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Stock Status of Striped Marlin in the North Pacific Ocean in 2005

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Introduction

Striped Marlin (*Tetrapturus audax*) is a wide-ranging member of the billfish family *Istiophoridae*. They are among the most widely distributed of the billfishes, with abundance reportedly increasing with distance from the continental shelf (Kailola et al. 1993). Considerable uncertainty remains about the data, basic biology, distribution, stock structure and movement patterns of this species. Despite the gaps in our knowledge of striped marlin, the Striped Marlin Working Group (SMWG) of the International Scientific Committee (ISC) recommended assessing the stock status in the North Pacific Ocean (NPO) using data compiled at a WG meeting in Honolulu, Hawaii. Given the uncertainty in stock structure, a single NPO wide stock was assumed, although the veracity of this assumption has been questioned.

At the September, 2005 SMWG meeting in Shimizu, Japan, the WG recommended that assessments be conducted using biomass dynamic models (Bayesian Surplus Production) and an integrated statistical length-based age-structured models (Multifan-CL). However, these models may represent different ends of a continuum of model complexity. A stock assessment method that bridges the span of complexity and realism between the two methods may be useful.

Stock Synthesis II (SS2) is a stock assessment model that estimates the population dynamics of a stock through use of a variety of fishery dependent and fishery independent information. Stock Synthesis has been the primary assessment tool for groundfishes off the Pacific West coast of the United States for nearly a decade. In 2004, SS2 was recoded using AD Model Builder to take advantage of the advanced features and processing speed of that modeling platform. The structure of the model allows for Bayesian estimation, use of the Markov-Chain Monte Carlo (MCMC) algorithm as well as parametric bootstrapping methods and the normal approximation.

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SS2 incorporates 3 primary model subcomponents, **1)** a population subcomponent that recreates estimates of the numbers/ biomass at age of the population using estimates of M, growth, fecundity, catch etc., **2)** an observational sub-component that consists of the observed (measured) quantities such as CPUE or proportion at length/age, and **3)** a statistical sub-component that quantifies using likelihoods the fit of the observations to the recreated population. For a complete description see "Technical Description of the Stock Synthesis II Assessment Program Version 1.21- March 2005 by Richard Methot.

Because of the generalized nature of the SS2 code, models can be configured to perform over a range of complexity, from a biomass dynamic model (Piner et al. 2005) to a spatially and temporally structured model (Methot and Stewart 2005). The complexity of the model is defined by the types and complexity of the underlying population and the available data types. A nice feature of this kind of structural flexibility is that various levels of complexity can be run using the same operational files, allowing the easy comparison of different assumptions.

Of particular relevance to this application is the flexibility of SS2 to combine many features of both fully integrated and simple biomass dynamic models. It is possible not only to replicate a simple biomass dynamic model, but users are able to produce a model that contains important dynamic subcomponents (for instance age structure) but also collapses the observational subcomponent to that of a simple biomass dynamic model. In this way it is possible to achieve more realism in the estimated dynamics, allow the use of auxiliary data (such as lengths), do sensitivity analysis over a wider range of key assumptions and still estimate parameters within the structural complexity of a biomass dynamic model. These kinds of relatively simple integrated analyses are common in data limited assessments of groundfish (Piner et al. 2005, Piner et al. 2000) off the Pacific coast of the U.S.

This paper presents the results of an assessment of the stock status of Striped Marlin in the North Pacific Ocean using SS2. In accordance with the guidance provided by the SMWG chair, we configured the model as an age structured biomass dynamics model. Details of the data considered, likelihood components and model structure are given in the methods section. Results of the assessment are cast in both a maximum likelihood estimate (MLE) and using the posterior to express both the uncertainty and to characterize parameter estimates. Because of considerable uncertainty in the compilation of the data used, results presented in this paper should be considered a first effort that could be greatly improved with more exploratory analyses.

Methods

Data

Data were originally compiled by the SMWG at a November, 2005 meeting in Honolulu, Hawaii. Subsequent to this meeting new information was incorporated and final data sets (summarized) were distributed to stock assessment teams in February of 2006. This paper includes no data treatment beyond using the summarized series to model the population dynamics. The exception to the above statement was the combining of the estimates of quarterly CPUE within fisheries to create an annual CPUE series, and the combining of the annual series across similar fleet/gears to create a stock-wide estimate of CPUE. The following sections give a brief overview of the biology and data used:

Stock Structure

For the purpose of this assessment, striped marlin in the North Pacific Ocean is considered a single stock. Catch and CPUE are compiled by regions that are thought to relatively homogeneous with respect to population dynamics or fishery operations. Area definitions were as follows:

Area 1: 20-40^o N Lat, West of 180^o Long
Area 2: Equator to 20^o N. Lat, West of 180^o Long
Area 3: 20-40^o N Lat, 180-125^o W Long
Area 4: Equator to 20^o N. Lat, 180-125^o W Long
Area 5: Equator to 40^o N Lat, East of 125^o W Long

Growth

The age-length relationship was characterized by the Von Bertalanffy growth curve (Melo-Barrera et al. 2003), where K=0.23 and Linf=225cm (Figure 1). This estimate is smaller than Skillman and Yong (1976) estimated in the north central Pacific, or those from more distant waters (Merrett 1971; van der Elst 1981; Holdsworth and Saul 2004). The length-weight relationship was described by $W=0.0000972L^{2.57}$ (Ware and Sakagawa 1975), and maturity-at-length was described by a logistic function with an assumed slope of -0.64 and 50% maturity occuring at 155 cm (Figure 1). Natural Mortality was assumed to be M=0.3 yr^{-1} for a long-lived stock, which corresponds to approximately 1% of a cohort surviving to age 15.

Catch

A total of 25 individual fisheries were identified at the November WG meeting (Table 1). Missing catch values in the last 3 years were replaced by the average of the preceding 3 years. We did not fill in missing catch years for any years prior to the last 3 as we considered only the missing values at the end of the series to be the result of time lags in reporting. The historical period (pre 1964) was characterized by stable catches of 100,000-200,000 fish. Total catch peaked in the early-mid 1960 at around 400,000 fish (Figure 2). Catch steadily declined after the peak to similar levels as the history (100,000-200,000) by the end of the series. Model inputs are catch in numbers.

Striped marlin catch occurs primarily in only 2 of the 5 areas (Figure 3). Roughly 60% of the striped marlin catch has been taken in area 1. Area 5 accounts for roughly 10-20% of the total catch, and the other 3 areas make up the remaining catch. There is no obvious time trend in location of landings.

CPUE

Eleven quarterly CPUE series were compiled and distributed by the SMWG for potential use in the model. The quarterly CPUE were combined into annual series by weighting each quarter by its effort. We define the 11 series by area and fleet and each series is defined below (Figure 4):

> Area 1- Japanese Distant Water longline (JPN DW LL); Japanese Coastal Longline (JPN C LL); Japanese Driftnet (JPN DFTN)
>
> Area 2- Japanese Distant Water longline; Japanese Coastal Longline; Japanese Driftnet
>
> Area 3- Japanese Distant Water longline; Hawaiian longline (HWN LL)
>
> Area 4- Japanese Distant Water longline; Hawaiian longline
>
> Area 5- Japanese Distant Water longline

We also combined the above mentioned 11 area-specific series into 3 CPUE series using an area weighted approach (Figure 5) within the same fishing fleet type (example all JPN DW LL). Years with missing area CPUE were not included. The CPUE values used in the model are given in (Table 2), and all CPUE series assumed that S.E. = 0.2. The fleets were defined as:

> Japanese distant water longline, (all 5 areas combined)
>
> Japanese Coastal longline, (area 1 and 2 combined)
>
> Hawaiian longline, (Area 3 and 4 combined)

(Note: the JPN DFTN CPUE was dropped due to an insufficient number of points concurrent in both areas.)

All CPUE series showed relatively good agreement, describing a generally declining population. The HWN LL and JPN C LL series show good agreement at the end of the time period with the JPN DW LL series that CPUE continued to decline. This supports the assertion that the series may be tracking relative abundance. For the purpose of this assessment, we assumed the JPN DW LL to be the most trustworthy series due to its standardization, spatial/temporal coverage and history of its use. However, the WG should try to arrive at a consensus on the appropriateness of their use in subsequent assessments.

Proportion at Length

Numbers-(proportion) at-length data were available for 8 of the 25 fisheries. All fisheries, except EPO purse seine, primarily capture fish between 100-200cm. (Figure 6). The EPO purse seine catch was generally 150-250 cm. In a single year (2000), the area 5 JPN DW LL fishery also caught that same size group. Whether this indicates a different size/stock structure in the eastern EPO, ontogenetic distribution, or depth preferences is not known. Length bins were defined as the following :

70cm	71	74	77	80	83	86	89	92	95	98	101
104	107	110	113	116	119	122	125	130	135	140	145
150	155	160	165	170	175	180	185	190	195	200	210
220	230	240	250	260	270	280	290	300			

Assessment Model

In this section we describe the assessment models used to assess the stock status of striped marlin. Many different models were run using different assumptions, however we present in graphical detail two models that differ only in the assumption of the estimability of a specific parameter. The first model (A) estimated population resilience described by the Beverton and Holt Spawner Recruit (BH S/R) steepness parameter (h). The other model (B) assumed that h=0.7. The BH S/R relationship is given below:

$$R_y=4_h R_0 S_y/(S_0(1-h)+S_y(5h-1))$$

where h= steepness, R_0= initial recruitment, S_0 unfished spawn biomass, S_y=Spawn biomass in year y

Model Structure

To maintain the properties of a biomass dynamic model and incorporate the available data (catch, proportion-at-length and CPUE) we configured SS2 to operate as an annual age-structured production model. In this model, a BH S/R function was both estimated (Model A) and fixed (Model B). In this configuration, the steepness of the S/R curve (h) was analogous to the intrinsic rate of increase in a surplus production model (with population increase also governed by fixed values of M and growth). An estimate of R_0 (unfished recruitment) was also estimated and this was analogous to the carrying capacity. Both M and growth were fixed at estimates derived outside of the model, because we had some information or could make reasonable guesses. The growth and survival patterns were assumed to be the same for both sexes, thus the model was a single sex model. All parameters were assumed to have a uniform prior that was uninformative.

Fishery length data was used to estimate selectivity patterns, which control the size (and age) distribution of the removals. To reduce the contribution of the length data to the total likelihood, the length likelihoods were down-weighted (using a likelihood multiplier λ=0.1). Because recruitment was constrained to a deterministic prediction and selectivity patterns are assumed constant across years, we felt it was justified to reduce the fitting to the length components so that they did not unduly influence the estimates of the underlying population dynamics. In other words, we did not want to detract from the fit to the CPUE data to get better fits to the length data. Thus, CPUE was assumed linearly proportional to available biomass, with constant catchability. This assumption was consistent with the biomass dynamic approach recommended for this assessment. We gave more weight to the JPN DW LL CPUE (λ=1) relative to the other CPUE series (λ=0.1). The model begins in 1952 with a population at unfished levels. We specified 17 age bins to be modeled, with the last bin (age 20) acting as an accumulator. For both CPUE and proportion at length series, the originally inputted SE and effective N values were iteratively re-estimated using a process originally described by McAllister and Ianelli (1997). A total of 36 and 35 parameters were estimated for models A and B, respectively. We assumed catch was known without error and removed half way through the year. Likelihood λ's and iterated effective sample sizes or CV are in Table 4. The SS2 control file (Model A) is given in appendix II.

***Likelihood Components*:**

3 CPUE by fleet (assumes lognormal error structure)
HWN LL (1991-2003)
JPN DW LL (1962-2003)
JPN C LL (1994-2004)

8 proportion-at-length series (assumes multinomial error structure):
EPO Area 5 Purse seine (1991-2004)
Area 3 HWN LL (1994-2003)
Area 4 HWN LL (1994-2003)
Area 1 JPN DW LL (1970-2002)
Area 2 JPN DW LL (1970-2002)
Area 3 JPN DW LL (1970-2002)
Area 4 JPN DW LL (1970-2002)
Area 5 JPN DW LL (1970-2002)

Selectivity patterns

Because proportion-at-length information was available for 8 of 25 fisheries, we assumed that the selectivity patterns of the other 17 fisheries mirrored the JPN DW LL fishery selectivity pattern from the same area. This was not true for the area 5 recreational and Costa Rican fleets, which we assumed mirrored the EPO purse seine data. The CPUE series were treated as surveys with selectivity patterns equivalent to its fishery. The following is a list of the fishery with length data followed by the fisheries with assumed selectivity patterns which were the same. All selectivity patterns were assumed to be domed except the Area 5 recreational and Costa Rican fisheries which were characterize by the EPO purse seine data. All selectivity patterns are assumed constant across time, thus one pattern is estimated for each fishery. All selectivity patterns were estimated as length-based as these were the units of observation. Each fishery with data is given followed by each fishery we assumed to have the same selectivity pattern. Note the area 5 EPO purse seine is not a specified fishery but only length observations.

Area 5 EPO purse seine- recreational, Costa Rica
Area 3 Hawaiian longline
Area 4 Hawaiian longline
Area 1 Japanese distant water longline- Japan coastal LL, Japan dfnt, Taiwan, Korea, Other
Area 2 Japanese distant water longline- Japan coastal LL, Japan dfnt, Taiwan, Korea, Other
Area 3 Japanese distant water longline- Taiwan, Korea
Area 4 Japanese distant water longline-Taiwan, Korea
Area 5 Japanese distant water longline- Taiwan, Korea

Convergence Criteria

The model was assumed to have converged if the Hessian inverted and S.E. estimates could be derived. The correlation matrix was investigated for problematic correlations (or lack of correlations). Parameters found to have been estimated at a bound was also considered a diagnostic of a non-convergence. Finally, for the base case Bayesian diagnostics were employed to determine if the trace chain converged. Internally, a 10^{-3} convergence criterion was set with SS2 during optimization.

Sensitivity Runs

Results of the following sensitivity runs using Model A are presented in a table in the sensitivity section to examine the effects of key assumptions. The change from the base model is given followed by (in parenthesis) the main reason for the sensitivity run.

1) M=0.25 (effect of a lower mortality rate)
2) M=0.35 (effect of a higher mortality rate)
3) K=0.18 (effect of a slower growth rate)
4) K=0.28 (effect of a faster growth rate)
5) Asymptotic selectivity for all fisheries (effect of all gears taking largest sizes)
6) Increase emphasis on Length likelihood components lambda=1 (effect of sampled lengths on estimated dynamics)
7) Use the area specific CPUE series instead of aggregated across different areas but the same gears(examine effects and fits to all of 11 series Note: the 11 series include the Japanese Drift Net CPUE)
8) Eliminate CPUE data prior to 1973 (Remove the potential effects of early targeting and resulting changes in CPUE *q*)

A smaller subset of sensitivity was produced for Model B because many of the effects above could be assumed for Model B.

1) M=0.45 (Fish only live to ~age 10)
3) K=0.15 (effect of slower growth)
4) K=0.4 (effect of faster growth)

Model Results

Model Fits and performance

Both models had a relatively good statistical fit to the JPN DW LL CPUE series, which apriori was considered the primary tuning index. A reasonable fit the JPN DW LL CPUE series (Figure 7) and was also the primary visual diagnostic of model performance. Model B showed a more immediate decline in the early part of the series. Model A shows a more gradual decline. Both models appeared to underestimate the decline in CPUE from the HWN LL, however that time series was lightly weighted in the model. The fit to the JPN C LL series appear reasonable, however the short time span and the variability make judging fit difficult. The JPN C LL was also lightly weighted in the model. Note that the general patter of the estimated CPUE is smooth and does not show much yearly fluctuation. This is the result of a model with deterministic recruitment.

The model fit to the proportion-at-length data also appeared reasonable, especially considering the recruitment constraints imposed (Figure 8a and b). It was unlikely that this model can achieve really good predictions of the proportion-at-length given that recruitment was deterministic. The proportion-at-length contribution to the total likelihood was reduced (λ=0.1), the idea was to estimate the general selectivity patterns from this data but limit those likelihood components contribution to the total likelihood.

Key Estimated and Derived Parameters

All parameters appeared reasonable, except that the steepness estimate was much lower than expected in Model A. Key estimated and derived parameters are given in Table 3. Appendix I lists all parameters, both fixed and estimated, in the Base A model run.

The estimated selectivity patterns are given in Figure 9a and b. We have no method to judge the accuracy of those selectivity patterns except through the fits to the above mentioned proportion-at-length data.

Estimated Time Series

Estimated recruitment declined over the time series to account for the diminishing CPUE described by the JPN DW LL series (Figure of 10). The estimated recruitment declines nearly linearly with the decline in spawning biomass in Model A and follows the specified curvature of Model B. Spawning biomass in Model A declines (Figure 11) slowly in the historical period (pre 1964), but the decline increases dramatically as catch doubles in the mid-1960s. Model B indicates rapid decline throughout the early period. The rate of decline in absolute abundance slows as the catch declined into the recent period. Spawning biomass declines not only because the total number of predicted fish declines, but the model predicts a disproportional loss of the oldest age-classes (Figure 12)

Sensitivity

Key parameters, likelihood values and important derived quantities from the sensitivity analyses are given in Table 3a and 3b for Model A and B, respectively. It is clear the confounded structure of the basic production parameters, such as k, M and h. Assuming higher productivity through higher levels of h, the model compensates through estimating a smaller but more productive stock (Figure 13). Therefore, the tradeoff is larger less productive or smaller and more productive. Using Model A, the level of depletion is not greatly affected by changes to any one of the assumed parameters, as the model can compensates through changes to h. However, estimates of MSY are affected by different assumptions to M and the resulting estimates of h. More work in this area is necessary before reliable MSY estimates could be derived.

Retrospective

A retrospective analysis was performed on Model A (Figure 14) to determine model performance as if assessments had been conducted using the same data starting in 1998. The retrospective pattern is characterized by increasingly smaller estimates of both initial spawning biomass and terminal biomass with the addition of additional years of data. The pattern also indicates a more pessimistic 1998 relative biomass (1998 spawn bio/

unfished spawn bio) with the addition on new years of data 30%, 28%, 26% and 24% for model runs ending data in 1998, 2000, 2002 and 2004, respectively. However, the retrospective is not so problematic to suggest a modeling issue, but reflects the continuing decline of the newer CPUE data.

Bayesian Results

A MCMC chain of 15,000,000 iterations was produced for the Model A. The first 5,000,000 iterations were discarded and the subsequent chain was thinned, keeping every 25,000th observation. A problem with MCMC is not knowing whether the chain has converged to the actual posterior distribution. We evaluated convergence by applying the diagnostic statistics developed by Geweke (1992), Heidelberger and Welch (1983) and by examining the extent of auto-correlation among the samples in the chain. After satisfying those criteria, we considered the trace to have converged to characterize the posterior. The posterior appears to be relatively normally distributed with the median estimates of the posterior very similar to those based upon MLE. Trace chain patterns for several key derived and estimated parameters are given in Figure 15.

Stock Status

The stock in 2005 was estimated to be at 24% (95% C.I. 10-38%) of the unfished biomass based upon the MLE and 28% (19-41%) based upon the median of the posterior of Model A. Model B is more pessimistic about stock status (more optimistic about productivity) due to the constraint of the assumption of *h*. Unfished spawning biomass was assumed to be the population reproductive output just prior to 1952, and was calculated as:

$$S0 = \sum_{a=0}^{A} N0aWaMa$$

where: A is the maximum age, N0a is the initial number at age a, Wa is weight at age a and Ma is the proportion mature at age a

The population was estimated to have declined slightly over the last 10-15 years, with the majority of the absolute decline occurring much earlier. The results are very uncertain, with estimated CV on the level of spawning biomass >50% in the recent years. Uncertainty is also expressed in the range of stock status generated from alternative assumptions, which ranged from 10-60% of unfished spawning biomass (see Sensitivity Section).

Forecasting and MSY

MSY was calculated and the ratios of current biomass to biomass at MSY are given in Table 3a and b. However, until we have a better understanding of the basic biology, these estimates are preliminary. Projections are not given because control rules or default harvest rates do not yet exist to govern future catches. However, the projections can easily be done inside SS2 as part of the estimation phase. Catches can derived from specified harvest rates or absolute catches.

Discussion

These results indicated a moderately depleted population. This was not unexpected given the CPUE series declined even as catches levels were themselves declining. This suggested that either the stock was driven down to levels that reduced spawning out so that the population could not compensate even for declining catches, or that catchability of the fleet has declined due to changes in targeting. Both hypotheses would explain the decline in CPUE and catches. The first hypothesis results in a stock less than a third of the unfished biomass (Table 3 Model A and B), and the second a stock that is likely above half the unfished levels (Table 3 run 8). Our assumption of the constant proportionality of CPUE and abundance, however, allowed the model to explain the data in only one way. A non-proportionality coefficient could be calculated inside SS2 to account for changes in *q*, however that requires knowing something about the population trend or absolute size (which was what the CPUE was used for).

The level of depletion level estimated in Model A were similar in magnitude to those developed by Hinton and Maunder (2003) for the EPO using a Pella-Tomlinson production model. The authors estimated that biomass in 2002 was 33-34% of unfished, which compares reasonably well with the 20-30% range of most models in this assessment. Estimates of unfished biomass were also consistent with the result form the Pell-Tomlinson models, with our NPO roughly twice the more area restricted EPO result.

The sensitivity analyses that eliminated CPUE data prior to 1973 (run 8 Table 3a) predicted a larger relative biomass in comparison to the base model. This model assumed that the early decline in the CPUE is due solely to changes in catchability due to targeting. The subsequent period does not show dramatic declines in CPUE. This result is similar in the level of depletion as reported by Hinton and Maunder (2003) using a delay difference approach with two *q* values associated with the JPN DW LL CPUE to account for changes in targeting. The authors in that study estimated stock size in the EPO 25-70% of unfished, which compares favorably to the 56% in run 8. Supporting the argument that the initial decline in JPN DW LLCPUE (which could be due to targeting changes) greatly affects our interpretation of stock status.

It should be viewed as cautionary that both the JPN DW LL and the HWN LL series decline over the last 10 years (most recent data) when targeting could be assumed to be relatively constant and when catches are at the lowest levels in decades. Those effects are seen in the retrospective analysis (Figure 14). Although not given Table 3, a model excluding early CPUE and weighting all likelihood components equally was similar in the estimates of depletion to the base model. It is therefore unlikely that the decline in the model population is the result solely from changes in targeting/catchability in the early years unless it affects the other data as well. The truth may lie somewhere between the two explanations. Plausible hypothesis for both increases as well decreases in catchability should be examined in future data workshops. A fundamental understanding of this issue is critical to this and any future stock assessments.

The emphasis of this assessment was to do something very computationally simple that could still make use of all available data. We caution that production models generally fare poorly in simulation studies when recruitment is highly variable (NRC 1998). We assumed an S/R curve and estimated selectivity using the available length data, but otherwise collapsed the observational subcomponent of the mode to a biomass dynamic model. To do this we made the assumption in this assessment that the JPN DW LL CPUE series was the best representations of changes in relative abundance. To a lesser extent we included the HWN LL and JPN C LL fishery CPUE, but because they did not have the same spatial coverage or history of use, they were not as highly weighted. More work should be devoted to evaluating these series as their use generally stabilizes the model (based upon sensitivity analyses not presented in this paper).

The proportion-at-length data was also down-weighted in this assessment to reduce its contribution to the total likelihood. These subjective decisions and are not the optimal method of treating different data sources. However, numerous observations from proportion-at-length data can overwhelm the contribution to the total likelihood from other components such as indices, which were thought to be the most reliable source of changes in population abundance. Balancing the contribution from length/age composition information against survey/CPUE data is an area of consideration in most stock assessments. This first attempt at the assessment has not solved this issue and it is an area of future research.

Model results in this assessment are particularly uncertain with estimated CV's ranging from 30-50% around terminal abundance. This is due, in part, to the down-weighting of data other than the JPN DWLL and the estimation of h (Model A). It also appears that there are several different slopes of predicted CPUE that fit the JPN DW LL data nearly as well. The large estimated uncertainty (both in estimated CV and range of model results), however, is likely a fair representation of how much we know about the stock dynamics.

We note here that the estimate of h (Table 3a) appear to be too low for a pelagic species. Misspecification of other parameters influences its estimated value (run 2 and 3 Table 3). Under or over-reporting of catch either early or late in the series would also bias estimates of h. A mischaracterization of the actual stock structure or the inability to capture spatial dynamics with this model could also contribute. Although, it is also possible that striped marlin may be more solitary than other schooling pelagic fishes (Frimodt 1995), and this may affect the resilience of the population to diminishing numbers of adults (relative to a schooling animal). Estimates of relative depletion may be robust to the issue of mis-estimation of population resilience, but the estimates of corresponding MSY are not. This is exemplified by the conclusions that the NPO stock is below biomass at MSY in this work, whereas Hinton and Maunder (2003) generally found that the EPO stock above biomass at MSY. Both studies found similar depletion levels but estimates of MSY were different. We do not have much faith in the MSY estimates calculated in this work. Estimates of MSY based upon the fixed h appear more reasonable; however we should treat them as assumptions given that the resilience parameter was specified. Some management bodies have considered proxies for MSY to dampen the variability in estimated MSY due to changes in both data and model assumptions.

There is considerable debate regarding the estimation of *h* in stock assessments. It is often assumed that the parameter is not reliably estimated given sparse data sets (or even relatively good assessment data). Often the estimates of R0 and *h* are highly correlated, and this was the case in this work (>95%). These correlations can make estimation problematic and cause problems in MCMC. This is the primary reason that the chain had to be so severely thinned (small number of draws to characterize the distributions). On the other hand, fixing *h* in such a simple biomass dynamic approach also fixes the population size and understates uncertainty (Figure 13). This is a typical problem of over- vs. under-parameterized associated with such simple models (Piner et al. 2005). Iteratively re-estimating the model at progressively different levels of *h* until achieving a visually reasonable fit to the CPUE was not a good option as this is essentially estimating without the penalty for the parameter. Future work that allows the estimation of recruitment deviations using a fixed level of *h* may be an appropriate compromise (We have done some work on this and the results are comparable to those presented, allowing for flexibility in production but elimination the R0-*h* correlations). The working group should consider using the advice from the August-September meeting in Shimizu, Japan and use different levels of complexity beyond the simplest approaches.

During the course of the assessment several area of data uncertainty were discovered. These include the unusually large-size fish in the EPO purse seine fishery. These size composition data were used to define the selectivity pattern of area 5 recreational and Costa Rican catches. However, the sizes are much larger than anything typically seen in the other fisheries including JPN DW LL area 5 (except for year 2000). Based on this we allowed the other fisheries to have domed shaped selectivity patterns. This poses unanswered questions about the selectivity pattern of longline fisheries in all areas or potentially separate stocks in the region of the Coastal area 5 and the other NPO areas with very different growth patterns. This question of appropriate selectivity is relevant as shown in sensitivity run 5 (Table 3). Furthermore, if the stock is a single NPO wide population, it may suggest that the largest fish migrate to the EPO. Alternatively, the longline fisheries would have to be de-selective for the largest fish due to gear or area effects. These ideas need to be better developed.

The model results are also sensitive to the weighting given to the individual area-specific series derived from the JPN DW LL fleet. In the current model, the area specific JPN DW LL series are weighted based upon the both density (area-specific CPUE) and the size of each area. This method seems statistically justified, but gives disproportional weight to area 5 because the CPUE from that area is much higher than the other 4 areas even though the areas themselves are not too different in size. If the absolute CPUE derived from the same gears across areas does not reflect the relative densities, then it may be that the assessment results are biased. If all 5 JPN DW LL series are included as separate likelihood components (run 7 Table 3a), there is still the question of how much weight to give to the different series. Sensitivity runs (11 CPUE not presented) indicate that emphasizing one area JPN DW LL over another affects model results as the series do not show the exact same time trends.

Based upon these initial model results, there does not appear to be an irresolvable conflict between the length composition data and the CPUE series (run 6 Table 3). The decline in CPUE is mirrored, in some of the fisheries length composition information, by declining mean size and reduction of the distribution of sizes (Figure 6). Of course, the degree of model agreement is conditioned on assumptions such as growth and variability around the assumed size-at-age. However, the use of length information allows for a much more detailed recreation of the population dynamics and contributes to overall model stability judging by the decrease in estimated CV's when the full likelihood contribution of the length data was used (run 6 Table 3a). Future assessment work should consider using more complex models that make full use of the length data. The estimation of recruitment deviations would help explain some of the variability seen in all the proportion-at-length data and would allow for greater use of the length data without the constrained assumptions of a deterministic recruitment process.

Finally, there was much debate during the August-September meeting of the SMWG about the stock structure of striped marlin in the NPO. This issue remains an open question but also one that is of great importance to the assessment. All five areas showed similar (but not identical) time trends in CPUE, however some areas also showed considerable changes to the size structure of length data while other did not. It is beyond the scope of this paper to use this information to hypothesize about the assumption of a single/multiple stock or the extent of localized depletions. However, these issues are critical to assessing the population and ultimately managing the species in the NPO.

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Table 1. Catch of striped marlin (numbers) in the North Pacific Ocean by fleet.

	1	2	3	4	5	6	7	8	9	10	11	12
	area 5	area 3	area 4	area 1	area 2	area 3	area 4	area 5	area 1	area 2	area 3	area 4
year	rec	Hawaii L	Hawaii LI	JPN DWI	jpn dwll	jpn dwll	jpn dwll	jpn dwll	twn	twn	twn	twn
1950												
1951												
1952	0	0	0	85911	1626	524	1135	0	0	0	0	0
1953	0	0	0	62072	2437	2594	856	0	0	0	0	0
1954	0	0	0	99861	1473	1730	1231	0	0	0	0	0
1955	0	0	0	87739	1620	7308	1387	41	0	0	0	0
1956	0	0	0	102307	3620	11431	871	0	0	0	0	0
1957	0	0	0	86699	7808	7747	1610	133	0	0	0	0
1958	0	0	0	104395	6569	14712	4705	38	0	0	0	0
1959	0	0	0	82093	11849	32655	3883	95	0	0	0	0
1960	0	0	0	70414	2647	38528	4994	1021	0	0	0	0
1961	0	0	0	75869	16582	20393	7891	13345	0	0	0	0
1962	0	0	0	85746	6756	31106	16678	34557	0	0	0	0
1963	0	0	0	62353	4074	24491	28892	55413	0	0	0	0
1964	0	0	0	87348	5451	48667	65349	192982	0	0	0	0
1965	0	0	0	70387	7453	46352	25777	163190	0	0	0	0
1966	0	0	0	60928	3523	12334	16797	117916	0	0	0	0
1967	0	0	0	62714	4984	64265	16926	154065	0	36	0	9
1968	0	0	0	57153	4554	53174	29952	266848	0	0	0	10
1969	0	0	0	47850	5955	28089	15567	112245	0	0	0	27
1970	0	0	0	56686	7490	132242	40755	84921	0	0	0	0
1971	0	0	0	61136	3488	41918	23373	115629	0	0	0	0
1972	0	0	0	35977	6504	15587	13883	99554	0	0	167	0
1973	0	0	0	37390	9962	32215	21892	65323	0	7	0	0
1974	0	0	0	52040	7586	12084	12125	81300	0	535	0	0
1975	0	0	0	30164	4035	9793	10738	73536	0	900	0	0
1976	0	0	0	21920	3681	15010	11273	67643	0	726	0	0
1977	0	0	0	16567	1531	13007	7958	23185	17	183	91	8
1978	0	0	0	21120	2818	19677	7609	12446	0	1	0	3
1979	0	0	0	31718	6573	30148	18941	30585	52	549	0	2
1980	0	0	0	49832	7354	12081	14524	48892	0	1538	0	0
1981	0	0	0	32973	4792	12449	9568	43213	48	244	25	21
1982	0	0	0	22799	4106	10179	8145	70929	7	108	0	1
1983	0	0	0	17939	2759	10376	7543	43150	0	0	0	0
1984	0	0	0	32962	1825	19697	5405	17833	0	0	0	0
1985	0	0	0	51831	4683	9252	15840	13507	0	0	0	0
1986	0	0	0	72937	11725	12683	14670	16136	0	0	0	0
1987	0	0	0	34737	5634	16863	15306	44159	0	0	0	0
1988	0	0	0	58661	6002	20802	40862	22953	0	0	0	0
1989	0	0	0	39714	4720	17189	25107	26441	0	0	0	128
1990	0	1617	436	24504	2104	7953	16293	7205	0	0	0	42
1991	4878	14162	4121	38363	4733	8894	15065	6163	0	16	0	509
1992	9876	11072	4977	34848	3413	11011	11667	6964	0	0	0	11
1993	11146	12885	5325	52058	5324	14696	15797	6022	0	61	0	0
1994	11349	13512	5109	39471	3949	9033	15305	5294	0	13	0	0
1995	12197	21989	12446	43203	2445	20866	11753	10955	0	0	425	57
1996	17715	16732	8420	25974	4038	6976	7761	3163	91	6	235	32
1997	13665	14849	8814	27095	1314	3320	4158	15283	2	309	159	704
1998	22741	9726	6721	29685	3450	3529	4092	5725	0	216	357	1038
1999	16642	11739	6347	22962	3223	9885	7264	812	376	264	573	225
2000	19511	5122	4704	13544	2555	2724	4636	2534	70	41	1301	802
2001	15468	8506	10133	11090	2840	2218	3788	2841	64	11	208	1104
2002	19863	4551	5485	7484	3013	1622	4929	1791	39	0	105	3703
2003	20976	12826	14224	12288	2718	7011	5033	972	58	17	538	1870
2004	18769	2926	4975	4536	880	1663	4631	1523	54	9	284	2226

Table 1 Continued

year	area 5 twn	area 5 coast Ric	area 1 jpn cll	area 2 jpn cll	area 1 jpn dft	area 3 jpn dft	area 1 korea ll	area 2 korea ll	area 3 korea ll	area 4 korea ll	area 5 korea ll	area 1 other	area 2 other
1950													
1951													
1952	0	0	0	0	0	0	0	0	0	0	0	72018	0
1953	0	0	0	0	0	0	0	0	0	0	0	69875	0
1954	0	0	0	0	0	0	0	0	0	0	0	72554	0
1955	0	0	0	0	0	0	0	0	0	0	0	119137	0
1956	0	0	0	0	0	0	0	0	0	0	0	113743	0
1957	0	0	0	0	0	0	0	0	0	0	0	24328	0
1958	0	0	0	0	0	0	0	0	0	0	0	19362	0
1959	0	0	0	0	0	0	0	0	0	0	0	10002	0
1960	0	0	0	0	0	0	0	0	0	0	0	10610	0
1961	0	0	0	0	0	0	0	0	0	0	0	9395	0
1962	0	0	0	0	0	0	0	0	0	0	0	21613	0
1963	0	0	0	0	0	0	0	0	0	0	0	18505	0
1964	0	0	0	0	30	0	0	0	0	0	0	85057	0
1965	0	0	0	0	30	0	0	0	0	0	0	101167	18610
1966	0	0	0	0	61	0	0	0	0	0	0	61235	20164
1967	0	0	0	0	91	0	0	0	0	0	0	61379	18670
1968	0	0	0	0	0	0	0	0	0	0	0	46911	16966
1969	0	0	20392	837	91	0	0	0	0	0	0	95596	25980
1970	0	0	23451	962	91	0	0	0	0	0	0	43619	22980
1971	0	0	22670	930	303	0	0	0	0	0	0	82773	19652
1972	0	0	28447	1167	7364	0	0	0	0	0	0	40689	17248
1973	0	0	21480	881	98939	0	0	0	0	0	0	29472	24274
1974	0	0	11114	456	94303	0	0	0	0	0	0	29723	28719
1975	0	0	9720	399	198000	0	0	14	7	160	125	30153	18936
1976	0	0	8293	340	107909	0	6	74	44	132	94	26348	16311
1977	0	0	8701	357	158713	0	4	83	29	284	223	18829	24731
1978	0	0	8259	339	200652	0	1	229	846	1382	924	18942	0
1979	0	0	12439	510	90836	0	0	201	35	581	520	18569	18524
1980	0	0	20630	846	124276	104	0	31	38	178	497	19710	41611
1981	1	0	8803	361	135187	3508	32	44	1559	997	21319	19712	19573
1982	0	0	9177	377	80658	3685	63	96	1327	1760	18244	25310	17471
1983	0	0	10876	446	63171	3686	0	6	478	452	25073	28365	0
1984	0	0	13119	538	71953	11320	1	21	640	1618	9246	26811	0
1985	0	0	24165	991	71200	13351	1	90	416	777	1959	34943	23562
1986	0	0	30623	1256	115688	12621	0	0	0	0	0	28011	10458
1987	502	0	40343	1655	59818	7736	0	42	475	2894	2243	25431	18159
1988	141	0	25559	1049	66831	12188	0	18	227	2840	333	41078	21466
1989	0	0	36740	1507	53667	5461	0	53	85	1420	1242	53520	10567
1990	0	0	38236	1569	65100	4572	0	66	0	1023	4097	47445	12085
1991	0	2341	40683	1669	45200	2326	0	1	0	850	1325	44456	15241
1992	0	1726	42382	1739	42245	755	0	78	0	1819	14297	20373	13415
1993	0	3181	183464	7528	29705	0	0	36	0	2330	18346	27352	11836
1994	0	3516	43640	1791	43727	0	0	13	0	2999	15793	15016	10184
1995	0	4235	62537	2566	29394	0	0	45	124	3316	12340	11283	5090
1996	2	3436	62401	2560	21303	0	0	19	34	1655	22313	6443	5873
1997	0	3651	47582	1952	24636	0	0	506	48	1567	32923	6725	10675
1998	0	3829	67125	2754	33091	0	3	38	67	6291	17071	12158	7625
1999	0	4349	52714	2163	34121	0	0	115	2	5264	14914	7324	0
2000	0	2512	37692	1547	32182	0	0	29	9	4402	11544	12092	6165
2001	774	3678	45067	1849	32636	0	0	7	11	3908	3819	9994	4587
2002	534	1813	26932	1105	38303	0	0	50	7	649	146	11568	9427
2003	436	1869	93159	3822	34374	0	0	29	9	2986	5170	8634	4392
2004	581	450	102744	4216	35104	0	0	29	9	2514	3045	376	3776

Table 2. Estimated annual CPUE series used in the base models.

year	CPUE series		
	hawian LL	jp dw ll	jpn CLL
1962		0.636008	
1963		0.649897	
1964		0.79222	
1965		0.687705	
1966		0.652504	
1967		0.864334	
1968		0.711269	
1969		0.581697	
1970		0.815759	
1971		0.789213	
1972		0.417607	
1973		0.334972	
1974		0.377946	
1975		0.370261	
1976		0.29618	
1977		0.252606	
1978		0.277323	
1979		0.437269	
1980		0.461542	
1981		0.351406	
1982		0.319881	
1983		0.278107	
1984		0.339617	
1985		0.456122	
1986		0.341254	
1987		0.444982	
1988		0.425498	
1989		0.458829	
1990		0.304416	
1991	0.001505	0.264037	
1992	0.001415	0.303248	
1993	0.001436	0.359016	
1994	0.001531	0.368072	0.010783
1995	0.002402	0.492489	0.028077
1996	0.001706	0.330743	0.010614
1997	0.001502	0.485313	0.007742
1998	0.000973	0.280118	0.015117
1999	0.000928	0.220927	0.004252
2000	0.000639	0.30753	0.004019
2001	0.000956	0.251065	0.018588
2002	0.000439	0.21689	0.010152
2003	0.001012	0.233361	0.005004
2004			0.008314

Table 3a. Estimated (MLE) and derived parameters of the base model. Values in parenthesis are the CV based upon the normal approximation. Run number corresponds to the sensitivity number in the sensitivity section and below (in parenthesis) is the major assumption change.

Run	Model A	1 (M=0.25)	2 (M=0.35)	3 (k=0.18)	4 (k=0.28)	5 (asym sel)	6 (len λ=1)	7 (11 CPUE)	8 (CPUE 1973-2004)
Likelihood Components and Resulting Likelihood Values									
EPO Length	8.97	9.12	8.84	8.98	8.98	0.94	87.69	0.24	9.65
HWN LL Len	6.84(	6.86	6.85	6.86	6.89	1.14	68.84	0.28	6.79
HWN LL Len	11.48	11.57	11.38	11.21	11.81	1.68	113.75	0.29	11.85
JPN LL Len Area 1	28.56	28.43	28.67	28.64	28.49	5.03	283.82	1.44	28.78
JPN LL Len Area 1	37.43	37.35	37.58	37.58	37.47	4.67	375.39	2.33	37.23
JPN LL Len Area 1	30.89	30.82	30.92	30.70	31.22	4.92	306.53	2.43	31.25
JPN LL Len Area 1	42.09	41.77	42.48	42.46	42.15	5.32	419.74	2.11	42.04
JPN LL Len Area 1	18.44	18.51	18.43	18.40	18.57	3.28	185.62	0.95	18.26
HWN LL CPUE	0.652	0.66	0.637602	0.63	0.67	0.80	0.50	1.48	0.71
JPN DW LL CPUE	15.55	15.83	15.5035	15.61	15.70	25.09	19.06	74.06	9.15
JPN C LL CPUE	0.712	0.72	0.706683	0.70	0.72	0.55	0.65	1.29	0.73
Total	201.65	201.66	201.998	201.765	202.6	53.41	1861.61	87.01	196.45
Estimated and Derived Parameters									
h	0.36	0.45	0.31	0.31	0.42	0.67	0.38	0.29	0.24
Unfished Spawn Biomass (t)	223390 (31%)	2.20E+05 (24%)	2.32E+05 (0.37%)	2.54E+05 (0.37%)	2.02E+05 (26%)	1.22E+05	2.04E+05 (10%)	3.11E+05 (42%)	5.71E+05 (167%)
2005 Spawn Biomass (t)	52199 (56%)	4.22E+04 (54%)	6.24E+04 (59%)	6.84E+04 (60%)	4.11E+04 (55%)	1.75E+04	2.62E+04 (37%)	9.97E+04 (58%)	3.18E+05 (224%)
Depletion (%)	24	19	27	27	20	14	13	32	56
MSY harvest rate (%) Yield/ avail biomass	0.06	0.08	0.05	.04	.09	.20	0.07	0.04	0.02
SPR at MSY	0.66	0.56	0.75	.75	.59	.37	0.64	0.79	0.89
2005 Biomass/Bio MSY (%)	61	57	65	65	58	59	36	74	118

Note: run 7 reported CPUE Likelihoods summed by gear (example all 5 JPN DW LL).

Table 3b. Estimated (MLE) and derived parameters of the base model. Values in parenthesis are the CV based upon the normal approximation. Run number corresponds to the sensitivity number in the sensitivity section.

Run	Model B	1 (M=0.45)	2	3 (K-0.15)	4 (K=0.4)	5	6	7	8
Likelihood Components and Resulting Likelihood Values									
EPO Length	7.99	10.64		Non-Convergence	8.29				
HWN LL Len	7.62	8.69			7.60				
HWN LL Len	11.60	12.43			12.25				
JPN LL Len Area 1	28.26	28.41			27.82				
JPN LL Len Area 1	39.34	40.57			40.14				
JPN LL Len Area 1	30.41	30.80			32.01				
JPN LL Len Area 1	45.45	51.99			47.70				
JPN LL Len Area 1	19.14	19.59			19.73				
HWN LL CPUE	0.65	0.76			0.5801				
JPN DW LL CPUE	16.94	17.73			17.4834				
JPN C LL CPUE	0.71	0.77			0.68				
Total	208.12	222.67			214.29				
Estimated and Derived Parameters									
h	0.7	0.7			0.7				
Unfished Spawn Biomass (t)	1.12E+05 (<1%)	6.33E+04 (<1%)			8.23E+04 (1%)				
2005 Spawn Biomass (t)	1.04E+04 (<1%)	7.50E+03 (<1%)			6.27E+03 (46%)				
Depletion (%)	9	12			8				
MSY harvest rate (%) Yield/ avail biomass	.20	0.27			.1				
SPR at MSY	.34	0.33			0.34				
2005 Biomass/Bio MSY (%)	47	60			40				

Table 4. The average effective sample size (length) or CV (CPUE) and likelihood weights (λ) in parenthesis for each likelihood component and model run from Table 3a and b.

Model Run Likelihood Component	Base Model A And B	1	2	3	4	5	6	7	8
Proportion at length									
EPO purse seine	41 (0.1)	41 (0.1)	41 (0.1)	41 (0.1)	41 (0.1)	41 (0.01)	41 (1.0)	4 (0.25)	41 (0.1)
Area 3 HWN LL	47 (0.1)	47 (0.1)	47 (0.1)	47 (0.1)	47 (0.1)	47 (0.01)	47 (1.0)	8 (0.25)	47 (0.1)
Area 4 HWN LL	59 (0.1)	59 (0.1)	59 (0.1)	59 (0.1)	59 (0.1)	59 (0.01)	59 (1.0)	6 (0.25)	59 (0.1)
Area 1 JPN DW LL	49 (0.1)	49 (0.1)	49 (0.1)	49 (0.1)	49 (0.1)	49 (0.01)	49 (1.0)	10 (0.25)	49 (0.1)
Area 2 JPN DW LL	37 (0.1)	37 (0.1)	37 (0.1)	37 (0.1)	37 (0.1)	37 (0.01)	37 (1.0)	9 (0.25)	37 (0.1)
Area 2 JPN DW LL	35 (0.1)	35 (0.1)	35 (0.1)	35 (0.1)	35 (0.1)	35 (0.01)	35 (1.0)	10 (0.25)	35 (0.1)
Area 2 JPN DW LL	48 (0.1)	48 (0.1)	48 (0.1)	48 (0.1)	48 (0.1)	48 (0.01)	48 (1.0)	10 (0.25)	48 (0.1)
Area 2 JPN DW LL	28 (0.1)	28 (0.1)	28 (0.1)	28 (0.1)	28 (0.1)	28 (0.01)	28 (1.0)	6 (0.25)	28 (0.1)
CPUE									
HWN LL	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4,0.4 (0.1,.1)	0.4 (0.1)
JPN DW LL	0.3 (1.0)	0.3 (1.0)	0.3 (1.0)	0.3 (1.0)	0.3 (1.0)	0.25 (1.0)	0.3 (1.0)	0.4,0.5,0.4, 0.7,0.35 (0.5,0.5,0.5, 0.5,1.0)	0.3 (1.0)
JPN C LL	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)	0.6 (0.1)	0.5 (0.1)	0.5,0.7 (0.1,0.1)	0.5 (0.1)
JPN DFTN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3,0.6 (0.01,0.01)	N/A

Notes
N/A indicated not used
Multiple values indicated the values for each area with that gear/fleet combination. First value area 1 followed by area 2 etc.

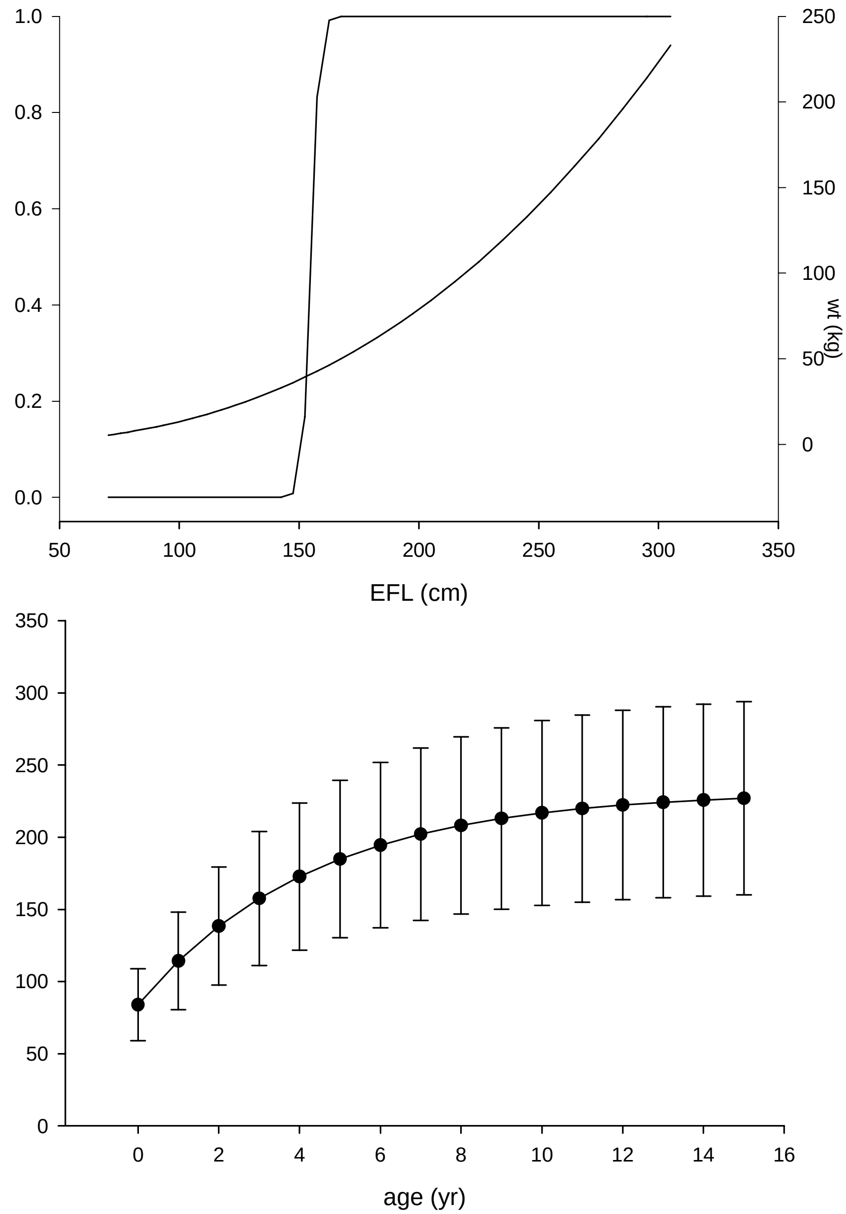


Figure 1. A) plot of the weight at length and proportion mature at length of striped marlin. B) a plot of the length at age used in the striped marlin assessment. Error bars are the 95% CI based upon the assumed CV=0.15.

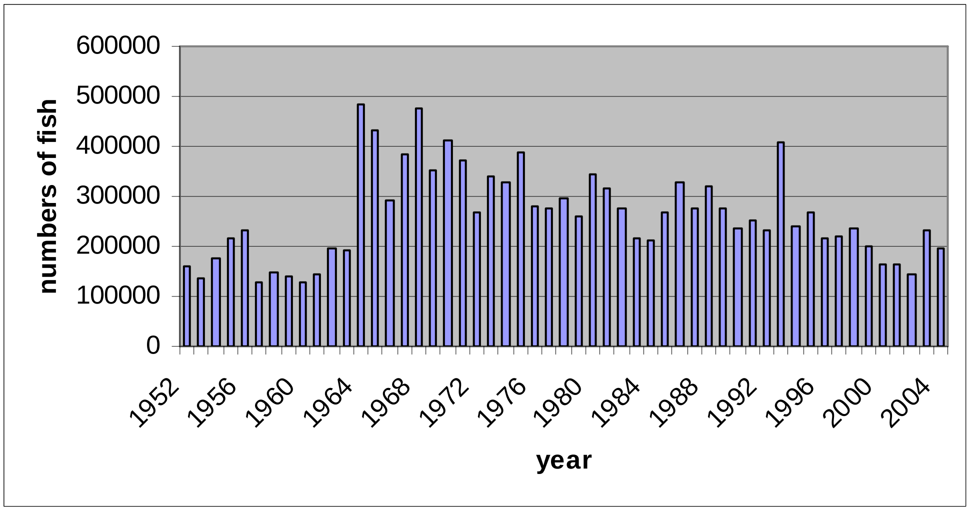


Figure 2. Total Catch (in numbers) of striped marlin in the NPO.

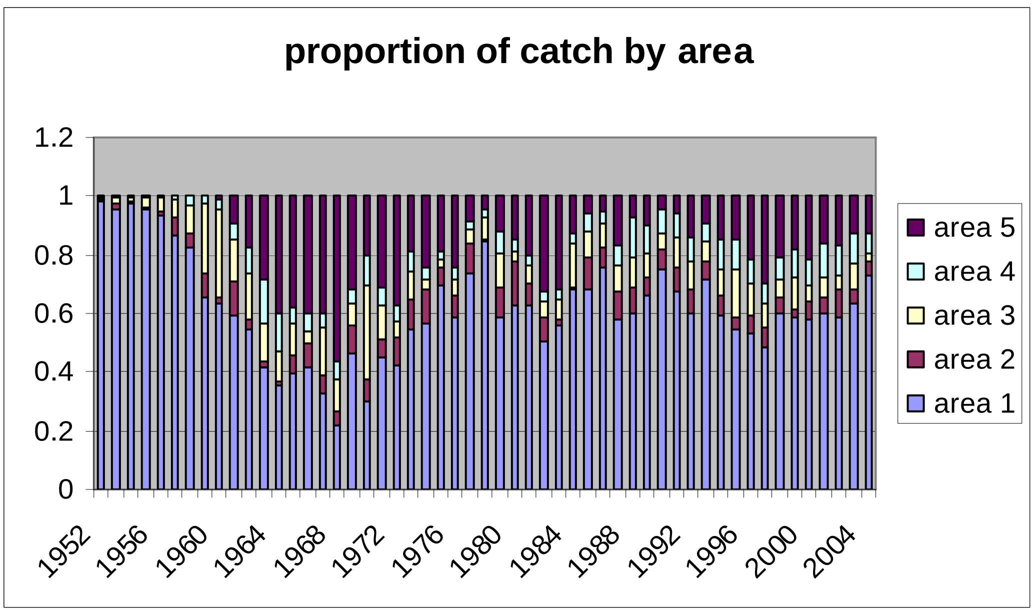


Figure 3. Proportion of yearly catch from each of the sub-areas by year.

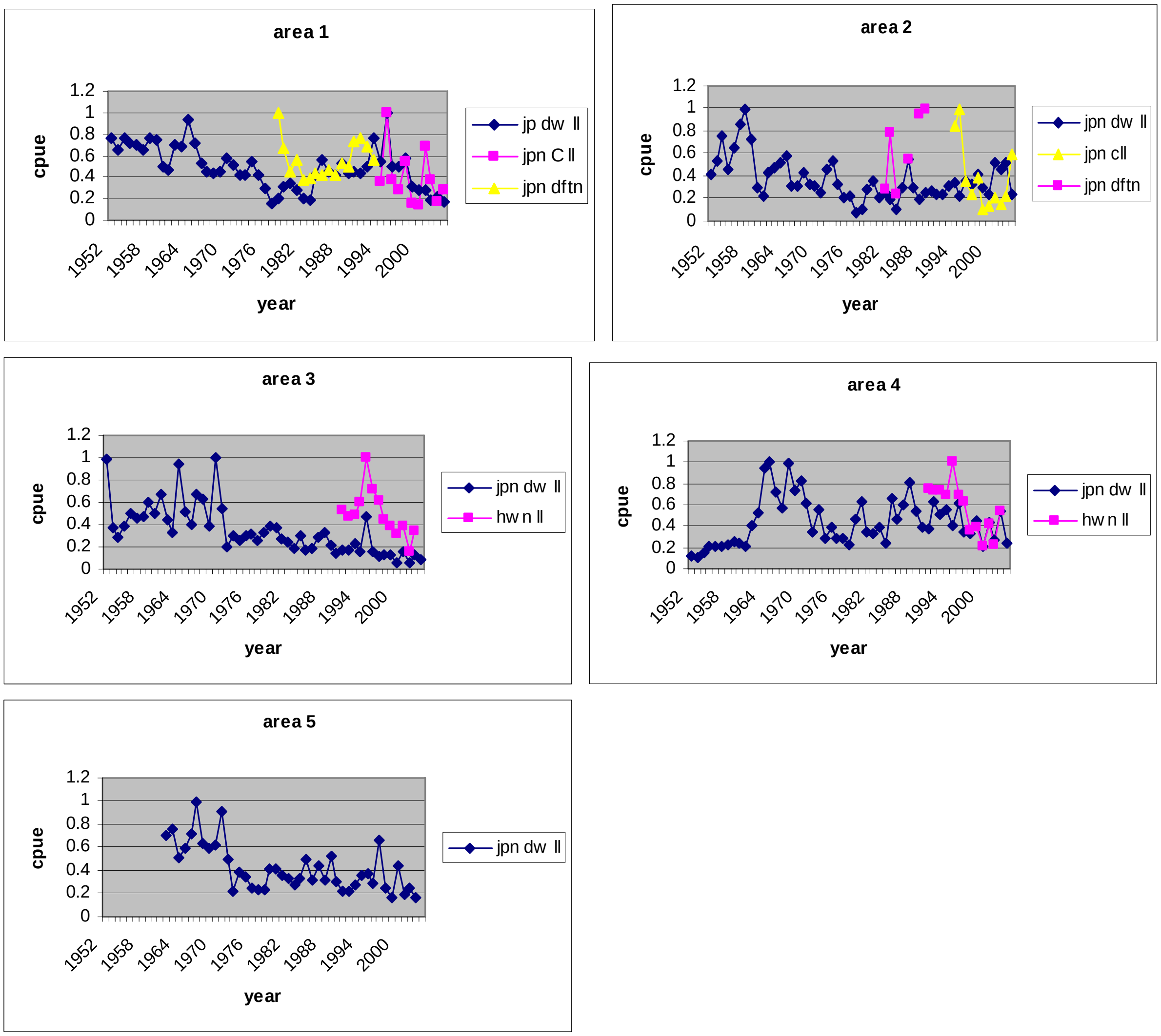


Figure 4. CPUE trends by area. All CPUE are standardized 0-1 by dividing each series by the maximum value.

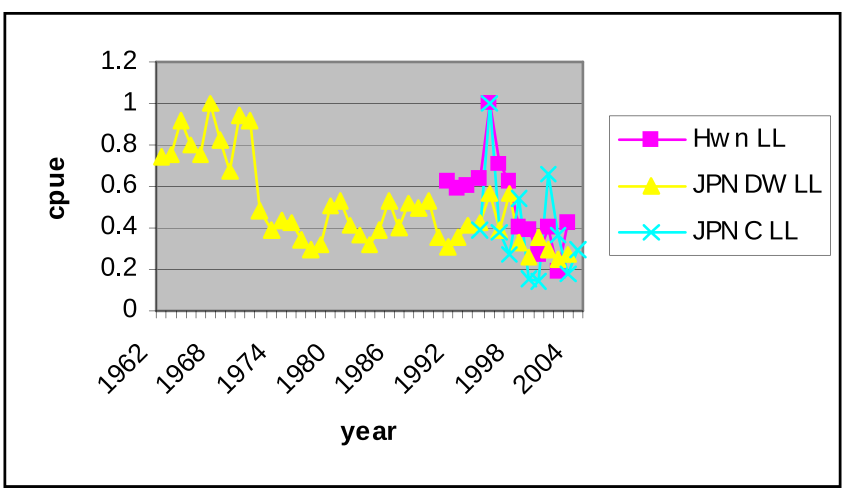
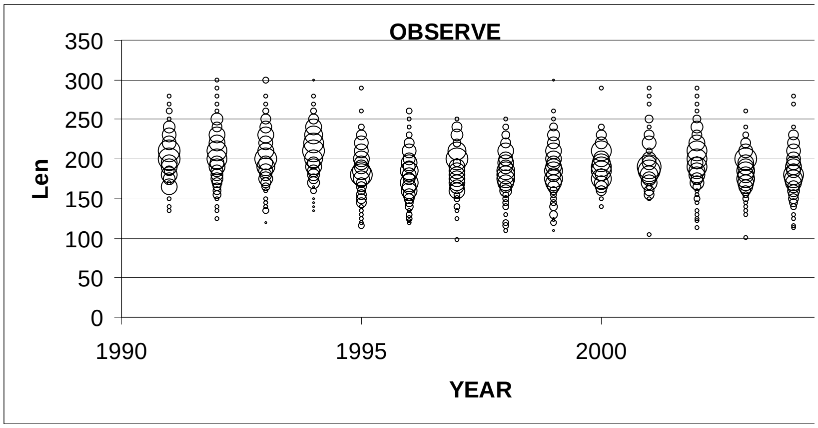
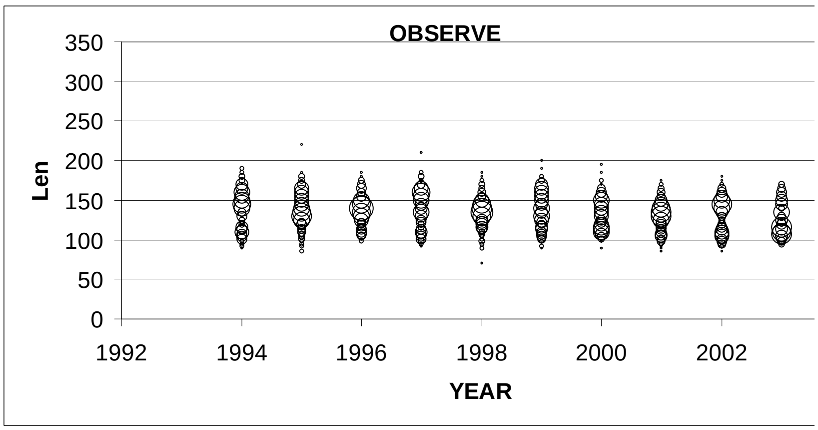


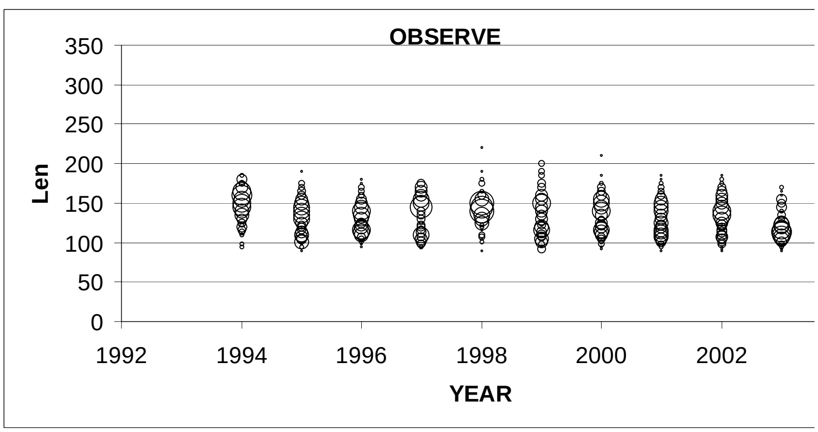
Figure 5. CPUE trends compiled for similar fisheries across areas and standardized 0-1. Actual values are given in Table 2.


OBSERVE
Len
YEAR
350
300
250
200
150
100
50
0
1990
1995
2000

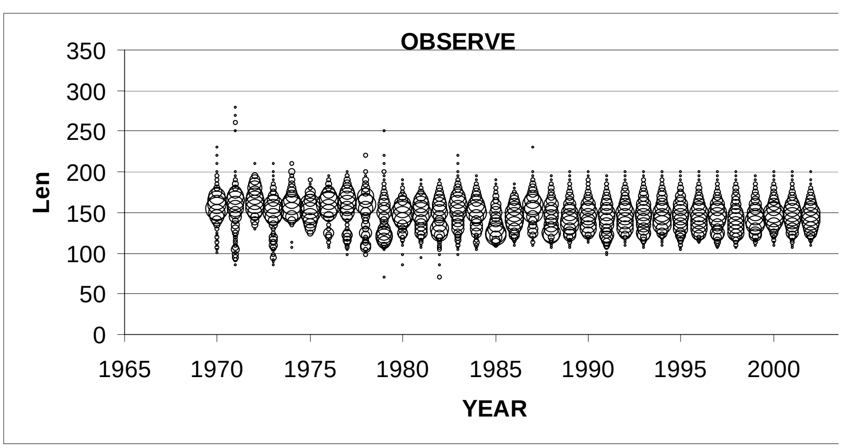
a


OBSERVE
Len
YEAR
350
300
250
200
150
100
50
0
1992
1994
1996
1998
2000
2002

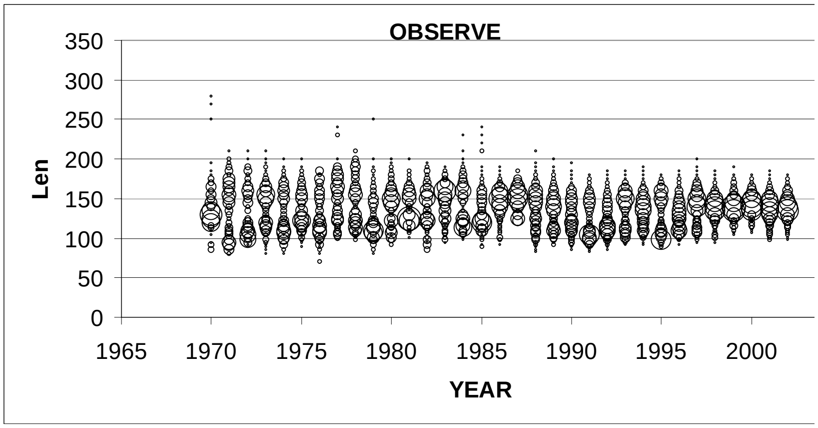
b


OBSERVE
Len
YEAR
350
300
250
200
150
100
50
0
1992
1994
1996
1998
2000
2002

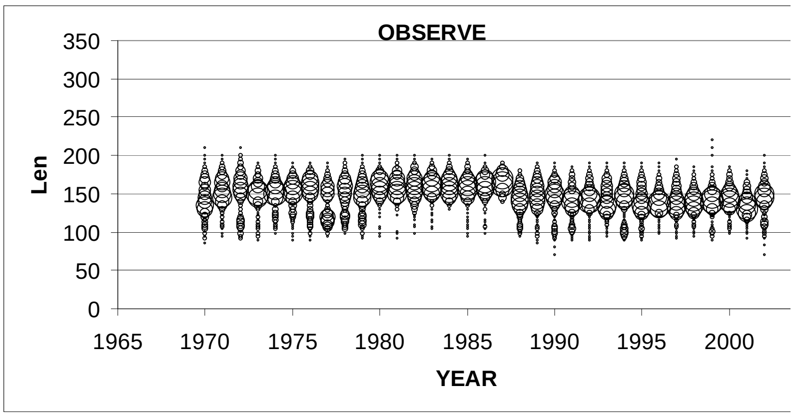
c


OBSERVE
Len
YEAR
350
300
250
200
150
100
50
0
1965
1970
1975
1980
1985
1990
1995
2000

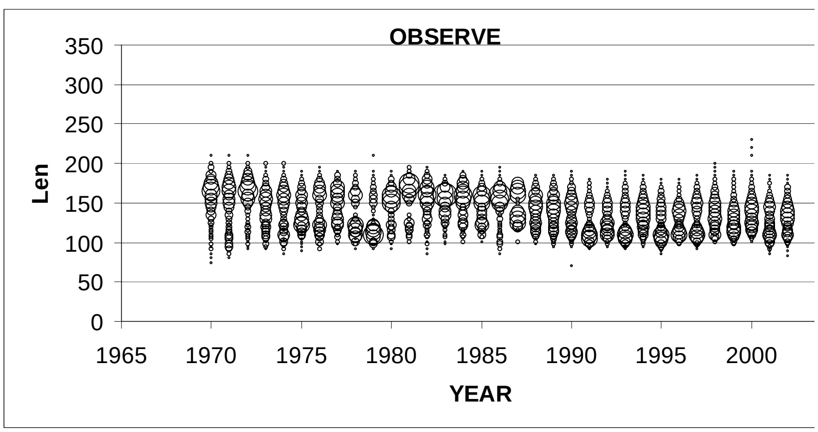
d



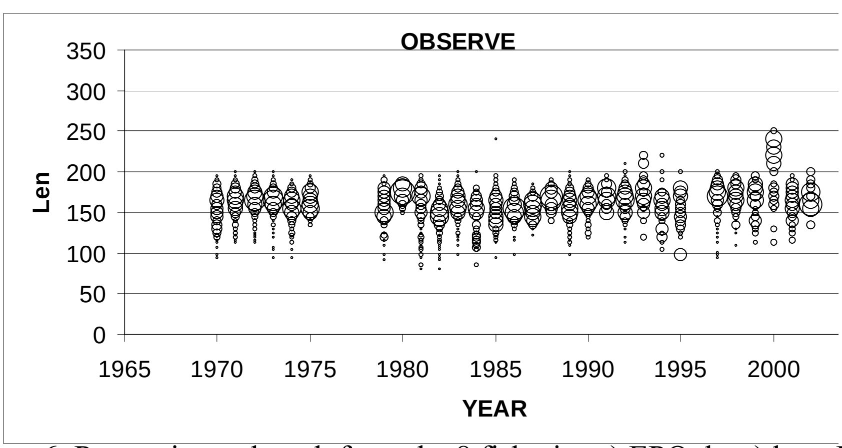
e



f



g



h

Figure 6. Proportion at length from the 8 fisheries a) EPO, b-c) hwn LL area 3 and 4, d-h) JPN DW LL areas 1-5. The size of the bubble corresponds to the proportion at that length.

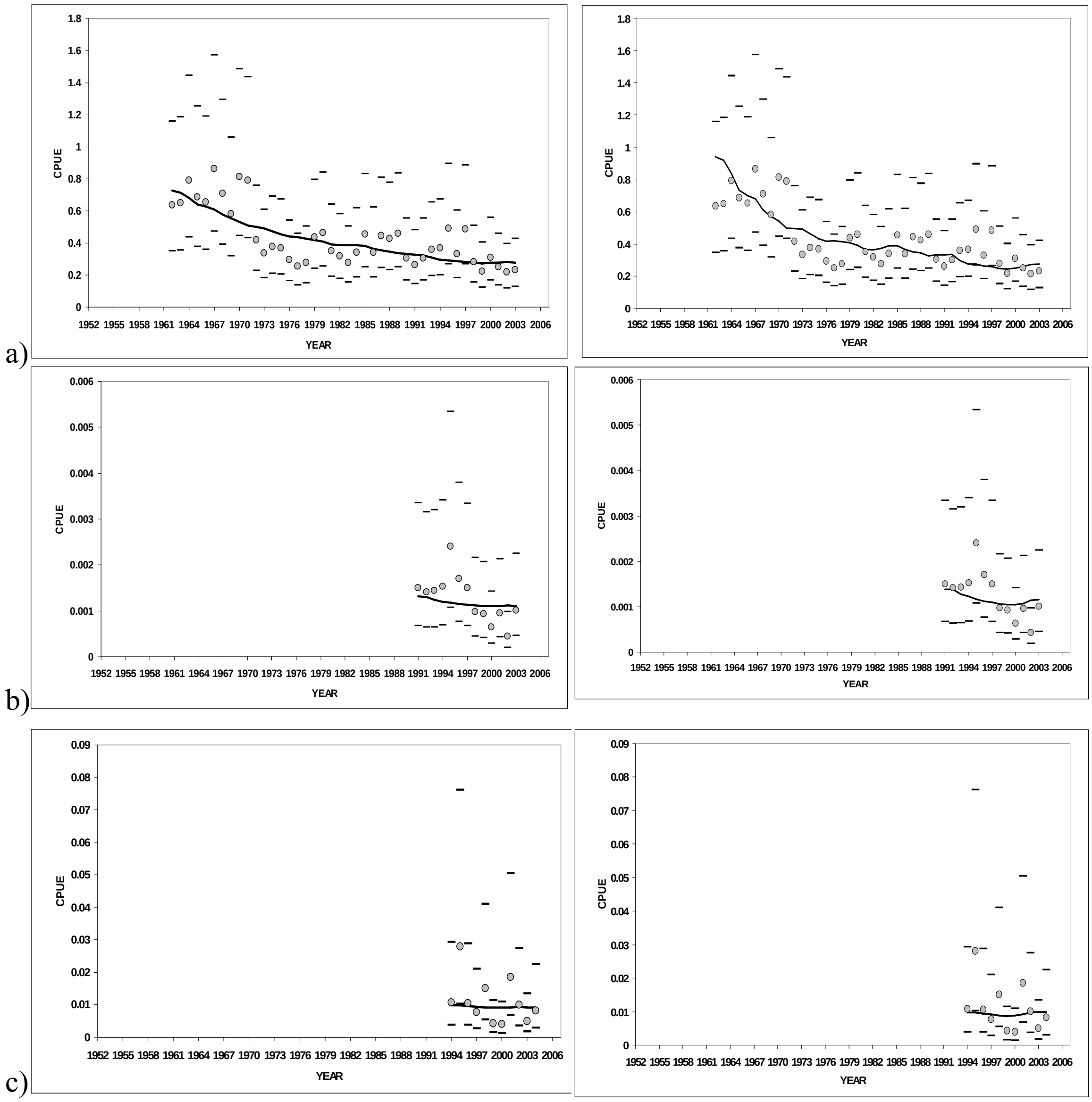


Figure 7. Observed (circles) and predicted CPUE for the JPN DW LL, b) HWN LL, and c) JPN C LL fleets. Bars are 95% CI around the observed values. Left panels are results from Model A) estimated *h*. Right panels are results from model B) with *h*=0.7 (Fixed).

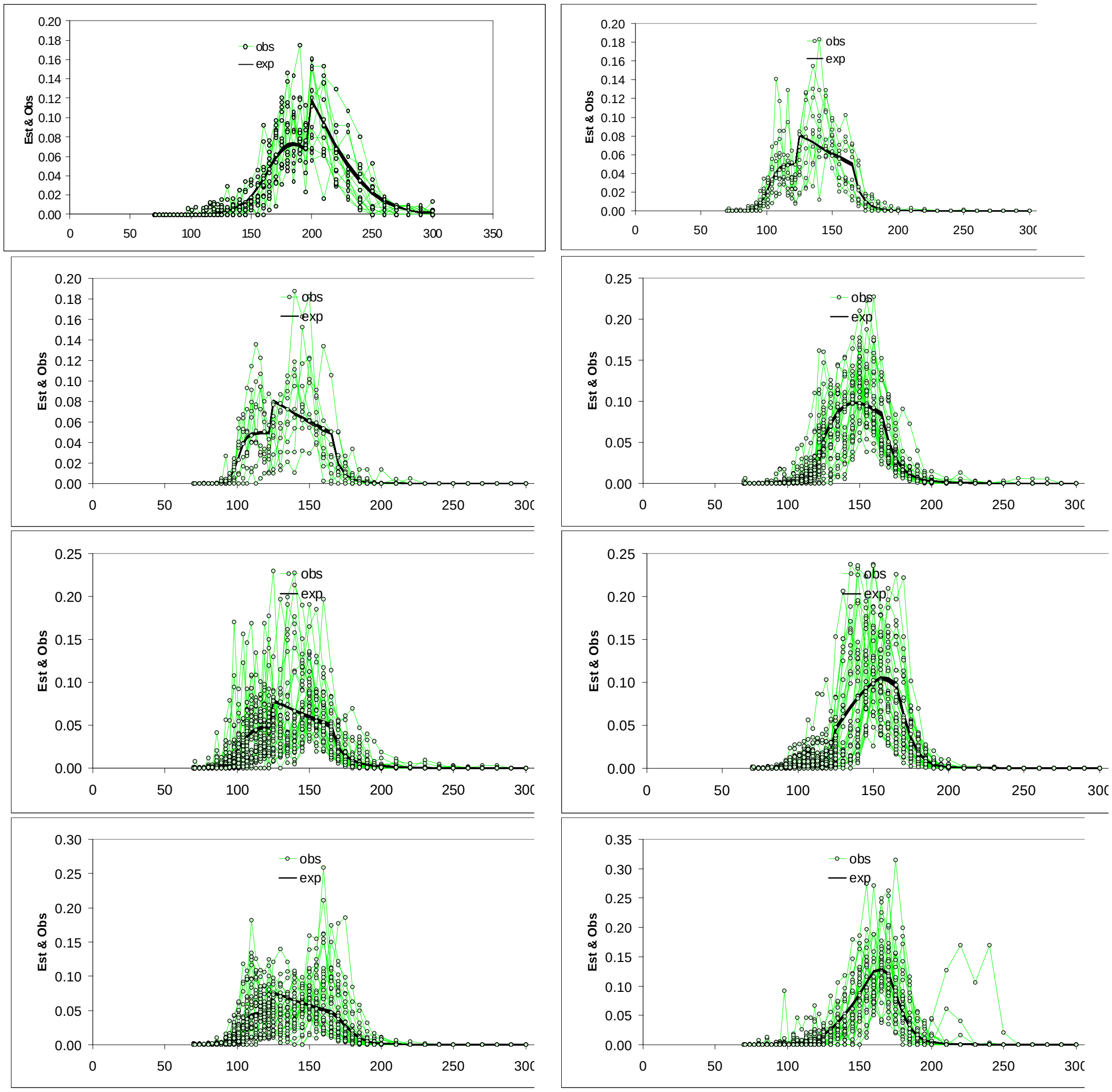


Figure 8a. Predicted and observed proportion at length for Model A: Panels (left to right and top to bottom) a) area 5 recreational, b) area 3 HWN LL, c) area 4 HWN LL, d) area 1 JPN DW LL, e) area 2 JPN DW LL, f) area 3 JPN DW LL, g) area 4 JPN DW LL, and h) area 5 JPN DW LL. Predicted values are given by the solid line and observed by the green lines.

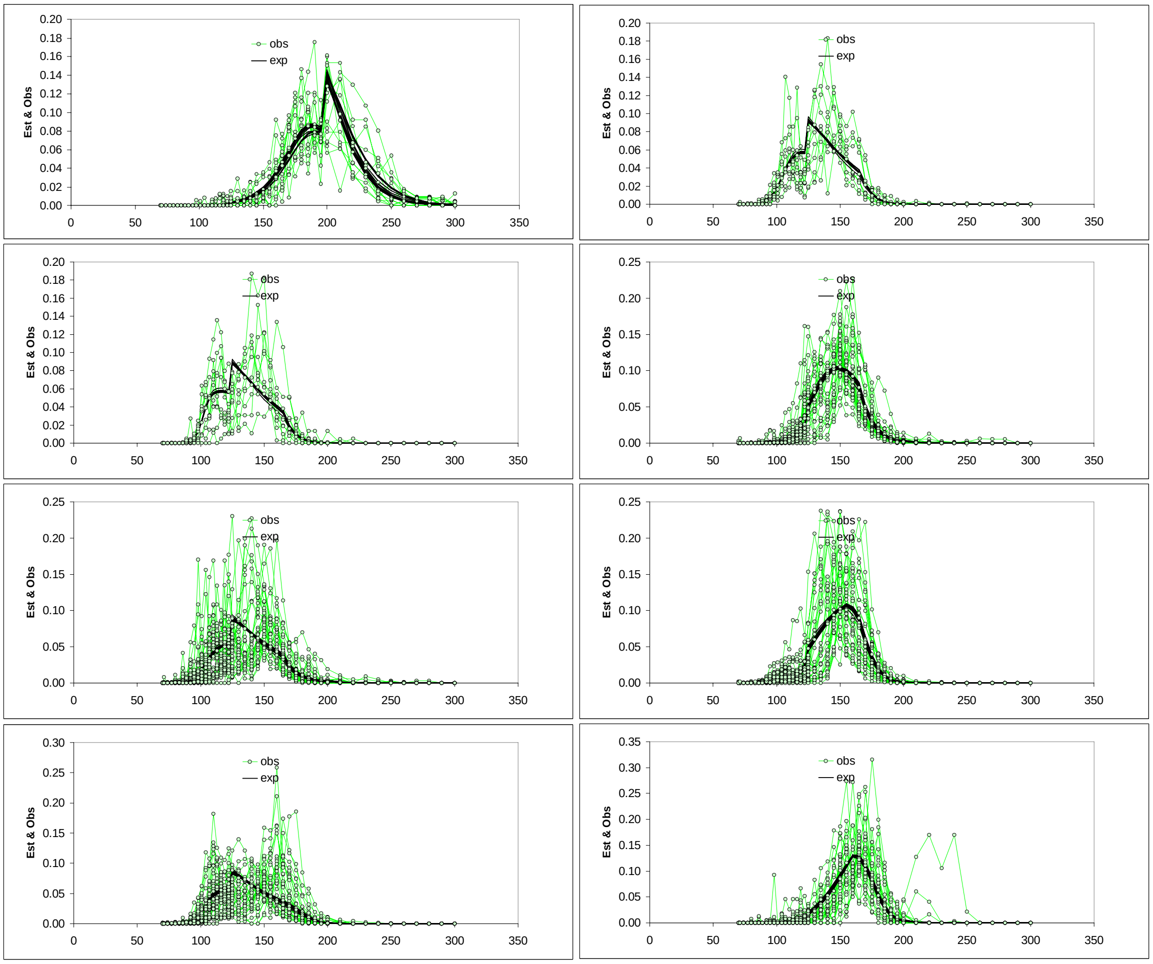


Figure 8a. Predicted and observed proportion at length for Model A: Panels (left to right and top to bottom) a) area 5 recreational, b) area 3 HWN LL, c) area 4 HWN LL, d) area 1 JPN DW LL, e) area 2 JPN DW LL, f) area 3 JPN DW LL, g) area 4 JPN DW LL, and h) area 5 JPN DW LL. Predicted values are given by the solid line and observed by the green lines.

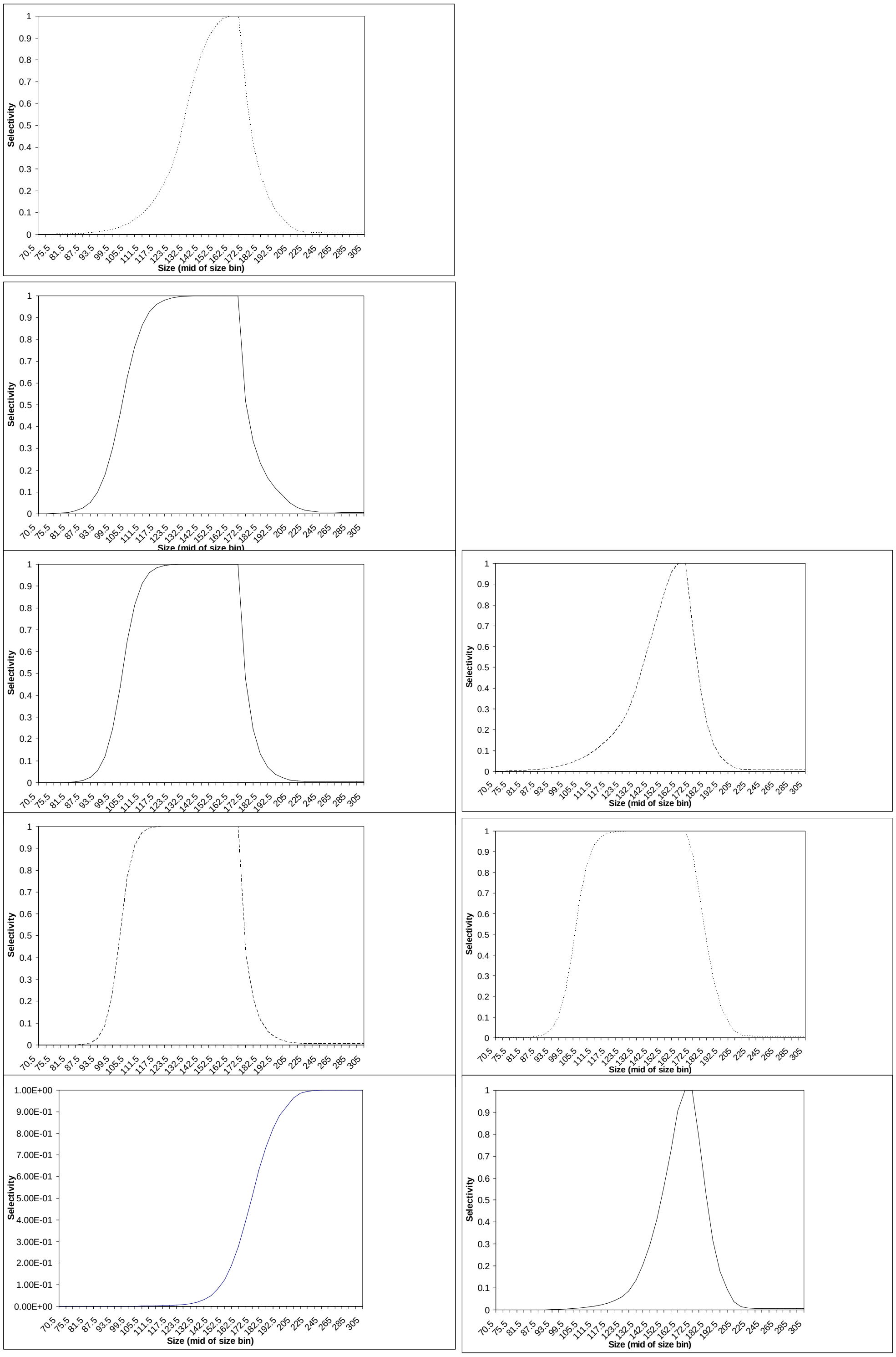


Figure 9a. Estimated selectivity patterns from Model A by area: Panels (left to right and top to bottom) a) area 1 JPN DW LL, b) area 2 JPN DW LL, c) area 3 HWN LL, d) area 3 JPN DW LL, e) area 4 HWN LL, f) area 4 JPN DW LL, g) area 5 EPO PS, and h) area 5 JPN DW LL.

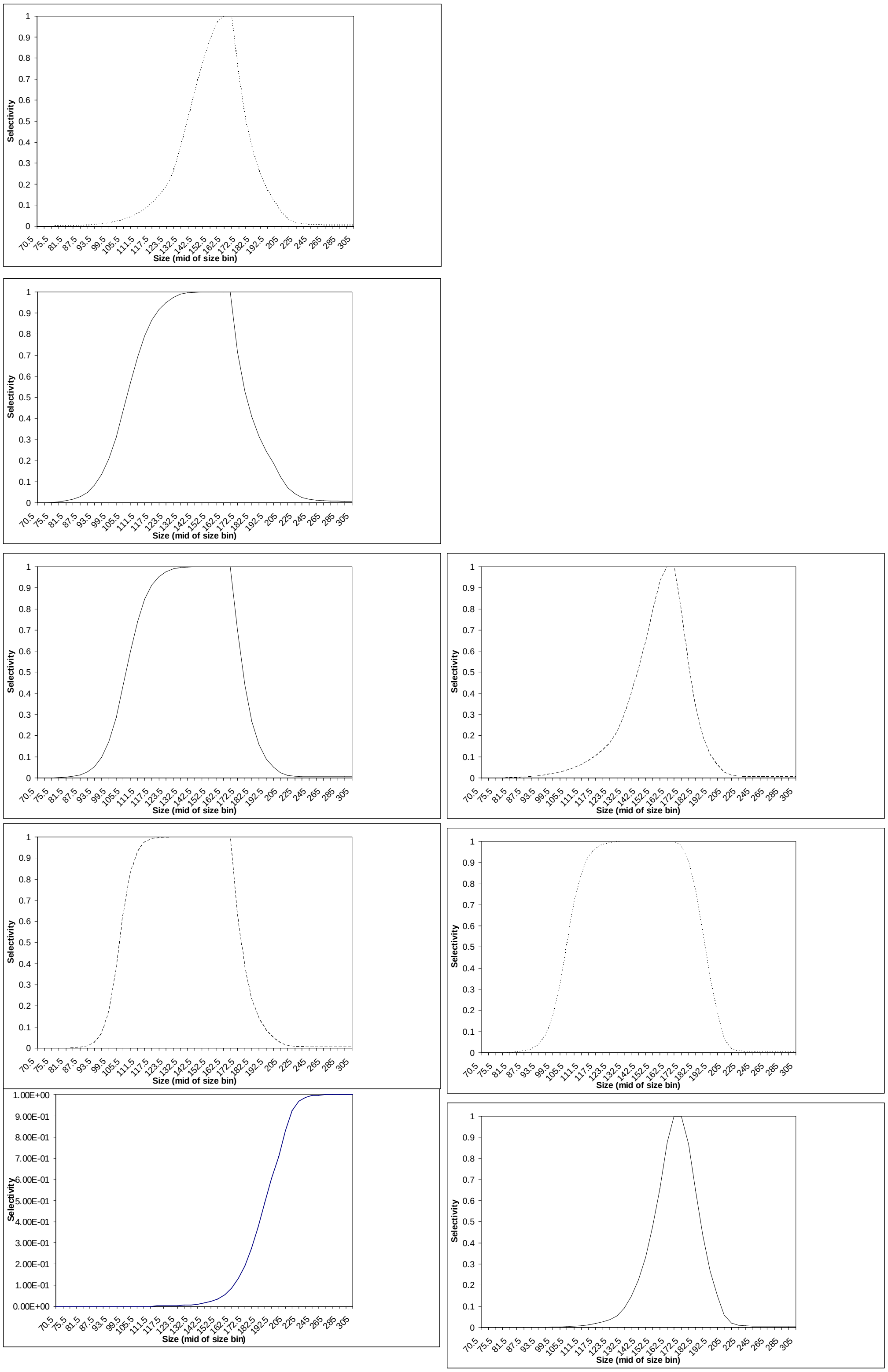


Figure 9b. Estimated selectivity patterns from Model A by area: Panels (left to right and top to bottom) a) area 1 JPN DW LL, b) area 2 JPN DW LL, c) area 3 HWN LL, d) area 3 JPN DW LL, e) area 4 HWN LL, f) area 4 JPN DW LL, g) area 5 EPO PS, and h) area 5 JPN DW LL.

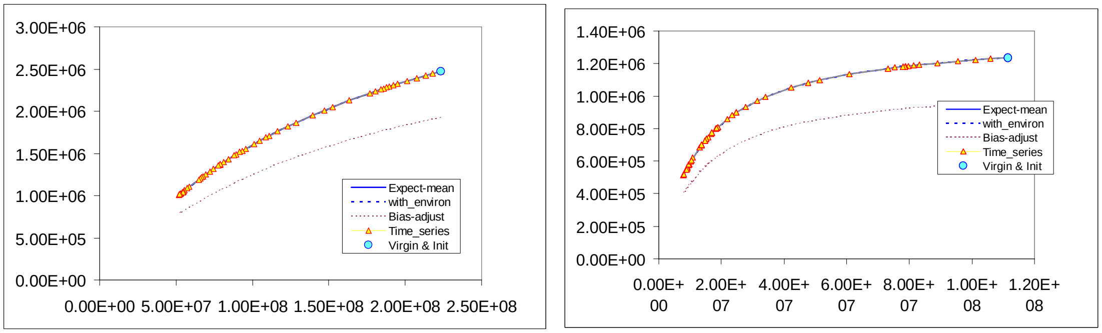


Figure 10. Estimated recruits and spawner-recruit relationship. Left panel is Model A and right panel Model B.

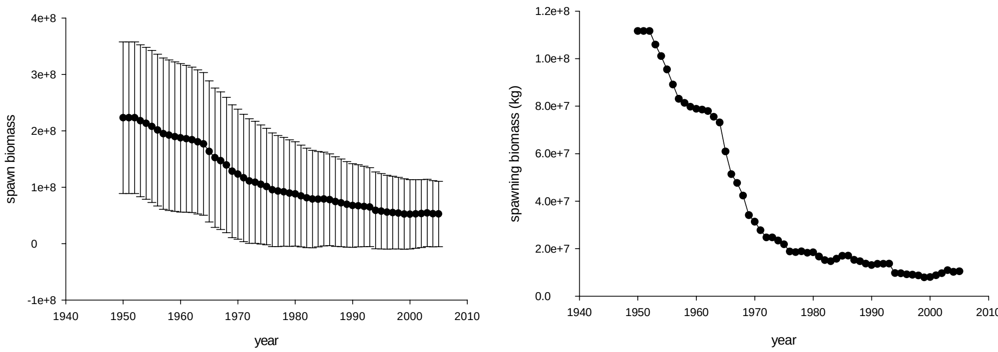


Figure 11. Plot of spawning biomass (kg) with 95% CI based upon the normal approximation. Left panel is Model A and right panel Model B.

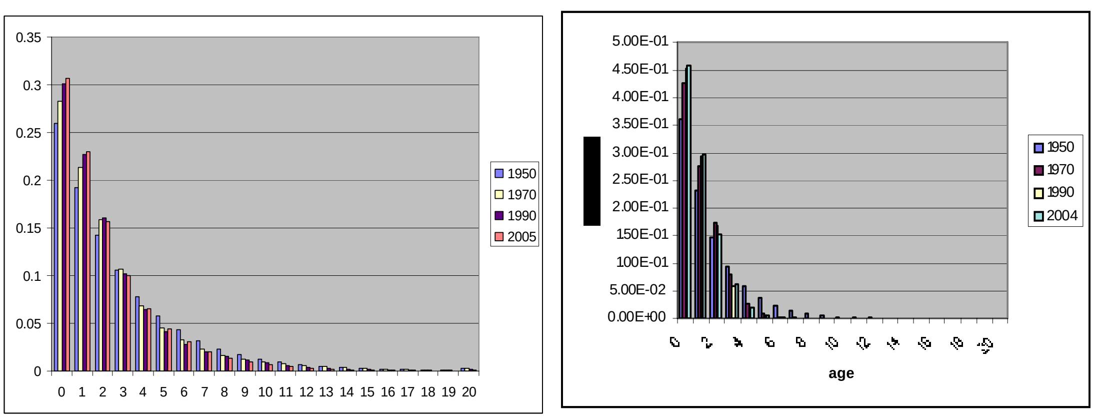


Figure 12. The estimated proportion of fish in each age-classes in 1950 (unfished) and subsequent years. Left panel is Model A and right panel Model B.

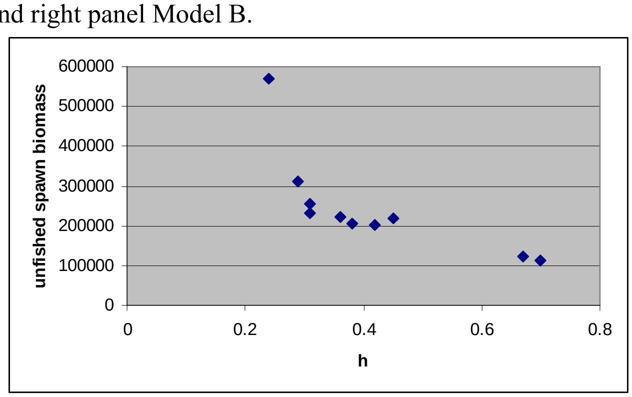


Figure 13. Plot of steepness (h) against estimated initial spawning biomass.

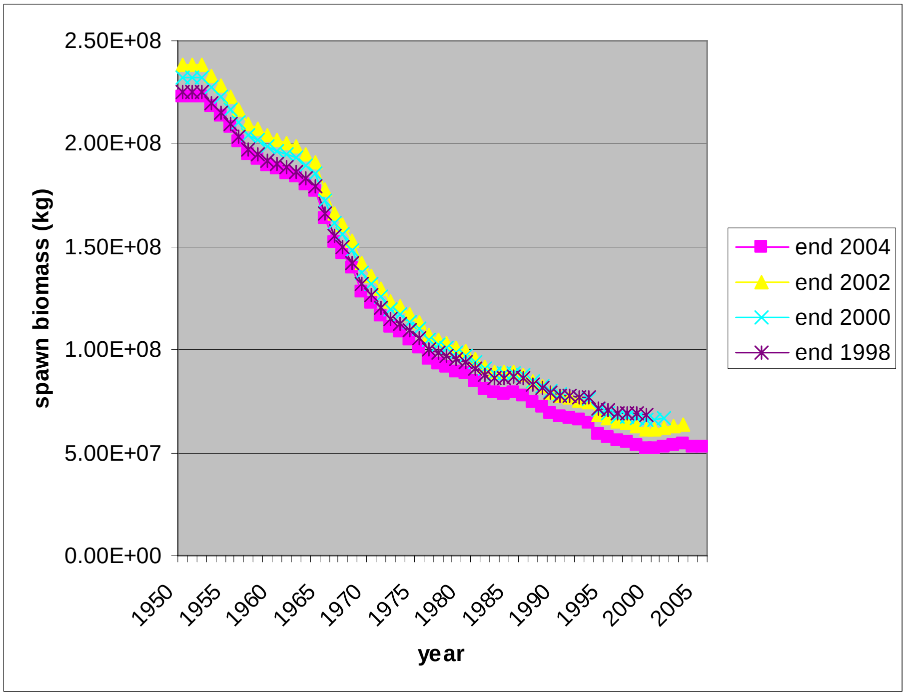


Figure 14. Retrospective analysis of the Model A. For each run presented 2 years of data was removed (2004-1998) and the trajectory of spawning biomass.

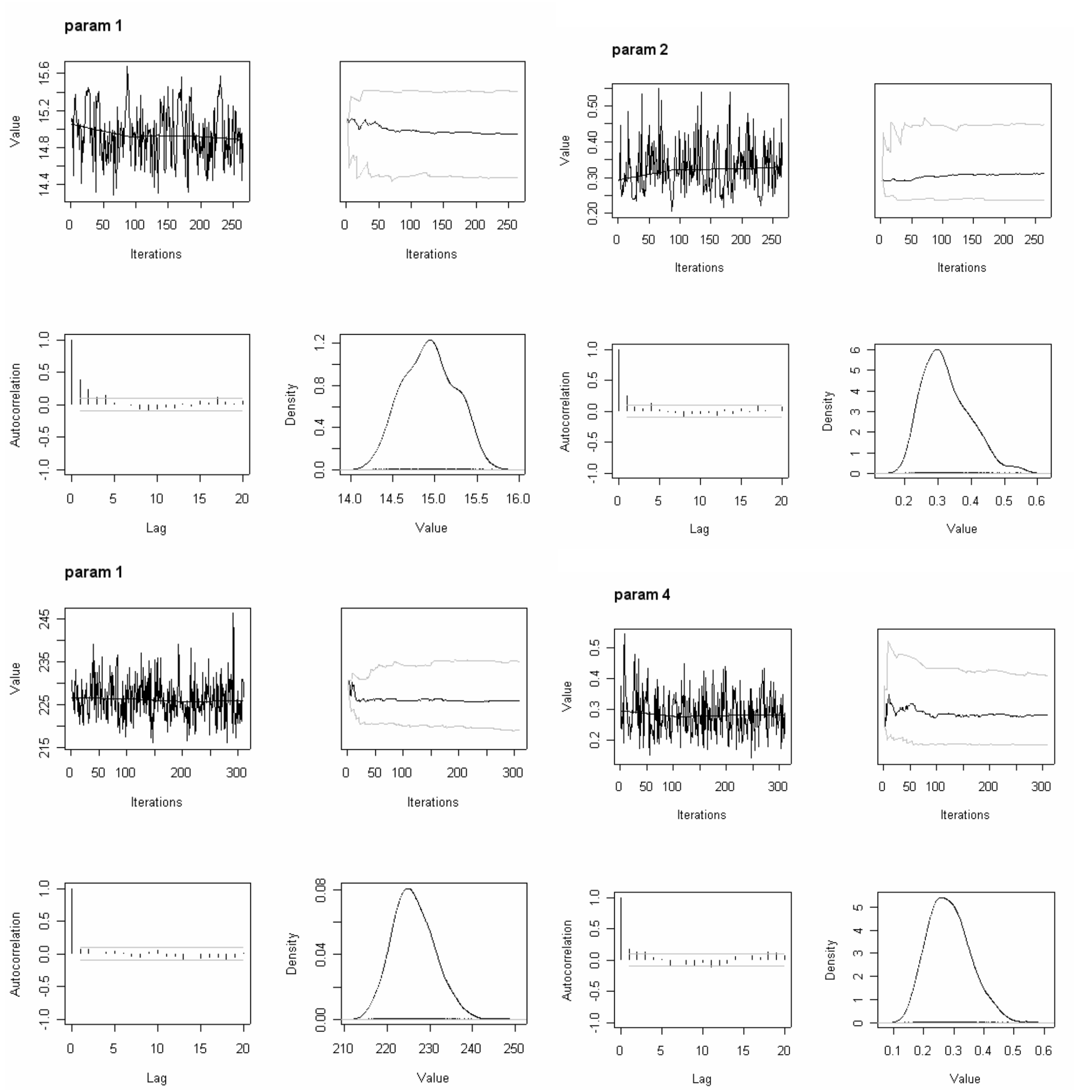


Figure 15 . Bayesian diagnostic of 4 derived and estimated parameters a) LN R0 depletion, b) steepness (*h*), c) objective function and d) depletion. Panels represent the trace chain, running median and 5th and 95th percentiles, autocorrelation lag, and the posterior density function.

Appendix I. Estimated (positive phase), fixed (negative phase) and iteratively fit and fixed (-9999 phase) parameters in the base model A.

parameter	estimate	phase	parameter	estimate	phase
Biology			Area 1 JPN DW LL Selectivity		
M	0.3	-3	Peak	160	-9999
Size age 1	100	-3	Initial Sel	0.0001	-2
Size age 14	225	-3	Inflection	0.708019	2
K	0.23	-3	Slope	0.117106	3
CV Len-age	0.15	-4	Final Sel	-5	-3
Wt-len parm	9.72E-05	-3	Descending Inflection	-3.21714	3
Allometry Coeff	2.568	-3	Descending Slope	0.10634	5
Size at 50% maturity	155	-3	Peak Width	10	-4
slope of maturity relation	-0.64	-3	Area 2 JPN DW LL Selectivity		
SR_parms			Peak	160	-9999
LN RO	14.7201	1	Initial Sel	0.0001	-2
h	0.362408	5	Inflection	-0.53509	2
Stdev Recruitment	0.7	-3	Slope	0.225874	3
Initial F fishery 4	8.29E-06	1	Final Sel	-5	-3
HWN LL CPUE q	-20.9	1	Descending Inflection	-3.8744	3
JPN DW LL q	-14.8638	1	Descending Slope	0.07582	5
JPN C LL q	-18.2618	1	Peak Width	10	-4
sel_parms			Area 3 JPN DW LL Selectivity		
area 5 Rec Selectivity			Peak	160	-9999
Inflection	172.19	2	Initial Sel	0.0001	-2
Slope	29.635	3	Inflection	1.07214	2
area 3 HWN LL			Slope	0.063773	3
Peak	160	-9999	Final Sel	-5	-3
Initial Sel	0.0001	-2	Descending Inflection	-3.13267	3
Inflection	-0.52794	2	Descending Slope	0.149598	5
Slope	0.288891	3	Peak Width	10	-4
Final Sel	-5	-3	Area 4 JPN DW LL Selectivity		
Descending Inflection	-4.13624	3	Peak	160	-9999
Descending Slope	0.140272	5	Initial Sel	0.0001	-2
Peak Width	10	-4	Inflection	-0.53162	2
Area 4 HWN LL Selectivity			Slope	0.316573	3
Peak	160	-9999	Final Sel	-5	-3
Initial Sel	0.0001	-2	Descending Inflection	-2.37656	3
Inflection	-0.57038	2	Descending Slope	0.155137	5
Slope	0.391441	3	Peak Width	10	-4
Final Sel	-5	-3	Area 5 JPN DW LL Selectivity		
Descending Inflection	-4.52258	3	Peak	165	-9999
Descending Slope	0.138193	5	Initial Sel	0.0001	-2
Peak Width	10	-4	Inflection	1.71646	2
			Slope	0.051203	3
			Final Sel	-5	-3
			Descending Inflection	-2.73514	3
			Descending Slope	0.151206	5
			Peak Width	10	-4

Appendix II . The control file for the base model

```
1       # num growth morphs
1       #assign sex to morph
1       #numb areas
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1   #area for each fleet survey
0       #do migration
0       # numb blocks
# mortality and growth parms
1       #last age for nat mortality young
2       #first age for nat mortality old
1       #age lmin
14      #age lmax
-4      #MG parm dev phase
#mortality and growth
#       lo      hi      init    prior   pr_type sd      phase env-var   use_dev dvmnyr  dvmxyr
        dvsddv  block   blktype
        0.01    0.5     0.3     0.3     0       0.8     -3      0       0       0       0
        0.5     0       0       #M young
        0       0       0       0       0       0.8     -3      0       0       0       0
        0.5     0       0       #M old  as exp offset
        3       200     100     100     0       10      -3      0       0       0       0
        0.5     0       0       #Lmin
        201     400     225     230     0       0.8     -3      0       0       0       0
        0.5     0       0       #Lmax
        0.01    0.65    0.23    0.23    0       0.8     -3      0       0       0       0
        0.5     0       0       #vbk
        0.01    0.25    0.15    0.15    0       99      -4      0       0       0       0
        0.5     0       0       #cv lmin
        0       0.1     0       0       0       0.8     -3      0       0       0       0
        0.5     0       0       #cv old as offset
#len-wt and maturity
        -3      3       0.0000972 0.0000972 0   0.8     -3      0       0       0       0
        0.5     0       0       #wt len
        -3      3       2.568   2.568   0       0.8     -3      0       0       0       0
        0.5     0       0       # wt len2
        -3      3       155     155     0       0.8     -3      0       0       0       0
        0.5     0       0       #Maturity1
        -3      3       -.64    -.64    0       0.8     -3      0       0       0       0
        0.5     0       0       #Maturity 2
        0       1       1       1       0       0.8     -3      0       0       0       0
        0.5     0       0       #egg/gram
        0       1       0       0       0       0.8     -3      0       0       0       0
        0.5     0       0       #egg.gram slope
#pop*growth morph for the prop of each morph in each area
        0       1       1       1       0       0.8     -3      0       0       0       0
        0.5     0       0       # fraction morph 1 to area 1
#pop lines for the prop assigned to each area
        0       1       1       1       0       0.8     -3      0       0       0       0
        0.5     0       0       # fraction to area 1
# cust env read
0
#custom block read
0
# lo    hi      init    prior   prtype  sd      phase
#SR section
1       #1=beverton holt
#       lo      hi      init    prior   prtype  sd      phase
        1       100     15      15      0       1000    1       # Ln(R0)
        0.2     1       0.7     0.7     0       .05     5       #Steepness
        0       2       0.7     0.9     0       1000    -3      #sd recruitments
        -5      5       0       0       0       1       -3      #env link
        -5      5       0       0       0       1       -3      #init_eq

0 #index of environ variable to be used
#       start_rec end_rec Lower upper   phase
        2004    2003    -15     15      -2
#init_F
#       Lo      Hi      init    prior   prtype  sd      phase
```

0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.00000001	0.000	0	1000	1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1
0	.2	0.000	0.000	0	1000	-1

#Qsetup
#add param row for each positive entry below

#float	dopowe	doenv	dodev	envvar	numbio (1=biomass, 0=num)
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0

#lo	hi	init	prior	prtype	sd	phase
-50	50	-15	-5	0	1000	1 # float est for
-50	50	-15	-5	0	1000	1 # float est f0r
-50	50	-15	-5	0	1000	1 # float est for

#selex and retention

#selextype	doretention		do male		mirror
1	0	0	0	#fleet1	
7	0	0	0	#fleet2	
7	0	0	0	#fleet3	
7	0	0	0	#fleet4	
7	0	0	0	#fleet5	
7	0	0	0	#fleet6	

7	0	0	0	#fleet7
7	0	0	0	#fleet8
5	0	0	4	#fleet9
5	0	0	5	#fleet10
5	0	0	6	#fleet11
5	0	0	7	#fleet12
5	0	0	8	#fleet13
5	0	0	1	#fleet14
5	0	0	4	#fleet15
5	0	0	5	#fleet16
5	0	0	4	#fleet17
5	0	0	6	#fleet18
5	0	0	4	#fleet19
5	0	0	5	#fleet20
5	0	0	6	#fleet21
5	0	0	7	#fleet22
5	0	0	8	#fleet23
5	0	0	4	#fleet24
5	0	0	5	#fleet25
5	0	0	2	#survey1
5	0	0	4	#survey2
5	0	0	4	#survey3

#age selex

10	0	0	0	#fleet1
10	0	0	0	#fleet2
10	0	0	0	#fleet3
10	0	0	0	#fleet4
10	0	0	0	#fleet5
10	0	0	0	#fleet6
10	0	0	0	#fleet7
10	0	0	0	#fleet8
10	0	0	0	#fleet9
10	0	0	0	#fleet10
10	0	0	0	#fleet11
10	0	0	0	#fleet12
10	0	0	0	#fleet13
10	0	0	0	#fleet14
10	0	0	0	#fleet15
10	0	0	0	#fleet16
10	0	0	0	#fleet17
10	0	0	0	#fleet18
10	0	0	0	#fleet19
10	0	0	0	#fleet20
10	0	0	0	#fleet21
10	0	0	0	#fleet22
10	0	0	0	#fleet23
10	0	0	0	#fleet24
10	0	0	0	#fleet25
10	0	0	0	#survey1
10	0	0	0	#survey2
10	0	0	0	#survey3

#LO HI INIT PRIOR PR_type SD PHASE env-variable use_dev dev_minyr dev_maxyr
dev_stddev Block_Pattern

70 270 200 200 0 99 2 0 0 0 0 0 0 0 0
0.001 60 30 2 0 99 3 0 0 0 0 0 0 0 0

70 290 160 160 0 1000 -4 0 0 0 0 0.5
0 0 #peak
0.0001 0.2 0.0001 .001 0 1000 -2 0 0 0 0 0.5
0 0 #init
-5 4 -.5 -.5 0 1000 2 0 0 0 0 0.5 0
0 #infl
0.001 5 .26 .26 0 1000 3 0 0 0 0 0.5
0 0 #slope
-5 10 -5 -5 0 1000 -3 0 0 0 0 0.5
0 0 #final

-10.	5	2.7	2.7	0	1000	3	0	0	0	0	0.5
	0	0	#infl2								
.001	5	0.001	0.001	0	1000	5	0	0	0	0	0.5
	0	0	#slope2								
0.1	20	10	10	0	1000	-4	0	0	0	0	0.5
	0	0	#width of top								

70	290	160	160	0	1000	-4	0	0	0	0	0.5
	0	0	#peak								
0.0001	0.2	0.0001	.001	0	1000	-2	0	0	0	0	0.5
	0	0	#init								
-5 4	-.5	-.5	0	1000	2	0	0	0	0	0.5	0
	0	#infl									
0.001	5	.26	.26	0	1000	3	0	0	0	0	0.5
	0	0	#slope								
-5	10	-5	-5	0	1000	-3	0	0	0	0	0.5
	0	0	#final								
-10.	5	2.7	2.7	0	1000	3	0	0	0	0	0.5
	0	0	#infl2								
.001	5	0.001	0.001	0	1000	5	0	0	0	0	0.5
	0	0	#slope2								
0.1	20	10	10	0	1000	-4	0	0	0	0	0.5
	0	0	#width of top								

70	290	160	160	0	1000	-4	0	0	0	0	0.5
	0	0	#peak								
0.0001	0.2	0.0001	.001	0	1000	-2	0	0	0	0	0.5
	0	0	#init								
-5 4	-.5	-.5	0	1000	2	0	0	0	0	0.5	0
	0	#infl									
0.001	5	.26	.26	0	1000	3	0	0	0	0	0.5
	0	0	#slope								
-5	10	-5	-5	0	1000	-3	0	0	0	0	0.5
	0	0	#final								
-10.	5	2.7	2.7	0	1000	3	0	0	0	0	0.5
	0	0	#infl2								
.001	5	0.001	0.001	0	1000	5	0	0	0	0	0.5
	0	0	#slope2								
0.1	20	10	10	0	1000	-4	0	0	0	0	0.5
	0	0	#width of top								

70	290	160	160	0	1000	-4	0	0	0	0	0.5
	0	0	#peak								
0.0001	0.2	0.0001	.001	0	1000	-2	0	0	0	0	0.5
	0	0	#init								
-5 4	-.5	-.5	0	1000	2	0	0	0	0	0.5	0
	0	#infl									
0.001	5	.26	.26	0	1000	3	0	0	0	0	0.5
	0	0	#slope								
-5	10	-5	-5	0	1000	-3	0	0	0	0	0.5
	0	0	#final								

70	290	160	160	0	1000	-4	0	0	0	0	0.5
	0	0	#peak								
0.0001	0.2	0.0001	.001	0	1000	-2	0	0	0	0	0.5
	0	0	#init								
-5 4	-.5	-.5	0	1000	2	0	0	0	0	0.5	0
	0	#infl									
0.001	5	.26	.26	0	1000	3	0	0	0	0	0.5
	0	0	#slope								
-5	10	-5	-5	0	1000	-3	0	0	0	0	0.5
	0	0	#final								
-10.	5	2.7	2.7	0	1000	3	0	0	0	0	0.5
	0	0	#infl2								

```
.001     5      0.001   0.001   0      1000    5      0      0      0      0      0.5
         0      0       #slope2
0.1      20     10      10      0      1000    -4     0      0      0      0      0.5
         0      0       #width of top

70       290    160     160     0      1000    -4     0      0      0      0      0.5
         0      0       #peak
0.0001   0.2    0.0001  .001    0      1000    -2     0      0      0      0      0.5
         0      0       #init
-5   4   -.5    -.5     0       1000   2       0      0      0      0      0.5    0
         0      #infl
0.001    5      .26     .26     0      1000    3      0      0      0      0      0.5
         0      0       #slope
-5       10     -5      -5      0      1000    -3     0      0      0      0      0.5
         0      0       #final
-10.     5      2.7     2.7     0      1000    3      0      0      0      0      0.5
         0      0       #infl2
.001     5      0.001   0.001   0      1000    5      0      0      0      0      0.5
         0      0       #slope2
0.1      20     10      10      0      1000    -4     0      0      0      0      0.5
         0      0       #width of top

70       290    165     160     0      1000    -4     0      0      0      0      0.5
         0      0       #peak
0.0001   0.2    0.0001  .001    0      1000    -2     0      0      0      0      0.5
         0      0       #init
-5   4   -.5    -.5     0       1000   2       0      0      0      0      0.5    0
         0      #infl
0.001    5      .26     .26     0      1000    3      0      0      0      0      0.5
         0      0       #slope
-5       10     -5      -5      0      1000    -3     0      0      0      0      0.5
         0      0       #final
-10.     5      2.7     2.7     0      1000    3      0      0      0      0      0.5
         0      0       #infl2
.0001    5      0.001   0.001   0      1000    5      0      0      0      0      0.5
         0      0       #slope2
0.1      20     10      10      0      1000    -4     0      0      0      0      0.5
         0      0       #width of top
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45  46   45  45  0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
```

```
1     14     1      1     0      25     -99    0      0       0      0      0.5    0      0      # fleet 2 start mirror low
45     46     45      45    0      25     -99    0      0       0      0      0.5    0      0      #fleet 2 upper mirror

1     14     1      1     0      25     -99    0      0       0      0      0.5    0      0      # fleet 2 start mirror low
45     46     45      45    0      25     -99    0      0       0      0      0.5    0      0      #fleet 2 upper mirror

1     14     1      1     0      25     -99    0      0       0      0      0.5    0      0      # fleet 2 start mirror low
45     46     45      45    0      25     -99    0      0       0      0      0.5    0      0      #fleet 2 upper mirror

1     14     1      1     0      25     -99    0      0       0      0      0.5    0      0      # fleet 2 start mirror low
45     46     45      45    0      25     -99    0      0       0      0      0.5    0      0      #fleet 2 upper mirror
# custom env read
0
#custom block read
0
-4              # phase for selex parms dev
#variance adjustment factors
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 .2 .1 .3
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 .6 1 .5 .4 .35 .5 .5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 #max lambda phases
0 # include (1) or not (0) the constant offset for Logs(s) in the Log(like) calculation
# survey lambdas
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 .1 1 .1
# discard lambdas
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
# mean body wt
0
#lenfreq lambda
.1 .1 .1 .1 .1 .1 .1 .1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
#age freq lambda
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
# size at age
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
#init equlib catch
1
#rec lambda
1
#parm prior lambda
0
#prior dev timeseries lambda
0
#crashpen lambda
100
#max F
0.9
9999
```