Development of a State Space Assessment Model for Cod (*Gadus morhua*) in NAFO Subdivision 3Ps

J. Champagnat[1], J. Vigneau[1], D.A. Varkey[2], P. Regular[2], D.W. Ings[2,] J. Babyn[2], J. Morgan[2]

[1]IFREMER
Av. du Général de Gaulle, 14520
Port en Bessin, France

[2]Science Branch
Fisheries and Oceans Canada
P.O. Box 5667
St. John's, NL A1C 5X1

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

TABLE OF CONTENTS

ABSTRACT

A state-space assessment model (SAM) that incorporates commercial catches and survey indices is developed for the 3Ps cod stock. It allows for process and observations errors and uses random walks in fishing mortality rate to estimate time variant selectivity. The model provides estimates of stock size, fishing mortality and recruitment together with their uncertainties and would eventually have the ability to provide stochastic forecasts. The objective of the study is to achieve an accurate estimation of the stock dynamics and better account for uncertainty.

Four runs of the model are presented here with different options on mortality and survey inputs. Runs produce comparable estimation but lead to different stock status in the recent period. They also perform differently in terms of retrospective analysis, residual patterns, and description of latent processes. Three runs out of four produced outputs with concerning issues, so they could not be accepted as basis for assessment advice. The last one (called sentinel run) was kept as a "control model," which means it would be use for comparison purpose alongside with the accepted model (i.e., state-space model [HYBRID]).

INTRODUCTION

In 2006, the analytical 3Ps cod assessment models using commercial catches (Sequential Population Analysis, SPA) were discontinued due to concerns about stock structure, accuracy of landings statistics and inconsistencies between offshore trawl surveys and indices issued from inshore sentinel fixed gear catch rate indices (Brattey et al. 2007, Cadigan 2010).

Since then, a survey based analytical model (SURBA; Cadigan 2010) has been used. This model was implemented in SAS PROC NLMIXED software and relied on a single series of indices: the spring Fisheries and Oceans Canada (DFO) Research Vessel (RV) survey. This stratified random survey has been conducted since 1983 and covers the majority of Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps. It has been acknowledged that this RV survey time series is subject to large inter-annual variability, year effects, unbalanced contribution of strata to the global index and substantial uncertainties (Ings et al. 2019).

Recently the assessment model started to show a strong directional retrospective pattern in the estimates of stock spawning biomass and stock status (Rideout et al. 2017). Also, previous scientific assessments have underlined the need to improve the current assessment model to characterize the impact of fishing pressure on the stock and be able to better advise management in terms of catch projection and resulting effects on stock status. Consequently, an assessment framework was initiated in 2017 in order to explore potential improvements to the 3Ps cod stock assessment methodology.

The analyses presented in this document build upon the requisite data review conducted prior to the modeling framework. The comprehensive work on the data enabled the setting of a revised time series of catch at age and time series of indices from different surveys (Varkey et al. 2024).

A state-space assessment model (e.g., SAM, Nielsen and Berg 2014, Berg and Nielsen 2016) was considered to be a good candidate to explore for the assessment of this stock, based on the available input datasets. First, SAM integrative approach allows incorporation of several data series which would be optimally weighted through a joint likelihood optimization process (Berg and Nielsen 2016, Maunder and Punt 2013). Then the state-space framework accounts for both process and observation errors while keeping relatively few parameters. This efficiency is reached by assuming a log-normal distribution of the states (process) and space (observation) variables and estimating their respective variance. Finally, SAM has been effectively used in a wide range of European stock assessments, including some cod stocks (ICES 2019, 2020). In addition, the SAM package under the R programming language (R Development Core Team 2005) makes it accessible and transparent, which are assets for assessment frameworks.

This document presents an application of the SAM model for the 3Ps cod stock. A brief overview of the model is provided but more details can be found in Nielsen and Berg (2014) and Berg and Nielsen (2016).

METHODS

MODEL STRUCTURE

The model was developed with the stock assessment package, which uses Template Model Builder (TMB; Kristensen et al. 2015) and Laplace approximation to minimize a complex likelihood function. All the variables are in log scale, and the description follows the notation of Nielsen and Berg (2014).

Process Equations

Population Equation

The model follows the general population dynamic formula

$$log(N_{y,a}) = log\, log\, \left(N_{y-1,a-1} \times exp\left(-(M_{y,a} + F_{y,a})\right)\right) + \eta_{y,a} \quad, \eta_{y,a} \sim N(0, \sigma_S) \quad R < a < A$$

$$log(N_{y,a}) = log\, log\, \left(N_{y-1,A-1}\right) + log\left(N_{y,A} \times exp\left(-(M_{y,A} + F_{y,A})\right)\right) \times +\eta_{y,A} \quad, \eta_{y,a} \sim N(0, \sigma_S) \quad A$$
$$= max\,(a)$$

where $M_{y,a}\ and\ F_{y,a}$ are the natural and fishing mortality incurred by the fish population and $\eta_{y,A}$ is the process error within the population.

It has been noted that stock mixing occurs on a seasonal basis between the 3Ps cod stock and the neighboring Northern Gulf cod stock in the Burgeo Bank area, and that the presence of fish of Northern Gulf origin within the 3Ps stock area at the time of the Spring RV survey could potentially be problematic for the 3Ps cod assessment (Méthot et al. 2005, Brattey et al. 2007). Here the SAM accounts for any seasonal immigration into the stock area as part of the process error in *N*.

The recruitment process can be implemented following three options:

- Random walk: $log(N_{y,R}) = log\,(N_{y-1,R}) + \eta_{y,R}$,

- Beverton-Holt: $N_{y,R} = \frac{\alpha \times SSB_y}{1 + \beta \times SSB_y} + \eta_{y,R}$, and

- Ricker: $N_{a,R} = \alpha \times SSB_y \times e^{-\beta \times SSB_y} + \eta_{y,R}$,

where R is the recruitment age and $\eta_{y,R}$ the recruitment error which follows a normal distribution $\eta_{y,R} \sim N(0, \sigma_R)$.

Fishing Mortality Equation

Fishing mortality rates at age follow random walks across years. Those random walks can be correlated among ages using a multivariate-normal distribution. This distribution is driven by a correlation matrix (of dimensions ages*ages) following three options, which result in different selectivity patterns.

- Independent structure (ID), all random walks will develop independently through time, the correlation between two different ages equal 0.

- Compound symmetry (CS), which means that the correlation is the same for each pair of ages.

- Autoregressive process (AR1), the correlation depends on the distance between two ages, which mean that neighbor ages are more highly correlated than more distant ages.

Hence, $F_{y,a}$ is described as following:

$$log(F_y) = log(F_{y-1}) + \xi_y$$

where ξ_y the process error in fishing mortality, follows a multivariate-normal distribution, $\xi_y \sim MVN(0, \Sigma)$, and Σ is the covariance matrix of this distribution allowing the between age coupling.

Observation Equation

Survey indices are defined as follows:

$$log(I_{y,a,s}) = log(Q_{a,s}) + log(N_{y,a}) - Z_{y,a} \times tf_s + \varepsilon_{y,a}^s$$

where $Q_{a,s}$ is the catchability of the survey, $Z_{y,a}$ the total mortality applied to the fish population $Z_{y,a} = F_{y,a} + M_{y,a}$, tf_s is the year fraction of the survey and $\varepsilon_{y,a}^s$ is the observation error.

Catches are modeled using the Baranov catch equation:

$$log(C_{y,a}) = log\ log\left(\frac{F_{y,a}}{Z_{y,a}} \times \left(1 - exp(-M_{y,A} - F_{y,A})\right) \times N_{y,a}\right) + \varepsilon_{y,a}^c$$

where $\varepsilon_{y,a}^c$ is the observation error for catch.

Catch and survey errors follow multivariate normal distributions, defined by the associated correlation matrices $\Sigma_y^{I(S)}\ and\ \Sigma^C$. These matrices can be implemented in various ways resulting in various correlation structures between observations:

- Independent, so no correlated structure.

- An autoregressive process allowing irregular distances between ages (IRAR[1]).

- Unstructured, which allows more flexibility but costs a lot of parameters (US).

All standard deviation parameters can be set as identical or age variant. The subsequent age groups were chosen based on Akaike Information Criterion (AIC) and residual patterns.

Catch Uncertainty

Catch uncertainty has been a concern for the stock, especially during the pre-moratorium period for over or under reporting, and after-moratorium for high grading and discarding (Shelton et al. 1996).

SAM presents a feature aiming to consider misreported catches. However, the model needs a few accurate years to anchor the estimations. A year and age matrix "catch scalar" can be estimated, such as the catch equation become:

$$C_{y,a} = \frac{\hat{C}_{y,a}}{S_{y,a}}$$

where $\hat{C}_{y,a}$ is the predicted catch at age matrix, $C_{y,a}$ is the reported catch matrix and $S_{y,a}$ the scalar matrix.

INPUT DATA

The input data were discussed during a data review meeting that took place in St. John's, Newfoundland and Labrador (NL) in May 2019 and are detailed in Varkey et al. (2024). A brief overview of the input datasets:

Fisheries dependent data:

- Catch at age from 1959 to 2017 with age from 2 to 14 (Figure 1, 2 and 3).

- Catch weights at age directly derived from catch at age.

- Sentinel fishery data from 1995 to 2017. Through this program fish harvesters engage in gillnet and line-trawl fisheries at pre-determined inshore sites. The data thus collected is

analyzed to produce standardized catch per unit of effort (Mello et al. 2018). Two series of indices from age 3 to 10 are produced: for gillnet (GN) and line trawl (LT) sentinel surveys (Figure 4 and 5).

Fisheries independent data:

- Indices from random stratified surveys, all following the same stratification scheme (Figure 6).

  o Indices from a French RV survey called ERHAPS (Estimation des Ressources HAlieutiques du 3Ps) for 1978–91 for ages 2–12+ (Figure 7 and 8). Data from 1992 has not been included because the change of boat for this year was a concern (Bishop et al. 1994).

  o Spring RV DFO survey has been running since 1983. The boat and gear have changed over time, but comparative fishing experiments allow us to have converted indices. Between 1994 and 1997, 13 inshore strata were added to the initial stratification, this inclusion increased the trawlable area by 18% (Ings et al. 2019). Moreover, it leads to a change in the age composition of fish surveyed as more young fishes tend to be caught inshore (Ings et al. 2019). Eventually, three time series were available for inclusion in the model (Figure 7 and 8)

    ▪ OFF - Offshore only 1983–2019

    ▪ In - Inshore only 1997–2019

    ▪ IO - A combined inshore-offshore index 1983–2019

  o An industry related survey performed by the Groundfish Economic Allocation Council (GEAC) was conducted at the end of fall between 1997 and 2007 (Figure 7 and 8). Due to poor strata coverage in some years, data only from years 1998–2005 were used (McClintock 2003).

- Stock weights at age from a model based on DFO RV survey sampling (N. Cadigan, pers. comm.).

- Maturity at age based on a cohort model using DFO RV survey sampling (Ings et al. 2019).

- Natural mortality inputs with two options:

  o Time and age invariant: 0.3 for all year and all ages as the base case. This specific value has been chosen based on tagging analysis in 3Ps which suggests natural mortality value is higher than 0.2, even though the coverage of tagging data extends only post-moratorium. Moreover, neighboring cod stocks (Northern cod 2J3KL and Flemish cod 3M) display estimates for M higher than 0.2 as well.

  o Time varying from a model based on fish condition analysis (adapting methodology from Casini et al. 2016, see Appendix C in Varkey et al. 2022). This model predicts that below a certain condition index value, fish have a higher probability to die. The condition index estimates rely on survey sampling from 1978 onward. For former years (1959–77) an invariant M equal to 0.3 is used, derived from the average of the first five years (1978–82) of condition-based M estimates (Figure 9).

RESULTS

Numerous SAM runs (>100) were conducted in order to evaluate different data inputs and model formulations. Presenting the results and outputs for all of these model runs would not be practical. Therefore, only the most appropriate model runs are presented, based on expert

knowledge about the stock, goodness of fit and output analysis (residual patterns, retrospective analyses, and leave out runs).

A two-step approach was developed due the variety and large amount of data inputs that were made available during the 3Ps cod framework (Varkey et al. 2024). The first step aimed at setting up a sound model parametrization (called basic run) allowing for the inclusion of two supplementary data inputs in a second phase (i.e., time varying natural mortality and/or sentinel fishery indices).

BASIC RUN

The basic run (i.e., run 139) parametrization (Appendix 1) was developed through numerous trials of option settings and data use to achieve a sound basis for representing stock dynamics (see Appendix 7 for details). Based on the available data, the inputs used in this run are detailed in Table 1. The rationales for the main parametrization choices and assessment of the run outputs are presented below.

Considering the poor internal consistency in the most recent years of survey data for ages >12 (IO and GEAC, Figure 8), the age matrices used in the model were restricted to the range 2–12+. This led to a reduction of the overall abundance process error (Table 2).

Fishing mortality was estimated separately for all ages up to age 9 and fixed to be the same for ages 10 to 12. This choice resulted from a tradeoff between an improvement of the fit when all F at age are estimated, parsimony (fewer parameters when some F at age are estimated together) and a realistic selectivity pattern over time (Figure 10). The selectivity is mainly flat-topped until the 70s, which matches with important offshore catch by Canadian and non-Canadian trawlers; then progresses to a more domed shape before the 90s when cod traps were primarily used. After the moratorium (1997) a slight domed shape selectivity can be observed resulting from a mix between gillnets, trawls, and line trawls (Figure 11).

An AR1 was used to describe fishing mortality evolution over time, and the standard deviation parameter for F was estimated for ages 2/3–4/5+ (Table 2). The AR1 process for fishing mortality was preferred over the other processes because it produces a better fit to the varying catches, and consequently an improved AIC. The break in standard deviation estimation for F was found to be essential to allow the model to deal with the sudden drop in the catch at the moratorium, and the overall great variability of gear contribution to catches (Figure 11) resulting in change in catch age composition over time (Figure 1).

Catchabilities were estimated by age up to age 6 and then jointly for 7 to 12 (Figure 12, Table 3). To deal with the addition of inshore strata in the RV survey from 1997 onward, the series was split in two parts: offshore (OFF; 1983–96) and inshore/offshore (IO, 1997–2017). Considering these two parts as two different surveys, e.g., two sets of different catchabilities, led to a jump of retrospective bias in the estimates. It was inferred that the model needed a survey bridging over the moratorium period. To solve this issue, the approach adopted was that the two series were sharing some catchability parameters. A fraction index was computed dividing offshore total index by the overall index, this fraction shows the contribution of offshore strata to the overall index for each age (Figure 13). Based on this we can see that after age 5, in half of the years more than 90% of the index comes from offshore strata, so we tried to estimate inshore/offshore and offshore catchabilities together from age 5, 6, 7 and 8. Runs with age 5+ and 6+ mapping failed to converge while 7+ and 8+ were pretty similar. Based on AIC and expected catchability shape for trawl survey, ages 7 to 12 were chosen to be estimated jointly for each survey (except for OFF and IO where those parameters are shared). The slight bump in IO catchability at age 3 and 4 (Figure 12), probably reflects a known higher availability of

those fishes in inshore strata (Ings et al. 2019), but this availability is confounded with catchability in the model.

The standard deviation parameters for each survey were kept age invariant based on residuals and AIC screening. The standard deviation parameters for catch observation were estimated separately for age 2/3–4/5+, reflecting the fact that younger ages are sparser in the catch and thus less sampled (Figure 1).

The recruitment was modelled as a random walk since no stock-recruitment relationship has been previously evidenced for this stock (Shelton and Morgan 2013). Moreover, this option was providing a lower AIC than Ricker or Beverton-Holt functions. The variance in the population process was different for recruitment (age 2) and older ages.

The standard deviation parameters are summarized in a table (Table 2). The high values for survey observations suggests that the model is mostly fitting to the catch (mostly age 5+ catch due to high value of standard deviation parameters for age 2 and 3–4).

The process standard deviation parameters for the population are relatively small which suggests that overall, the population equation is describing the population dynamics well. However, fishing mortality rate variance estimates are relatively high, which is probably caused by the substantial changes in fishing levels: particularly the switch happening in the early 1990s, from high level of catch to only by-catch during the moratorium. The variance estimates are especially high for age 2 and 3–4, which is likely an effect of the changes in catch age composition caused by gear switch over time. In addition, the age and time invariant natural mortality rate used in this run might also add to uncertainty around F.

The predicted and observed total catch comparison (Figures 14 and 15), show an overall good fit, although the model has difficulties to fit some high catch records.

The observation residuals (Figure 16) display some year effects for surveys, which is concerning but not surprising. Indeed, year effects have been noted in the 3Ps surveys many times previously (e.g., Ings et al. 2019, Brattey et al. 2007). To deal with this specific issue, post-stratification on RV indices was attempted, but it did not lead to any improvements (Champagnat and Vigneau in press).

Process residuals (Figure 17) do not show concerning trends; the large bubble in F process in the 1990s are a side effect of the moratorium.

Leave-out fleet runs do not exhibit undue influences of the different surveys over time (Figure 18). Retrospective plots show a strong directional pattern in stock spawning biomass (SSB), average F and recruitment (Figure 19, see also Mohn's rho indices values Table 4). The bump in SSB for the y-10 retro (e.g., year 2007) is likely due to high IO survey catches of age 5, 6, 7, 8 and 9 in inshore strata in 2005 and 2007 (Figure 7), which probably lead to an overestimation of SSB. The recruitment bump in 2013 (green line) is related to the strong year class of 2011 being detected by the IO RV survey (Figure 7). The direction of the retrospective pattern is concerning because the SSB estimates are decreasing for every addition of new year data, which could lead to an over-optimistic perception of the status of the stock.

RUN WITH CONDITION MORTALITY INPUTS

In order to address the retrospective pattern seen in all SAM runs, but also in the SURBA model used previously for the stock assessment and in alternative models developed by DFO colleagues (Varkey et al. 2022), the natural mortality parameter was the first candidate for an in-depth analysis. After considering several options (see Appendix 2), the best fit was found to be with mortality inputs as time varying and based on a condition model (Figure 9). In the following

run (called condition run hereafter, i.e., run 140), these condition-based estimates of mortality replaced the assigned value of 0.3 used in the basic run (see inputs Table 5 and parametrization Appendix 3).

As a result, both recruitment and survival variance estimates decreased compared to the basic run (Table 2). This is logical: if the new M inputs are closer to reality, then the dynamic of the stock is better explained in this run, though process residuals in population and fishing mortality rates do not show important changes (Figure 20).

The observation residuals display fewer negative residuals in the last 3–4 years at age >7 for catches (Figure 21) than the basic model run. For the IO survey, this run gets rid of the patch of negative residuals at ages >3 in the last 3–4 years, suggesting that the higher natural mortality inputs match better the IO survey indices. Consequently, the IO standard deviation parameter decreases, while the ones for OFF, GEAC and ERHAPS increase slightly. The standard deviation parameters for catch observations do not change much (Table 2).

The catchability (Q) patterns are similar to the basic run (Figure 11 and 22), except for the inshore/offshore series where the elevated values for ages 3 and 4 have disappeared and a more traditional flat-topped shape is apparent. This decrease in IO Q might be an adjustment for the recent high recruitment predicted by the model. On the contrary, catchability parameters for OFF and ERHAPS are slightly higher at every age in comparison with the basic run (Table 3).

The leave out fleet analysis shows a higher influence of IO in the recent period, which is probably linked with the better fit of the model to this survey (Figure 23). The retrospective analysis points to an opposite directional pattern than the basic run (Figures 19 and 24). The retrospective pattern is also downscaled as reflected by the Mohn's rho indices (Table 4).

As the mortality is time variant but identical across ages, mostly the scale of SSB, F and recruitment estimates are modified mostly starting from the 1980s (Figure 25), and more pronounced differences are seen during the most recent period. During the 1980–90 period, the differences of scale between the two runs may be explained by the fact that M value used in run 140 for that time period (Figure 9) is lower than 0.3, which is the value used in run 139. Around 1978, and since 2005 the recruitment estimates are substantially higher than in the basic run, because at that time the condition based natural mortality is particularly high (Figure 9), and the model needs to 'create' fish to match both observations and high M. This leads to a recent level of recruitment similar to the 1960s', which is unlikely knowing the recent poor productivity of the 3Ps ecosystem (Ings et al. 2019). Since 2013, the sharp increase of estimated M, has led to a decline in SSB and an increase in F. The selectivity pattern estimated by this run is similar to the basic run.

In conclusion, the addition of a time varying condition M inputs to basic run performs well in terms of population variance and bias reduction. However, the recent estimates for recruitment are huge, which is not supported by survey nor fishery observations. In addition, it seems unlikely that current levels of recruitment are close to the 1960s levels. This leads to an increase in recruitment variance in comparison with the basic run. An attempt of using the condition model to produce M grouped by age was made but led to poor estimations and an increase in retrospective bias. However, the variance estimate for recruitment was closer to the basic run (Table 2). This emphasizes the need of splitting M estimation at least for younger ages, which aligns with common knowledge about fish life-history traits.

RUN WITH SENTINEL INDICES

Sentinel surveys using gillnets and line trawls began in 1995, during the moratorium. They aim to produce a time-series of indices based on a different and more extended annual sampling

period (i.e., June to November) than RV, along with incorporating fishermen knowledge. These sentinel fisheries are located in inshore 3Ps areas (e.g., Placentia, Fortune, and Hermitage bays) which are shoreward compared to survey stratification. The time and spatial differences with RV surveys allows for capturing information on fish not caught by RV surveys. The interpretation and thus use of sentinel indices have always been difficult. There has been speculation that changes in mean annual catch rates may have been influenced by competition with commercial fishers at the re-opening of the fishery (1997), local depletion, inter annual changes in the availability of fish, and shifts in the timing of sentinel fishing. There are also inconsistencies in cohort tracking between the sentinel and RV surveys, which suggests that misunderstood processes are happening. These differences could be due to changes in stock distribution within the year, gear selectivity, spatial coverage of sampling or underlying stock dynamics of a sub-component (Mello et al. 2018, Rideout et al. 2017). The formulation of this run (called sentinel run hereafter, i.e., run 143) is close to the basic one except small changes due to the addition of sentinel indices (Table 6, Appendix 4).

The catchability parameters for the sentinel line trawl survey were estimated jointly after age 5 to constrain a flat-top shape, on the contrary they remain variant at every age for the sentinel gillnet survey and display a dome shape (Figure 26). The high values of line trawl catchabilities result from the scale of the index which is expressed in mean number of fish by thousand hooks (Table 3). The catchabilities of ERHAPS and OFF surveys decreased in comparison with the basic run (Table 3). Whereas IO catchabilities are increasing at younger ages (2–5) and decreasing after age 6. It is probably pointing to a recent decrease of young fish in the population in comparison with the basic run.

Observation residuals are very similar to the basic run for catch and OFF, GEAC, ERHAPS surveys (Figure 27). Red patches of negative residuals for the last 3–4 year at age 4+ from the basic run tend to decrease, though they still appear for age 8+ (Figures 16 and 27). Some patches of residuals are visible for line trawl survey, which emphasizes the conflicts with other data. Gillnet residuals display a positive trend for age 3, this can be explained by the index values which are really close to 0 for this age.

The observation standard deviation parameters do not change much for catches compared to the basic run (Table 2). They decrease a bit for ERHAPS and OFF, pointing to a better fit to the survey observations. It is high for gillnet indices which pointed to a bad fit with this series but small for line trawl suggesting a higher influence of this series. Meanwhile, variance estimates for IO and GEAC increase, which probably underline discrepancies between those series and sentinel line trawl. The leave out fleet analysis (Figure 28) is consistent with those assumptions showing a substantially different trend without line trawl. Particularly, recent estimation of recruitment is highly sensitive to sentinel line trawl indices because the IO and line trawl indices show conflicting signals for ages 2 and 3 estimations (Figure 4).

The population variance is increased compared to the basic run, pointing to a poorer description of the population dynamics or observation discrepancies. The F standard deviation parameters at age 2 and 3–4 decrease whereas at age 5+ it increases. (Table 2). Nevertheless, process residuals seem the same (Figure 29).

The retrospective analysis remains one directional but with a lesser magnitude (Figure 30). The reduction of retrospective bias is underlined by Mohn's rho indices which are reduced by more than half for each variable (Table 4). The low values of sentinel indices at mature ages in the recent period produce lower estimates of SSB (compared to the basic run estimations), so that these estimations appear less subjected to retrospective bias.

The stock estimates from sentinel run are different from the basic run (Figure 31) even though the trends are mostly the same. The recruitment (R) differs from the basic run for a few spikes:

the peak of 1976 is attenuated, inversely the late-1980s and early-1990s levels of R are higher. This is likely due to a better fit to ERHPAS and OFF surveys (reduced standard deviation parameters as above), in 1978, few age 4 fishes are seen by ERHAPS, which reduces the recruitment peak estimated by catches two years before. In the late-1980s catch numbers reported larger catch of age 3 fishes and survey indices tracked high records of age 2 fishes which align to estimate higher recruitment (See Figure 1 for catch standardized proportions at age per year (SPAY) plot and Figure 7 for ERHAPS indices plot). Recently the peak of 2000 is higher in the sentinel run because the line trawl index tracks a high number of age 3 fish this year, after 2010 this index goes down which is pulling the overall recruitment estimate down.

The average F displays a fairly large reduction in the 1992 peak, probably resulting from higher numbers of fish at age 5 produced by previous large recruitment events. In the late-1990s, average F is estimated higher, before passing below the basic run estimates around 2005 and then above again after 2013. The F spike in the late 90s is likely due to the sharp decline in sentinel line trawl indices at that time, then the indices bounce back in 2005. The leave out run without sentinel tends to confirm that assumption (Figure 30). The differences in stock spawning biomass can easily be explained by the differences in average F.

The selectivity pattern is also impacted recently, after 2010 a more dome shape is evidence in the sentinel run (Figure 32).

In conclusion, the addition of mainly the line trawl catch per unit effort (CPUE) time series significantly changes the overall estimation of stock dynamics during the post-moratorium period compared to the basic run. Some concerns need to be resolved on the instability of the recruitment estimates especially in the recent period, although the resulting retrospective pattern is halved, which is thus an improvement from the basic run. Adding the sentinel fisheries data as input to the model might lead to identify specific inshore dynamics of the stock, which seems to perform well here.

RUN WITH SENTINEL INDICES AND CONDITION M ("COMBINED")

This run was conducted to assess the combined effects of sentinel indices and time-varying natural mortality (M) on the basic run (see inputs in Table 7 and parametrization Appendix 5). This run will be called 'combined run' in the following paragraphs.

It is first noticeable that the shapes of the estimated catchabilities (Figure 33) seem similar to those with the sentinel run. However, most catchability parameters change, for example for ERHAPS survey estimates increase compared to sentinel and basic run and get close to condition M run values. On the contrary, sentinel catchabilities values decrease at all ages in comparison with sentinel run (Table 3).

The observation residuals remain very similar to the previous runs for ERHAPS, GEAC, offshore and gillnet surveys (Figure 34). Catch residuals display a positive patch for ages 4 to 9 in the last years, which is close to both sentinel and condition M runs. The recent residuals for IO survey display less negative residual than basic run and thus is closer to residuals from both sentinel and condition M runs. Finally, the sentinel line trawl exhibits a positive trend in age 6 to 10 residuals since the late-2000s. The recent overall trend of positive residuals underline lower population estimates than observations which is probably caused by the increase of natural mortality in the last 10 years in this run (Figure 34).

The variance estimates of observations associated with catches (Table 2) are close to previous runs (basic, condition M and sentinel), although the age 5+ is slightly lower. Both OFF, IO and ERHAPS have lesser variance estimates than the basic run, whereas in sentinel and condition M runs they were not all reduced. GEAC and sentinel GN standard deviation parameters remain

around 1 or above, thus the model is not fitting to them. The standard deviation parameter for sentinel line trawl have slightly increased compared to sentinel run, which is probably a trade off with decrease in IO variance, as those data disagree in the recent period (Figure 4).

Variance estimates for *F* process remains close to other runs estimations for 3–4 and 5+ and reach an intermediary between previous values for age 2. Recruitment has the lowest variance of all the runs and survival the highest. This increase in population variance is visible in *N* process residual plot where a patch of positive residuals appears in the recent period (Figure 35). A positive pattern means that the process error needs to add fish to the equation, which suggests a lack of fish, probably caused by high natural mortality and low survey observations. The fishing mortality process residuals do not exhibit really different patterns than previous runs.

Leave out analysis displays higher influences of surveys in *F* and *R* spikes, this agrees with the decrease of variance around most survey indices (Figure 36). It also underlines the conflicts between data sources.

The retrospective analysis exhibits patterns in the opposite direction of the basic run, thus in the same direction as the condition *M* run (Figure 37). When comparing Mohn's rho index values, it appears that retrospective bias is higher for SSB and *F* in this run than in the *M* condition run, but smaller for recruitment (Table 4). This makes sense because the huge estimates of recruits created by high *M* are downscaled by sentinel indices in this run. The magnitude of the retrospective bias is lower in this run than in the basic and sentinel runs, but the unidirectional pattern remains.

In conclusion, the confrontation of sentinel indices with condition *M* input in the basic run leads to mitigate performance issues. The larger population variance (Table 2), instability of stock estimates (leave out analysis, Figure 36) along with more patterns in the residuals (Figures 34 and 35) indicate a model that is attempting to make trade-offs between conflicting data inputs. Regarding recruitment, the combined model input modification provides a way to downscale recent estimates from the modified *M* run (Figure 38) and thus display a low standard deviation parameter along with the smallest retrospective bias observed among runs (Table 2). Concerning average *F* and SSB, the combined effect of high natural mortality and survey observation impact the scale of estimation so much that a retrospective bias is observed in the opposite direction than in the basic run. It can be acknowledged that the sentinel surveys are bringing most of the data conflict and thus difference in trajectories of various output.

COMPARISON OF MODEL RUNS

Trends in SSB, *F* and *R* for the presented model runs are compared in Figure 38 in order to allow easy comparison of model estimates and the influence of the various model inputs. Only confidence intervals for the basic run were shown to avoid visual saturation.

The SSB trends are quite noticeable since two different stories are displayed, each of them by two runs. The combined and condition *M* runs (i.e., runs 144 and 140, respectively) suggest a slow and steady decrease in SSB after 2005 and a recent shift to a sharper decrease during the last two years. The other two runs (basic and sentinel run, i.e., runs 139 and 143, respectively) suggest that SSB decreased at a higher rate after 2005 until the most recent estimates when an upward trend starts to appear.

For *F* estimates, the same duos are providing different stories in the 1980s and will differ between them only during the moratorium. *F* estimates are identical across runs until the end of the 1970s, then the combined run (144) estimates follow those from the condition *M* run (139) with spikes in the 1980s (same duo as for SSB). After, the duos seen for SSB are displaying

approximately the same trends, expectedly inverse from SSB, but with more differences in scales than for SSB.

Looking at the recruitment estimates four periods can be identified, aligning with the addition of the diverse data sources. For the period 1959–75 recruitment estimates are very close for all runs. With the addition of ERHAPS indices and *M* condition estimates in 1978, the four run estimates differed until 1991 when ERHAPS discontinued. From 1995 to 2005, the four runs show strong consistency in recruitment estimates, despite the inclusion of sentinel indices in 1995 and the shift to IO indices in 1997. Finally, in 2005, the dramatic increase in condition-based estimates led to a sharp increase of recruitment estimates from *M*-condition run (i.e., run 140). On the contrary, the steady decline in line trawl sentinel indices at age 3 from 2005 drove very low recruitment estimates for sentinel run (i.e., run 143). Noticeably, the combined run (i.e., run 144) displays a trade-off between those two extremes. Except the sentinel run (i.e., run 143), the well observed strong cohort of 2011 (e.g., 2013 peak at age 2) is tracked, but with different magnitudes.

The estimated selectivity shape (Figure 39) is consistent between all runs until 2011. Afterward, the sentinel run (i.e., run 143) starts to display a dome shape while the three others remain flat-topped.

OTHER RUNS

Runs With Between Age Correlation in Observations

During the Framework meeting, some advice was given concerning the use of correlation between age in observations, and few tries were attempted using the basic run as a basis (Appendix 6).

Overall, using correlated observations reduced AIC, year effects seen in observation residuals, and some retrospective bias. Nevertheless, it was also leading to convergence issues, and an increase of correlation between estimated parameters.

Finally, the 'best' correlated run (run 161 in Appendix 6) displays unexpected residual correlation, with a lot of negative correlations, indicating that the age-AR1 correlation structure chosen is probably not appropriate. This might be linked with the mixing concerns this stock is facing. Indeed, migration events can impact survey indices, for example, it could lead to year effects in certain ages. Whereas the AR1 age-correlation structure is meant to track some cohort effect in the residuals. Therefore, it was decided to not use this feature.

Run Including Landings Uncertainty

Based on a survey with fishermen aiming to identify potential periods of inaccurate landings (Carruthers and Ings, pers. comm.), attempts were made to estimate catches over- or under-reporting for some years. See runs 73, 74, 77, 78, 79, 90, 91, 92, 95 and 122 in Appendix 7. However, all of these runs estimated over-reporting of catch during the pre-moratorium period which is opposite to expert knowledge. Thus, we did not keep this feature.

DISCUSSION AND CONCLUSION

The SAM model has been applied to the 3Ps cod stock as a potential method for assessing the stock status. Four model formulations ("runs") were presented and discussed at the framework meeting held from the October 8–10, 2019 (DFO In press).

The "basic run" could not be accepted because of the important retrospective patterns in the estimates of recruitment, stock spawning biomass and fishing mortality.

The run using condition-based estimates of natural mortality presented great improvements regarding the retrospective pattern but introduced issues with respect to recruitment estimation. There were also concerns expressed about using the natural mortality values estimated based on condition indices (Appendix C in Varkey et al. 2022) in SAM:

1. reliability: the condition-based estimation of natural mortality is new for 3Ps area, and some revisions might be needed;

2. accuracy: mortality estimates are not split by age which causes issues mentioned above.

Those two concerns stand for any model using condition-based estimates of M. Also, because SAM uses the M values directly as inputs and fit exactly to the values, they cannot be mitigated by scaling at age or exploited as a trend as was done in the HYBRID model (Varkey et al. 2022). Some alternative approaches have been suggested, including building a function that would estimate parameters at age to scale M values. However, attempts to do this have been unsuccessful so far. Given this, it was decided that runs with M condition should not be carried on further.

The run with sentinel indices performed well in terms of retrospective patterns. Despite the discussion about the inclusion of sentinel data in the model (inconsistent trend with DFO RV survey and spatial contraction) it was decided to keep them as inputs (DFO in press).

Compared to HYBRID, the SAM model displays some weaknesses (less flexibility inducing weaker fit to 3Ps data) but also benefits ("simpler" structure, parametrization and use, validated framework, worldwide use). Accordingly, the group suggested using the HYBRID model as a basis for advice and the SAM alongside as a "control model." It means that any inconsistency between outputs of the two models should be explored and commented (DFO in press).

A general concern raised during the framework meeting was about the poor fit of all runs to RV survey data (DFO in pre[4]). Indeed, the bottom trawl survey is designated for scientific purposes and should be an important data source. Moreover, it has a good spatial coverage of 3Ps area and a high set density. However recurring issues in the survey outcomes are identified: inter-annual variability, unbalanced contribution of strata to the global index inducing some year effects and substantial uncertainty around indices (DFO 2020, Ings et al. 2019). Several approaches have been attempted to overcome those issues as indices post-stratification (Champagnat and Vigneau in press), spatial treatment (Babyn *et al.* 2021), or inclusion of a year effect in the assessment modeling design (Varkey et al. 2022), but to date no satisfying solutions have been found. These issues might be related to some stock dynamics which remain not fully resolved. As mentioned above, the 3Ps stock is subjected to seasonal stock mixing in the Burgeo Bank area (Méthot et al. 2005, Brattey et al. 2007), and the impact on fisheries and survey data is still not clearly understood. This remains as an area for improvement and an important research perspective.

ACKNOWLEDGMENTS

REFERENCES CITED

Babyn, J., Varkey, D., Regular, P., Ings, D., and Flemming, J.M. 2021. A gaussian field approach to generating spatial age length keys. Fish. Res. 240: 105956.

Berg, C.W., and Nielsen, A. 2016. Accounting for correlated observations in an age-based state-space stock assessment model. ICES J. Mar. Sci. 73(7): 1788–1797.

Bishop, C.A., Murphy, E.F., and Davis, M.B. 1994. An assessment of the cod stock in NAFO Subdivision 3Ps. DFO Atl. Fish. Res. Doc. 1994/033. 33 p.

Brattey, J., Cadigan, N.G., Healey, B.P., Murphy, E.F. and Mahé J.-C. 2007. Assessment of the cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps in October 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/053. v + 54 p.

Brodziak, J., Ianelli, J., Lorenzen, K., and Methot Jr., R.D. (eds). 2011. Estimating natural mortality in stock assessment applications. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-119: 38 p.

Cadigan, N.G. 2010. Trends in Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Cod (*Gadus morhua*) stock size based on a separable total mortality model and the Fisheries and Oceans Canada Research Vessel survey index. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/015. iv + 43 p.

Casini, M., Eero, M., Carlshamre, S., and Lövgren, J. 2016. Using alternative biological information in stock assessment: condition-corrected natural mortality of Eastern Baltic cod. ICES J. Mar. Sci. 73(10): 2625–2631.

Champagnat, J., and Vigneau, J. In press. A post-stratification analysis on 3Ps cod RV survey indices. IFREMER Technical Report.

DFO. 2020. Stock Assessment of NAFO Subdivision 3Ps Cod. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/018.

ICES. 2019. Arctic Fisheries Working Group (AFWG). ICES Scientific Reports. 1:30. 930 pp.

ICES. 2020. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp.

DFO. In press. Proceedings of the Framework Project on Population Models for Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Atlantic Cod; October 8-10, 2019. DFO Can. Sci. Advis. Sec. Proceed. Ser.

Ings, D.W., Rideout, R.M., Wheeland, L., Healey, B.P., Morgan, M.J., Regular, P., and Vigneau, J. 2019. Assessing the status of the cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps in 2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/024. iv + 83 p.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2015. TMB: Automatic Differentiation and Laplace Approximation. J. Stat. Soft. 70(5): 1–21.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. J. Fish. Bio. 49(4): 627–642.

Maunder, M.N., and Punt, A.E. 2013. A review of integrated analysis in fisheries stock assessment. Fish. Res. 142: 61–74.

McClintock, J. 2003. Cod catch results 2002: Year six of the NAFO Subdivision 3Ps Fall GEAC Surveys. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/097. i + 28 p.

Mello, L.G.S., Miri, C.M., Maddock-Parsons, D., Rockwood, H., and Simpson, M.R. 2018. Sentinel Surveys 1995-2016 – Catch rates and biological information on Atlantic Cod (*Gadus morhua*) in NAFO Subdivision 3Ps. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/033. iv + 25 p.

Méthot, R., Castonguay, M., Lambert, Y., Audet, C., and Campana, S.E. 2005. Spatio-temporal Distribution of Spawning and Stock Mixing of Atlantic Cod from the Northern Gulf of St. Lawrence and Southern Newfoundland Stocks on Burgeo Bank as Revealed by Maturity and Trace Elements of Otoliths. J. Northw. Atl. Fish. Sci. 36: 31–42.

Nielsen, A., and Berg, C.W. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fish. Res. 158: 96–101.

R Development Core Team. 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0

Rideout, R.M., Ings, D.W., Healey, B.P., Brattey, J., Morgan, M.J., Maddock Parsons, D., and Vigneau, J. 2017. Assessing the status of the cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps in 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/063. v + 68 p.

Shelton, P.A., Stansbury, D.E., Murphy, E.F., Brattey, J., and Lilly, G.R. 1996. An Assessment of the cod stock in NAFO subdivision 3Ps. DFO Atl. Fish. Res. Doc. 1996/091.

Shelton, P.A., and Morgan, M.J. 2013. Virtual population assessment (VPA) estimates of stock size and maximum sustainable yield (MSY) reference points for 3Ps cod. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/173. ii + 39 p.

Varkey, D.A., Babyn, J., Regular, P., Ings, D.W., Kumar, R., Rogers, B., Champagnat, J. and Morgan, M.J. 2022. A state-space model for stock assessment of cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/022. v + 78 p.

Varkey, D.A., Ings, D.W., Champagnat, J., Penney, H., Rogers, B., Robertson, G., Regular, P.M., Novaczek, E. 2024. Report of the data-review meeting in preparation for the assessment framework of 3Ps Cod stock in southern Newfoundland. Can. Data Rep. Fish. Aquat. Sci. 1381: x + 56 p.

TABLES

Table 1: Data inputs used for the basic run.

Type	Year Range	Age Range	Sources
Catch at age in number	1959–2019	2–12+	Fisheries sampling
Catch weight at age	1959–2019	2–12+	Fisheries sampling
Stock weight at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Maturity at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Natural mortality at age	1959–2019	2–12+	Age and year invariant hypothesis. Value set at 0.3
Survey indices	-	-	-
ERHAPS	1978–1991	2–12+	French RV survey
OFF	1983–1996	2–12+	DFO RV survey
IO	1997–2019	2–12+	DFO RV survey
GEAC	1998–2005	2–12+	Industry based

Table 2: Standard deviation parameters estimated and number of iterations before convergence of each run. Lowest value for each parameter presented in bold.

Standard Deviation Parameters	Basic Run (139)	Condition-Based *M* Run (140)	Sentinel Run (143)	Combined Run (144)
Recruitment	0.32	0.37	0.31	**0.27**
Survival/population	0.13	**0.08**	0.20	0.24
Age 2 F	0.80	0.86	**0.65**	0.77
Age 3–4 F	1.06	1.04	**1.01**	**1.01**
Age 5+ F	0.63	**0.60**	0.66	0.64
Age 2 catch	1.70	1.70	**1.69**	**1.69**
Age 3–4 catch	0.64	0.65	0.63	**0.62**
Age 5+ catch	0.29	0.30	0.27	**0.25**
OFF	0.78	0.80	**0.73**	0.74
IO	0.75	**0.66**	0.81	0.73
GEAC	**0.95**	0.99	0.99	0.99
ERHAPS	0.8	0.85	**0.76**	0.79
Sentinel LT	X	X	**2.76**	2.79
Sentinel GN	X	X	**0.32**	0.39
Number of iterations before convergence	**108**	122	124	114

Table 3: Catchability parameter estimated for each survey by each run.

Survey	Run	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
OFF	**139**	0.16	0.23	0.30	0.5	0.69	0.92	0.92	0.92	0.92	0.92	0.92
	140	0.22	0.31	0.37	0.61	0.82	0.91	0.91	0.91	0.91	0.91	0.91
	143	0.14	0.21	0.27	0.45	0.61	0.84	0.84	0.84	0.84	0.84	0.84
	144	0.16	0.23	0.29	0.49	0.66	0.82	0.82	0.82	0.82	0.82	0.82
IO	**139**	0.38	0.92	1.0	0.93	0.89	0.92	0.92	0.92	0.92	0.92	0.92
	140	0.21	0.59	0.74	0.74	0.75	0.91	0.91	0.91	0.91	0.91	0.91
	143	0.46	1.1	1.16	1.0	0.91	0.84	0.84	0.84	0.84	0.84	0.84
	144	0.27	0.75	0.89	0.86	0.80	0.82	0.82	0.82	0.82	0.82	0.82

Survey	Run	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
GEAC	139	0.01	0.1	0.29	0.37	0.45	0.60	0.60	0.60	0.60	0.60	0.60
GEAC	140	0.01	0.1	0.28	0.36	0.45	0.62	0.62	0.62	0.62	0.62	0.62
GEAC	143	0.01	0.1	0.27	0.38	0.50	0.79	0.79	0.79	0.79	0.79	0.79
GEAC	144	0.072	0.78	0.23	0.34	0.46	0.72	0.72	0.72	0.72	0.72	0.72
ERHAPS	139	0.062	0.09	0.13	0.22	0.31	0.42	0.42	0.42	0.42	0.42	0.42
ERHAPS	140	0.09	0.12	0.15	0.25	0.36	0.49	0.49	0.49	0.49	0.49	0.49
ERHAPS	143	0.059	0.09	0.13	0.22	0.31	0.41	0.41	0.41	0.41	0.41	0.41
ERHAPS	144	0.077	0.11	0.15	0.25	0.35	0.45	0.45	0.45	0.45	0.45	0.45
Sent GN	143	X	0.000	0.044	0.051	0.2	0.29	0.32	0.30	0.22	X	X
Sent GN	144	X	0.000	0.004	0.046	0.18	0.28	0.31	0.29	0.23	X	X
Sent LT	143	X	0.39	1.5	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
Sent LT	144	X	0.29	1.24	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69

Table 4: Mohn's rho index for stock spawning biomass, average fishing mortality rate and recruitment. Closest values to zero are presented in bold.

Variable/Run	Basic Run (139)	Condition-Based *M* Run (140)	Sentinel Run (143)	Combined Run (144)
SSB	1.27	**0.004**	0.28	-0.18
Average *F*	-0.58	**0.03**	-0.27	0.21
Recruitment	1.1	-0.36	0.53	**-0.27**

Table 5: Data inputs used for the M condition run (run 140). Modifications from the basic run are shaded in grey.

Type	Year Range	Age Range	Sources
Catch at age in number	1959–2019	2–12+	Fisheries sampling
Catch weight at age	1959–2019	2–12+	Fisheries sampling
Stock weight at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Maturity at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Natural mortality at age	1959–2019	2–12+	Year variant. Model based on fish condition index from DFO RV survey
Survey indices	-	-	-
ERHAPS	1978–1991	2–12+	French RV survey
OFF	1983–1996	2–12+	DFO RV survey
IO	1997–2019	2–12+	DFO RV survey
GEAC	1998–2005	2–12+	Industry based

Table 6: Data inputs used for the sentinel run (run 143). Modifications from the basic run are shaded in grey.

Type	Year Range	Age Range	Sources
Catch at age in number	1959–2019	2–12+	Fisheries sampling
Catch weight at age	1959–2019	2–12+	Fisheries sampling
Stock weight at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Maturity at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Natural mortality at age	1959–2019	2–12+	Age and year invariant hypothesis. Value set at 0.3

Type	Year Range	Age Range	Sources
Survey indices	-	-	-
ERHAPS	1978–1991	2–12+	French RV survey
OFF	1983–1996	2–12+	DFO RV survey
IO	1997–2019	2–12+	DFO RV survey
GEAC	1998–2005	2–12+	Industry based
Sentinel line trawl	1995–2018	3–10	Fishery based
Sentinel gillnet	1995–2018	3–10	Fishery based

Table 7: Data inputs used for the combined run (run 144). Modifications from the basic run are shaded in grey.

Type	Year Range	Age Range	Sources
Catch at age in number	1959–2019	2–12+	Fisheries sampling
Catch weight at age	1959–2019	2–12+	Fisheries sampling
Stock weight at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Maturity at age	1959–2019	2–12+	Model based on DFO RV survey sampling
Natural mortality at age	1959–2019	2–12+	Year variant. Model based on fish condition index from DFO RV survey
Survey indices	-	-	-
ERHAPS	1978–1991	2–12+	French RV survey
OFF	1983–1996	2–12+	DFO RV survey
IO	1997–2019	2–12+	DFO RV survey
GEAC	1998–2005	2–12+	Industry based
Sentinel line trawl	1995–2018	3–10	Fishery based
Sentinel gillnet	1995–2018	3–10	Fishery based
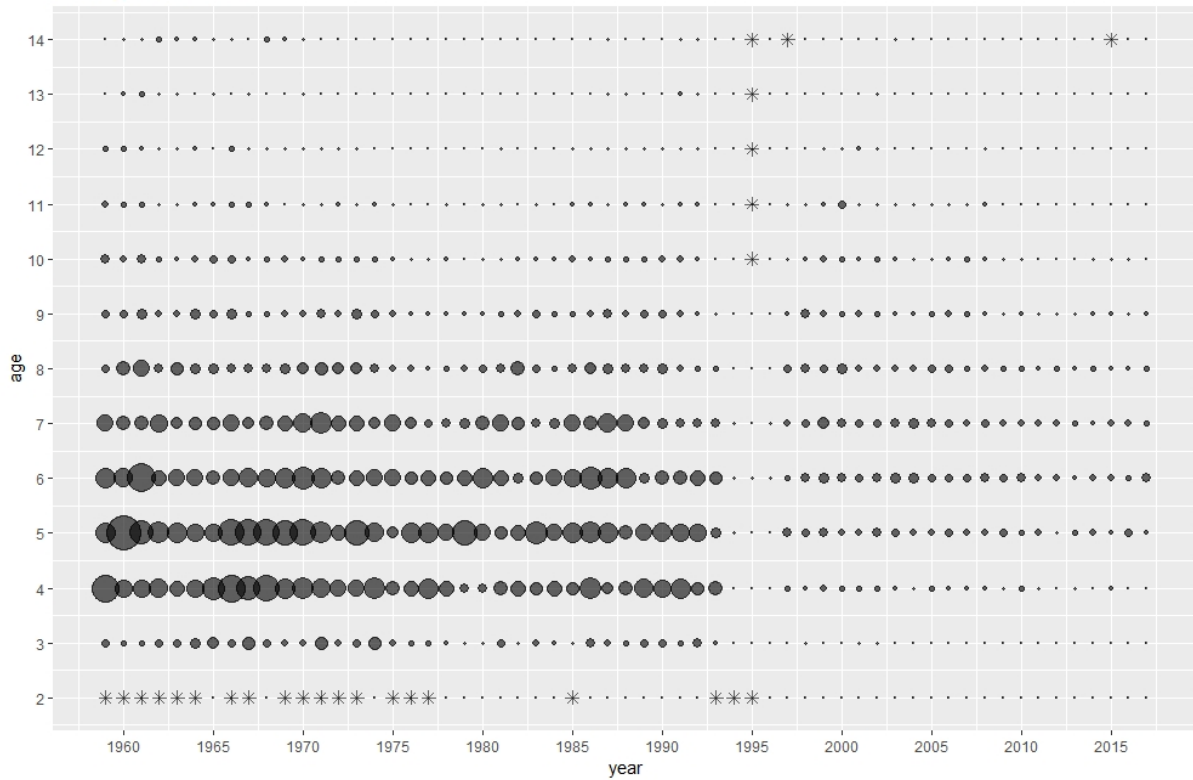
Figure 1: Catch at age data, upper panel: bubble plot displaying catch at age composition.
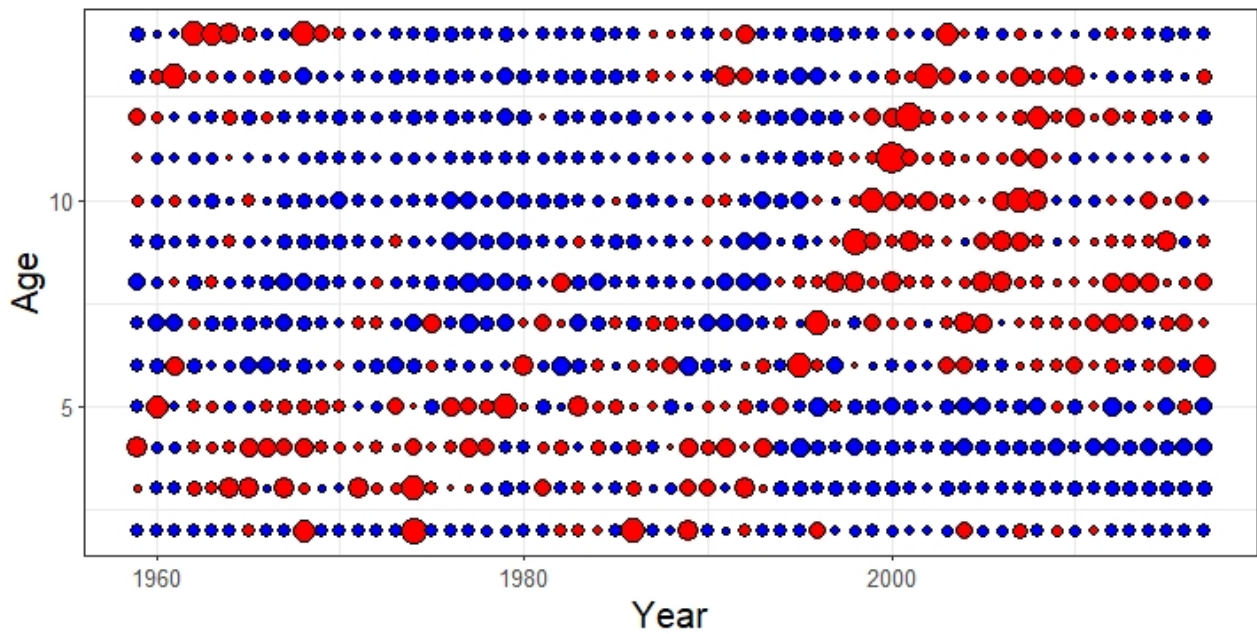
Figure 2: Catch at age data: SPAY of catch.
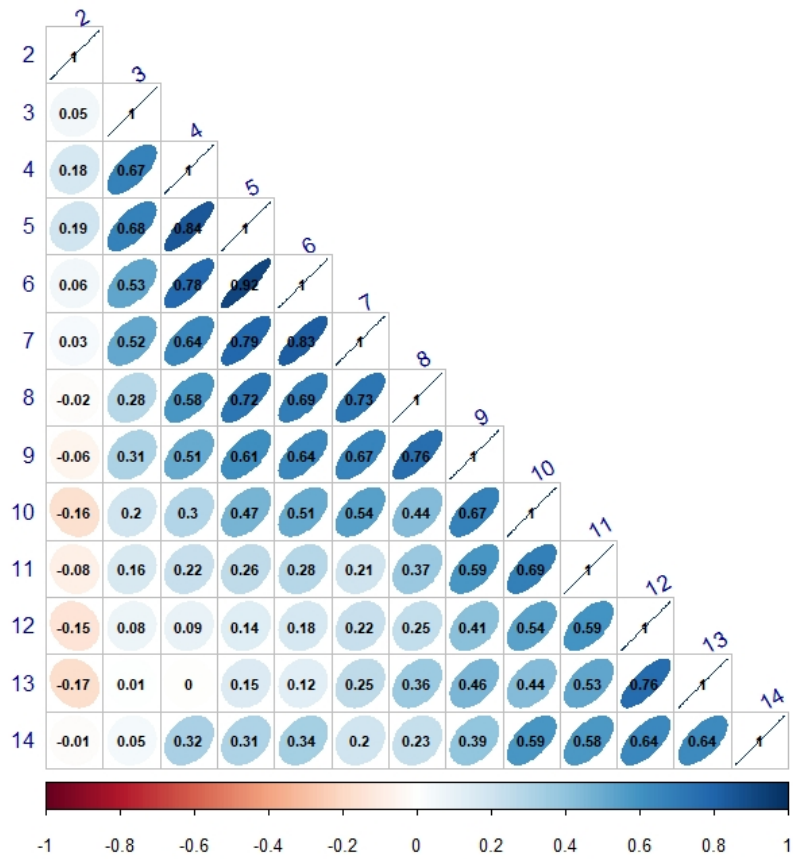
Figure 3: Internal consistency of the catch at age series.
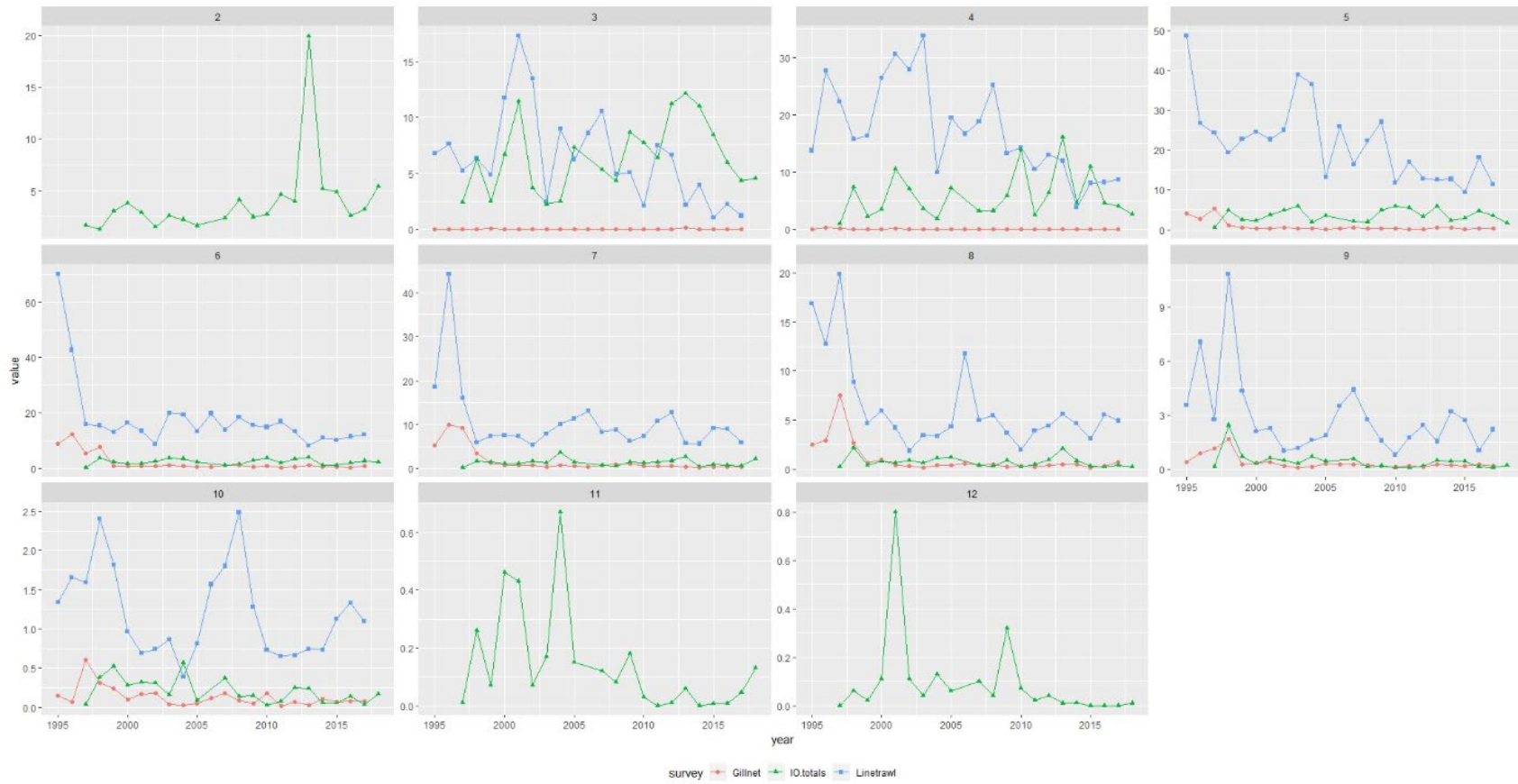
Figure 4: IO survey and sentinel line trawl and gillnet survey time series.
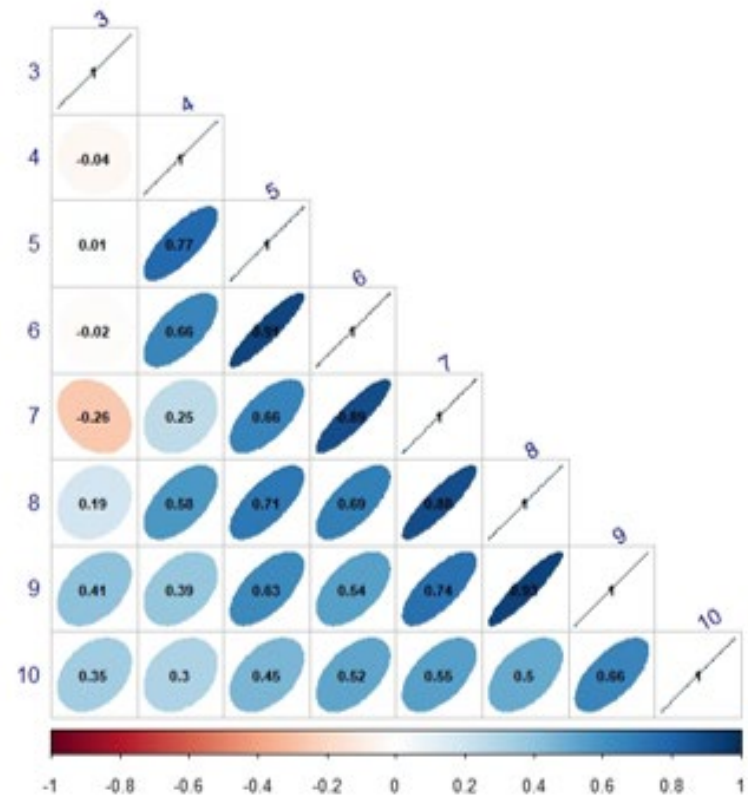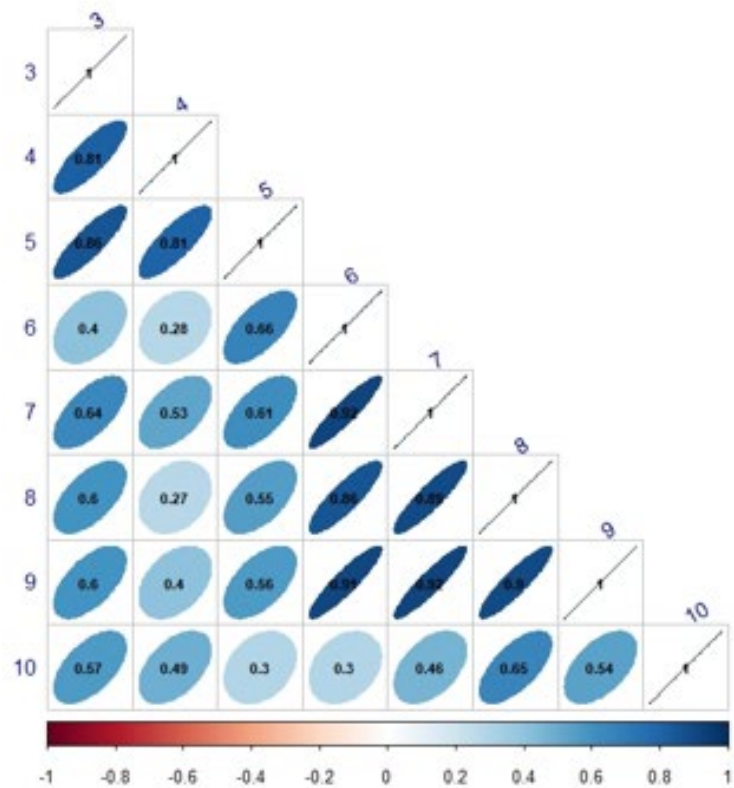
Figure 5: Sentinel line trawl (left) and gillnet (right) survey internal consistency plots.
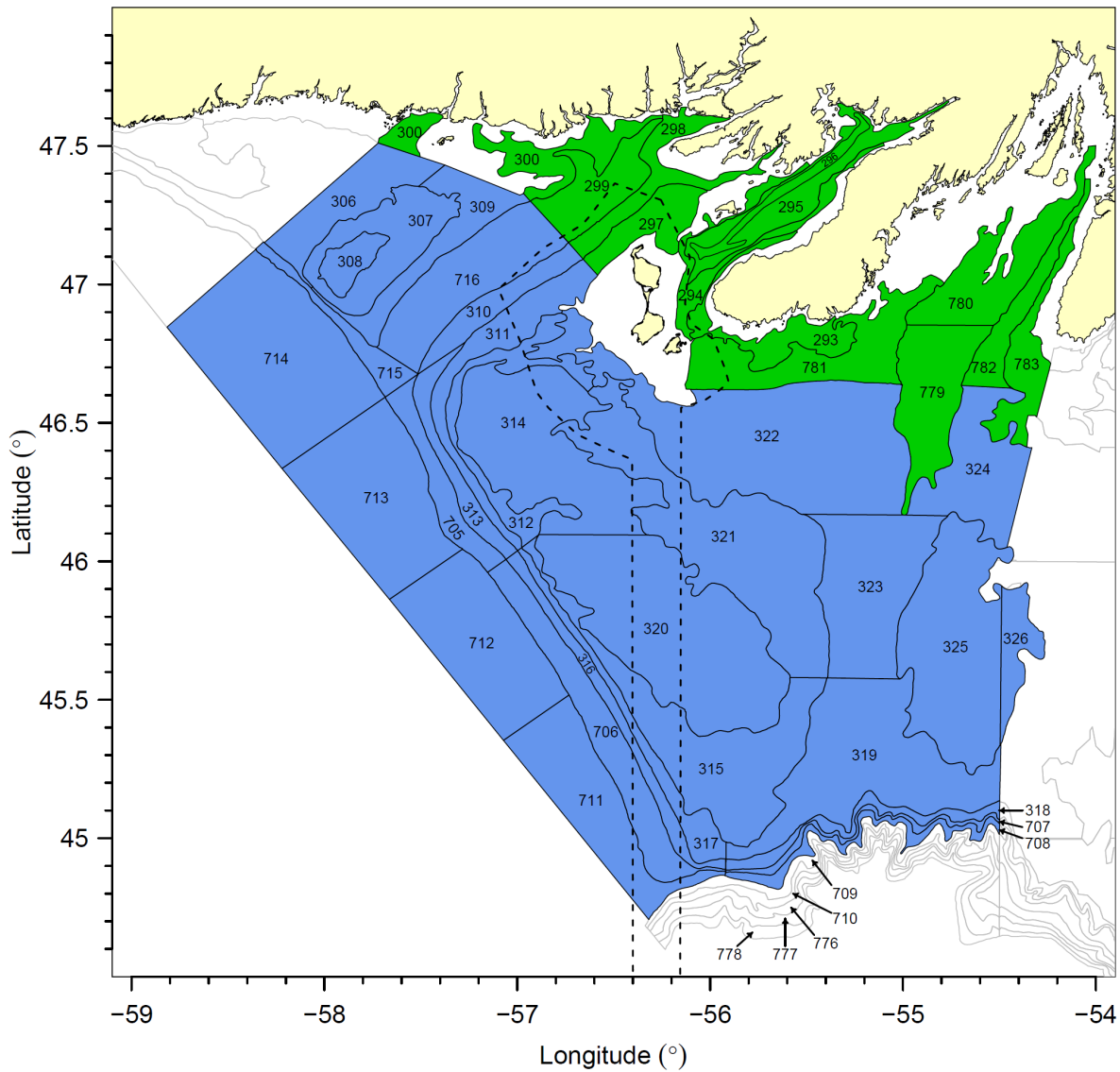
Figure 6: Stratum area boundaries and area surveyed during the research vessel bottom-trawl survey of NAFO Subdiv. 3Ps. Offshore strata are shaded blue. Inshore strata were added in 1994 (strata 779–783) and 1997 (strata 293–300) and are shaded green. The dashed line represents the boundary of the French economic zone.
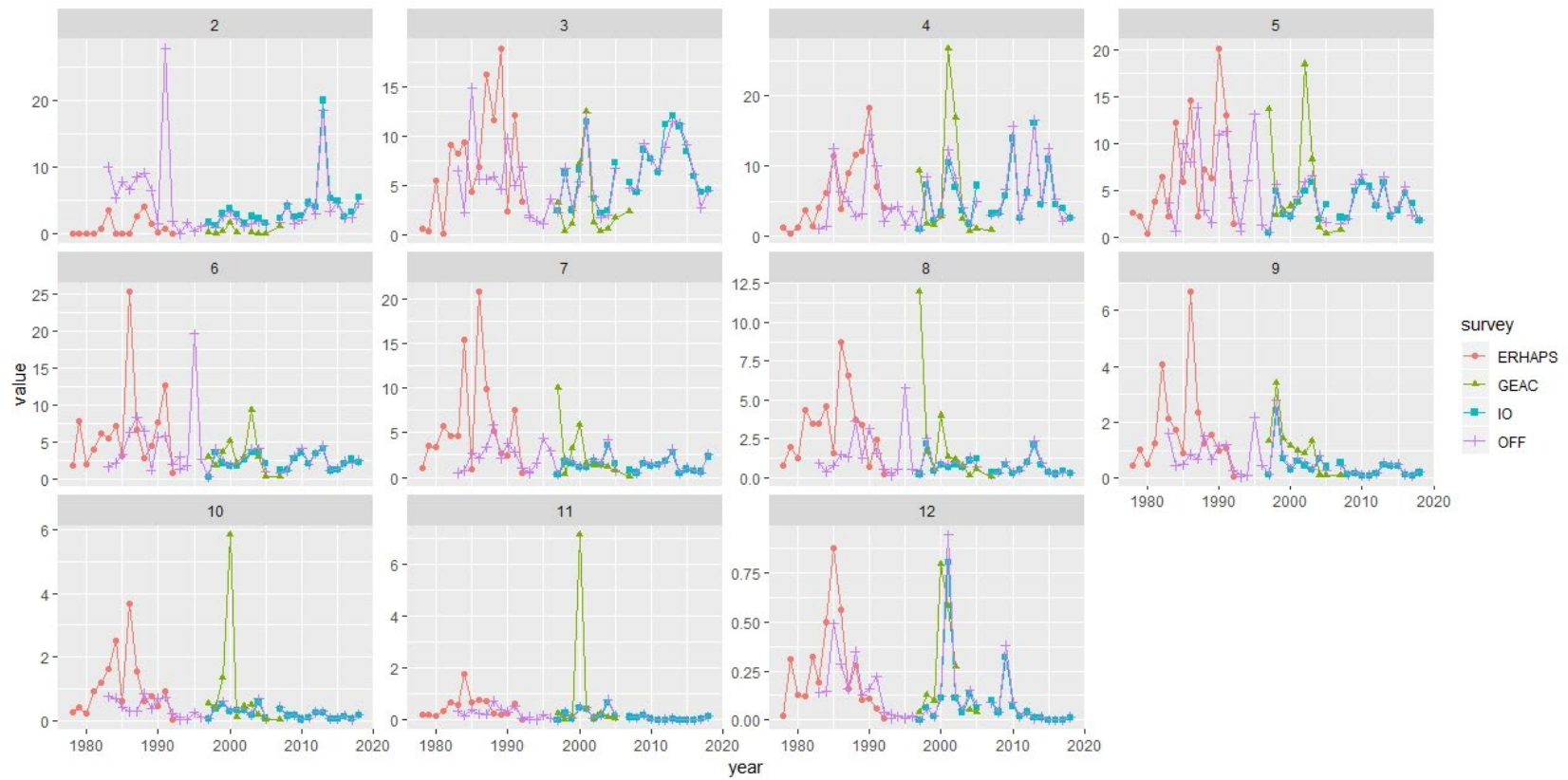
Figure 7: Indices at age for ERHAPS, GEAC, Offshore and inshore/offshore RV DFO surveys.
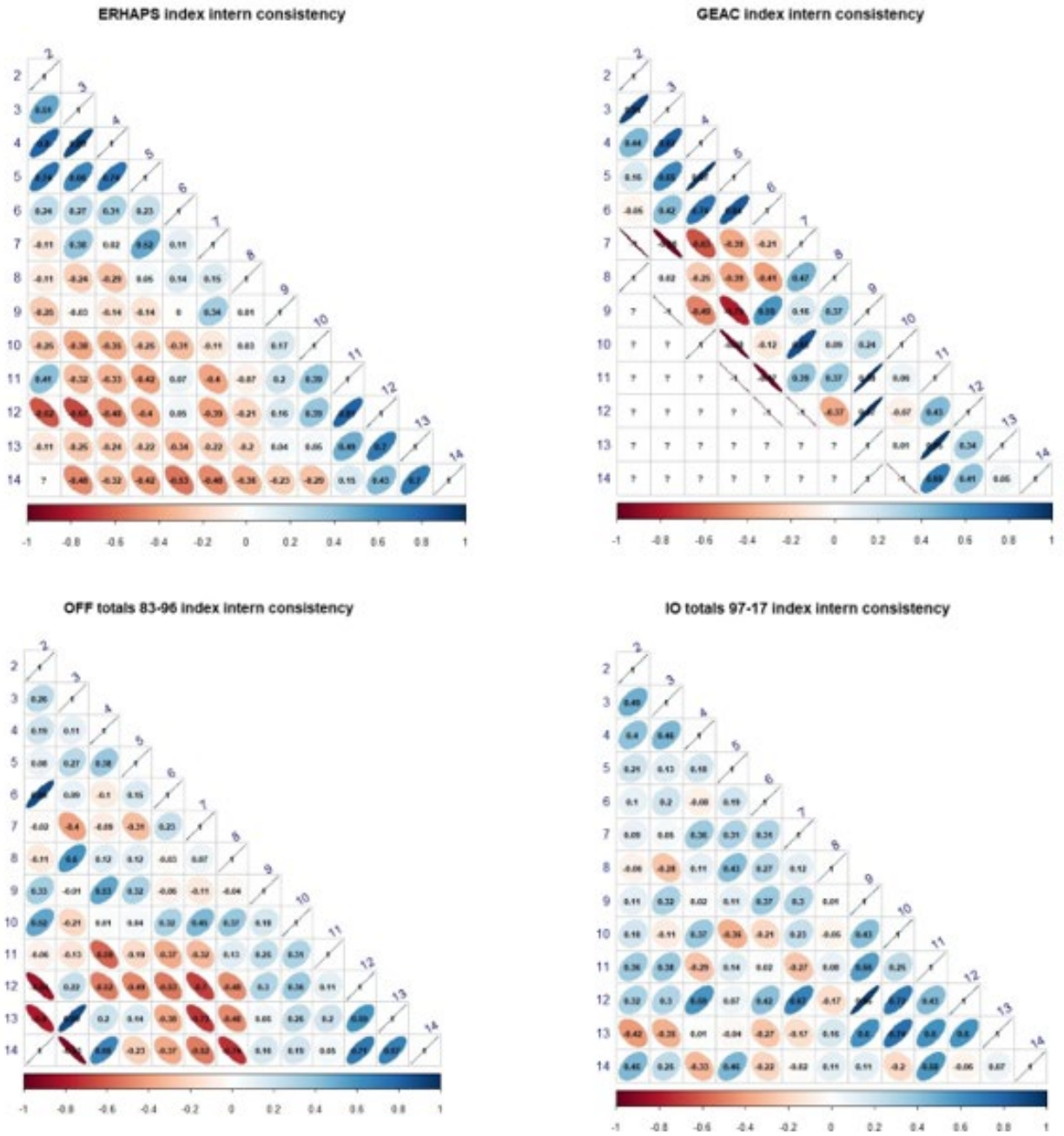
Figure 8: ERHAPS, GEAC, Offshore and inshore/offshore RV DFO surveys internal consistency plots.
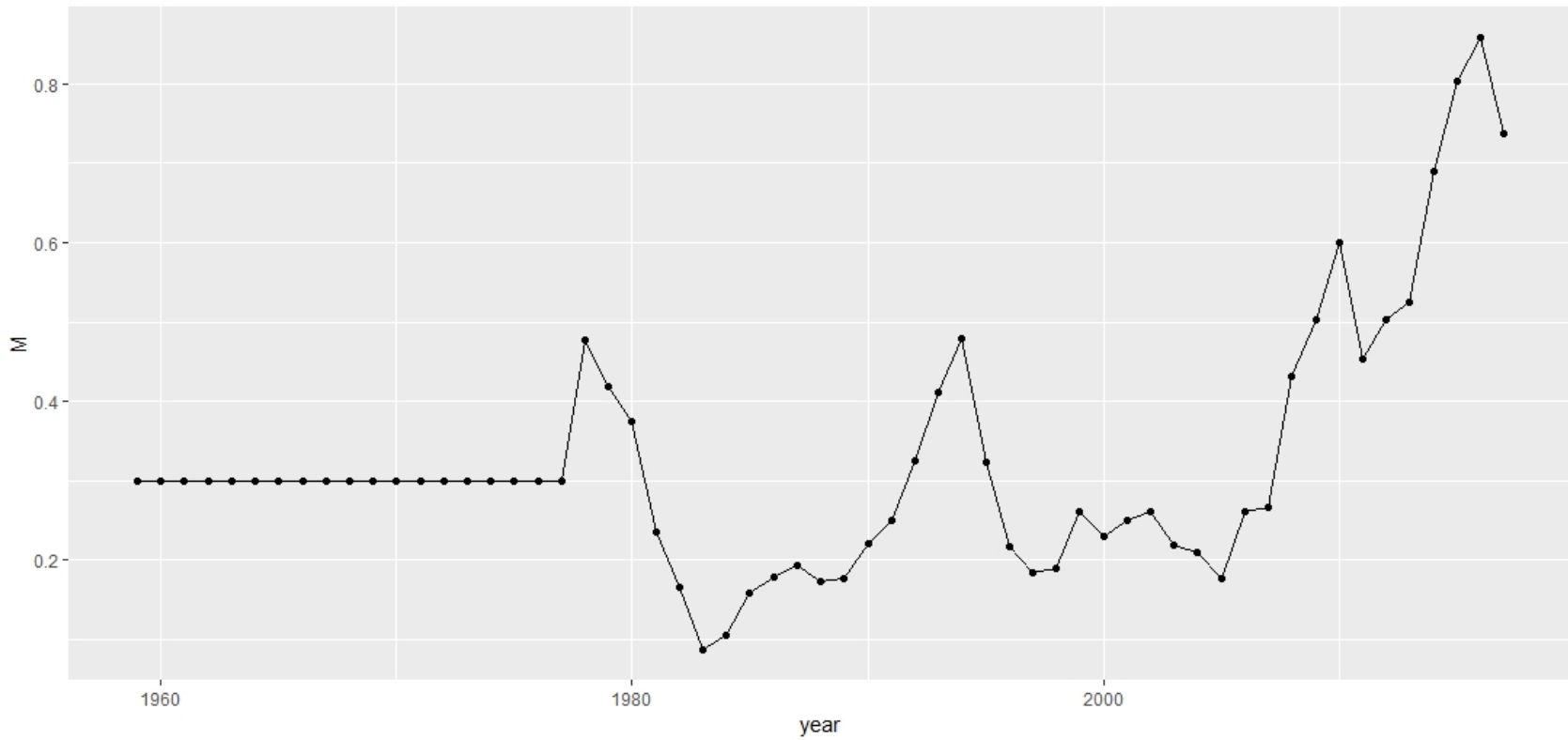
Figure 9: Natural mortality estimates from condition model (Appendix C in Varkey et al 2022).
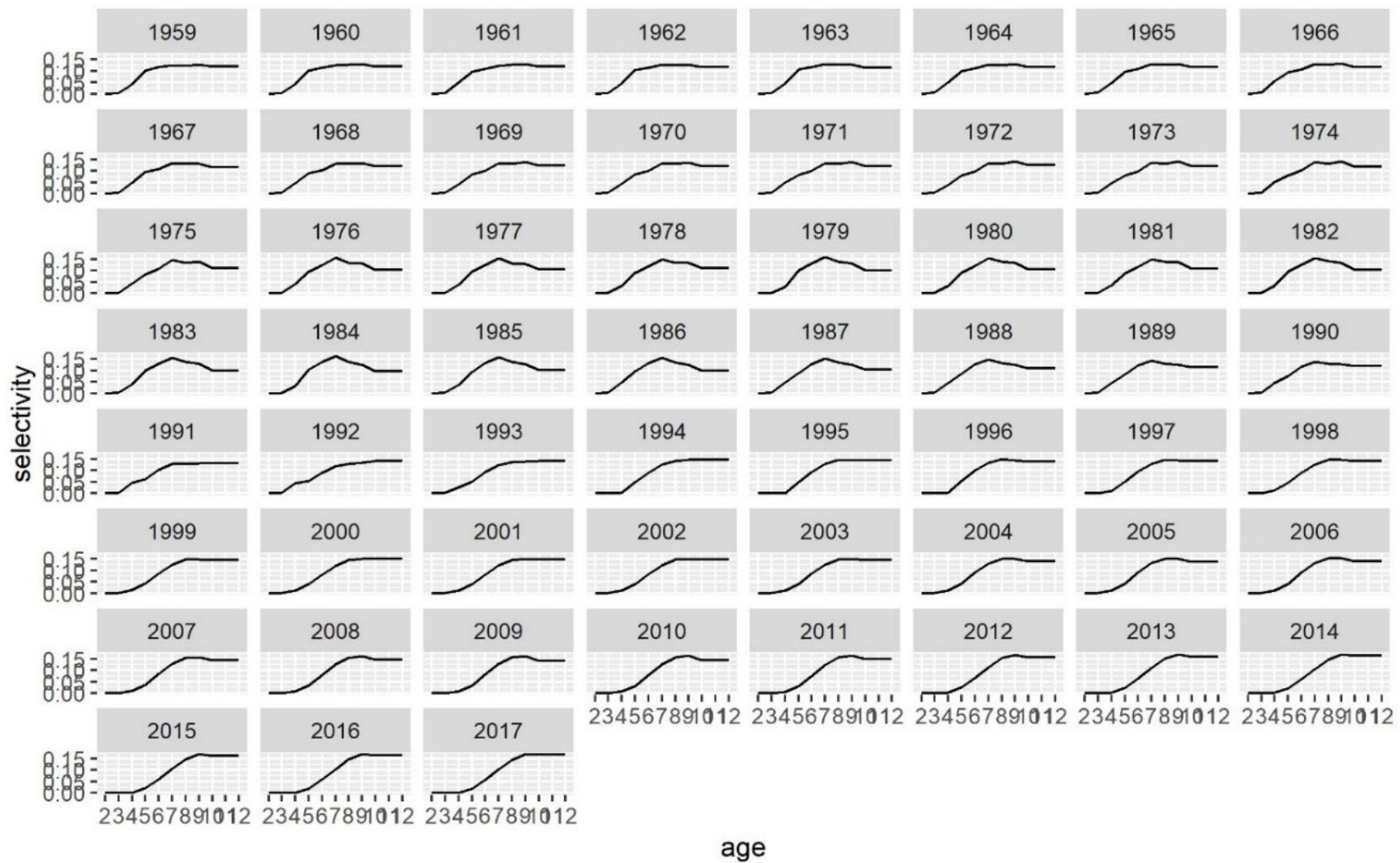
Figure 10: Estimated selectivity pattern of the fishery for 3Ps cod by the basic SAM run (i.e., run 139).
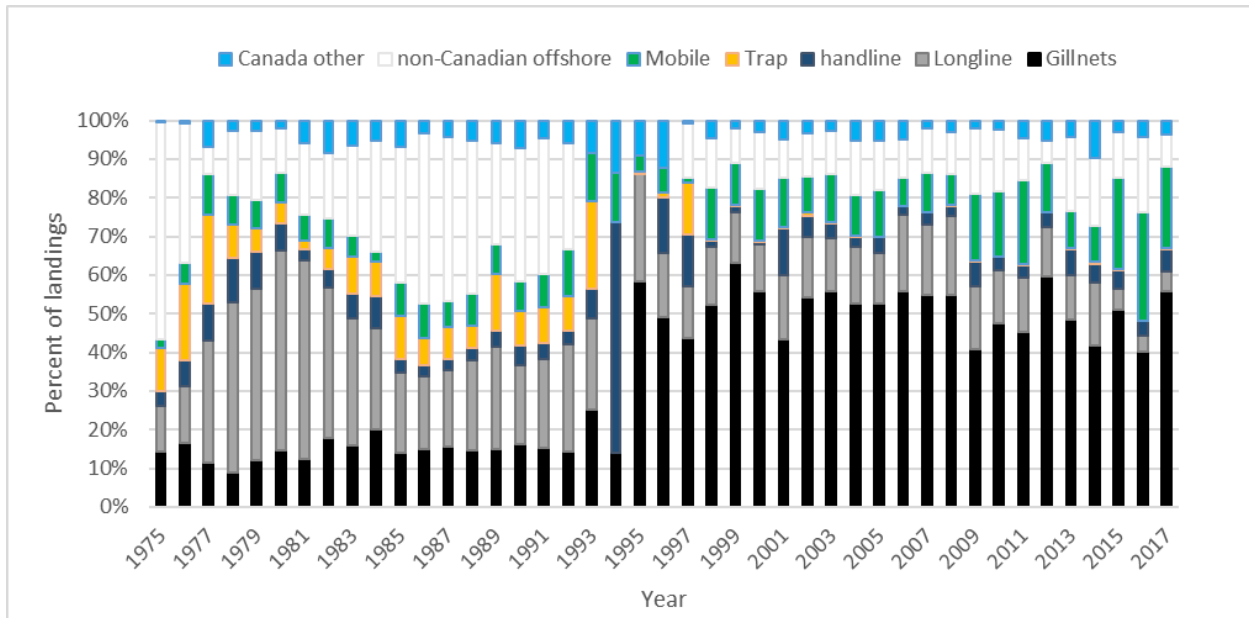
Figure 11: Gear contribution to catch over year. "Canadian other" refers to other Canadian provinces other than Newfoundland.
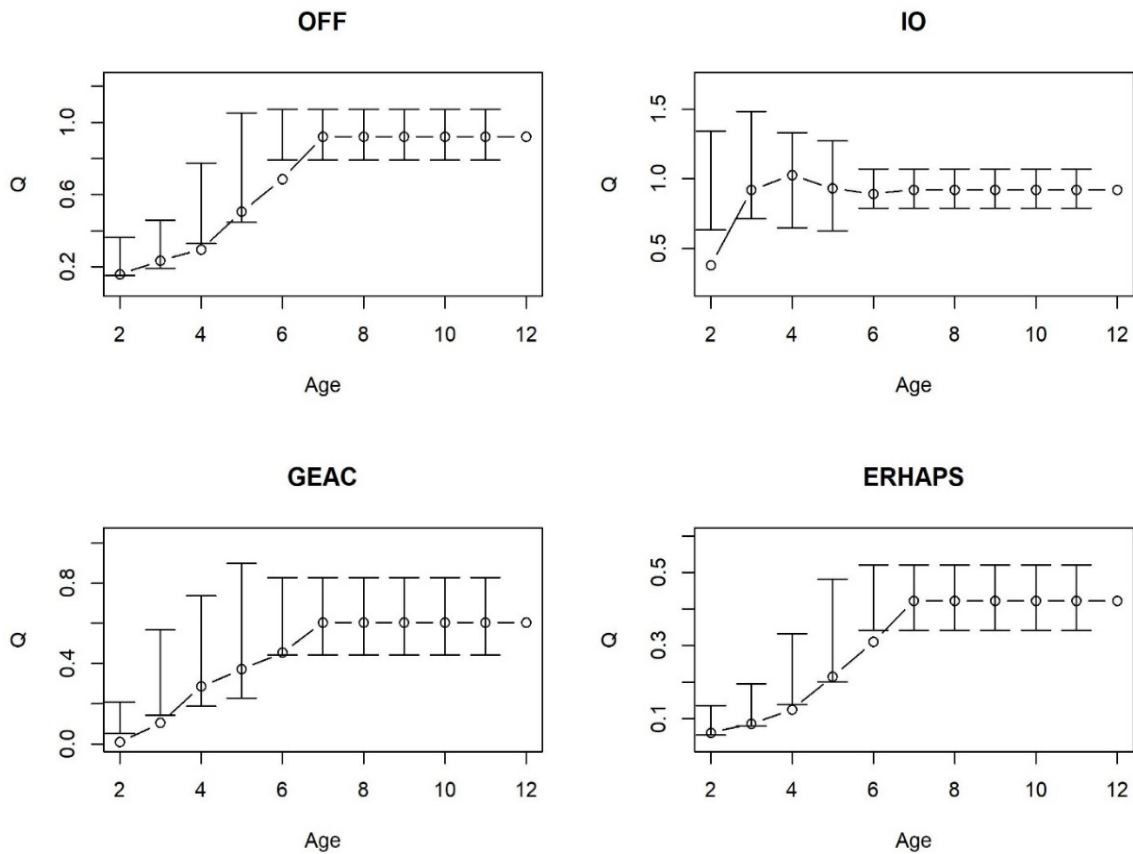
Figure 12: Catchability estimates for each survey by the basic SAM run (i.e., run 139).
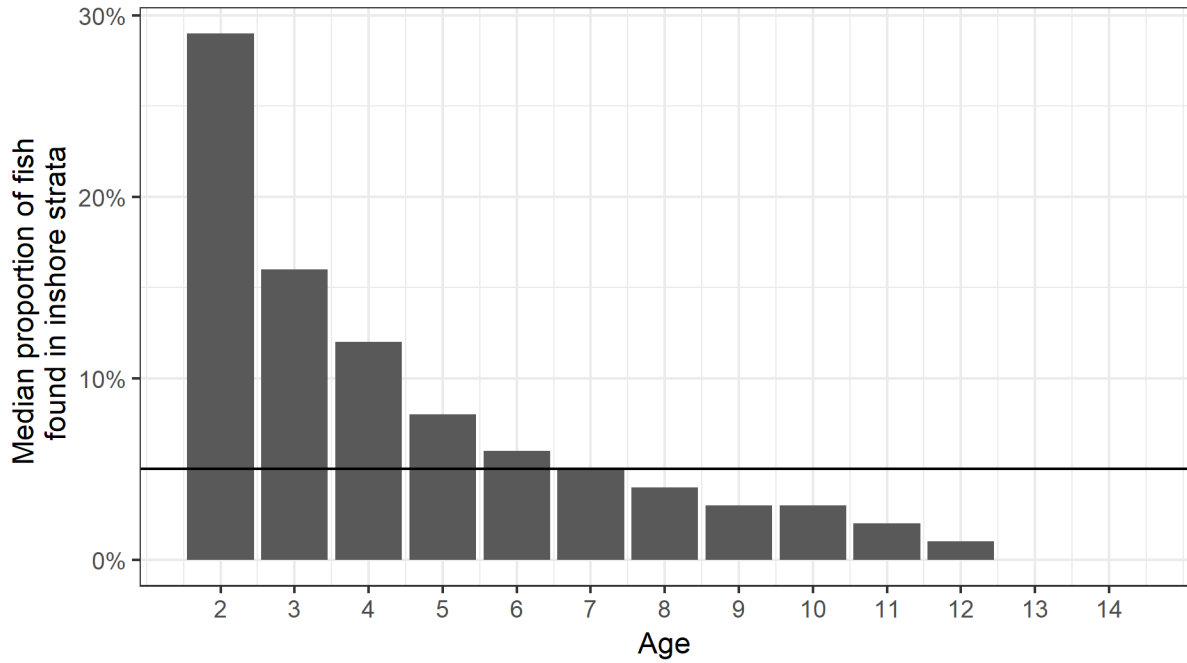
Figure 13: Proportion of fish by age in the inshore versus combined inshore-offshore area in the Canadian-RV surveys from 1997–2018. The horizontal line indicates 5% which was used as a cut-off for ages to apply the offset (from Varey et al. 2022).
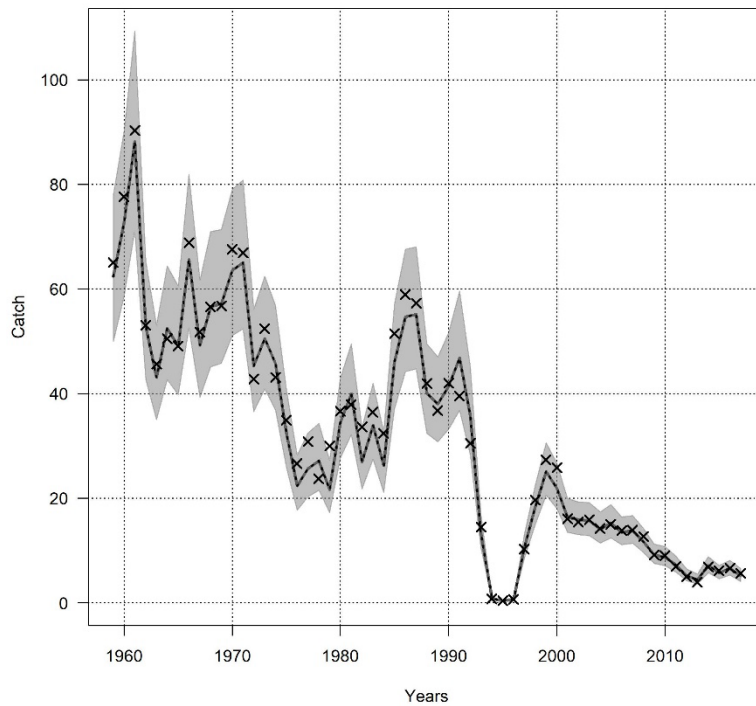
Figure 14: Global catch fit of the basic SAM run (i.e., run 139).
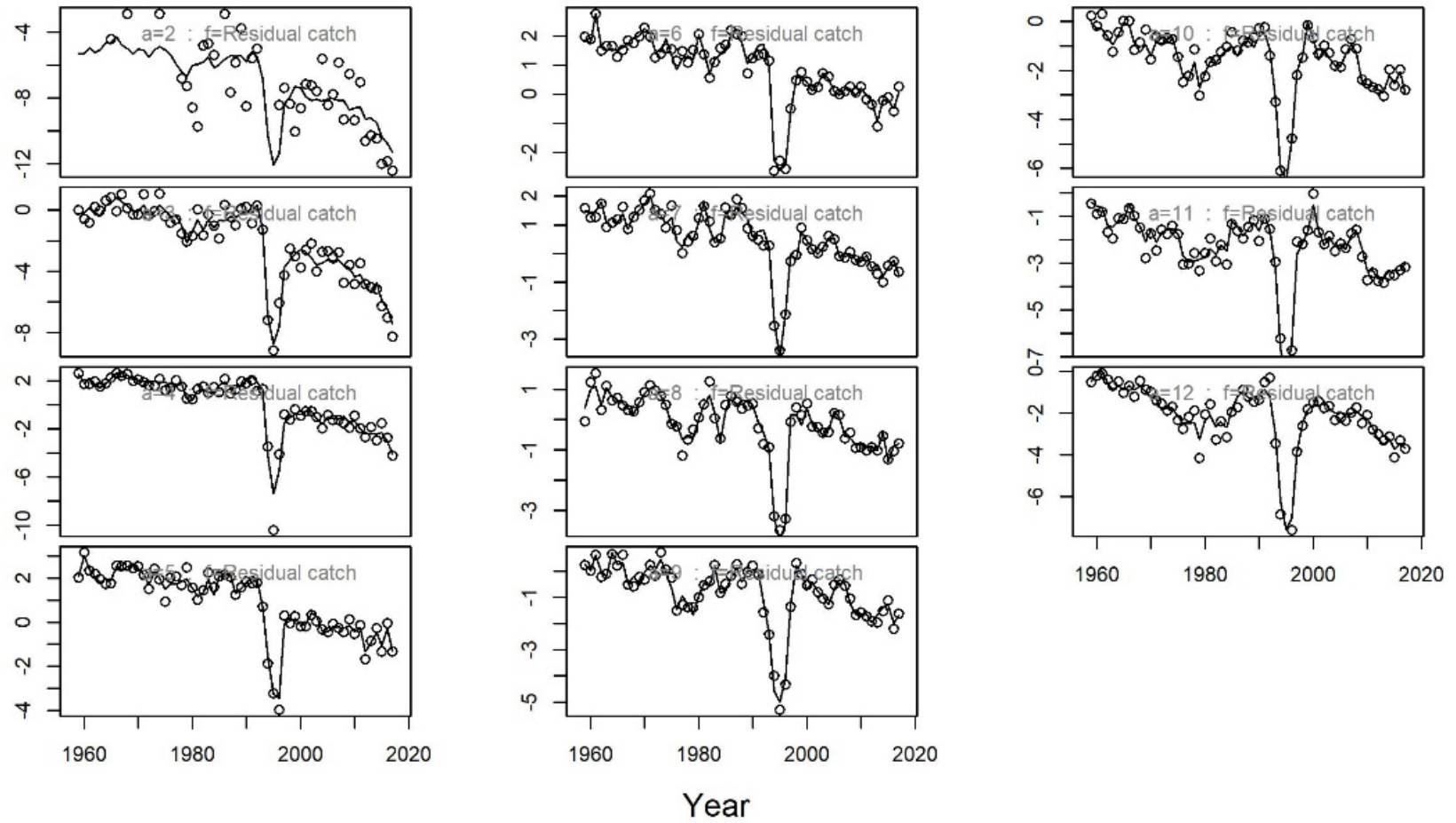
Figure 15: Catch fit at ages of the basic run (i.e., run 139). Ages span from 2 to 12 and are distributed by columns.
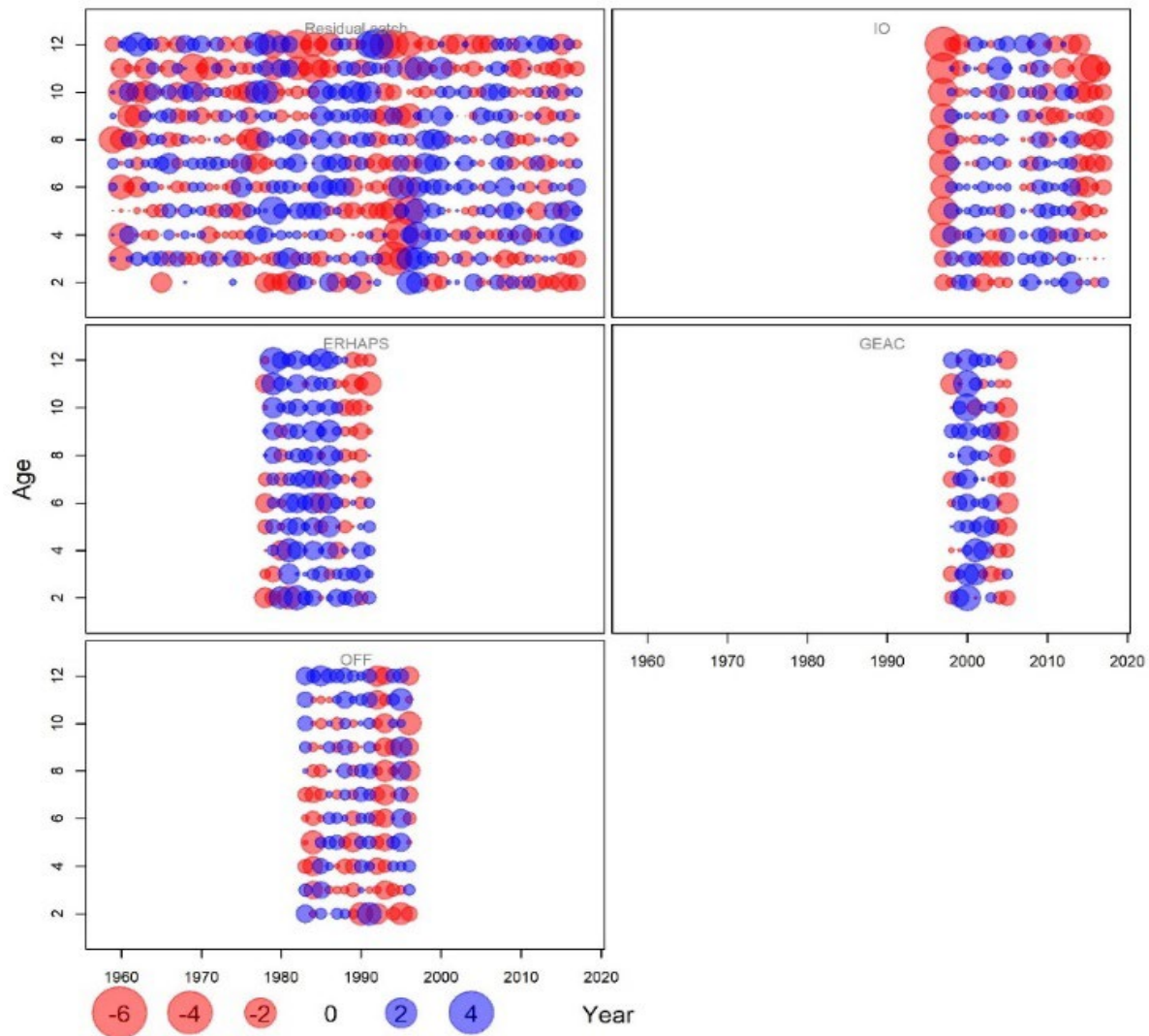
Figure 16: Observation residuals of the basic run (i.e., run 139).
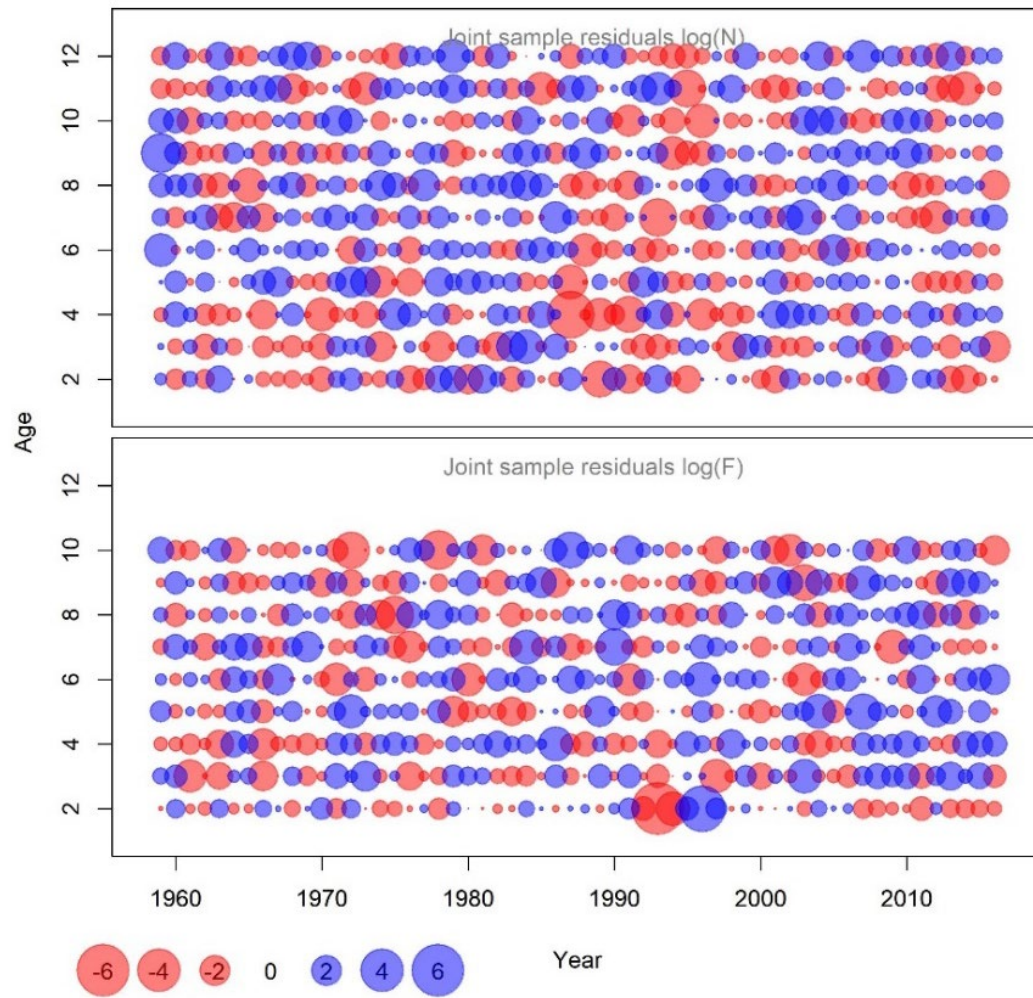
Figure 17: Process residuals of the basic run (i.e., run 139).
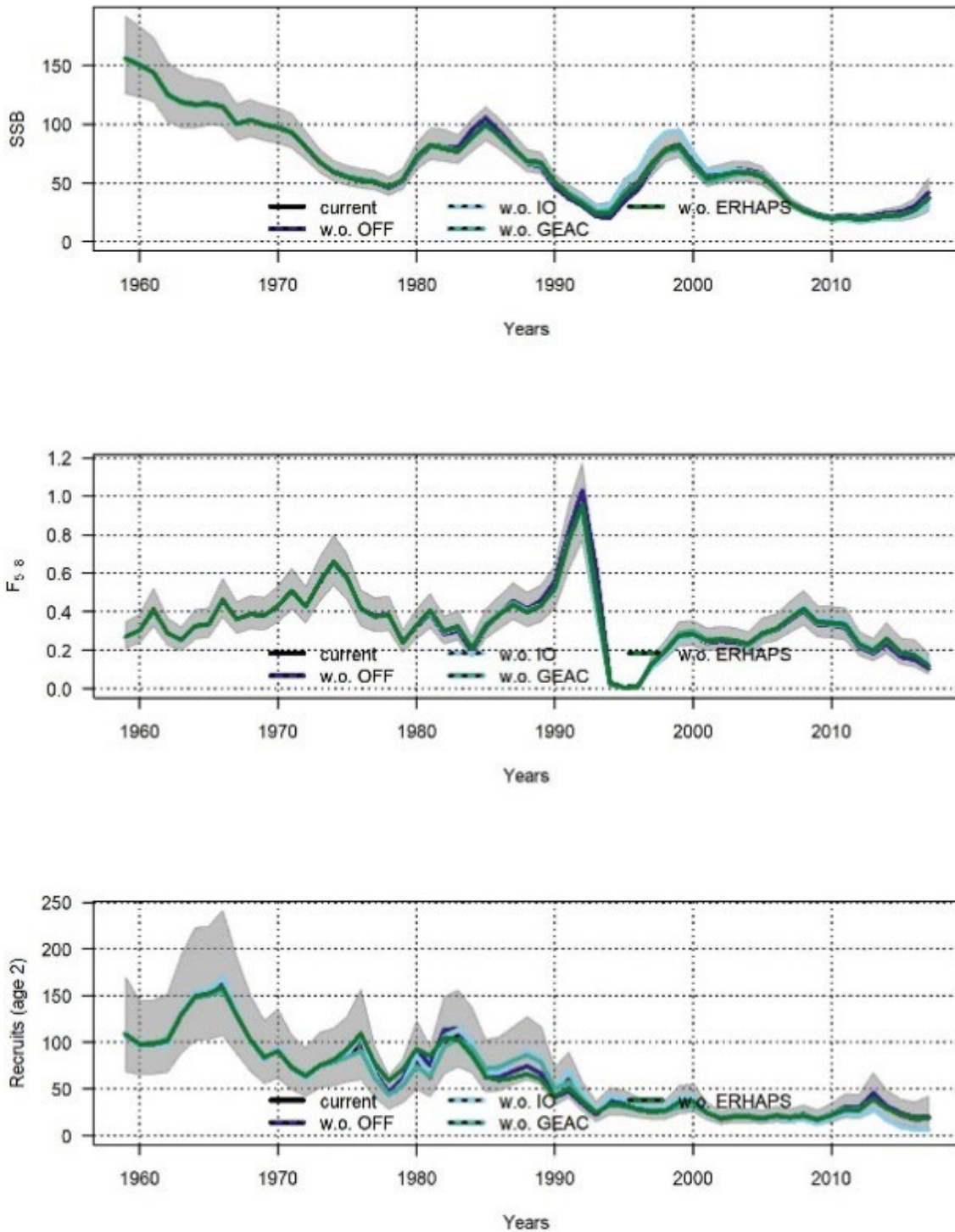
Figure 18: Model diagnostic plots for the basic run (i.e., run139): leave out analysis. The legend is the same for each panel: current (black line), w.o. OFF (deep-blue line), w.o. IO (light-blue solid line), w.o. GEAC (turquoise solid line), w.o. ERHAPS (green solid line). Grey ribbons show the 95% confidence intervals around the current run.
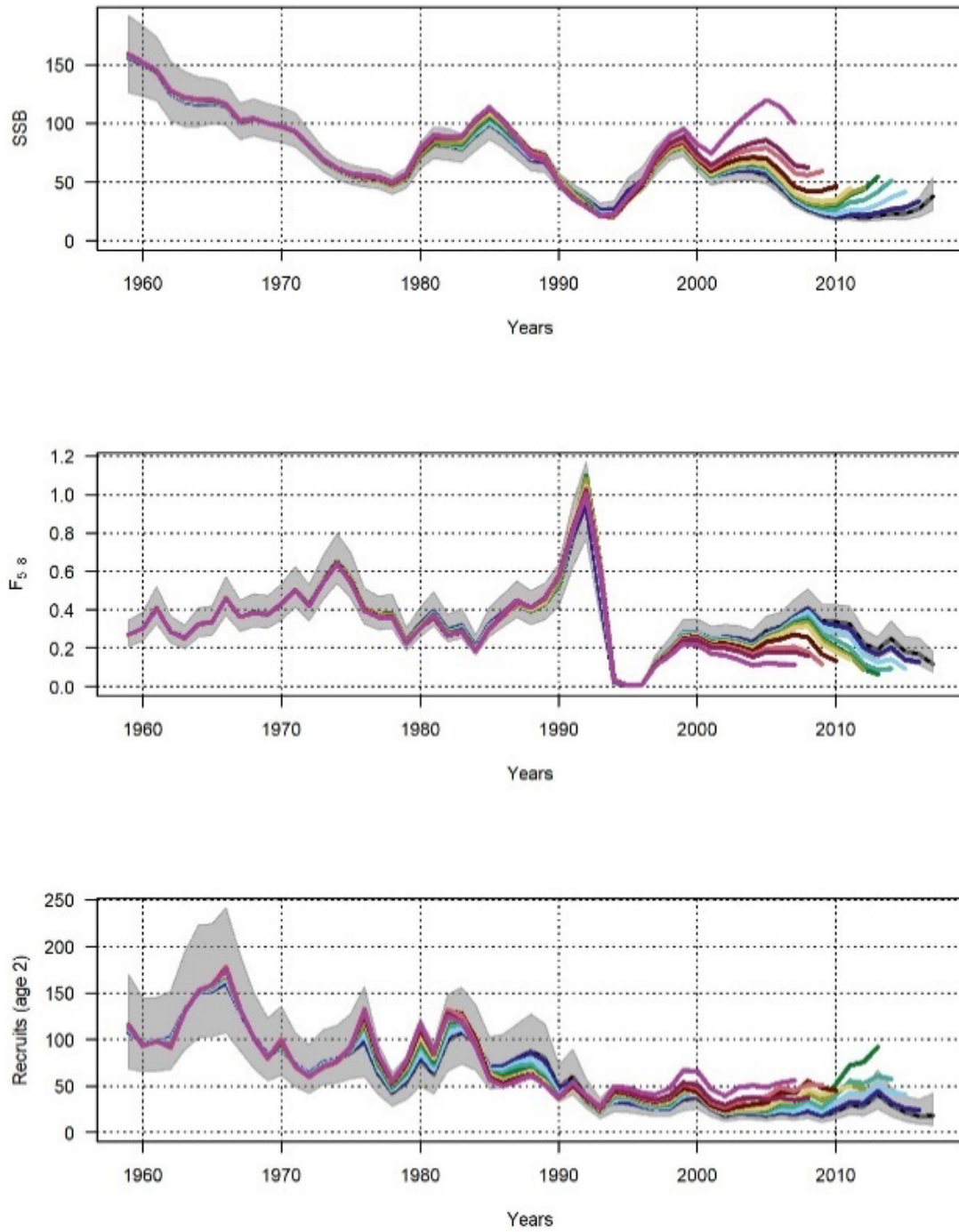
Figure 19: Model diagnostic plots for the basic run (i.e., run139): retrospective analysis. Grey ribbons show the 95% confidence intervals around the current run.
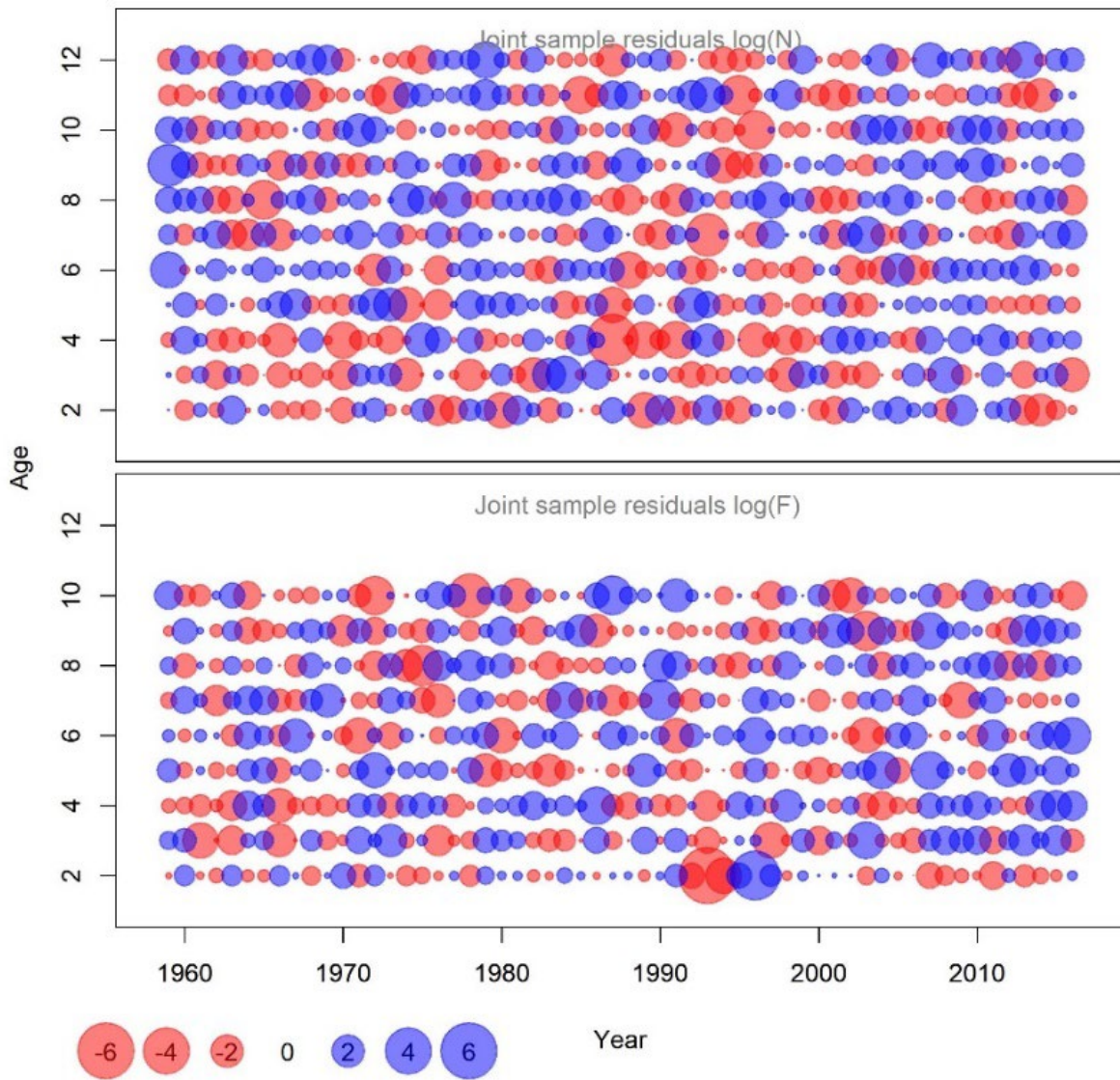
Figure 20: Process residuals for the condition M run (i.e., run 140).
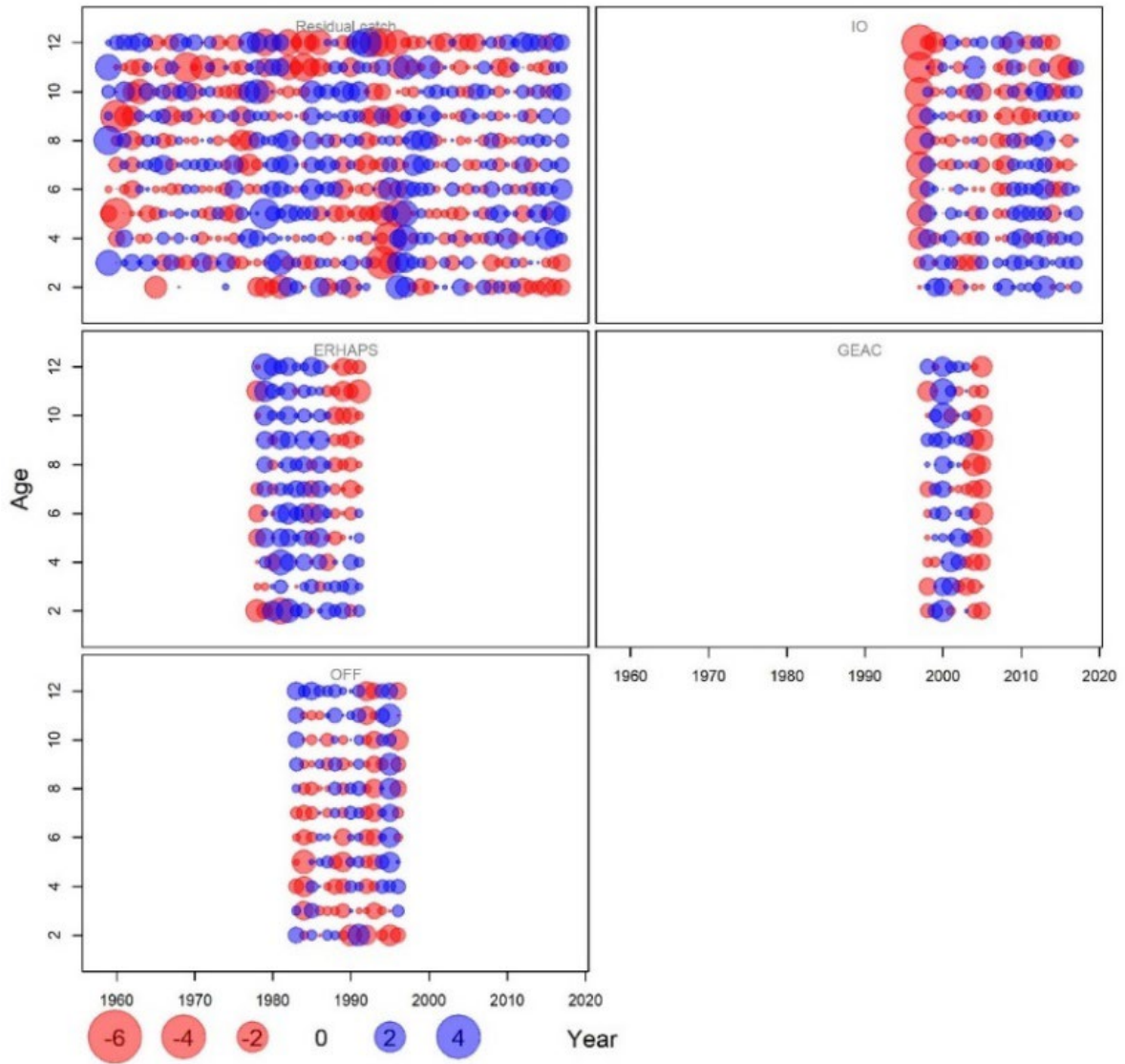
Figure 21: Observations residuals from the condition M run (i.e., run 140).
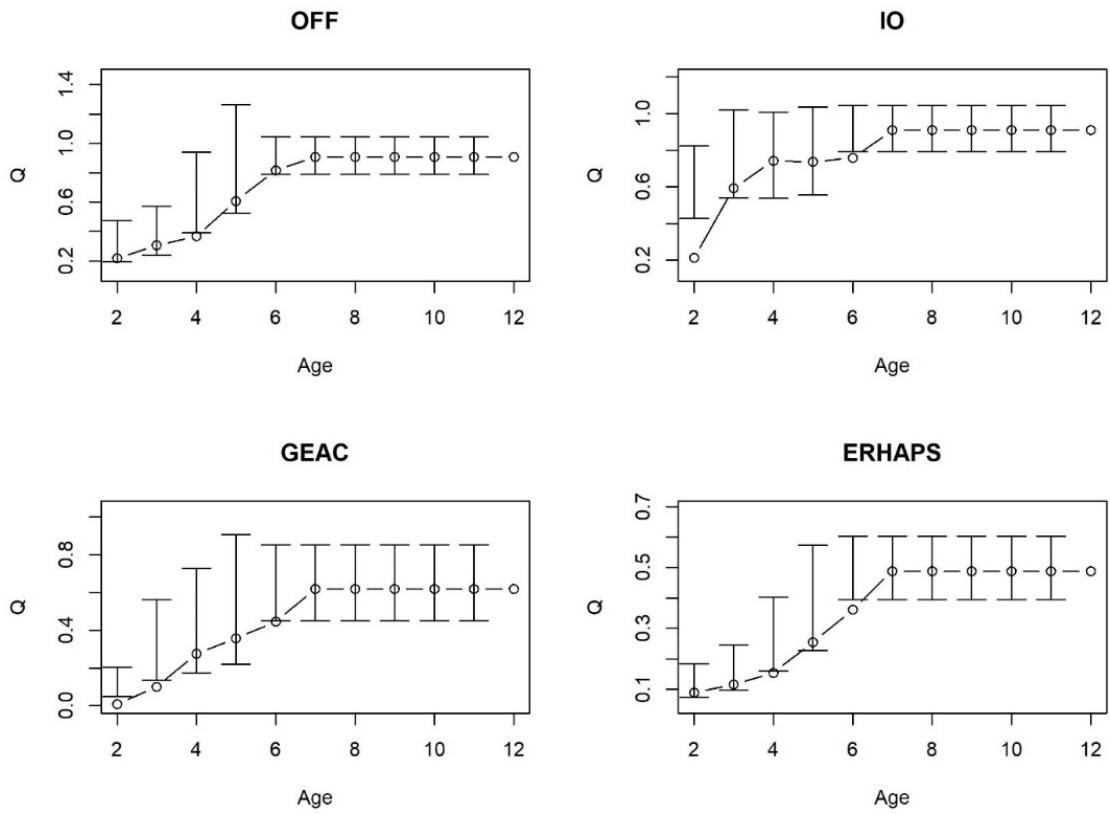
Figure 22: Estimated catchabilities for each survey by the condition M run (i.e., run 140).
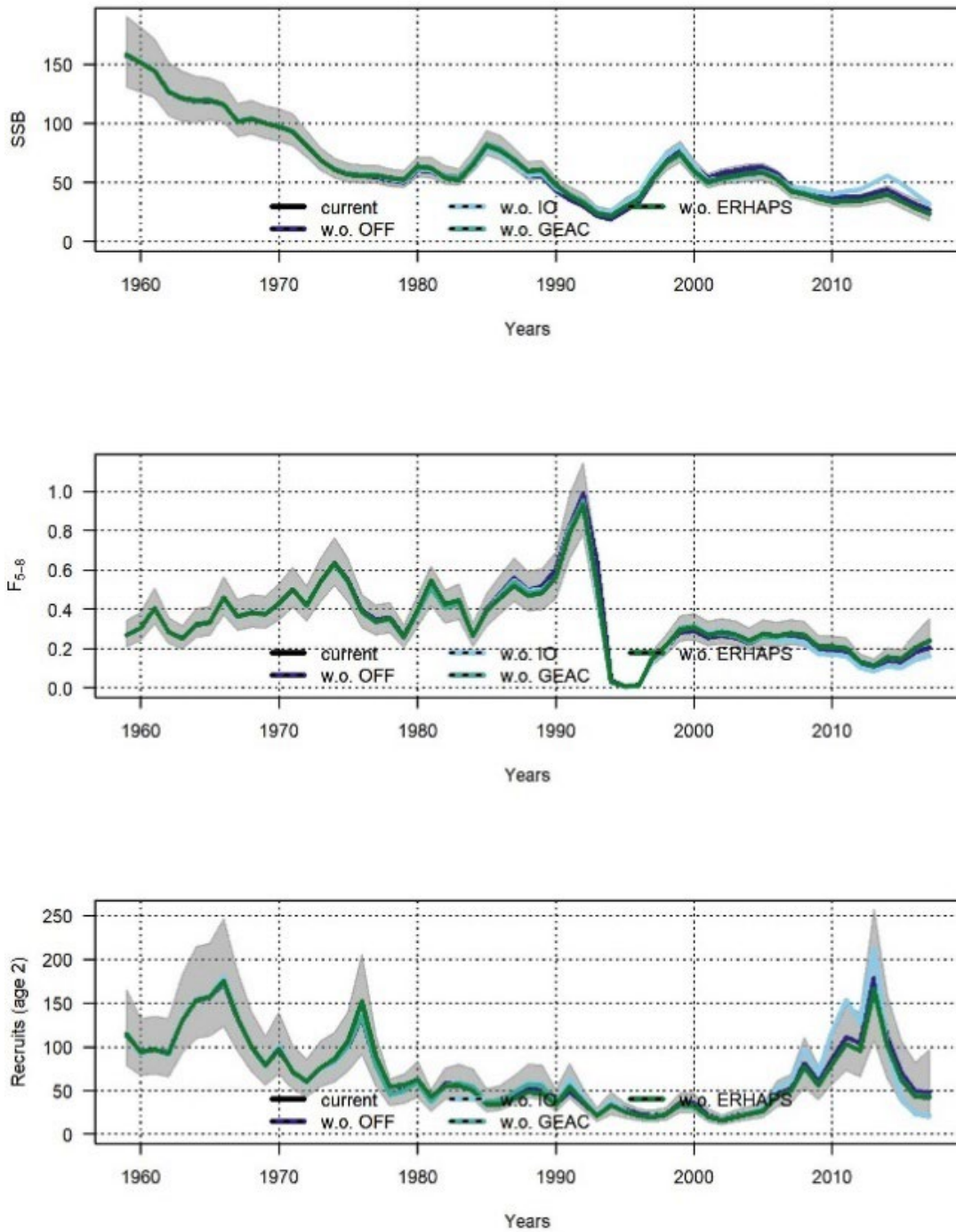
Figure 23: Model diagnostic plots for the condition M run (i.e., run 140): leave out analysis. The legend is the same for each panel: current (black line), w.o. OFF (deep-blue line), w.o. IO (light-blue solid line), w.o. GEAC (turquoise solid line), w.o. ERHAPS (green solid line). Grey ribbons show the 95% confidence intervals around the current run.
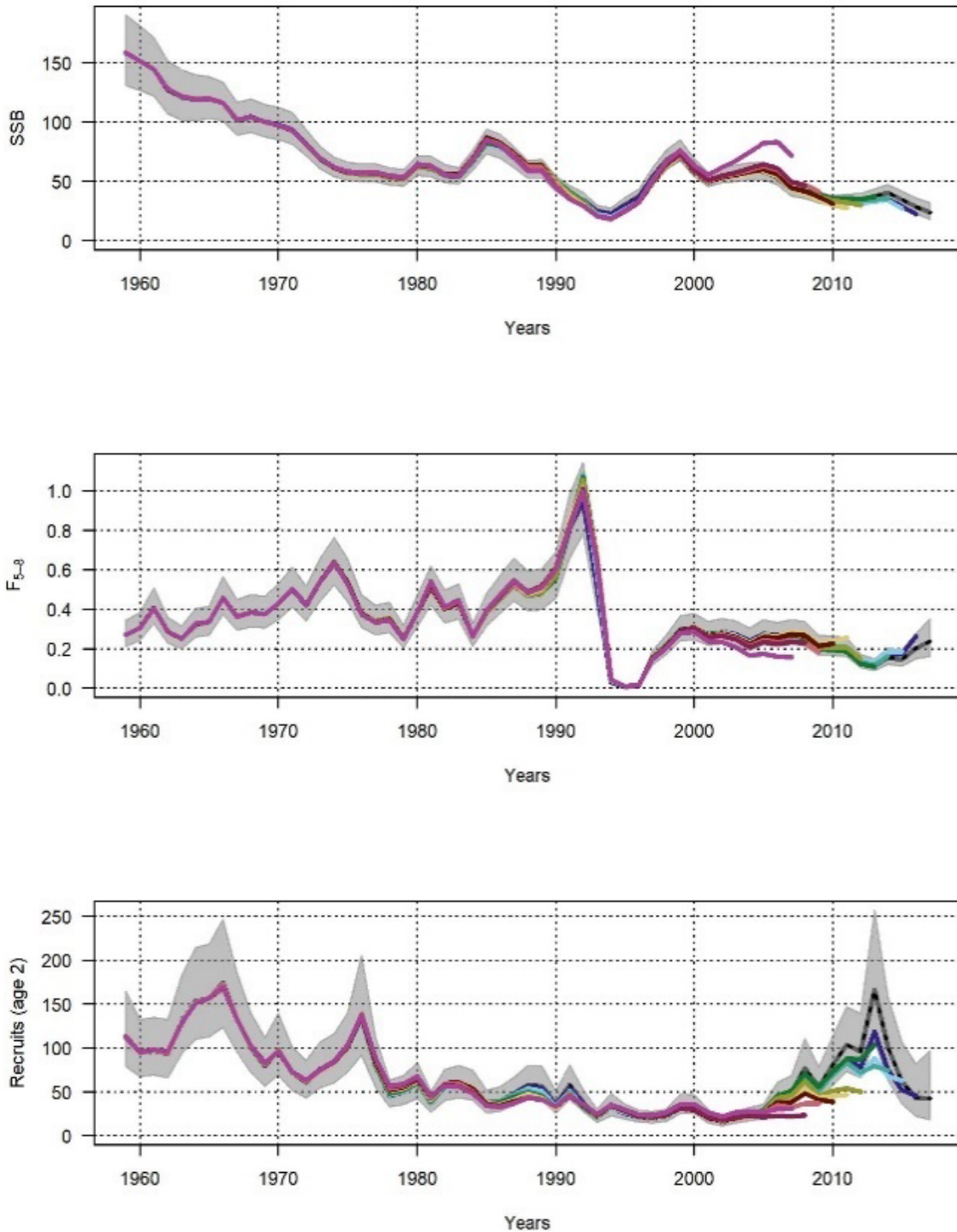
Figure 24: Model diagnostic plots for the condition M run (i.e., run 140): retrospective analysis. Grey ribbons show the 95% confidence intervals around the current run.
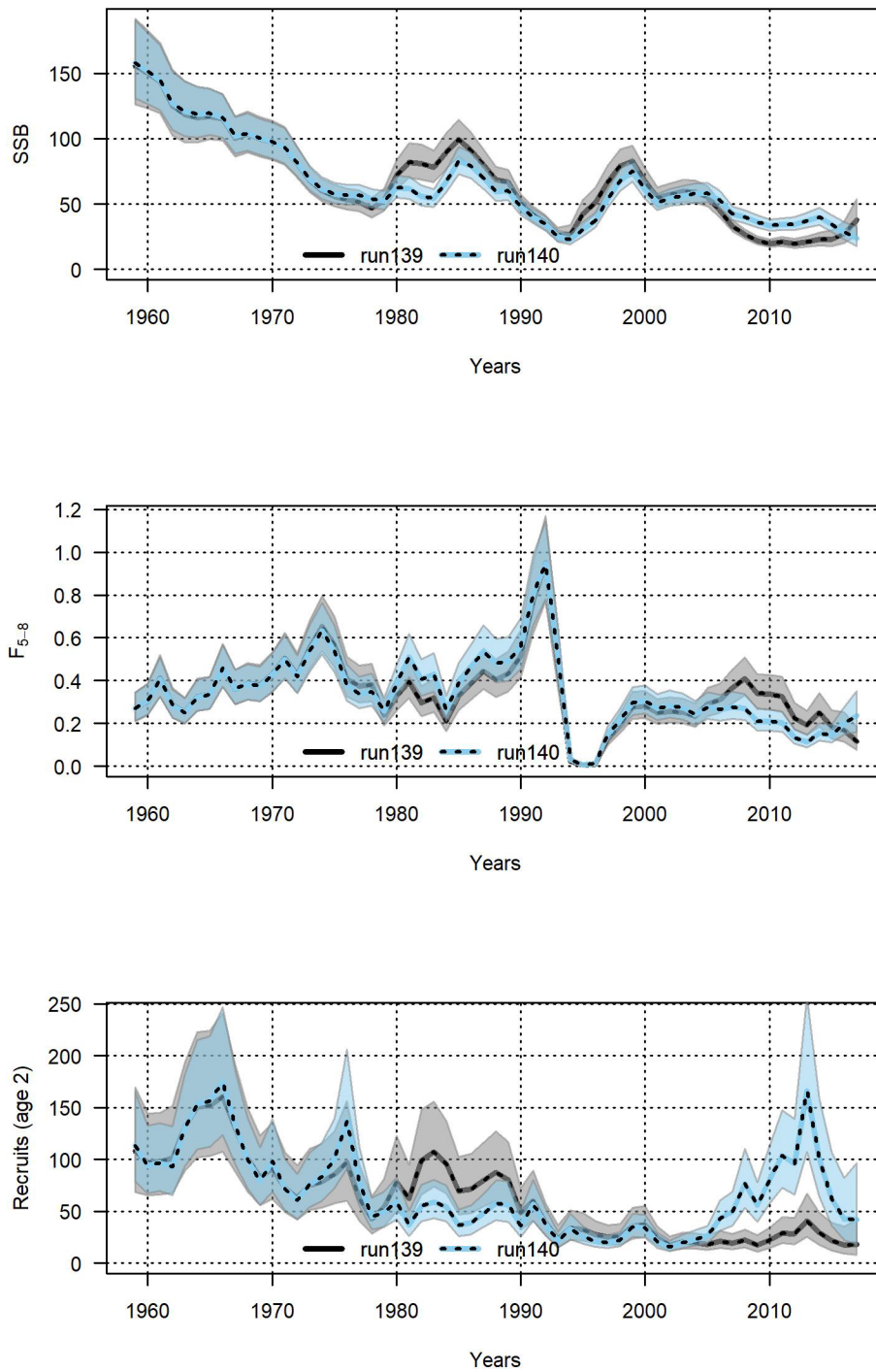
Figure 25: Stock variables estimates comparison between the basic run (i.e., run 139, grey and black dashed line) and the condition M run (i.e., run 140, light-blue and black dashed line). Ribbons show the 95% confidence intervals.
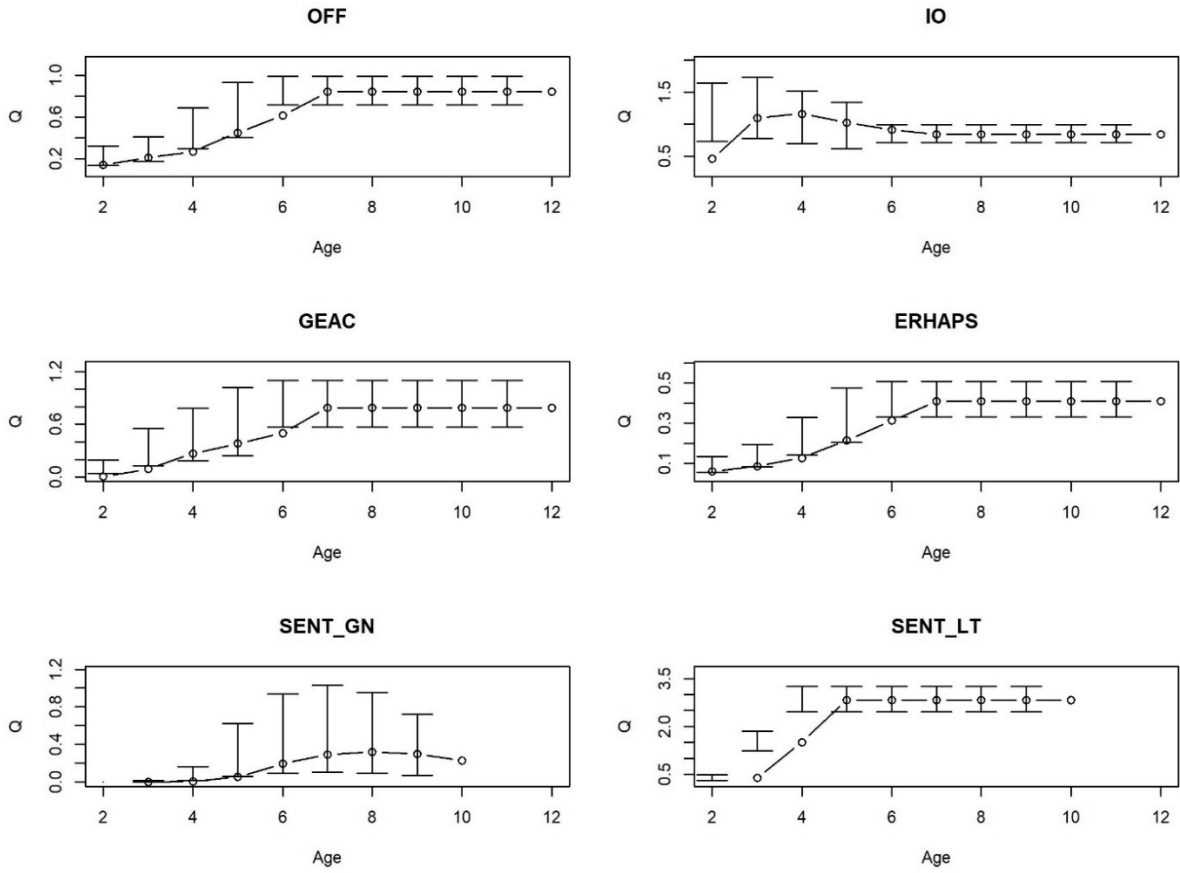
Figure 26: Catchability parameter at age by survey for the sentinel run (i.e., run 143).
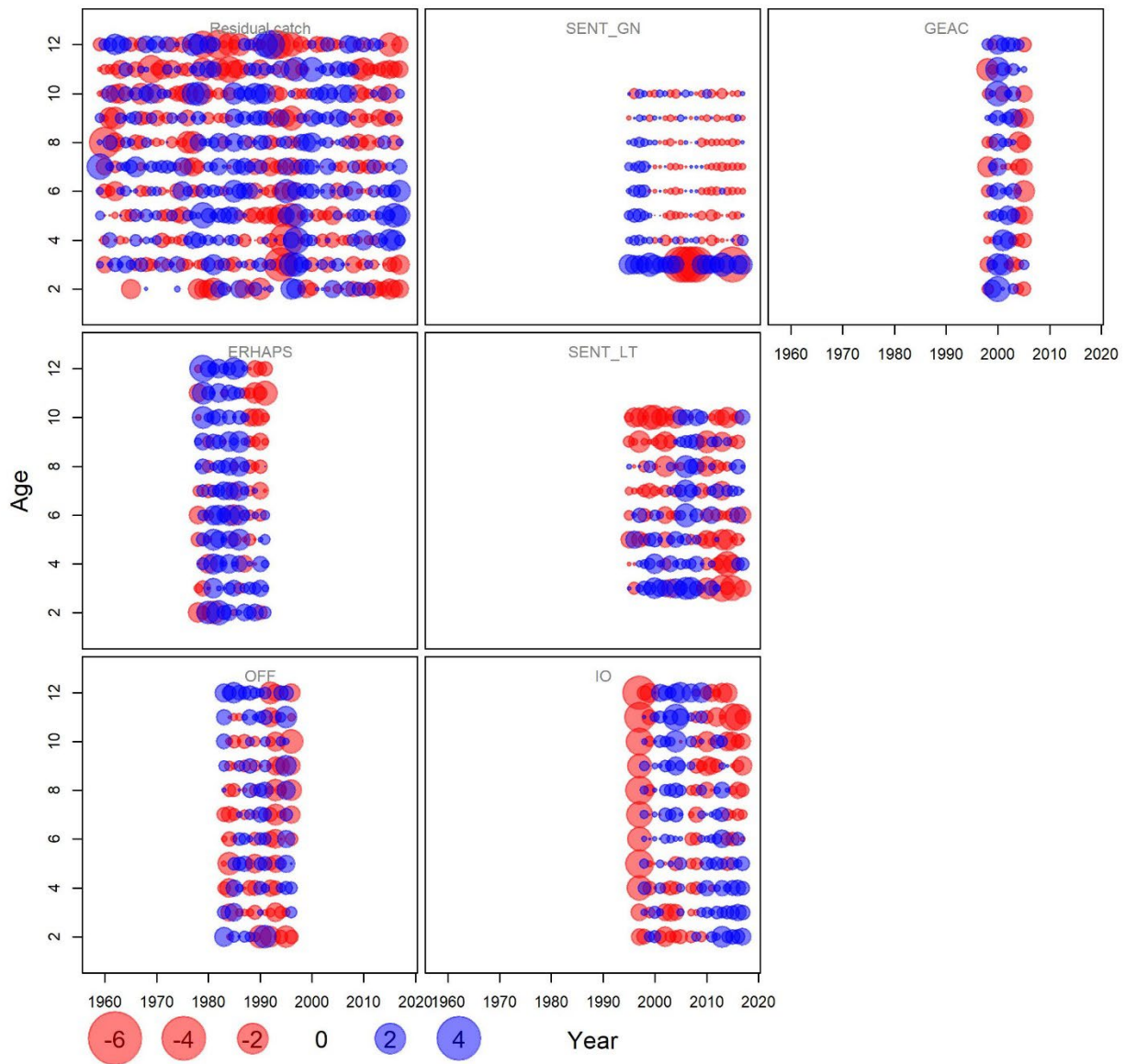
Figure 27: Observation residuals from the sentinel run (i.e., run 143).
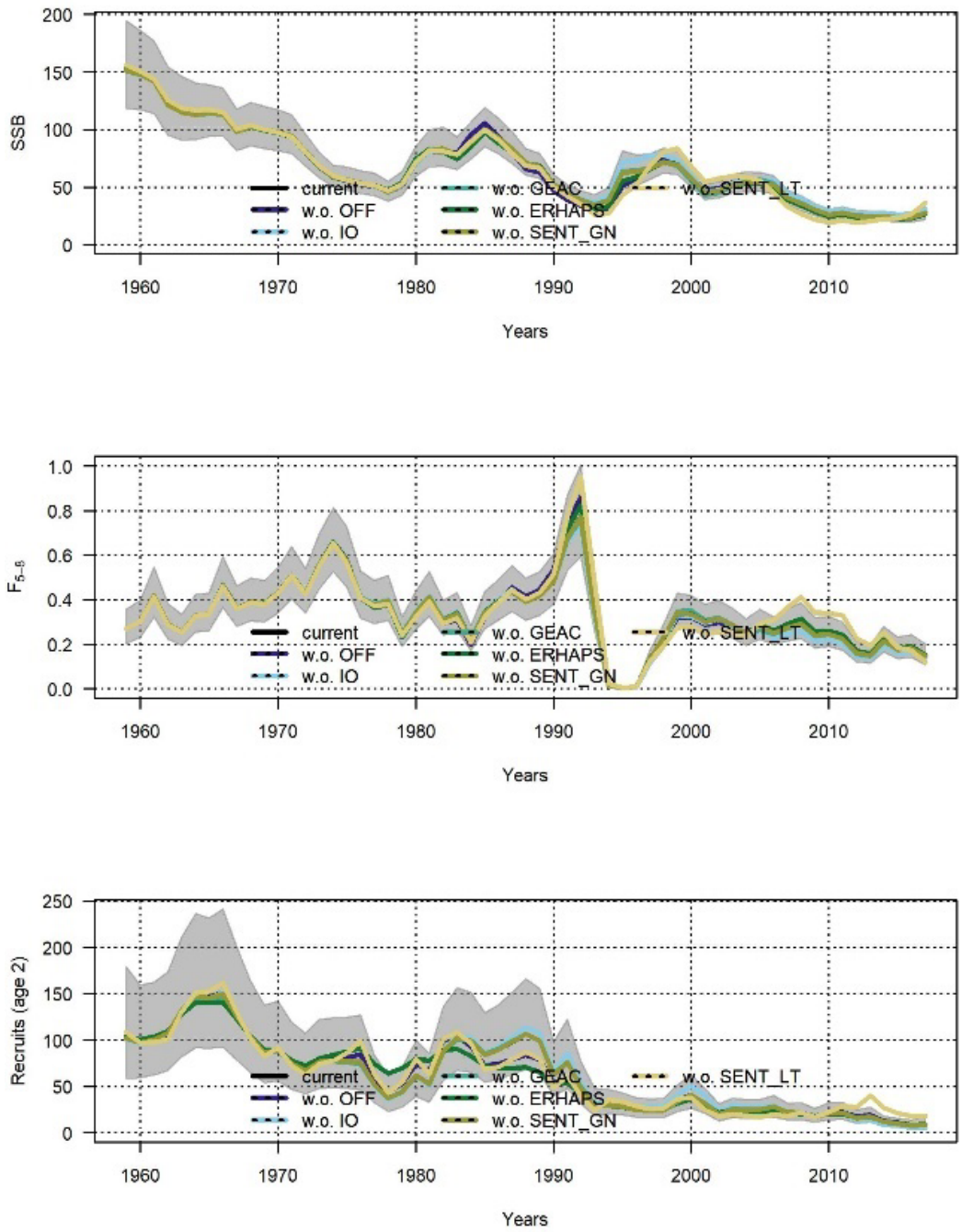
Figure 28: Model diagnostic plots for the sentinel run (i.e., run 143): leave out fleet analysis. The legend is the same for each panel: current (black line), w.o. OFF (deep-blue line), w.o. IO (light-blue solid line), w.o. GEAC (turquoise solid line), w.o. ERHAPS (green solid line), w.o. Sent_GN (khaki solid line), w.o. Sent_LT (yellow solid line). Grey ribbons show the 95% confidence intervals around the current run estimate.
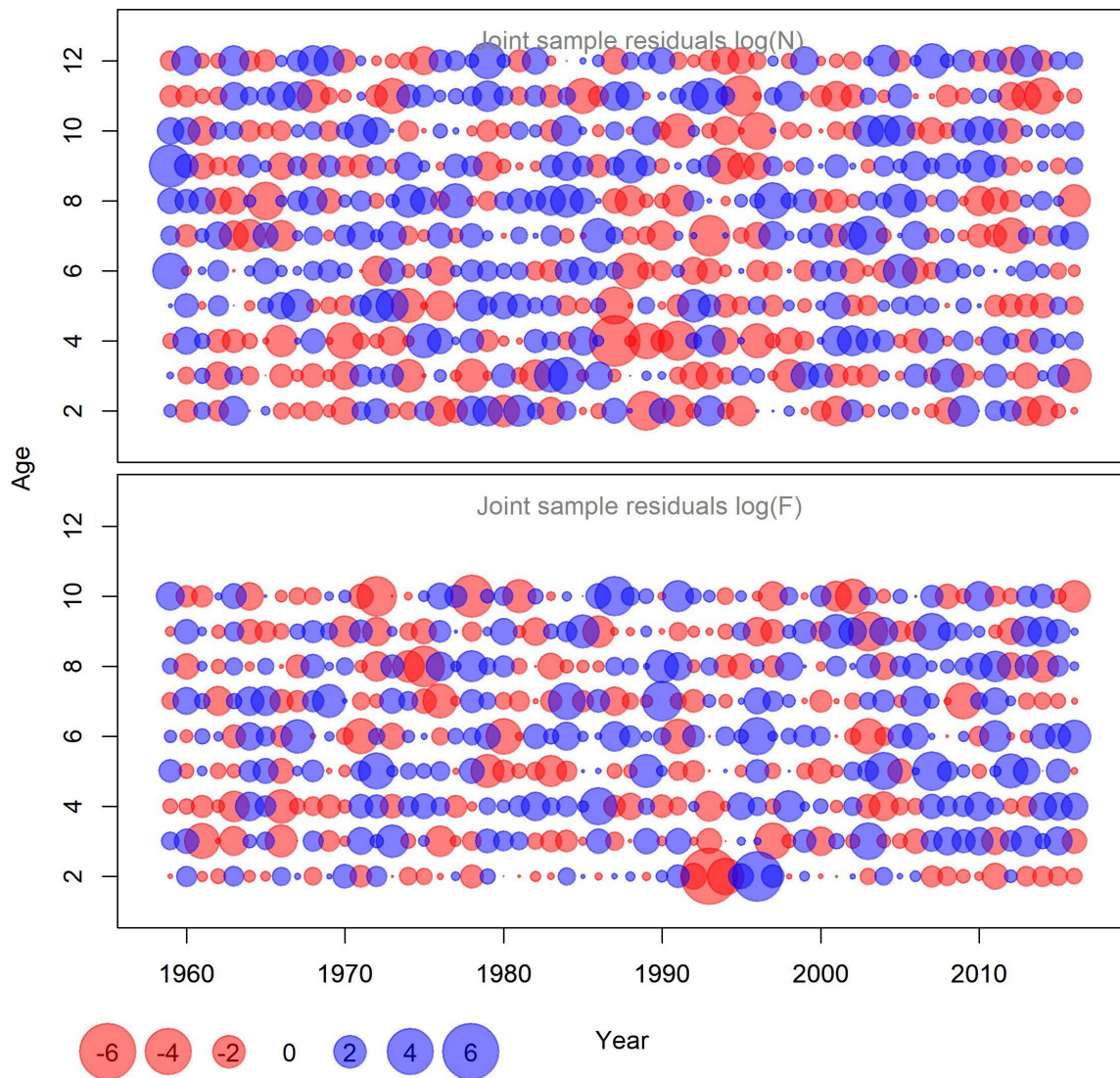
Figure 29: Process residuals from the sentinel run (i.e., run 143).
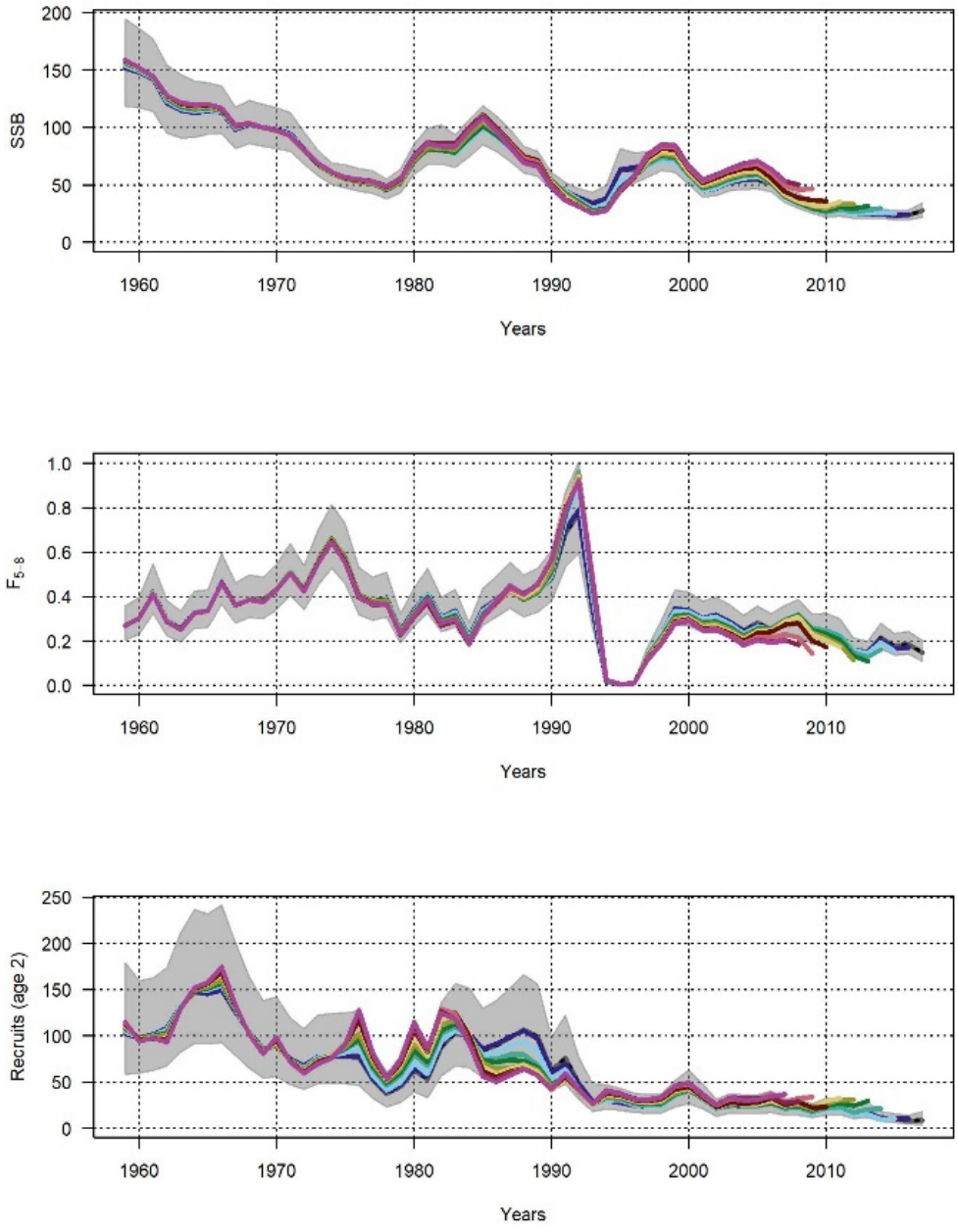
Figure 30: Model diagnostic plots for the sentinel run (i.e., run 143): retrospective analysis. Grey ribbons show the 95% confidence intervals around the current run estimates.
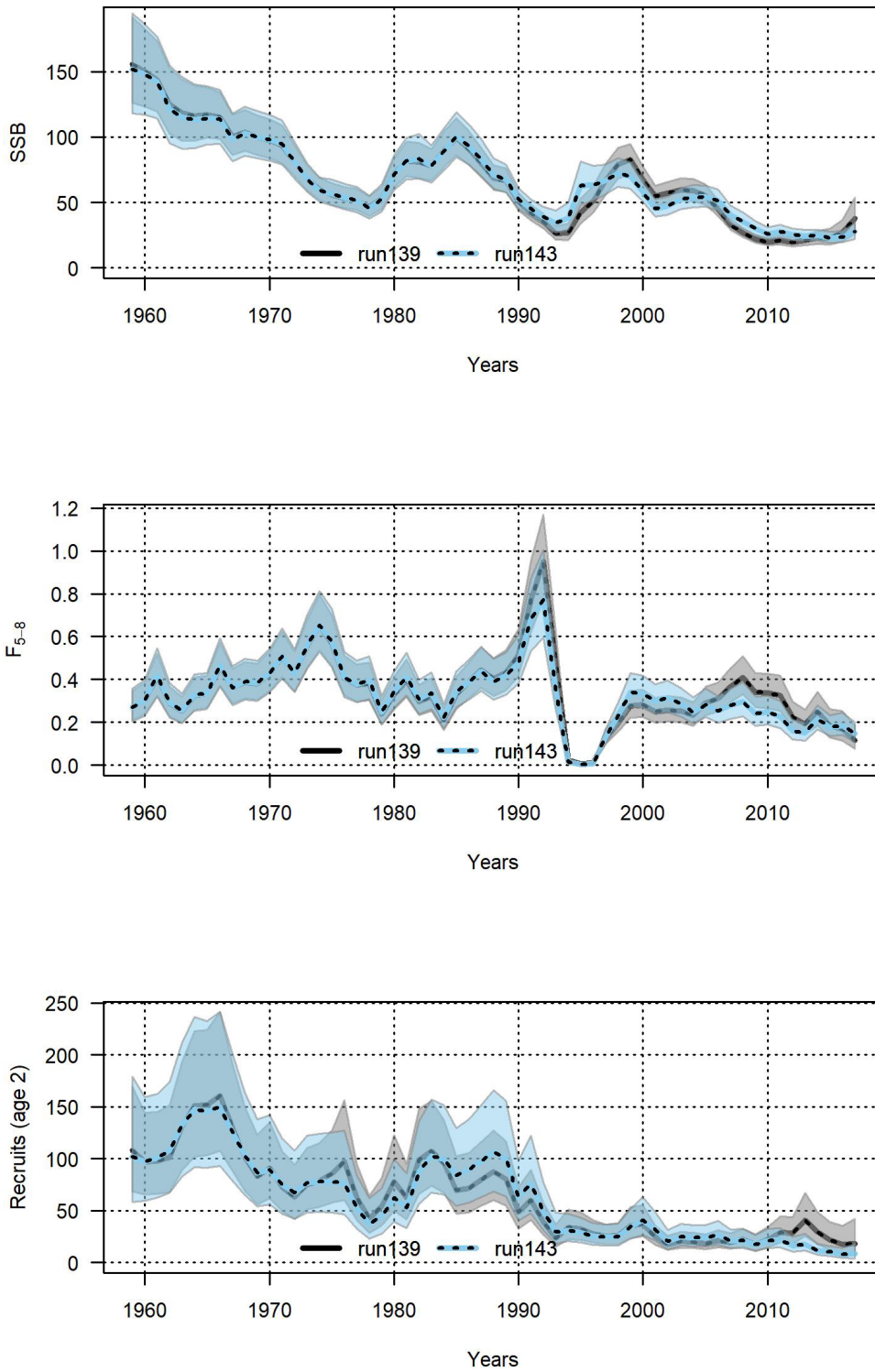
Figure 31: Stock variables estimates comparison between the basic run (i.e., run 139, grey and black dashed line) and the sentinel run (i.e., run 143, light-blue and black dashed line) Ribbons show the 95% confidence intervals.
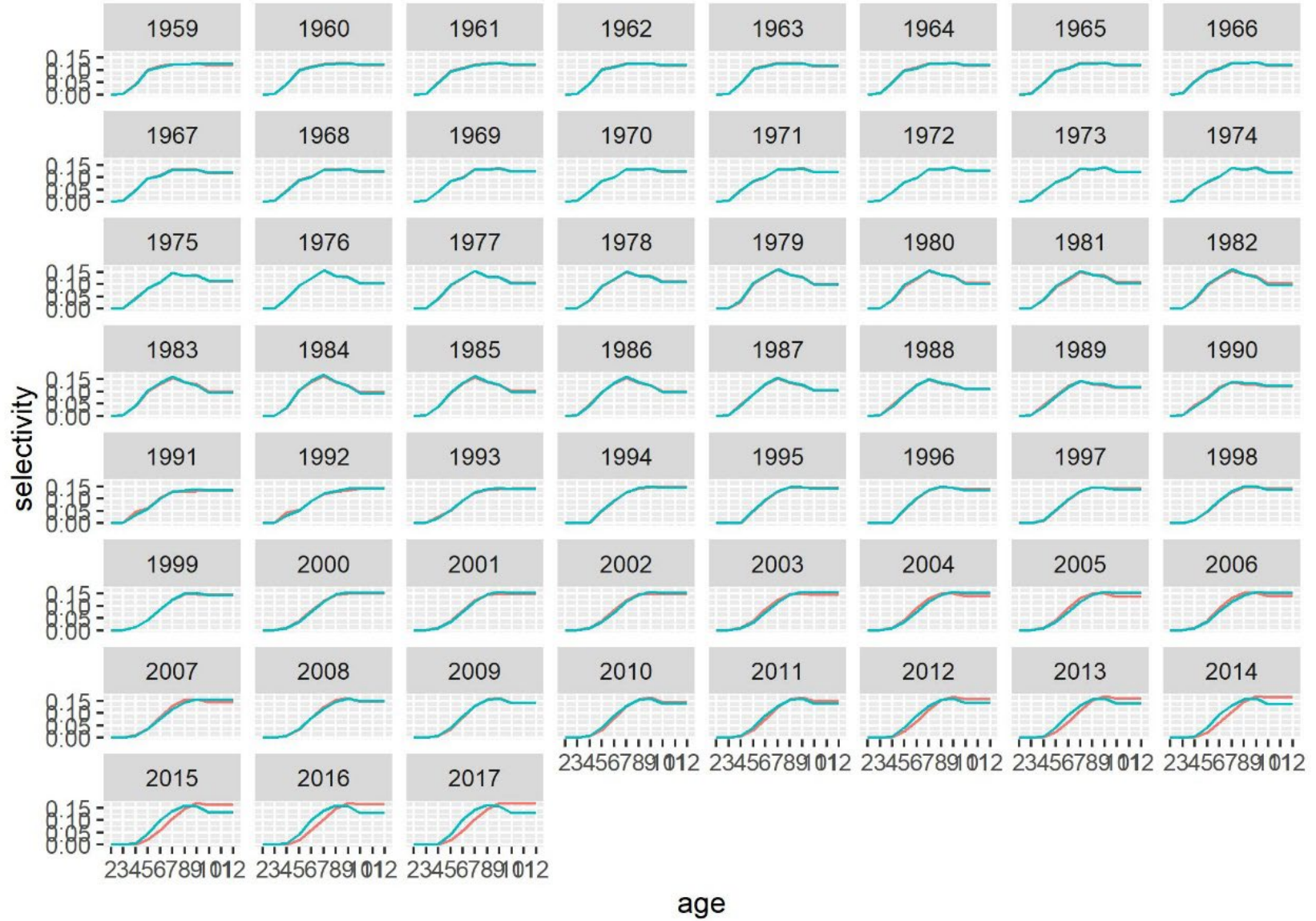
Figure 32: Selectivity pattern across time estimated by the basic (i.e., run 139, pink line) and the sentinel (i.e., run 143, turquoise line) runs.
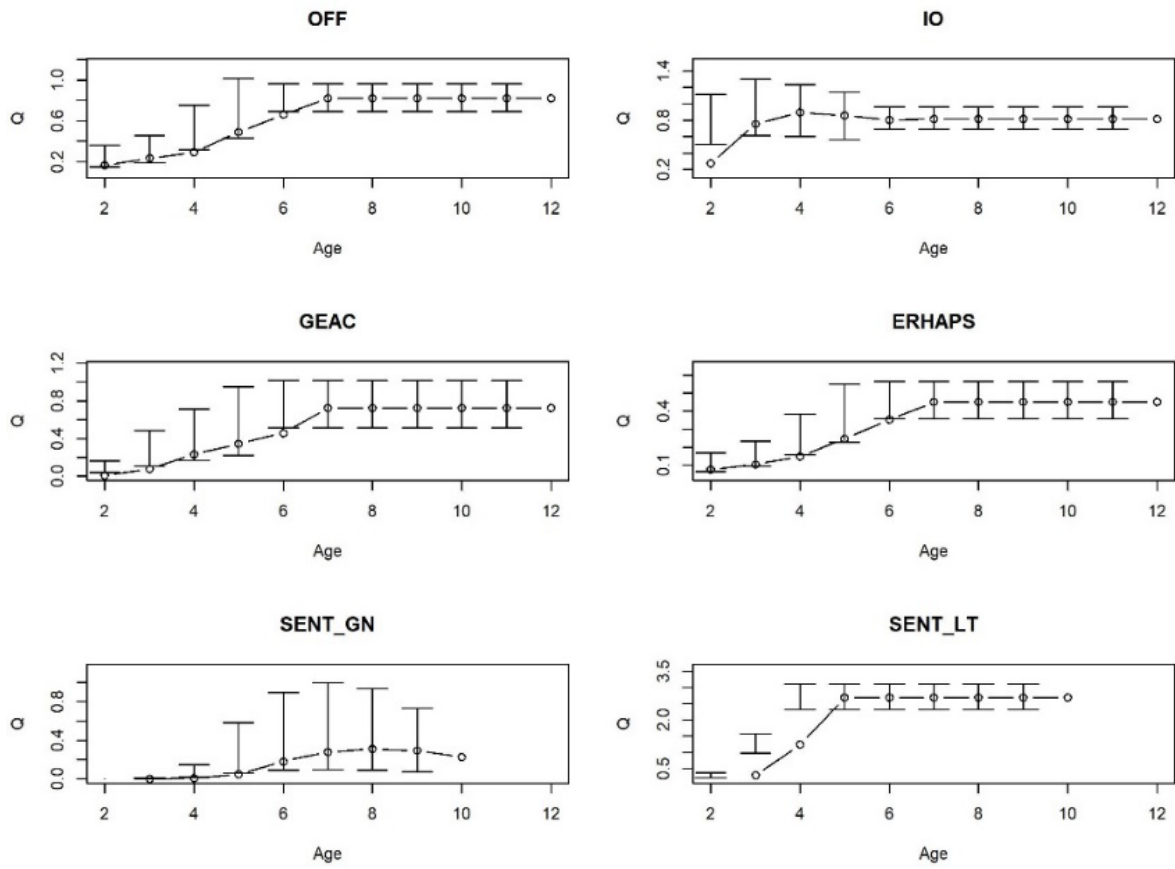
Figure 33: Estimated catchabilities at age by survey from the combined run (i.e. run 144).
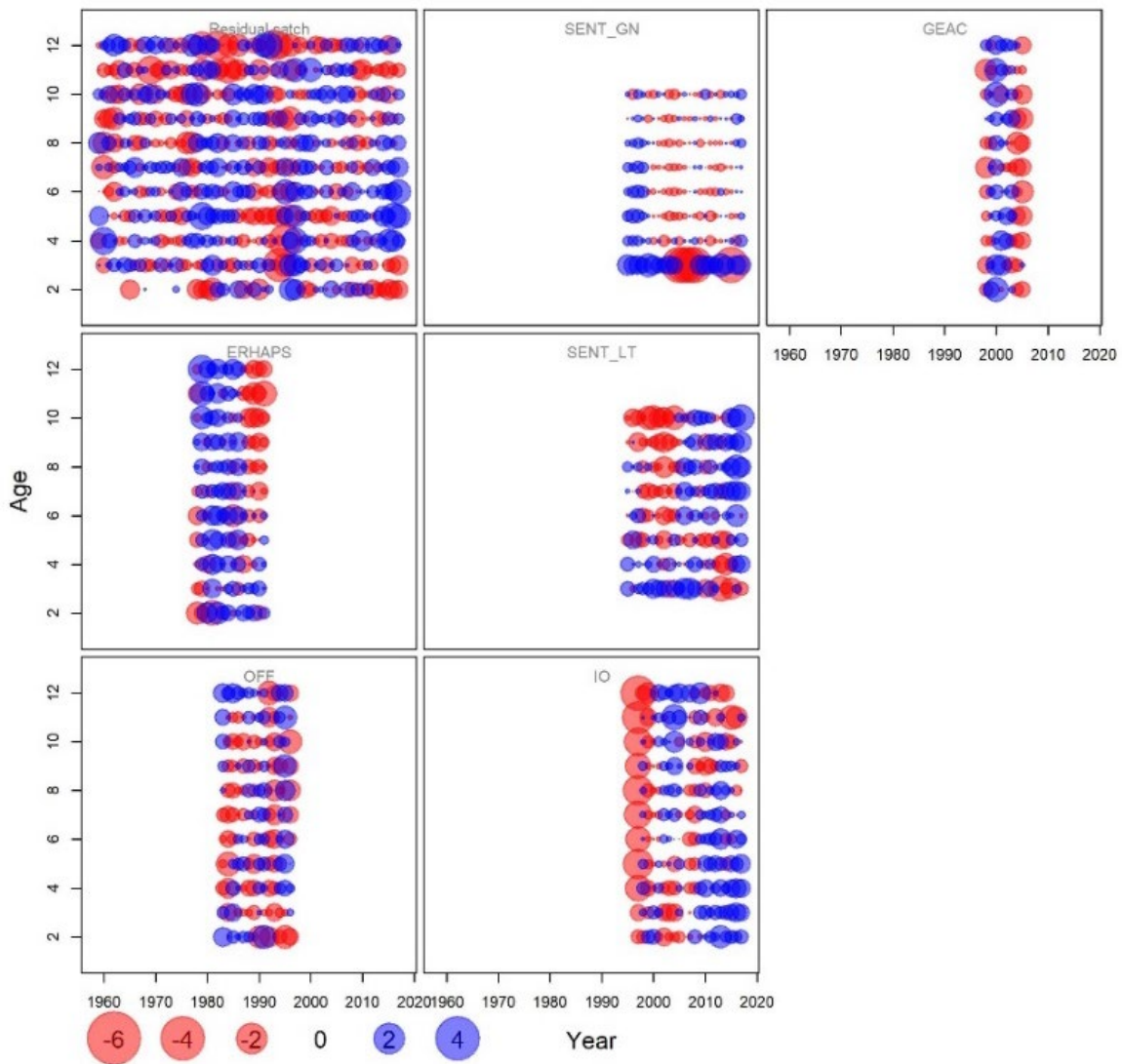
Figure 34: Observations residuals from the combined run (i.e. run 144).
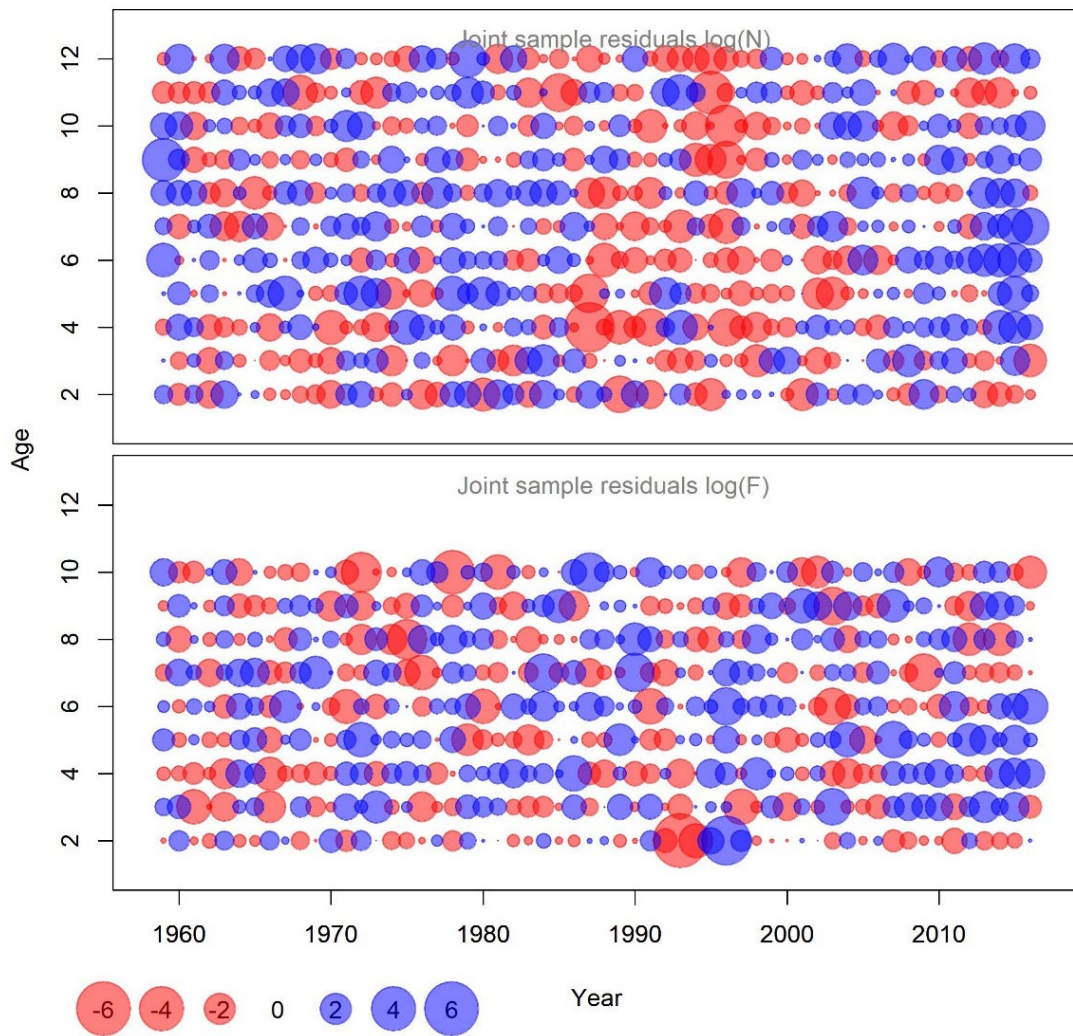
Figure 35: Process residuals from the combined run (i.e., run 144).
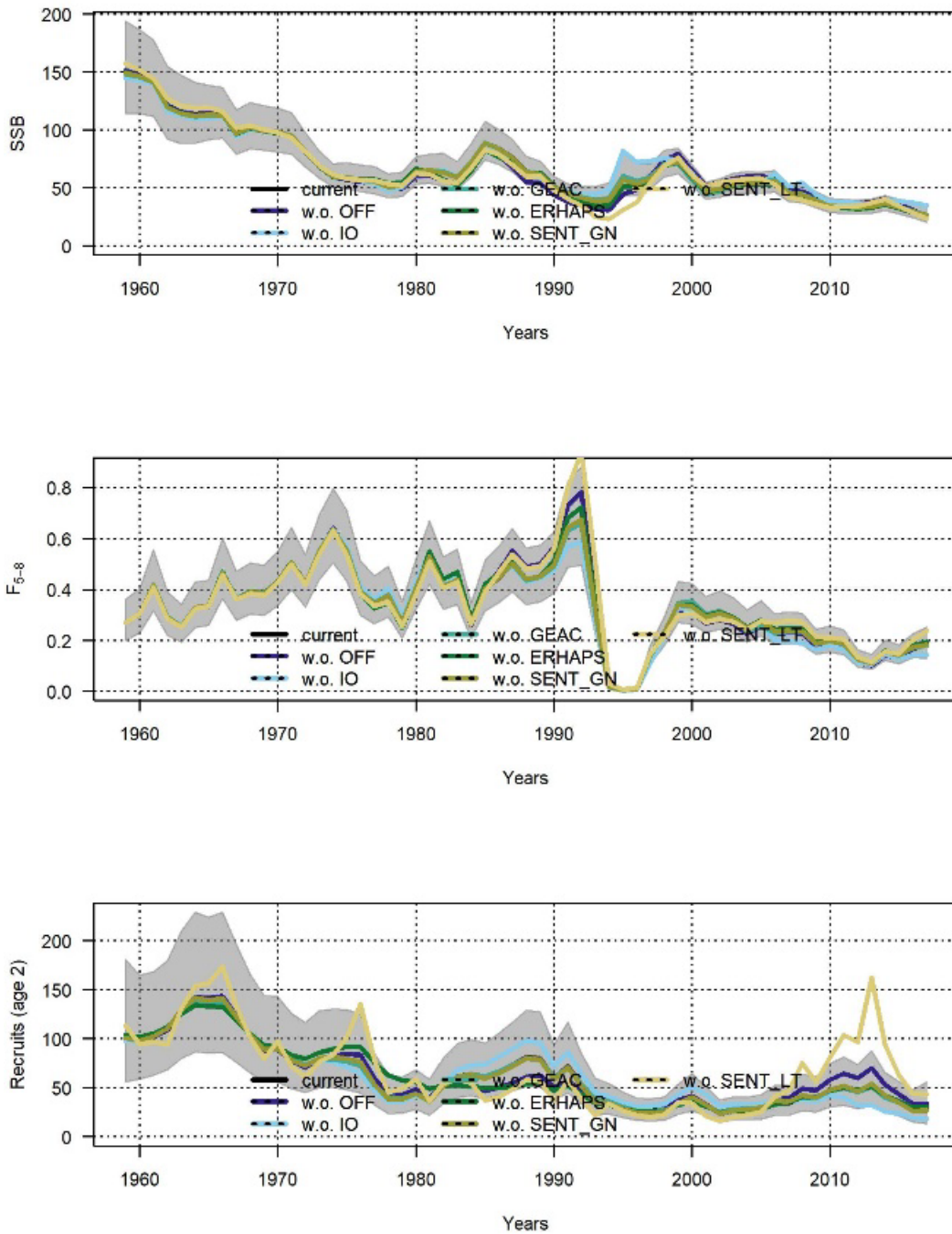
Figure 36: Model diagnostic plot for the combined run (i.e., run 144): leave out analysis. The legend is the same for each panel: current (black line), w.o. OFF (deep-blue line), w.o. IO (light-blue solid line), w.o. GEAC (turquoise solid line), w.o. ERHAPS (green solid line), w.o. Sent_GN (khaki solid line), w.o. Sent_LT (yellow solid line). Grey ribbons show the 95% confidence intervals around the current run estimate.
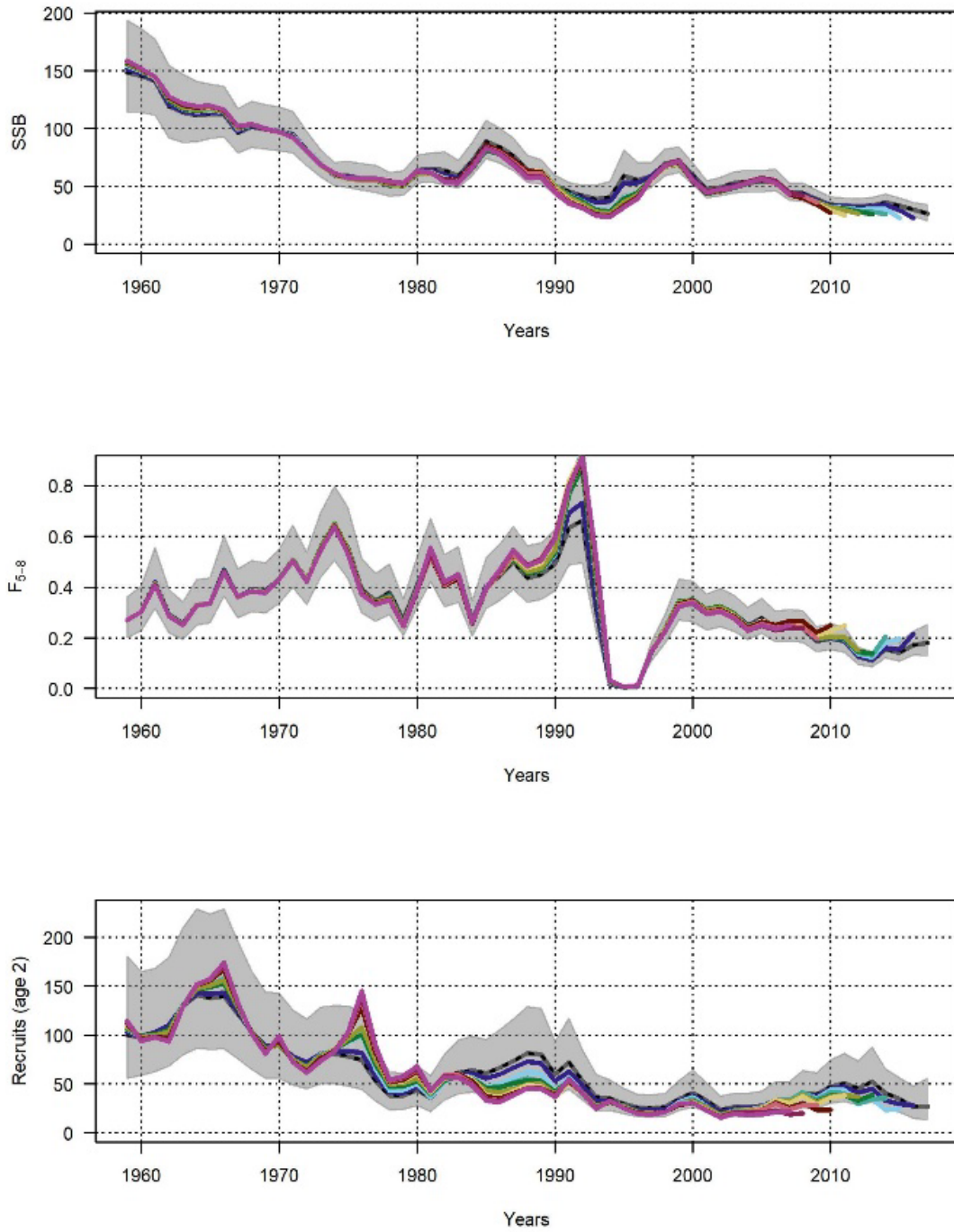
Figure 37: Model diagnostic plot for the combined run (i.e., run 144): retrospective analysis. Grey ribbons show the 95% confidence intervals around the current run.
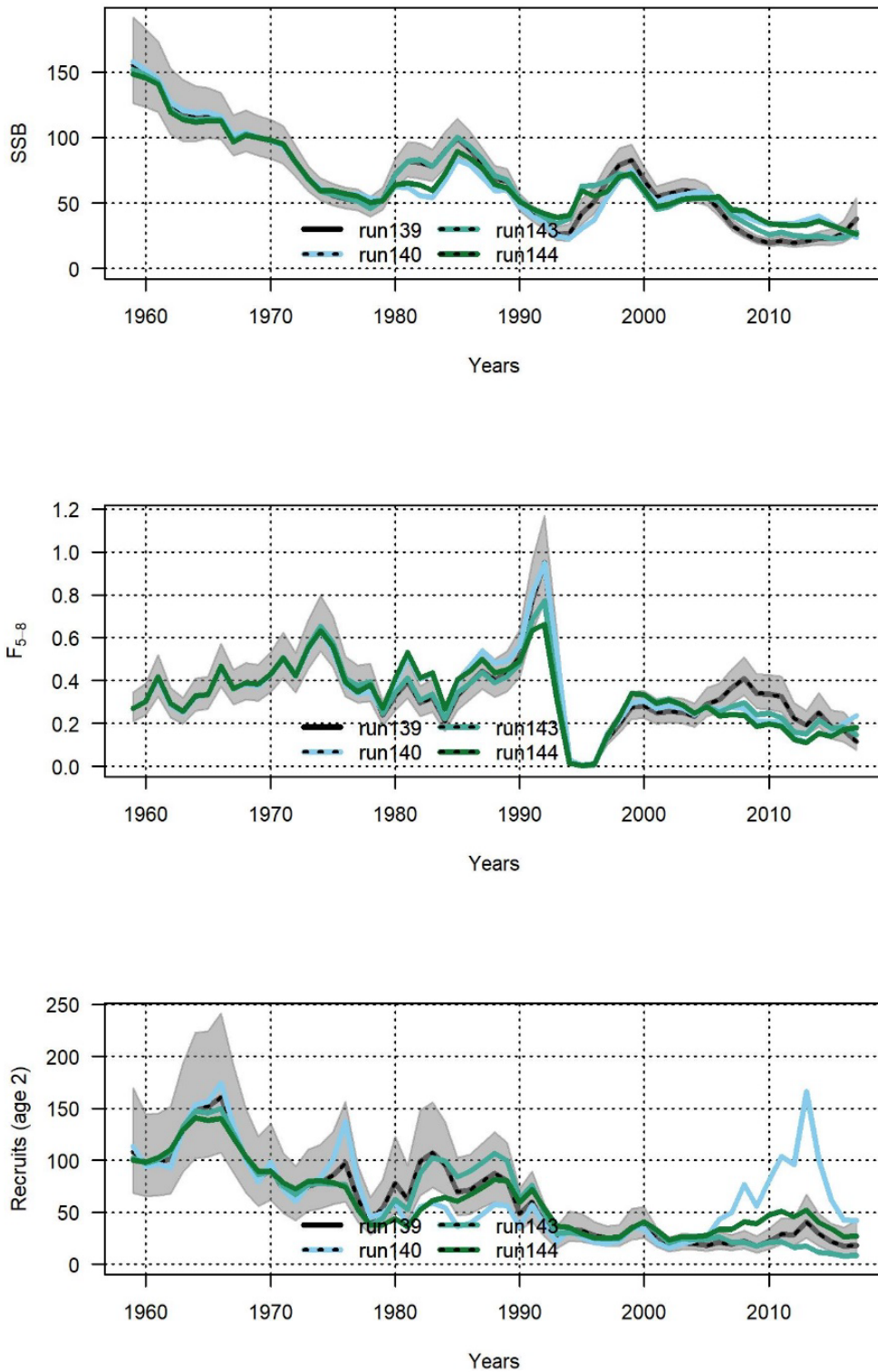
Figure 38: Stock variables estimates comparison between the basic (i.e., run 139, grey and black dashed line), the condition M (i.e., run 140, light-blue solid line), the sentinel (i.e., run 143, turquoise solid line) and the combined (i.e., run 144, green solid line) runs. Grey ribbons show the 95% intervals around the basic run estimates.
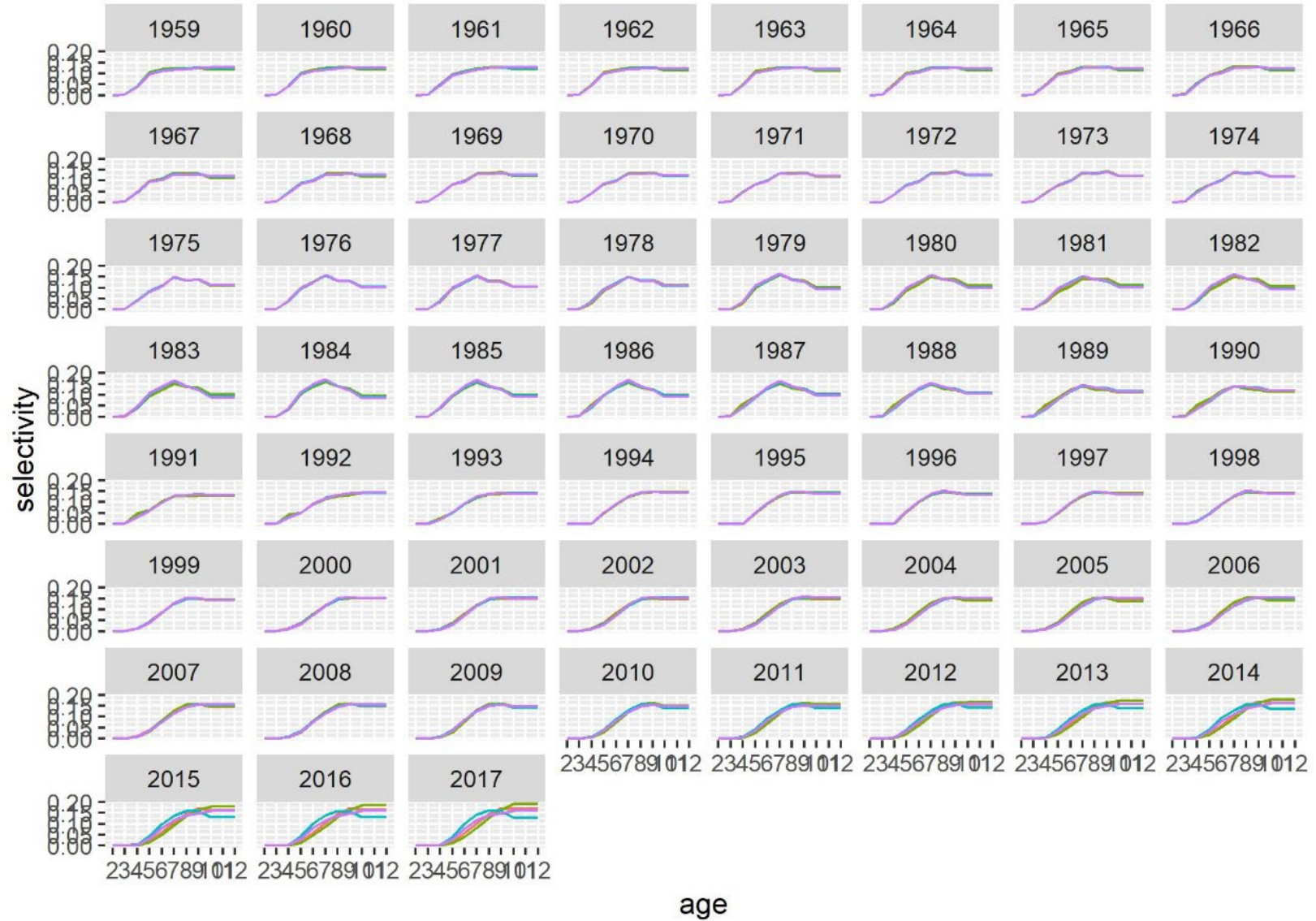
Figure 39: Comparison of estimated selectivity between the basic (run 139, pink line), the condition M (run 140, green line), the sentinel (run 143, turquoise line) and the combined (run 144, purple line) runs.

APPENDICES

APPENDIX 1: BASIC RUN CONFIGURATION IN SAM (RUN 139)

Configuration saved: Mon Sep 23 12:53:34 2019

Where a matrix is specified rows corresponds to fleets and columns to ages.

Same number indicates same parameter used

Numbers (integers) starts from zero and must be consecutive

#

$minAge

The minimium age class in the assessment

 2

$maxAge

The maximum age class in the assessment

 12

$maxAgePlusGroup

Is last age group considered a plus group (1 yes, or 0 no).

 1

$keyLogFsta

Coupling of the fishing mortality states (nomally only first row is used).

  0 1 2 3 4 5 6 7 8 8 8

$corFlag

Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, or 2 AR(1)

 2

$keyLogFpar

Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing mortality).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

  0 1 2 3 4 5 5 5 5 5 5

  6 7 8 9 10 5 5 5 5 5 5

 11 12 13 14 15 16 16 16 16 16 16

 17 18 19 20 21 22 22 22 22 22 22

$keyQpow

Density dependent catchability power parameters (if any).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

```
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

$keyVarF

Coupling of process standard deviation parameters for log(F)-process (nomally only first row is used)

```
 0  1  1  2  2  2  2  2  2  2  2
```

$keyVarLogN

Coupling of process variance parameters for log(N)-process

```
 0 1 1 1 1 1 1 1 1 1 1 1
```

$keyVarObs

Coupling of the variance parameters for the observations.

```
 0  1  1  2  2  2  2  2  2  2  2
 3  3  3  3  3  3  3  3  3  3  3
 4  4  4  4  4  4  4  4  4  4  4
 5  5  5  5  5  5  5  5  5  5  5
 6  6  6  6  6  6  6  6  6  6  6
```

$obsCorStruct

Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured).

```
 "ID" "ID" "ID" "ID" "ID"
```

$keyCorObs

Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
NA's indicate where correlation parameters can be specified (-1 where they cannot).
#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12

```
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
```

$stockRecruitmentModelCode

Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and 3 piece-wise constant).

```
 0
```

$noScaledYears

Number of years where catch scaling is applied.
 0

$keyScaledYears
A vector of the years where catch scaling is applied.

$keyParScaledYA
A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange
lowest and higest age included in Fbar
 5 8

$keyBiomassTreat
To be defined only if a biomass survey is used (0 SSB index, 1 catch index, and 2 FSB index).
 -1 -1 -1 -1 -1

$obsLikelihoodFlag
Option for observational likelihood | Possible values are: "LN" "ALN"
 "LN" "LN" "LN" "LN" "LN"

$fixVarToWeight
If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).
 0

$fracMixF
The fraction of t(3) distribution used in logF increment distribution
 0

$fracMixN
The fraction of t(3) distribution used in logN increment distribution
 0

$fracMixObs
A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet
 0 0 0 0 0

$constRecBreaks

Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock-recruitment code 3).

APPENDIX 2: SUMMARY OF FEW RUNS WITH VARIATIONS IN NATURAL MORTALITY INPUT

Different natural mortality inputs:

- Time block estimation: based on expert knowledge the time series is split in two blocks with moratorium start (1993) as a break. $M_y = \begin{cases} 0.2, & y < 1993 \\ 0.4, & y \geq 1993 \end{cases}$

- Lorenzen estimate: $M(a) = 3{,}69\, \overline{W}_a^{-0{,}305}$ (Lorenzen 1996)

- Casini: Time variant only (Casini-NoAge) and Time and age group variant (Casini-age) (Appendix C in Varkey et al. 2022; based on Casini et al. 2016)

- M 'Brodziack*0.2' : $M_a = \begin{cases} M_{base} \times \frac{L_{mat}}{L_a}, & a < a_{mat} \\ M_{base}, & a \geq a_{mat} \end{cases}$, with M$_{base}$=0.2. Based on length at maturity from survey sampling (Brodziack et al. 2011)

- Brodziack*Casini' : $M_a = \begin{cases} M_{base} \times \frac{L_{mat}}{L_a}, & a < a_{mat} \\ M_{base}, & a \geq a_{mat} \end{cases}$, with M$_{base}$= time variant M from Casini method.
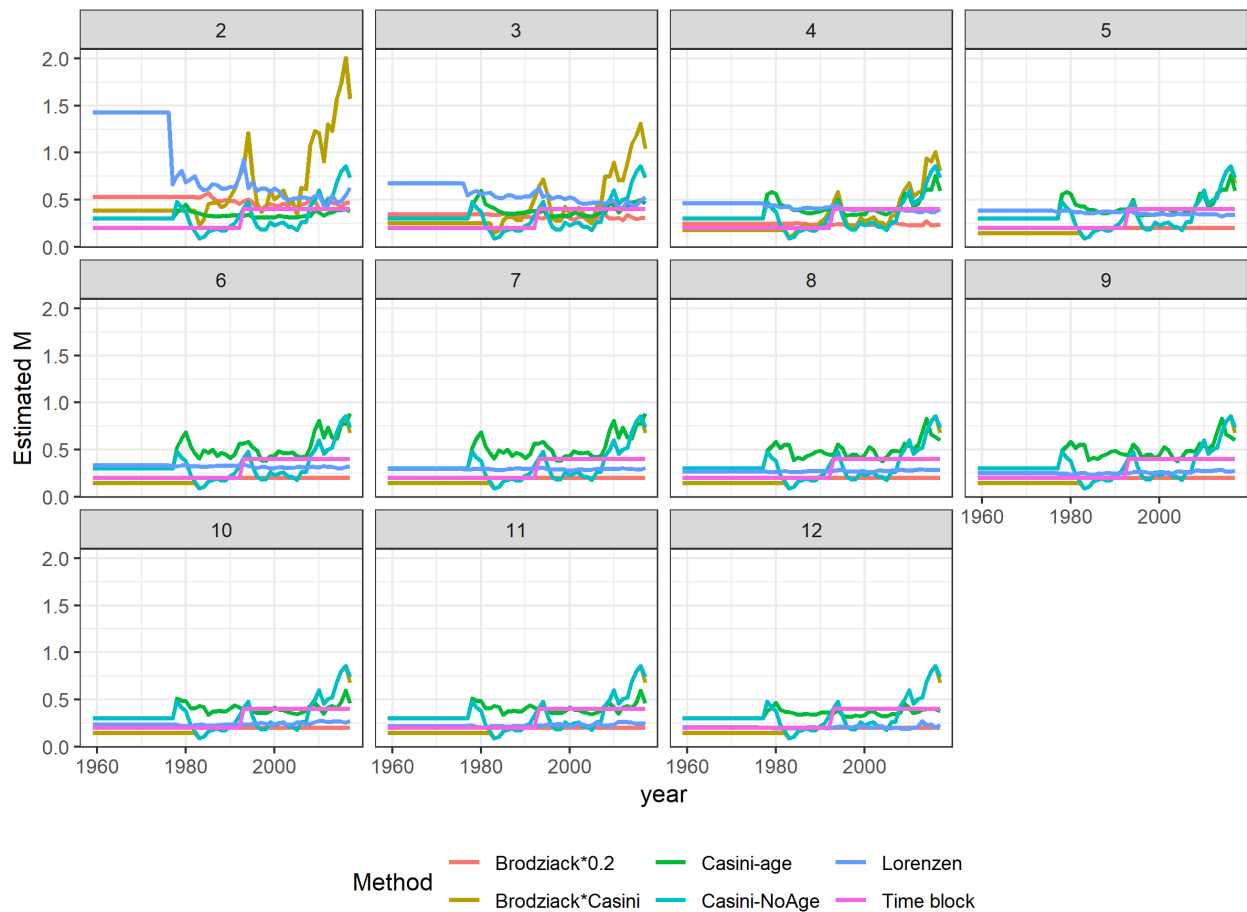
Figure A2.1: Natural mortality at age estimated by different methods.

Table A2.1: Run comparison for different natural mortality input.

*all outputs are compared to a similar run with a 0.2 natural mortality input.

Output/Run	Time Block	Lorenzen	Brodziack	Brodziack * Casini	Casini – NoAge	Casini – Age
Convergence & parameters estimations	Ok	Ok	Ok	Ok	Ok	Ok
Retrospective analysis	Increase of directional bias	Slight decrease of directional bias	Identical	Decrease directional bias and invert direction (lesser extent than age invariant condition M)	Decrease directional bias and invert direction	Decrease directional bias (but to lesser extent than Casini-NoAge)
Process residuals	Same or slightly worst	Same	Same	Slight decrease	Slightly better	Same
N std.dev	Increase	Increase	Same	Decrease	Decrease	Increase
R std.dev	Slight decrease	Increase	Same	Increase	Increase	Slight increase
F std.dev	Same	Same	Same	Age 2: Slight decrease Age 3–4: Slight decrease Age 5+: Slight decrease	Age 2: Increase Age 3–4: Slight decrease Age 5+: Decrease	Age 2: Increase Age 3–4: Decrease Age 5+: Same
Comments	Pattern in process residuals	Higher SSB and R estimates	Higher R estimates	Higher R estimates (higher that Casini-NoAge)	Higher R estimates and different recent trend in SSB	Higher SSB and R estimates

APPENDIX 3: CONDITION M RUN CONFIGURATION IN SAM (RUN 140)

Configuration saved: Mon Sep 23 12:44:41 2019

Where a matrix is specified rows corresponds to fleets and columns to ages.

Same number indicates same parameter used

Numbers (integers) starts from zero and must be consecutive

#

$minAge

The minimium age class in the assessment

 2

$maxAge

The maximum age class in the assessment

 12

$maxAgePlusGroup

Is last age group considered a plus group (1 yes, or 0 no).

 1

$keyLogFsta

Coupling of the fishing mortality states (normally only first row is used).

  0   1   2   3   4   5   6   7   8   8   8

$corFlag

Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, or 2 AR(1)

 2

$keyLogFpar

Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing mortality).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
  0   1   2   3   4   5   5   5   5   5   5
  6   7   8   9 10   5   5   5   5   5   5
 11 12 13 14 15 16 16 16 16 16 16
 17 18 19 20 21 22 22 22 22 22 22

$keyQpow

Density dependent catchability power parameters (if any).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

```
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

$keyVarF

Coupling of process variance parameters for log(F)-process (nomally only first row is used)
```
 0  1  1  2  2  2  2  2  2  2  2
```

$keyVarLogN

Coupling of process variance parameters for log(N)-process
```
 0 1 1 1 1 1 1 1 1 1 1 1
```

$keyVarObs

Coupling of the variance parameters for the observations.
```
 0  1  1  2  2  2  2  2  2  2  2
 3  3  3  3  3  3  3  3  3  3  3
 4  4  4  4  4  4  4  4  4  4  4
 5  5  5  5  5  5  5  5  5  5  5
 6  6  6  6  6  6  6  6  6  6  6
```

$obsCorStruct

Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"
```
 "ID" "ID" "ID" "ID" "ID"
```

$keyCorObs

Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.

NA's indicate where correlation parameters can be specified (-1 where they cannot).

#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12
```
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
```

$stockRecruitmentModelCode

Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and 3 piece-wise constant).
```
 0
```

$noScaledYears

Number of years where catch scaling is applied.

0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange

lowest and highest age included in Fbar

 5 8

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, and 2 FSB index).

 -1 -1 -1 -1 -1

$obsLikelihoodFlag

Option for observational likelihood | Possible values are: "LN" "ALN"

 "LN" "LN" "LN" "LN" "LN"

$fixVarToWeight

If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).

 0

$fracMixF

The fraction of t(3) distribution used in logF increment distribution

 0

$fracMixN

The fraction of t(3) distribution used in logN increment distribution

 0

$fracMixObs

A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet

 0 0 0 0 0

$constRecBreaks

Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock-recruitment code 3).

APPENDIX 4: SENTINEL RUN CONFIGURATION IN SAM (RUN 143)

ConfiguratCion saved: Wed Sep 25 15:56:06 2019

Where a matrix is specified rows corresponds to fleets and columns to ages.

Same number indicates same parameter used

Numbers (integers) starts from zero and must be consecutive

#

$minAge

The minimium age class in the assessment

 2

$maxAge

The maximum age class in the assessment

 12

$maxAgePlusGroup

Is last age group considered a plus group (1 yes, or 0 no).

 1

$keyLogFsta

Coupling of the fishing mortality states (nomally only first row is used).

  0 1 2 3 4 5 6 7 8 8 8

$corFlag

Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, or 2 AR(1)

 2

$keyLogFpar

Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing mortality).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

  0 1 2 3 4 5 5 5 5 5 5

  6 7 8 9 10 5 5 5 5 5 5

 11 12 13 14 15 16 16 16 16 16 16

 17 18 19 20 21 22 22 22 22 22 22

 -1 23 24 25 26 27 28 29 30 -1 -1

 -1 31 32 33 33 33 33 33 33 -1 -1

$keyQpow

Density dependent catchability power parameters (if any).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

```
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

$keyVarF
Coupling of process variance parameters for log(F)-process (nomally only first row is used)
```
 0  1  1  2  2  2  2  2  2  2  2
```

$keyVarLogN
Coupling of process variance parameters for log(N)-process
```
 0 1 1 1 1 1 1 1 1 1 1
```

$keyVarObs
Coupling of the variance parameters for the observations.
```
 0  1  1  2  2  2  2  2  2  2  2
 3  3  3  3  3  3  3  3  3  3  3
 4  4  4  4  4  4  4  4  4  4  4
 5  5  5  5  5  5  5  5  5  5  5
 6  6  6  6  6  6  6  6  6  6  6
-1  7  7  7  7  7  7  7  7 -1 -1
-1  8  8  8  8  8  8  8  8 -1 -1
```

$obsCorStruct
Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are:
"ID" "AR" "US"
```
 "ID" "ID" "ID" "ID" "ID" "ID" "ID"
```

$keyCorObs
Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
NA's indicate where correlation parameters can be specified (-1 where they cannot).
#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12
```
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA  NA  NA
 -1  NA  NA  NA  NA  NA  NA  NA  -1  -1
```

```
-1 NA NA NA NA NA NA NA -1 -1
```

$stockRecruitmentModelCode

Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and 3 piece-wise constant).

```
 0
```

$noScaledYears

Number of years where catch scaling is applied.

```
 0
```

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange

lowest and higest age included in Fbar

```
 5 8
```

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, and 2 FSB index).

```
 -1 -1 -1 -1 -1 -1 -1
```

$obsLikelihoodFlag

Option for observational likelihood | Possible values are: "LN" "ALN"

```
 "LN" "LN" "LN" "LN" "LN" "LN" "LN"
```

$fixVarToWeight

If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).

```
 0
```

$fracMixF

The fraction of t(3) distribution used in logF increment distribution

```
 0
```

$fracMixN

The fraction of t(3) distribution used in logN increment distribution

```
 0
```

$fracMixObs

A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet

 0 0 0 0 0 0 0

$constRecBreaks

Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock-recruitment code 3).

APPENDIX 5: COMBINED RUN CONFIGURATION IN SAM (RUN 144)

Configuration saved: Wed Sep 25 18:18:31 2019

Where a matrix is specified rows corresponds to fleets and columns to ages.

Same number indicates same parameter used

Numbers (integers) starts from zero and must be consecutive

#

$minAge

The minimium age class in the assessment

 2

$maxAge

The maximum age class in the assessment

 12

$maxAgePlusGroup

Is last age group considered a plus group (1 yes, or 0 no).

 1

$keyLogFsta

Coupling of the fishing mortality states (nomally only first row is used).

  0 1 2 3 4 5 6 7 8 8 8

$corFlag

Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, or 2 AR(1)

 2

$keyLogFpar

Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing mortality).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
  0 1 2 3 4 5 5 5 5 5 5
  6 7 8 9 10 5 5 5 5 5 5
 11 12 13 14 15 16 16 16 16 16 16
 17 18 19 20 21 22 22 22 22 22 22
 -1 23 24 25 26 27 28 29 30 -1 -1
 -1 31 32 33 33 33 33 33 33 -1 -1

$keyQpow

Density dependent catchability power parameters (if any).

 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

```
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

$keyVarF

Coupling of process variance parameters for log(F)-process (nomally only first row is used)
```
 0  1  1  2  2  2  2  2  2  2  2
```

$keyVarLogN

Coupling of process variance parameters for log(N)-process
```
 0 1 1 1 1 1 1 1 1 1 1
```

$keyVarObs

Coupling of the variance parameters for the observations.
```
 0  1  1  2  2  2  2  2  2  2  2
 3  3  3  3  3  3  3  3  3  3  3
 4  4  4  4  4  4  4  4  4  4  4
 5  5  5  5  5  5  5  5  5  5  5
 6  6  6  6  6  6  6  6  6  6  6
-1  7  7  7  7  7  7  7  7 -1 -1
-1  8  8  8  8  8  8  8  8 -1 -1
```

$obsCorStruct

Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"
```
 "ID" "ID" "ID" "ID" "ID" "ID" "ID"
```

$keyCorObs

Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.

NA's indicate where correlation parameters can be specified (-1 where they cannot).
```
#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 NA NA NA NA NA NA NA NA NA NA
 -1 NA NA NA NA NA NA NA -1 -1
```

```
 -1  NA  NA  NA  NA  NA  NA  NA  -1  -1
```

$stockRecruitmentModelCode

Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and 3 piece-wise constant).

 0

$noScaledYears

Number of years where catch scaling is applied.

 0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange

lowest and higest age included in Fbar

 5 8

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, and 2 FSB index).

 -1 -1 -1 -1 -1 -1 -1

$obsLikelihoodFlag

Option for observational likelihood | Possible values are: "LN" "ALN"

 "LN" "LN" "LN" "LN" "LN" "LN" "LN"

$fixVarToWeight

If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).

 0

$fracMixF

The fraction of t(3) distribution used in logF increment distribution

 0

$fracMixN

The fraction of t(3) distribution used in logN increment distribution

 0

$fracMixObs

A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet

 0 0 0 0 0 0 0

$constRecBreaks

Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock-recruitment code 3).

APPENDIX 6: SUMMARY OF FEW RUNS WITH CORRELATION BETWEEN AGE IN OBSERVATIONS

As mentioned in the model description, SAM allows implementation of an age correlation between the observations.

- An autoregressive process allowing irregular distances between ages (IRAR[1]). For this a $\Delta d_{a,\tilde{a}}$. is defined. If all $\Delta d_{a,\tilde{a}}$. are the same, the lattice of distance is regular, if they are different it is irregular.

- An unstructured structure, which allows more flexibility but cost a lot of parameter (US).

Table A6.1: Description of attempted runs: characteristics in formulation and outputs. Outputs are compared with an equivalent run without any correlation between age in observations

	Run	154	155'	161	164	164'
Characteristics	**Correlation in catch**	IRAR – distances all free	IRAR – shared distances	IRAR – one distance	US	US
	Correlation in OFF	IRAR – all free	IRAR – shared rho	IRAR – one distance	IRAR – one distance	US
	Correlation in IO	IRAR – all free	IRAR – shared rho	IRAR – one distance	IRAR – one distance	US
	Correlation in GEAC	IRAR – all free	IRAR – shared rho	IRAR – one distance	IRAR – one distance	US
	Correlation in ERHAPS	IRAR – all free	IRAR – shared rho	IRAR – one distance	IRAR – one distance	US
Outputs	**Convergence**	Yes	No	Yes	Yes	No
	Other issue	No convergence of one retrospective run	x	No	No convergence of some retrospective runs	x
	ΔAIC	633	-	557	683	x
	Year effects in observation residuals	Decrease	-	Decrease	Decrease	x
	Retrospective pattern	x	-	Slight decrease	x	x
	Comments	Increase correlation between estimated parameters	-	Increase correlation between estimated parameters	Increase correlation between estimated parameters	x
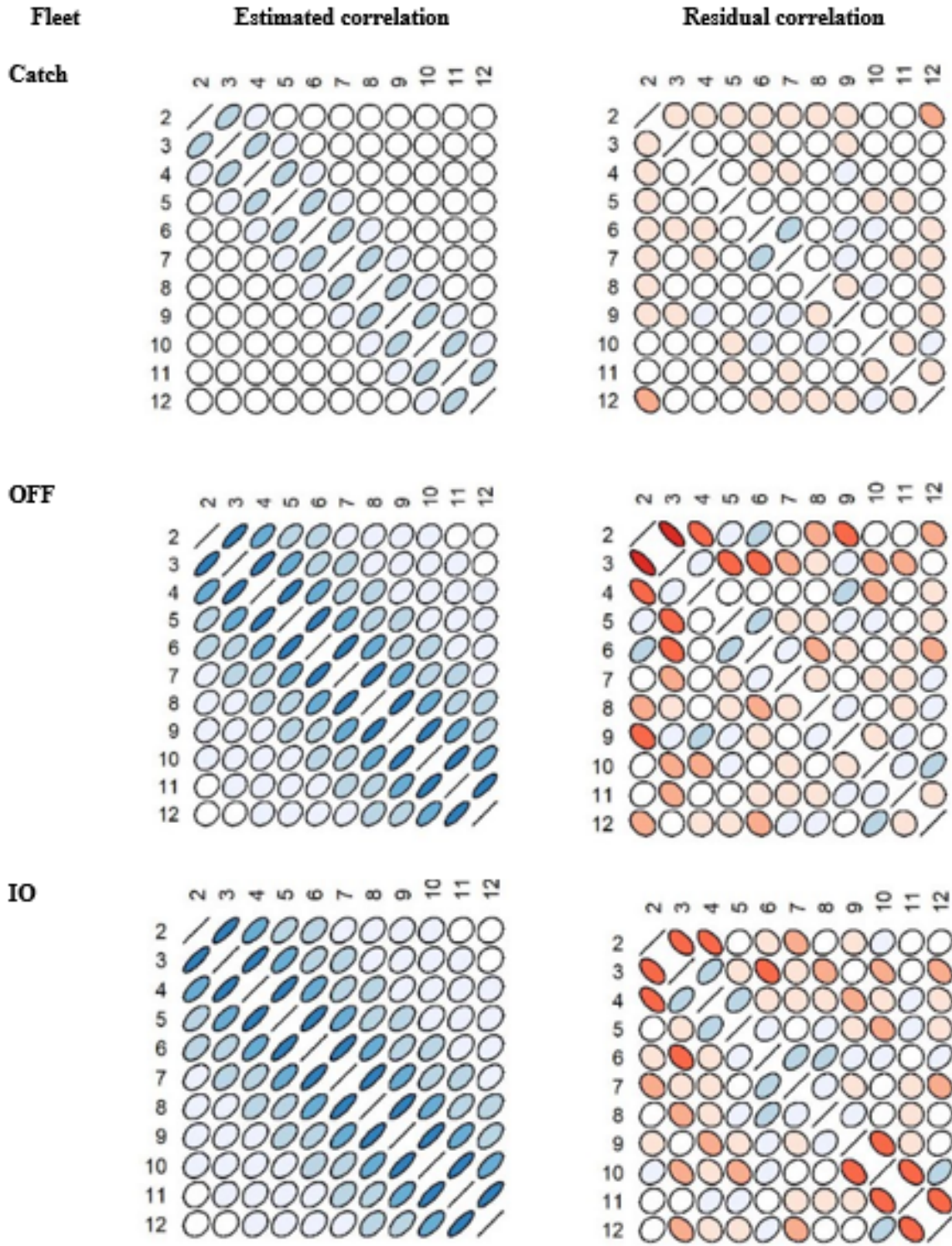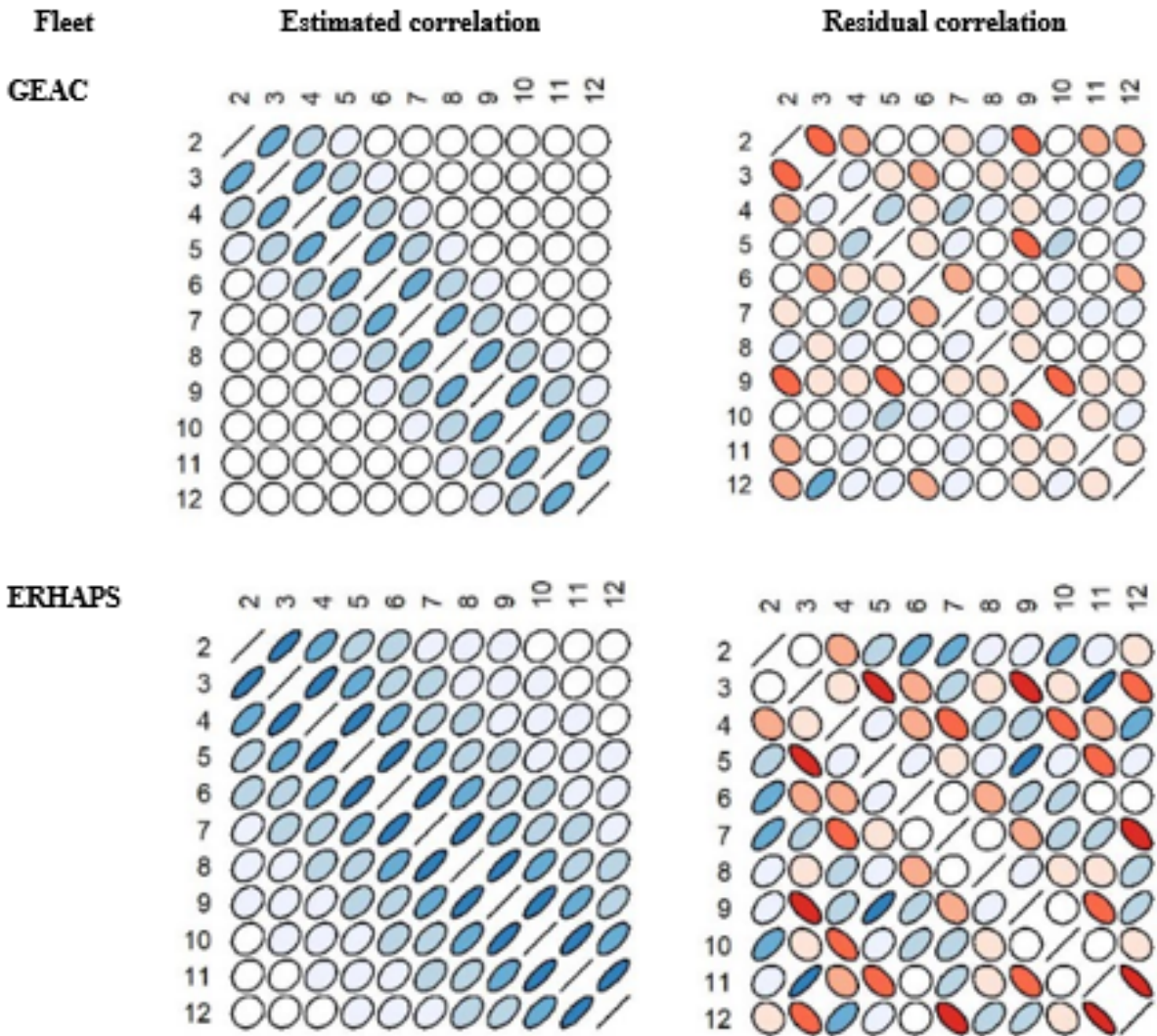
Figure A6.1: Estimated and residual between age correlation for each fleet of run 161.

APPENDIX 7: EXHAUSTIVE DESCRIPTION OF ALL RUNS PERFORMED

As mentioned in the text numerous SAM runs were performed in order to find the combinations of data inputs and parametrization which produces the most sensible population dynamics.

A synthetic summary of all run performed is given Table A7.1. It aims to give a glimpse of the main trials conducted.
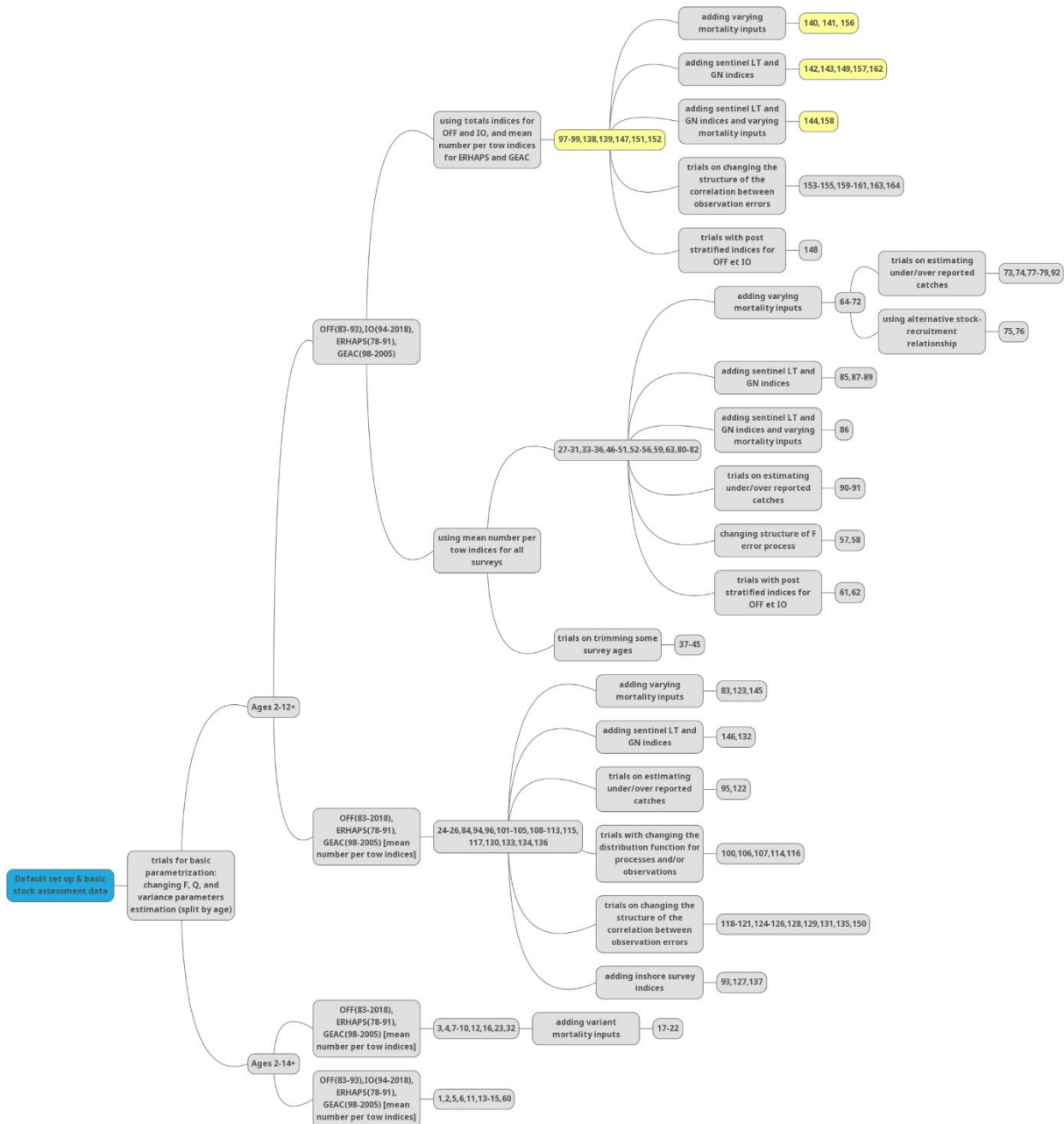
Figure A7.1: Summary of the runs conducted. The four main runs (detailed in the text) are in yellow nodes.

Table A7.1: Exhaustive description of all runs performed. Blue shaded cells precise which DFO RV survey inputs where used: dark blue OFF (1983–93) and OI (1994–2018), light blue: OFF (1983–2018). Orange shaded cells indicate a change from a run to another, grey shaded columns are runs which did not converge.

Characteristics	1	1bis	2	5	2bis	6	11	13	14	15	27	27bis	28	29	30
-	~matt's run	-	-	~run1 ms Qoff=Qio	-	~run1 + Qio bloqué 3+	~matt's run + mod F	~matt's run +modF =12 + IO	run 13 + Qio 3+	run 13 + Qio ==Qoff	~run 24	run 27+ mod F	run27 + mod F	run 28+ bloque Qio	run 28+ bloque Qio
Results															
CV	OK	NO	ok	ok	NO	OK	ok	ok	ok	ok	ok	NO	ok	ok	ok
nll	-1481.67	-	-1445	-1510	-	-1484	-1546	-1459	-1462	-1494.3	-1211.52	-	-1185.99	-1188.5	-1189.62
nb par	29	-	61	24	-	26	29	29	26	24	29	-	29	27	26
AIC	3012	-	3011.6	3067	-	3020	3151	2976.6	2977.3	3036.6	2481.03	-	2429.99	2431.03	2431.23
BIC	2063	-	2889.6	3019	-	2968	3093	2918	2925	2988.6	2423.03	-	2371.99	2377.03	2379.23
Inputs															
C@A	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
Survey indices	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS
Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
Stock wt	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model
Comm wt	DFO	~DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Formulation															
Ages	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–12+	2–12+	2–12+	2–12+	2–12+
SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
F selectivity	all free	all free	all free	all free	all free	all free	ID 6+	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	6+	all free	7+	7+	7+
F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
-	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Q DFO IO	ID 6+	ID 6+	all free	ID 6+	all free	ID 3+	ID 6+	ID 6+	ID 3+	ID 6+	ID 6+	ID 6+	ID 6+	ID 4+	ID 3+
Q DFO OFF	ID 6+	ID 6+	all free	ID 6+	all free	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
Q GEAC	ID 6+	ID 6+	all free	ID 6+	all free	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
Q ERHAPS	ID 6+	ID 6+	all free	ID 6+	all free	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Characteristics	1	1bis	2	5	2bis	6	11	13	14	15	27	27bis	28	29	30
-	~matt's run	-	-	~run1 ms Qoff=Qio	-	~run1 + Qio bloqué 3+	~matt's run + mod F	~matt's run +modF =12 + IO	run 13 + Qio 3+	run 13 + Qio ==Qoff	~run 24	run 27+ mod F	run27 + mod F	run 28+ bloque Qio	run 28+ bloque Qio
N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
F var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage catch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor	ID	AR1/all ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor	ID	AR1/all ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr OFF + btw age Cor	ID	AR1/all ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor	ID	AR1/all ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor	ID	AR1/all ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics		31	33	34	35	36	37	38	39	40	41	42	43	44	45	46
-	-	run30 + change effort OFF/IO	run30 + modF	run30 + modF	run34 + mod Fprocess	run30 + modF	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + no DFO idx	run30 + new catch
Results	CV	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	nll	-1189.62	-1290	-1193	-1252	-1205	-1162	-954.5	-1122.9	-1070	1120	-1176.6	-966.7	-966.7	-791	-1423
	nb par	26	26	26	26	26	22	22	25	23	26	24	26	26	17	26
	AIC	2431,23	2632	2439.3	2556.7	2463.9	2369	1953	2295.7	2186.9	2292.2	2401.2	1985.5	1985.5	1616.3	2898.3
	BIC	2379,23	2580	2387.3	2504.74	2411.9	2325	1909	2245.7	2140.9	2240.2	2353.3	1933.5	1933.5	1582.3	2846.3
Inputs	C@A	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	newDFO
	Survey indices	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF4-12, IO,GEAC,ERHAPS	cutOFF4-12, IO2-4,GEAC, ERHAPS	cutOFF, IO,GEAC,ERHAPS 3-10	cutOFF, IO,GEAC, ERHAPS5-9	cutOFF, IO,GEAC 2-6,ERHAPS	OFF4-12, IO2-3,GEAC, ERHAPS	OFF, IO2-3,GEAC, ERHAPS	OFF4-12, IO2-3,GEAC 2-6,ERHAPS3-10	GEAC ERHAPS	cutOFF, IO, GEAC, ERHAPS
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO model	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	0.2	0.2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0.2
Formulation	Ages	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+	2-12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	7+	11+	8+	8+	9+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+
	F process	AR1	CS	AR1	CS	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	x	ID 3+
	Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	x	ID 6+
	Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 5+	ID 5+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	F var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics	31	33	34	35	36	37	38	39	40	41	42	43	44	45	46
-	run30 + change effort OFF/IO	run30 + modF	run30 + modF	run34 + mod Fprocess	run30 + modF	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + truncated idx	run30 + no DFO idx	run30 + new catch
Var couplage catch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr OFF + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics		47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
-	-	run30 + no IO idx	run 46 + modF	run 46 + modF	run 46 + modF	run 46 + modF	run 51 + mod VarF	run 51 + mod VarF	run 51 + mod VarF	run 49 + mod VarF	run50 + mof varF	run 54 + mod Fprocess	run 54 + mod Fprocess	run 46 + mod Var F	run51 + mod age+	run46 + idx PS
Results	CV	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	nll	-941.5	-1453.1	-1459	-1460	-1458.7	-1430.3	-1418.2	1350.5	-1364.4	-1460	-1431.2	-1633.4	-1340.2	-1726	-1189.62
	nb par	23	26	26	26	26	27	28	29	29	29	29	28	26	26	26
	AIC	1928.9	2958.2	2970	2972.6	2969.5	2914.7	2892.5	2759.2	2786.9	2771.3	2920.3	3322.8	2738.4	3504	2431.23

Characteristics		47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
-	-	run30 + no IO idx	run 46 + modF	run 46 + modF	run 46 + modF	run 46 + modF	run 51 + mod VarF	run 51 + mod VarF	run 51 + mod VarF	run 49 + mod VarF	run50 + mof varF	run 54 + mod Fprocess	run 54 + mod Fprocess	run 46 + mod Var F	run51 + mod age+	run46 + idx PS
	BIC	1882.9	-	-	-	-	-	-	-	2728.9	2713.3	2862.3	3266.8	2680.4	3452	2379.23
Inputs	C@A	DFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices	cut OFF GEAC ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	PScutOFF,ps IO, GEAC, ERHAPS
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Formulation	Ages	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–14+	2–12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	7+	9+	10+	11+	all free	all free	all free	all free	10+	11+	all free	all free	7+	all free	7+
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	CS	Indep	AR1	AR1	AR1
	Q DFO IO	x	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+
	Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	F var couplage	ID	ID	ID	ID	ID	2/3+	2/3/4+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	ID	ID
	Var couplage catch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics		47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
-	-	run30 + no IO idx	run 46 + modF	run 46 + modF	run 46 + modF	run 46 + modF	run 51 + mod VarF	run 51 + mod VarF	run 51 + mod VarF	run 49 + mod VarF	run50 + mof varF	run 54 + mod Fprocess	run 54 + mod Fprocess	run 46 + mod Var F	run51 + mod age+	run46 + idx PS
Var couplage ERHAPS		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr OFF + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics			62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
-		-	run30 + idx PS	run 48+ mod VarF	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 64 + catch bounds	run 64 + catch bounds2	run 64+ mod R process	run 64+ mod R process
Results	CV		ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	nll		-1227.8	-1359	-1330.3	-1366.3	-1347.2	-1350.1	-1325.5	-1364	-1374.6	-1364.7	-1330.3	-1248.2	-1310.9	-1331.9	-1331.9
	nb par		26	29	29	29	29	29	29	29	29	29	29	32	43	31	31
	AIC		2507.6	2776.4	2718.6	2790.7	2752.4	2759.7	2709.1	2786	2807.3	2787.4	2718.6	2560.5	2707.8	2725.7	2725.7
	BIC		2455.6	2718.4	2660.6	2732.7	2694.4	2701.7	2651.1	2728	2749.3	2729.4	2660.6	2496.5	2621.8	2663.7	2663.7
Inputs	C@A		DFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices		PScutOFF,ps IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS

Characteristics	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
-	run30 + idx PS	run 48+ mod VarF	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 64 + catch bounds	run 64 + catch bounds2	run 64+ mod R process	run 64+ mod R process
Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
Stock wt	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model
Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
M	0.2	0.2	Casini age-id	Lorenzen catch	block 0.2/0.4 1992	block 0.2/0.4 1993	Casini * Brodziack survey	Brodziack 0.2 survey	Tagging	Tagging + sm3y	Casini age-id + smooth 3y	Casini age-id	Casini age-id	Casini age-id	Casini age-id
Ages	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	Ricker	BH
F selectivity	7+	9+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
Q DFO IO	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+
Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
Q sent GN	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Q sent LT	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
F var couplage	ID	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+
Var couplage catch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
-	-	run30 + idx PS	run 48+ mod VarF	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 55 + mod M	run 64 + catch bounds	run 64 + catch bounds2	run 64+ mod R process	run 64+ mod R process
Estimated scalar for catch		x	x	x	x	x	x	x	x	x	x	x	0:59-75.78-86.2010-11 1:76-77.97-09.12-18 3: 87-93	1976 1977 1987:1989 1992 1993 2001 2002 2004 2009 2012 2013 2015	x	x
Obs corr catch + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr OFF + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics		77	78	79	80	81	82	90	91	92	97	98	98b	99	138	139
-		run 64 + catch bounds3	run 64 + catch bounds6	run 64 + catch bounds7	run 55 + new NC sw	run 55 + DFO sw	run 55 + NC cw	run 80 + catch bounds10	run 80 + catch bounds10	run 91 + mod M	run 80+ total + change Q	run 97 + change Q	run 97 + change Q	run 97 + change Q	run 99 + run 136 form	run138 + M0.3
Results	CV	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	nll	-1307.6	-1308.4	-1303	-1364.4	-1364.4	-1364.4	-	-1184.4	-	-1363.1	-1376.3	-1346.1	-1377.4	-1308.3	-1303.5
	nb par	46	38	47	29	29	29	-	85	-	56	39	31	35	36	36
	AIC	2707.3	2692.8	2700.8	2786.9	2786.9	2786.9	-	2538.7	-	2838.2	2830.6	2754.2	2824.9	2688.5	2679
	BIC	2615.3	2616.8	2606.8	2728.9	2728.9	2728.9	-	2368.7	-	2726.2	2752.6	2692.2	2754.9	2616.5	2607

Characteristics	77	78	79	80	81	82	90	91	92	97	98	98b	99	138	139
-	run 64 + catch bounds3	run 64 + catch bounds6	run 64 + catch bounds7	run 55 + new NC sw	run 55 + DFO sw	run 55 + NC cw	run 80 + catch bounds10	run 80 + catch bounds10	run 91 + mod M	run 80+ total + change Q	run 97 + change Q	run 97 + change Q	run 97 + change Q	run 99 + run 136 form	run138 + M0.3
Inputs C@A	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
Survey indices	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS
Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
Stock wt	NC model	NC model	NC model	NC model2	DFO (old)	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
Comm wt	DFO	DFO	DFO	DFO	DFO	NCmodel2	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
M	Casini age-id	Casini age-id	Casini age-id	0.2	0.2	0.2	0.2	0.2	Casini age id	0.2	0.2	0.2	0.2	0.2	0.3
Formulation Ages	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
F selectivity	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
Q DFO IO	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+	all free	8+	6+	7+	7+	7+
Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	all free	8+ (same than IO)	6+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)
Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	all free	8+	6+	7+	7+	7+
Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	all free	8+	6+	7+	7+	7+
Q sent GN	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Q sent LT	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
F var couplage	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3-4/5+	2/3-4/5+
Var couplage catch	-	-	-	-	-	-	-	-	-	-	-	-	-	2/3-4/5+	2/3-4/5+
Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics	77	78	79	80	81	82	90	91	92	97	98	98b	99	138	139
-	run 64 + catch bounds3	run 64 + catch bounds6	run 64 + catch bounds7	run 55 + new NC sw	run 55 + DFO sw	run 55 + NC cw	run 80 + catch bounds10	run 80 + catch bounds10	run 91 + mod M	run 80+ total + change Q	run 97 + change Q	run 97 + change Q	run 97 + change Q	run 99 + run 136 form	run138 + M0.3
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	1976 1977 1987:1993 2001 2002 2004 2009 2012 2013 2015 2016	76-77/87 88-89/90 91-92/93 01-02/04 09-12-13-15	76-77/87 88-89/90 91-92/93 01-02/04 09-12-13-15 + age 2-3/4+	x	x	x	all year except 94-95-96	76/77/87 88/89/90 91/92/93 97/98/99 00/01/02 03/04/05 06/07/08 09/12/13 14/15/16 17	76/77/87 88/89/90 91/92/93 97/98/99 00/01/02 03/04/05 06/07/08 09/12/13 14/15/16 17	x	x	x	x	x	x
Obs corr catch + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr OFF + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics	140	141	142	143	144	147	148	149	151	152	152	153	154	154b	155
-	-	run138+ Mcasini age id	run 138 + Mcasini at age	run 138 + sentinelle	run 142+ M0.3	run 143+M casini age id	RUN 139+ TOTALS NN ps	RUN 139+ TOTALS ps	run 143 - 95-96 pour sent	run 139+ updated cw	run 151+varN free	run 151+varN free	run 151+ corr survey	run 151+ corr obs	run 151+ corr obs	run 153+ shared rho
Results CV	ok	ok	ok	-	-	-	-	-	ok	ok	ok	ok	-	-	ok
nll	-1289.3	-1301.1	-1882	-	-	-	-	-	-1303.5	-	-1291.9	-999.2	-	-	-1002.4
nb par	36	36	49	-	-	-	-	-	36	-	38	76	-	-	46
AIC	2650.6	2674.2	3862	-	-	-	-	-	2679	-	2659.7	2150.4	-	-	2096.8
BIC	2578.6	2602.2	3764	-	-	-	-	-	2607	-	2583.7	1998.3	-	-	2004.8
Inputs C@A	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
Survey indices	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT wo95-97	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS
Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
Stock wt	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2 new	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO
M	Casini age id	Casini at age	0.2	0.3	Casini age id	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Formulation Ages	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
F selectivity	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
Q DFO IO	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+
Q DFO OFF	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)
Q GEAC	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+
Q ERHAPS	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+
Q sent GN	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Q sent LT	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Characteristics	140	141	142	143	144	147	148	149	151	152	152	153	154	154b	155
-	run138+ Mcasini age id	run 138 + Mcasini at age	run 138 + sentinelle	run 142+ M0.3	run 143+M casini age id	RUN 139+ TOTALS NN ps	RUN 139+ TOTALS ps	run 143 - 95-96 pour sent	run 139+ updated cw	run 151+varN free	run 151+varN free	run 151+ corr survey	run 151+ corr obs	run 151+ corr obs	run 153+ shared rho
N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	all free	2/3-4/5-9/10+	ID	ID	ID	ID
F var couplage	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+
Var couplage catch	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+
Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	IRAR+all free	ID	ID
Obs corr IO + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	IRAR+all free	IRAR+all free	US	IRAR+shared rho
Obs corr OFF + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	IRAR+all free	IRAR+all free	US	IRAR+shared rho
Obs corr GEAC + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	IRAR+all free	IRAR+all free	US	IRAR+shared rho
Obs corr ERHAPS + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	IRAR+all free	IRAR+all free	US	IRAR+shared rho

Table A7.1 continued.

Characteristics		156	157	158	159	160	161	162	163	164	164bis	85	86	87	88	89
-	-	run 151+ casini M	run 151+ sent	run 151+ sent+Mcond	run 151 + corr catch IRAR free	run 151+ cor US catch	run 151 + corr obs atch IRAR	run 157 but NO GEAC	run 151+ sent cut LT5-10	run 151 + corr obs atch IRAR	run 151 + corr obs atch IRAR	run 80+ sent GN et LT	run 80+ sent GN et LT	run 80+ sent GN	run 80+ sent LT	run 80+ sent GN et LT
Results	**CV**	ok	-	-	-	-	-	-	-	-	-	ok	ok	ok	ok	ok
	nll	-1289.3	-	-	-	-	-	-	-	-	-	-1945.3	-1943.2	-1813.6	-1496.2	-
	nb par	36	-	-	-	-	-	-	-	-	-	42	42	38	33	-
	AIC	2650.6	-	-	-	-	-	-	-	-	-	3974.5	3970.4	3703.2	2058.4	-
	BIC	2578.6	-	-	-	-	-	-	-	-	-	3890.5	3886.4	3627.2	2992.4	-
Inputs	**C@A**	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, ERHAPS sentGN et LT	totals cutOFF, IO, GEAC, ERHAPS sentGN et LT cut 5-10	totals cutOFF, IO, GEAC, ERHAPS	totals cutOFF, IO, GEAC, ERHAPS	cutOFF, IO, GEAC, ERHAPS, sent GN et LT	cutOFF, IO, GEAC, ERHAPS, sent GN et LT	cutOFF, IO, GEAC, ERHAPS, sent GN	cutOFF, IO, GEAC, ERHAPS, sent LT	cutOFF, IO, GEAC, ERHAPS, sent GN et LT
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model2 new	NC model2 new	NC model2 new	NC model2	NC model2	NC model2	NC model2 new	NC model2 new	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
	Comm wt	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO	new DFO	DFO	DFO	DFO	DFO	DFO
	M	Casini age id	0.3	Casini age id	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	Casini age-id	0.2	0.2	0.2
Formulation	**Ages**	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	ID 3+	ID 3+	ID 3+	ID 3+	ID 3+
	Q DFO OFF	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	7+ (same than IO)	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q GEAC	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q ERHAPS	7+	7+	7+	7+	7+	7+	7+	7+	7+	7+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q sent GN	x	x	x	x	x	x	x	x	x	x	all free	all free	all free	x	all free
	Q sent LT	x	x	x	x	x	x	x	x	x	x	3/4/5+	3/4/5+	x	3/4/5+	3+
	Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Characteristics	156	157	158	159	160	161	162	163	164	164bis	85	86	87	88	89
-	run 151+ casini M	run 151+ sent	run 151+ sent+Mcond	run 151 + corr catch IRAR free	run 151+ cor US catch	run 151 + corr obs atch IRAR	run 157 but NO GEAC	run 151+ sent cut LT5-10	run 151 + corr obs atch IRAR	run 151 + corr obs atch IRAR	run 80+ sent GN et LT	run 80+ sent GN et LT	run 80+ sent GN	run 80+ sent LT	run 80+ sent GN et LT
N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
F var couplage	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+
Var couplage catch	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	-	-	-	-	-
Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor	ID	ID	ID	IRAR free	US	IRAR 1rho	ID	ID	US	US	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor	ID	ID	ID	ID	ID	IRAR 1rho	ID	ID	IRAR 1rho	US	ID	ID	ID	ID	ID
Obs corr OFF + btw age Cor	ID	ID	ID	ID	ID	IRAR 1rho	ID	ID	IRAR 1rho	US	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor	ID	ID	ID	ID	ID	IRAR 1rho	ID	ID	IRAR 1rho	US	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor	ID	ID	ID	ID	ID	IRAR 1rho	ID	ID	IRAR 1rho	US	ID	ID	ID	ID	ID

Table A7.1 continued.

	Characteristics	3	3bis	4	7	8	9	10	12	16	17	18	19	20	21	22
	-	~matt's run	-	-	~run3 & mod F	~run3 & mod F	~run3 & mod F	~run3 & mod F	~run3 & mod F	~run12 + change sw	~run16 + change M	~run16 + change M	~run16+ change M	~run12+ change M	~run12 + change M	~run12 + change M
Results	CV	ok	NO	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	-	-	-
	nll	-1521	-	-1521	-1587	-1571	-1524	-1499	-1492	-1492	-1476.3	-1494	-	-	-	-
	nb par	23	-	23	23	23	23	23	23	23	23	23	-	-	-	-
	AIC	3089.95	-	3089.95	3220	3188	3095	3043	3031.6	3031.6	2998.7	3035.7	-	-	-	-
	BIC	3043.95	-	3043.95	3173	3142	3028	2997	2885.6	2885.6	2952.7	2989.8	-	-	-	-
Inputs	C@A	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	Survey indices	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model	NC model	DFOcw +backward	NC model	NC model	NC model	NC model	NC model	DFOcw +backward	DFOcw +backward	DFOcw +backward	DFOcw +backward	NC model	NC model	NC model
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2/0.4 (1992)	Brodziack0.2	Lorenzen	Lorenzen	Brodziack0.2	0.2/0.4 (1992)
Formulation	Ages	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+	2–14+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	all free	all free	all free	ID 6+	ID 6-9/10+	ID 6-9/10-12/13	ID 7-11/12-13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14	ID 7-11/12/13/14
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Q DFO OFF	ID 6+	all free	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q GEAC	ID 6+	all free	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q ERHAPS	ID 6+	all free	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	F var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics		3	3bis	4	7	8	9	10	12	16	17	18	19	20	21	22
-	-	~matt's run	-	-	~run3 & mod F	~run3 & mod F	~run3 & mod F	~run3 & mod F	~run3 & mod F	~run12 + change sw	~run16 + change M	~run16 + change M	~run16+ change M	~run12+ change M	~run12 + change M	~run12 + change M
Var couplage catch		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Var couplage DFO IO		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Var couplage DFO OFF		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage GEAC		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Obs corr catch + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr OFF + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor		ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics		23	3ter	24	25	26	26bis	32	83	84	94	95	96	100	101	102
-	-	run12 + sm mat	~run 3 + age 2-12+	~run 12 + age 2-12+	~run 24+ mod F	~run 24+ mod F	~run 26 + truncated indices	run12 + change in VarN	run 64 + NC sw2	run 55 + new NC sw	run 84 + Qpower parameter	run 84 + catch bounds 11	run 84 + Qpower parameter	run 84 + tmix OFF0.05	run 84 + change var obs	run 84 + change var obs
Results	CV	-	NO	ok	ok	ok	NO	ok	ok	ok	ok	ok	ok	ok	ok	ok
	nll	-	-	-1211.99	-1335.69	-1248	-	-1492.81	-1351.7	-1385.3	-1372.2	-	-1372.2	-1385.2	-1306.2	-1383.7
	nb par	-	-	23	23	23	-	24	26	26	28	-	28	26	30	28
	AIC	-	-	2469.98	2717.37	2543	-	3033.6	2755.4	2822.7	2800.5	-	2800.5	2822.5	2672.4	2823.5
	BIC	-	-	2423.98	2671.38	2497	-	2985.6	2703.4	2770.7	2744.5	-	2744.5	2770.5	2612.4	2767.5
Inputs	C@A	DFO	DFO	DFO	DFO	DFO	DFO	DFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF2-12, GEAC2-6, ERHAPS3-10	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS
	Maturity	DFO model+ sm5	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model	NC model	NC model	NC model	NC model	NC model	NC model	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	Casini age-id	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Formulation	Ages	2–14+	2–12+	2–12+	2–12+	2–12+	2–12+	2–14+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	ID 7-11/12/13/14	all free	2/3/4/5/6/7-10/11/12	2/3/4/5-8/9/10/11/12	6+	6+	ID 7-11/12/13/14	10+	10+	10+	10+	10+	10+	10+	10+
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q power	-	-	-	-	-	-	-	-	-	OFF, ERHAPS 5+	-	all free	-	x	x
	N var couplage	ID	ID	ID	ID	ID	ID	2/3/4+	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics	23	3ter	24	25	26	26bis	32	83	84	94	95	96	100	101	102
-	run12 + sm mat	~run 3 + age 2-12+	~run 12 + age 2-12+	~run 24+ mod F	~run 24+ mod F	~run 26 + truncated indices	run12 + change in VarN	run 64 + NC sw2	run 55 + new NC sw	run 84 + Qpower parameter	run 84 + catch bounds 11	run 84 + Qpower parameter	run 84 + tmix OFF0.05	run 84 + change var obs	run 84 + change var obs
F var couplage	ID	ID	ID	ID	ID	ID	ID	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+	2/3/4/5+
Var couplage catch	-	-	-	-	-	-	-	-	-	-	-	-	-	2/3/4/5-10/11-12	ID
Var couplage DFO IO	x	x	x	x	x	x	x	ID	ID	ID	ID	ID	ID	ID	x
Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	2/3-10/11-12
Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	-	-	-	-	-	-	-	x	x	x	every year except 78-86.94-96.2012-2017	x	x	x	x
Obs corr catch + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr OFF + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

Characteristics		103	104	105	106	107	108	109	110	111	112	113	114	115	116	117
-	-	run 84 + change var obs	run 84 + change var obs	run101 + retire VarF	run 84 + tmix OFF0.03	run 84 + tmix OFF0.01	run101 + retire VarF	run101 + retire VarF	run 84 + varF id	run 110 + var obs catch	run 111 + varF	run 84 + change VarF	run 84 + tmix OFF0.1	run 112 + var F mod	run 84 + tmix N0.1	run 112 + var F mod
Results	CV	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	nll	-1384.4	-1380	-1306.2	-1385.3	-1385.3	-1311.7	-1324.4	-1479.8	-1346.2	-1319.3	-1385.3	-1385.3	-1346.2	-1385.3	-1319.3
	nb par	28	28	30	26	26	33	26	23	25	28	25	26	26	26	27
	AIC	2824.9	2816.4	2672.4	2822.6	2822.6	2689.4	2700.8	3005.5	2742.4	2694.6	2821.3	2822.6	2744.3	2822.6	2692.6
	BIC	2768.9	2760.4	2612.4	2770.6	2770.6	2623.5	2648.8	2959.5	2692.4	2638.6	2771.3	2770.6	2692.3	2770.6	2638.6
Inputs	C@A	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Formulation	Ages	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+
	Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q power	x	x	x	-	-	x	x	-	-	-	-	-	-	-	-
	N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	F var couplage	2/3/4/5+	2/3/4/5+	ID	2/3/4/5+	2/3/4/5+	ID	ID	ID	ID	2/3/4+	2/3-4/5+	2/3/4/5+	2/3+	2/3/4/5+	2/3-4/5+
	Var couplage catch	ID	ID	2/3/4/5-10/11-12	-	-	all free	2/3-4/5-9/10+	ID	2/3-4/5+	2/3-4/5+	-	-	2/3-4/5+	-	2/3-4/5+
	Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117
- -	run 84 + change var obs	run 84 + change var obs	run101 + retire VarF	run 84 + tmix OFF0.03	run 84 + tmix OFF0.01	run101 + retire VarF	run101 + retire VarF	run 84 + varF id	run 110 + var obs catch	run 111 + varF	run 84 + change VarF	run 84 + tmix OFF0.1	run 112 + var F mod	run 84 + tmix N0.1	run 112 + var F mod
Var couplage GEAC	2/3-10/11-12	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Var couplage ERHAPS	ID	2/3-10/11-12	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Estimated scalar for catch	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr IO + btw age Cor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr OFF + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr GEAC + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Obs corr ERHAPS + btw age Cor	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Table A7.1 continued.

	Characteristics	118	119	120	121	122	123	124	125	126	126	128	129	130	131	133
	- -	run 111+cor obs catch	run 111+cor obs OFF	run 111+cor obs GEAC	run 111+cor obs ERHAPS	run 84+catch bounds 12	run 117 +Mcasini	run 117+cor obs catch	run 117+cor obs off	run 117+cor obs	run 117+cor obs erhaps	run 117+cor obs	run 128+free F	run 84+varF free	run 117+cor obs	run 117+free Q
Results	CV	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Results	nll	-1219.9	-1136.9	-1293.3	-1245.9	-	-1291.2	-1181.7	-1100.6	-	-	-994	-984.1	-1375.6	-939.1	-1309.6
Results	nb par	37	37	37	37	-	27	82	82	-	-	38	38	31	112	45
Results	AIC	2513.8	2347.7	2660.5	2565.8	-	2636.4	2527.5	2365.3	-	-	2063.9	2044.2	2813.3	2102.3	2709.3
Results	BIC	2439.8	2273.7	2586.5	2491.8	-	2582.4	2363.5	2201.3	-	-	1987.9	1968.2	2751.3	1878.3	2619.3

Characteristics	118	119	120	121	122	123	124	125	126	126	128	129	130	131	133
-	-	run 111+cor obs catch	run 111+cor obs OFF	run 111+cor obs GEAC	run 111+cor obs ERHAPS	run 84+catch bounds 12	run 117 +Mcasini	run 117+cor obs catch	run 117+cor obs off	run 117+cor obs	run 117+cor obs erhaps	run 117+cor obs	run 128+free F	run 84+varF free	run 117+cor obs	run 117+free Q

Inputs

		118	119	120	121	122	123	124	125	126	126	128	129	130	131	133
	C@A	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	0.2	0.2	Mcasini id age	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Formulation

		118	119	120	121	122	123	124	125	126	126	128	129	130	131	133
	Ages	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Q DFO OFF	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	free
	Q GEAC	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	free
	Q ERHAPS	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	ID 6+	free
	Q sent GN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q sent LT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Q power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	F var couplage	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3/4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	10+	2/3-4/5+	2/3-4/5+
	Var couplage catch	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	-	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	ID	2/3-4/5+	2/3-4/5+	2/3-4/5+
	Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics	118	119	120	121	122	123	124	125	126	126	128	129	130	131	133
- -	run 111+cor obs catch	run 111+cor obs OFF	run 111+cor obs GEAC	run 111+cor obs ERHAPS	run 84+catch bounds 12	run 117 +Mcasini	run 117+cor obs catch	run 117+cor obs off	run 117+cor obs	run 117+cor obs erhaps	run 117+cor obs	run 128+free F	run 84+varF free	run 117+cor obs	run 117+free Q
Estimated scalar for catch	x	x	x	x	every year except 59-74 94-97 2012 onward	x	x	x	x	x	x	x	x	x	x
Obs corr catch + btw age Cor	AR1 + free at age	ID	ID	ID	ID	ID	US	ID	ID	ID	AR1 + rho shared	AR1 + rho shared	ID	US	ID
Obs corr IO + btw age Cor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Obs corr OFF + btw age Cor	ID	AR1 + free at age	ID	ID	ID	ID	ID	US	ID	ID	AR1 + rho shared	AR1 + rho shared	ID	AR1 + free at age	ID
Obs corr GEAC + btw age Cor	ID	ID	AR1 + free at age	ID	ID	ID	ID	ID	US	ID	AR1 + rho shared	AR1 + rho shared	ID	AR1 + free at age	ID
Obs corr ERHAPS + btw age Cor	ID	ID	ID	AR1 + free at age	ID	ID	ID	ID	ID	US	AR1 + rho shared	AR1 + rho shared	ID	AR1 + free at age	ID

Table A7.1 continued.

	Characteristics	134	135	136	145	146	150	93	127	137	132
	- -	117 + Q8+	run 117 + cor obs US all	117 + Q7+	117 + Mcond	154 + sent	run 117 + cor obs survey	mod 80 + I 2-4	mod 80 + I 2-6	136 + In 26	run 117 + sent
Results	CV	ok	ok	ok	ok	-	-	ok	ok	ok	ok
	nll	-1316	-5393.6	-1317.7	-	-	-	-1364.4	-1550.5	-1483.4	-1902.8
	nb par	33	247	30	-	-	-	29	32	36	40
	AIC	2698	11281.2	2695.4	-	-	-	2786.9	3165	3038.7	3885.6
	BIC	2632	10787.2	2635.4	-	-	-	2728.9	3101	2966.7	3805.6

Characteristics		134	135	136	145	146	150	93	127	137	132
-	-	117 + Q8+	run 117 + cor obs US all	117 + Q7+	117 + Mcond	154 + sent	run 117 + cor obs survey	mod 80 + I 2-4	mod 80 + I 2-6	136 + In 26	run 117 + sent
Inputs	**C@A**	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO	newDFO
	Survey indices	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS, sentGN et sent LT	OFF, GEAC, ERHAPS	OFF, GEAC, ERHAPS, In2-4	OFF, GEAC, ERHAPS, In2-4	OFF, GEAC, ERHAPS, In2-4	OFF, GEAC, ERHAPS, sentGN et sent LT
	Maturity	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model	DFO model
	Stock wt	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2	NC model2
	Comm wt	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO	DFO
	M	0.2	0.2	0.2	Mcasini id age	Mcasini id age	0.2	0.2	0.2	0.2	0.2
Formulation	**Ages**	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+	2–12+
	SR	RW	RW	RW	RW	RW	RW	RW	RW	RW	RW
	F selectivity	10+	10+	10+	10+	10+	10+	10+	10+	10+	10+
	F process	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1	AR1
	Q DFO IO	x	x	x	x	x	x	x	x	x	x
	Q DFO OFF	8+	ID 6+	7+	7+	7+	ID 6+	ID 6+	ID 6+	ID 7+	ID 6+
	Q GEAC	8+	ID 6+	7+	7+	7+	ID 6+	ID 6+	ID 6+	ID 7+	ID 6+
	Q ERHAPS	8+	ID 6+	7+	7+	7+	ID 6+	ID 6+	ID 6+	ID 7+	ID 6+
	Q sent GN	-	-	-	-	-	-	x	x	x	free
	Q sent LT	-	-	-	-	-	-	x	x	x	3/4/5+
	Q power	-	-	-	-	-	-	-	-	-	-
	N var couplage	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	F var couplage	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3/4/5+	2/3/4/5+	2/3-4/5+	2/3-4/5+
	Var couplage catch	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	2/3-4/5+	-	-	2/3-4/5+	2/3-4/5+
	Var couplage DFO IO	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage DFO OFF	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID

Characteristics		134	135	136	145	146	150	93	127	137	132
-	-	117 + Q8+	run 117 + cor obs US all	117 + Q7+	117 + Mcond	154 + sent	run 117 + cor obs survey	mod 80 + I 2-4	mod 80 + I 2-6	136 + ln 26	run 117 + sent
	Var couplage GEAC	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Var couplage ERHAPS	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
	Estimated scalar for catch	x	x	x	x	x	x	x	x	x	x
	Obs corr catch + btw age Cor	ID	US	ID	ID	ID	ID	ID	ID	ID	ID
	Obs corr IO + btw age Cor	x	x	x	x	x	x	ID	ID	ID	x
	Obs corr OFF + btw age Cor	ID	US	ID	ID	ID	AR1 + free at age	ID	ID	ID	ID
	Obs corr GEAC + btw age Cor	ID	US	ID	ID	ID	AR1 + free at age	ID	ID	ID	ID
	Obs corr ERHAPS + btw age Cor	ID	US	ID	ID	ID	AR1 + free at age	ID	ID	ID	ID