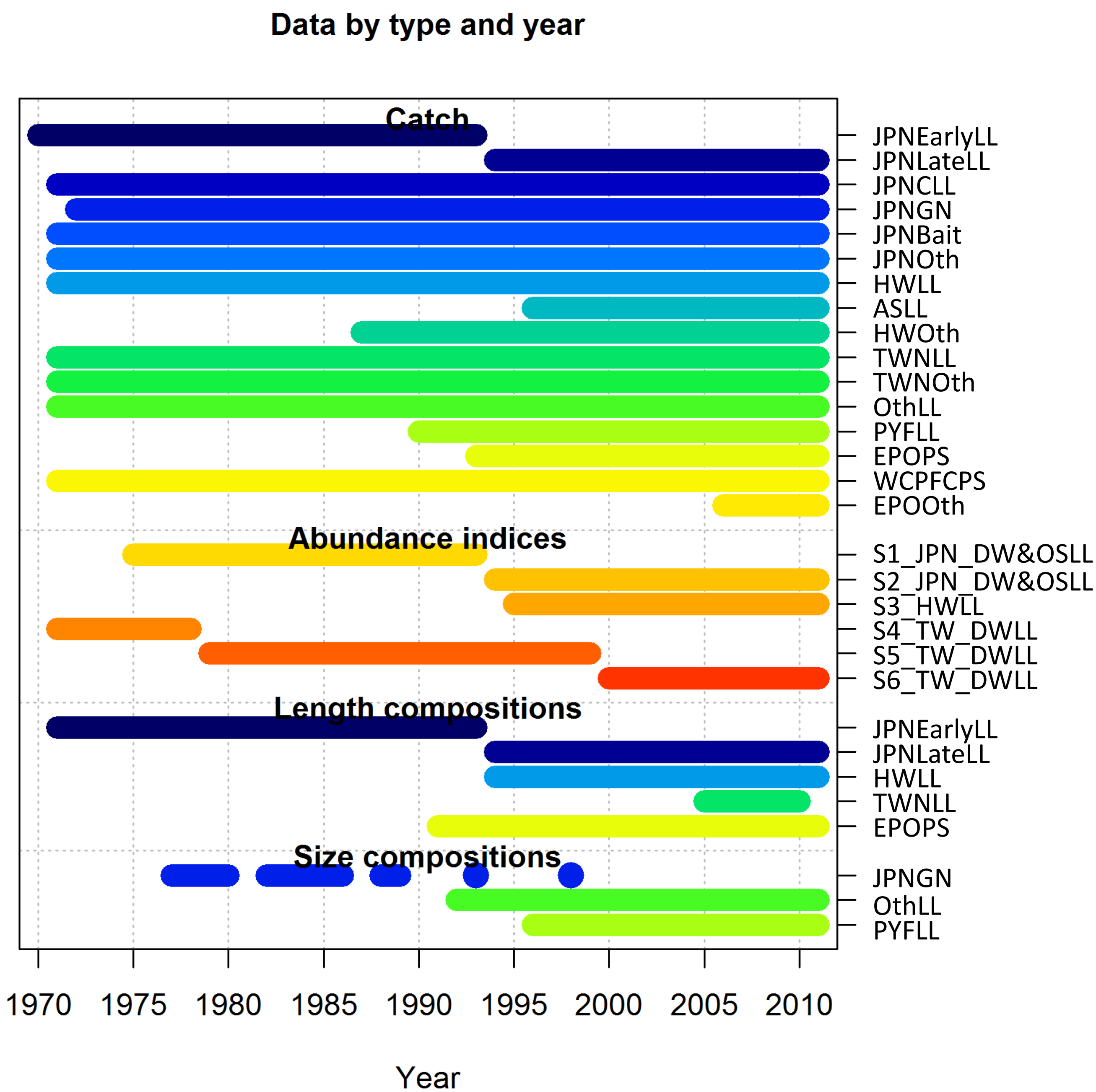

Figure 2.1. Available temporal coverage and sources of catch, CPUE and length/size composition for the Pacific blue marlin

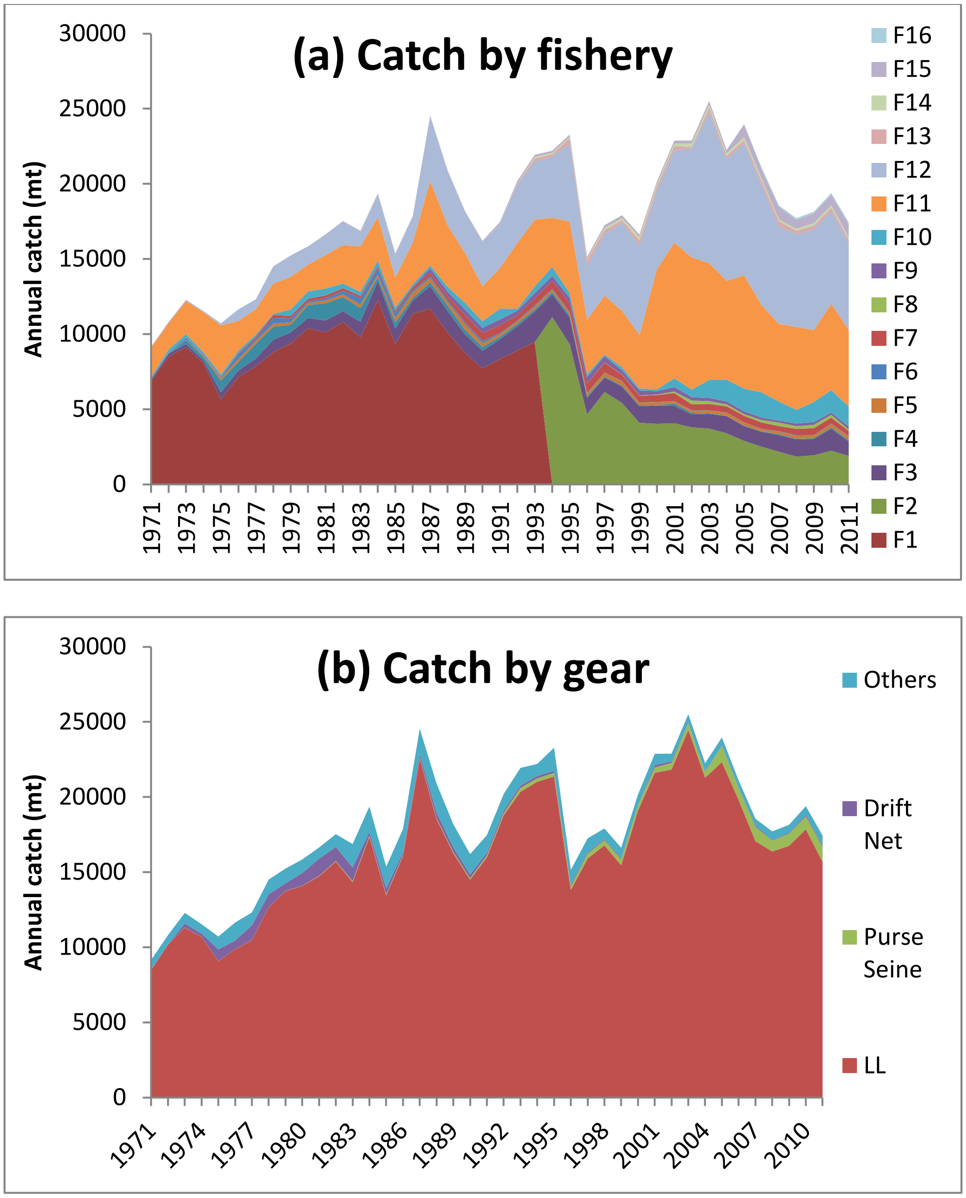

Figure 2.2. Catch (t) of Pacific blue marlin by year and fishery (upper panel) and by year and gear (lower panel). Fisheries with catch reported in numbers were converted into t inside the stock assessment model.

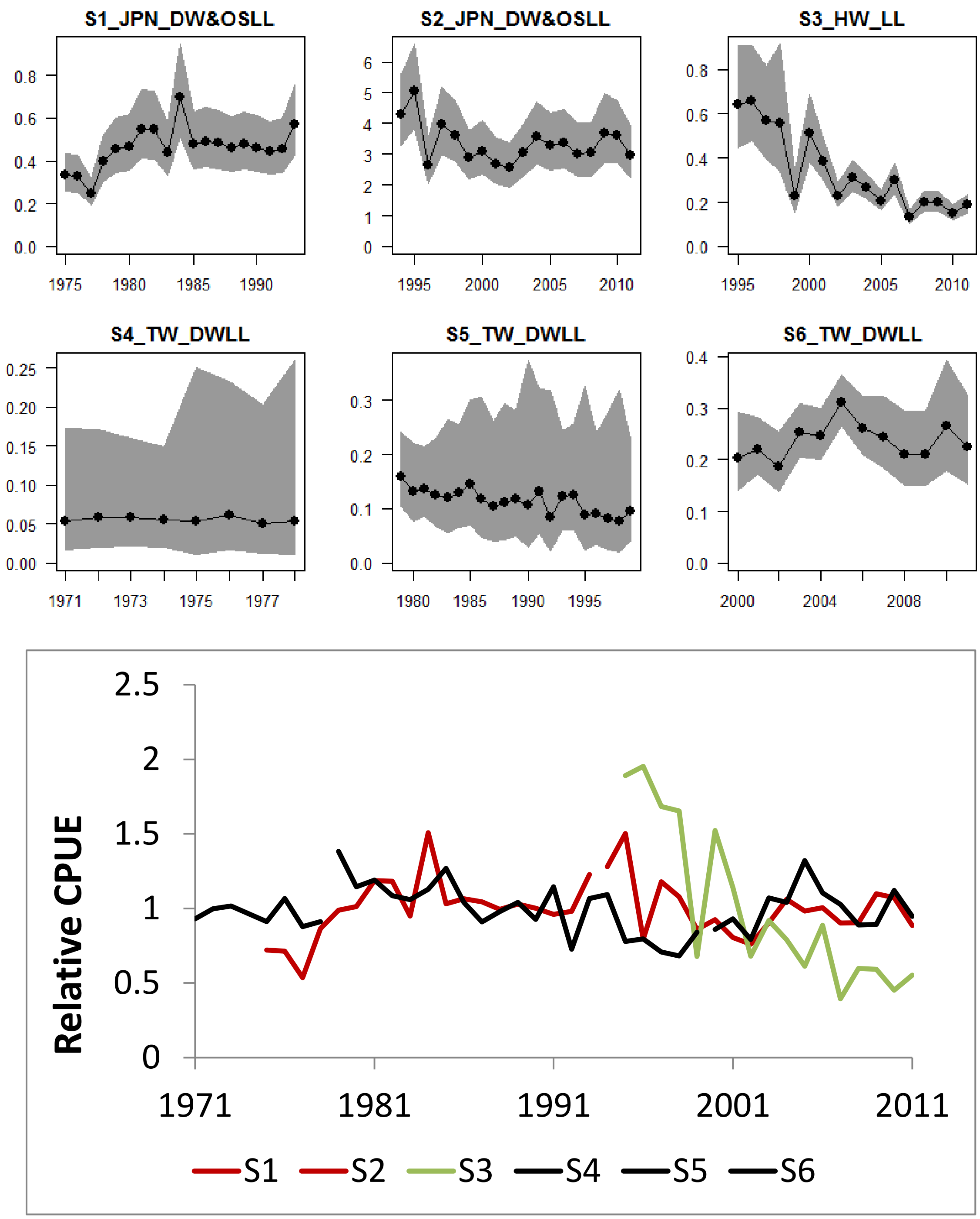

Figure 2.3. Plot of the observed CPUE by fishery. Upper panel present the individual index where the gray areas indicate the estimated confidence intervals around the CPUE values used in the SS model. Lower panel present the relative CPUE for comparison.

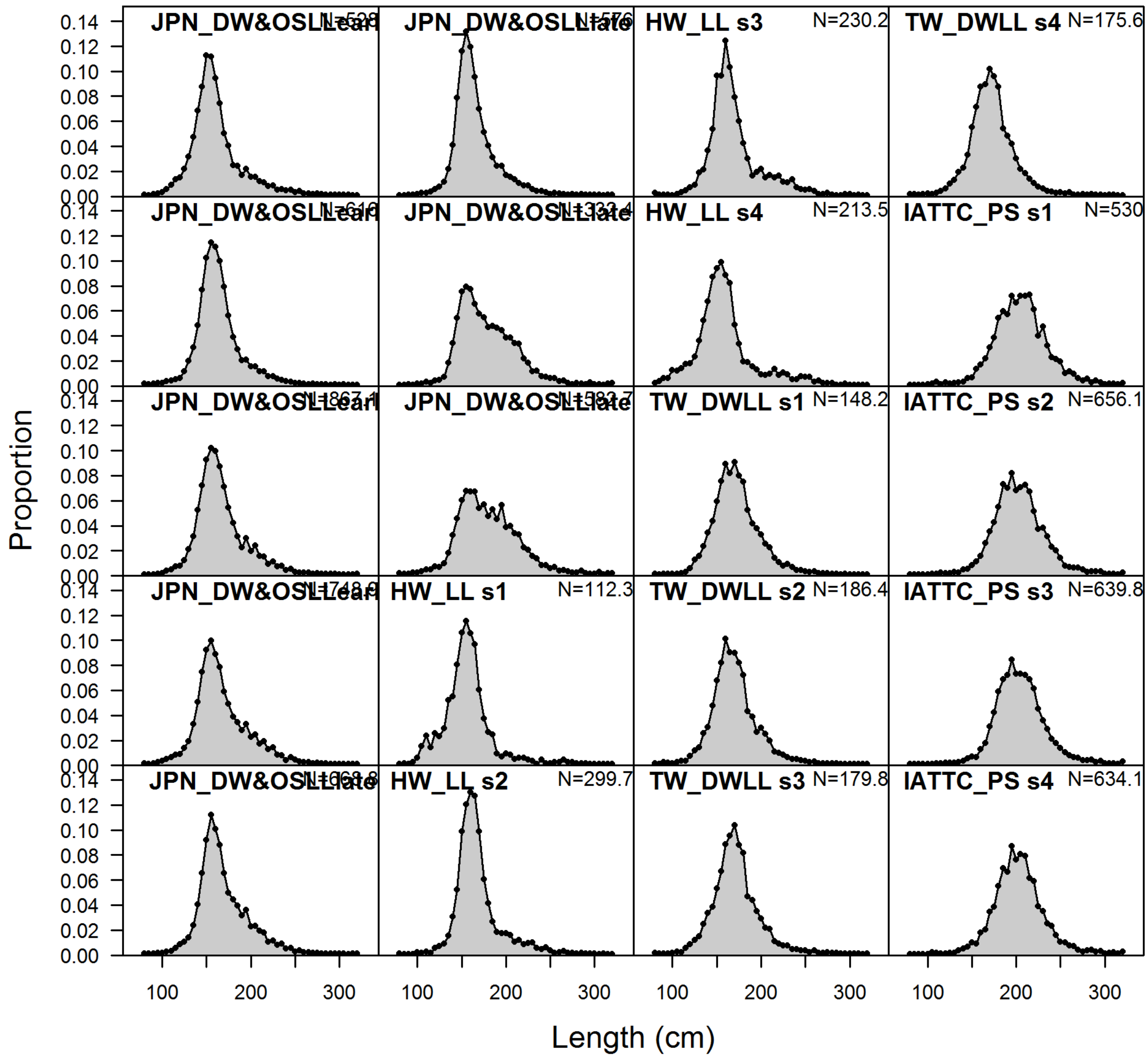

Figure 2.4.a. Observed proportion at length from fisheries F1, F2, F7, and F14. Samples were aggregated across year by fishery and season.

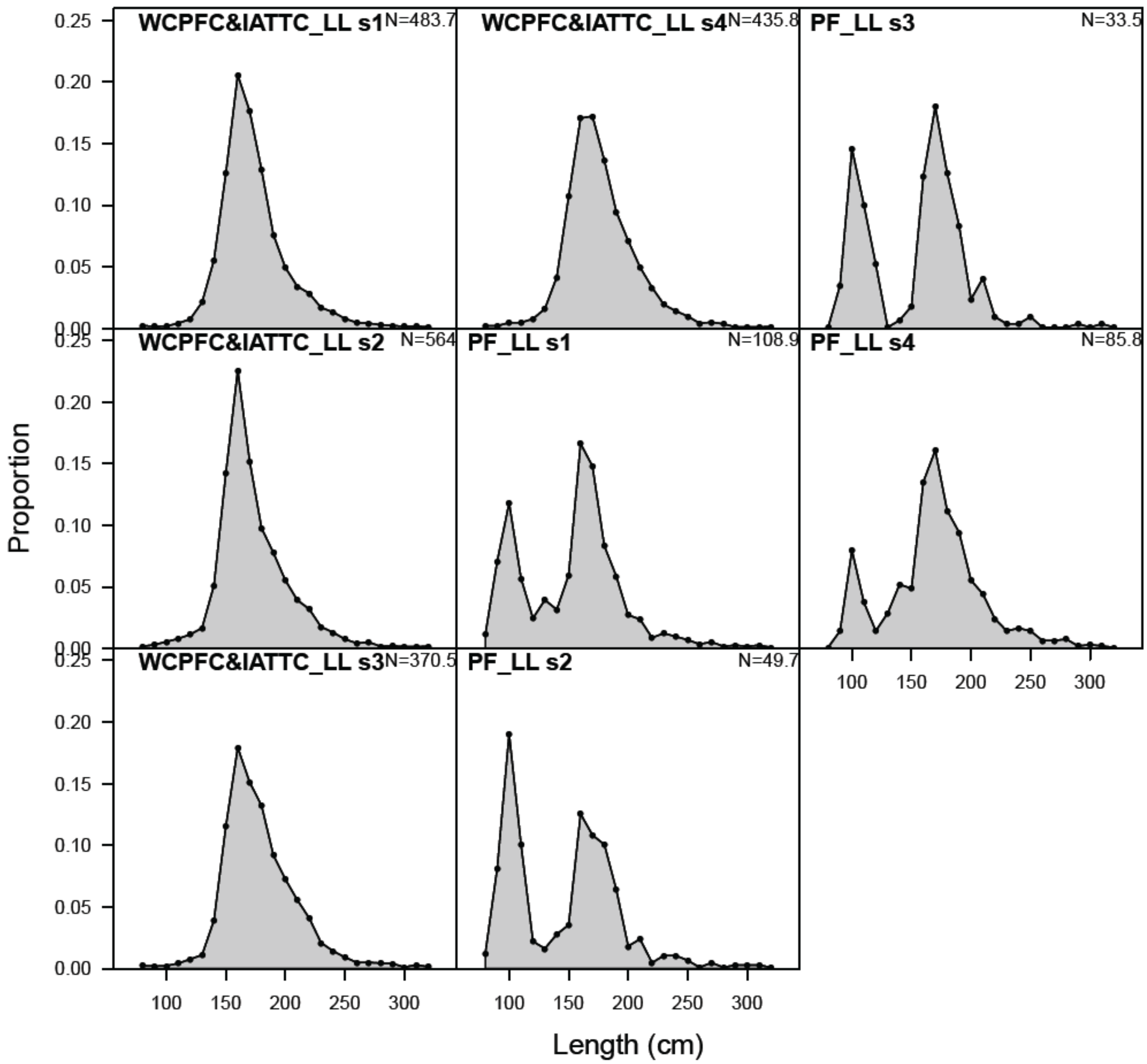

Figure 2.4.b. Observed proportion of fish at length from fisheries F12 and F13. Samples were aggregated across year by fishery and season.

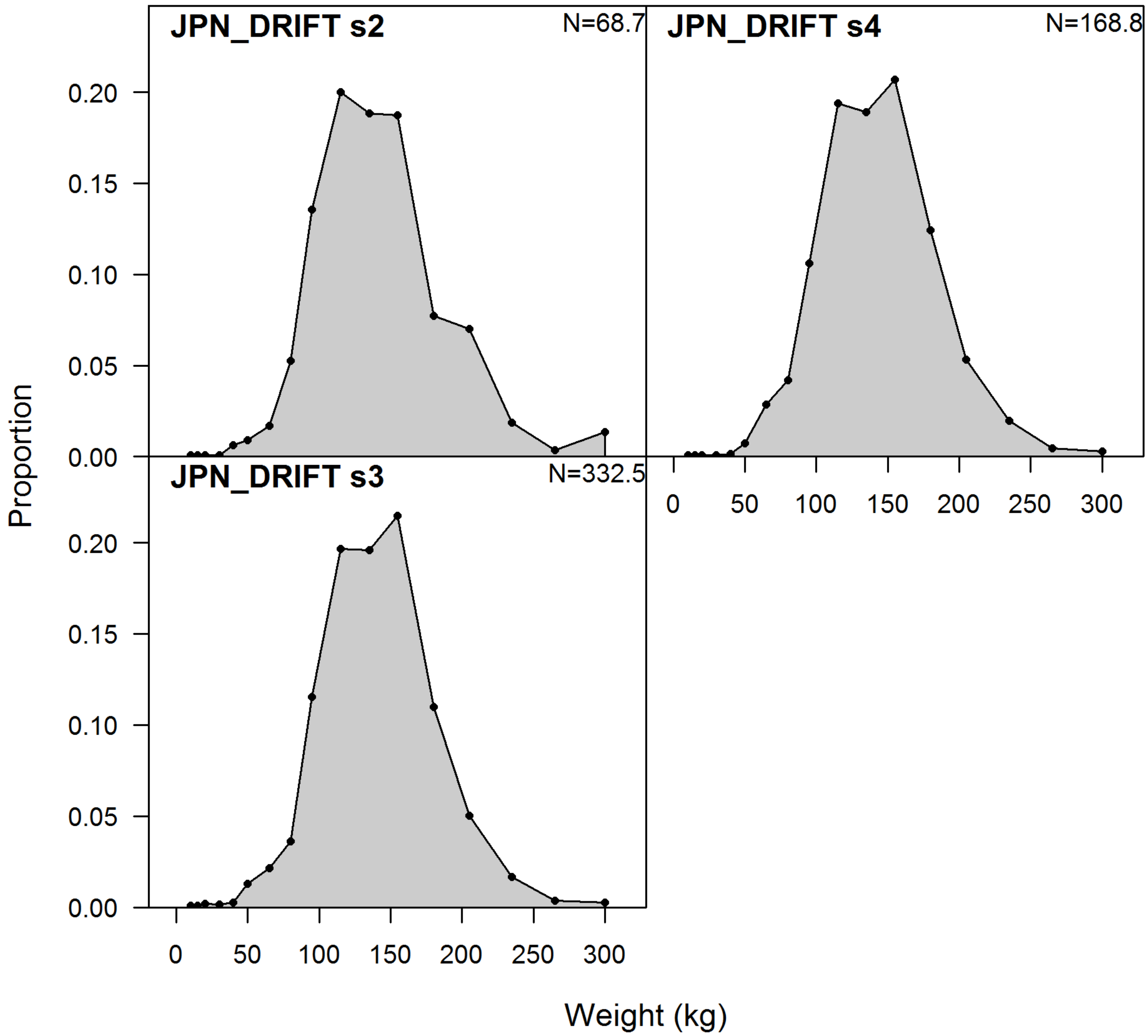

Figure 2.4.c. Observed proportion of fish at length from fishery F4. Samples were aggregated across year by fishery and season.

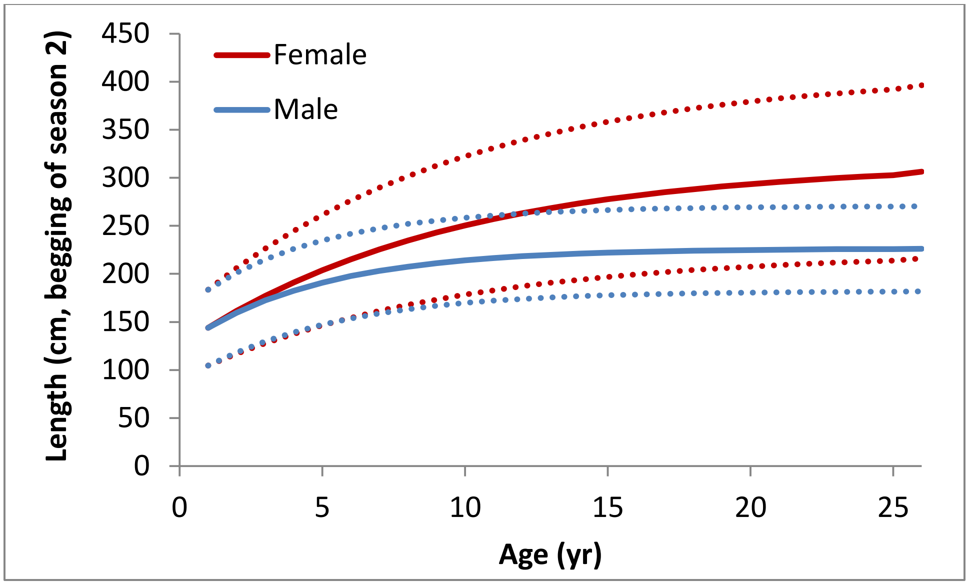

Figure 2.5. Plot of the WG length at age based on Shimose's otolith microstructure studies (2009, unpublished data) and meta-analyses from Chang *et al.* (2013) where red lines represent female and blue lines represent male. The dotted lines represent the inputted CV of length at age 1 and length at age 26 in the stock assessment model.

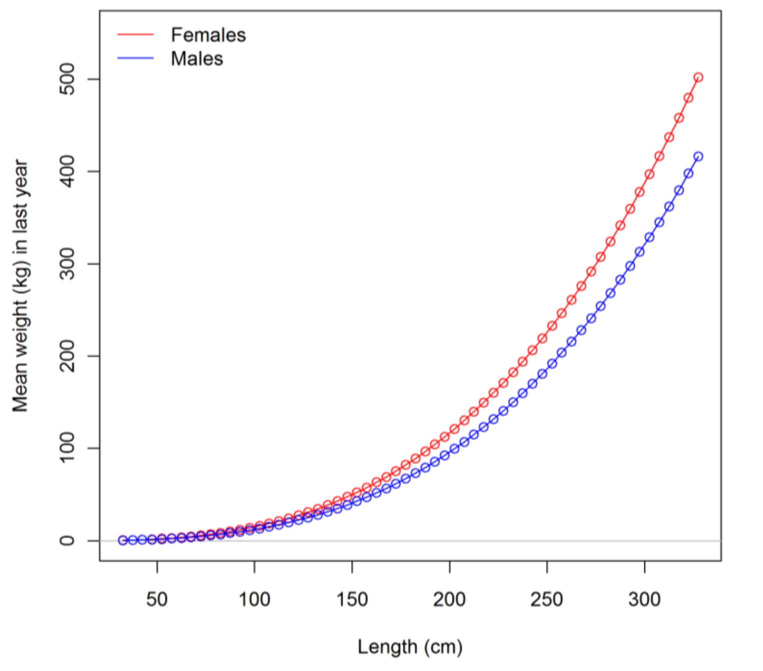

Figure 2.6. Weight at length used in the stock assessment model where red line represent female and blue line represent male.

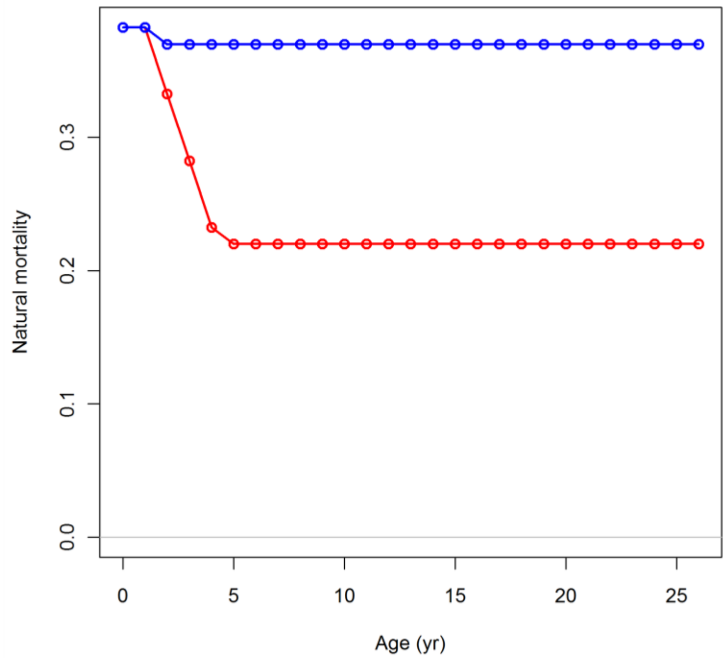

Figure 2.7. Natural mortality at age assumed in the population dynamics model where red line represent female and blue line represent male.

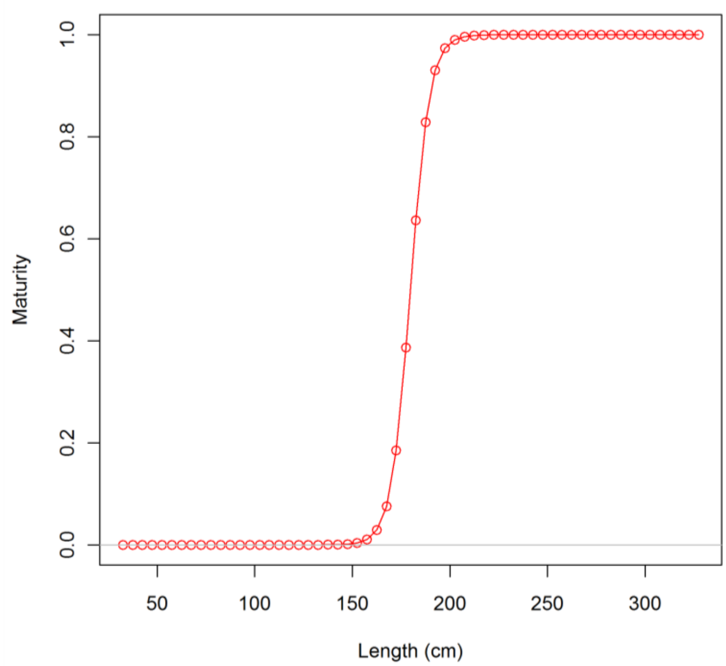

Figure 2.8. Maturity-at-length (eye fork length) for female Pacific blue marlin used in the stock assessment model where the size-at-50 percent-maturity was 179 cm.

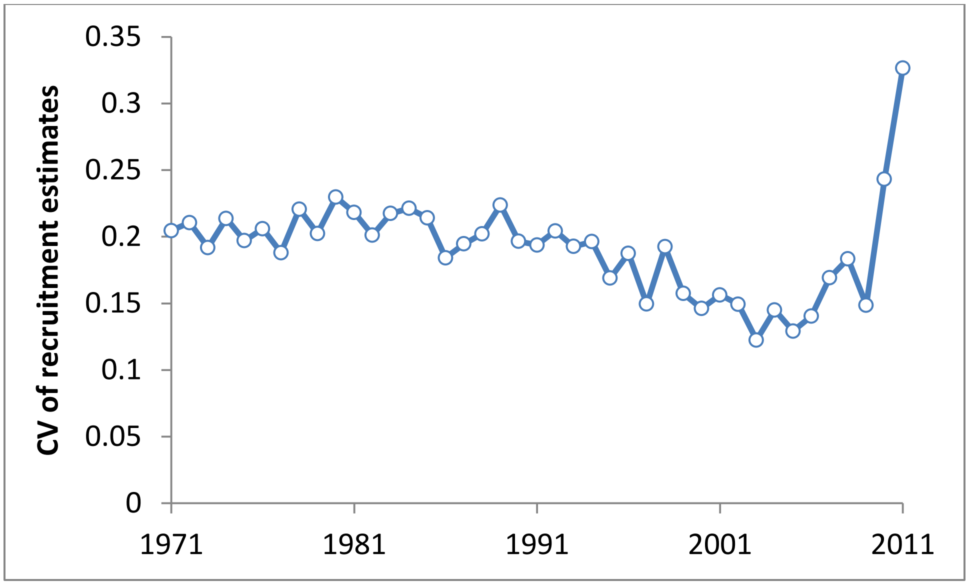

Figure 2.9. Coefficient of variation (CV) of estimated recruitment from 1971-2011.

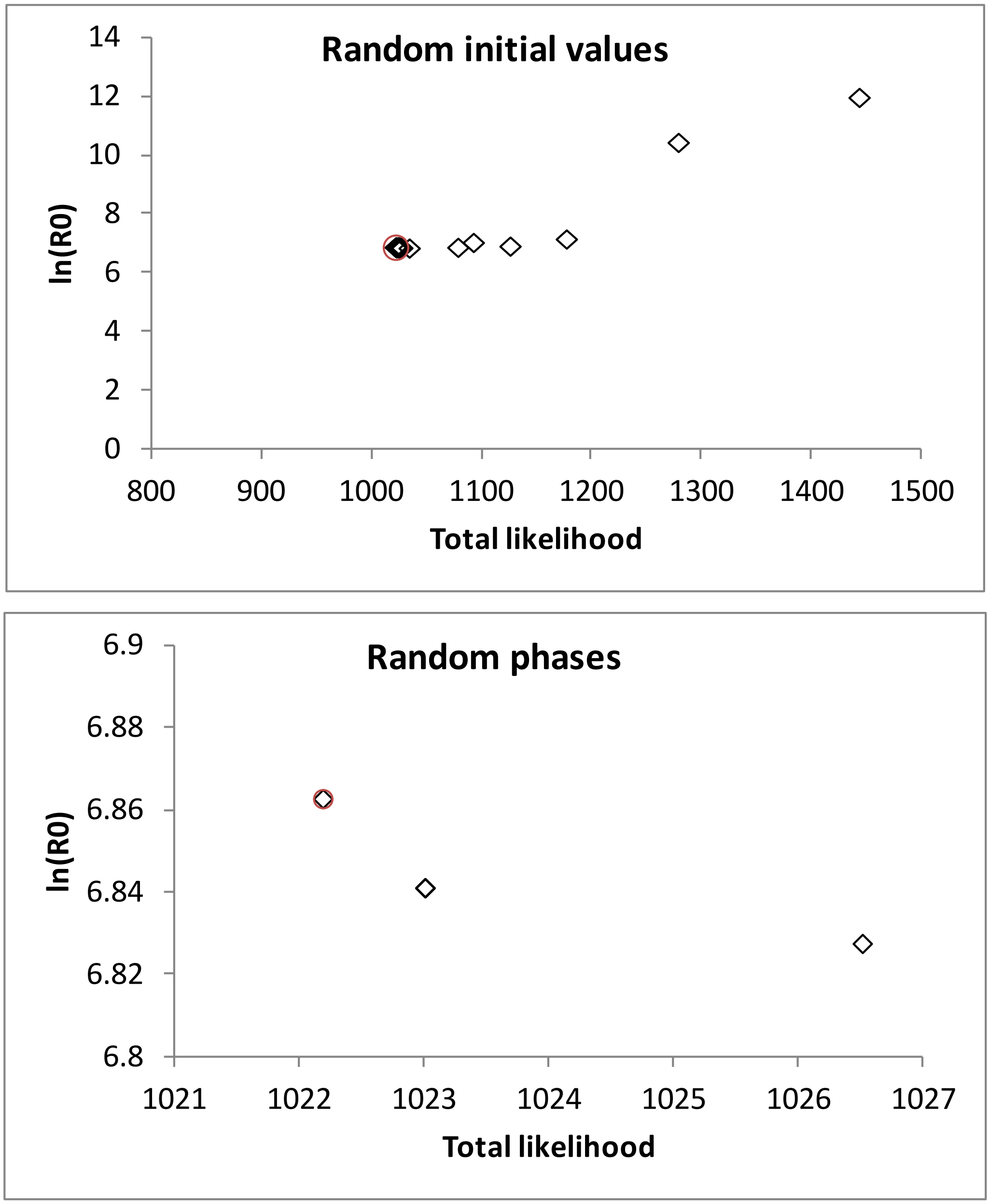

Figure 3.1. Plot of estimated ln(R_0) (y-axis) and total ending likelihood (x-axis) for random starting values of the model (upper panel) and random phases of the model (lower panel) for model 2. Circle represents the base model and diamonds represent random changes of the model.

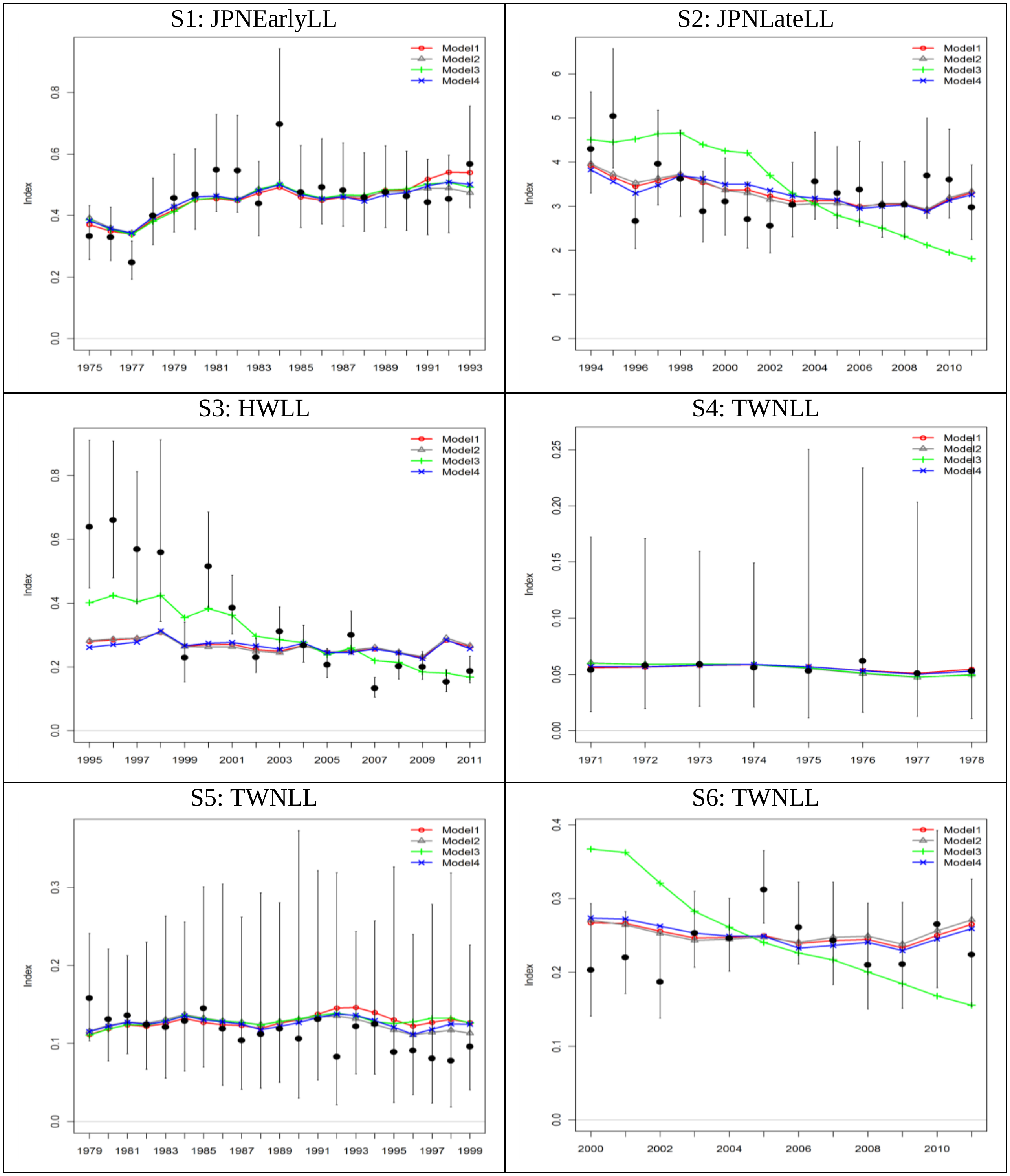

Figure 3.2. Model fits to the standardized CPUE data from different fisheries (model 1-4). The lines are the model predicted values and the solid circles are observed (data) values. The vertical lines represent the estimated confidence intervals (± 2 standard deviations) around the CPUE values.

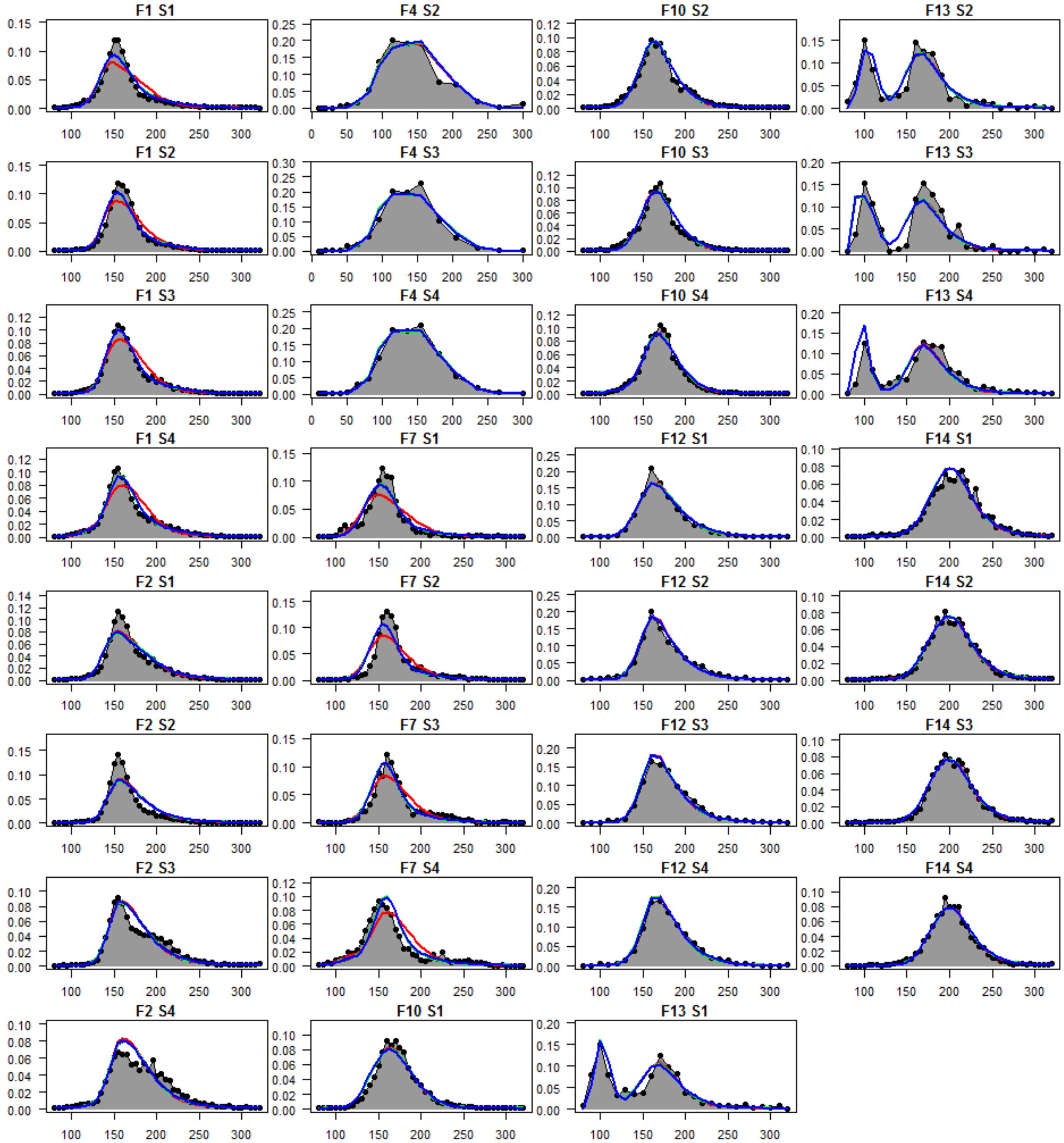

Figure 3.3. Comparison of observed (gray shaded area) and model predicted length compositions from 4 models: model 1 (red), model 2 (gray), model 3 (green), and model 4 (blue). Gray and green lines are hidden behind the blue line. Observed and expected have been summed across all years.

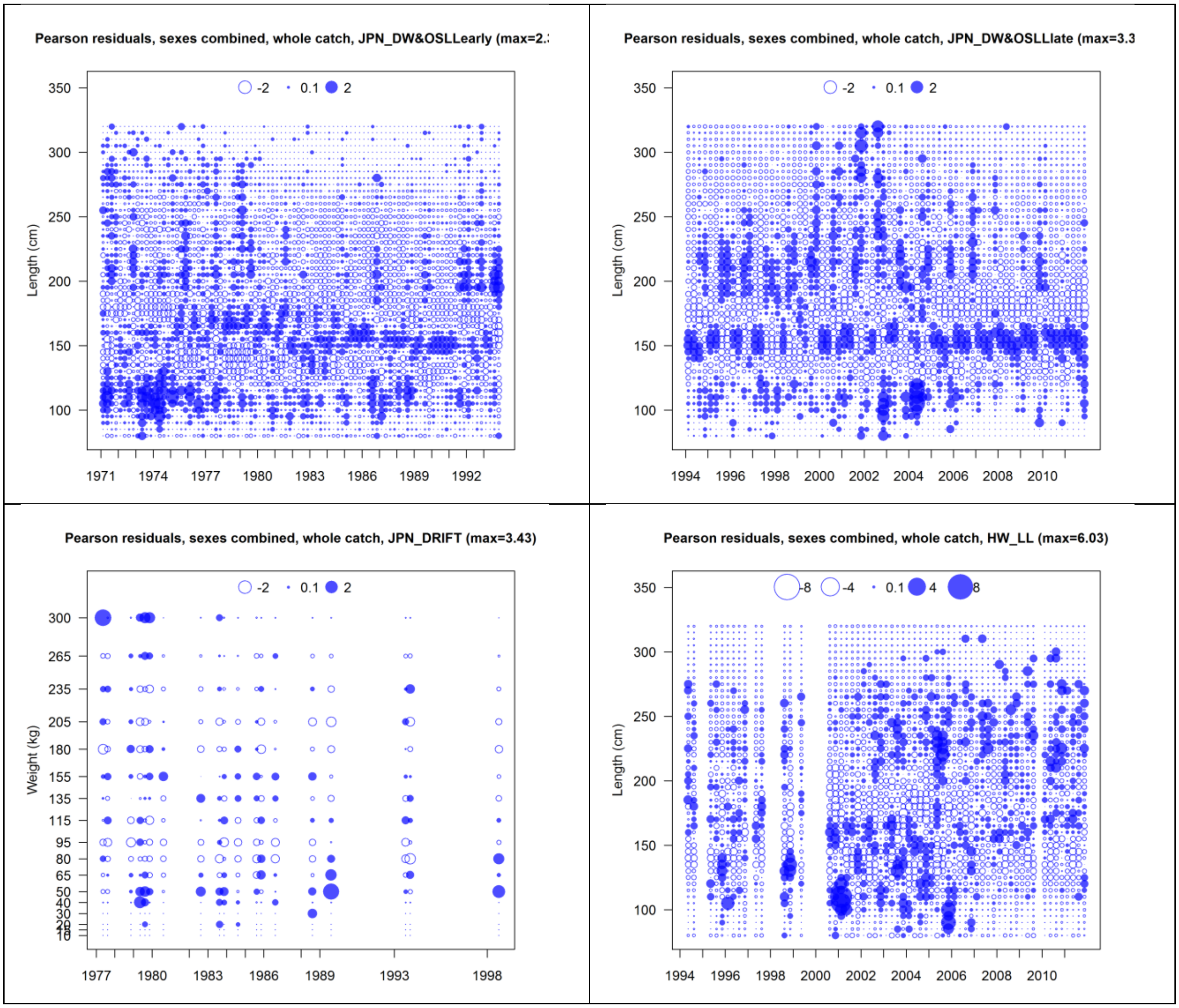

Figure 3.4. Pearson residual plots of model fits to the size-composition data by fishery, season and year for the Pacific blue marlin fisheries used in the model 2. The filled and hollow blue circles represent observations that are higher and lower than the model predictions, respectively. The areas of the circles are proportional to the absolute values of the residuals.

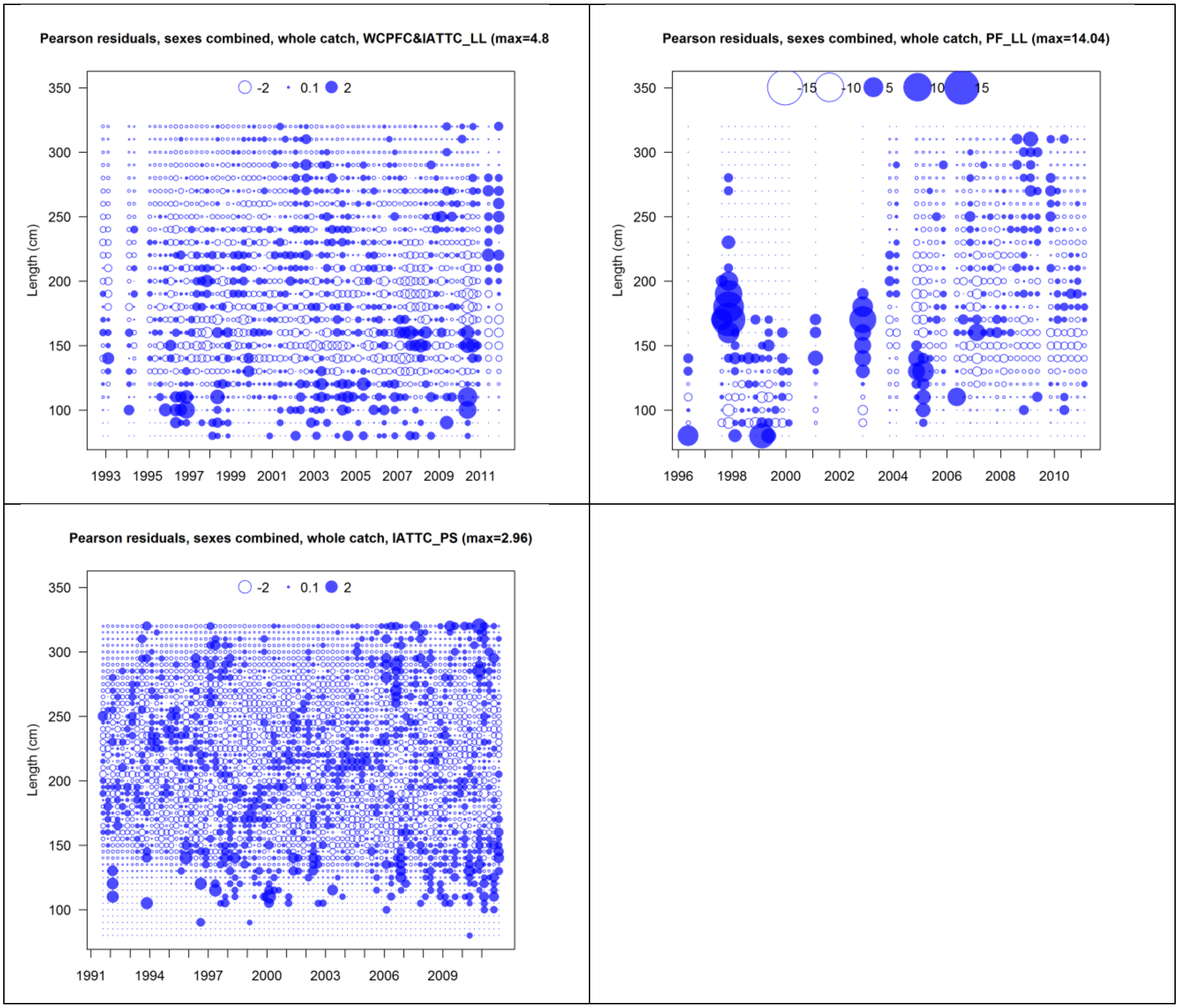

Figure 3.4. Continued.

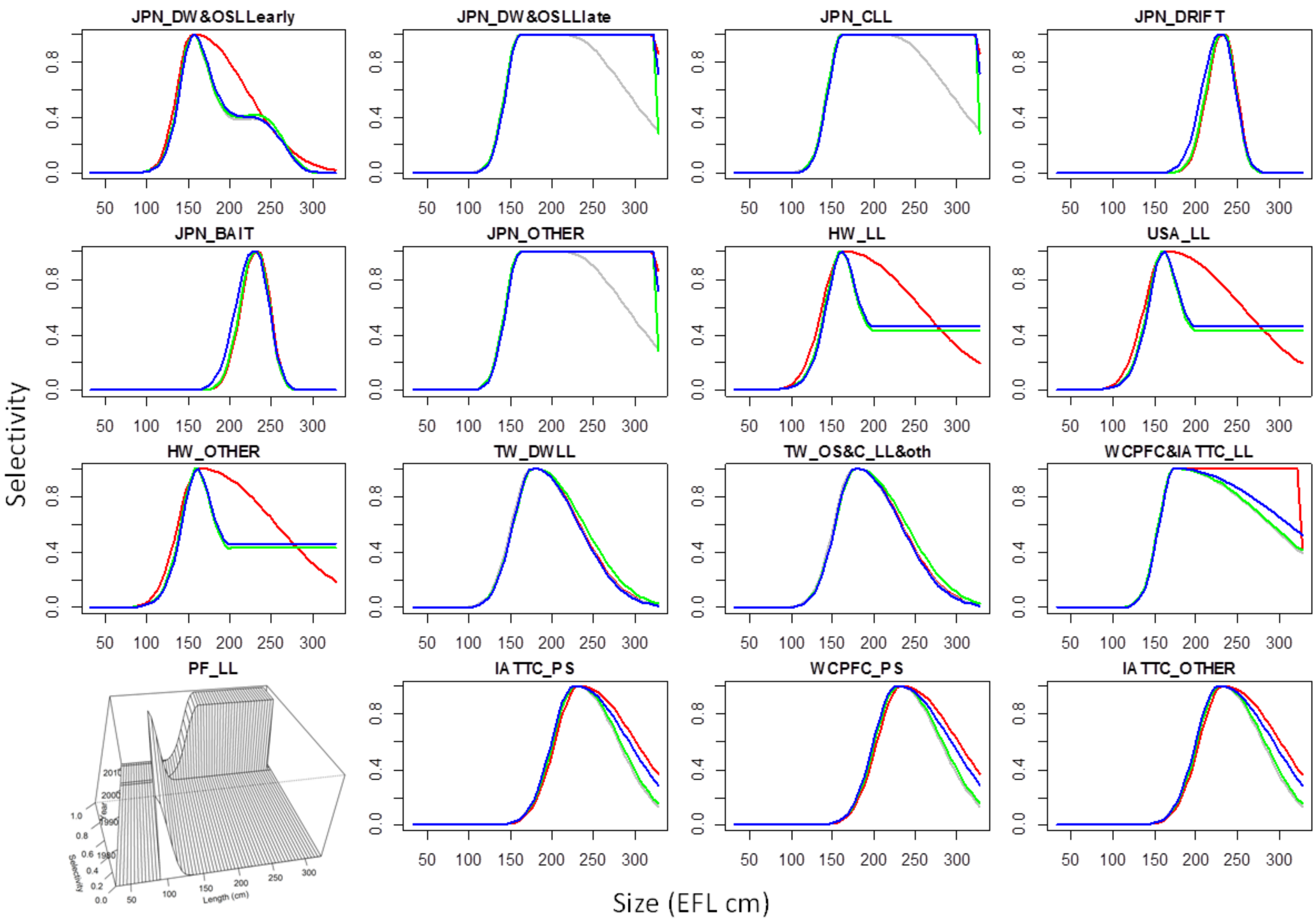

Figure 3.5. Estimated selectivity patterns by fishery from 4 models: model 1 (red), model 2 (gray), model 3 (green), and model 4 (blue). Fisheries with time varying selectivity patterns are displayed in 3-D plots (they are identical for 4 models).

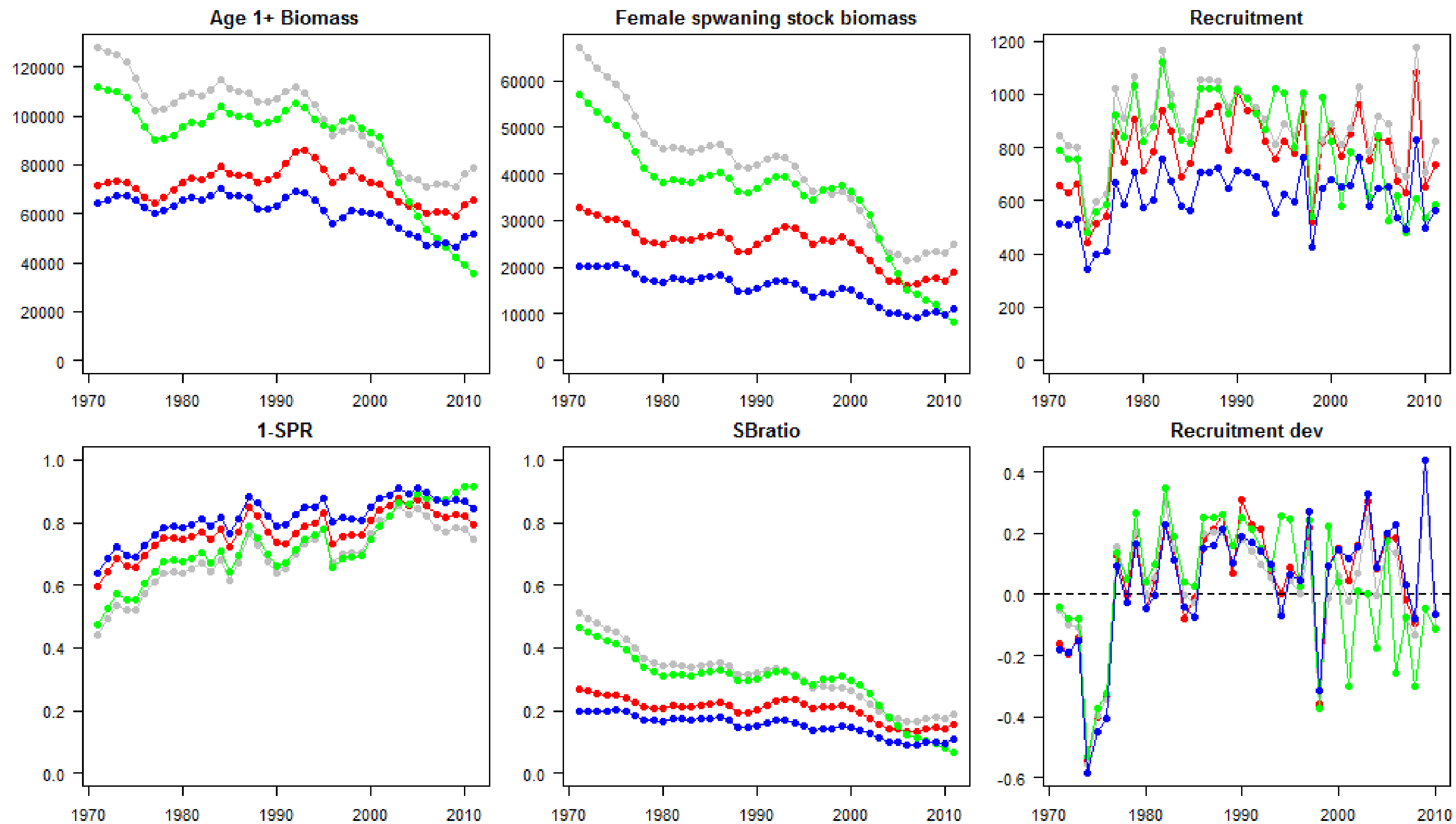

Figure 3.6. Estimated age 1+ biomass (t), female spawning stock biomass (t), recruitment (number), fishing intensity (1-spawning potential ratio), spawning stock biomass relative to the virgin spawning stock biomass (SBratio), and recruitment deviations from 4 models: model 1 (red), model 2 (gray), model 3 (green), and model 4 (blue). Female spawning stock biomass in model 4 is estimated from half of the spawning stock biomass.