REPORT OF THE 2015 ICCAT BLUE SHARK STOCK ASSESSMENT SESSION

(Oceanário de Lisboa, Lisbon, Portugal - July 27 to 31, 2015)

1. Opening, adoption of agenda and meeting arrangements

The Meeting was held at the Oceanário de Lisboa, in Lisbon (Portugal) from July 27 to 31, 2015. Dr Enric Cortés (USA), meeting Chairperson opened the meeting and welcomed participants ("the Group"). The Secretariat Scientific Coordinator welcomed meeting participants and thanked the Oceanário and IPMA for hosting the meeting and for providing all the logistical arrangements. Mr. Miguel Oliveira also welcomed the participants and highlighted the importance of hosting the meeting, due to the Oceanário de Lisboa general objective of promoting overall conservation of the marine environment and fisheries resources. The Chair 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 following participants served as rapporteurs:

Item	*Rapporteur*
Item 1	Miguel Neves dos Santos
Item 2.1	Paul de Bruyn, Agostino Leon
Item 2.2	Paul de Bruyn, Guillermo Diaz and Andres Domingo
Item 2.3	Paul de Bruyn, Kwang-Ming Liu
Item 2.4	Paul de Bruyn, Enric Cortés
Item 2.5	Paul de Bruyn
Items 3.1 and 3.2	Paul de Bruyn, Elizabeth Babcock, Felipe Carvalho
Item 3.3	Paul de Bruyn
Item 4.1	Laurence Kell, Elizabeth Babcock and Felipe Carvalho
Item 4.2	Laurence Kell, Dean Courtney
Item 4.3	Laurence Kell
Item 4.4	Laurence Kell, Elizabeth Babcock and Dean Courtney
Item 5.	Laurence Kell
Item 6.	Enric Cortes, David Die and Miguel Neves dos Santos
Items 7 and 8	Miguel Neves dos Santos

2. Summary of available data for assessment

2.1 Stock identity

SCRS/P/2015/031 reported on a new EU project (MedBlueSGen) which based on the Next Generation Sequencing technology seeks to develop a new restriction-site associated DNA genotyping to improve the current knowledge on blue shark (*Prionace glauca*), by creating a robust baseline of data describing the species genetic stratification in the Mediterranean. The project will tackle aspects related to the population structure, the connection to non-Mediterranean populations, and help to design management schemes in order to strengthen conservation efforts for the blue shark. The key objectives are: i) to scrutinize the prevailing assumption that Mediterranean blue shark consists of a single population (stock); and, ii) to predict if it may rely on external reinforcements from the Atlantic Ocean due to the tremendous impact of blue shark by-catch in Mediterranean fisheries. Given the extreme mobility of the species, juveniles, most linked to the coastal environment than adults, will be analyzed. The availability of samples approximately one-generation old within the MedBlueSGen Consortium will offer the unique opportunity to assess stability of genetic features in relation to the high level of vulnerability of Mediterranean BS.

The Group thanked the presenter for this interesting study and presentation of the project. The Group requested the presenter to consider making sure samples from outside the Mediterranean to be used in the project are representative to determine which part of the Atlantic population (if any) is connected to the populations in the Mediterranean. The latter may require a wider distribution of non-Mediterranean samples than the project is presently considering. If required, national scientists could help in the collection of such samples.

2.2 Catches

Document da Silva *et al*. (2015) described how chondrichthyans (sharks, skates, rays and chimaeras) are captured in many marine fisheries. Management and research efforts directed at chondrichthyan fishing are often neglected because of low product value, taxonomic uncertainty, low capture rates, and harvesting by multiple fisheries. In South Africa's diverse fishery sectors, which include artisanal as well as highly industrialised fisheries, 99 (49%) of 204 chondrichthyan species that occur in southern Africa are targeted regularly or taken as bycatch. Total reported dressed catch for 2010, 2011 and 2012 was estimated to be 3 375 t, 3 241 t and 2 527 t, respectively. Two-thirds of the reported catch was bycatch. Regulations aimed at limiting chondrichthyan catches, coupled with species-specific permit conditions, currently exist in the following fisheries: demersal shark longline, pelagic longline, recreational line, and beach-seine and gillnet. Limited management measures are currently in place for chondrichthyans captured in other South African fisheries. Catch and effort data series suitable for stock assessments exist for fewer than 10 species. Stock assessments have been attempted for five shark species: soupfin *Galeorhinus galeus*, smoothhound *Mustelus mustelus*, white *Carcharodon carcharias*, spotted ragged-tooth *Carcharias taurus*, and spotted gully *Triakis megalopterus*. Fishery-independent surveys and fishery observer data, which can be used as a measure of relative abundance, exist for 67 species. Compared with most developing countries, South African shark fishing is relatively well controlled and managed. As elsewhere, incidental capture and bycatch remain challenges to the appropriate management of shark species. In 2013, South Africa's National Plan of Action for the Conservation and Management of Sharks (NPOA-Sharks) was published. Implementation of the NPOA-Sharks should help to improve chondrichthyan management in the near future.

The Group noted that the catch ratio of shortfin mako to blue shark described in the paper is very high. It was explained that this is probably due to the fact the information provided is landings in dressed weight only, and thus would not include discarded blue sharks. It was suggested that in certain areas and during certain times of the year, the discarding of blue sharks is very high, thus biasing this ratio.

2.3 Indices of abundance

Document SCRS/2015/137 presented the updated (from 2008) results from Ireland's blue shark recreational fishery spanning the period 2007-2013 for the purposes of the 2015 ICCAT stock assessment. The tagging programme commenced in 1970 and continues to the present day. Up to 2013 a total of 18,278 blue sharks were tagged and 895 recaptures were reported. Analysis of data from 2007-2013, available CPUE data from the total fishery and from a subset of angling charter vessel skippers consistently operating in the fishery, are presented. Data includes 1,431 new tagging events and 83 recaptures since the last report to ICCAT in 2008. Recapture rates were higher than those reported previously, although the numbers tagged is much reduced from the levels observed in the 1990s. CPUE for the overall fishery remained low and was consistent with lower values observed initially from 2000 onwards. This was also observed in the skipper subset. Effort has reduced substantially arising from decreased levels of boat angling and also in response to low catch rates. Data suggest that blue shark abundance has stabilised at the reduced levels first observed in the mid-2000s.

The Group discussed that these data would be important for future assessments, especially with regards to the inclusion of tagging data from this study and from other tagging programmes on both sides of the Atlantic (e.g. US and Spain) in integrated assessment models.

In document SCRS/2015/132, the blue shark catch and effort data from observers' records of Taiwanese large longline fishing vessels operating in the Atlantic Ocean from 2004-2013 were analysed. Based on the shark by-catch rate, five areas, namely, A (north of 20ºN), B (5ºN-20ºN), C (5ºN-15ºS), D (15ºS-50ºS, west to 20ºW) and E (15ºS-50ºS, 20ºW-20ºE), were categorized. To cope with the large percentage of zero shark catch, the catch per unit effort (CPUE) of blue shark, as the number of fish caught per 1,000 hooks, was standardized using a two-step delta-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately. Standardized indices with 95% bootstrapping confidence intervals are reported. The standardized CPUE of blue sharks peaked in 2006 decreased thereafter and increased after 2011 in the South Atlantic and peaked in 2005, decreased to the lowest in 2008 and increased thereafter for the North Atlantic blue sharks. The results obtained in this study can be improved if longer time series observers' data are available.

It was noted that the trends in the CPUE series may be in part explained by changes in targeting. In the North Atlantic the big increase in CPUE in 2005 may be unrealistic and a result of the standardisation method. It was explained that in that year, there was very little zero catch observed (due to high observer coverage in the North that year). The standardisation model included a targeting factor and the vessels identified to be targeting sharks were excluded to reduce the effect. It was further discussed that in 2006 every vessel targeting bigeye tuna had an observer which resulted in a large number of observations. In other years sampling was less complete and so this would also impact the model, and reflects different fishing patterns in different years. The difference between 2006 and 2012 in terms of number of hooks per set was also questioned. It was explained that the number of hooks per set increased in 2006 because the bigeye tuna quota decreased dramatically in that year and so fishermen tried to catch more of other species to compensate. For certain time periods it appears that vessels targeted sharks and thus zero catches over these periods were low. It was suggested that a distribution map of the CPUE and/or zero catch ratio of BSH on an annual basis may be interesting in the future to look at changes in catch trends over time. It was noted that it may be necessary to downweight these data in the assessment and/or start the CPUE series in 2005 to avoid this low coverage rate due to the observer programme only starting in 2004.

As discussed during the data preparatory meeting in 2015, with respect to the standardized CPUE indices in general the effect of targeting requires further consideration in the future, as it is unclear whether this factor is currently properly addressed during the standardization process.

Document SCRS/2015/133 described how catch and effort information from the Brazilian tuna longline fleet (national and chartered) operating in the equatorial and Southwestern Atlantic Ocean between 1978 and 2012 was used to generate a standardized CPUE index for the South Atlantic blue shark. A total of 92,766 sets were analysed. The CPUE was standardized using a Generalized Linear Mixed Model (GLMM) using a Delta Lognormal approach. The factors used in the model were: quarter, year, area, and fishing strategy. The standardized CPUE series shows a significant oscillation over time, with a general increasing trend after 1996.

It was noted that in the late 1990s, light sticks were introduced and the fisheries began to target swordfish and to expand into different fishing areas. In more recent years as a result of increased market demand for blue shark, starting in 2001 the CPUE series increases rapidly. These changes are difficult to account for, but attempts are being made to address this issue within the model. It was noted that this series probably does not reflect stock abundance and thus its use may not be appropriate at this stage. The development of two series to account for the targeting shift was suggested. Further discussion on this document was deferred to the assessment discussions in order to identify the effects this series may have on the assessment models.

Document SCRS/2015/141 showed how indices of relative abundance (CPUEs) available for the stock assessments of blue shark in the North Atlantic and South Atlantic Ocean were combined using different methods. Following the work conducted for the 2008 SCRS blue shark stock assessment, indices were combined through a GLM with two choices of weighting: by the catch of the flag represented by each index and by the area of the flag represented by each index. Additionally, a hierarchical index of abundance that combines all available indices into a single series was also developed. The three indices obtained for the North Atlantic and South Atlantic generally followed very similar trends, with a flat tendency in the North Atlantic and an increasing trend in the South Atlantic in recent years of the time series. These indices can potentially be used in sensitivity analyses in the stock assessments.

It was noted that in several recent SCRS meetings the process of combining CPUE indices was discouraged as they tend to mask the individual trends of the series and the underlying reasons as to why the series are different. In addition, certain models can stochastically make use of the different series without need to combine these indices. As such combined indices may not be appropriate for use in assessment models. It may be more useful to group CPUEs according to similar trends and include these as separate scenarios as was discussed during the 2015 bigeye tuna assessment (SCRS/2015/015).

Lastly, it was noted that the changes to the Uruguayan CPUE series requested during the 2015 Blue Shark data preparatory meeting were carried out. The standardisation was redone, omitting the final two years of the series.

2.4 Biology

Document SCRS/2015/142 described the computation of maximum population growth rates (r_{max}) and steepness (h) values of the Beverton-Holt stock-recruitment relationship for North and South Atlantic stocks of blue shark based on the latest biological information available gathered at the 2015 Blue Shark Data Preparatory Meeting. To encompass a plausible range of values, uncertainty in the estimates of life history inputs (reproductive age, lifespan, fecundity, von Bertalanffy growth parameters, and natural mortality) was incorporated through Monte Carlo simulation by assigning statistical distributions to those biological traits in a Leslie matrix approach. Estimated productivity was high (r_{max}=0.31-0.44 yr^{-1} for the North Atlantic stock; r_{max}=0.22-0.34 yr^{-1} for the South Atlantic stock) as previously found for these and other populations of this species. Consequently analytically derived values of steepness were also high (h=0.73- 0.93 for the North Atlantic stock; h=0.55-0.84 for the South Atlantic stock). These estimates can be used as inputs into both surplus production (r_{max}) and age-structured (h) stock assessment models.

The Group noted that there are large differences between the parameters estimated for the northern and southern population, which was unexpected. It was discussed that in the south there are more studies and so the estimates may be more biologically realistic. Among the main reasons that could explain the differences in productivity and steepness between the North and South Atlantic stocks are the von Bertalanffy growth curve parameters, which result in substantially different estimates of M through the indirect life history invariant methods used, and the availability of a maternity ogive for the South Atlantic. It was suggested that the spatial coverage of the individual studies included in the estimations should be investigated for both North and South Atlantic for future analyses. The author suggested that the values for scenarios 1 and 2, which used the average annual survivorship obtained from seven life-history invariant methods, and constant and increasing fecundity, respectively, are more in line with previous studies and that the values for scenarios 3 and 4, which used maximum annual survivorship, and constant and increasing fecundity, respectively, seemed unreasonably high even for a very productive shark species such as the blue shark. It was noted that in the future more collaborative work should be conducted to increase the amount of information available for these types of analysis and improve these estimated values.

2.5 Other relevant data

Presentation SCRS/P/2015/030 detailed a statistical modeling framework approach, provided by an external contractor, to estimating overall Atlantic fishing effort on tuna and tuna-like species is being developed using ‘Task 1’ nominal catch and ‘Task 2’ catch and effort data from the EFFDIS database. The main problem arises because Task 1 data, which are thought to be totally comprehensive, are available only as annual totals for each species, flag and gear combination. Task 2 data, on the other hand, are more detailed and information is available for location and seasonality but are often incomplete. The challenge then is to combine both sources of information to produce the best estimates of fishing effort. The method currently being developed relies on a suite of generalised additive models (GAMs) being fitted to the Task 2 data. GAMs were selected because they are highly flexible, they can deal with skew distributions, and high prevalences of zeros; both features of the EFFDIS data. The models take the relevant variables (e.g. number of hooks set) and model them as smooth functions of various combinations of covariates of location (e.g. latitude, longitude, depth) and time (e.g. month and long-term trend). Specific model formulations can also deal with interactions between terms, hence allowing the shapes of spatial distributions generated to change with time which is important. Once fitted and tested the models can then be used to 'predict' values of catch-per-unit-effort as functions of any combination of the relevant covariates together with error or variance. Total effort is estimated by 'raising' with the Task 1 totals according to the formula: Effort (Task 1) = Catch (Task 1) / CPUE (Task 2). Initial findings are promising but problems of confounding (non-random sampling in both space and time) are substantial and proving difficult to ignore. The purpose of the presentation was to describe the models, the outputs and the estimates of fishing effort made for the Atlantic thus far.

Feedback from the Group was positive and the overall modeling strategy/framework was approved. Some members of the Group were, however, concerned about the treatment of the 'fleet' or 'flag'. Aggregating the data by location and temporal variables could be too much of an oversimplification. Some fleets, for example, set surface longlines, others set them in mid or deepwater. Hook sizes, baits and targeting strategies all vary, and have varied substantially over time. Given that the data are particularly patchy prior to the 1960s it was suggested that the modeling framework could concentrate on more recent years only. This would substantially reduce the burden on computation. Also the contractor was asked to include data on artisanal fisheries and to consider ways to include information on fleet/flag combinations that report only Task 1 data. Data catalogues, prepared by the Secretariat are freely available for this.

The method being developed is modular in nature so it could easily be altered to include information from fleet or flag. Polygons could be set up around the data for each fleet and the same regression model (i.e. catch fitted to covariates of location and time) fitted to the data within each fleet. 'Surfaces' estimated using the models could then be built up for each fleet, and effort estimated in the same manner as described above. The contractor agreed that aggregation of data was probably only 'hiding' the underlying variability due to the fleet effect and agreed to experiment with this but noted that problems would arise because of: (i) non-random sampling in space and time; (ii) the fact that some fleets fail to report task 2 data at all; and (iii) that the difficulty understanding the different fishing methods/activities is daunting.

The contractor was urged to remember the original purpose of the work. The main interest in these spatio-temporal effort estimates is the need to identify effort distribution by areas and time of year. This information is needed to estimate fishing impact on target and by-catch species. The Group discussed that because fishing strategies are different among fleets, the estimation of EFFDIS by fleet is the preferable approach. It was also suggested that task 2 data on their own would be enough for this and that the 'raising' to Task 1 might be unnecessary as an intermediate step. The contractor was also asked to consider the inclusion of artisanal fisheries which are important but it remains unclear where the data for this would come from and their likely quality.

In summary the contractor agreed to explore the effect of fleet/flag in more detail and make an effort to better understand the needs of the potential users for these data. The contractor is also extending the analysis too far south and the ICCAT Secretariat agreed to provide more realistic boundaries within which interpolation would take place.

3. Methods and other data relevant to the assessment

The Group noted in Section 2 that nearly all the input data available for the models are comprehensively described and presented in the 2015 Blue Shark Data Preparatory Meeting report (SCRS/2015/012). The only new datasets available to the assessment models were CPUE series provided prior to the 2015 blue shark stock assessment meeting. **Tables 1** and **2** provide all the CPUE series (including new series) and related CVs, available for use in the assessment models.

3.1 Production models

Bayesian state space surplus production model

SCRS/2015/153 presented initial results of the stock assessment of the South Atlantic blue shark stock. The assessment consisted of fitting a Bayesian state-space surplus production model to CPUE data for South Atlantic blue shark. The catch time series is derived from the 2015 Blue Shark Data Preparatory Meeting report, relative abundance indices for blue shark consisted of standardized catch-per-unit effort (CPUE) for Japan, Brazil, Uruguay, Spain, and Taiwan, longline fisheries. One run that included all input CPUE indices and prior mean values was developed as a base-case. Two alternative models were developed to evaluate the sensitivity of the model to different assumptions regarding the initial depletion of the stock and changes in input data.

The full specifications of the initial models presented are detailed in the SCRS document. Based on Group discussions, additional runs were requested in order to address identified issues and uncertainties in the initial model runs. These new runs are all variations on the initial model. The details of these new runs are provided in **Table 3**. In the initial model, fishery catch data from 1971-2013 were used (as described in the 2015 Blue Shark Data Preparatory Meeting report). Standardised CPUE from Japan, Brazil, Uruguay, Spain, and Taiwan were used in the model. Time-block catchabilities were estimated for CPUE series of Japan (changing point in 1994) and Brazil (changing point in 2001) as described in the SCRS document. The loess smoother method recommended by Francis (2011) was used to weight the data. This method involves fitting a log-transformed CPUE index using loess smoothers, and calculating the CV of the residuals of the fit of the smoother to the data.

An informative prior distribution for r and a moderately informative prior for K was assumed. For r a lognormal distribution with mean 0.21 and SD = 0.07 as suggested by the Group was used. Following the approach by Meyer and Millar (1999), who suggested taking the 10th and 90th percentiles of a lognormal distribution, values of 100 and 850 metric tons respectively (in 1000s) were used to express an interval of (moderately) high prior probability for K. The percentiles equate to a lognormal random variable with mean and standard deviation of 291 metric tons (in 1000s) and 0.835, respectively, and a CV of 100% was assumed. A non-informative inverse gamma prior for the catchability parameter (0.001, 0.001) was used. Process error (sigma) was fixed at 0.05 (see Ono *et al*., 2012 for details). For the base-case model the biomass in the first year was assumed to be equal to K (i.e. $P1= \psi = 1$), which means that the population was unfished in 1970.

Additional Bayesian state-space surplus production model runs requested by the Group were conducted at the meeting (**Table 3**). The sensitivity runs included assuming a less informative prior for *K*, as well as adding a constant of 0.2 and 0.1 to the CV of the different CPUE indices. As the estimated CV for the EU-Spain CPUE time series in the base-case model was very small (0.03), a model run was conducted adding a constant of 0.1 to the CVs for this index only. To evaluate the impact of including process error in the stock assessment model, sensitivity runs included removing process error from the model, as well as assuming different values (i.e. 0.01). In addition, in the models without process error different levels of CV for the CPUE time series were also assumed.

Bayesian Surplus Production Model

Document SCRS/2015/150 presented runs from the Bayesian Surplus Production (BSP) software used for the 2004 and 2008 assessments using newly available catch and CPUE data for North and South Atlantic blue sharks. The informative prior for the rate of population increase (*r*) was updated to reflect new biological information. Following the recommendations of the 2015 Blue Shark Data Preparatory Meeting, the indices used were for the North: US longline observer, Japanese longline, US observer cruise, Portuguese longline, Venezuelan longline, Spanish longline and Chinese Taipei longline, and for the South: Uruguayan longline, Brazilian longline, Japanese longline, Chinese Taipei longline and Spanish longline. Index data points were weighted either by catch, by effort, or equally. Catch data are incomplete for most of the history of the fishery. Therefore, several runs used a version of the BSP model that can be fitted to a series of longline effort data rather than catch in the early part of the time series. Bayesian decision analysis was used to examine the sustainability of various levels of future catch under each catch or effort scenario. Kobe plots were also presented.

The full specifications of the initial model are detailed in the document SCRS/2015/150. The first year of the fishery was assumed to be 1957 in the North and 1971 in the South, consistent with the 2008 assessment. The catch data calculated at the data preparatory meeting included reported Task I catches, catches inferred from ratios of blue shark catch to tuna catch, and catches estimated based on effort and catch rates and was available from 1971 in both regions. For the North Atlantic population, catches were estimated from effort for the years 1957 to 1970. For both regions, in an alternative model run, catches were estimated from effort through 1996, on the assumption that catches reported from 1997 to 2013 are the most reliable. The CPUE data points were either weighted by the relative catch in each fleet, or by the relative effort in each fleet, or all data points were weighted equally. In another model run, a combined index calculated by catch weighting was used, rather than fitting each series independently.

Priors were set up as follows. The starting biomass ratio (*Bo/K*) was lognormal with a mean of 1.0 and CV of 0.2, bounded between 0.2 and 1.1. The base case prior for *K* was uniform on log(*K*), and the maximum value of *K* was increased until it no longer influenced the posterior (5.0E7 in the North, 1.0E8 in the South). The priors for *r* were lognormal with, for the North Atlantic, a median of 0.324, and a standard deviation of 0.043 (log-variance=0.0173), and for the South Atlantic, a median of 0.218 and a standard deviation of 0.0719 (log-variance=0.106) (based on SCRS-2015-142). In both regions, *r* was bounded between 0.001 and 2. If the residual standard deviation was estimated, it was given an uninformative uniform prior between 1.0E-5 and 100. If effort was used to infer catches, the catchability q_c was given a uniform prior between 1.0E-9 and 0.1. B_{MSY}/K was set equal to 0.5 for all runs.

Additional BSP model runs, all variations of the initial model, were conducted at the meeting at the request of the Group (**Table 4**). For the North, these included a run that started in 1971 rather than 1957 so that no effort data was used, and a run with process error with a standard deviation (sigma) of 0.05. Process error models were run using the software BSP2, which is an alternative version of the BSP software (SCRS/2013/100). In addition, the model without process error was applied to each index independently. For the South (**Table 4**), additional model runs included one without the Brazilian CPUE index, one with the Brazilian index split at the year 2002, two with process error, and runs for each index separately. To evaluate why the state-space production model in JAGS and the BSP model were giving different results, despite using the same equations for the population dynamics, priors and likelihoods, post-model pre data (PMPD) runs were conducted. The PMPD runs used uninformative CPUE data (a single point in each series) to evaluate the implications of the model structure, priors, and catch time series for the posteriors of each parameter. In **Table 4**, run S-PMPD1 used the BSP2 software, with a prior CV for *B[1]/K* of 0.01, and a revised *r* prior (mean=0.38, log-sd=0.326, see **Appendix 5**). Run S-PMPD2 used JAGS, with the base prior for *r* from the state space model (mean = 0.21, log-sd=0.07), with a prior CV for *B[1]/K* of 0.001, and a minimum allowable value of *B/K* equal to 0.01. Run S-PMPD-3 used JAGS, with the revised *r* prior, a prior CV of B[1]/K of 0.2, and the B/K minimum equal to 0.001.

3.2 Length-based age-structured models: Stock Synthesis

Document SCRS/2015/151 presented preliminary Stock Synthesis (SS3) model runs conducted for North Atlantic blue shark (*Prionace glauca*) based on the available catch, CPUE, length composition, and life history data compiled by the sharks species group. A combined sex model was implemented in order to reduce model complexity. Beverton-Holt stock-recruitment was assumed. The steepness of the stock recruitment relationship and natural mortality at age were fixed at independently estimated values. However, several of the preliminary model runs resulted in unreasonable convergence diagnostics, and model results appeared to be sensitive to the weights assigned in the model likelihood to length composition data (sample size) relative to CPUE data (inverse CV weighting). Two preliminary model runs which utilized multiplication factors to reduce the input sample size assigned to length composition data in the model likelihood resulted in reasonable convergence diagnostics. Model fits to CPUE and length composition data were similar for both models. Both models resulted in sustainable spawning stock size and fishing mortality rates relative to maximum sustainable yield. The model with a relatively lower sample size assigned to the length composition data resulted in a relatively more depleted stock size.

The Group acknowledged the comprehensive work conducted to prepare the stock synthesis model for this species for the first time in the North Atlantic, and noted the importance of this initial step for future assessment purposes. Based on available time series of catch data, the start year of the model was 1971, and the end year was 2013. Catch in metric tons by major flag for North Atlantic blue shark was obtained from data compiled during the 2015 Blue Shark Data Preparatory Meeting and assigned to "fleets" F1 – F9. Equilibrium catch (Eq. catch = 17,077 mt) at the beginning of the fishery (1970) was obtained from an average of 10 posterior years (1971 to 1980) for fleets F1 (EU España + Portugal) + F2 (Japan) + F3 (Chinese Taipei). Indices of abundance for North Atlantic blue shark and their corresponding coefficients of variation (CV) were also obtained from data compiled during the 2015 Blue Shark Data Preparatory Meeting (**Tables 1 and 2**), except for updated Irish recreational and Chinese Taipei time series which were submitted separately. The available abundance indices and their associated CVs were assigned to "surveys" S1 – S10.

Length composition data for North Atlantic blue shark (35 – 390 cm FL, 5 cm FL bins) was obtained from data compiled during the 2015 Blue Shark Data Preparatory Meeting, as reported in SCRS/2015/039 (Coelho *et al*. 2015), for EU (Spain + Portugal, 1993-2013), JPN (Japan, 1997-2013), TAI (Chinese Taipei, 2004-2013), USA (1992-2013), and VEN (Venezuela, 1994-2013) and assigned to "fleets" F1 – F9 and "surveys" S1 – S10. The bin width was increased to 10 cm FL because a jagged pattern in the length compositions of some data sources (TAI and VEN) indicated the lengths may not have been measured at a 5 cm FL resolution. The final size distributions used in the SS3 model are presented in **Figure 1**. Length composition data for males and females were then combined for use in the SS3 preliminary model runs in order to reduce preliminary model complexity.

Life history inputs were obtained from data first assembled at the 2014 Intersessional Meeting of the Shark Species Group as reported in Anon. 2015 and additional information provided during the 2015 Blue Shark Data Preparatory Meeting and as reported in document SCRS/2015/142. The maximum age was fixed at 16. Growth in length at age was assumed to follow a von Bertalanffy growth (VBG) relationship. A total of 71 population length bins (35 – 385+ cm FL, 5 cm FL bins) were defined. A combined sex model was implemented by calculating the average sex specific VBG length at age-0 (Combined *LAmin*, 62.3 cm FL), the average sex specific VBG *L_inf* (Combined *Linf* = 296.0), and the average sex specific VBG growth coefficient (combined *k* = 0.16). The distribution of mean length at each age was modeled as a normal distribution, and the CV in mean length at age was modeled as a linear function of length. The CVs in length at age were fixed at 0.15 for *LAmin* and 0.12 for *Linf*, and linearly interpolated between *LAmin* and *Linf*. A combined sex length-weight relationship was used to convert body length (cm FL) to body weight (kg).

The steepness of the stock recruitment relationship (h) and natural mortality at age (M_a) were obtained from preliminary results based on life history invariant methods described separately in document SCRS/2015/142. A Beverton-Holt stock-recruitment relationship was assumed. The steepness parameter, h, was fixed at the mean of the distribution of steepness values obtained from the life history invariant methods (h = 0.73). Similarly, sex-specific survival at each age was calculated here as the mean of the distribution in survival at age, S_a, obtained from document SCRS/2015/142. Sex-specific natural mortality at age was then obtained as $-\ln(S_a)$. Combined sex natural mortality was then computed as the average mortality of males and females at each age.

A total of 6 preliminary model runs were conducted to explore model sensitivity to likelihood component weighting (**Table 5**). For Preliminary Run 1, the observed sample sizes (the number of sharks measured) obtained from the available length compositions (fleets F1–F5) were used directly in the model likelihood variance calculations to "weight" the length composition data. The observed CVs obtained from the available abundance indices (surveys S1–S10) were used in the model likelihood as inverse CV "weights" for the abundance indices (SCRS/2015/151). Preliminary Run 2 was the same as Preliminary Run 1 except that a constant CV of 20% was applied as the inverse CV weighting to the abundance index obtained for survey S9 (ESP-LL-N). Preliminary Run 3 was the same as Preliminary Run 2 except that the input length composition sample size was fixed at a maximum of 200. Preliminary Run 4 was the same as Preliminary Run 2 except that the input sample sizes for the length composition data for fleets F1–F5 were adjusted with variance adjustment multiplication factors (0.01, 0.01, 0.1, 0.1, 0.1, respectively) so that the effective sample sizes for fleets F1–F5 were approximately equal to 50-200. Preliminary Run 5 was the same as Preliminary Run 2 except that the input sample sizes for the length composition data for fleets F1–F5 were adjusted with variance adjustment multiplication factors (0.0184, 0.0478, 0.0261, 0.1373, 0.2236, respectively) so that the effective sample sizes for fleets F1 F5 were approximately equal to the effective sample size obtained from Stock Synthesis output (SCRS/2015/151). Preliminary Run 6 was the same as Preliminary Run 2 except that the input sample sizes for the length composition data for fleets F1–F5 were adjusted with variance adjustment multiplication factors (0.0019, 0.0047, 0.0046, 0.0573, 0.0403, respectively) so that the effective sample sizes for fleets F1–F5 were approximately equal to the effective sample size obtained from the program r4ss (SCRS/2015/151).

The Group discussed some aspects of the size distribution data that appeared to influence model results. One aspect was the bimodal distributions of some length compositions (especially EU.PRT+EU.ESP and JPN) within the North Atlantic (north of 30ºN). Smaller sized blue sharks appeared to dominate north of 30ºN, while larger sized blue sharks dominated south of 30ºN. Splitting the size data north and south of 30ºN removed much of the bimodal distribution of those fleets (**Figure 2**).

When comparing SS3 preliminary model runs, the Group noted that the weight given to the EU size data in the model had a large influence on the model outputs (Run 4 and Run 6). This seems to be happening because of the bimodal distribution in the data (especially EU.PRT+EU.ESP, but also JPN), and the fact that with Run 4 the model predicted catching more juveniles while Run 6 is predicting catching more adults. Given that the EU fleet is responsible for ~82% of the catch, and that the bimodal length composition of EU.PRT+EU.ESP is not fit well in either of the current models, the fit to size data in the model may be improved in future assessments by splitting the North Atlantic blue shark catches (especially EU.PRT+EU.ESP, but also JPN) into geographic regions that have similar length compositions (e.g. north and south 30ºN).

In general, the Group discussed the relative importance of the CPUE indices vs. the length composition data in the model. On one hand, the inclusion of the size data in the SS3 model represents a breakthrough in terms of modelling the stock. On the other hand, according to the method proposed by Francis (2011), it is generally not recommended to let the length composition data exert a stronger influence on the estimation of global quantities (R_0) in the model than the CPUE indices. There is a danger that the model, in an attempt to improve the fit to the length composition data, can produce poor fits in relation to the CPUE indices, therefore appropriate weighting is necessary. In simple terms, the apparent differences between preliminary Runs 4 and 6 relate to how the SS3 model is attempting to balance the fit between the length compositions (which are relatively more influential for Run 4) and the CPUE indices (which are relatively more influential in Run 6).

It was noted that several scenarios are important for future consideration, such a sex–specific, spatially disaggregated model. The Group discussed exploring the size frequency distributions to inform splitting the catches by area in the model (e.g. using regression tree analysis). This can be used to investigate how the different fleets are related based on geographic areas with similar available length composition data. The Group also noted that besides this spatial structure of sizes, some of the observed differences between JPN and EU fleets are also due to different hook types and sizes used, as well as the depth of setting of the fishing gear.

The Group also suggested that given this new knowledge on the spatial size distribution of blue shark and the consequent difficulties in fitting production models to this species, this type of integrated models that can use size distribution data should also be explored for the South Atlantic in the future. It was confirmed to the Group that the coverage of the size data in the South Atlantic is also good, and that such size data can be prepared and integrated in SS3 models in the future.

Sensitivity Run 1 was developed to evaluate the influence of different data components on the maximum likelihood estimate of equilibrium recruitment (R_0) for Preliminary Run 6. R_0 likelihood profiles were computed for Preliminary Run 6 at fixed values of equilibrium recruitment (R_0) on either side of the maximum likelihood estimate (8.8) for length composition and abundance index data components. A review of the R_0 likelihood profile plot for Preliminary Run 6 by the Group indicated that length composition data from fleet F1 (EU-Spain and EU-Portugal) and the abundance index S10 (CTP-LL-N) had relatively large influences on the model likelihood. For Sensitivity Run 1, the model run used for Preliminary Run 6 was modified by fixing selectivity of fleet F1 to its estimated value, and turning off the fits to F1 length composition data and S10 abundance index data in the model.

Sensitivity Run 2 utilized an age structured production model diagnostic to evaluate the influence of recruitment deviations and length composition data on model fits to abundance indices. An age structured production model was developed from Preliminary Run 6 as follows. The full integrated model (Preliminary Run 6) was run to obtain the MLEs of all the parameters. The model was rerun (Sensitivity Run 2) with the parameters of the selectivity curve fixed at those estimated from the fully integrated model. The annual recruitment deviates were not estimated and were fixed at zero, and the size-composition data were not used.

3.3 Other methods

A hierarchical cluster analysis (Murtagh and Legendre, 2014) was used to group the CPUE indices used in the biomass dynamic model North and South Atlantic assessments. It is not uncommon for indices to contain conflicting information and therefore fitting often involves weighting contradictory trends which generally produces parameter estimates intermediate to those obtained from the data sets individually. Therefore likelihood profiles were calculated by data component (i.e. CPUE series) to evaluate the information by series.

4. Stock status results

In the North Atlantic, catches peak in the 1987, decline to 2000 and then increase. The indices show a relatively flat trend throughout the time series, with high variance. In the South Atlantic, catches increase gradually to a peak in 2010. The Japanese longline index decreases in the 1970s and 1980s, but all the other indices are either flat or increasing throughout the time series. The Brazilian longline fishery, in particular, increases strongly during the recent years when catch is also increasing. Trends in in the catches and CPUE indices for the North and South Atlantic are provided in **Figure 3**.

4.1 Production models

Bayesian state space surplus production model

The predicted CPUE indices for each model were compared to the observed CPUE to determine model fit. Overall, the fits to CPUE for all models were relatively flat, which indicates lack of fitting, as exemplified here using results from model M4 (**Figure 4**) (see **Appendix 4**). The autocorrelation function plot indicated a thinning interval of 100, which was large enough to address potential autocorrelation in the MCMC runs. The visual inspection of trace plots of the major parameters showed a good mixing of the three chains (i.e., moving around the parameter space), also indicative of convergence of the MCMC chains. The only concern was the evidence for strong autocorrelation and the fairly poor mixing in the posteriors of the estimated initial biomass depletion psi in models M1 and M2.

Plots of posterior densities of the model parameters are presented in the **Appendix 4**, together with their respective prior densities. Summaries of posterior quantiles of parameters and quantities of management interest for each model are provided in **Table 6**. The estimated trajectory of B/B_{MSY} and H/H_{MSY} plots showed that the South Atlantic blue shark stock status over the model time frame (197-2013) is highly sensitive to changes in values used to fix process error, as well as the CVs attributed to the CPUE time series (**Figure 5**).

Bayesian Surplus Production Model

For the North Atlantic, the models consistently estimated a posterior for r that was similar to the prior, and a posterior for K that had a long right tail with high mean and CV (**Table 7**). The estimated biomass trajectory stayed close to K for most runs, and the estimated harvest rate was low (**Figure 6**). The inclusion of process error (run N8) did not improve the results. When each index was fitted separately (**Table 8** and **Figure 7**), the posterior mean of K varied, but the CVs were large, implying that none of the indices were particularly informative about the value of K. See **Appendix 5** for details on all BSP model runs.

For the South Atlantic, due to the fact that the indices increased while the catches were high and increasing, the model was unable to estimate plausible values of *K* (**Table 9**). Without process error, the posterior means of *K* ranged from 20 to 50 million. With process error (runs S9 and S10) the posterior means were an order of magnitude lower. All runs found that the population has remained close to *K* with low harvest rates (**Table 9** and **Figure 8**). Leaving out or splitting the Brazil index (runs S7 and S8) did not improve the results. When the indices were run separately, the results were similar to the results with all the indices together (**Table 10** and **Figure 9**).

The BSP models consistently found much larger means and CVs of *K* than the state-space Bayesian surplus production model implemented in JAGS (see previous section). Post-model pre-data runs in both JAGS and BSP demonstrated that very small differences in the modeling assumptions made large differences in the model results in the absence of informative data (**Table 11** and **Appendix 5**). Due to the correlation between the starting biomass ratio ($B[1]/K$), K and r, using a very informative prior for the starting biomass ratio favors smaller values of *K* (S-PMPD2 versus S-PMPD3). Slight changes in the *r* prior also influence the posterior distribution of *K* in the absence of data. Also, the JAGS models set B/K equal to the minimum value (e.g. 0.01 or 0.001) if the parameter values being considered cause the population to collapse, while the BSP throws out parameter values that cause the population to collapse. These small differences in model assumptions would not make a difference if the data were informative; however, with uninformative and inconsistent data, the model assumptions influence the results.

4.2 Stock synthesis

Several of the preliminary model runs resulted in unreasonable convergence diagnostics, and model results were sensitive to the weights assigned in the model likelihood to length composition data (sample size) relative to CPUE data (inverse CV weighting). Two preliminary model runs which utilized multiplication factors to reduce the input sample size assigned to length composition data in the model likelihood (Preliminary Runs 4 and 6) resulted in reasonable convergence diagnostics, described below. Model fits to CPUE and length composition data were similar for both models and both models resulted in sustainable spawning stock size and fishing mortality rates relative to maximum sustainable yield. The model with a relatively lower sample size assigned to the length composition data resulted in a relatively more depleted stock size. However, model fits to length composition were insufficient for annual length composition data, for which a bimodal pattern was strong. This is related with spatial segregation of the population. It was suggested that more work should be done to improve fits to length composition data before using the model to develop management advice.

Convergence diagnostics

Preliminary Runs 1 – 3 and 5 had poor model convergence diagnostics, which were interpreted as a diagnostic for possible problems with data or the assumed model structure. Consequently results were not presented for Preliminary Runs 1–3 and 5. Preliminary Runs 4 and 6 had reasonable convergence diagnostics, but Run 6 had the best convergence diagnostics. Therefore, model results were only presented for Preliminary Runs 4 and 6. The main difference between Preliminary Runs 4 and 6 was that Preliminary Run 6 had relatively less weight applied to the length composition data in the model likelihood.

Model fits

Model fits to time series of abundance and length composition were similar for Preliminary Runs 4 and 6. Model fits to abundance trends well and were within most annual 95% confidence intervals for many abundance indices, including S3 (JPLL-N-e), S4 (JPLL-N-l), S6 (US-Obs-cru), S7 (POR-LL), and S9 (ESP-LL-N) (**Figures 10** and **11**). Model fits tracked trends reasonably well for abundance index S2 (US-Obs), but were often outside annual 95% confidence intervals. Predicted abundance was flat for abundance indices S8 (VEN-LL) and S10 (CTP-LL-N), probably because of large 95% confidence intervals for S8 and high inter-annual fluctuations in the early years for S10. Indices S1 (US-Log) and S5 (IRL-Rec) were only included in the model for exploratory purposes, were not fit in the model likelihood (lambda = 0), and had no influence on model results or predicted values. Model fits to length composition were reasonable for aggregate data (**Figure 12**).

Recruitment, fishing mortality and spawning stock size

The expected recruitment from the stock-recruitment relationship differed substantially between Preliminary Run 4 and Preliminary Run 6. However, based on model diagnostics there was very little information in the data to estimate recruitment. Expected fishing mortality, and predicted spawning stock size also differed substantially between Preliminary Run 4 and Preliminary Run 6. Predicted spawning stock biomass was substantially larger for Preliminary Run 4 than Preliminary Run 6. Predicted exploitation rates were higher for Preliminary Run 6 than for Preliminary Run 4.

Stock status

Both Preliminary Run 4 and Preliminary Run 6 resulted in sustainable spawning stock size and fishing mortality rates relative to maximum sustainable yield (**Figures 13** to **15**). However, Preliminary Run 6 (the model run with relatively less weight applied to the length composition data in the model likelihood) resulted in a relatively more depleted stock size, compared to Preliminary Run 4 (**Figures 13** to **15**).

Sensitivity runs

Sensitivity Run 1 R_0 likelihood profiles were compared to those obtained for Preliminary Run 6. The length composition data had relatively more influence on the maximum likelihood estimate than the abundance index data in Preliminary Run 6. In contrast, the length composition data had about the same influence on the maximum likelihood estimate as the abundance index data in Sensitivity Run 1 (**Figure 16**). Similar results were obtained for individual length composition and abundance index data components (**Figure 17**). However, the location of the minimum values of the R_0 likelihood profiles differed between the total length composition and total abundance index data components and among individual abundance index data components (**Figure 18**).

The R_0 likelihood profile plots were considered to be a useful diagnostic for evaluating the influence of different data components on the maximum likelihood estimate of equilibrium recruitment, R_0, an important parameter determining the absolute population size (scale) in the integrated model. Ideally the length composition data should not dominate over the abundance index data in the model likelihood (i.e. the Francis approach).

Sensitivity Run 2 fits to each index of abundance were compared to those obtained for Preliminary Run 6. The predicted time series of relative abundance obtained for Sensitivity Run 2 were flat and differed substantially from those obtained for Preliminary Run 6. An example is provided for the abundance index for S7 (POR-LL; **Figure 19**). The relatively poorer fits to the observed indices of abundance for Sensitivity Run 2 indicated that the inclusion of length data, and estimation of recruitment deviations, was necessary to fit the relative abundance trends accurately. In theory the age-structured production model (Sensitivity Run 2) should be able to track trends in relative abundance. Consequently, the results of this sensitivity analysis may indicate that the CPUE indices were not informative enough.

4.3 Other models

The CPUE indices used in the biomass dynamic (i.e. production) model assessments for the North and South Atlantic are presented in **Figure 20** and **21**. It is not uncommon for indices to contain conflicting information, in which case fitting multiple indices involves weighting contradictory trends, which generally produces parameter estimates intermediate to those which would be obtained if the data sets were fitted individually. A hierarchical cluster analysis (Murtagh and Legendre, 2014) was used to group the CPUE series (**Figure 22** and **23)**. Likelihood profiles were then calculated for each CPUE series (data component) based on a fit to all the indices (SCRS/2015/073). **Figure 24** shows *r* profiles for the North and **Figure 25** shows *r* profiles for the South. In the case of the North only one index shows a maximum; for the South no profile showed a maximum, i.e. r is either larger or smaller than the estimate obtained by fitting all the indices simultaneously. An additional run was preformed removing the Chinese-Taipei and Venezuela CPUE series (**Figure 26**).

When CPUE indices are conflicting, including them in a single assessment (either explicitly or after combining them into a single index) tends to result in parameter estimates intermediate to what would be obtained from the data sets individually. Schnute and Hilborn (1993) showed the most likely parameter values are usually not intermediate but occur at one of the apparent extremes. Including conflicting indices in a stock assessment scenario may also result in residuals not being Identically and Independently Distributed (IID) and so procedures such as the bootstrap cannot be used to estimate parameter uncertainty. An alternative is to assume that indices reflect hypotheses about states of nature and to run scenarios for single or sets of indices that represent a common hypothesis.

A jackknife procedure was conducted for the North Atlantic to evaluate the importance of individual observations, i.e. by removing in turn individual points from each series. The parameter estimates are shown in **Figures 27** and **28**; the panels show the estimates when the point was removed from that series and the color corresponds to five year blocks. Removing points from some indices has a large effect (e.g. ESP LL) and in some cases (e.g. JP LL) the influence of removing points depends on the period in the time series.

4.4 Synthesis of assessment results

Considerable progress was made on the integration of new data sources (in particular size data) and modelling approaches (in particular model structure). Uncertainty in data inputs and model configuration was explored through sensitivity analysis, which revealed that results were sensitive to structural assumptions of the models. The production models had difficulty fitting the flat or increasing trends in the CPUE series combined with increasing catches. Overall, assessment results are uncertain (e.g. level of absolute abundance varied by an order of magnitude between models with different structures) and should be interpreted with caution.

For the North Atlantic stock, scenarios with the BSP estimated that the stock was not overfished (B_{2013}/B_{MSY}=1.50 to 1.96) and that overfishing was not occurring (F_{2013}/F_{MSY}=0.04 to 0.50). Estimates obtained with SS3 varied more widely, but still predicted that the stock was not overfished (SSF_{2013}/SSF_{MSY}=1.35 to 3.45) and that overfishing was not occurring (F_{2013}/F_{MSY}=0.15 to 0.75). Comparison of results obtained in the assessment conducted in 2008 and the current assessment revealed that, despite significant differences between inputs and models used, stock status results did not change drastically (B_{2007}/B_{MSY}=1.87-2.74 and F_{2007}/F_{MSY}=0.13-0.17 for the 2008 base runs using the BSP and a catch-free age-structured production model).

For the South Atlantic stock, scenarios with the BSP estimated that the stock was not overfished (B_{2013}/B_{MSY}=1.96 to 2.03) and that overfishing was not occurring (F_{2013}/F_{MSY}=0.01 to 0.11). Comparison of results obtained in the 2008 and current assessment were very similar for the BSP (B_{2007}/B_{MSY}=1.95 and F_{2007}/F_{MSY}=0.04 for the 2008 base runs). Estimates obtained with the state-space BSP were generally less optimistic, especially when process error was not included, predicting that the stock could be overfished (B_{2013}/B_{MSY}=0.78 to 1.29) and that overfishing could be occurring (F_{2013}/F_{MSY}=0.54 to 1.19).

5. Projections

Due to the difficulty of determining current stocks status, in particular absolute population abundance, the Group considered that it was not appropriate to conduct quantitative projections of future stock condition based on the scenarios (runs) considered at the meeting.

6. Recommendations

6.1 Research and statistics

- National scientists should consider using the available tag recapture and age reading data to improve growth estimates for the North Atlantic.

- Future implementations of the Stock Synthesis model for blue shark should investigate the incorporation of tag-recapture data for the North Atlantic. These data are particularly valuable because they cover both the eastern and western side of the ocean and thus could represent a large portion of the North Atlantic stock. The data may be informative in regards to mortality.

- The Group requested that, when possible, the estimation of the new EFFDIS be made at fleet level to account for fleet specific characteristics.

- The identification of which CPUE indices are appropriate for stock assessments should be done by the Group prior to the assessment, ideally by the end of the data preparatory meeting if there is one. This should be done using the guidelines developed by the WGSAM in the context of the assessment models to be used. Ideally the diagnostics shown by SCRS/2015/073, to help choose alternative hypotheses about CPUE indices, should be run and be available during the data preparatory meeting.

- It is best not to combine standardized CPUE series into combined indices. A better practice would be to consider that indices identified to be reliable for assessments be considered as alternative and plausible hypotheses about the evolution of abundance. However, sets of individual indices indicative of similar trends in abundance may be used in assessment models.

- Future implementations of Stock Synthesis should consider spatial structure in the fleets for the northern stock in order to be able to account for the differences in size composition of fish in different areas. That would also allow for the estimation of differences in selectivity for each fleet/area. This will require estimating fleet and area specific CPUE indices, catch and size distributions. Ideally the model could also be separated by sex.

- Stock Synthesis should also be implemented for the South Atlantic stock. This will require similar preparatory work to develop input data streams, as done for the northern stock.

- More guidance should be developed by the SCRS on the relative reliability and consistency of different data streams with each other, and with knowledge of the species biology and fisheries.

- The WGSAM should develop guidelines on how SCRS species groups should implement alternative hypotheses with Stock Synthesis. More specifically, the WGSAM should consider providing guidance to the groups on how to assign variance adjustment factors and relative weights (lambdas) to the different data inputs to Stock Synthesis (fleet-specific size data distributions, relative abundance indices, etc.). Guidelines on appropriate diagnostics (e.g. likelihood profiles for R_0 for each data component, convergence criteria, sensitivity to variance adjustment scheme, etc.) for Stock Synthesis should also be developed by the WGSAM.

- The WGSAM should develop guidelines and criteria for evaluating the plausibility of model scenarios, including model diagnostics that could lead to accepting or rejecting model results.

- The mismatch between catch, CPUE indices, and biological parameters for the southern stock should be further investigated within the framework of the Shark Research and Data Collection Programme (SRDCP).

- WGSAM should evaluate the benefits of incorporation of process error into biomass dynamic models.

- The Group recommended the evaluation of data-poor methods and use of empirical fisheries indicators as an alternative to conventional stock assessment. Such methods should be tested using MSE.

- The Group reminds of the need to follow the guidelines developed by the WGSAM and adopted by the SCRS for the development and presentation of standardized CPUE series, in particular the information with regards changes in fishing practices.

- SCRS scientists should consider participating in the upcoming CAPAM Data Weighting Workshop (October 19-23, 2015, La Jolla, California, USA).

6.2 Management

- Given the uncertainty in South Atlantic stock status results it is not possible to discount that in recent years the stock may have been at a level near B_{MSY} and that fishing mortality has been approaching F_{MSY}. This implies that future increases in fishing mortality could push the stock to be overfished and experience overfishing. The Group therefore recommends that until this uncertainty is resolved that catch levels should not increase beyond those of recent years.

- Based on the scenarios and models explored, the status of the North Atlantic stock is unlikely to be overfished nor subject to overfishing. However, due to the level of uncertainty, the Group could not reach a consensus on a specific management recommendation. Some participants expressed the opinion that fishing mortality should not be increased while others thought this was not necessary.

The uncertainty in the results highlights the need for continued monitoring of the fisheries by observer and port sampling programmes.

7. Other matters

The Group recalled that in 2014 a proposal for the implementation of the Shark Research and Data Collection Programme (SRDCP) was prepared and subsequently funded for the first year. The initial phase of this Programme focuses on biological aspects relevant to stock assessment of the shortfin mako. The Group was informed that, as requested during the 2015 Blue Shark Data Preparatory Meeting, proposals related to the agreed components of the project had been submitted to the Secretariat. These key components are related to genetic studies, age-and-growth analysis and tagging. These proposals have been reviewed by the Group Chair, the SCRS Chair and the Secretariat and approved for financing. The Group expressed its continued support for this Programme and its satisfaction that the proposed work has been initiated.

8. Adoption of the report and closure

The report was adopted during the meeting. Dr Cortes thanked the participants and the Secretariat for their hard work, and the external expert for his important contributions to the Group discussions. The meeting was adjourned.

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Table 1. Indices of abundance for North and South Atlantic blue shark stocks.

			North Atlantic									South Atlantic			
Year	Usobs	JPLLe	JPLLl	USOLD	PORLL	VENLL	ESPLL	CHTPLL		URULL	BRLL	JPLLe	JPLLl	ESPLL	CHTPLL
1957				0.98											
1958				0.48											
1959				1.11											
1960				1.18											
1961				1.13											
1962				1.5											
1963				0.7											
1964				0.87											
1965				1.55											
1966				1.27											
1967				1.43											
1968				1.31											
1969				1.96											
1970				0.97											
1971		0.87		1.08								1.32			
1972		1.46		1.93								0.87			
1973		1.12										1.94			
1974		2.62										1.28			
1975		1.85		0.88								1.29			
1976		1.07		0.75								1.58			
1977		1.89		1.82								7.48			
1978		1.58		1.06							0.094	4.51			
1979		1.3		0.860							0.441	4.45			
1980		2.21		0.830							0.614	4.52			
1981		2.19		1.050							0.338	1.52			
1982		2.08		0.780							0.543	3.18			
1983		1.81		1.010							0.362	2.69			
1984		1.22		0.680							0.532	3.07			
1985		1.51		0.740							1.005	2.54			
1986		1.52		0.480							0.896	3.18			
1987		2.13		0.500							0.723	3.13			
1988		1.21		0.440							0.861	3.14			
1989		1.51		0.800							0.878	2.28			
1990		1.34		0.940							0.893	2.31			
1991		1.26		1.220							0.202	2.23			
1992	7.455	1.9		0.63						138.8	0.805	2.27			
1993	11.076	2.43		0.95						24.6	0.143	2.17			
1994	9.717		2.33	0.98		0.047				311.2	0.558		1.48		
1995	10.17		2.1	0.73		0.073				81.9	0.272		0.96		
1996	8.208		2.05	0.47		0.017				346.7	0.132		1.07		
1997	14.439		2.05	1.25	158.14	0.154	156.83			351.0	0.493		1.33	330.6	
1998	18.408		1.72	1.16	169.02	0.216	154.45			315.7	1.336		1.25	349.4	
1999	6.663		1.89	0.76	149.83	0.117	179.91			182.8	0.469		1.23	352.4	
2000	9.541		1.58	0.78	201.44	0.151	213.05			166.1	0.455		0.82	435.1	
2001	2.306		1.71		222.14	0.133	215.63			99.1	1.984		1.02	389.1	
2002	2.277		1.37		200.86	0.074	183.94			72.7	1.175		1.03	361.5	
2003	1.876		1.97		238.77	0.044	222.88			99.7	2.725		1.82	326.3	
2004	9.503		1.79		266.16	0.034	177.27	0.749		107.3	3.568		1.21	325.3	0.28
2005	3.193		1.9		218.55	0.006	166.82	2.195		116.4	2.898		1.18	369.6	0.82
2006	4.674		2.16		212.63	0.013	177.11	1.308		111.0	3.260		1.35	369.2	2.31
2007	9.645		2.18		241.32	0.060	187.06	0.561		296.4	3.187		1.32	380.0	0.90
2008	8.512		2.48		225.68	0.088	215.80	0.495		250.1	2.501		1.81	359.3	1.12
2009	8.322		2.46		228.30	0.045	196.08	0.570		130.6	4.456		1.49	394.5	0.88
2010	13.545		2.45		276.76	0.040	209.03	0.877		436.5	4.966		1.94	379.2	1.35
2011	21.806		2.37		233.29	0.044	221.13	0.765			3.206		1.34	386.9	0.87
2012	8.128		2.6		305.53	0.107	238.00	0.668			1.769		1.49	400.9	1.40
2013	7.374		2.09		304.08	0.044	203.49	1.045					2.17	418.0	1.61

Table 2. Coefficients of variation (CVs) for North and South Atlantic blue shark stocks.

			North Atlantic									South Atlantic			
Year	Usobs	JPLLe	JPLLl	USOLD	PORLL	VENLL	ESPLL	CHTPLL		URULL	BRLL	JPLLe	JPLLl	ESPLL	CHTPLL
1957				0.17											
1958				0.16											
1959				0.25											
1960				0.38											
1961				0.35											
1962				0.27											
1963				0.25											
1964				0.17											
1965				0.17											
1966				0.23											
1967				0.21											
1968				0.21											
1969				0.22											
1970				0.32											
1971		0.53		0.23								0.48			
1972		0.39		0.21								0.56			
1973		0.45										0.35			
1974		0.32										0.39			
1975		0.34		0.19								0.26			
1976		0.47		0.29								0.06			
1977		0.27		0.2								0.01			
1978		0.32		0.11							0.65	0.08			
1979		0.24		0.11							0.72	0.13			
1980		0.29		0.09							0.73	0.18			
1981		0.36		0.09							0.88	0.44			
1982		0.36		0.09							0.86	0.34			
1983		0.37		0.1							0.86	0.22			
1984		0.50		0.1							0.65	0.34			
1985		0.44		0.1							0.69	0.41			
1986		0.39		0.09							0.63	0.37			
1987		0.35		0.1							0.60	0.37			
1988		0.49		0.12							0.65	0.37			
1989		0.44		0.39							0.61	0.47			
1990		0.49		0.17							0.74	0.48			
1991		0.47		0.11							0.56	0.49			
1992	0.31	0.43		0.1						0.63	0.61	0.44			
1993	0.29	0.40		0.09						1.20	0.72	0.49			
1994	0.29		0.50	0.1		1.08				0.62	0.57		0.43		
1995	0.29		0.55	0.1		0.87				0.90	0.58		0.50		
1996	0.50		0.51	0.3		1.90				0.57	0.64		0.45		
1997	0.33		0.52	0.13	0.084	`	0.008			0.54	0.57		0.43	0.006	
1998	0.35		0.53	0.15	0.076	0.67	0.008			0.54	0.60		0.39	0.007	
1999	0.34		0.49	0.13	0.077	0.84	0.008			0.51	0.54		0.42	0.006	
2000	0.32		0.28	0.12	0.083	0.74	0.008			0.60	0.54		0.45	0.006	
2001	0.39		0.56		0.089	0.77	0.008			0.63	0.60		0.39	0.005	
2002	0.39		0.62		0.086	1.03	0.008			0.67	0.58		0.35	0.006	
2003	0.37		0.59		0.082	1.26	0.009			0.65	0.65		0.25	0.006	
2004	0.30		0.69		0.084	1.53	0.009	0.12		0.61	0.55		0.41	0.007	0.23
2005	0.35		0.71		0.087	3.88	0.010	0.19		0.55	0.55		0.41	0.007	0.10
2006	0.31		0.69		0.084	2.24	0.010	0.06		0.56	0.54		0.42	0.007	0.04
2007	0.32		0.61		0.085	1.35	0.011	0.22		0.51	0.65		0.44	0.007	0.06
2008	0.32		0.69		0.085	1.16	0.011	0.28		0.51	0.66		0.39	0.007	0.07
2009	0.31		0.64		0.086	1.56	0.012	0.17		0.51	0.58		0.41	0.006	0.06
2010	0.31		0.64		0.089	1.54	0.010	0.10		0.53	0.54		0.36	0.007	0.06
2011	0.29		0.51		0.079	1.51	0.010	0.12			0.50		0.44	0.007	0.05
2012	0.34		0.51		0.081	1.00	0.010	0.11			0.58		0.43	0.007	0.06
2013	0.31		0.21		0.085	1.84	0.011	0.14					0.34	0.007	0.04

Table 3. Model runs presented to the Group during the assessment meeting, for the state-space production model in JAGS.

Model	CPUEs	Prior r	Prior K	Initial condition	Process error	CVs for CPUE series
M1	All	*LN* ~(log(0.21),0.07)	*LN* ~(log(291 mt),0.835)	B_1 = K (P1=1)	Fixed (0.05)	Francis method
M2	All	*LN* ~(log(0.21),0.07)	*LN* ~(log(291 mt),0.835)	P_1 = psi	Fixed (0.05)	Francis method
M3	All (Japan 1982-2013)	*LN* ~(log(0.21),0.07)	*LN* ~(log(291 mt),0.835)	P_1 = psi	Fixed (0.05)	Francis method
M4	All - Brazil	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	Fixed (0.05)	Francis method
M5	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	Fixed (0.05)	Francis method
M6	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	Fixed (0.05)	Francis method+0.1(Spain only)
M7	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	Fixed (0.05)	Francis method+0.1(all series)
M8	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	NO	Francis method + 0.1(all series)
M9	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	NO	Francis method + 0.2(all series)
M10	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	NO	Francis method
M11	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	Fixed (0.01)	Francis method
M12	All	*LN* ~(log(0.21),0.07)	*K*~1/gamma(0.001,0.001)	B_1 = K	Fixed (0.01)	Francis method + 0.01 (all series)

Table 4. Model runs using the Bayesian Surplus Production (BSP) model software, BSP2, and an alternative JAGS formulation used for model testing. The base indices were, in the North: US-Obs, JPLL-N-e, JPLL-N-l, US-Obs-cru, POR-LL, VEN-LL, ESP-LL-N, and CH-TA-LLN, and in the South: UR LL, BR LL, JPLL-S-e, JPLL-S-l, ESP-LL-S, and CH-TA-LLS.Runs.

	North						
	Initial Year	First Catch	Catch estimated method	CPUE variance	Indices	Process error	Software
N1	1957	1971	effort	equal estimated	base	0	BSP
N2	1957	1997	effort	equal estimated	base	0	BSP
N3	1957	1971	effort	catch weighting	base	0	BSP
N4	1957	1971	effort	effort weighting	base	0	BSP
N5	1957	1971	effort	equal estimated	combined	0	BSP
N6	1957	1971	effort	equal, sigma=1	base	0	BSP
N7	1971	1971	NA	effort weighting	base	0	BSP
N8	1957	1957	effort	effort weighting	base	0.05	BSP2
US-Obs	1957	1971	effort	equal estimated	US-Obs	0	BSP
JLL	1957	1971	effort	equal estimated	JLL	0	BSP
US-Obs-cru	1957	1971	effort	equal estimated	US-Obs-cru	0	BSP
POR-LL	1957	1971	effort	equal estimated	POR-LL	0	BSP
VEN-LL	1957	1971	effort	equal estimated	VEN-LL	0	BSP
ESP-LL-N	1957	1971	effort	equal estimated	ESP-LL-N	0	BSP
CH-TA-LLN	1957	1971	effort	equal estimated	CH-TA-LLN	0	BSP
	South						
	Initial Year	First Catch	Catch estimated method	CPUE variance	Indices	Process error	Software
S1	1971	1971	NA	equal estimated	base	0	BSP
S2	1971	1997	effort	equal estimated	base	0	BSP
S3	1971	1971	NA	catch weighting	base	0	BSP
S4	1971	1971	NA	effort weighting	base	0	BSP
S5	1971	1971	NA	equal estimated	combined	0	BSP
S6	1971	1971	NA	equal, sigma=1	base	0	BSP
S7	1971	1971	NA	equal estimated	not Brazil	0	BSP
S8	1971	1971	NA	effort weighting	Brazil split	0	BSP
S9	1971	1971	NA	effort weighting	base	0.05	BSP2
S10	1971	1971	NA	Francis method +0.1	Brazil split	0.05	BSP2
S-PMPD	1971	1971	NA	Francis method +0.1	Brazil split	0.05	BSP2
UR LL	1971	1971	NA	equal estimated	UR LL	0	BSP
BR LL	1971	1971	NA	equal estimated	BR LL	0	BSP
JLL	1971	1971	NA	equal estimated	JLL	0	BSP
ESP-LL-S	1971	1971	NA	equal estimated	ESP-LL-S	0	BSP
CH-TA-LLS	1971	1971	NA	equal estimated	CH-TA-LLS	0	BSP
S-PMPD2	1971	1971	NA	Francis method	Brazil split	0.05	JAGS
S-PMPD3	1971	1971	NA	Francis method	Brazil split	0.05	JAGS

Table 5. A total of 6 preliminary SS3 model runs were conducted to explore model sensitivity to likelihood component weighting.

Model Run	Model Adjustments				
Preliminary Run 1	Natural weights used in model likelihood				
	Length composition input sample size (n = observed)				
	Abundance indices (inverse CV weighting; SCRS/2015/151)				
Preliminary Run 2	Same as Preliminary Run 1 + Adjust CV of S9 (ESP-LL-N)				
CV adjustment	Constant CV of 20% applied to S9 (ESP-LL-N)				
Preliminary Run 3	Same as Preliminary Run 2 + Adjust input sample size for length comp				
Sample size adjustments	Maximum length composition input sample size (n=200)				
Preliminary Run 4	Same as Preliminary Run 2 + Apply variance adjustment to length comp.				
Fleet	F1	F2	F3	F4	F5
Variance adjustments	0.01	0.01	0.1	0.1	0.1
Preliminary Run 5	Same as Preliminary Run 2 + Apply variance adjustment to length comp.				
Fleet	F1	F2	F3	F4	F5
Variance adjustments	0.0184	0.0478	0.0261	0.1373	0.2236
Preliminary Run 6	Same as Preliminary Run 2 + Apply variance adjustment to length comp.				
Fleet	F1	F2	F3	F4	F5
Variance adjustments	0.0019	0.0047	0.0046	0.0573	0.0403
Sensitivity 01	R_0 Likelihood profile (Preliminary Run 6 with the changes indicated in section 3.2)				
Sensitivity 02	Age structured production model diagnostic (Preliminary Run 6)				

Table 6. Summary of posterior quantiles of parameters for models M1 to M12 from the state-space production model. Biomass related values are in thousands of tons.

Parameters						**Models**						
		M1			**M2**			**M3**			**M4**	
	2.50%	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**
B2013/B_{MSY}	1	1.15	1.31	0.97	1.12	1.27	0.94	1.08	1.24	0.98	1.13	1.29
B_{MSY}	113.78	126.95	142.52	117.07	131.23	148.41	119.67	135.4	154.8	126.13	142.2	161.7
H2013/H_{MSY}	0.83	0.97	1.12	0.86	1	1.16	0.87	1.02	1.18	0.82	0.96	1.12
H_{MSY}	0.13	0.15	0.17	0.12	0.14	0.16	0.12	0.14	0.16	0.12	0.14	0.16
K	227.56	253.9	285.04	234.13	262.46	296.82	239.35	270.79	309.6	252.26	284.4	323.41
MSY	16.68	18.7	20.83	16.71	18.66	20.74	16.89	18.86	21.01	17.08	19.28	21.68
r	0.26	0.29	0.34	0.25	0.28	0.32	0.24	0.28	0.32	0.24	0.27	0.31
psi				0.55	0.64	0.77	0.73	0.86	1			
		M5			**M6**			**M7**			**M8**	
	2.50%	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**
B2013/B_{MSY}	1.01	1.15	1.3	1.03	1.2	1.4	0.78	0.94	1.13	0.79	0.89	0.99
B_{MSY}	114.07	126.77	142.74	114.35	127.46	143.48	114.91	128.9	145.59	121.85	134.71	148.87
H2013/H_{MSY}	0.83	0.97	1.12	0.77	0.92	1.09	0.97	1.19	1.47	0.85	0.99	1.16
H_{MSY}	0.13	0.15	0.17	0.13	0.15	0.17	0.12	0.14	0.16	0.16	0.18	0.2
K	228.15	253.53	285.47	228.7	254.92	286.95	229.82	257.8	291.18	243.69	269.42	297.75
MSY	16.68	18.71	20.88	16.85	18.91	21.09	16.48	18.54	20.68	22.57	23.58	24.75
r	0.26	0.29	0.34	0.26	0.3	0.34	0.25	0.29	0.33	0.31	0.35	0.39
psi												
		M9			**M10**				**M11**		**M12**	
	2.50%	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**	**2.50%**	**50%**	**97.50%**
B2013/B_{MSY}	0.67	0.78	0.9	1.22	1.28	1.35	1.22	1.29	1.35	0.79	0.89	0.99
B_{MSY}	121.93	134.96	149.48	138	151.34	166.62	137.97	151.58	166.43	121.62	134.7	149.17
H2013/H_{MSY}	0.98	1.18	1.43	0.48	0.54	0.6	0.48	0.54	0.59	0.85	0.99	1.16
H_{MSY}	0.15	0.17	0.19	0.18	0.2	0.22	0.18	0.2	0.22	0.15	0.18	0.2
K	243.86	269.91	298.97	275.99	302.68	333.24	275.93	303.15	332.86	243.25	269.39	298.34
MSY	21.59	22.58	23.68	28.52	30.09	32.01	28.56	30.12	32	22.58	23.57	24.71
r	0.29	0.34	0.38	0.36	0.4	0.44	0.36	0.4	0.44	0.31	0.35	0.39
psi												

Table 7. Means and CVs of model outputs from the BSP model. BSP results for the North Atlantic. Biomass related values are in thousands of tons.

Variable	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**
K (1000)	4871.3 (1.70)	4871.5 (1.8)	4951.3 (1.3)	3506.6 (1.5)	4006.1 (0.94)	2260.1 (1.7)	16081.29 (0.79)	10020 (1.19)
r	0.4 (0.14)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.14)	0.4 (0.1)	0.38 (0.13)	0.39 (0.13)
MSY (1000)	467.3 (1.70)	461.5 (1.8)	477.8 (1.3)	338.1 (1.5)	380.6 (0.94)	220.0 (1.8)	1547.49 (0.81)	976 (1.21)
B_{cur} (1000)	4766.8 (1.74)	4760.8 (1.8)	4846.2 (1.3)	3398.0 (1.5)	3904.3 (0.96)	2151.9 (1.8)	15982.68 (0.80)	9892 (1.2)
B_{init} (1000)	4377.9 (1.76)	4482.3 (1.8)	4540.6 (1.3)	3207.7 (1.5)	3780.1 (0.96)	2087.1 (1.7)	14784.43 (0.80)	9104 (1.22)
B_{cur}/B_{init}	1.1 (0.15)	1.0 (0.2)	1.1 (0.1)	1.0 (0.2)	1.0 (0.10)	1.0 (0.1)	1.08 (0.11)	1.05 (0.19)
C_{cur}/MSY	0.3 (0.78)	0.4 (0.9)	0.3 (1.0)	0.4 (0.9)	0.2 (0.96)	0.4 (0.7)	0.07 (1.73)	0.21 (1.29)
B_{cur}/B_{MSY}	1.8 (0.08)	1.8 (0.1)	1.8 (0.1)	1.8 (0.1)	1.9 (0.06)	1.8 (0.1)	1.96 (0.04)	1.86 (0.12)
F_{cur}/F_{MSY}	0.2 (0.89)	0.3 (1.1)	0.2 (1.3)	0.2 (1.1)	0.1 (1.10)	0.2 (0.8)	0.04 (2.45)	0.14 (1.68)

Table 8. BSP results for each fleet fit separately, for the North Atlantic. Biomass related values are in thousands of tons.

Variable	**US.Obs**	**JLL**	**US.Obs.cru**	**POR.LL**	**VEN.LL**	**ESP.LL.N**
K (1000)	2489.0(1.9)	7490.3(1.36)	1934.4(1.5)	1171.5(2.4)	4447.0(1.8)	3886.6(1.5)
r	0.4(0.1)	0.4(0.14)	0.4(0.1)	0.4(0.1)	0.4(0.1)	0.4(0.1)
MSY (1000)	228.5(1.8)	716.3(1.36)	185.0(1.5)	112.8(2.4)	426.4(1.8)	378.6(1.5)
B_{cur} (1000)	2376.3(2.0)	7387.8(1.38)	1825.0(1.6)	1042.5(2.8)	4338.5(1.8)	3778.6(1.5)
B_{init} (1000)	2301.2(1.9)	6623.3(1.42)	1762.2(1.6)	1072.3(2.6)	3877.8(1.9)	3541.0(1.5)
B_{cur}/B_{init}	1.0(0.2)	1.2(0.14)	1.0(0.2)	0.9(0.2)	1.1(0.2)	1.1(0.1)
C_{cur}/MSY	0.4(0.7)	0.2(0.97)	0.4(0.7)	0.7(0.5)	0.4(0.8)	0.3(0.9)
B_{cur}/B_{MSY}	1.7(0.1)	1.9(0.07)	1.8(0.1)	1.5(0.2)	1.8(0.1)	1.8(0.1)
F_{cur}/F_{MSY}	0.3(1.1)	0.1(1.08)	0.2(1.0)	0.5(0.7)	0.2(1.1)	0.2(1.1)

Table 9. BSP results for the South Atlantic. Biomass related values are in thousands of tons.

Variable	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
K (1000)	48202.32 (0.59)	18301.6 (1.3)	20020.16 (1.23)	36795.40 (0.74)	46089.48 (0.64)	38258.15 (0.75)	43229.29 (0.64)	32505.14 (0.80)	5321 (0.52)	3453 (0.74)
r	0.22 (0.40)	0.3 (0.5)	0.24 (0.33)	0.24 (0.34)	0.22 (0.40)	0.23 (0.38)	0.26 (0.32)	0.24 (0.33)	0.23 (0.35)	0.2 (0.26)
MSY (1000)	2631.27 (0.71)	925.3 (1.3)	1194.32 (1.34)	2171.53 (0.84)	2369.13 (0.76)	2117.25 (0.86)	2795.65 (0.73)	1931.9 (0.91)	306 (0.65)	173 (0.84)
B_{cur} (1000)	48046.22 (0.59)	18157.1 (1.3)	19900.56 (1.24)	36677.21 (0.74)	45906.62 (0.64)	38119.55 (0.75)	43113.77 (0.64)	32387.42 (0.81)	5319 (0.56)	3544 (0.76)
B_{init} (1000)	39531.07 (0.61)	14453.5 (1.3)	17542.22 (1.24)	32304.23 (0.75)	33391.33 (0.66)	31981.78 (0.78)	24900.64 (0.70)	28459.08 (0.81)	4514 (0.55)	3453 (0.74)
B_{cur}/B_{init}	1.25 (0.19)	1.2 (0.3)	1.11 (0.15)	1.15 (0.14)	1.40 (0.24)	1.22 (0.19)	1.82 (0.26)	1.15 (0.14)	1.18 (0.21)	1.01 (0.06)
C_{cur}/MSY	0.02 (2.01)	0.2 (1.2)	0.13 (1.44)	0.03 (2.23)	0.03 (1.91)	0.03 (1.74)	0.02 (2.33)	0.04 (2.07)	0.13 (1.09)	0.21 (0.66)
B_{cur}/B_{MSY}	1.99 (0.02)	1.9 (0.1)	1.91 (0.08)	1.98 (0.03)	1.98 (0.02)	1.98 (0.02)	1.99 (0.02)	1.98 (0.03)	1.96 (0.13)	2.03 (0.07)
F_{cur}/F_{MSY}	0.01 (2.17)	0.1 (1.4)	0.08 (1.86)	0.02 (2.88)	0.01 (2.06)	0.02 (1.87)	0.01 (2.66)	0.02 (2.93)	0.07 (1.36)	0.11 (0.69)

Table 10. BSP results for each fleet fit separately, for the South Atlantic. Biomass related values are in thousands of tons.

Variable	UR.LL	BR.LL	JLL	ESP.LL.S	CH.TA.LLS
K (1000)	33122.78(0.80)	33315.02(0.80)	43239.55(0.63)	39887.31(0.72)	27803.04(0.88)
r	0.24(0.34)	0.24(0.34)	0.24(0.30)	0.24(0.36)	0.24(0.34)
MSY (1000)	1984.56(0.92)	1994.25(0.91)	2602.88(0.72)	2366.81(0.82)	1648.69(0.96)
B_{cur} (1000)	33004.85(0.80)	33196.97(0.80)	43124.43(0.64)	39768.96(0.72)	27685.03(0.88)
B_{init} (1000)	30312.62(0.82)	30513.25(0.82)	33709.15(0.65)	35846.75(0.74)	25517.86(0.89)
B_{cur}/B_{init}	1.11(0.13)	1.11(0.13)	1.30(0.15)	1.14(0.14)	1.10(0.13)
C_{cur}/MSY	0.04(2.33)	0.04(2.33)	0.02(2.37)	0.03(2.02)	0.05(2.14)
B_{cur}/B_{MSY}	1.97(0.05)	1.97(0.05)	1.99(0.02)	1.98(0.02)	1.96(0.05)
F_{cur}/F_{MSY}	0.03(5.92)	0.03(5.85)	0.01(2.86)	0.02(2.20)	0.03(5.42)

Table 11. Results of post-model pre-data diagnostic runs for the South Atlantic, using BSP and JAGS.

	S-PMPD1	S-PMPD2	S-PMPD3
K (1000)	2769 (0.92)	32.84(1.08)	37.57(0.32)
r	0.25 (0.32)	0.22(0.09)	2.74(00.38)
B[1]/K	1.00 (0.03)	2(0.00)	1.22 (0.32)

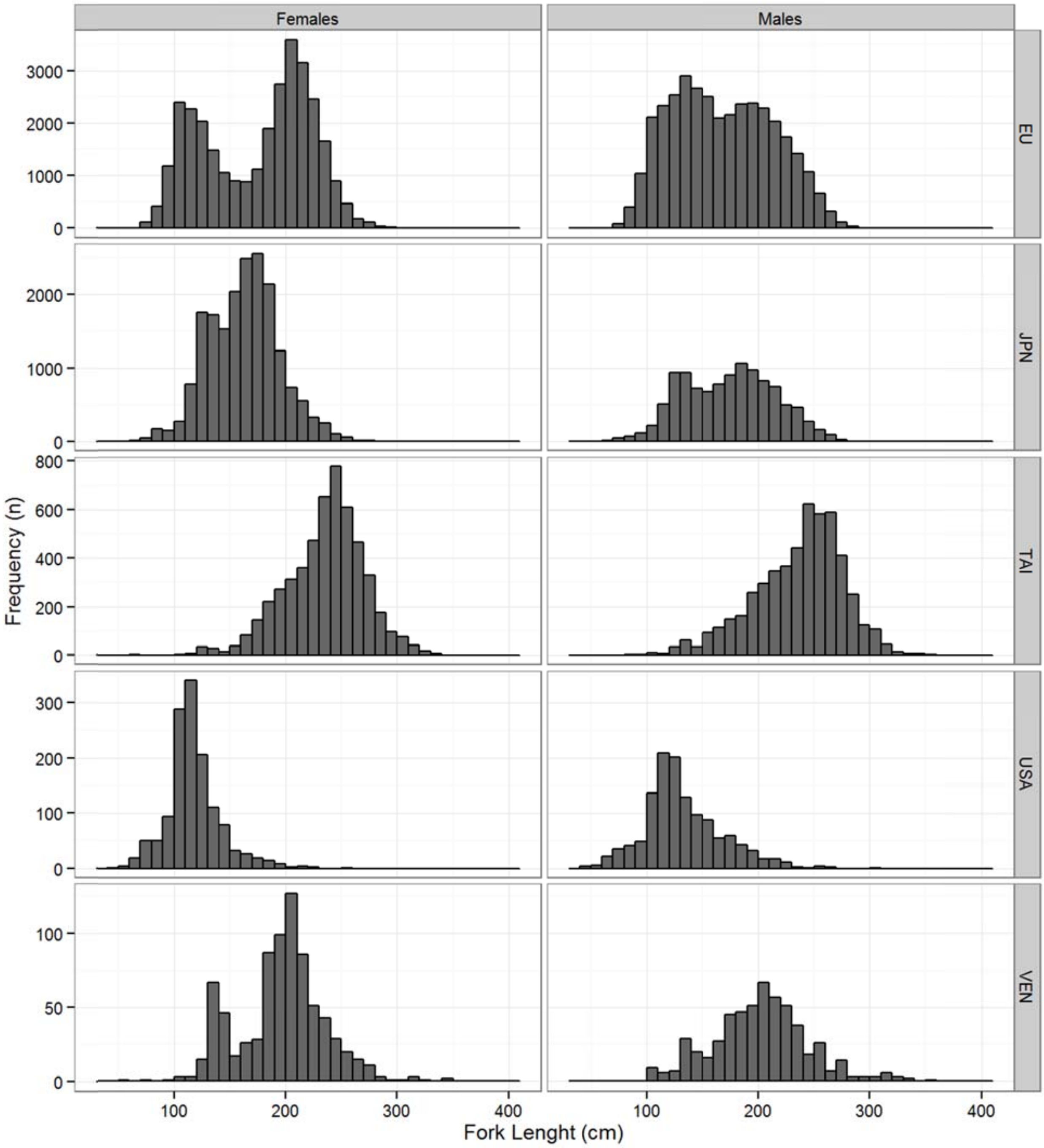


Figure 1. Size distributions (10cm FL size classes) for EU (EU-Portugal + EU-Spain), Japan, Taiwan, USA and Venezuela used for the SS3 models in the North Atlantic.

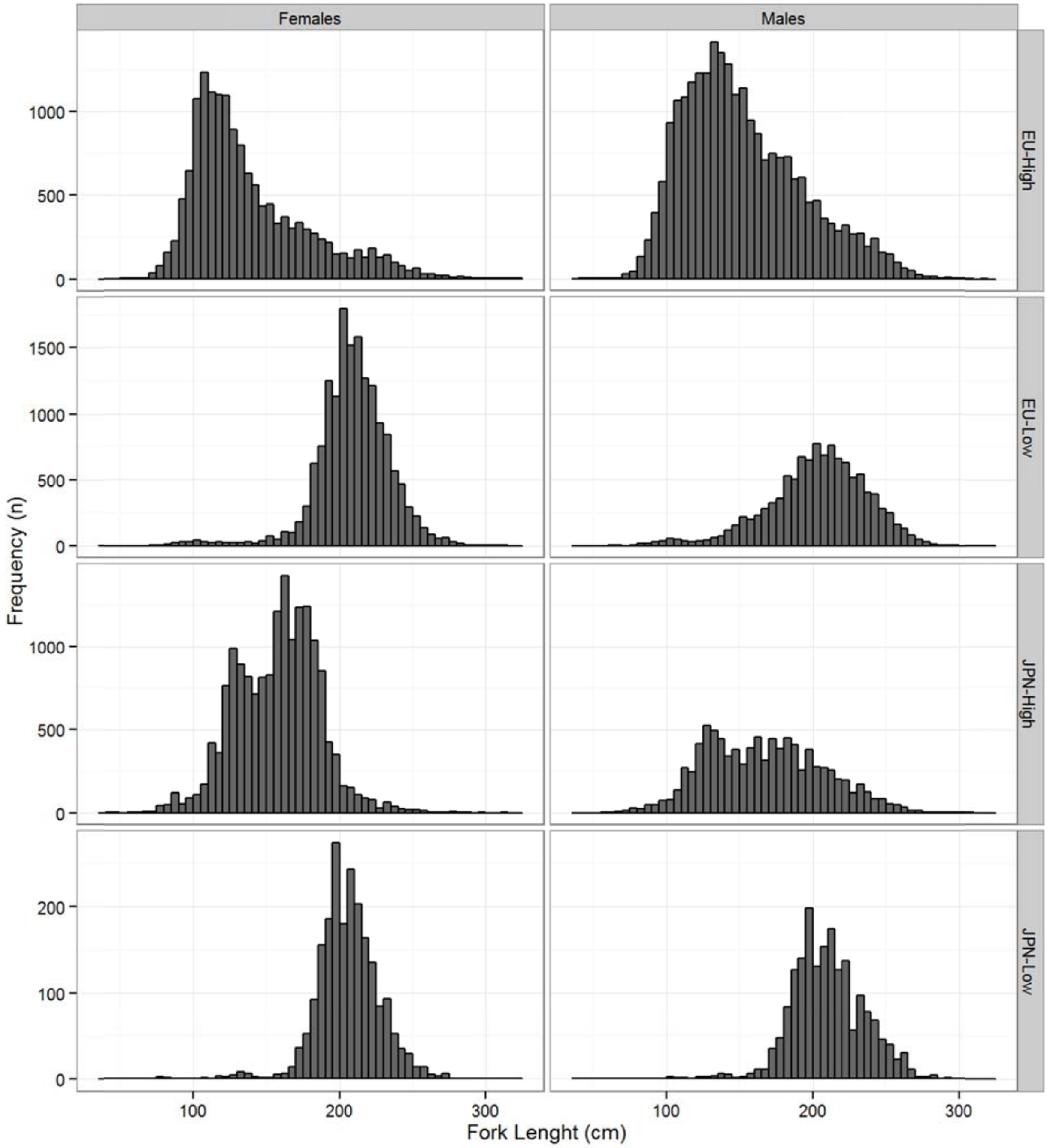


Figure 2. Size distributions EU-Portugal+EU-Spain and Japan split at 30ºN within the North Atlantic (north of 5ºN).

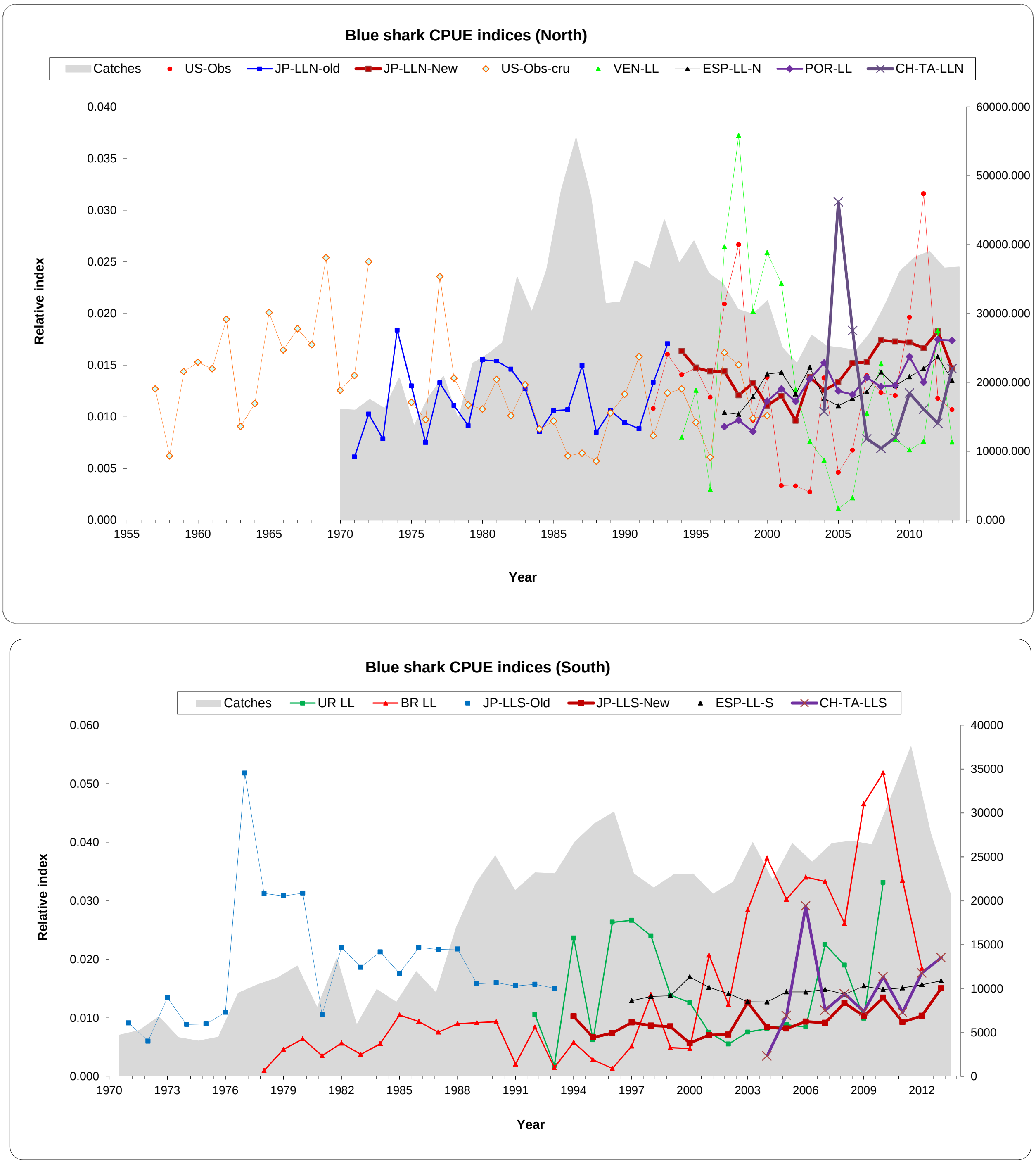


Figure 3. Indices of abundance and catches for the North Atlantic and South Atlantic blue shark stocks.

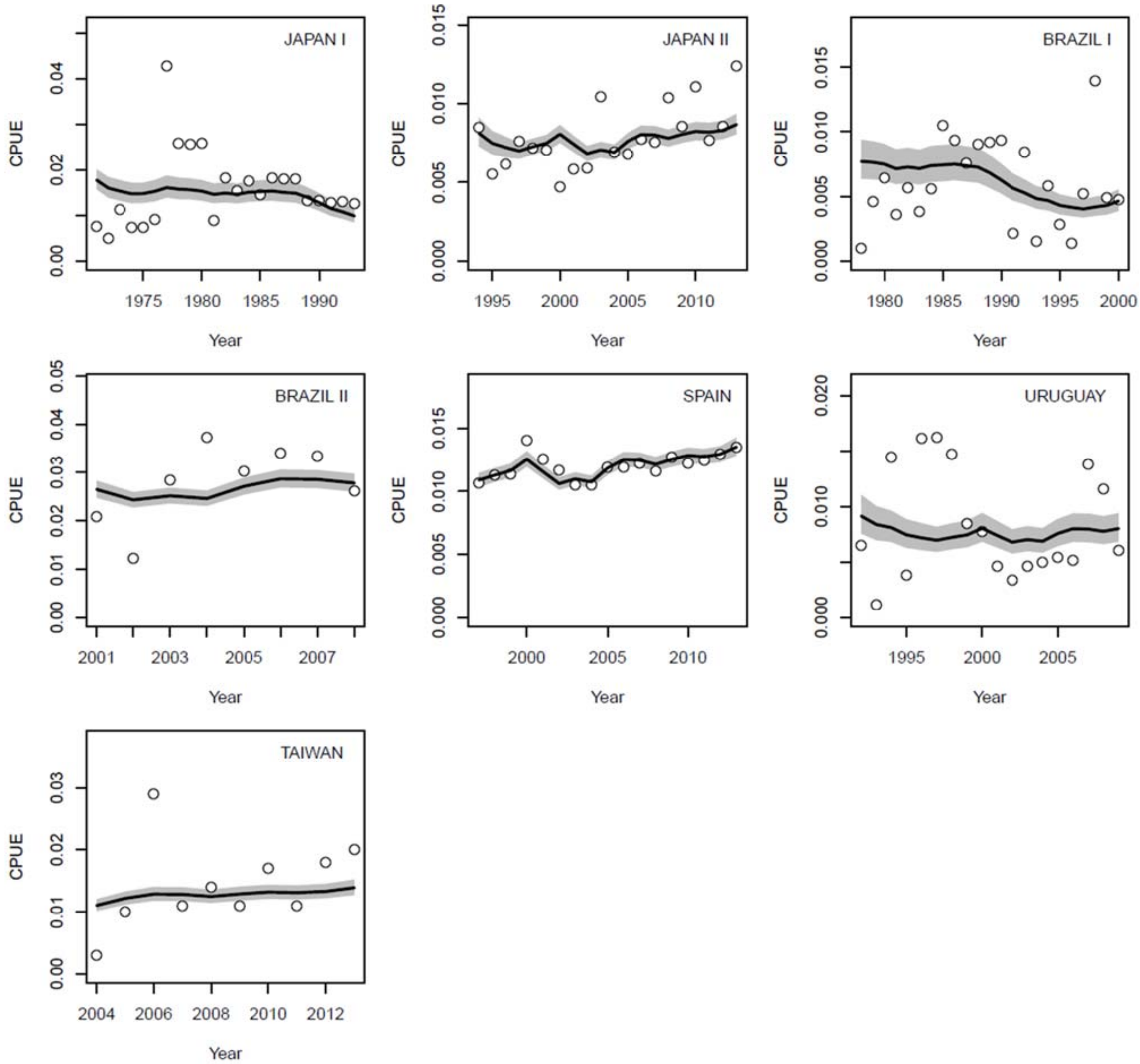


Figure 4. Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M4. Shaded grey area indicates 95% C.I.

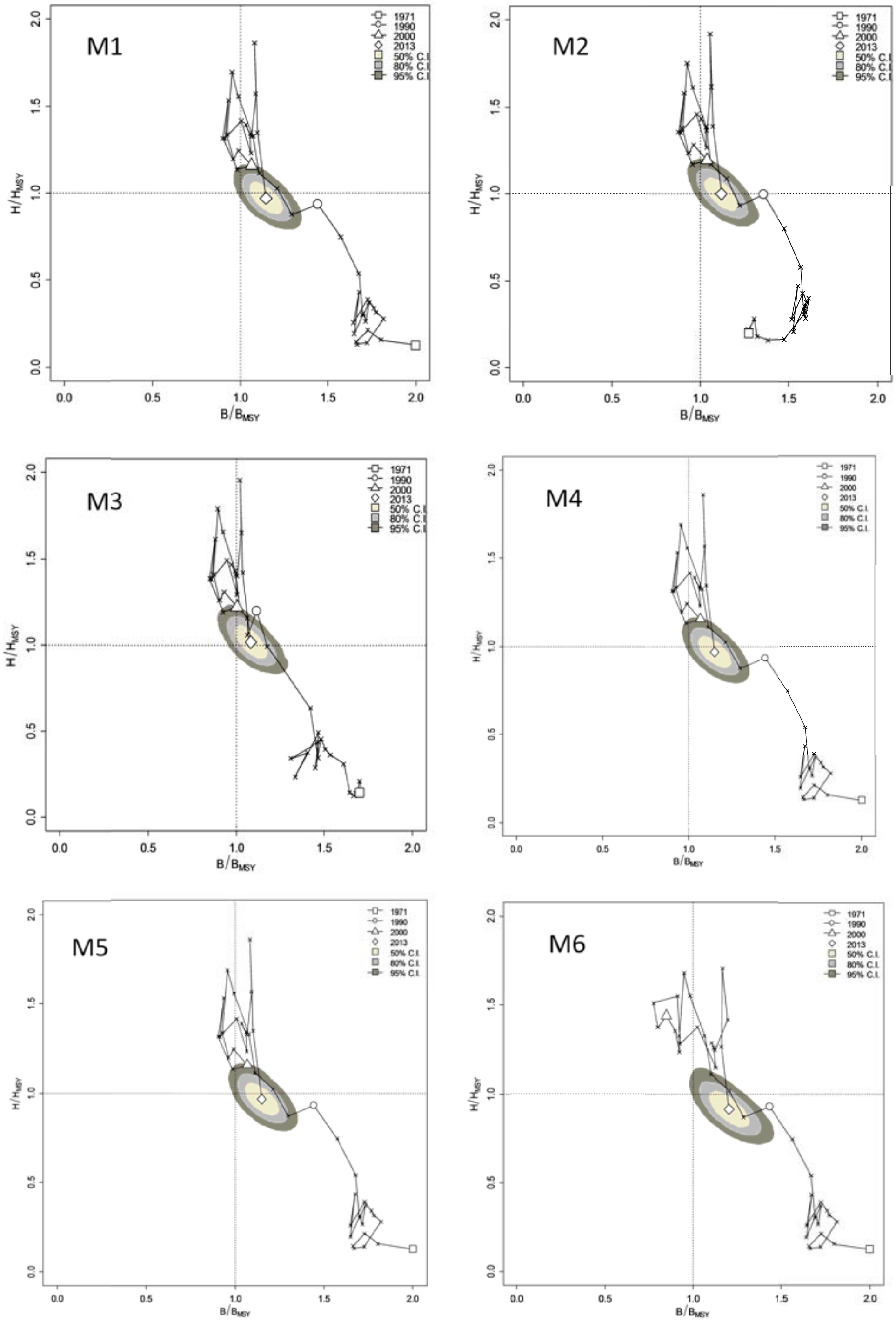


Figure 5. Kobe diagram showing the estimated trajectories (1971-2013) of B/B_{MSY} and H/H_{MSY} for the models M1 to M6.

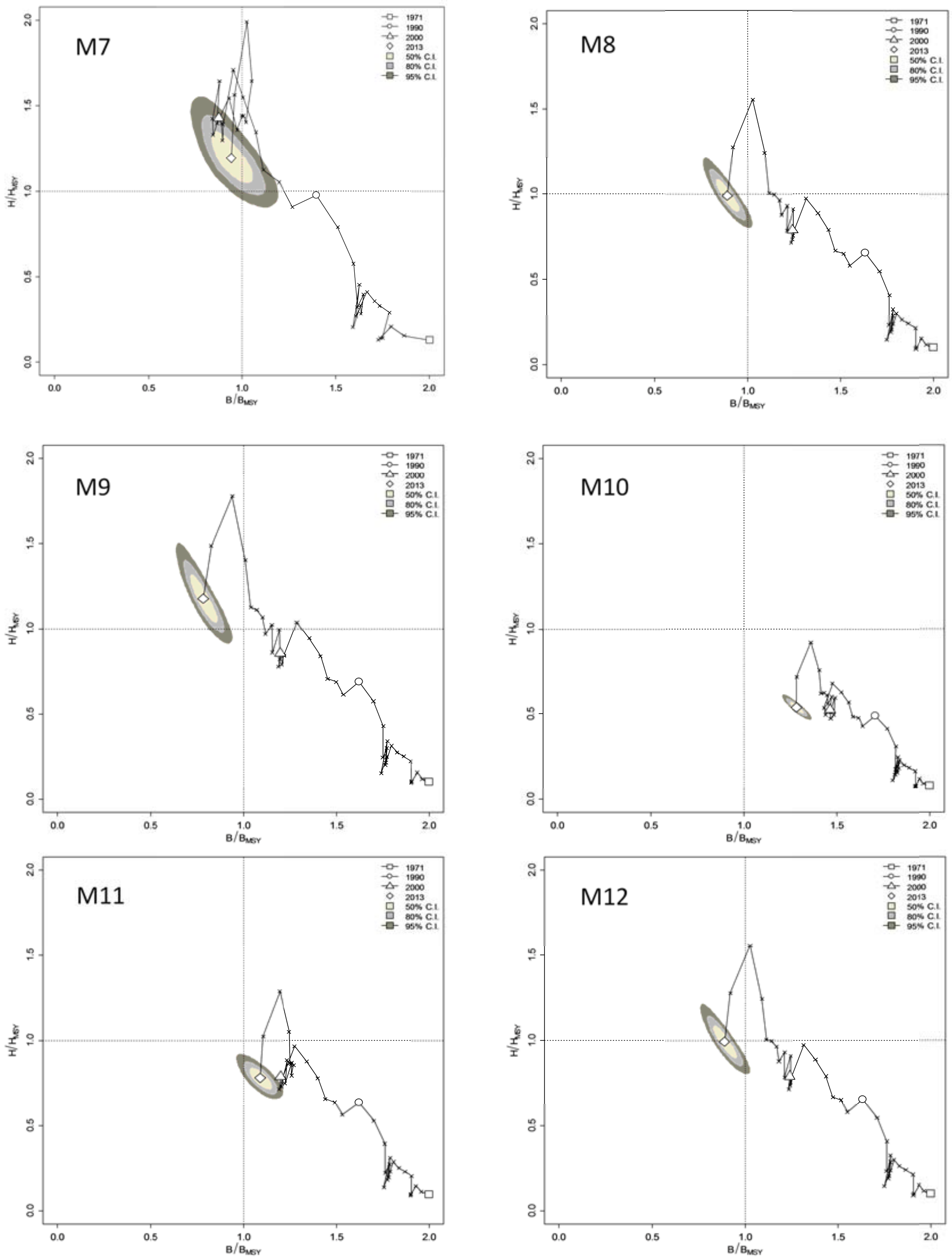


Figure 5 (continued). Kobe diagram showing the estimated trajectories (1971-2013) of B/B_{MSY} and H/H_{MSY} for the models M7 to M12.

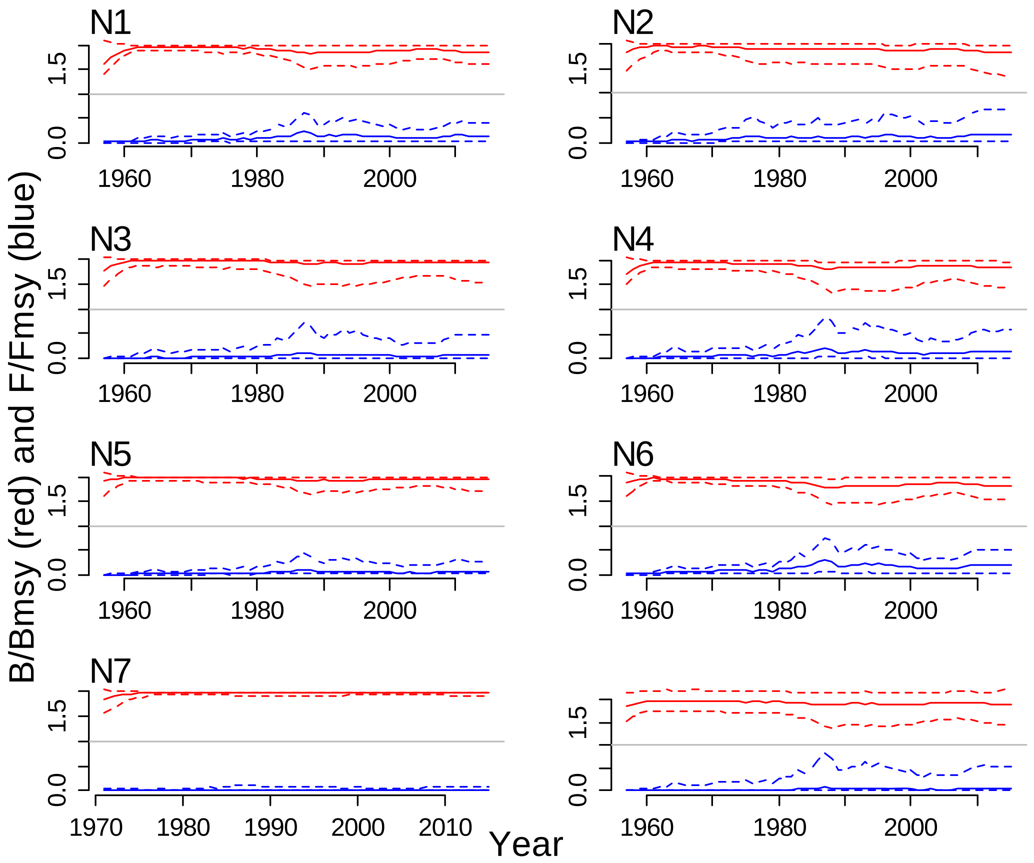


Figure 6. Estimated biomass relative to B_{MSY} (in red) and harvest rate relative to the MSY level (blue), for the North Atlantic BSP runs.

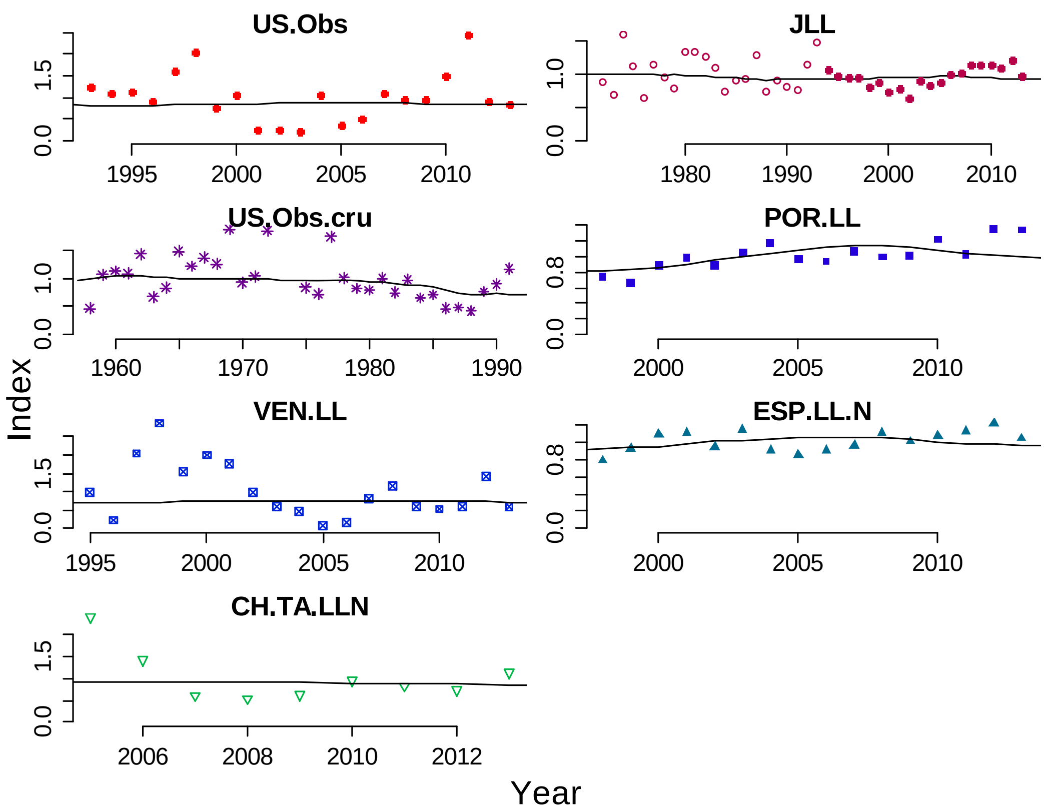


Figure 7. Fits to each CPUE series separately, for the BSP model in the North Atlantic.

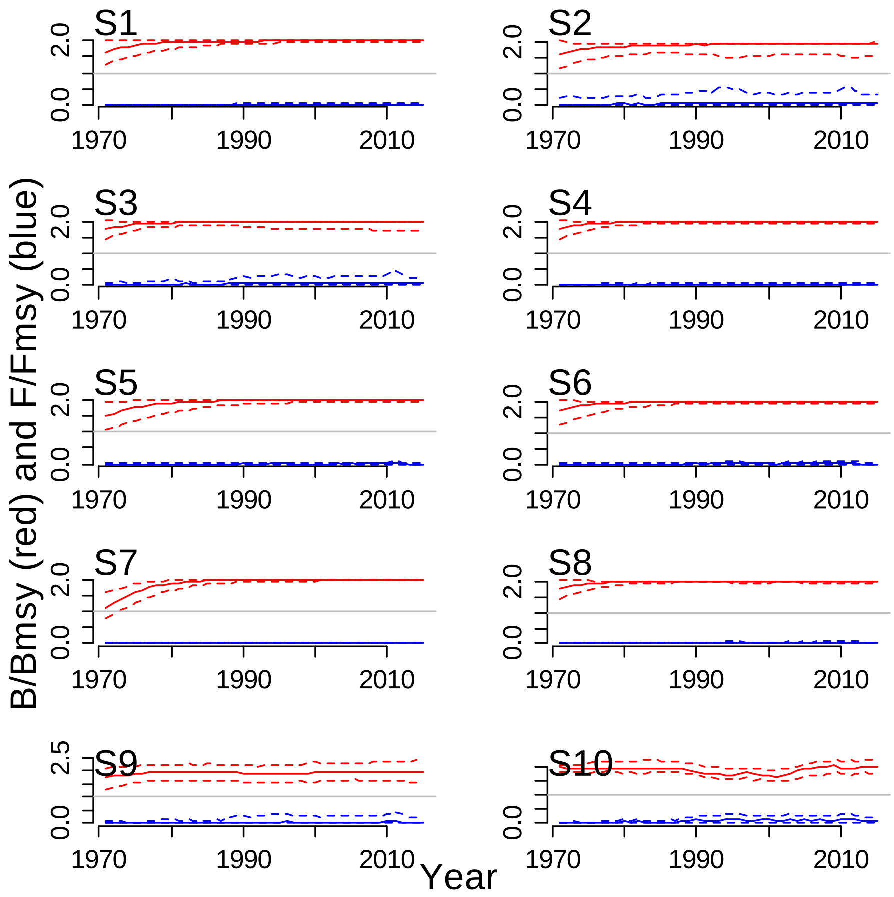


Figure 8. Estimated biomass relative to B_{MSY} (in red) and harvest rate relative to the MSY level (blue), for the South Atlantic BSP runs.

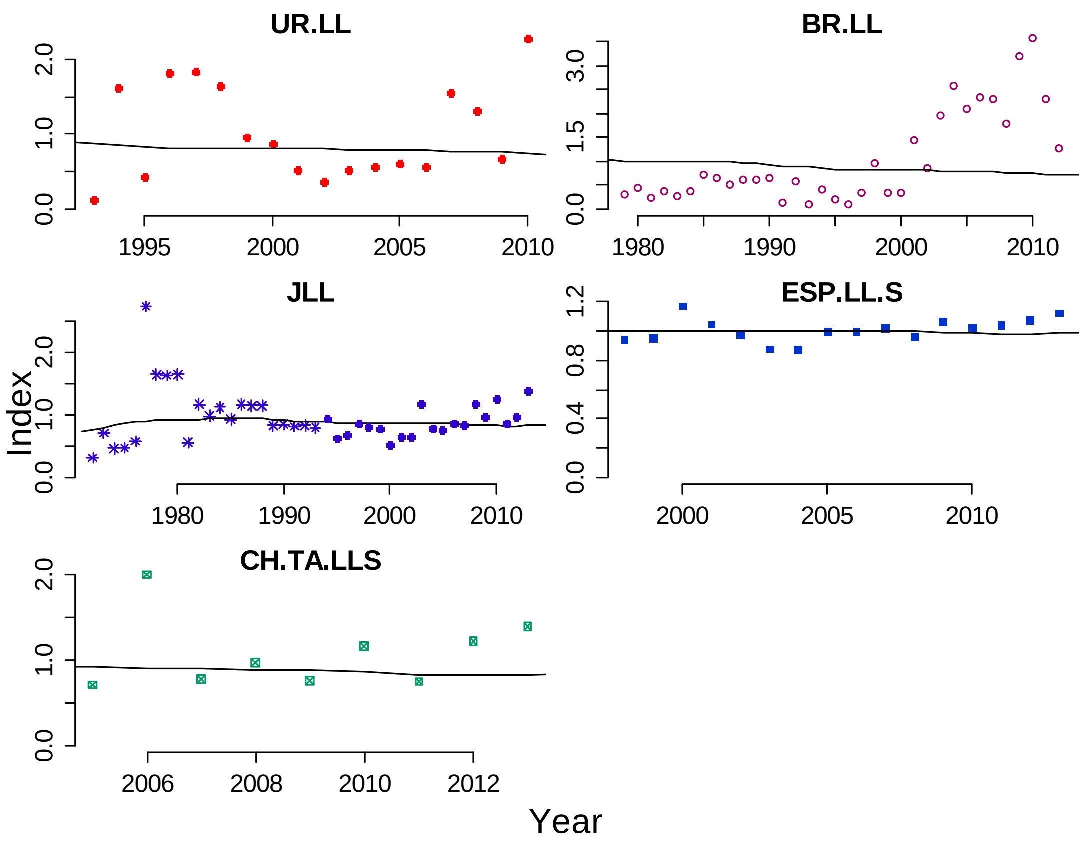


Figure 9. Fits to each CPUE series separately, for the BSP model in the South Atlantic.

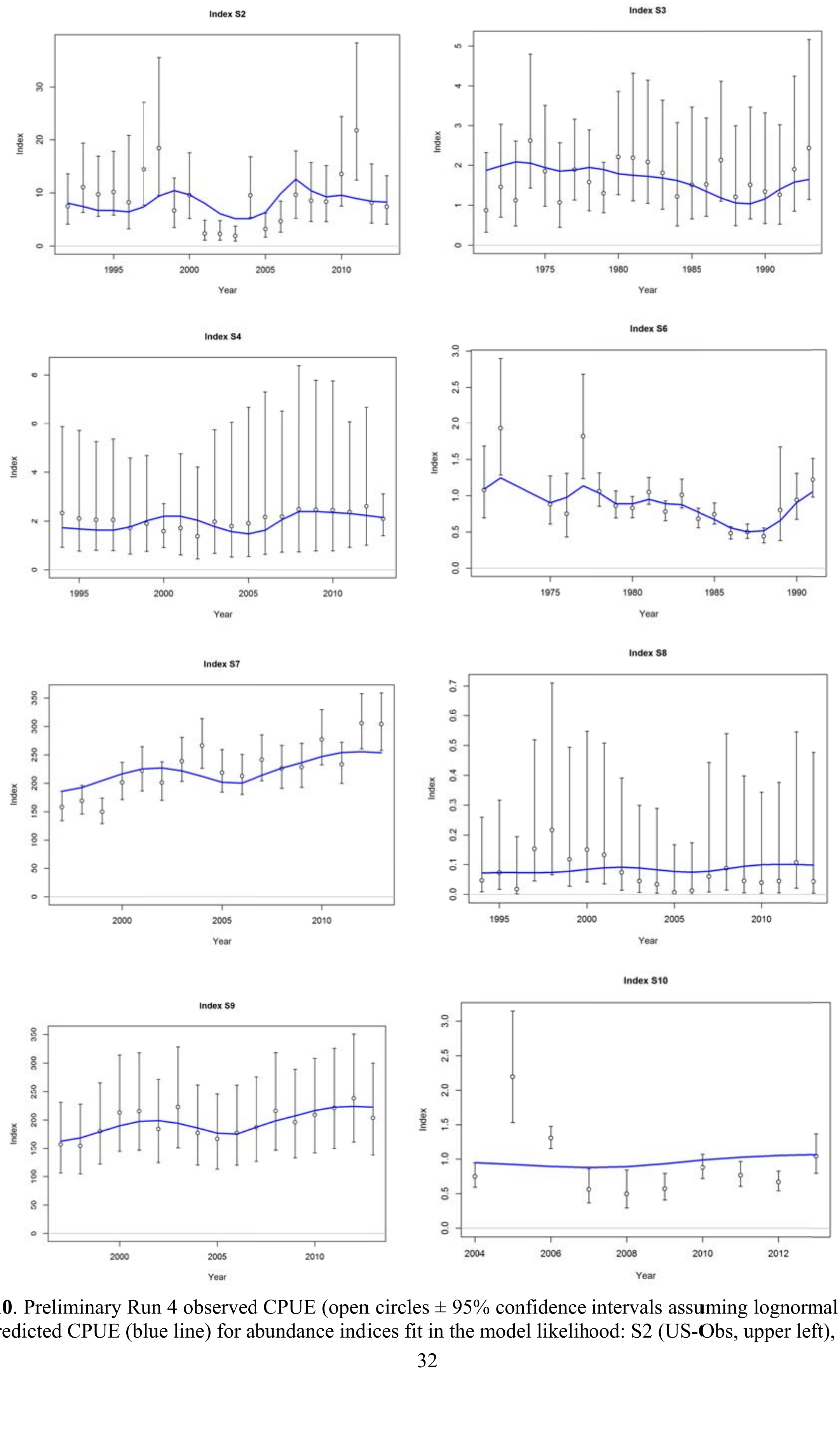


Figure 10. Preliminary Run 4 observed CPUE (open circles ± 95% confidence intervals assuming lognormal error) and model predicted CPUE (blue line) for abundance indices fit in the model likelihood: S2 (US-Obs, upper left), S3 (JPLL-

N-e, upper right), S4 (JPLL-N-l, middle left), S6 (US-Obs-cru, middle right), S7 (POR-LL, middle left), S8 (VEN-LL, middle right), S9 (ESP-LL-N, lower left), and S10 (CTP-LL-N, lower right).

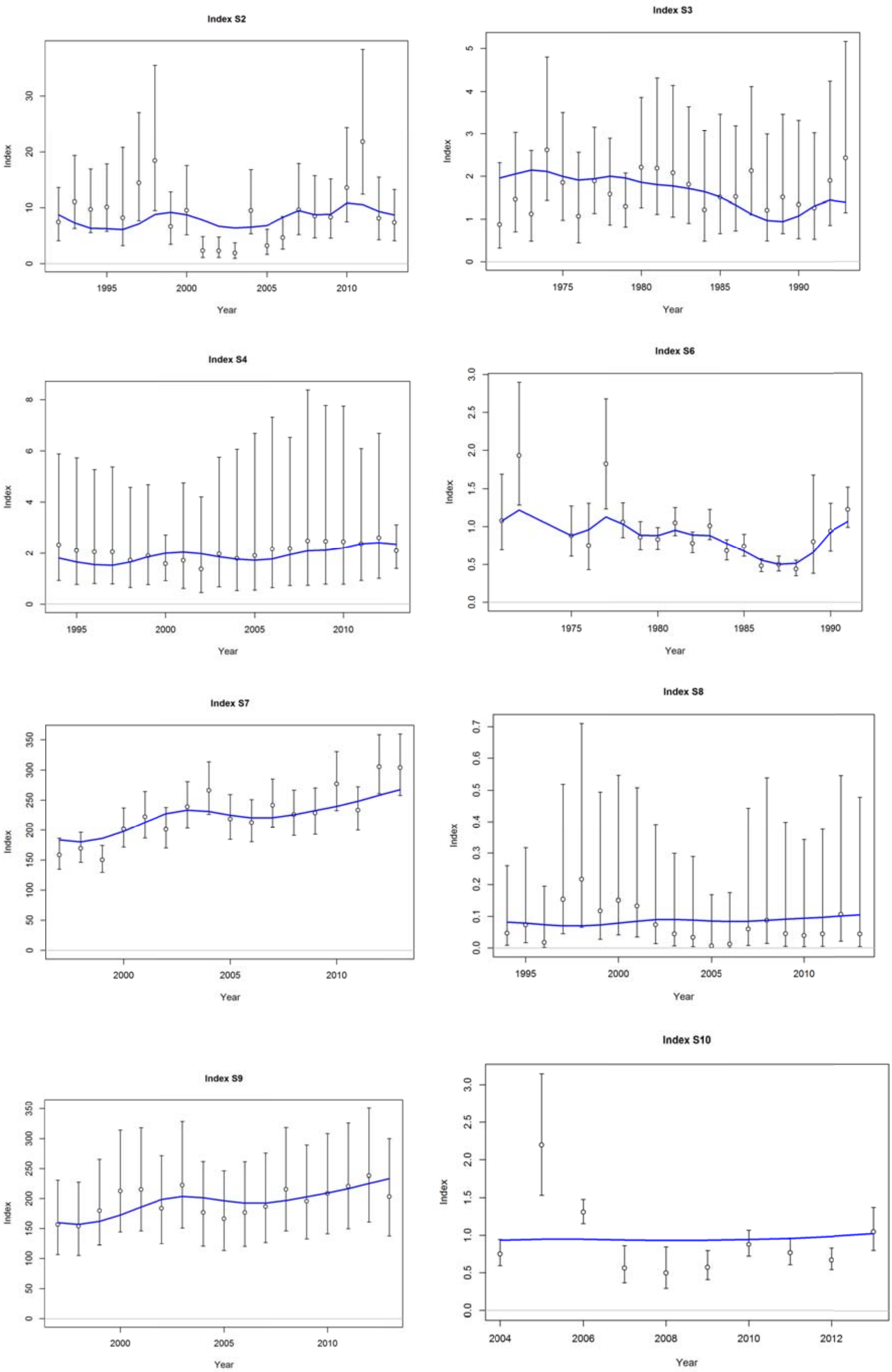
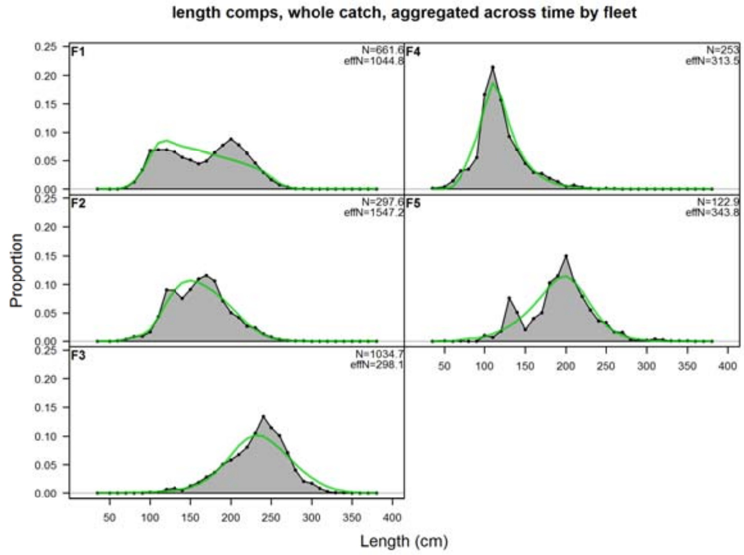


Figure 11. Preliminary Run 6 observed CPUE (open circles ± 95% confidence intervals assuming lognormal error) and model predicted CPUE (blue line) for abundance indices fit in the model likelihood: S2 (US-Obs, upper left), S3 (JPLL-

N-e, upper right), S4 (JPLL-N-l, middle left), S6 (US-Obs-cru, middle right), S7 (POR-LL, middle left), S8 (VEN-LL, middle right), S9 (ESP-LL-N, lower left), and S10 (CTP-LL-N, lower right).



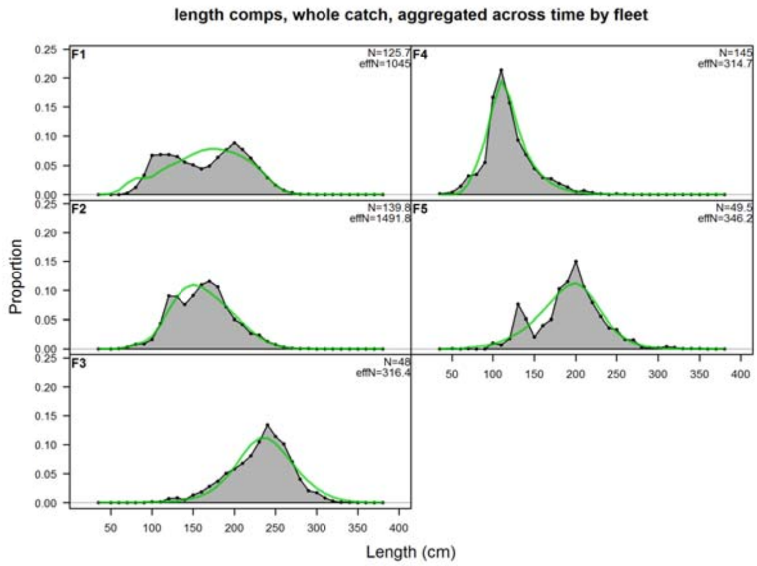


Figure 12. Model predicted (line) and observed (shaded) aggregated annual length compositions (female + male) for Preliminary Run 4 (upper panel) and Preliminary Run 6 (lower panel).

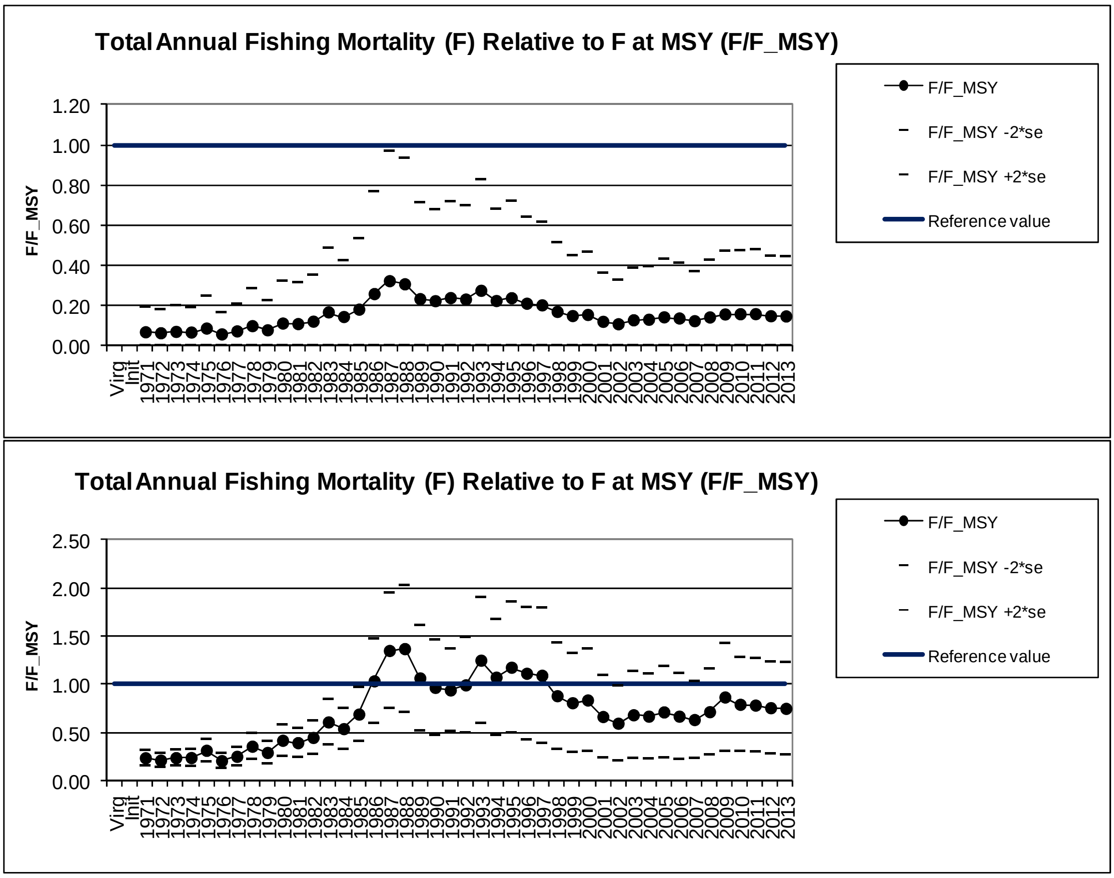


Figure 13. Estimated annual total exploitation rate in numbers (total fishing mortality for all fleets combined) relative to fishing mortality at *MSY* (F/F_{MSY}), obtained from Stock Synthesis output for Preliminary Run 4 (upper panel) and Preliminary Run 6 (lower panel).

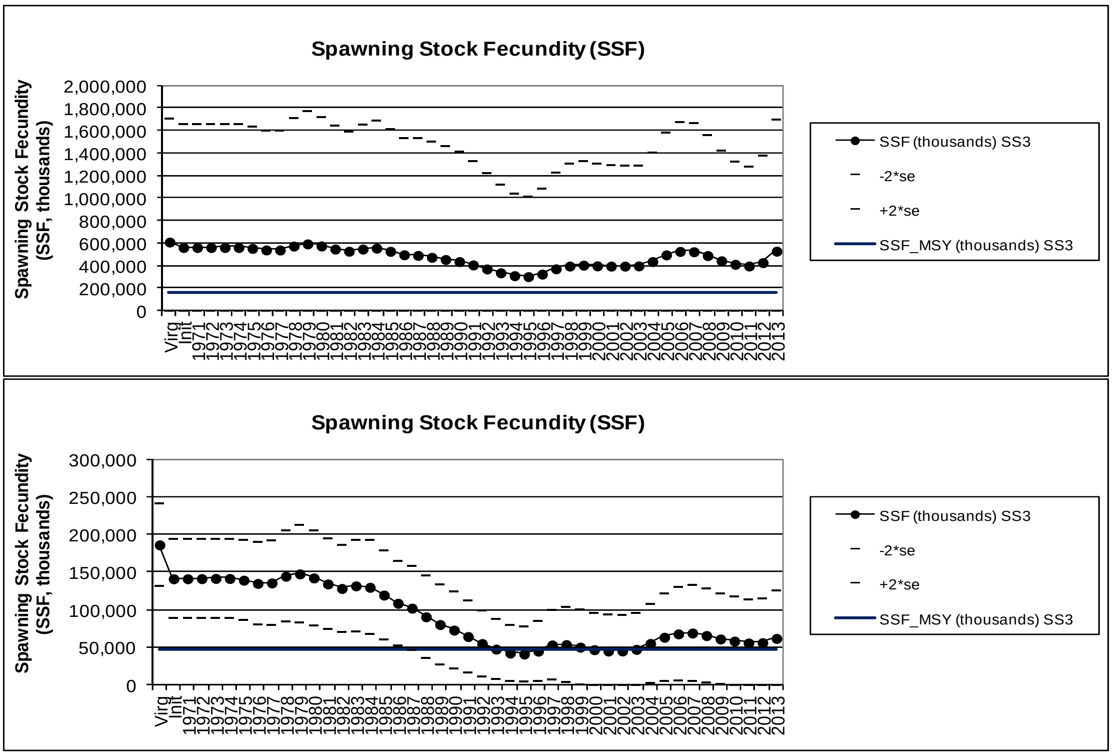


Figure 14. Estimated spawning stock size (spawning stock fecundity, SSF) along with approximate 95% asymptotic standard errors (+- 2*s.e.) relative to spawning stock size at *MSY* (SSF_{MSY}) for Preliminary Run 4 (upper panel) and

Preliminary Run 6 (lower panel).

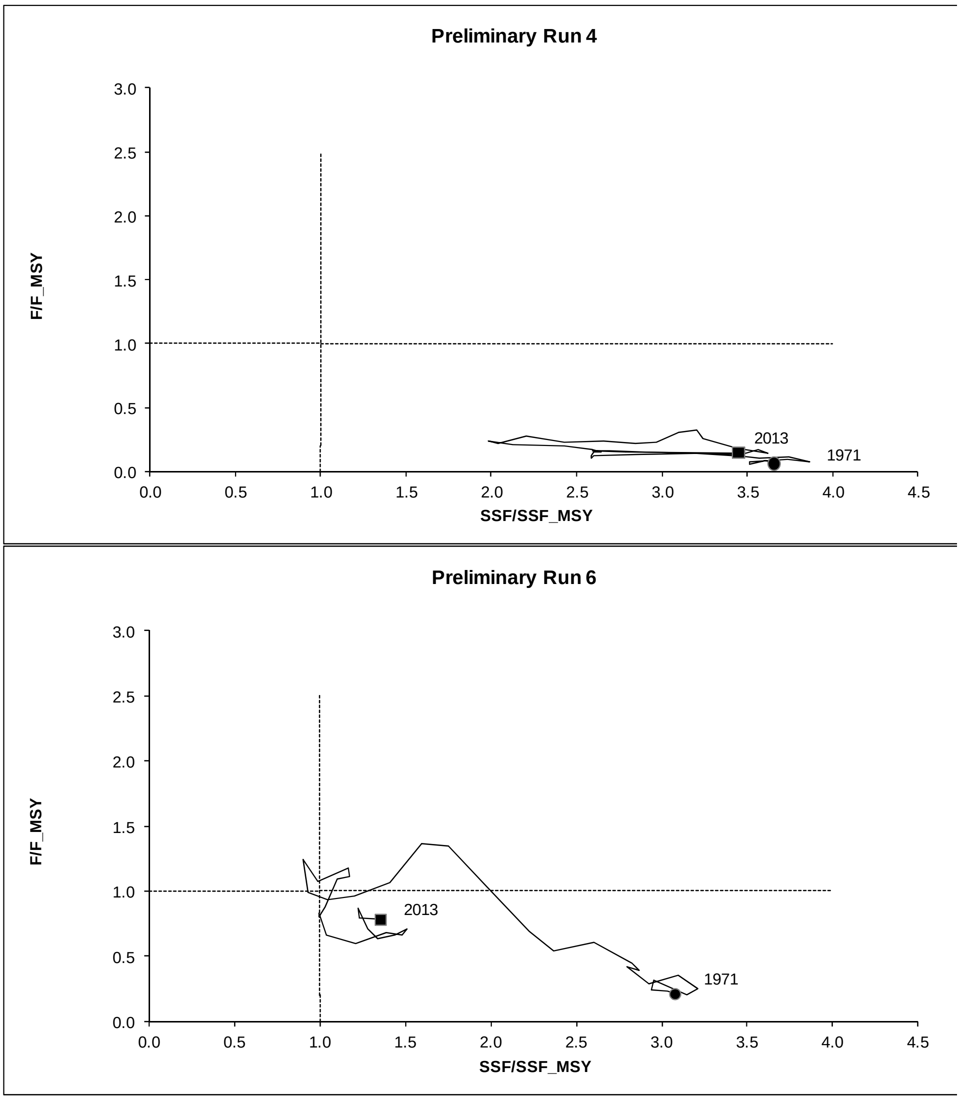


Figure 15. Kobe Phase plots for Preliminary Run 4 (upper panel) and Preliminary Run 6 (lower panel). The circle indicates the position of the start year of the model (1971) and the square represents the end year of the model (2013). The horizontal (dotted) line identifies the fishing mortality reference at maximum sustainable yield (F_{MSY}). The vertical (dotted) line identifies the reference spawning stock fecundity at maximum sustainable yield (SSF_{MSY}).

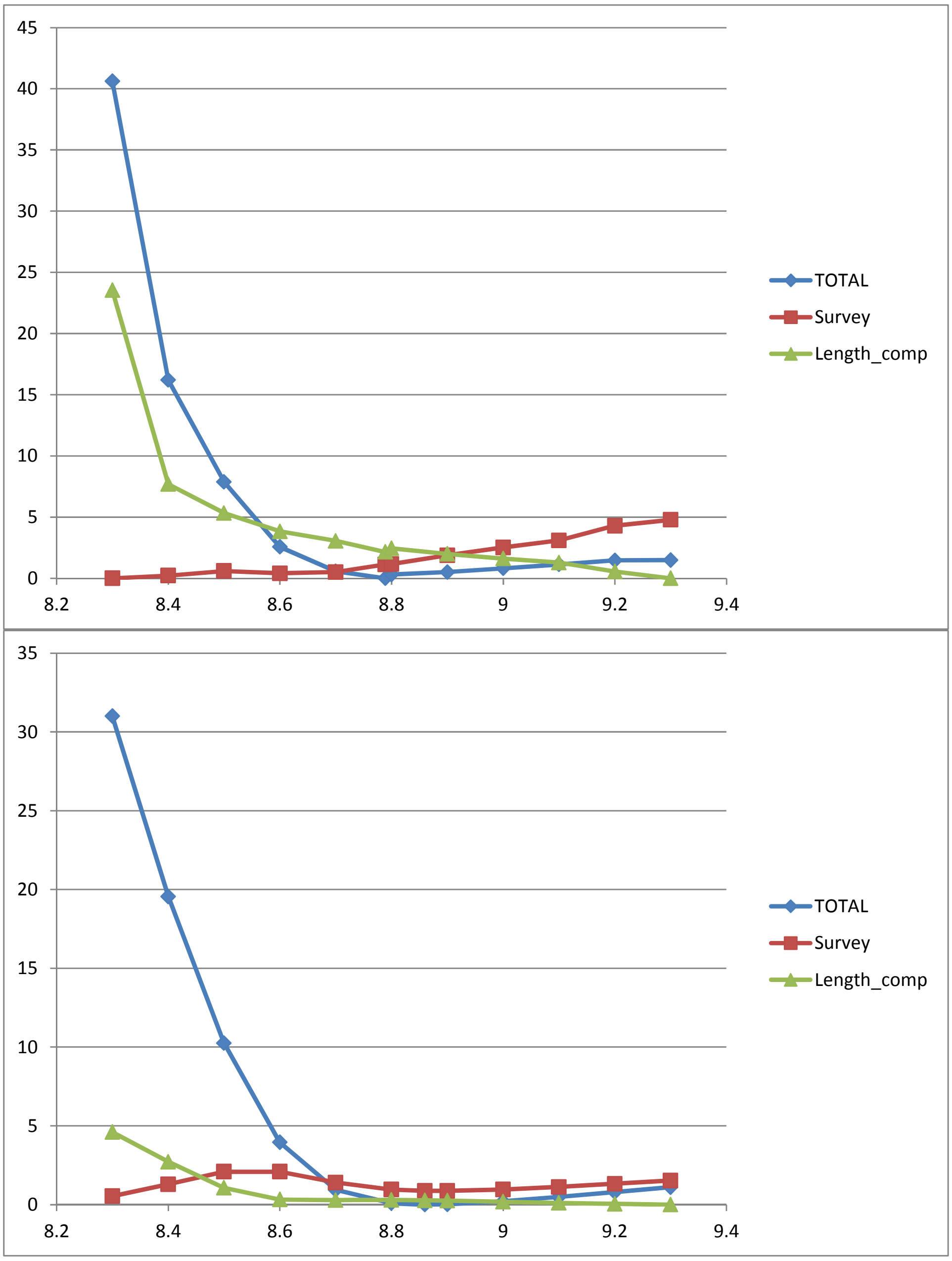


Figure 16. R_0 likelihood profiles were compared for different data components (Length_comp, Survey, and Total) at fixed values of R_0 on either side of the maximum likelihood estimate (8.8) obtained for Preliminary Run 6 (upper panel) and Sensitivity Run 1 (lower panel). The x-axis represents equilibrium recruitment (R_0) on the log scale. The y-axis represents likelihood units.

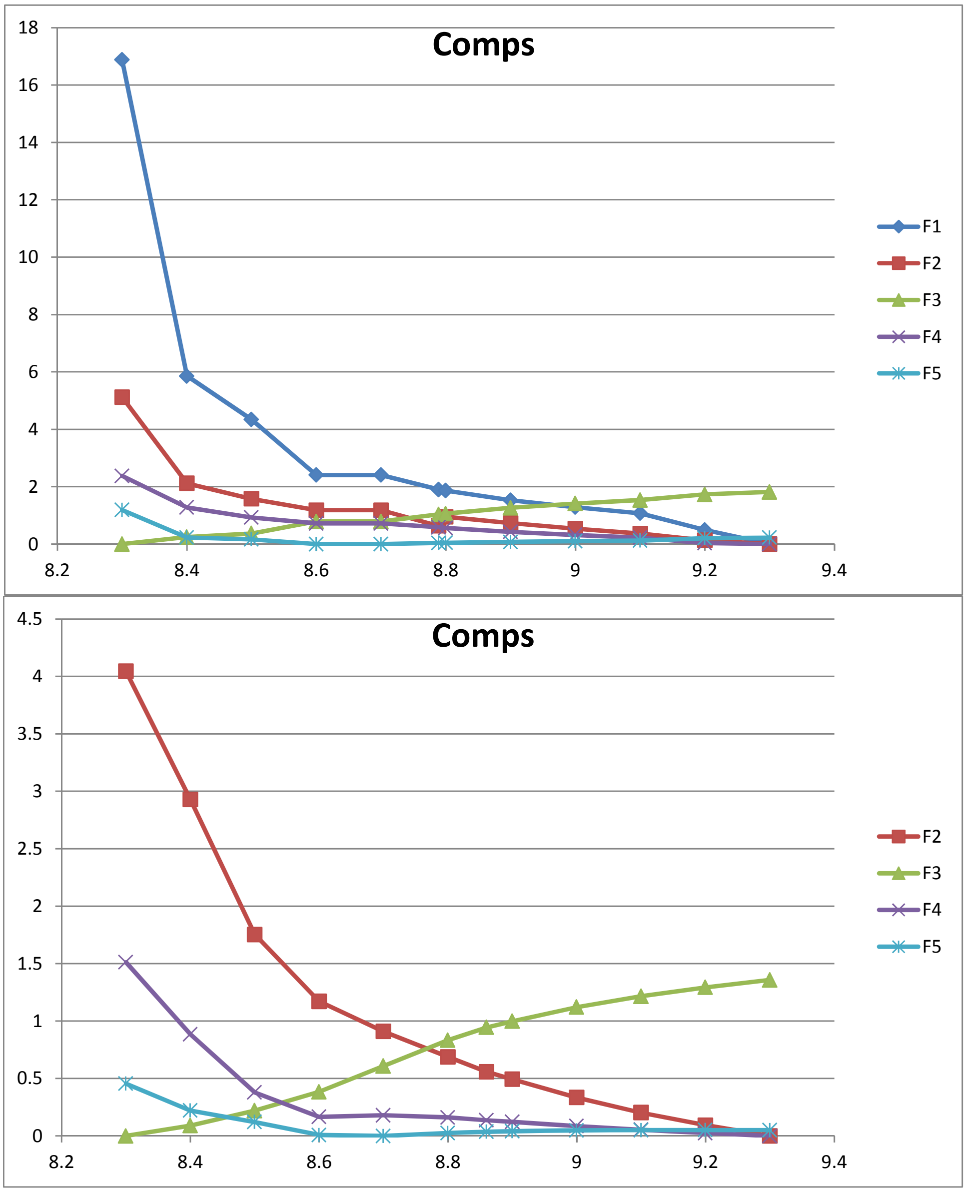


Figure 17. R_0 likelihood profiles were compared for individual length composition data components (F1-EU, F2-JPN, F3-CTP, F4-USA, F5-VEN) at fixed values of R_0 on either side of the maximum likelihood estimate (8.8) obtained for Preliminary Run 6 (upper panel) and Sensitivity Run 1 (lower panel). The x-axis represents equilibrium recruitment (R_0) on the log scale. The y-axis represents likelihood units.

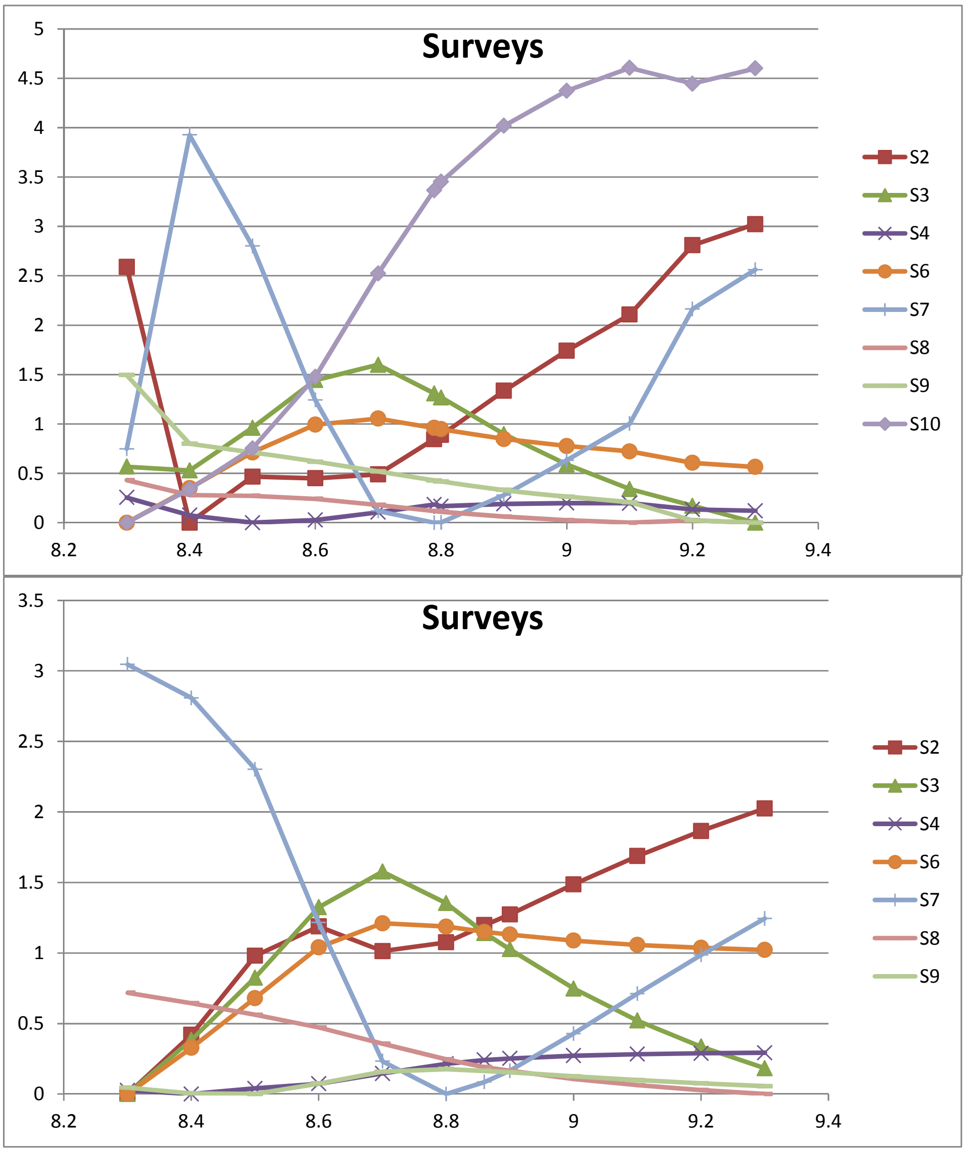


Figure 18. R_0 likelihood profiles were compared for individual abundance index data components (S1- US-Log, S2-US-Obs,S3- JPLL-N-e,S4- JPLL-N-l, S5- IRL-Rec,S6- US-Obs-cru,S7-POR-LL,S8- VEN-LL,S9- ESP-LL-N,S10-CTP-LL-N) at fixed values of R_0 on either side of the maximum likelihood estimate (8.8) obtained for Preliminary Run 6 (upper panel) and Sensitivity Run 1 (lower panel). The x-axis represents equilibrium recruitment (R_0) on the log scale. The y-axis represents likelihood units.

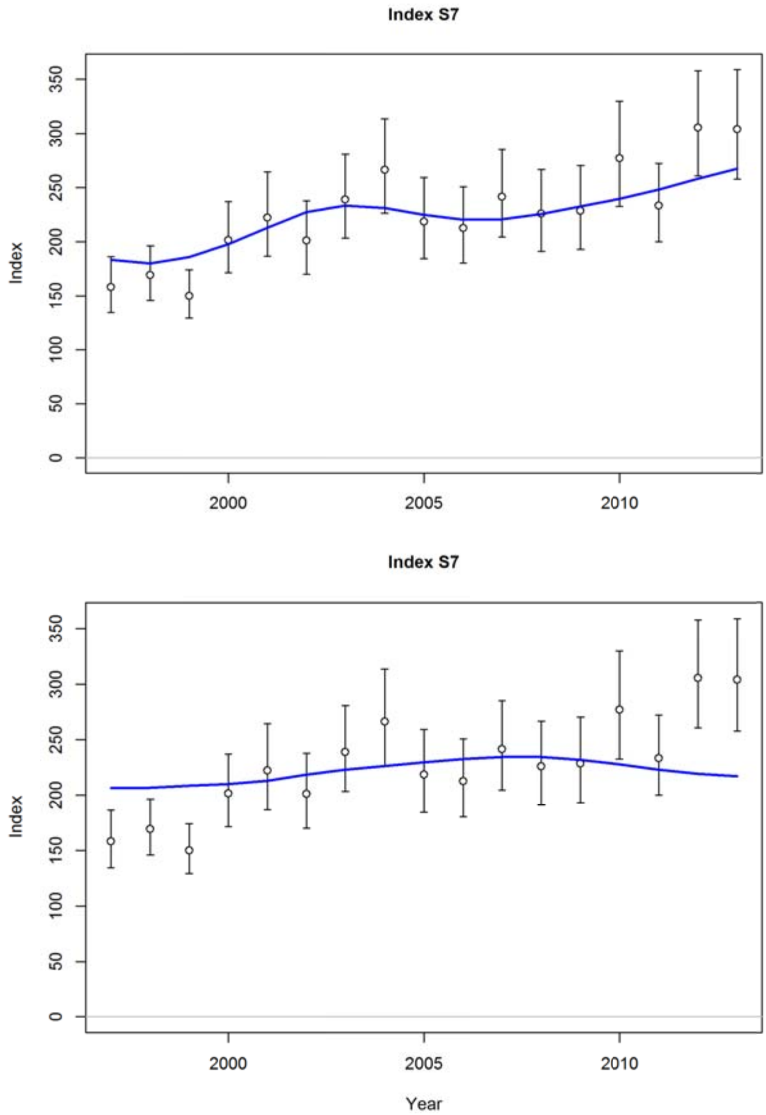


Figure 19. Fits to S7 (POR-LL) for Preliminary Run 6 (upper panel) and Sensitivity Run 1 (lower panel).

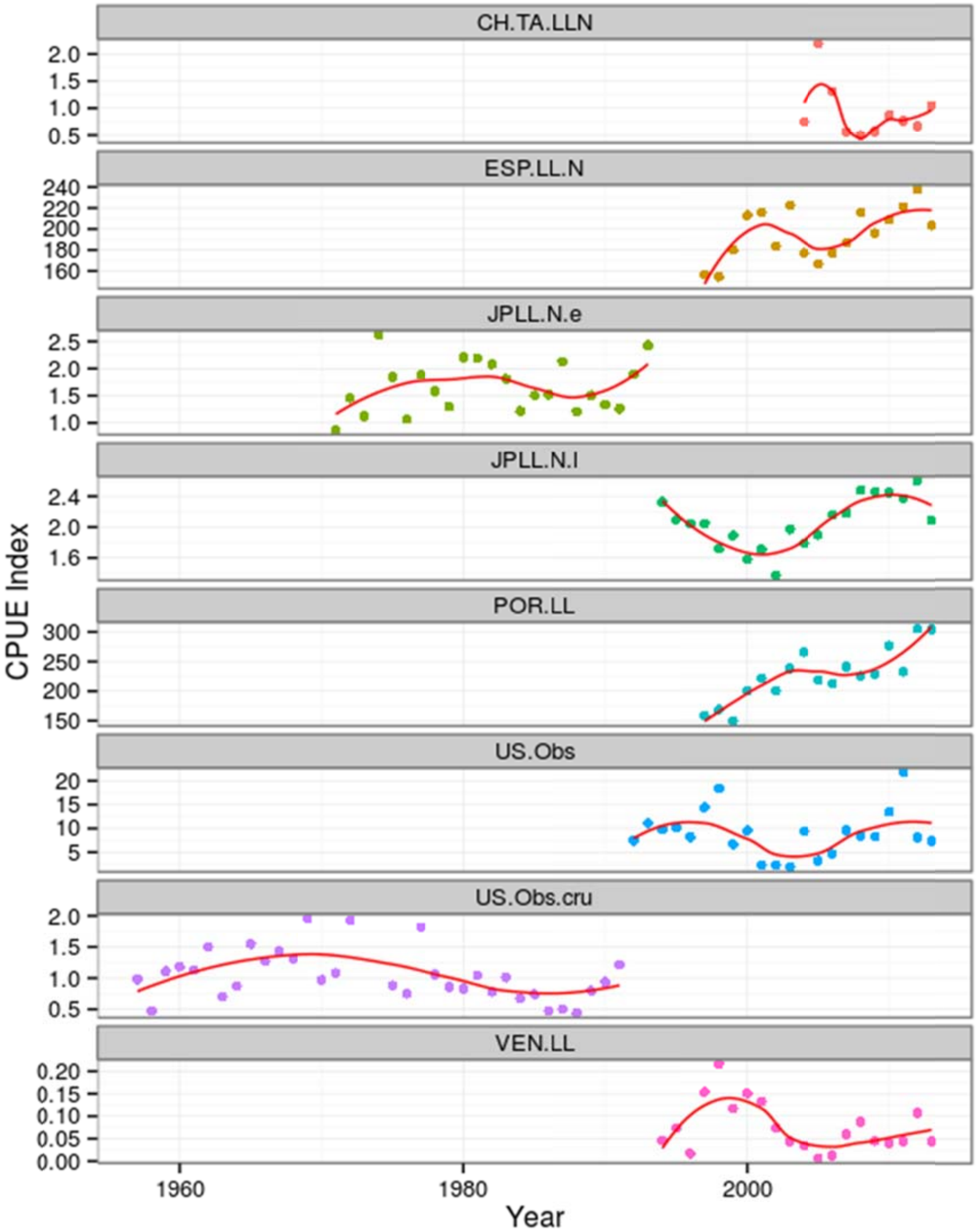


Figure 20. North Atlantic CPUE series; points are the standardised values, lines are loess smoothers by index.

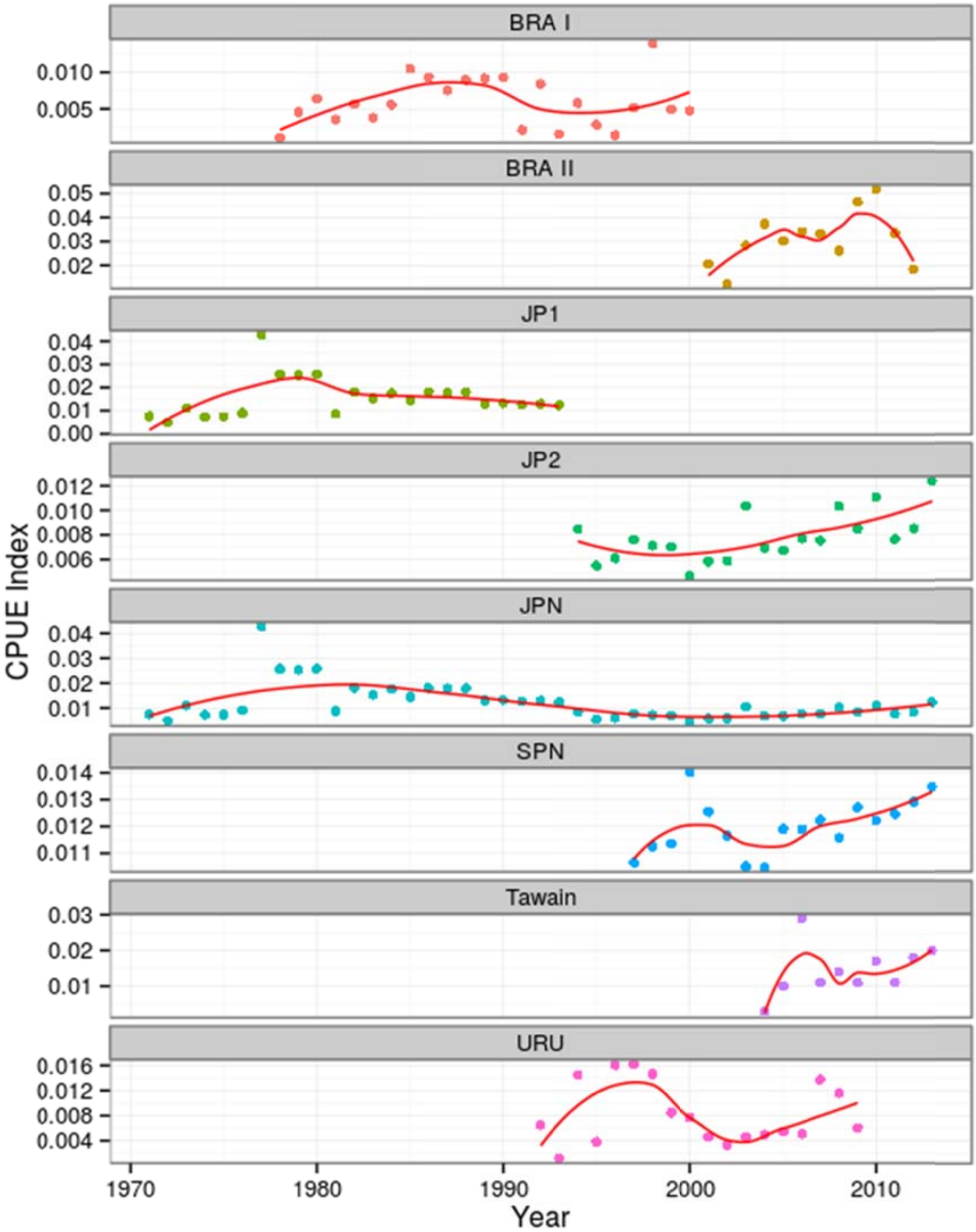


Figure 21. North Atlantic CPUE Series; points are the standardised values, lines loess smoothers by index.

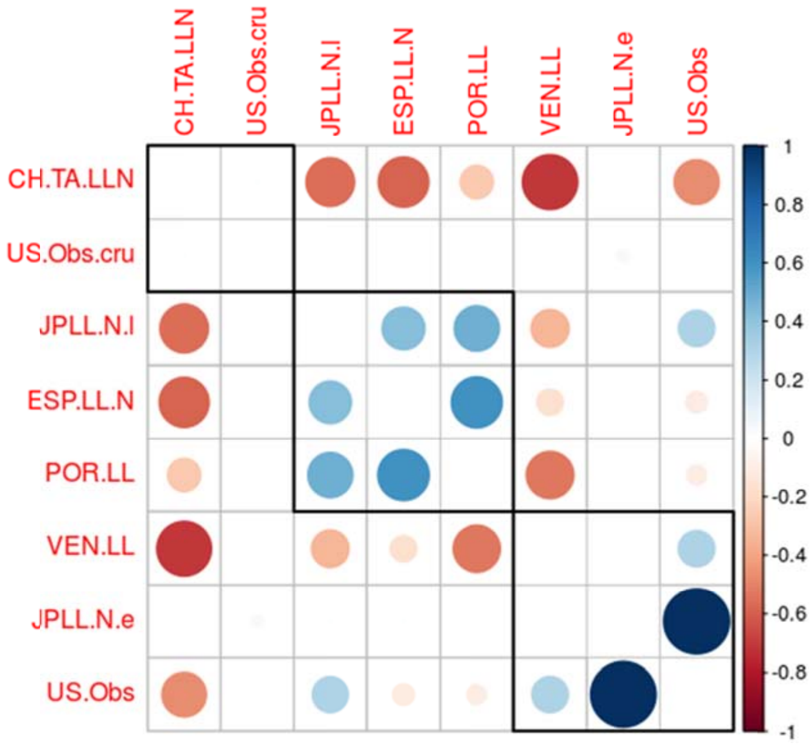


Figure 22. North Atlantic correlation matrix for the agreed indices; blue indicates positive and red negative correlations, the order of the indices and the rectangular boxes are chosen based on a hierarchical cluster analysis using a set of dissimilarities.

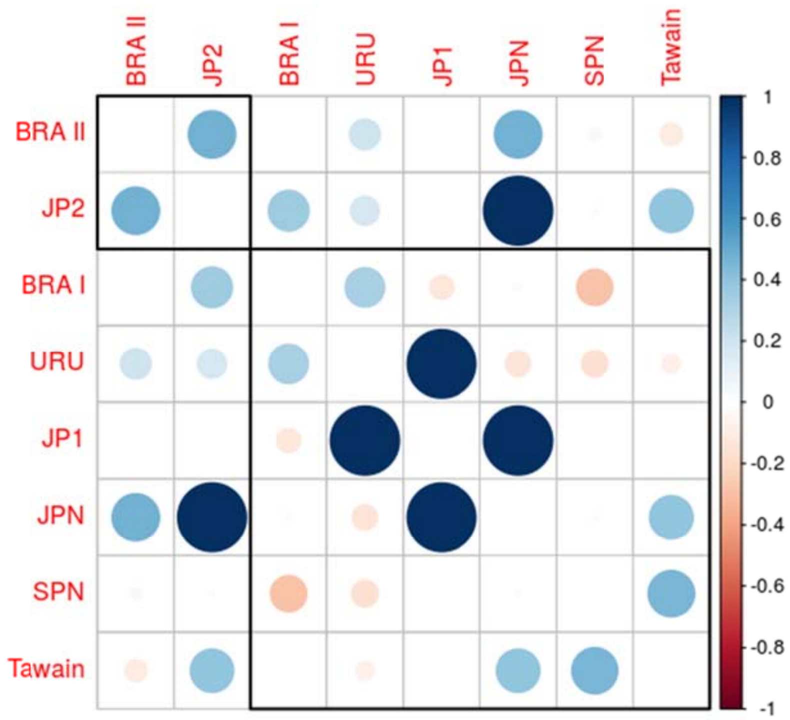


Figure 23. South Atlantic correlation matrix for the agreed indices; blue indicates positive and red negative correlations, the order of the indices and the rectangular boxes are chosen based on a hierarchical cluster analysis using a set of dissimilarities.

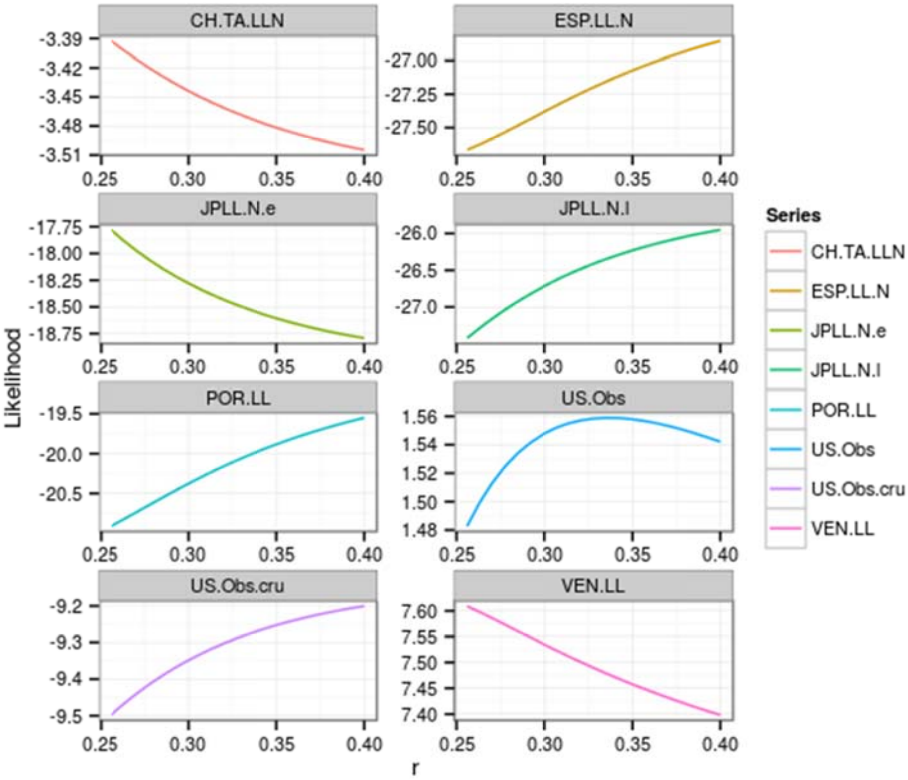


Figure 24. North Atlantic likelihood profiles for *r* by CPUE series.

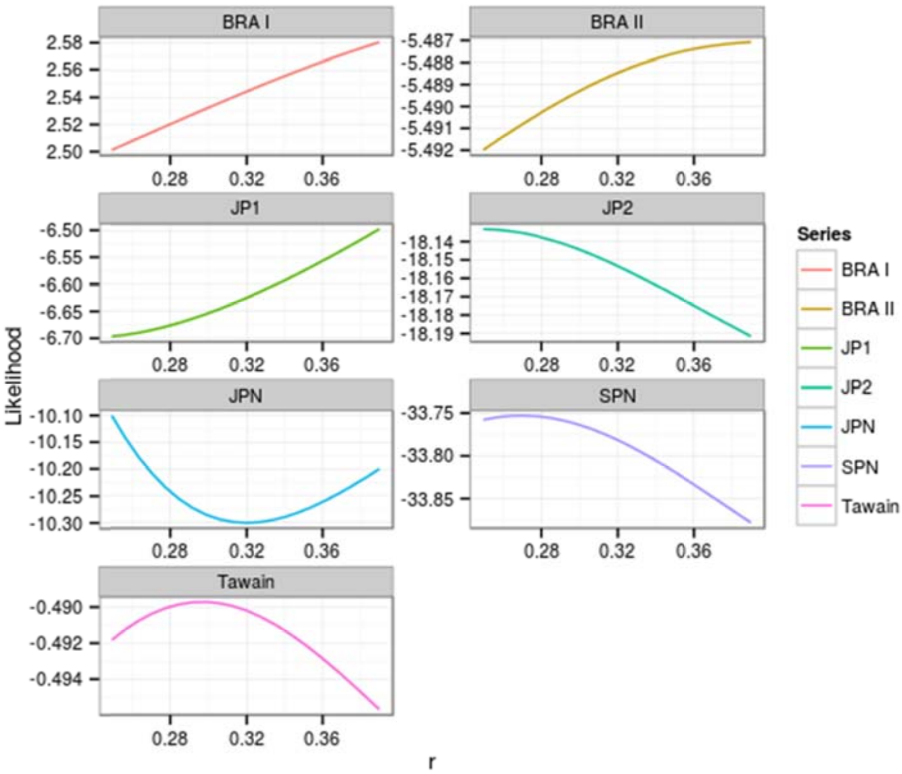


Figure 25. South Atlantic likelihood profiles for *r* by CPUE series.

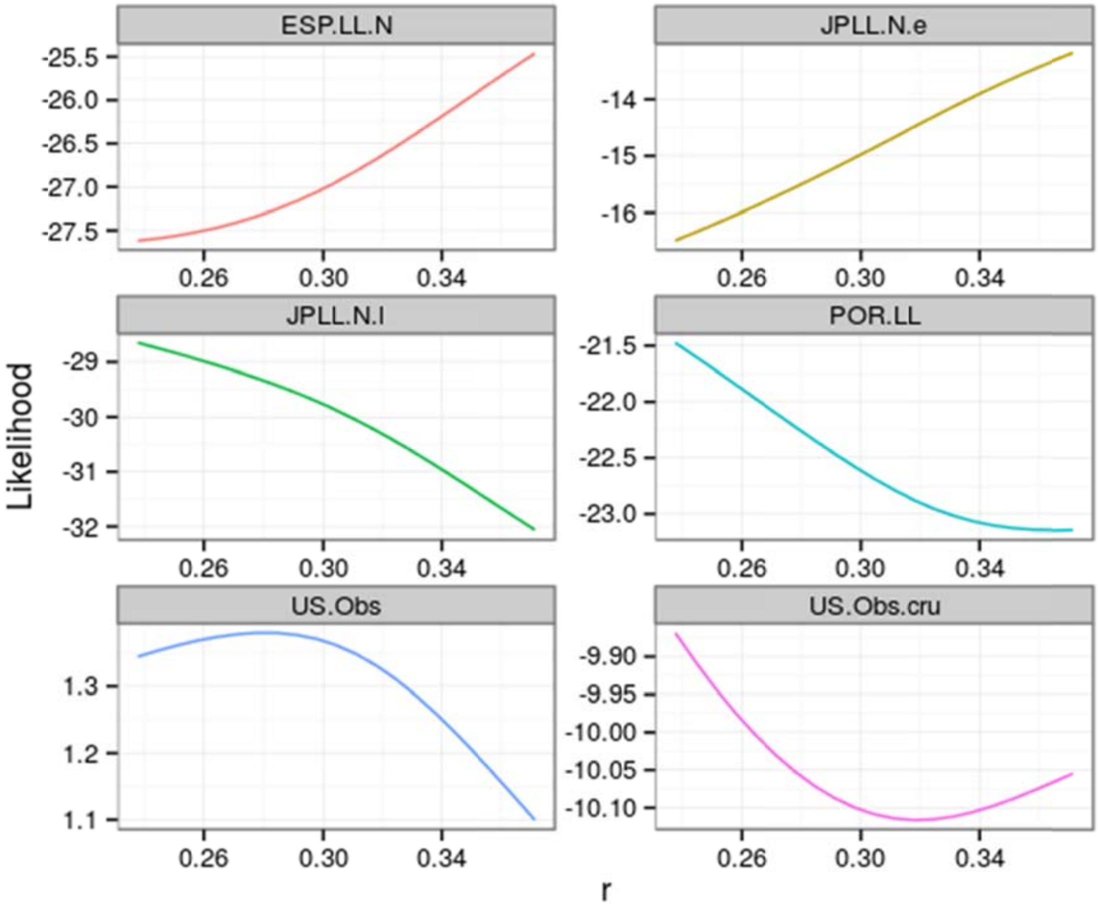


Figure 26. North Atlantic likelihood profiles for *r* by CPUE series, when Chinese-Taipei and Venezuela removed.

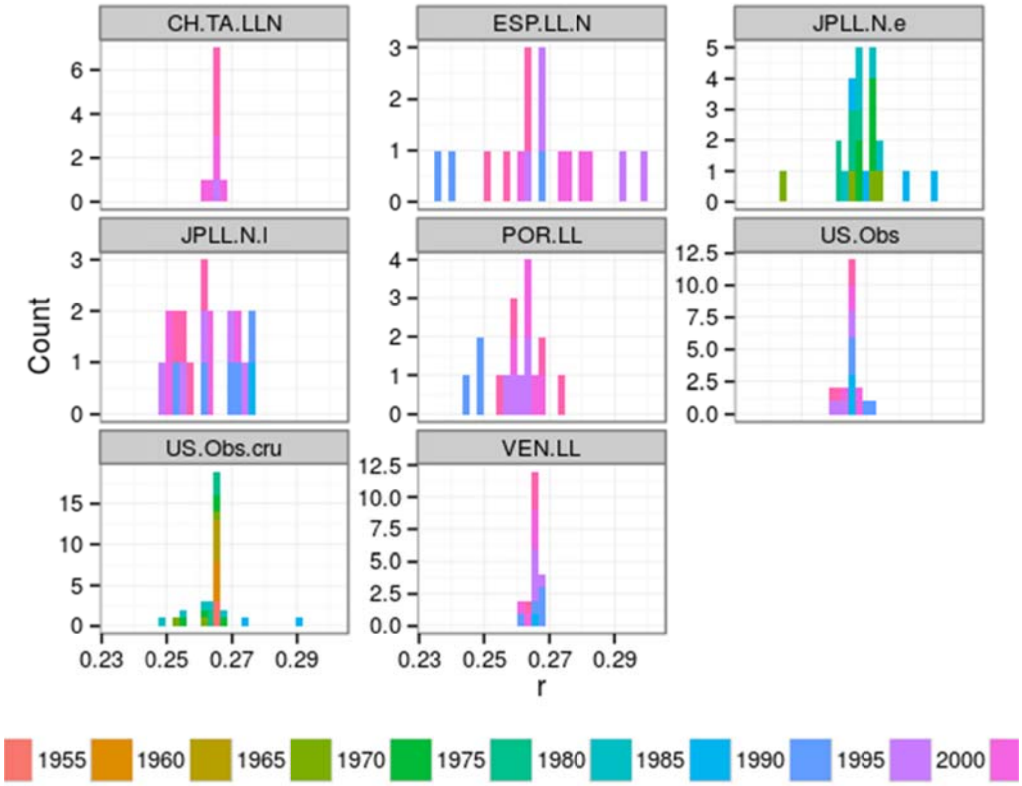


Figure 27. Jackknifed estimates of *r* for the North Atlantic, colors correspond to 5 year periods and panels, the indices.

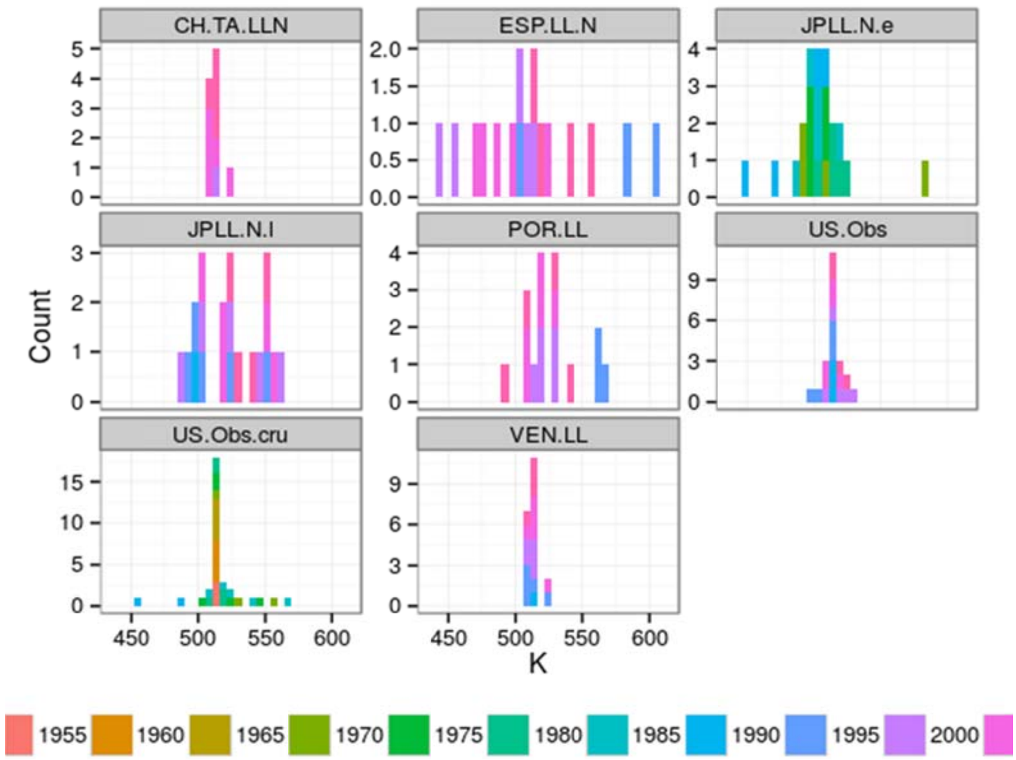


Figure 28. Jackknifed estimates of *K* for the North Atlantic, colors correspond to 5 year periods and panels, the indices.

Appendix 1

AGENDA

1. Opening, adoption of Agenda and meeting arrangements
2. Summary of available data for assessment
   - 2.1 Stock identity
   - 2.2 Catches
   - 2.3 Indices of abundance
   - 2.4 Biology
   - 2.5 Other relevant data
3. Methods and other data relevant to the assessment
   - 3.1 Production models
   - 3.2 Length-based age-structured models: Stock Synthesis
   - 3.3 Other methods
4. Stock status results
   - 4.1 Production models
   - 4.2 Stock Synthesis
   - 4.3 Other methods
   - 4.4 Synthesis of assessment results
5. Projections
6. Recommendations
   - 6.1 Research and statistics
   - 6.2 Management
7. Other matters
8. Adoption of the report and closure

Appendix 2

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De Bruyn, Paul
Kell, Laurence

Appendix 3

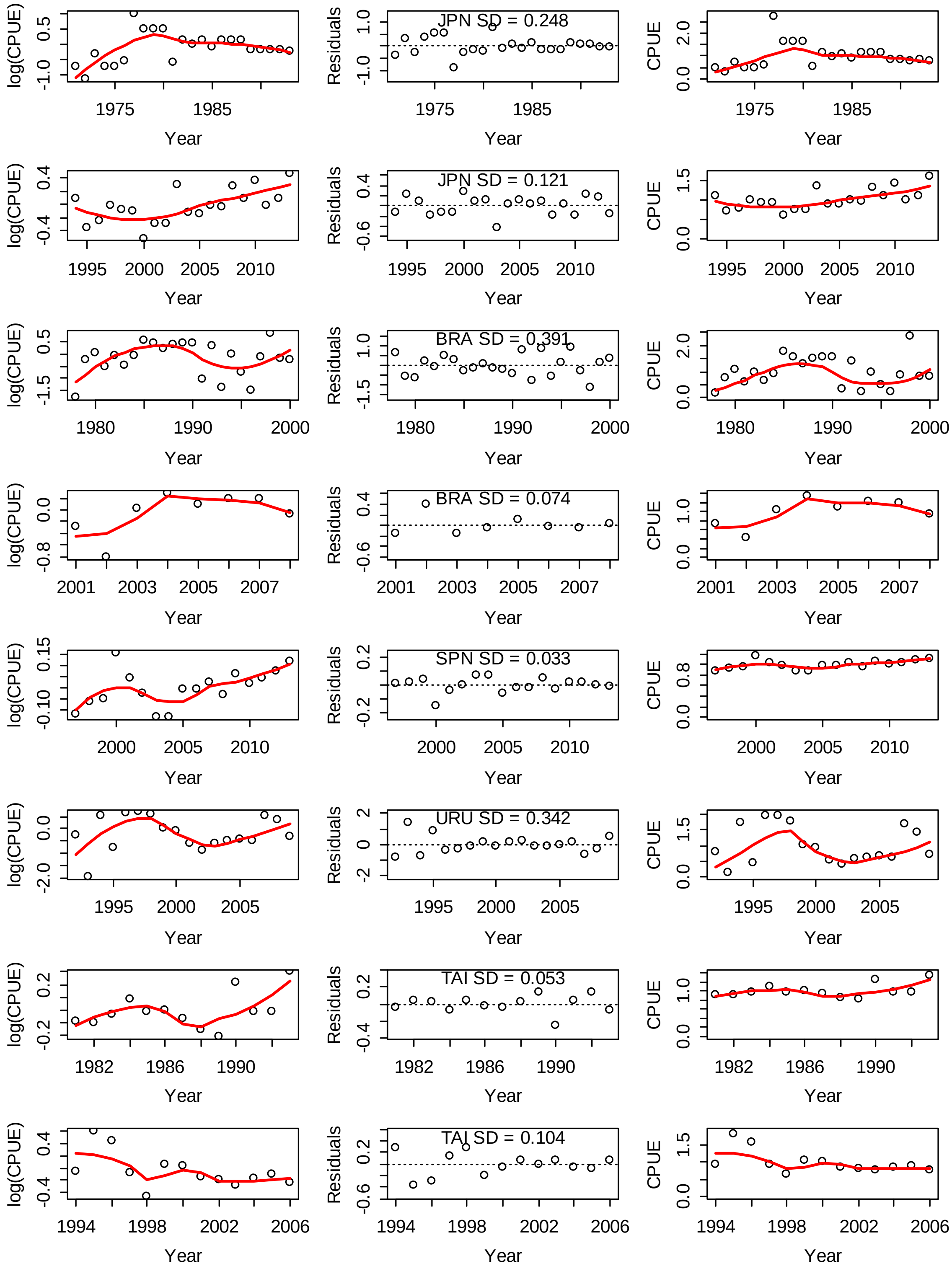
LIST OF DOCUMENTS

Document #	*Title*	*Authors*
SCRS/2015/132	Updated and revised standardized catch rates of blue sharks caught by the Taiwanese longline fishery in the Atlantic Ocean	Tsai W.-P. and Liu K.-M.
SCRS/2015/133	Standardized catch rates of blue shark (*Prionace glauca*) caught by the Brazilian tuna longline fleet (1978-2012) using generalized linear mixed models (GLMM)	Hazin H., Hazin F.H.V. and Mourato B.
SCRS/2015/137	Recent data (2007-2013) from the Irish blue shark recreational fishery	Wögerbauer C., O'Reilly S., Doody C., Green P. and Roche W.
SCRS/2015/141	Combined indices of abundance of blue shark in the north and south Atlantic Ocean	Cortés E.
SCRS/2015/142	Estimates of maximum population growth rate and steepness for blue sharks in the north and south Atlantic Ocean	Cortés E.
SCRS/2015/150	Bayesian surplus production model applied to blue shark catch, CPUE and effort data	Babcock E.A. and Cortés E.
SCRS/2015/151	Preliminary stock synthesis (SS3) model runs conducted for north Atlantic blue shark	Courtney D.
SCRS/2015/153	Stock assessment of south Atlantic blue shark (*Prionace glauca*) through 2013	Carvalho F. and Winker H.
SCRS/P/2015/030	A modelling approach to estimate overall Atlantic fishing effort by time-area strata (EffDis)	Beare D.
SCRS/P/2015/031	MedBluesGen: A population genetic study on Mediterranean blue shark for stock identification and conservation	Leone A.

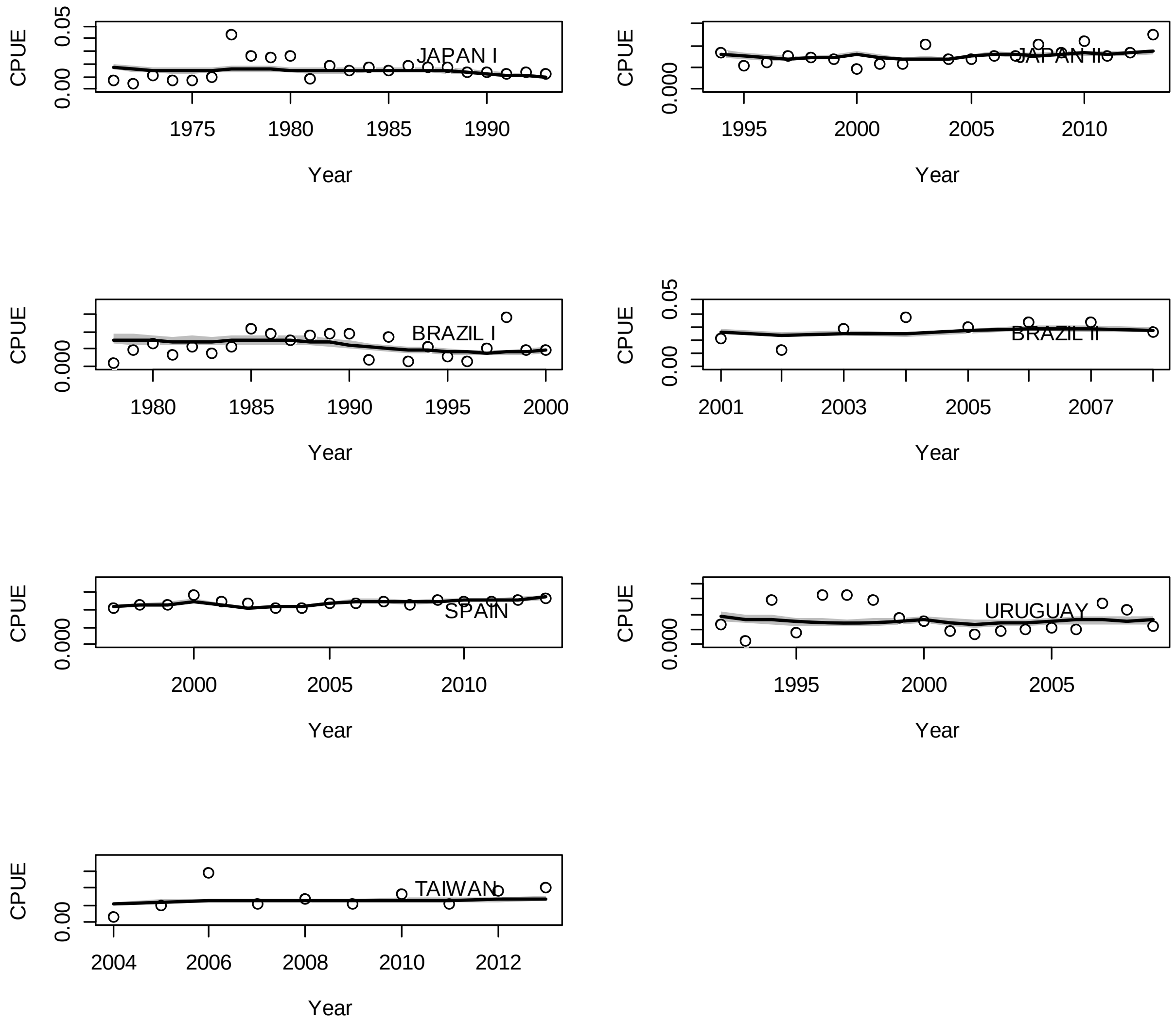
Appendix 4

DETAILS OF THE BAYESIAN STATE SPACE SURPLUS PRODUCTION MODEL RUNS

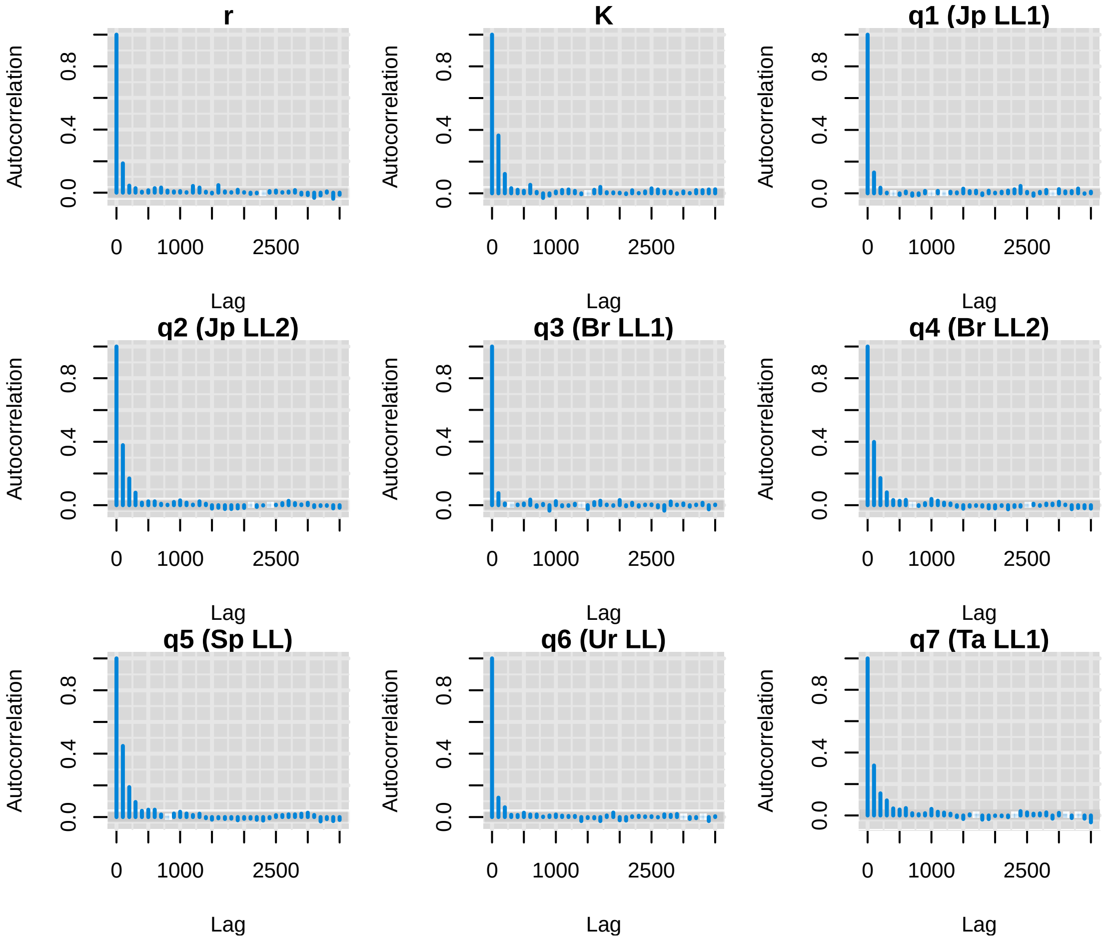
Model: M1



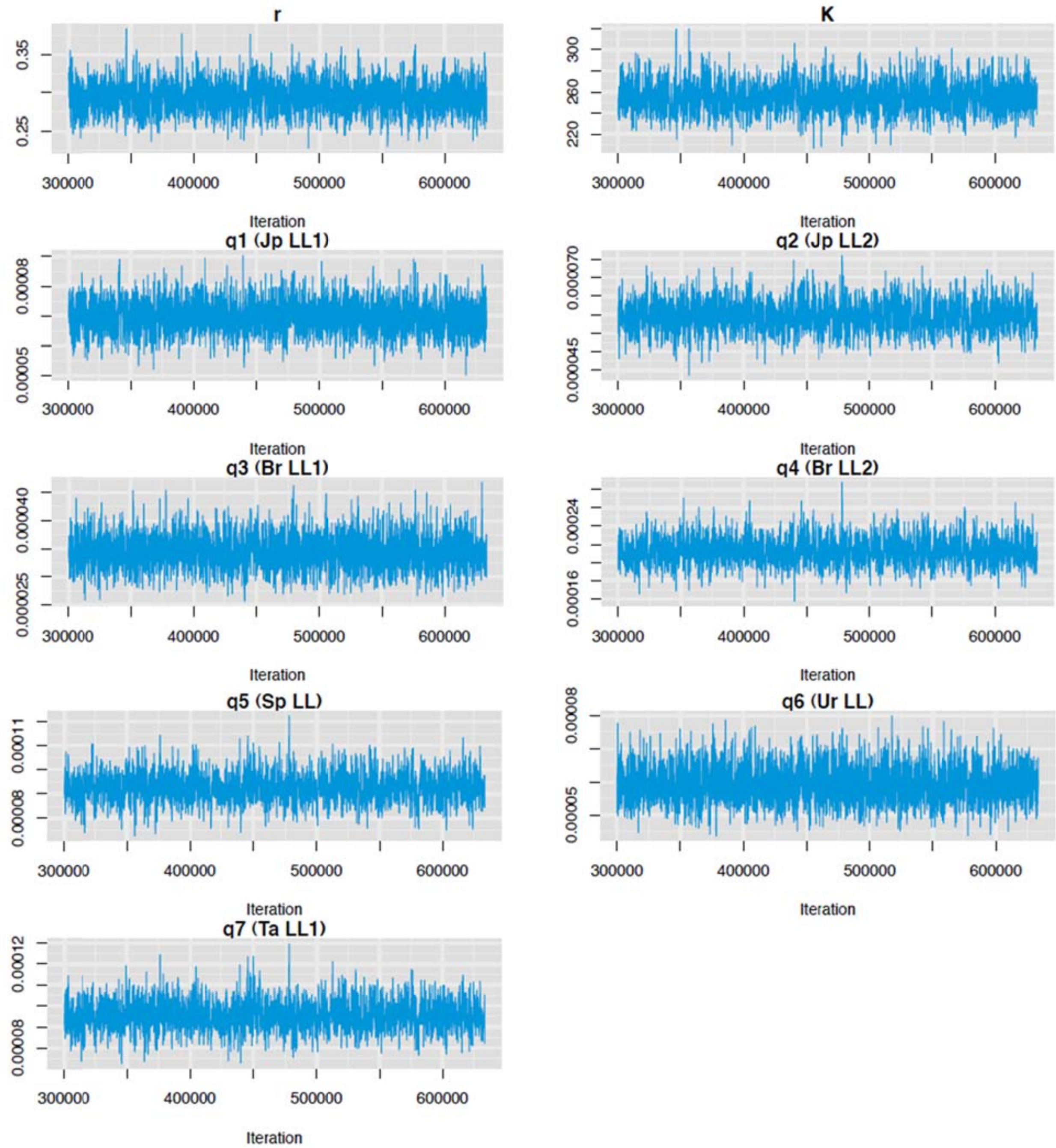
Loess smoother fits used to estimate CVs for CPUE series as input for the assessments (c.f. Francis 2011). Left panel: Smoother fits to log(CPUE) data; Middle panel: Residual plots and estimated CVs for each times series and time-block (where applicable). Right panel: Loess smoother fits illustrated for CPUE indices.



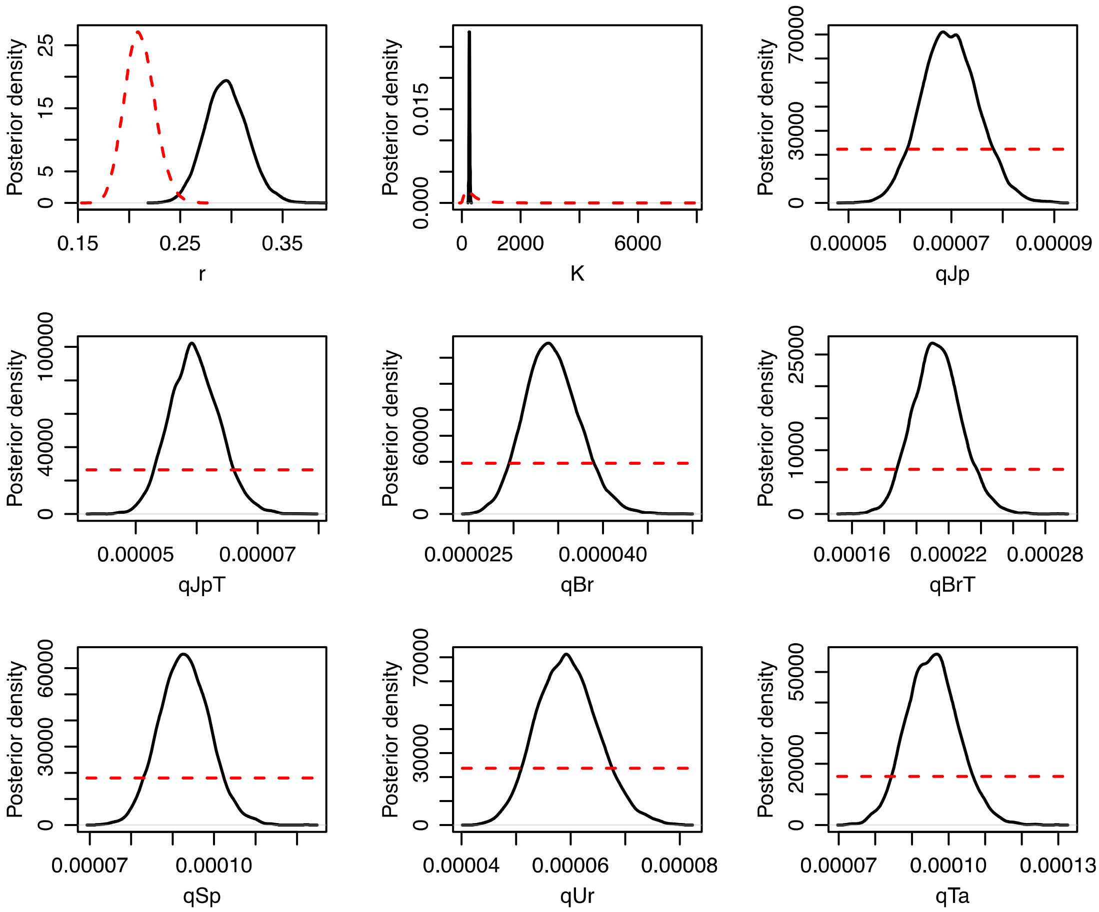
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M1. Shaded grey area indicates 95% C.I.



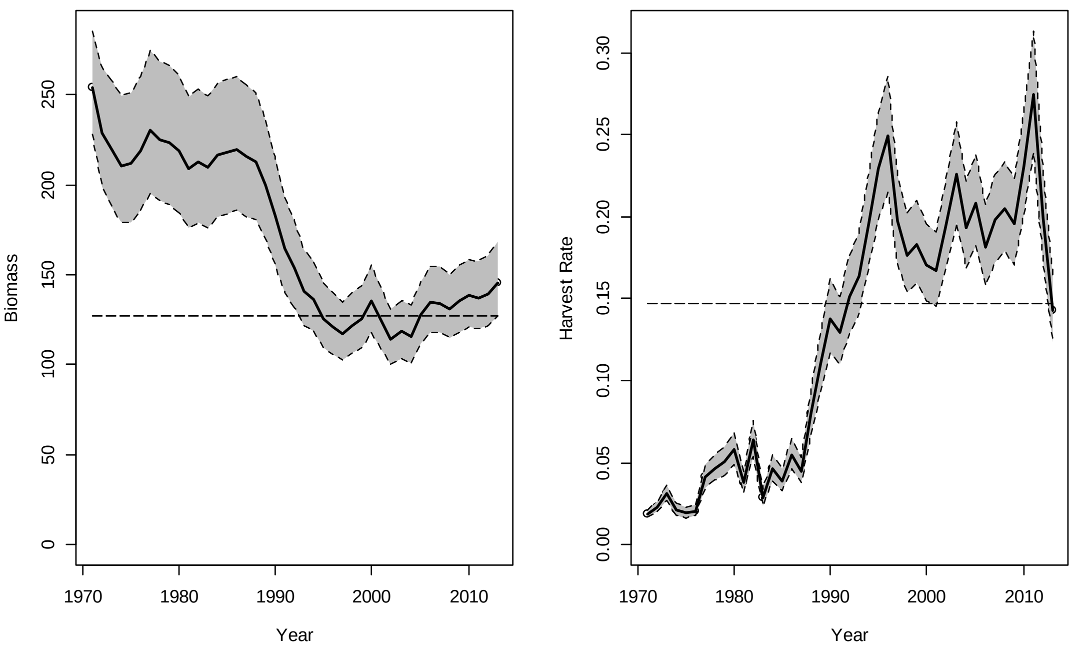
Autocorrelation function plots of main model parameters for M1. Three chains showed highly coherent autocorrelation plots.



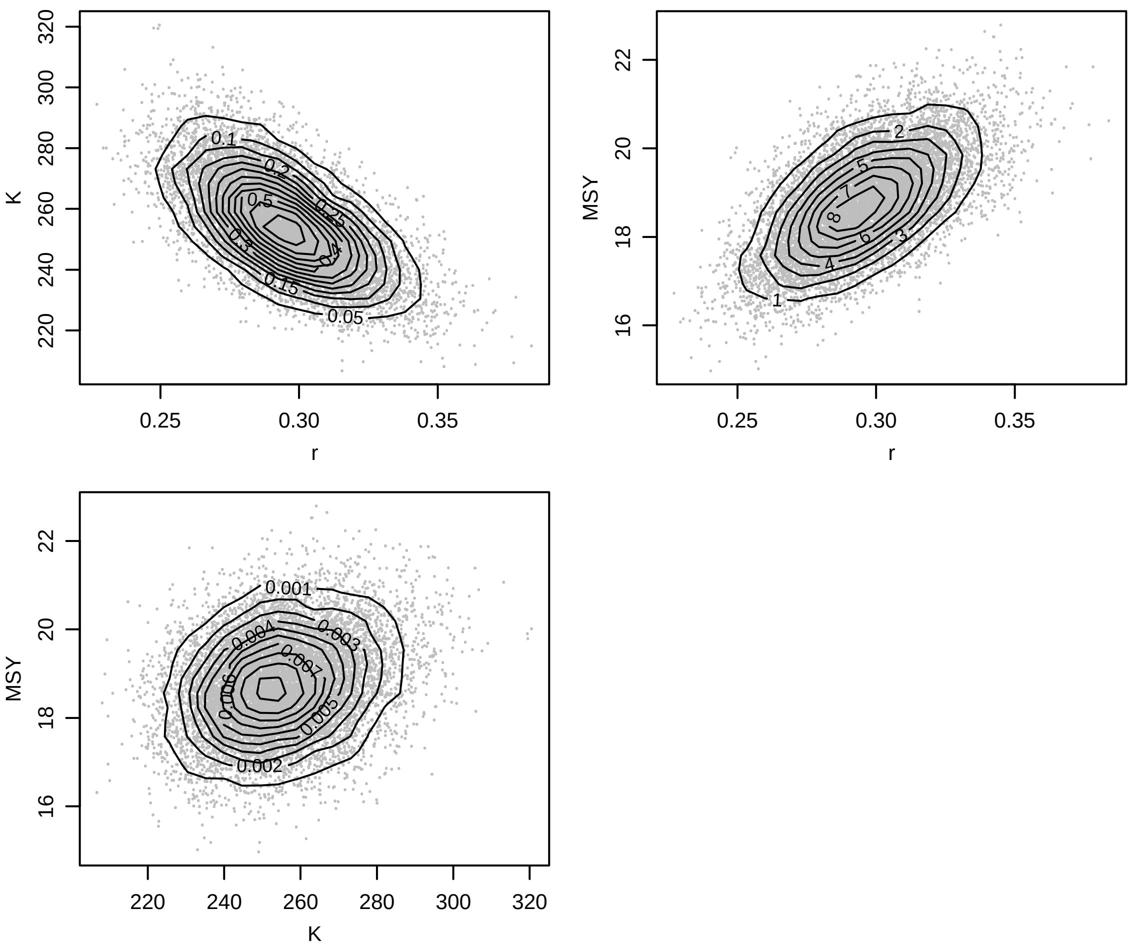
Trace plots for the main model parameters drawn from MCMC samples for M1 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M1 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

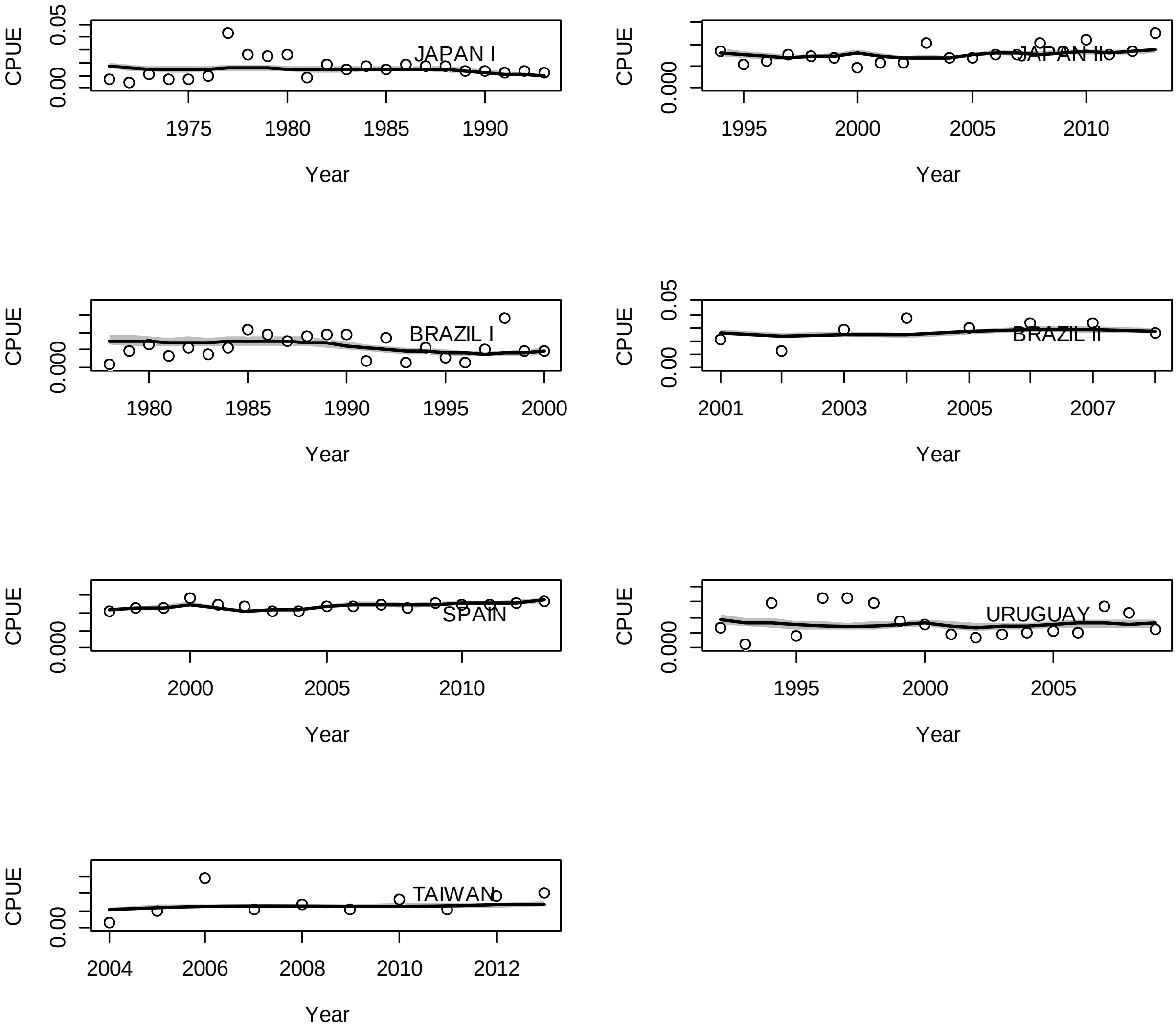


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M1 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

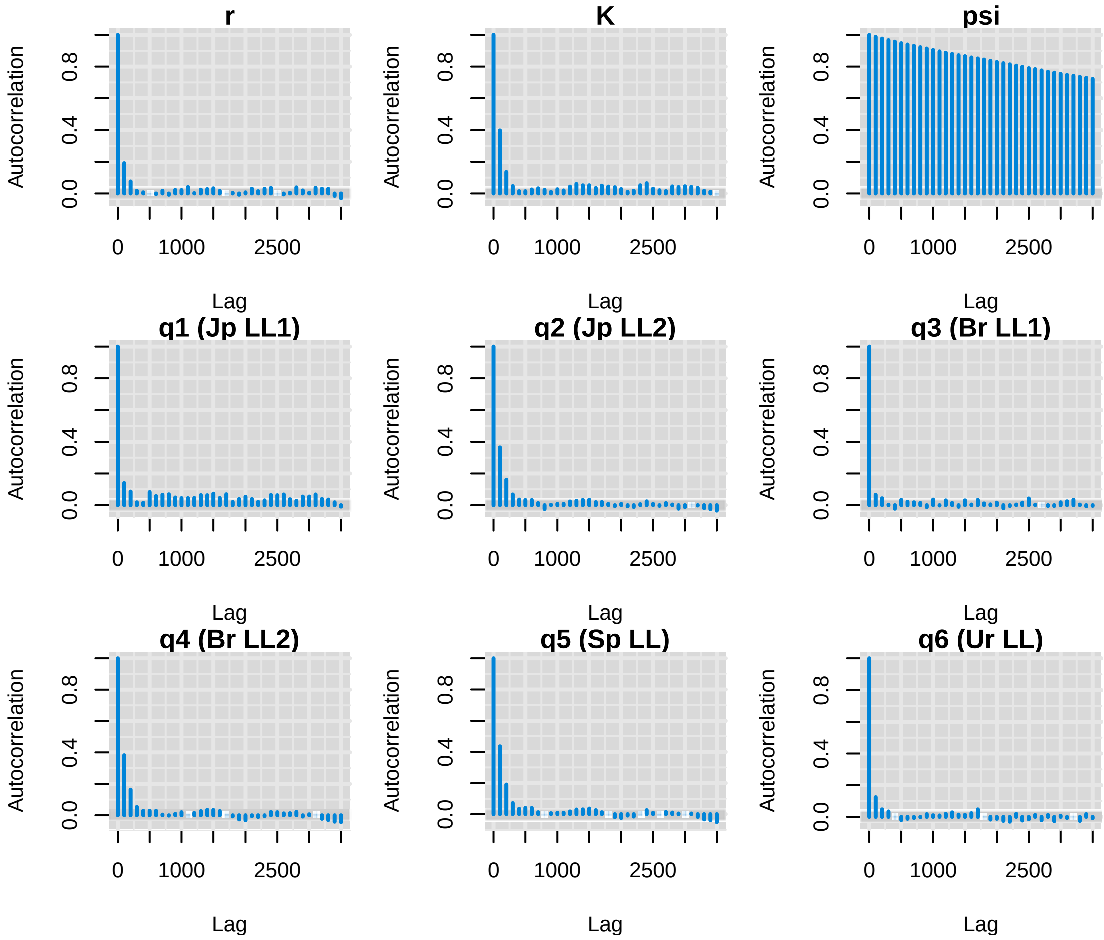


Joint-posterior plots of main model parameters for the alternative M1 for the blue shark in the South Atlantic Ocean.

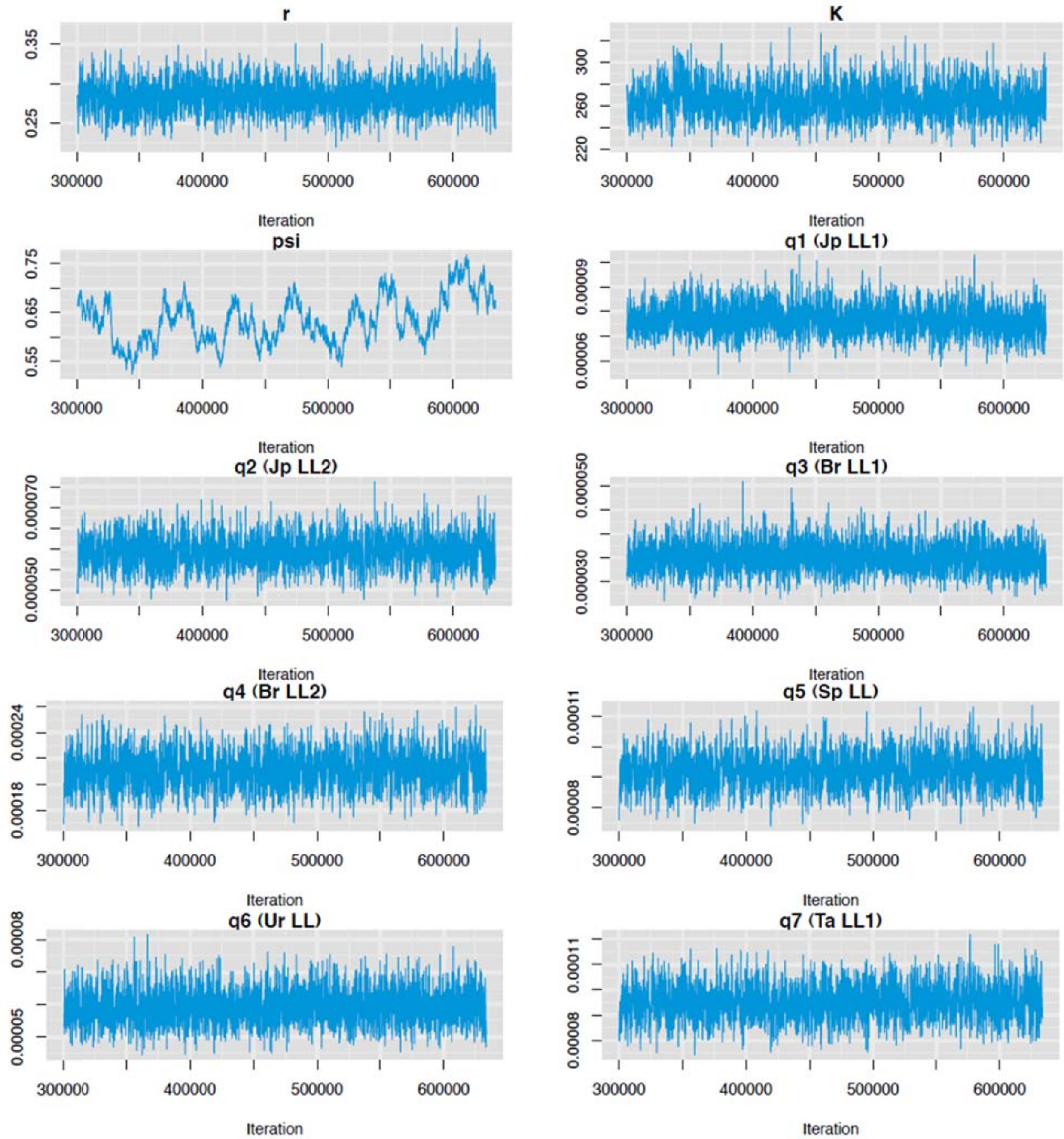
Model: M2



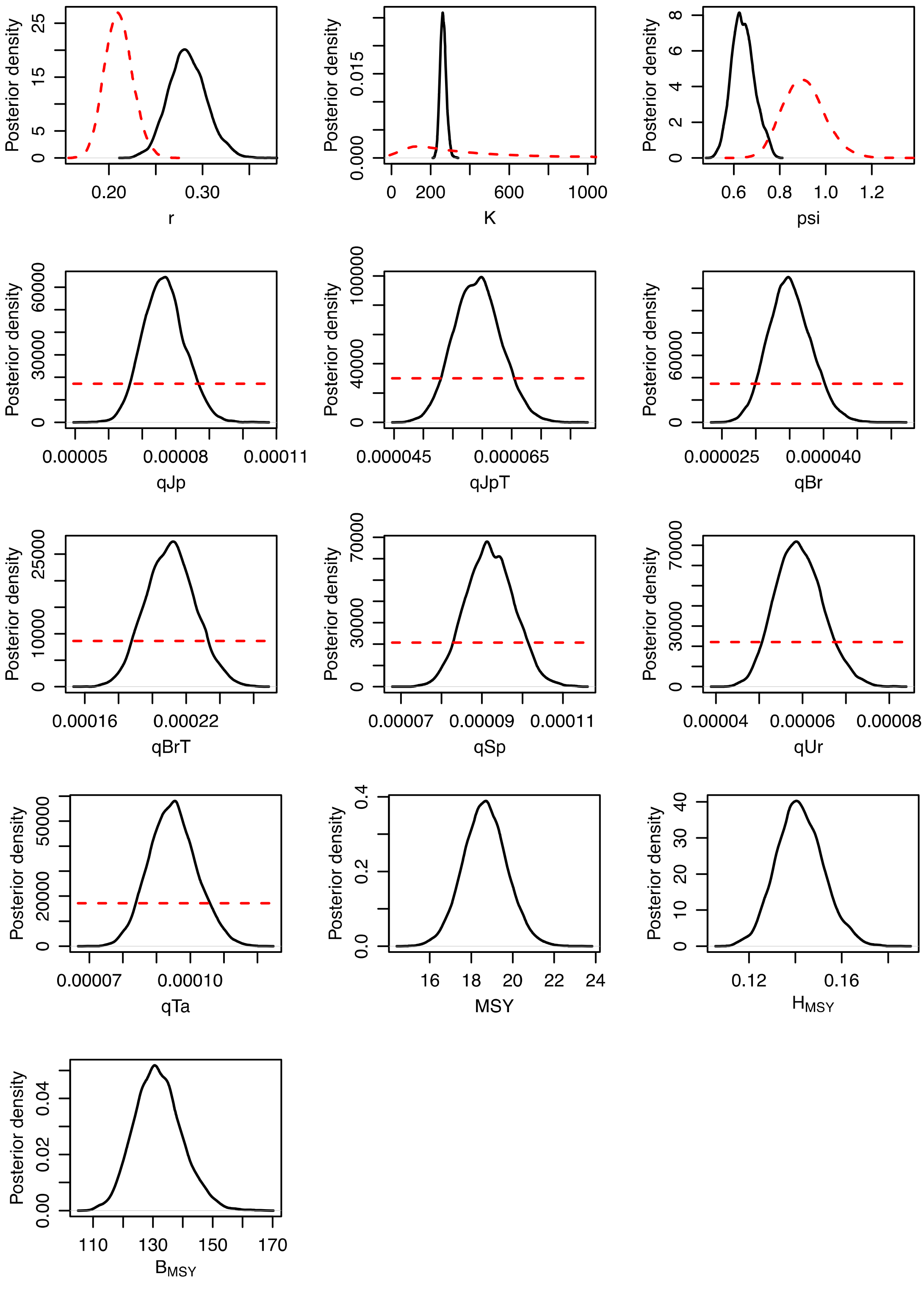
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M2. Shaded grey area indicates 95% C.I.



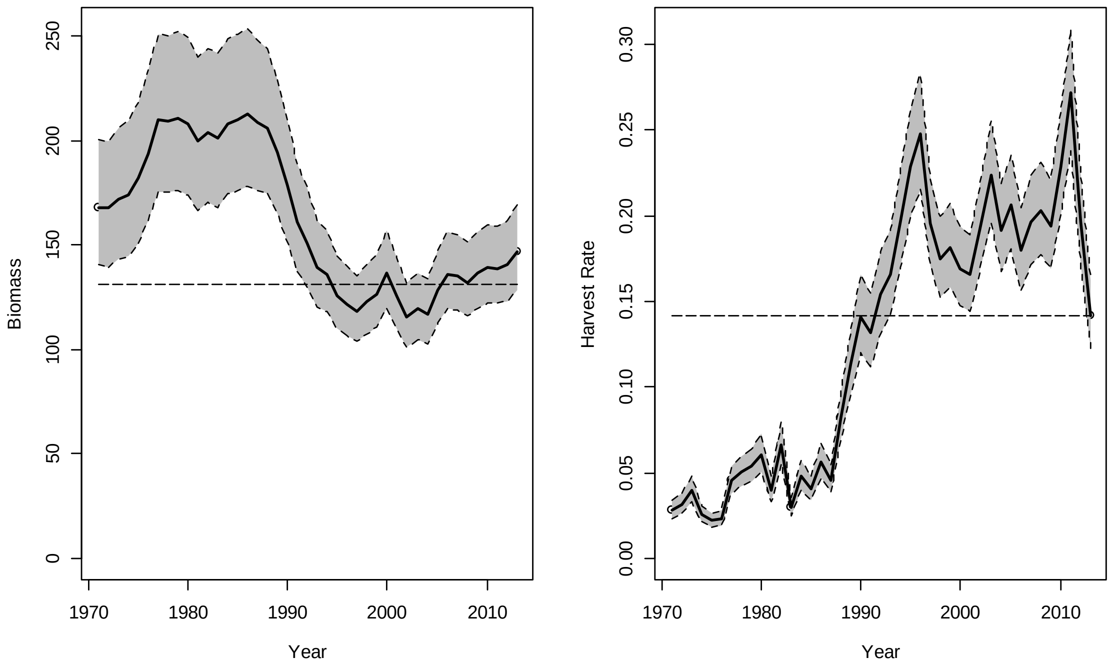
Autocorrelation function plots of main model parameters for M2. Three chains showed highly coherent autocorrelation plots.



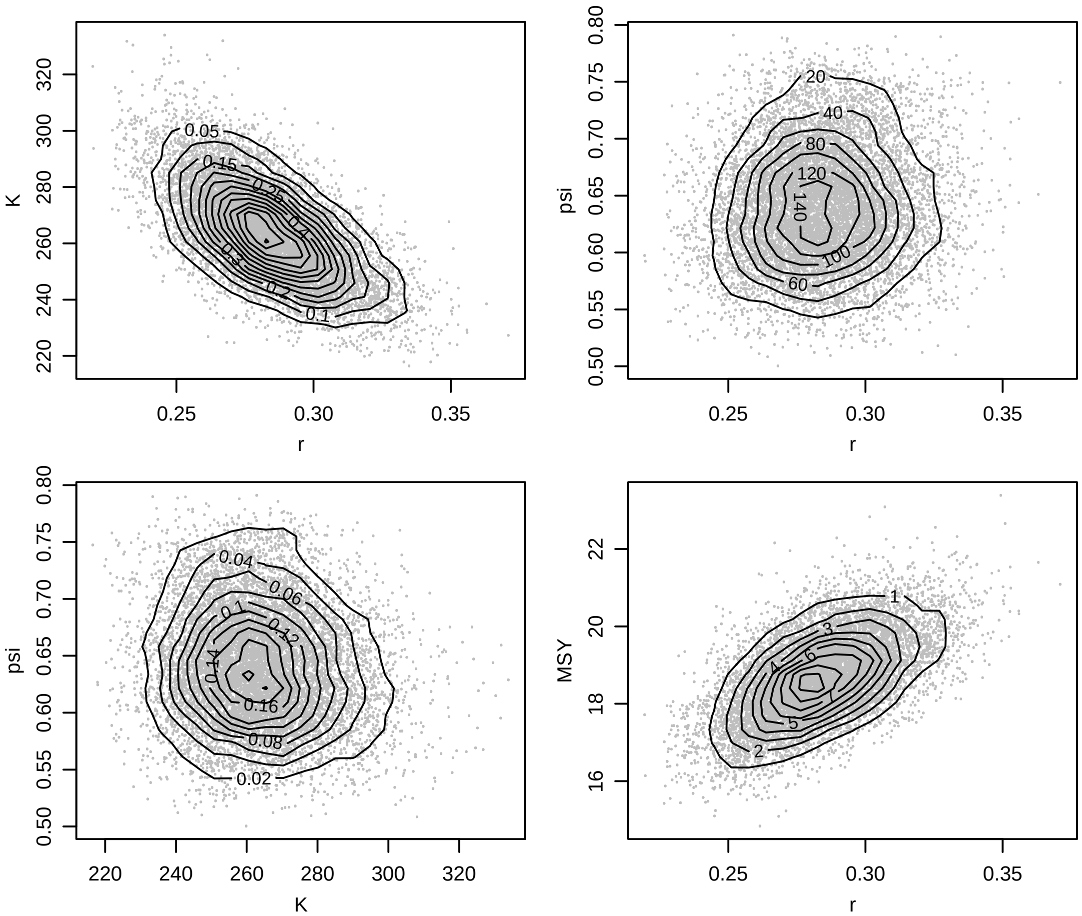
Trace plots for the main model parameter drawn from MCMC samples M2 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M2 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

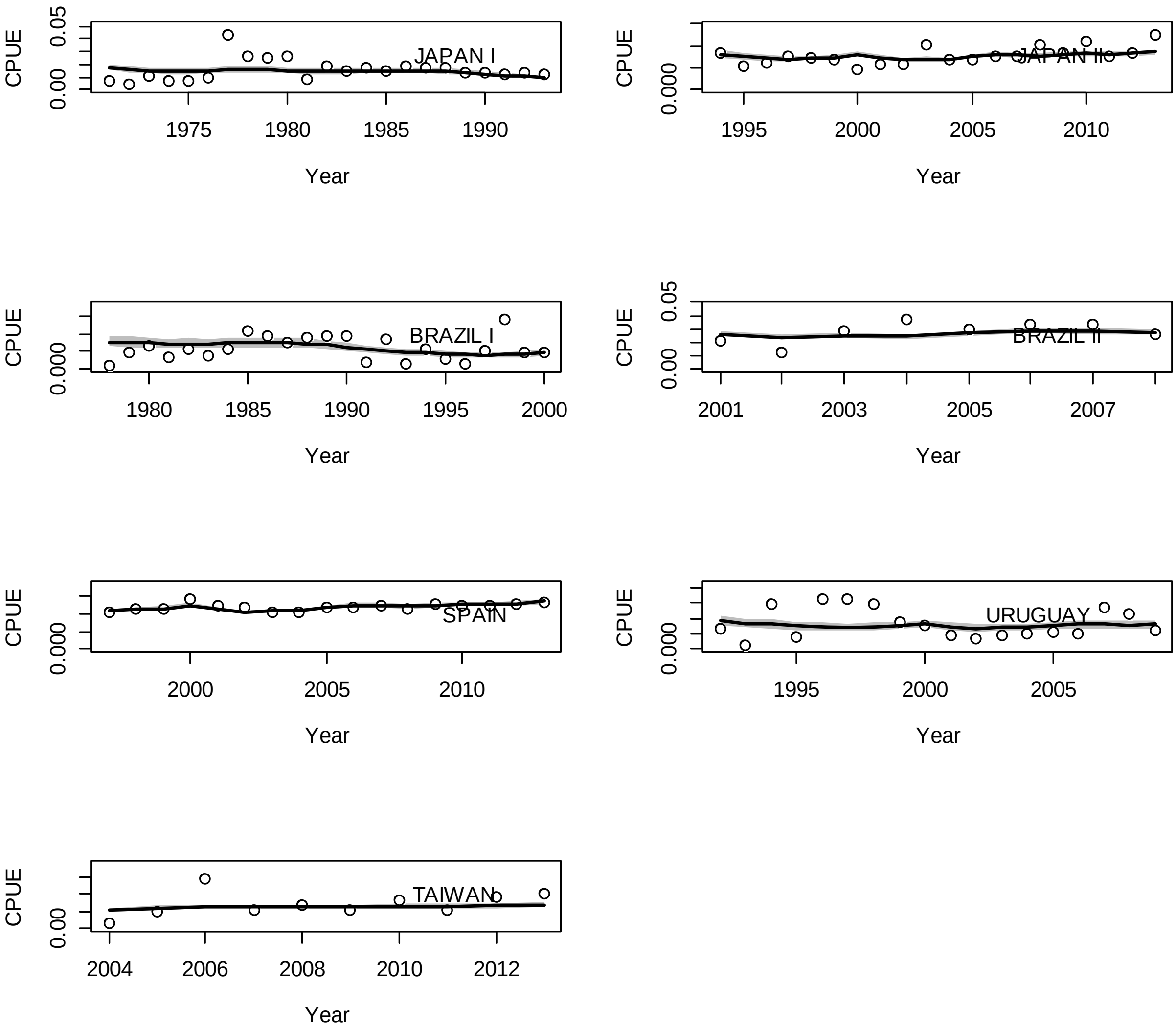


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M2 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

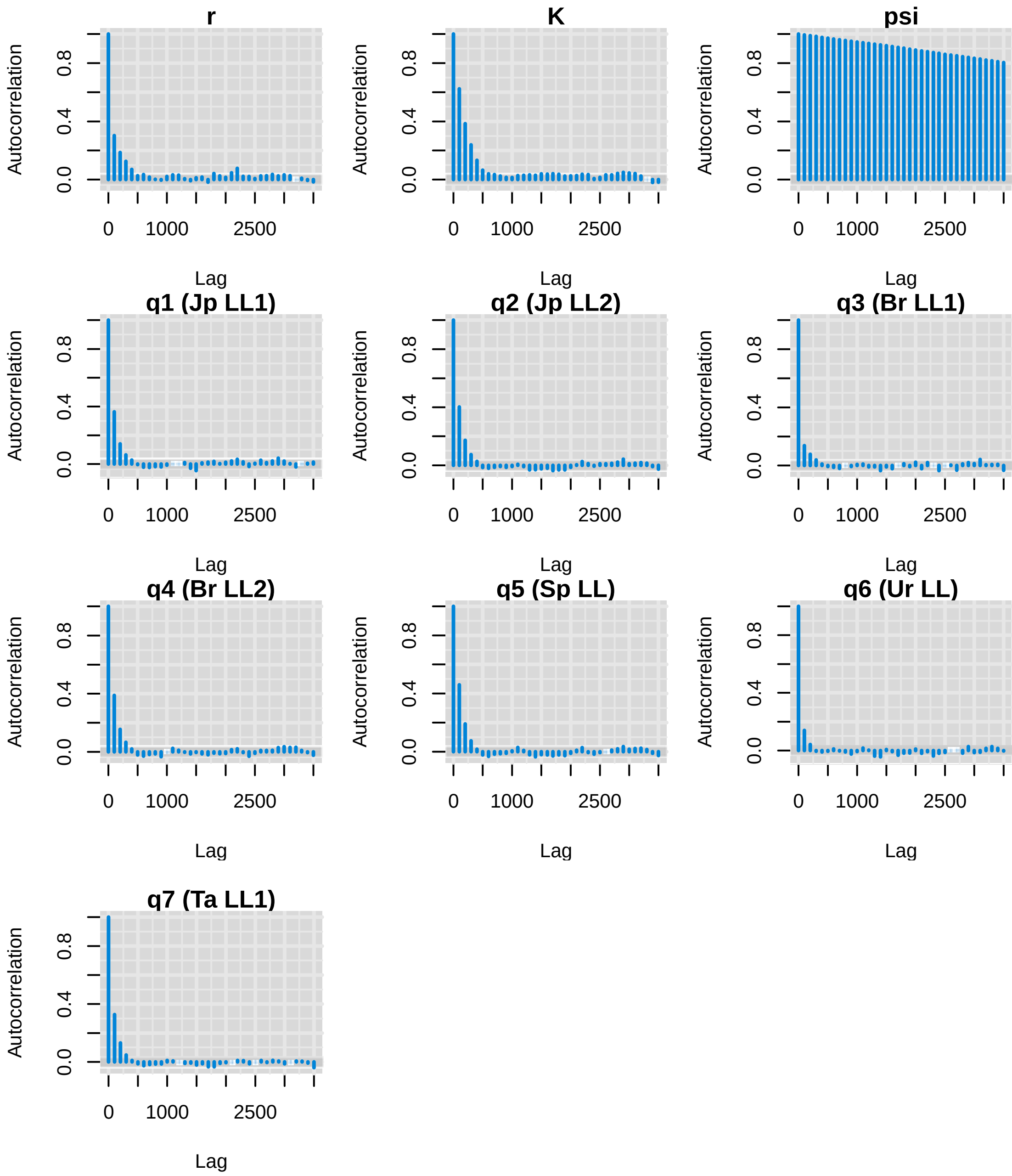


Joint-posterior plots of main model parameters for the alternative M2 for the blue shark in the South Atlantic Ocean.

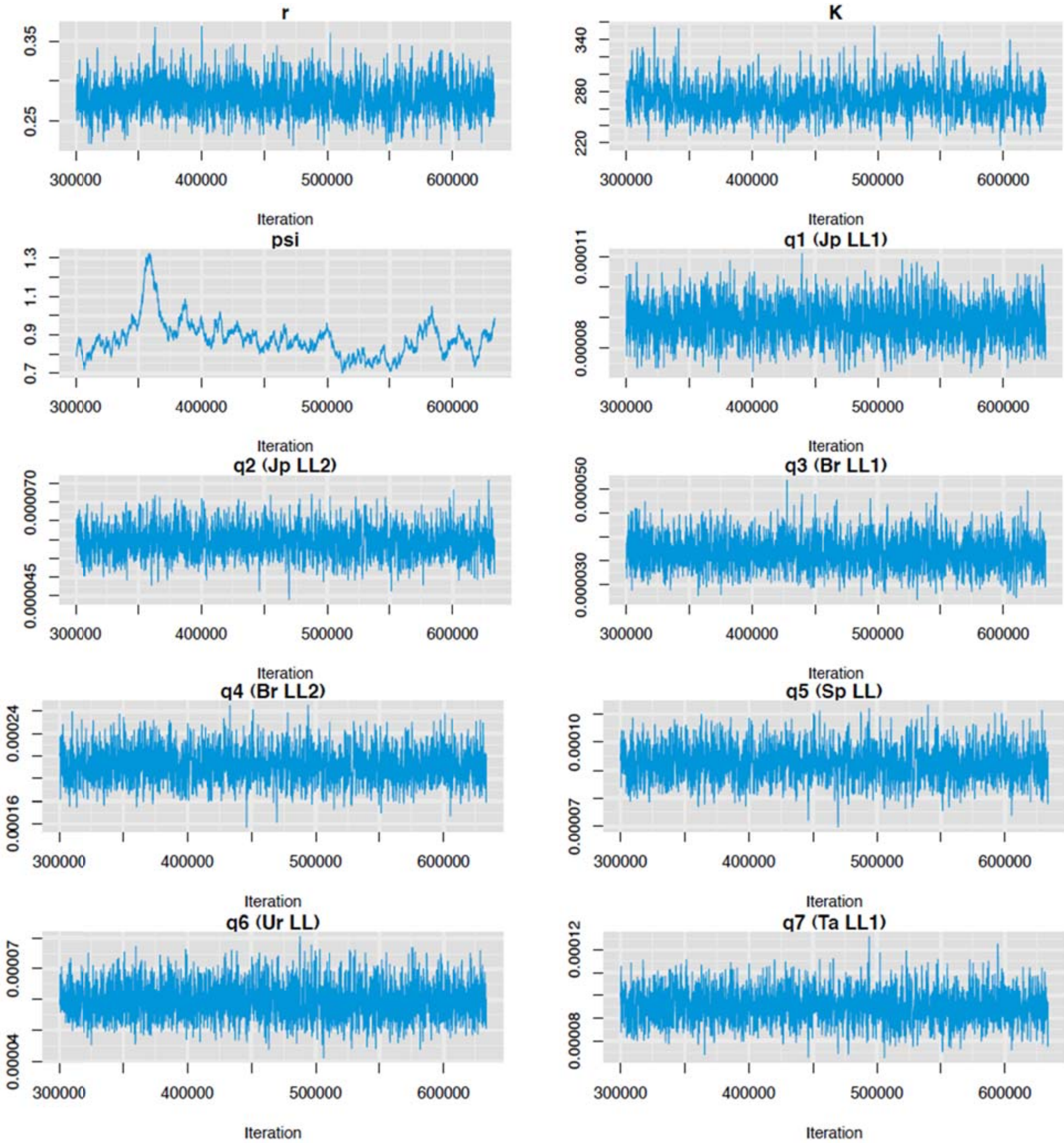
Model: M3



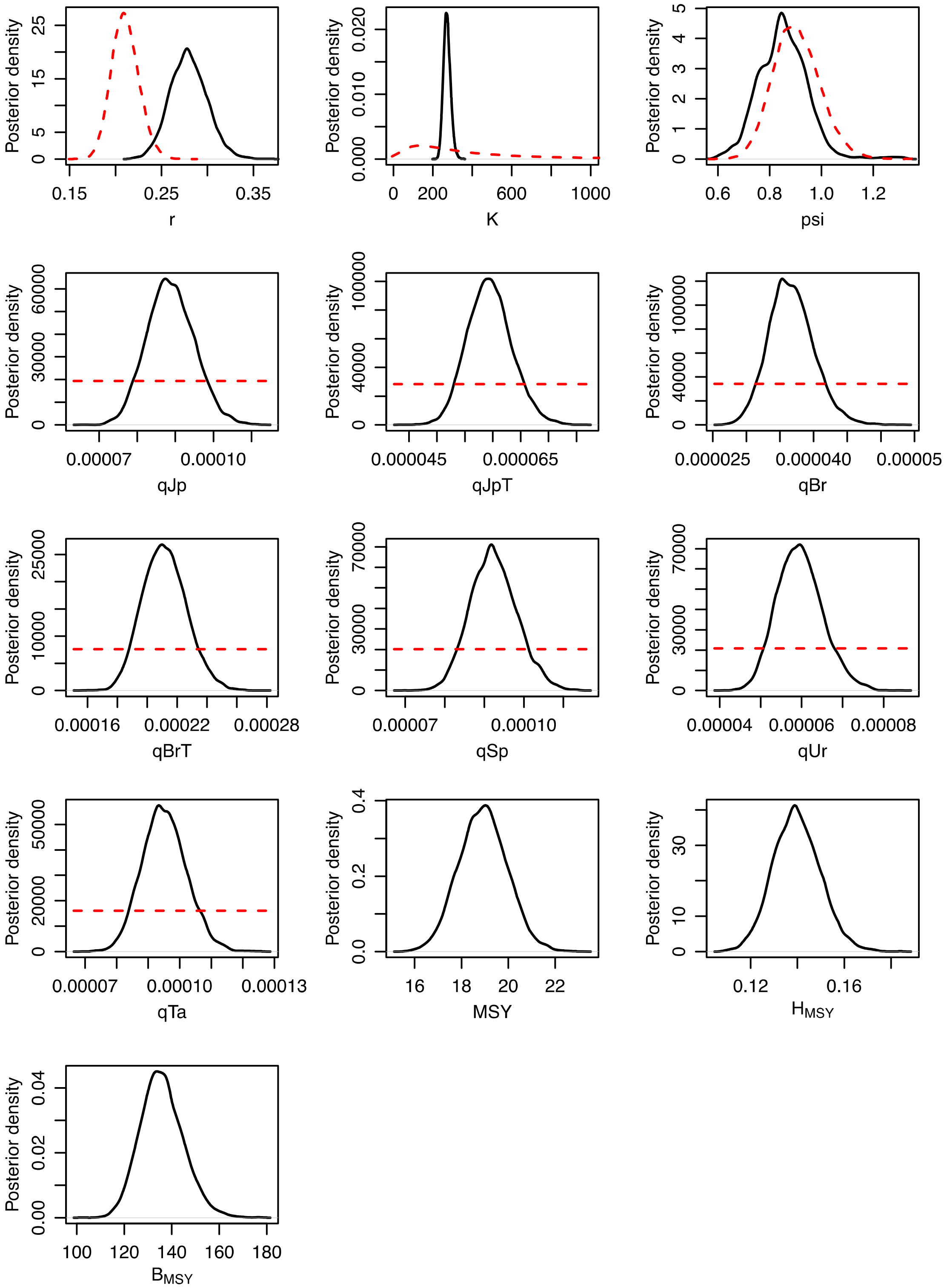
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M3. Shaded grey area indicates 95% C.I.



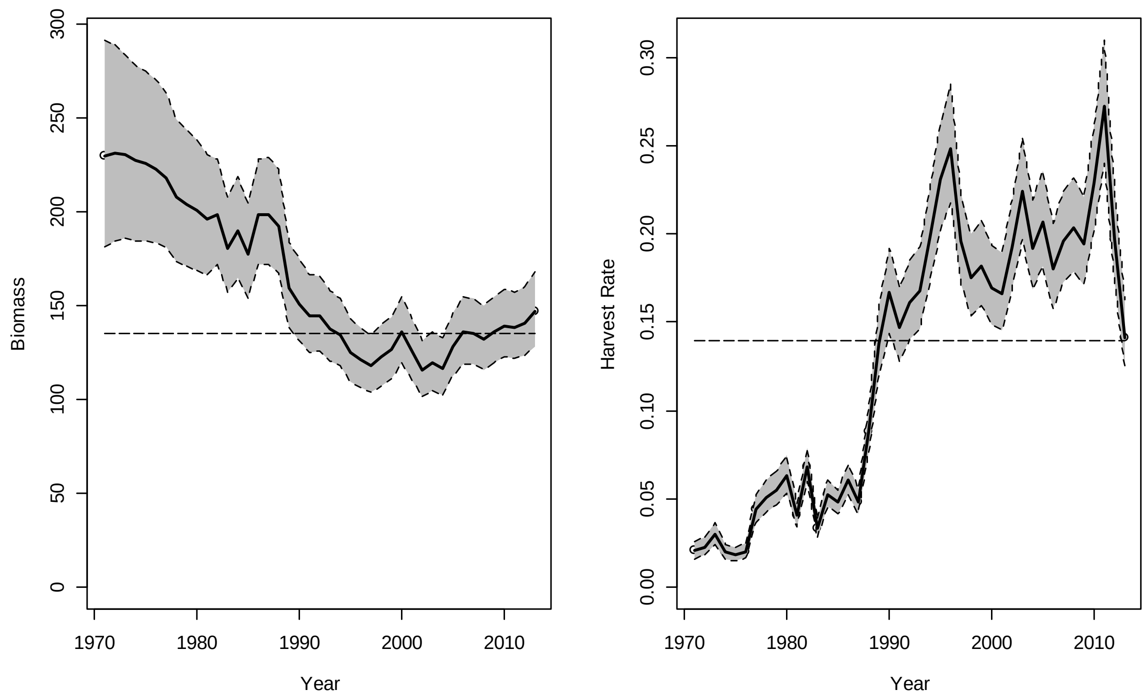
Autocorrelation function plots of main model parameters for M3. Three chains showed highly coherent autocorrelation plots.



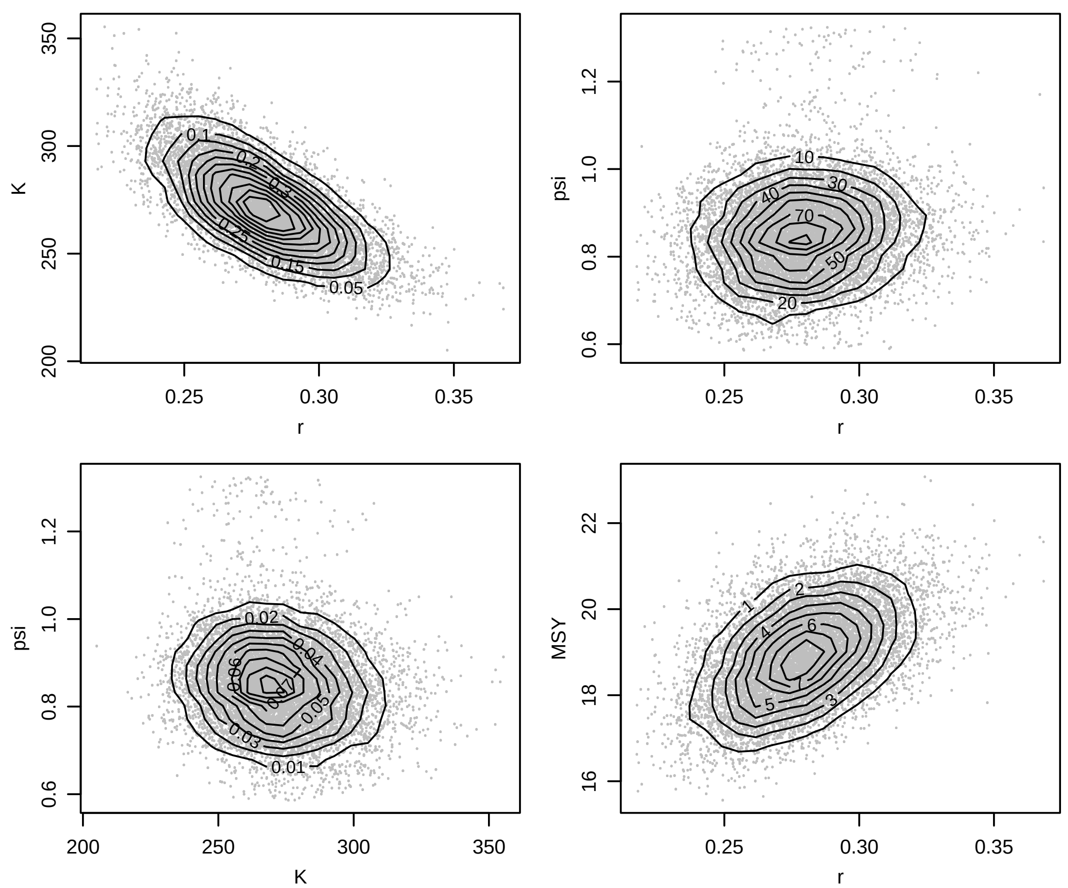
Trace plots for the main model parameter drawn from MCMC samples in M3 for the South Atlantic blue shark.



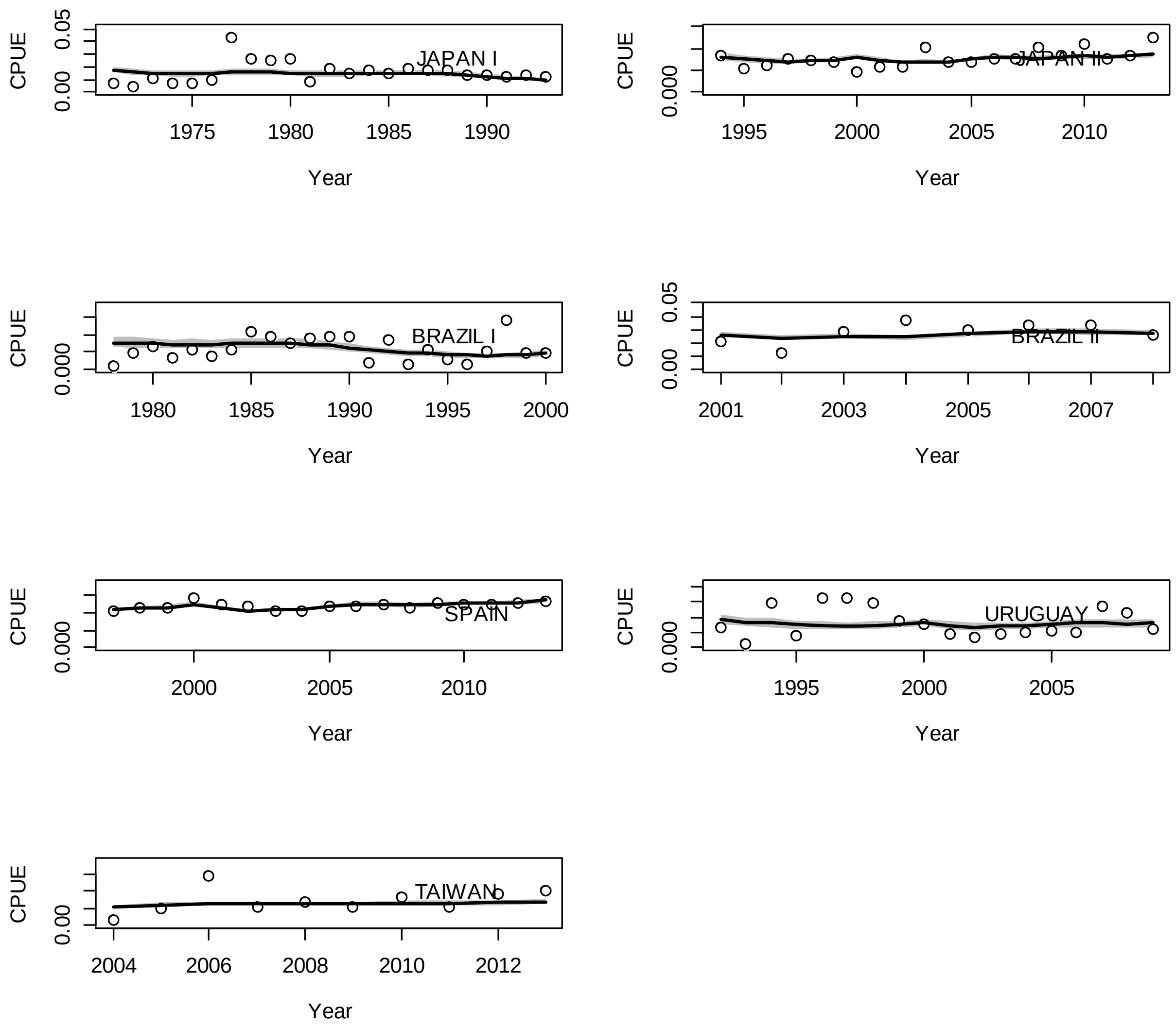
Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M3 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.



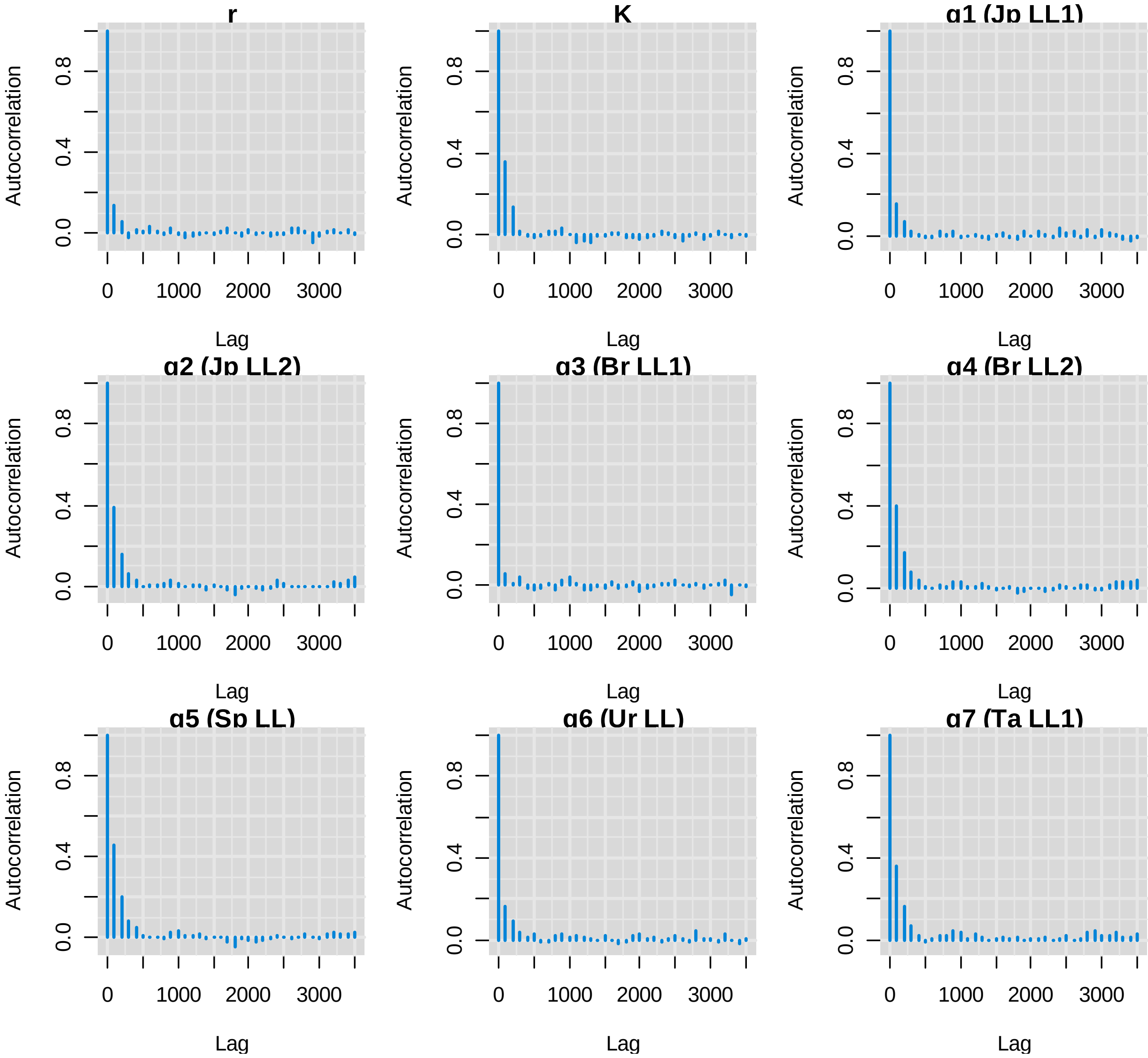
Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M3 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.



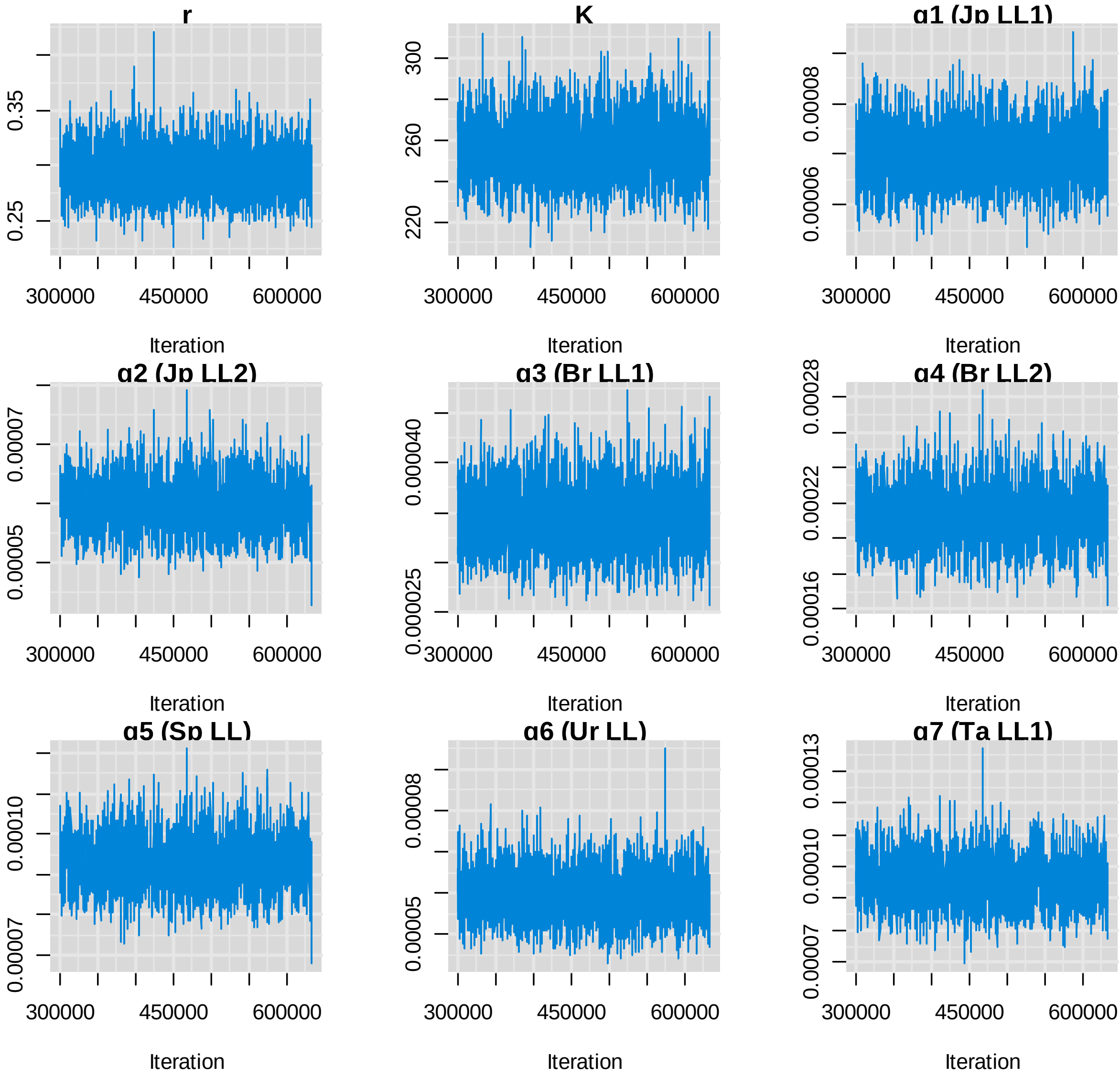
Joint-posterior plots of main model parameters for M3 for the blue shark in the South Atlantic Ocean.
Model: M4



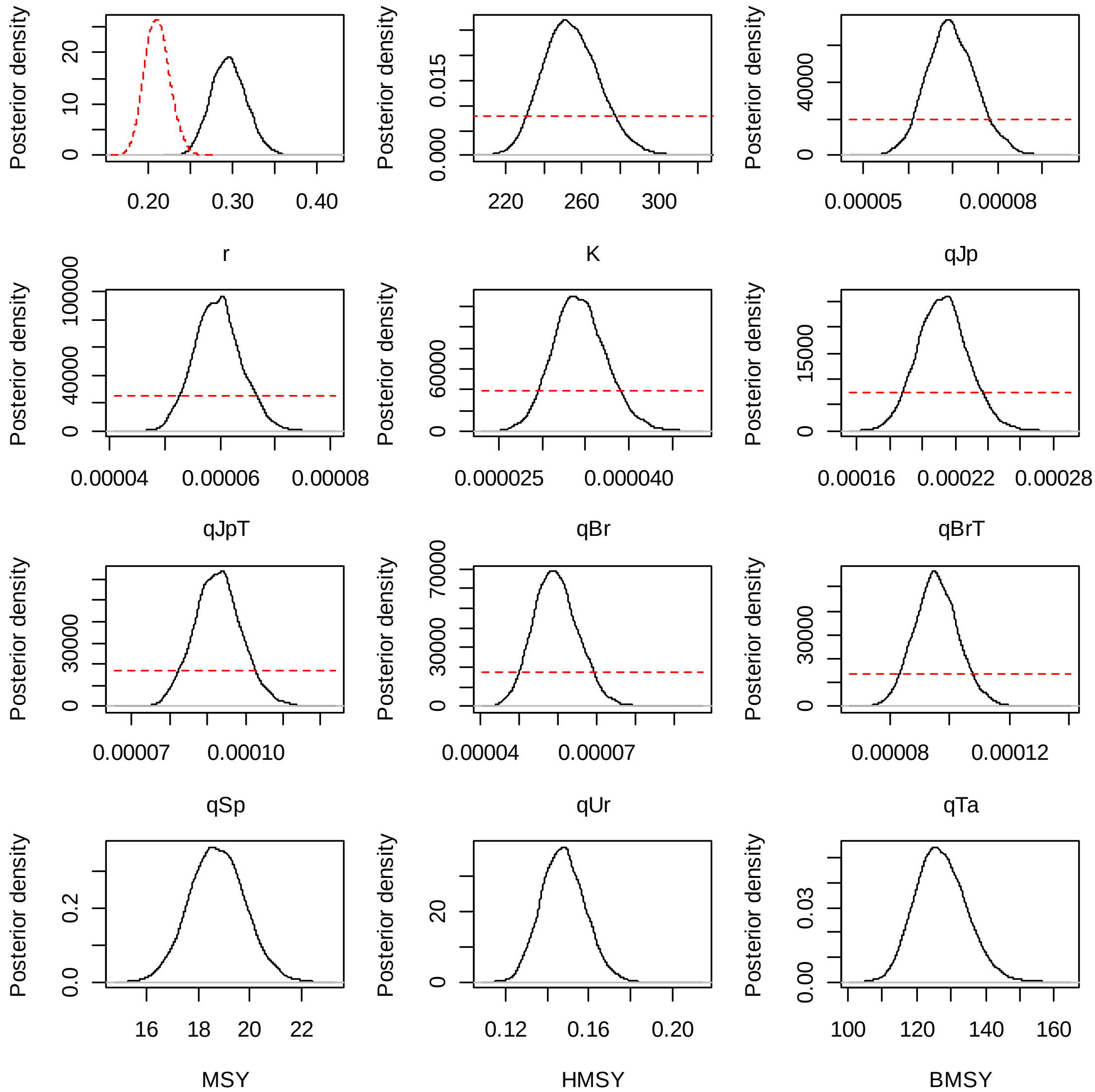
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M4. Shaded grey area indicates 95% C.I.



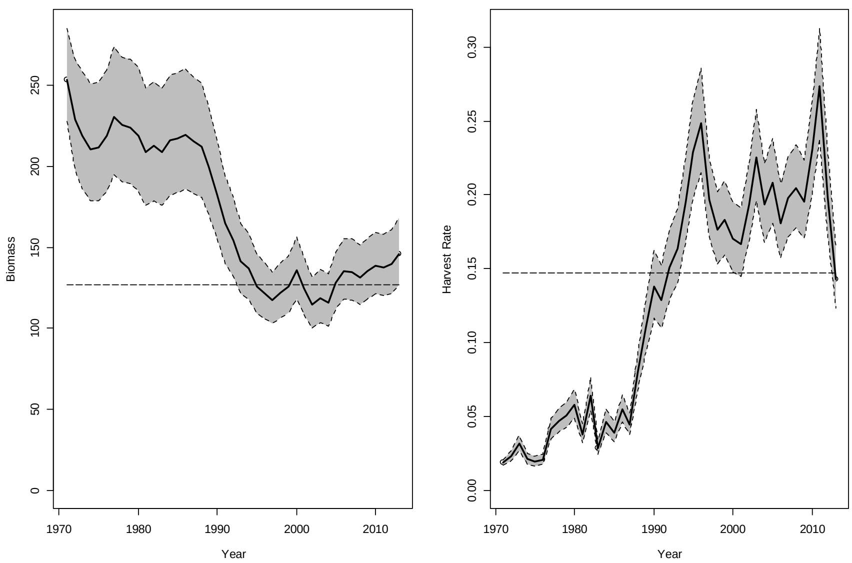
Trace plots for the main model parameter drawn from MCMC samples for M4 for the South Atlantic blue shark.



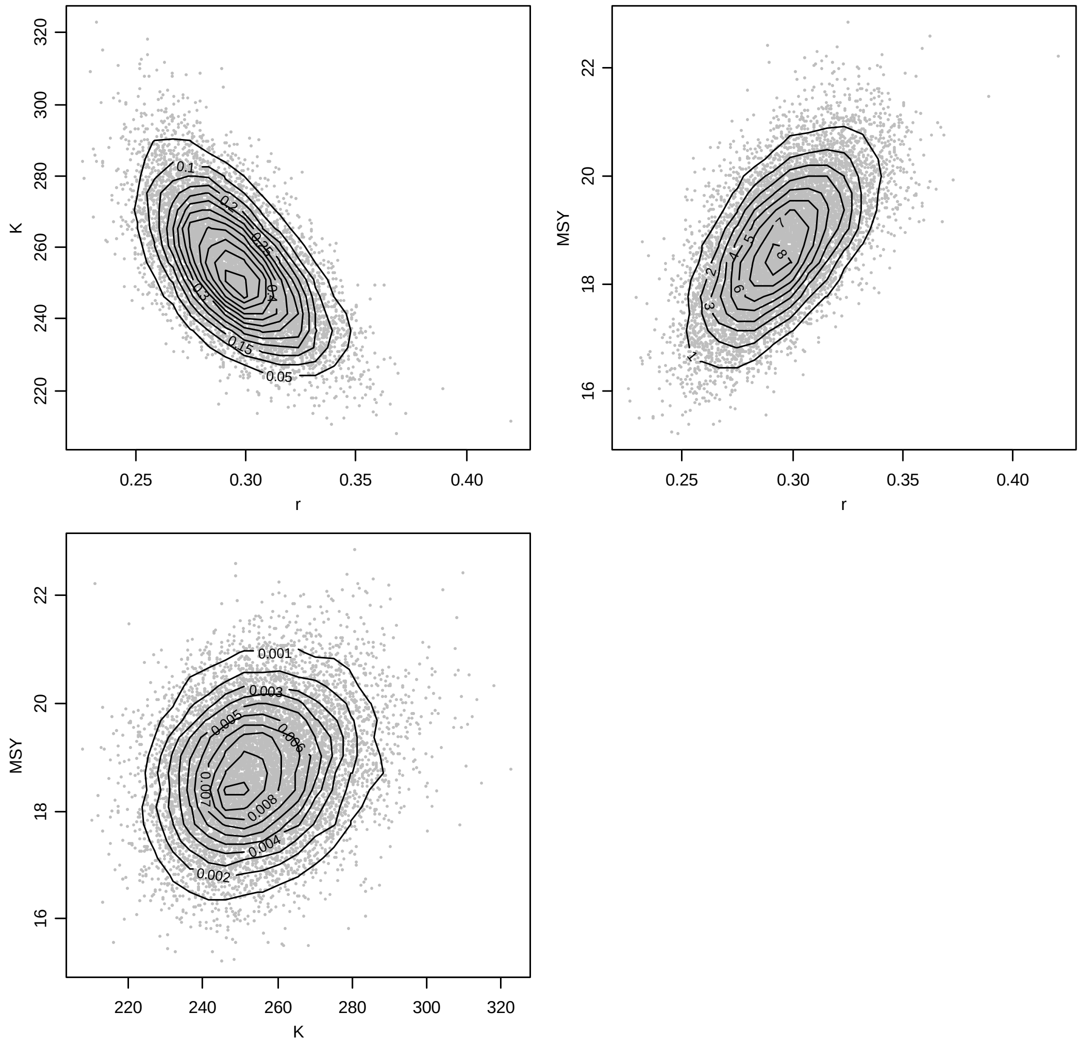
Trace plots for the main model parameter drawn from MCMC samples in M4 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M4 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

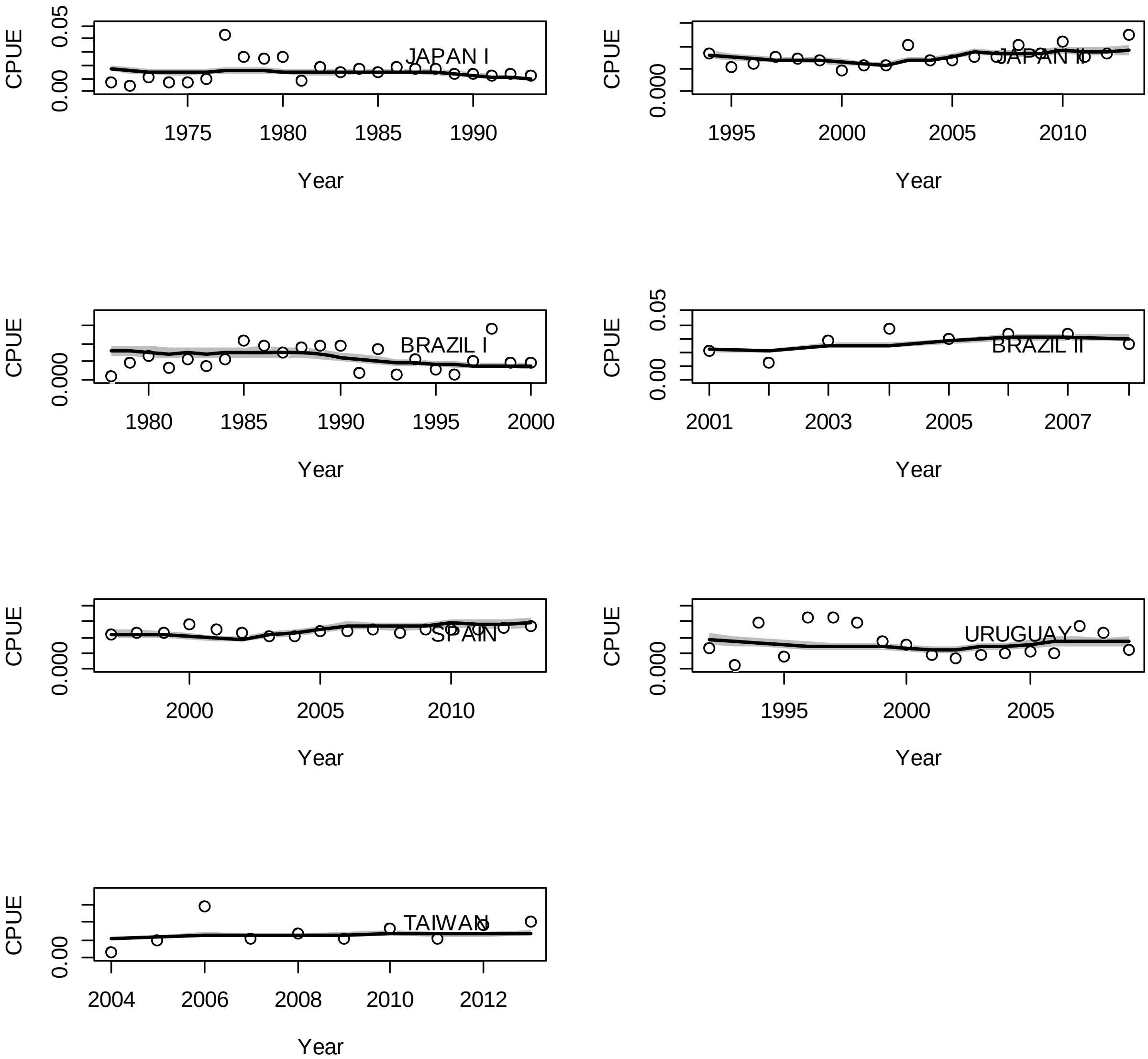


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M4 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

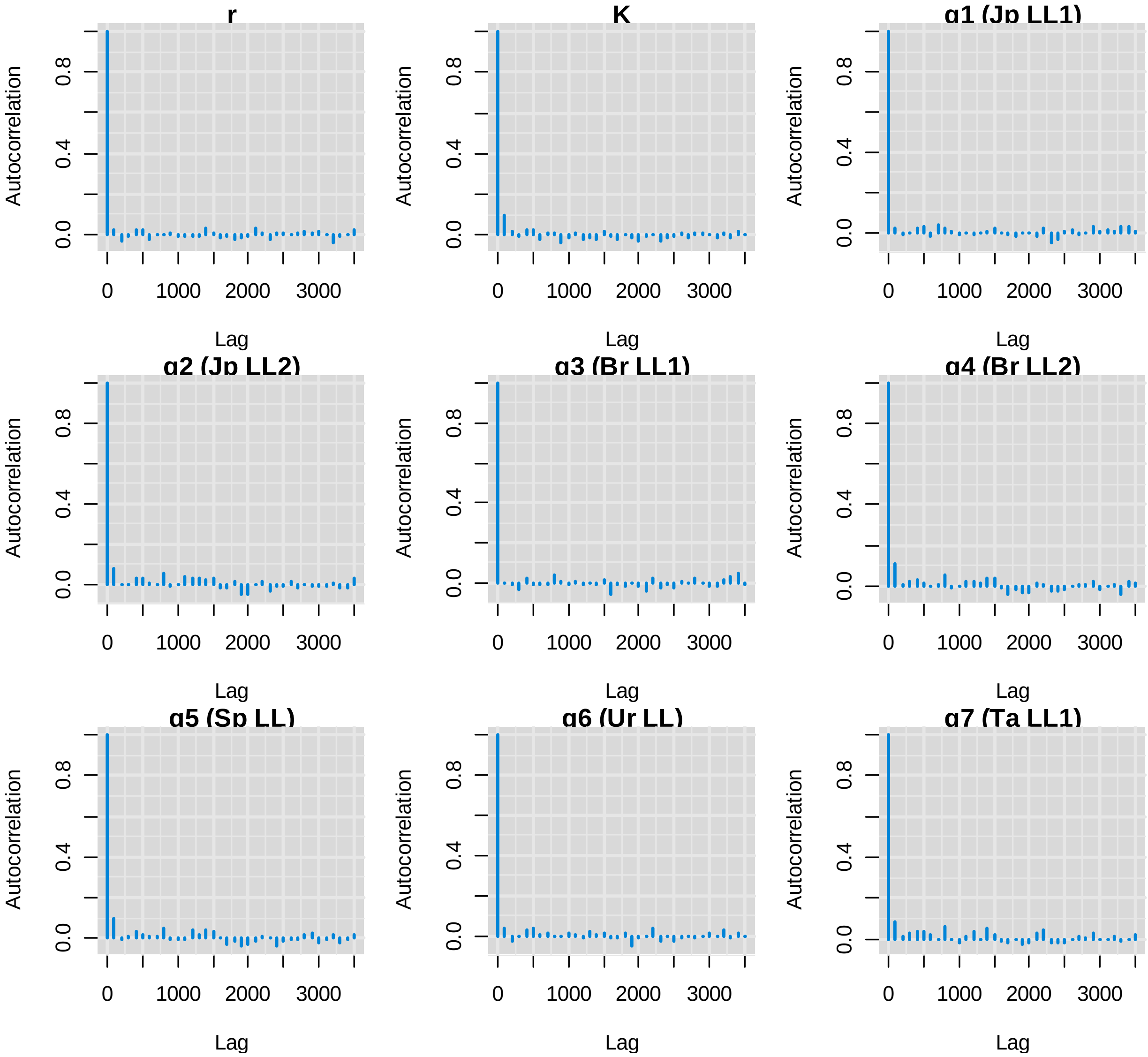


Joint-posterior plots of main model parameters for the alternative M4 for the blue shark in the South Atlantic Ocean.

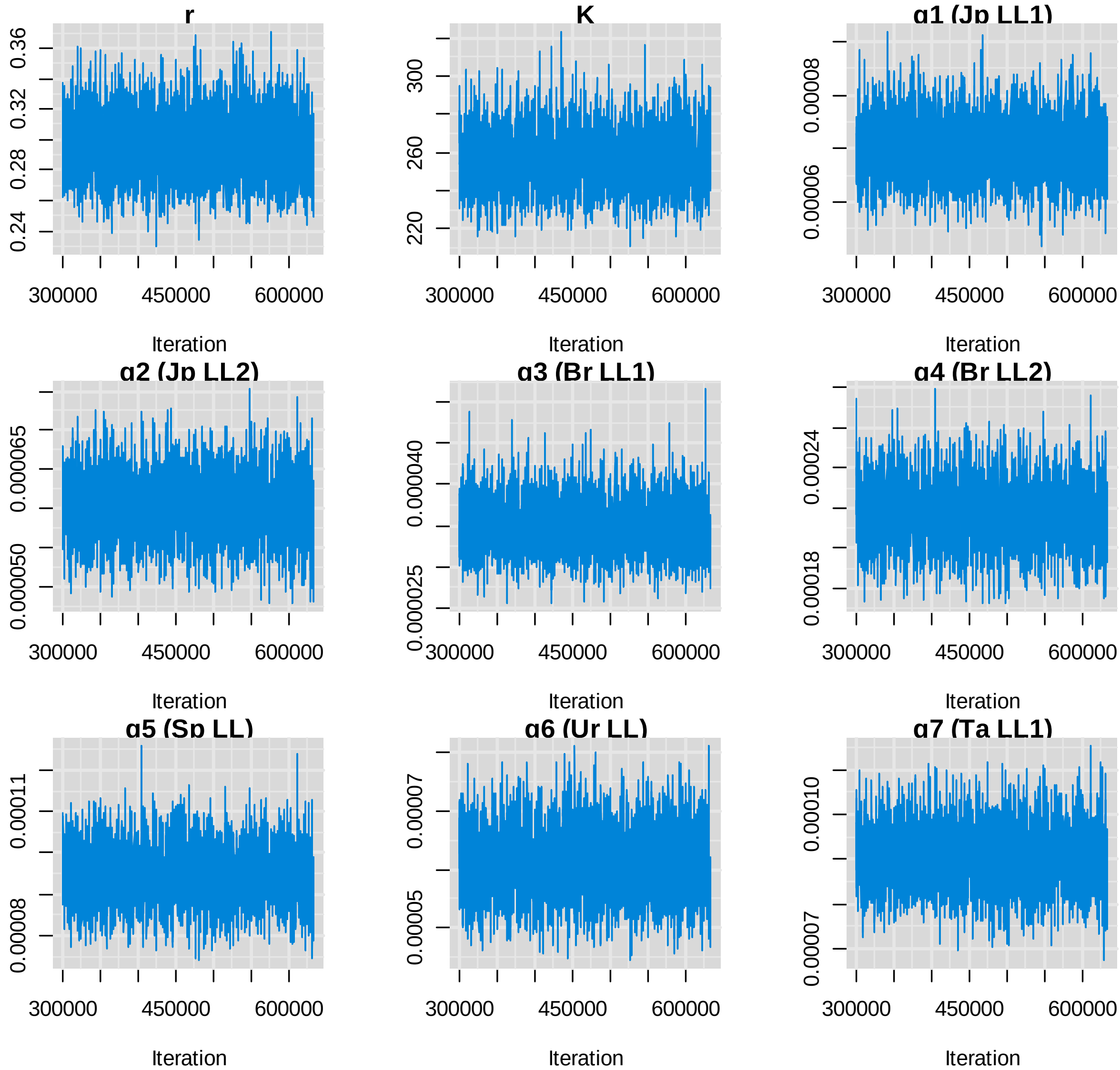
Model: M5



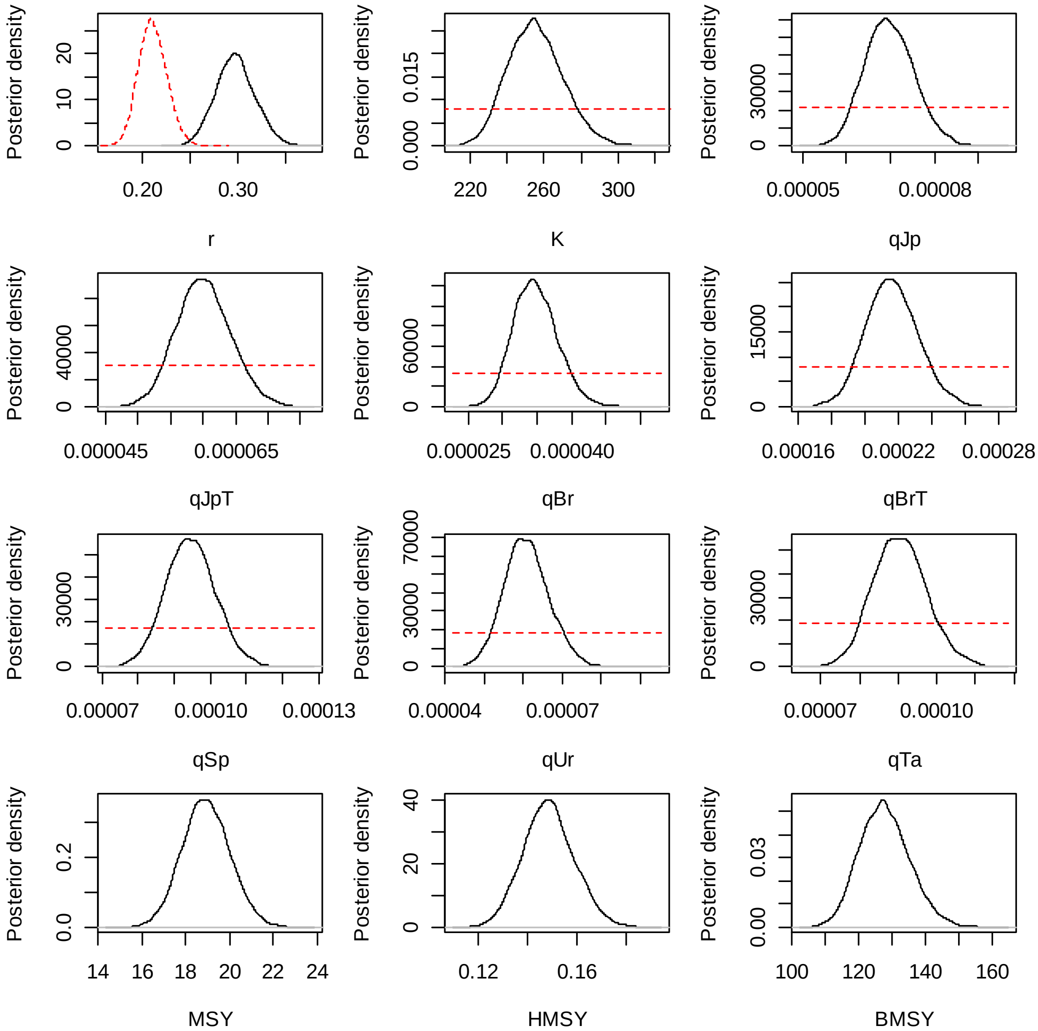
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M5. Shaded grey area indicates 95% C.I.



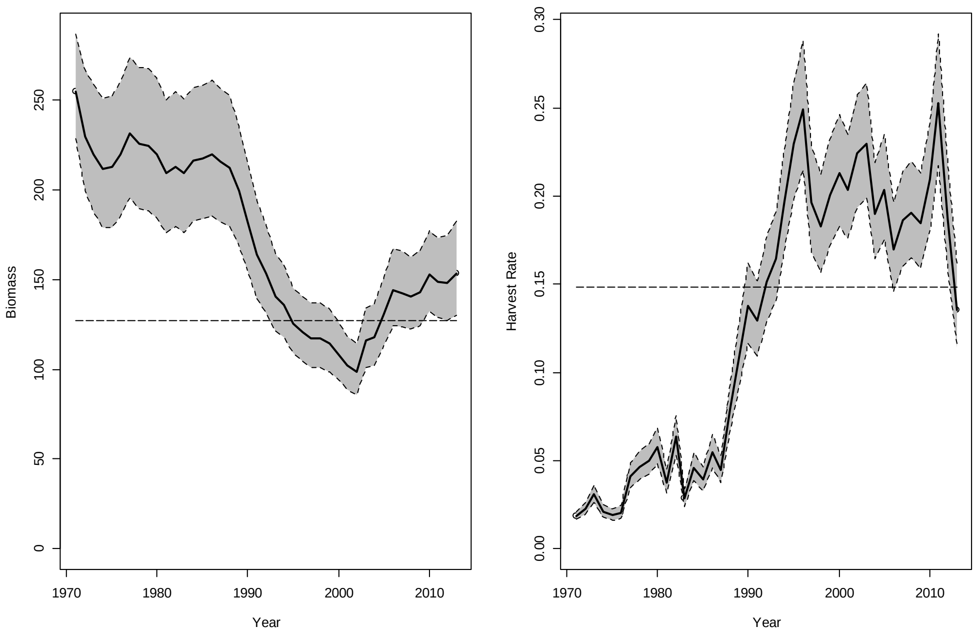
Trace plots for the main model parameter drawn from MCMC samples for M5 for the South Atlantic blue shark.



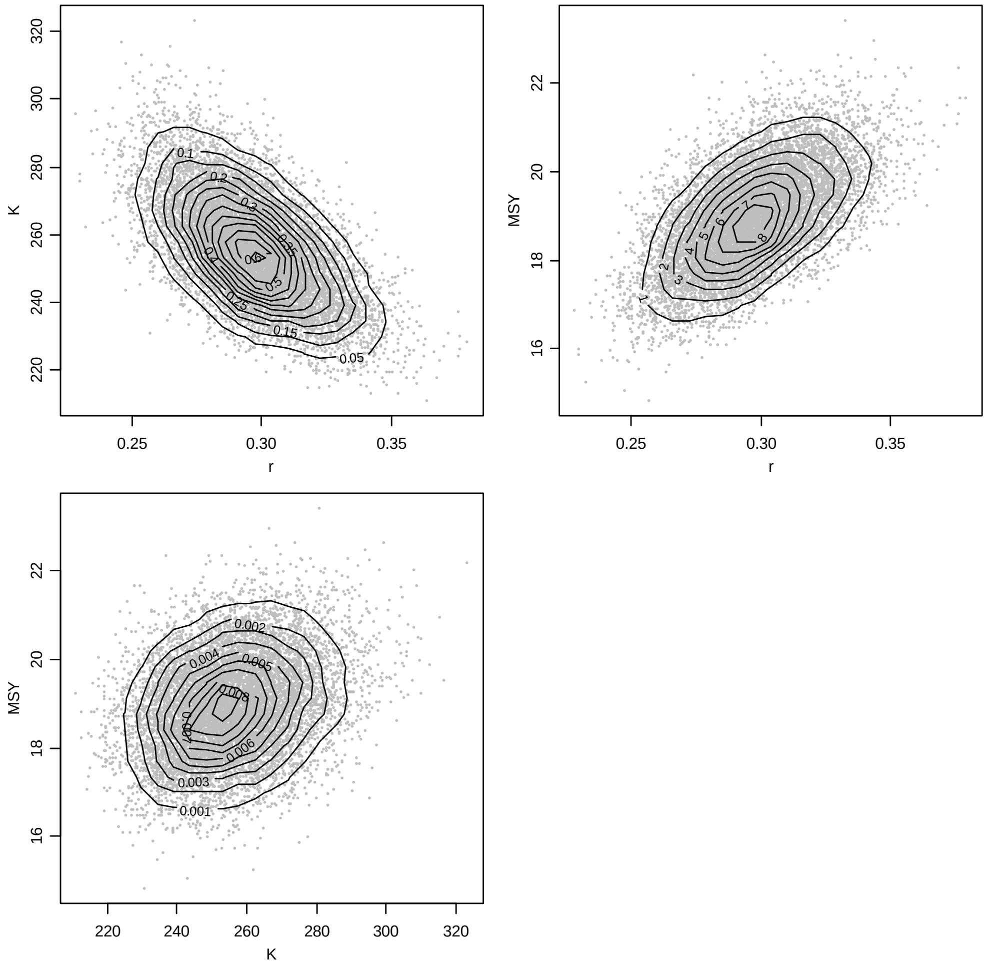
Trace plots for the main model parameter drawn from MCMC samples in M5 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M5 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

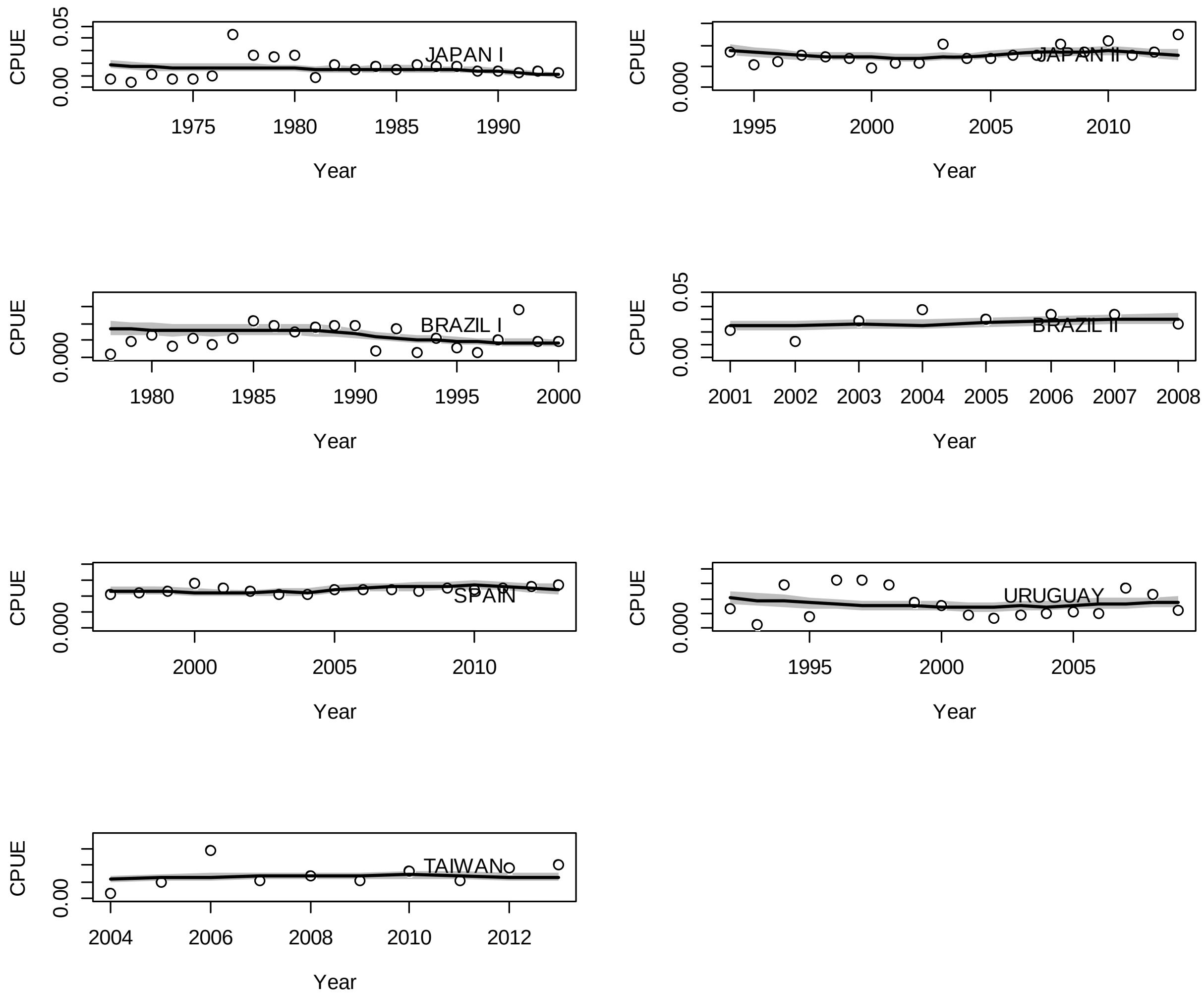


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M5 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

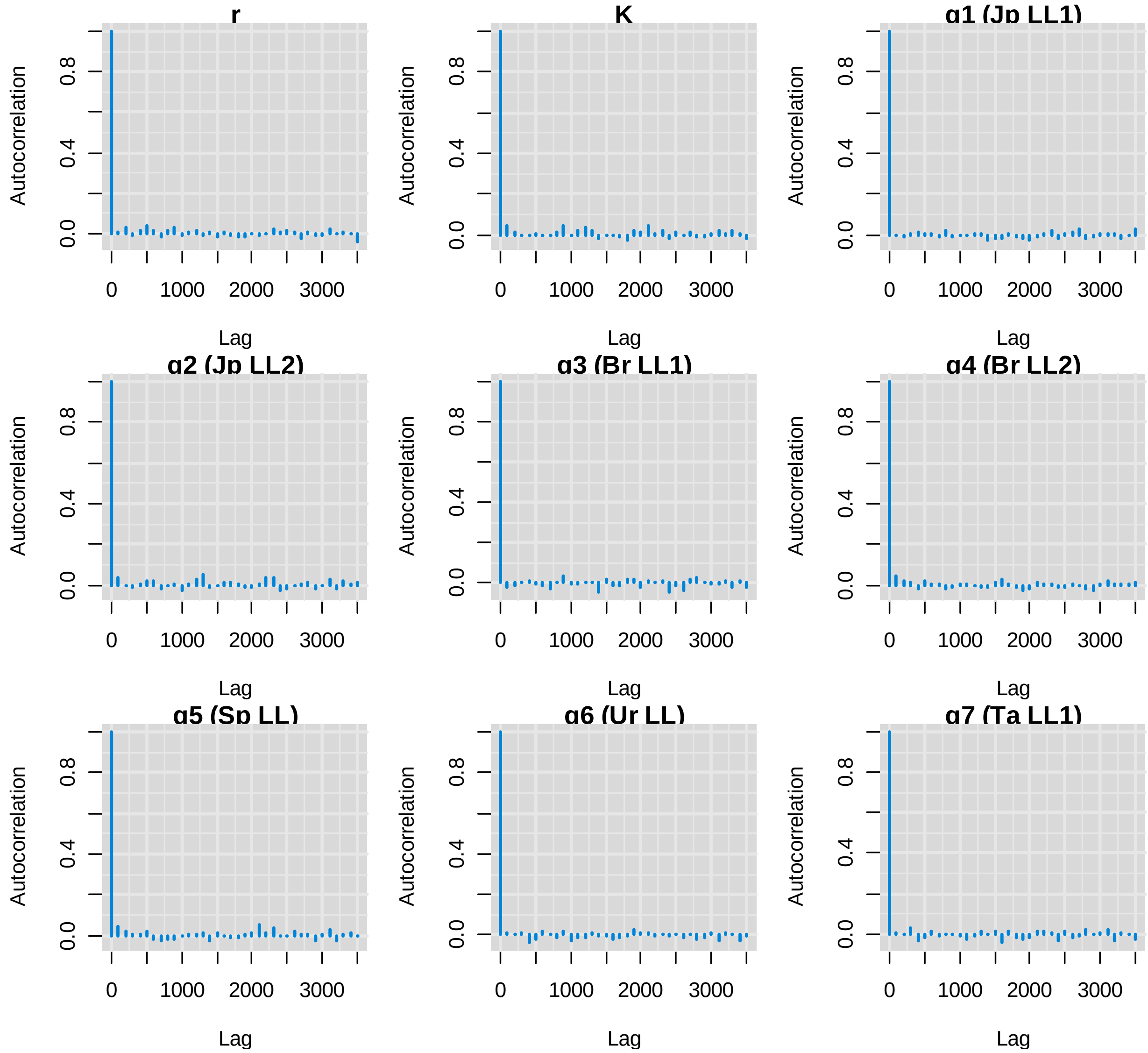


Joint-posterior plots of main model parameters for the alternative M5 for the blue shark in the South Atlantic Ocean.

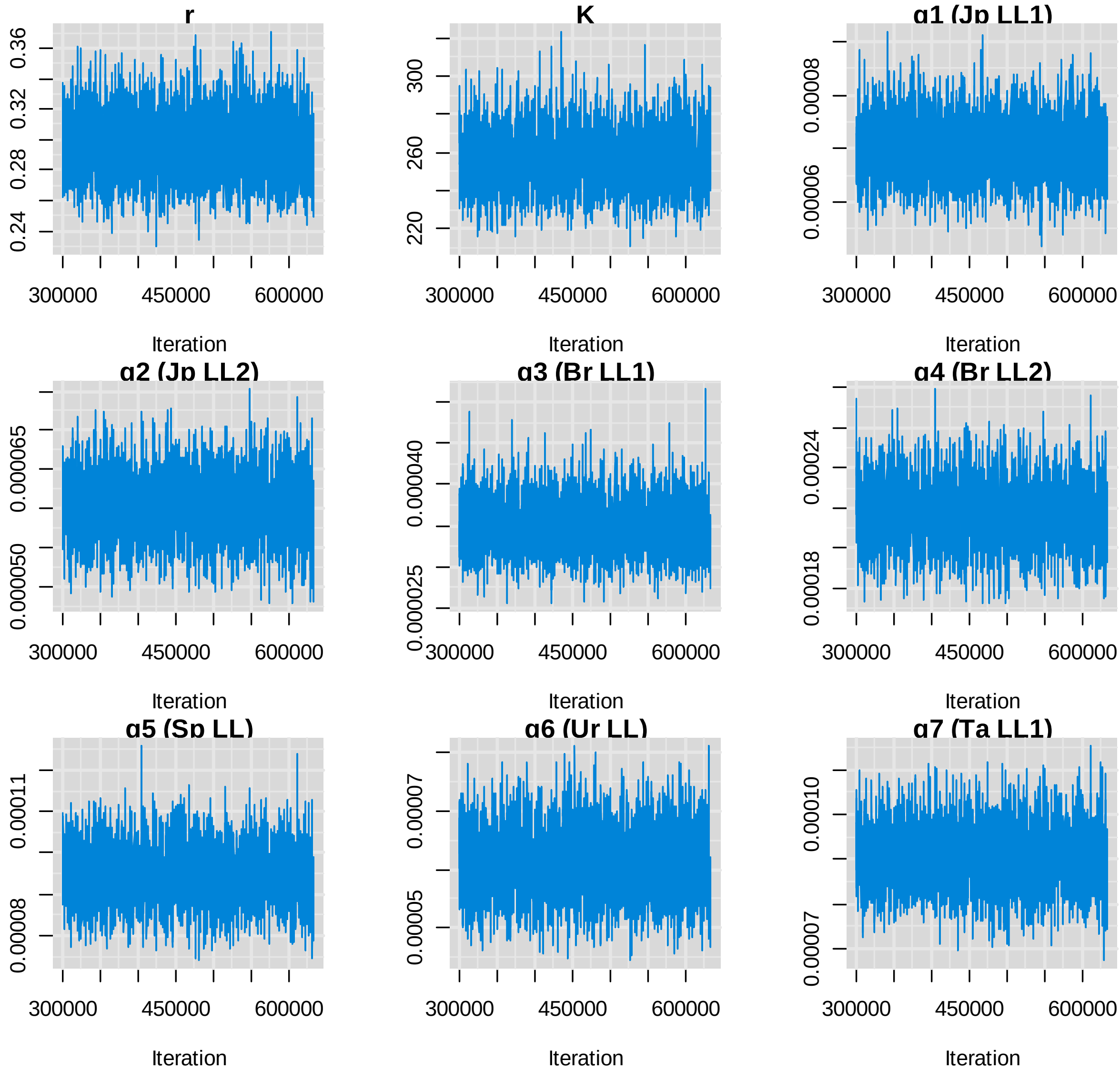
Model M6:



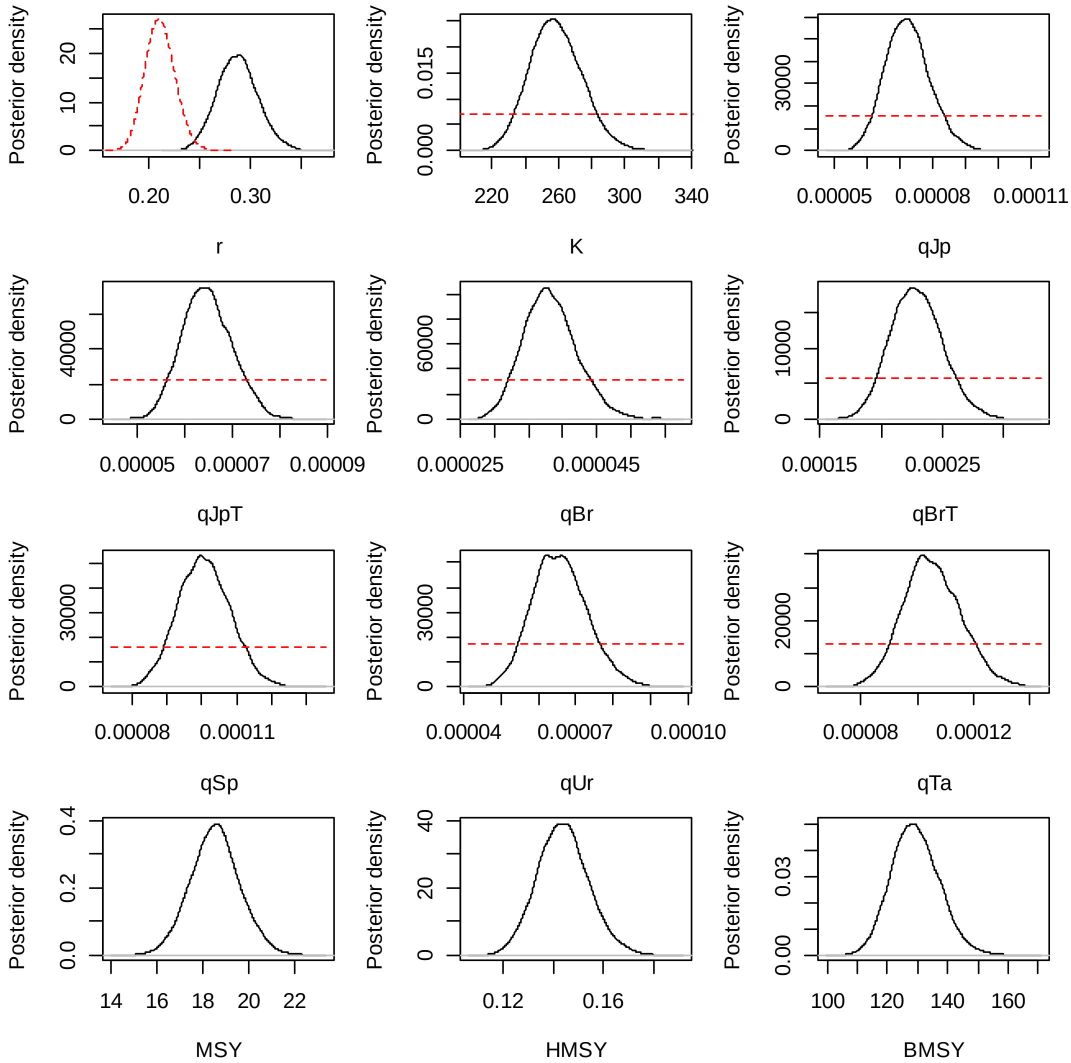
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M6. Shaded grey area indicates 95% C.I.



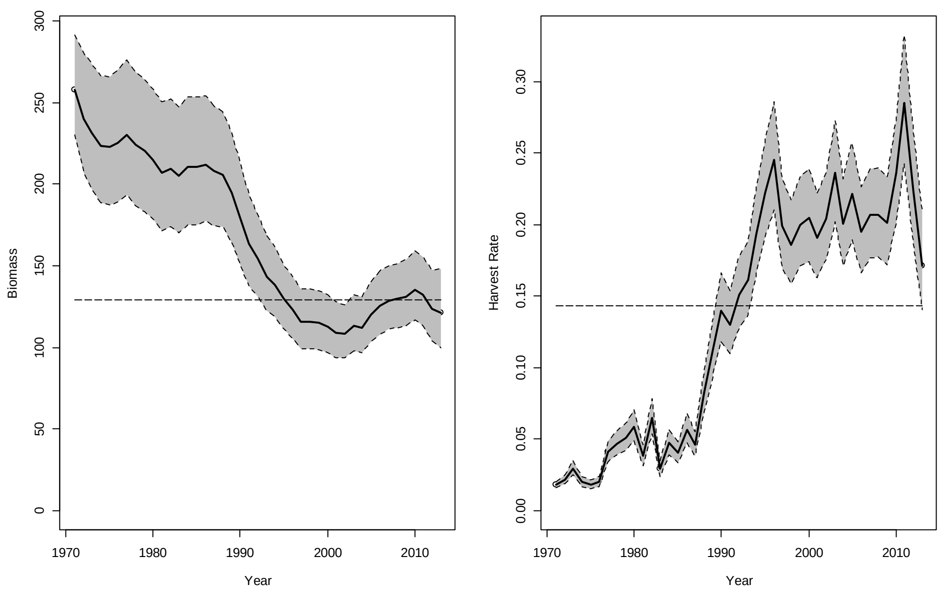
Trace plots for the main model parameter drawn from MCMC samples for M6 for the South Atlantic blue shark.



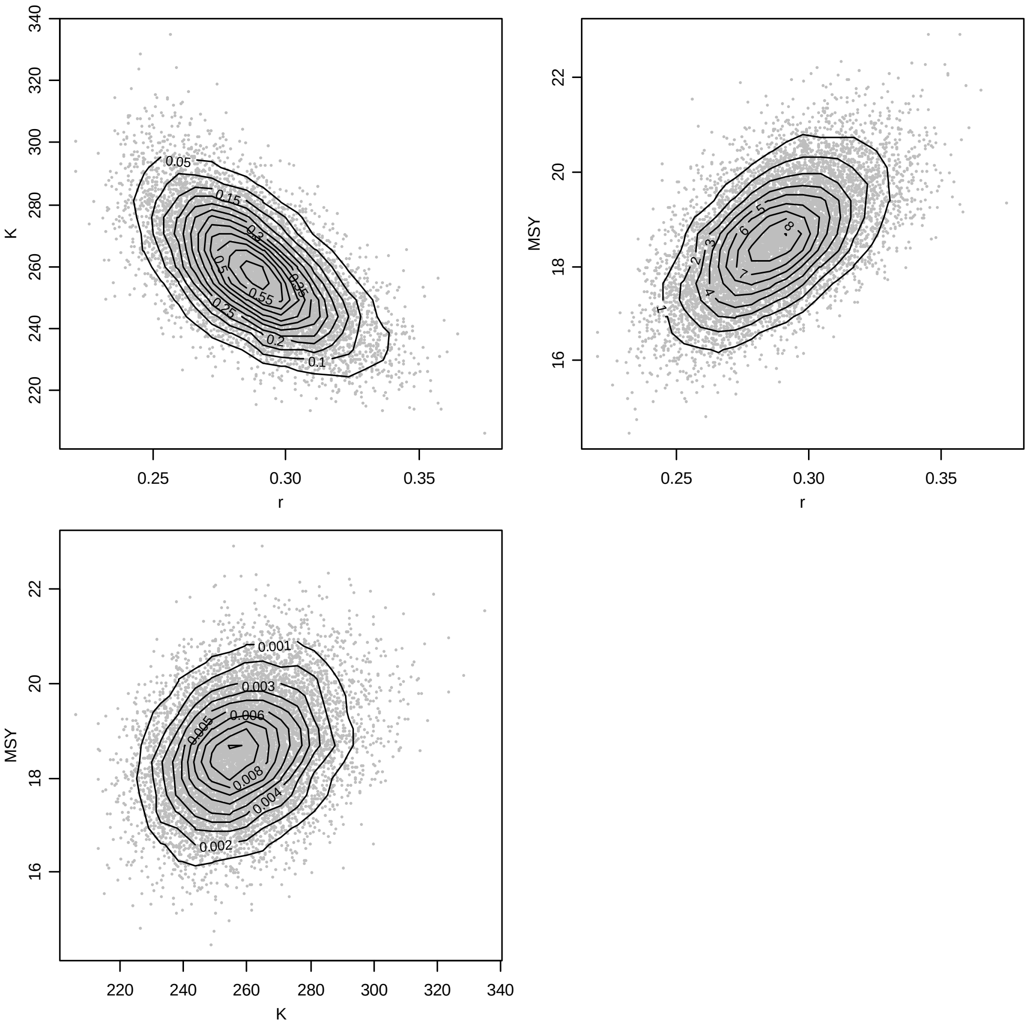
Trace plots for the main model parameter drawn from MCMC samples in M6 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M6 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

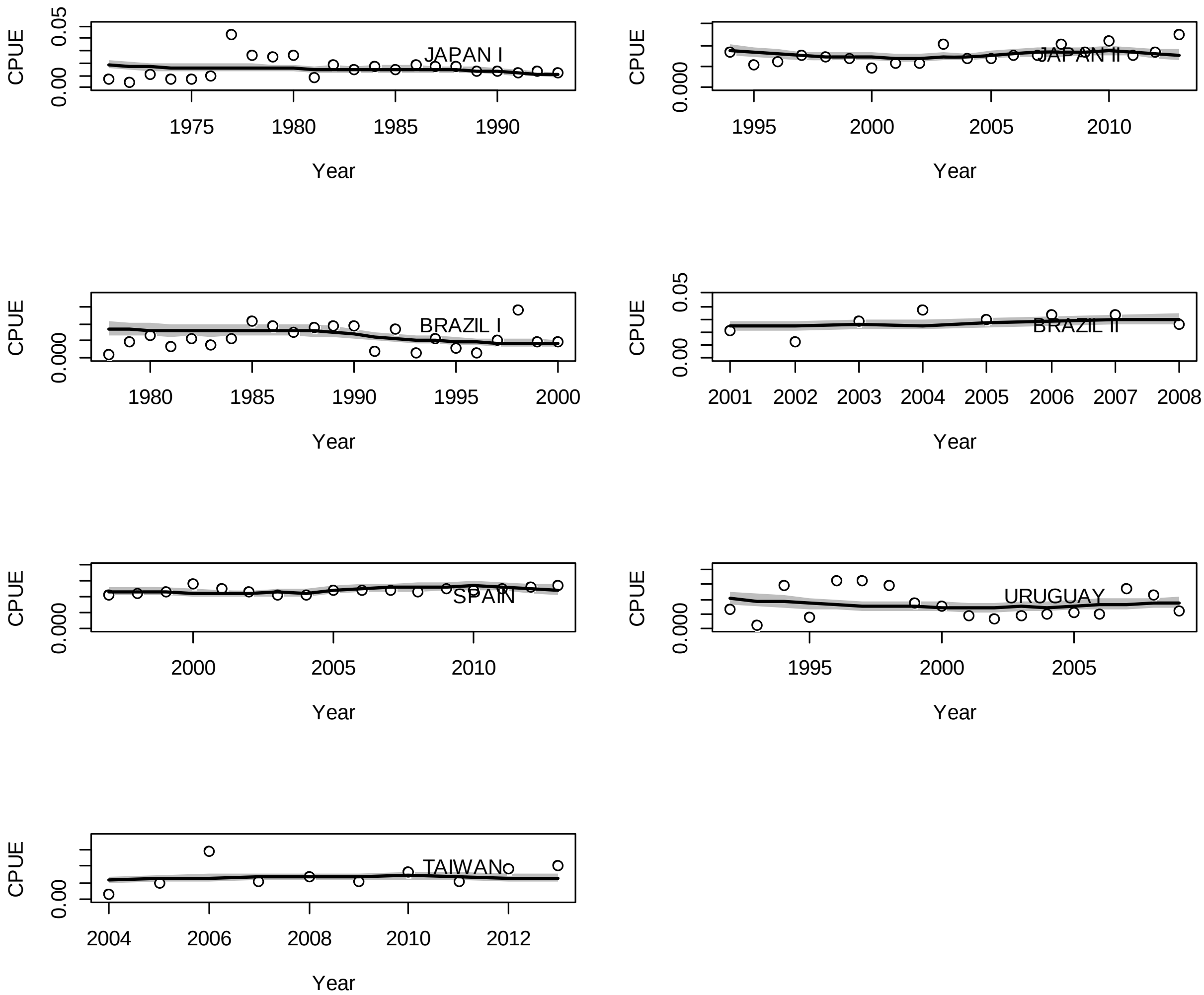


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M6 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

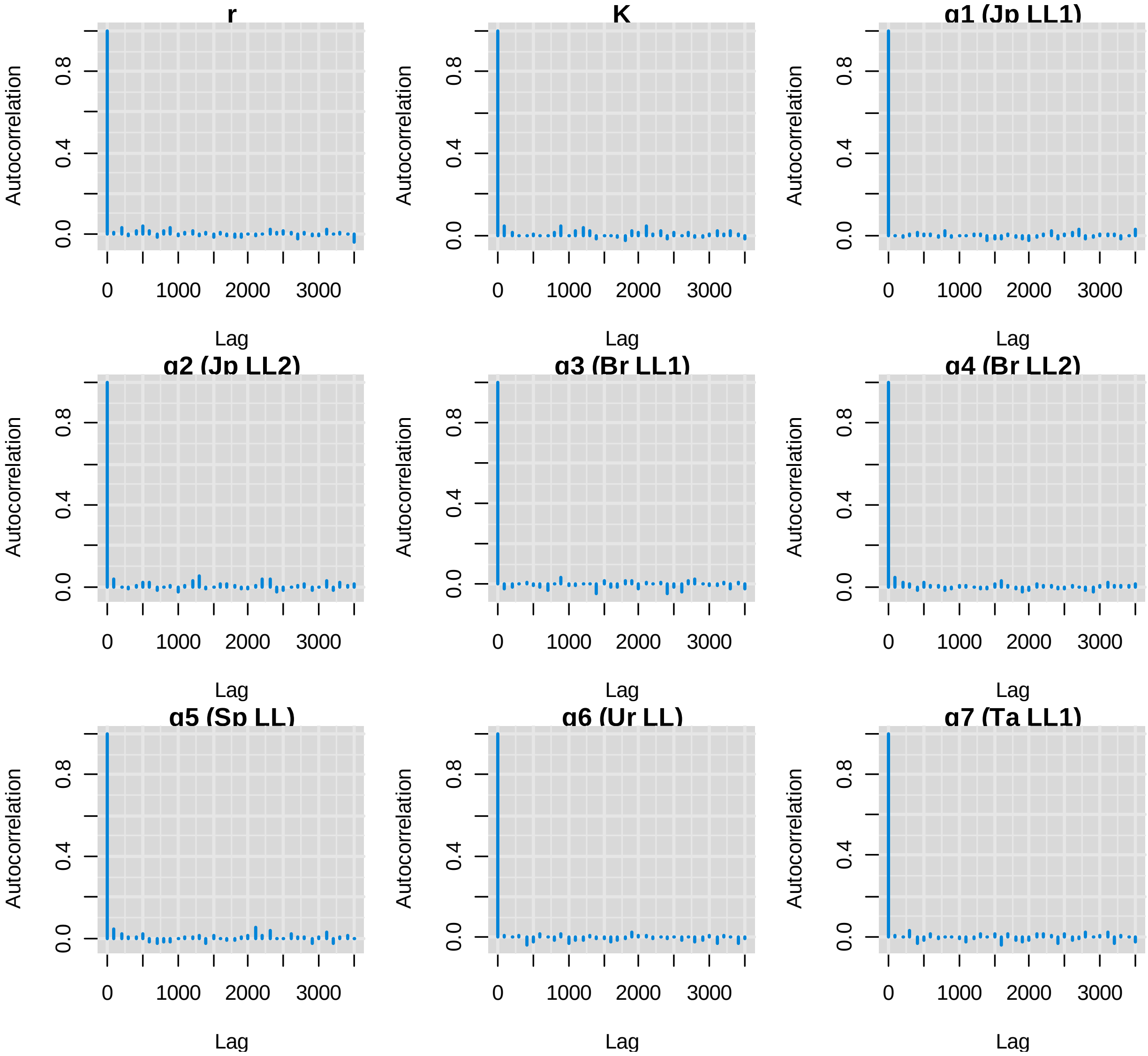


Joint-posterior plots of main model parameters for the alternative M6 for the blue shark in the South Atlantic Ocean.

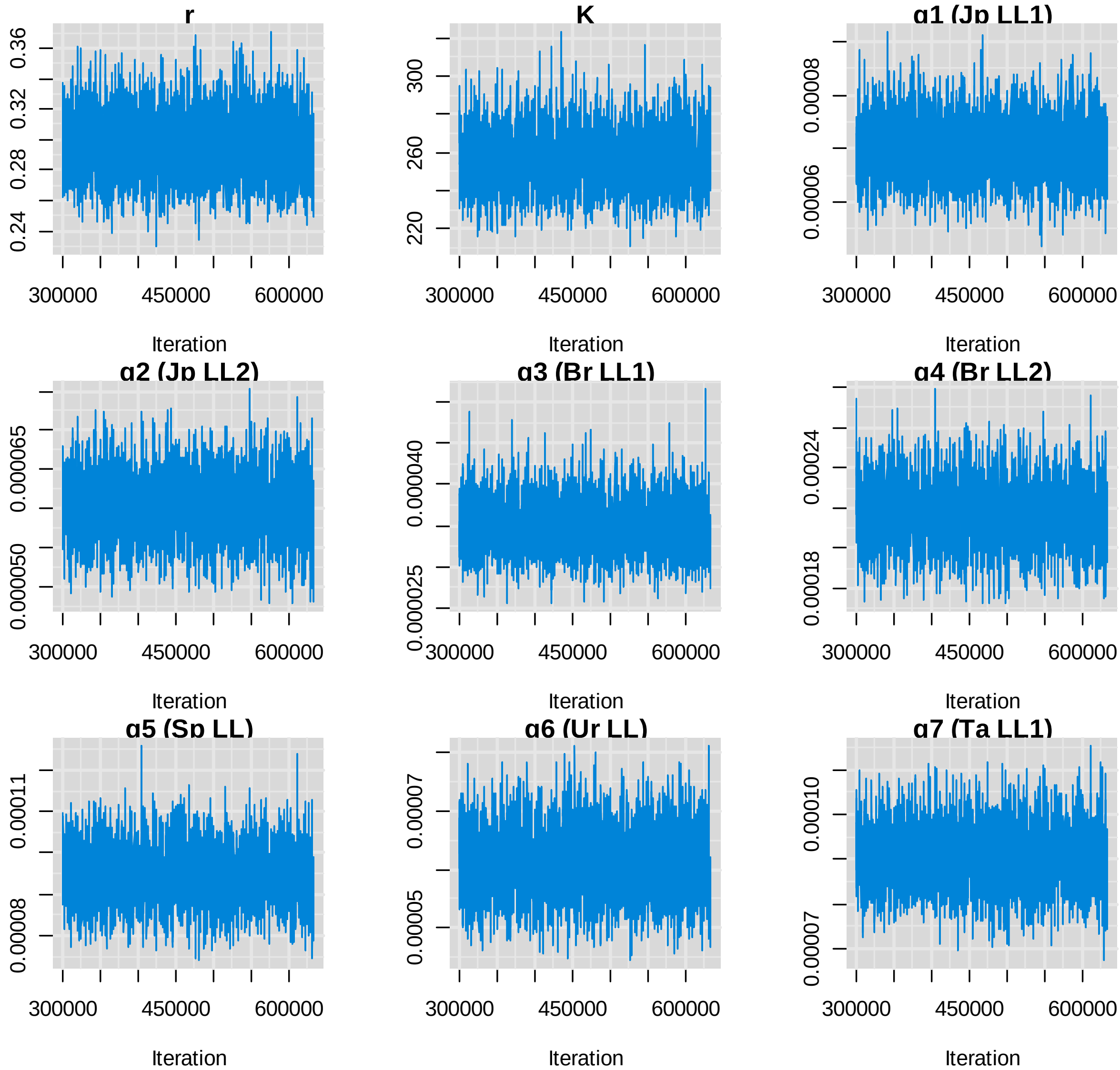
Model: M7



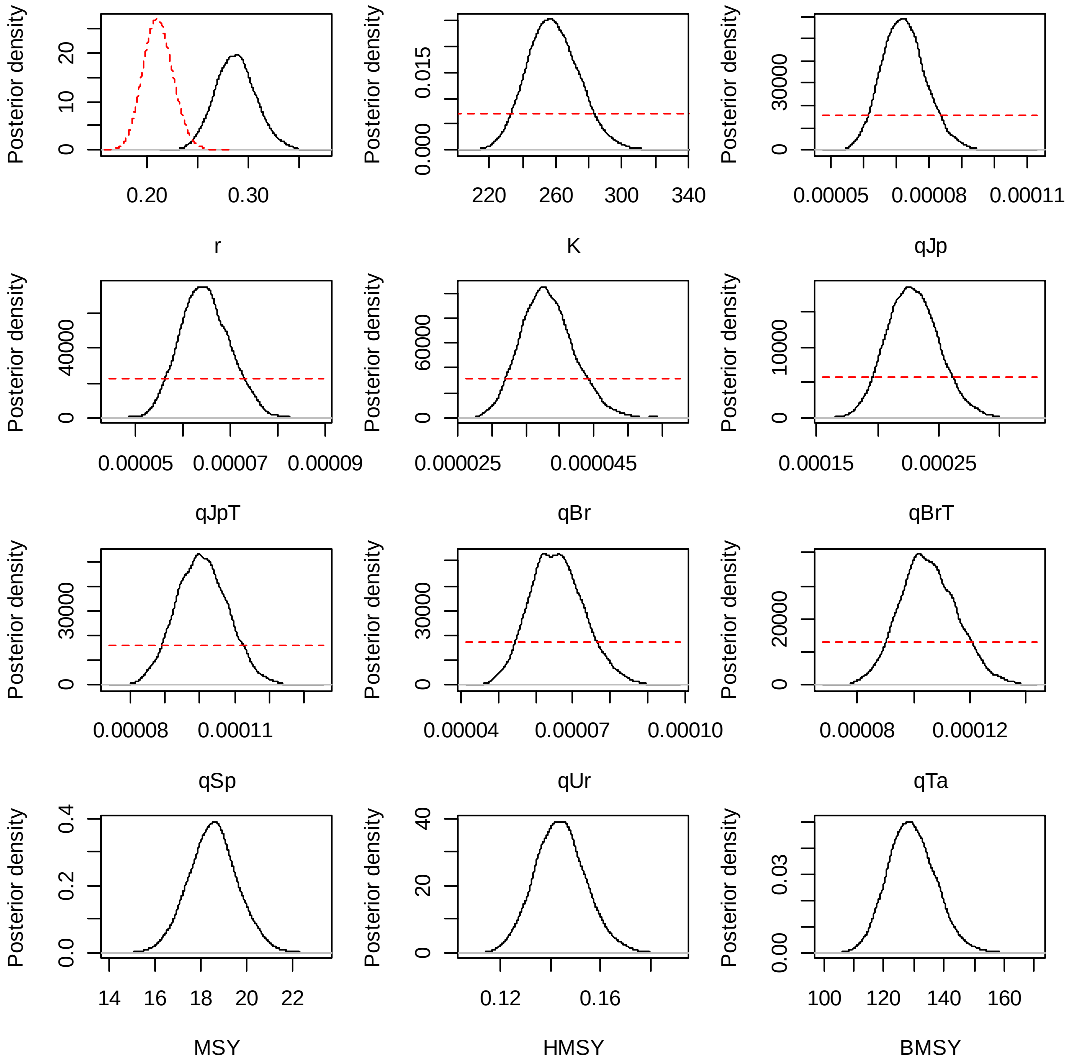
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M7. Shaded grey area indicates 95% C.I.



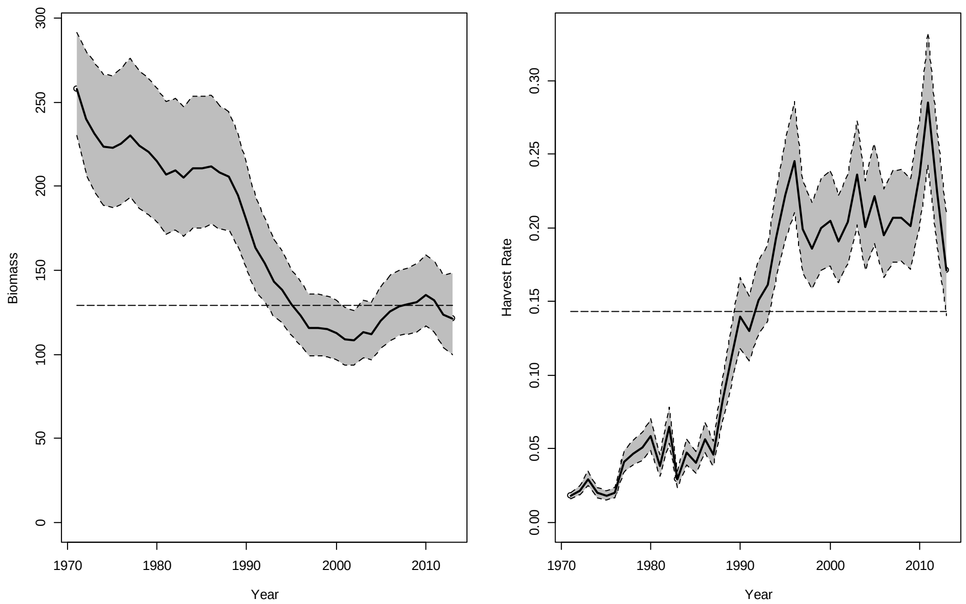
Trace plots for the main model parameter drawn from MCMC samples for M7 for the South Atlantic blue shark.



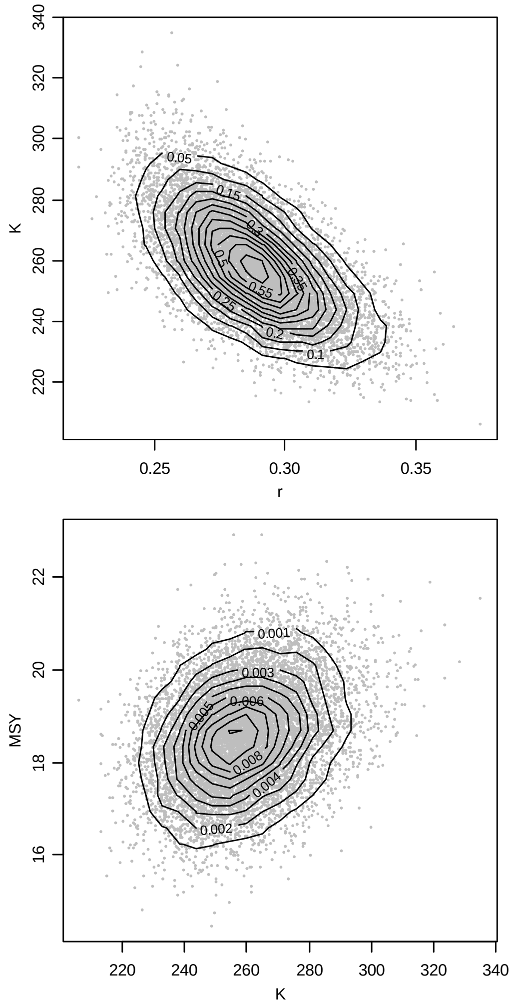
Trace plots for the main model parameter drawn from MCMC samples in M7 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M7 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

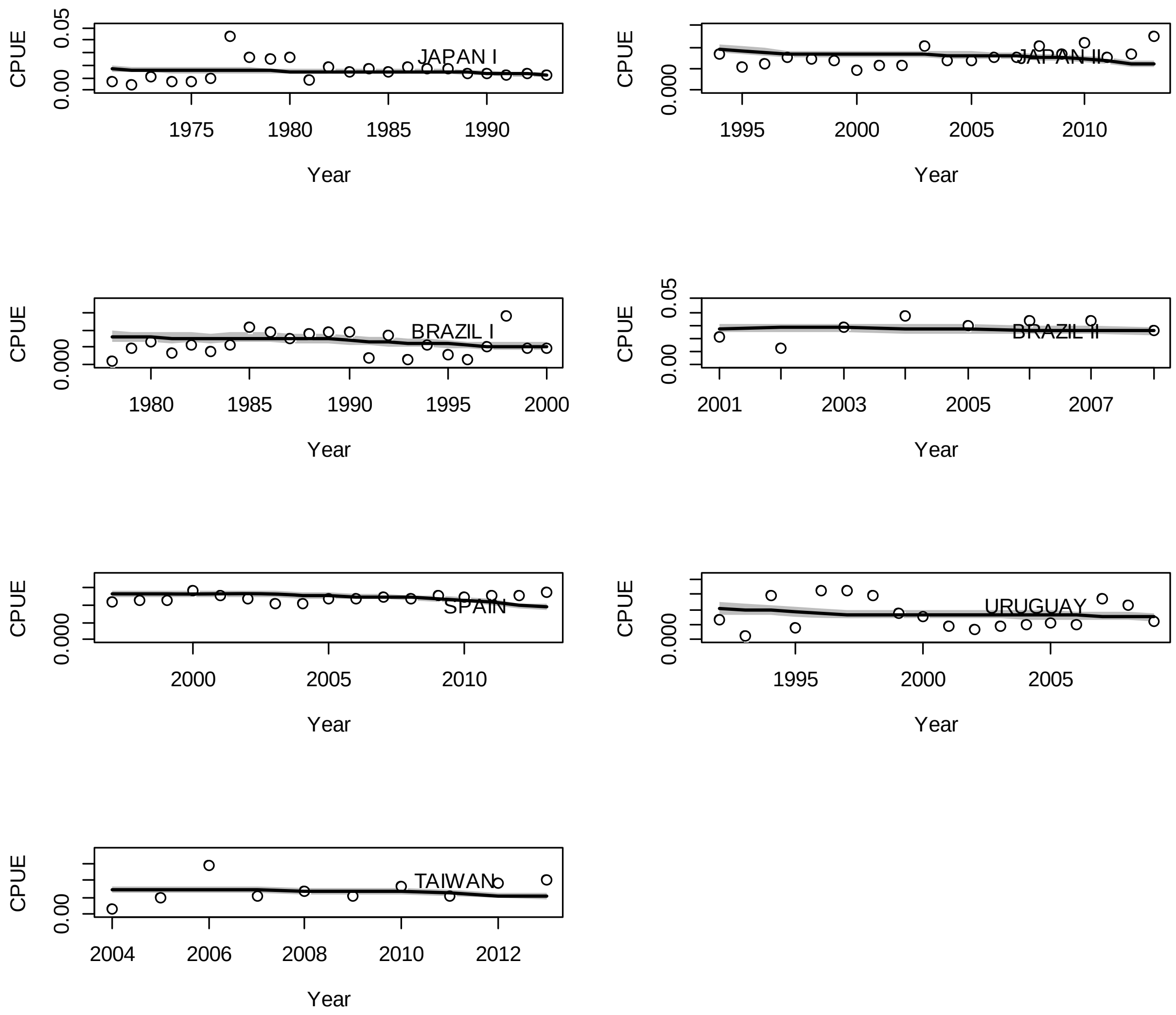


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M7 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

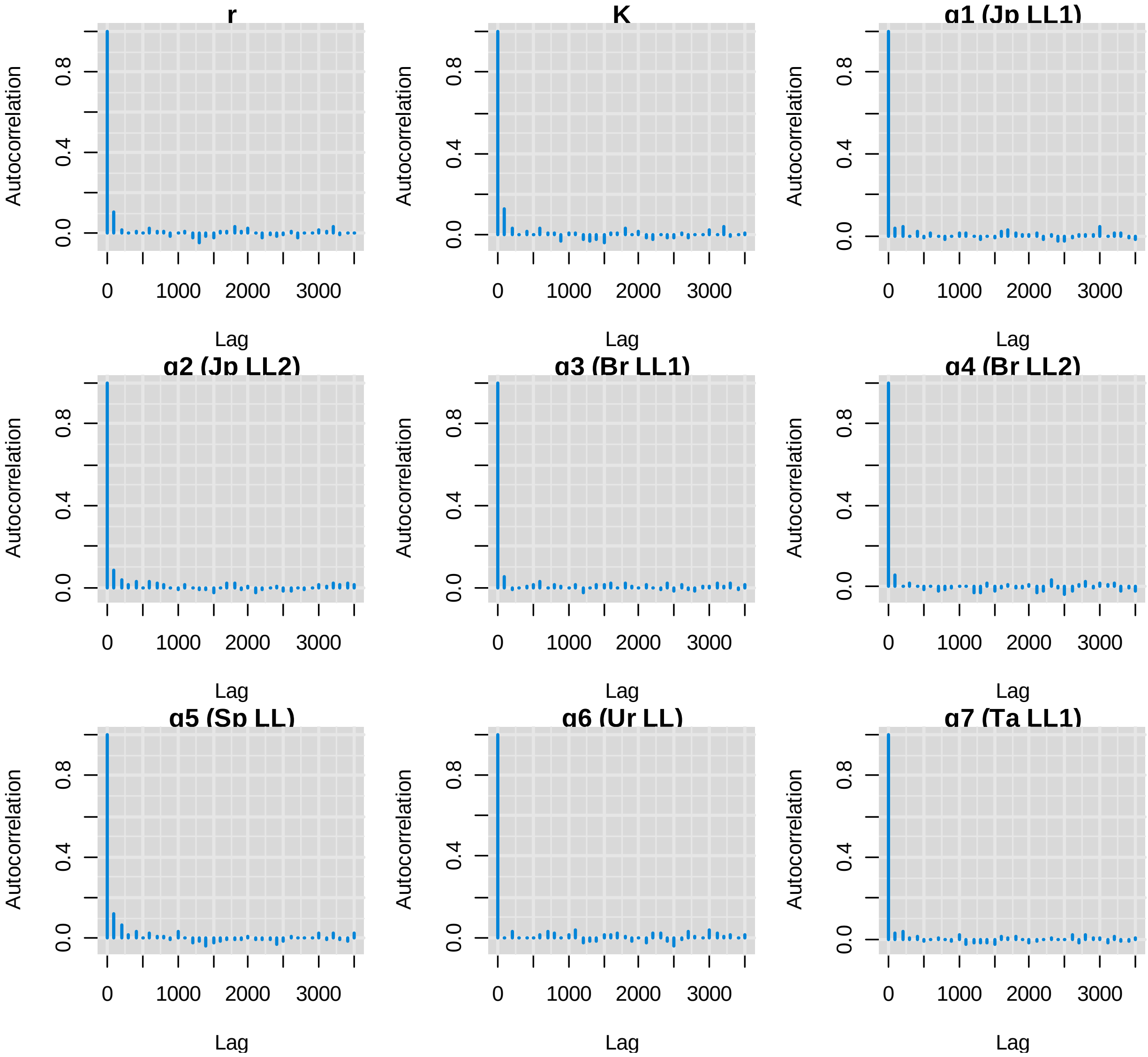


Joint-posterior plots of main model parameters for the alternative M7 for the blue shark in the South Atlantic Ocean.

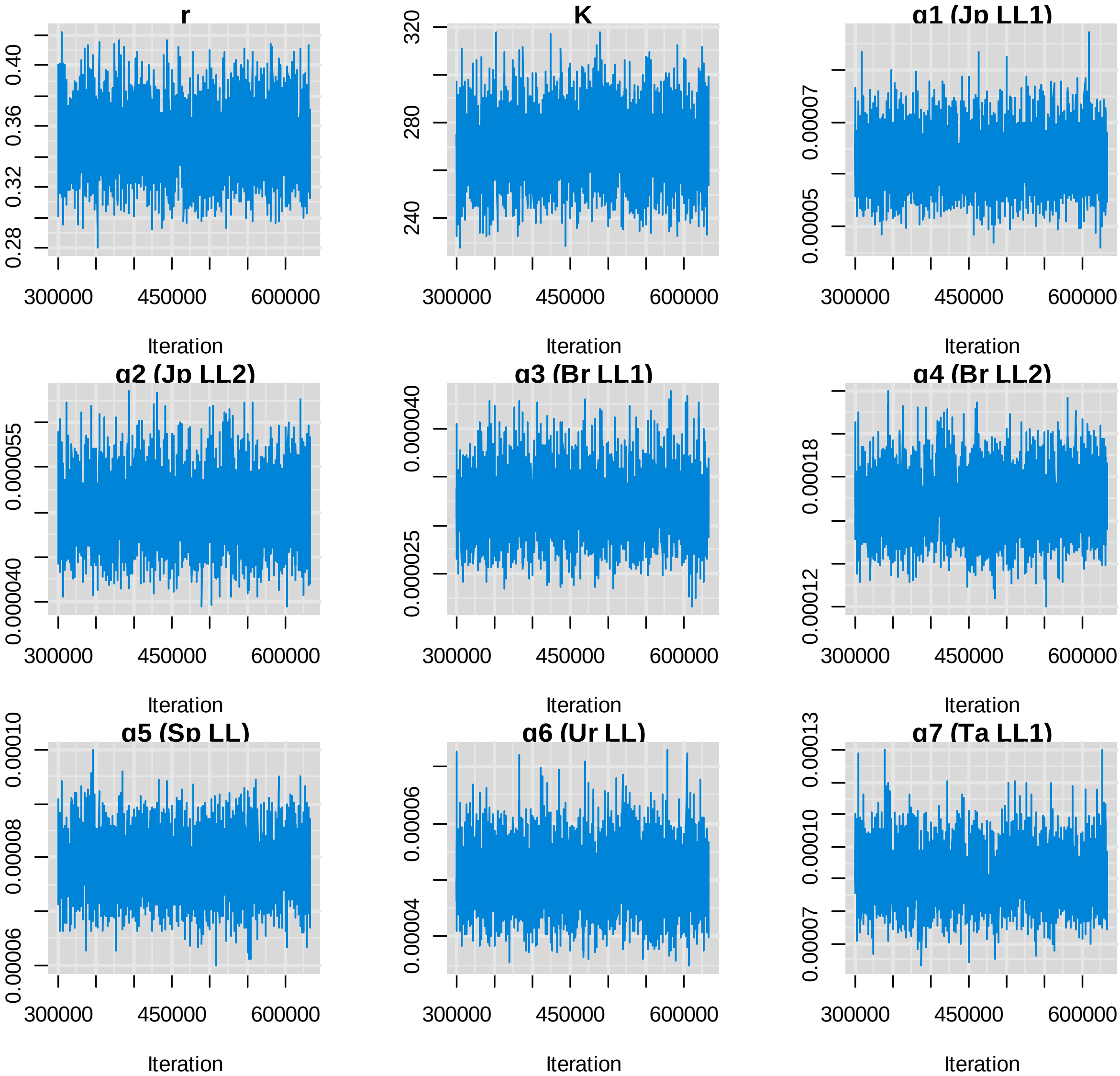
Model: M8



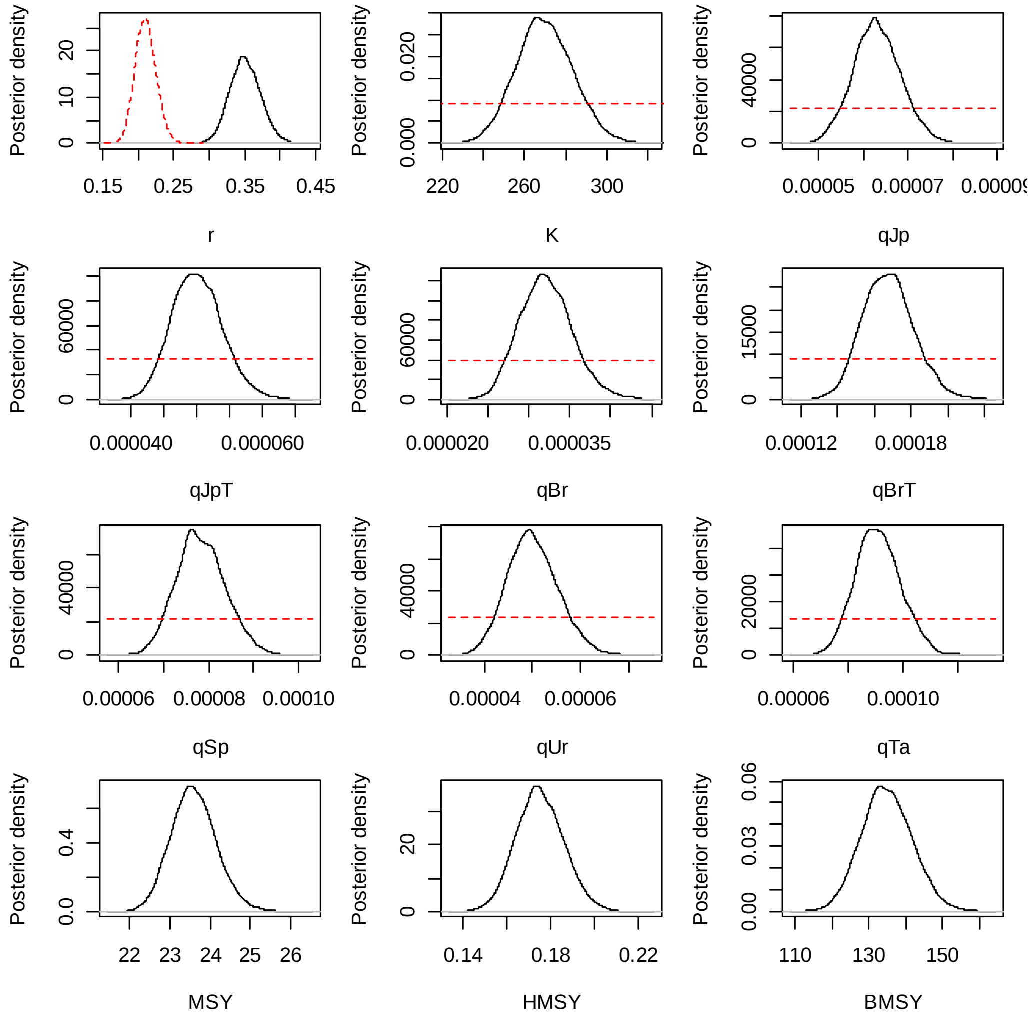
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M8. Shaded grey area indicates 95% C.I.



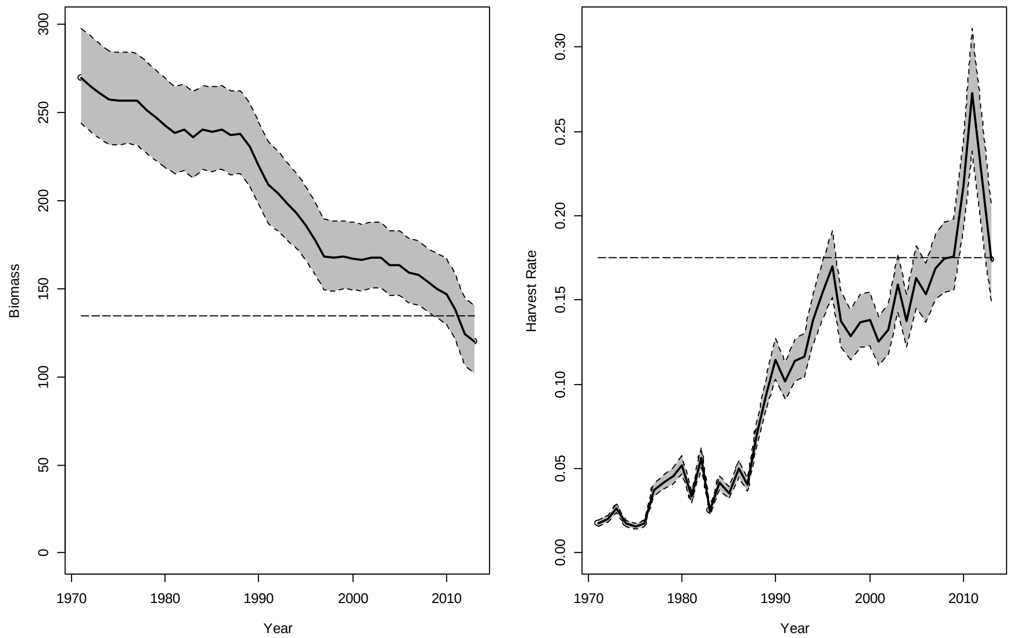
Trace plots for the main model parameter drawn from MCMC samples for M8 for the South Atlantic blue shark.



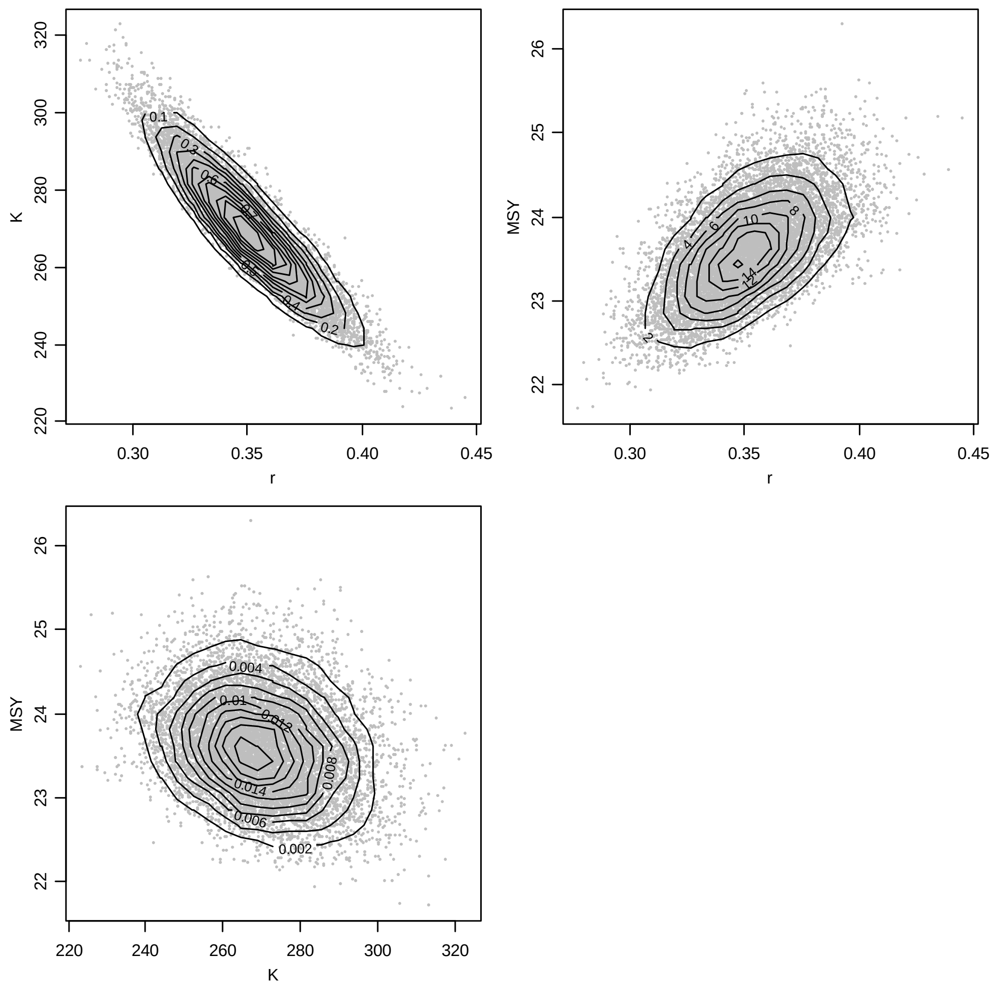
Trace plots for the main model parameter drawn from MCMC samples in M8 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M8 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

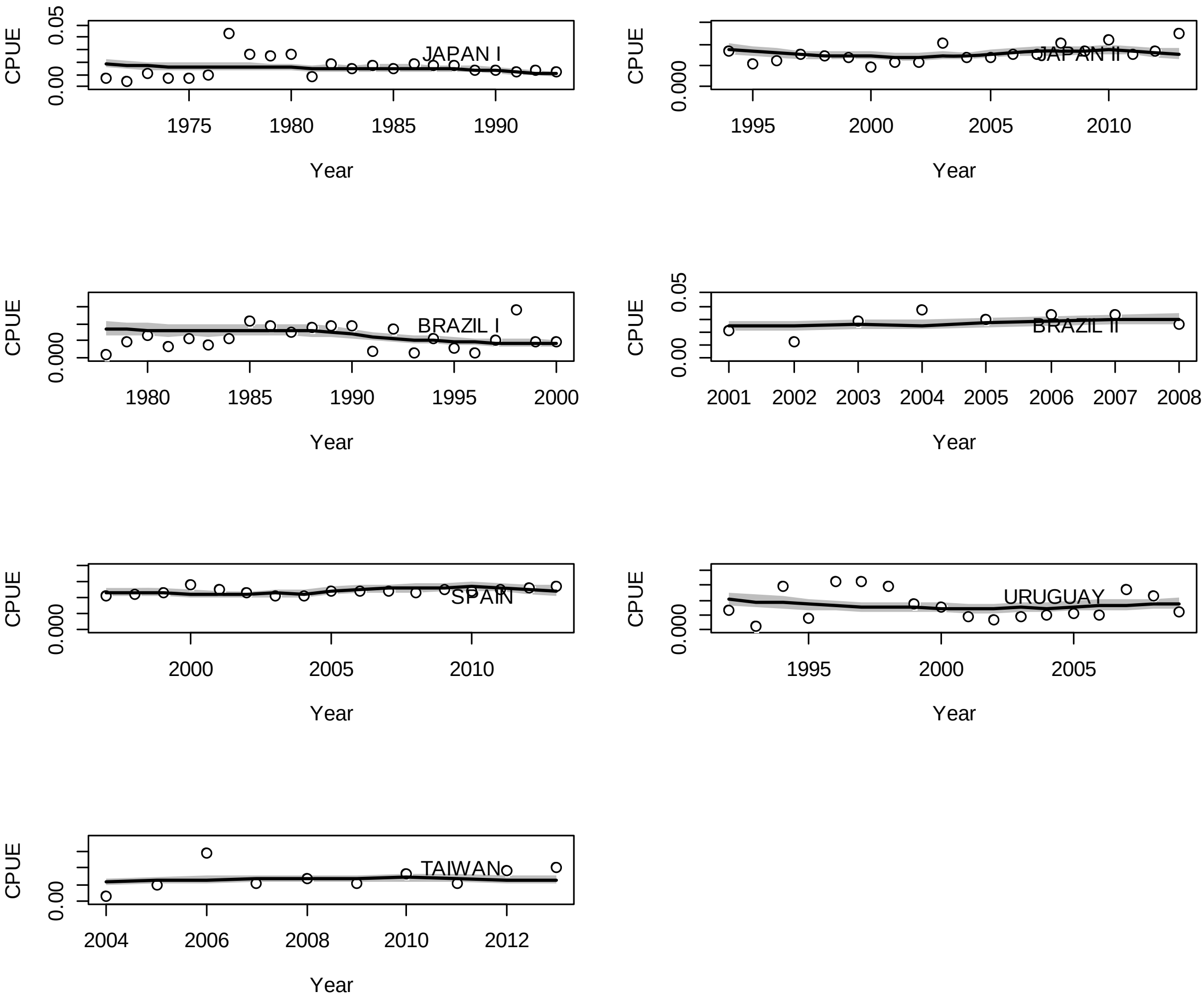


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M8 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

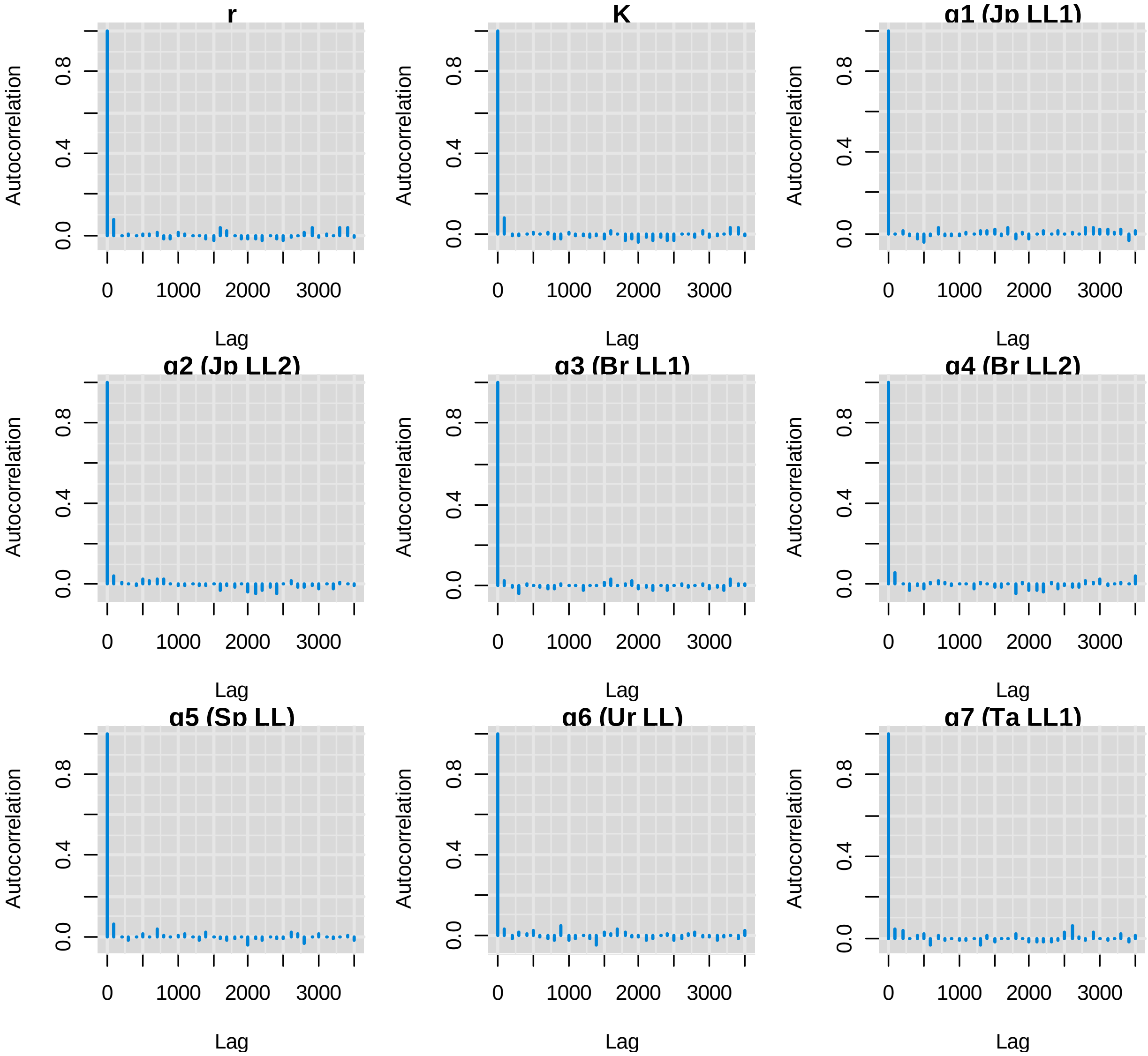


Joint-posterior plots of main model parameters for the alternative M8 for the blue shark in the South Atlantic Ocean.

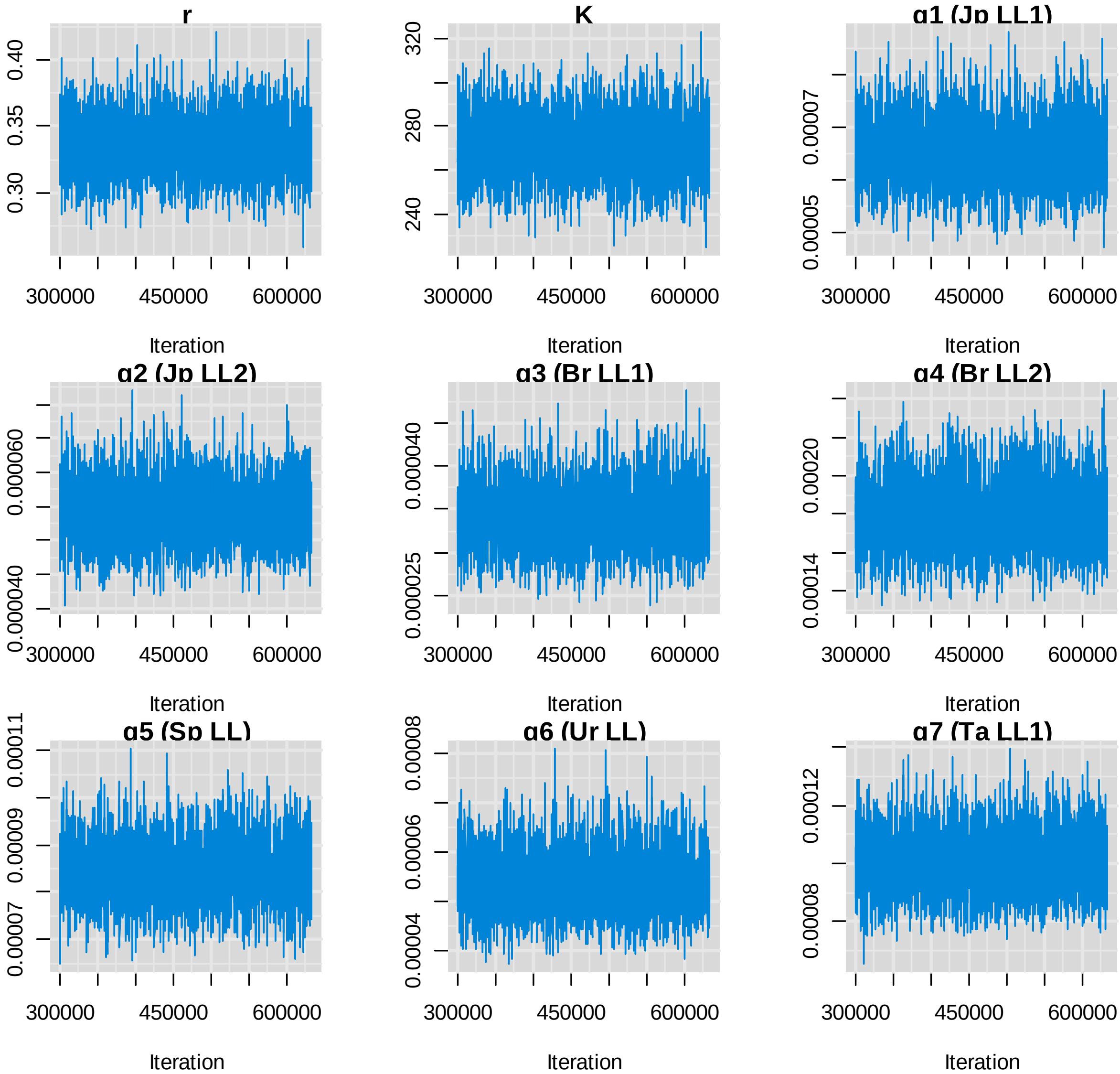
Model: M9



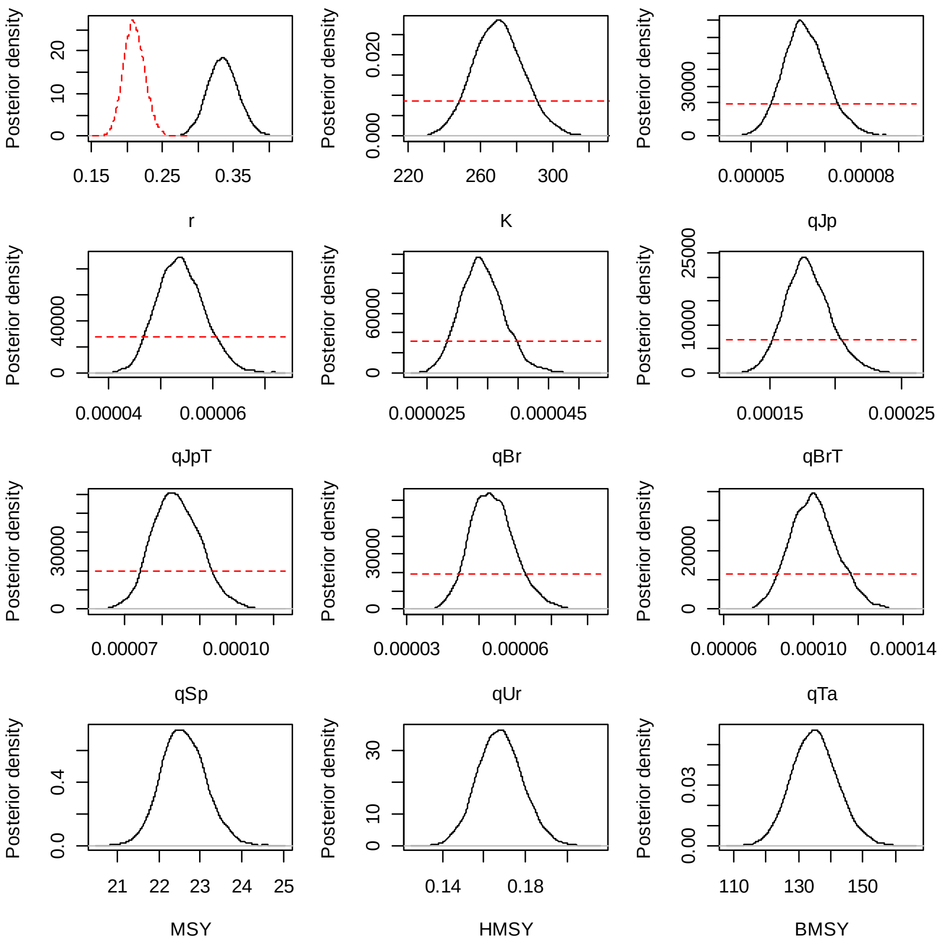
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M9. Shaded grey area indicates 95% C.I.



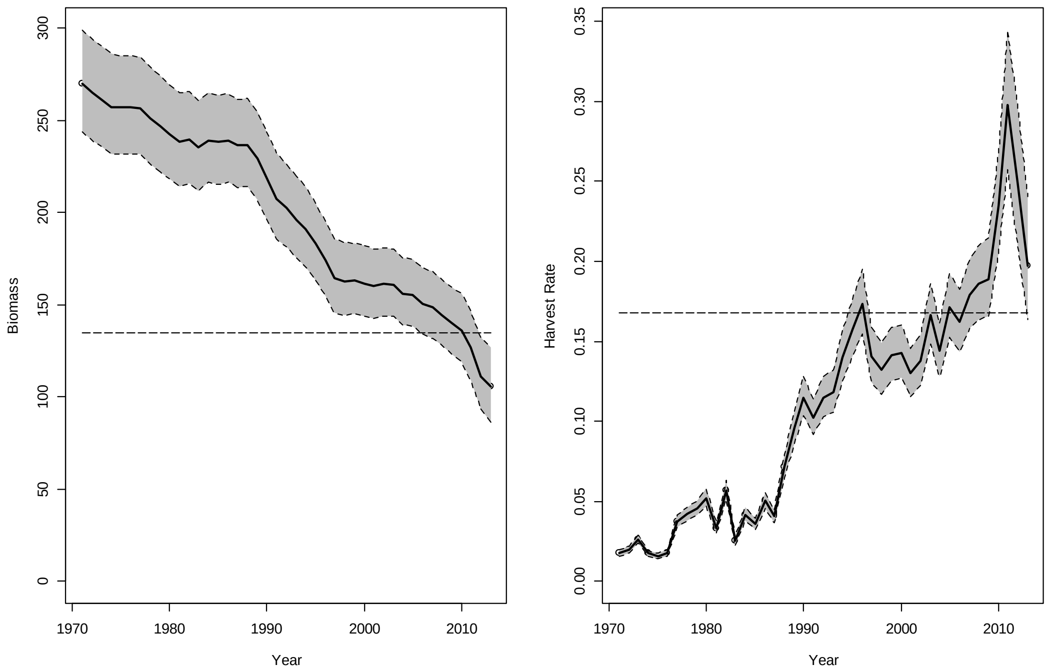
Trace plots for the main model parameter drawn from MCMC samples for M9 for the South Atlantic blue shark.



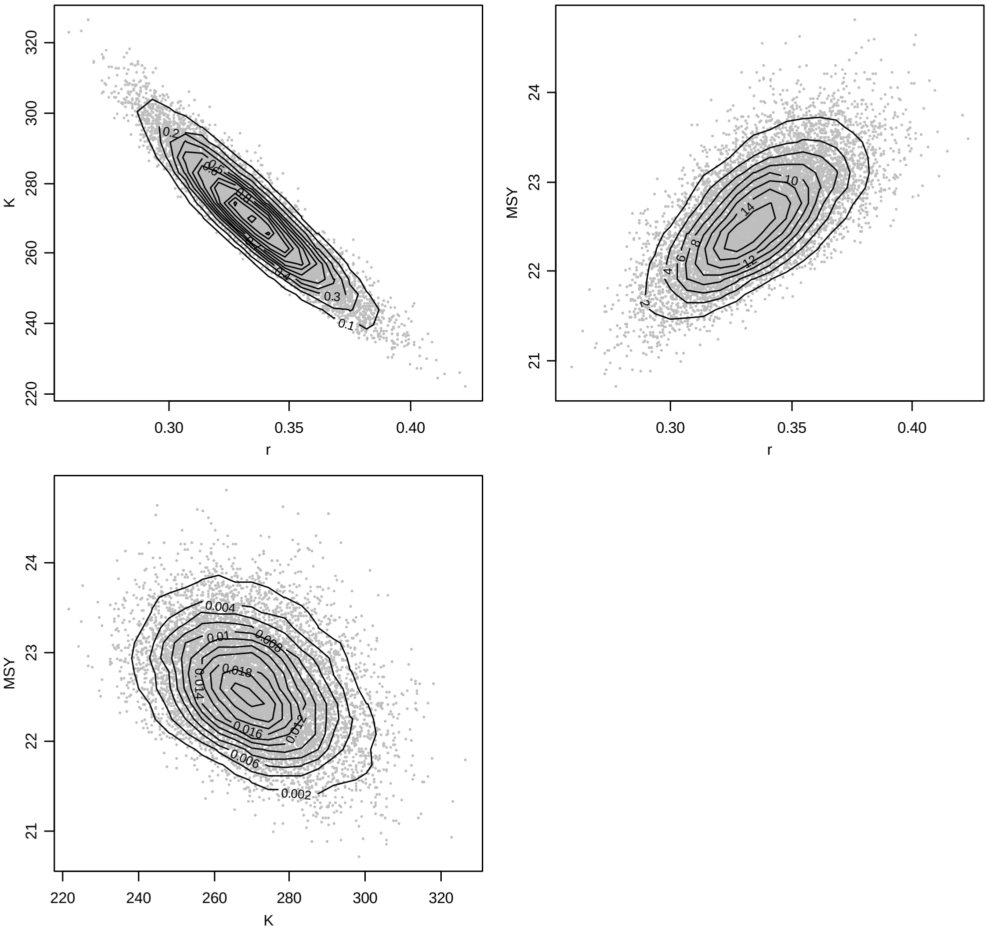
Trace plots for the main model parameter drawn from MCMC samples in M9 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M9 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

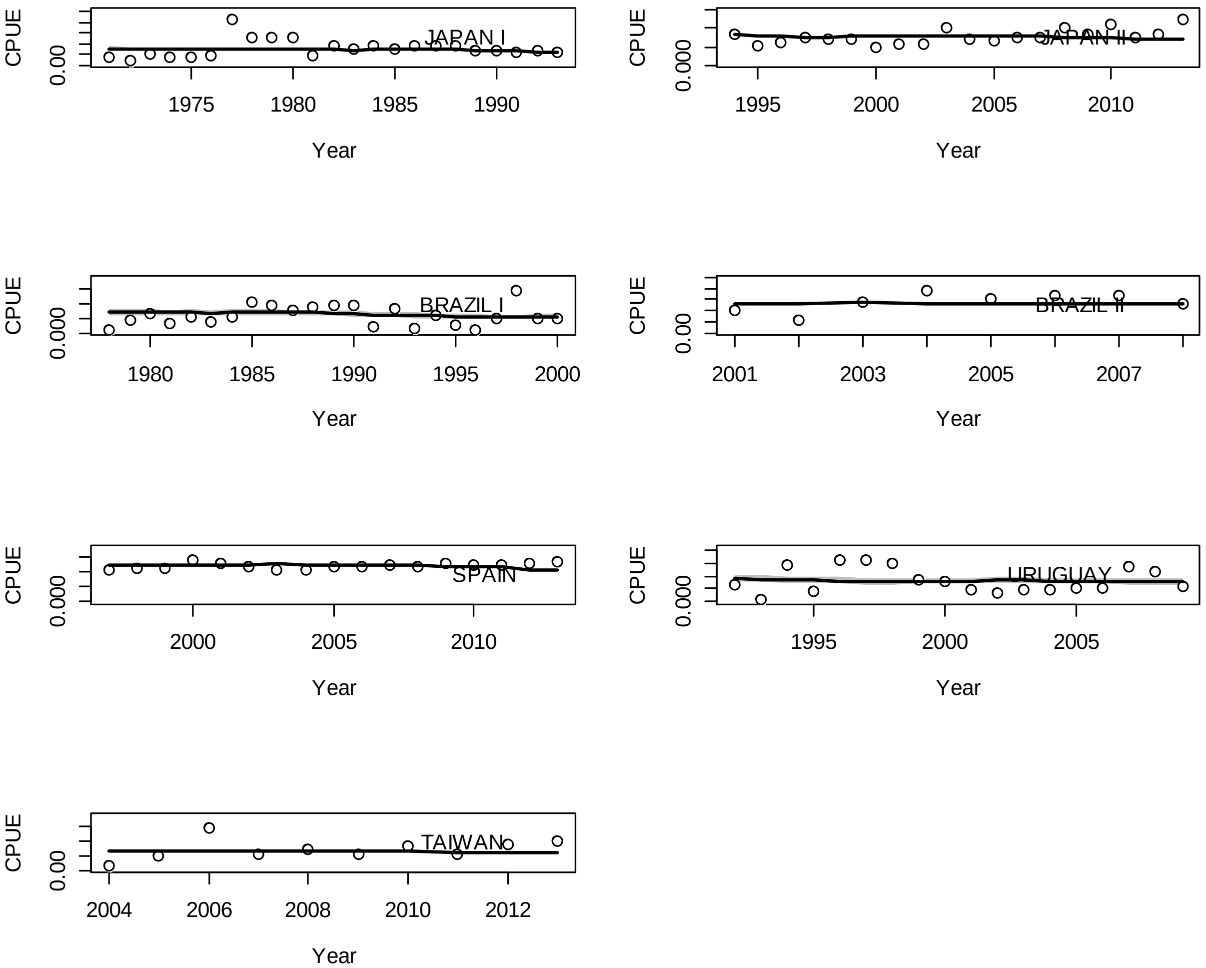


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M9 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

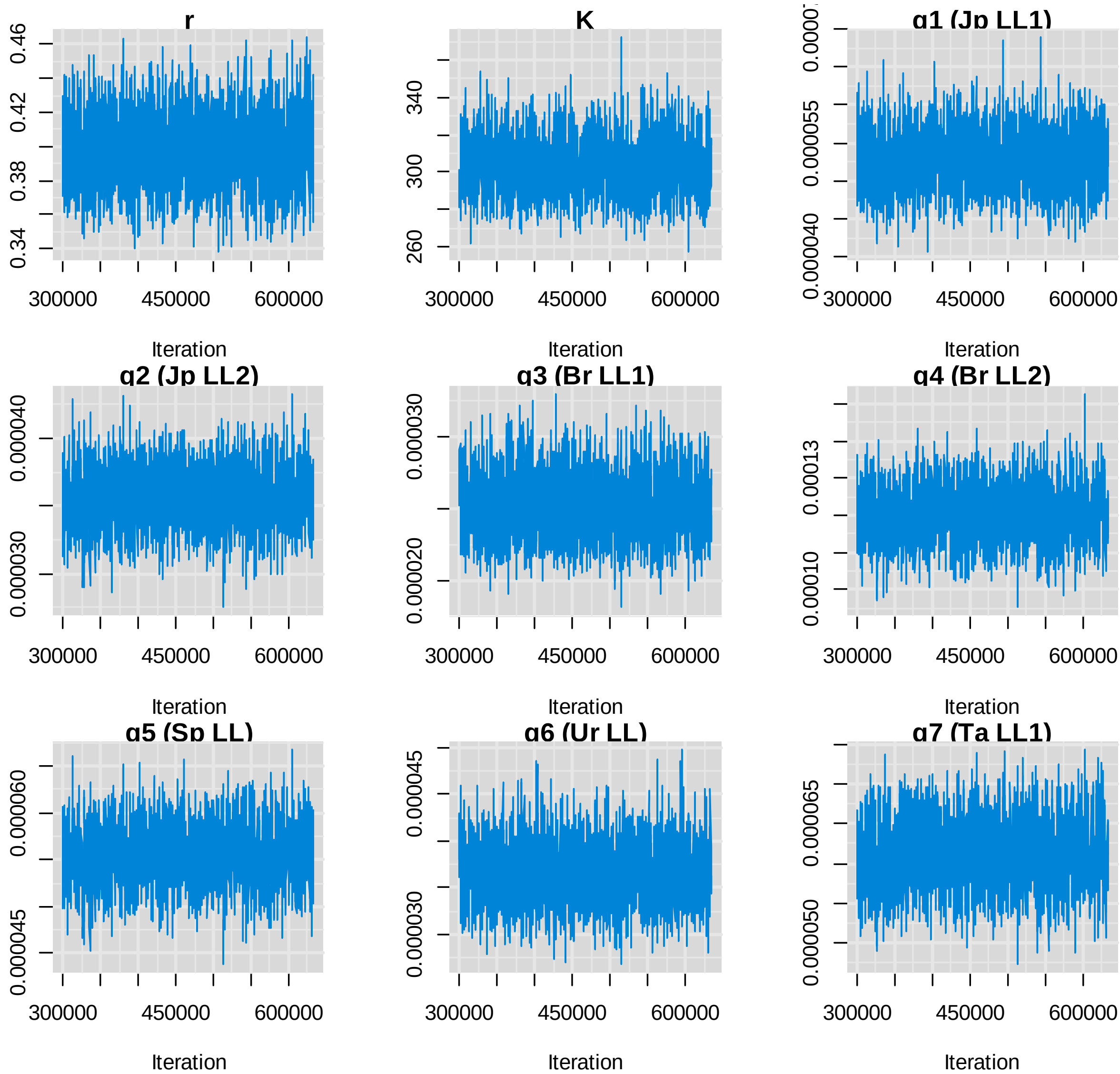


Joint-posterior plots of main model parameters for the alternative M9 for the blue shark in the South Atlantic Ocean.

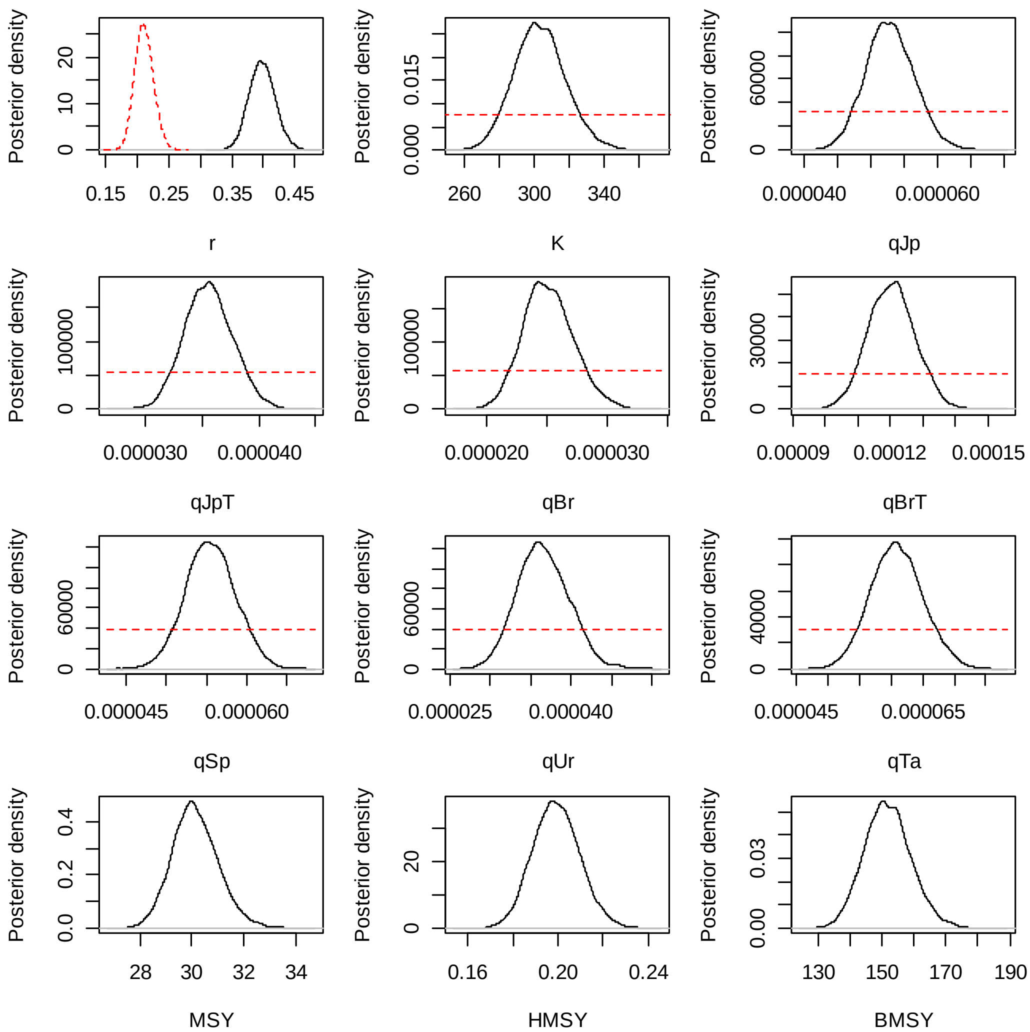
Model: M10



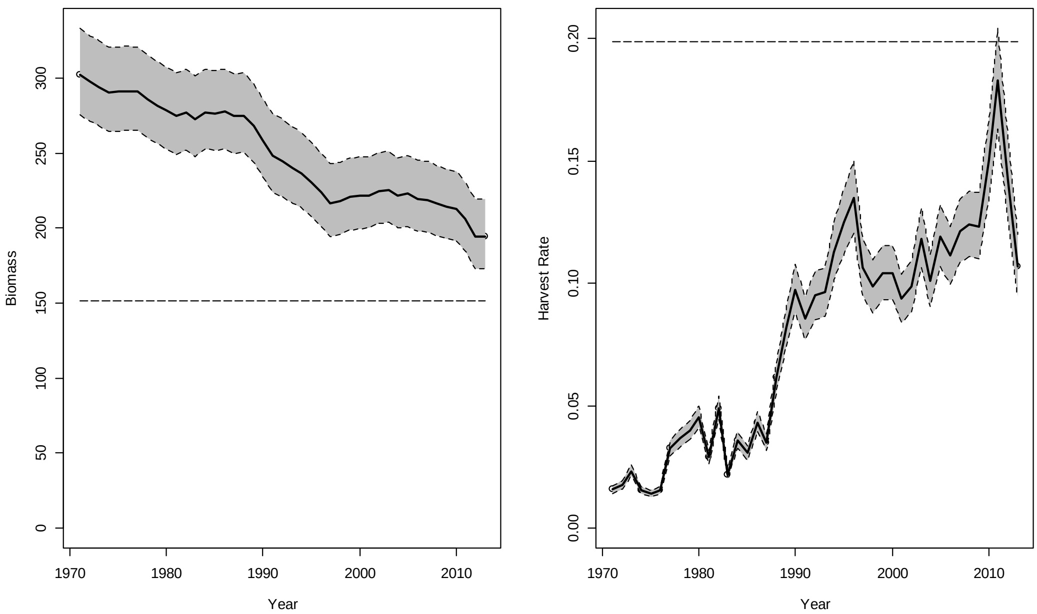
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M10. Shaded grey area indicates 95% C.I.



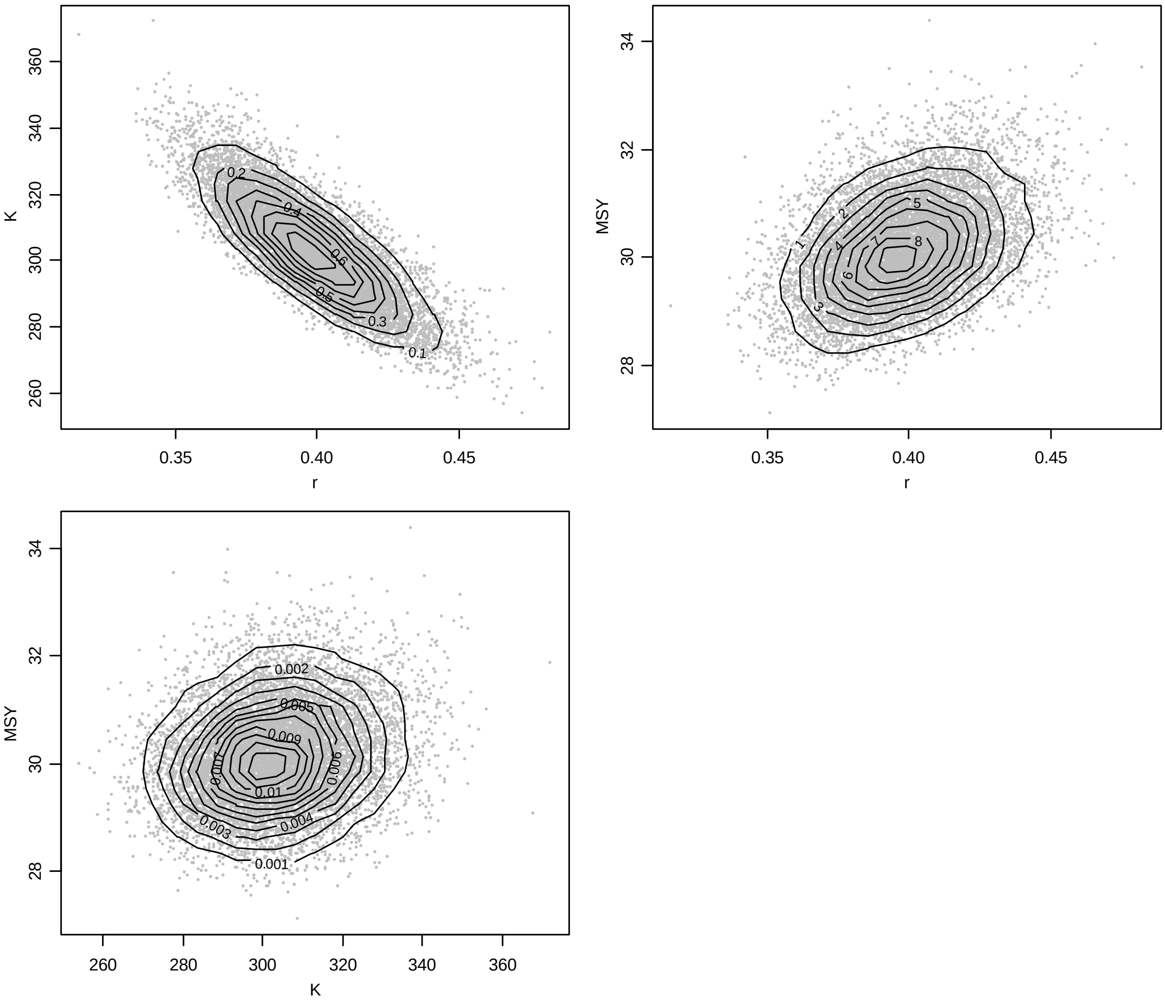
Trace plots for the main model parameter drawn from MCMC samples in M10 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M10 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

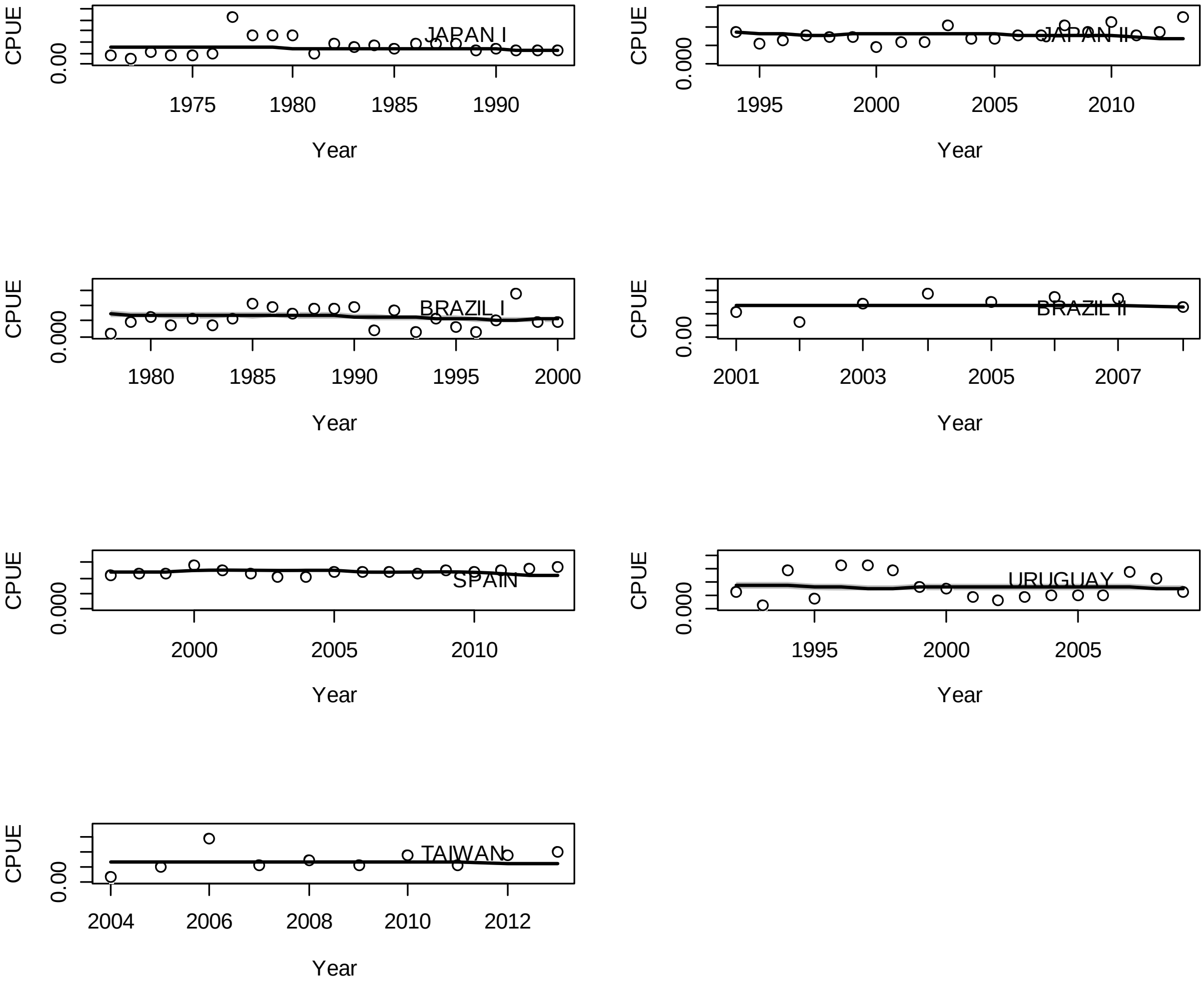


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M10 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

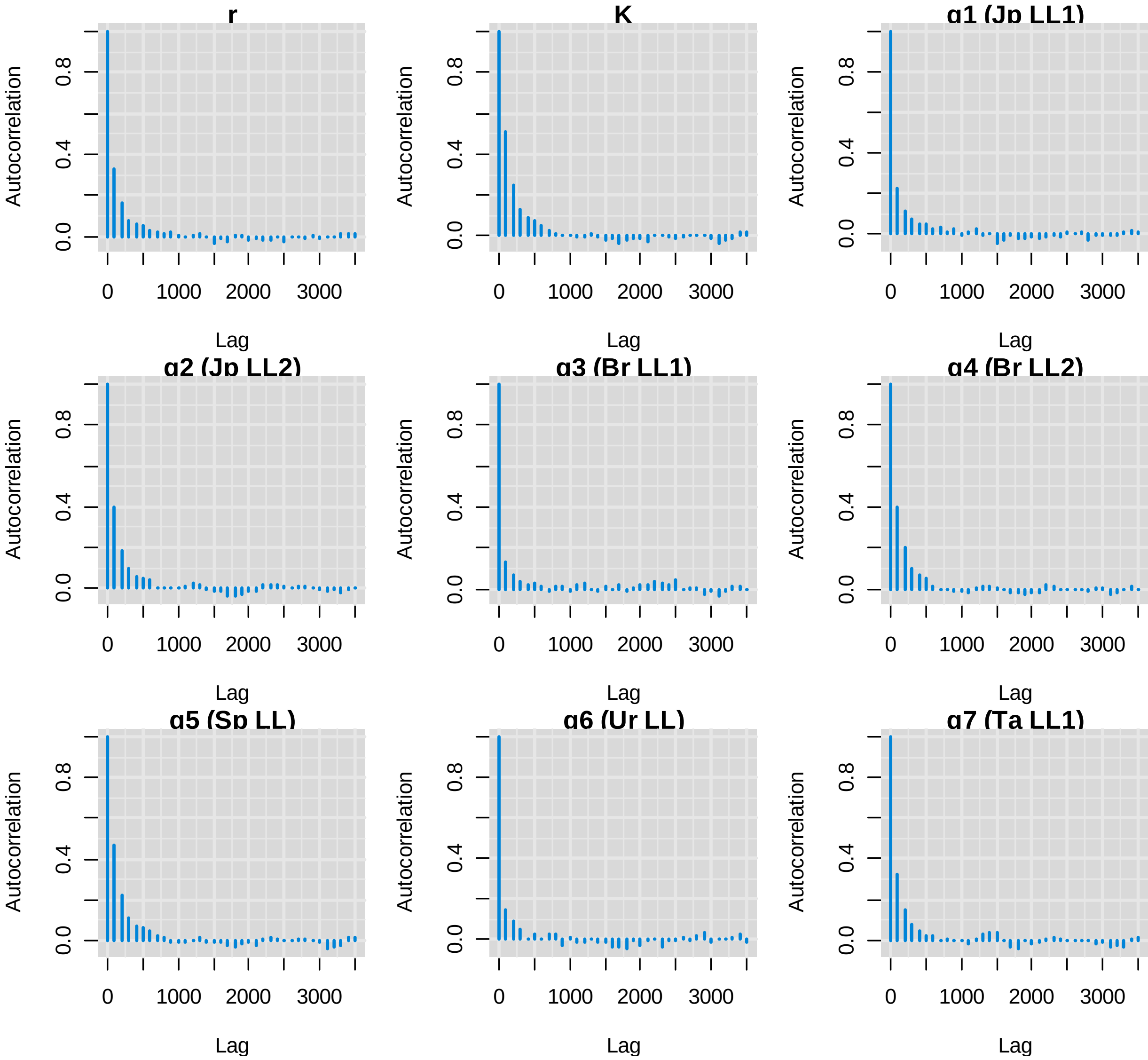


Joint-posterior plots of main model parameters for the alternative M10 for the blue shark in the South Atlantic Ocean.

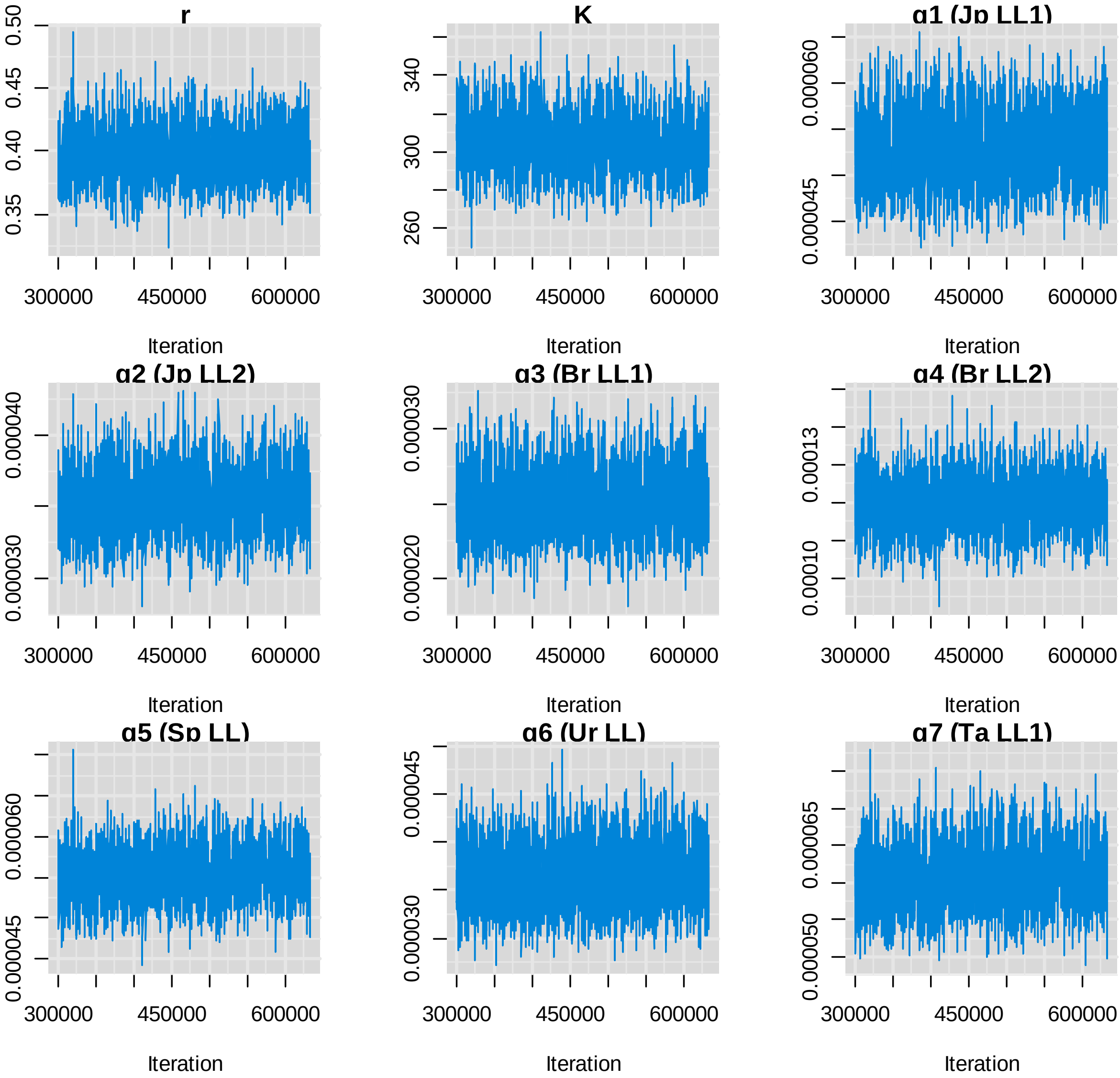
Model: M11



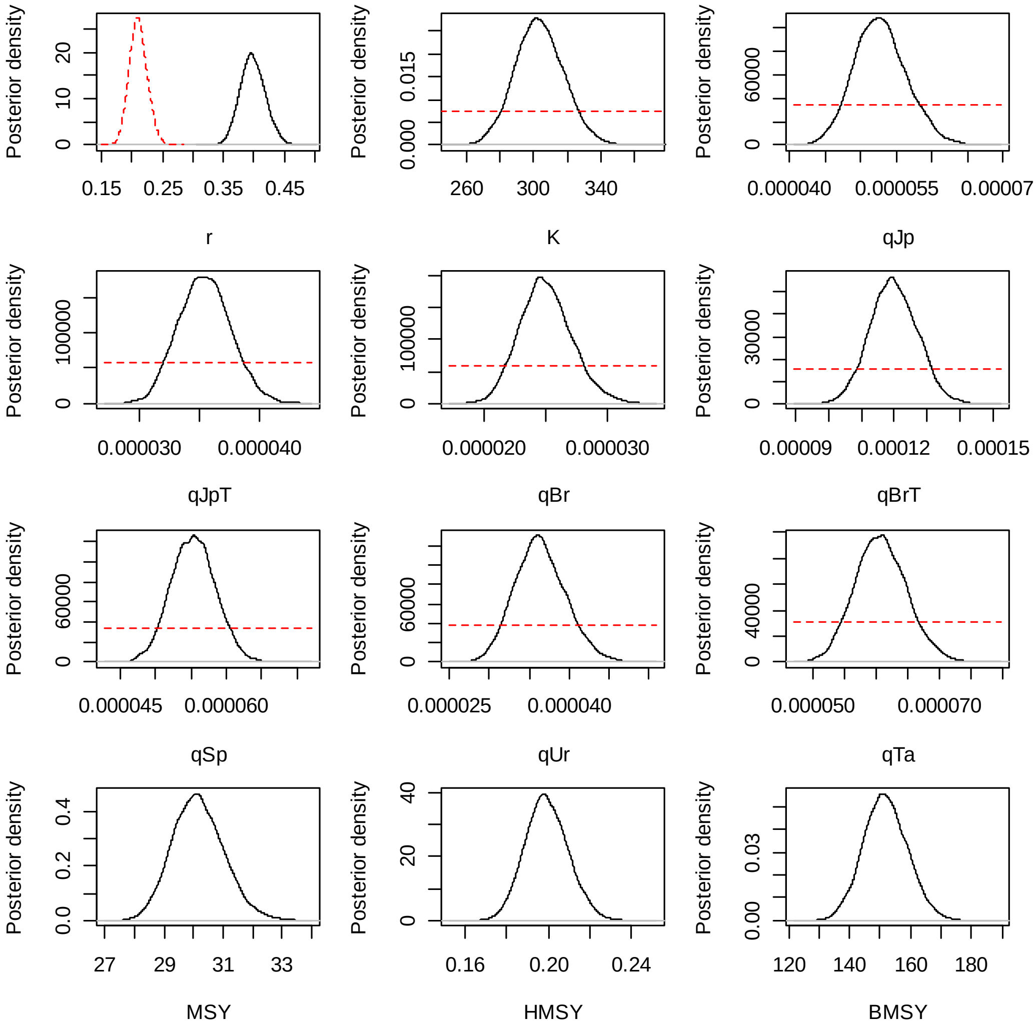
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M11. Shaded grey area indicates 95% C.I.



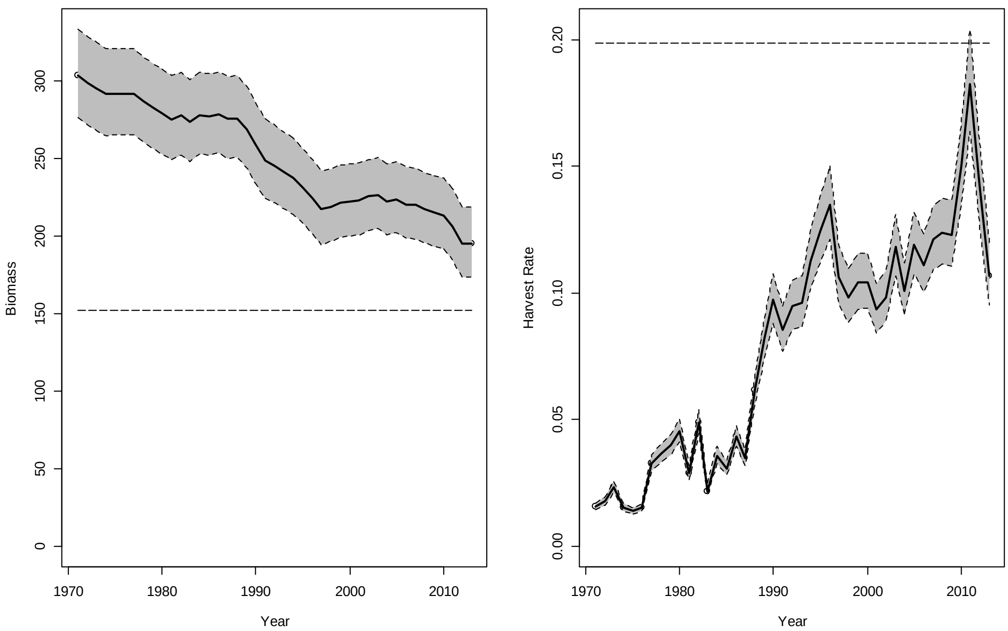
Trace plots for the main model parameter drawn from MCMC samples for M11 for the South Atlantic blue shark.



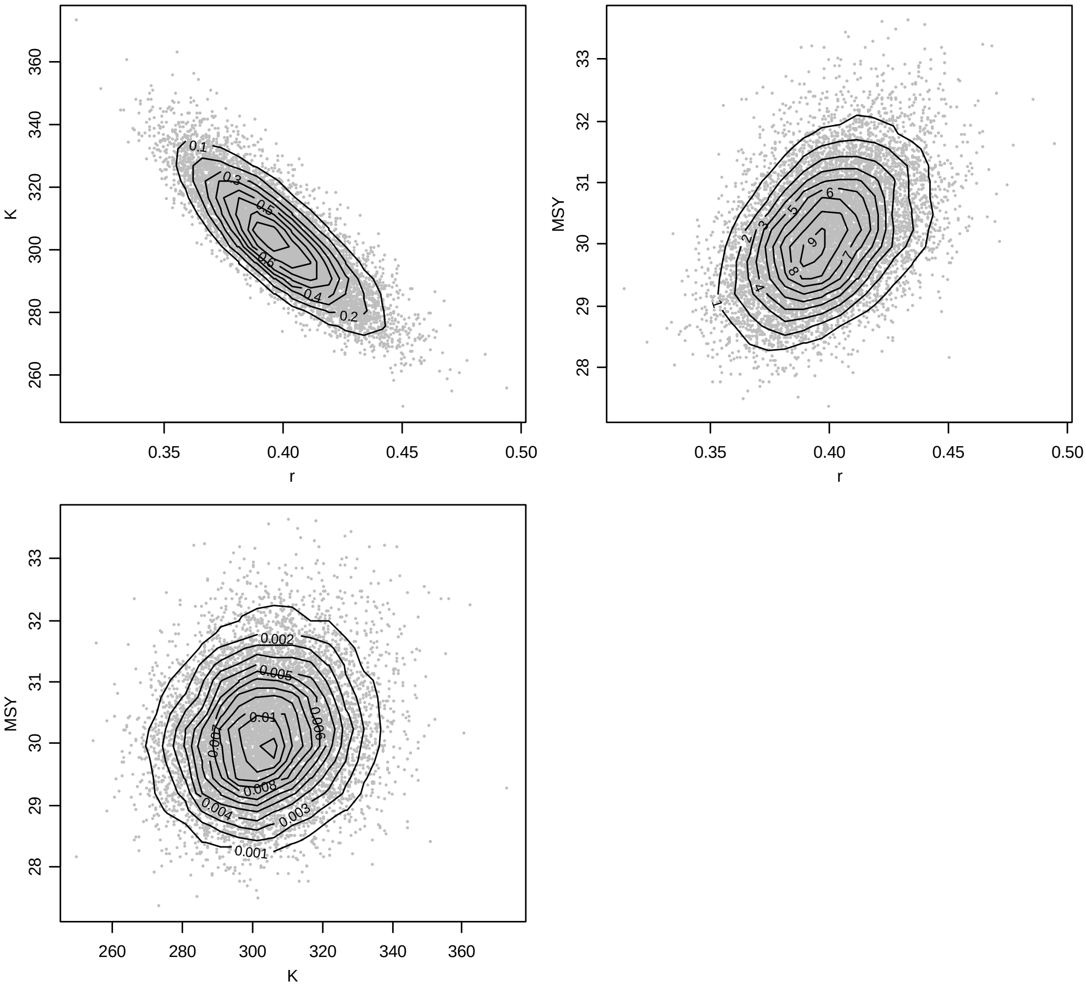
Trace plots for the main model parameter drawn from MCMC samples in M11 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M11 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.

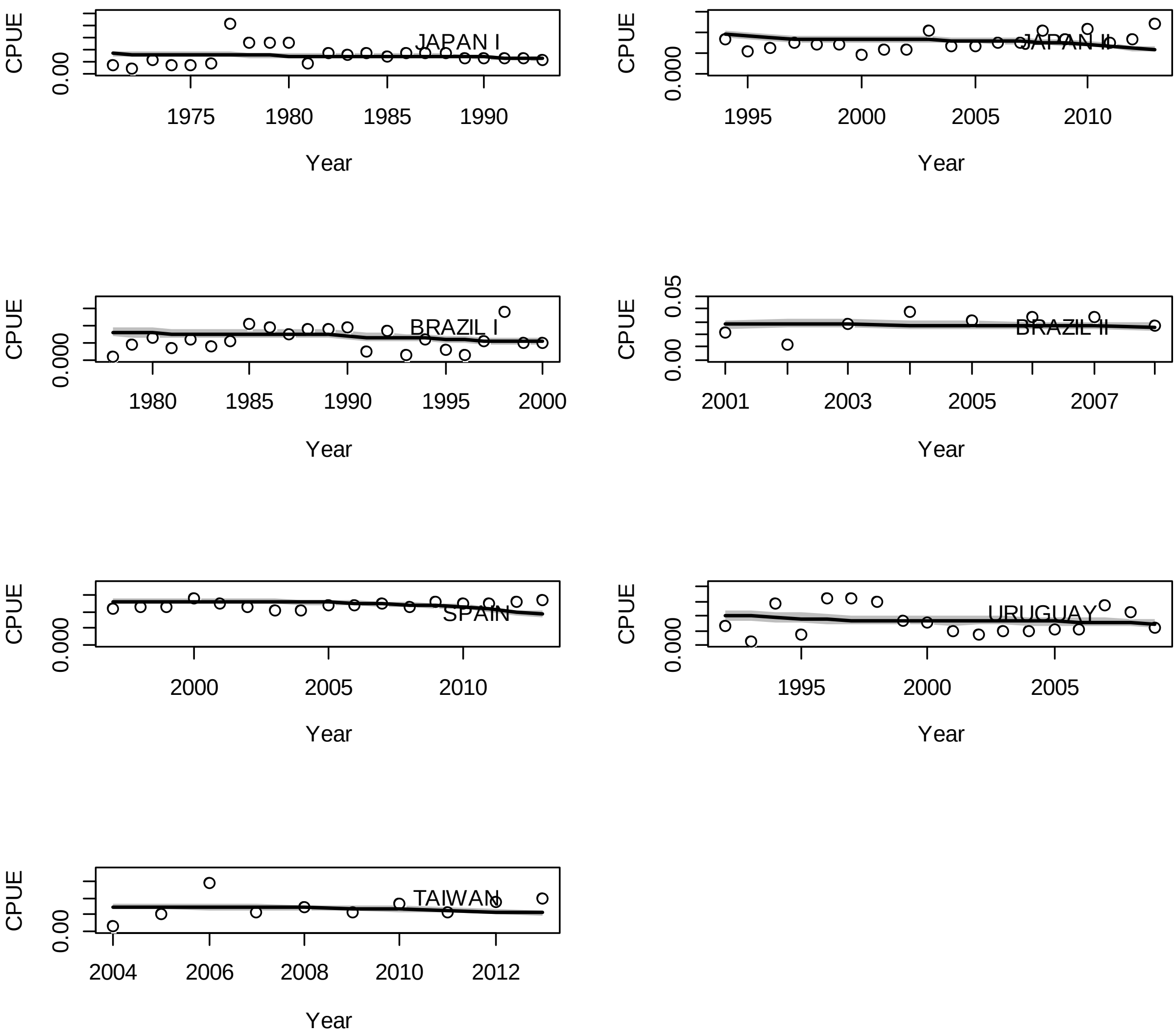


Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M11 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.

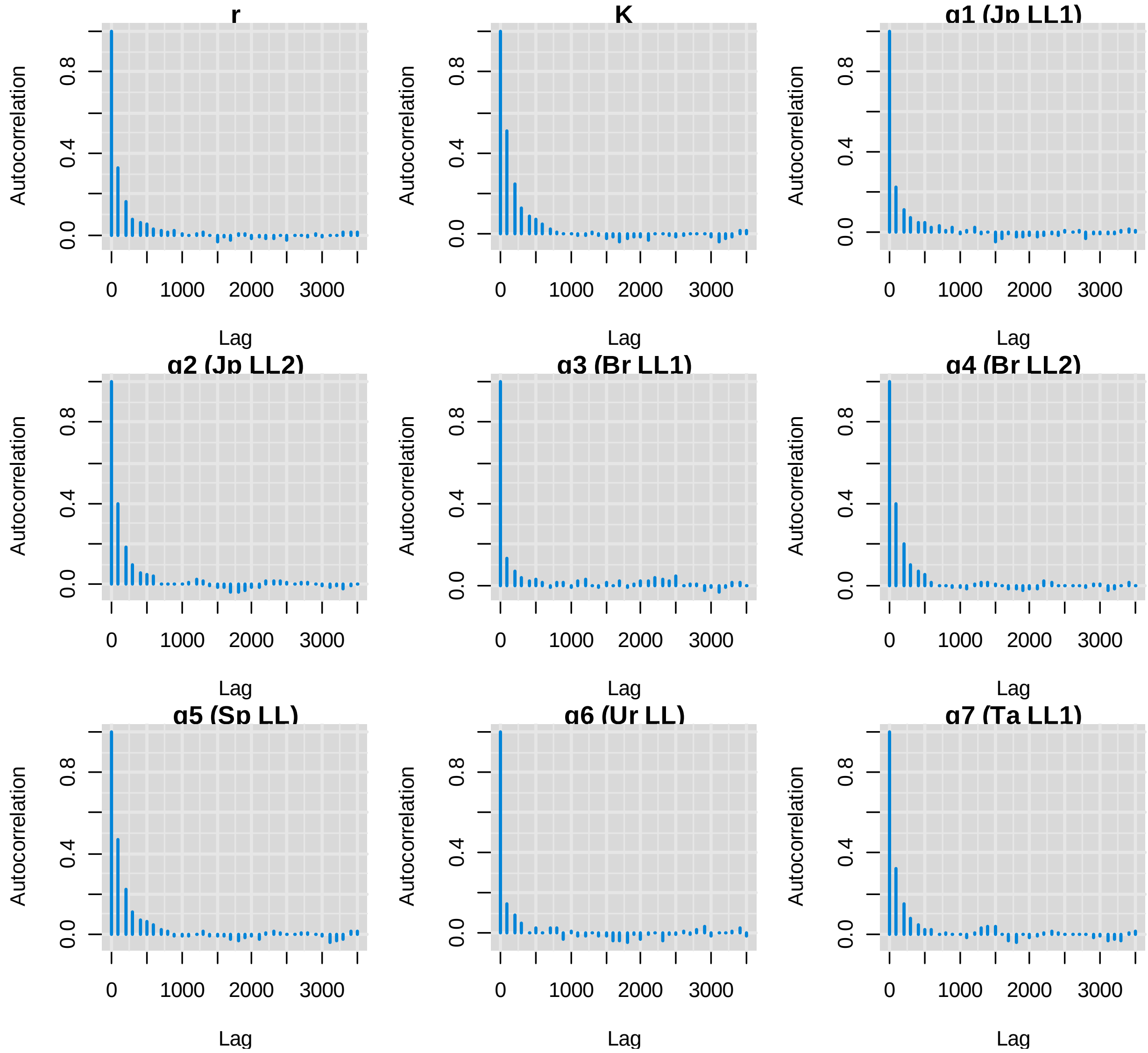


Joint-posterior plots of main model parameters for the alternative M11 for the blue shark in the South Atlantic Ocean.

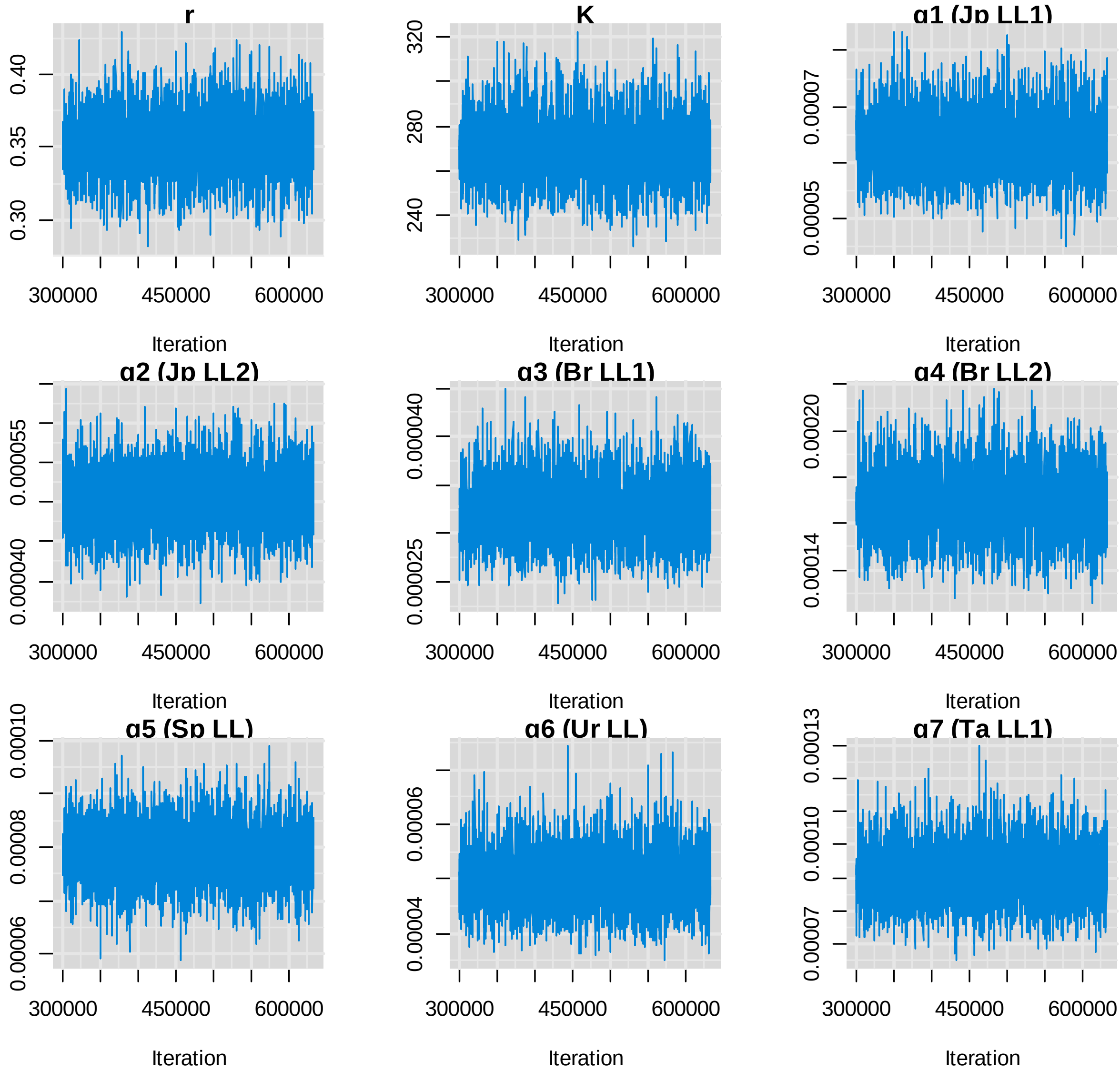
Model: M12



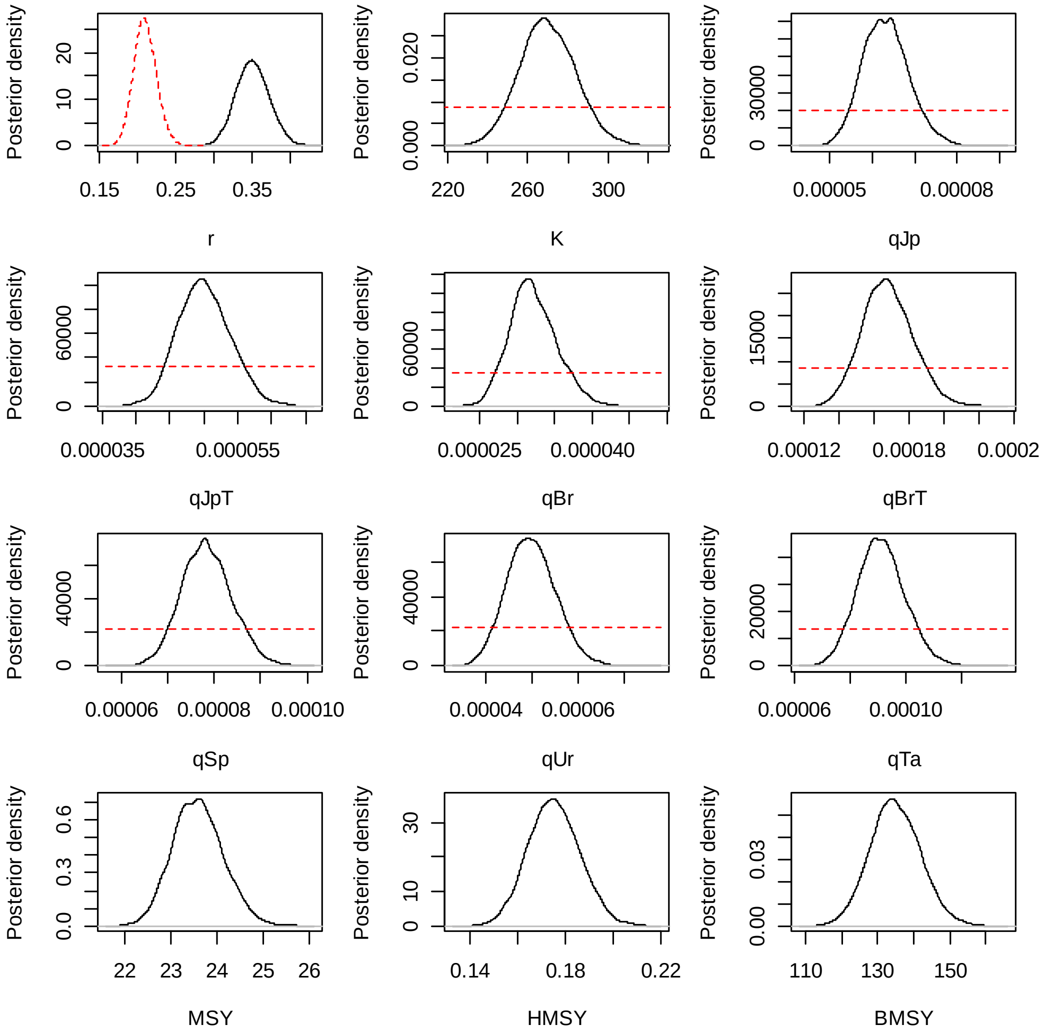
Time-series of observed (circle) and predicted (solid line) catch per unit effort (CPUE) of blue shark in the South Atlantic Ocean for M12. Shaded grey area indicates 95% C.I.



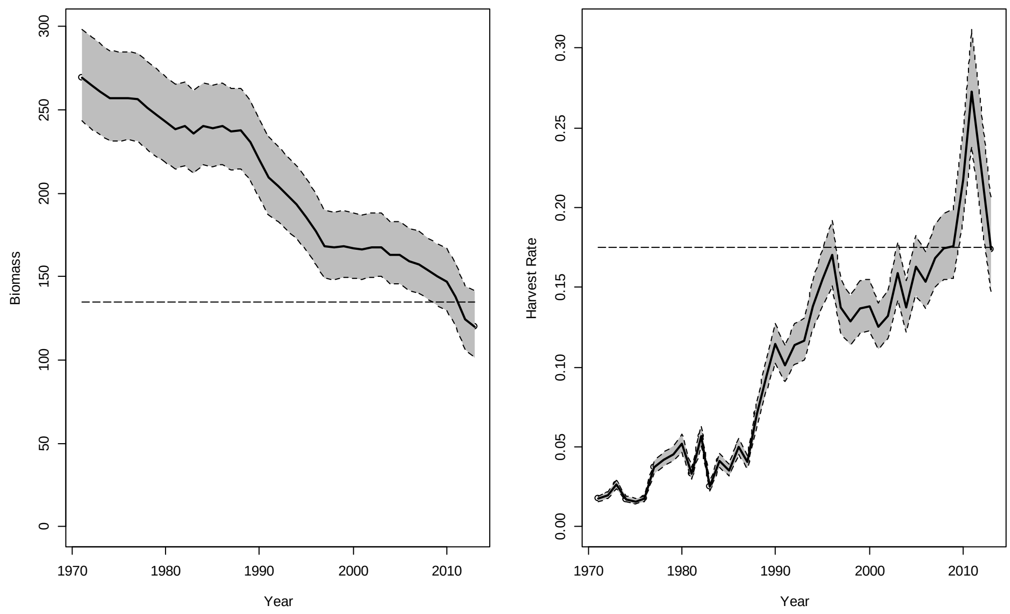
Trace plots for the main model parameter drawn from MCMC samples for M12 for the South Atlantic blue shark.



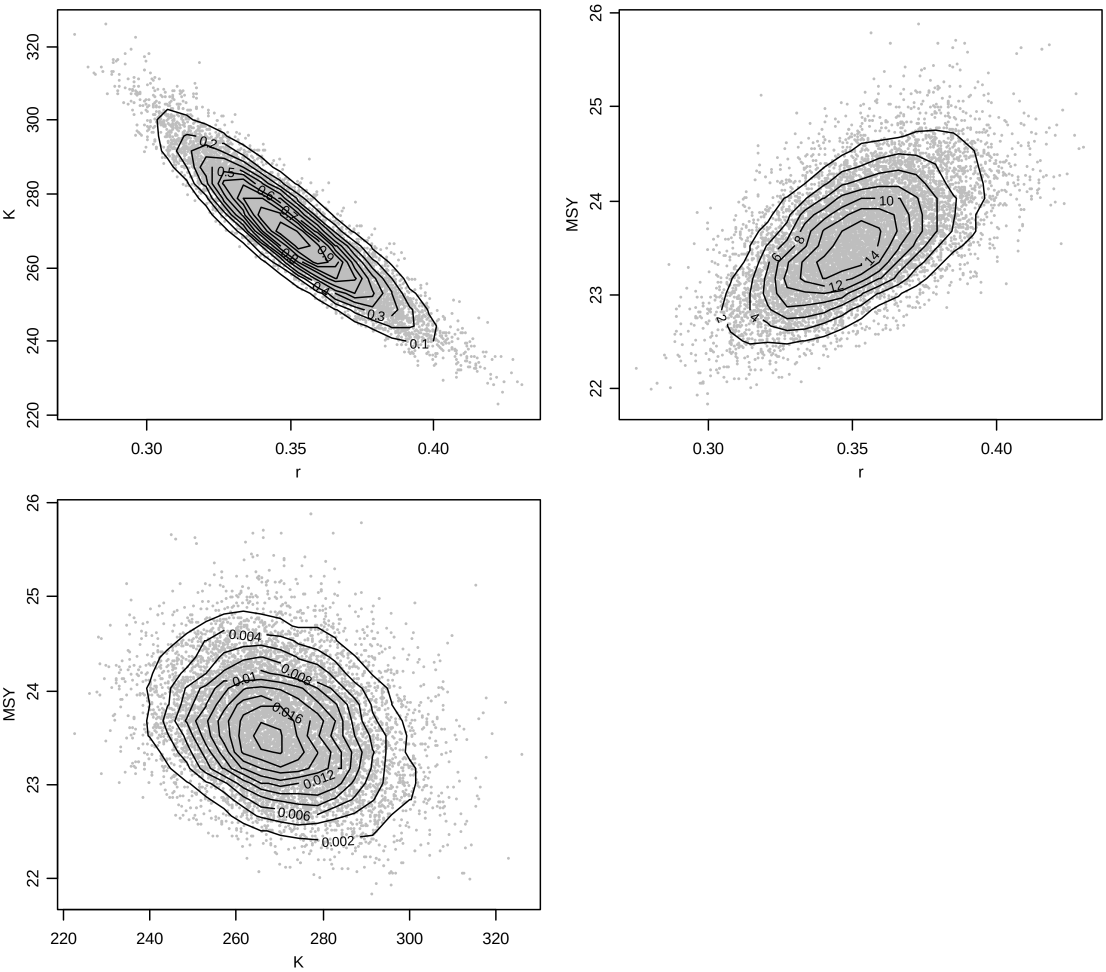
Trace plots for the main model parameter drawn from MCMC samples in M12 for the South Atlantic blue shark.



Kernel density estimates (black lines) of the posterior distribution of various model and management parameters for M12 for the blue shark in the South Atlantic Ocean. Prior densities are given by the red lines.



Trends in exploitable biomass (in 1000s metric ton) and harvest rate for M12 for the South Atlantic blue shark. Shaded grey area indicates 95% C.I. The horizontal dashed lines denote the B_{MSY} and H_{MSY}.



Joint-posterior plots of main model parameters for the alternative M12 for the blue shark in the South Atlantic Ocean.

Appendix 5

DETAILS OF THE BSP MODEL RUNS

Runs N1-N6 and S1-S6 (**Table 4**) were exactly as described in SCRS/2015/150, except that the prior for *r* was revised. Because the annual time-step version of the surplus production model was used:

$$B_{t+1} = rB_t - \frac{r}{K}B_t^2 - C_t$$

while the demographic estimate of *r* is for an instantaneous rate:

$$\frac{dNt}{dt} = r$$

the prior mean values for *r* inputted into the BSP models were corrected by taking the exponent. The mean of *r* for the north is exp(0.3248)-1=0.384, and for the south is exp(0.2148)-1=0.240. This prior was used for all the model runs done with BSP and BSP2.

All BSP and BSP2 model runs adequately converged on the posterior distribution, based on a maximum importance weight less than ~0.05, and the CV of the weights less than ~2 times the CV of the likelihood times the priors.

Figure A.1 shows the fits of each model to the CPUE indices in the North, and **Figure A.2** shows the priors and posteriors. **Figure A.3** shows the fits for the South Atlantic model runs, and **Figure A.4** shows the priors and posteriors. **Figures A.5**, **A.6** and **A.7** show the priors, posteriors and trajectory for the post-model pre-data runs. Note that the posterior distribution is concentrated at low values for the JAGS run, compared to the BSP run.

Alternative model runs were made using the same inputs as run N4 and S4, except that catch was estimated from effort through 1983, and catch estimates from fin trade data (SCRS/2015/069) were used from 1984 to the present. The results of these runs were similar to the runs using the base catch series (**Table A.1, Figure A.8**).

Table A.1 Results of BSP model runs using the alternative catch data estimated from fin trade data.

	North	South
K (1000)	5939.0(1.4)	13629.33(1.29)
r	0.40(0.1)	0.29(0.34)
MSY (1000)	572.4(1.4)	897.65(1.27)
B_{cur} (1000)	5836.6(1.4)	13456.35(1.30)
B_{init} (1000)	5396.8(1.4)	11676.18(1.27)
B_{cur}/B_{init}	1.1(0.1)	1.13(0.16)
C_{cur}/MSY	0.3(1.1)	0.11(0.84)
B_{cur}/B_{MSY}	1.8(0.1)	1.95(0.02)
F_{cur}/F_{MSY}	0.2(1.4)	0.06(0.90)

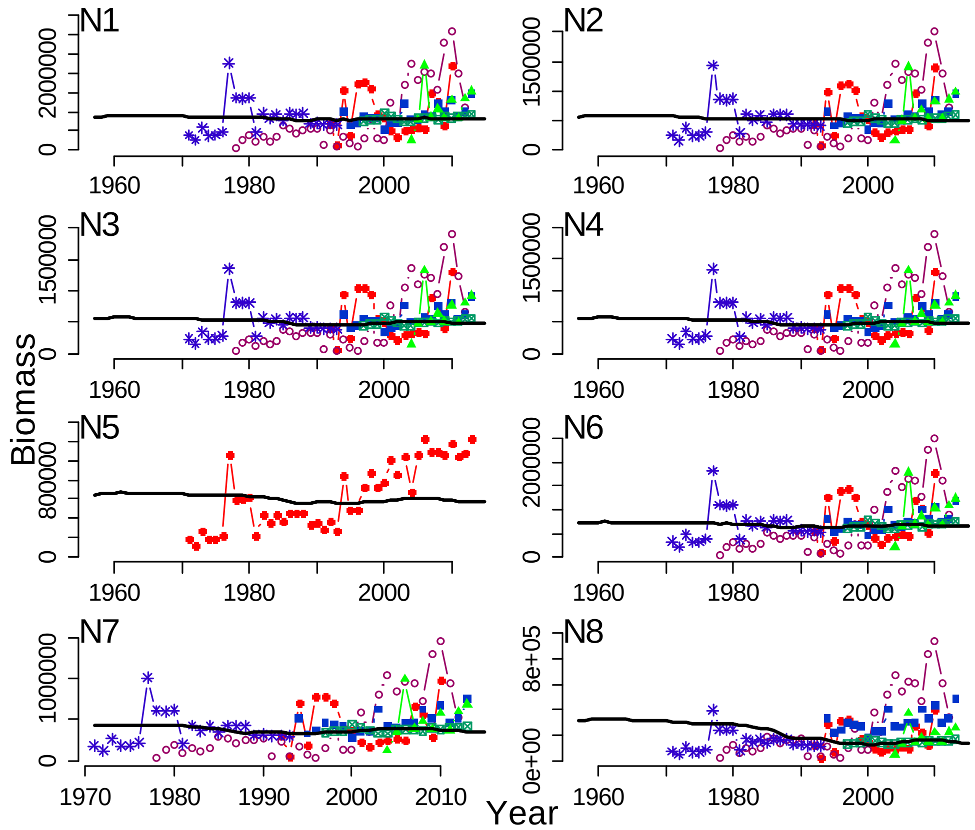


Figure A.1 Fits to the CPUE series for each run in the North Atlantic.

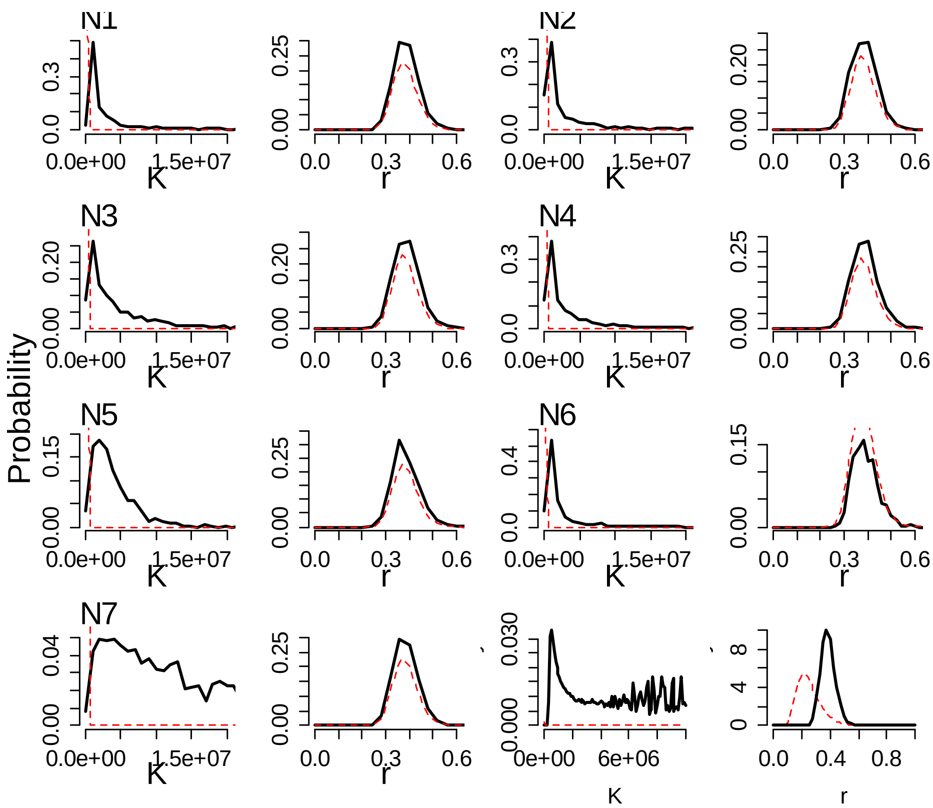


Figure A.2 Posteriors (solid black lines) and priors (dashed red lines) for K and r for the North Atlantic runs.

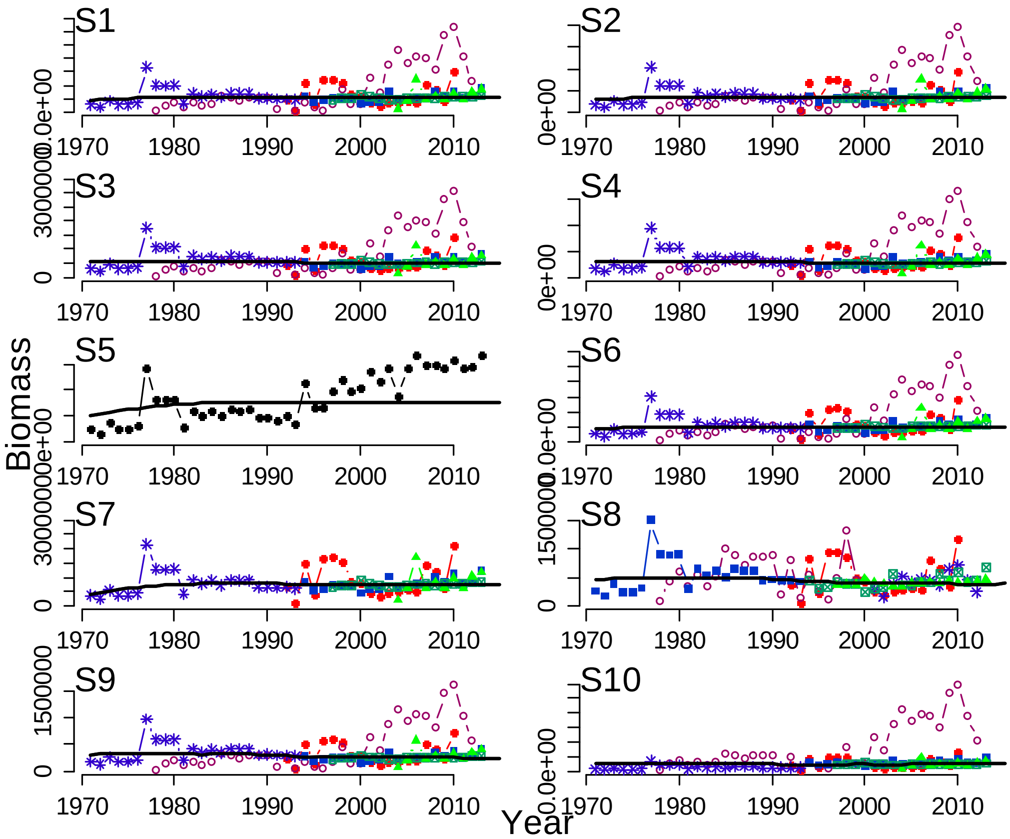


Figure A.3 Fits to the indices for the South Atlantic.

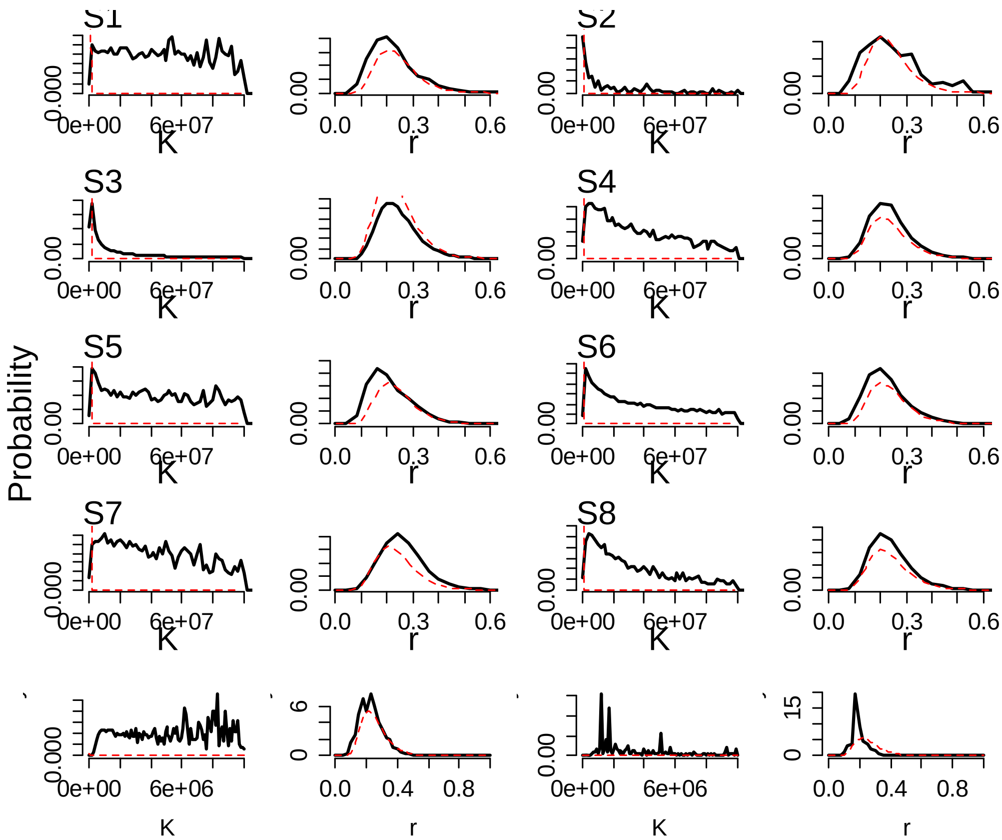


Figure A.4 Posteriors and priors for the South Atlantic runs.

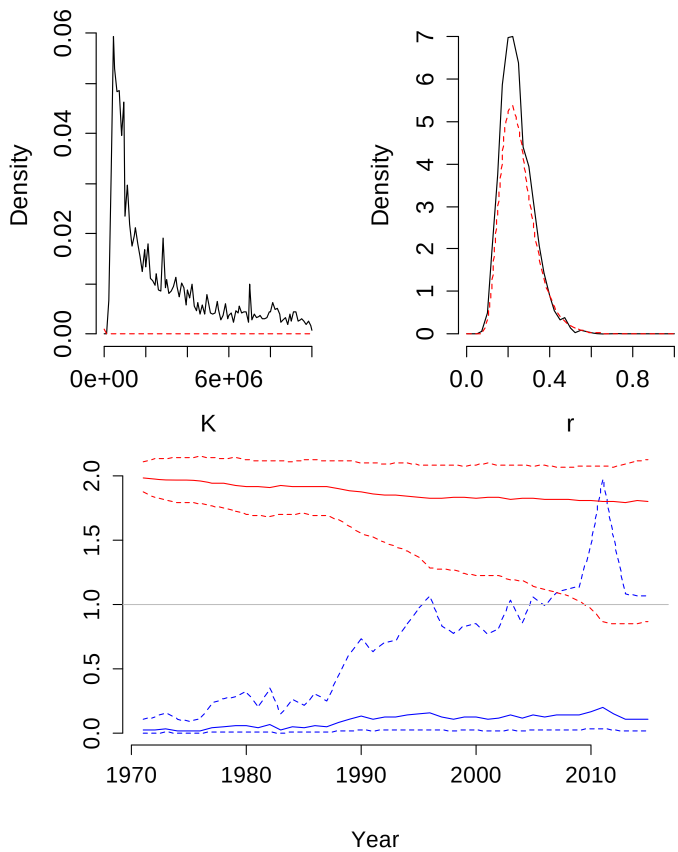


Figure A.5 BSP2 software post model pre data run (S-PMPD1). CV of *B[1]/K* is 0.01, the revised *r* prior is used. Draws that fall below *B/K* threshold are discarded by the SIR algorithm.

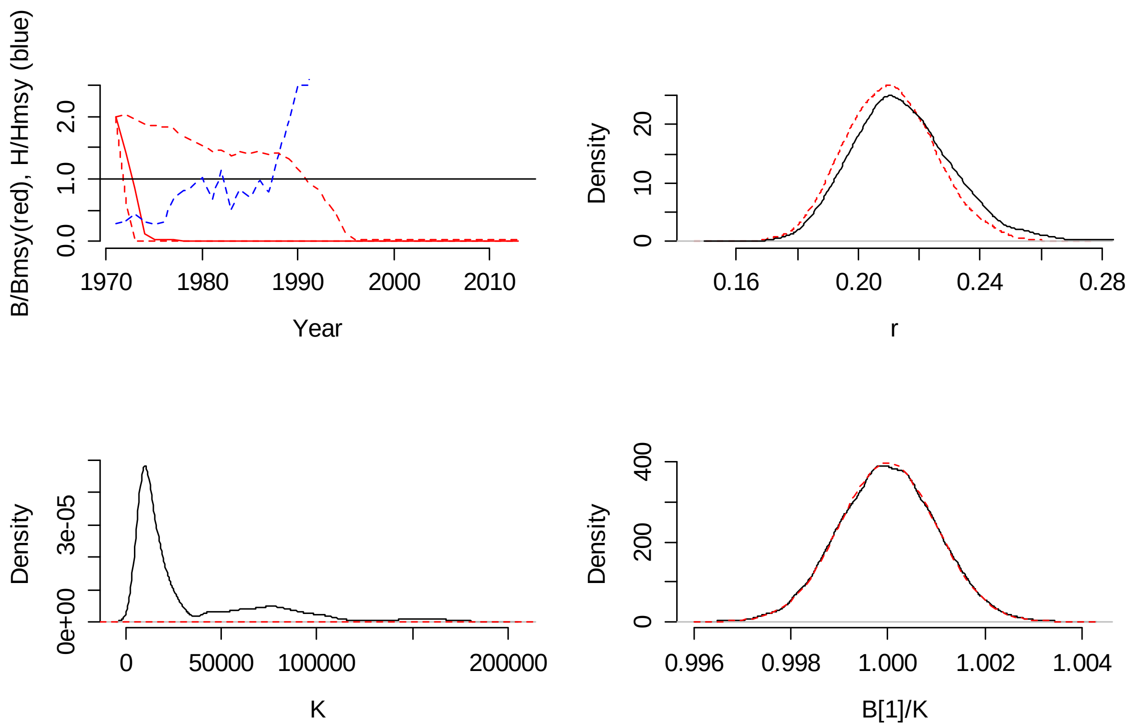


Figure A.6 Post model pre data diagnostic run S-PMPD2. With base prior from the state space model, minimum *B/K* = 0.01, *B[1]/K* has a low CV (0.001).

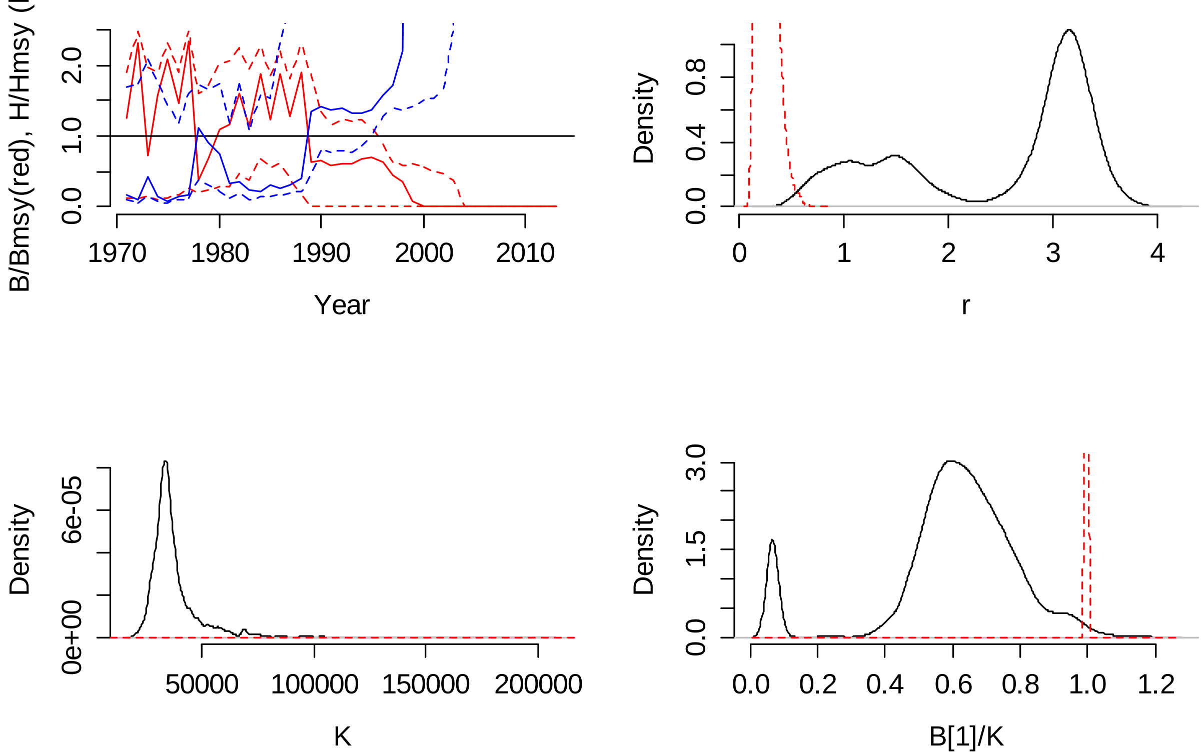


Figure A.7 Post model pre-data run from JAGS, with revised *r* prior (slightly higher and more precise). CV of *B[1]/K*=0.2, and *B/K* minimum of 0.001.

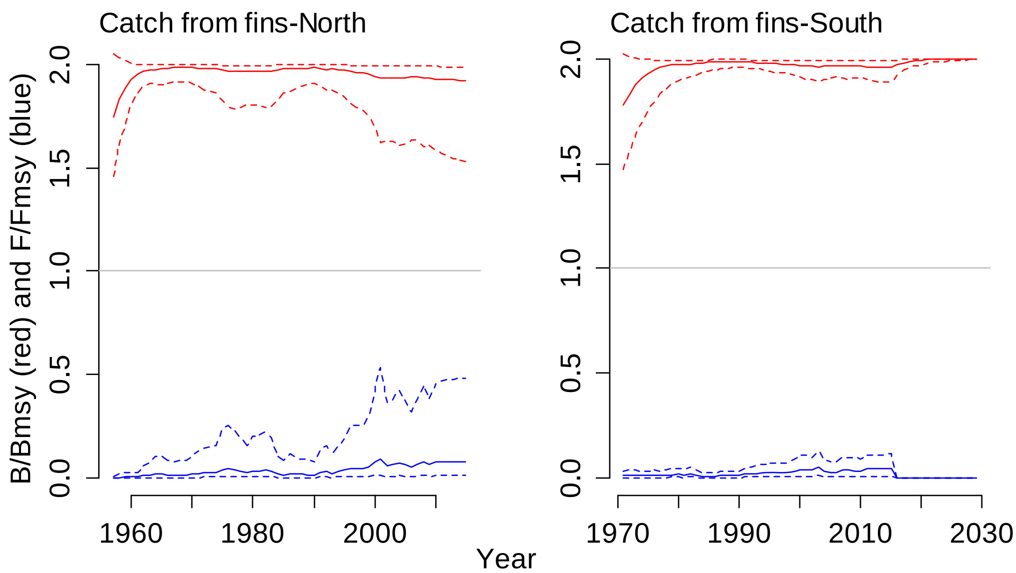


Figure A.8 Biomass and harvest rate trajectory for BSP models fitted to the alternative catch series estimated from fin data.