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STOCK SYNTHESIS MODEL FOR ATLANTIC YELLOWFIN TUNA

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SUMMARY

This paper represents a stock assessment of Atlantic yellowfin tuna using Stock Synthesis (SS). The model configuration is largely similar to that of the 2016 assessment and benefits from a joint longline index rather than several separate longline indices and homogenized the fleet structure. Initially we constructed a reference model and tested its performance across a suite of standard model diagnostic tests which indicated decent model performance. Then we produced a series of sensitivity models that evaluated different model formulations. After evaluation of the sensitivity runs, a structured uncertainty grid was developed, designed to capture much of the key uncertainties in model inputs and parameter assumptions. Four models were chosen for the uncertainty grid; two steepness (0.8 and 0.9) and inclusion/exclusion of the buoy acoustic index of recruits. Biomass trends were similar across model runs however the inclusion of the buoy index resulted in very high estimates of recent recruitment. Stock status averaged over the runs indicates that the stock is not overfished (mean SSB/SSB_{MSY} =1.27) and that fishing mortality is slightly above the target fishing rate (mean F/F_{msy}=1.01).

RÉSUMÉ

Le présent document représente une évaluation des stocks d'albacore de l'Atlantique à l'aide de Stock Synthesis (SS). La configuration du modèle est largement similaire à celle de l'évaluation de 2016 et bénéficie d'un indice palangrier conjoint plutôt que de plusieurs indices palangriers distincts et a homogénéisé la structure de la flottille. Au départ, nous avons construit un modèle de référence et testé sa performance à travers une série de tests diagnostiques standard qui indiquaient une performance décente du modèle. Nous avons ensuite produit une série de modèles de sensibilité qui ont évalué différentes formulations de modèles. Après l'évaluation des scénarios de sensibilité, une grille d'incertitude structurée a été élaborée afin de saisir une grande partie des principales incertitudes dans les données d'entrée du modèle et les postulats des paramètres. Quatre modèles ont été choisis pour la grille d'incertitude : deux steepness (0,8 et 0,9) et inclusion/exclusion de l'indice acoustique de bouée pour les recrues. Les tendances de la biomasse étaient semblables dans tous les scénarios des modèles, mais l'inclusion de l'indice de bouée a donné lieu à des estimations très élevées du recrutement récent. La moyenne de l'état du stock calculée pour les scénarios indique que le stock n'est pas surexploité (moyenne de SSB/SSB_{PME} = 1,27) et que la mortalité par pêche est légèrement supérieure au taux de pêche cible (moyenne de F/F_{PME} = 1,01).

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RESUMEN

Este documento representa una evaluación del stock de rabil del Atlántico utilizando Stock Synthesis (SS). La configuración del modelo es muy similar a la de la evaluación 2016 y los beneficios de un índice conjunto de palangre en vez de varios índices de palangre separados y la estructura de la flota homogeneizada. En principio construimos un modelo de referencia y probamos su desempeño a través de una serie de pruebas de diagnóstico de modelos estándar que indicaban un rendimiento decente del modelo. Luego produjimos una serie de modelos de sensibilidad que evaluaron diferentes formulaciones de modelos. Después de la evaluación de los ensayos de sensibilidad, se desarrolló una matriz de incertidumbre estructurada, diseñada para captar gran parte de las incertidumbres clave en los datos de entrada del modelo y en los supuestos de los parámetros. Se eligieron cuatro modelos para la matriz de incertidumbre; dos de inclinación (0,8 y 0,9) e inclusión/exclusión del índice acústico de boyas de los reclutas. Las tendencias de la biomasa fueron similares entre los ensayos de los modelos, sin embargo, la inclusión del índice de boyas dio lugar a estimaciones muy altas del reclutamiento reciente. El estado del stock promediado entre los ensayos indica que el stock no está sobrepescado (media de SSB/SSB_{RMS} = 1,27) y que la mortalidad por pesca está ligeramente por encima de la tasa de pesca objetivo (media de F/F_{RMS} = 1,01).

KEYWORDS

Yellowfin tuna, stock assessment, stock synthesis

Introduction

This paper presents a Stock Synthesis model for Atlantic yellowfin tuna with a timeframe from 1950 – 2018. Stock Synthesis assessment models have been applied throughout the tuna RFMOs. The integrated modeling framework allows for incorporation of multiple data sources including length, age, indices or environmental time series and provides age or length-structured catch advice. The current application provides an age and length-structured model useful for providing catch advice as well as informing on changes in size selectivity or fleet allocations. Stock synthesis version 3.24 was used for the 2016 assessment advice. In this application, we convert the model to version 3.30 which provides a number of useful additional features.

The basic model structure is similar to that of the 2016 YFT assessment (Walter and Sharma 2017) except that the model has joint longline indices calculated for three regions (SCRS-2019-081), reflecting potential differences in fish availability. All indices and fleets also conform to this spatial structure and there is no explicit modeling of movement across the areas, e.g. this represents a ‘fleets as areas’ model structure similar to the structure used in the 2018 BET assessment. The 2016 models entertained two index ‘clusters’; whereas the joint CPUE modeling exercise was able to reconcile conflicting indices across CPCs resulting in three indices, one for each region. The 2019 models also consider two additional indices; a juvenile index derived from acoustic biomass estimates from FAD buoys deployed prior to fishing (SCRS-2019-075) and a purse seine free school index (SCRS/2019/066) that attempts to account for fishing days without sets to better partition effort. Additionally a series of changes to the model to better account for fleet structural partitioning and changes in selectivity were incorporated.

The modeling approach also follows the structure of the 2018 BET assessment (SCRS-2019-111) to build an initial reference grid, then develop a series of sensitivities, screen these sensitivities across a suite of diagnostics and eventually build an uncertainty grid to account for both model and structural uncertainties in the eventual provision of management advice (ISSF 2018).

Methods

Stock Synthesis

Stock Synthesis (SS) is an integrated statistical catch-at-age model which is widely used for many stock assessments in the United States and throughout the world (Methot and Wetzel 2013). SS takes relatively unprocessed input data and incorporates many of the important processes (mortality, selectivity, growth, etc.) that operate in conjunction to produce observed catch, size and age composition and CPUE indices. Because many of these inputs are correlated, the concept behind SS is that they should be modeled together, which helps to ensure that uncertainties in the input data are properly accounted for in the assessment. SS is comprised of three subcomponents: 1) a population subcomponent that recreates the numbers/biomass at age using estimates of natural mortality, growth, fecundity, etc; 2) an observational sub-component that consists of observed (measured) quantities such as CPUE or proportion at length/age; and 3) a statistical sub-component that uses likelihoods to quantify the fit of the observations to the recreated population. Basic equations and technical specifications underlying Stock Synthesis can be found in Methot (2000). In these models, we use SS version 3.30.09.

SS Version 3.30 has many updated features from previous versions, notably it allows for greater precision in modeling temporal dynamics, in specifying future recruitment and more streamlined modeling of time-varying processes.

Conversion to SS3.30

The Run 5 (cluster 1) from 2016 model was converted from SS 3.24 to SS 3.30. The model gave almost identical results (**Figure 1**) with less than 1 loglikelihood difference.

Model spatial structure, temporal domain and initial conditions

The current model is constructed as a seasonal model with 4 seasons and a timeframe from 1950 – 2018. Much of the composition data is not available for 2018 so the model does not fit to any length or age data from 2018. Provisional catches for 2018 are input as data, however 42% of the 2018 catch represents carry overs of the same values from 2017.

The model has three areas for partitioning fleets-as areas, similar to the 2016 model and the 2018 BET model but does not have explicit movement between the areas and hence functions as a non-spatial, one-area model. The model starts in 1950 and assumes that the stock starts at virgin conditions and initial Fs were fixed at zero. The spatial structure for fleet construction is similar to the 2018 BET structure with some slight differences (**Figure 2**). This spatial structure as determined based on the work conducted by the joint CPUE modeling group and it also largely reflects spatial differences in mean size of the catch from the longline fleets.

Biological parameters

Biological parameters remain the same as in 2016, however the length-weight relationship used in 2016 was slightly different than that of Caveriviere (1976) and this relationship was used for the current model. Biological parameters are shown below.

Parameter	*Yellowfin*
Length-weight	Caveriviere (1976) length-weight relationship: $W(kg) = 2.1527 \times 10^{-5} * L(cm)^{2.976}$
Maturity schedule	Maturity at length as described in Diaha *et al.*, 2015: $P_{mature} = e^{\alpha+\beta L}/1 + e^{\alpha+\beta L}$ with 50% maturity at 115 cm, halfway between the estimates based on cortical alveoli (99 cm) and advanced vitellogenic oocytes (124 cm).
Fecundity	Use length-weight relationship
Sex ratio at birth	50:50 males:females
Birth date	One birth month (January, April, July and October) for each of the four seasons; with recruitment allocation estimated between the four seasons

Growth

Three sets of age data were available corresponding the Pacicco et al (2019) dataset from the longline and rod and reel in primarily the Gulf of Mexico, United States, the Shuford et al (2007) daily age dataset from Gulf of Guinea and North Carolina, U.S and the mean length at age derived from model progression from Gascuel et al., (1992) (**Figure 3**).

Regarding the utility of each dataset, the bomb-radiocarbon validation makes the Pacicco et al. (2019) annual aging dataset of high value. The Gascuel et al. (1992) assumed ages of cohorts makes an extremely strong assumption of a single January 15th birthdate for all cohorts, which is the reason for the flattening of the apparent growth data; earlier born fish appear to be very fast growing and later born fish appear to be slow growing. This is almost entirely a product of this assumed birthdate for a species with more continuous cohort production. Secondly, all of the 'apparent' ages in the Gascuel dataset used to fit the growth curve above age 4 were created by extrapolation and do not represent data. Additionally, this dataset is just length compositions with an assumed age and would be input more appropriately to SS as length composition rather than as actual age data. Hence, for the reference model this data will not be fit.

Originally daily ages from Shuford et al. (2007) up to age 1 were to be used to fit the models, however due to the potential bias that truncating the ages at age 1 (365 days) could have on estimated selectivities for the fleet that these fish came from this was undesirable. Hence for the reference model this data was not included in the model fitting.

A conditional age-at-length likelihood approach was used, the expected age composition within each length bin was fit to age data conditioned on length (conditional age-at-length) in the objective function, rather than fitting the expected age-composition data, which are typically calculated external to the model as a function of the conditional age-at-length data and the length-composition data. Eleven age classes (0-10) with 10 as a plus group were modeled. A plus group of 10 was used as very few (1.3%) of fish were present in the Pacicco et al. (2019) dataset beyond this age and none in either of the other datasets.

For input into SS data file, the Pacicco et al. (2019) dataset was assigned to the US rod and reel fishery (23_US_RR) and 19_Other_LL_N and assigned to the year and month they were collected. The Shuford dataset was assigned to either the 23_US_RR or to the Free school purse seine fishery (3_PS_ESFR2_9118_S1). Otoliths from very small fish captured in stomachs were not used as these fish could not be assigned to a gear. Mean length at assumed age from the Gascuel dataset was assigned to 1_PS_ESFR2_6585 and the corresponding year and month. Input sample sizes were equal to the number of observations in each dataset. Fish in the Pacicco et al. dataset above age 10 were assigned to age the plus group age 10.

Growth estimation

Data workshop recommendations for the reference model were to estimate growth internally to SS with a Richards (or von Bertanannfy) function fitted to the Pacicco otolith data and the Shuford daily ages up to age 1 and to fit to the Gascuel assumed cohorts as a sensitivity run.

Both a von Bertalanffy growth curve and a Richards growth curve was estimated by the model using the conditional age-at-length data and an aging error vector derived from the reference otolith collection aging workshop (Allman et al 2018) where multiple readings were conducted on bomb radiocarbon (Andrews et al 2019 *in review*) validated ages to estimate aging error. Multiple readings on the same otolith were combined and the standard deviation of estimated age at known age was used to obtain a vector of aging error (**Figure 4**). This provided an empirical estimate of aging error for input to SS.

age	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
error	0.19	0.31	0.43	0.55	0.68	0.80	0.92	1.04	1.16	1.28	1.75

To estimate growth in the models it was necessary to fix the seasonal recruitment allocations at values estimated from model runs without growth estimated, due to the fact that much of the Pacicco growth data came from the Gulf of Mexico with presumed birth dates of ~July 1. This too strongly influenced the estimation of seasonal allocation of recruitment. Hence, to estimate growth, these parameters were fixed at 0, which corresponds to a seasonal allocation of recruitment.

To estimate growth in the first couple of months it is necessary to grow fish from the size at settlement or hatching. Most growth curve estimates have unrealistic y-axis intercepts, Gascuel et al., (1992) and Pacicco et al., (2019), included, so it is necessary to invoke a useful scaling from around the 0,0 point up to the first observations of size at age. For yellowfin tuna we are fortunate to have the Shuford et al (2007) daily ages and fish captured from predator stomachs that were only several days old, providing an anchor point as well as a size (*size at amin*, assumed to be 25 cm, based on visual inspection of the daily aging (**Figure 1**)) and age (the *amin* parameter in SS, assumed to be 0.38, also based on visual inspection) for which SS applies a linear ramp from the minimum population bin size (5 cm). In this case the growth curve goes linearly from age 0 at the first size bin (10) through the very young fish and up to the age 0.38 and size of 25 cm data point and then estimates the remaining growth parameters (L_{inf}, *K*, *Richards parameter* and *CV young* and *CV old*). The CV on size at age is modeled as function of length at age and was estimated initially in the modeling and then fixed for the reference grid models.

As a sensitivity run (Run 2) growth was also estimated with a Von Bertalanffy function and was quite similar but with a slightly higher L_{inf} (**Figure 2**). This model had better diagnostic performance in jittering and fewer strongly correlated parameters and was overall more stable for use as an estimation model, though once growth was fixed at the Richards function for the reference and uncertainty grid models this instability was no longer an issue.

Natural mortality

Natural mortality was originally specified at the data workshop as three vectors scaled according to the Pacicco growth curve using a maximum age of 18 and the Then et al. (2016) M estimator giving a baseline M=0.35. This scaling yielded two curves and then using a range of M based on 1.96 x the standard error around the Then et al estimator gave upper and lower values of 0.65 and 0.18. There were several problems with this scaling. First the Pacicco et al (2019) growth curve estimates age 0 fish at 70 cm; an unrealistic size in the first year of life. Second, the upper and lower values were quite extreme representing a 49% reduction and 86% increase from the reference value of 0.35. A similar issue exists with the Gascuel et al growth curve as neither Pacicco nor Gascuel et al curves address age 0 growth well. The best available information on age-0 growth comes from the daily aging work of Shuford et al (2007). Hence it was desirable to scale M according to a growth curve that more realistically represents growth during age 0. Size at age 1 from the daily aging is much closer to 50 cm than 70 cm. Similarly, size at age 0.5 appears much closer to ~30 cm than the 40 cm that the Gascuel et al. (1992) curve would indicate. Hence to achieve a scaling of M that is consistent with the need to parameterize growth in the first couple of months we used the growth curve estimated in SS, as specified in the section below on growth.

The original scaling of M as provided by the DW was as follows:

	0	1	2	3	4	5	6	7	8	9	10
DW low M=0.18	0.322	0.258	0.224	0.204	0.192	0.183	0.177	0.173	0.170	0.168	0.166
DW reference M=0.35	0.627	0.501	0.436	0.397	0.373	0.356	0.345	0.337	0.331	0.327	0.324
DW high M=0.65	1.164	0.930	0.809	0.738	0.692	0.661	0.640	0.625	0.614	0.607	0.601

Subsequently we reevaluated this scaling using the SS estimated growth curve and provide a scaling with a range of +/- 20%

M=0.55, 2016 scaling using Gascuel et al. 1992	1.59	1.19	0.75	0.55	0.48	0.45	0.44	0.43	0.43	0.43	0.43
M=0.35, scaled to SS estimated Richards growth	1.55	0.80	0.49	0.38	0.34	0.32	0.31	0.30	0.30	0.30	0.30
M + 20%= 0.42	1.88	0.97	0.59	0.46	0.41	0.39	0.37	0.37	0.37	0.36	0.36
M - 20% = 0.28	1.25	0.65	0.39	0.31	0.27	0.26	0.25	0.25	0.24	0.24	0.24

At the assessment workshop natural mortality (M) was reparametrized by age according to Lorenzen (2005), scaling to the growth curve (section 3.1.3). This was conducted internally to the model to be consistent with the growth treatment in the model by assuming a value of natural mortality of 0.35 assigned to age 5 (baseline M), consistent with the Then et al. (2017) estimator of M, and assuming a maximum age of 18. The resulting M-at-age vector is defined below and was used in the final grid models:

Age	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
M	1.3	0.66	0.48	0.4	0.37	0.35	0.34	0.34	0.34	0.33

Fleet structure

Twenty-five fleets were used in the model set up (**Table 1**). Fleet structure received a substantial restructuring from the 2016 model with the fleets mostly created to match the 2018 BET assessment with a few differences specific to YFT. The US rod and reel fleet was maintained as a separate fleet as well as the PS-West which was purse seines from the U.S and primarily Venezuela. The emergent Brazilian handline fishery was assigned to its own fleet however the limited size composition meant that its selectivity required mirroring with that of a fishery with assumed similar selectivity (TRO BB north Dakar Late). Later in the assessment meeting this was replaced with a prior distribution developed from AOTTP tag return data. Another-other fleet comprised of a mix of handline and longline and other fleets was subsequently reallocated to longline or baitboat fleets when it could be identified as such.

Initially each of the four PS FAD and PS FS fleets were allowed to have their own selectivity, however preliminary testing indicated that the slightly improved resolution in seasonal selectivities did not improve model fit when accounting for the additional 7 parameters necessary for each separate spline functions. Hence the selectivities were mirrored across all four PS FAD and PS FS fleets (**Table 2**).

Selectivity

Three different selectivity functions were used, depending on the nature of the length composition data. For many of the purse seine fisheries the length data is bimodal as the fisheries are often a mixture of targeting of large YFT on free schools and setting on floating objects (logs, debris, etc.) to target smaller tunas, primarily skipjack. Historically there was no separation in the data which necessitated modeling bimodal length composition fleets. Since 1991 the Purse seine fleet has increasing deployed Fish Aggregating Devices, primarily to target skipjack tuna. Data is separated now between FAD (and other floating objects) and Free school fisheries allowing for greater precision in modeling removals, however there remains some clear bimodality in the length composition of this fleet as well as in the 11_BB_PS_Ghana_6518 fleet.

To model these complex length compositions it was necessary to employ cubic spline functions estimated independently for the selectivity of the Purse seine fleets and the 11_BB_PS_Ghana_6518 fleet. Selectivity parameters were estimated for a series of length-class nodes, with cubic spline interpolation between nodes (the default node spacing within SS3 corresponding to the first node is at the size corresponding to the 2.5% percentile of the cumulative size distribution and the last at the 97.5% percentile). The length-based concept is applied in the calculation of the predicted catch-at-length distribution. However, the length-based selectivity is converted to an age-based selectivity for purposes of removing the appropriate portion of the population in the catch. The function is flexible enough to represent dome-shaped, monotonically increasing (e.g. logistic), and polymodal functions (and was motivated by the clear bimodal distribution of the PS fleet). Several time blocks were employed to match changes selectivity of the fleets (**Table 2**).

The tropical (Region 2) longline fleets used logistic selectivity with an asymptote to full selectivity at an estimated length. For longline fleets in Region 1 (North) and Region 2 (South) double normal selectivity was estimated to allow for either domed or asymptotic. This decision was based on maps of the mean size (**Figure 4**) which indicated the largest mean size in Region 2. For the baitboat and other fisheries, double normal selectivity functions which could be estimated as either domed or asymptotic were used. For estimation of most of the double normal selectivities a smooth increase from 0 or a smooth decrease (-999 in SS coding) was used, depending on the absence of either small or large (or both) fish in the composition data.

Several time blocks for selectivity were imposed corresponding to apparent changes in the selectivity (**Table 1**). The PS FAD fleets (7-10) have time blocks imposed starting in 2003 where the fleet switched to almost all FAD fishing. Fleet 11_BB_PS_Ghana_6518 and the fleet 12_BB_area2_Sdak fleet both had time blocks in 2010 where there was a clear shift in the size composition, however it is not clear what caused this. A size limit of 69 cm was put in place for the US RR size composition due to regulatory size limit. 100% discard survival was assumed for the discards. The 20_Other_LL_TRO and 17_Japan_LL_TRO longline fleets had time blocks starting in 1992 similar to BET. A time block starting in 1979 was explored in sensitivity run 23. Several additional time blocks were recommended at the data workshop and are documented in **Table 1.**

Catch

Catch data was partitioned into the 25 different fleets by quarter and year and input with a standard error of 0.01, which conditions the model on catch and assumes that it is almost known without error. A number of options in SS 3.30 allow for different error on catch, which may be useful to explore for fleets where quantification of the catch has proven problematic, however this was not explored at this time.

Catch data for 2018 consists required carry over assumptions for about 42% of the catch as not all 2018 data was available for every fleet by the start of the modeling.

Length composition

Length composition data (in straight fork length in centimeters) was initially processed by the Secretariat to remove outlier fish sizes and to achieve generally homogenous fleet structure. Fifty length bins from 5-220 cm in mostly 4 cm increments were used for the data and the population and no tail compression was applied, nor appeared necessary in the fits. Originally the length composition data was provided in 2 cm bins, however condensing the bins decreased run time with no detectable difference in results.

Length composition was input with an initial sample size equal to the ln (N) to decrease the weight of replicate samples within a fleet, season, year combination. Length composition weights (lambdas) were initially given a value of 0.5 to further reduce their influence on the overall log likelihood with subsequent reductions to 0.25 and eventually 0.1. These weighting factors are multiplied by the corresponding likelihood component to calculate the overall negative log likelihood to be minimized and lower lambdas reduce the influence of a component.

No length composition data is available for 2018 so the model did not include any length data for this year.

Indices

A major advancement in this assessment is the development of a joint longline index with data from Japan, USA, Brazil, Korea, and Chinese Taipei (SCRS_2019_081). This index was constructed for 3 regions (**Figure 1**) and the index for region 2 (Equatorial) was recommended for the reference grid with the indices for region 1 and 3 to be used in sensitivity runs. This index was linked to the Japan longline composition data for estimating its selectivity. Selectivity was estimated separately for region 2 and selectivity was mirrored for region 1 and 3 and modeled as double normal. A time block on selectivity was imposed starting in 1992 to account for changes in targeting to bigeye tuna. The reason to use the Japan longline selectivity for this index was to be able to maintain a consistent set of length composition, as the variable sample sizes of different fleets over time would have created a variable length composition. Additionally, the Japan longline fleet represents the majority of the length composition and would generally dominate the selectivity for the joint index.

Two other additional indices were considered for inclusion as sensitivity runs; an acoustic index derived from echosounder receivers placed on FAD buoys prior to fishing (SCRS-2019-075) and a purse seine free school index (SCRS_2019_066) that improves upon the definition of effort in the purse seine fishery and includes searching time as well as zero sets. The Buoy index was linked to the PS FAD fishery in each of the four quarters and should presumably inform the model on recruitment.

The PS FS index was calculated separately for each quarter but as the fishery catches (and presumably the availability of YFT in the tropical region) peak in quarter 1, only quarter 1 index was used. The index selectivity is for very large fish and the model has no ability to account for seasonal variation in the availability of large fish, other than through different selectivity and catchability for each quarter. As the decision was made to mirror selectivity across all four seasons, there was no strong reason to use all four quarters of the index, as the expected values of the index would be almost entirely parallel. The first two years of the FS index were considered to have uncertain reporting and were removed from fitting.

Longline Indices were input as annual indices with a mean CV=0.2 but allowed to vary with the interannual variability in the estimated standard error of the index. The index variance was modeled as lognormal and the index CV was converted to log-scale standard errors for input = logscale SE= $\sqrt{\ln(1 + CV^2}$. The buoy acoustic and the purse seine free school index were input with mean CVs of 0.3, but allowing for interannual variability in precision according to the model-estimated variance.

To obtain the interannual variance for the joint index the geometric mean of each seasonal CV was obtained and used as input for the annual index. Indices were input as annual values. Evaluation of the 2015 model comparing index input as seasonal or annual indicated very little difference between either type of input.

Tagging data

Tagging data, mostly from AOTTP was formatted for input to the assessment. The tagging data may be valuable to assist in estimation of fishing and natural mortality rates and was formatted for input to SS as a sensitivity run. Time limitations of the meeting prohibited more comprehensive evaluation of this model.

Data weighting

Input sample sizes for the length composition were initially input as the natural log of the sample size. This greatly diminished the input sample sizes which often were in the 1000s. We futher reduced the length composition weight by using an emphasis factor of 0.5, 0.25 and then eventually for the reference model a value of 0.5. This was necessary to allow the model to fit the single index due to the substantially greater likelihood contribution from the length data. Then the input variance adjustments were altered according to recommendations in Francis 2011 where the input sample size for each fleet was adjusted upward or downward with a multiplier (the variance adjustment) corresponding to Francis (2011) method TA1.8 which allows for correlations and finds weights that minimize the difference between the observed and expected variance of mean size. Then the model was re-rerun, repeatedly until the input length composition sample size achieved a stable reweighting.

Stock recruitment parameterization

A Beverton-Holt stock recruitment relation was used to model the number of recruits as a function of spawning stock biomass. Virgin recruitment (R0) was freely estimated and steepness (h) was either fixed at a value of 0.8 for the reference case and at 0.7 or 0.9 for other models. Profiling of steepness indicated that there was insufficient information in the model to freely estimate it. Annual variation in recruitment (sigma-r) was estimated. The estimated total annual recruitment was distributed across the four seasons according to seasonal allocations estimated in the model. Deviations in annual recruitment were estimated from 1960 to 2017 with the lognormal bias correction ($-0.5\sigma^2$) for the mean of the stock recruit relationship applied during the period 1960 to 2017 with a bias correction ramp applied initially according Methot and Taylor (2011) recommendations.

Model Diagnostics

Model convergence was assessed using several means. The first diagnostic was whether the Hessian, (i.e., the matrix of second derivatives of the likelihood with respect to the parameters) inverts. The second measure is the maximum gradient component which, ideally, should be low (<0.0001 is a standard value). The third diagnostic involved altering or jittering the starting values of the parameters to evaluate whether the model converges to a global solution, rather than a local minimum.

Other diagnostics included likelihood profiling of key parameters (steepness, R0 and M), evaluation of fits to residuals for indices and length composition, retrospective analyses and sensitivity to different indices and compositional data inputs. Likelihood profiles were completed for three key model parameters: steepness of the stock-recruit relationship (h) and the log of unexploited equilibrium recruitment (R_0) (including the log(R_o) with steepness estimated, for run 3) and M for several of the models in consideration for the reference model. Likelihood profiles elucidate conflicting information among various data sources, determine asymmetry around the likelihood surface surrounding point estimates and evaluate the precision of parameter estimation. Retrospective analyses are also standard diagnostic practice and were conducted on models 1 and 3 and 20 for 5 year retrospective peels as well as many of the sensitivity runs and all of the uncertainty grid models.

Parameters Estimated

Overall the models have 122-126 estimated parameters, consisting of 58-60 selectivity parameters, 2 stock recruitment parameters, 0-6 growth parameters, 3 seasonal recruitment allocations and 59 recruitment deviations (**Table 4**). For several of the cubic spline parameters Beta prior distributions were used to aid in model stability (**Table 4**). Parameter estimates, standard errors and prior distributions for model 1 are shown (**Table 4**) results are similar for most parameters across the other models and are not shown here for brevity.

Benchmark and fishing mortality calculations

For overall fishing mortality rate, the exploitation rate in biomass was used, similar to the 2016 assessment. The F is calculated numbers weighted F as Z-M where Z and M are each calculated an ln(N(t+1)/N(t)) with and without F active, respectively. The numbers are summed over all areas for the beginning of the year. Benchmarks *MSY*, B_{MSY}, F_{MSY} and equilibrium yield estimates were calculated on the basis of the F_{age} distribution (selectivities) estimated for the terminal 3 years in the model (2016-2018). Given the substantial changes in overall selectivity over time, the F and B_{msy} benchmarks are also estimated on a year-specific basis according to the fleet allocation in that year for the Kobe 'snail plots'.

Uncertainty Quantification

Uncertainty in model parameters, derived quantities and stock status was quantified by using asymptotic standard errors derived from the variance-covariance matrix. Kobe advice was developed similar to the approach used in BET by using the uncertainty grid and the log-multivariate normal approximation approach to quantify structural or across model uncertainty (SCRS/2019/080) or within model uncertainty (Winker et al., 2019).

Development of a reference case

Initially the model structure was designed to be similar to the 2016 assessment (Walter and Sharma 2017) and a series of stepwise changes were made (**Table 2**). The major changes from 2016 were in the assumed natural mortality baseline rate for the reference model (m=0.35) and its scaling according to the estimated growth from Run 1 (Richards) rather than using Gascuel et al., (1992). This resulted in a much higher total biomass in the population as overall M is substantially lower. Other major changes included restructuring the longline fleets and seasonal separation of the recent purse seine FAD and FS fleets.

Development of sensitivity runs

A series of 19 runs (**Table 4**) were outlined at the data workshop. An additional three sensitivity runs were added to evaluate fixing growth at the best estimate (from run 1) but also including the conditional age at length data rather than excluding at as it was done in run 3. Two additional runs also use the 3.30-converted Run 5 from 2016 to evaluate the reason for the differences between the 2016 assessment and the current assessment.

Additional analyses conducted during the assessment workshop

At the assessment workshop several key data issues emerged. First the length composition for Fleet 12 BB_area2_Sdak exhibited a substantial increase in average size (**Figure 10**) which was determined to be due to inclusion of fish from South Africa. During the assessment workshop meeting, a more detailed review of the size composition of each fleet and feedback from scientists familiar with the fisheries, suggested a need to restructure of some of the fleets, add in time blocks on selectivity and remove clear data outliers. These changes are documented in the assessment workshop report and not further documented here. These changes led to a better prediction of mean lengths and improved the Pearson residuals from the fit to the length composition.

Additional sensitivity runs

At the assessment workshop a series of additional 14 sensitivity runs were conducted to address various concerns of the group (**Table 3**).

Changes to recruitment estimation

During the meeting analyses showed that the reference model fit tended to produce unusually large recruitment peaks in 2017 and 2018, due primarily to the information from the BAI index that is treated as a recruitment index. Noting that there is no size composition data in 2018 in this model to corroborate or contrast with these high recruitment estimates, the Group decided to fix the 2018 estimates of recruitment to the stock recruitment curve rather than estimate them. Not estimating the recruitment deviation for 2018 substantially improved the reference model diagnostics.

Data weighting

Input variance adjustments were iteratively adjusted according to recommendations in Francis (2011), as outlined above. For the final reference grid models the length composition was further downweight the length composition data with a lamda of 0.5 to better fit the indices relative to the length composition.

Index inclusion

During the assessment workshop the group evaluated the inclusion of the PS_FS index and the buoy acoustic index (BAI). Initial model runs did not include these indices, however the group found not clear diagnostic performance rationale for excluding the PS_FS index and the BAI index from the models, nor was there any strong objection from the group for including them. Therefore, the group decided to include the PS_FS index in all four grid runs. As the BAI index was highly influential for recent recruitment, particularly for 2018 when no composition data was available to observed age 0 fish, the group determined the recruitment deviations should not be estimated for 2018.

Projections

Projections were conducted on the uncertainty grid models and are documented in SCRS/2019/145. Quantification of uncertainty for the Kobe 2 strategy matrix was conducted using the multivariate log normal approximation method (Walter et al., 2019, Winker et al., 2019).

Results

Most all of the initial changes and sensitivity runs outlined at the data workshop were implemented (**Table 2)** and they provide a solid foundation for developing a reference model and an uncertainty grid. The full listing of model runs, likelihoods and some diagnostic criteria are in **Table 3**.

Initial diagnostic performance for initial reference model and selected sensitivity runs

All sensitivity runs had positive definite hessians and maximum gradient components less than 0.0001 (**Table 3**). Most parameters (only estimates for preliminary Run 1 shown in **Table 4**) had relatively low standard errors except some of the spline parameters, the Richards K parameters and the descending limb of the PS-West, though some of the CVs are misleading as the parameters themselves were estimated to be very close to zero, inflating the CV. Plots of the parameter prior distribution and maximum likelihood estimates are included in each of the run folders and are more informative about parameter estimability. Also there were relatively few highly correlated parameters (**Table 5-7**) with a few notable exceptions being K and the Richards growth parameter. Only the 3 area model has some bounded parameters and all other models have no bounded parameters. The dynamic B0 diagnostic showed that the initial reference model exhibited a noticeable positive trend in recruitment from 1995-2005 (**Figure 16**).

We conducted full diagnostic evaluation at this point only on runs 1 and 3 which constitute the initial settings of the reference grid with CAL and growth estimated (Run 1) and without CAL and growth fixed (Run 3). Initial diagnostic performance based on jitters indicates some instability for Run 1 (**Figure 14**.) This jitter instability is largely attributable to the very strong negative correlation (-0.95) between K and the Richards shape parameter (**Tables 4-6**). The instability largely disappears with von Bertalannfy growth (Run 2) and entirely with growth fixed at the parameters of the lowest log-likelihood from Run 1.

Profiling of the key parameters (R0, steepness, sigmaR and M) for run 1 (Figures 15 and 16) and run 3 (**Figures 17-20**) indicates that R0 can be estimable but that steepness is not. There is some conflict between the age data and the length data regarding R0, where the age data favor a higher value of R0, relative to the length data. Further due to the rather high correlation between steepness and R0, fixing certain values of steepness largely pre-determines R0. Hence it was necessary to fix steepness or employ prior distributions acknowledging that it has an effect on the estimated R0. Sigma R appears estimable (**Figure 20)** using the Methot and Taylor bias correction ramping. Hence it is probably unnecessary to include different values of sigmaR as part of the uncertainty grid as in BET. Further profiles for natural mortality at age 5 for Run 3 (no age comp, fixed growth) appear to indicate a minimum at around 0.4, which is largely driven by the length composition data from the two tropical longline fleets which have assumed asymptotic selectivity and the early purse seine fleet, which also has estimated asymptotic selectivity due to free school fishing. Hence there appears signal in the length composition data alone to estimate M and two additional model sensitivities (16 and 17) do exactly that.

Retrospective performance indicates some bias in preliminary Run 1 where growth was estimated (**Figure 23**). A similar pattern was observed in the 2016 assessment and it entirely disappears when growth is fixed at the subsequent estimates (**Figure 24**) and mostly disappears when growth is fixed and the CAL data retained in the fitting (**Figure 25**). As the Pacicco growth data starts in 2011 and most of the data is post-2013, this pattern is likely a result of the model simply getting a better estimate of growth with each additional year of otolith data. Hence it is unlikely to be a pathological problem for future projections.

Plots of the dynamic B0, which show the population trajectory with and without fishing to determine if the model has to deviate substantially from the stock recruitment function to maintain the population trajectory. In both cases the model does allow recruitment deviations to build the population up to virgin conditions in 1975, which is odd given that this is the start of intensive fishing.

Fit to the joint index, region 2 show some residual patterns (**Figures 26 and 27**) particularly at the start of the time series for both model 1 and 3. Fit to the buoy index was relatively good though the model does not match the seasonal variability (**Figure 27)**. This warranted further evaluation, in particular allowing the model to better capture the seasonal variation, particularly as it relates to whether the index can actually indicate seasonal recruitment variability or seasonal availability. If it reflects availability then it can be modeled as assigned to each fleet so that it would have a separate q for each season. In contrast, if the variability is indeed due to seasonal recruitment, we would want a constant q and then let this seasonal difference in index scale inform recruitment. At the assessment workshop the group decided to model the index as linked to each fleet and hence having a separate q.

This provided improved fits but did not use the seasonal variation of the relative value of the index to inform allocation of recruitment. Further consideration of this index and how best to model it is needed in the future. Similarly the model does not fit the seasonal variation in the PS FS index unless, nor would it be able to do so unless separate q's were estimated for each season (**Figure 29**). Hence the index was input for just season 1 when the bulk of the PS FS catch comes from. The model generally does not fit the index well and it remains to be seen how best to treat this index in the modeling, an issue considered in a later section.

When all three joint longline indices are fit together the model (**Figure 30**) it fits the region 1 and 3 indices better but, surprisingly, does not downgrade the fit to Region 1 substantively, indicating that the model can reconcile the apparently conflicting patterns (by eye) through selectivity differences.

Log likelihoods	run 3 (fit to just 17)	run 12 (fit all 3)
16	-44.061	-51.4382
17	-50.9733	-51.5579
18	-36.5579	-51.721

Diagnostic evaluation of fits to length composition data indicate no particularly problematic fits and quite acceptable performance overall (**Figure 31**). There is noticeable attraction to whole number bin sizes (50cm, 100, 150 cm) that resonates throughout all of the length composition data (**Figures 9-13**) It seems possible that these are due to recording and not due to either biology or the fishery. Hence the horizontal lack of fit at these sizes may reflect the fact that the model cannot account for the higher proportion of 50, 100 and 150 cm fish in the samples. The full suite of diagnostics (Pearson residual plots, fits for each season, year and fleet) for length composition fits are shown in the individual report files for each model but not shown in this report for brevity.

Selectivities showed three general patterns (**Figure 32**). Selection for small fish for the PS fleets and a switch from bimodal but mostly smaller fish to bimodal but more larger fish for Purse Seine Fleets (**Figure 33**) and then a clear selection for very small fish in the most recent Purse Seine FAD fisheries. Fleet 11_BB_PS_Ghana_6518 was modeled with a cubic spline but the remainder of the baitboat fleets were modeled with double normal functions and relatively strong doming (**Figure 34)**. For the longline fleets most of selectivities in region 1 and 2 were modeled with double normal selectivity and showed strong doming (**Figure 35**). For region 2 (tropical areas) these longline fleets were modeled with logistic selectivity. Handline, rod and reel, PS-West and Oth-Oth fleets were modeled as double normal selectivity (**Figure 36).** Given the magnitude of the Oth_Oth fleet's catches and its relatively consequential impact in profiling, it was advisable to better categorize these catches into some of other fleets so that the selectivity can be better modeled, a task accomplished at the assessment workshop.

The estimated stock recruitment relationship shows little evidence of a relationship between SSB and recruits (**Figure 37**). The effect of using the low value of the maximum bias correction is that there is very little difference in absolute magnitude of the expected recruitment with or without the bias adjustment. Time series of SSB indicates a long-term decline in SSB with the current estimates to be at the lowest level in the time series (**Figure 38**). Recruitment deviations shows some trend in residuals with higher recruitment around 1975 as well as a noteworthy spike in 2017.

Moving from 2016 models to 2019 models

Two model runs 21 (Run 5, 2016 and new M vector) and 22 (Run 5, 2016 and joint LL index) were conducted to evaluate the impact of the changes to the modeling. Clearly the major change is the absolute scale of the virgin biomass which is now estimated to be much higher than in the 2016 model. This scaling change comes about due to the change from the old M vector (with a baseline M=0.55, scaled to Gascuel growth) to the new m vector with a base of 0.35, scaled with the revised growth. The effect of the joint index alone has no effect on scaling. However it appears that it is not just the natural mortality nor the index (**Figure 34**) that scales the population so this may warrant further evaluation.

Reference grid development

Four runs were chosen for the reference grid: 1: The following characteristics were common to all runs: the Richards growth function was fixed to parameter values estimated internally by stock synthesis using age data from US/GOM, no conditional age at length data was used in the likelihood (lambda set to 0), M was scaled according to the growth curve using $M_{age\ 5=}$0.35, recruitment deviations were not estimated for 2018, a lambda of 0.5 was used to downweight the length composition data. Runs 1 and 2 used steepness values of 0.8 and 0.9, respectively. Runs 3 and 4 added the buoy acoustic index.

The reference grid runs were developed by evaluation of the diagnostics, notably the hindcasting and retrospective patterns. These are documented in the assessment report (Anon 2019).

Index fits (**Figures 41-44**), aggregate length composition fits (**Figures 45-48**) show fairly good fits. Trends in SSB, total biomass, F (exploitation rate in biomass) and recruitment are shown for models 1-4 (**Figures 49-52).** Parameter estimates, correlated parameters and index variance estimates are shown in **tables 10-14**. Estimated selectivities are almost identical across the model runs (**Figure 53**) as well as stock recruitment relationships, with the exception of the assumed fixed steepness values (**Figure 54**). Recruitment and recruitment distribution by season are similar, except in the recent years where high recruitment is estimated in the models that use the BAI index (**Figure 55**). Numbers at age show little evidence of very strong cohorts and a slight decline in mean age of the population over time (**Figure 56**). Overall the model runs are quite similar in SSB trends (**Table 15**), recruitment and fishing mortality rate (**Table 16**, **Figure 57**) with the primary difference being recent recruitment and Fstatus and SSB status differ slightly (**Figure 58**) for the two values of steepness. Stock status advice averaged over the four runs (**Table 17**) indicates that the stock is not overfished (mean SSB/SSB_{msy} =1.27) and that fishing mortality is slightly above the target fishing rate (mean F/F_{msy}=1.01).

Dynamic benchmark calculations were obtained to estimate the year-specific F_{msy}, SSB_{msy} and MSY that would result from each year's fleet allocation and selectivity patterns. The SSB_{msy} and Fmsy show an increase and a decrease in MSY since the initiation of the FAD fishery. There is a slight increase in the MSY in the recent three years due to a slight increase in selectivity on older fish in recent years (**Figure 60**).

Full diagnostic evaluations of the reference grid

Full diagnostic evaluations of the four reference grid models were conducted and included jittering starting values, likelihood profiling of key parameters, retrospective analyses, ASPM diagnostics and retrospective hindcasting. Full results of these diagnostics are included in the full stock assessment report and figures are not repeated here.

Discussion

Overall the four grid models exhibit fairly good diagnostic performance and span several ranges of uncertainty. The first range is in basic stock productivity captured by two steepness values (0.8 and 0.9). The second range is in recent recruitment in which case use of the BAI index indicates the highest recruitment in 35 years, for which the only support comes from the BAI index as no length composition data is used in the model for 2018 that would confirm these recruitments. Hence the uncertainty grid equally encompasses two alternative views about recent recruitment, either that it is high or that it reverts to the average for 2017 and 2018.

This SS modeling treatment differs substantively from previous models in several ways. First the model uses two novel indices: the buoy acoustic index and the purse seine free school index. These buoy acoustic index is novel in that it uses the FAD echosounder buoy data from the ~30 days before that FAD is actually fished to obtain an acoustic biomass index which is partitioned by Task II species composition into fraction of YFT. This index is intriguing as it provides a recruitment signal to the model, however it remains unclear how best to model it, and there remains some concerns over whether the species partitioning obtained from Task II data adequately applies to partition the acoustic biomass underneath an individual buoy. The index is poorly fit during the time period when there is length composition and other index data to inform recruitment, so it is unclear whether the index is a good indicator of YFT recruitment. Further work with the species partitioning and construction of the index for both SKJ and BET would be useful. Additionally, it would be useful to incorporate the variance of the species partitioning into the variance of the index. Lastly, the treatment of the index as conducted in this modeling does not allow for it to inform the seasonal partitioning of recruitment, which the index likely should, unless there is major seasonal change in availability of recruits.

The free school index is also intriguing as it accounts for search time and zero catches. Nonetheless concerns could remain that the index could suffer from unaccounted for technological creep and hyperstability, a condition known to plague purse seine indices. While the index was used in the modeling, maintaining the integrity of purse seine indices in the face of constant technological change as well as a changing regulatory and fishery environment is necessary. Further we note that the index does not account for potential environmental change such as expanding of the oxygen minimum zone that might increase vulnerability of fish to surface gear.

Additionally, this modeling uses a single joint longline index rather than two index ‘clusters’ as in 2016. This reduces the conflict apparent in the 2016 models and provided a consistent longline index. The group chose to use only the index from the equatorial region as this is where the bulk of the catches come from.

The major differences in the results between the 2016 SS models and the current grid models lies in the absolute scale of the estimated biomass. The reduction in natural mortality from 0.55 to 0.35 resulted in an expected reduction in F_{msy} and in the productivity of the stock. However the current assessment estimates the population to be substantially larger than in 2016. The exact reason for this is that the current assessment has overall selectivity much lower on older ages than the 2016 model (**Figure 61**). Several major fleets have more domed selectivity (**Figure 62**), notably the PS-FAD fleets in the early time period (1991-2014) are now estimated to be very dome shaped versus near asymptotic in the 2016 assessment (**Figure 63**). Secondly this assessment explicitly partitions the longline fleets into three areas (North, equatorial and south) and estimates selectivity in the North and South regions to be domed (**Figure 62**). The early time period of PS-FAD selectivity in 2016 was likely due to the inclusion of length composition from free school sets, and the improved partitioning of PS-FS and PS_FAD in the compositon data appears to have rectified this and produced much more clearly differentiated fleet selectivity. These, now more dome-shaped selectivities affect the overall selection pattern of the fishery resulting more biomass that is less available to the fishery and resulting in higher estimates of the total biomass in the population. This is despite the, now lower, natural mortality that, all things being otherwise equal, would likely have resulted in a less productive stock.

The SS-estimated growth clearly addresses two of the clear limitations of previous growth estimates: substantial overestimation of L_{inf} and poor estimation of size during the first year of life. Much of the disparities between different externally derived growth curves stem from these two ends of the growth curve. Externally derived von Bertalanffy curves and the Gascuel et al., 1992 curve estimate far too large sizes of very young fish, when compared with the daily aging data of Shuford et al 2007 which has excellent information to parameterize age-0 growth. This overestimation of size at age-0 has substantial impact on the scaling of the Lorenzen M and, for the same, baseline M, made age 0 fish have likely too low M and older fish too high. When the previous (2016) model run 5 was run with the new Lorenzen scaled base M the fit was 68 log likelihood units better, indicating greater evidence for the new value of M and the revised scaling to the baseline M=0.35.

The estimated growth also reconciles the issue of L_{inf}. Extensive previous work (SCRS-2019-080) profiling L_{inf}, M and doming of selectivity indicate that L_{inf} is estimable and clearly the length data favor lower values of L_{inf}, than those indicated by Gascuel et al (1992) as well as numerous other authors e.g. Draganick and Pelczarski (1984) and Shuford et al (2007). As preliminary evaluations conducted by AOTTP indicate that daily rings are lost at older ages, this calls into question their utility as well as growth curves for the entire range of ages. It is quite apparent that the Shuford et al (2007) growth data diverges substantially from otolith derived ages (**Figure 2**).

The remaining differences between the SS-estimated growth curves and the Pacicco et al., (2019) curve and Gascuel et al., (1992) curve lie in sizes at ages 1-3. The SS-curves estimate smaller sizes than Pacicco, which is likely a function of accounting for size limits and the strong size selectivity of the rod and reel gear used to capture the bulk of the samples. The Gascuel et al., (1992) size at age 2 (80 cm) is now only 7% smaller than the SS estimated size (86) and the curves match up exactly at age 1 and again at 3, indicating that the effect of a growth slow-down during year 2 of life, as posited by Gascuel et al (1992) and others, is not that extreme. Much of the apparent slow-down is an artifact of the gross overestimation of the sizes during age 0.

As noted in the data workshop report there were concerns that the growth data from Pacicco et al (2019) that comes mainly from the West might not be representative of the Eastern areas. However, in the absence of data from these areas, and given the clear problems with simply using the Gascuel et al., (1992) curve, it was most parsimonious to use the Pacicco et al data to inform growth in a previous version of the model and then fixing it as part of the assessment.

Regarding natural mortality, there were concerns that the baseline estimate of 0.35 might not represent M from the Eastern areas. Given the potential estimability of M (with CAL data M~0.34; without CAL data M~0.41) this may provide some data-informed guidance. The differences between the two M estimates (0.34 vs 0.41) may be a result of whether the M estimate is informed by the descending limb of the catch curve of the age data (0.34) which comes from the West or the length data dominated by the East (0.41) which could indicate two different natural mortality rates. These two estimates may sufficiently span potential ranges of M for the overall population to inform potential axes for the uncertainty grid. Subsequent profiling of M using the reference grid models (figures shown in the assessment report) did not extend past a value for M of age 5 of 0.47 but showed only a slight minimum. Given this performance the group did not deem that M was well estimated in the model and it was subsequently fixed at 0.35 for age 5 and scaled internally to SS as a Lorenzen function of growth.

Conclusions:

*Strengths***:** The model performance is greatly enhanced by having only one longline index rather than having two separate index 'clusters'. The incorporation of internally estimated (and then fixed) growth and growth variability as obtained by including validated otolith data provides greater resolution on growth and natural mortality, two key uncertainties in the 2016 assessment. The SS-estimated growth greatly reduces much of the previously apparent conflicts between growth models.

*Weaknesses***.** The model required fixing key parameters such as steepness, which, due to its inherent correlation with R_0, then largely pre-determines R_0; for a given value of steepness. There remains some conflict between data sources (length composition and indices) in R0 and between individual fleet length composition for other key parameters. It remains unknown how well the buoy index estimates 2017 recruitment; the model relies entirely on this index for recent recruitment. Much of the inference on growth and natural mortality comes from age data obtained in the West. Until more age data is available from the Eastern region this is the best available information but it may not be applicable, particularly for estimating total mortality.

Research recommendations that would improve integrated models:

1) Obtain, age and incorporate growth data from the Gulf of Guinea where the majority of the catch comes from. This is a priority of AOTTP and is ongoing.
2) focus on the timing of the biology of growth and recruitment, presumably the buoy index is quite informative of the influx of new recruits.
3) standardize the length composition data of the joint longline fleet so that there is no need to make diminish the index signal each time a new selectivity of the fleet is necessary.
4) address the uncertainties associated with species composition partitioning associated with the buoy acoustic index.
5) Evaluate using the AOTTP tagging data inside the modeling.

References

Andrews, A., Pacicco, A., Allman, R., Faltermen, B. J., Lang, E. K. and Golet, W. et al. In review . Validated longevity of yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna of the northwestern Atlantic Ocean.

Anon. 2017. Report of the 2016 yellowfin stock assessment session (San Sebastian, Spain, 27 June to 1 July 2016). SCRS/2016/009.

Caverivière, A. 1976. Longueur prédorsale, longueur a la fourche et poids des albacores (*Thunnus albacares*) de l'Atlantique. Cah ORSTOM Sér Océan 14:201–208.

Diaha, N.C., Zudaire, I., Chassot, E., Pecoraro, C., Bodin, N., Amandè, M.J. and Gbeazere, D.A. 2015. Present and future of reproductive biology studies of yellowfin tuna (*Thunnus albacares*) in the eastern Atlantic Ocean. Col. Vol. Sci. Pap. ICCAT: 71(1), 489-509.

Draganik, B. & Pelczarski, W. 1984. Growth and age of bigeye and yellowfin tuna in the Central Atlantic as per data gathered by R/V Wieczno. Col.Vol.Sci.Pap. ICCAT, 20 (1): 96-103.

Francis, R.C., and Hilborn, R. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68(6): 1124–1138. NRC Research Press.

Gascuel, D., A. Fonteneau, A. Capisano. 1992. A two-stanza growth model for the yellowfin tuna (*Thunnus albacares*) in the eastern Atlantic. Aquatic Living Resources, Vol. 5, No. 3, pp. 155-172.

Hallier, J-P, B. Stequert, O. Maury, F-X. Bard. 2005. Growth of bigeye tuna (*Thunnus obesus*) in the eastern Atlantic Ocean from tagging-recapture data and otolith readings. Col. Vol. Sci. Pap. ICCAT, SCRS/2004/039.

Hoyle, S. D, J. Wang, D. N. Kim, M. K.Lee, T. Matsumoto, and J. Walter III. 2018. Collaborative study of bigeye tuna CPUE from multiple Atlantic Ocean longline fleets in 2018. SCRS/2018/058.

Lang, E.T., Falterman, B.J., Kitchens, L.L., and Marshall, C.D. 2017. Age and growth of yellowfin tuna (*Thunnus albacares*) in the northern Gulf of Mexico. Collect. Vol. Sci. Paper ICCAT 73: 423–433.

Lorenzen, K. 2005. Population dynamics and potential of fisheries stock enhancement: practical theory for assessment and policy analysis. Philosophical Transactions of the Royal Society of London B: Biological Sciences 360(1453): 171-189.

Methot, R.D. 2000. Technical description of the Stock Synthesis assessment program. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-43, 46 p.

Methot, R.D. and Taylor, R.G. 2011.Adjusting for bias due to variability of estimated recruitments in fishery assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68:1744-1760.

Methot, R.D. and Wetzel C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management, Fisheries Research 142: 86-99.

Pacicco A. et al. 2019. AGE VALIDATION, GROWTH, AND MORTALITY OF YELLOWFIN TUNA *(Thunnus albacares)* FROM THE U.S GULF OF MEXICO AND ATLANTIC. SCRS/2019.

Santiago, J., Merino, G., Murua. H, Urtizberea, A., Pascual, P. 2018. STANDARDIZED BIGEYE TUNA CPUE INDEX OF THE BAITBOAT FISHERY IN DAKAR (2005-2017).

Shuford, R.L., J.M. Dean, B. Stéquert, M. Morize. 2007. Age and growth of yellowfin tuna in the Atlantic Ocean, 2007. Collect. Vol. Sci. Pap. ICCAT, 60(1): 3330-341.

Walter, J. and R. Sharma. 2017. Atlantic Ocean yellowfin tuna stock assessment 1950-2014 using stock synthesis. SCRS/2016/110.

Walter, J., Hiroki, Y., Satoh, K., Matsumoto, T., Winker, H., Ijurco, A.U., Schirripa, M., 2019.Atlantic bigeye tuna stock synthesis projections and kobe 2 matrices. Col. Vol. Sci. Pap. ICCAT 75, 2283–2300.

Winker, H., Kell, L.T. , Fu, D, Sharma, R., Courtney D. , Carvalho F., Schirripa M and Walter, J. 2019. A rapid approach to approximate Kobe posteriors from age-structured assessment models with applications to North Atlantic shortfin mako. ICCAT – SCRS/2019/093.

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Table 1. Fleet structure, gear, dates and selectivity specifications for SS YFT model.

Fleet	Region	Name	Gear	start	end	Selectivity	time blocks
1	2	Early PS	PS	1963	1985	5 node cubic spline	
2	2	Transition PS	PS	1986	1990	5 node cubic spline	
3	2	Late PS Free Schools S1	PS	1991	2018	5 node cubic spline	
4	2	Late PS Free Schools S2	PS	1991	2018	mirrored to 3	
5	2	Late PS Free Schools S3	PS	1991	2018	mirrored to 3	
6	2	Late PS Free Schools S4	PS	1991	2018	mirrored to 3	
7	2	Late PS FAD S1	PS	1991	2018	5 node cubic spline	2003 2018 (switch to FADs)
8	2	Late PS FAD S2	PS	1991	2018	mirrored to 7	2003 2018 (switch to FADs)
9	2	Late PS FAD S3	PS	1991	2018	mirrored to 7	2003 2018 (switch to FADs)
10	2	Late PS FAD S4	PS	1991	2018	mirrored to 7	2003 2018 (switch to FADs)
11	2	Ghana BB+PS	PS/BB	1965	2018	double norm	1981, 1988, 1995 (switch to FADs)
12	2	TRO BB south Dakar	BB	1955	2018	double norm, smooth inc/dec	2010 (selex change)
13	2	TRO BB north Dakar Early	BB	1955	1980	double normal, smooth inc/dec	
14	2	TRO BB north Dakar Late	BB	1981	2018	double normal, smooth inc/dec	
15	1	North BB Azores	BB	1962	2018	mirror 14	
16	1	LL North JPN	LL	1957	2018	double normal, smooth increase	
17	2	LL Tropical JPN	LL	1956	2018	logistic	1992 2018 (selex change), potentially in 1979 also
18	3	LL South JPN	LL	1959	2018	mirror 16	
19	1	LL North Other fleets	LL	1959	2018	double norm, smooth increase	
20	2	LL Tropical Other fleets	LL	1957	2018	logistic	3: 1979, 1992, 2004 (selex change)
21	3	LL South Other fleets	LL	1962	2018	mirror 19	
22	1	RR USA	RR	1951	2018	double norm, smooth inc/dec	1998 (69 cm SL)
23	2	HL Brazil north	HL	1951	2018	mirror 14	
24	1	24_PS_WEST	PS	1963	2018	double normal	
25	2	Others	OT	1950	2018	double normal	

Table 2. List of model changes.

1. Convert from SS 3.24 to 3.30	done, get same results +/- 1 likelihood point
2. Address several parameter bounding issues and high CVs on some selectivity parameters	done, no current parms on bounds
3. Check the plus group 10+ specifications to determine if a change is necessary	checked, 1.3% of age data >= 10, no need to extend
4. Annual indices will be used, though the model retains quarterly time step for length composition and recruitment partitioning. Though juvenile index may be retained as quarterly to reflect quarterly recruitment	done, Buoy acoustic index quarterly, French PS Free school index quarter 1 used in sens. Runs
5. Model will be one area, with fleets-as areas assigned according to revised 3 area definitions (**Figure 7.1**).	done
6. Movement will not be estimated.	done, not estimated
7. Recruitment estimated quarterly	done
8. Francis reweighting of composition data	done, iteratively several times for Run 1
9. Lambda on size composition data =1	done
10. Reevaluate selectivities for baitboats and purse seine fleets, correcting for some bounded parameters.	done
11. Reevaluate seasonal selectivity/seasonal fleet structure to match seasonality of movement/availability for Purse Seine and Longline indices. Split into 4 seasonal fleets.	explored, no improved fit to seasonal selectivity, selex mirrored across 4 seasons
12. The longline fleets will be initially 6 separate fleets as specified in the BET model and consideration of condensing them into 3 fleets will be based on inspection of the composition data) Selectivity for area 2 (north) will be estimated with an asymptotic function. Selectivity will be estimated as double normal for areas 1 and 3, based on larger average sizes from longline caught fish in area 2 (SCRS-2019-042).	done, selex for LL N(1) and S (3) areas mirrored
13. A time block on selectivity for the longline fleet selectivity will be applied starting in 1979; similar time blocks as in the bigeye tuna assessment should be incorporated	tested on 7/6/2019, better fit, should continue with other models
14. Growth estimated internally in the model with Richards using otolith data from SCRS-2019/025) and daily aged otoliths only out to age 1.	done, better fit with Richards, though some instability and retro pattern
15. Baseline M=0.35 (as estimated from Then et al. using t_{max} of 18)	done
16. Attempt to estimate sigmaR (using the bias correction ramping of Methot and Taylor, 2016).	done, profile good
17. Initial size composition data sample size input as ln(N).	dine
18. Brasil handline fleet landings assigned a new fleet, use size information from AOTTP tagging data	Brasil handline selex mirrored to TRO BB north Dakar Late
19. Joint index for area 2 from 1979-2018 with vessel ID (one index).	done
20. Model will start in 1950 and go to 2018 (with preliminary catch used for 2018. This allows for the use of the 2018 index value; likely no composition data will be available for 2018 but it is not needed by the model). Stock status could be determined for 2017 in this case.	done
21. Beverton-Holt stock recruitment, steepness fixed at 0.8, but profiled as part of the diagnostic evaluation	done
22. Joint index will be input with a common CV of 0.2 but with interannual variability to account for differential precision of the index.	done
23. China-Taipei (2005-2014) size composition; recommendation is to remove size composition after 2004 as the reported data may be uncertain and to confirm with National scientists whether the data prior to 2005 is reliable.	remove >= 2005
24. Evaluate whether the Oth_Oth fleet can be moved into another fleet.	maintain separate fleet
25. Tagging data will be formatted for input to the data file, but likely not used in estimation	incomplete
26. Incorporate size limit and retention function for US RR fishery to account for size selection of samples at 69 cm.	done
27. Remove size composition data > 200 cm from24_PS_West fleet	done
28. Incorporate selex priors for Brazil BB from AOTTP	done
29. Incorporate AOTTP tagging data	incomplete
30. Growth estimated internally in the model Richards fit to Gascuel et al. (1992) data	not done

Table 3. Table of run specifications, likelihoods and gradients.

run	description	LL	grad	hessian	ssb0	time (m)	parms	AIC	comments
Run5	run5 (cluster 1, 2016)	3711.5	7.00E+00	PD	784,400	31	122	7667	2016 model
1	growth fit, richards	6594.5	4.00E-08	PD	1,650,500	30	124	13437	
2	est VB growth	6635.9	9.00E-05	PD	1,820,510	33	123	13518	
3	no CAL, fixed Richards growth	5657.5	8.00E-05	PD	1,494,240	33	122	11559	
4	no CAL, convert to Lor M (m5=0.318)	5665.9	5.00E-05	PD	1,561,390	41	123	11578	
5	like 3 but ASPM, fix all selex, est R0, sigmaR, rec devs	5665.9	3.00E-05	PD	1,561,390	29	65	11462	
6	like 6 but no rec devs	5917	2.00E-05	PD	1,625,900	24	6	11846	
7	Like3 but with continuity M from 2016	5658.4	1.00E-04	PD	2,212,980	11	122	11561	1 bnd; MSY is 2X max catch
8	lambda on len comp (0.5) on model 3	2793.1	5.00E-05	PD	1,479,810	40	122	5830	sigma R hit bound (0.2)
9	Run 3 + buoy (CV 0.3)	5678.2	2.00E-05	PD	1,541,600	37	122	11600	
10	Run 3 + buoy (CV 0.3) + PS FS index	5680.3	4.00E-05	PD	1,569,200	41	122	11605	lo bound: rec dist Month 10
11	Run 3 + PS FS index	5657.5		PD	1,534,960	41	122	11559	
12	run 3 + 3 Joint indices	5561.4		PD	1,549,260	39	122	11367	
13	Steepness 0.7	5659.8	5.00E-05	not run	1,592,210	7	122	11564	
14	Steepness 0.9	5656	1.00E-05	not run	1,426,960	7	122	11556	
15	Steepness 0.99	5655		not run	1,382,260	6	122	11554	
16	Est. M, fix growth no CAL	5651.4	9.00E-05	PD	1,667,780	34	123	11549	m5 ~ 0.41
17	Est. M, fix growth use CAL	6615.7	9.00E-05	PD	1,726,650	32	123	13477	m5 =0.34
18	low M=0.28	5693.5	3.00E-05	PD	1,704,020	11	122	11631	
19	High M = 0.42	5646.5	3.00E-05	PD	562,323	40	122	11537	
20	Fix growth, use CAL	6621.2	2.00E-05	PD	1,655,080	40	122	13486	
21	Run 5, 2016 new M	3642.8	3.00E-05	not run	1,202,350	14	122	7530	use to explain diffs
22	Run 5, 2016 only joint index	3601.4	6.00E-05	not run	730,560	10	122	7447	use to explain diffs
23	like 3, but TB LL JPN and LL trop at 79	5647.6	9.00E-06	PD	1,427,500	33	126	11547	better fit with time block
24	like 3 but fix 2017 rec dev at zero	5652.3	2.05E-05	not run	1425040		126	11556.6	
25	like 23 but split JLL and Trop at 2004, downweight the OthOth comp data	6594.4	0	not run	1650500	0	0	0	
26	like 25, but with new data file	5103.0	0	not run	1441030		130	10466.0	
27	like 25, same data file, but ctl file mods	5071.2	8.38E-05	not run	1396630	0	138	10418.4	
28	lorenzen scaled M, like 27 but remove BR HL 1992 and Ghana BB/PS 1996-2008	4934.4	0	not run	1380990	0	138	10144.8	
29	no CAL; M=0.35; Lorenzen scaled	5335.1	6.834E-06	PD	1467890	0	132	10934.3	
30	no CAL; M=0.35; Lorenzen scaled, PSFS and Buoy index	5340.9	5.719E-05	PD	1382960	0	132	10945.8	
31	with CAL; M=0.35; Lorenzen scaled	6252.3	2.792E-05	PD	1583140	0	132	12768.7	
32	with CAL; M=0.35; Lorenzen scaled, on run 30 (with PSFS and Buoy index)	6248.6	9.903E-05	PD	1687650	0	132	12761.3	
33	run with 2016 M and growth	5388.9		PD	1013260	0	132	11041.9	

34	low M=0.28; or other low M on run 30 (with PSFS and Buoy index)	5371.4	0.000126	PD	1647610	0	132	11006.9
35	High M = 0.42, or other high M run 30 (with PSFS and Buoy index)	5324.1	6.78E-05	PD	1572970	0	132	10912.2
36	like 29 but ASPM, fix all selex, est R0, sigmaR, rec devs	5340.9		PD	1382960		64	10809.8
37	lambda on len comp (0.5) on run 30 (with PSFS and Buoy index)	2635.7	0	PD	1499290	0	132	5535.48
38	Steepness 0.7 (with PSFS and Buoy index)	5338.1	0.000086	PD	1575300	35 m	132	10940.2
39	Steepness 0.9 (with PSFS and Buoy index)	5333.0		PD	1392340	0	132	10930.0
40	run 30 + 3 all indices	5236.3		PD	1504010	0	132	10736.6
41	3 LL indices	5243.3	4.71E-05	PD	1435570	0	132	10750.6
42	just FSPS	5358.0	3.38E-05	PD	1317460	32	132	10980.0
43	like 30 no rec devs in 2017,18	5369.3	0	PD	1551880	32	130	10998.6

Table 4. Estimated parameters, phase of estimation, CV, gradient and priors, if used. Parameters with CVs> .5 are shown in gray for preliminary run 1.

	Value	Phase	CV	Gradient	Pr_type	Prior	Pr_SD
L_at_Amax_Fem_GP_1	152.99	4	0.4%	-4.2E-09	no	NA	NA
VonBert_K_Fem_GP_1	0.67	4	5.5%	1.5E-08	no	NA	NA
Richards_Fem_GP_1	0.11	4	96.9%	1.6E-08	no	NA	NA
CV_young_Fem_GP_1	0.12	5	6.8%	-5.2E-09	no	NA	NA
CV_old_Fem_GP_1	0.07	5	3.0%	-4.7E-10	no	NA	NA
SR_LN(R0)	11.62	1	0.5%	1.7E-08	no	NA	NA
SR_sigmaR	0.27	6	12.5%	-2.7E-09	no	NA	NA
SizeSpline_Val_2_1_PS_ESFR2_6585(1)	0.03	5	119.2%	-5.3E-10	SBeta	0.18	2
SizeSpline_Val_4_1_PS_ESFR2_6585(1)	-0.03	4	-413.8%	-5.1E-09	SBeta	-0.02	2
SizeSpline_Val_5_1_PS_ESFR2_6585(1)	0.76	4	14.1%	2.1E-09	SBeta	0.68	2
SizeSpline_Val_2_2_PS_ESFR2_8690(2)	0.25	2	22.9%	-6.2E-10	no	NA	NA
SizeSpline_Val_4_2_PS_ESFR2_8690(2)	-0.57	2	-34.4%	-3.6E-10	no	NA	NA
SizeSpline_Val_5_2_PS_ESFR2_8690(2)	1.72	2	8.5%	-9.6E-10	no	NA	NA
SizeSpline_Val_2_3_PS_ESFR2_9118_S1(3)	0.06	5	108.4%	-5.8E-10	SBeta	0.38	2
SizeSpline_Val_4_3_PS_ESFR2_9118_S1(3)	-0.25	4	-81.5%	1.1E-09	SBeta	-0.82	2
SizeSpline_Val_5_3_PS_ESFR2_9118_S1(3)	2.43	4	5.9%	1.5E-09	SBeta	1.79	2
SizeSpline_Val_2_7_ESFR_FADS_PS_9118_S1(7)	0.91	5	2.2%	5.3E-10	no	NA	NA
SizeSpline_Val_4_7_ESFR_FADS_PS_9118_S1(7)	-0.97	4	-13.0%	-4.7E-10	no	NA	NA
SizeSpline_Val_5_7_ESFR_FADS_PS_9118_S1(7)	-0.83	5	-14.6%	1.2E-09	no	NA	NA
SizeSpline_Val_2_11_BB_PS_Ghana_6518(11)	0.42	5	8.3%	1.5E-09	SBeta	0.24	1
SizeSpline_Val_4_11_BB_PS_Ghana_6518(11)	-5.29	4	-7.9%	2.0E-08	SBeta	-5.70	1
SizeSpline_Val_5_11_BB_PS_Ghana_6518(11)	-2.83	4	-9.7%	1.9E-08	SBeta	-2.97	1
Size_DblN_peak_12_BB_area2_Sdak(12)	46.43	3	3.2%	2.9E-09	no	NA	NA
Size_DblN_ascend_se_12_BB_area2_Sdak(12)	3.77	5	8.9%	4.2E-09	SBeta	4.02	1
Size_DblN_descend_se_12_BB_area2_Sdak(12)	7.62	4	1.4%	1.8E-09	no	NA	NA
Size_DblN_peak_13_BB_DAKAR_62_80(13)	58.39	3	2.3%	-3.2E-09	no	NA	NA
Size_DblN_ascend_se_13_BB_DAKAR_62_80(13)	4.44	5	5.5%	7.9E-10	SBeta	4.39	1
Size_DblN_descend_se_13_BB_DAKAR_62_80(13)	7.33	4	1.5%	-1.2E-10	no	NA	NA
Size_DblN_peak_14_BB_DAKAR_81_18(14)	52.33	5	1.9%	-2.5E-09	SBeta	###	1
Size_DblN_ascend_se_14_BB_DAKAR_81_18(14)	4.23	5	4.3%	-1.9E-09	SBeta	4.81	1
Size_DblN_descend_se_14_BB_DAKAR_81_18(14)	8.50	5	1.0%	-2.5E-09	SBeta	6.76	1
Size_DblN_peak_16_Japan_LL_N(16)	117.98	3	1.3%	9.5E-09	no	NA	NA
Size_DblN_ascend_se_16_Japan_LL_N(16)	6.32	5	1.6%	-2.3E-09	SBeta	6.49	1
Size_DblN_descend_se_16_Japan_LL_N(16)	5.28	4	5.7%	6.1E-09	no	NA	NA
Size_DblN_end_logit_16_Japan_LL_N(16)	-1.61	4	-12.4%	9.4E-09	no	NA	NA
Size_inflection_17_Japan_LL_TRO(17)	117.47	3	1.3%	1.2E-09	no	NA	NA
Size_95%width_17_Japan_LL_TRO(17)	26.82	3	6.4%	-5.1E-09	no	NA	NA
Size_DblN_peak_19_Other_LL_N(19)	124.30	3	0.7%	3.4E-10	no	NA	NA
Size_DblN_ascend_se_19_Other_LL_N(19)	6.88	5	0.6%	-5.3E-09	SymBeta	6.49	1
Size_DblN_descend_se_19_Other_LL_N(19)	5.21	4	2.9%	4.8E-10	no	NA	NA
Size_DblN_end_logit_19_Other_LL_N(19)	-2.53	4	-8.0%	2.5E-09	no	NA	NA
Size_inflection_20_Other_LL_TRO(20)	87.67	3	1.4%	-5.4E-09	no	NA	NA
Size_95%width_20_Other_LL_TRO(20)	18.42	3	8.1%	-2.0E-09	no	NA	NA
Size_DblN_peak_23_US_RR(23)	78.48	3	1.9%	6.9E-10	no	NA	NA
Size_DblN_ascend_se_23_US_RR(23)	4.86	5	4.3%	-2.2E-09	SBeta	5.64	1
Size_DblN_descend_se_23_US_RR(23)	6.99	4	1.5%	2.6E-09	no	NA	NA
Size_DblN_ascend_se_24_PS_WEST(24)	5.18	4	2.5%	-1.5E-08	SBeta	5.34	2
Size_DblN_descend_se_24_PS_WEST(24)	4.07	4	32.5%	-5.1E-09	SBeta	5.18	2
Size_DblN_end_logit_24_PS_WEST(24)	-0.24	6	-136.8%	3.9E-08	SBeta	-0.50	2
Size_DblN_peak_25_OTH_OTH(25)	70.61	3	1.6%	1.8E-09	no	NA	NA
Size_DblN_ascend_se_25_OTH_OTH(25)	5.35	5	2.2%	-2.2E-09	SBeta	6.49	1
Size_DblN_descend_se_25_OTH_OTH(25)	7.99	4	1.1%	1.3E-09	no	NA	NA
SizeSpline_Val_1_7_ESFR_FADS_PS_9118_S1(7)_BLK1repl_2003	-7.26	6	-4.9%	5.5E-09	no	NA	NA
SizeSpline_Val_4_7_ESFR_FADS_PS_9118_S1(7)_BLK1repl_2003	-2.33	6	-7.0%	-5.3E-09	no	NA	NA
SizeSpline_Val_5_7_ESFR_FADS_PS_9118_S1(7)_BLK1repl_2003	-3.19	6	-7.2%	-1.5E-09	no	NA	NA
SizeSpline_Val_1_11_BB_PS_Ghana_6518(11)_BLK4repl_2009	-7.03	6	-15.5%	-1.7E-09	SBeta	-7.79	3
SizeSpline_Val_4_11_BB_PS_Ghana_6518(11)_BLK4repl_2009	0.10	6	231.3%	-1.2E-08	SBeta	-0.26	3
SizeSpline_Val_5_11_BB_PS_Ghana_6518(11)_BLK4repl_2009	-0.83	6	-31.2%	7.3E-09	SBeta	-1.40	3
Size_DblN_peak_12_BB_area2_Sdak(12)_BLK2repl_2010	150.07	6	7.5%	1.1E-09	SBeta	###	2
Size_DblN_ascend_se_12_BB_area2_Sdak(12)_BLK2repl_2010	8.24	6	2.7%	-2.6E-09	SBeta	8.76	2
Size_inflection_17_Japan_LL_TRO(17)_BLK6add_1992	13.65	6	13.9%	-8.6E-10	no	NA	NA
Size_95%width_17_Japan_LL_TRO(17)_BLK6add_1992	3.75	6	61.8%	-2.3E-09	no	NA	NA
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	129.40	6	0.8%	1.8E-08	no	NA	NA
Size_inflection_20_Other_LL_TRO(20)_BLK1add_2003	21.31	6	12.8%	-1.0E-09	no	NA	NA
Size_95%width_20_Other_LL_TRO(20)_BLK1add_2003	14.09	6	21.6%	-7.5E-10	no	NA	NA

Table 5. Correlated parameters above a 70% threshold for Run 1 (estimate Richards growth).

label.i	label.j	corr
Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	91%
Size_DblN_ascend_se_14_BB_DAKAR_81_18(14)	Size_DblN_peak_14_BB_DAKAR_81_18(14)	90%
Size_DblN_ascend_se_25_OTH_OTH(25)	Size_DblN_peak_25_OTH_OTH(25)	90%
Size_DblN_ascend_se_23_US_RR(23)	Size_DblN_peak_23_US_RR(23)	88%
Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	84%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_peak_19_Other_LL_N(19)	81%
Size_DblN_ascend_se_13_BB_DAKAR_62_80(13)	Size_DblN_peak_13_BB_DAKAR_62_80(13)	80%
Size_DblN_ascend_se_12_BB_area2_Sdak(12)_BLK2repl_2010	Size_DblN_peak_12_BB_area2_Sdak(12)_BLK2repl_2010	76%
Size_DblN_ascend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	76%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_ascend_se_19_Other_LL_N(19)	75%
CV_old_Fem_GP_1	L_at_Amax_Fem_GP_1	-72%
VonBert_K_Fem_GP_1	L_at_Amax_Fem_GP_1	-74%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_descend_se_19_Other_LL_N(19)	-79%
Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-80%
Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-81%
Richards_Fem_GP_1	VonBert_K_Fem_GP_1	-95%

Table 6. Correlated parameters above a 70% threshold for Run 2 (estimate von Bertanlanffy growth).

label.i	label.j	corr
Size_DblN_ascend_se_25_OTH_OTH(25)	Size_DblN_peak_25_OTH_OTH(25)	89%
Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	88%
Size_DblN_ascend_se_14_BB_DAKAR_81_18(14)	Size_DblN_peak_14_BB_DAKAR_81_18(14)	88%
Size_DblN_ascend_se_13_BB_DAKAR_62_80(13)	Size_DblN_peak_13_BB_DAKAR_62_80(13)	88%
Size_DblN_ascend_se_23_US_RR(23)	Size_DblN_peak_23_US_RR(23)	86%
Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	83%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_peak_19_Other_LL_N(19)	77%
Size_DblN_ascend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	71%
VonBert_K_Fem_GP_1	L_at_Amax_Fem_GP_1	-71%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_descend_se_19_Other_LL_N(19)	-76%
Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-78%
Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-80%

Table 7. Correlated parameters above a 70% threshold for Run 3 (fix growth at Richards estimates from Run 1).

label.i	label.j	corr
Size_DblN_ascend_se_14_BB_DAKAR_81_18(14)	Size_DblN_peak_14_BB_DAKAR_81_18(14)	91%
Size_DblN_ascend_se_25_OTH_OTH(25)	Size_DblN_peak_25_OTH_OTH(25)	91%
Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	90%
Size_DblN_ascend_se_23_US_RR(23)	Size_DblN_peak_23_US_RR(23)	88%
RecrDist_month_10	RecrDist_month_4	86%
Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	83%
Size_DblN_ascend_se_13_BB_DAKAR_62_80(13)	Size_DblN_peak_13_BB_DAKAR_62_80(13)	82%
Size_DblN_ascend_se_12_BB_area2_Sdak(12)_BLK2repl_2010	Size_DblN_peak_12_BB_area2_Sdak(12)_BLK2repl_2010	76%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_peak_19_Other_LL_N(19)	73%
Size_DblN_ascend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	71%
Size_95%width_17_Japan_LL_TRO(17)_BLK6add_1992	Size_95%width_17_Japan_LL_TRO(17)	-70%
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_descend_se_19_Other_LL_N(19)	-73%
Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-78%
Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-81%

Table 8. Table of log-likelihoods for grid models 1-4.

	Run 1	Run 2	Run 3	Run 4
TOTAL	2591.64	2590.71	2568.17	2567.02
Equil_catch	0.00	0.00	0.00	0.00
Survey	-82.15	-82.06	-103.85	-104.00
Length_comp	2668.20	2667.62	2677.43	2676.69
Age_comp	0.00	0.00	0.00	0.00
Recruitment	-17.62	-18.08	-28.34	-28.64
InitEQ_Regime	0.00	0.00	0.00	0.00
Forecast_Recruitment	0.00	0.00	0.00	0.00
Parm_priors	23.19	23.21	22.91	22.94
Parm_softbounds	0.03	0.03	0.03	0.03
Parm_devs	0.00	0.00	0.00	0.00
F_Ballpark	0.00	0.00	0.00	0.00
F_Ballpark 2000	0.16	0.16	0.15	0.15
Crash_Pen	0.00	0.00	0.00	0.00

Table 9. Index variance tuning checks indicating fits to the indices.

Run 1	**Npos**	**RMSE**	**mean_input_SE**	**VarAdj**	**New VarAdj**	**use**
3_PS_ESFR2_9118_S1	26	0.17	0.315	0	-0.15	yes
7_ESFR_FADS_PS_9118_S1	36	0.51	0.198	0	0.31	no
16_Japan_LL_N	40	0.19	0.200	0	-0.01	no
17_Japan_LL_TRO	40	0.14	0.200	0	-0.06	yes
18_Japan_LL_S	40	0.20	0.200	0	0.00	no
Run 2	**Npos**	**RMSE**	**mean_input_SE**	**VarAdj**	**New_VarAdj**	**use**
3_PS_ESFR2_9118_S1	26	0.16	0.315	0	-0.15	yes
7_ESFR_FADS_PS_9118_S1	36	0.51	0.198	0	0.31	no
16_Japan_LL_N	40	0.19	0.200	0	-0.01	no
17_Japan_LL_TRO	40	0.14	0.200	0	-0.06	yes
18_Japan_LL_S	40	0.19	0.200	0	-0.01	no
Run 3	**Npos**	**RMSE**	**mean_input_SE**	**VarAdj**	**New_VarAdj**	**use**
3_PS_ESFR2_9118_S1	26	0.16	0.315	0	-0.15	yes
7_ESFR_FADS_PS_9118_S1	9	0.21	0.203	0	0.01	yes
8_ESFR_FADS_PS_9118_S2	9	0.21	0.211	0	0.00	yes
9_ESFR_FADS_PS_9118_S3	9	0.42	0.202	0	0.22	yes
10_ESFR_FADS_PS_9118_S4	9	0.26	0.176	0	0.09	yes
16_Japan_LL_N	40	0.18	0.200	0	-0.02	no
17_Japan_LL_TRO	40	0.14	0.200	0	-0.06	yes
18_Japan_LL_S	40	0.19	0.200	0	-0.01	no
Run 4	**Npos**	**RMSE**	**mean_input_SE**	**VarAdj**	**New_VarAdj**	**use**
3_PS_ESFR2_9118_S1	26	0.16	0.315	0	-0.15	yes
7_ESFR_FADS_PS_9118_S1	9	0.21	0.203	0	0.01	yes
8_ESFR_FADS_PS_9118_S2	9	0.21	0.211	0	0.00	yes
9_ESFR_FADS_PS_9118_S3	9	0.42	0.202	0	0.22	yes
10_ESFR_FADS_PS_9118_S4	9	0.26	0.176	0	0.08	yes
16_Japan_LL_N	40	0.18	0.200	0	-0.02	no
17_Japan_LL_TRO	40	0.14	0.200	0	-0.06	yes
18_Japan_LL_S	40	0.19	0.200	0	-0.01	no

Table 10. Parameter estimates, phases, CVs for final grid model (run 1). Most parameter estimates are similar. Recruitment deviations not shown for brevity.

name	Value	Phase	Min	Max	CV	Grad	Pr type	Prior	Pr SD
NatM_p_1_Fem_GP_1	0.35	-4				-			
L_at_Amax_Fem_GP_1	153.0	-2	120	190	-	-	no	-	-
VonBert_K_Fem_GP_1	0.67	-4	0.1	0.9	-	-	no	-	-
Richards_Fem_GP_1	0.11	-4	-2	2	-	-	no	-	-
CV_young_Fem_GP_1	0.21	-4	0.1	0.3	-	-	no	-	-
CV_old_Fem_GP_1	0.07	-5	0.1	0.3	-	-	no	-	-
RecrDist_month_4	-0.06	3	-4	4	-509.6%	-2E-05	Sbeta	0.17	2.00
RecrDist_month_7	-0.41	3	-4	4	-35.8%	2E-05	Sbeta	-0.72	2.00
RecrDist_month_10	-1.81	4	-4	4	-39.6%	1E-05	Sbeta	-0.23	2.00
SR_LN(R0)	11.33	1	9	13	0.6%	8E-05	no	-	-
SR_BH_flat_steep	0.80	-3	0.2	1	-	-	no	-	-
SR_sigmaR	0.35	6	0.2	1	15.6%	4E-06	no	-	-
SizeSpline_Val_2_1_PS_ESFR2_6585(1)	0.01	5	-2	2	324.9%	1E-05	Sbeta	0.18	2
SizeSpline_Val_4_1_PS_ESFR2_6585(1)	0.06	4	-2	2	268.8%	2E-06	Sbeta	-0	2
SizeSpline_Val_5_1_PS_ESFR2_6585(1)	0.80	4	-2	2	17.7%	1E-05	Sbeta	0.68	2
SizeSpline_Val_2_2_PS_ESFR2_8690(2)	-0.01	2	-3	3	-907.6%	3E-08	no	-	-
SizeSpline_Val_4_2_PS_ESFR2_8690(2)	-0.44	2	-3	3	-95.6%	-3E-06	no	-	-
SizeSpline_Val_5_2_PS_ESFR2_8690(2)	1.88	2	-2	5	17.5%	7E-06	no	-	-
SizeSpline_Val_2_3_PS_ESFR2_9118_S1(3)	0.07	5	-2	2	116.8%	2E-07	Sbeta	0.38	2
SizeSpline_Val_4_3_PS_ESFR2_9118_S1(3)	-0.39	4	-2	2	-70.8%	-3E-06	Sbeta	-0.8	2
SizeSpline_Val_5_3_PS_ESFR2_9118_S1(3)	2.46	4	-2	5	8.1%	6E-06	Sbeta	1.79	2
SizeSpline_Val_2_7_ESFR_FADS_PS_9118_S1(7)	0.92	5	-2	2	3.0%	3E-06	no	-	-
SizeSpline_Val_4_7_ESFR_FADS_PS_9118_S1(7)	-1.11	4	-5	2	-14.9%	5E-06	no	-	-
SizeSpline_Val_5_7_ESFR_FADS_PS_9118_S1(7)	-0.77	5	-5	2	-20.8%	9E-06	no	-	-
SizeSpline_Val_1_11_BB_PS_Ghana_6518(11)	-8.00	4	-10	7	-14.1%	5E-07	no	-	-
SizeSpline_Val_2_11_BB_PS_Ghana_6518(11)	0.77	5	-1	1	5.0%	2E-06	Sbeta	0.24	1
SizeSpline_Val_4_11_BB_PS_Ghana_6518(11)	-4.92	4	-10	2	-17.1%	2E-07	Sbeta	-5.7	1
SizeSpline_Val_5_11_BB_PS_Ghana_6518(11)	-4.26	4	-10	2	-27.2%	-7E-08	Sbeta	-3	1
Size_DblN_peak_12_BB_area2_Sdak(12)	46.08	3	30	180	3.9%	6E-06	Sbeta	46.5	0.5
Size_DblN_ascend_se_12_BB_area2_Sdak(12)	3.74	5	-5	9	11.8%	7E-07	Sbeta	3.78	1
Size_DblN_descend_se_12_BB_area2_Sdak(12)	7.66	4	-5	9	2.0%	1E-05	no	0	0
Size_DblN_ascend_se_13_BB_DAKAR_62_80(13)	4.46	5	-5	9	3.6%	-3E-06	Sbeta	4.39	1
Size_DblN_descend_se_13_BB_DAKAR_62_80(13)	7.33	4	-5	9	1.4%	4E-06	no	-	-
Size_DblN_ascend_se_14_BB_DAKAR_81_18(14)	4.61	5	-5	9	2.3%	-7E-06	Sbeta	4.81	1
Size_DblN_descend_se_14_BB_DAKAR_81_18(14)	8.81	5	-5	9	1.6%	4E-06	Sbeta	6.76	0.2
Size_DblN_peak_16_Japan_LL_N(16)	118.9	3	70	130	1.7%	8E-06	Sbeta	119	0.5
Size_DblN_ascend_se_16_Japan_LL_N(16)	6.35	5	-5	9	2.1%	-1E-05	Sbeta	6.49	0.5
Size_DblN_descend_se_16_Japan_LL_N(16)	5.14	4	-5	10	8.5%	9E-06	no	-	-
Size_DblN_end_logit_16_Japan_LL_N(16)	-1.43	4	-9	15	-18.5%	1E-05	no	-	-
Size_inflection_17_Japan_LL_TRO(17)	118.1	3	70	180	2.5%	2E-05	no	-	-
Size_95%width_17_Japan_LL_TRO(17)	29.33	3	10	60	12.0%	-3E-06	no	-	-
Size_DblN_peak_19_Other_LL_N(19)	125.4	3	70	150	0.8%	3E-05	Sbeta	125	1
Size_DblN_ascend_se_19_Other_LL_N(19)	6.89	5	-5	9	0.7%	-4E-05	Sbeta	6.49	1
Size_DblN_descend_se_19_Other_LL_N(19)	5.06	4	-5	10	3.9%	3E-05	no	-	-
Size_DblN_end_logit_19_Other_LL_N(19)	-2.27	4	-9	15	-11.2%	2E-05	no	-	-
Size_inflection_20_Other_LL_TRO(20)	85.93	3	40	180	2.4%	1E-05	Sbeta	85.9	0.2
Size_95%width_20_Other_LL_TRO(20)	14.01	3	10	60	18.6%	2E-07	Sbeta	13.5	0.2
Size_DblN_peak_22_HL_Braz_N(22)	54.47	5	40	100	3.4%	-2E-06	Norm	60	10
Size_DblN_descend_se_22_HL_Braz_N(22)	5.88	5	-5	9	7.9%	6E-07	Norm	4.5	2
Size_DblN_ascend_se_23_US_RR(23)	4.95	5	-5	9	2.7%	-6E-06	Sbeta	5.64	1
Size_DblN_descend_se_23_US_RR(23)	7.02	4	-5	9	1.8%	7E-06	no	-	-
Size_DblN_ascend_se_24_PS_WEST(24)	4.96	4	-5	9	4.4%	3E-06	Sbeta	5.34	2
Size_DblN_descend_se_24_PS_WEST(24)	5.13	4	-5	10	15.1%	5E-07	Sbeta	5.18	2
Size_DblN_end_logit_24_PS_WEST(24)	-0.98	6	-9	15	-61.1%	2E-06	Sbeta	-0.5	2
Size_DblN_peak_25_OTH_OTH(25)	78.33	3	50	130	8.3%	-6E-06	Sbeta	71.2	0.2
Size_DblN_descend_se_25_OTH_OTH(25)	8.93	4	-5	10	12.8%	-8E-06	Sbeta	8.06	0.2
SizeSpline_Val_1_7_ESFR_FADS_PS_9118_S1(7)_BLK1repl_2003	-6.70	6	-10	7	-7.1%	2E-06	no	-	-
SizeSpline_Val_4_7_ESFR_FADS_PS_9118_S1(7)_BLK1repl_2003	-2.44	6	-5	2	-9.3%	6E-07	no	-	-
SizeSpline_Val_5_7_ESFR_FADS_PS_9118_S1(7)_BLK1repl_2003	-3.12	6	-5	2	-10.3%	-1E-06	no	-	-
SizeSpline_Val_1_11_BB_PS_Ghana_6518(11)_BLK3repl_1981	-8.51	6	-10	7	-8.3%	5E-07	Sbeta	-7.8	0.2
SizeSpline_Val_1_11_BB_PS_Ghana_6518(11)_BLK3repl_1988	-8.36	6	-10	7	-6.9%	-4E-07	Sbeta	-7.8	0.2
SizeSpline_Val_1_11_BB_PS_Ghana_6518(11)_BLK3repl_1996	-7.87	6	-10	7	-12.9%	-5E-08	Sbeta	-7.8	0.2
SizeSpline_Val_4_11_BB_PS_Ghana_6518(11)_BLK3repl_1981	-2.07	6	-5	2	-21.1%	-1E-06	Sbeta	-0.3	0.1
SizeSpline_Val_4_11_BB_PS_Ghana_6518(11)_BLK3repl_1996	0.28	6	-5	2	80.5%	5E-07	Sbeta	-0.3	0.1
SizeSpline_Val_5_11_BB_PS_Ghana_6518(11)_BLK3repl_1981	-0.77	6	-2	2	-43.7%	4E-07	Sbeta	-1.4	0.2
SizeSpline_Val_5_11_BB_PS_Ghana_6518(11)_BLK3repl_1988	-2.83	6	-3	2	-11.7%	7E-07	Sbeta	-1.4	0.2
SizeSpline_Val_5_11_BB_PS_Ghana_6518(11)_BLK3repl_1996	-0.78	6	-2	2	-35.7%	-3E-06	Sbeta	-1.4	0.2

Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1979	2.67	6	-10	30	147.6%	-1E-06	no	-	-
Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	13.04	6	-10	30	29.4%	4E-06	no	-	-
Size_inflection_17_Japan_LL_TRO(17)_BLK7add_2005	20.86	6	-10	30	20.9%	2E-06	no	-	-
Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1979	-3.43	6	-15	25	0.0%	4E-06	no	-	-
Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1992	-2.96	6	-15	25	0.0%	-3E-06	no	-	-
Size_95%width_17_Japan_LL_TRO(17)_BLK7add_2005	8.27	6	-15	25	0.0%	-2E-07	no	-	-
Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	130.4	6	30	180	0.0%	3E-05	no	-	-
Size_inflection_20_Other_LL_TRO(20)_BLK7add_1979	15.51	6	-10	30	0.0%	2E-06	no	-	-
Size_inflection_20_Other_LL_TRO(20)_BLK7add_1992	4.93	6	-10	30	0.0%	-3E-06	no	-	-
Size_inflection_20_Other_LL_TRO(20)_BLK7add_2005	24.47	6	-10	30	0.0%	-2E-07	no	-	-
Size_95%width_20_Other_LL_TRO(20)_BLK7add_1979	14.27	6	-15	25	0.0%	-2E-06	no	-	-
Size_95%width_20_Other_LL_TRO(20)_BLK7add_1992	9.10	6	-15	25	0.0%	2E-07	no	-	-
Size_95%width_20_Other_LL_TRO(20)_BLK7add_2005	20.57	6	-15	25	0.0%	3E-06	no	-	-

Table 11. Correlated parameters above a 70% threshold for final grid Run 1.

	label.i	label.j	corr
1	Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	0.871
2	RecrDist_month_10	RecrDist_month_4	0.845
3	Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	0.826
4	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1992	Size_95%width_17_Japan_LL_TRO(17)	-0.801
5	Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-0.798
6	Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-0.776
7	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)	-0.776
8	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1979	Size_95%width_17_Japan_LL_TRO(17)	-0.774
9	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_2005	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	0.769
10	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1979	0.766

Table 12. Correlated parameters above a 70% threshold for final grid Run 2.

	label.i	label.j	corr
1	Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	0.872
2	RecrDist_month_10	RecrDist_month_4	0.847
3	Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	0.826
4	Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-0.805
5	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1992	Size_95%width_17_Japan_LL_TRO(17)	-0.801
6	Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-0.797
7	Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_peak_19_Other_LL_N(19)	0.779
8	Size_DblN_peak_19_Other_LL_N(19)_BLK1repl_2003	Size_DblN_descend_se_19_Other_LL_N(19)	-0.775
9	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1979	Size_95%width_17_Japan_LL_TRO(17)	-0.774
10	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)	-0.773

Table 13. Correlated parameters above a 70% threshold for final grid Run 3.

	label.i	label.j	corr
1	RecrDist_month_10	RecrDist_month_4	0.893
2	Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	0.871
3	Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	0.825
4	Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-0.802
5	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1992	Size_95%width_17_Japan_LL_TRO(17)	-0.798
6	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)	-0.779
7	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1979	Size_95%width_17_Japan_LL_TRO(17)	-0.777
8	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_2005	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	0.768
9	Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-0.766
10	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1979	0.764

Table 14. Correlated parameters above a 70% threshold for final grid Run 4.

	label.i	label.j	corr
1	RecrDist_month_10	RecrDist_month_4	0.892
2	Size_DblN_ascend_se_12_BB_area2_Sdak(12)	Size_DblN_peak_12_BB_area2_Sdak(12)	0.871
3	Size_DblN_ascend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	0.826
4	Size_DblN_descend_se_16_Japan_LL_N(16)	Size_DblN_peak_16_Japan_LL_N(16)	-0.801
5	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1992	Size_95%width_17_Japan_LL_TRO(17)	-0.798
6	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)	-0.776
7	Size_95%width_17_Japan_LL_TRO(17)_BLK7add_1979	Size_95%width_17_Japan_LL_TRO(17)	-0.776
8	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_2005	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	0.770
9	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1992	Size_inflection_17_Japan_LL_TRO(17)_BLK7add_1979	0.766
10	Size_DblN_descend_se_19_Other_LL_N(19)	Size_DblN_peak_19_Other_LL_N(19)	-0.759

Table 15. Estimates of SSB between 1950 and 2018 from SS Grid runs 1-4. Confidence intervals are 95% and based on the hessian standard errors.

	run 1	lci	uci	run 2	lci	uci	run 3	lci	uci	run 4	lci	uci
1950	1433860	1244168	1623552	1370660	1178805	1562515	1527430	1313853	1741007	1452100	1241978	1662222
1951	1433100	1243401	1622799	1369910	1178048	1561772	1526680	1313095	1740265	1451340	1241212	1661468
1952	1431490	1241803	1621177	1368290	1176440	1560140	1525060	1311487	1738633	1449720	1239602	1659838
1953	1428550	1238884	1618216	1365360	1173531	1557189	1522100	1308546	1735654	1446770	1236672	1656868
1954	1424420	1234795	1614045	1361240	1169452	1553028	1517950	1304433	1731467	1442620	1232559	1652681
1955	1419730	1230171	1609289	1356560	1164838	1548282	1513210	1299754	1726666	1437910	1227910	1647910
1956	1414770	1225276	1604264	1351630	1159973	1543287	1508220	1294823	1721617	1432950	1223009	1642891
1957	1408500	1219062	1597938	1345410	1153808	1537012	1501910	1288562	1715258	1426690	1216798	1636582
1958	1388390	1199007	1577773	1325370	1133823	1516917	1481740	1268443	1695037	1406600	1196757	1616443
1959	1355210	1165932	1544488	1292300	1100861	1483739	1448480	1235277	1661683	1373450	1163705	1583195
1960	1310960	1121851	1500069	1248210	1056945	1439475	1404110	1191060	1617160	1329240	1119651	1538829
1961	1270380	1081389	1459371	1207850	1016712	1398988	1363410	1150468	1576352	1288770	1079297	1498243
1962	1243510	1054362	1432658	1181390	990145	1372635	1336710	1123633	1549787	1262480	1052911	1472049
1963	1205240	1005300	1405180	1144730	944126	1345334	1302020	1079229	1524811	1229200	1011048	1447352
1964	1153670	921061	1386279	1095730	865994	1325466	1255230	1001043	1509417	1184840	938417	1431263
1965	1096870	837821	1355919	1041430	787949	1294911	1201810	921426	1482194	1133900	863849	1403951
1966	1033980	762508	1305452	981260	716911	1245609	1141820	848622	1435018	1076590	795277	1357903
1967	1009050	729458	1288642	957558	685973	1229143	1117190	815550	1418830	1053220	764471	1341969
1968	985510	699981	1271039	935303	658455	1212151	1093250	785783	1400717	1030630	736793	1324467
1969	936854	655341	1218367	888915	616097	1161733	1043550	740242	1346858	983444	693776	1273112
1970	917664	632731	1202597	870518	594252	1146784	1022840	716092	1329588	963698	670700	1256696
1971	909130	622370	1195890	863759	585598	1141920	1014340	705709	1322971	957127	662259	1251995
1972	1011860	710506	1313214	966014	672839	1259189	1113380	788843	1437917	1055670	745135	1366205
1973	1261610	901979	1621241	1211210	859876	1562544	1358180	972628	1743732	1295230	925211	1665249
1974	1449720	1046479	1852961	1397390	1002446	1792334	1543650	1111509	1975791	1478150	1062740	1893560
1975	1480160	1074436	1885884	1430050	1032103	1827997	1571560	1135648	2007472	1508340	1089139	1927541
1976	1408370	1022644	1794096	1362130	983423	1740837	1495600	1079617	1911583	1436750	1036765	1836735
1977	1293290	939436	1647144	1251510	903857	1599163	1376970	993467	1760473	1323200	954546	1691854
1978	1159460	842408	1476512	1122150	810471	1433829	1238930	892943	1584917	1190330	857847	1522813
1979	1026490	743354	1309626	993301	714924	1271678	1101760	790459	1413061	1057950	759003	1356897
1980	884225	636028	1132422	855263	611394	1099132	956096	680745	1231447	917259	653204	1181314
1981	759276	541324	977228	733965	520002	947928	827903	583632	1072174	793424	559549	1027299
1982	669706	470374	869038	646785	451201	842369	734806	509414	960198	703253	487710	918796
1983	600930	412549	789311	579840	395066	764614	664392	450019	878765	635013	430144	839882
1984	562215	378923	745507	542440	362617	722263	623862	414446	833278	596104	395978	796230
1985	593061	405237	780885	573845	389378	758312	655341	440903	869779	628164	423015	833313
1986	671442	466442	876442	651382	449647	853117	734064	500951	967177	705837	482466	929208
1987	750207	524146	976268	729436	506694	952178	816312	560632	1071992	786929	541555	1032303
1988	762763	535191	990335	742736	518404	967068	829607	572090	1087124	801017	553794	1048240
1989	776761	552862	1000660	757497	536734	978260	843599	590014	1097184	815868	572371	1059365
1990	756827	539988	973666	738274	524467	952081	821477	575519	1067435	794688	558518	1030858
1991	685668	480293	891043	668273	465852	870694	748259	514845	981673	722921	498844	946998
1992	644989	452334	837644	628819	438983	818655	704623	484901	924345	680831	470000	891662
1993	648847	459810	837884	633086	446736	819436	705673	490293	921053	682395	475737	889053
1994	650386	463151	837621	634947	450308	819586	706127	492959	919295	683194	478686	887702
1995	640529	454147	826911	625316	441525	809107	695720	483462	907978	672993	469402	876584
1996	637080	449676	824484	621905	437112	806698	692249	478852	905646	669479	464790	874168

1997	616345	430200	802490	601384	417837	784931	671557	459430	883684	649004	445515	852493
1998	594285	410688	777882	579737	398699	760775	649264	439897	858631	627224	426346	828102
1999	568665	386370	750960	554615	374845	734385	624232	416376	832088	602763	403264	802262
2000	591719	402955	780483	577583	391341	763825	649503	434711	864295	627743	421441	834045
2001	680132	471337	888927	664922	458777	871067	741079	504875	977283	717651	490560	944742
2002	735881	510383	961379	720209	497547	942871	799681	545749	1053613	775269	530984	1019554
2003	748127	519319	976935	733031	507141	958921	812618	555386	1069850	788613	541096	1036130
2004	769542	538609	1000475	754795	526827	982763	833251	574272	1092230	809332	560094	1058570
2005	763959	534492	993426	749629	523100	976158	826826	570111	1083541	803069	555972	1050166
2006	719032	500619	937445	705636	490001	921271	780020	535741	1024299	757318	522171	992465
2007	693117	482864	903370	680181	472582	887780	752231	517147	987315	729957	503673	956241
2008	688492	482106	894878	675614	471835	879393	746075	515422	976728	723688	501702	945674
2009	651183	453541	848825	638771	443647	833895	706712	485440	927984	684949	472054	897844
2010	603356	415579	791133	591594	406218	776970	657759	446845	868673	636866	433988	839744
2011	578770	395844	761696	567404	386806	748002	633549	427820	839278	613038	415168	810908
2012	580649	396257	765041	569394	387324	751464	651616	442680	860552	630404	429461	831347
2013	595234	405565	784903	584038	396743	771333	687554	471303	903805	665017	457069	872965
2014	621142	424915	817369	610082	416317	803847	697100	480085	914115	674080	465428	882732
2015	639491	437368	841614	628665	429135	828195	670885	459858	881912	648133	445269	850997
2016	624059	420286	827832	613782	412739	814825	630732	425512	835952	608194	410936	805452
2017	569324	369135	769513	559988	362645	757331	579610	378545	780675	557280	364022	750538
2018	506273	308672	703874	498006	303393	692619	528253	330142	726364	506320	315853	696787

Table 16. Estimates of SSB relative to SSB_{MSY}, and fishing mortality relative to F_{MSY} between 1951 and 2018 from SS Grid runs 1-4. Confidence intervals are 95% and based on the hessian standard errors.

	run 1,			run 2			run 3			run 4			run 1			run 2			run 3			run 4		
	MLE	lci	uci	MLE	lci	uci	MLE	lci	uci	MLE	lci	uci	MLE	lci	uci	MLE	lci	uci	MLE	lci	uci	MLE	lci	uci
1951	3.39	3.34	3.45	3.82	3.72	3.91	3.38	3.33	3.42	3.79	3.71	3.86	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1952	3.39	3.34	3.44	3.81	3.72	3.90	3.37	3.33	3.42	3.78	3.71	3.85	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1953	3.38	3.33	3.43	3.80	3.71	3.89	3.37	3.32	3.41	3.77	3.70	3.85	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1954	3.37	3.32	3.43	3.79	3.70	3.88	3.36	3.31	3.40	3.76	3.69	3.84	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1955	3.36	3.31	3.41	3.78	3.69	3.87	3.35	3.30	3.39	3.75	3.68	3.82	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1956	3.35	3.30	3.40	3.76	3.67	3.86	3.34	3.29	3.38	3.74	3.66	3.81	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1957	3.33	3.28	3.39	3.75	3.65	3.84	3.32	3.28	3.37	3.72	3.65	3.80	0.08	0.07	0.09	0.07	0.06	0.08	0.07	0.06	0.08	0.06	0.06	0.07
1958	3.29	3.23	3.34	3.69	3.60	3.79	3.28	3.23	3.33	3.67	3.59	3.75	0.14	0.12	0.16	0.12	0.10	0.14	0.12	0.11	0.14	0.11	0.10	0.12
1959	3.21	3.15	3.27	3.60	3.50	3.70	3.20	3.15	3.26	3.58	3.50	3.67	0.20	0.17	0.23	0.18	0.15	0.20	0.18	0.16	0.20	0.16	0.14	0.18
1960	3.10	3.04	3.17	3.48	3.37	3.58	3.11	3.04	3.17	3.47	3.37	3.56	0.25	0.21	0.28	0.21	0.18	0.24	0.22	0.19	0.25	0.19	0.17	0.22
1961	3.01	2.93	3.08	3.36	3.25	3.48	3.02	2.95	3.09	3.36	3.26	3.46	0.22	0.19	0.25	0.19	0.16	0.22	0.19	0.17	0.22	0.17	0.15	0.19
1962	2.94	2.86	3.03	3.29	3.17	3.41	2.96	2.88	3.04	3.29	3.18	3.40	0.22	0.19	0.25	0.19	0.16	0.22	0.19	0.17	0.22	0.17	0.15	0.20
1963	2.85	2.69	3.01	3.19	2.99	3.38	2.88	2.73	3.03	3.21	3.03	3.39	0.25	0.21	0.30	0.22	0.18	0.26	0.23	0.19	0.26	0.20	0.16	0.23
1964	2.73	2.43	3.04	3.05	2.70	3.40	2.78	2.49	3.07	3.09	2.76	3.42	0.28	0.23	0.34	0.25	0.19	0.30	0.25	0.20	0.30	0.22	0.18	0.26
1965	2.60	2.20	2.99	2.90	2.45	3.35	2.66	2.28	3.04	2.96	2.53	3.39	0.29	0.22	0.36	0.26	0.19	0.32	0.26	0.20	0.31	0.23	0.18	0.28
1966	2.45	2.00	2.89	2.73	2.23	3.24	2.53	2.10	2.95	2.81	2.33	3.29	0.26	0.20	0.33	0.23	0.17	0.29	0.23	0.18	0.28	0.20	0.15	0.25
1967	2.39	1.92	2.86	2.67	2.14	3.19	2.47	2.02	2.92	2.75	2.24	3.25	0.28	0.20	0.35	0.24	0.18	0.31	0.24	0.18	0.30	0.21	0.16	0.26
1968	2.33	1.85	2.82	2.61	2.06	3.15	2.42	1.95	2.89	2.69	2.16	3.21	0.40	0.29	0.50	0.34	0.25	0.44	0.34	0.26	0.43	0.30	0.22	0.38
1969	2.22	1.73	2.70	2.48	1.93	3.02	2.31	1.84	2.78	2.57	2.04	3.09	0.45	0.33	0.58	0.40	0.28	0.51	0.39	0.29	0.49	0.35	0.26	0.44
1970	2.17	1.68	2.67	2.42	1.87	2.98	2.26	1.79	2.74	2.51	1.98	3.05	0.36	0.26	0.46	0.31	0.22	0.40	0.31	0.23	0.39	0.27	0.20	0.35
1971	2.15	1.65	2.65	2.41	1.84	2.97	2.24	1.76	2.73	2.50	1.96	3.04	0.32	0.24	0.41	0.28	0.20	0.35	0.28	0.21	0.35	0.25	0.18	0.31
1972	2.40	1.89	2.90	2.69	2.12	3.26	2.46	1.98	2.95	2.75	2.21	3.30	0.35	0.26	0.44	0.30	0.22	0.38	0.31	0.23	0.38	0.27	0.20	0.34
1973	2.99	2.40	3.58	3.37	2.70	4.05	3.01	2.44	3.57	3.38	2.74	4.02	0.31	0.23	0.39	0.27	0.20	0.34	0.28	0.21	0.35	0.24	0.18	0.30
1974	3.43	2.78	4.09	3.89	3.15	4.64	3.42	2.79	4.04	3.86	3.14	4.57	0.34	0.25	0.42	0.29	0.21	0.36	0.30	0.23	0.38	0.26	0.20	0.33
1975	3.50	2.86	4.15	3.98	3.24	4.72	3.48	2.85	4.10	3.93	3.23	4.64	0.40	0.30	0.50	0.34	0.26	0.43	0.36	0.27	0.45	0.31	0.24	0.39
1976	3.33	2.73	3.94	3.79	3.10	4.49	3.31	2.72	3.90	3.75	3.08	4.41	0.43	0.32	0.53	0.37	0.28	0.46	0.39	0.29	0.48	0.33	0.25	0.41
1977	3.06	2.51	3.61	3.49	2.85	4.12	3.05	2.51	3.58	3.45	2.84	4.06	0.49	0.37	0.61	0.42	0.32	0.52	0.44	0.34	0.55	0.38	0.29	0.48
1978	2.74	2.26	3.23	3.13	2.57	3.69	2.74	2.26	3.22	3.10	2.57	3.64	0.56	0.43	0.70	0.48	0.36	0.60	0.51	0.39	0.62	0.44	0.33	0.54
1979	2.43	2.00	2.86	2.77	2.27	3.26	2.44	2.01	2.87	2.76	2.28	3.24	0.61	0.46	0.76	0.52	0.39	0.65	0.55	0.42	0.68	0.47	0.36	0.59
1980	2.09	1.71	2.47	2.38	1.95	2.82	2.12	1.74	2.50	2.39	1.97	2.82	0.71	0.54	0.88	0.60	0.46	0.75	0.63	0.48	0.78	0.54	0.41	0.67
1981	1.80	1.46	2.13	2.04	1.66	2.43	1.83	1.49	2.17	2.07	1.69	2.45	0.93	0.71	1.16	0.79	0.60	0.99	0.82	0.62	1.02	0.71	0.54	0.88
1982	1.59	1.27	1.90	1.80	1.45	2.16	1.63	1.31	1.95	1.83	1.48	2.19	1.08	0.81	1.34	0.92	0.69	1.15	0.95	0.71	1.18	0.82	0.61	1.02
1983	1.42	1.12	1.73	1.62	1.27	1.96	1.47	1.16	1.78	1.66	1.31	2.01	1.14	0.85	1.43	0.97	0.72	1.23	1.00	0.74	1.26	0.87	0.64	1.09
1984	1.33	1.03	1.63	1.51	1.17	1.85	1.38	1.07	1.69	1.55	1.21	1.90	0.79	0.58	0.99	0.67	0.49	0.85	0.69	0.51	0.87	0.60	0.44	0.76
1985	1.40	1.10	1.71	1.60	1.25	1.95	1.45	1.13	1.77	1.64	1.28	1.99	0.95	0.72	1.19	0.81	0.61	1.01	0.84	0.63	1.05	0.73	0.54	0.91
1986	1.59	1.26	1.92	1.81	1.44	2.19	1.62	1.28	1.97	1.84	1.46	2.22	0.84	0.63	1.05	0.71	0.53	0.89	0.75	0.56	0.93	0.64	0.48	0.80
1987	1.78	1.41	2.14	2.03	1.61	2.45	1.81	1.43	2.18	2.05	1.63	2.47	0.81	0.61	1.01	0.69	0.51	0.86	0.72	0.54	0.90	0.62	0.46	0.77
1988	1.81	1.44	2.17	2.07	1.65	2.49	1.84	1.46	2.21	2.09	1.67	2.51	0.75	0.57	0.93	0.63	0.48	0.79	0.67	0.50	0.83	0.57	0.43	0.71
1989	1.84	1.48	2.19	2.11	1.70	2.52	1.87	1.50	2.23	2.13	1.72	2.53	0.90	0.69	1.11	0.76	0.58	0.94	0.80	0.61	0.99	0.68	0.52	0.85
1990	1.79	1.45	2.13	2.06	1.67	2.45	1.82	1.47	2.17	2.07	1.68	2.46	1.12	0.86	1.39	0.95	0.72	1.18	1.00	0.76	1.24	0.85	0.65	1.06

1991	1.62	1.29	1.95	1.86	1.48	2.24	1.66	1.32	1.99	1.89	1.51	2.26	1.03	0.79	1.28	0.87	0.66	1.08	0.92	0.70	1.14	0.79	0.60	0.98
1992	1.53	1.22	1.84	1.75	1.40	2.10	1.56	1.24	1.88	1.78	1.42	2.13	1.02	0.78	1.26	0.87	0.66	1.07	0.91	0.69	1.13	0.78	0.59	0.97
1993	1.54	1.24	1.84	1.76	1.42	2.11	1.56	1.25	1.87	1.78	1.44	2.12	1.02	0.79	1.26	0.87	0.66	1.07	0.91	0.70	1.13	0.78	0.60	0.97
1994	1.54	1.25	1.83	1.77	1.43	2.10	1.56	1.26	1.87	1.78	1.44	2.12	1.09	0.84	1.34	0.92	0.71	1.14	0.97	0.75	1.20	0.83	0.64	1.03
1995	1.52	1.22	1.81	1.74	1.41	2.08	1.54	1.24	1.84	1.76	1.42	2.09	1.00	0.76	1.23	0.84	0.64	1.04	0.89	0.67	1.10	0.76	0.58	0.94
1996	1.51	1.21	1.80	1.73	1.40	2.07	1.53	1.23	1.84	1.75	1.41	2.09	0.99	0.75	1.23	0.84	0.63	1.04	0.88	0.66	1.10	0.75	0.57	0.94
1997	1.46	1.16	1.76	1.68	1.34	2.01	1.49	1.18	1.79	1.69	1.35	2.03	0.95	0.71	1.18	0.80	0.60	1.00	0.84	0.63	1.05	0.72	0.54	0.90
1998	1.41	1.11	1.70	1.62	1.28	1.95	1.44	1.13	1.74	1.64	1.30	1.98	1.01	0.76	1.27	0.86	0.64	1.08	0.90	0.67	1.13	0.77	0.57	0.97
1999	1.35	1.05	1.64	1.55	1.20	1.89	1.38	1.07	1.69	1.57	1.23	1.92	0.92	0.69	1.16	0.78	0.58	0.98	0.82	0.61	1.03	0.70	0.52	0.88
2000	1.40	1.09	1.71	1.61	1.26	1.96	1.44	1.12	1.75	1.64	1.28	1.99	0.82	0.61	1.03	0.69	0.52	0.87	0.73	0.54	0.91	0.62	0.46	0.78
2001	1.61	1.28	1.94	1.85	1.47	2.24	1.64	1.30	1.98	1.87	1.49	2.25	0.89	0.67	1.11	0.75	0.56	0.94	0.79	0.59	0.99	0.67	0.50	0.84
2002	1.74	1.38	2.10	2.01	1.59	2.42	1.77	1.40	2.14	2.02	1.61	2.43	0.77	0.57	0.96	0.65	0.48	0.81	0.68	0.51	0.85	0.58	0.43	0.73
2003	1.77	1.40	2.14	2.04	1.62	2.46	1.80	1.43	2.17	2.06	1.64	2.47	0.69	0.52	0.86	0.58	0.43	0.73	0.61	0.46	0.77	0.52	0.39	0.66
2004	1.82	1.46	2.19	2.10	1.68	2.52	1.84	1.48	2.21	2.11	1.70	2.52	0.68	0.51	0.85	0.57	0.43	0.72	0.61	0.45	0.76	0.52	0.39	0.65
2005	1.81	1.45	2.17	2.09	1.67	2.50	1.83	1.46	2.19	2.09	1.69	2.50	0.63	0.47	0.79	0.53	0.39	0.66	0.56	0.42	0.70	0.48	0.36	0.60
2006	1.70	1.35	2.05	1.97	1.57	2.36	1.73	1.38	2.08	1.98	1.58	2.37	0.65	0.49	0.81	0.55	0.41	0.69	0.58	0.43	0.72	0.49	0.37	0.62
2007	1.64	1.31	1.98	1.89	1.51	2.28	1.66	1.33	2.00	1.90	1.53	2.28	0.63	0.47	0.79	0.53	0.40	0.67	0.56	0.42	0.70	0.48	0.36	0.60
2008	1.63	1.30	1.96	1.88	1.51	2.26	1.65	1.32	1.98	1.89	1.52	2.26	0.73	0.55	0.91	0.62	0.46	0.77	0.65	0.49	0.81	0.56	0.42	0.70
2009	1.54	1.23	1.86	1.78	1.42	2.14	1.56	1.25	1.88	1.79	1.43	2.14	0.81	0.61	1.01	0.68	0.51	0.86	0.72	0.54	0.90	0.62	0.46	0.77
2010	1.43	1.12	1.73	1.65	1.30	2.00	1.46	1.15	1.76	1.66	1.32	2.01	0.84	0.63	1.06	0.71	0.53	0.89	0.74	0.55	0.93	0.63	0.47	0.80
2011	1.37	1.07	1.67	1.58	1.24	1.92	1.40	1.10	1.70	1.60	1.26	1.94	0.82	0.61	1.03	0.69	0.51	0.87	0.70	0.53	0.88	0.60	0.45	0.75
2012	1.37	1.07	1.68	1.59	1.24	1.93	1.44	1.14	1.75	1.64	1.30	1.99	0.81	0.60	1.02	0.68	0.50	0.86	0.69	0.52	0.86	0.59	0.44	0.74
2013	1.41	1.10	1.72	1.63	1.27	1.98	1.52	1.21	1.83	1.73	1.38	2.09	0.73	0.54	0.92	0.62	0.46	0.78	0.64	0.48	0.80	0.55	0.41	0.68
2014	1.47	1.15	1.79	1.70	1.33	2.07	1.54	1.23	1.85	1.76	1.41	2.11	0.76	0.56	0.95	0.64	0.47	0.80	0.69	0.52	0.86	0.59	0.44	0.74
2015	1.51	1.18	1.85	1.75	1.37	2.13	1.48	1.18	1.79	1.69	1.35	2.03	0.86	0.64	1.09	0.73	0.53	0.92	0.81	0.60	1.01	0.69	0.52	0.87
2016	1.48	1.14	1.82	1.71	1.32	2.10	1.40	1.09	1.70	1.59	1.25	1.93	1.07	0.77	1.36	0.90	0.65	1.15	1.00	0.73	1.27	0.86	0.63	1.09
2017	1.35	1.01	1.69	1.56	1.17	1.95	1.28	0.98	1.59	1.45	1.11	1.80	1.09	0.74	1.43	0.91	0.62	1.20	1.00	0.71	1.29	0.86	0.61	1.12
2018	1.20	0.85	1.55	1.39	0.99	1.79	1.17	0.86	1.48	1.32	0.97	1.67	1.19	0.74	1.63	1.00	0.62	1.37	1.00	0.68	1.32	0.86	0.59	1.14

Table 17. Derived quantities and benchmark values for the four uncertainty grid runs

	Run 1 (95% CI)	Run 2 (95% CI)	Run 3 (95% CI)	Run 4 (95% CI)
SSB_unfished	1433860 (1244168,1623552)	1370660 (1178805,1562515)	1527430 (1313853,1741007)	1452100 (1241978,1662222)
Totbio_unfished	1847760 (1603285,2092235)	1766280 (1519006,2013554)	1966670 (1691521,2241819)	1869710 (1599012,2140408)
Recr_unfished	83296 (71503,95089)	79580 (67712,91447)	86978 (73715,100241)	82734 (69744,95723)
Dead_Catch_Btgt	101768 (88245,115291)	106738 (92164,121312)	114826 (102512,127140)	119899 (106601,133197)
SSB_SPR30%	363244 (315189,411299)	383785 (330066,437504)	386949 (332843,441055)	406587 (347753,465421)
Fstd_SPR30%	0.186 (0.17,0.2)	0.187 (0.17,0.2)	0.195 (0.18,0.21)	0.196 (0.18,0.21)
SSB_MSY	422487 (367459,477515)	359054 (310133,407975)	452022 (389789,514255)	383482 (329596,437368)
SPR_MSY	0.34 (0.33,0.34)	0.28 (0.28,0.29)	0.34 (0.34,0.34)	0.29 (0.28,0.29)
Fstd_MSY	0.16 (0.15,0.18)	0.2 (0.18,0.21)	0.17 (0.16,0.18)	0.21 (0.19,0.22)
MSY (mt)	101779 (88255,115303)	107301 (92650,121952)	114833 (102513,127153)	120468 (107048,133888)
SSB_MSY/SSB_unfished	0.295 (0.29,0.3)	0.26 (0.26,0.27)	0.296 (0.29,0.3)	0.26 (0.26,0.27)
SSB/SSBmsy (2018)	1.2 (0.85,1.55)	1.39 (0.99,1.79)	1.17 (0.86,1.48)	1.32 (0.97,1.67)
F/Fmsy(2018)	1.14 (0.74,1.53)	0.953 (0.62,1.28)	0.999 (0.69,1.3)	0.86 (0.6,1.13)
SSB_2018	506273 (308672,703874)	498006 (303393,692619)	528253 (330142,726364)	506320 (315853,696787)

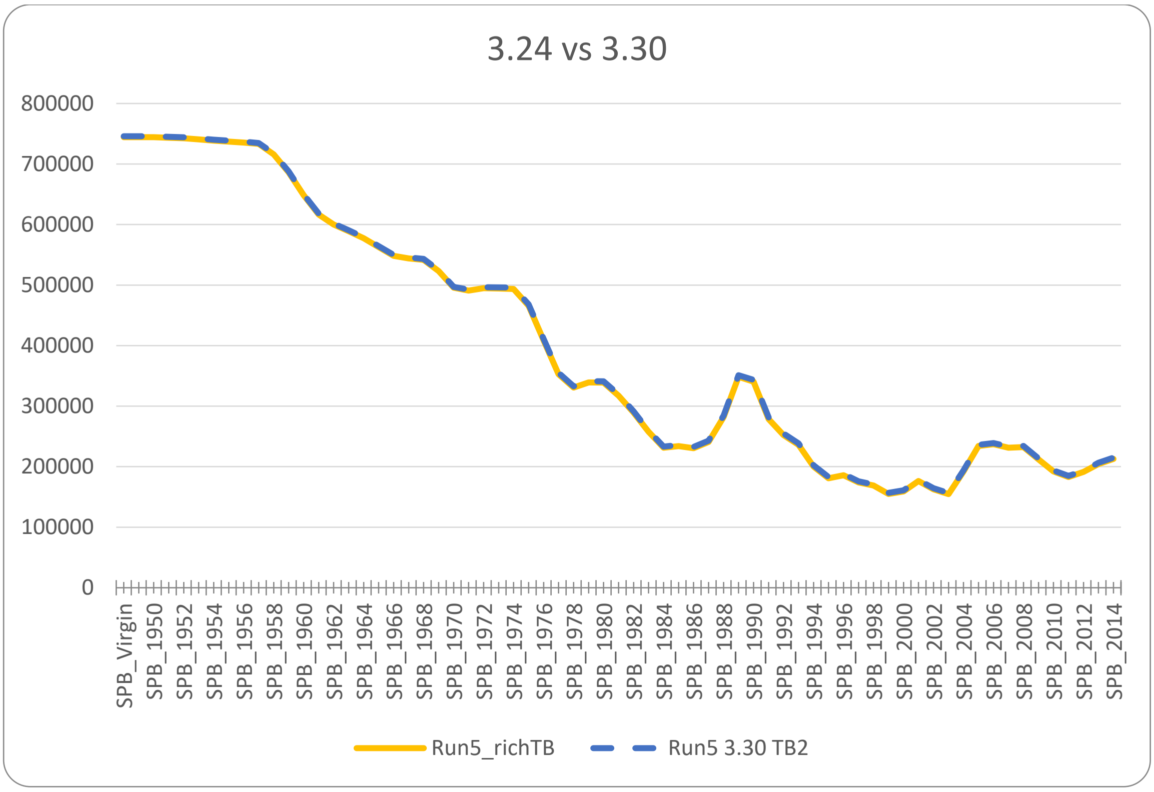


Figure 1. Comparison of SSB for run 5 model in 2016 in SS 3.24 and the same model in 3.30.

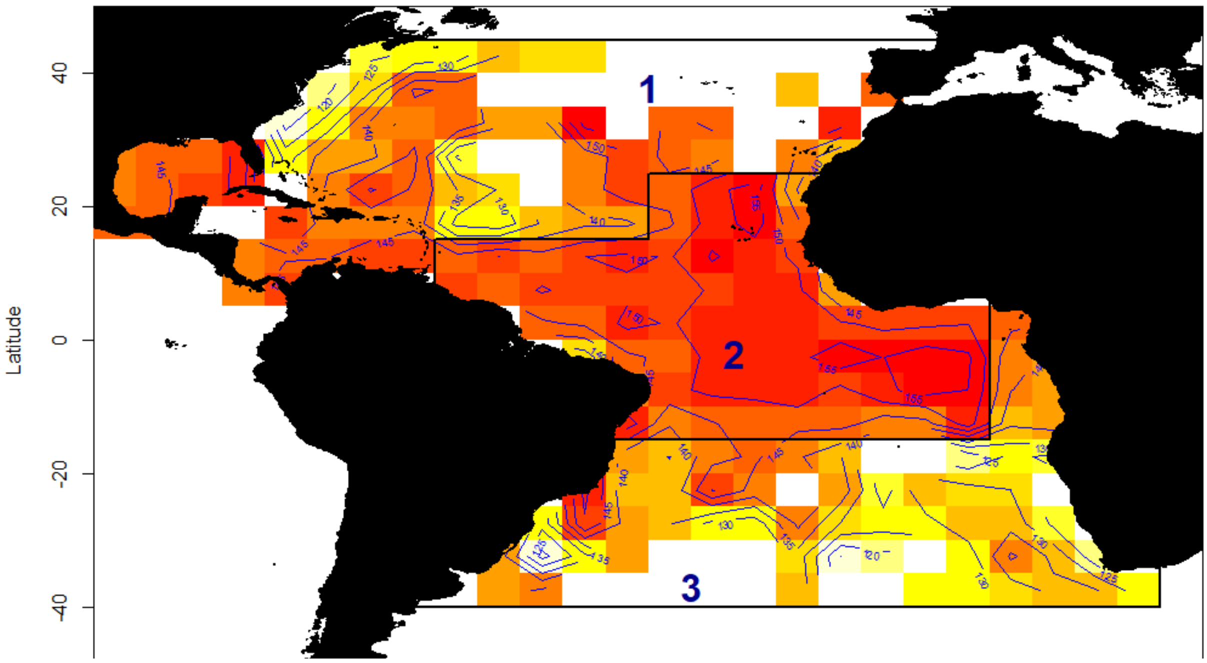


Figure 2. Proposed spatial partitioning for assessment model fleet structure. Colors and contours map the mean lengths in the longline fisheries. From SCRS-2019-081.

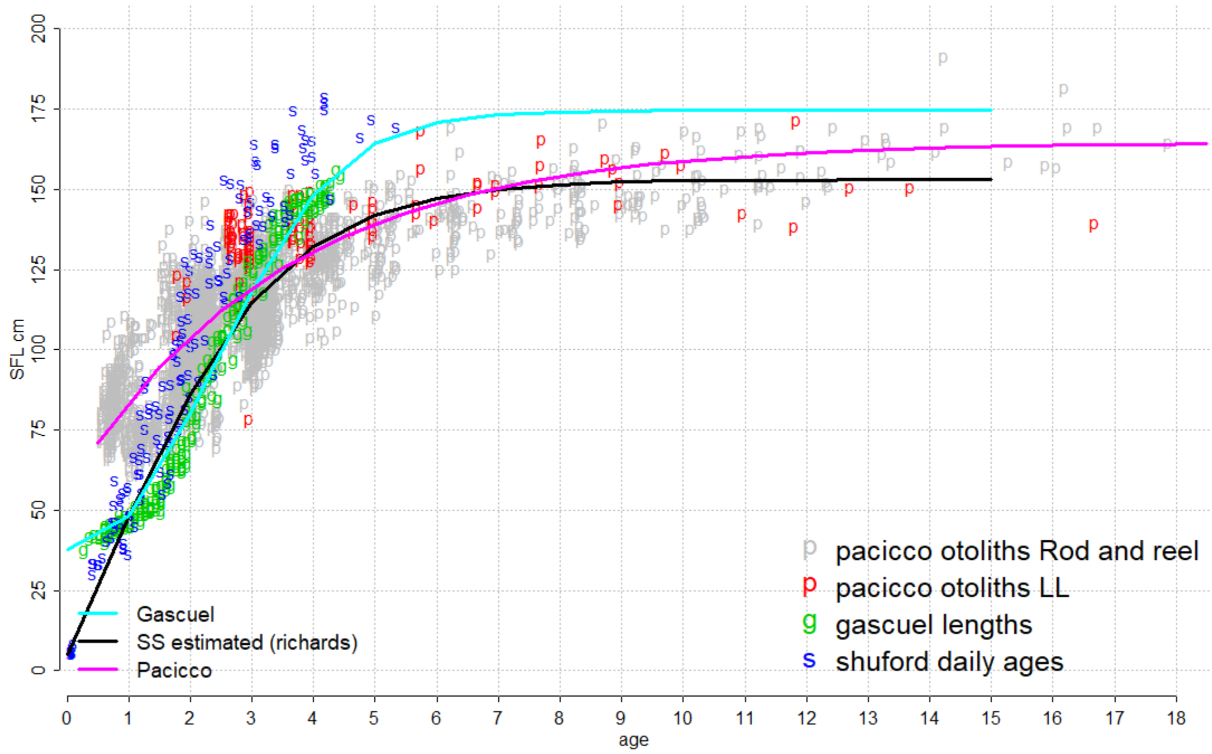


Figure 3. Age information from Pacicco et al. 2019, Gascuel et al. 1992 and Shuford et al. 2007 with estimated growth curves.

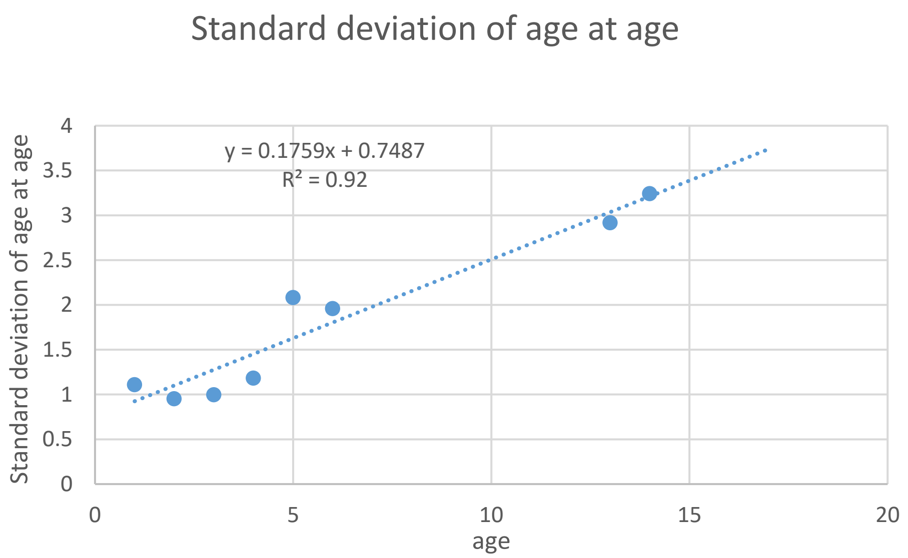


Figure 4. Estimated standard deviation of age at age from reference set multiple read experiments.

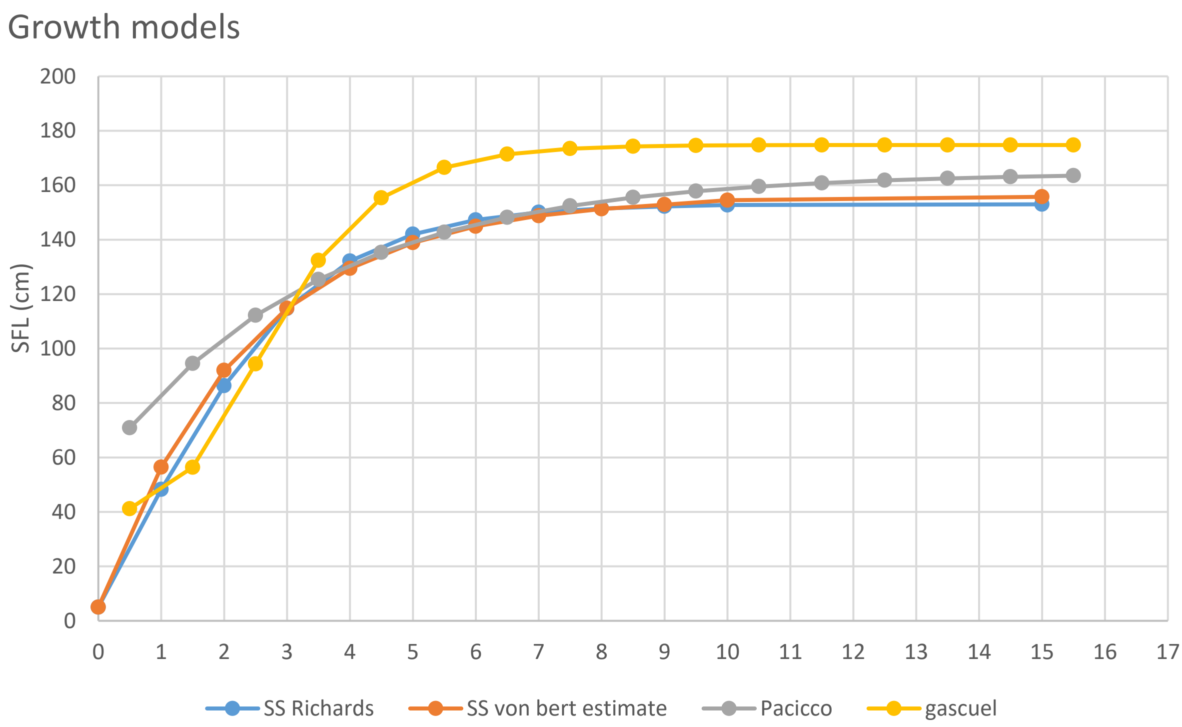


Figure 5. Growth models considered in this assessment. Gascuel et al (1992) and Pacicco et al 2019) are shown for reference but not used. Growth is estimated within the SS models with a Richards function (blue line) or a Von bertalannfy function (orange line) and, depending on the model run, growth is either estimated or fixed at the growth models shown here.

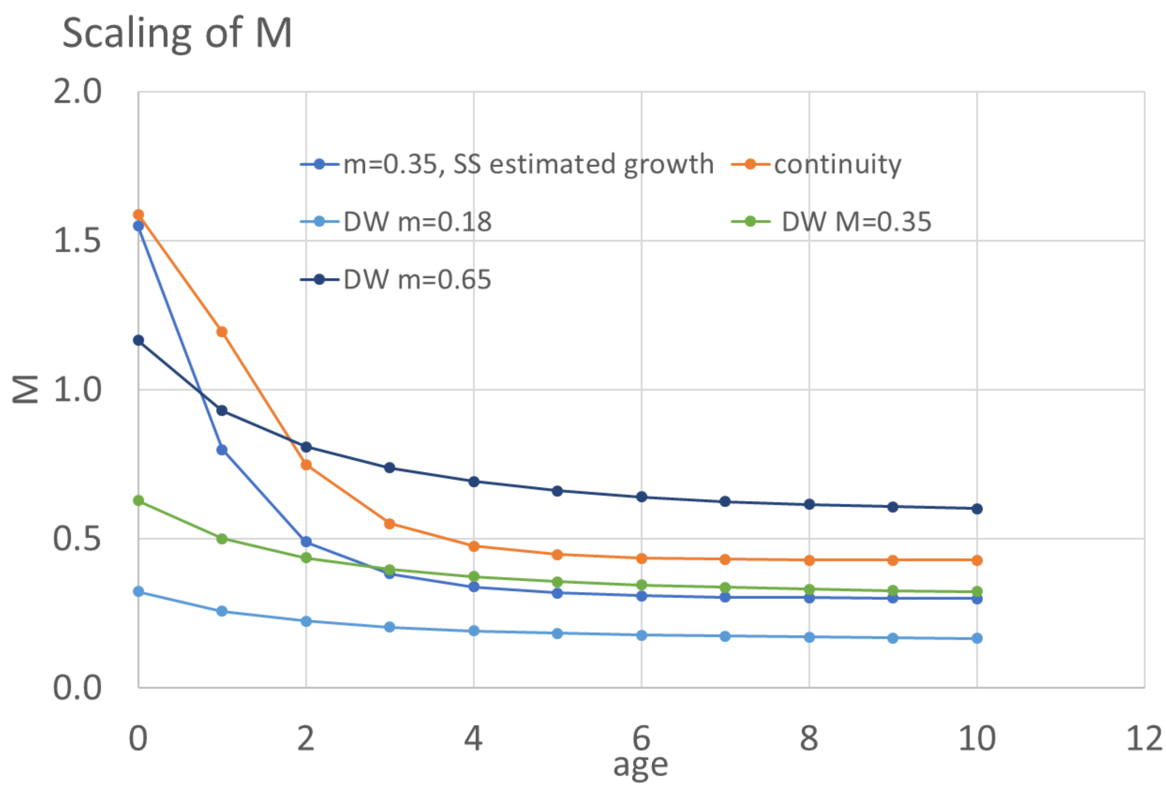


Figure 6. Comparison of scaled natural mortality rate estimates. The "reference' M is M=0.35. The DW recommended baseline M upper (0.65) and lower (0.18) values. We recommend less extreme upper and lower values of 0.42 and 0.28 for the high and low values.

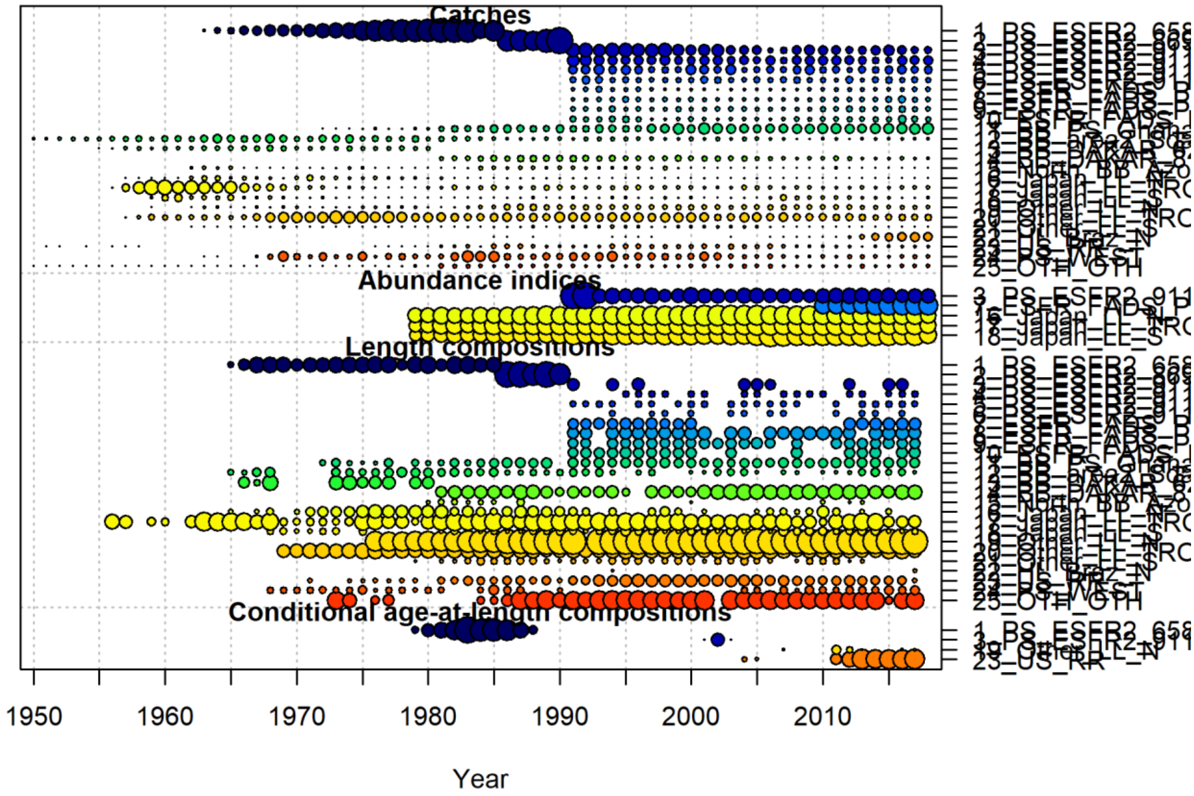


Figure 7. Time series of data inputs to the YFT SS model. Data presence by year for each fleet, where circle area is relative within a data type. Circles are proportional to total catch for catches; to precision for indices, discards, and mean body weight observations; and to total sample size for compositions and mean weight- or length-at-age observations. 'Ghost' observations (not included in the likelihood) have equal size for all years.

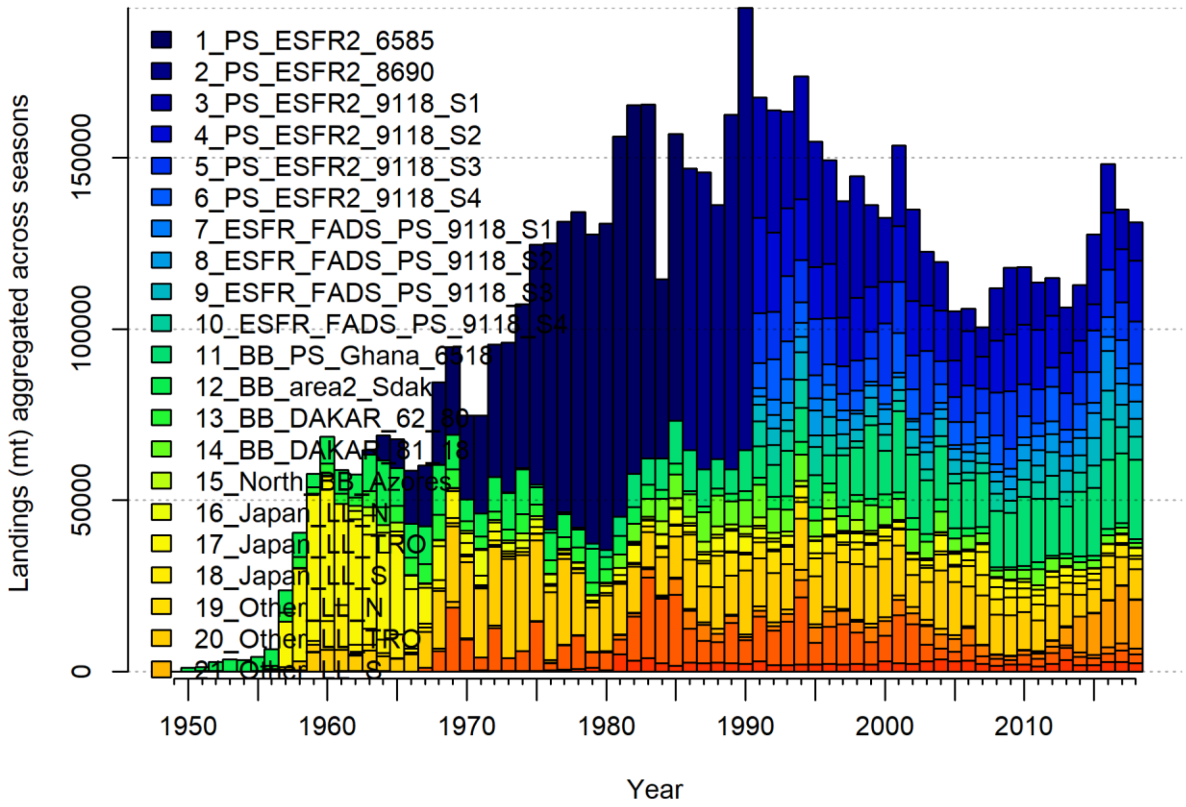


Figure 8. Task I catch (t) by SS fleet.

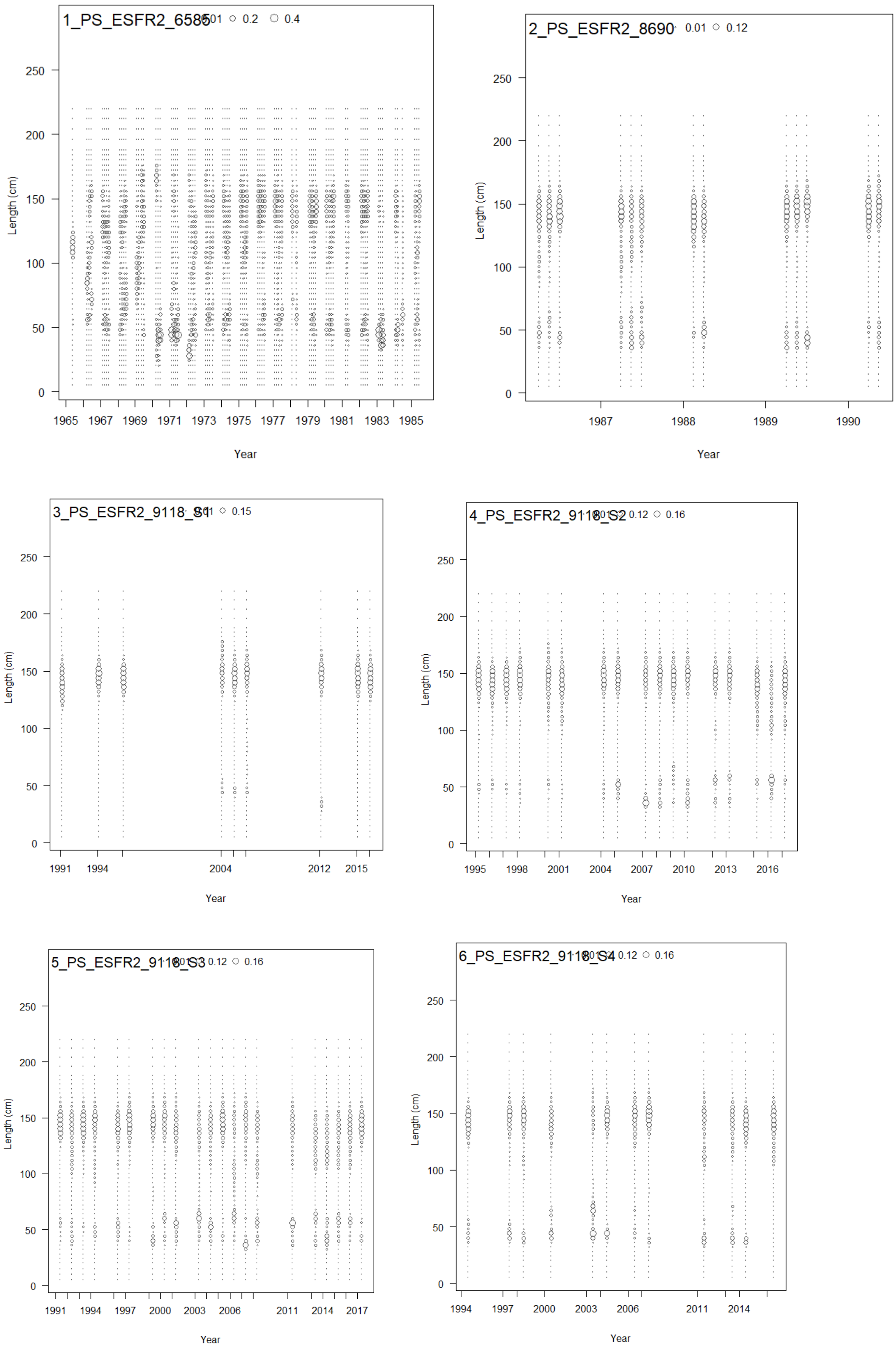


Figure 9. Size composition input for fleets 1-6.

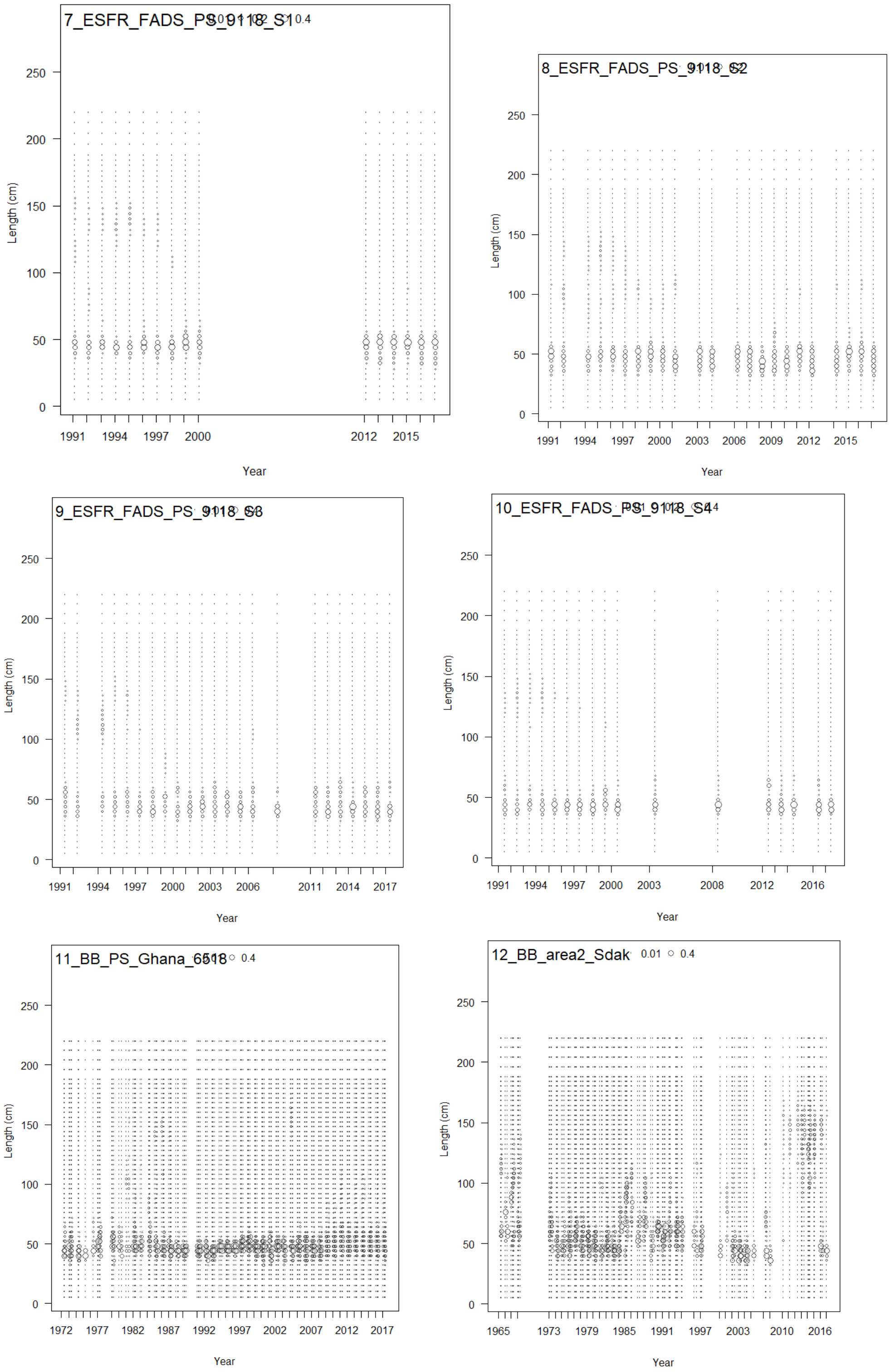


Figure 10. Size composition input for fleets 7-12.

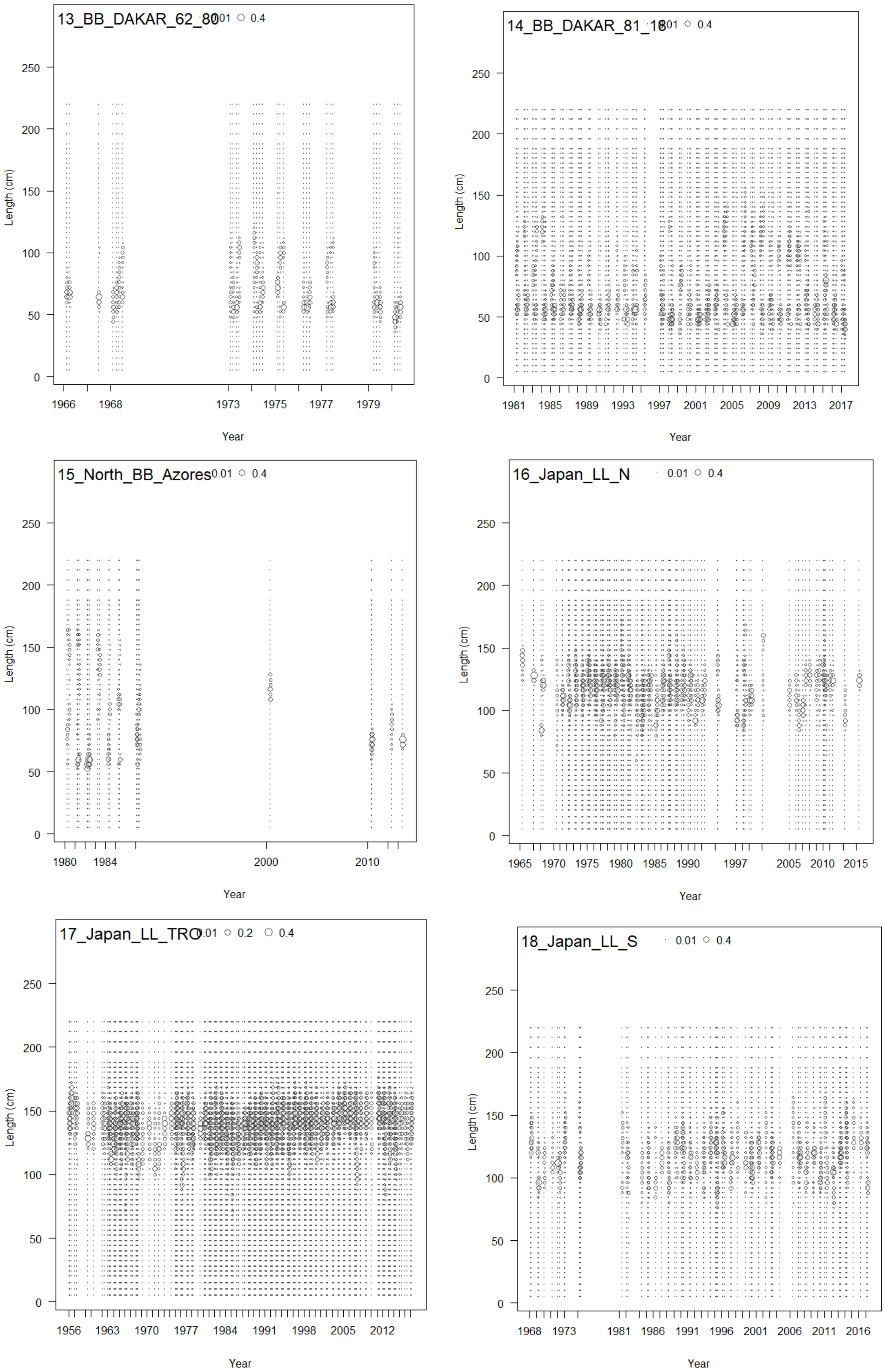


Figure 11. Size composition input for fleets 13-18.

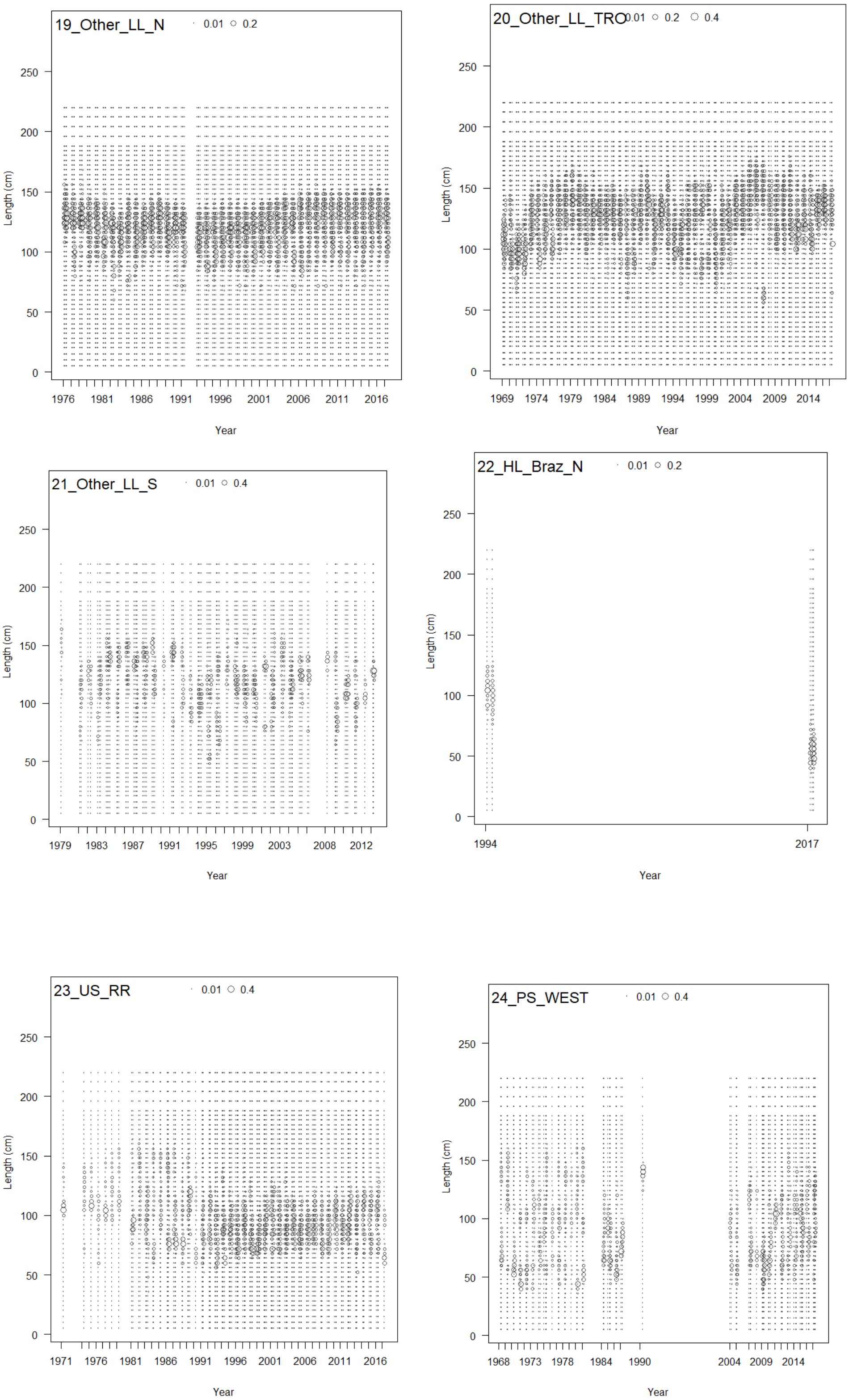


Figure 12. Size composition input for fleets 19-24

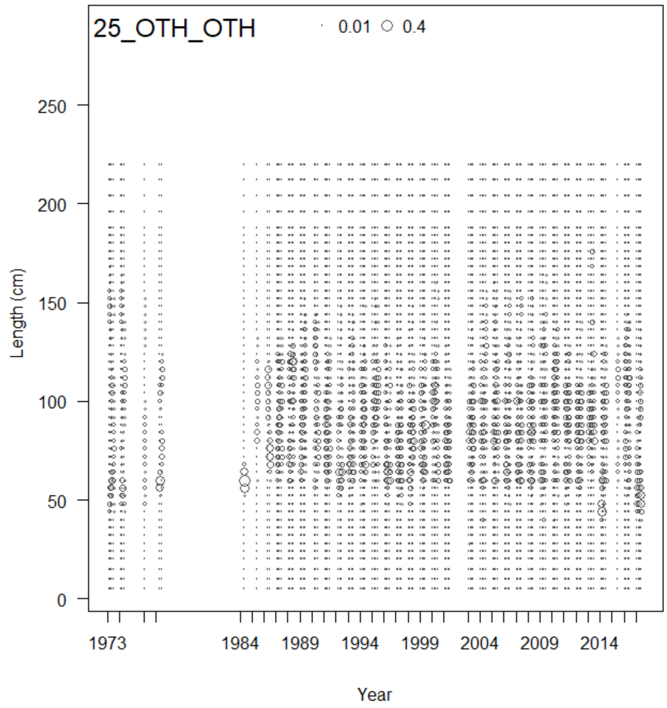


Figure 13. Size composition input for fleet 25.

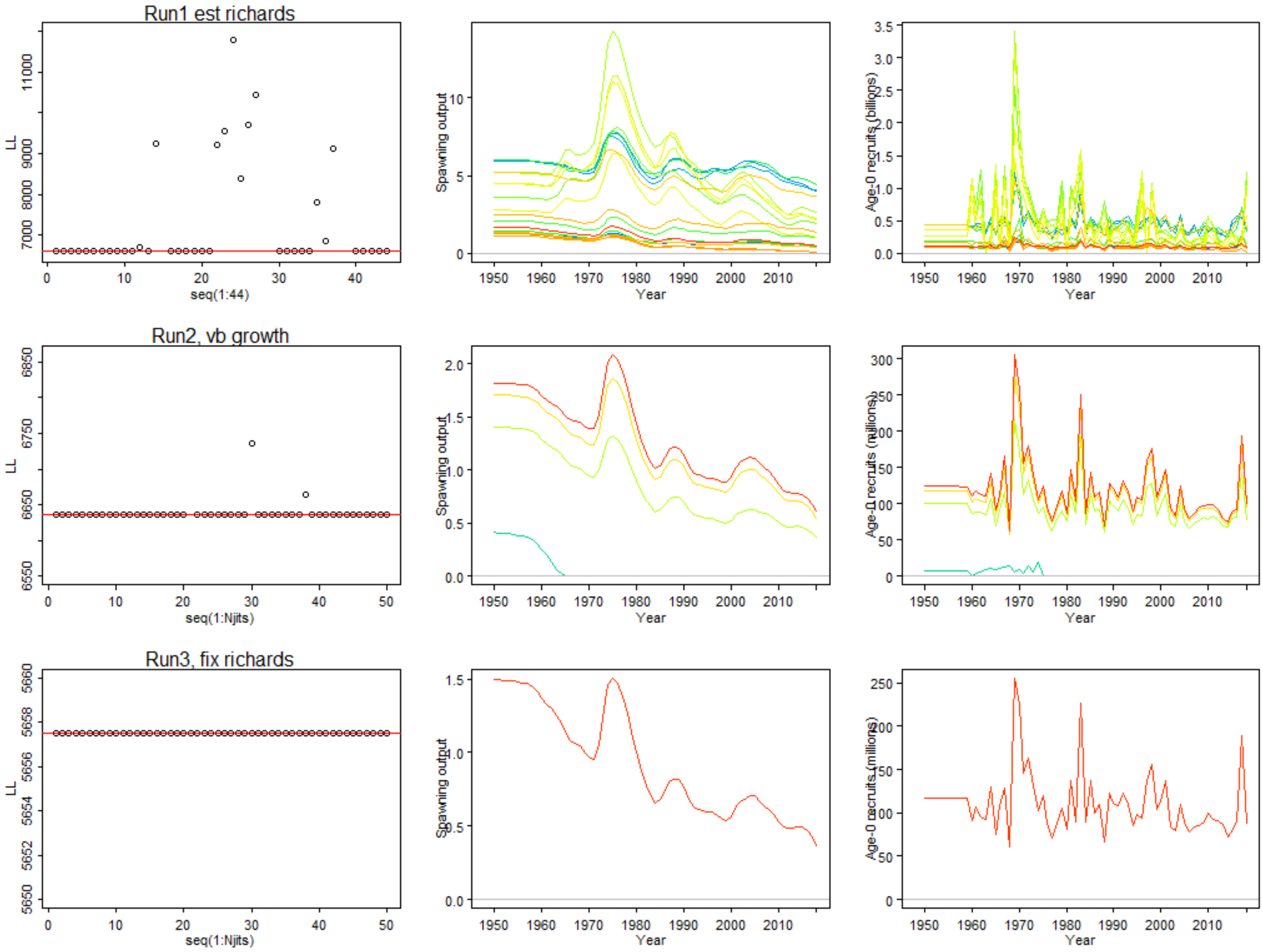


Figure 14. Jitter results for Preliminary model run 1, 2 and 3. Red line on left panels is the negative log likelihood for the converged model.

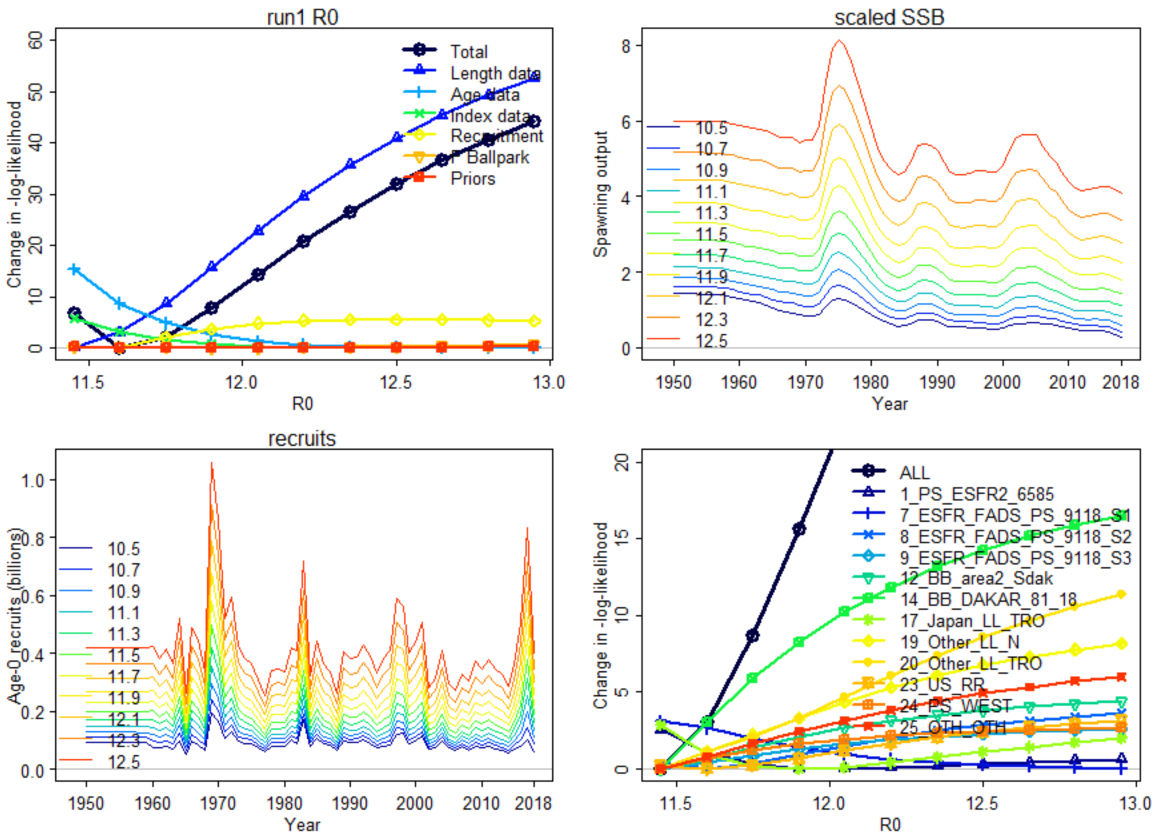


Figure 15. Preliminary Run 1 profiles of R0 and resulting SSB and recruitment and likelihoods by fleet.

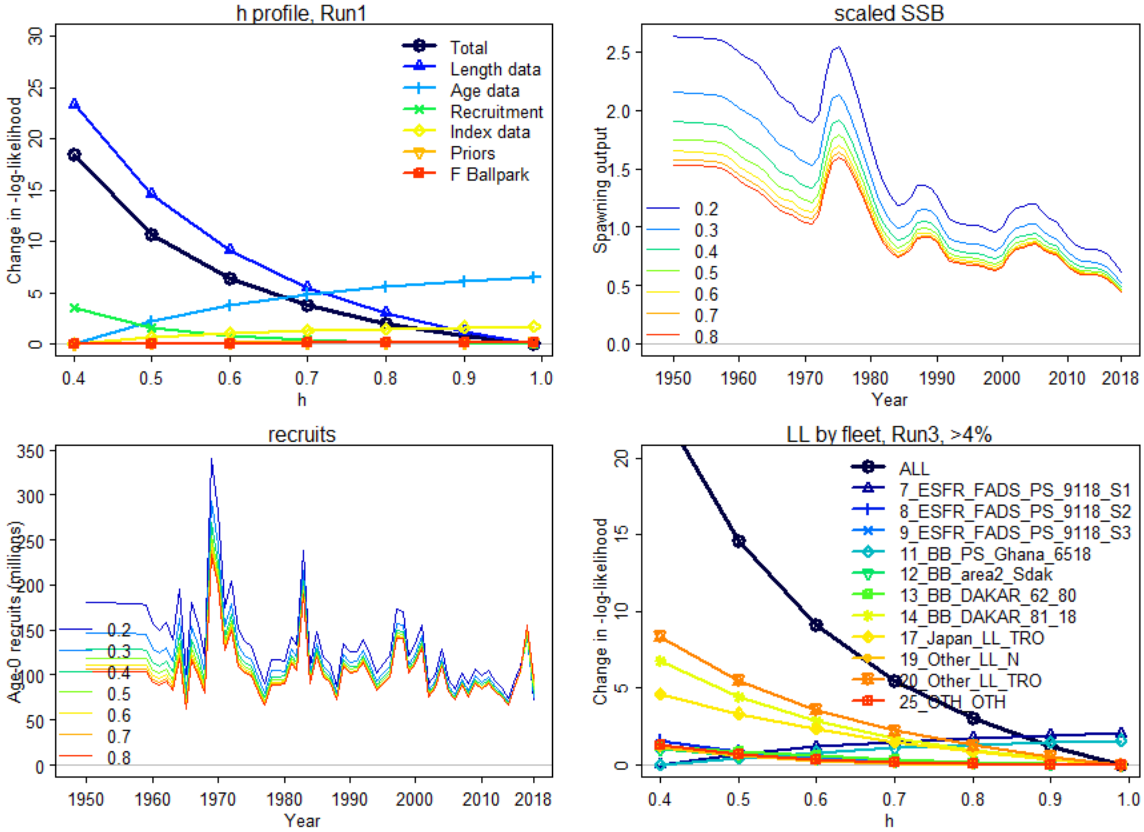


Figure 16. Preliminary Run 1 profiles of steepness and resulting SSB and recruitment and likelihoods by fleet.

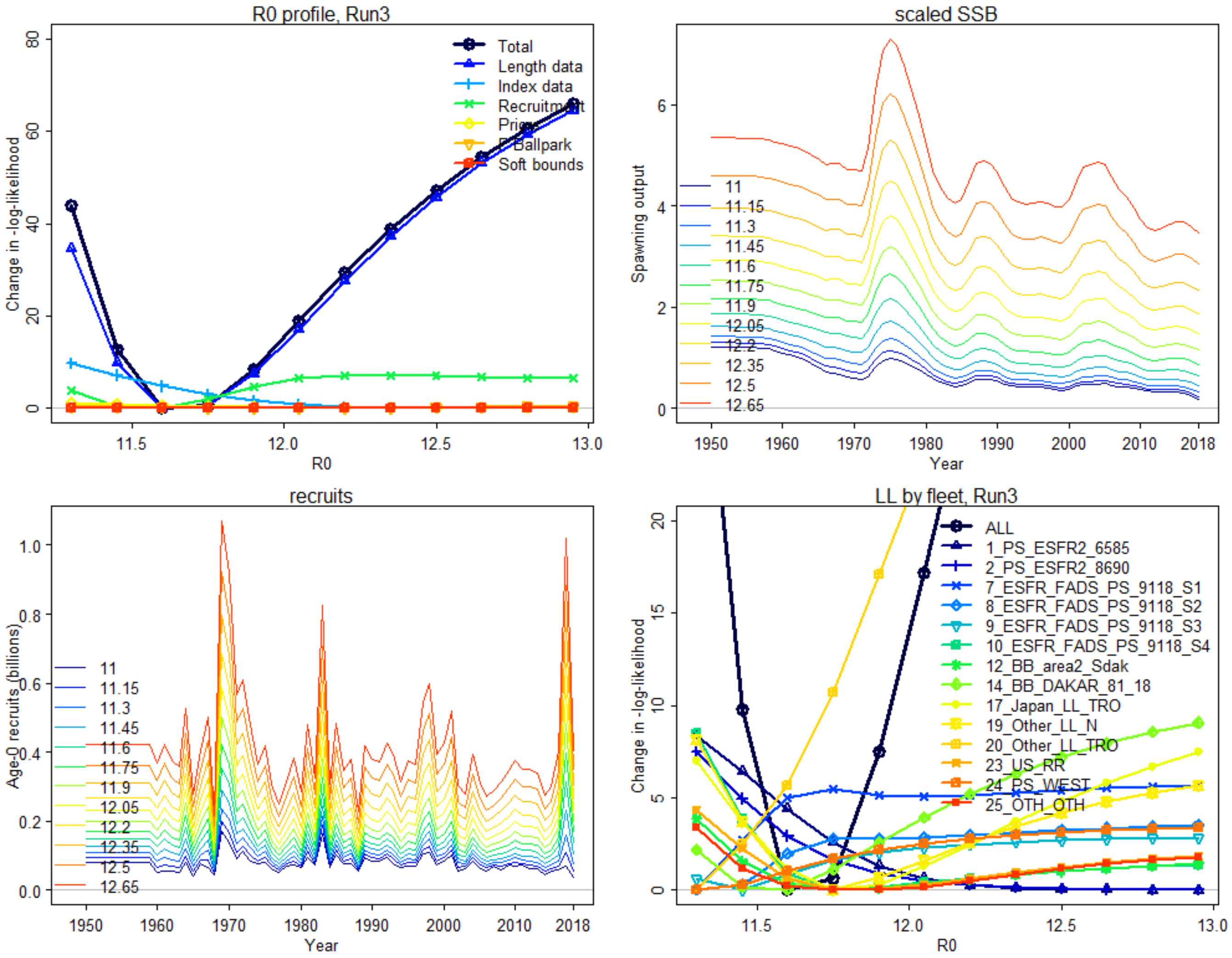


Figure 17. Preliminary Run 3 R0 likelihood profile.

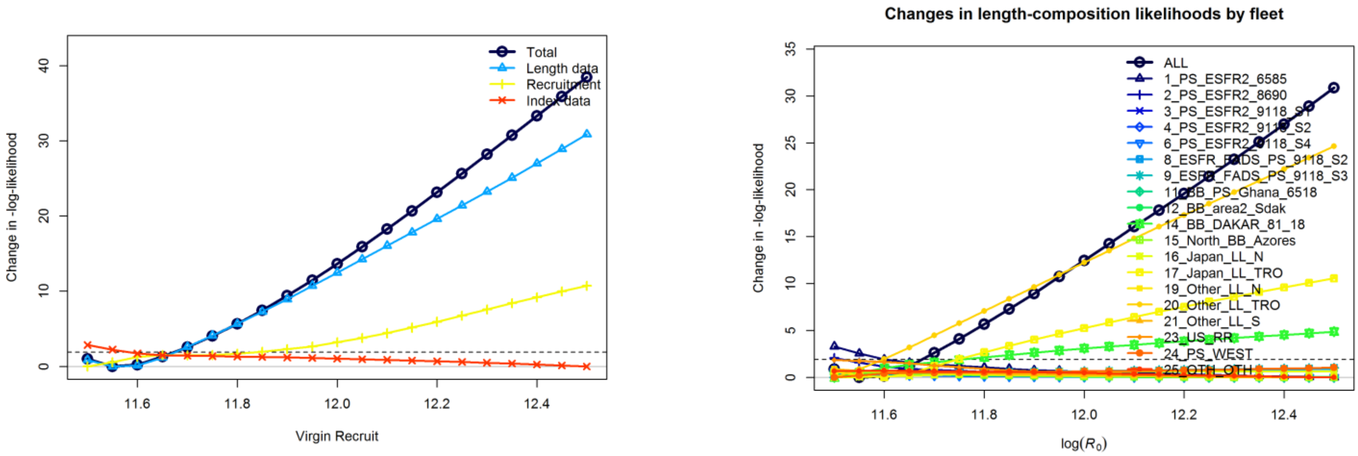


Figure 18. Preliminary Run 3 R0 likelihood profile, estimated steepness

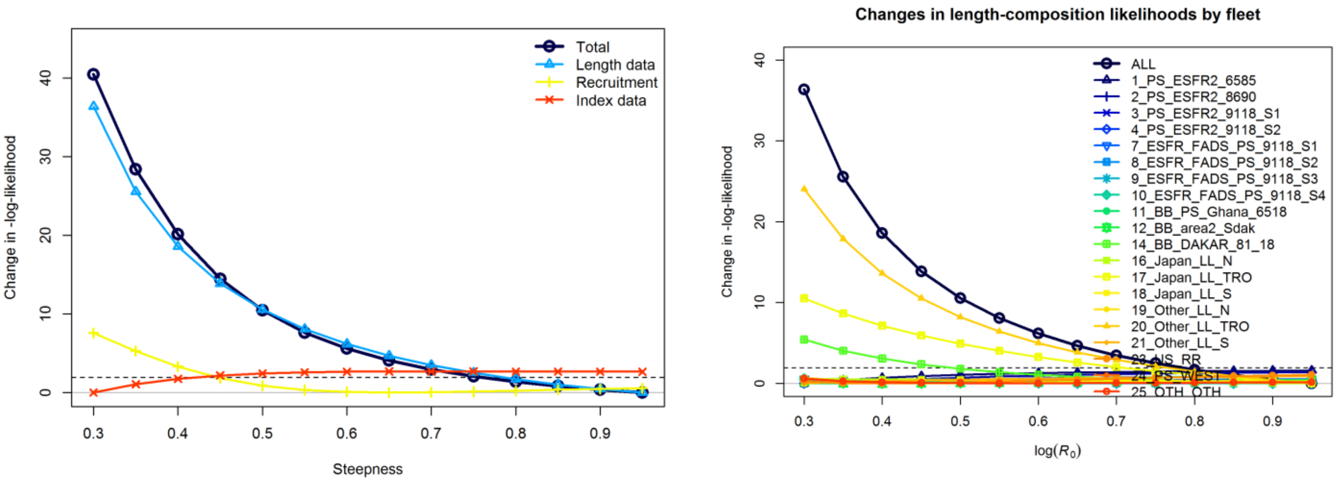


Figure 19. Preliminary un 3. steepness likelihood profile

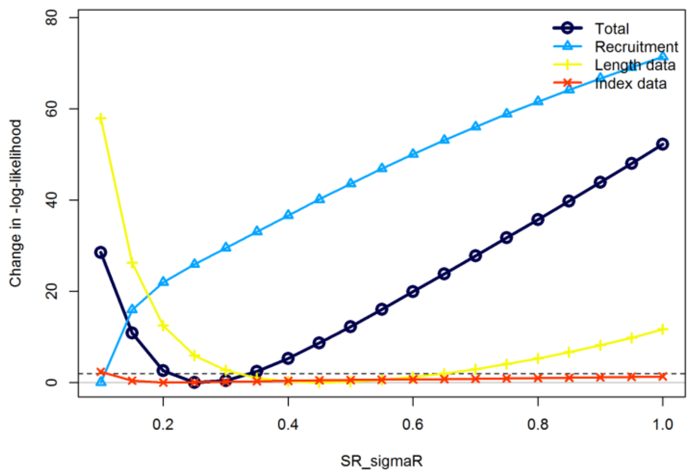


Figure 20. Preliminary Run 3. sigmaR likelihood profile

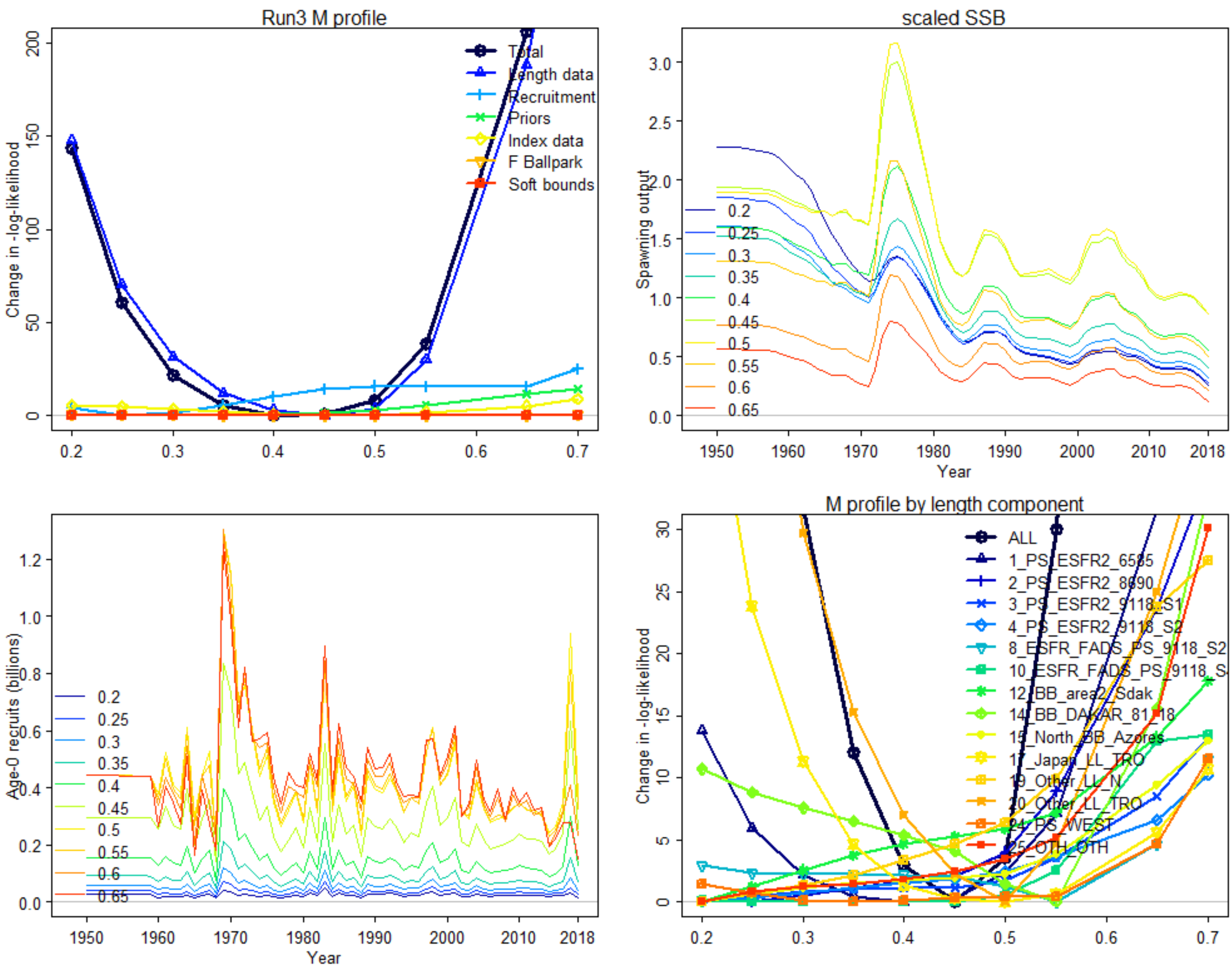


Figure 21. Preliminary Run3 Profile of M5 by length composition likelihood component. Only fleets with >3% of the loglikelihood difference are shown.

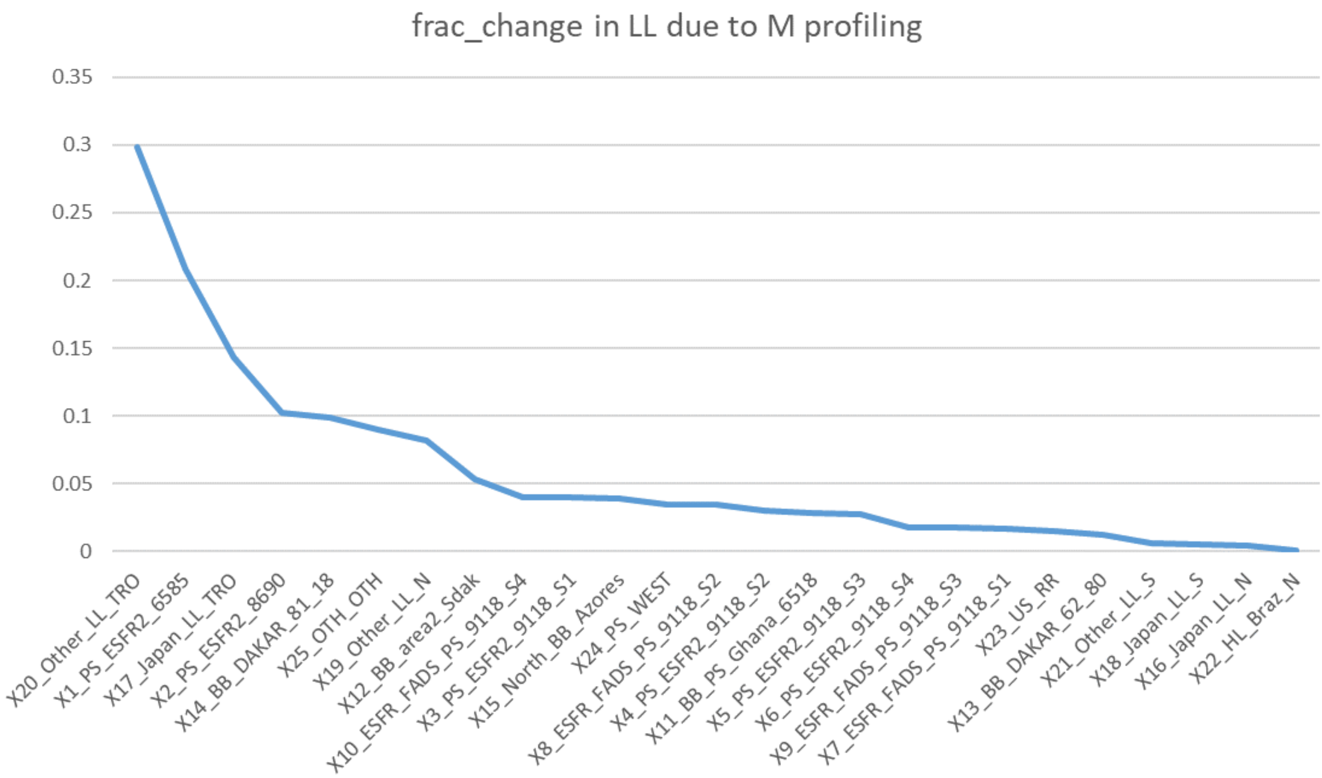


Figure 22. Fractional change in LL.

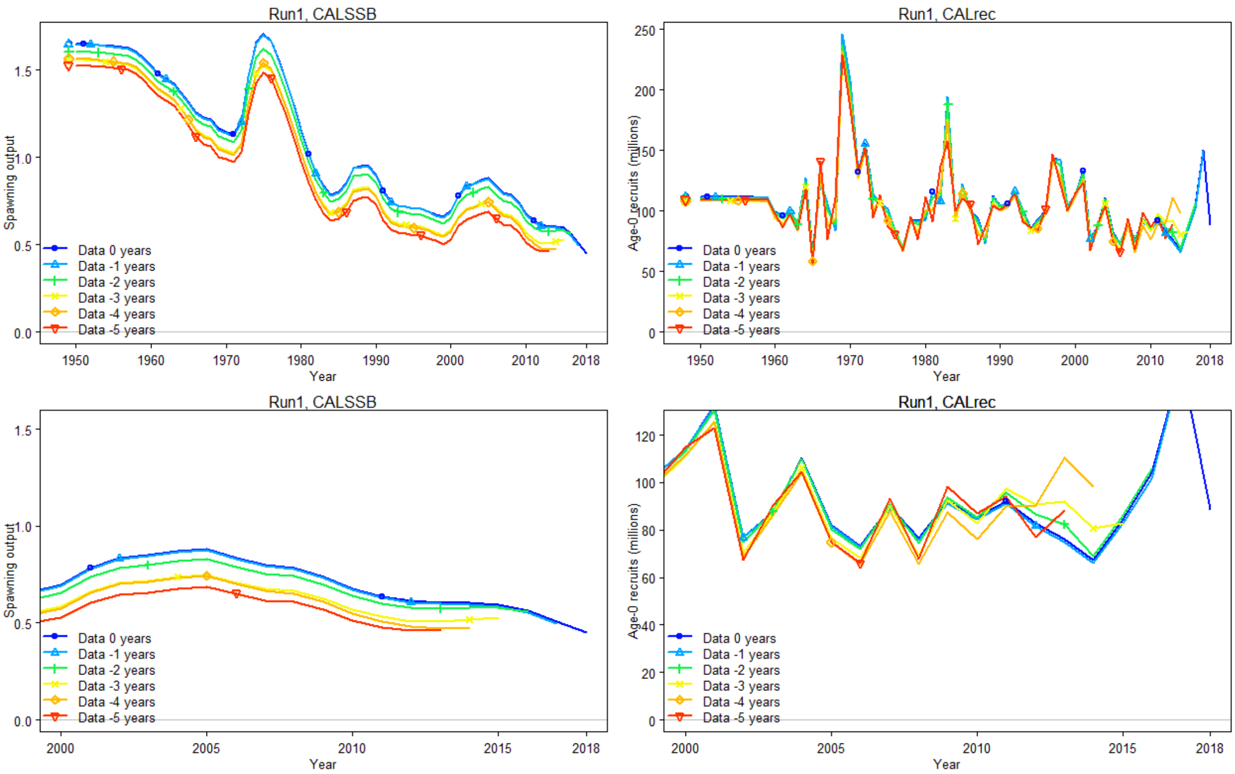


Figure 23. Run 1 retrospectives.

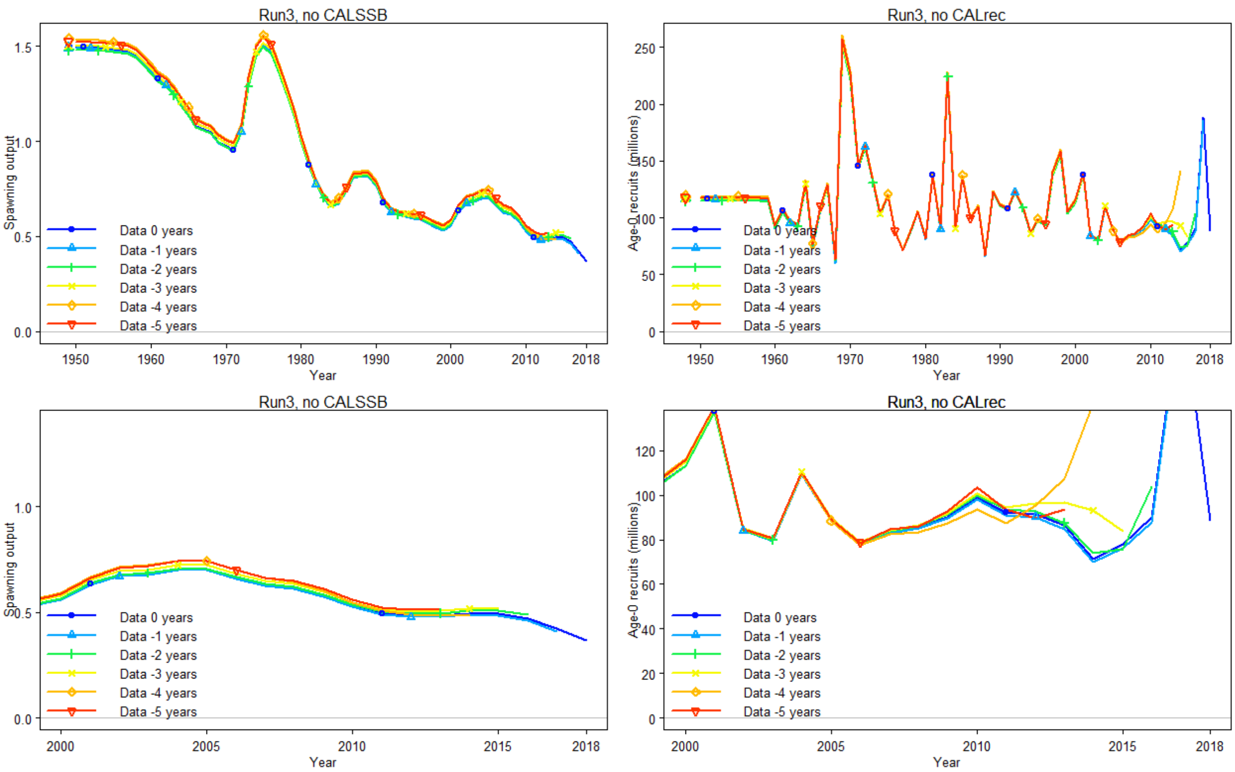


Figure 24. Run 3 (fix growth, no CAL) retrospectives

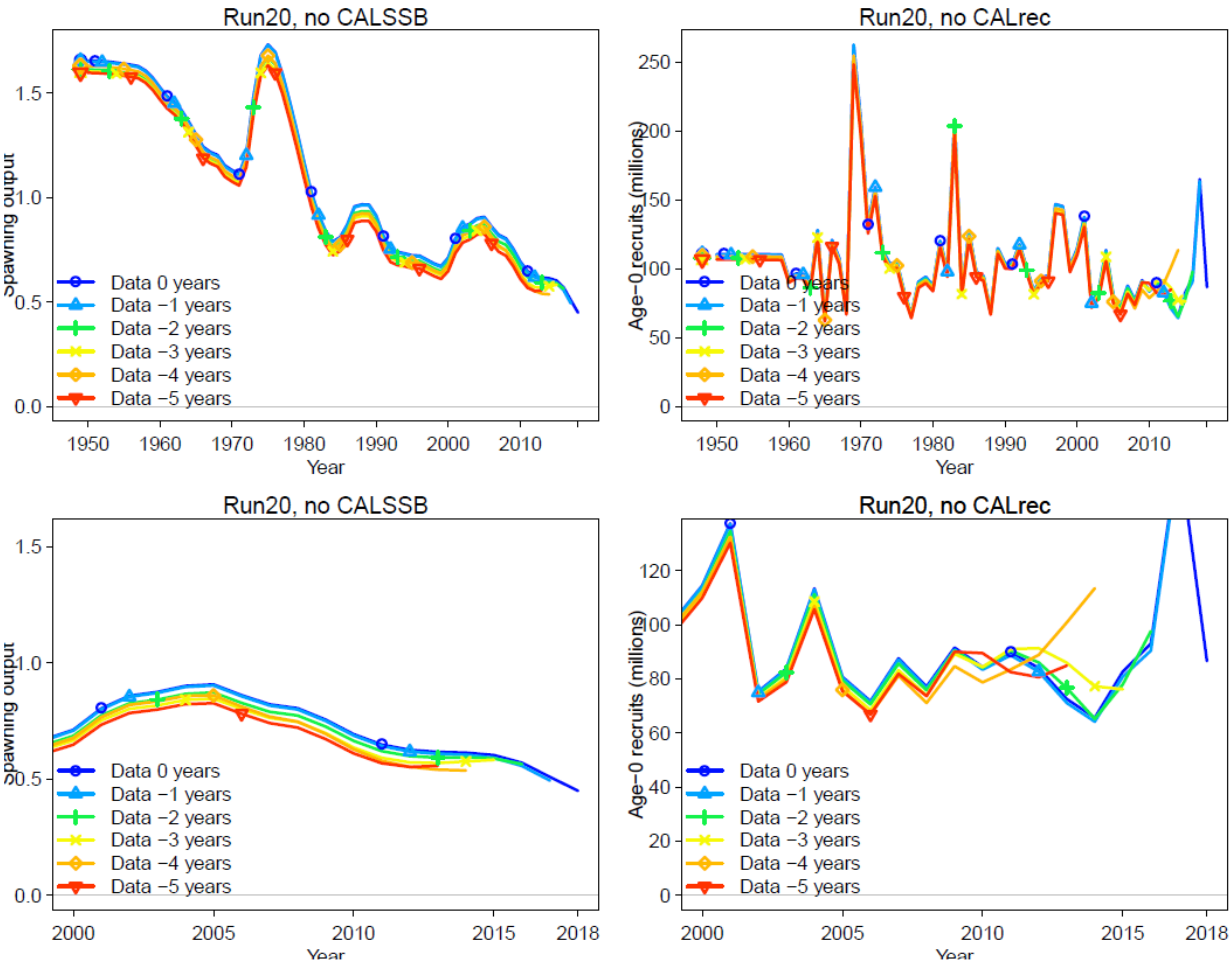


Figure 25. Run 20 (use CAL but fix growth) retrospectives

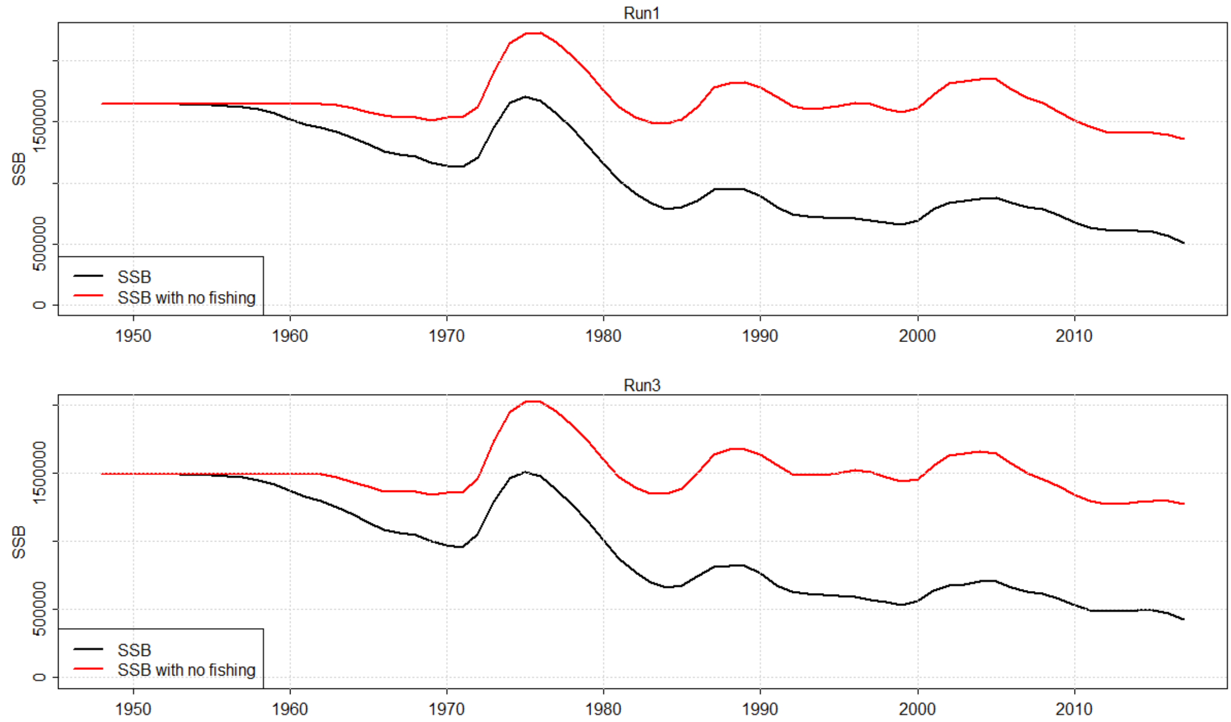


Figure 26. Dynamic SSB0 plot indicating SSB with and without fishery, Run 1 (top) and run 3 (bottom).

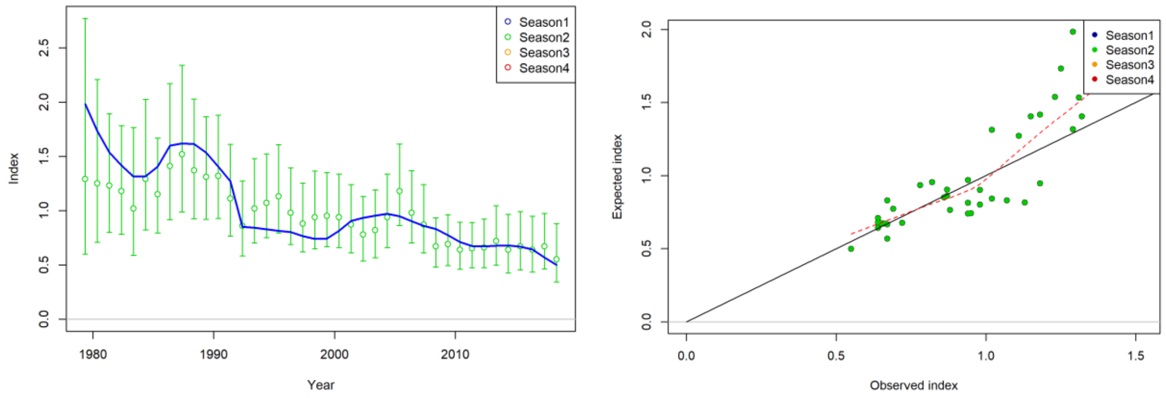


Figure 27. Fits to joint CPUE index full time series for run 3.

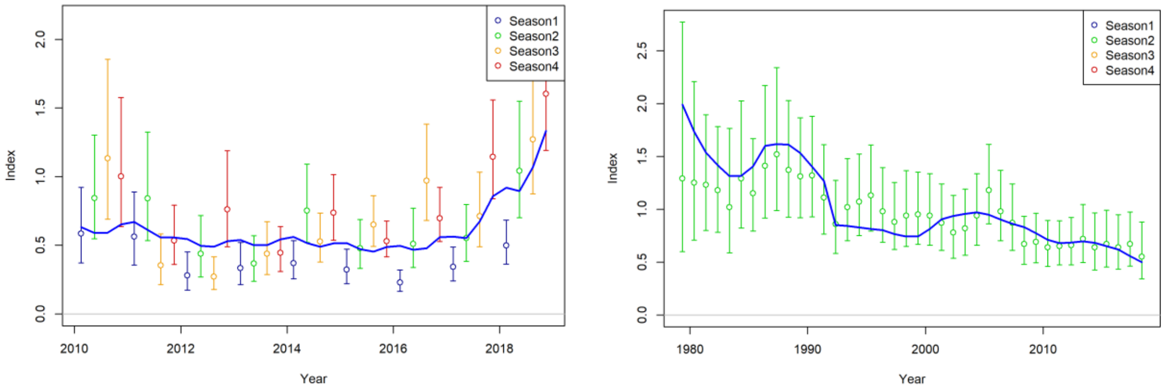


Figure 28. Fits to buoy acoustic index and the joint CPUE index for run 9 which is fit to both indices.

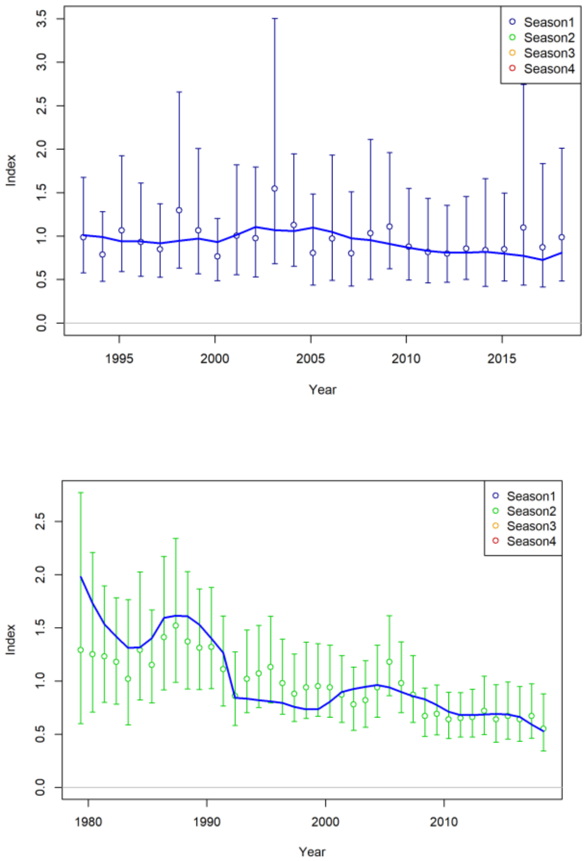
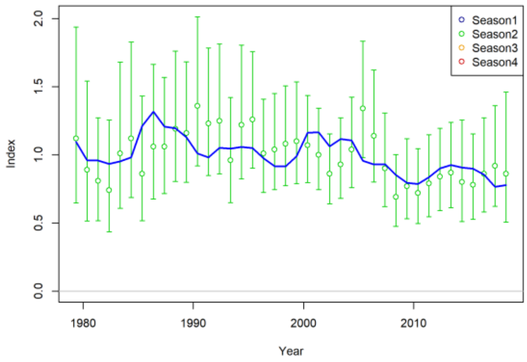
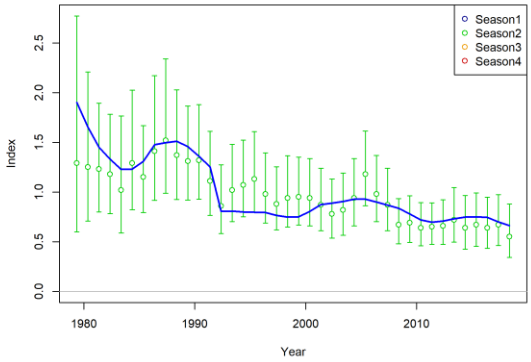
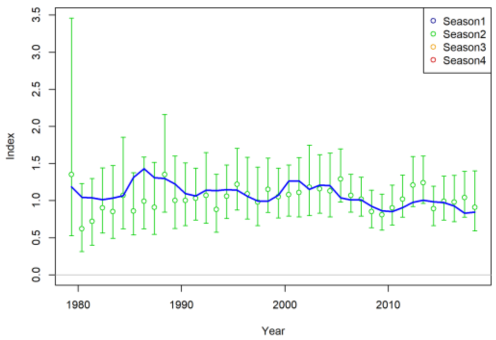


Figure 29. Fits to PS FS index and joint CPUE index for run 11 which is fit to both indices.



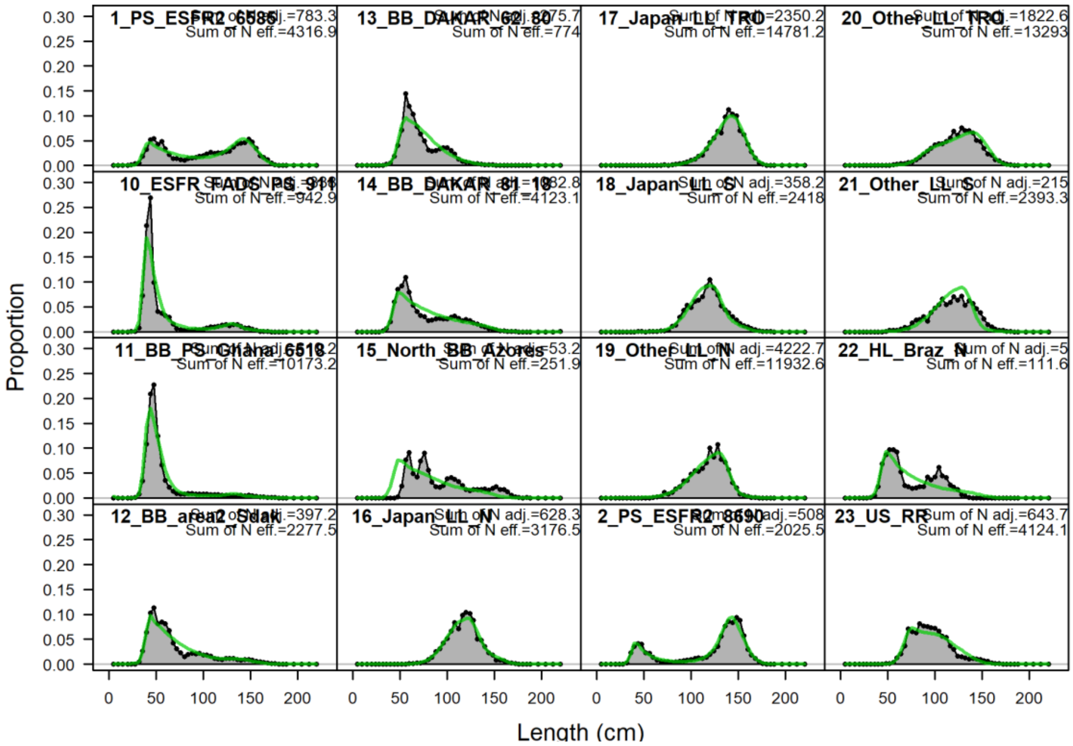


16_Japan_LL_N. 17_Japan_LL_S.



18_Japan_LL_S

Figure 30. Fits to PS FS index and joint CPUE index full time series for run 12 which is fit to both indices.



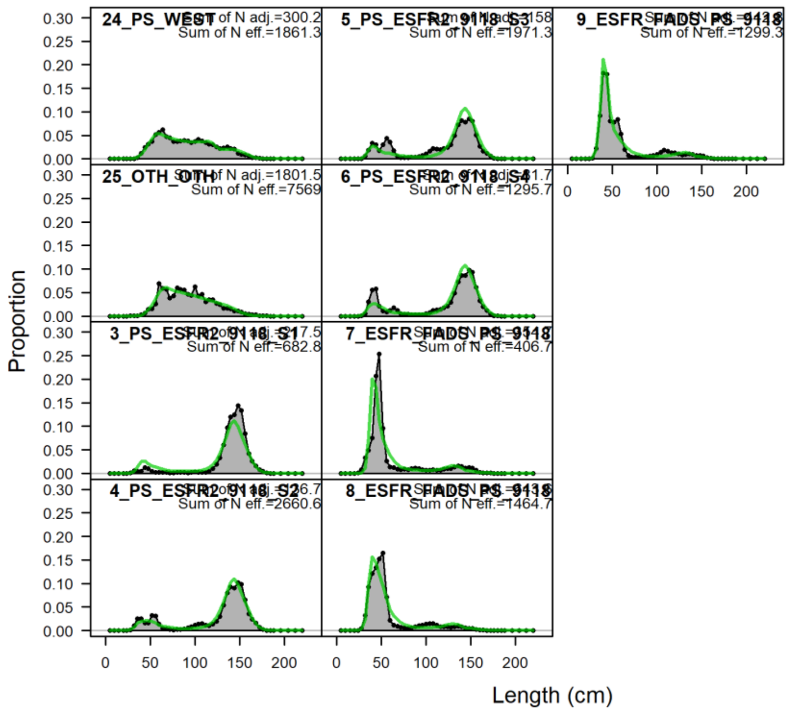


Figure 31. Fits to length composition data over all years for model 1.

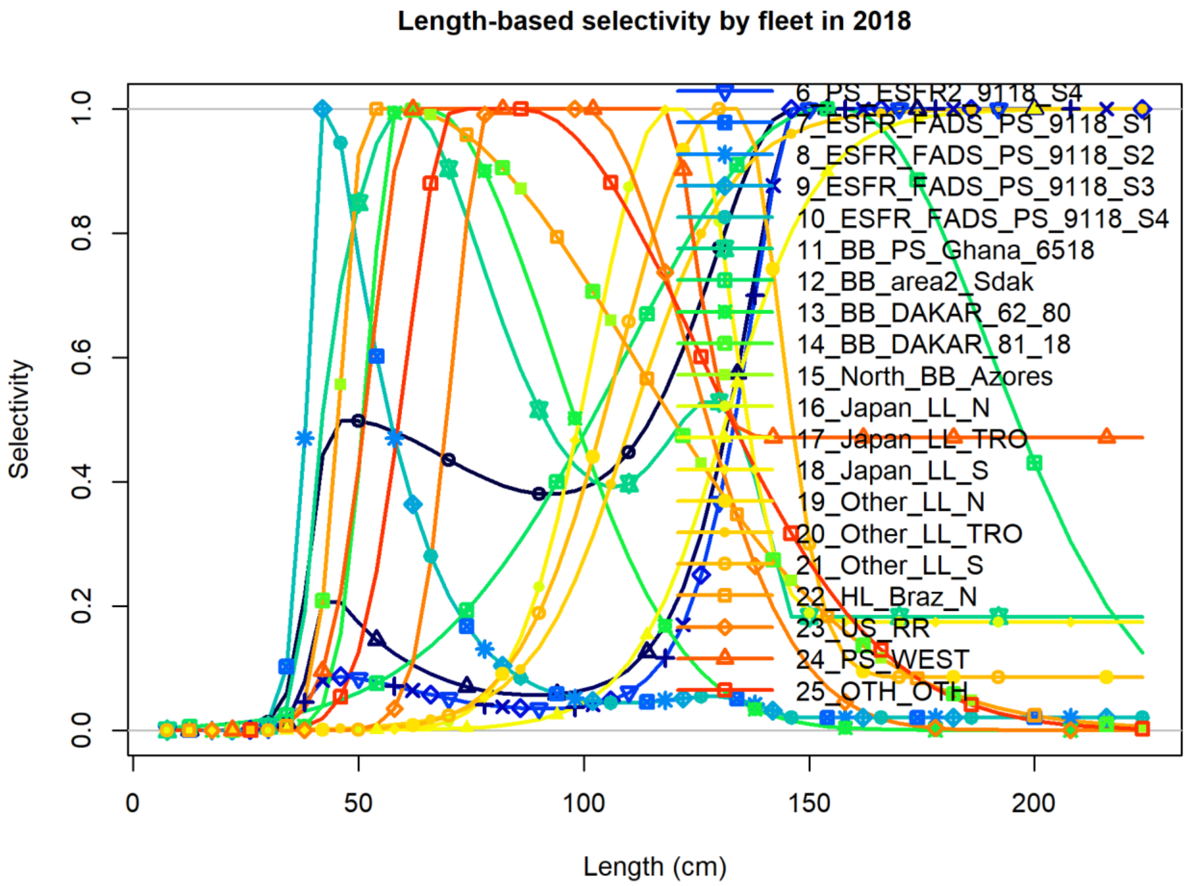


Figure 32. Estimated selectivities for Run 1 for all fleets.

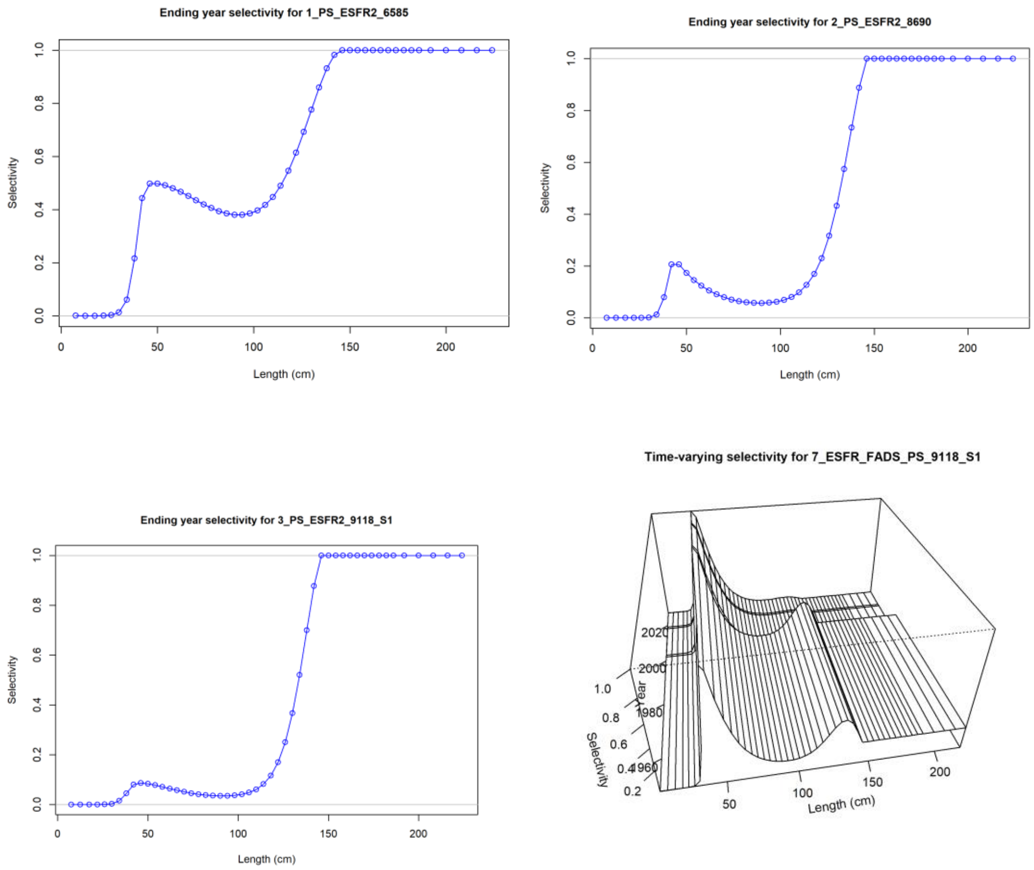


Figure 33. Estimated selectivities for Run 1 for purse seine fleets.

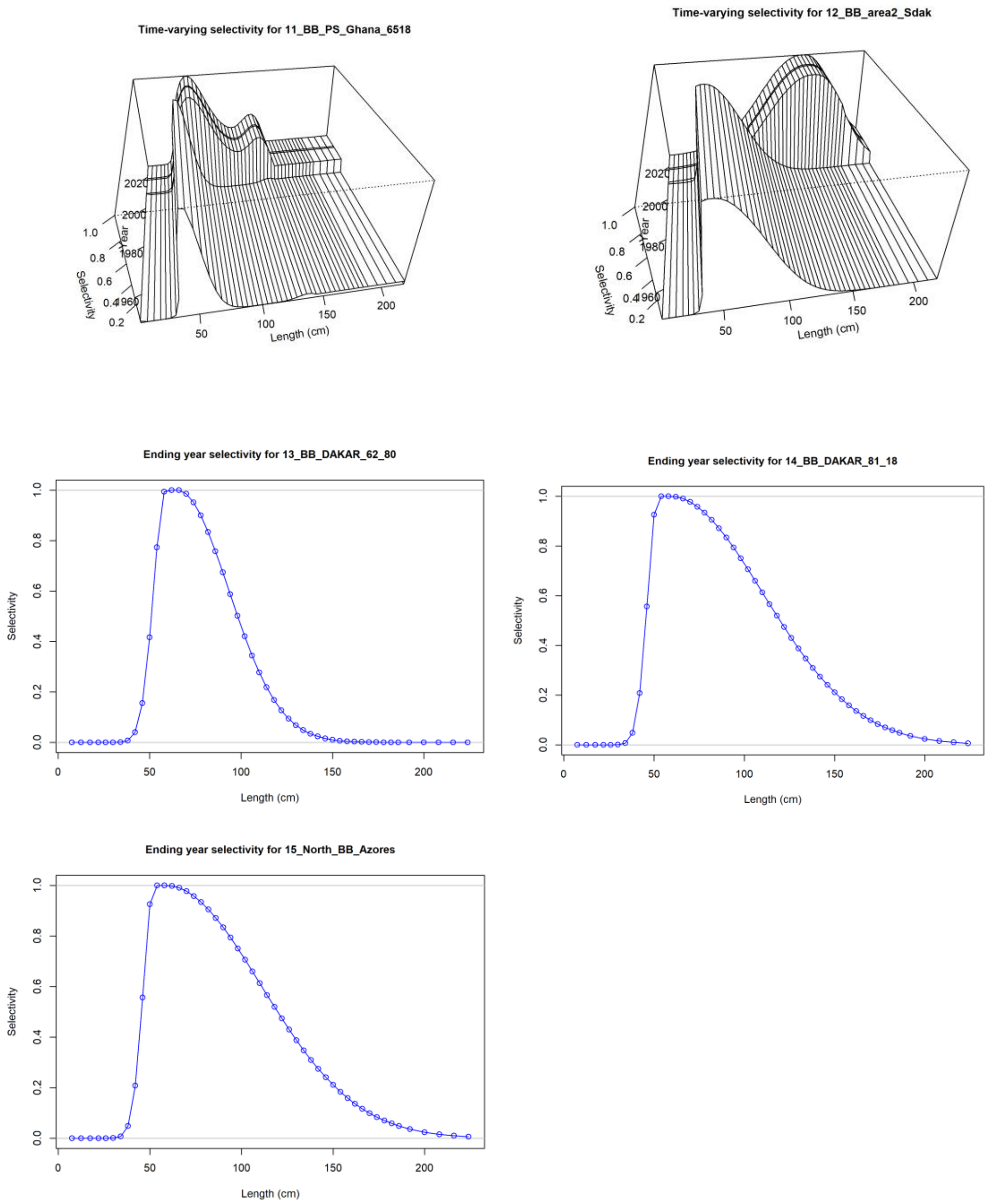


Figure 34. Estimated selectivities for Run 1 for baitboat fleets.

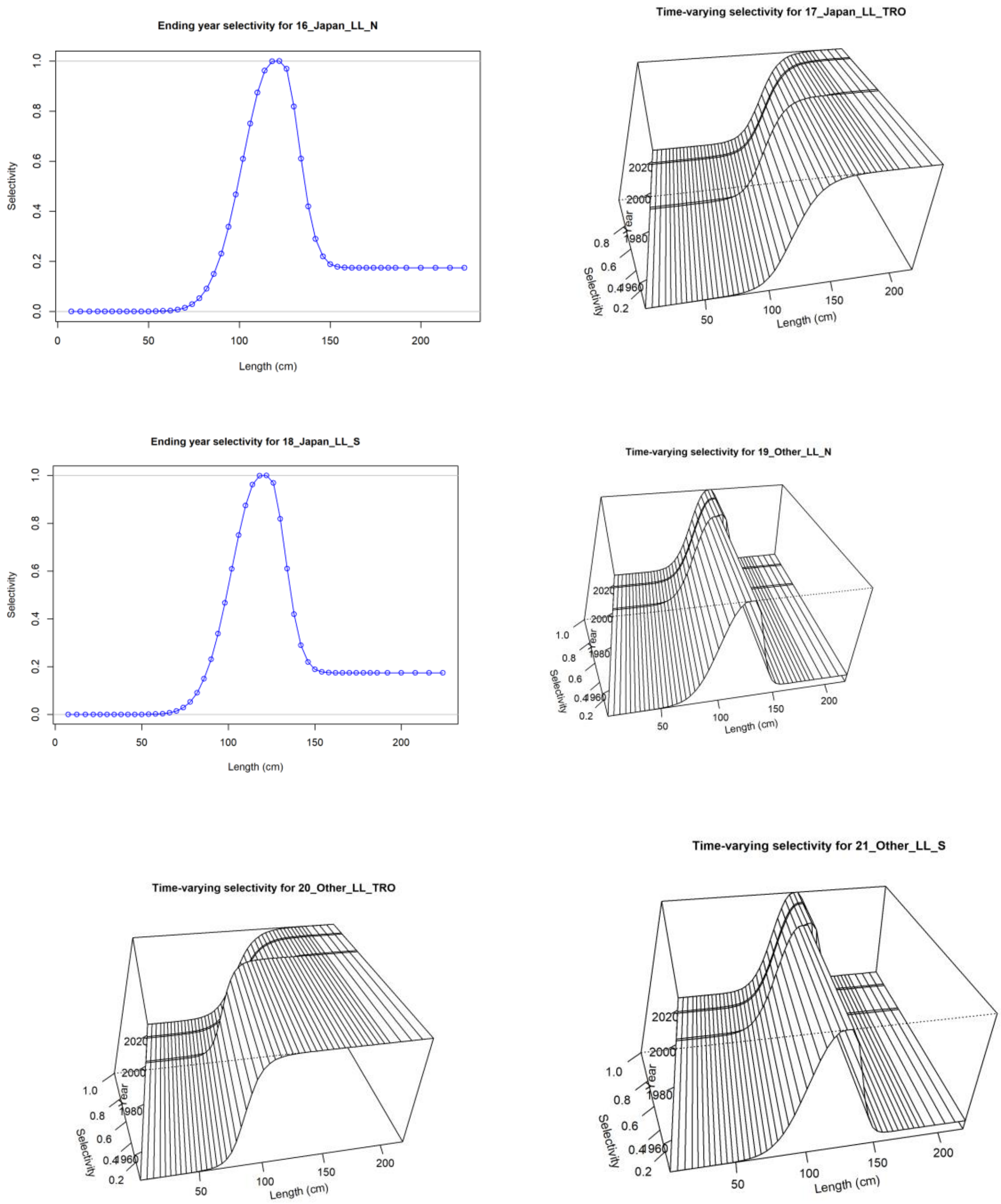


Figure 35. Estimated selectivity for Run 1 for longline fleets.

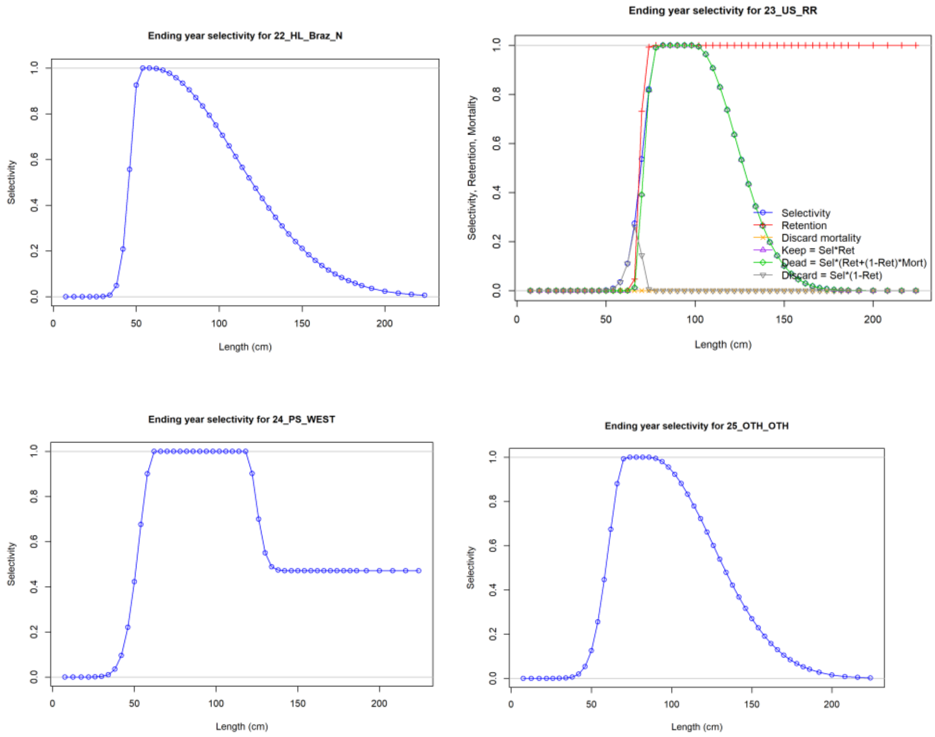


Figure 36. Estimated selectivity for Run 1 for handline and other fleets

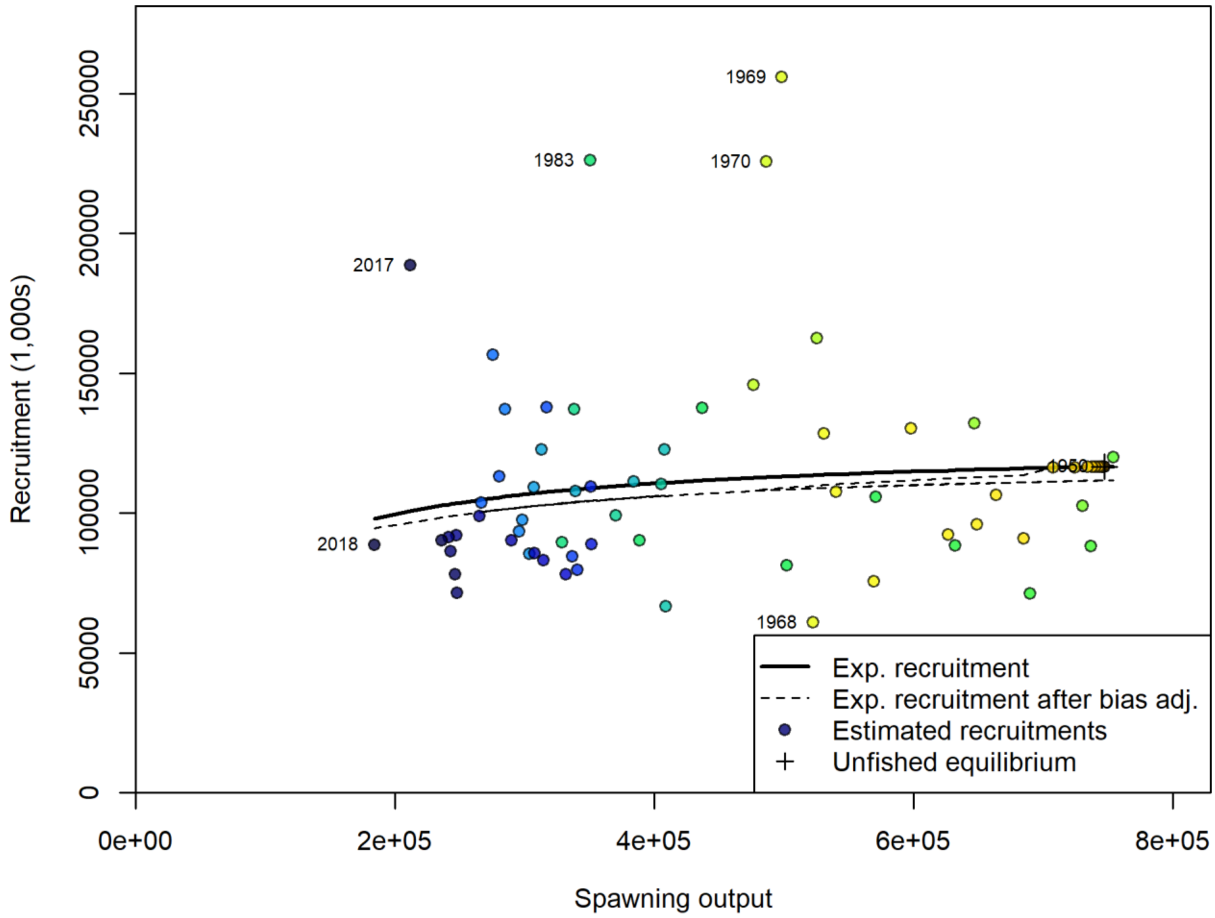


Figure 37. Estimated Beverton-Holt Spawner-recruit relationship and recruitment (age 0) estimates (with darker colors for more recent values) for Run 1. Dashed line is the bias-adjusted recruitment level during the period where recruitment deviations are estimated. The level of the adjustment, or reduction in recruitment level is determined by the bias correction factor that makes the mean recruitment level during the recruitment deviation estimation period equal to R0. Steepness is fixed at 0.8.

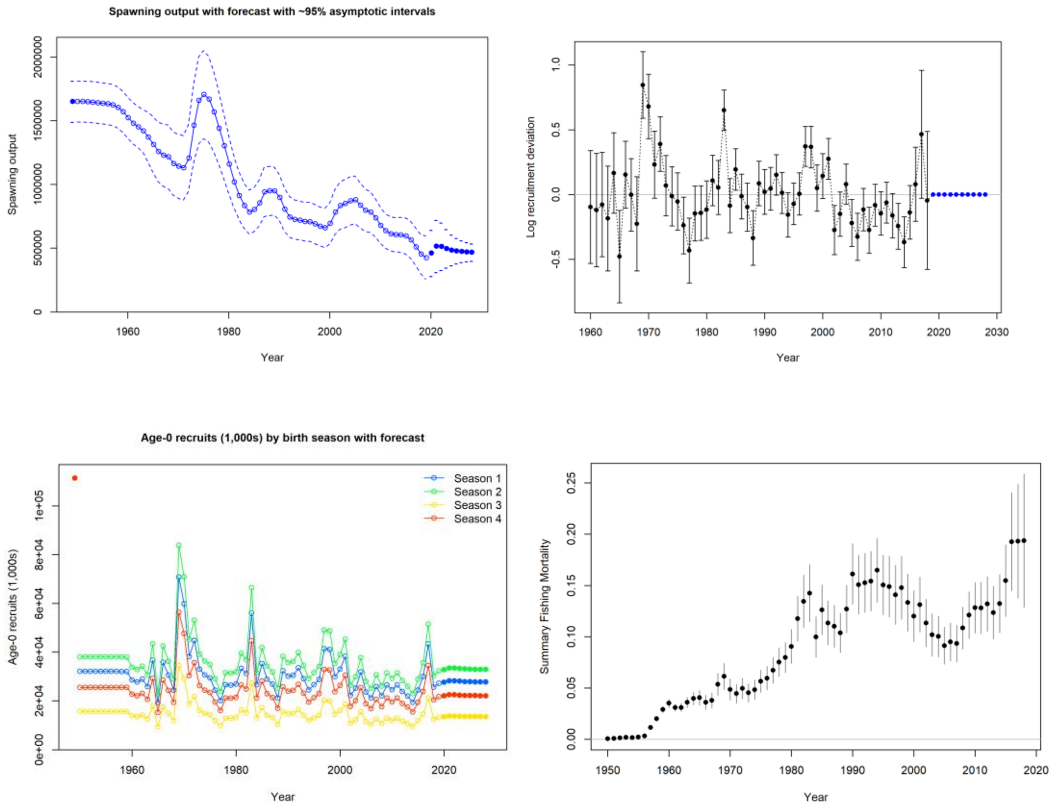


Figure 38. Time series of SSB, recruit deviations (age 0), recruits by season and F (exploitation in biomass) for model 1.

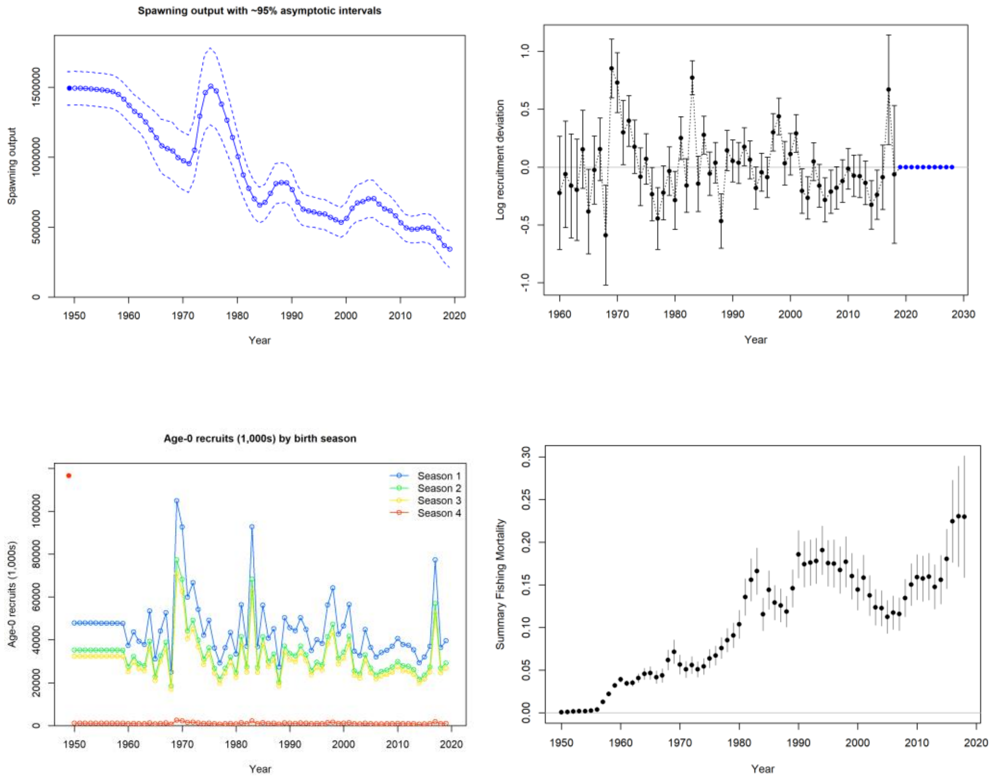


Figure 39. Time series of SSB, recruit deviations (age 0), recruits by season and F (exploitation in biomass) for model 3.

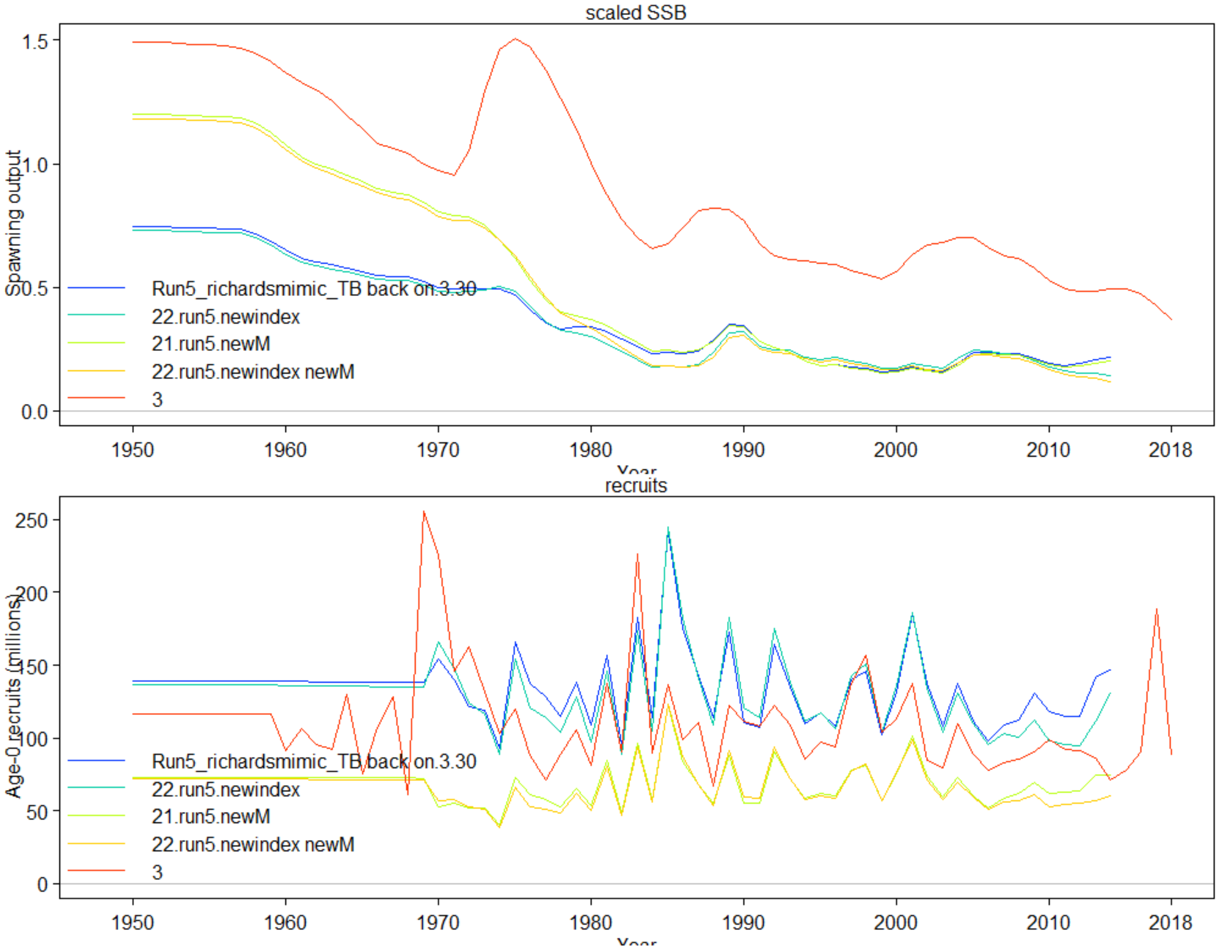


Figure 40. SSB and recruitment for Run 5, 2016 and several variations on this run that use the new joint index (22) and then a run that is the same as run 5 but with the new M vector. These runs are compared with run 3 from this paper.

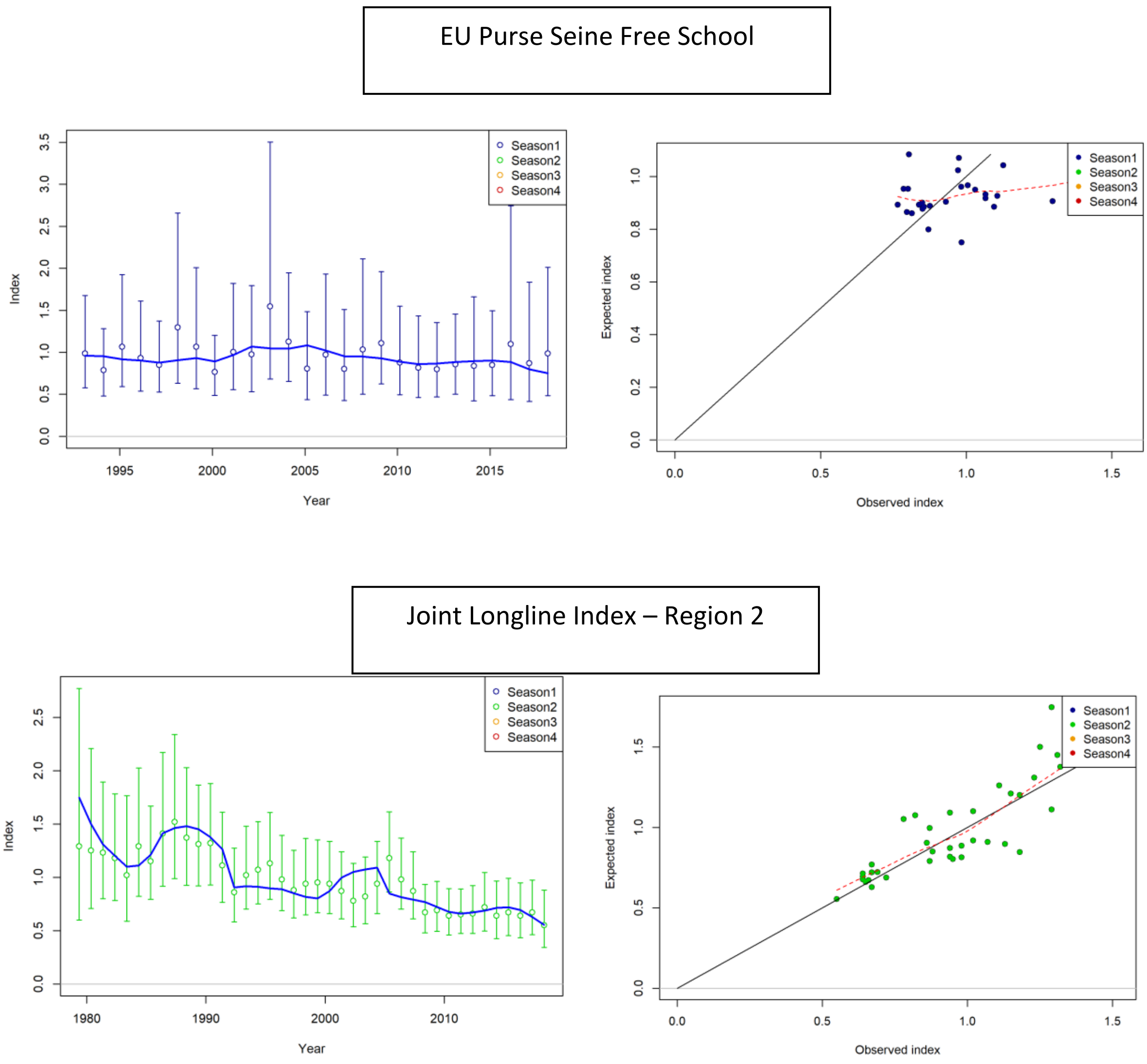
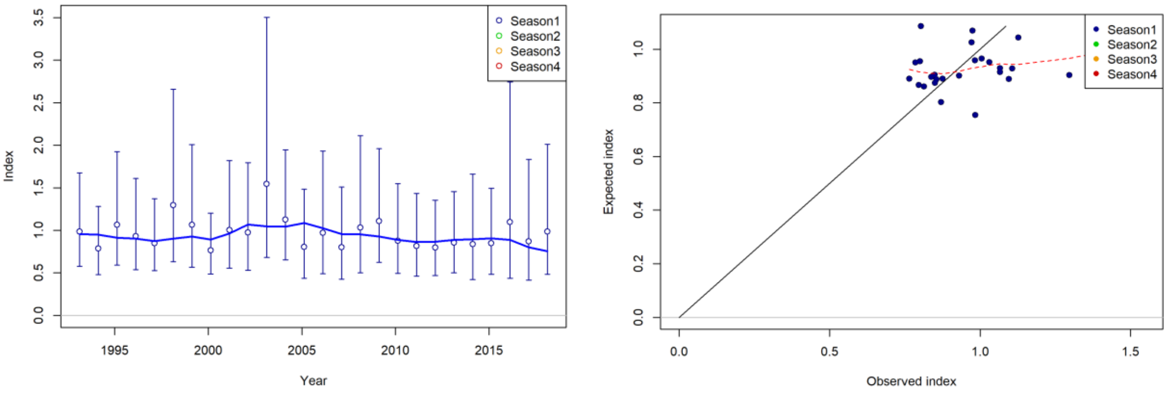


Figure 41. Fits to indices of abundance for Stock Synthesis Run 1.

EU Purse Seine Free School



Joint Longline Index – Region 2

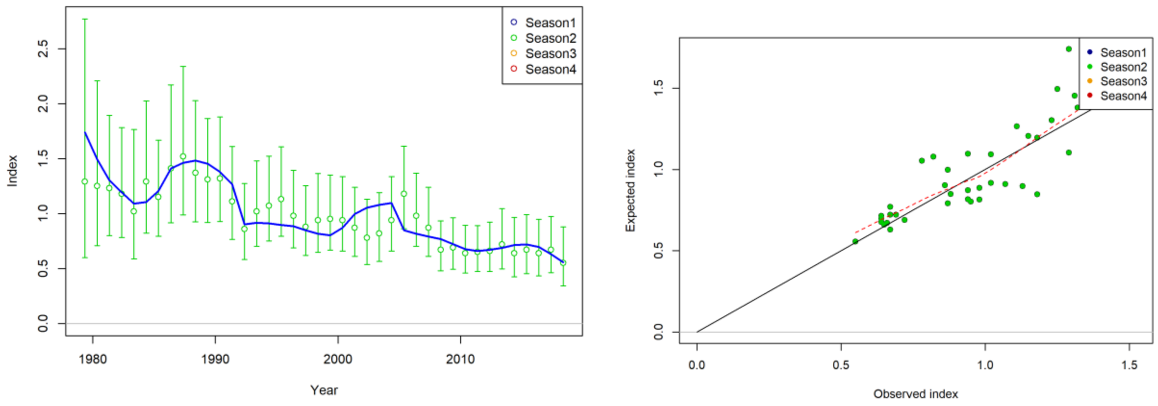


Figure 42. Fits to indices of abundance for Stock Synthesis Run 2.

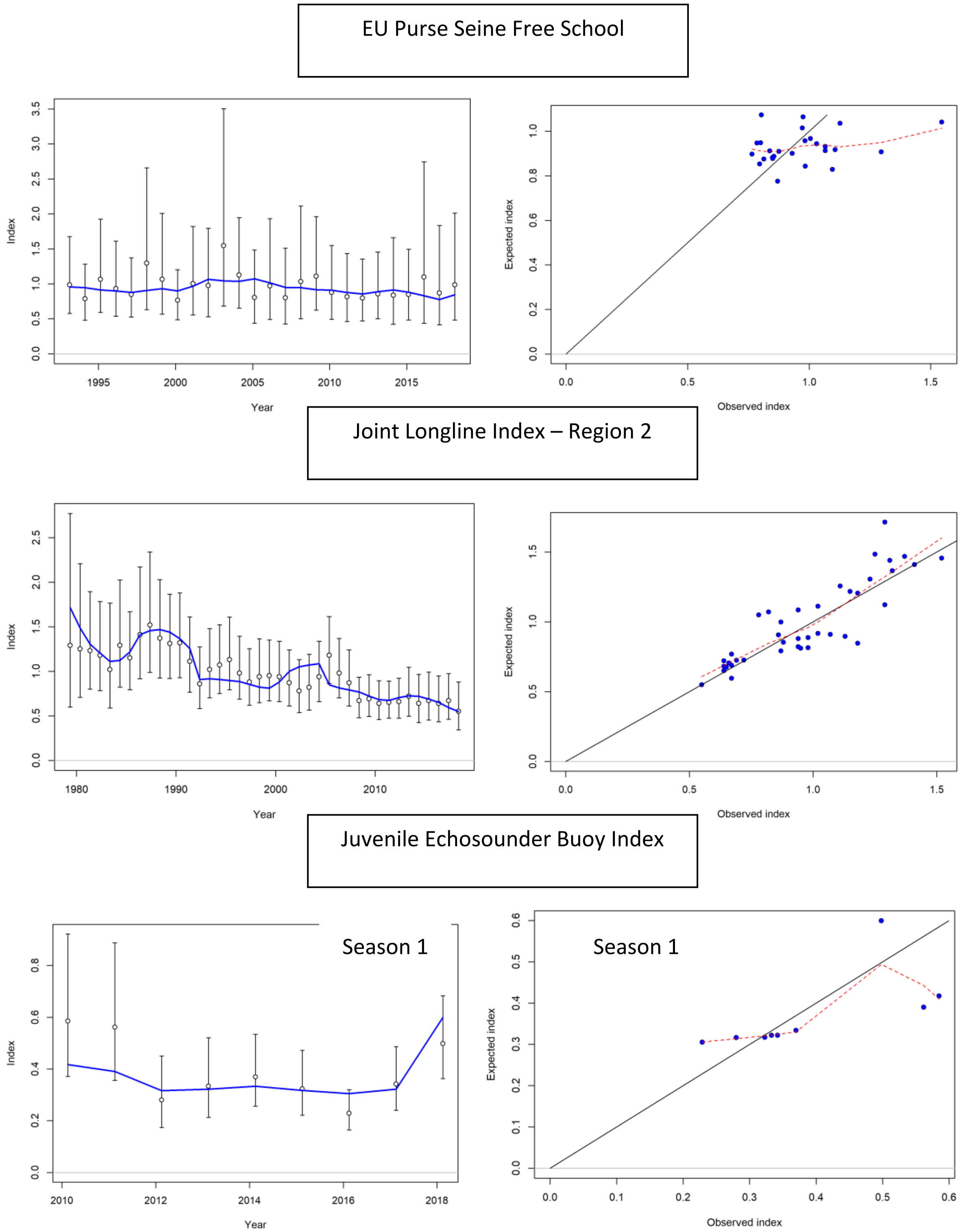


Figure 43. Fits to indices of abundance for Stock Synthesis Run 3.

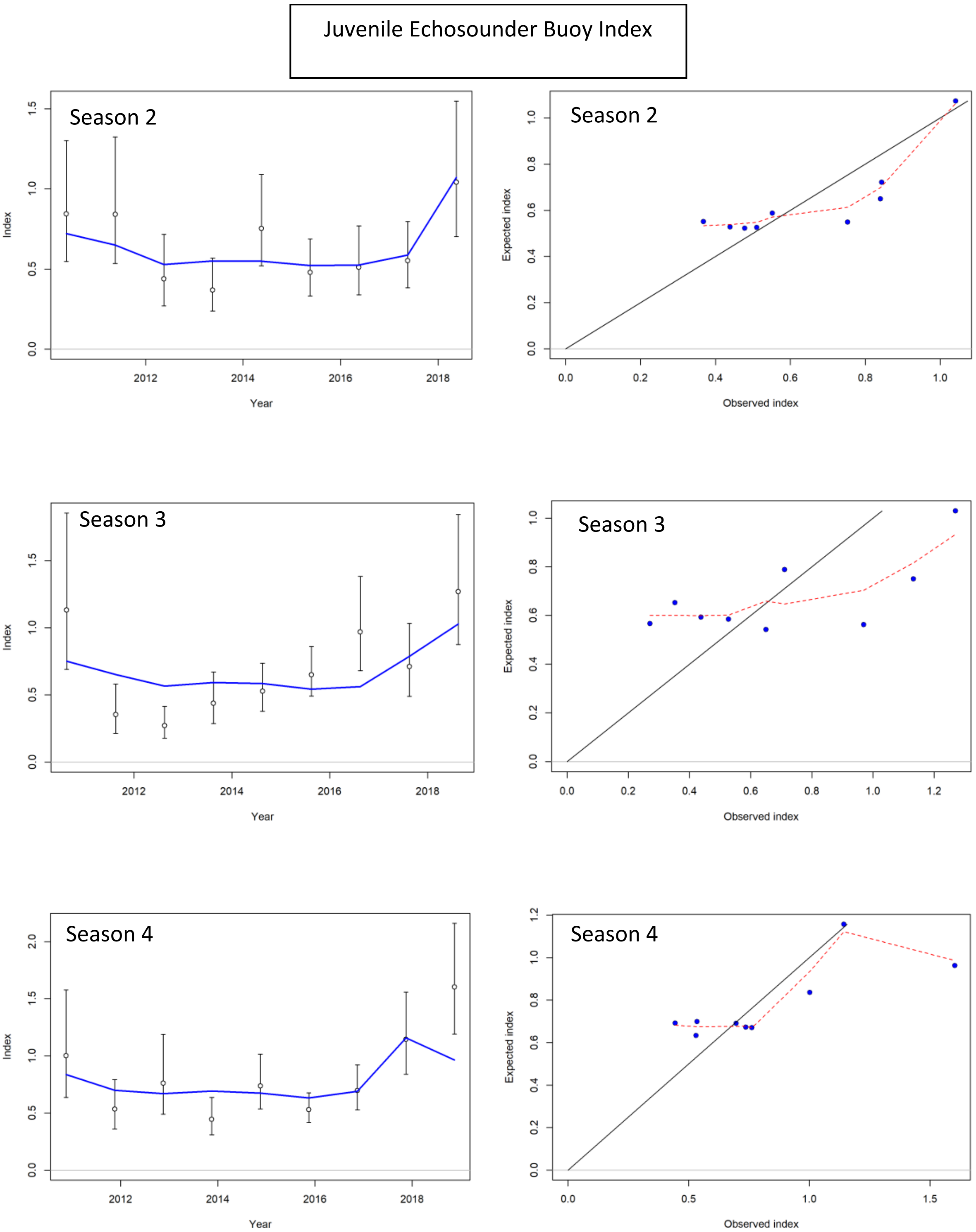


Figure 43.continuted. Fits to indices of abundance for Stock Synthesis Run 3.

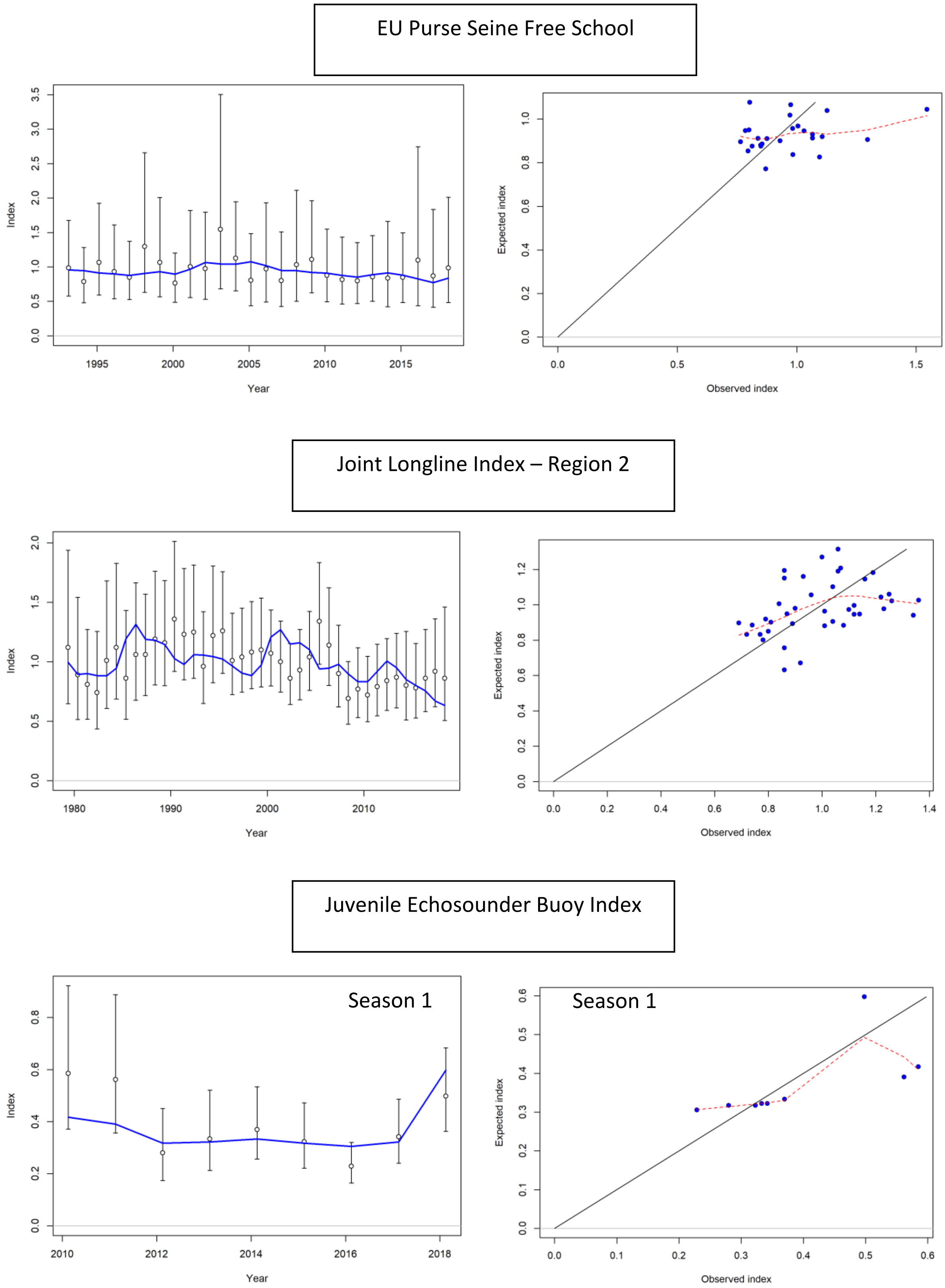


Figure 44. Fits to indices of abundance for Stock Synthesis Run 4.

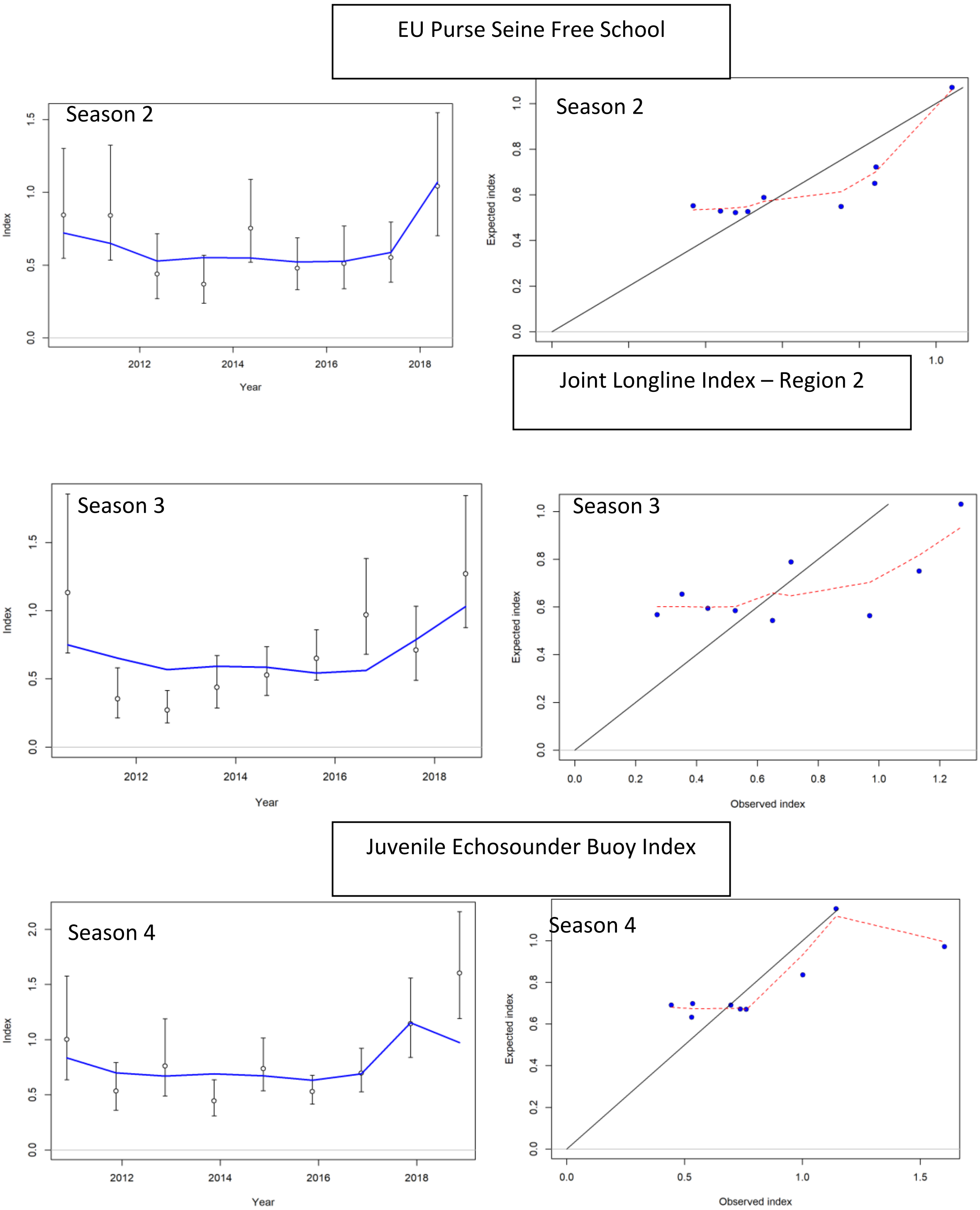
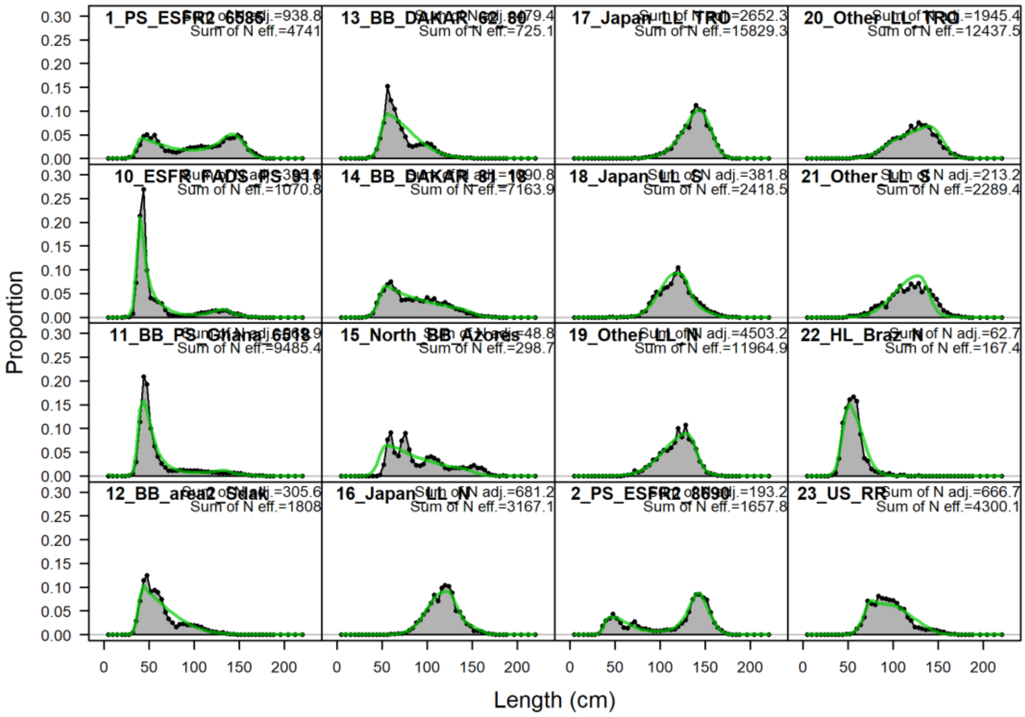


Figure 44. *continued.* Fits to indices of abundance for Stock Synthesis Run 4.



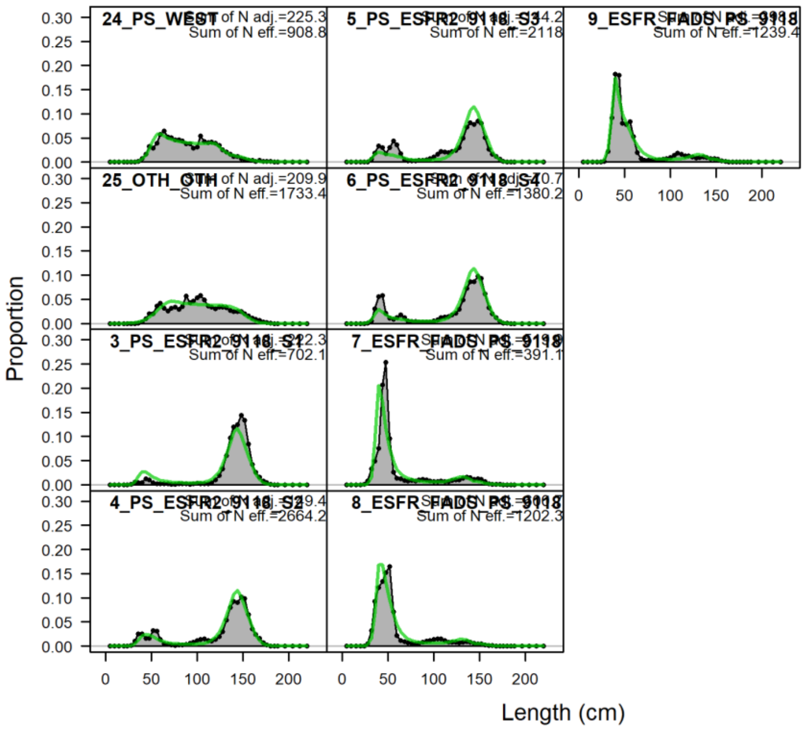


Figure 45. The fits to the length composition, aggregated by fleet for Stock Synthesis Run 1.

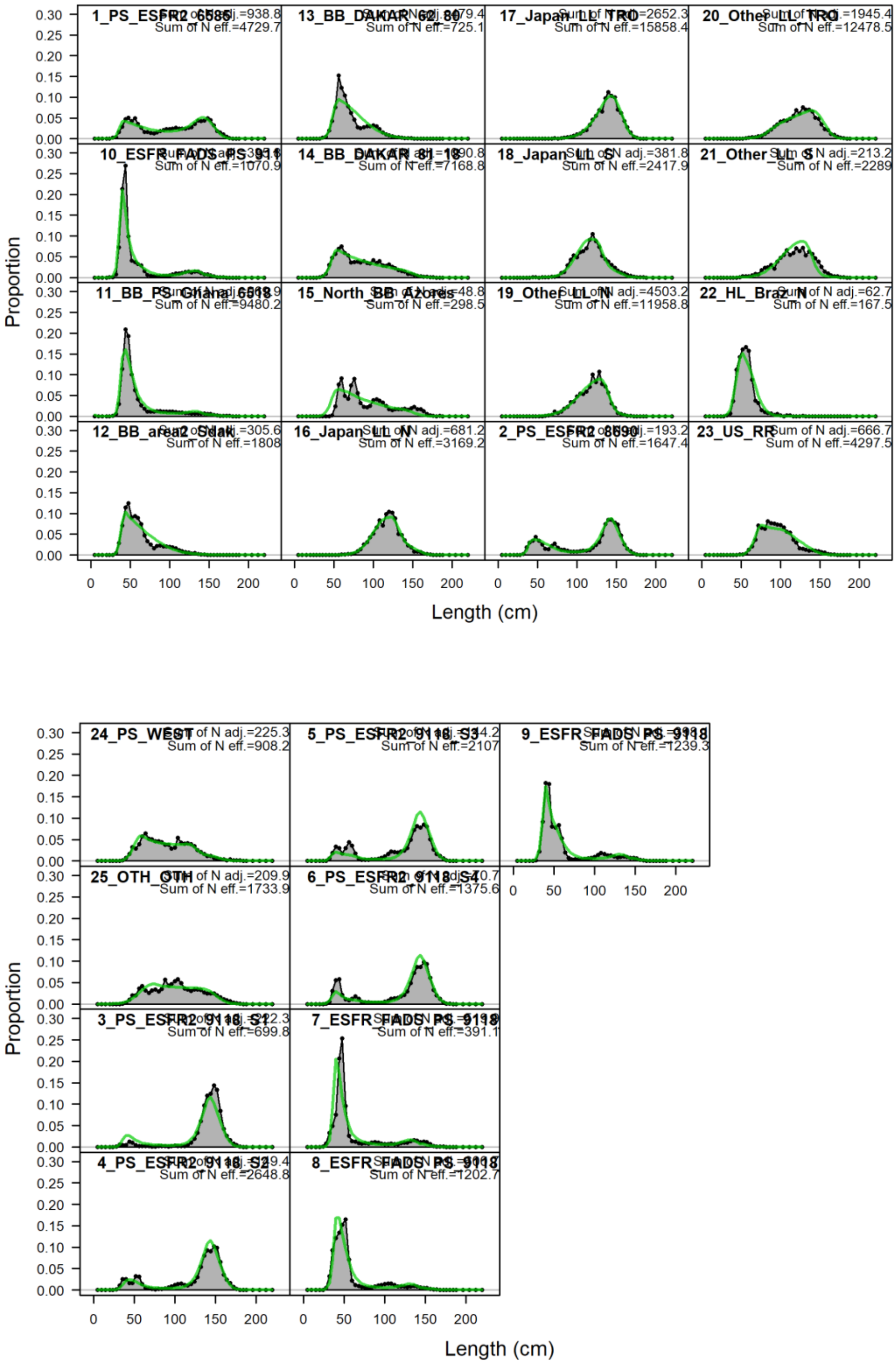


Figure 46. The fits to the length composition, aggregated by fleet for Stock Synthesis Run 2.

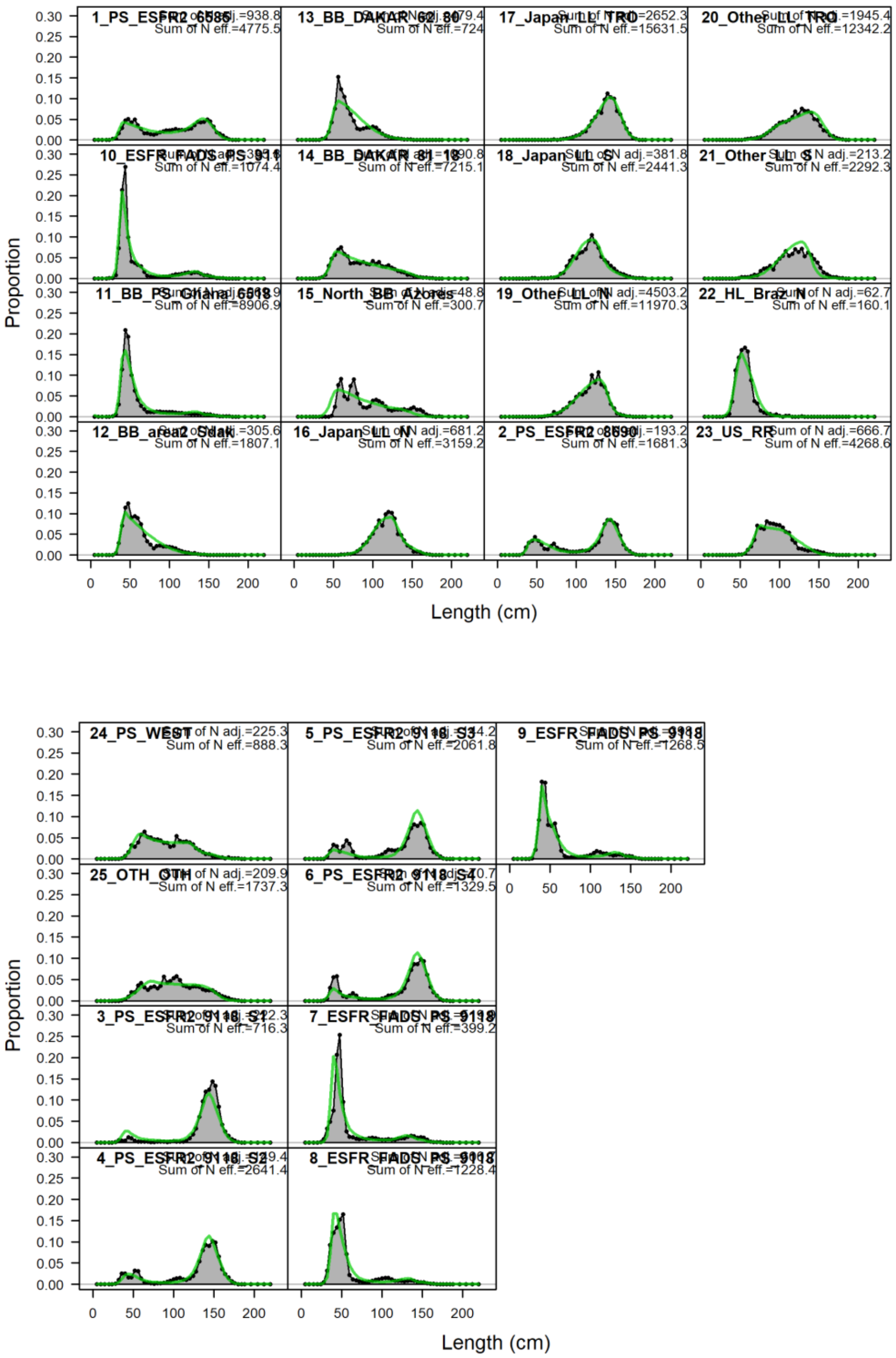


Figure 47. The fits to the length composition, aggregated by fleet for Stock Synthesis Run 3.

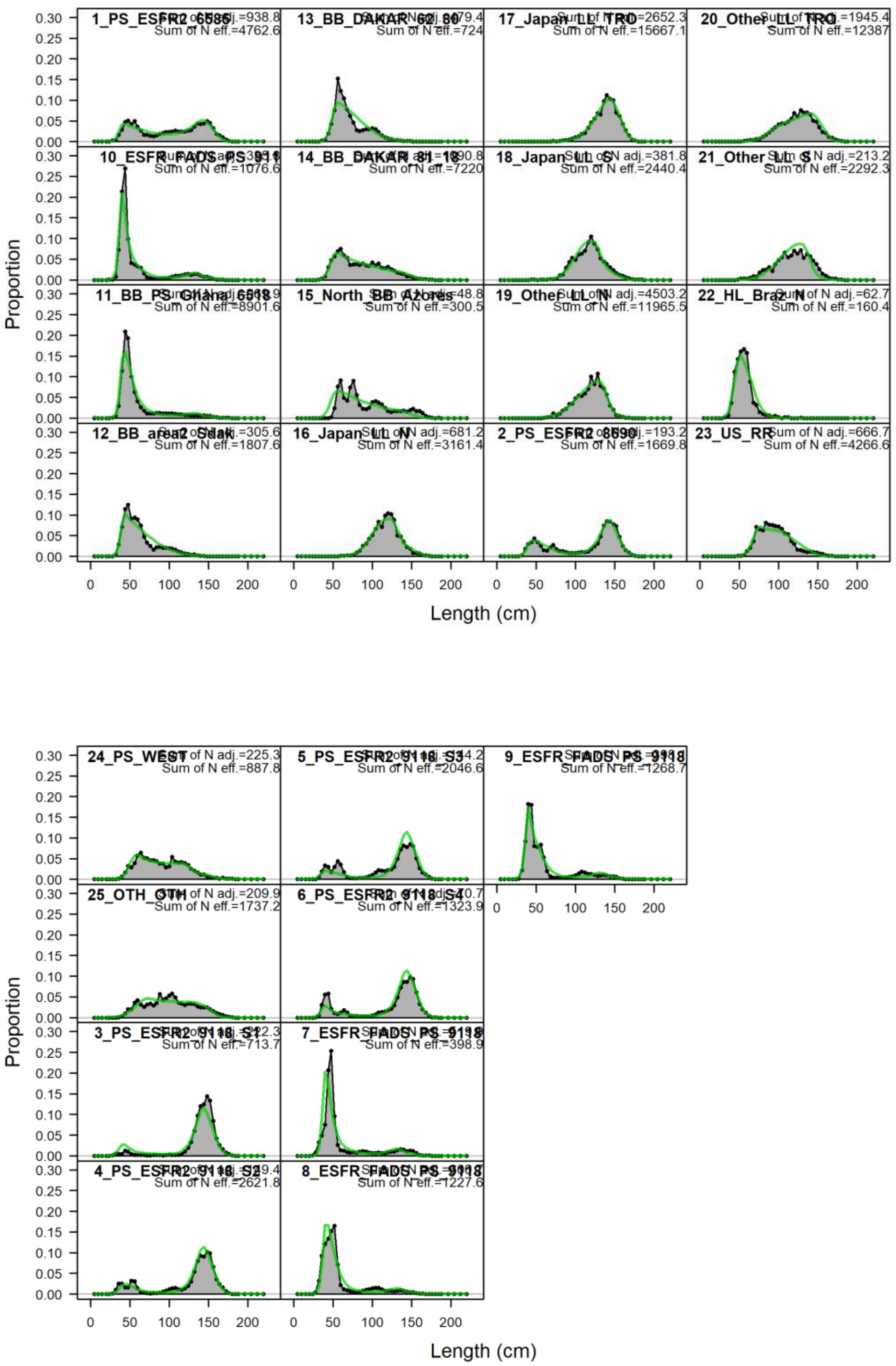


Figure 48. The fits to the length composition, aggregated by fleet for Stock Synthesis Run 4.

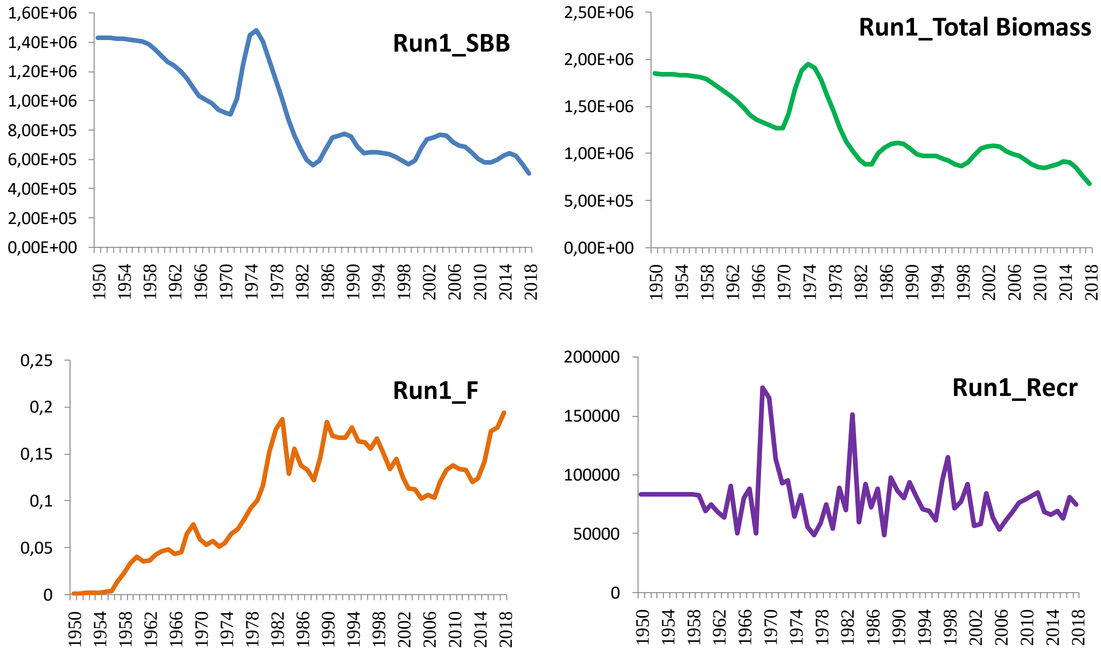


Figure 49. Trends in spawning biomass, total biomass, fishing mortality and recruitment for Stock Synthesis model Run 1.

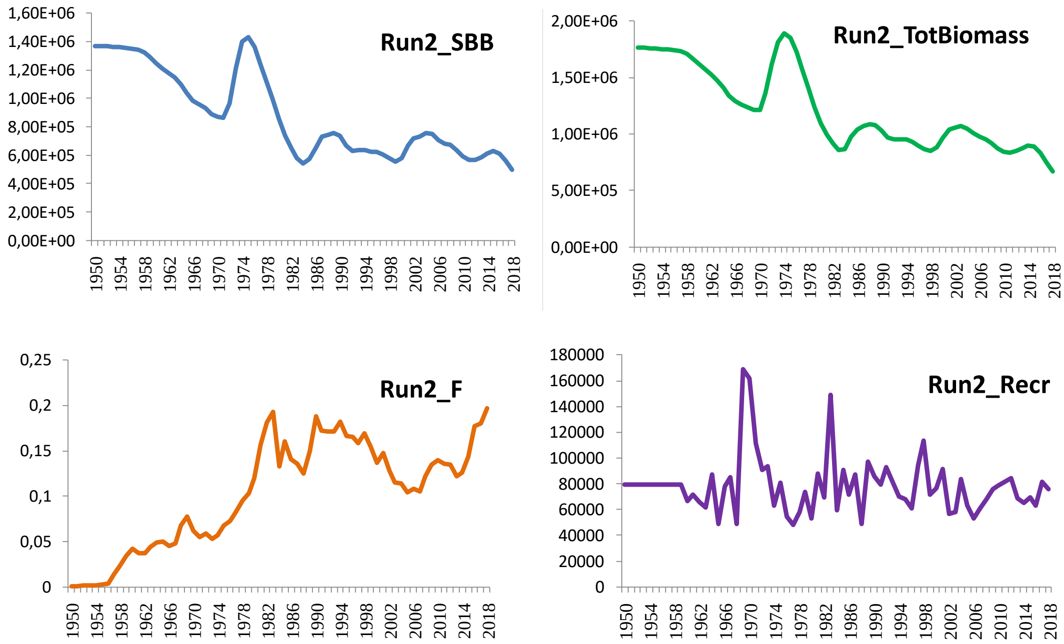


Figure 50. Trends in spawning biomass, total biomass, fishing mortality and recruitment for Stock Synthesis model Run 2.

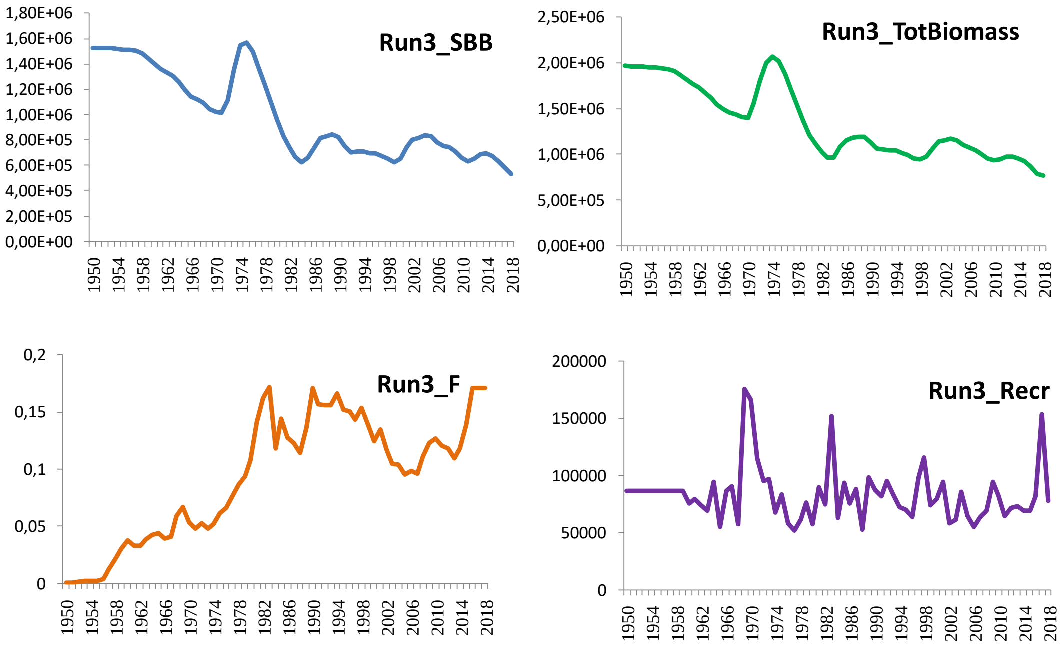


Figure 51. Trends in spawning biomass, total biomass, fishing mortality and recruitment for Stock Synthesis model Run 3.

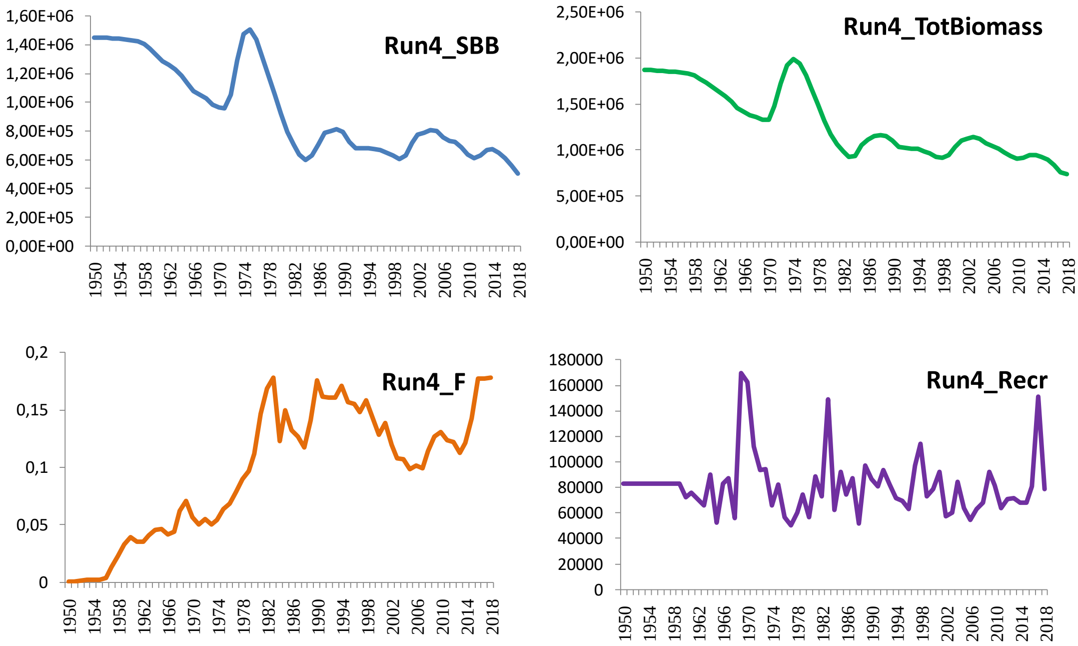


Figure 52. Trends in spawning biomass, total biomass, fishing mortality and recruitment for Stock Synthesis model Run 4

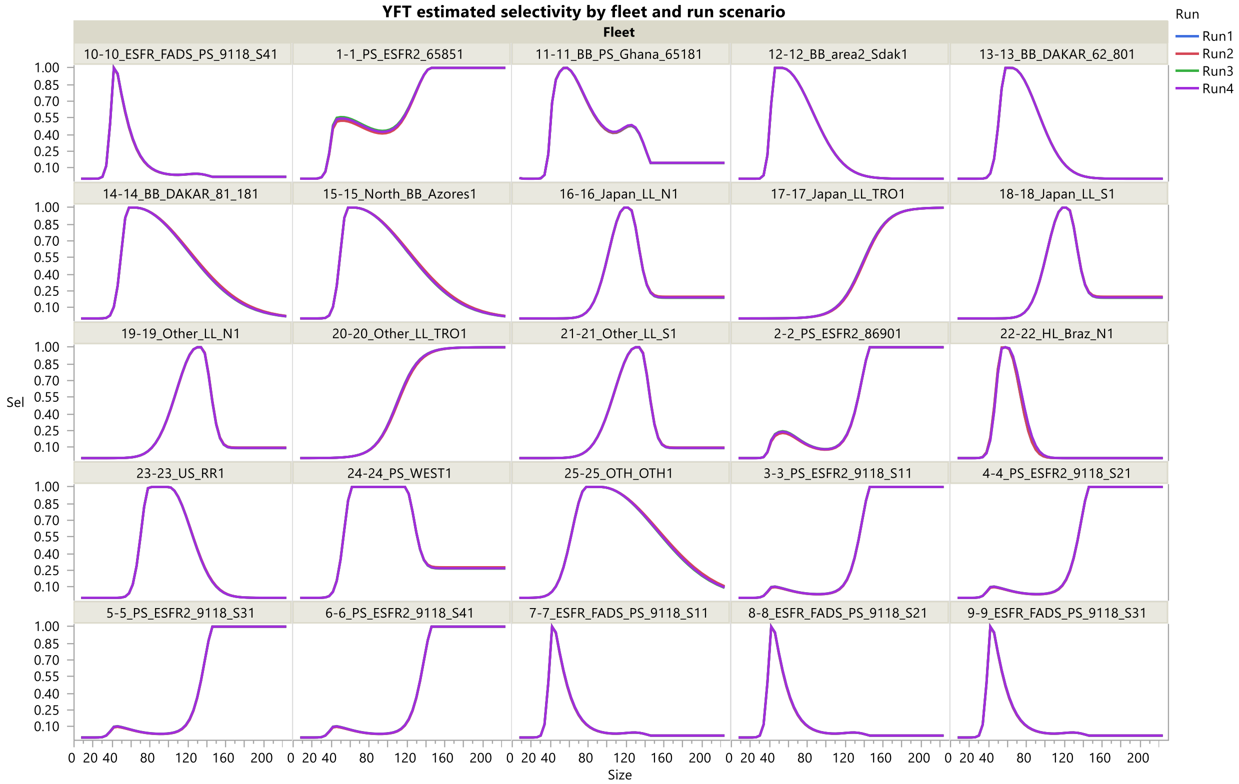


Figure 53. The model estimated selectivity values by fleet ID for the Stock Synthesis runs.

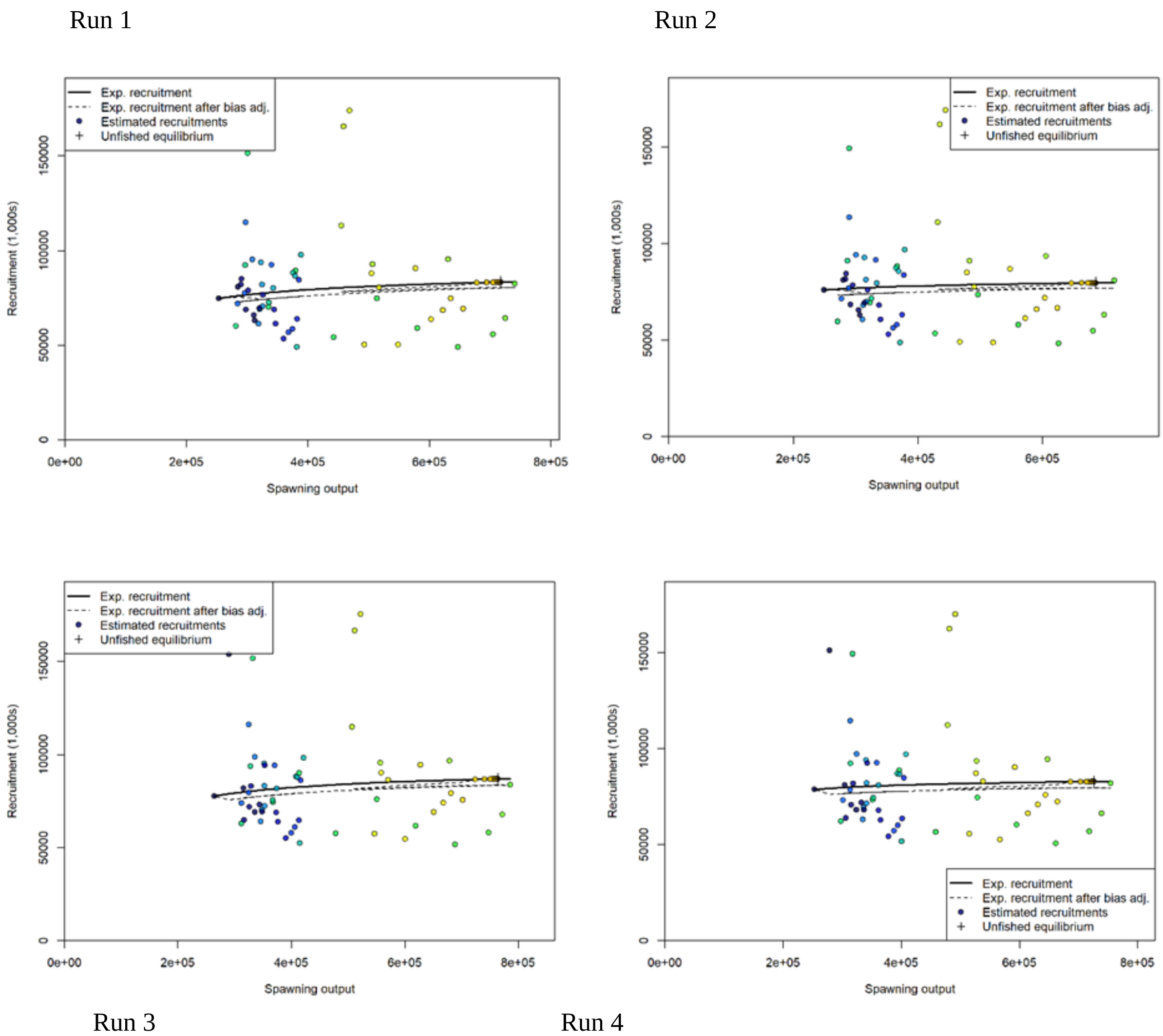


Figure 54. The estimated stock recruitment relationships showed little evidence of a relationship between SSB and recruits for the Stock Synthesis runs.

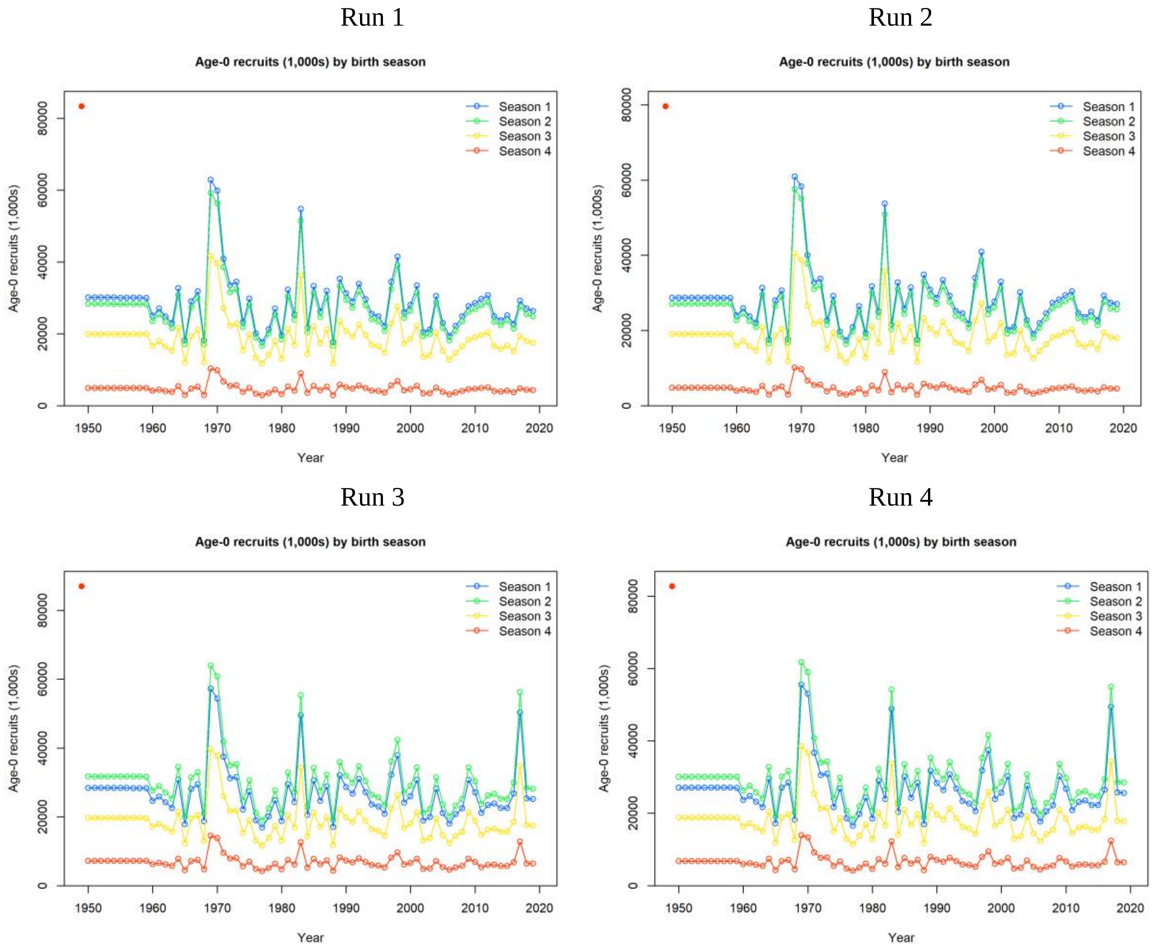


Figure 55. Recruitment by season for the Stock Synthesis runs indicates that the highest fraction of recruits was estimated to be born in seasons 1 and 2 (Jan-June) and the lowest in season 4 (Oct-Dec).

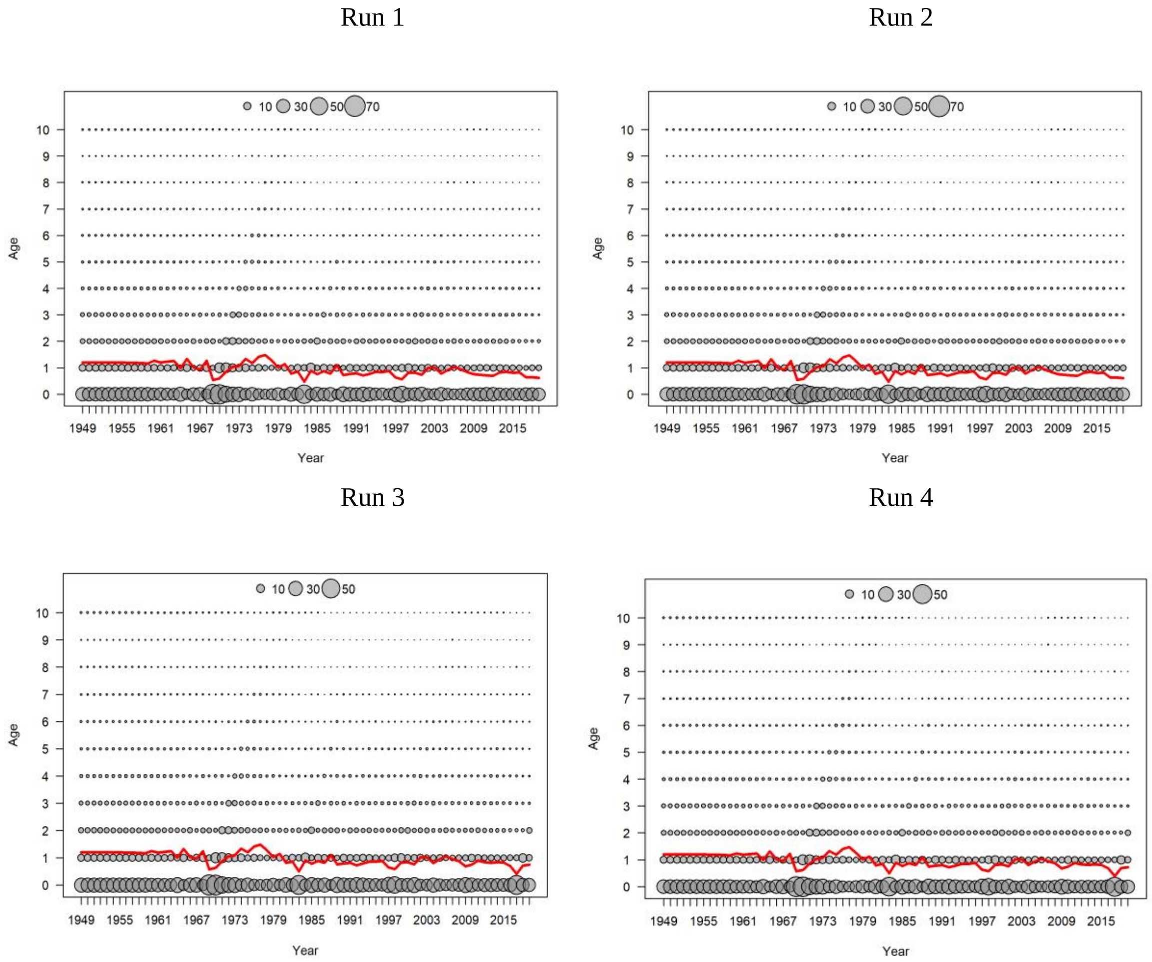


Figure 56. Time series of the numbers at age from Stock Synthesis runs shows little evidence of strong cohort structure and a decline in the mean age in the population over time.

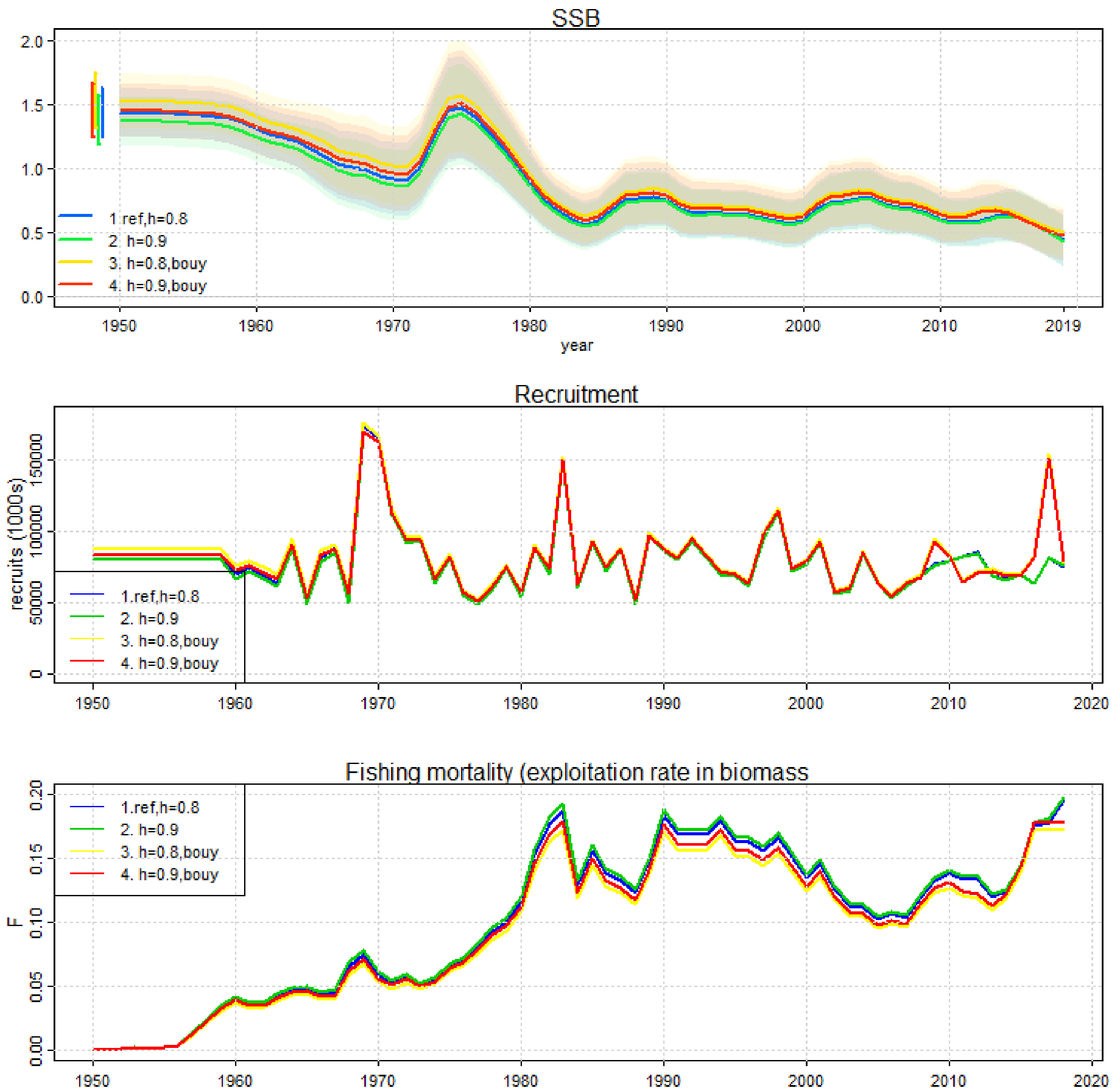


Figure 57. Spawning stock biomass (100,000 t), recruitment (age 0), fishing mortality (exploitation rate in biomass) (age 0) for the 4 integrated model uncertainty grid runs.

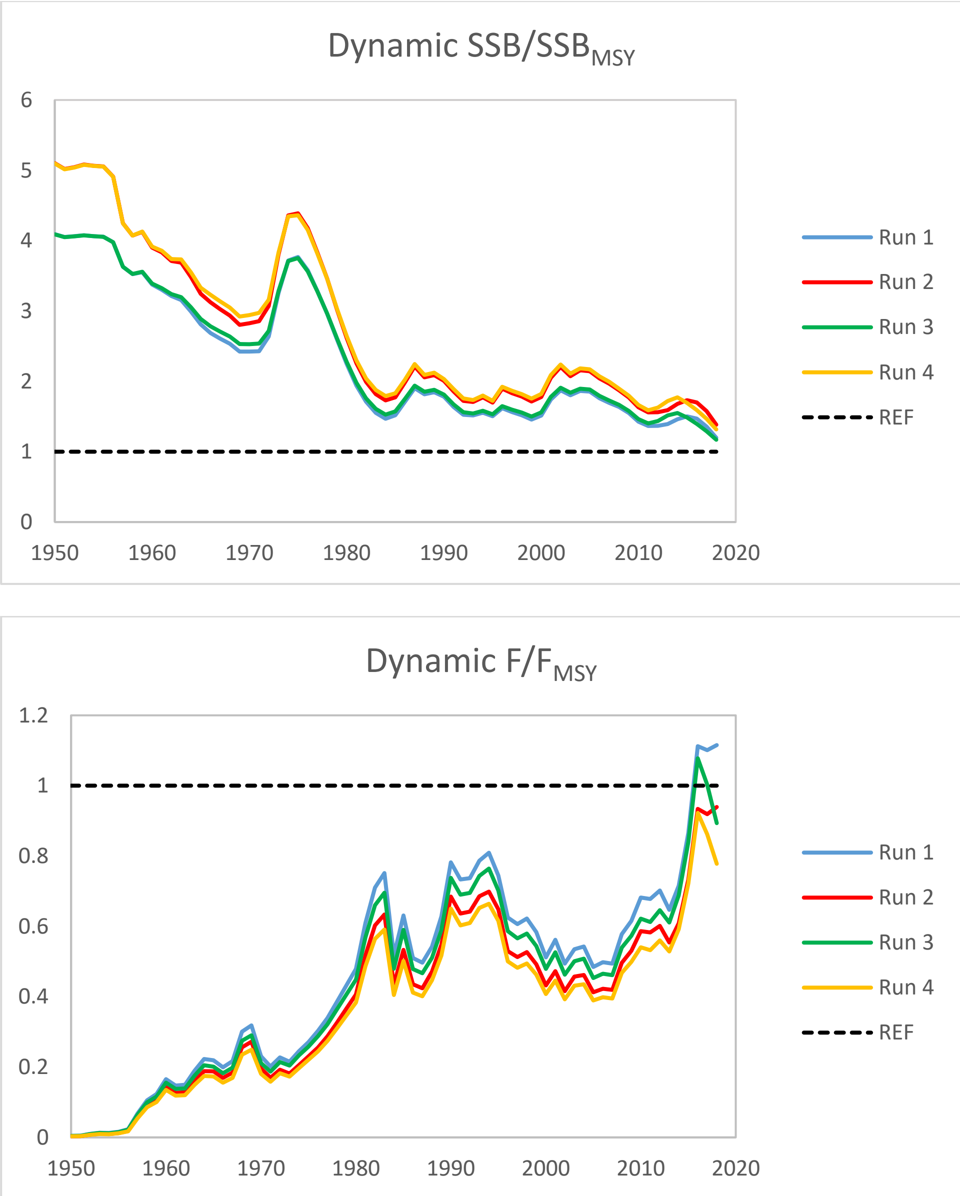
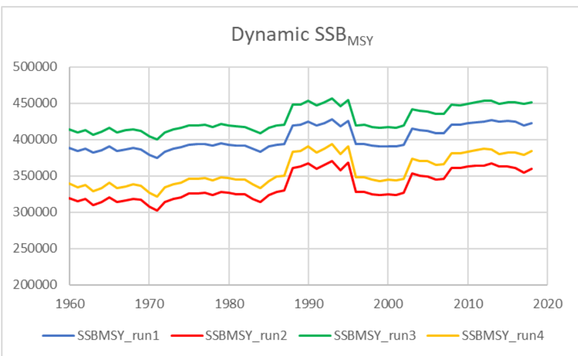
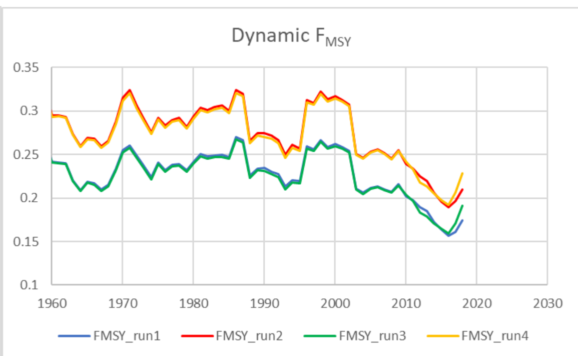


Figure 58. The dynamic SSB/SSBMSY and F/FMSY for the Stock Synthesis runs.





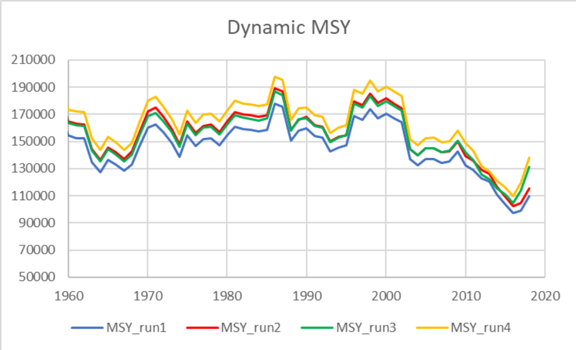


Figure 59. Dynamic SSB_{MSY}, F_{MSY} and MSY for the Stock Synthesis runs.

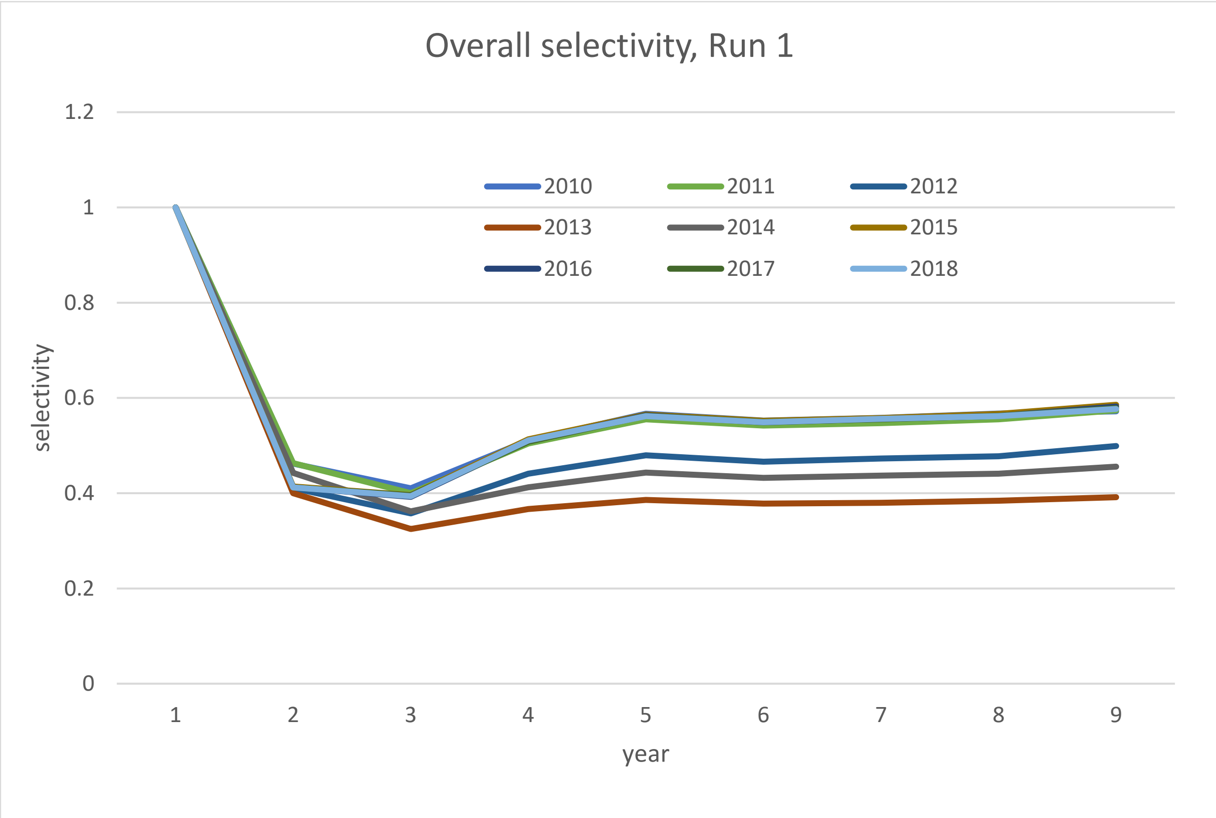


Figure 60. Overall selection at age showing the slight increase in selectivity for older fish in the most recent three years that is the reason for the slight uptick in the dynamic MSY.

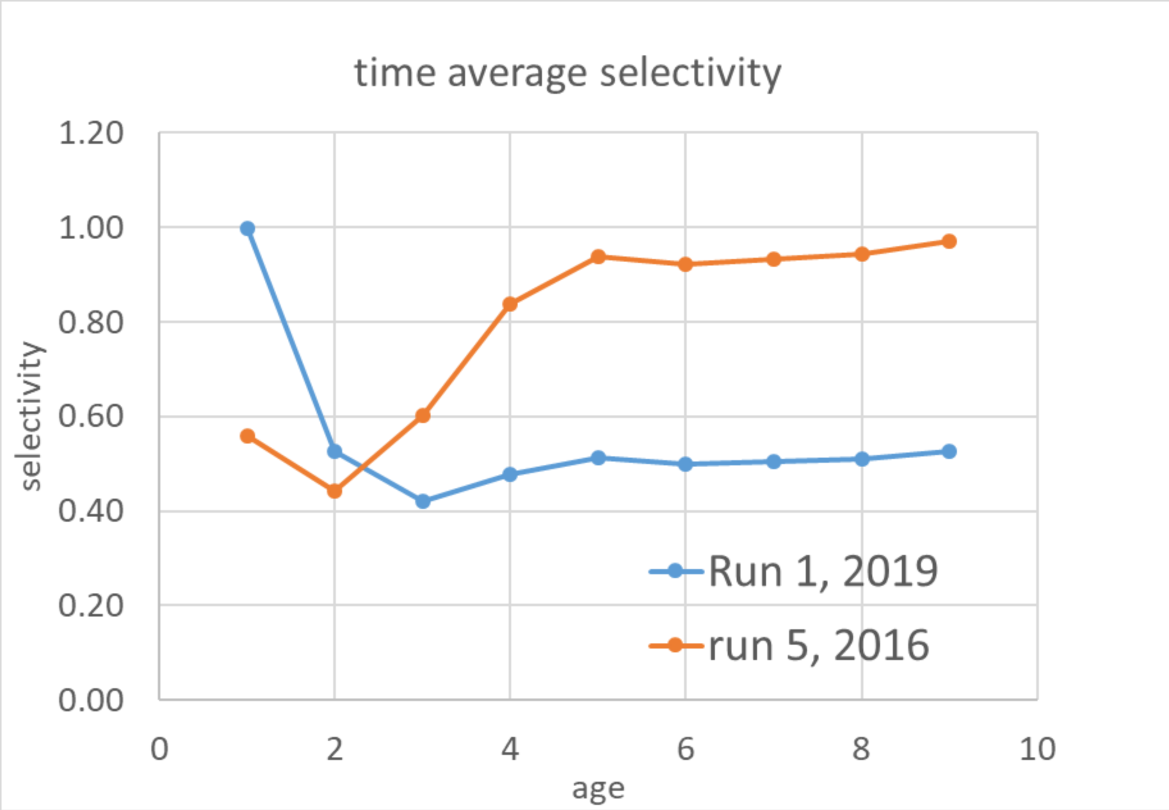
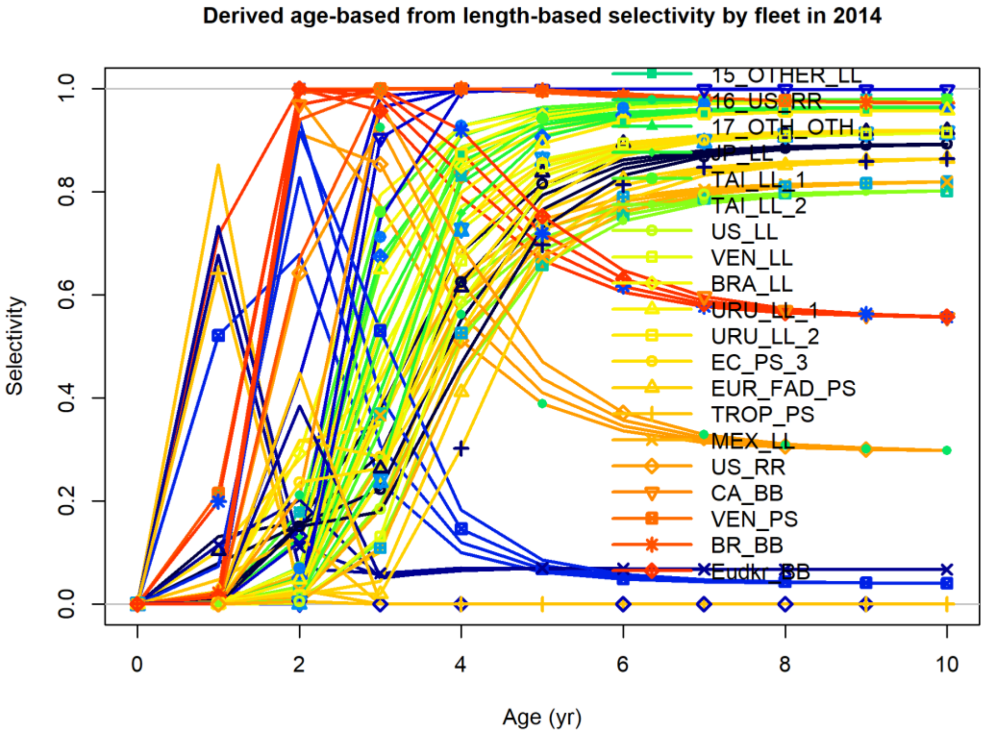


Figure 61. Average selectivity at age derived from length based selectivity for Run 1 in this assessment compared with Run 5 in 2016. The primary difference is that the spatial partitioning of the longline fleets and modeling of the area 1 and 2 fleets as domed lead to lower selectivity on older ages relative to the 2016 assessment model.

A



B

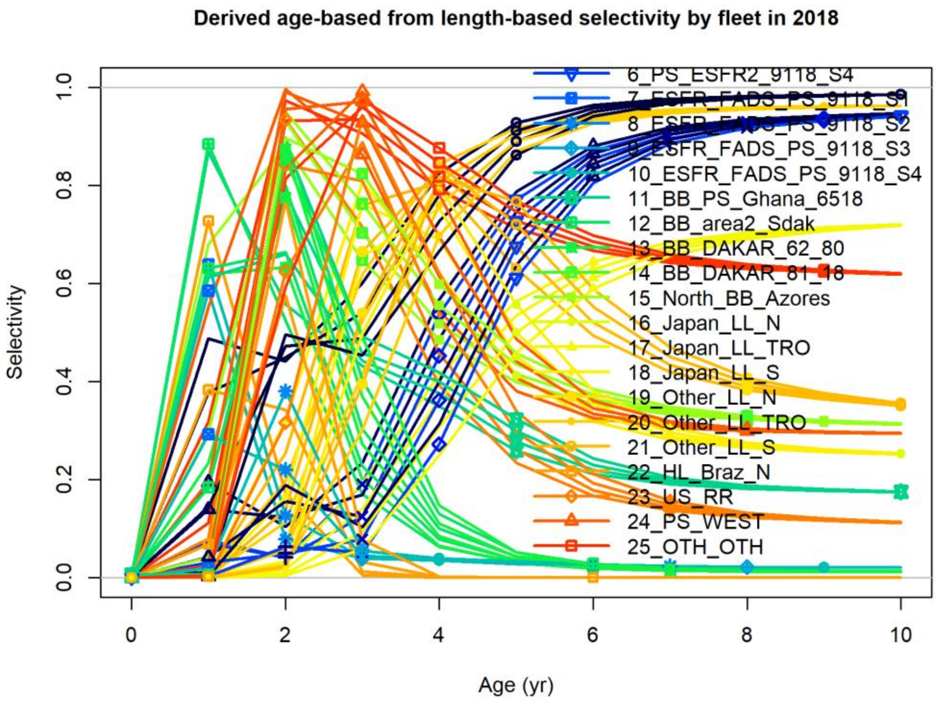
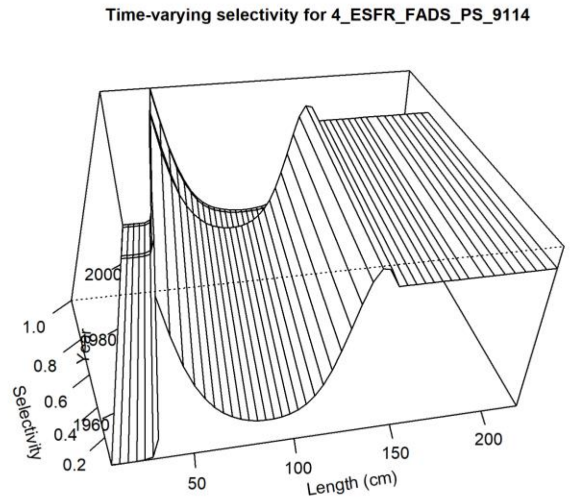


Figure 62. A. Fleet specific selectivity at age derived from length based for Run 5 from 2016 in 2014 versus the same for plot for Grid run 1 illustrating the generally more dome-shaped selectivity estimated in the current assessment for several notable fleets.

A



B

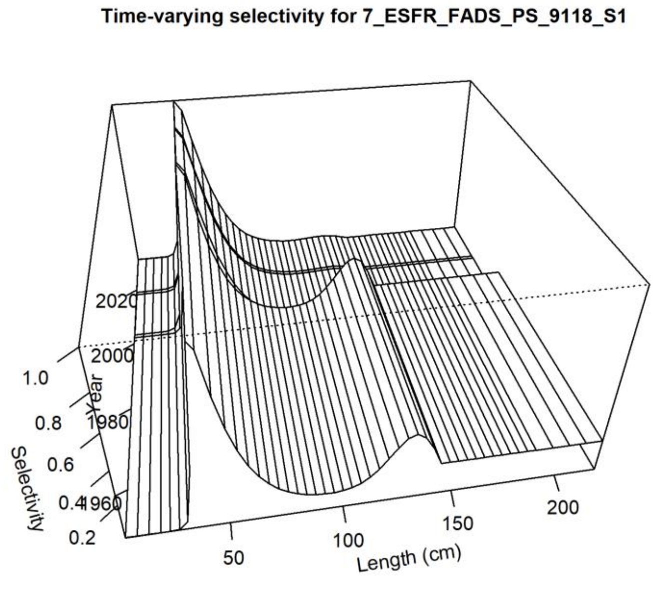


Figure 63. Time varying selectivity for the PS_FAD fleet from the 2016 assessment versus the current assessment showing the difference in the estimated selectivity for larger fish.