REPORT OF THE 2017 ICCAT ATLANTIC SWORDFISH STOCK ASSESSMENT SESSION

(Madrid, Spain 3-7 July, 2017)

1. Opening, adoption of agenda and meeting arrangements

The meeting was held at the ICCAT Secretariat in Madrid, July 3 to 7, 2017. Dr Rui Coelho (EU-Portugal), the Species Group ("the Group") coordinator and meeting Chairman, opened the meeting, welcomed participants and the Group Co-rapporteur (Dr Humber Andrade). Dr Miguel Neves dos Santos (ICCAT Assistant Executive Secretary and Scientific Coordinator) adressed the Group on behalf of the ICCAT Executive Secretary, welcomed the participants and highlighted the importance of the meeting due to the fact that the Atlantic swordfish stocks' statuses have not been assessed for 4 years. The Chairman proceeded to review the Agenda which was adopted without changes (**Appendix 1**).

The List of Participants is included in **Appendix 2**. The List of Documents presented at the meeting is attached as **Appendix 3**. The abstracts of all SCRS documents presented at the meeting are included in **Appendix 4**. The following served as rapporteurs:

Sections	*Rapporteur*
Items 1, 11	M. Neves dos Santos
Item 2	P. De Bruyn, C. Palma, D. Rosa
Item 3	A. Hanke, F. Arocha, H. Andrade
Item 4	M Ortiz, J. Costa, H. Andrade
Itmes 5, 6	E. Babcock, M Ortiz, M. Schirripa, L. Kell, H. Winker
Item 7	E. Babcock, M. Schirripa, L. Kell, H. Winker
Item 8	D. Die, F. Arocha
Item 9	R. Coelho, D. Die, M. Neves dos Santos, G. Diaz
Item 10	P. De Bruyn, D. Die, G. Diaz, R. Forselledo
Data rapporteur	H. Andrade

2. Summary of available data submitted by the assessment data deadline (30 April 2017)

During the swordfish data preparatory meeting, the Group agreed to establish a deadline (April 30, 2017) to incorporate all the revisions provided by the CPCs on basic fisheries statistics (Task I and Task II) data. The final datasets (including estimations of CATDIS and CAS) were prepared by the Secretariat.

2.1 Catches

The final Task I nominal catches (T1NC) of both swordfish Atlantic stocks (SWO-N and SWO-S) are presented in **Table 1** and **Figure 1**. The preliminary 2016 catch estimations (including Task I submissions and carry overs) were used for projections only.

2.2 Biology

Document SCRS/2017/133 presented a species distribution model (SDM) for swordfish using a habitat suitability framework. Currently, the model integrates ocean depth, annual average estimated total chlorophyll, temperature and oxygen. Model predictions and general distributions of North Atlantic swordfish catches are used as criteria for the inclusion and treatment of variables. Initial trials demonstrated that the habitat cannot be predicted using temperature and oxygen alone. The inclusion of the spatial annual average productivity via chlorophyll markedly improved distribution predictions. The current formulation predicts the north-south seasonal migration in the North Atlantic but also predicts high abundance in areas of low swordfish catch. Better, time-varying data for ecosystem productivity relevant to swordfish might resolve this problem, but important habitat features may also be missing.

The Group stressed that it would be useful to have more tags from a wider area to support the temperature and depth utilization patterns (per the Swordfish Work Plan). The Group suggested that the high catches in areas of predicted low abundance might be related to bottom features, it was mentioned that a new layer could be added to the model to include these features. It was also noted that the model should be extended to the Mediterranean Sea which is currently not included. This is an initial model that included chlorophyll to predict habitat utilization of swordfish, but it is expected that improvements to the model will move from chlorophyll to higher levels in the food web which will potentially better capture swordfish habitat utilization. The Group acknowledged the importance of this work and its continuity as it can provide valuable information on habitat use and stock boundaries of swordfish.

2.3 Length compositions

The Task II size frequencies (T2SZ) presented, which include several revisions (being the most relevant ones, Chinese Taipei longline 1980-2007 series, and, the USA 1962-1985 series corrections involving various gears), were used to, prepare the stock synthesis (SS) input files, categorised by the fleet structure of the SS model (SS-fleet). Size frequency samples were created for stock, year, SS-fleet, and gear strata from the swordfish Task 2 SZ available in ICCAT DB. Size samples reported as weight category were not included, also size measures of 10 cm bins or larger were excluded. All size data were standardized to LJFL measures, fish over 450 cm were considered outliers and removed. For a given size frequency observation, a minimum of 100 measured fish was required for use in the SS model. The Secretariat also provided an update of the catch-at-size (CAS, 1978-2015) estimations for both north and south Atlantic stocks.

2.4 Other relevant data

The CATDIS (1950-2015) estimations were also updated by the Secretariat (**Figures 2** and **3**), aiming to reflect the most up-to-date T1NC of swordfish. The CATDIS was then used (instead of T1NC, with poor time-area detail) as the input of the SS models, as the biomass removals catch series by stock.

3. Catch data, including catch at size and fisheries trends

The CAS of both swordfish Atlantic stocks (SWO-N and SWO-S) were updated (revision to the 1978-2013 period, and, new estimations for the 2014-2015 period) in order to reflect in weight equivalent (numbers transformed into weight) the current T1NC. The methodology used (in particular the substitution criteria) was revised by this Group during the 2017 ICCAT Swordfish Data Preparatory Meeting (Anon., in press a). All the new and revised information, received until the deadline, was used on the estimations. **Tables 2** and **3** presents the North and South SWO CAS overall matrixes, respectively. **Figure 4** shows the mean weights (kg) of both Atlantic stocks.

4. Relative abundance indices: overview of indexes to be used - provided by the CPUE index and data deadline (30 April 2017)

4.1 Relative abundance indices – North

During the data preparatory meeting several indices were presented and discussed for the North Atlantic: Canada, Japan, Morocco, EU-Portugal and USA. Most of them were considered suitable as input data for the stock assessment models. However, the Group asked Canada and Japan to provide updates based on WG comments, and asked Spain to present updated CPUE series with a supporting document. In addition the Group decided to conduct a collaborative work among national scientists to calculate a combined biomass index for the North Atlantic.

Document SCRS/2017/137 provided an updated combined biomass index of abundance for the North Atlantic swordfish stock 1963-2015. In this working paper the standardized biomass index of abundance developed for the 2006, 2008 and 2012 ICCAT SCRS meetings for north Atlantic swordfish assessments were revised and updated with data through 2015. Generalized Linear Modeling (GLM) procedures were used to standardize swordfish catch (biomass) and effort (number of hooks) data from the major longline fleets operating in the North Atlantic: United States, EU-Spain, Canada, Japan, Morocco and EU-Portugal. As in past analyses, main effects included: year, area, quarter, a nation-operation variable accounting for gear and operational differences thought to influence swordfish catchability, and a target variable to account for trips where fishing operations varied according to the main target species. Interactions among main factors were also evaluated.

The Group discussed the results in the light of the potential advantages and disadvantages of using combined or separated indices as input data in the models. The Group noticed that there was a gap (1971-1974) and that the differences between nominal and standardized CPUEs were higher in the beginning of the time series when only data of Canada and Japan were available. In addition it was noted that the scales of the standardized estimations calculated for the period before and after the gap of the very beginning time series were different. It was noted that the model predicted large confidence bounds for the early years compared to recent period when more information was available. It was recommended that annual estimates of variance of the standardized index could be included in the assessment models when possible.

Document SCRS/2017/105 provided standardized catch rates of swordfish from the Spanish surface longline fleet in the North Atlantic. Log-normal Generalized Linear Models (GLM) were used to update the standardized catch rates (in number of fish and weight) of the Spanish surface longline fleet targeting swordfish during the period 1986-2015. Factors such as year, area, quarter, gear and bait as well as the fishing strategy – based on the ratio between the two most prevalent species and those most highly valued by skippers – were considered. Some sensitivity analyses were conducted concerning the model structure: base case – year not included in the interactions, alternative case – year included in random effects interactions. The base case models explained 51% and 53% of CPUE variability in number and weight, respectively.

The Group noted that the standardized CPUE trends were flat and that the coefficients of variations were very low. Despite the overall flat trend, there was an increase in the CPUE values at the end of 1990, when the Spanish fleet changed the gear from multifilament to monofilament. Catch ratios were used as a proxy for targetting. The potential disadvantages (or advantages) of using this approach were discussed, but the Group considered that the estimations presented are the best available information, and that it is worth using them in the stock assessment.

Document SCRS/2017/107 provided an updated standardized CPUEs in number of fish by age for the North Atlantic inferred for the Spanish longline fleet. Log-normal General Linear Modeling (GLM) from trips carried out by the surface longline fleet targeting swordfish in the North Atlantic stock were used in the calculations. Indices were developed for a 34-year period (1982-2015) using a sex-combined growth model for ageing the size data per trip. The criteria used to define areas, time periods and models were similar to those used in papers presented in the last stock assesment. The model also takes into consideration other factors such as gear style and type of trip (as target proxy) to allow for two important changes in fishing strategy which have occurred in recent periods. The base case models explained between 42% and 44% of CPUE variability. The standardized CPUE index for age 1 suggests an increasing trend of recruitment between the years 1997-2012.

Results suggest a positive correlation between standardized CPUE of age 1 and the Atlantic Multidecadal Oscillation (AMO), but a negative correlation with North Atlantic Oscillation (NAO). The Group recognizes that the investigation of correlations between the recrutiment and climatological and oceanographic indexes are valuable. In addition the Group noted that the correlations between the standardized CPUEs of a given age and the estimations of the subsequent ages with a lag were not always evident. Drawbacks of using the slicing method to convert length in age when there are no age-length keys available for most of the period analyzed were recognized by the Group. The intrinsic dependence of the standardized CPUEs calculated for the different age groups were discussed as some stock assessment methods demand independent relative abundance indices.

After considerations the Group decides to use the age specific standardized CPUE in the SS assessment models, while the CPUE for age 4 could be an alternative to production models in order to estimate a proxy of spawning biomass.

Document SCRS/2017/144 provided standardized CPUE of swordfish for Chinese Taipei tuna longline fishery in the North Atlantic. A generalized linear model was used to estimate standardized CPUEs of swordfish caught by Chinese Taipei distant-water tuna longline fishery between 1968 and 2015. Four periods of 1968-2015, 1968-1989, 1990-2015 and 1997-2015 and information on operation type (the number of hooks per basket, HPB, for the model of 1997-2015) were considered in order to account for targeting changes in this fishery. The HPB did not explain much of the variability of CPUE. Abundance indices developed for swordfish for 1968-1989, 1990-2015and 1997-2015 showed almost identical trends to those derived from the model of entire period (1968-2015). The standardized CPUE trend of swordfish started to decrease in the early 1970s, but increase quickly from 1989 to 1990, and then did not change much from 1997 until the end of the time series. The difference between the standardized CPUE of 1989 and of 1990 was large, which indicated a discontinuity due to an important change in the fishing strategy. In the beginnig of 1990's the fleet changed from targetting albacore to bigeye tuna. The proportional reduction of deviance was low, which indicates that most of the CPUE variability could not be explained by the variables included in the models.

Standardized CPUEs of Chinese Taipei were not available in the data preparatory meeting and they were not discussed inter-sessionally. Therefore the Group decided not to consider them in base cases but in sensitivity analysis. However, the Group strongly encourages the further development of these series.

The standardized CPUE indices selected to be considered in the stock assessment analyses are provided in **Table 4** and in **Figure 5**. **Figure 6** shows the North Atlantic Combined biomass index used in the production models.

4.2 Relative abundance indices – South

During the 2017 ICCAT Swordfish Data Preparatory Meeting the standardized CPUEs of three CPCs (Brazil, Japan and Uruguay) were presented (Anon., in press a). The Group asked Japan to provide updated series based on Group comments, and asked Spain to present an updated CPUE series with a supporting document. Chinese Taipei and South Africa were also contacted to provide CPUE series.

The update of the Japanese CPUE index was not completed in time to use in the assessment models, but work is progressing. The Group decided therefore to use the estimations presented in the data preparatory meeting as input for stock assessment models as the Japanese series convey important information concerning the early years of the fisheries. In addition, the Japanese series would be split into two parts (1990-2005 and 2006-2015) in order to account for important changes in the fisheries which resulted in large changes in catches particularly in the 2000s. This decision is supported by statistics on catches as they appear in the national report of Japan, which was showed by the Japanese scientist present at the stock assessment meeting.

Document SCRS/2017/106 provided an update standardized catch rates for swordfish (number and weight) from the Spanish longline fleet in the South Atlantic for the period 1989-2015. The updated standardized CPUEs were estimated using a Generalized Linear Model. Like in the analyses conducted for the North Atlantic (SCRS/2017/105) year, area, quarter, gear, bait and type of trip were considered as explantory variables. Catch ratios were used as a proxy for targetting. Sensitivity analyses were conducted concerning the model structure: base case – year not included in the interactions, alternative case – year included as random effects interactions. The base case model explained 65% and 71% of CPUE variability in number and in weight respectively.

Time series of standardized CPUEs were flat across the years and the coefficients of variations were very low. It was reminded that the same considerations concerning the use of ratios between catches of species (swordfish and blue shark in this case) for North Atlantic applies also to the South Atlantic. However, the Group recommended that the EU-Spain time series should be considered in the stock assessment models.

Document SCRS/2017/145 provided standardized CPUEs of Chinese Taipei distant-water tuna longline fishery in the South Atlantic for the period 1968-2015. Generalized linear models were used to analyse catch rates in order to estimate the standardized CPUEs. Four time spans (1968-2015, 1968-1990, 1991-2015 and 1998-2015) were considered. Explanatory variables considered were year, season and area. Number of hooks per basket (HPB) was also included as explanatory variable when analyzing 1998-2015 time span. Standardized CPUE calculated for 1968-1990 and 1991-2015 time spans were similar to those estimated based on the entire data set in the periods the time spans overlap. The inclusion of HPB in the model used to analyze 1998-2015 did not change much the standardized estimations and did not result in much reduction of the deviance. In general, the standardized CPUE series for the South Atlantic swordfish decreased in the 1970s, but it was flat from the mid 1970s until the end of the 1980s. There was an increase from 1989 to 1990, followed by a decreasing trend until the end of the time series.

The Group noted that the standardized CPUE trend calculated for the South Atlantic was similar to that calculated for the North Atlantic. In addition, just like for the North Atlantic, there was a discontinuity between 1989 and 1990 for the South Atlantic, in the sense the difference between the estimations for these two years was very high due to targeting change.

Document SCRS/2017/138 explained that swordfish is a target species in the South African pelagic longline fleet operating along the west and east coast of South Africa. A standardization of the swordfish CPUE of the South African longline fleet for the time series 2004-2015 was carried out with a Generalized Additive Mixed Model (GAMM) with a Tweedie distributed error. Explanatory variables of the final model included year, month, geographic position (Lat, Long) and a targeting factor with 2 levels, derived by clustering of PCA scores of the root-root transformed, normalized catch composition. Vessel was included as a random effect. Swordfish CPUE had a definitive seasonal trend, with catch rates higher in winter and lower in summer. The standardised CPUE analysis indicates a consistently declining trend over the period 2004-2012, followed by a notable increase between 2012 and the final assessment year 2015.

The Group acknowledged this new series and agreed to consider it for the stock assessment.

Standardized CPUE indices selected to be considered in the stock assessment analyses are in **Table 5** and in **Figure 7**.

5. Methods and other data relevant to the assessment

5.1 North Atlantic

5.1.1 ASPIC / BioDyn

BioDyn

To take uncertainty about stock dynamics and the quality of data into account the SCRS routinely considers a range of scenarios comprising alternative model structures and datasets for a single stock. When running multiple scenarios, however, models have to be compared and validated before advice can be given. This is difficult where different models and datasets have been considered. Cross-validation, is a technique for validating models by evaluating prediction skill. It is conceptually simple, with few parametric or theoretic assumptions, and so can be used to make comparisons across datasets and model structures. Model predictions should be compared to observations rather than quantities such as fishing mortality (F) and spawning stock biomass (SSB) that cannot be observed, otherwise there is a danger of subjectively choosing model solutions. If the data (e.g. CPUE and catches) are regarded as being representative of the dynamics of the stock then they can be used as a model-free validation measure.

To address this, a continuity run was conducted for the ASPIC scenario conducted in 2013, i.e. for a logistic production function and combined CPUE index, using the dataset available in 2017 (CPUE and catch up to and including 2015). The analysis using BioDyn is presented in **Appendix 5**. This method is based on prediction residuals. This showed that as new data became available, in recent years, from the region around the biomass at maximum sustainable yield (B_{MSY}), the evidence supported a fox (skewed) rather than a logistic (symetric) production function.

ASPIC

For the North SWO stock a continuity run was done with a surplus production model (SPM) using the same software (ASPIC-7) as in 2013, with the catch series 1950–2015, and the combined biomass index of abundance (1963–2015). This continuity run used the same assumptions and settings as the 2013 base model; briefly assuming a logistic production model function, estimating *K* and *r*, and fixing the B1/K parameter at 0.85.

5.1.2 BSP2

The BSP2 software in VisualBASIC was used to run Bayesian surplus production models for the North Atlantic, as was done in the 2013 assessment. The BSP2 software is a variation on the BSP software that is cataloged in the ICCAT catalog of methods, and it is written in an older programming language. The Group decided to use the BSP2 software but recommended that the method be revised to run in a more modern language and the revised software should be included in the catalog of methods.

The base case model had a Schaefer functional form, which assumes that maximum sustainable yield (MSY) occurs when biomass is at half the unfished biomass (*K*). The differential equation version of BSP2 was used, so that the fishing mortality rate was estimated as an instantaneous rate rather than a proportional harvest rate.

The prior for *r* was lognormal, with mean 0.424 and logsd 0.40, the same as in the 2013 assessment (SCRS/2013/100). The prior for *K* was uniform on log(K) between log(500 t) and log(1,000,000 t). The prior for the starting biomass ratio (B_{1950}/K) was lognormal with a mean of 0.875 and logsd of 0.25 with boundaries of 0.001 and 3.5. The constant of proportionality *q* for each series was estimated with an uninformative uniform prior between 0.000000001 and 2.

For the base case, the combined index was used as an index of abundance (SCRS/2017/137). The observation error CV was input as 0.23, which was approximately the MLE estimate when each point was given the same value. Process error was lognormal, with a log standard deviation input as a fixed parameter equal to 0.05.

The sensitivity runs included a generalized production model with B_{MSY}/K equal to either 0.4 (shape parameter=1.189) or 0.6 (shape parameter=3.39), a less informative prior for *r* (logsd=1), and including the indices separately with several alterative methods to set the observation error standard deviaton. Diagnostic runs included a post model pre data (PMPD) model, which is a model run with only a single CPUE data point to evaluate the influence of the priors and the catch time series on the estimated dynamics. Retrospective analysis were conducted in which the CPUE data were progressively truncated to earlier years, and the biomass after the end of the CPUE series was projected using the catch data. A bootstrap analysis, which included the CPUE series separately, then dropped out one index at a time, was also conducted (**Table 6**). See **Appendix 6** for details of the methods, diagnostics and sensitivity analyses.

5.1.3 Stock Synthesys (SS)

Initial Model

Based on data presented at the 2017 Swordfish Data Preparatory Meeting, the Stock Synthesis (SS) model was configured using seven longline fisheries and one "other". The longline fisheries were Spain, United States, Canada, Japan, Portugal, Chinese Taipei, and Morocco. These fisheries collectively accounted for 92% of the total northern swordfish landings, with the other countries and gears making up the remaining 8 percent. The SS configuration uses one season, one area, and two sexes. Length samples for the eight fisheries were available from about 1978 to 2015. Fourteen indices of abundance were available for fitting population trends. (**Figure 8**)

Natural mortality for both male and female were fixed at 0.20 per age. Maturity was set to be 50% at age-5 and 100% thereafter. Fecundity was made a function of body weight. Growth parameters were fixed at values developed during the 2017 ICCAT Swordfish Data Preparatory Meeting (Anon., in press a).

For the western North Atlantic, from 1995-2011, catch rates for those fisheries in the western Atlantic tended to decrease while those in the eastern tended to increase. This was investigated further by hypothesizing that environmental phenomena were causing the population densities where changing as a result of changing oceanography (Goodyear *et al*., 2017). This hypothesis was developed by realizing that several ecosystem indicators had switched from negative to positive (or visa-versa) in 1995. The indicator that covered the greatest area and has been shown to be influential was the Atlantic Multidecadal Oscillation (AMO) (Goodyear *et al*., 2017). Based on regressions between CPUE residuals and the AMO, the Canadian (west), Japan (west), EU-Portugal (east), Morocco (east), EU-Spanish Age_1, Age_2, Age_4, and Age_5+ (all east) catchability (q) were made a function of the AMO (**Figure 9**).

Selectivity was modeled to be length based with all ages (0-25) available. Dome-shaped selectivity was allowed for EU-Spain, US, Japan, EU-Portugal and Morocco. Asymptotic selectivity was assumed for Canada, Chinese-Taipei and "other". Spanish age-specific CPUE was modeled with a fixed age-based selectivity (**Figure 10**). Length composition effective size was established by adjusting the effective-n until unity was reached between the modeled effective-n and the Francis suggested sample size. Selectivity fits to the length data were very satisfactory but with some deviances at times in the smaller fish (**Figure 11**).

A Beverton-Holt stock recruitment relation was assumed with maximum recruitment estimated and a standard deviation on recruitment deviations of 0.60, and a fixed steepness value of 0.80, as agreed on during the Data preparatory meeting. Deviations from the stock recruitment function showed no outstanding deviations or trends (**Figure 12**).

Model diagnostics provided evidence of model stability without any apparent retrospective patterns (**Figure 13**).

Various values of steepness were considered, as is often the case, results were indeed sensitive to the assumed values of not only steepness but natural mortality as well (**Figure 14**). Initially there was no clear evidence as to which values were best for these parameters.

To examine the influence of each CPUE, each index was removed one at a time and the model refit. The results of this diagnostic showed that the model was most sensitive to the Canadian and Japan CPUE (**Figure 15**). This result followed the fact that these two time series were the longest ones available and was not unexpected.

A diagnostic to the effect of the various length composition effective sample sizes 25 runs were made with randomly chosen sample sizes that were based on a mean equal to the fitted sample size with a coefficient of variation of 40 percent. Results from this diagnostic showed that the effective sample size had minor effects on the overall biomass trend (**Figure 16**).

Given that GLMs of CPUEs can often have CVs that are seemingly under estimated, a variance reweighting was used on each of the CPUE time series. The highest adjusted variance was assigned to the shorter Japanese time series and the smallest to the Spanish age-based CPUEs (**Figure 17**). The CV's of the added variance parameters was inversely proportional to the amount of required added variance. Trends in biomass both with and without the added variance had the most effect on the biomass trend in early years and the least on the latest years.

Much of the discussion surrounding the SS model centered on the assumption of the fixed value of steepness and the subsequent setting of the MSY value.

Base Model

The most significant change made to the initial model configuration was changing the assumed standard deviation in the recruitment deviations (sigma-r) from 0.60 to 0.20. This change was based on the fact that the assumed sigma-r was set to 0.6, but residual mean square error of recruitment deviations was only 0.17, so the bias adjustment of 1.0 was inappropriate. The suggestion was to reduce sigma-r to about 0.20.

These modifications did not result in any significant change in the biomass trend or current status of the stock. However, after these modifications were made the steepness parameter was found to be estimable by using an informative prior with a Beta distribution, a mean of 0.80 and a standard deviation of 0.06. The estimation of steepness resulted in a change to the perceived productivity of the stock. The Group discussed at length the implication of estimating steepness. Noticing that the value was in good agreement with the value that was suggested by a meta-analysis based on life history of swordfish (SCRS/2017/143) the Group agreed that estimating steepness was superior to fixing the parameter at an assumed value. This method resulted in the steepness estimate to be higher than the prior (steepness = 0.88, SD = 0.03) and no longer hitting the upper bound of the parameter (1.0) as in the original model configuration (**Figure 18**).

The full final SS model diagnostics and fits are provided in **Appendix 7**.

5.2 South Atlantic

5.2.1 BSP2

The BSP2 in VisualBASIC software was used to run Bayesian surplus production models for the South Atlantic, as was done in the 2013 assessment. The base case model had a Schaefer functional form, with fishing mortality calculated as an instantaneous rate.

The prior for *r* was lognormal, with mean=0.42 and logsd=0.46, the same as in the 2013 assessment (McAllister, 2014). The prior for K was uniform on log(K) bounded between log(500t) and log(1,000,000t). The prior for the starting biomass ratio was lognormal with a mean of 1 and logsd of 0.25 with boundaries of 0.001 and 3.5. The constant of proportionality *q* for each series was estimated with an uninformative uniform prior between 0.000000001 and 2 in most cases. In some cases *q* was estimated using the MLE value within the model to improve convergence.

The base case model excluded the historical Brazil series, which was flat and highly variable, but included Brazil-recent, EU-Spain, Uruguay, South Africa and Japan. The Japanese longline series was split in two at 2005/2006, and the EU-Spain series was split at 1999/2000 to account for changes in fishing methods that were not adequately captured in the standardization of the indices. Observation error was input at CV=0.2 for all data points. Process error was lognormal, with a log standard deviation input as a fixed parameter equal to 0.1.

The sensitivity runs included a generalized production model with B_{MSY}/K equal to either 0.4 (shape parameter=1.189) or 0.6 (shape parameter=3.39), a less informative prior for r (logsd=1), reducing process error to 0.05, and including or excluding various indices. Diagnostic runs were as described for the North Atlantic, and included a post model pre data (PMPD) model, retrospective analyses, and a bootstrap analysis (**Table 7**). See **Appendix 6** for details of the methods, diagnostics and sensitivity analyses.

5.2.2 JABBA

The stock assessment software 'Just Another Bayesian Biomass Assessment' JABBA was applied in the 2017 South Atlantic swordfish stock assessment. Building on recent advances in optimizing the fitting procedures through the development of Bayesian state-space modelling approaches (Meyer and Millar, 1999; Thorson *et al.*, 2012; Froese *et al.*, 2016), JABBA originates from a continuous development process of a Bayesian State-Space SPM software that has been applied and tested in the Report of the 2015 ICCAT Blue Shark Stock Assessment Session (Anon., 2016), the Report of the 2017 ICCAT Albacore Species Group Intersessional Meeting (including Assessment of Mediterranean Albacore) (Anon., 2017a) and the 2017 ICCAT Shortfin Mako Assessment Meeting (Anon, in press b). The motivation for developing JABBA was to provide a user-friendly R to JAGS interface for fitted generalized Bayesian State-Space SPMs to generate reproducible stock status estimates and diagnostics.

Initial assessment runs and sensitivity runs has been presented to group (SCRS/P/2017/027). The source code and *R* files for reproducing the final assessments runs have been made available to the Group. A full description of JABBA model formulation is provided in **Appendix 8** and is also documented by Winker *at al*. (2017).

Prior formulations

All priors were kept consistent across all the scenarios. A vaguely informative lognormal prior for K = 200,000 metric tons with a CV of 100%. For *r*, the same lognormal prior (mean = log(0.42), sd = 0.37) was assumed as for the 2013 ICCAT South Atlantic swordfish assessment. The prior means for *r* were translated into F_{MSY} as $F_{MSY} = r / 2$ (see **Appendix 8**). The initial biomass depletion prior ($\varphi = B_{1950}/K$) was inputted in the form of a lognormal prior, assuming that the South Atlantic stock was unexploited in 1950 with a CV = 0.25. All catchability parameters were formulated as uninformative uniform priors, while the process variance and observation variance priors were implement by assuming inverse-gamma distributions (Meyer and Miller, 1999), such that:

$$\sigma_{\eta}^{2} \sim \frac{1}{gamma(4,0.01)}$$

$$\sigma_{ADD,f}^{2} \sim \frac{1}{gamma(2,0.01) + 0.25^{2}}$$

The process variance prior corresponds to mean process error of σ_{η} = 0.056 (CV = 0.65) and the additional observation variance prior corresponds to a mean of $\sigma_{ADD,f}$ = 0.1 (CV = 1.96). Because most of the indices provided were considered over-precise with CV's < 0.1, an additional observation error variance of 0.25^2 was added a priori to all time series.

Scenarios

In 2013, ICCAT last carried out a stock assessment for South Atlantic swordfish using the surplus production software packages ASPIC and BSP2. Preliminary runs of ASPIC and BSP2 were performed on nine separate indices indicated that the historical Brazilian index was driving the model lack of fit as a result of conflicting trends with most of the other indices. Only after removing the historical Brazilian index, it had been possible to achieve model convergence, though undesirable systematic trends in the residuals and the variance remained across the time series, with notably strong residual patterns in the Japanese longline CPUE for the years 2000-2005.

During the 2017 South Atlantic swordfish assessment, the Group therefore focused specifically on identifying and resolving potential CPUE data conflicts that may arise from fitting of multiple standardized CPUE time series. The following CPUE time series were available for the South Atlantic swordfish assessment: Brazil historical (1978-2004) and Brazil-recent (2005-2012); EU-Spain (1989-2015); Japan (1990-2015); Uruguay (2001-2012); and South Africa (2004-2015). In addition, the Chinese Taipei CPUE was presented and subsequently considered as sensitivity run. In contrast to the 2013 assessment, the Brazilian CPUE series was revised and split two separate time periods. Based on initial JABBA fits and residual diagnostics, it was noted that the early Brazilian CPUE series was very noisy, lacked a discernable abundance signal and conflicted with other CPUE indices. In addition, the group identified that the introduction of the "American-style" longline gear in the Spanish fleet had likely caused changes in swordfish catchability (García-Cortés *et al.*, 2010). Similarly, changes in targeting between

2005 and 2006 may have caused the apparent increase in the Japanese CPUE index, which also resulted in a strong residual pattern in the Japanese CPUE over this period as already noted during the 2013 assessment. Similar effects on yellowfin tuna between 2005 and 2006 has been also noted in the Report of the 2016 ICCAT Yellowfin Tuna Data Preparatory Meeting (Anon., 2017b). The Group explored the option of introducing time-blocks within the Spanish (1999/2000) and the Japanese (2005/2006) CPUE series to account for changes in fishing methods that were not adequately captured in the standardization of the indices. For this purpose, the following four scenarios runs were evaluated in detail for both Fox and Schaefer production functions:

1. Scenario 1: All CPUE indices (excl.TAI)
2. Scenario 2: All CPUE indices, excl. TAI and historical BRA
3. Scenario 3: All CPUE, excl. TAI and historical BRA, and time blocks for JPN and EU.ESP
4. Scenario 4: All CPUE, incl. TAI and excl. historical BRA, and time blocks for JPN and EU.ESP

The Group decided that Scenario 3 was the most plausible base-case scenario. The base-case CPUE data therefore included Brazil-recent, EU-Spain, Uruguay, South Africa and Japan but excluded the historical Brazil series, where the Japanese CPUE was split at 2005/2006, and the EU-Spain series was split at 1999/2000.The base-case scenario was used as a reference case to conduct sensitivity runs with various combinations of CPUE indices based on both the Schaefer and the Fox production function (**Table 8**). Sensitivity was assessed with respect to the stock status estimates B/B_{MSY} and F/F_{MSY}.

6. Stock status results

6.1 North Atlantic Swordfish

6.1.1 ASPIC / BioDyn

BioDyn

The results of the BioDyn analysis are provided in **Appendix 5**.

ASPIC

The results showed similar trends of biomass and fishing mortality as estimated in the prior assessments (**Figure 19**) until 1995, afterwards the trends of the relative biomass (B/B_{MSY}) show a general increase, but the rate of recovery varied between the assessments results. By 2006, the stock was below the B_{MSY} in all assessments. In 2013 assessment the results indicated that the stock biomass was at or over the B_{MSY}. In the current assessment (2017), the surplus production model indicates that the rate of recovery has been much slower compared to 2013 results, although by 2015 the stock biomass is above B_{MSY}. This basically implies changes in the perception of the productivity of stock between 2013 and 2017 assessments.

In general, the results from the continuity run agree with those from the Bayesian surplus production model (BSP2) and the catch statistical model (Stock Synthesis) from the present assessment. It was noted that shape parameter showed a trend when more data became available around the MSY, which supported a skewed production function. It is noted that these models did not include process error. The trends of the SPM parameters were explored using the Fox and generalized (Pella and Tolimson) production models with the ASPIC software. **Table 9** shows the parameter estimates (K, r, and $B1/B_{MSY}$) and derived quantities for each of the three surplus production models. The generalized and Fox models produced identical estimates, while the logistic model varied slightly, although 80% confidence bounds overlapped among models. **Figure 20** shows the trend in the SPM parameter estimates when one year of data was removed at a time between 2015 and 2009. The Fox and generalized models predicted again similar parameters for all the years, while the logistic model estimated consistently different parameters for 2009-2015. From 2009 to 2012 the estimates of K decreased in all three model formulations while estimates of MSY increased suggesting a more productive stock. However, this trend shifted in 2012 and from 2012 to 2015 the estimates of K increased while MSY decreased suggesting a less productive stock. This trend is likely associated with a high point in the standardized index of abundance in 2012. However, all SPM formulations agreed in that at 2015, the stock biomass is above B_{MSY}, and the fishing mortality is below F_{MSY}.

6.1.2 BSP2

The base case model, which used the combined CPUE index, gave fairly precise estimates of the model parameters (**Table 10**), compared to the sensitivity runs using all the data series separately (**Table 11**, see **Appendix 6**). The means and CVs of *r* and *K* from model runs with all the indices were quite similar to the values from the post model pre data model diagnostic (run N5), which was run with no CPUE data. The more precise estimates from the combined index were caused by the fact that some of the contradictory trends between series were accounted for in the GLM that generated the combined index which is using operational data from the major longline fisheries in the North. Thus, the combined index probably gives a more accurate measure of the trend in abundance.

Alternative estimates of the observation error, and different priors for *r* and *K* had only a small impact on the estimates of the parameters and the current status. Using alternative shapes of the production function did not change the estimated biomass trajectory, but did change the reference points (**Table 11, Figures 21** and **22**). Thus, the median current biomass was near B_{MSY} with the base case, which was a Schaefer model ($B_{MSY}/K=0.5$), but median current biomass was above B_{MSY} using the generalized production function ($B_{MSY}/K=0.4$). Both models found that the median current F was around $0.8F_{MSY}$.

For the North Atlantic BSP2 base case model, the retrospective analysis showed that there was no consistent retrospective pattern (**Figure 23a**). However, the retrospective run that ended in 2012 when the combined CPUE was high (**Figure 5**) estimated a slightly higher 2015 biomass than runs with other end years. Because of the lower values of the CPUE index after 2012, models with data ending in 2014 or 2015 were more pessimistic. The low CPUE values since 2013 may explain why the current assessment found that the population is around B_{MSY} despite the fact that the population is increasing and was estimated to be around B_{MSY} in the 2013 assessment. The generalized production model also showed no retrospective bias (**Figure 23b**).

6.1.3 Stock Synthesis

The SS model results indicated that the northern swordfish were not overfished nor was overfishing occurring. The estimates of B/B_{MSY} and F/F_{MSY} are shown in **Figure 24**. Terminal year (2015) values and approximate 95% confidence intervals for B/B_{MSY} were 1.13 (0.81-1.45) and those for F/F_{MSY} were 0.75 (0.57-0.92). The estimates of total yield at MSY was 12,708 (12,175-13,240) metric tons. The estimate of fishing mortality at MSY was 0.17 (0.14-0.21).

6.2 South Atlantic swordfish

6.2.1 BSP2

The base case, which excluded the early Brazil series, included Japan, and split both Japan and EU-Spain into early and late periods, estimated that the population remained high until around 1990 and then declined rapidly as catches increased (**Figures 25** and **26**). The current biomass was below B_{MSY} and current F was above F_{MSY} (**Table 12**). The sensitivity analyses varied greatly depending on which CPUE series were included and how they were split into time blocks (**Table 13**). Runs that included the highly variable series from Brazil in the early years estimated very little change in biomass over the time series. Runs that did not split EU-Spain, or that included Chinese Taipei, showed some decline, but not as much as the base case. Changing the way the observation error was specified, or using different priors had less of an effect than the choice of indices. Using a generalized model rather than the Schaefer model did not change the biomass trend, but did change the reference points, so that current biomass was closer to B_{MSY}.

A retrospective analysis on the base case run found that there were no consistent trends in the estimated production functions, or the biomass estimates (**Figure 27**). However, when the data ended in 2011, the model was more pessimistic about current status.

6.2.2 JABBA

For the South Atlantic, all scenarios for JABBA were able to converge adequately as judged by the Gelman and Rubin (1992) and Heidelberger and Welch (1983) diagnostic test and satisfying stationary behaviour of the MCMC chains.

The initial fit to Scenario 1 provided evidence that the very noisy historical Brazil CPUE disguised the abundance signals of the other CPUE indices, which resulted in an overall poor fit associated with fairly high a Residual-Mean-Square-Error (RMSE) of 30.8% (**Figure 28**). Excluding the historical Brazil CPUE in Scenario 2 slightly improved the fit (RMSE = 24.1%), but revealed notable data conflicts between the standardized CPUE from Japan (1990-2015) and Spain (1989-2016). The Base-Case Scenario (Scenario 3), including the two change points in the catchability coefficients (time-blocks) within the EU-Spanish CPUE and Japanese CPUE series, substantially improved the residual pattern (RMSE = 19%) and also produced a noticeable improved DIC = 169.7 compared to Scenario 2 with a DIC = 182.3, despite adding additional degrees of freedoms (df = 4). Adding the Chinese Taipei CPUE in the additional sensitivity run (Scenario 4) indicated no data conflict with the Base-Case and showed a similar fit in terms of the RMSE = 19.9% (**Figure 28**). Schaefer and Fox model versions showed no discernible difference in the fitting diagnostics. Sensitivity runs (**Table 8**) showed that excluding the Spanish CPUE had the strongest effect on stock status results out all CPUE series relative to the Base-Case (**Figure 29**). The trends of the final Schaefer base-case JABBA model is presented in **Figure 30**.

Stock depletion (B/K) and status estimates (B/B_{MSY} and F/F_{MSY}) are provided for the Schaefer and Fox Base-Case scenarios together with the model parameter estimates in **Table 14**. Both Schaefer and Fox models estimated that South Atlantic swordfish catches remained under the stock's expected surplus production since 2010 (**Figure 29**), which is in agreement with the predicted rebuilding of biomass over this period (**Figure 30**). For the final assessment year 2015, both Schaefer and Fox models consistently estimated that biomass depletion was just below $B_{MSY,}$ while fishing mortality was estimated at around F_{MSY} (**Table 15**; **Figure 31**). The JABBA results for the base-case scenario therefore closely resemble the BSP2 results for the South Atlantic.

6.3 Synthesis of assessment results

Considerable progress was made since the last Atlantic swordfish assessment on the integration of new data sources, in particular biology and size information for the North Atlantic using integrated SS models. The specific results for each swordfish stock are summarized below.

North Atlantic

For the North Atlantic, the final base case BSP2 model estimated that current biomass (B_{2015}) was near B_{MSY} (median = 0.99, 95% CIs = 0.77-1.24) and current F (F_{2015}) was lower than F_{MSY} (median = 0.81, 95% CIs = 0.61-1.10). The final base case SS model estimated that B_{2015} was above B_{MSY} (median = 1.13, 95% CIs = 0.81-1.45) and F_{2015} was lower than F_{MSY} (median = 0.75, 95% CIs = 0.57-0.92).

Both models agreed that overfishing is not occurring and biomass is either higher or very close to B_{MSY}. The results obtained in this evaluation are not entirely comparable with those obtained in the last assessment (2013) due to the incorporation of more data sources and updated information. It was noted that catches in the last years have been below the TACs adopted by the Commission. It is also particularly noteworthy that the CPUE series has been decreasing since 2012 causing biomass trends to shift to lower levels compared to the 2013 assessment. This was also noted in the continuity run using ASPIC with the updated CPUE series and catch data.

The Group agreed that this assessment represents a significant improvement in our understanding of current stock status for North Atlantic swordfish using updated information and integration of the new data sources. The Group therefore agreed that management advice, including stock status and projections, should be based on BSP2 and SS.

South Atlantic

For the South Atlantic, the final base case BSP2 model estimated that current biomass (B_{2015}) was lower than B_{MSY} (median = 0.64, 95% CIs = 0.43-1.00) and current F (F_{2015}) was higher than F_{MSY} (median = 1.15; 95% CIs = 0.61-1.82). The final base case JABBA model estimated that B_{2015} was below B_{MSY} (0.72, 95% CIs = 0.53-1.01) and F_{2015} was very close to F_{MSY} (0.98, 0.70-1.36).

Both models agreed that the southern swordfish stock biomass is overfished, and that overfishing is either occurring or current F is very close to F_{MSY}. The results obtained in this assessment are not comparable with those obtained in the last assessment (2013) due to the use of individual CPUEs compared to the use of a single CPUE combined across indices in the previous assessment. There was also an informative prior for *K* based on values from the North Atlantic in the 2013 assessment, but not in the current assessment.

The Group agreed that this assessment represents an improvement in our understanding of current stock status for South Atlantic swordfish using updated information, individual CPUEs and integration of prior biological knowledge. The Group also agreed that either one of the models (BSP2 or JABBA) could be used for Management advice, but given that both are very similar in structure and use of information only one should be used. Given that JABBA is written in open-source software with more capabilities for future evolutions, the Group agreed that the management advice, including stock status and projections, should be based on JABBA model.

7. Projections

7.1 North Atlantic swordfish

7.1.1 BSP2

Projections were only conducted for the final base case model. As projections incorporated process error the predicted trajectories are variable. These are therefore more realistic of the future uncertainty in the stock status. Although MSY is estimated to be around 13,400 t, taking into account process error, only catches up to 13,200 t are expected to allow the population to remain at or above B_{MSY} throughout the projected time period (**Figure 32**). Catches around the current level or lower (11,000 t) have an increasing probability of remaining in the green quadrant of the Kobe plot (**Table 16**).

7.1.2 SS

Projections of stock status at various levels of future catch are shown **Figure 33**. Given the current status of the stock being quite close to the MSY benchmarks, values of catch below MSY are projected to maintain biomass above B_{MSY} during the projected time frame while catches above MSY would be expected to lower future biomass.

7.2 South Atlantic swordfish

7.2.1 BSP2

Projections were only conducted for the final base case model. The median MSY was around 14,400. However, because the poplulation is currently depleted to a median B/B_{MSY} of 0.7, catches would need to be reduced below about 12,000 to rebuild the population (**Figure 34**).

7.2.2 JABBA

Projections were only conducted with Schaefer JABBA final model base-case scenario. Although the median MSY was around 14,600 metric tons, the 2015 biomass depletion level at $B/B_{MSY} = 0.72$ would require catches be at or below 14,000 tons to rebuild the population to biomass levels that can produce MSY by the end of the projection period in 2030 (**Figure 35**). However, the Group noted that projections for this long term are highly uncertain. As the JABBA base-case mode is used for management advice in the South Atlantic, Kobe strategy matrices are presented in **Tables 17** to **19**.

8. Limit reference points

Document SCRS/2017/143 used a mathematical approach to estimate steepness based on life history data, and then used that information in assessing resiliency in time of rebuilding to target and limit reference points for the SWO north stock. The mathematical model to assess risk to the stock and the fishery showed that while 0.4 SSB_{MSY} maybe a good reference point for a biomass limit, it results in a high type II error (i.e. failing to protect the stock when needed 80% of the time). If this risk is reduced, it increases the risk to a loss in yield when it is not required. Thus, the resulting action would tend to over-protect the resource and penalize the fisheries or vice versa. Therefore, a conservative limit around 0.6 SSB_{MSY} was suggested for the SWO North stock, to balance the risk between the resource and the fishery.

The Group discussed these results and noted that they depend on strong assumptions on the knowledge of larval survival. Future work would need to incorporate estimates of uncertainty on biological parameters (eg. maturity-at-age, fecundity-at-age, quality of fecundity per unit of kg of females and early life history parameters such as larval growth and survival). The Group noted that the estimate of steepness from this study is consistent with those obtained from Stock Synthesis for the Northern Stock.

In 2016 the Commission agreed on a roadmap for the completion of MSE in support of the adoption of a harvest control rule for North Atlanic SWO. During the current meeting, the SCRS chair summarized the implications of the calendar described in the roadmap. This road map calls for the process of development of MSE to start in earnest in 2017 and be completed by 2019 for a possible adoption of an HCR by the Commission.

The Standing Working Group to Enhance Dialogue between Fisheries Scientists and Managers (SWGSM) met the week prior to the swordfish assessment and briefly considered the swordfish MSE during its discussions. The SWGSM supported the idea that the SCRS should use the guidance provided for the northern albacore in order to advance the northern Atlantic swordfish MSE:

- an objective to be in the green quadrant of the Kobe plot ($B>B_{MSY}$ and $F<F_{MSY}$) with at least 60% probability
- use the performance indicators from the North Atlantic albacore MSE
- use the types of HCRs tested in the North Atlantic albacore MSE

It was pointed out that work on MSE for swordfish is less advanced than for albacore or bluefin tuna and therefore that it will be challenging to abide by the schedule adopted by the Commission. To date no swordfish study has completed a “full MSE” including:

- a structured consultation process with managers about objectives, performance indicators and candidate harvest control rules
- the development of a broad set of operating model hypotheses involving directly the swordfish working group, and an agreed way to reject and weight Operating Model hypotheses
- an observation error model which can mimic the data types, and their error structure, to be included in the management procedure
- Identification of candidate management procedures
- Testing of management procedures with the full feedback loop, including implementation uncertainty

However, elements to inform an MSE process have been completed. For example, Tserpes *et al.* (2009) developed an operating model for Mediterranean swordfish which they used to test the performance of seasonal closures and constant effort controls, however, error models were limited to generating stochastic recruitment and stochastic landings into the future and did not include a proper testing of a management procedure. Kell *et al.* (2012) developed a preliminary MSE which did have most of the elements above except the broad consultation with managers and the Working Group. However, the authors did complete MSE simulations with full feedback loops and testing of a reduced set of harvest control rules. In this research the operating model was conditioned on an aged based assessment (i.e. Adapt VPA) and the management procedure was based on a biomass dynamic stock assessment with a harvest control rule based on a hockey stick with target and limit reference points. Harvest control rules tested were developed in consultation with the WGSAM and the management procedure included a production model. The authors acknowledge that the study was intended to demonstrate the usefulness of MSE and not to provide advice about N swordfish. The same software framework was used to conduct the North Albacore MSE (Kimoto and Itoh, 2017).

For northern swordfish, Schirripa, 2017a (see Anon., in press a) used two alternative operating models, one based on a Fox production model the other on a Shaeffer production model to evaluate the performance of using two alternative target reference points. The simulation assumed TACs were implemented without error on the assumption that future stock status was known without error.

Schirripa (2016) also used a similar approach to that of Schirripa (2017a) to evaluate how two alternative HCRs would have performed in the past if they were applied to determine TACs and implemented for the first time during the years that ICCAT had completed assessments (1991, 1996, 1999, 2003, 2006 and 2009). These simulations incorporate an assessment based on a production model, and thus had some of the elements of an MSE, including an HCR.

It was pointed out that the SS model developed (Schirripa, 2017b – see Anon., in press a – and SCRS/2017/023) for the 2017 assessment may be in the future considered as the basis of the development of a future operating model for the North Atlantic SWO MSE.

The Group recognized that delivering MSE results for North Atlantic SWO according to the schedule agreed upon by the Commission will be very challenging and require time and resources that are not presently available to the SCRS. The Group agreed that a detailed proposal for the research plan to support the agreed North Atlantic SWO MSE timetable, including costs, should be developed by the SCRS and presented to the Commission. Ideally such proposal would integrate the needs to conduct an MSE for tropical tunas, because it is likely that many CPC scientists would have to be involved in both, and draw on the experience of the albacore MSE. The Group also recommended that the funding for this work should be additional to the proposed strategic research fund for the SCRS.

Any work on MSE for North Atlantic swordfish will be useful for the future Mediterranean swordfish MSE.

9. Recommendations and workplan

9.1 Research and statistics recommendations

- CPUE index for the South: Given some continuing conflicting trends among the CPUE indices for the South Atlantic, the Group recommended considering a joint CPUE index using raw data, similar to what has been done for the North Atlantic.

- CPUE provision: The Group reiterates that all CPCs with major fisheries for northern and/or southern swordfish should provide standardized CPUE indices. This should adhere to the guidelines developed by the WGSAM.

- Data submission: The Group reiterates that CPCs should comply with all aspects of their data submission obligations which include the reporting of estimates of dead discards and, when possible, live releases.

- Estimation of dead discards: The Group recommended that, until CPCs fully comply with their obligations to report dead discards, the use of observer data as a tool to estimate dead discards as a proportion of the total landed catch be explored.

- CPUE standardisation. For the WGSAM to provide guidelines on how and when to include interactions between years and other factors in the CPUE standardization. Also how to account for targeting effects (e.g. catch ratios, clustering of catch composition and other alternatives). To ask for guidance on how to interpret measures of variance associated with the index in the presence of different model structures, especially in the context of the use of these measures of variances in the process of population modeling (e.g. in the weighting of different CPUEs).

- MSE timetable: The Group recommended that a detailed proposal to support the agreed North Atlantic SWO MSE timetable, including costs, should be developed by the SCRS and presented to the Commission. The Group expressed concern over the existing timeline for provision of the MSE to the Commission. This concern should be addressed in the proposal. Ideally such proposal would integrate the needs to conduct an MSE for tropical tunas, because it is likely that many CPC scientists would have to be involved in both, and draw on the experience of the albacore MSE.

- MSE funding: Delivering MSE results for northern SWO according to the schedule agreed upon by the Commission will be very challenging and require time and resources that are not presently available to the group or the SCRS. The Group recommended that the funding for the MSE for SWO should be in addition to a proposed strategic research fund for the SCRS.

- Model predictions cross validation: Model predictions should be compared to observations rather than quantities such as F and SSB that cannot be observed, otherwise there is a danger of subjectively choosing model solutions. If the data (e.g. CPUE and catches) are regarded as being representative of the dynamics of the stock then they can be used as a model-free validation measure. It is recommended that the WGSAM uses the North Atlantic swordfish assessment to explore the use of cross-validation of predicted data for model validation. This can also be used for weighting or selecting operating model scenarios in an MSE.

9.2 Management recommendations

North Atlantic:

It was determined that future catches around or above 12,900 t would likely result in a decrease in biomass. The group agreed to review this estimate once the combined Kobe matrix is produced.

South Atlantic:

Current level of catches (10,058 t) will rebuild the stock to achieve the Convention objectives by 2020. Catches of 13,000t will result in about 60% probability of the stock reaching the green quadrant of the Kobe plot by 2024. The TAC should not exceed 13,000 t.

10. Other matters

Presentation SCRS/P/2017/026 analyzed hooking mortality at haulback, of swordfish captured by longliners in the Southwestern Atlantic Ocean. Data were gathered by the Uruguayan National Observer Program (PNOFA) on board the Uruguayan and Japanese fleets. The latter fleet operated within the Uruguayan EEZ with an experimental fishing license or under a leasing agreement. Results show that the overall mortality for swordfish was 71.5%; for individuals smaller or equal to 125 cm mortality was 78.4% and for individuals smaller or equal to 119 cm mortality was 79.9%. Mortality was found to be related to size and Sea Surface Temperature. Smaller specimens have higher probabilities of being dead at-haulback as do specimens captured in warmer waters. These mortality estimates are not as high as the ones presented by Coelho and Muñoz-Lechuga (2017) which may be due to differences in areas of operation, with the latter occurring in warmer waters and including smaller individuals. However, the results address the question as to whether the minimum retention sizes currently in place in ICCAT are effective if the main objective is to protect juvenile swordfish.

The Group noted that even though the management measure might not be effective due to the high mortality rates observed, the measure might be working in other ways, such as encouraging vessels to avoid areas of high concentration of juveniles. Knowing this, it is important to identify those areas of high juvenile concentration. This study would necessitate the use of various CPCs observer data as well as the existing ICCAT official data. The extent of discarding also needs to be evaluated between countries as not all fishing operations are the same. It was suggested that including additional factors such as soak time and hook type and depth will also improve understanding of mortality.

11. Adoption of the report and closure

The report was adopted by the Group and the meeting was adjourned.

References

Anonymous. (in press a). Report of the 2017 ICCAT Swordfish Data Preparatory Meeting *(Madrid, Spain 3-7 April, 2017*). SCRS/2017/003: 63 p.

Anonymous. (in press b). Report of the 2017 ICCAT Shortfin Mako Assessment Meeting (*Madrid, Spain 12-16 June 2017*). SCRS/2017/002: 64 p.

Anonymous. 2016. 2015 Blue Shark Data Preparatory Meeting (*Tenerife, Spain –March 23 to 27, 2015*). Collect. Vol. Sci. Pap. ICCAT, 72 (4): 793-865.

Anonymous. 2017a. Report of the 2017 ICCAT Albacore Species Group Intersessional Meeting (including Assessment of Mediterranean Albacore) *(Madrid, Spain 5-9 June, 2017)*. Collect. Vol. Sci. Pap. ICCAT, 74 (2): 508-583.

Anonymous. 2017b. Report of the 2016 ICCAT Yellowfin Tuna Data Preparatory Meeting (*San Sebastián, Spain - March 7 to 11, 2016*). Collect. Vol. Sci. Pap. ICCAT, 73 (1):1-75.

Coelho R., Muñoz-Lechuga R. 2017. Hooking mortality of swordfish in pelagic longlines: comments on the efficiency of the minimum retention size currently in place in ICCAT. ICCAT paper SCRS/2017/052.

Froese, R., Demirel, N., Coro, G., Kleisner, K.M., and Winker, H. 2016. Estimating fisheries reference points from catch and resilience. Fish 83: 506–526, doi:10.1111/faf.12190.

García-Cortés B., Mejuto J., de la Serna J.M., and Ramos-Cartelle A. 2010. A summary on the activity of the Spanish surface longline fleet catching swordfish (*Xiphias gladius*) during the years 2006-2007. Collect. Vol. Sci. Pap. ICCAT, 65 (1):135-146.

Gelman, A. and Rubin, D.B. 1992. Inference from Iterative Simulation Using Multiple Sequences. Statistical Science 7: 457-472.

Heidelberger, P. and Welch, P.D. 1983. Simulation Run Length Control in the Presence of an Initial Transient.

Kell, L.T., De Bruyn, P., Mosqueira, I., and Magnusson, A. 2012. An evaluation of the performance of the Kobe strategy matrix: an example based upon a biomass dynamic assessment model. Collect. Vol. Sci. Pap. ICCAT, 68 (3):1018-102.

Kimoto A., and Itoh T. 2017. The standardized bluefin CPUE of Japanese longline fishery in the Atlantic up to 2017 fishing year. ICCAT paper SCRS/2017/025.

McAllister M.K. 2014. A generalized Bayesian Surplus Production stock assessment software (BSP2). Collect. Vol. Sci. Pap. ICCAT, 70 (4):1725-1757.

Meyer, R., and Millar, R.B. 1999. BUGS in Bayesian stock assessments. Canadian Journal of Fisheries and Aquatic Sciences 56: 1078–1087.

Schirripa M. 2016. Building a management strategy evaluation for northern swordfish: part 1. Collect. Vol. Sci. Pap. ICCAT, 72(8): 2031-2041.

Schirripa M. 2017a. Simulation of Harvest Control Rules for North Atlantic swordfish utilizing a historic perspective. ICCAT presentation SCRS/P/2017/006.

Schirripa M. 2017b. North Atlantic Swordfish Stock Synthesis configuration v1.0. ICCAT presentation SCRS/P/2017/007.

Thorson, J.T., Cope, J.M., Branch, T.A., and Jensen, O.P. 2012. Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information. Can. J. Fish. Aquat. Sci. 69(9): 1556–1568. NRC Research Press. doi:10.1139/f2012-077.

Tserpes, G., E. Tzanatos, P. Peristeraki, V. Placenti, and L. T. Kell. 2009. A bio-economic evaluation of different management measures for the Mediterranean swordfish. Fisheries Research 96: 160-166.

Winker H, Carvalho F., Sharma R., Parker D., and Kerwath S. 2017. Initial stock assessment results for the North and South Atlantic shortfin mako (*Isurus oxyrinchus*) using a Bayesian Surplus Production Model and the Catch-Resilience method CMSY. ICCAT paper SCRS/2917/135.

Table 1. Task I nominal catches (t, landings and dead discards) by stock and major gear, between 1950 and 2016 (estimations for 2016 are preliminary).

	SWO-N					SWO-S				
	Longline		Other surf.		TOTAL	Longline		Other surf.		TOTAL
Year	Landings	Discards	Landings	Discards		Landings	Discards	Landings	Discards	
1950	1445		2201		3646			100		100
1951	966		1615		2581			200		200
1952	966		2027		2993			200		200
1953	1203		2100		3303			200		200
1954	305		2729		3034			100		100
1955	619		2883		3502			100		100
1956	374		2984		3358	1		0		1
1957	1010		3568		4578	124		100		224
1958	875		4029		4904	92		0		92
1959	1428		4804		6232	71		100		171
1960	1042		2786		3828	359		100		459
1961	2060		2321		4381	816		200		1016
1962	3202		2140		5342	769		0		769
1963	9193		997		10190	1418		0		1418
1964	10833		425		11258	2030		0		2030
1965	7759		893		8652	2578		0		2578
1966	8503		846		9349	1952		0		1952
1967	8679		428		9107	1577		0		1577
1968	8985		187		9172	2348		100		2448
1969	9003		200		9203	4281		200		4481
1970	9484		94		9578	5426				5426
1971	5243		23		5266	2164		2		2166
1972	4717		49		4766	2580				2580
1973	5929		145		6074	3078				3078
1974	6267		95		6362	2753				2753
1975	8778		61		8839	3062				3062
1976	6663		33		6696	2812		0		2812
1977	6370		39		6409	2840		15		2855
1978	11125		702		11827	2749		17		2766
1979	11177		760		11937	3265		29		3294
1980	12831		727		13558	5179		144		5323
1981	10549		631		11180	3938		37		3975
1982	13019		196		13215	6364		83		6447
1983	14023		504		14527	5307		95		5402
1984	12664		127		12791	8920		242		9162
1985	14240		143		14383	9224		362		9586
1986	18269		217		18486	4982		912		5894
1987	20026		212		20238	5797		233		6030
1988	18907		606		19513	12602		570		13172
1989	15315		1935		17250	16573		482		17055
1990	14027		1645		15672	16705		599		17304
1991	14233	215	486		14934	13496		397		13893
1992	14318	383	693		15394	13422		391		13813
1993	15670	408	660		16738	15739		391		16130
1994	14365	708	428		15501	17839		1119		18958
1995	15850	526	496		16872	21584		346		21930
1996	13819	562	815	26	15222	17859	1	429		18289
1997	12203	439	371	12	13025	18299	21	222		18542
1998	10961	476	778	9	12223	13748	10	269		14027
1999	10715	525	377	4	11622	14823	6	672		15502
2000	9921	1137	394	1	11453	15448	1	278		15728
2001	8676	896	433	6	10011	14302	0	825	0	15128
2002	8799	607	240	8	9654	13576	0	527		14104
2003	10333	618	486	5	11442	11712	0	920		12633
2004	11407	313	341	7	12068	12485	1	591		13077
2005	11528	323	512	10	12373	12915		248		13162
2006	10838	215	409	8	11470	13723		522		14245
2007	11475	273	546	8	12302	14967	91	572		15630
2008	10341	235	465	9	11050	11761	6	779		12546
2009	11439	151	485	7	12081	12106		741		12846
2010	10964	148	437	5	11553	11920	147	629		12697
2011	11610	392	511	9	12523	10833	74	547		11455
2012	12955	391	512	10	13868	10255	140	291	0	10686
2013	11344	199	526	0	12069	7889	0	322		8212
2014	10059	149	462	0	10670	9733	0	177		9910
2015	10135	148	386	0	10668	10014	0	263	0	10277
2016					11296					10002

Table 2. Catch-at-size matrix for the North Atlantic swordfish (*Xiphias gladius*) stock.

Li5cm (ll)	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
50	0	0	0	0	19	0	4	10	158	15	0	3	2	132	214	156	230	23	55
55	0	0	0	0	0	22	0	15	8	2	34	0	0	20	196	92	105	351	299
60	0	3	8	2	34	6	21	65	22	10	29	2	26	252	432	697	394	197	178
65	0	30	42	18	58	65	60	54	80	41	146	144	112	426	760	1254	597	1007	1786
70	2	58	234	52	209	89	213	184	240	303	600	254	366	695	1281	984	1258	1996	3660
75	103	201	452	438	450	406	575	493	1110	907	1684	740	974	1138	1216	2381	3215	2470	4290
80	430	360	644	643	852	729	954	1039	2920	3432	4576	1634	3037	1671	3879	4574	4113	3333	6998
85	191	593	1048	1012	1101	1543	1889	1834	6079	9482	10414	4274	6742	2713	2976	4091	6259	6412	11500
90	696	750	1993	1631	1718	2198	2361	2494	5223	9608	10662	5602	7195	3703	4493	5876	7019	4960	10512
95	792	1372	2744	2373	1757	3247	2905	3052	5811	10984	12221	8071	7500	6601	5350	9147	8483	7374	11583
100	852	1820	4797	2905	3850	4554	5106	5957	8837	12409	21426	15273	9425	8962	8744	12093	13239	11668	10806
105	2003	3105	6616	3704	6302	7946	7596	9246	12900	19511	23025	21634	13089	10904	9606	15468	13519	13774	10566
110	1872	2846	6462	3560	5092	8252	7261	9319	12623	18023	21951	19389	13565	10945	12480	16443	15542	14112	12705
115	2173	4171	7604	4931	6122	11521	9159	10097	16797	21148	31856	24351	20129	13492	14298	18126	21623	19441	18511
120	3395	5754	9015	7213	6850	10879	10940	12494	21181	24603	26071	24291	24431	16067	18367	21092	23813	23912	21386
125	3879	6196	9442	8443	6559	11550	10820	12567	20888	24114	26427	22796	25091	17389	19821	22131	22855	26589	23405
130	4226	5734	10601	8105	7012	11571	11878	13275	19809	25243	32514	24754	26709	20435	22628	25317	25561	32699	28060
135	5498	6855	11976	9419	9693	12163	13128	15164	20968	26236	27379	24195	24873	21919	22444	24743	23132	29015	25931
140	7153	6928	11508	10276	10139	12711	13968	16566	21911	27203	28763	23279	24568	23379	22812	26144	21479	26299	24677
145	8657	7810	12002	10168	11461	13262	13842	16318	21476	25107	25922	22219	22704	23529	20193	22509	20083	25270	22979
150	8199	8705	10709	9400	10471	13974	14124	17054	21352	26214	24989	21965	20293	24659	21094	23538	19357	22841	22453
155	9982	8701	11994	9878	11816	16132	14876	17714	22665	25519	23357	21193	19965	22135	19780	20679	18276	21543	20429
160	9706	8866	11983	10033	11905	15344	14242	17127	21170	22605	19540	18007	17156	17852	17752	17843	16205	19426	18751
165	11228	8605	10726	9136	11907	13279	12384	15210	19074	20943	18935	16047	14804	13958	14731	15675	14496	16179	14724
170	10250	10607	12067	10464	13287	15970	13298	14513	18149	20490	14823	15130	13642	13430	14667	14032	12173	12775	12685
175	9051	8882	10093	9174	11360	12363	11293	11961	15026	16500	19197	16162	11114	11173	10721	11676	11164	11101	10034
180	8749	8056	9504	8207	11427	12363	9320	10236	12886	12608	11884	10276	9700	9667	10301	9823	9175	9241	8082
185	9687	8284	9304	6849	8882	10461	8523	9298	10956	11699	8703	8237	7674	7320	8220	9491	7743	7720	5970
190	7872	7248	7339	5810	7724	8228	7193	7347	9217	9263	6584	6699	5944	6459	7100	7582	6187	6072	5063
195	6267	6527	6789	5264	5920	6538	5284	5680	6891	7039	6453	5257	4638	4509	4880	5404	5064	4756	4032
200	6095	5841	6544	4850	5320	5670	4581	4720	5969	5906	4445	4200	3846	4118	4395	4183	4169	3845	3785
205	4981	5217	4917	4176	4333	4552	3538	3976	4145	3416	4771	3958	2990	2699	3483	3307	3245	2941	2559
210	4384	4293	4423	3446	4534	3558	2708	3289	3289	3241	3114	2819	2155	2272	2356	2747	2579	2290	2065
215	2507	3584	3162	2737	3490	2776	2250	2595	2865	2241	2140	2003	1829	1611	1842	1919	1907	1963	1652
220	3420	3332	3189	2357	2623	2150	1622	1971	2483	2195	1787	1710	1466	1349	1784	1726	1512	1595	1195
225	2185	2579	2015	1723	1775	1565	1318	1239	1728	1788	1259	1380	975	905	1185	1130	1266	1181	1010
230	1938	2258	1548	1411	1519	1290	1002	991	1291	1084	1025	820	758	695	771	947	847	835	735
235	1382	1675	1476	1329	1223	1092	853	726	953	766	661	714	585	594	581	825	726	737	571
240	1245	1172	1100	894	842	793	655	601	669	654	483	482	395	487	565	622	523	633	445
245	672	968	846	643	767	499	371	405	587	390	319	450	359	301	352	325	401	435	326
250	623	709	492	475	515	392	375	272	415	485	220	288	208	219	223	236	300	296	290
255	277	474	379	313	510	250	193	207	304	223	172	194	189	146	226	192	202	269	204
260	239	212	153	161	264	183	104	147	179	195	94	165	117	101	140	179	126	225	104
265	130	109	135	175	234	90	66	125	128	125	69	180	102	50	112	106	334	169	79
270	113	83	110	76	140	53	38	63	123	91	67	131	89	103	105	68	72	144	63
275	98	11	87	58	111	18	23	40	72	69	61	59	30	44	36	84	43	110	35
280	112	8	14	3	33	14	22	47	66	35	45	29	53	39	35	26	25	76	34
285	22	20	2	11	84	1	15	35	34	42	17	29	18	22	11	29	26	76	10
290	20	13	0	7	66	8	9	13	18	37	22	58	23	11	32	29	13	51	4
295	2	14	0	14	24	1	19	2	20	10	7	8	4	10	14	41	8	39	3
300+	68	17	21	87	85	33	17	2	13	19	31	42	51	21	10	80	25	67	11
TOTAL	163426	171654	228311	184056	212470	262355	242994	277849	381780	454271	480971	401593	371707	331333	339696	387862	370704	400532	387291

Li5cm (ll)	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
50	50	25	25	76	18	0	12	1	0	1	1	0	463	39	5	13	51	20	7
55	44	2	0	1	7	27	22	0	20	0	2	3	215	3	3	7	40	67	23
60	195	510	219	493	66	401	0	0	39	11	3	22	277	374	137	847	580	414	266
65	760	794	640	730	35	51	25	4	4	4	4	13	197	61	17	42	193	151	22
70	2378	700	1367	2017	149	607	106	65	161	32	14	28	139	175	24	260	268	258	5
75	3905	1395	2834	1732	366	1543	834	130	656	119	27	90	261	171	81	266	403	510	28
80	5813	3411	3513	4279	1584	4728	1277	2103	3209	4866	1572	2604	1188	3920	2306	404	528	580	57
85	10847	3254	2390	2824	3119	2924	1765	1859	4970	1046	941	1179	1387	2141	1416	492	626	922	378
90	9924	5552	5249	7890	5220	4738	2801	3372	6647	4862	3697	1675	2856	2458	3151	1919	1842	3144	1428
95	13949	9819	10323	9401	7607	6073	5790	8157	7171	3881	8698	3717	5454	4638	7071	10542	3812	6451	2870
100	13291	8446	8296	7487	4636	4303	4014	4235	4416	5759	5974	2383	3464	3591	5466	3203	2299	3287	1742
105	13452	11858	11783	8147	4510	4902	4461	4114	4998	8127	9373	4924	6179	8935	12094	5851	4685	6805	5819
110	14786	13673	11078	11523	8783	7512	8131	9727	10366	10818	11227	10396	7481	7757	11109	12983	8673	8741	10692
115	16522	19393	16477	17878	12337	12868	15047	14235	15697	17365	18167	15968	13410	12771	18711	19978	12758	12112	12145
120	28806	25805	22060	23551	17449	17868	19946	20053	22731	23572	24262	21209	24111	16999	21078	28668	17320	13463	14018
125	20311	25679	22012	19643	18323	15593	21613	19108	20783	23052	23243	22883	25725	16279	18103	30151	21010	14171	11758
130	22244	25426	24806	25538	20849	18661	23353	22434	23058	24476	24757	21753	28441	23649	20294	31635	25677	16019	15439
135	18650	22051	20824	19303	16596	14983	20347	20680	20521	19367	20895	19600	22751	18785	17935	25878	22895	16038	14017
140	18203	19385	21492	21797	17455	16480	20073	19729	20229	19553	19781	16404	17964	21612	18975	17801	17987	14772	12969
145	16550	16032	17258	17182	13688	14224	17781	17170	16478	14767	17206	14284	16457	19039	16165	14802	15128	14754	11941
150	15666	15529	17456	16803	13510	14188	17761	17399	18173	14668	15820	13820	13928	12574	13556	14654	13563	12510	13059
155	16193	14157	14257	13246	10813	11056	14203	14248	13868	12396	13416	11434	11899	11872	12696	11625	11586	10986	11016
160	13508	12290	12136	12609	10031	10363	12184	13508	13905	12000	11615	9671	11024	11889	11113	10351	9811	11093	11093
165	10741	9984	9801	9483	8338	8205	9630	11511	10604	9113	9624	8980	9013	9071	10120	10407	8525	8452	8675
170	12458	9329	8042	7903	7381	7128	8261	9576	10115	8133	8442	7405	7534	7825	8567	8506	6920	6812	7658
175	7829	7159	6508	6848	6284	6153	7727	8553	8109	6292	7303	6034	6945	7662	7943	7633	5810	6782	6601
180	8117	5845	5087	5546	5966	5077	5704	6298	6811	5842	6795	5674	5809	5815	6946	6313	5736	5892	5368
185	5686	4974	4366	4268	4336	3819	4485	5155	5242	4592	5307	4509	5003	4951	5900	6130	5646	5084	5174
190	5213	4584	4081	3352	4395	3147	4112	4436	4590	4008	4846	4311	4190	4154	4926	5159	4335	4169	4042
195	3404	3324	2969	3215	3204	2503	3291	3687	3834	3267	3892	3717	4012	3383	4119	4650	3982	3715	3408
200	3230	2605	2311	2707	2258	2275	2451	2812	3044	2618	3101	2968	3193	3603	3565	4053	3423	2609	3262
205	2151	2022	2037	1826	2002	1580	1894	2416	2339	2370	2628	2461	2778	2480	3223	3429	3634	2298	2791
210	2082	1865	1723	1778	1384	1459	1958	2060	1868	2033	2242	2118	2368	2150	2434	3091	2496	2081	2586
215	1228	1316	1392	1175	1138	1095	1284	1406	1780	1523	1612	1629	1825	1744	2179	2450	2371	1524	2037
220	1299	1075	873	927	988	1178	1187	1257	1221	1225	1164	1319	1836	1308	1895	2176	1766	1710	1765
225	872	910	843	751	775	679	812	954	923	859	923	853	1084	1350	1330	1752	1375	1514	1514
230	602	676	720	662	687	1077	721	655	657	867	843	1135	985	924	1185	1280	1535	1277	1288
235	611	588	436	362	381	460	507	505	554	598	558	777	958	797	869	1103	1039	1052	745
240	432	391	361	359	368	508	406	464	420	466	580	637	572	692	739	810	925	807	828
245	261	353	266	251	302	283	323	358	370	286	388	354	482	395	563	644	680	585	571
250	200	324	322	206	184	217	229	240	335	314	260	292	332	265	413	443	523	432	421
255	180	177	153	200	111	173	177	244	193	239	158	238	265	205	268	392	384	338	433
260	125	110	90	86	127	158	108	160	214	176	130	241	201	187	219	246	290	270	310
265	96	58	73	71	63	129	86	108	74	140	102	119	122	117	86	183	238	123	131
270	76	86	31	67	64	54	57	79	49	70	39	55	103	73	84	104	140	109	126
275	45	30	28	34	35	45	44	34	30	82	33	76	73	77	60	73	60	37	76
280	29	18	21	10	34	26	14	54	42	19	41	72	24	30	29	37	71	24	41
285	7	9	6	9	12	10	17	16	8	17	48	29	32	14	26	10	20	23	31
290	9	6	7	7	19	7	5	15	7	2	10	8	11	12	16	12	24	13	18
295	10	2	6	1	2	3	1	11	3	5	1	2	2	1	1	6	10	1	18
300+	27	3	7	10	25	10	11	9	2	5	43	11	13	8	30	13	13	33	99
TOTAL	343067	313010	299055	296267	238015	231553	267050	275404	291537	275902	291806	250082	275034	259024	279238	313478	253703	225034	210810

Table 3. Catch-at-size matrix for the South Atlantic swordfish (*Xiphias gladius*) stock.

Li5cm	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
50	0	0	0	0	21	0	0	0	0	0	0	0	26	0	0	24	2	0	10	0	0	0	0	0	0	2	0	91	31	9	1	16	0	7	0	75	51	57
55	0	0	0	0	40	0	0	2	0	0	0	0	0	0	0	0	2	0	3	0	12	5	6	8	6	2	4	114	27	0	0	0	0	6	0	53	29	35
60	0	0	2	1	2	1	0	16	0	0	55	0	15	41	56	47	27	23	7	0	25	12	178	17	1	0	4	99	43	21	13	48	45	22	268	38	59	57
65	0	0	6	5	3	4	0	2	0	0	2	58	4	40	74	24	36	0	7	0	54	42	229	72	57	21	15	58	46	19	5	7	22	67	22	269	519	390
70	0	0	9	10	40	0	1	32	0	1	59	134	107	203	235	41	150	77	43	53	151	128	1254	144	147	80	177	239	330	200	169	123	133	366	319	818	1168	1290
75	10	0	18	21	14	13	22	53	3	4	15	216	391	235	310	138	194	789	91	190	168	180	1728	241	215	104	234	322	306	202	178	85	728	272	88	777	1180	680
80	17	8	18	26	175	52	107	92	10	8	1194	145	1081	320	1396	1479	1471	3313	548	513	440	533	1911	285	1856	187	1004	700	1971	1889	965	276	625	861	371	442	1143	1517
85	19	11	32	71	61	55	186	169	53	35	935	2012	924	994	850	2456	2707	2108	1407	462	520	614	3301	1232	1462	579	1384	1008	1519	603	1812	401	372	1197	642	543	482	1255
90	43	87	76	117	168	171	702	392	369	108	900	1506	1373	513	717	1063	2434	1912	1293	433	432	971	1656	909	710	331	1623	1562	1935	1770	2213	493	338	891	1093	617	358	526
95	34	68	20	73	76	57	479	293	269	177	1721	1309	753	405	1299	2586	2876	4240	7672	6758	4726	6175	7649	5890	5703	4803	2331	10526	8939	6113	6232	3042	1659	6431	3503	1394	1326	546
100	74	50	172	203	652	394	1243	1439	1317	519	1362	9447	1427	696	741	1435	2111	3172	1422	2259	1906	2340	3812	2238	1593	1575	2940	2706	4411	2506	4456	2668	1330	1722	1289	794	1181	1187
105	93	68	161	238	425	316	1346	1284	947	522	4779	5456	2516	2504	1354	2842	4431	6624	836	3541	1814	2131	3592	2181	2960	2668	4872	3133	6478	4388	6425	5157	1989	4011	1956	1593	1929	2836
110	147	275	249	312	998	577	1736	1910	1434	947	2228	8233	2740	2311	1539	2511	3226	4628	1823	3254	3794	4195	6658	4052	3271	2283	5061	4955	6725	6966	5661	4989	3780	4688	2808	2015	2109	3353
115	182	149	218	293	1732	938	2000	2510	1479	1298	7535	13752	4820	4597	3809	4470	7734	6509	3379	9329	5571	6471	9828	5696	7417	3081	6056	6787	7527	11455	5550	6201	5949	7530	4126	3743	3460	4826
120	350	271	521	1281	2878	2160	4143	4141	1927	2031	2094	6995	4946	3245	4859	4804	10064	14493	10383	10777	10387	12954	16867	17405	11375	6877	7158	12670	13058	17402	11668	12702	8274	9108	9592	6016	3584	4574
125	27	272	738	1199	2805	1625	2248	5416	3692	2963	4341	8845	5480	4033	5170	5816	10126	13135	14014	11445	13064	16047	20780	18785	11351	8271	7439	14603	11564	12866	10992	12307	9772	12386	8404	5912	4650	4145
130	305	470	634	1216	2260	2811	4419	4886	2973	2477	11600	16145	7960	8657	8177	7144	16841	20929	23899	18231	16255	18266	22419	21366	20740	15097	17621	14352	16434	17657	16018	18927	18480	15682	12362	9185	8005	12394
135	305	923	907	1611	6233	3536	6672	6536	3802	3126	6896	20521	12088	8533	9473	9440	16216	20234	19231	14885	16566	17880	21392	16138	15602	12024	12310	14326	14421	17926	13941	17420	12625	18975	10035	8401	6705	6574
140	267	994	1091	1395	2913	3086	5739	5678	4231	2978	9015	19658	16087	11156	11900	10815	21155	26931	26986	22334	21964	25063	26941	20047	23109	16839	20796	16578	20746	20121	18896	21229	14886	16245	10914	8908	10278	10995
145	337	1442	1840	1798	8200	5311	8873	8499	4450	4854	15382	21585	24736	19414	16809	18208	24156	30083	22600	22033	20866	22420	23974	16235	18554	15938	16607	16627	15869	19168	16316	21498	13066	17658	8775	9456	10373	12117
150	280	2585	1672	1961	4628	4184	6929	6804	4036	3854	10882	24851	18381	14312	21610	18149	21192	27709	24839	20519	20870	24212	28607	19846	18602	18934	18837	19019	22455	20152	19894	18362	15050	15723	11096	9849	9865	9722
155	338	1760	1643	1620	9991	4769	8377	8070	3889	3808	15682	18065	25796	23597	29828	22131	28547	28539	21605	22509	22241	19714	19651	14295	17891	17222	17448	15148	15422	18613	13554	15327	12930	14890	9863	8369	11011	10263
160	562	1826	2299	2016	6372	4338	7815	11406	5022	4447	17581	20153	21012	22238	27581	18162	25410	29711	23199	22599	18716	18318	20660	17398	15835	18866	19510	16923	18423	17771	14862	14893	19746	12674	9382	6904	12884	12707
165	491	1951	2974	2141	4151	3176	6783	9691	4908	4594	10562	19685	16484	18335	18925	13416	22681	27375	18388	21758	17264	18490	14393	12918	13750	15025	14689	12310	15136	15950	12008	12151	10923	11293	10016	6988	10252	9409
170	488	1869	3282	2538	5953	4049	10331	12378	5775	5137	8827	13597	18828	15673	12709	13396	13746	20959	20214	19132	15692	13106	12800	12258	13753	11810	11177	12253	14110	15756	12140	11432	9973	10062	8763	6333	9635	8420
175	858	1355	3379	2181	4344	4807	6284	10257	4667	4700	16347	32038	20765	14343	10326	13794	18676	20037	14428	18046	11889	13805	11669	8481	11124	10654	10141	10998	11438	14253	10158	8877	9162	8651	9384	5640	8073	8101
180	982	2559	2314	2603	5762	5561	8606	10029	4742	6047	9593	14731	20909	12149	11747	13915	14889	16772	17556	15419	9475	11205	9763	10524	10751	9786	9436	9790	9411	12994	9651	8265	8232	7826	6642	5860	7077	8881
185	1243	2119	3787	2747	5031	4867	6603	9172	5329	6176	12824	12354	11973	8354	8696	11849	12567	12800	9197	12048	7788	8166	7597	6880	7089	6386	6580	7700	6624	8182	6200	5860	5740	6201	7999	5211	5770	6353
190	1692	1635	5740	2400	5149	5360	7523	6567	3777	5524	9195	8628	8772	7504	8008	10644	10929	12498	12070	10067	6257	8609	8138	9151	7596	6043	7013	7123	7686	8658	6588	5096	8044	5046	5256	3968	5227	5364
195	2849	2402	7305	2333	4092	4924	5305	5321	3385	6040	9593	7865	7027	6608	6879	9433	9817	9722	7352	8350	4762	6068	5600	5509	5281	4779	5175	5532	4904	5940	4764	4623	4341	4146	6095	3389	3882	5226
200	2771	2360	5845	2099	3098	3538	5526	3791	3115	4703	6574	5837	9569	4874	4343	8740	7293	7067	7626	6287	3943	4766	5335	6083	5387	6503	3905	4174	4963	5958	4639	4169	4515	3088	3425	2784	4456	4777
205	1460	1553	4704	2195	2631	2437	4212	2766	3481	2117	4327	4880	3142	2514	4099	5977	4658	4820	3858	4511	2873	3574	3489	3705	3148	2574	2428	2938	2878	3752	2186	2433	2342	2143	3255	2366	2631	3390
210	1596	1875	2727	1380	2257	2013	3361	2533	1520	1962	4316	3770	3836	2941	3011	5531	4859	5573	4769	4596	2714	2645	3149	3070	3015	2311	2511	2428	3471	3236	2595	3231	2430	2101	1672	2356	2408	2324
215	586	1320	1662	1745	1295	877	2299	1762	1912	554	3072	1526	1743	1790	1937	3440	3956	3527	2201	3290	1874	2622	2063	2265	1929	1702	1857	1910	1977	2298	1728	2295	1601	1718	2250	1963	1963	2468
220	1772	2310	1748	1689	1512	1203	2225	1892	1638	1298	2118	1581	2771	1562	1461	5020	2840	3696	2707	2332	1472	2066	1891	2801	2138	2404	2070	1848	2095	2015	1897	2243	2953	1514	1612	1560	1793	2227
225	848	1598	617	968	693	285	1253	689	949	643	930	576	359	731	1097	703	1812	2349	1802	2059	1196	1447	1520	1998	1119	1595	1306	1317	1172	1380	1087	1342	899	1203	1197	1489	1490	1385
230	990	556	837	825	740	509	791	820	414	525	1186	488	539	641	652	1010	1329	1579	1190	2026	1108	1206	1339	1336	931	839	1026	1290	1682	1193	1394	1222	831	926	984	1030	1430	1176
235	755	459	478	955	513	379	992	517	822	771	539	400	1021	648	605	1490	879	1576	838	1444	805	749	697	1207	675	517	656	545	676	915	840	904	615	699	1139	804	1168	812
240	536	101	263	484	174	112	450	439	268	247	496	325	604	483	180	1153	817	790	870	1120	565	565	543	845	734	596	726	759	862	847	758	806	1679	747	855	1019	649	507
245	447	34	135	674	299	126	390	257	143	86	299	298	1183	397	133	675	534	551	720	841	308	545	389	932	721	424	536	454	555	356	402	539	338	492	529	429	547	432
250	153	121	48	256	143	92	182	147	175	110	184	34	309	169	184	234	437	416	445	543	425	451	304	841	685	254	861	414	530	629	522	245	1292	432	228	426	386	334
255	224	251	102	252	199	129	212	302	133	218	287	142	777	40	60	319	260	457	144	369	189	153	193	269	257	117	228	422	333	372	165	167	336	257	430	252	327	311
260	94	15	18	191	48	45	50	128	60	111	27	23	162	60	138	160	205	286	346	184	173	139	106	737	563	193	219	174	390	144	134	175	610	173	233	279	356	270
265	213	6	11	91	22	62	65	32	109	114	40	55	450	81	66	130	221	191	88	46	138	86	57	133	102	60	92	319	135	199	92	163	79	255	593	192	212	179
270	248	5	14	133	38	12	36	102	91	2	2	31	142	71	109	39	158	63	124	236	84	60	64	213	64	126	203	91	292	134	50	289	1030	143	57	86	92	62
275	5	4	32	33	18	0	69	201	2	6	7	63	208	34	31	94	57	191	41	37	56	60	58	108	117	26	91	71	333	129	99	79	57	43	313	147	174	136
280	5	1	4	6	36	17	8	7	30	2	23	13	34	56	4	3	43	107	57	59	13	37	8	240	30	17	125	112	92	92	49	41	365	156	66	141	130	113
285	9	1	13	3	0	0	8	74	28	0	0	2	48	55	4	66	51	22	10	12	5	15	13	54	35	46	107	83	18	24	55	23	4	31	12	56	98	91
290	0	4	7	4	16	0	0	75	3	8	22	13	196	141	2	5	24	12	49	2	2	90	8	139	28	14	40	24	72	100	30	12	257	29	18	10	33	22
295	2	0	1	1	3	0	0	46	35	2	1	11	36	349	2	5	10	9	29	2	16	17	6	23	18	11	20	25	7	4	4	8	20	10	25	1	149	12
300+	7	4	2	30	33	0	54	86	14	4	19	21	181	1031	4	15	121	108	24	54	69	106	4	507	117	100	73	72	45	21	112	150	414	61	510	28	15	8
TOTAL	24713	37727	60376	46422	98933	78977	136660	149709	87429	85862	215668	328071	284736	229681	243201	255039	334975	398714	332441	326995	271698	299522	334288	277705	269616	230700	246725	257721	280569	303347	250165	253006	220879	230859	180469	140976	162774	174836

Table 4. Standardized swordfish CPUE indices selected to be considered in the North Atlantic stock assessment.

series	Canada LL old		Canada LL smooth		Canada LL Revised		EU-Portugal LL		EU-Spain LL		EU-Spain LL - Age 1		EU-Spain LL - Age 2		EU-Spain LL - Age 3		EU-Spain LL - Age 4		EU-Spain LL - Age 5+		Japan LL historic		Japan LL time 2		Japan LL time 3		USA LL Revised		USA Larval		Morocco LL		Chinese Taipei LL time 1		Chinese Taipei LL time 2		Chinese Taipei LL time 3		Combined - Base case	
Use in 2017 stock assessment	NO		NO		YES		YES		YES		YES		YES		YES		YES		YES		YES		YES		YES		YES		NO		YES		NO		NO		NO		YES	
age											1		2		3		4		5+																					
units of index	count		count		count		weight		weight		weight		weight		weight		weight		weight		weight		weight		weight		count		count		weight		count		count		count		weight	
area	NW ATL		NW ATL		NW ATL		NE Atl		NE Atl		NE Atl		NE Atl		NE Atl		NE Atl		NE Atl		Northwest Atlantic		Northwest Atlantic		Northwest Atlantic		Northwest Atlantic		Gulf of Mexico		SE Atl off Morocco		North Atlantic		North Atlantic		North Atlantic		North Atlantic	
method	GLMM		GAM-NB		GAM-NB		GLMM - lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM – lognormal		GLM-NB		GLM-ZIB		GLM-lognormal		GLM-lognormal(+const)		GLM-lognormal(+const)		GLM-lognormal(+const)		GLM-delta-lognormal	
time of the year	Mar to Dec		Mar to Dec		Mar to Dec		All months		All quarters		All quarters		All quarters		All quarters		All quarters		All quarters		All quarters		All quarters		All quarters		All months		April-May		All months		All months		All months		All months		All months	
source	SCRS/2013/059		SCRS/2017/064		SCRS/2017/064_rev		SCRS/2017/053		SCRS/2017/105		SCRS/2017/107		SCRS/2017/107		SCRS/2017/107		SCRS/2017/107		SCRS/2017/107		SCRS/2017/075		SCRS/2017/075_rev		SCRS/2017/075_rev		SCRS/2017/075_rev		SCRS/2017/074		SCRS/2017/063		SCRS/2017/144		SCRS/2017/144		SCRS/2017/144		SCRS/2017/137	
Year	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV
1961																																								
1962			112.832	0.075	109.27	0.19																																		
1963	2.021802	12.7213	85.863	0.065	201.92	0.07																																	1164.2	0.3533291
1964	0.947101	9.2871	66.555	0.058	79.73	0.06																																	409.4	0.349197091
1965	0.709528	8.6203	53.705	0.054	55.55	0.06																																	252.7	0.348434019
1966	0.723401	8.2421	45.959	0.052	58.74	0.05																																	255.1	0.347718556
1967	0.853628	8.3164	42.087	0.053	78.04	0.05																																	299.1	0.347194316
1968	0.616087	8.7741	41.11	0.054	54.03	0.05																													0.168	9.908					238.3	0.351484946
1969	0.588066	8.5733	42.264	0.055	51.12	0.05																													0.221	7.999					217.2	0.347451078
1970	0.720468	8.3425	44.895	0.058	65.66	0.05																													0.164	6.606					246.9	0.347836661
1971			48.503	0.06																													0.212	7.367						
1972			52.852	0.064																													0.217	10.286						
1973			57.71	0.067																													0.221	10.085						
1974			62.734	0.07																			27.5301	0.086											0.191	7.892						
1975			67.451	0.073																			18.7565	0.055											0.127	8.235					433.4	0.318711162
1976			71.266	0.075																			20.5882	0.072											0.058	7.823					354.6	0.319006343
1977			73.511	0.075																			5.1727	0.077											0.058	7.414					409.4	0.320319867
1978			73.548	0.073																			5.1105	0.063											0.069	8.55					467.2	0.286652939
1979	0.851114	13.4044	70.91	0.07	94.62	0.1															6.2764	0.054											0.069	11.093					357.9	0.197668148
1980	0.833899	10.6192	65.686	0.065	81.66	0.07															7.043	0.042											0.126	9.283					359	0.196853189
1981	0.721771	12.9569	59.241	0.061	85.02	0.1															9.9073	0.067											0.137	8.286					329.7	0.204171498
1982	0.622022	14.8502	53.329	0.059	66.7	0.1					0.227	0.209	0.884	1.535	0.767	0.731	1.242	1.110	1.569	0.537	8.489	0.069							0.15	0.28			0.117	7.81					321.5	0.177994069
1983	0.45361	13.2441	49.193	0.06	57.93	0.11					0.317	0.210	0.772	0.663	0.887	1.242	1.048	5.258	1.220	0.995	11.3197	0.074							0.04	0.52			0.117	7.474					258	0.175905046
1984	0.359984	12.8202	47.371	0.062	57.23	0.11					0.315	0.209	0.632	0.382	0.868	1.069	1.063	3.608	1.302	0.726	11.4093	0.066							0.04	0.71			0.086	6.776					232.7	0.170207168
1985	0.554422	14.4622	47.856	0.063	67.85	0.1					0.308	0.201	0.891	1.359	0.947	2.419	1.089	2.358	1.205	1.042	11.9203	0.059											0.073	6.599					266.3	0.167614479
1986	0.677919	15.5152	50.207	0.063	112.51	0.11			260.618	0.016	0.446	0.282	1.091	2.449	1.009	40.050	0.987	6.108	1.048	5.535	7.2491	0.062							0.03	0.72			0.084	6.565					258.9	0.167448078
1987	0.39539	14.6983	53.513	0.062	80.25	0.1			248.251	0.016	0.695	0.611	1.653	0.368	1.302	0.654	1.127	1.591	1.097	2.331	9.1233	0.065							0.00				0.081	8.901					209.2	0.167112928
1988	0.460263	13.7489	56.399	0.061	77.46	0.1			211.431	0.017	0.850	1.226	1.381	0.564	1.099	1.955	0.929	1.874	0.919	1.747	10.1965	0.060							0.00				0.062	17.851					218	0.166094926
1989	0.403304	12.6571	57.393	0.059	73.07	0.09			213.384	0.016	0.734	0.693	1.642	0.362	1.016	53.233	0.884	1.197	0.871	1.136	8.5092	0.059							0.08	0.36			0.056	20.8					189.4	0.159011319
1990	0.702762	13.3607	55.642	0.057	105.1	0.09			213.613	0.016	0.394	0.244	1.787	0.308	1.328	0.589	0.900	1.370	0.826	0.840	5.2557	0.061							0.04	0.43					0.185	14.839			214.2	0.157815962
1991	0.398924	11.1455	51.455	0.053	70.71	0.06			217.388	0.016	0.364	0.224	1.357	0.599	1.433	0.458	1.078	2.644	0.941	2.281	3.8598	0.069							0.11	0.30					0.134	9.633			215.2	0.156259015
1992	0.437623	10.9598	46.105	0.049	83.75	0.06			213.590	0.016	0.398	0.245	1.315	0.668	1.293	0.650	1.105	1.872	1.064	3.680	3.9965	0.076					0.99	0.09	0.03	0.51					0.274	13.758			179.3	0.157470754
1993	0.444564	9.6796	41.08	0.046	70.63	0.05			188.931	0.017	0.486	0.311	1.297	0.706	1.107	1.795	0.884	1.189	0.900	1.442	4.3247	0.087					0.94	0.08	0.02	0.52					0.181	11.862			175.4	0.156551901
1994	0.360857	9.1662	37.461	0.044	51.84	0.04			180.793	0.017	0.483	0.307	1.413	0.523	0.946	2.331	0.749	0.536	0.746	0.559	1.9829	0.162					0.97	0.08	0.04	0.40					0.148	8.827			144.6	0.164196042
1995	0.347262	9.5532	35.8	0.043	64.4	0.04			199.415	0.016	0.514	0.333	1.802	0.299	1.290	0.651	0.858	0.969	0.782	0.657	1.2971	0.149					0.96	0.08	0.05	0.34					0.155	9.166			156.9	0.159553061
1996	0.233978	10.1905	36.291	0.043	39.37	0.05			169.367	0.017	0.512	0.331	1.160	1.286	0.961	3.027	0.698	0.433	0.634	0.365	1.6313	0.121					0.80	0.09	0.05	0.40					0.256	7.928			117.3	0.161530282
1997	0.414612	9.3266	38.914	0.044	56.1	0.05			168.786	0.017	1.075	5.077	1.361	0.589	0.781	0.611	0.590	0.300	0.522	0.259	2.7716	0.102					0.95	0.09	0.08	0.33							0.176	10.772	132.3	0.153524369
1998	0.56583	9.8046	43.413	0.044	78.32	0.05			184.014	0.017	0.929	2.297	1.908	0.274	0.818	0.743	0.540	0.258	0.526	0.263	2.7845	0.081					1.38	0.09	0.05	0.40							0.164	12.584	153.2	0.153954241
1999	0.729512	9.3695	49.124	0.045	104.47	0.05	217.6	0.13	207.825	0.016	1.112	2.957	2.240	0.220	1.180	1.048	0.624	0.338	0.440	0.208							1.29	0.09	0.10	0.26							0.063	8.265	166.9	0.152776074
2000	0.425672	9.5099	54.881	0.046	77.58	0.05	308.5	0.16	256.514	0.016	1.117	2.822	2.627	0.184	1.499	0.409	0.888	1.236	0.763	0.611							0.99	0.09	0.08	0.30							0.071	10.729	167.3	0.159600576
2001	0.525499	9.8325	59.271	0.046	89.67	0.05	323.3	0.16	222.245	0.017	1.162	1.908	2.480	0.195	1.378	0.520	0.709	0.459	0.587	0.318							0.88	0.09	0.08	0.34							0.082	9.377	171.9	0.174683114
2002	0.542629	10.5928	61.288	0.046	134.23	0.06	281.9	0.14	193.003	0.016	0.844	1.189	1.919	0.274	1.215	0.879	0.716	0.471	0.636	0.373							1.08	0.09	0.02	0.60							0.089	7.943	181.5	0.172734049
2003	0.88916	10.8315	60.908	0.046	94.73	0.05	328.9	0.14	218.935	0.016	0.831	1.109	2.053	0.250	1.352	0.561	0.853	0.957	0.725	0.521							0.94	0.08	0.06	0.39							0.076	8.821	185.8	0.171283972
2004	0.88329	9.6144	59.067	0.046	88.85	0.05	395.9	0.14	200.237	0.016	0.932	2.428	1.545	0.425	0.941	2.212	0.666	0.397	0.589	0.326							0.81	0.08	0.04	0.52							0.048	7.126	149	0.155101914
2005	0.935406	9.4047	57.094	0.047	106.22	0.05	305.2	0.12	196.070	0.016	0.967	3.865	2.123	0.247	1.049	4.929	0.553	0.281	0.570	0.314							1.16	0.08	0.05	0.35	558.30	0.06					0.064	7.193	134.2	0.155455945
2006	0.972183	9.991	56.125	0.047	92.8	0.05	301.2	0.12	181.629	0.017	1.264	1.238	1.943	0.289	0.893	1.341	0.514	0.258	0.548	0.303			4.74	0.31			1.08	0.08	0.06	0.33	277.40	0.05					0.112	7.267	137.4	0.158423459
2007	1.019434	10.3131	56.811	0.048	86.94	0.06	329.4	0.12	209.764	0.016	1.593	0.619	2.475	0.224	1.048	6.043	0.498	0.260	0.803	0.833			5.823	0.376322605			1.347	0.081	0.0828	0.3321	227.1	0.07					0.064	8.778	177.7	0.156988436
2008	1.357214	10.5894	59.251	0.048	110.49	0.06	305.1	0.12	242.613	0.016	1.356	0.970	3.366	0.162	1.256	0.840	0.567	0.313	0.732	0.586			9.318	0.295565747			1.249	0.08	0.06061	0.34339	294.3	0.06					0.043	8.918	201.8	0.156463954
2009	1.184244	10.6163	62.936	0.048	96.25	0.06	365.6	0.12	222.930	0.016	0.645	0.556	2.574	0.209	1.475	0.479	0.743	0.583	0.792	0.772			18.956	0.274965441			1.035	0.079	0.01017	1.01938	294.7	0.06					0.052	9.404	215.6	0.157553387
2010	1.403108	11.5769	66.703	0.049	137.25	0.06	416.4	0.12	221.276	0.016	0.631	0.512	2.301	0.228	1.128	1.615	0.487	0.238	0.524	0.282			18.937	0.259022128			0.736	0.08	0.02037	1.00408	450.5	0.05					0.039	8.592	224.1	0.156844922
2011	1.132747	10.5902	68.923	0.05	100.51	0.06	357.0	0.11	227.707	0.016	0.975	4.433	1.585	0.429	0.920	1.765	0.614	0.355	0.696	0.500					26.051	0.273854504	1.011	0.081	0.02703	0.59757	314.4	0.05					0.091	8.585	218.7	0.158378872
2012	1.154961	10.79	68.131	0.05	108.48	0.06	487.2	0.12	237.277	0.016	0.844	1.333	1.843	0.341	1.012	31.217	0.690	0.496	0.933	2.258					21.305	0.313713845	1.025	0.08	0.091	0.40138	331.4	0.05					0.101	9.647	241.9	0.157409649
2013			63.861	0.049	105.22	0.06	457.2	0.13	228.416	0.016	0.377	0.282	1.228	1.144	0.618	0.388	0.394	0.210	0.551	0.344					7.574	0.38261938	0.92	0.079	0.04512	0.46813	362.9	0.05					0.069	10.175	158.8	0.159084333
2014			56.961	0.048	84.92	0.05	426.2	0.11	210.977	0.016	0.583	0.535	1.795	0.394	1.226	1.087	1.138	1.922	1.276	1.003					11.709	0.319002825	0.719	0.08	0.04562	0.59587	273.4	0.05					0.075	11.648	188.2	0.159728964
2015			49.038	0.05	88.35	0.05	583.3	0.12	217.127	0.016	0.645	0.582	2.782	0.203	1.670	0.378	1.106	2.331	1.331	0.765					20.417	0.30584257	0.733	0.08	0.04217	0.39044	304.9	0.05					0.073	8.835	177.4	0.159980629
2016			41.519	0.054	65.27	0.05	551.6	0.14																							357.7	0.06								

Table 5. Standardized swordfish CPUE indices selected to be considered in the South Atlantic stock assessment.

series	BRA-LL - Old		BRA-LL - Recent		EU-Spain LL - time 1		EU-Spain LL - time 2		Japan LL - time 1		Japan LL - time 2		Uruguay LL		South Africa LL		Chinese Taipei LL 1		Chinese Taipei LL 2		Chinese Taipei LL 3	
Use in 2017 stock assessment	NO		YES		YES		YES		YES		YES		YES		YES		NO		NO		NO	
age																						
units of index	count		count		weight		weight		count		count		count		weight		count		count		count	
area	SW Atlantic		SW Atlantic		S Atl		S Atl		S Atlantic		S Atlantic		SW Atlantic		SE Atlantic		S Atlantic		S Atlantic		S Atlantic	
method	GLM – NB		GLM – NB		GLM – lognormal		GLM – lognormal		GLM-lognormal		GLM-lognormal		GLM-delta-lognormal		GAMM-Tweedie		lognormal(+const)		lognormal(+const)		lognormal(+const)	
time of the year	all months		all months		All quarters		All quarters		All months		All months		All months		All months		All months		All months		All months	
source	SCRS/2017/068		SCRS/2017/068		SCRS/2017/106		SCRS/2017/106		SCRS/2017/075_rev		SCRS/2017/075_rev		SCRS/2017/078		SCRS/2017/138		SCRS/2017/145		SCRS/2017/145		SCRS/2017/145	
Year	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV			Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV	Std. CPUE	CV
1968																	0.311	7.492				
1969																	0.270	5.357				
1970																	0.262	4.995				
1971																	0.282	5.435				
1972																	0.241	5.546				
1973																	0.267	7.215				
1974																	0.236	5.915				
1975																	0.222	6.312				
1976																	0.117	5.848				
1977																	0.121	5.350				
1978	2.9494	0.2254															0.144	5.143				
1979	2.4268	0.2224															0.187	6.052				
1980	4.0450	0.2231															0.182	5.309				
1981	5.7217	0.2294															0.175	5.168				
1982	6.2309	0.2402															0.142	4.936				
1983	3.6204	0.2268															0.149	6.171				
1984	2.3361	0.1625															0.186	6.829				
1985	2.9703	0.2216															0.126	5.827				
1986	3.7012	0.2183															0.124	5.248				
1987	6.4285	0.3042															0.146	5.339				
1988	3.1920	0.1912															0.170	7.238				
1989	1.9056	0.2042			535.9100	0.0083											0.189	7.328				
1990	4.1683	0.2660			403.9090	0.0060			2.6770	0.0135							0.175	6.252				
1991	3.8570	0.2274			390.4670	0.0056			1.6100	0.0155									0.320	6.147		
1992	3.8068	0.2751			354.7610	0.0051			1.3280	0.0173									0.380	7.460		
1993	1.6782	0.3006			307.8310	0.0044			1.2990	0.0169									0.246	5.872		
1994	3.1031	0.2626			352.4050	0.0045			1.4840	0.0151									0.356	5.507		
1995	5.2806	0.3696			402.1940	0.0043			1.0740	0.0162									0.251	4.889		
1996	6.3446	0.2609			362.5810	0.0042			1.0900	0.0169									0.290	4.520		
1997	4.1544	0.2040			340.0350	0.0037			0.9610	0.0202									0.202	4.467		
1998	2.6688	0.1886			331.4220	0.0041			0.9420	0.0217											0.167	6.041
1999	3.5965	0.1895			356.2450	0.0042			0.8010	0.0223											0.126	4.721
2000	4.9840	0.1915					430.2240	0.0044	0.5760	0.0239											0.139	4.492
2001	2.1907	0.2023					380.5380	0.0039	0.4760	0.0289			6.4700								0.120	4.079
2002	4.0703	0.2090					364.0410	0.0040	0.6010	0.0306			4.1300	0.7600							0.118	3.765
2003	7.2621	0.2877					319.5660	0.0045	0.5150	0.0238			6.1700	0.4300							0.112	4.173
2004	6.9652	0.2492					314.0200	0.0057	0.5510	0.0231			5.2200	0.4200	401.0270	0.0800					0.088	3.451
2005			0.8605	0.0954			378.8940	0.0054	0.4440	0.0333			5.2100	0.4300	381.0010	0.0780					0.082	3.552
2006			1.2962	0.1179			382.6130	0.0052			0.7830	0.0267	5.5000	0.3400	304.3550	0.0750					0.115	4.032
2007			1.9030	0.1442			369.4360	0.0054			1.0410	0.0353	4.9600	0.3900	328.6740	0.0720					0.092	3.746
2008			1.2108	0.1133			356.2770	0.0049			0.9290	0.0308	3.2300	0.4400	268.1860	0.0780					0.105	4.001
2009			1.2607	0.1054			389.4490	0.0046			1.0380	0.0290	3.5100	0.4100	254.1120	0.0730					0.084	3.849
2010			1.4001	0.1156			379.4790	0.0048			0.9550	0.0294	3.2900	0.4500	284.7520	0.0760					0.071	3.962
2011			1.1468	0.1248			367.4800	0.0047			0.7970	0.0288	2.0000	0.4300	226.2490	0.0790					0.076	3.662
2012			1.1365	0.1099			392.3460	0.0051			1.0380	0.0364	5.0800	0.4700	212.3880	0.0880					0.073	3.929
2013							393.1160	0.0053			0.9760	0.0288			289.2010	0.0750					0.093	4.156
2014							412.8170	0.0054			1.0060	0.0482			273.6220	0.0750					0.078	4.226
2015							447.3950	0.0055			1.0070	0.0365			304.2400	0.0720					0.087	4.446
2016																						

Table 6. Model runs for BSP2 in the North Atlantic. * indicates base case.

Run	Process error	K prior uniform on:	Indices	Weighting	Bmsy/K	rprior	Diagnostics
N1	0.05	log(K)	separate	equal	0.5	base	retrospective, drop index
N2	0.05	log(K)	separate	equal	0.4	base	
N3	0.05	log(K)	separate	equal	0.6	base	
N4	0.05	log(K)	separate	equal	0.5	logsd=1	
N5	0.05	log(K)	PMPD	NA	0.5	base	
N6*	0.05	log(K)	combined	equal	0.5	base	retrospective
N7	0.05	log(K)	combined	equal	0.5	base	
N8	0.05	log(K)	separate plusChT	equal	0.5	base	
N9	0.05	log(K)	separate	iterative	0.5	base	
N10	0.05	log(K)	combined	equal	0.4	base	retrospective
N11	0.05	log(K)	combined	equal	0.6	base	
N12	0.05	log(K)	Separate, Split Canada	iterative	0.5	base	
N13	0.05	log(K)	combined	added var	0.5	base	

Table 7. Model runs for BSP2 in the South Atlantic. * indicates base case.

Run	Process error	K prior	Indices	Weighting	Bmsy/K	rprior	Diagnostics
S1	0.1	log(K)	Br1, Br2, Esp,Uru,SAf	equal	0.5	base	retrospective, drop index
S2	0.1	log(K)	Br1, Br2, Esp,Uru,SAf	equal	0.4	base	
S3	0.1	log(K)	Br1, Br2, Esp,Uru,SAf	equal	0.6	base	
S4	0.1	log(K)	Br1, Br2, Esp,Uru,SAf	equal	0.5	logsd=1	
S5	0.1	log(K)	PMPD	NA	0.5	base	
S6	0.1	log(K)	Br1, Br2, Esp,Uru,SAf	equal	0.5	base	
S7	0.1	log(K)	Br1, Br2, Esp,Uru,SAf	iterative	0.5	base	
S8	0.1	log(K)	Br1, Br2, Esp, Uru, SAf, ChT	equal	0.5	base	
S9	0.1	lognormal	Br2, Esp,Uru,SAf	equal	0.5	base	
S10 *	0.1	log(K)	Br2, Esp1, Esp2, Uru,SAf, JLL1, JLL2	equal	0.5	base	retrospective
S11	0.1	log(K)	Br2, Esp, Uru,SAf, JLL1,JLL2	equal	0.5	base	
S12	0.05	log(K)	Br2, Esp1, Esp2, Uru,SAf, JLL1, JLL2	equal	0.5	base	
S13	0.1	log(K)	Br2, Esp1,Esp2,Uru,SAf, JLL1,JLL2	equal	0.4	base	

Table 8. Summary of sensitivity runs from JABBA for various combinations of swordfish CPUE indices for the South Atlantic.

Run	Description CPUE series combination
Base-case	Scenario 3: Split EU-Spain (1999/2000) and Japan (2005/2006) excl. Brazil historical
Comb.EU.ESP	As Base-Case but with Spain CPUE re-combined
Comb.JPN	As Base-Case but with Japanese CPUE re-combined
+ BRA1	As Base-Case but with historical Brazil CPUE added
+ TAI	As Base-Case but with Chinese Taipei CPUE added
- BRA2	As Base-Case but with Brazil-recent CPUE dropped
- EU.ESP1	As Base-Case but with Spain CPUE (1989-1999) dropped
- EU.ESP2	As Base-Case but with Spain CPUE (2000-2015) dropped
- JPN1	As Base-Case but with Japan CPUE (1989-2005) dropped
- JPN2	As Base-Case but with Japan CPUE (2006-2016) dropped
- URY	As Base-Case but with Uruguay CPUE dropped
- ZAF	As Base-Case but with ZAF CPUE dropped

Table 9. Parameter estimates from the surplus production model (ASPIC) for the 1963–2015 catch and CPUE (combined biomass index) data for different assumptions regarding the underlying function of the surplus model.

Parameter	Fox	Generalized Pella Tolimson	Logistic Schaefer
power	1.0001	0.915989	2
B1/K	1.018714	1.017495	2.999998
MSY	13.09124	13.11864	13.3252
F_{MSY}	0.219708	0.226635	0.192553
B_{MSY}	59.58464	57.88437	69.20287
K	161.9678	164.5089	138.4058
r	NA	NA	0.385106
phi	0.367879	0.351862	0.5
q.01	0.011064	0.011002	0.011732
B/B_{MSY}	1.253558	1.293425	1.046453
F/F_{MSY}	0.659021	0.637136	0.778897
Yield/eq	12.7022	12.64907	13.29645

Table 10. Summary statistics for final base case BSP2 model for the North Atlantic.

Variable	Mean	Median	CV
K (1000)	165.01	159.88	0.26
r	0.35	0.34	0.25
MSY (1000)	13.44	13.41	0.06
B_{2015} (1000)	81.44	78.53	0.27
B_{1950} (1000)	148.97	139.90	0.37
B_{2015}/B_{1950}	0.58	0.56	0.27
C_{2015}/MSY	0.80	0.80	0.06
B_{2015}/B_{MSY}	0.99	0.98	0.12
F_{2015}/F_{MSY}	0.82	0.81	0.15

Table 11. BSP2 means and CVs (in parenthesis) for sensitivity analyses in the North Atlantic (model N8 did not converge). *indicates the final base case.

Variable	N1	N2	N3	N4	N5	N6*	N7	N9	N10	N11	N12	N13
K (1000)	353.0 (0.5)	352.3 (0.5)	352.5 (0.5)	421.0 (0.5)	415.7 (0.5)	165.3 (0.25)	175.3 (0.27)	386.3 (0.5)	166.5 (0.25)	166.6 (0.25)	294.9 (0.5)	168.3 (0.25)
r	0.4 (0.3)	0.4 (0.3)	0.4 (0.3)	0.3 (0.5)	0.4 (0.4)	0.3 (0.25)	0.3 (0.26)	0.4 (0.3)	0.3 (0.24)	0.3 (0.24)	0.3 (0.3)	0.3 (0.25)
MSY (1000)	31.2 (0.6)	24.9 (0.6)	52.7 (0.6)	28.9 (0.6)	44.1 (0.6)	13.4 (0.06)	13.4 (0.06)	33.9 (0.5)	10.8 (0.06)	22.7 (0.06)	24.5 (0.5)	13.5 (0.06)
B_{2017} (1000)	317.1 (0.6)	316.4 (0.6)	316.5 (0.6)	370.6 (0.6)	379.1 (0.6)	85.1 (0.27)	90.0 (0.29)	345.2 (0.6)	85.8 (0.27)	85.8 (0.27)	244.8 (0.6)	87.1 (0.28)
B_{1950} (1000)	310.5 (0.6)	309.1 (0.6)	309.1 (0.6)	369.1 (0.5)	360.0 (0.6)	148.9 (0.36)	158.2 (0.37)	346.4 (0.5)	153.5 (0.37)	153.5 (0.37)	269.6 (0.5)	149.6 (0.35)
B_{2017}/B_{1950}	1.0 (0.3)	1.0 (0.3)	1.0 (0.3)	1.0 (0.3)	1.0 (0.3)	0.6 (0.28)	0.6 (0.27)	1.0 (0.3)	0.6 (0.29)	0.6 (0.29)	0.9 (0.3)	0.6 (0.26)
C_{2017}/MSY	0.4 (0.4)	0.5 (0.4)	0.3 (0.4)	0.5 (0.4)	0.4 (0.5)	0.8 (0.06)	0.8 (0.06)	0.4 (0.4)	1.0 (0.06)	0.5 (0.06)	0.5 (0.4)	0.8 (0.06)
B_{2017}/B_{MSY}	1.7 (0.1)	2.2 (0.1)	1.4 (0.1)	1.7 (0.1)	1.8 (0.1)	1.0 (0.15)	1.0 (0.15)	1.7 (0.1)	1.3 (0.15)	0.9 (0.15)	1.6 (0.2)	1.0 (0.14)
F_{2017}/F_{MSY}	0.3 (0.5)	0.3 (0.5)	0.2 (0.5)	0.3 (0.5)	0.2 (1.0)	0.8 (0.19)	0.8 (0.19)	0.2 (0.5)	0.8 (0.18)	0.6 (0.18)	0.4 (0.5)	0.8 (0.16)

Table 12. Summary statistics for the final base case BSP2 model for the South Atlantic.

Variable	**Mean**	**Median**	**CV**
K (1000)	251.32	233.51	0.40
r	0.26	0.24	0.37
MSY (1000)	14.36	14.14	0.18
B_{2015} (1000)	82.77	73.89	0.50
B_{1950} (1000)	252.62	229.57	0.46
B_{2015}/B_{1950}	0.35	0.33	0.34
C_{2015}/MSY	0.74	0.73	0.19
B_{2015}/B_{MSY}	0.66	0.64	0.23
F_{2015}/F_{MSY}	1.17	1.13	0.25

Table 13. BSP2 means and CVs (in parenthesis) for sensitivity analyses in the South Atlantic. *indicates the final base case.

Variable	S1	S2	S3	S5	S7	S8	S9	S10*	S11	S12	S13
K (1000)	491.2 (0.4)	491.1 (0.4)	495.72 (0.4)	418.3 (0.5)	490.8 (0.4)	310.0 (0.4)	176.9 (0.3)	250.2(0.4)	319.9 (0.6)	196.7 (0.30)	249.8 (0.4)
r	0.5 (0.4)	0.5 (0.4)	0.51 (0.4)	0.4 (0.4)	0.5 (0.4)	0.2 (0.4)	0.5 (0.3)	0.3(0.3)	0.3 (0.3)	0.3 (0.32)	0.3 (0.4)
MSY (1000)	61.0 (0.6)	48.8 (0.6)	105.18 (0.6)	44.3 (0.7)	60.6 (0.5)	15.6 (0.3)	23.6 (0.3)	14.4(0.2)	22.5 (0.6)	13.0 (0.09)	11.5 (0.2)
B_{2017} (1000)	480.9 (0.5)	480.8 (0.5)	486.26 (0.5)	373.5 (0.6)	486.6 (0.5)	158.0 (0.6)	149.1 (0.3)	88.9(0.5)	235.5 (0.7)	70.1 (0.33)	88.9 (0.5)
B_{1950} (1000)	473.6 (0.4)	473.6 (0.4)	477.34 (0.4)	405.0 (0.5)	472.2 (0.5)	314.8 (0.5)	178.2 (0.3)	251.0(0.4)	317.2 (0.6)	198.4 (0.39)	248.2 (0.4)
B_{2017}/B_{1950}	1.0 (0.2)	1.0 (0.2)	1.03 (0.3)	0.9 (0.3)	1.1 (0.3)	0.5 (0.4)	0.9 (0.3)	0.4(0.4)	0.7 (0.3)	0.4 (0.29)	0.4 (0.4)
C_{2017}/ MSY	0.2 (0.5)	0.3 (0.5)	0.14 (0.5)	0.3 (0.5)	0.2 (0.5)	0.7 (0.2)	0.5 (0.3)	0.7(0.2)	0.6 (0.4)	0.8 (0.10)	0.9 (0.2)
B_{2017}/B_{MSY}	1.9 (0.1)	2.4 (0.1)	1.61 (0.1)	1.7 (0.2)	2.0 (0.1)	1.0 (0.3)	1.7 (0.2)	0.7(0.3)	1.4 (0.2)	0.7 (0.17)	0.9 (0.3)
F_{2017}/F_{MSY}	0.1 (0.6)	0.1 (0.6)	0.09 (0.6)	0.3 (1.2)	0.1 (0.6)	0.8 (0.4)	0.3 (0.4)	1.1(0.3)	0.5 (0.5)	1.1 (0.21)	1.1 (0.3)

Table 14. Summary of posterior estimates (medians) and 95% Bayesian Credibility Intervals (C.I.s) of parameters from the JABBA base-case scenario fits to South Atlantic swordfish catch and CPUE series (1950-2015). *Schaefer formulation is used as final base-case model.

	Schaefer*			**Fox**		
Parameters	Median	2.50%	97.50%	Median	2.50%	97.50%
K	104930.8	70237.0	161902.3	125511.5	92171.5	190604.7
r	0.554	0.335	0.886	0.293	0.177	0.422
σ	0.06	0.032	0.084	0.055	0.032	0.084
F_{MSY}	0.277	0.167	0.443	0.293	0.177	0.422
B_{MSY}	52465.4	35118.5	80951.2	46196.2	33924.9	70154.6
MSY	14570.0	12961.8	16122.7	13569.0	11997.8	14722.1
B_{1950}/K	0.915	0.612	1.114	0.842	0.512	1.049
B_{2015}/K	0.359	0.263	0.503	0.279	0.199	0.397
B_{2015}/B_{MSY}	0.717	0.526	1.006	0.759	0.539	1.078
F_{2015}/F_{MSY}	0.983	0.703	1.360	1.002	0.703	1.418

Table 15. JABBA estimates of F/F_{MSY} and B/B_{MSY} (1950-2015) for Schaefer base-case scenario run for South Atlantic swordfish.

Year	F/F_{MSY}	B/B_{MSY}	Year	F/F_{MSY}	B/B_{MSY}
1950	0.004	1.831	1983	0.206	1.802
1951	0.007	1.917	1984	0.35	1.8
1952	0.007	1.959	1985	0.382	1.723
1953	0.007	1.974	1986	0.242	1.673
1954	0.003	1.98	1987	0.242	1.716
1955	0.003	1.986	1988	0.521	1.738
1956	0	1.99	1989	0.722	1.624
1957	0.008	1.993	1990	0.803	1.483
1958	0.003	1.991	1991	0.705	1.358
1959	0.006	1.993	1992	0.718	1.323
1960	0.016	1.993	1993	0.851	1.303
1961	0.035	1.988	1994	1.039	1.254
1962	0.027	1.974	1995	1.307	1.154
1963	0.049	1.974	1996	1.252	1.005
1964	0.071	1.96	1997	1.379	0.926
1965	0.091	1.943	1998	1.158	0.834
1966	0.07	1.925	1999	1.307	0.817
1967	0.056	1.929	2000	1.421	0.762
1968	0.087	1.937	2001	1.469	0.709
1969	0.16	1.924	2002	1.45	0.67
1970	0.198	1.878	2003	1.345	0.647
1971	0.081	1.838	2004	1.378	0.654
1972	0.094	1.882	2005	1.387	0.653
1973	0.112	1.895	2006	1.485	0.66
1974	0.1	1.891	2007	1.659	0.648
1975	0.111	1.896	2008	1.453	0.596
1976	0.102	1.892	2009	1.496	0.594
1977	0.103	1.895	2010	1.511	0.58
1978	0.1	1.896	2011	1.387	0.562
1979	0.119	1.897	2012	1.288	0.573
1980	0.193	1.888	2013	0.954	0.594
1981	0.148	1.844	2014	1.03	0.663
1982	0.239	1.849	2015	0.983	0.717

Table 16. Probabilities for the North Atlantic swordfish BSP2 Schaefer model.

a) Probability of being in the green (B>B$_{MSY}$, F<F$_{MSY}$)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
8000	50	54	62	72	80	85	89	91	93	95	96
9000	50	54	60	70	75	80	84	87	89	91	93
10000	50	54	59	65	70	74	79	81	82	84	86
11000	50	54	58	62	66	69	72	74	76	77	77
12000	50	54	57	58	61	62	64	65	66	67	68
13000	50	54	54	53	52	53	54	53	53	54	54
13200	50	54	53	52	51	52	51	50	50	50	50
13400	51	54	54	53	53	54	52	53	53	54	54
13500	50	54	51	51	49	50	49	48	47	47	46
13600	53	55	37	35	36	38	35	38	37	38	38
13700	50	54	49	49	48	47	47	45	44	44	43
13800	50	54	48	47	47	46	46	44	43	42	42
13900	50	54	48	46	46	44	44	43	42	40	39

b) Probability B>B$_{MSY}$

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
8000	50	54	62	72	80	85	89	91	93	95	96
9000	50	54	60	70	75	80	84	87	89	91	93
10000	50	54	59	65	70	74	79	81	82	84	86
11000	50	54	58	62	66	69	72	74	76	77	77
12000	50	54	58	58	61	62	64	66	67	67	68
13000	50	54	56	56	54	55	55	55	56	55	55
13200	50	54	56	55	54	54	54	52	52	53	52
13400	50	54	56	55	53	52	51	50	50	50	50
13500	53	55	53	47	47	47	42	44	41	42	42
13600	50	54	55	54	52	51	50	48	48	47	46
13700	50	54	55	53	52	50	49	47	47	46	45
13800	50	54	55	53	51	50	48	46	46	45	44
13900	50	54	55	52	50	49	48	46	45	43	43

c) Probability F<FMSY

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
8000	85	85	100	100	100	100	100	100	100	100	100
9000	85	85	98	98	99	99	99	99	99	99	99
10000	85	85	95	95	95	95	96	96	97	97	97
11000	85	85	87	87	88	88	89	89	89	90	90
12000	85	85	75	76	76	75	76	76	75	76	77
13000	85	85	60	58	58	58	59	58	58	59	58
13200	85	85	57	57	55	55	55	54	55	54	54
13400	85	85	54	55	52	52	52	50	50	50	48
13500	86	86	42	41	43	42	40	41	41	41	42
13600	85	85	51	51	50	50	49	47	46	45	45
13700	85	85	50	50	48	48	47	45	44	43	43
13800	85	85	49	48	47	45	46	44	43	41	41
13900	85	85	47	45	45	44	43	43	41	40	38

Table 17. Estimated projection probabilities (%) that fishing mortality is below F_{MSY} ($F < F_{MSY}$) for South Atlantic swordfish from Schaefer JABBA base-case model run. The projections were conducted using the JABBA Schaefer base-case model run over the period 2016-2030 with the range of fixed TACs (10000 - 16000 t).

TAC | Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10000	87	90	93	94	95	96	97	97	97	98	98	98	98
10500	83	87	90	92	93	94	95	95	96	96	97	97	97
11000	78	83	86	89	90	92	92	93	94	94	94	95	95
11500	74	79	82	85	86	88	89	90	91	92	92	92	93
12000	68	73	76	79	81	83	85	86	87	88	88	89	89
12500	63	67	70	73	75	77	78	80	81	82	83	83	84
13000	57	60	64	66	68	70	72	73	74	74	75	76	77
13200	53	57	60	63	65	66	68	69	70	71	72	72	73
13400	51	55	58	60	62	63	64	65	66	67	68	68	69
13600	49	52	54	56	58	59	60	61	62	63	64	64	65
13700	48	50	52	54	56	57	58	60	60	61	61	62	63
13800	46	48	51	52	54	55	56	57	58	58	59	59	60
13900	44	47	49	51	52	53	54	55	55	56	57	57	58
14000	44	46	48	49	50	51	52	53	53	54	54	55	55
14500	38	39	40	40	40	41	41	41	41	41	41	41	41
15000	33	32	32	31	31	30	30	29	29	29	28	27	27
15500	27	25	24	23	21	20	19	18	17	16	16	15	15
16000	22	20	18	15	14	12	11	10	9	8	7	7	7

Table 18. Estimated projection probabilities (%) that the biomass is above B_{MSY} ($B > B_{MSY}$) for South Atlantic swordfish from Schaefer JABBA base-case model run.

TAC | Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10000	36	52	66	75	81	86	89	91	93	94	95	96	96
10500	36	52	63	72	78	83	86	89	90	92	93	94	94
11000	35	49	60	68	74	79	83	85	87	89	90	91	92
11500	36	48	57	64	70	75	79	82	84	86	87	88	89
12000	36	46	54	60	67	71	74	77	80	81	83	84	85
12500	36	45	51	57	61	65	69	71	73	75	77	78	79
13000	36	43	48	52	56	60	62	65	67	69	70	71	72
13200	36	42	46	50	54	57	60	62	64	65	66	67	68
13400	36	41	46	50	52	55	57	59	60	61	63	64	64
13600	36	40	44	47	49	52	53	55	57	58	59	60	61
13700	36	40	43	46	48	51	52	54	55	56	57	58	59
13800	36	39	42	45	47	49	51	52	53	54	55	56	56
13900	36	38	41	44	46	48	49	50	51	52	53	54	54
14000	36	39	41	43	45	47	48	49	50	50	51	52	52
14500	36	36	37	38	39	39	40	40	40	40	40	40	40
15000	36	35	35	33	33	32	32	31	31	30	29	28	28
15500	36	34	31	29	27	25	23	22	20	20	18	18	17
16000	36	31	27	24	21	19	16	15	13	12	10	9	9

Table 19. Estimated projection probabilities (%) that both the fishing mortality is below F_{MSY} ($F < F_{MSY}$) and biomass is above B_{MSY} ($B > B_{MSY}$) for South Atlantic swordfish. The projections were conducted using the JABBA Schaefer base-case model run over the period 2016-2030 with the range of fixed TACs (4000-16000 t).

TAC | Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10000	36	52	66	75	81	86	89	91	93	94	95	96	96
10500	36	52	63	72	78	83	86	89	90	92	93	94	94
11000	35	49	60	68	74	79	83	85	87	89	90	91	92
11500	36	48	57	64	70	75	79	82	84	86	87	88	89
12000	36	46	54	60	67	71	74	77	80	81	83	84	85
12500	36	45	51	56	61	65	68	71	73	75	77	78	79
13000	36	43	48	52	56	60	62	65	67	69	70	71	72
13200	36	42	46	50	54	57	60	62	63	65	66	67	68
13400	36	41	45	49	52	54	57	59	60	61	63	64	64
13600	35	39	43	47	49	51	53	55	57	58	59	60	60
13700	35	39	43	45	48	50	52	54	55	56	57	58	59
13800	35	38	41	44	47	49	50	52	53	54	55	55	56
13900	35	38	41	43	45	47	48	50	51	52	52	54	54
14000	35	38	40	43	44	46	47	48	49	50	51	51	52
14500	34	34	35	36	37	38	38	38	39	39	39	39	39
15000	31	30	30	29	29	29	28	28	28	27	27	26	26
15500	27	25	24	22	21	20	18	17	17	16	16	15	14
16000	22	19	17	15	13	12	11	10	9	8	7	7	7

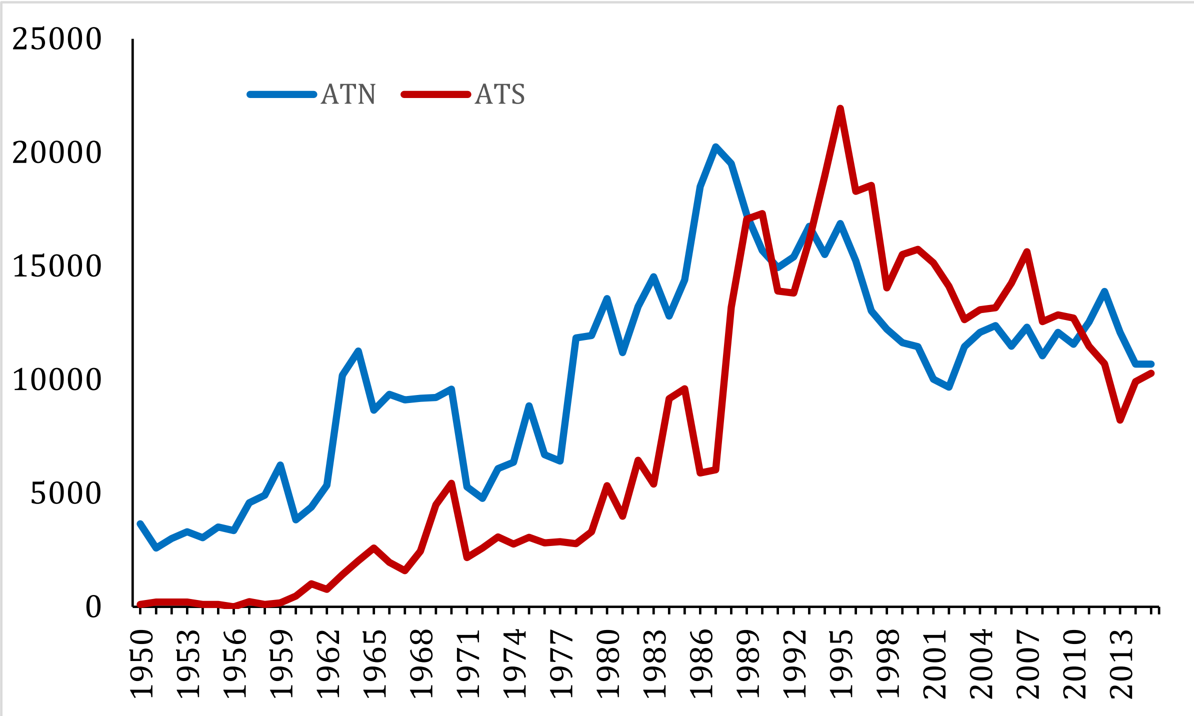


Figure 1. North and South Atlantic swordfish Task I catches (t) by year.

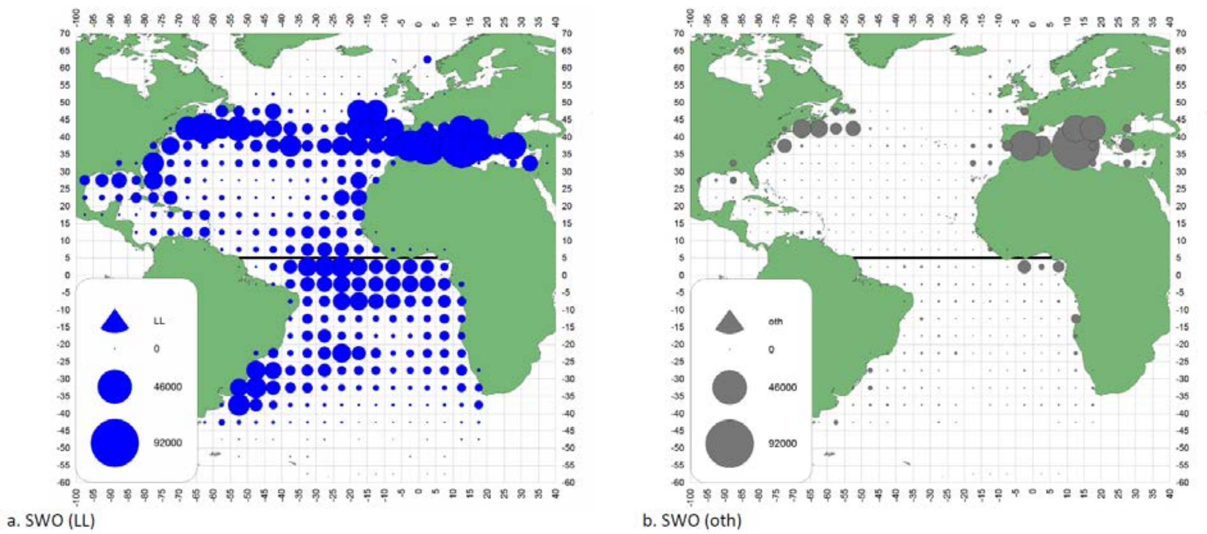


Figure 2. Geographical distribution of cumulative swordfish catch (t) by major gears for the period 1950-2015.

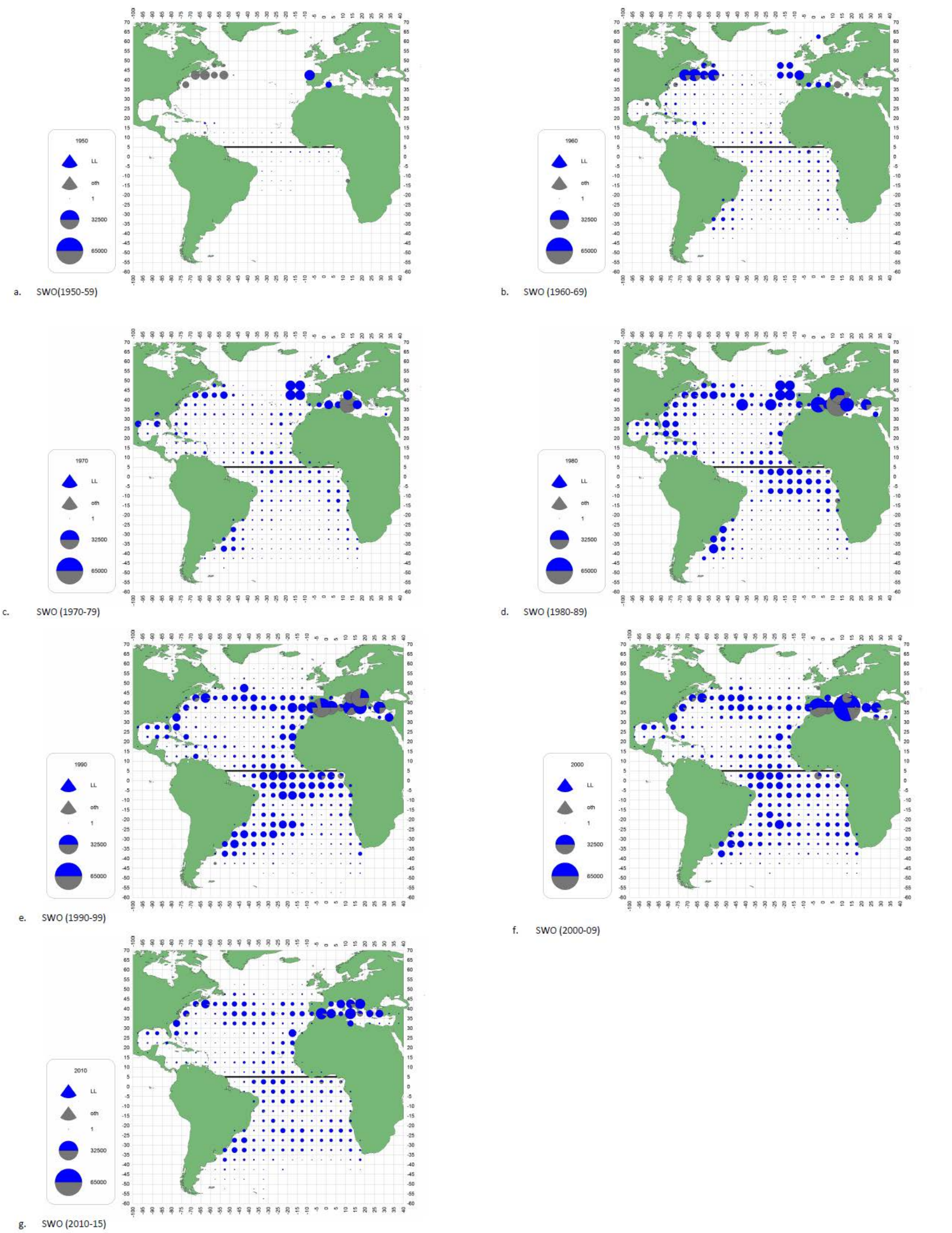


Figure 3. Geographical distribution of swordfish cumulative catch (t) by major gears, shown on a decadal scale for the period 1950-2015.

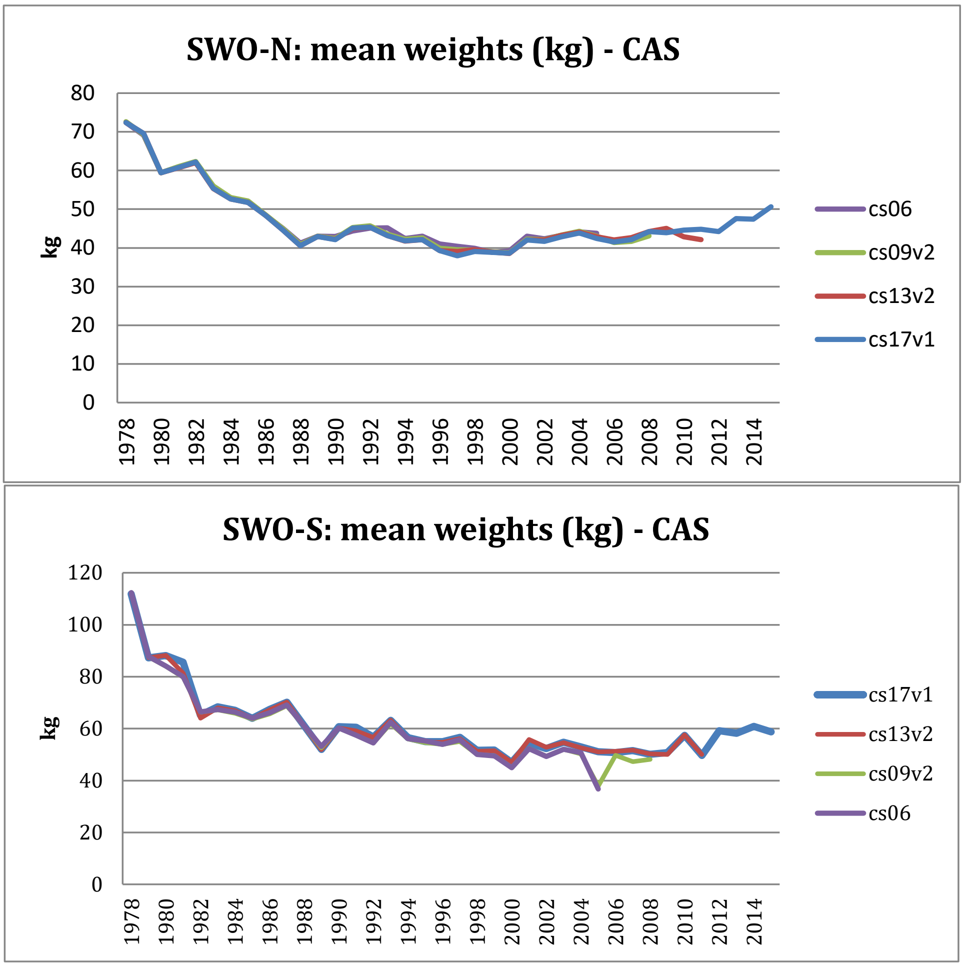


Figure 4. Swordfish mean weights (kg) obtained from the catch-at-size matrices for the North (upper panel) and South (lower panel) Atlantic stocks. Figure legend: The version of CAS used in the SWO-SA ("cs" + year + version adopted; e.g. cs09v2 = CAS (2009) version 2)

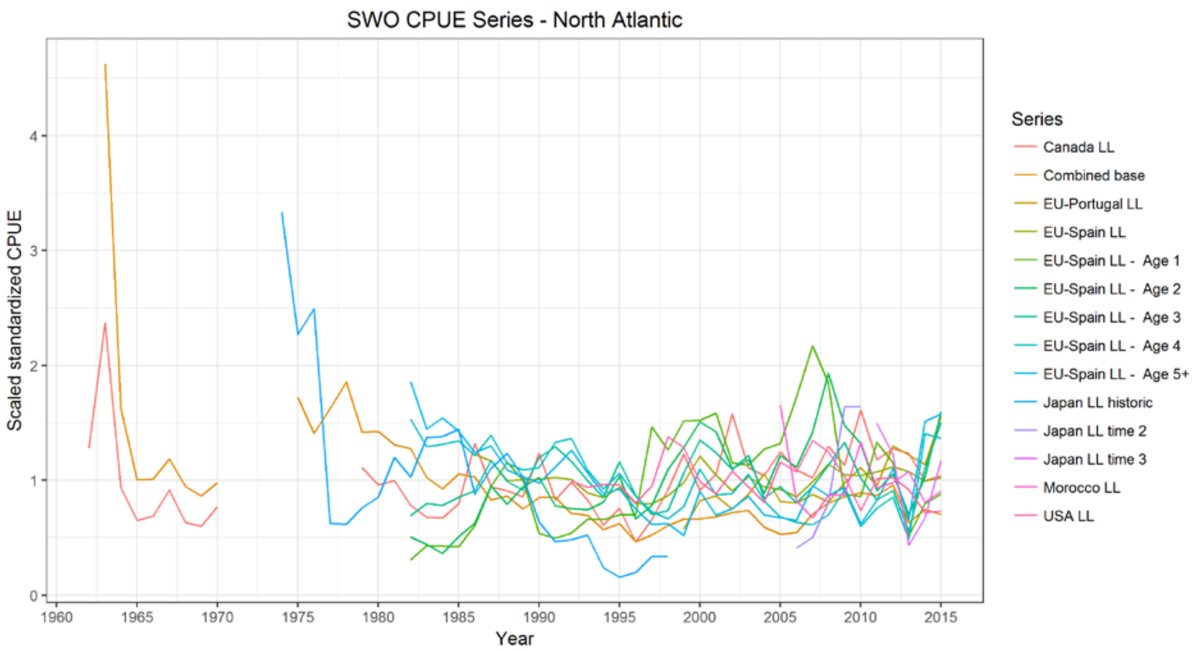


Figure 5. Standardized swordfish CPUE indices selected to be considered in the North Atlantic stock assessment.

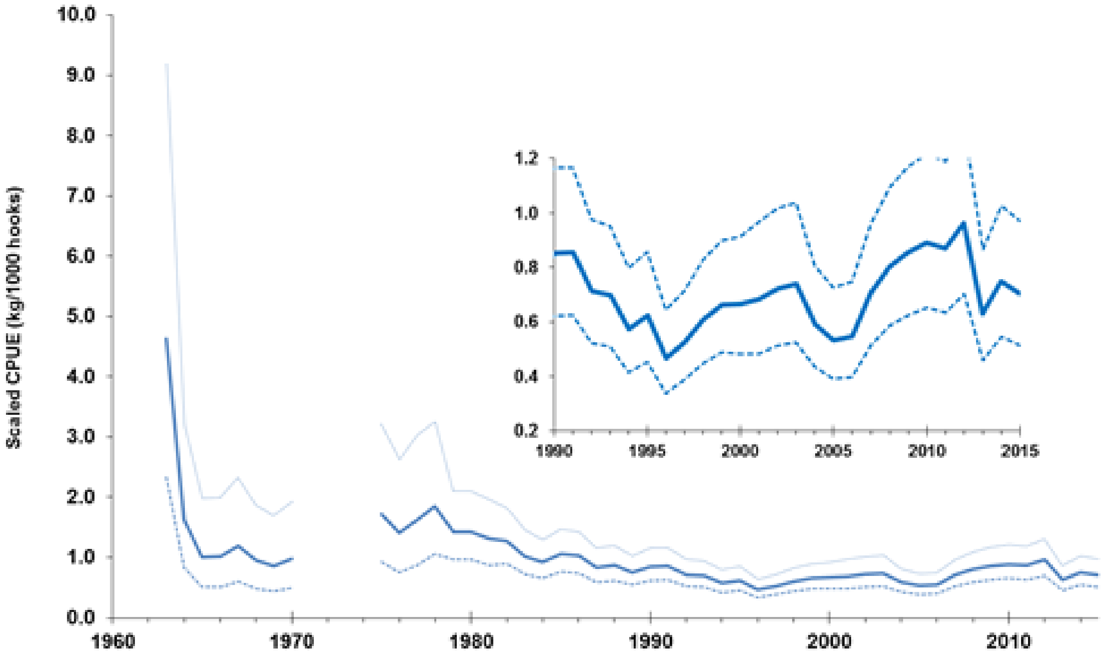


Figure 6. Standardized swordfish CPUE combined biomass index for North Atlantic and 95% confidence intervals, used in the production models. The inset plot shows the index trend since 1990.

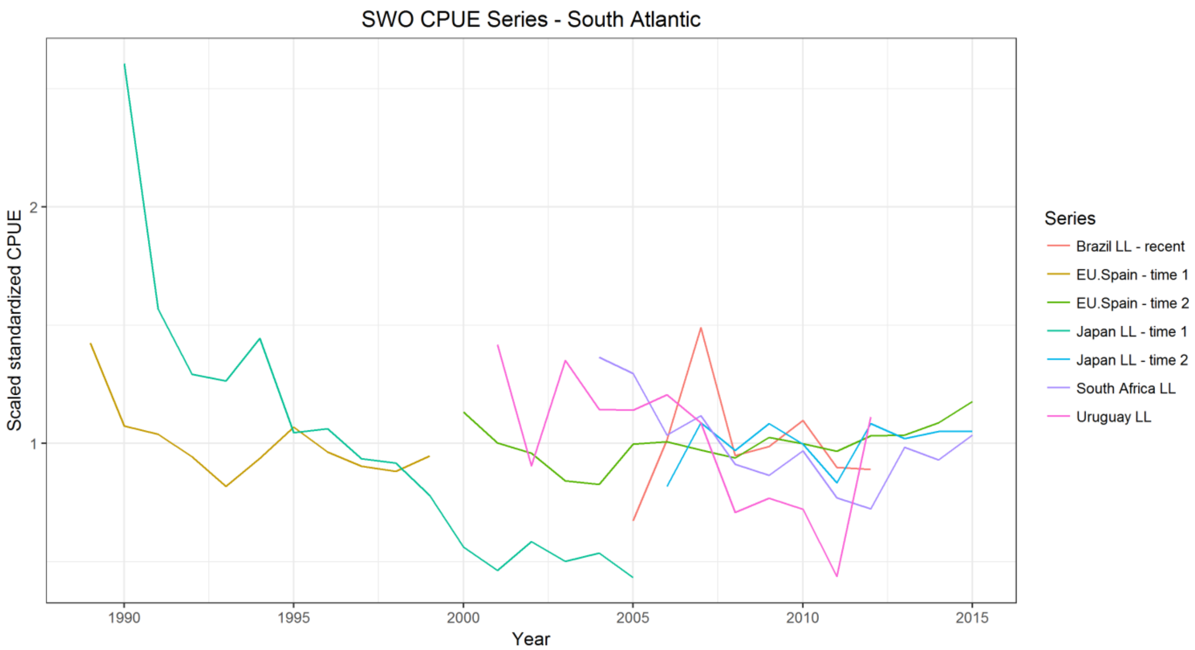


Figure 7. Standardized swordfish CPUE indices selected to be considered in the South Atlantic stock assessment.

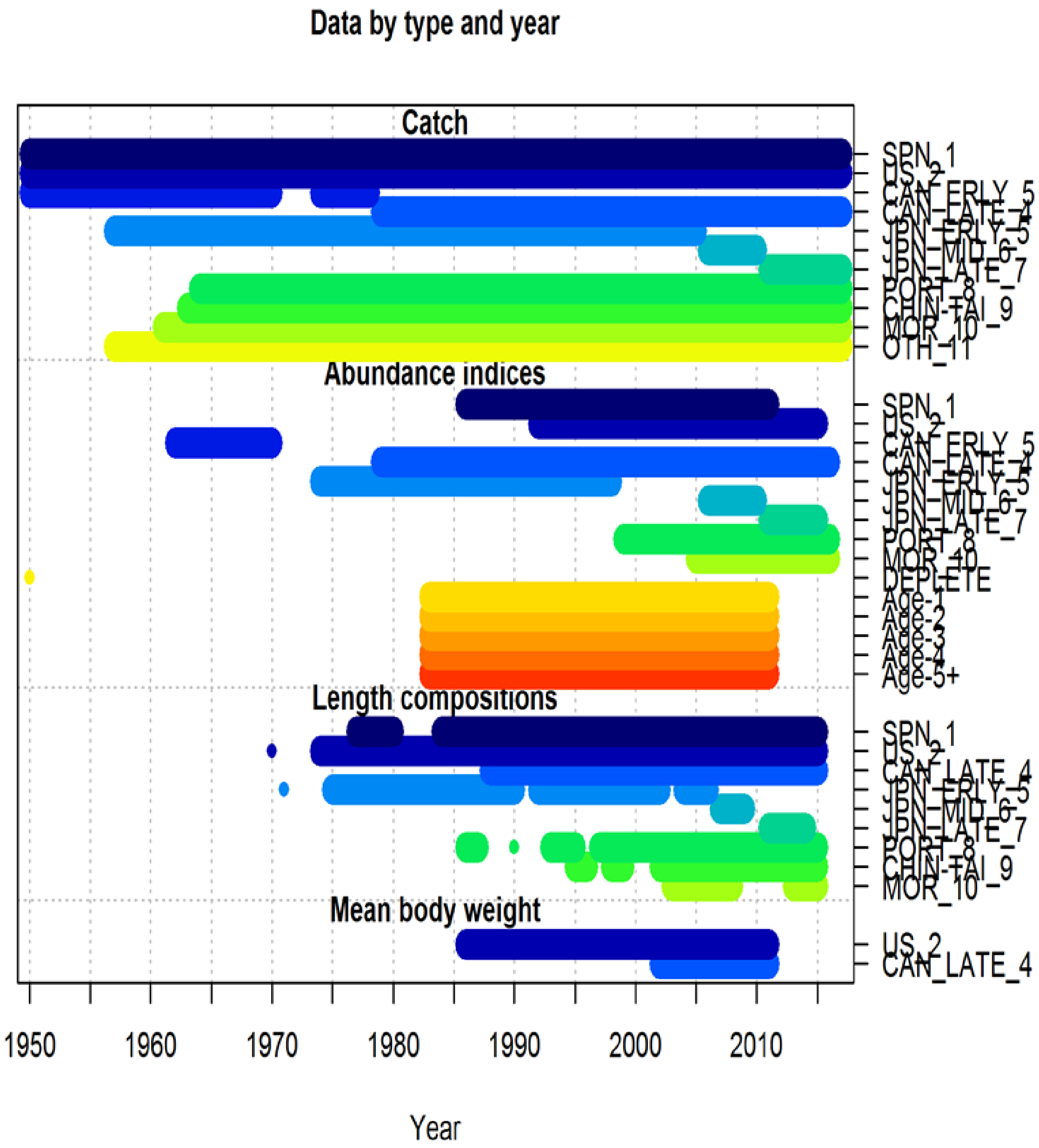


Figure 8. Data by type and year used in assessment using SS.

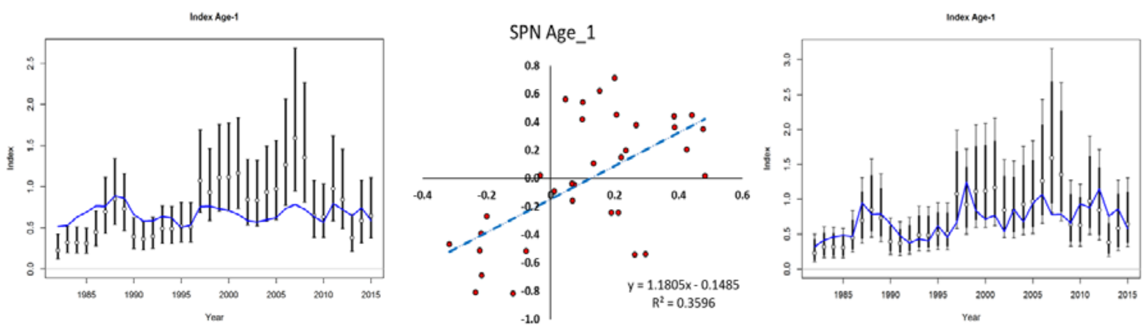


Figure 9. Spanish CPUE without (left panel) AMO modification; regression of residuals (middle panel); fit to CPUE with the AMO (right panel).

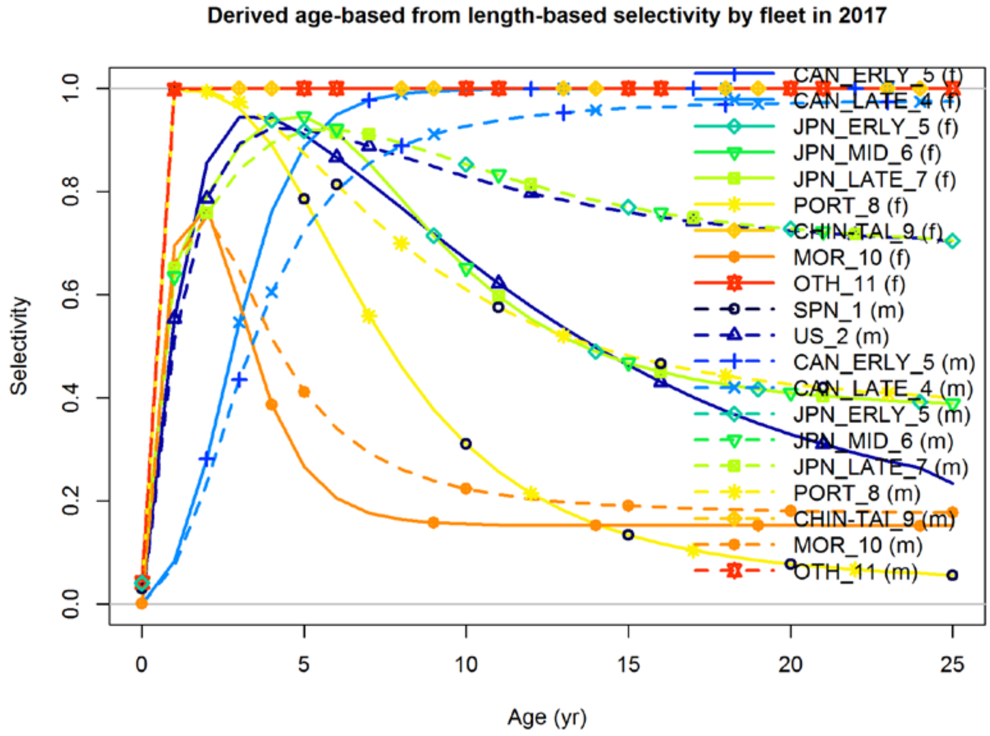


Figure 10. Derived age-based from length based selectivity by fleet for 2017.

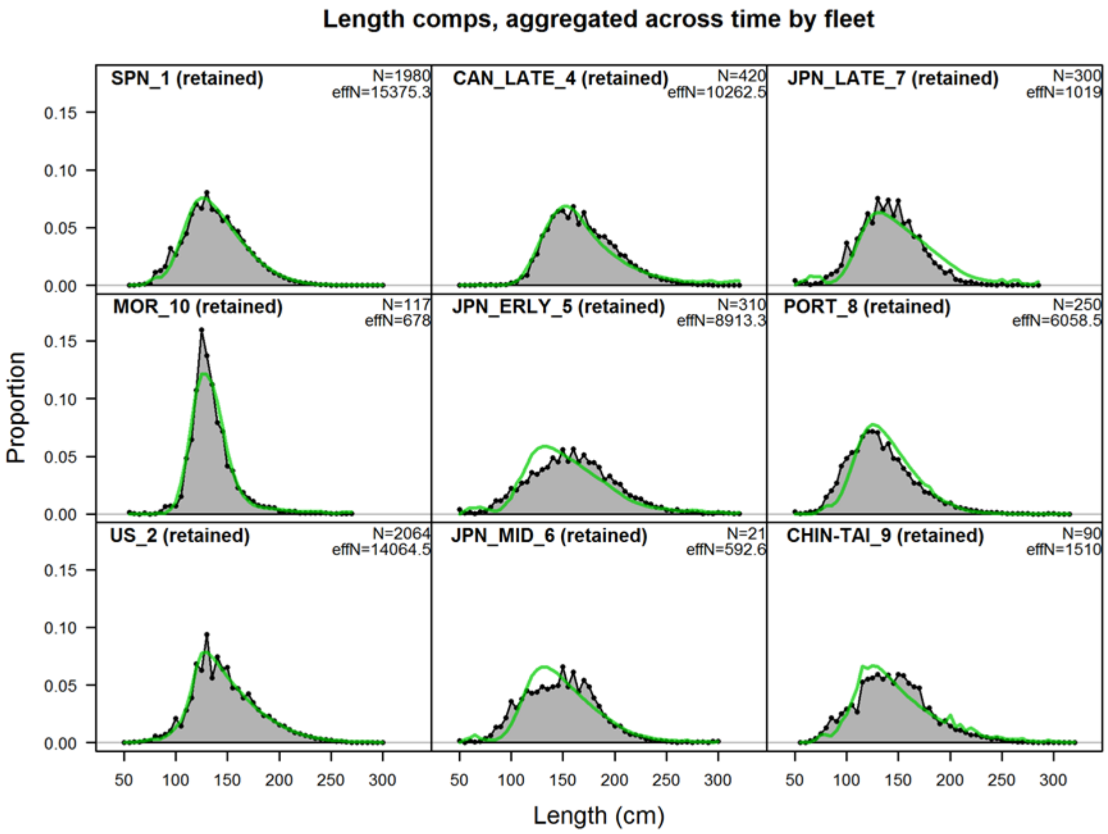


Figure 11. Fit to length compositional data by fleet for all years combined.

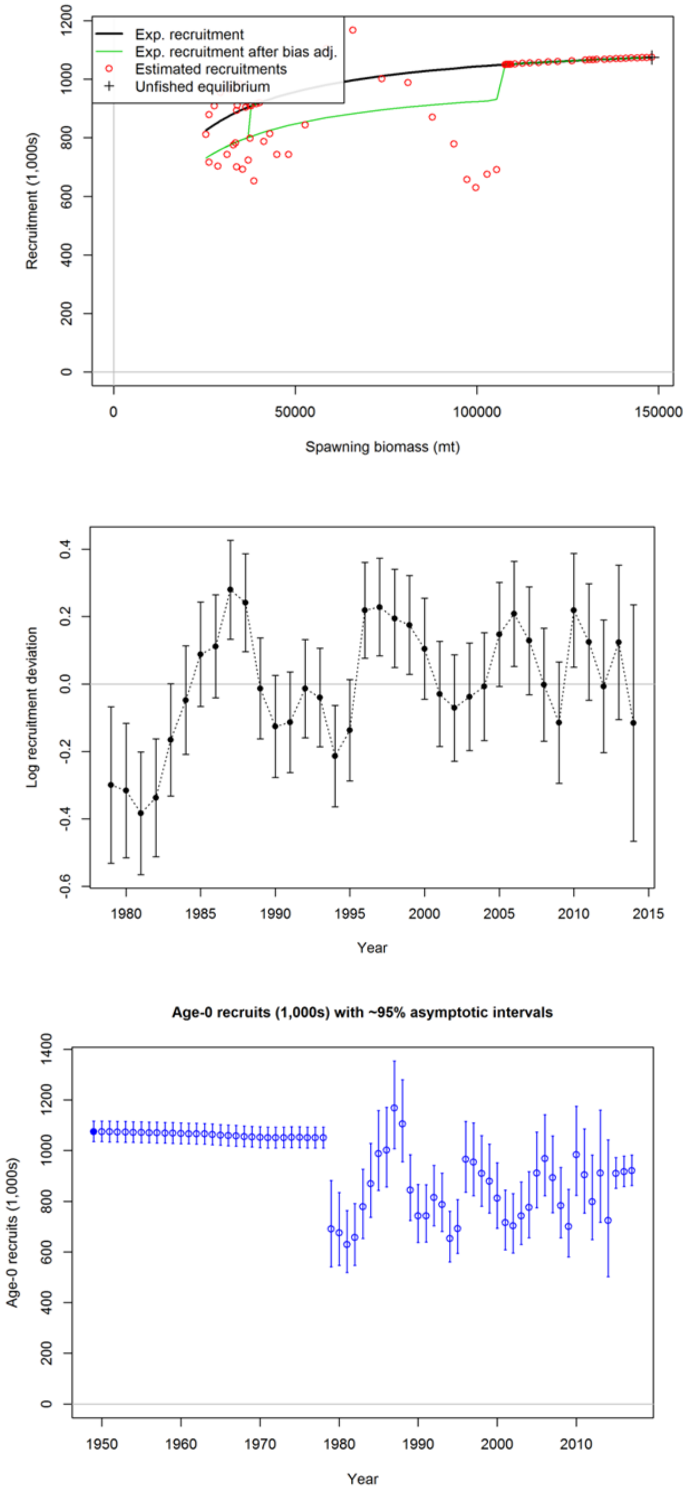
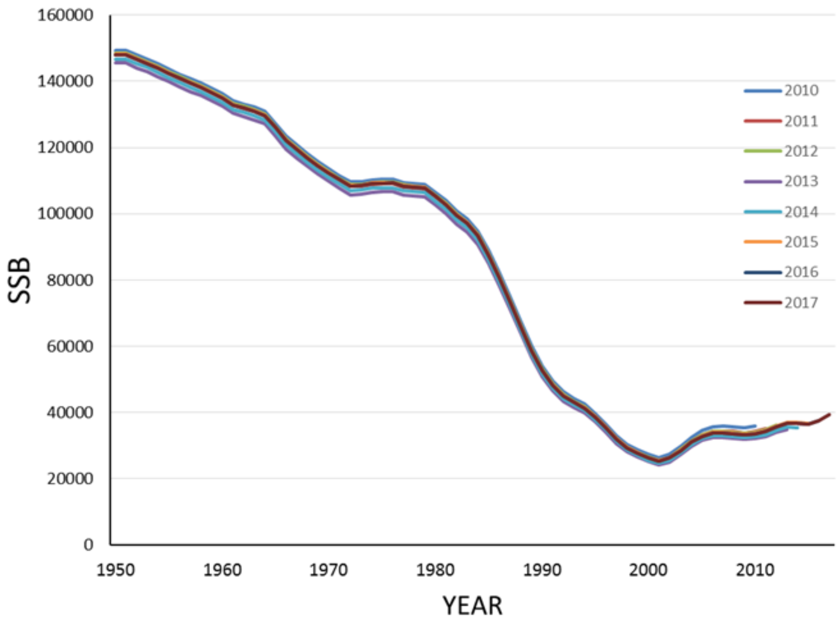


Figure 12. Stock-recruitment function with fixed steepness (0.80) (top); estimated recruitment deviations (middle); estimated trend in recruitment with approximate 95% confidence intervals (bottom).



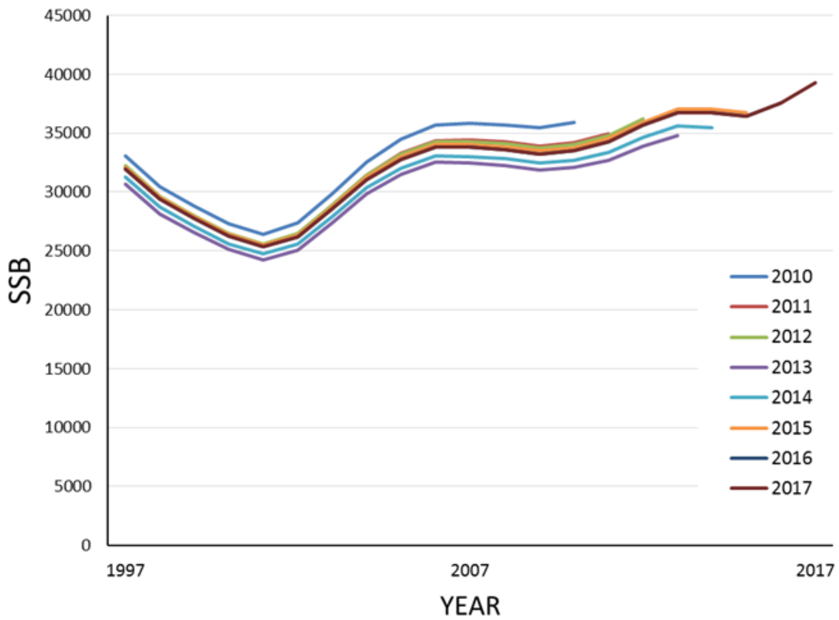


Figure 13. Results of retrospective analysis 1950-2017 (top) and for 1997-2017 (bottom).

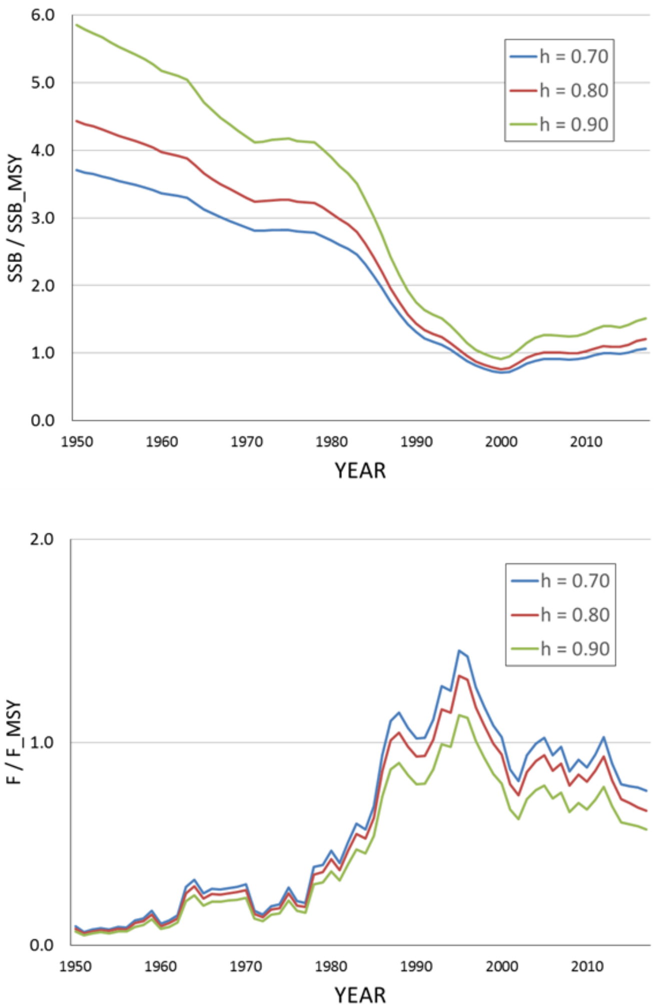


Figure 14. Trend in SSB/SSB_{MSY} (top) and F/F_{MSY} (bottom) for the three values of steepness examined.

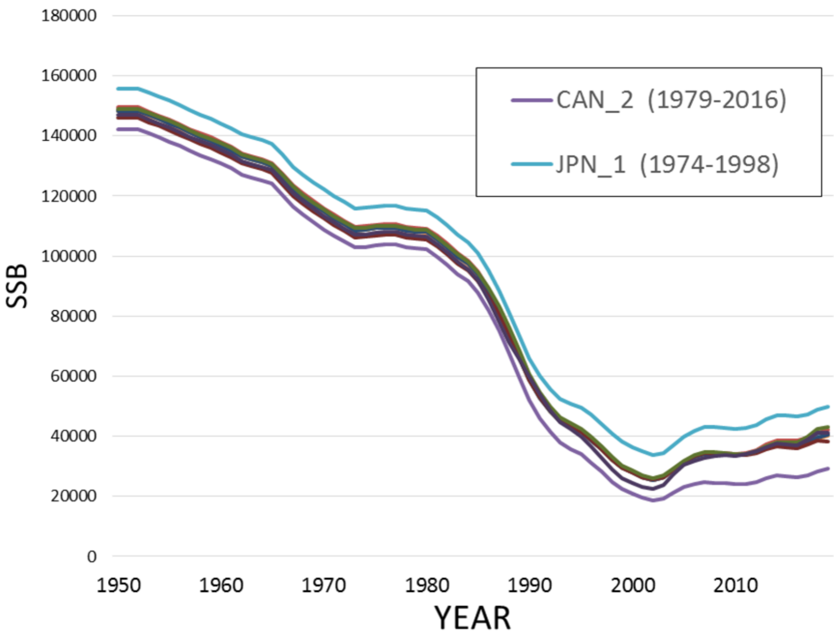


Figure 15. Trends in SSB when excluding one CPUE index at a time.

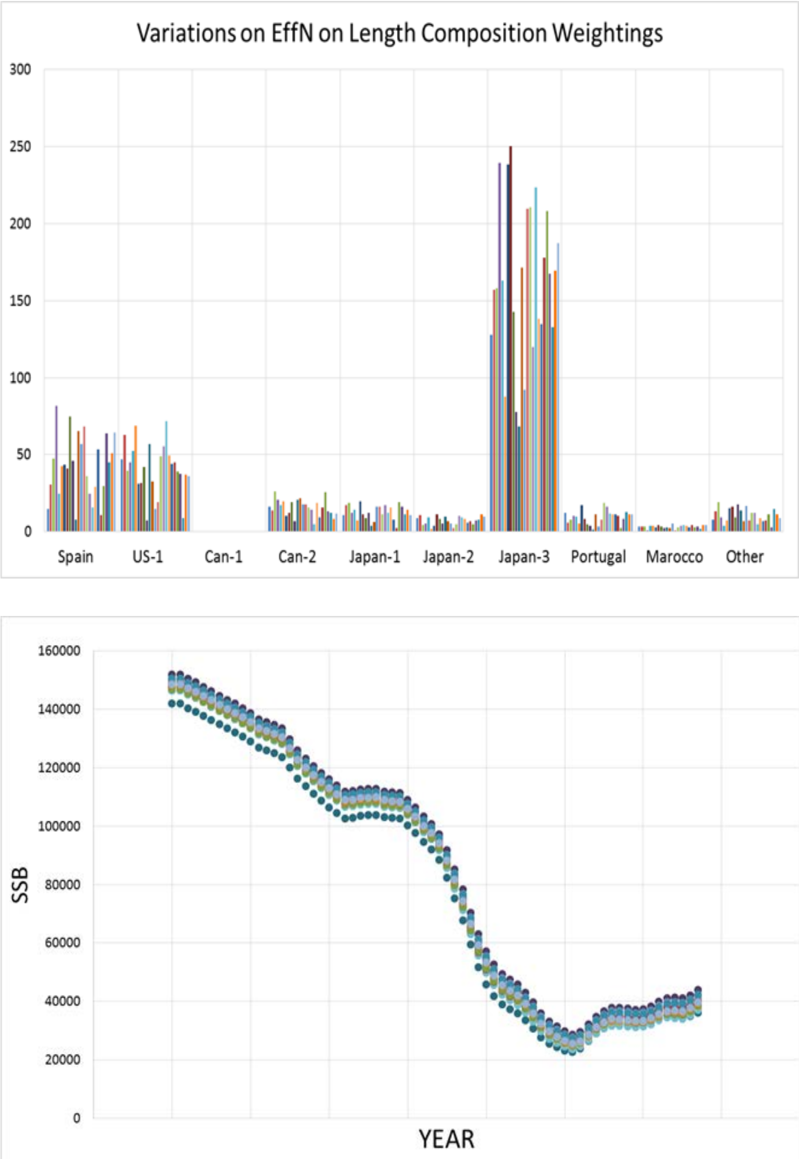


Figure 16. Assigned variations in effective sample size of length compositional data (top) and results trends in SSB (bottom).

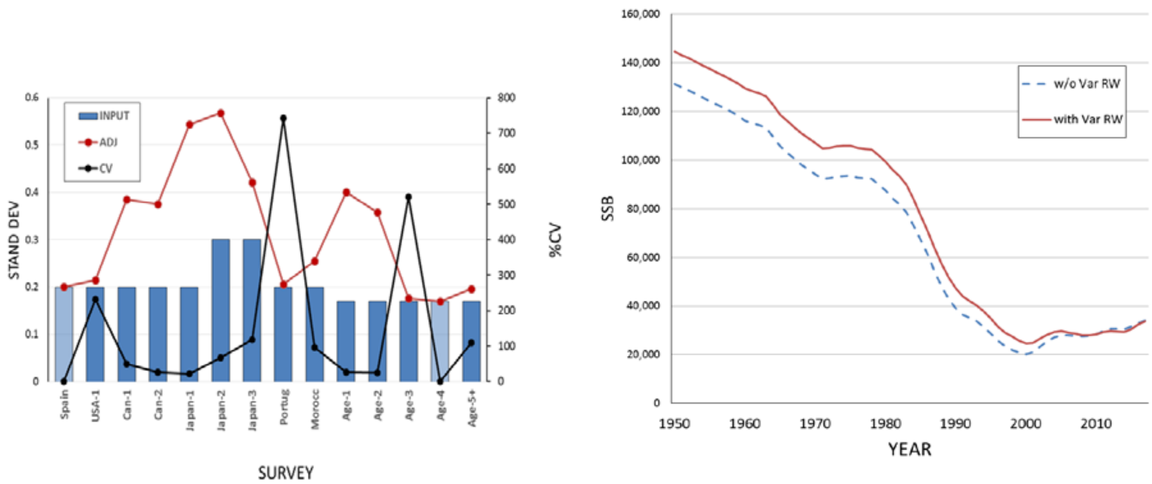


Figure 17. Input, adjusted, and CV for variance reweighting of CPUE time series (left) and trend is SSB (right) with (red solid) and without (blue dashed) adjustments.

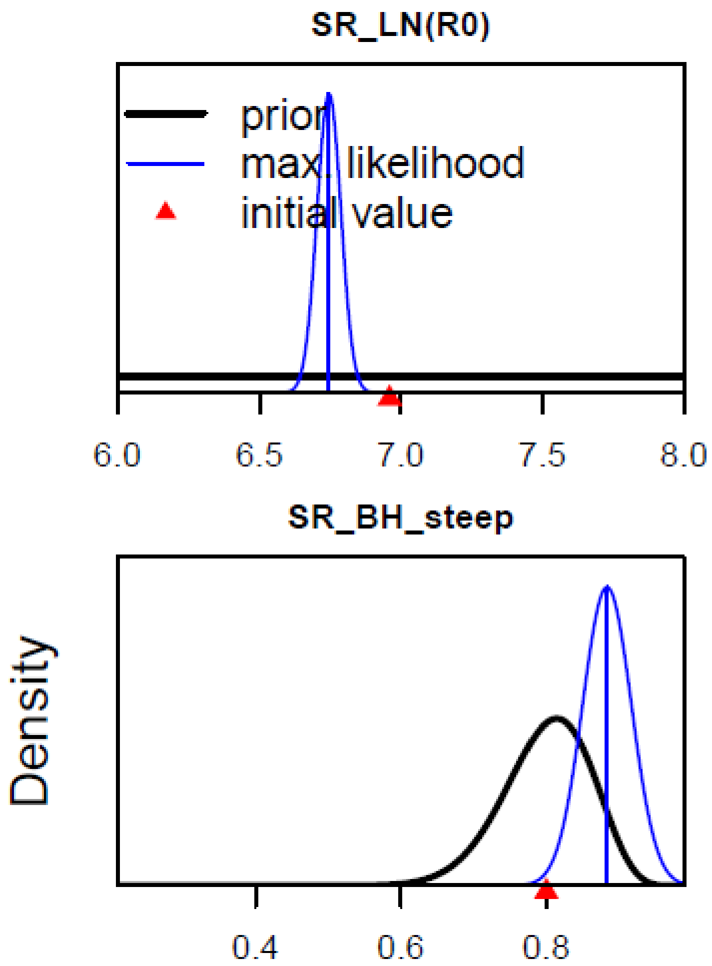


Figure 18. Prior, maximum likelihood and starting parameter values for maximum recruitment (top) and steepness (bottom).

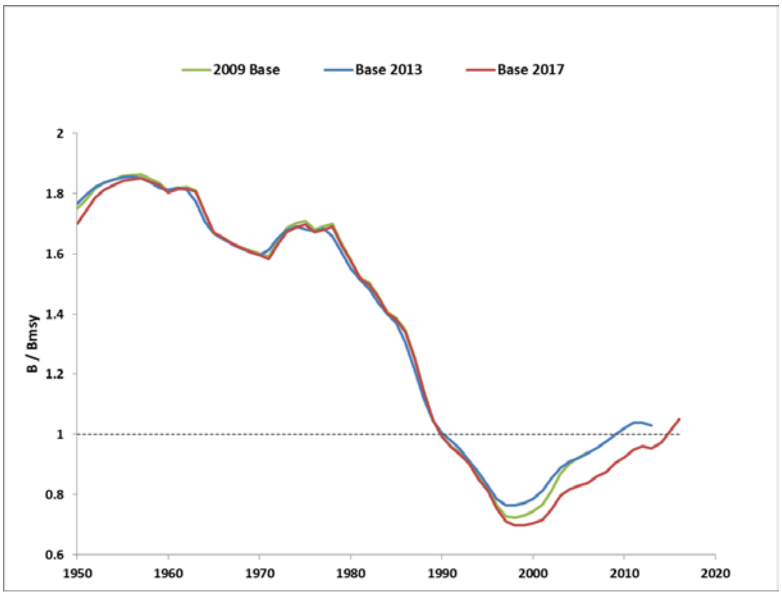


Figure 19. Comparison of B/B_{MSY} trends for the 2009, 2013 and 2017 North Atlantic swordfish stock assessments ASPIC base models.

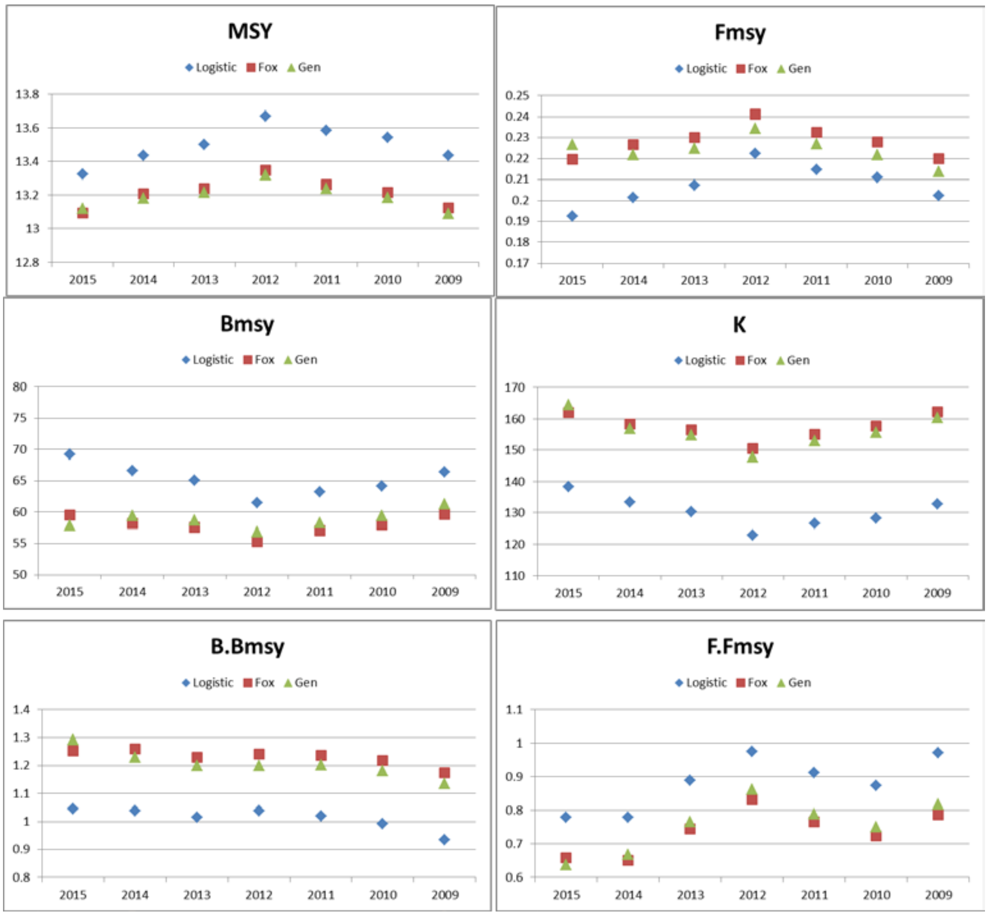


Figure 20. Retrospective estimates of SPM (ASPIC 7) parameters for the Catch (1963-2015) and CPUE (Combined biomass index N-SWO) assuming three surplus production functions: Logistics (Schaefer), Fox and Generalized (Pella Tomlinson). The x-axis indicates the last year of the catch CPUE data.

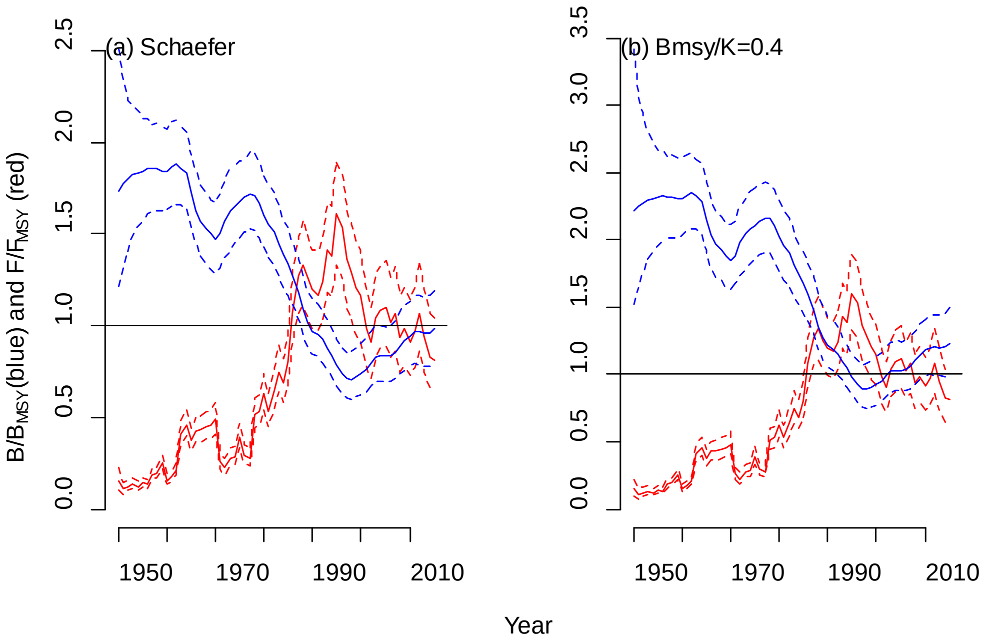


Figure 21. Biomass and fishing mortality rate relative to MSY levels, from BSP2 for North Atlantic swordfish for (a) the base case model and (b) a model that was the same expect that B_{MSY}/K was equal to 0.4.

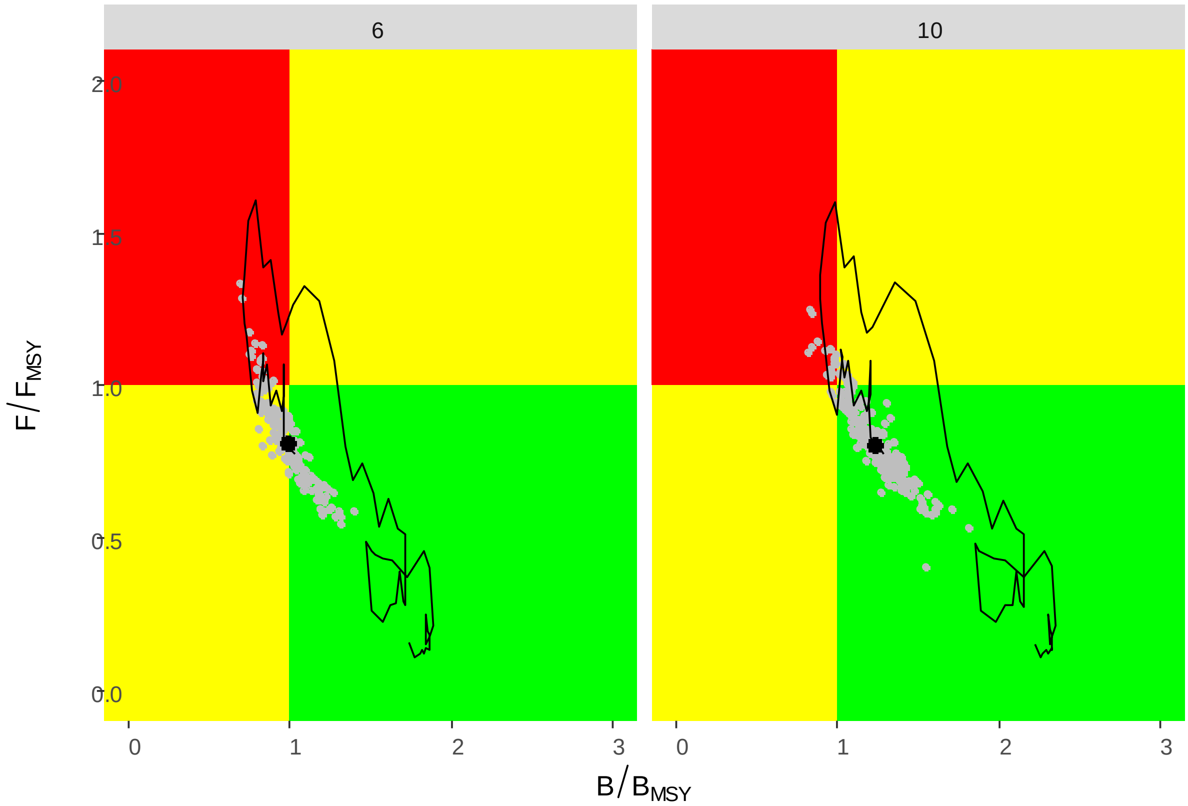


Figure 22. Kobe plots for North Atlantic swordfish (6) the base case and (10) a model that was the same expect that B_{MSY}/K was equal to 0.4.

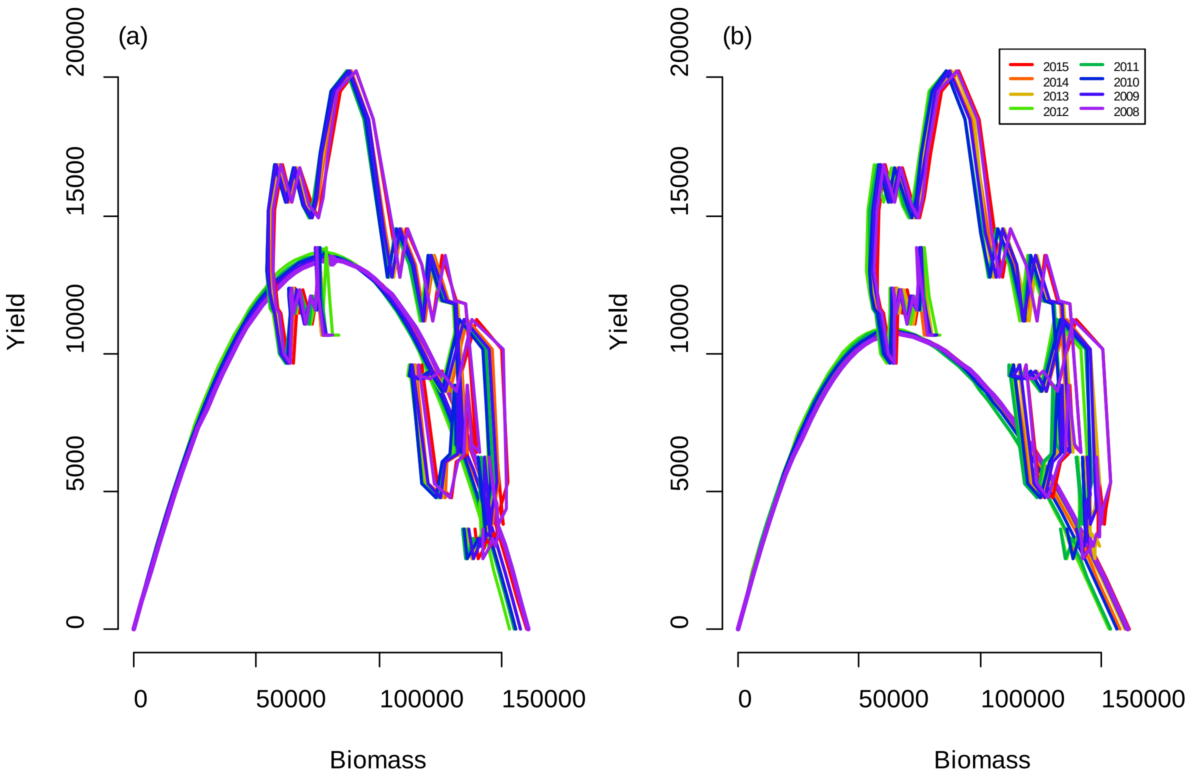
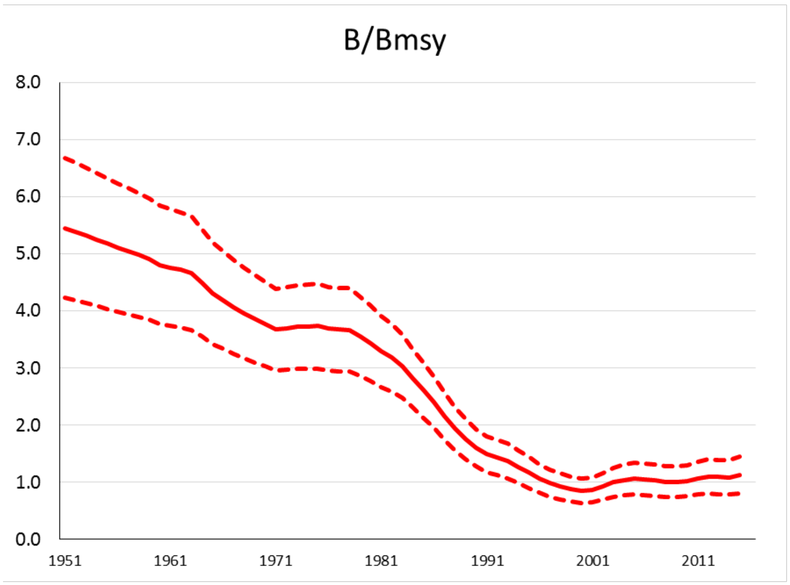


Figure 23. Retrospective analysis of yield and biomass for (a) the base case North Atlantic BSP2 model, and (b the generalized model, showing median production curves and catch plotted against median biomass in each year. Colors indicate the last year of CPUE data used in the fitting.



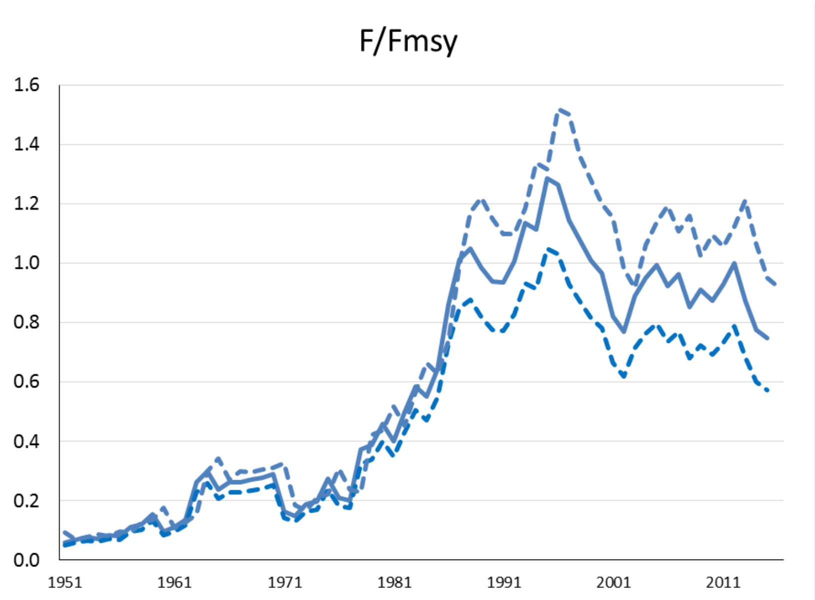


Figure 24. The estimates of B/B_{MSY} and F/F_{MSY} for North Atlantic swordfish from the SS model.

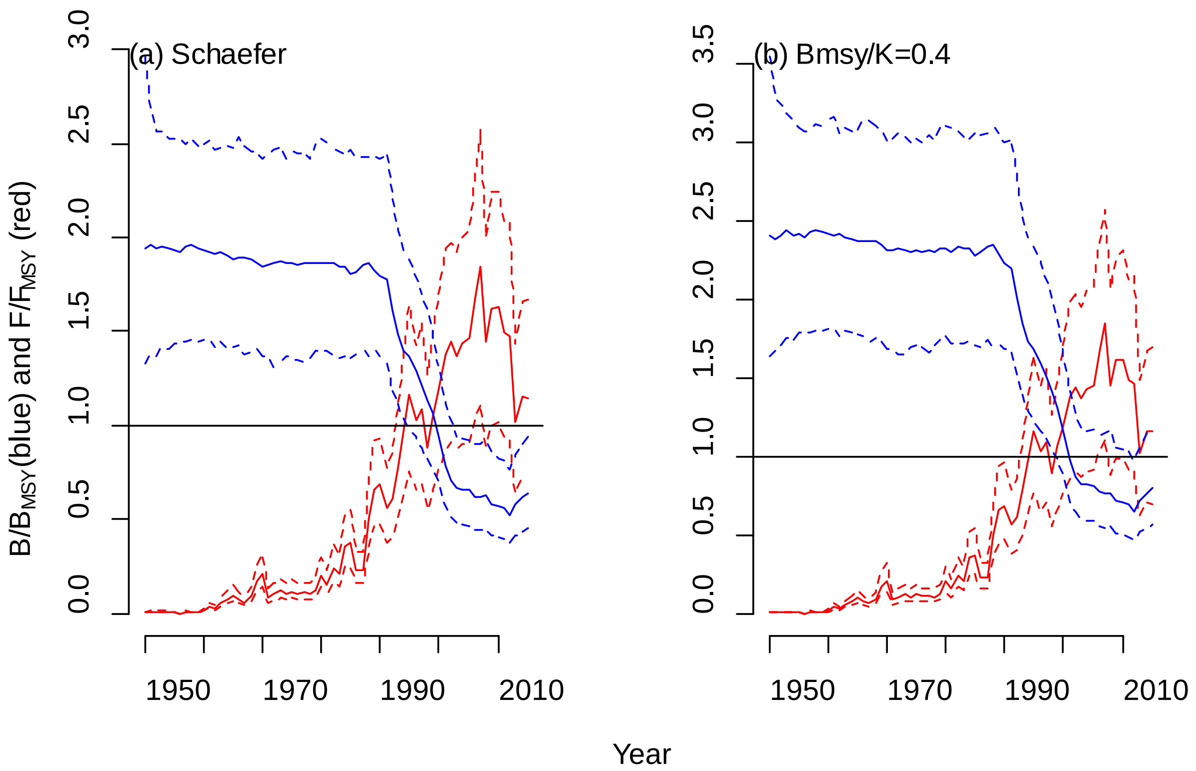


Figure 25. Biomass and fishing mortality rate relative to MSY levels, from BSP2 for South Atlantic swordfish for (a) the base case model and (b) a model that was the same expect that B_{MSY}/K was equal to 0.4.

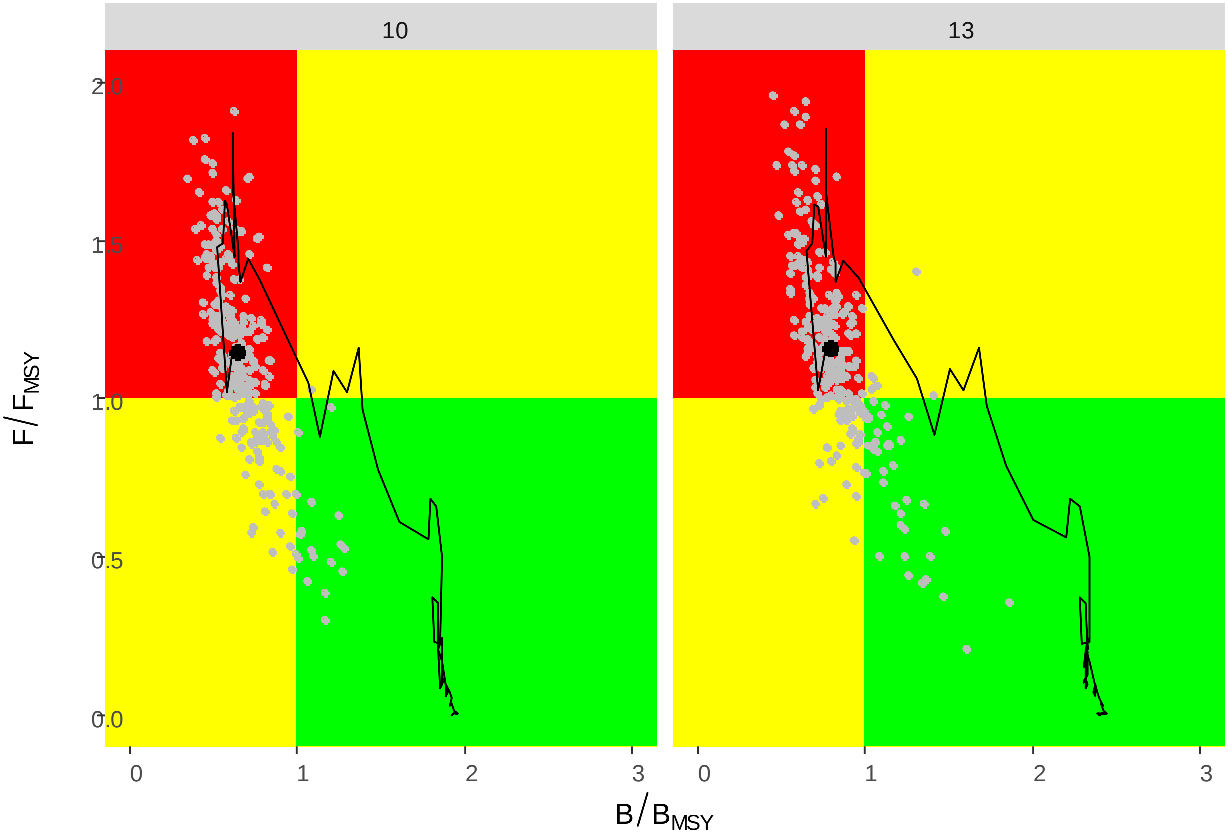


Figure 26. Kobe plots from BSP2 for South Atlantic swordfish for (10) the base case, and (13) a model that was the same expect that B_{MSY}/K was equal to 0.4.

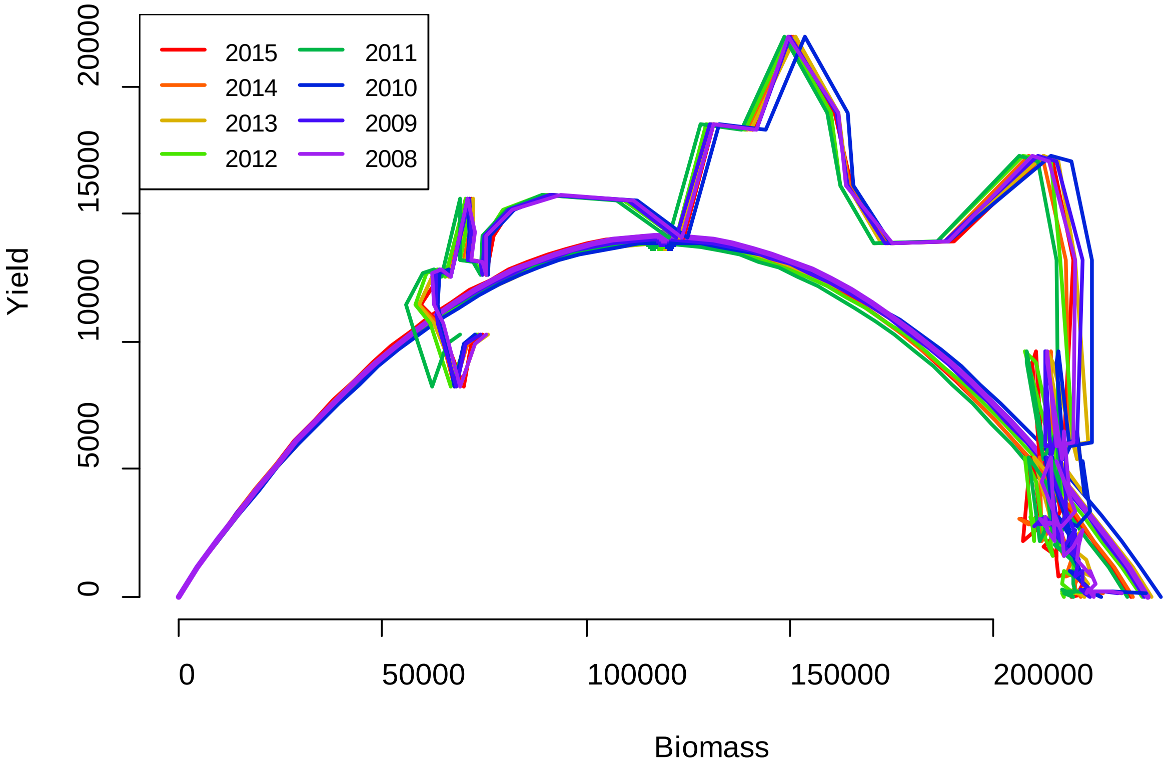


Figure 27. Retrospective plot for BSP2 South Atlantic swordfish Schaefer model, showing median production curves and catch plotted against median biomass in each year. Colors indicate the last year of CPUE data used in the fitting.

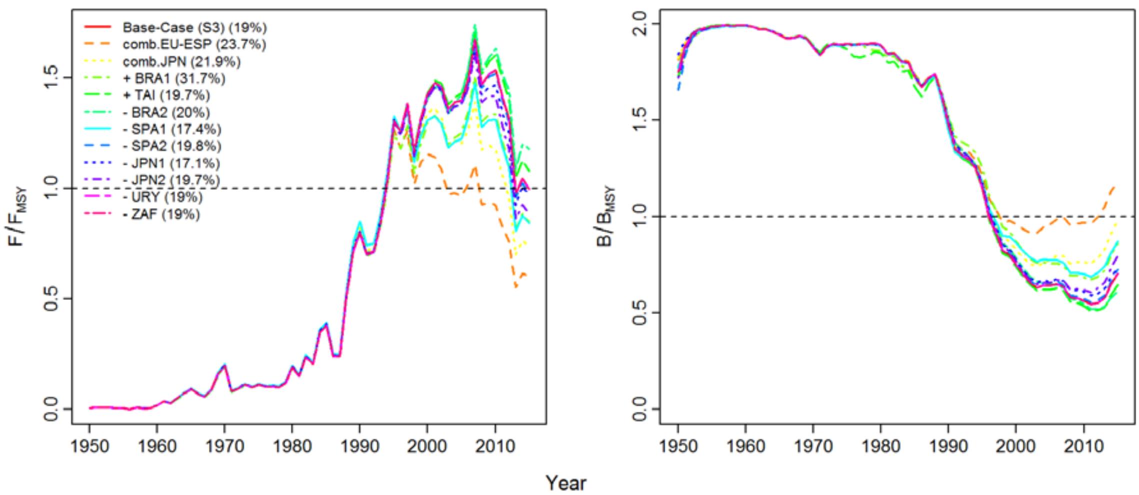


Figure 28. Sensitivity runs for JABBA for F/F_{MSY} and B/B_{MSY} (described in **Table 8** of this report) with respect the to the Schaefer base-case Scenario adopted for the South Atlantic swordfish base-case scenario. % indicate RMSE of the fits.

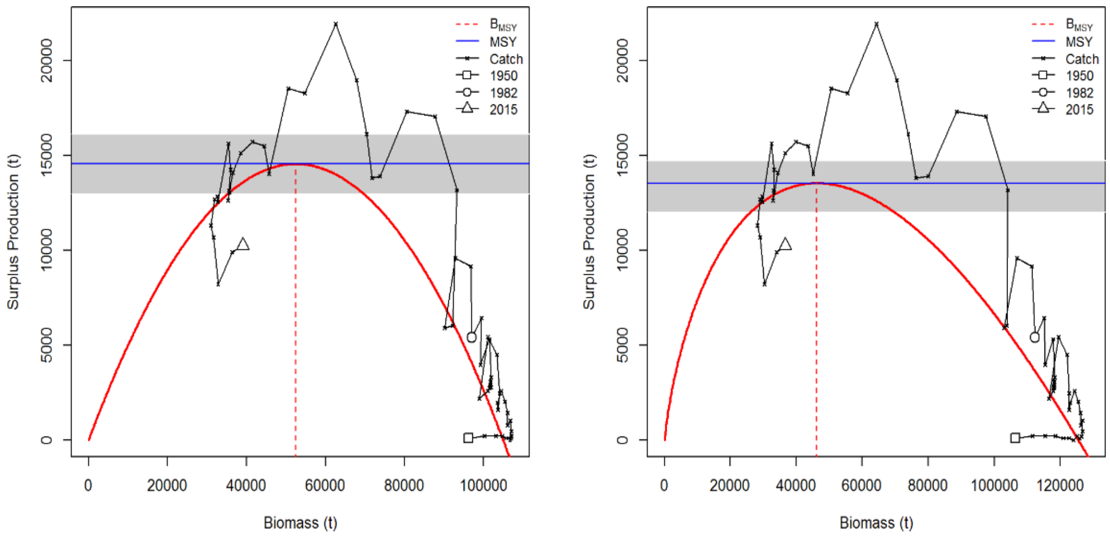


Figure 29. Estimated surplus production curves and catch trajectories as a function of biomass shown for the Schaefer* (left) and Fox (right) models over the period 1950-2015 for the South Atlantic swordfish JABBA stock assessment base-case scenario. MSY estimates are illustrated with 95% C.I.s (grey shaded area). *Schaefer formulation is used as final base-case model.

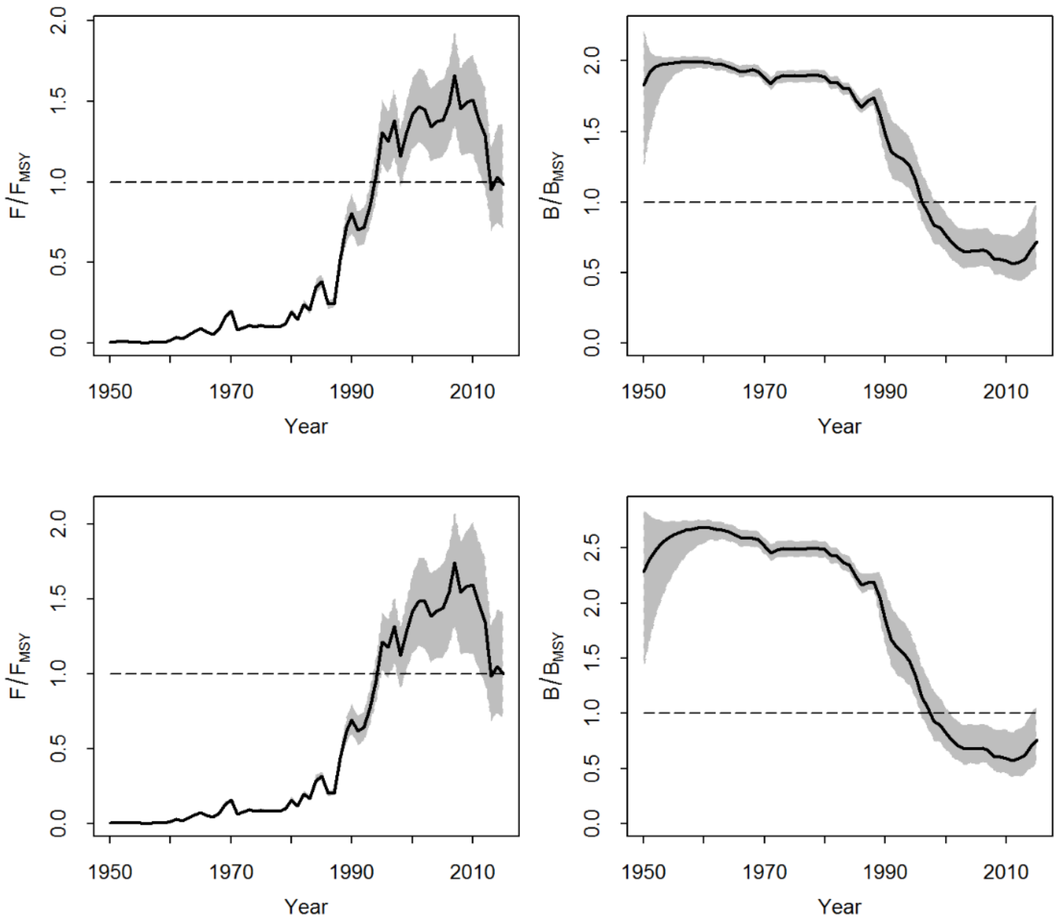


Figure 30. Trends of F/F_{MSY} and B/B_{MSY} for the period 1950-2015 for the South Atlantic swordfish stock assessment base-case scenario using the Schaefer* (top panel) and Fox (bottom panel) JABBA models. *Schaefer formulation is used as final base-case model. Grey shading indicates 95% credibility intervals.

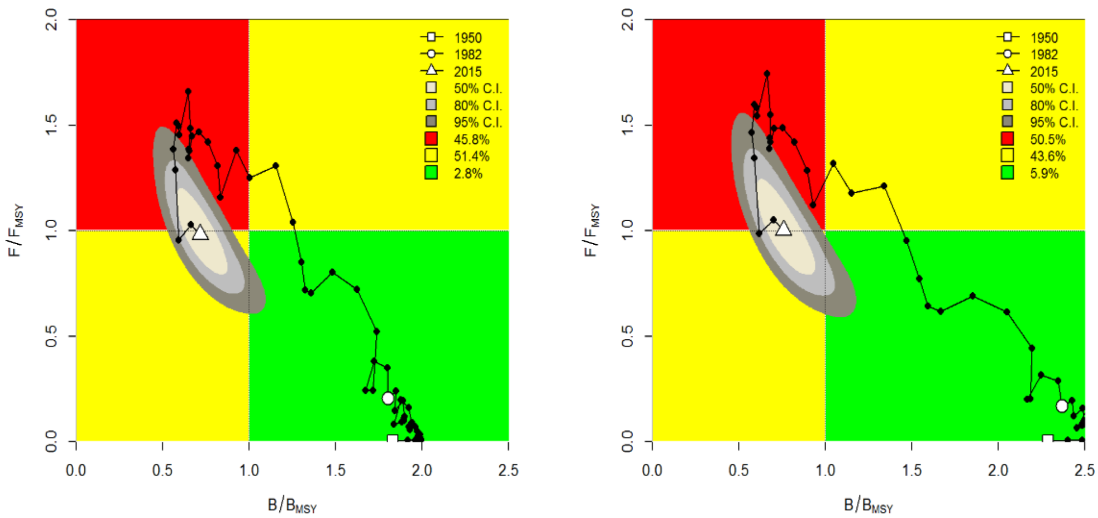


Figure 31. Kobe plots for the JABBA Schaefer* (left) and Fox (right) models, showing the estimated trajectories (1950-2015) of B/B_{MSY} and F/F_{MSY} for the base-case scenario for the South Atlantic swordfish stock assessment. Different grey shaded areas denote the 50%, 80% and 95% credibility interval for the final assessment years. *Schaefer formulation is used as final base-case model. The proportion of points falling within each quadrant is indicated in the figure legend.

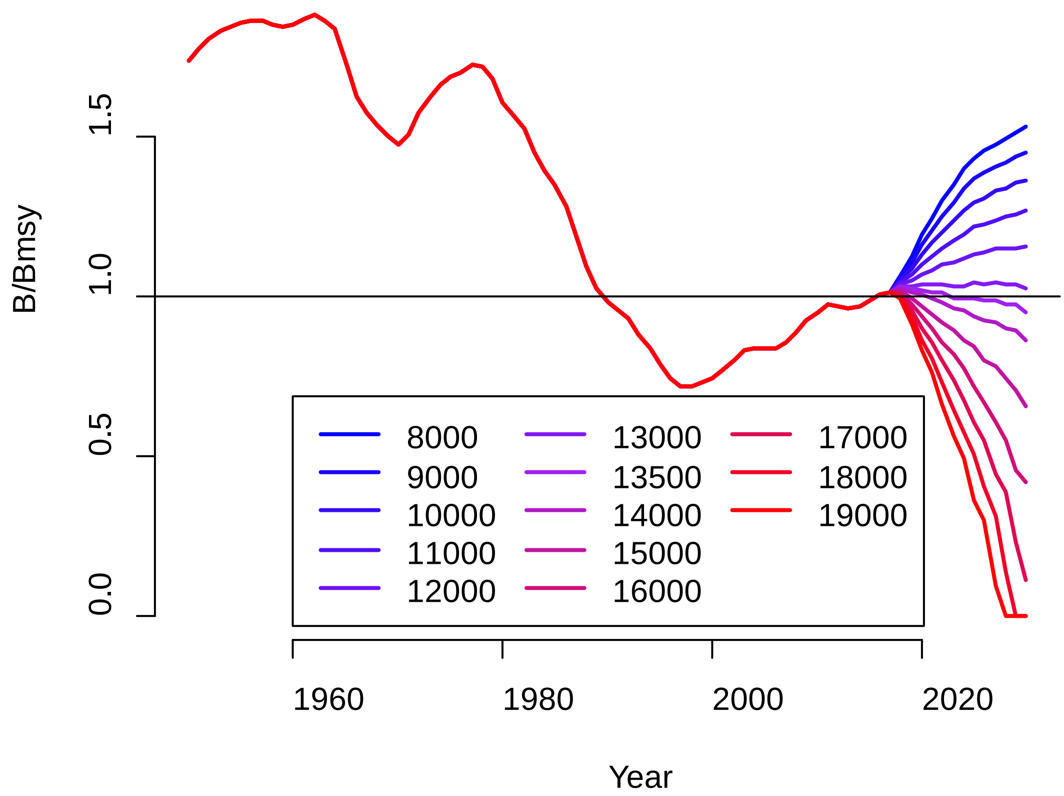


Figure 32. Projections for B/B_{MSY} of North Atlantic swordfish base case, which is the BSP2 Schaefer model, for various levels of future catch.

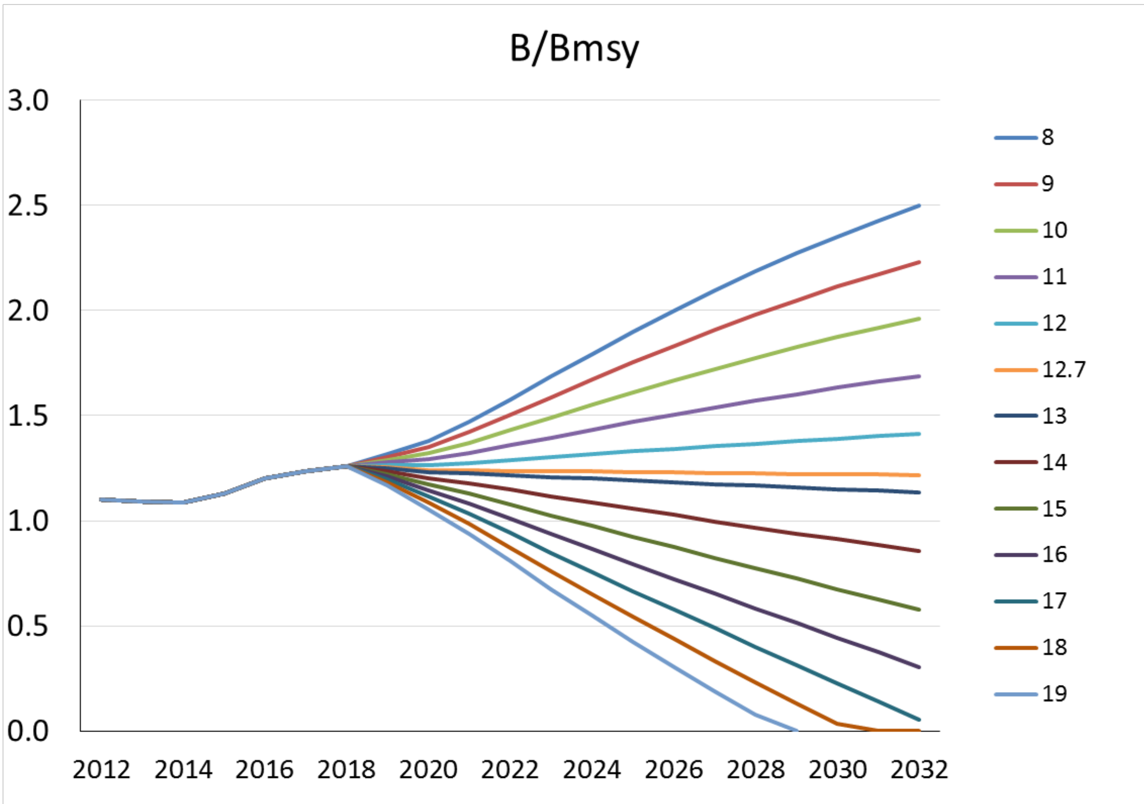


Figure 33. Projections for B/B_{MSY} of North Atlantic swordfish from the SS model for various levels of future catch.

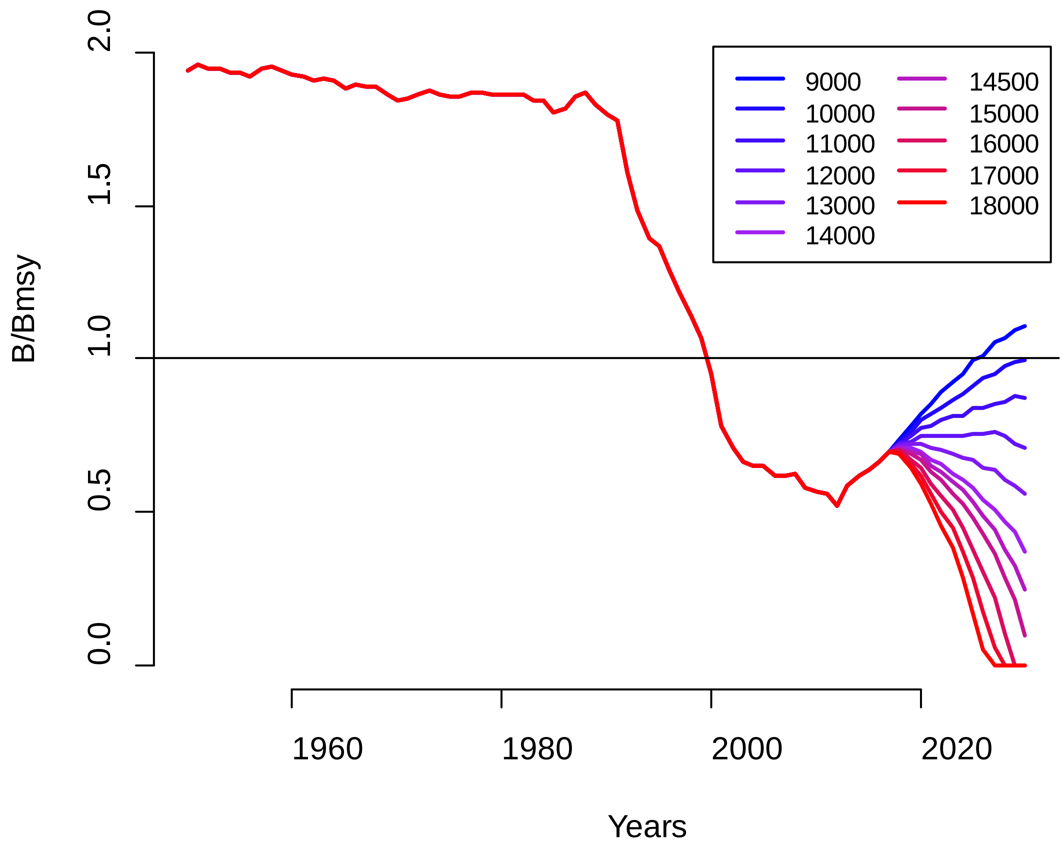


Figure 34. Projections for B/B_{MSY} of South Atlantic swordfish BSP2 Schaefer model, for various levels of future catch.

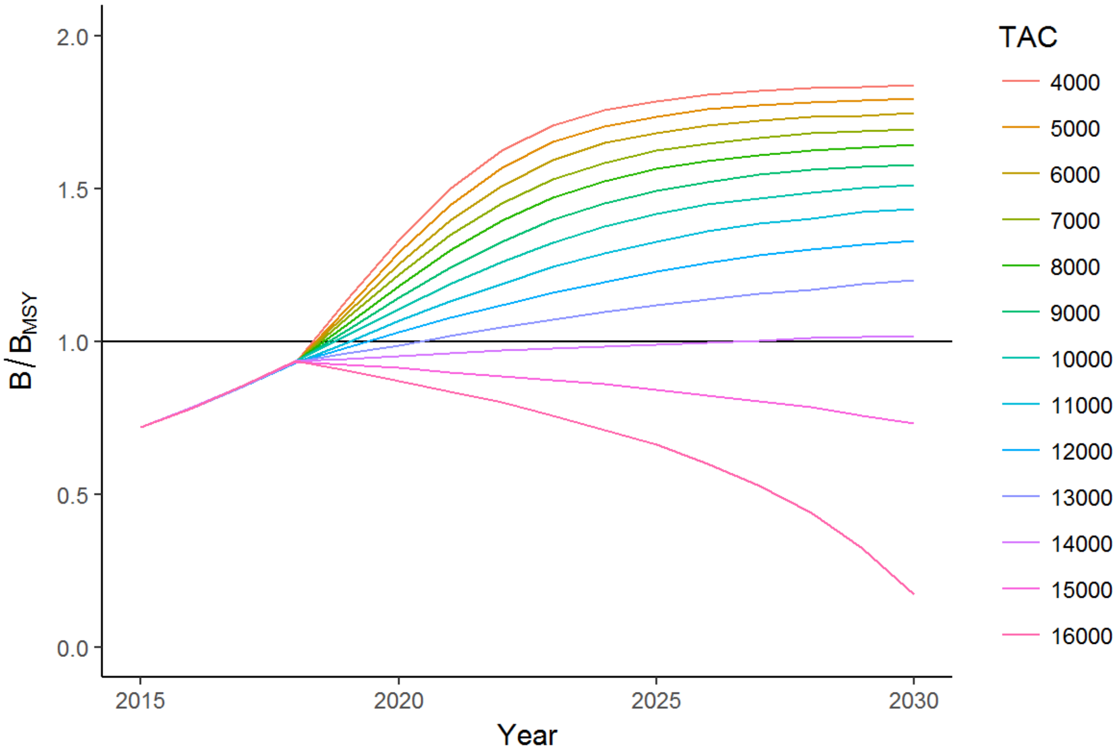


Figure 35. Projections based on the Schaefer model base case for South Atlantic swordfish for various levels of future catch. The initial catch for the years 2016-2017 was set to the 2016 preliminary total catch reports of 10,056 t. The dashed line denotes B_{MSY}.

Appendix 1

Agenda

1. Opening, adoption of Agenda and meeting arrangements

2. Summary of available data submitted by the assessment data deadline (30 April, 2017)

   2.1 Catches
   2.2 Biology
   2.3 Length compositions
   2.4 Other relevant data

3. Catch data, including catch at size and fisheries trends

4. Relative abundance indices: overview of indexes to be used - provided CPUE index by the data deadline (30 April, 2017)

   4.1 Relative abundance indices – North
   4.2 Relative abundance indices – South

5. Methods and other data relevant to the assessment

   5.1 Methods – North
   5.2 Methods – South

6. Stock status results

   6.1 Stock status – North
   6.2 Stock status – South

7. Projections

   7.1 Projections – North
   7.2 Projections – South

8. Limit reference points

9. Recommendations

   9.1 Research and Statistics
   9.2 Management

10. Other matters

11. Adoption of the report and closure

Appendix 2

List of Participants

CONTRACTING PARTIES

BRAZIL
Andrade, Humber
UFRPE/DEPAq, Laboratório de Modelagem Estatística Aplicada (MOE), Rua Dom Manuel de Medeiros, s/n, Dois Irmaos, 52171.900 Recife-PE
Tel: + 55 81 3320 6530, Fax: + 55 81 3320 6501, E-Mail: humber.andrade@gmail.com

CANADA
Hanke, Alexander
Scientific, St. Andrews Biological Station/ Biological Station, Fisheries and Oceans Canada, 531 Brandy Cove Road, St. Andrews New Brunswick E5B 2L9
Tel: +1 506 529 5912, Fax: +1 506 529 5862, E-Mail: alex.hanke@dfo-mpo.gc.ca

Melvin, Gary
Biological Station - Fisheries and Oceans Canada, Department of Fisheries and Oceans, 531 Brandy Cove Road, St. Andrews, New Brunswick E5B 2L9
Tel: +1 506 529 5874, Fax: +1 506 529 5862, E-Mail: gary.melvin@dfo-mpo.gc.ca

CÔTE D'IVOIRE
Bahou, Laurent
Chercher Hydrobiologiste, Centre de Recherches Océanologiques de Côte d'Ivoire, 29 Rue des pêcheurs, Treinchville, BP V 18 Abidjan 01
Tel: +225 084 02024, Fax: +225 213 51155, E-Mail: lbahoucrothon@yahoo.fr

EUROPEAN UNION
Coelho, Rui
Portuguese Institute for the Ocean and Atmosphere, I.P. (IPMA), Avenida 5 de Outubro, s/n, 8700-305 Olhão, Portugal
Tel: +351 289 700 504, E-Mail: rpcoelho@ipma.pt

Fernández Costa, Jose Ramón
Ministerio de Economía y Competitividad, Instituto Español de Oceanografía - C. Costero de A Coruña, Paseo Marítimo Alcalde Francisco Vázquez, 10 - P.O. Box 130, 15001 A Coruña, Spain
Tel: +34 981 218 151, Fax: +34 981 229 077, E-Mail: jose.costa@co.ieo.es

Ortiz de Urbina, José María
Ministerio de Economía y Competitividad, Instituto Español de Oceanografía, C. O de Málaga, Puerto Pesquero s/n, 29640 Fuengirola Málaga, Spain
Tel: +34 952 197 124, Fax: +34 952 463 808, E-Mail: urbina@ma.ieo.es

Rosa, Daniela
IPMA - Portuguese Institute for the Ocean and Atmosphere, Av. 5 de Outubro s/n, 8700-305 Olhao, Portugal
Tel: +351 289 700 500, E-Mail: daniela.rosa@ipma.pt

JAPAN
Satoh, Keisuke
Tuna Fisheries Resources Group, Tuna and Skipjack Resources Division, National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency, 5-7-1, Chome Orido, Shizuoka-Shi Shimizu-Ku 424-8633
Tel: +81 54 336 6044, Fax: +81 54 335 9642, E-Mail: kstu21@fra.affrc.go.jp

MOROCCO
Abdellah, Ikkiss
Centre régional de l'Institut national de Recherche Halieutique, Dakhda
Tel: +212 662 276 541, E-Mail: ikkiss.abdel@gmail.com

Zahraoui, Mohamed
Ingénieur en Chef à la Division de la Protection des Ressources Halieutiques, Ministère de l'Agriculture et de la Pêche Maritime, Service de l'Application de la Réglementation et de la Police Administrative, Nouveau Quartier Administratif, BP 476, Haut Agdal, Rabat
Tel: +212 666 155999, Fax: +212 537 688 134, E-Mail: zahraoui@mpm.gov.ma; zahraouiay@gmail.com

NAMIBIA
Kathena, Johannes Nduvudi
Senior Fisheries Biologist, Ministry of Fisheries and Marine Resources - NatMIRC, Strand Street, Box 912, Swakopmund
Tel: +264 64 410 1000, Fax: +264 64 404 385, E-Mail: John.Kathena@mfmr.gov.na

SOUTH AFRICA
Parker, Denham
Department of Agriculture, Forestry and Fisheries (DAFF), Fisheries Branch, 8012 Foreshore, Cape Town
Tel: +27 21 402 3165, E-Mail: DenhamP@DAFF.gov.za

Winker, Henning
Scientist: Research Resource, Centre for Statistics in Ecology, Environment and Conservation (SEEC), Department of Agriculture, Forestry and Fisheries (DAFF), Fisheries Branch, 8012 Foreshore, Cape Town
Tel: +27 21 402 3515, E-Mail: henningW@DAFF.gov.za; henning.winker@gmail.com

UNITED STATES
Babcock, Elizabeth
Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami Florida 33133
Tel: +1 305 421 4852, Fax: +1 305 421 4600, E-Mail: ebabcock@rsmas.miami.edu

Brown, Craig A.
Chief, Highly Migratory Species Branch, Sustainable Fisheries Division, NOAA Fisheries Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami Florida 33149
Tel: +1 305 586 6589, Fax: +1 305 361 4562, E-Mail: craig.brown@noaa.gov

Díaz, Guillermo
NOAA-Fisheries, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami Florida 33149
Tel: +1 305 898 4035, E-Mail: guillermo.diaz@noaa.gov

Schirripa, Michael
NOAA Fisheries, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami Florida 33149
Tel: +1 305 361 4568, Fax: +1 305 361 4562, E-Mail: michael.schirripa@noaa.gov

URUGUAY
Forselledo, Rodrigo
Dirección Nacional de Recursos Acuáticos - DINARA, Laboratorio de Recursos Pelágicos, Constituyente 1497, 11200 Montevideo
Tel: +598 2400 46 89, Fax: +598 2401 32 16, E-Mail: rforselledo@gmail.com

VENEZUELA
Arocha, Freddy
Instituto Oceanográfico de Venezuela, Universidad de Oriente, A.P. 204, 6101 Cumaná Estado Sucre
Tel: +58-293-400-2111 - movil: 58 416 693 0389, Fax: E-Mail: farocha@udo.edu.ve; farochap@gmail.com

OBSERVERS FROM COOPERATING NON-CONTRACTING PARTIES, ENTITIES, FISHING ENTITIES

CHINESE TAIPEI
Su, Nan-Jay
Assistant Professor, Department of Environmental Biology and Fisheries Science, No. 2 Pei-Ning Rd. Keelung
Tel: +886 2 2462-2192 #5046, E-Mail: nanjay@ntou.edu.tw

OBSERVERS FROM NON-GOVERNMENTAL ORGANIZATIONS

MARINE STEWARDSHIP COUNCIL - MSC
Gascoigne, Joanna (Jo)
MSC, Gwernfor, Spring Hill, Dinas Cross, Newport SA42 0XA, United Kingdom
Tel: +44 749 646 8968, E-Mail: jo.gascoigne@cantab.net

SCRS CHAIRMAN

Die, David
SCRS Chairman, Cooperative Institute of Marine and Atmospheric Studies, University of Miami, 4600 Rickenbacker Causeway, Miami Florida 33149, United States
Tel: +1 673 985 817, Fax: +1 305 421 4221, E-Mail: ddie@rsmas.miami.edu

******

ICCAT Secretariat/ Secrétariat de l'ICCAT/ Secretaría de ICCAT
C/ Corazón de María 8 – 6th floor, 28002 Madrid – Spain
Tel: +34 91 416 56 00; Fax: +34 91 415 26 12; E-mail: info@iccat.int

Neves dos Santos, Miguel
De Bruyn, Paul
Kell, Laurence
Ortiz, Mauricio

Appendix 3

List of Papers and Presentations

Reference	Title	Authors
SCRS/2017/102	North Atlantic swordfish biomass dynamic stock assessment revisited	Kell, L.T.
SCRS/2017/105	Updated standardized catch rates for the North Atlantic stock of swordfish (*Xiphias gladius*) from the Spanish surface longline fleet for the period 1986-2015	García-Cortés B., Ramos-Cartelle A., Fernández-Costa J. and Mejuto J.
SCRS/2017/106	Updated standardized catch rates for South Atlantic stock of swordfish (*Xiphias gladius*) from the Spanish longline fleet for the period 1989-201	Ramos-Cartelle A., García-Cortés B., Fernández-Costa J. and Mejuto J.
SCRS/2017/107	Standardized catch rates in number of fish by age for the North Atlantic swordfish (*Xiphias gladius*) inferred from the Spanish longline fleet for the period 1982-2015	Mejuto J., García-Cortés B., Ramos-Cartelle A. and Fernández-Costa J.
SCRS/2017/127	Model validation using prediction residuals	Kell L.T.
SCRS/2017/133	Creating a Species Distribution Model for Swordfish: Evaluations of Initial Habitat Variables	Goodyear C.P., Schirripa M. and Forrestal F.
SCRS/2017/134	Size distributions of Swordfish (*Xiphias gladius*) in the Caribbean Sea and adjacent waters of the Western Central Atlantic, from observer data of the Venezuelan longline fisheries	Arocha F., Marcano J.H., Evaristo E. and Gutiérrez X.
SCRS/2017/136	Catch-at-size and age analysis for Atlantic swordfish	Hanke A., Kell L.T. and Coelho R.
SCRS/2017/137	Updated combined biomass index of abundance of North Atlantic Swordfish stock 1963-2016	Ortiz M., Mejuto J., Hanke A., Ijima H., Walter J., Coelho R. and Ikkiss A.
SCRS/2017/138	Standardization of the Catch Per Unit of Effort for Swordfish (*Xiphias gladius*) for the South African longline fishery	Parker D., Winker H., West W. and Kerwath S.E.
SCRS/2017/142	Sexual proportion of swordfish (*Xiphias gladius*) caught by Brazilian fleet in Southwest Atlantic	Andrade H.A.
SCRS/2017/143	Resiliency for North Atlantic Swordfish using life history parameters	Sharma R. and Arocha F.
SCRS/2017/144	CPUE standardization of swordfish (*Xiphias gladius*) for the Taiwanese tuna longline fishery in the North Atlantic Ocean for 1968-2015	Su N-J. and Sun C-L.
SCRS/2017/145	Standardizing catch and effort of the Taiwanese distant-water longline fishery in the South Atlantic Ocean swordfish (*Xiphias gladius*), 1968-2015	Su N-J. and Sun C-L.
SCRS/P/2017/023	A North Atlantic swordfish assessment 2017 using stock synthesis	Schirripa M.
SCRS/P/2017/026	Hooking mortality of swordfish, *Xhipias gladius*, caught by longliners in the southwestern Atlantic Ocean	Forselledo R., Mas F. and Domingo A.
SCRS/P/2017/027	JABBA: Just Another Bayesian Biomass Assessment for South Atlantic swordfish	Winker H., Carvalho F., Parker D. and Kerwath S.

Appendix 4

SCRS Document summaries as provided by the authors

SCRS/2017/102 – North Atlantic swordfish was last assessed in 2013 using a biomass stock assessment model coded in the ASPIC software package. Since then ICCAT has developed a harvest control rule using Management Strategy Evaluation using a Management Procedure based on a biomass dynamic stock assessment package implemented in FLR. In this paper we compare the ASPIC and the R based assessments. We also include a range of diagnostics, including the Jackknife, not previously considered at the last assessment.

SCRS/2017/105 – Log-normal Generalized Linear Models (GLM) were used to update the standardized catch rates (in number of fish and weight) of the Spanish surface longline fleet targeting swordfish during the period 1986-2015. Factors such as area, quarter, gear and bait as well as the fishing strategy - based on the ratio between the two most prevalent species and those most highly valued by skippers - were considered. The base case models explained 51% and 53% of CPUE variability in number and weight, respectively.

SCRS/2017/106 – Updated standardized catch rates in number and in weight were obtained using General Linear Modeling (GLM) procedures from trips carried out by the Spanish surface longline fleet fishing the South Atlantic swordfish stock during the period 1989-2015. The criteria used to define factors were similar to those used in previous papers as were the models applied. The results explained 65% and 71% of CPUE variability in number and weight, respectively, pointing to very stable standardized CPUE and mean weight trends over time, with a slight increase of abundance in the last year analyzed. The statistical diagnoses were highly satisfactory.

SCRS/2017/107 – Standardized catch rates in number of fish for ages 1-5+ were updated using log-normal General Linear Modeling (GLM) from trips carried out by the Spanish surface longline fleet targeting swordfish in the North Atlantic stock. Indices were developed for a 34-year period (1982-2015) using a sex-combined growth model for ageing the size data per trip. The criteria used to define areas, time periods and models were similar to those used in previous papers. The models also take into consideration other factors such as gear style and the type of trip (target variable) to allow for the two important changes in fishing strategy which have occurred in recent periods. The base case models explained between 42% and 44% of CPUE variability. The standardized CPUE index for age 1 suggests a very positive phase of recruitments between the years 1997-2012, with an overall mean value of slightly more than double compared to the previous period 1982-1996. This positive phase also had positive effects on other ages.

SCRS/2017/127 – Fisheries management requires decision-making under uncertainty, to take uncertainty about stock dynamics and the quality of data into account stock assessment working groups commonly consider a range of scenarios comprising alternative model structures and datasets. This requires model to be compared and validated. Cross-validation is a technique for evaluating the predictive error of a model by testing it on a set of data not used in fitting. It is conceptually simple, with few parametric or theoretic assumptions, and so can be used for comparisons across different models and datasets. Cross-validation was used to validate stock assessment model scenarios using model-free validation based on prediction residuals, which are the difference between an observation and its out-of-sample predicted value. Examination of prediction residuals for an example based on a biomass dynamic stock assessment of Atlantic swordfish showed that model residuals were not able to identify influential points and the form of the production function was important.

SCRS/2017/133 – This study develops a species distribution model (SDM) for swordfish using a habitat suitability framework. When suitably parameterized, the model is intended to estimate the time-varying, three dimensional (3D) distribution of swordfish habitat that would be useful for many aspects of stock assessment, including visualizing stock boundaries and estimating abundance from catch per unit effort (CPUE) data. Currently, the model integrates ocean depth, annual average estimated total chlorophyll by latitude and longitude, and temperature and oxygen by latitude, longitude, depth, month and year. Model predictions and general distributions of North Atlantic swordfish catches are used as criteria for the inclusion and treatment of variables. Initial trials demonstrated that the habitat cannot be predicted using temperature and oxygen alone. The inclusion of the spatial annual average productivity via chlorophyll markedly improved distribution predictions. The current formulation predicts the north-south seasonal migration in the North Atlantic but also predicts high abundance in areas of low swordfish catch. Better, time-varying data for ecosystem productivity relevant to swordfish might resolve this problem, but important habitat features may also be missing.

SCRS/2017/134 – Swordfish (*Xiphias gladius*) is caught by the Venezuelan large pelagic fisheries over the past 29 years. The document analyzes the size distribution of swordfish caught by the pelagic longline fishery, namely, the industrial/tuna pelagic longline for the period of 1987-2016, recorded by at-sea scientific observers. A total of 9,327 swordfish records collected were analyzed. Sizes recorded ranged between 41 and 300 cm LJFL. The mean annual sizes were 140.5 cm LJFL for females (n=4577) and 129.8 cm LJFL for males (n=4120); a group of 630 fish with no sex id had a mean annual size of 111.7 cm LJFL, most likely juvenile fish. The largest volume of the overall swordfish catch was around 120 cm LJFL. The size variability in the mean size of males and females was evident in across years and season (months). Annual and seasonal mean sizes of females and males varied between swordfish target fishing years and non-target years.

SCRS/2017/136 – Analyses of the Task II Atlantic swordfish data provide insights into the change in selectivities, Z, size and age composition of both the northern and southern Atlantic swordfish stocks.

SCRS/2017/137 – Surplus Production Models of North Atlantic swordfish have been used in addition to age structured virtual population analyses by ICCAT's SCRS to evaluate the status of the resource and to provide a basis for management advice. Production models require a standardized index of relative abundance in terms of biomass. The standardized biomass index of abundance developed for the 2006, 2008 and 2012 ICCAT-SCRS meetings for north Atlantic swordfish was revised and updated with data through 2015. Generalized Linear Modeling (GLM) procedures were used to standardize swordfish catch (biomass) and effort (number of hooks) data from the major longline fleets operating in the North Atlantic; United States, Spain, Canada, Japan, Morocco and Portugal. As in past analyses, main effects included: year, area, quarter, a nation-operation variable accounting for gear and operational differences thought to influence swordfish catchability, and a target variable to account for trips where fishing operations varied according to the main target species. Interactions among main factors were also evaluated.

SCRS/2017/138 – Swordfish, *Xiphias gladius* is a target species in the South African pelagic longline fleet operating along the west and east coast of South Africa. A standardization of the swordfish CPUE of the South African longline fleet for the time series 2004-2015 was carried out with a Generalized Additive Mixed Model (GAMM) with a Tweedie distributed error. Explanatory variables of the final model included year, month, geographic position (Lat, Long) and a targeting factor with 2 levels, derived by clustering of PCA scores of the root-root transformed, normalized catch composition. Vessel was included as a random effect. Swordfish CPUE had a definitive seasonal trend, with catch rates higher in winter and lower in summer. The standardised CPUE analysis indicates a consistently declining trend over the period 2004-2012, followed by a notable increase between 2012 and the final assessment year 2015.

SCRS/2017/142 – Sexual proportion of swordfish (*Xiphias gladius*) caught in the west of South Atlantic was estimated based on information gathered by the Brazilian Program of Onboard Observers. Proportion of females was higher in the south sector, while the proportion of males was higher in west equatorial sector. Overall the results indicate that there are, to some extent, an spatial sexual segregation during most of the year. Proportions of females and males did not change much over the years. In the mid (along the 30ºW meridian) of South Atlantic proportions of females in the catches of boats leased from Honduras and Spain were higher than in the catches of boats leased from Morocco and Panama.

SCRS/2017/143 – North Atlantic SWO have been fished at high F/s until recently, this reduction in fishing pressure rebuilt the populations, and is touted as a success story in ICCAT management. However, reasons for this are not well understood, and we take a mathematical approach to estimating steepness based on life history data and studies, and then use that information in assessing resiliency in time of rebuilding to target and limit reference points for this stock. Steepness is implicitly a very important parameter in this and its effect on resiliency is quantified. In addition, we quantify a construct to assess risk to the stock and the fishery. Reference points set undue burden on either the fisherman or the conservationists, and balancing these risks in a mathematical construct is presented here. While 0.4 BMSY maybe a good target for a limit it creates a high type II error, i.e. failing to protect the stock when needed 80% of the time. If we try to reduce this risk, it increases the risk to a loss in yield when it is not required. We suggest a limit around 0.6 SMSY for this stock so as to balance the risk between the resource and the fishery.

SCRS/2017/144 – Catch and effort data of swordfish (*Xiphias gladius*) for the Chinese Taipei distant-water tuna longline fishery in the North Atlantic Ocean were standardized for 1968-2015 and by period using a generalized linear model (GLM). Four periods of 1968-2015, 1968-1989, 1990-2015 and 1997-2015 and information on operation type (the number of hooks per basket, HPB, for the model of 1997-2015) were considered in the standardization of CPUE (catch per unit effort) to address the issue of targeting change in this fishery. Abundance indices developed for swordfish for 1968-1989, 1990-2015 and 1997-2015 showed almost identical trends to those derived from the model of entire period (1968-2015). Results were insensitive to the inclusion of gear configuration (HPB) in the model as an explanatory variable. The standardized CPUE trend of swordfish started to decrease in the early 1970s, with another following slight decrease during the 1980s, but suddenly increased to a higher level during the early 1990s due to the targeting change and dropped sharply in the late 1990s, and then the trend stabilized from 1997 until present.

SCRS/2017/145 – Catch and effort data of the Chinese Taipei distant-water tuna longline fishery in the South Atlantic Ocean were standardized for swordfish (*Xiphias gladius*) by applying a generalized linear model (GLM). Four periods (1968-2015, 1968-1990, 1991-2015 and 1998-2015) and the information on operation type (i.e. number of hooks per basket, HPB) 1998-2015 were considered in the standardization of CPUE (catch per unit effort) for swordfish to address the issue of targeting change for this fishery. The standardized CPUE of swordfish for 1968-1990 and 1991-2015 were almost identical to the results based on the model applied for the entire period (1968-2015). Inclusion of HPB in the model for 1998-2015 produced similar and consistent trends, with a slight difference in the late 1990s, to that for the 1968-2015. In general, the standardized CPUE series for the South Atlantic swordfish showed a decreasing trend through the 1970s, and relatively stabilized during the 1980s, and then decreased from the early 1990s, with a drop to a lower level in the late 1990s, and stabilized from 1998 until present.

Appendix 5

BioDyn Model formulation and results

A continuity run was performed using the same setting as in the 2013 assessment, but with the latest dataset, i.e. catch and the combined CPUE up to and including 2015. **Figure 1** contrasts the 2013 run where a logistic production was assumed with two runs using the 2015 data set, for both a logistic and skewed (e.g. Fox) production functions. **Figure 2** shows the production functions and the stock/yield trajectories. **Figure 3** shows the time series relative to reference points. Likelihood profiles are shown for r in **Figure 4** for the two model scenarios using the latest dataset, and in **Figure 5** for the shape parameter.

Model residual diagnostics are shown in **Figures 6 to 10. Figures 11 and 12** show the production functions and trajectories for a retrospective analysis. In the case of the logistic function there is a change in B_{MSY} and MSY as more years are included in the analysis.

Influence diagrams showing the residual plotted against leverage, with the size of points equal to Cook's Distance statistic, which is a measure of the influence of a point, are presented in **Figure 13.** While **Figure 14** shows the DF Betas for r and K for each scenario, **Figure 15** compares DF Beta with Cook´s D. **Figure 16** plots the production function for the logistic and skewed production functions, and the historic trajectory was also shown. **Figure 17 and 18** compare models and prediction residuals. If the variance of the model residuals is significantly lower than the prediction residuals then this would suggest over fitting. Finally **Figure 19** compares the prediction residuals for different lengths of tail cutting. **Figure 20** shows the bootstraps, **Figure 21** the Kobe phase plot, and **Figure 22** the projections.

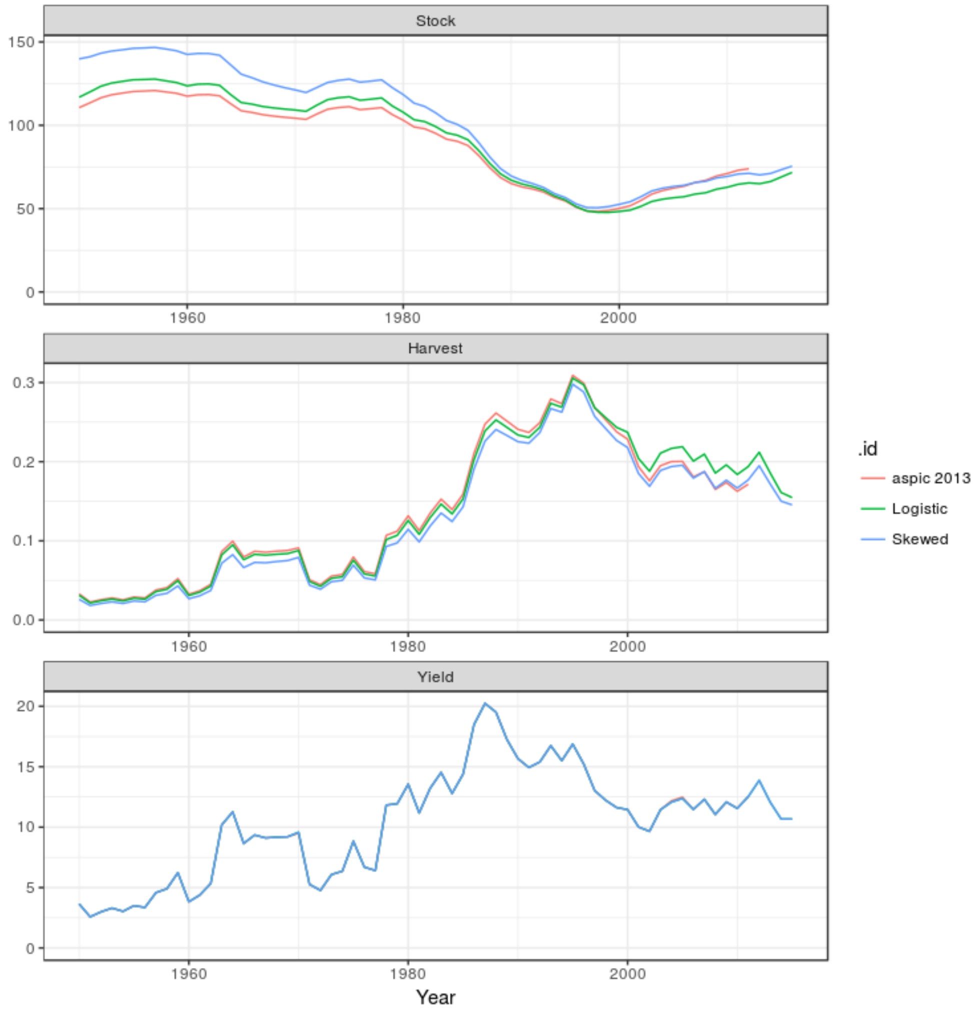


Figure 1. A comparison between the logistic production function, and a Pella-Tomlinson production function where the shape parameter was set to 0.001.

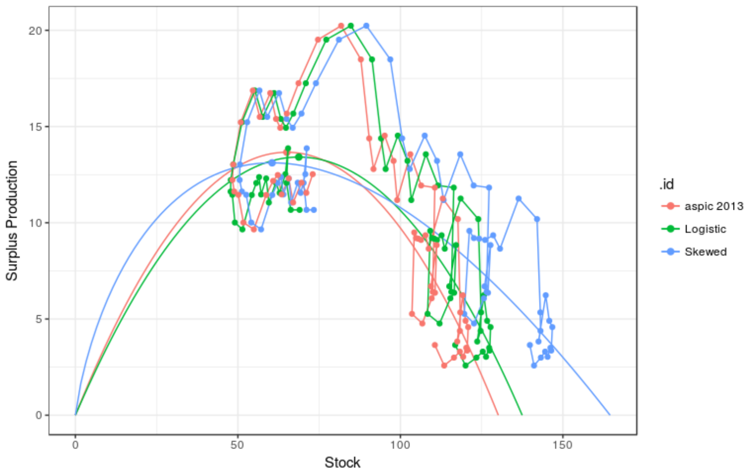


Figure 2. Production functions with historical trajectories.

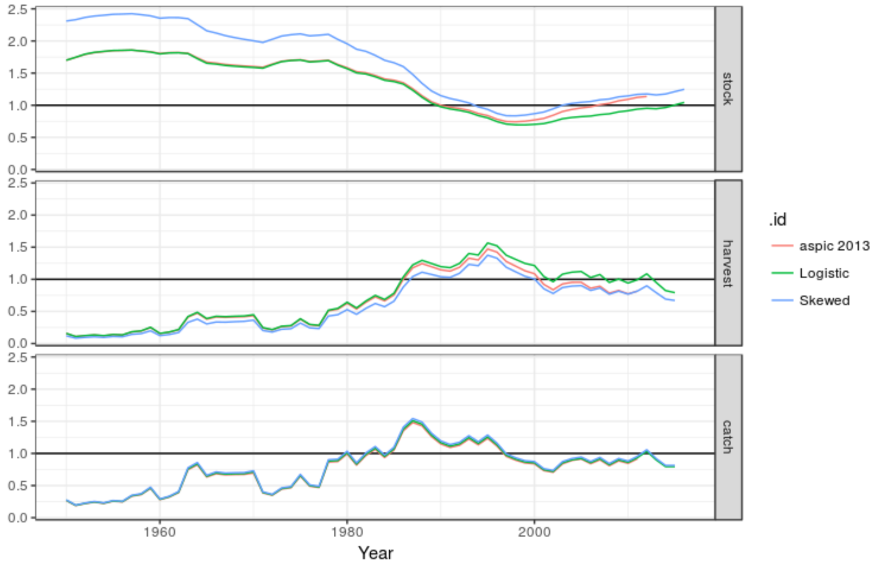


Figure 3. Time series relative to reference points.

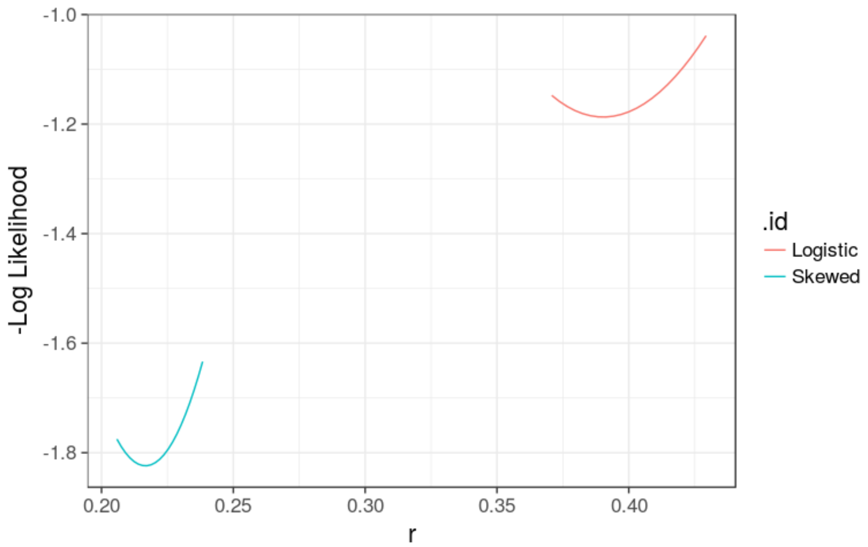


Figure 4. Likelihood profiles for r.

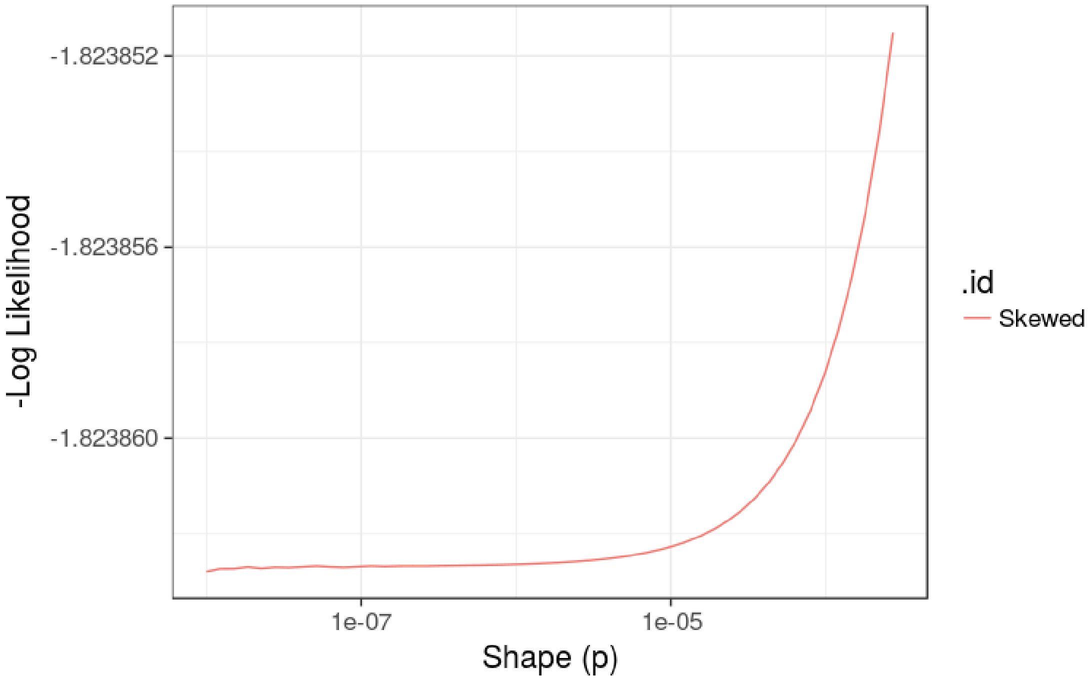


Figure 5. Likelihood profile for p.

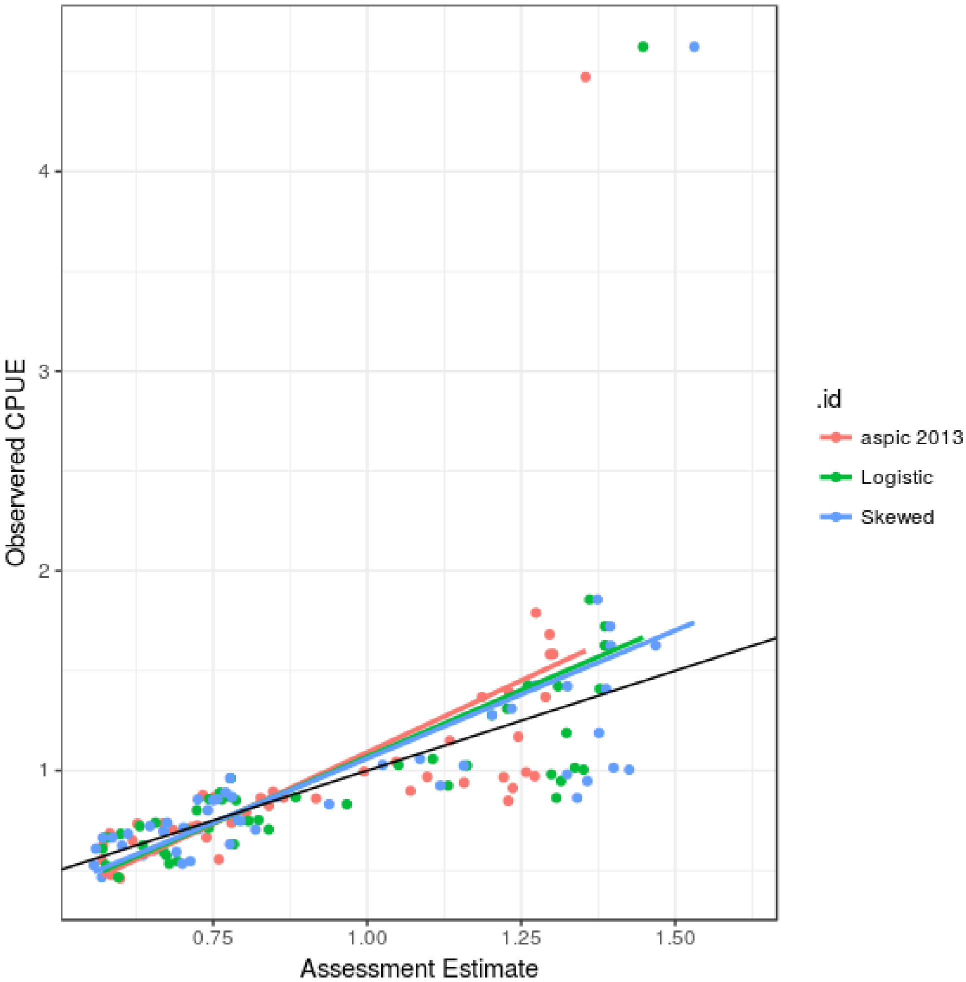


Figure 6. Observed against fitted CPUE points.

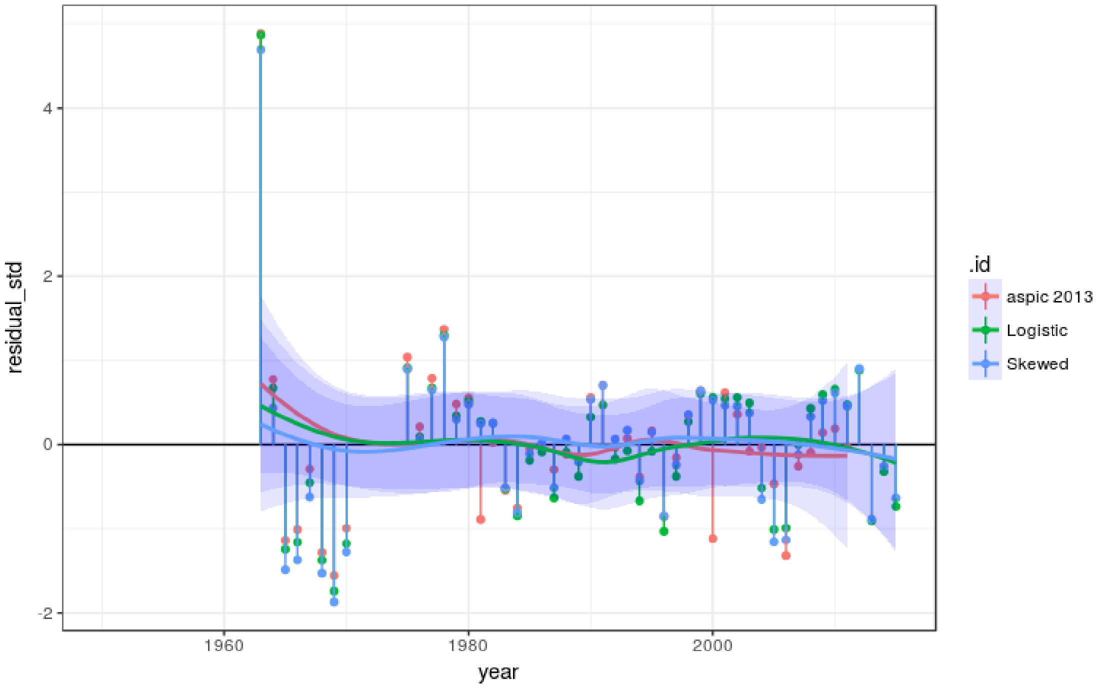


Figure 7. Standardized residuals by year.

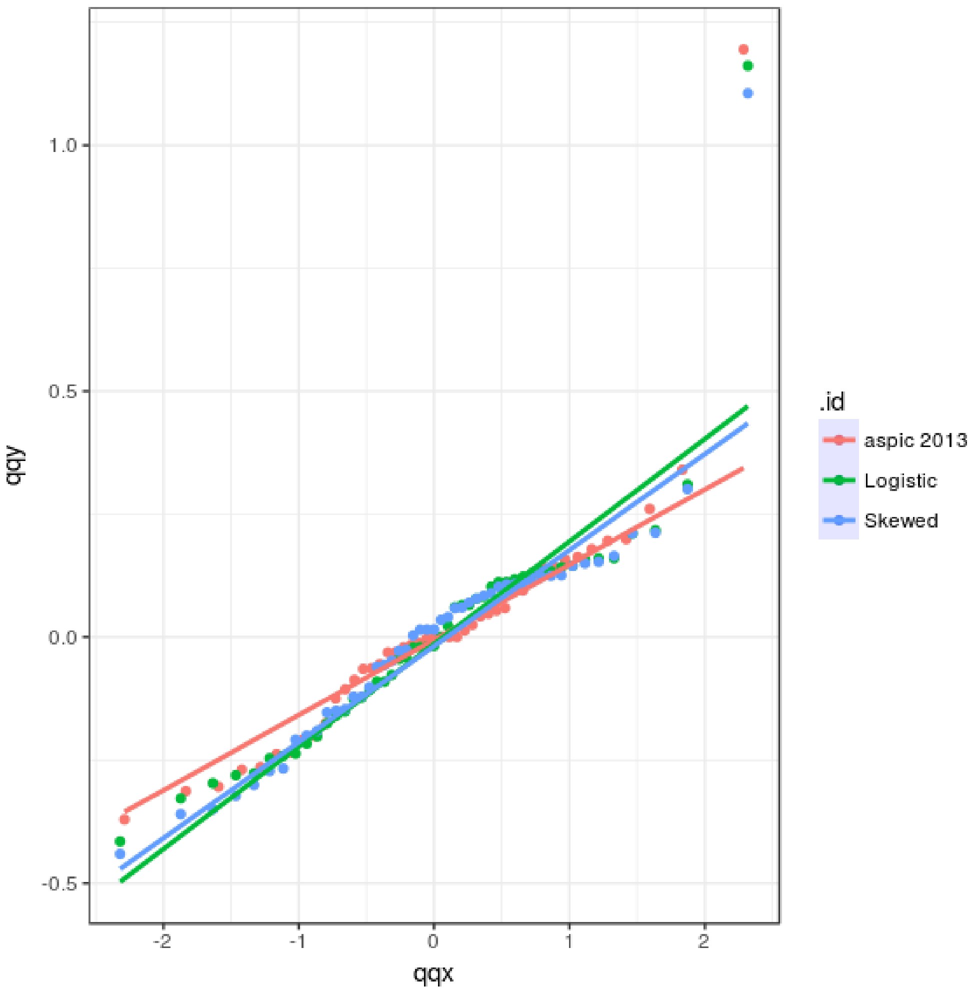


Figure 8. Quantile-quantile plot to check for normality.

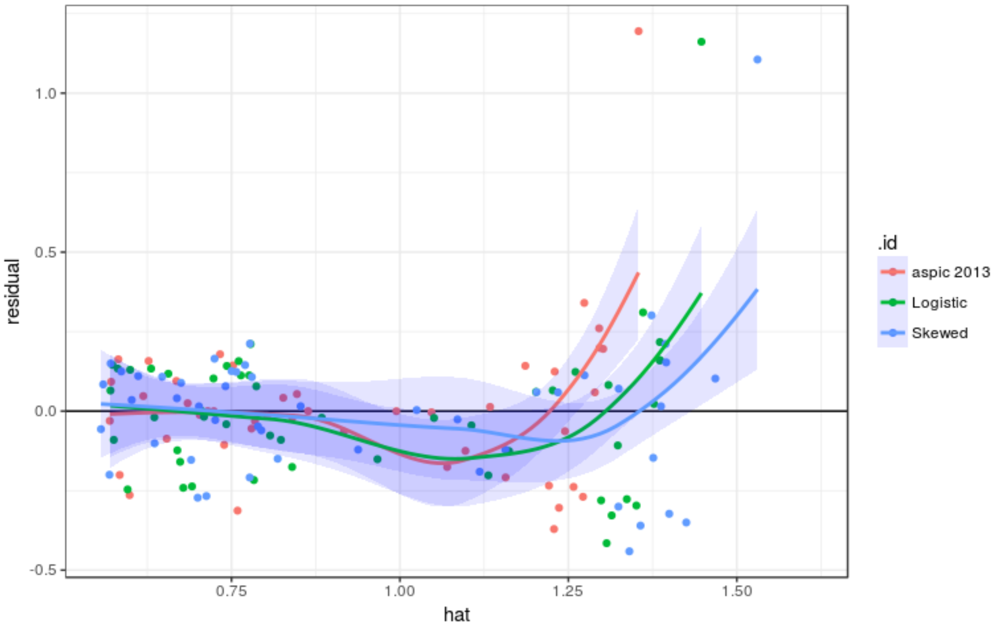


Figure 9. Plot of residuals against fitted values to check variance function.

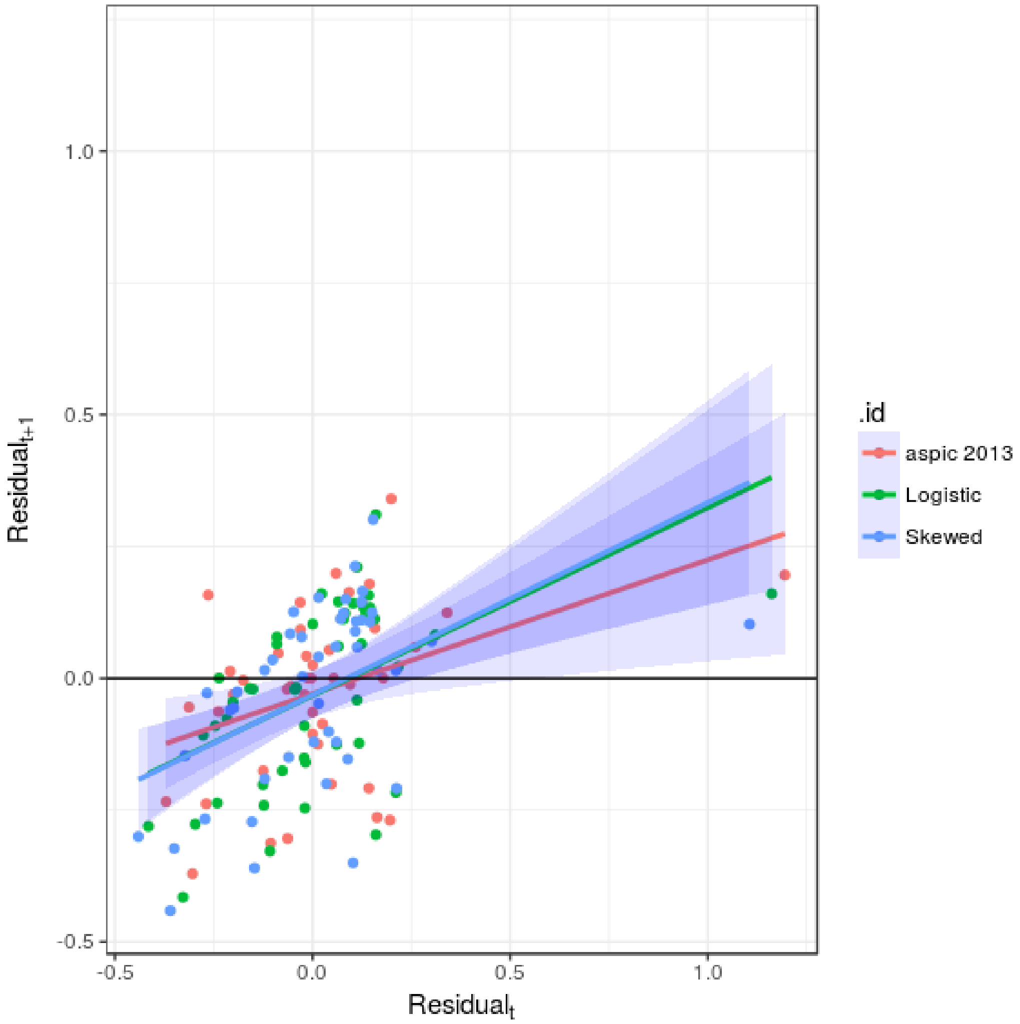


Figure 10. Check for autocorrelation.

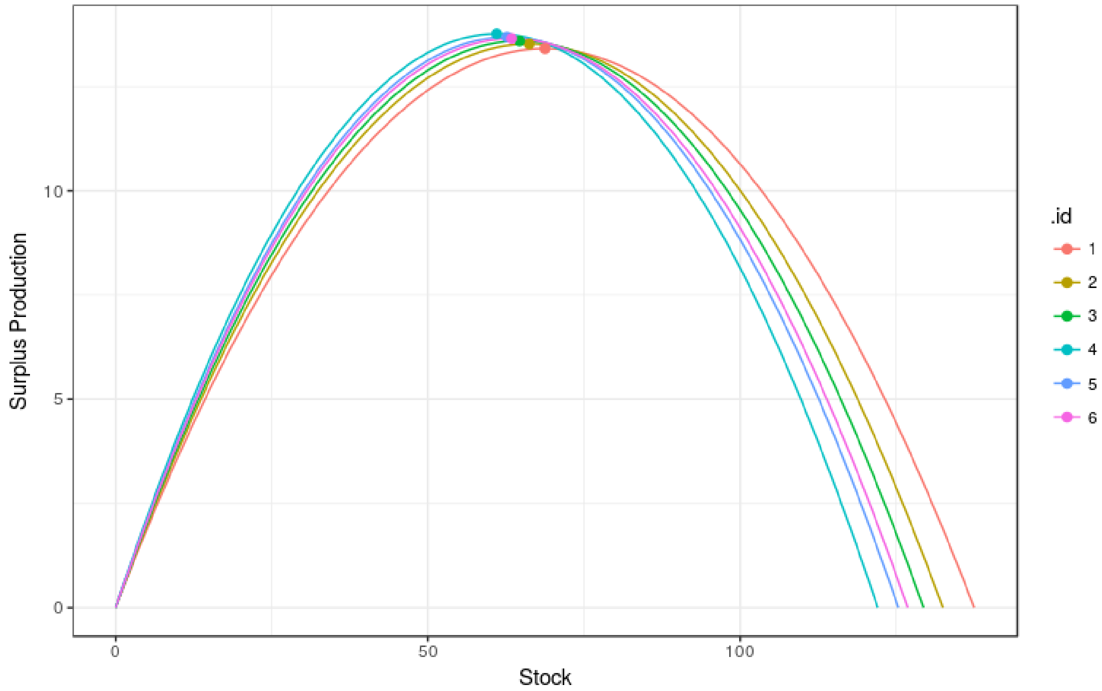


Figure 11. Logistic production functions with from retrospective analysis.

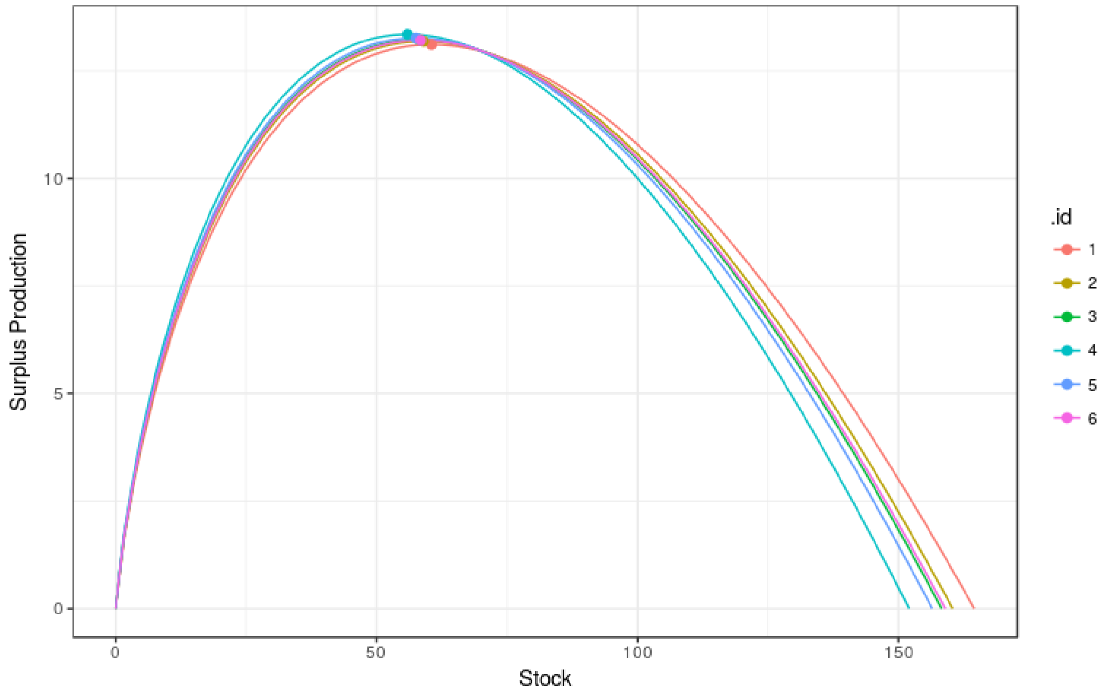


Figure 12. Skewed production functions with from retrospective analysis.

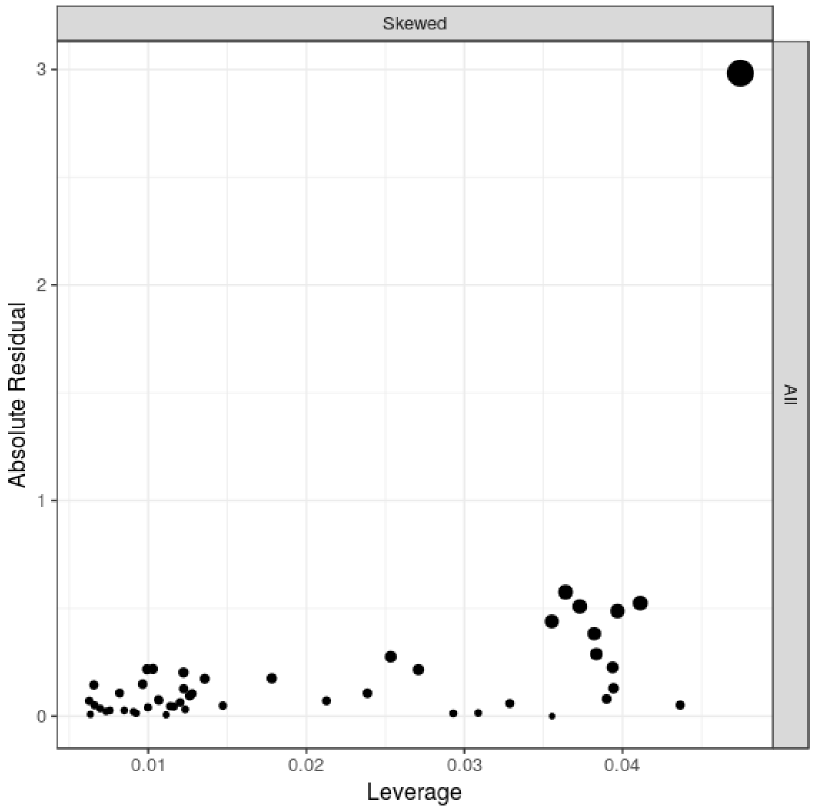


Figure 13. Influence diagrams showing the residual plotted against leverage, the size of points is equal to Cook's Distance statistic, a measure of the influence of a point.

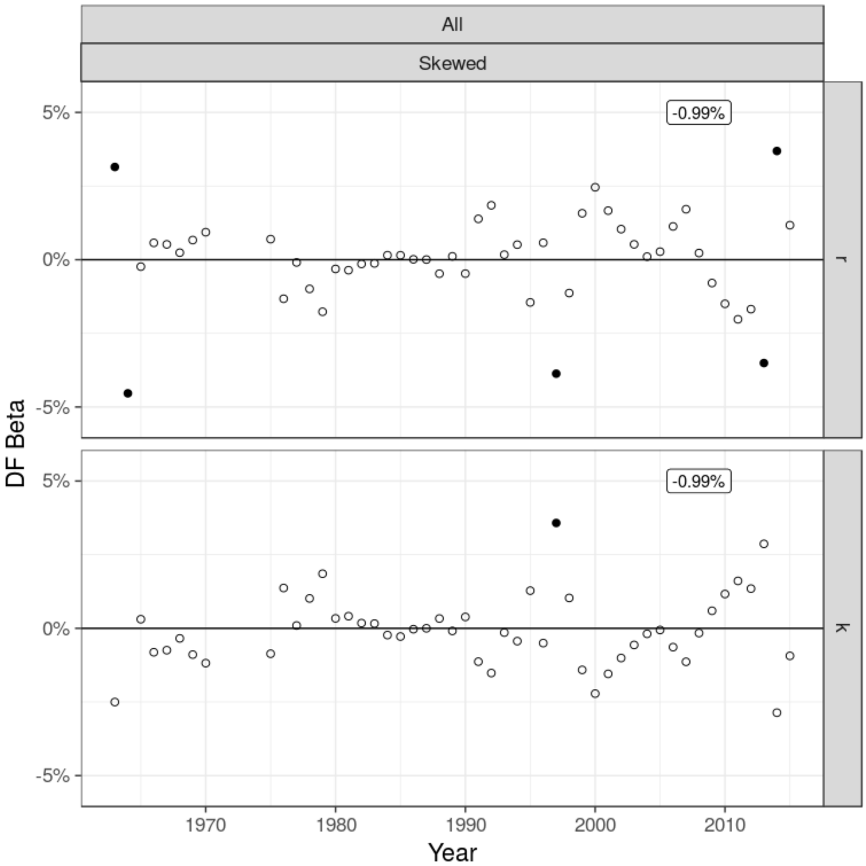


Figure 14. DF Betas from jackknife, by estimated parameters (r and K) for each scenario.

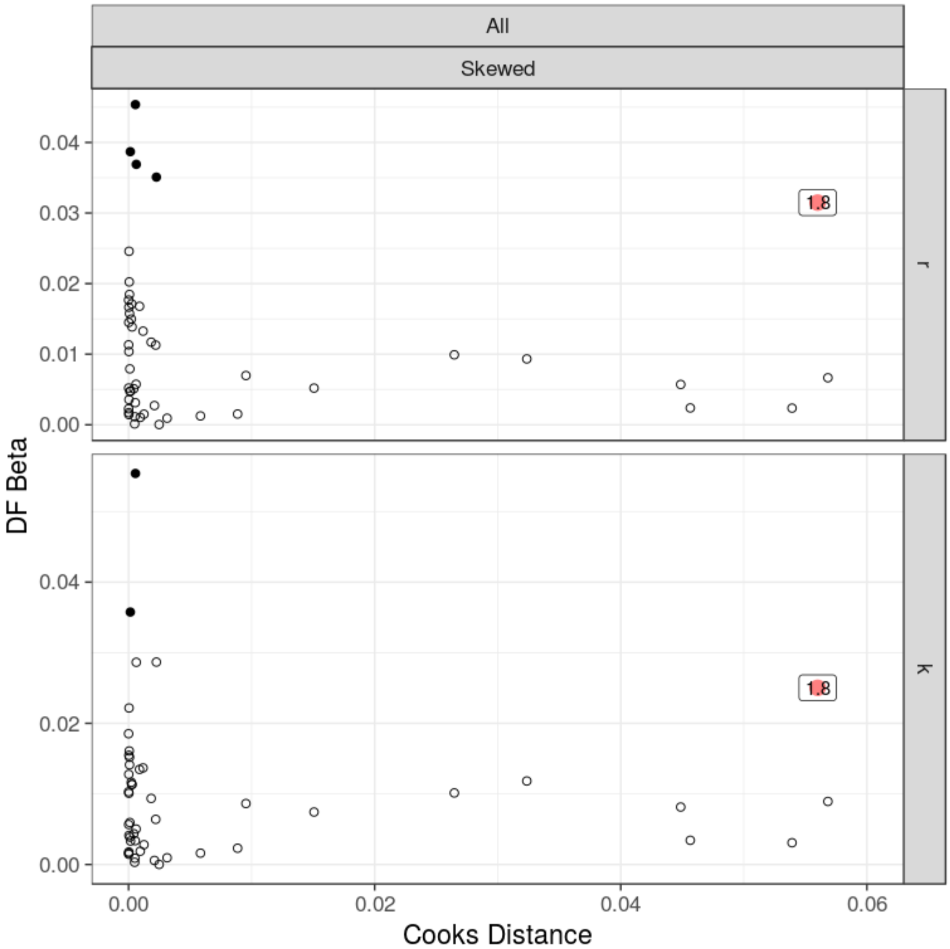


Figure 15. Plots of DF Beta against Cook´s D for the estimated parameters (r and K) for each scenario.

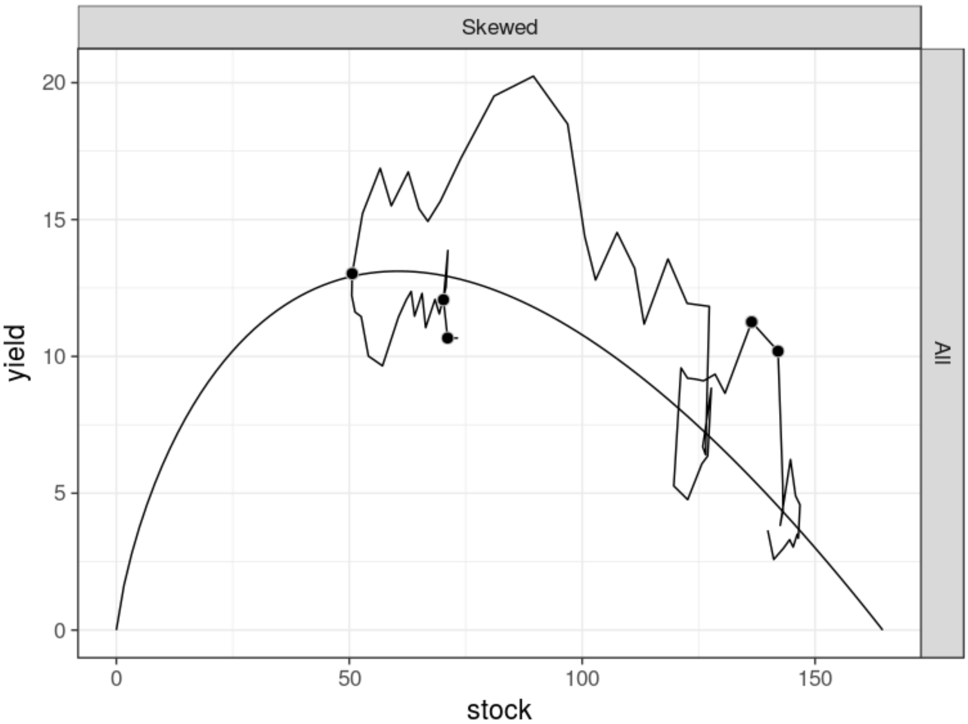


Figure 16. Production function for the logistic and skewed production functions, historic trajectory also shown.

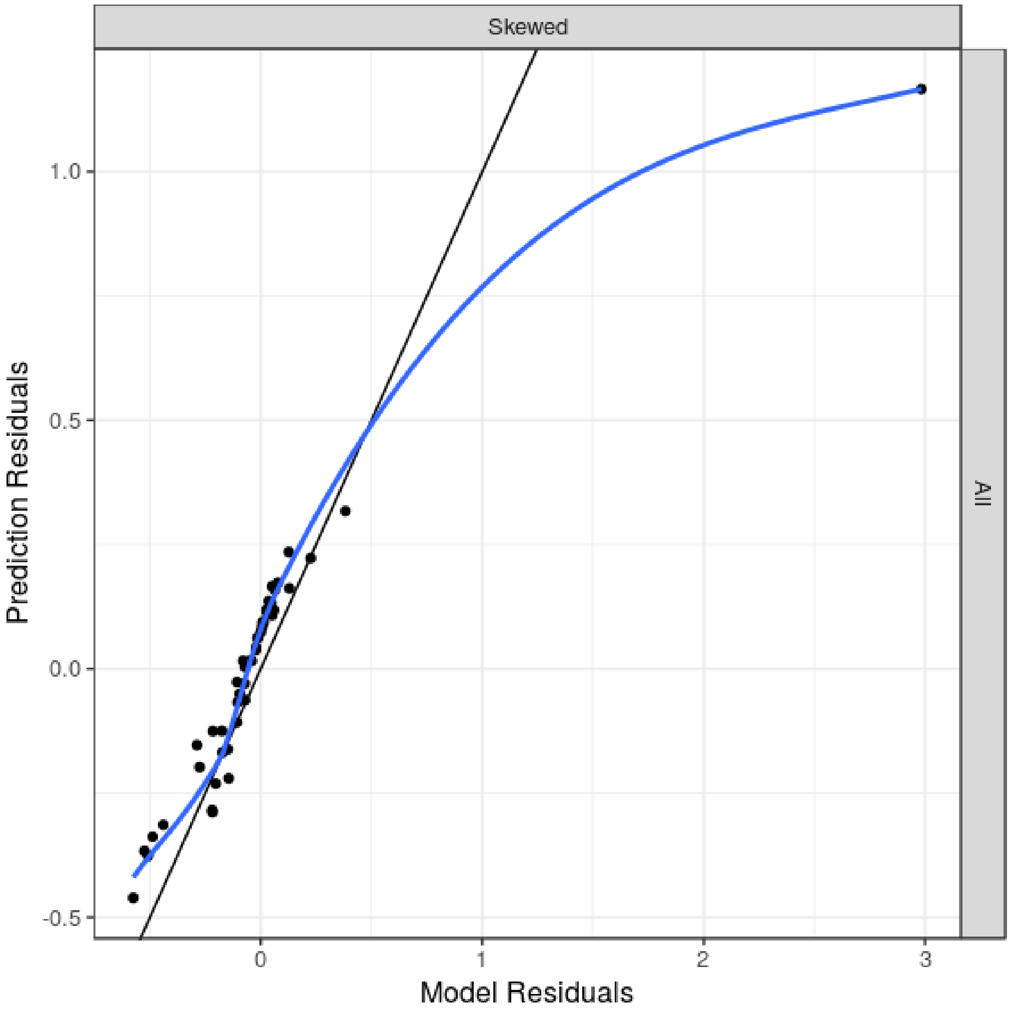


Figure 17. Comparison of model and prediction residuals.

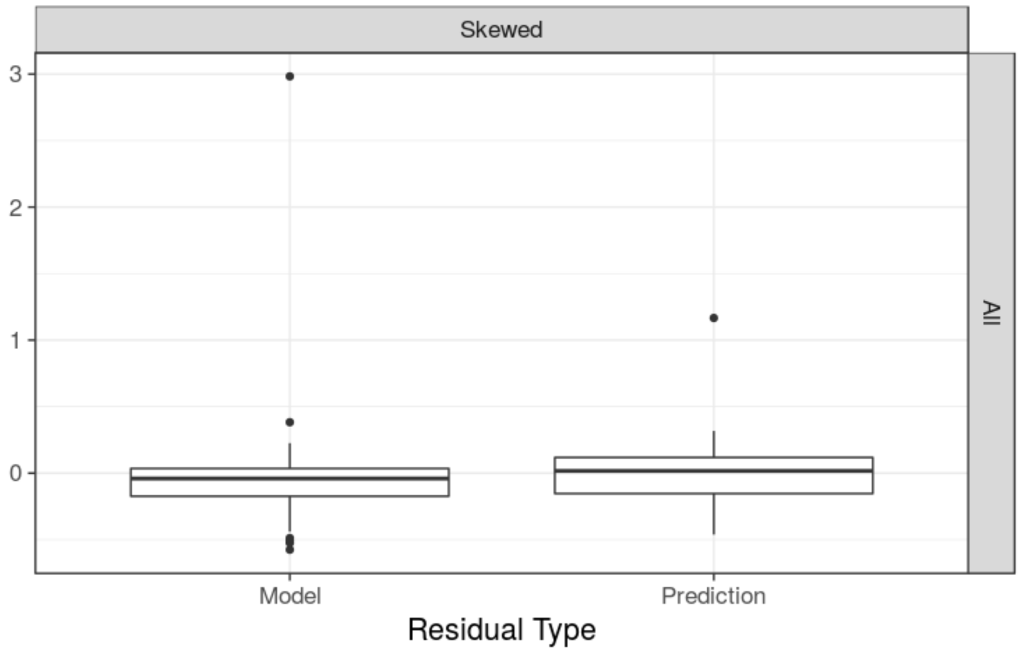


Figure 18. Comparison of model and prediction residuals.

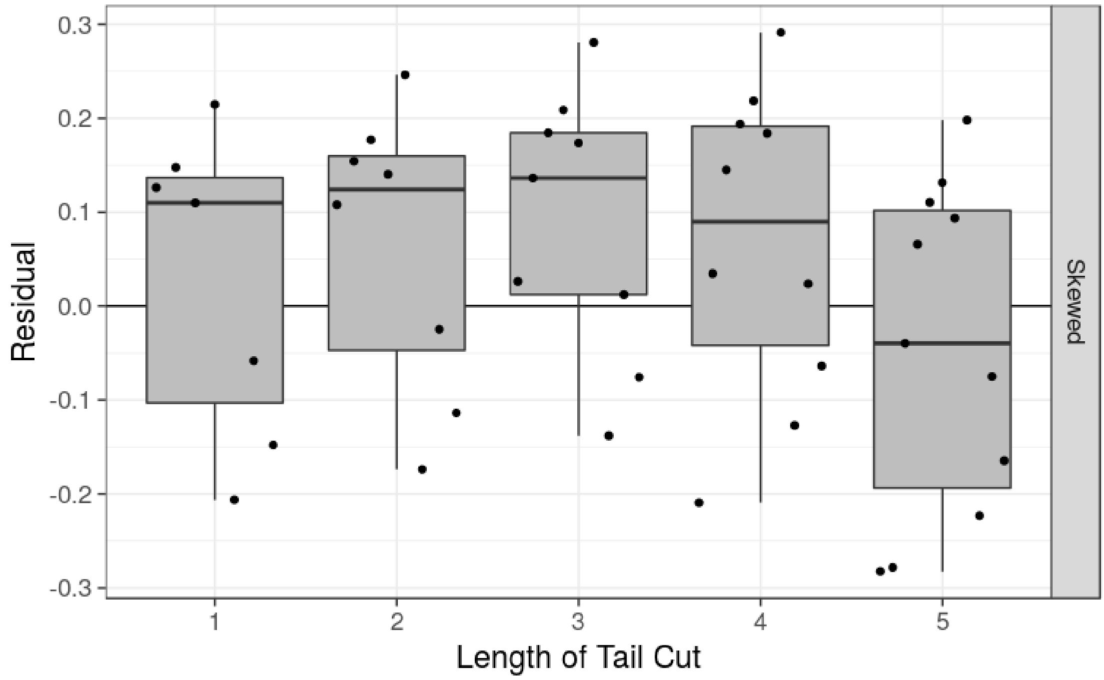


Figure 19. Comparison of prediction residuals, by CPUE series and production function shape, for different lengths of tail cutting.

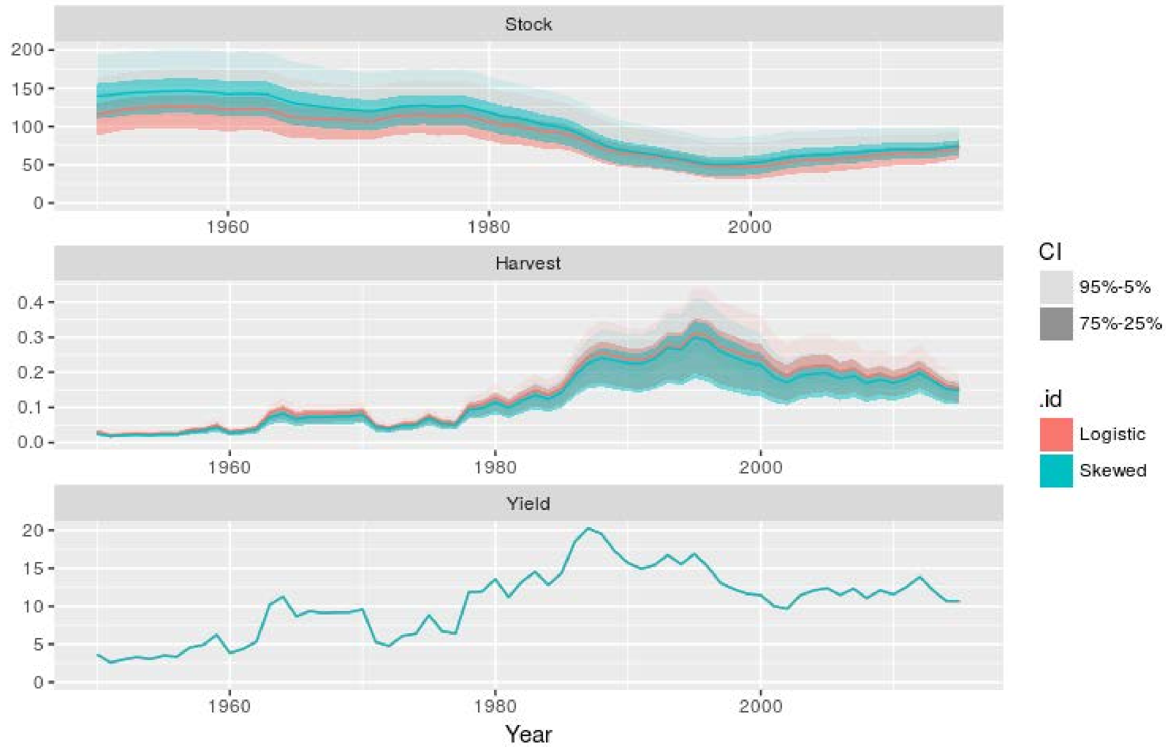


Figure 20. Time series for stock, harvest rate and catch from the bootstrapped runs for the two production function scenarios.

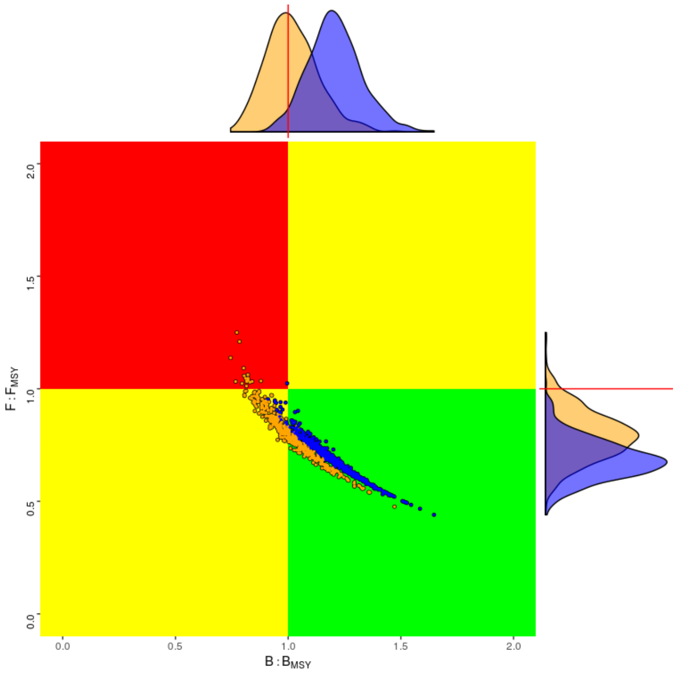


Figure 21. Kobe phase plot for the two production functions scenarios based on the bootstrapped estimations.

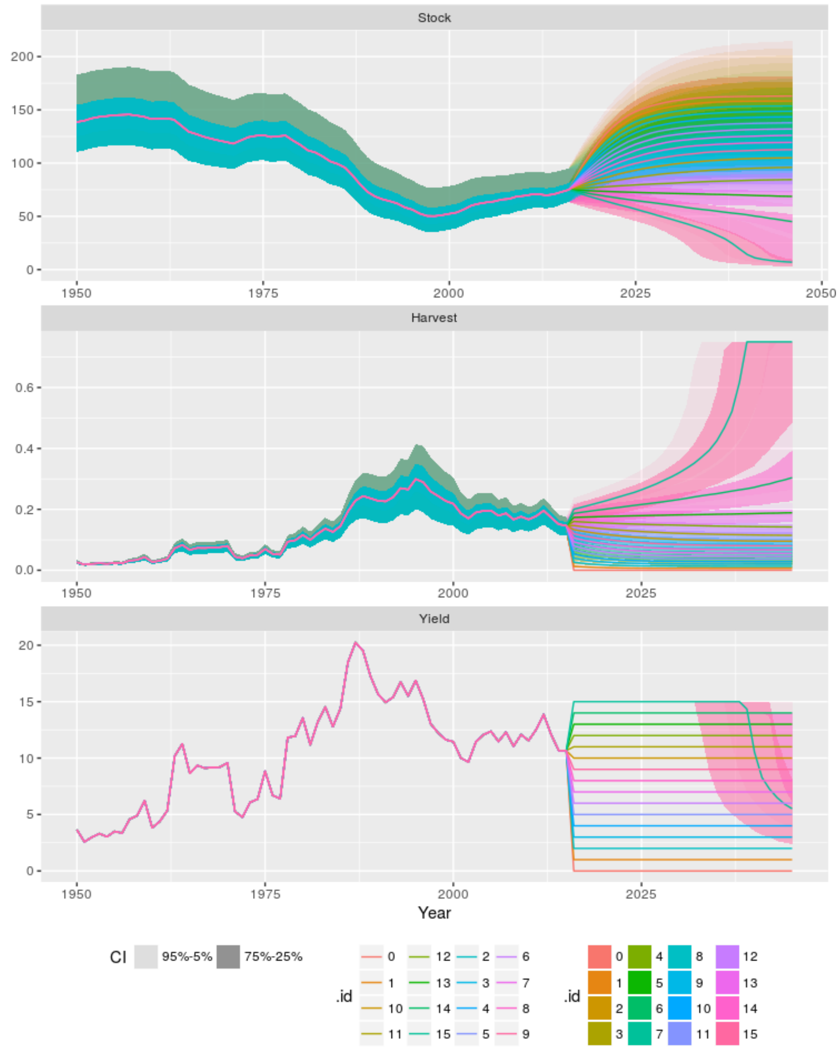


Figure 22. Projections for TACs ranging from 0 to 15,000 t, based on the two production function scenarios.

Appendix 6

Additional diagnostics and sensitivity runs for BSP2

Methods

The priors and other model specifications for the BSP2 model runs are described in section 5.1.2 and 5.2.1. This section provides additional details.

The sensitivity runs varied in how the observation error was specified. In most runs the error variance for each series was equal between all points, and the CV was set equal to 0.2, a value calculated from the MLE standard deviation across data points. In some cases (N12 and S7), the observation error standard deviation was estimated by iterative re-weighting; a starting guess for the CV of each series was input using a method that treats the error standard deviation as fixed and estimates the standard deviation from the CV. The output value of the CV was used in the input files. This was repeated twice for the base case run to get the approximate MLE values of the standard deviations. The same values were used for all subsequent runs with the same indices. For the runs with the combined index in the North, the weight was equal to 0.23, which was the MLE estimate. For one run (S13), the CVs estimated in the combined index were inputted, along with an added variance factor so that the mean standard deviation was equal to the 0.23.

For most models, the models converged adaquately with the specifications described in section 5.1.2 and 5.2.1. However, runs N10, N11 and N12 were adjusted to improve convergence. The q parameters were estimated using MLE rather than estimated as free parameters, and the upper limit of M was adjusted from 1 to 2. Runs N8, S4 and S6 failed to converge when the SIR algorithm was used. Run S12 was close to convergence, with a % maximum weight of 2.2%. All the other model runs were converged, based on a maximum weight less than 0.5%, and the CV of the weights being less than the CV of the likelihood*priors.

North Atlantic Results

For the North Atlantic, the indices were quite variable, although they were fairly consistent in showing an increase since 2000 when the catches were relatively low (**Figure A1**).

Model fits to all the original indices using either the Schaefer or generalized production model (B_{MSY}/K=0.4), or using the less informative prior for r showed nearly identifical fits, all of which dipped to a low point around 1999 and increased (**Figure A2**, runs N1-N4, N9). When the model was fitted to the combined index, the trend appeared similar in shape, but the population dropped below B_{MSY} in the late 1990s. The multiple index data appeared to be fairly uninformative, in that the posteriors for r were quite similar to the priors in all these models (**Figure A3**). The posterior for K was somewhat more concentrated in the cases with an informative prior for r. The combined index was more informative, and produced estimates of r and K that were more precise than the priors. All the models with multiple indices were more optimistic than previous assessments, in that they found that the population never dropped below B_{MSY} at its lowest point in 1999 (**Figure A4 and A5**). The low point in biomass in 1999 was apparantly driven by the CPUE data, since the PMPD model run, which did not include CPUE data, did not have this dip (run N5). The combined index models were more pessimistic, and also more consistent with previous assessments.

There was no retrospective bias in the model with separate indices, when the CPUE data was cut off in an earlier year and the biomass was projected forward using the catches (**Figure A6a**). The combined index model also showed no retrospective bias (**Figure A6d**). The bootstrap analysis found that that removing the Japanese historic series made the model more optimistic, and removing Canada made the model more pessimistic (**Figure A6b**). Adding the Chinese Taipei series to the model with separate indices made the model more pessimistic (**Figure A6b**). These results are at the mode of the distribution. The SIR algorithm did not converge for the run with additional data from Chinese Taipei (run N8), so posterior statistics are not given for this model.

The base case model, which was the combined index Schaefer model (N6) seemed to fit the data adequately based on the CPUE residuals, except that it failed to fit the very large value in the first year (**Figure A7 a-b**). Similarly, the generalized model with B_{MSY}/K=0.4 fit the data well except for the first year (**Figure A7 c-d**). Cross-validation was not done for the BSP2 model runs, although this should be done in the future.

South Atlantic results

For the South Atlantic, the CPUE series were highly variable, and showed no particular trend (**Figure A8**). The models fitted to the original series from the data meeting (runs S1-S4, S6 and S7) were quite similar for models with different production model shapes, or with a wider prior for r (**Figure A9**). Removing the Brazil1 series, adding the series from Japan or Chinese Taipei or the splitting the Spanish series all improved the fit.

Using the original indices, the posteriors for r and K were very broad, similar to the post model pre data run, due to the uninformative nature of the data (**Figure A10**, runs S1-S4, S6 and S7 include the indices, S5 is the PMPD). The model with the wider prior for r did not converge, implying that the informative prior was necessary to make up for the lack of information in the data. Removing the highly variable historical series from Brazil greatly improved the precision of both r and K. The informative prior for K did not make the results much more precise, although it did reduce the mean of K and increase the mean of r (run S9).

The trajectories of biomass and fishing mortality were quite different between runs (**Figure A11 and A12**). Removing Brazil1 makes the biomass decline during the second half of the time series, and splitting the JLL and Spain time series causes the population to drop below B_{MSY}.

There was no retrospective pattern in run S1 (**Figure A13**). Dropping out one index at a time did not change the biomass trajectory, except that removing the early Brazil series made the biomass decline more in the second half of the time series. The model including Chinese Taipei did not converge.

The base case run for BSP2 in the South was the Schaefer model including the index from Japan and splitting both Japan and Spain (S10) fit the model reasonably well according to the CPUE residuals (**Figure A14 a-b**). A generalized production model with $B_{MSY}/K=0.4$) (run S13) also fit adequately (**Figure A14 c-d**).

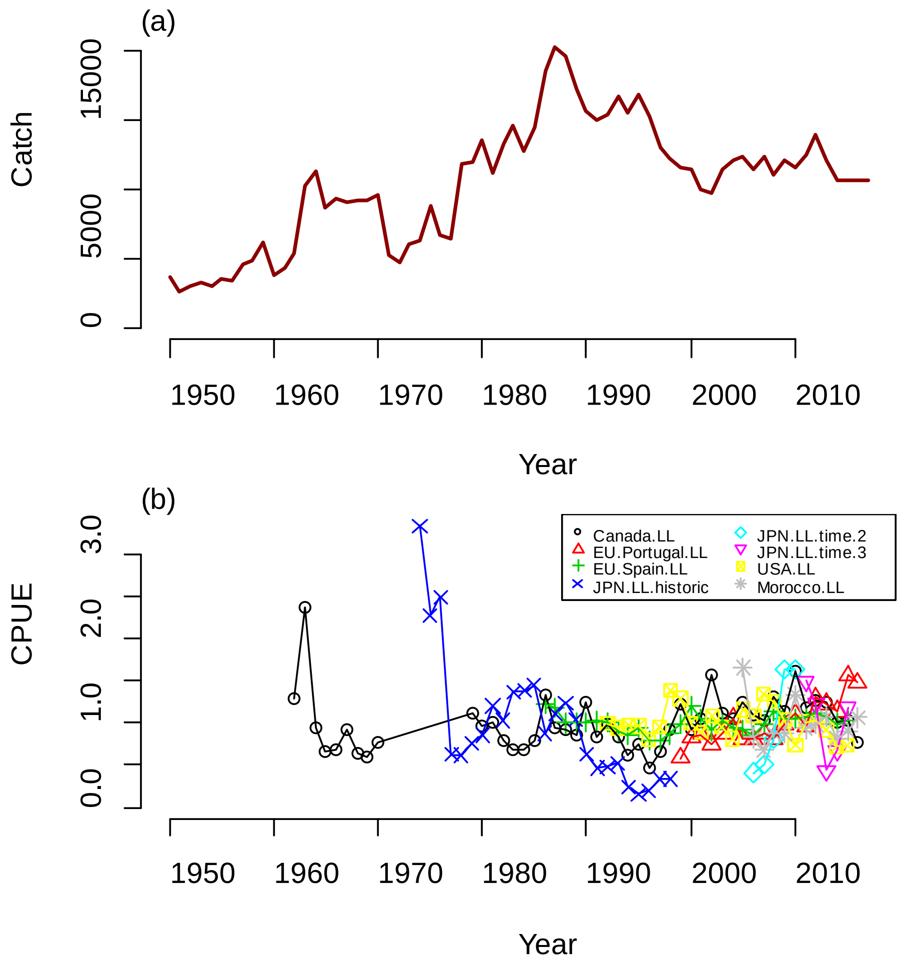


Figure A1. Catch and indices used in model N1, for North Atlantic swordfish.

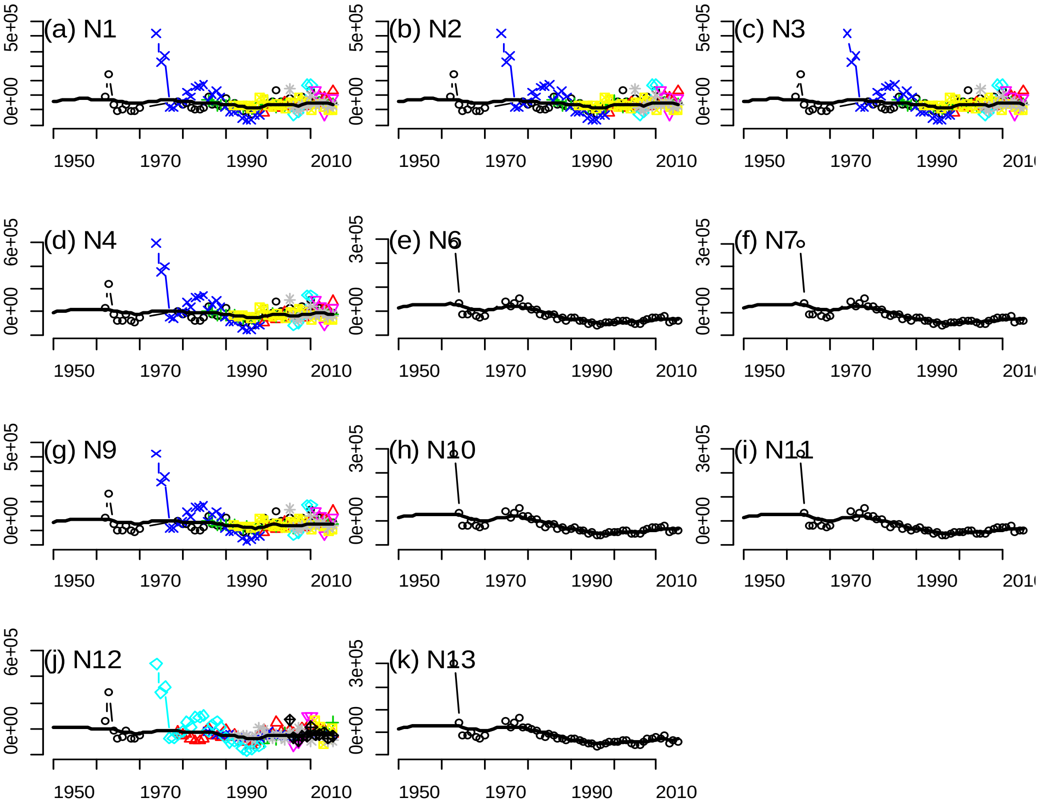


Figure A2. Fits for North Atlantic swordfish. Solid line is biomass at the mode of the posterior distribution, and points are the CPUE series resqualed by q.

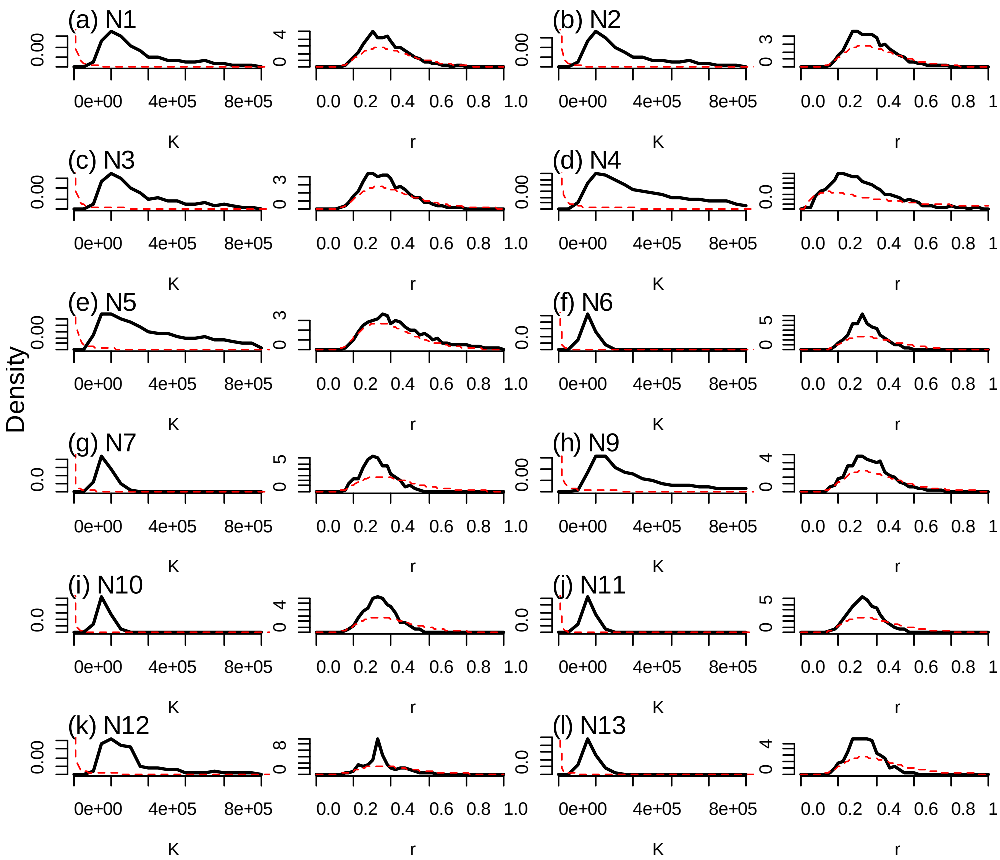


Figure A3. Priors (dashed red line) and posteriors (solid black line) of r and K for North Atlantic swordfish.

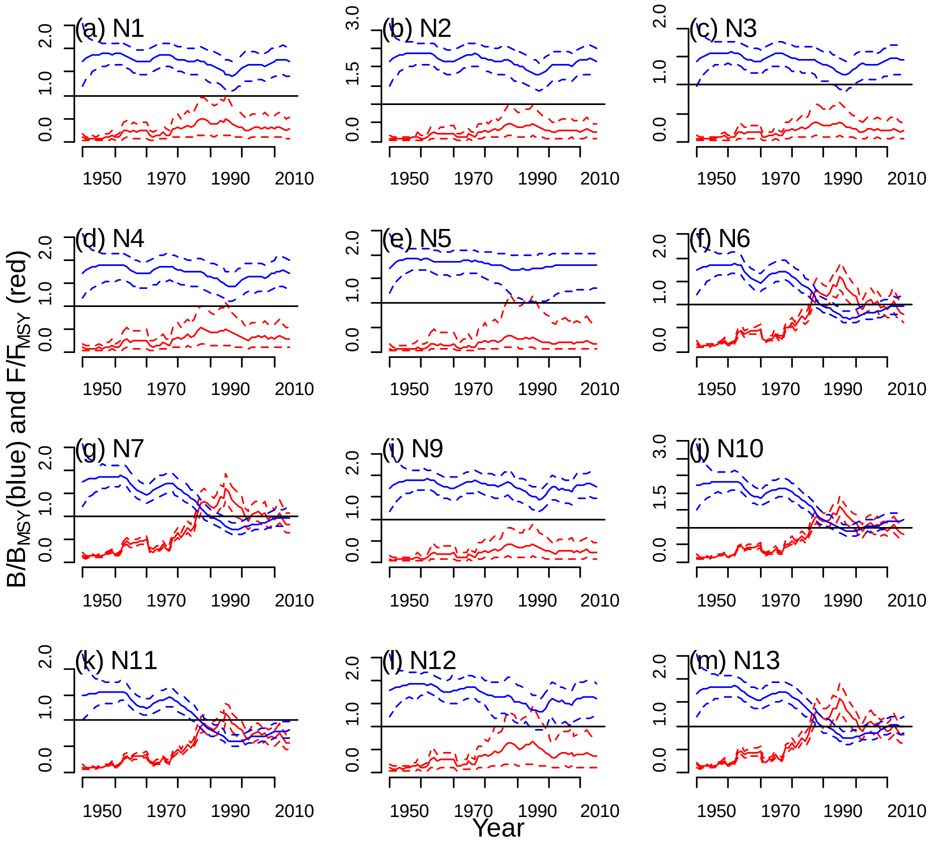


Figure A4. Biomass trajectories for the North Atlantic.

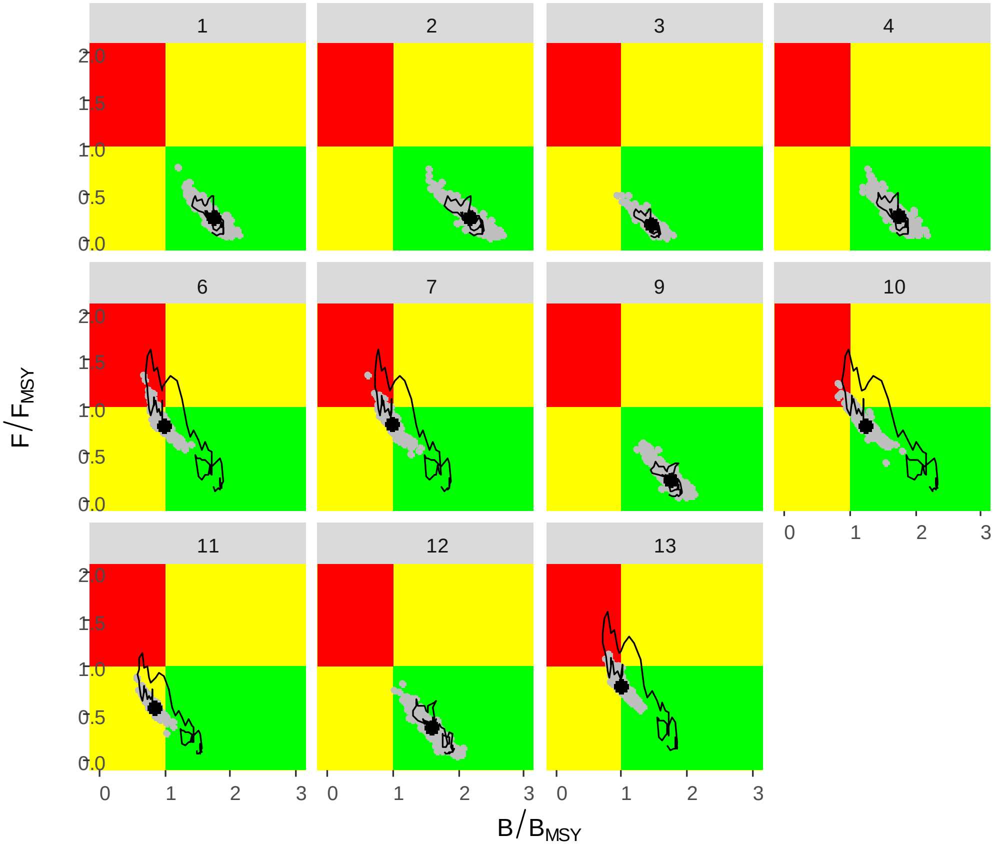


Figure A5. Kobe plots showing status in 2015 for North Atlantic swordfish. Run 6 is the base case.

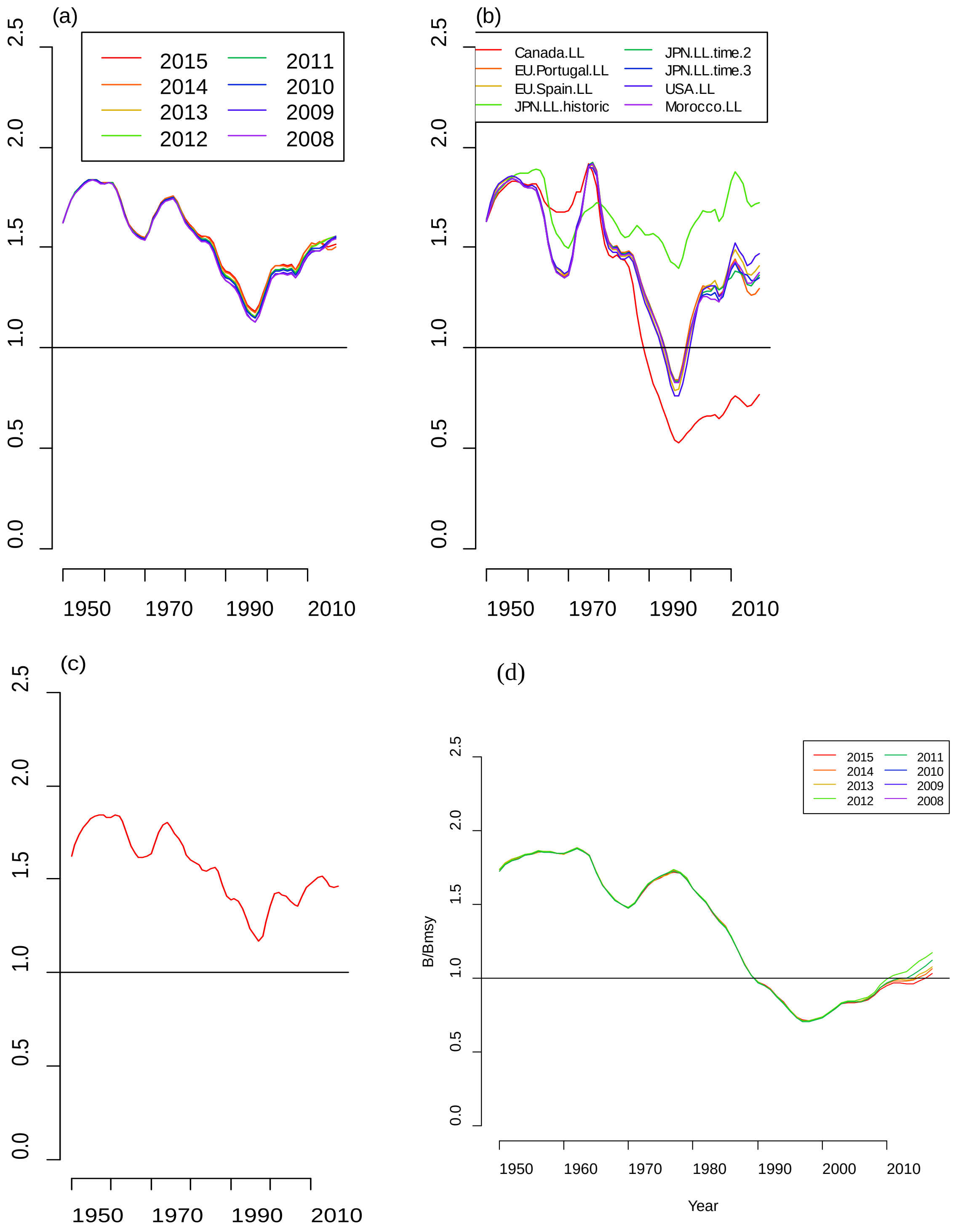


Figure A6. Mode of the B/B$_{MSY}$ trajectory for the North Atlantic, in (a) a retrospective analysis based on run N1 (b) dropping each index from run N1, (c) including Chinese Taipei, and (d) a retrospective analysis using the combined index (run N6).

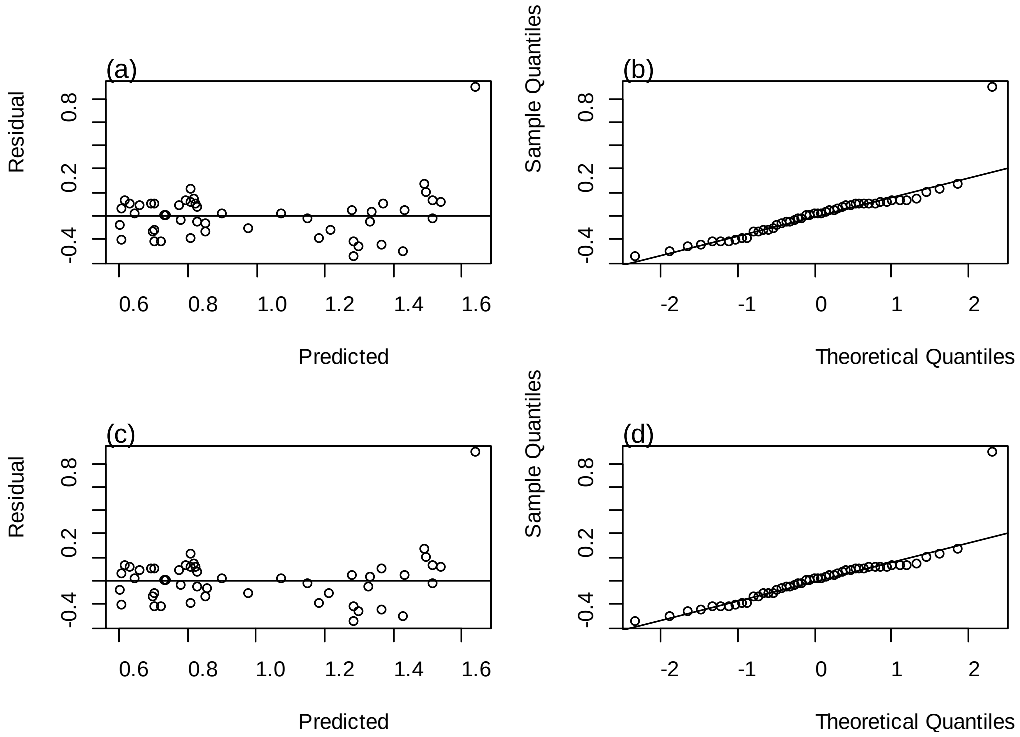


Figure A7. Residuals for North Atlantic Schaefer (N6) (a-b) and generalized production model (N10) (c-d).

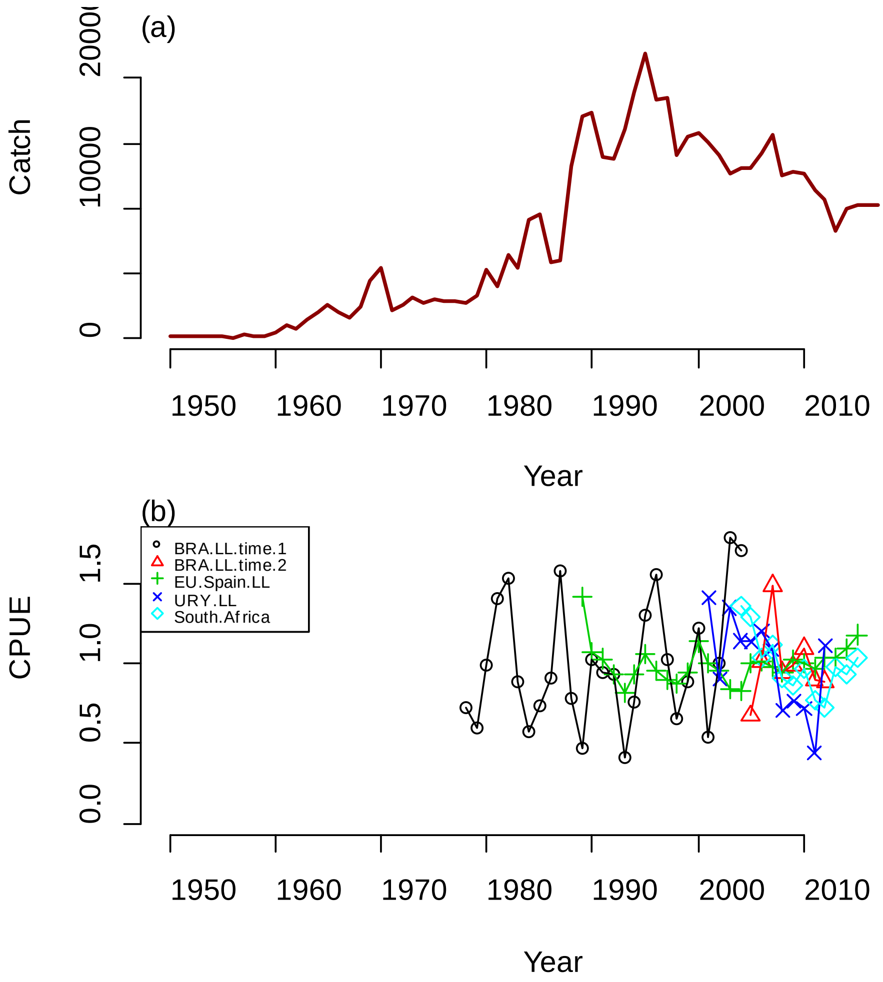


Figure A8. Catch and indices used in run S1 for South Atlantic swordfish.

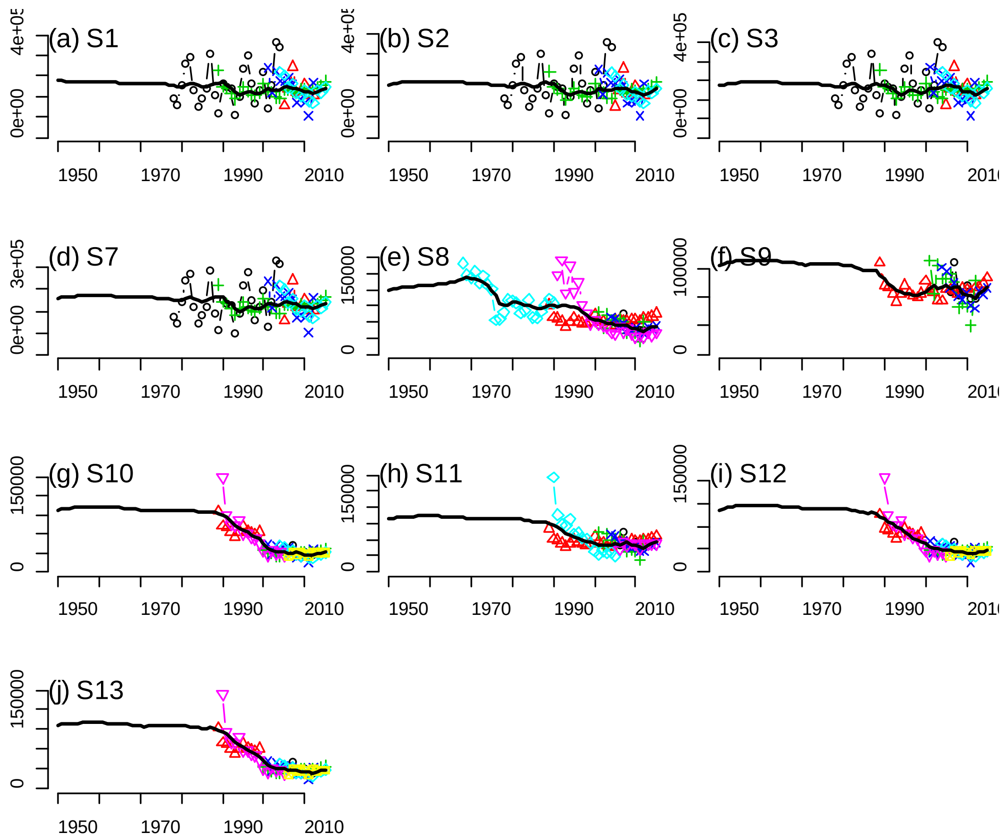


Figure A9. Fits to the CPUE indices at the posterior mode for the South Atlantic.

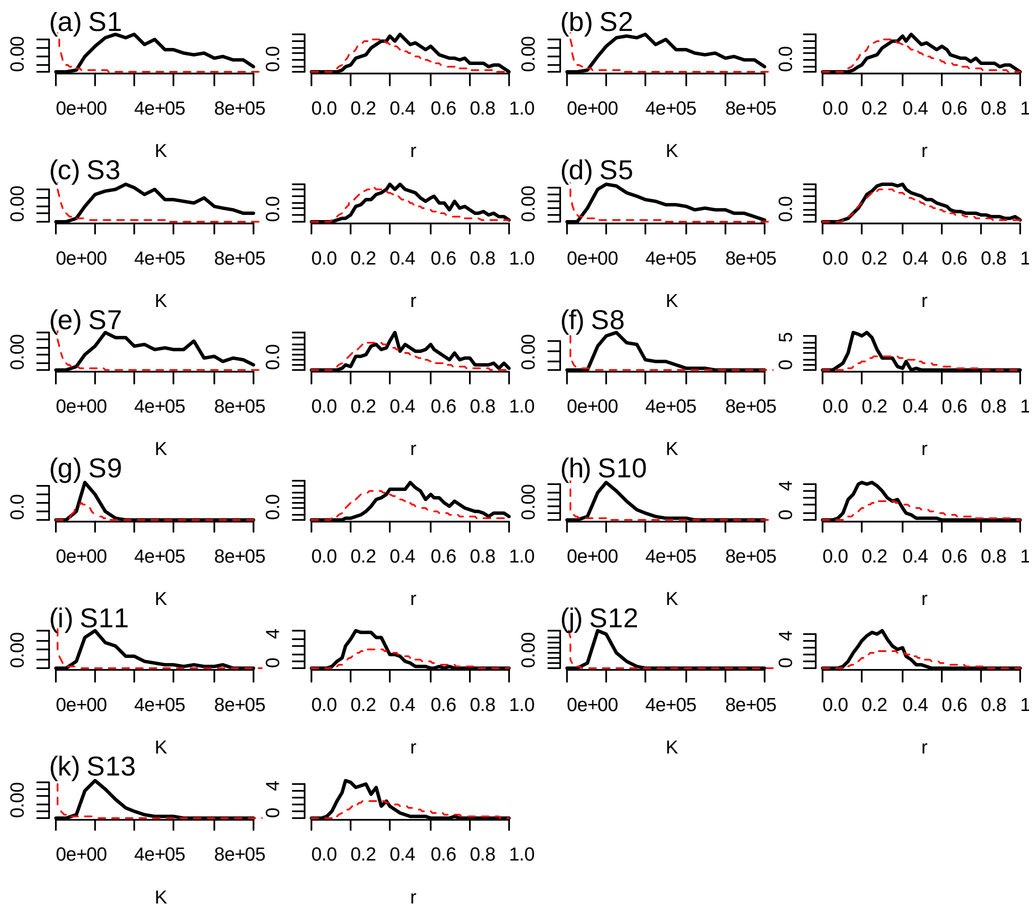


Figure A10. Priors (dashed red line) and posteriors (solid black line) for the South Atlantic.

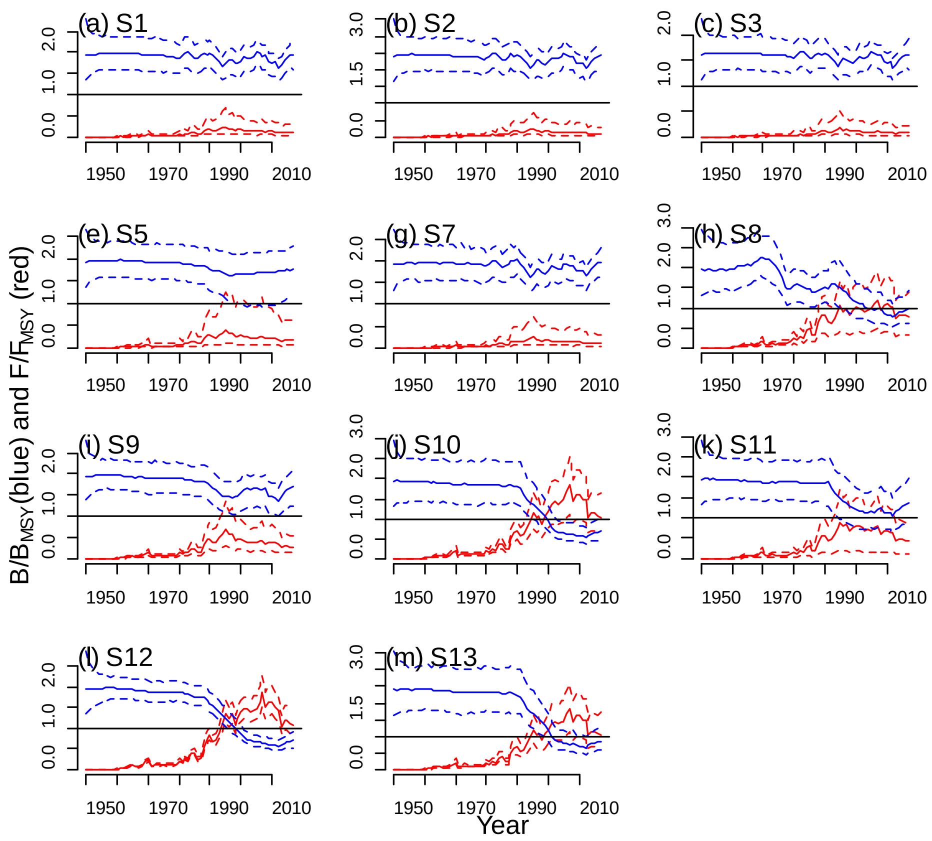


Figure A11. Trajectories for the South Atlantic.

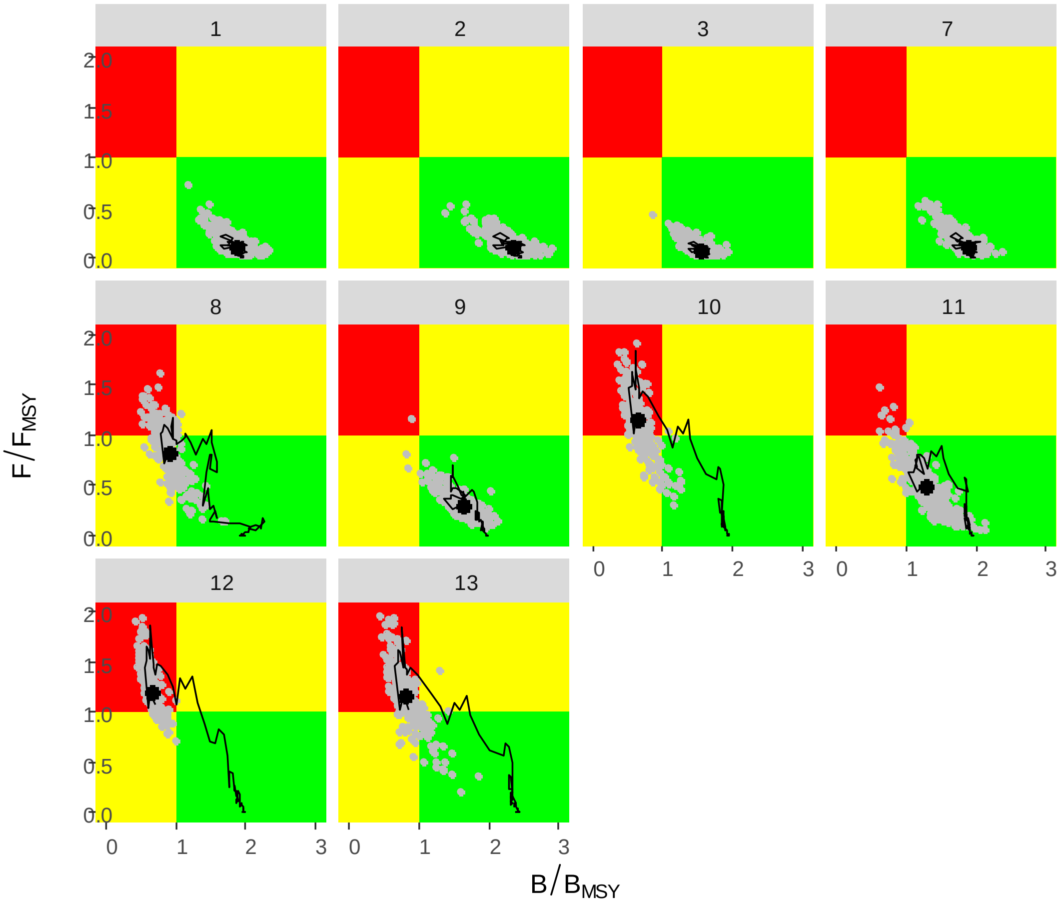


Figure A12. Kobe plots for the South Atlantic showing current status in 2015.

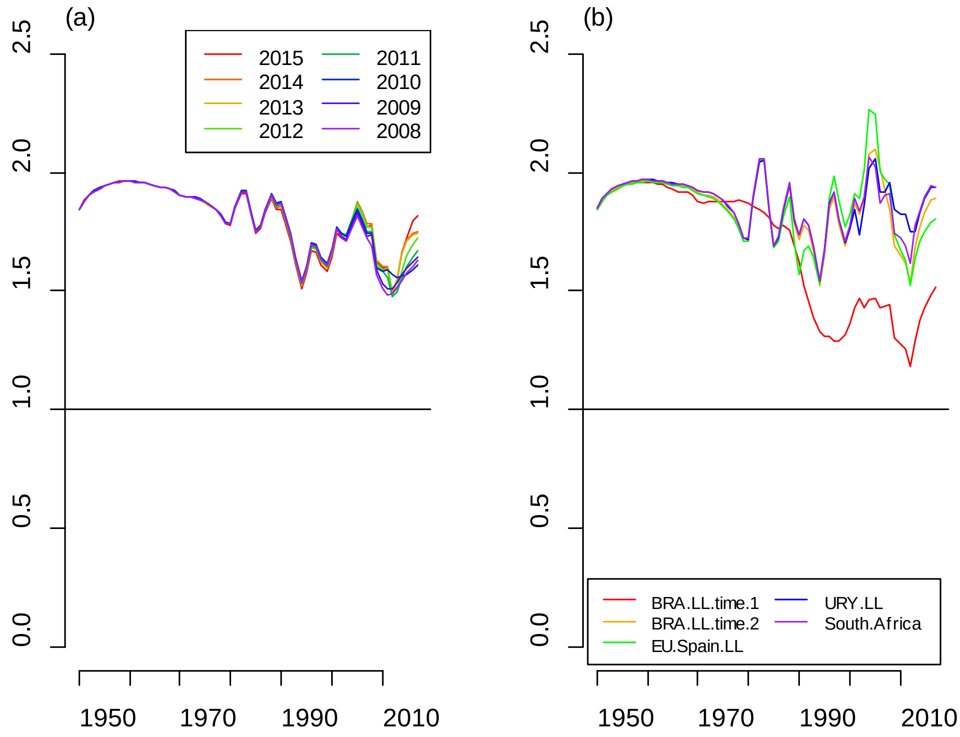


Figure A13. Mode of the posterior South Atlantic BSP2 (a) retrospective analysis from the model with separate indices (N1), and (b) dropping one index from N1.

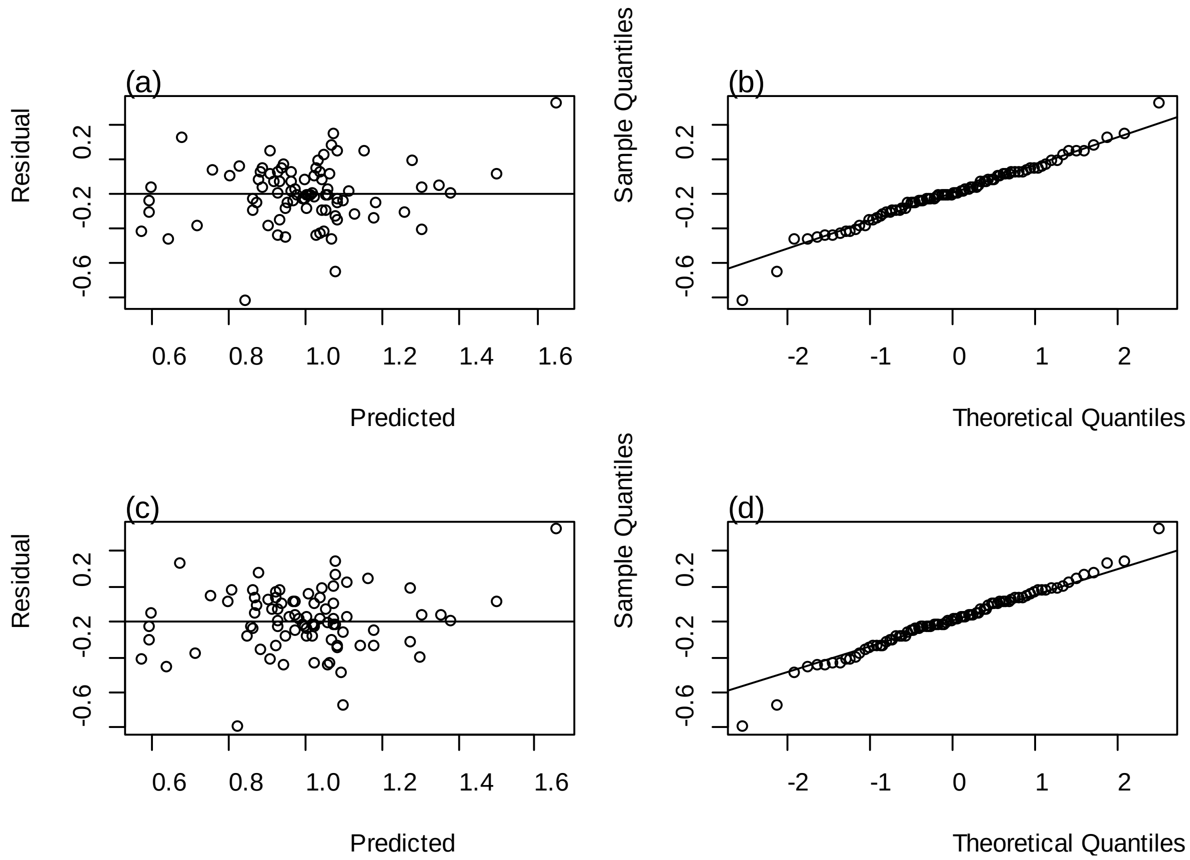


Figure A14. Residuals for South Atlantic Schaefer (S1) (a-b) and generalized production model (S13) (c-d).

Appendix 7

Final SS base case model fits and diagnostics

The final base case SS model fits and diagnostics is available as an online document.

Appendix 8

JABBA Model Formulation

JABBA seeks to improve the estimation properties of Bayesian state-space surplus production models (SPMs) by building on previous formulations by Pella and Tomlinson (1969), Gilbert (Gilbert, 1992; Wang *et al.*, 2014) and Fletcher (1978, c.f. Thorson *et al.*, 2012). An advantage of the proposed generalization is that it links surplus production models more directly to conventional age-structured model formulations. The automated inbuilt options include:

- Integrated state-space tool for averaging and aligning multiple CPUE series
- Automatic fitting of multiple CPUE time series and associated standard errors
- Fox, Schaefer or Pella Tomlinson production function (optional as input of B_{MSY}/K)
- Flexible r prior specification: (1) range or (2) mean + CV of lognormal distribution
- Kobe-type biplot plotting functions
- Improved Residual diagnostics
- Easy implementation of time-block changes in selectivity
- Forecasting of stock status under alternative TACs

First we focus on the surplus production function of the generalized three parameter SPM by Pella and Tomlinson (1969):

(1) $$SP_t = \frac{r}{m-1} B_{t-1}\left(1-\left(\frac{B_{t-1}}{K}\right)^{m-1}\right),$$

where r is the intrinsic rate of population increase at time t, K is the unfished biomass and m is a shape parameter that determines at which B/K ratio maximum surplus production is attained. If the shape parameter is $m = 2$, the model reduces to the Schaefer form, with the surplus production $g(B_t)$ attaining MSY at exactly $K/2$. If $0 < m < 2$, $g(B_t)$ attains MSY at depletion levels smaller than $K/2$ and vice versa. The Pella-Tomlinson model reduces to a Fox model if m approaches one ($m=1$) resulting in maximum surplus production at ~ $0.37K$, but there is no solution for the exact Fox SP with $m = 1$. B_{msy} is given by:

(2) $$B_{MSY} = K m^{\frac{-1}{m-1}},$$

and the corresponding harvest rate at MSY (H_{MSY}) is:

(3) $$F_{MSY} = \frac{r}{m-1}\left(1-\frac{1}{m}\right),$$

where the harvest rate F is defined here as the ratio of:

(4) $$F = \frac{C}{B} \,.$$

where C denotes the catch. Correspondingly F_{MSY} can be expressed by:

(5) $$F_{MSY} = \frac{MSY}{B_{MSY}} \,.$$

Combing and re-arranging equation (3) and (5), it follows that r in equation (1) can be expressed as:

(6) $$r = \frac{MSY}{B_{MSY}} \frac{m-1}{1-m^{-1}}$$

or

(7) $$r = F_{MSY} \frac{m-1}{1-m^{-1}}$$

This allows re-formulating the production function of the Pella-Tomlinson equation as a function of F_{MSY}, such that:

(8) $$SP_t = \frac{F_{MSY}}{(1-m^{-1})} SB_{t-1} \left(1 - \left(\frac{B_{t-1}}{K} \right)^{m-1} \right)$$

where, m can be directly translated into B_{MSY}/K and thus determines the biomass depletion level where MSY is achieved (Thorson *et al.*, 2012), using the following relationship:

(9) $$\frac{B_{MSY}}{K} = m^{\left(-\frac{1}{m-1}\right)}.$$

Because prior formulations for most SPM-based assessments are specified for r, we provide the following equation to easily convert r estimates (or prior means) into F_{MSY} for any given shape parameter input m:

(10) $$F_{MSY} = r \frac{(m-1)}{(1-m^{-1})}.$$

However, if the prior for r is derived based on Leslie matrix approach, as commonly used for a logistic Schaefer model, we recommend approximating the mean prior for as $F_{MSY} = r / 2$ for the purpose of comparability among Schaefer, Fox and Pella-Tomlinson production function.

Equations (5) - (10) illustrate the direct link between the Pella-Tomlinson SPM and the age-structured, which emphasizes the potential for deriving informative priors for r and m from spawning biomass- and yield-per-recruit analysis with integrated spawning recruitment relationships by generating deviates of $F_{MSY} = MSY/B_{MSY}$ and B_{MSY}/K, respectively (Maunder, 2003, Thorson *et al*., 2012, Wang *et al*., 2014).

Bayesian State-Space formulation

We formulated the JABBA building on the Bayesian state-space estimation framework proposed by Meyer and Millar (1999) using the difference equation (i.e. $F = C/B$). The biomass B_y in year y is expressed as proportion of K (i.e. $P_y = B_y / K$) to improve the efficiency of the estimation algorithm.

The model is formulated to accommodate multiple CPUE for fisheries f. The initial biomass in the first year of the time series was scaled by introducing model parameter φ to estimate the ratio of the spawning biomass in the first year to K (Carvalho *et al*., 2014). The stochastic form of the process equation is given by:

(11) $$P_y = \begin{cases} \varphi e^{\eta_y} & y = 1 \\ \left(P_{y-1} + \frac{F_{MSY}}{(1-m^{-1})} P_{y-1} \left(1 - P_{y-1}{}^{m} \right) - \frac{\sum_f C_{f,y-1}}{K} \right) e^{\eta_y} & y = 2,3,\ldots,n \end{cases}$$

where η_y is the process error, with $\eta_y \sim N(0, \sigma_\eta^2)$, $C_{f,y-1}$ is the catch in year y by fishery f.

The corresponding biomass for year y is:

(12) $$B_y = P_y K,$$

The observation equation is given by:

(13) $$I_{f,y} = q_f B_{f,y} e^{\varepsilon_y} \qquad y = 1, 2,\ldots, n.$$

where, q_f is the estimable catchability coefficient associated with the abundance index for fishery *f* and ε_y is the observation error, with $\varepsilon_{f,y} \sim N(0, \sigma^2_{\varepsilon,f,y})$, where is the observation variance for fishery *f* in year *y*.

To incorporate available standard errors of the year-effect estimated from the standardization models, we modified adopted an additional variance approach for the observation error variance (Booth and Quinn, 2006, Carvalho *et al*., 2014), such that:

(14) $$\sigma^2_{\varepsilon,y,f} = \hat{\sigma}^2_{SE,y,f} + \sigma^2_{Add,f} \quad \text{and} \quad \varepsilon_{y,f} \sim N(0, \sigma^2_{\varepsilon,y,f}) \ ,$$

where, $\hat{\sigma}^2_{SE,y,f}$ is the externally estimated standard error for year y and abundance index *f* and $\sigma^2_{Add,f}$ is the estimable additional variance.

The full JABBA model projected over n years requires a joint probability distribution over all unobservable hyper-parameters $\boldsymbol{\theta} = \{K, F_{MSY}, \varphi, \sigma^2_{\eta,} q_f, \sigma^2_{\varepsilon,y,f}\}$ and the *n* process errors relating to the vector of unobserved states $\boldsymbol{\eta} = \{\eta_1, \eta_2, \ldots \eta_y)$, together with all observable data in the form of the relative abundance indices for fisheries *f*, $\mathbf{I}_f = \{I_{f,1}, I_{f,2}, .. I_{f,y}\}$ (Meyer and Millar, 1999). According to Bayes' theorem, it follows that joint posterior distribution over all unobservable parameters, given the data and unknown states, can be formulated as:

(15) $$\begin{aligned} p(\boldsymbol{\theta} \mid \boldsymbol{\eta}, \mathbf{I}) &= p(K)p(F_{MSY})p(\varphi)p(\sigma^2_\eta)p(q_f)p(q_f)p(\sigma^2_\varepsilon) \\ &\times p(P_1 \mid \varphi, \sigma^2_\eta) \prod_{y=1}^{n} p(P_y \mid P_{y-1}, K, \varphi, \sigma^2_\eta) \times \prod_{y=1}^{n} p(I_{f,y} \mid P_{t,} q_f, \eta_t, \sigma^2_{\varepsilon,y,f}) \end{aligned}$$

Convergence and diagnostics

A critical issue when using MCMC methods is how to determine if random draws have converged to the posterior distribution. Convergence of the MCMC samples to the posterior distribution was checked by monitoring the trace, the Gelman and Rubin (1992) and Heidelberger and Welch (1983) diagnostics. In this study, two MCMC chains were used. The model was run for 100,000 iterations, sampled with a thinning rate of 10 with a burn-in period of 20,000 for each of the chains. Basic diagnostics of model convergence and fitting included visualization of the MCMC chains, noting the DIC and evaluating observation residuals for the multiple time series, including using Residual-Mean-Square Error metric for comparisons of alternative scenarios.

References

Booth, A.J. and Quinn, T.J., 2006. Maximum likelihood and Bayesian approaches to stock assessment when data are questionable. *Fisheries Research*, 80(2), pp.169-181.

Carvalho, F., Ahrens, R., Murie, D., Ponciano, J.M., Aires-da-silva, A., Maunder, M.N. and Hazin, F. 2014. Incorporating specific change points in catchability in fisheries stock assessment models : An alternative approach applied to the blue shark (*Prionace glauca*) stock in the South Atlantic Ocean. Fish. Res. 154: 135–146. Elsevier B.V. doi:10.1016/j.fishres.2014.01.022.

Gelman, A. and Rubin, D.B. 1992. Inference from Iterative Simulation Using Multiple Sequences. Statistical Science 7: 457-472.

Gilbert. 1992. A stock production modelling technique for fitting catch histories to stock index data.

Heidelberger, P. and Welch, P.D. 1983. Simulation Run Length Control in the Presence of an Initial Transient.

Maunder, M.N., 2003. Is it time to discard the Schaefer model from the stock assessment scientist's toolbox? *Fisheries Research*, 61(1), pp.145-149.

Meyer, R., and Millar, R. B. 1999. BUGS in Bayesian stock assessments. Canadian Journal of Fisheries and Aquatic Sciences 56: 1078–1087.

Pella, J.J. and Tomlinson, P.K. 1969. A generalized stock production model. Inter-American Trop. Tuna Comm. Bull. 13: 421–458.

Thorson, J.T., Cope, J.M., Branch, T.A. and Jensen, O.P. 2012. Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information. Can. J. Fish. Aquat. Sci. 69(9): 1556–1568. NRC Research Press. doi:10.1139/f2012-077.

Wang, S.-P., Maunder, M.N. and Aires-da-Silva, A. 2014. Selectivity's distortion of the production function and its influence on management advice from surplus production models. Fish. Res. 158: 181–193. Elsevier B.V. doi:10.1016/j.fishres.2014.01.017.