

## JABBA RUNS FOR THE NORTH ATLANTIC BLUE SHARK

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### SUMMARY

*This document presents a set of JABBA runs for Blue Shark in the North Atlantic for the period 1971-2021, intended to serve as a preliminary study contributing to the ICCAT 2023 stock assessment. Five different configurations of a Pella-Tomlinson biomass dynamic model were implemented, corresponding to different assumptions on the parameters  $r$  and  $m$ . Two data-weighting procedures were applied to the abundance indices (standardized CPUE series) used to fit the model, one with weights fixed in advance and another one with some components of the weights estimated within JABBA. Runs were conducted including all CPUE series accepted by the ICCAT Blue Shark Data Preparatory Meeting (scenario "All"). Four other scenarios corresponding to the different clusters of CPUEs indicated by the same Data Preparatory Meeting were also evaluated. In all, this resulted in 50 JABBA runs. This document presents detailed results for the scenario "All" and provides a comparison of results among all 50 runs. Most of the runs estimate that the harvest rate is currently below  $H_{MSY}$  and the stock biomass around or above  $B_{MSY}$ .*

### RÉSUMÉ

*Ce document présente un ensemble de scénarios de JABBA pour le requin peau bleue de l'Atlantique Nord pour la période 1971-2021, destinés à servir d'étude préliminaire contribuant à l'évaluation du stock de l'ICCAT de 2023. Cinq configurations différentes d'un modèle dynamique de biomasse de Pella-Tomlinson ont été mises en œuvre, correspondant à différentes hypothèses sur les paramètres  $r$  et  $m$ . Deux procédures de pondération des données ont été appliquées aux indices d'abondance (séries de CPUE standardisées) afin d'ajuster le modèle, l'une avec des poids fixés à l'avance et l'autre avec quelques composantes des poids estimées au sein de JABBA. Les scénarios ont été exécutés en incluant toutes les séries de CPUE acceptées lors de la réunion de préparation des données sur le requin peau bleue de l'ICCAT (scénario « tous »). Quatre autres scénarios correspondant aux différents groupes de CPUE retenus lors de cette réunion de préparation des données ont également été évalués. Au total, 50 scénarios JABBA ont été obtenus. Ce document présente les résultats détaillés du scénario « tous » et fournit une comparaison des résultats entre les 50 scénarios. La plupart des scénarios estiment que le taux de capture est actuellement inférieur à  $HPME$  et que la biomasse du stock se situe autour ou au-dessus du niveau de la  $PME$ .*

### RESUMEN

*Este documento presenta un conjunto de ensayos de JABBA para el tiburón azul en el Atlántico norte para el periodo 1971-2021, con la intención de que sirva como estudio preliminar que contribuya a la evaluación de stock de 2023 de ICCAT. Se implementaron cinco configuraciones diferentes de un modelo dinámico de biomasa de Pella-Tomlinson, correspondientes a distintos supuestos sobre los parámetros  $r$  y  $m$ . Se aplicaron dos procedimientos de ponderación de datos a los índices de abundancia (series de CPUE estandarizadas) utilizados para ajustar el modelo, uno con ponderaciones fijadas de antemano y otro con algunos componentes de las ponderaciones estimados en JABBA. Se realizaron ensayos incluyendo todas las series de CPUE aceptadas en la reunión de preparación de datos de tiburón azul de ICCAT (escenario "todos"). También se evaluaron otros cuatro escenarios correspondientes a los distintos conglomerados de CPUE indicados en la misma reunión de preparación de datos. En total, se realizaron 50 ensayos de JABBA. Este documento presenta resultados detallados para el escenario "todos" y ofrece una comparación de resultados entre los 50 ensayos. La mayoría de los ensayos estiman que la tasa de captura está actualmente por debajo de  $H_{RMS}$  y la biomasa del stock en torno o por encima de  $B_{RMS}$ .*

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## KEYWORDS

*Stock assessment, North Atlantic, Blue Shark, biomass dynamic model*

### 1. Introduction

This document presents 2023 preliminary stock assessment model runs for blue shark in the North Atlantic based on the Bayesian State-Space Surplus Production Model framework, JABBA (Just Another Bayesian Biomass Assessment; <https://github.com/jabbamodel/JABBA>; Winker *et al.*, 2018).

JABBA is a fully documented, open-source R package, that has been formally included in the ICCAT stock catalogue and applied in many recent ICCAT stock assessments. The JABBA software used in this document was downloaded and installed in R using this code from R:

```
library(devtools)
install_github("jabbamodel/JABBA")
```

As agreed in the ICCAT Blue Shark Data Preparatory Meeting (Anon. 2023), the assessment period is 1971-2021. JABBA runs were conducted with 5 different configurations of a Pella-Tomlinson biomass dynamic model; the 5 configurations correspond to different priors on the parameters  $r$  and  $m$ . Two different data-weighting procedures were applied to the abundance indices (standardized CPUE series) used to fit the model, one in which the weights were fixed in advance and another one in which some components of the weights were estimated within JABBA. Runs were conducted including all CPUE series accepted by the Data Preparatory Meeting (scenario “All”). In addition, four other scenarios corresponding to the different clusters of CPUEs indicated by the Data Preparatory Meeting were also evaluated. In all, this resulted in  $5 \times 2 \times 5 = 50$  JABBA runs. This document presents detailed results for the scenario “All” and also provides a comparison of results among all 50 runs.

### 2. Materials and methods

#### 2.1 Data

The data used are as agreed in the ICCAT Blue Shark Data Preparatory Meeting (Anon. 2023), and consist of:

- Total catch by year, for the years 1971-2021 (**Figure 1**).
- Abundance indices, corresponding to standardized CPUE series, for Venezuela, Spain, Portugal, USA (split in two series), Japan, Chinese Taipei, and Morocco, for the following years (**Figure 2**):

<i>VEN</i>	<i>SPN</i>	<i>POR</i>	<i>USA1</i>	<i>USA2</i>	<i>JPN</i>	<i>CTP</i>	<i>MOR</i>
1994 - 2013	1997 - 2021	1997 - 2021	1992 - 2014	2015 - 2021	1994 - 2021	2007 - 2021	2010 - 2021

The SPN, POR and MOR indices are in biomass, whereas the remaining indices are in numbers. This situation is not ideal for use in biomass dynamic models (such as JABBA is), where the population is represented as an undifferentiated biomass and all indices used to fit the model are assumed to be representative of this biomass (through an index-specific catchability factor  $q(i)$ ), normally referred to as “fishable biomass”.

JABBA runs were conducted for the following scenarios:

- “All”: all CPUE series used to fit the model
- In addition, different subsets of CPUE series were used to fit the model, following the clusters indicated at the Data Preparatory Meeting:
- “Trend1”: POR, MOR, VEN
- “Trend2”: JPN, CTP, SPN, USA1, USA2
- “Target”: POR, MOR, SPN
- “non-Target”: JPN, CTP, VEN, USA1, USA2

The Data Preparatory Meeting was not totally conclusive regarding how to treat the Venezuelan and USA indices. Provisionally, this document includes them in the clusters noted above.

## 2.2 Model settings

### 2.2.1 Surplus production function and prior distributions on the model parameters

A Pella-Tomlinson model with shape parameter  $m$ , which corresponds to  $B_{MSY}/K=(1/m)^{1/(m-1)}$ , was used. In this model,  $H_{MSY}=r/m$  and  $MSY=B_{MSY}H_{MSY}=(Kr)/(m^{m(m-1)})$ . The special cases of Pella-Tomlinson with  $m=2$  and  $m$  converging towards 1, correspond to the Schaefer and Fox models, respectively.

Five cases were considered for  $r$  and  $m$ . The first three were based on the values provided in document SCRS/2023/115 (Cortés and Taylor), whereas the last two were similar to the 2015 North Atlantic blue shark assessment settings with BSP and BSP2.

#### Case 1 (“Pellam, 23”):

Priors on  $r$  and  $m$  aiming to be consistent with the range of values and uncertainty shown in the first and last rows of Table 5A of SCRS/2023/115:

$$\begin{aligned} r &\sim \text{logNormal}(\text{median}=0.335, \text{CV}=0.3), \\ m &\sim \text{logNormal}(\text{median}=1.55, \text{CV}=0.22), \end{aligned}$$

resulting in prior 95% probability intervals of (0.189,0.596) for  $r$  and (1.01, 2.39) for  $m$ .

#### Case 2 (“Pella, Det<sup>a</sup>, 23”):

Values of  $r$  and  $m$  consistent with the penultimate column of Table 5A of SCRS/2023/115:

$$\begin{aligned} r &\sim \text{logNormal}(\text{median}=0.283, \text{CV}=0.01), \\ m &= 1.53. \end{aligned}$$

#### Case 3 (“Pella, Det<sup>b</sup>, 23”):

Values of  $r$  and  $m$  consistent with the right-most column of Table 5A of SCRS/2023/115:

$$\begin{aligned} r &\sim \text{logNormal}(\text{median}=0.386, \text{CV}=0.01), \\ m &= 1.2. \end{aligned}$$

#### Case 4 (“Pellam, 15”):

Prior on  $r$  consistent with that used in the 2015 assessment:

$$r \sim \text{logNormal}(\text{median}=0.324, \text{CV}=0.13258).$$

and prior on  $m$  centred on a Schaefer model ( $m=2$ ):

$$m \sim \text{logNormal}(\text{median}=2, \text{CV}=0.2),$$

resulting in prior 95% probability intervals of (0.25,0.42) for  $r$  and (1.35, 2.96) for  $m$ .

#### Case 5 (“Schaefer, 15”):

Prior on  $r$  consistent with that used in the 2015 assessment:

$$\begin{aligned} r &\sim \text{logNormal}(\text{median}=0.324, \text{CV}=0.13258), \\ m &= 2, \end{aligned}$$

resulting in prior 95% probability intervals of (0.25,0.42) for  $r$ , and fixed  $m=2$  (Schaefer).

### 2.2.2 Prior distributions on $K$ and $B(1971)/K$

$K$  was assigned the following logNormal prior distribution:

$$K \sim \text{logNormal}(\text{median}=8*\text{max}(\text{Catch})=443864, \text{CV}=1),$$

which are the “default” median and CV hyperparameter values for  $K$  in JABBA, resulting in a prior 95% probability interval of (86812, 2269456) for  $K$ .

The parameter  $\psi$ , which in JABBA corresponds to the median value of  $B(1971)/K$ , was assigned a Beta prior distribution:

$$\psi \sim \text{Beta}(\text{mean}=0.70, \text{CV}=0.2),$$

resulting in a 95% prior probability interval of (0.40, 0.93).

### 2.2.3 Observation equations on the abundance indices

The observation equations for each abundance index (standardized CPUE series) follow logNormal distributions, where for an index series “ $i$ ” and year “ $y$ ”, the median of the logNormal distribution is  $q(i)*B(y)$ , i.e. an index-specific catchability multiplied by the stock biomass in year  $y$ .

For each index series “ $i$ ”,  $q(i)$  is assumed to follow a Uniform prior distribution between  $10^{-30}$  and 1000, which is flat and very wide and can be regarded as “non-informative”.

Two options are used for the CV of the logNormal distribution of the observation equation:

- Runs labelled “*OEf*”:

In these runs, the CV of the logNormal distribution (actually, the standard deviation of the corresponding Normal distribution of the log(Index)) is treated as a fixed input and is not estimated in the stock assessment.

For the index series “ $i$ ”, and year “ $y$ ”, the following value is used for the standard deviation of the log(Index):

$$SD_{\text{JABBA}}(i, y) = \frac{SD_{\text{reported}}(i, y)}{SD_{\text{reported}}(i, \text{aver})} * \max \{ SD_{\text{reported}}(i, \text{aver}), RMSE_{\text{loess}}(i) \}$$

where  $SD_{\text{reported}}(i, y)$  corresponds to the CV of the standardized CPUE series as reported by the authors in the CPUE standardization documents (and after transformation from CV of logNormal to SD of Normal in log-scale), i.e.

$$SD_{\text{reported}}(i, y) = \{ \log(1 + CV_{\text{reported}}^2(i, y)) \}^{\frac{1}{2}}$$

$SD_{\text{reported}}(i, \text{aver})$  is the average of  $SD_{\text{reported}}(i, y)$  over the years for index “ $i$ ”, and  $RMSE_{\text{loess}}(i)$  is the RMSE of a “loess” smoother fit to the log(Index) [as in Courtney *et al.*, 2017]. The R pseudo-code to obtain this RMSE value for each CPUE series “ $i$ ” is (assuming the CPUE series are stored in R as columns in a matrix called “cpue”):

```
trend <- cpue[,i]/mean(cpue[,i], na.rm=T)
sm <- loess( log(trend) ~ c(1:nrow(cpue)), na.action=na.omit )
RMSEloess(i) <- sqrt( sum(sm$residuals^2)/sm$n )
```

For each CPUE series, the procedure results in the average standard deviation values of the log(CPUE) reported in **Table 1**. The procedure maintains the original interannual variability in the standard deviation values (**Figure 3**).

- Runs labelled “*OEest*”:

In these runs, a term “ $\tau^2(i)$ ” is added to the square of the  $SD_{\text{JABBA}}(i, y)$  value computed with the procedure described above, so that these  $SD_{\text{JABBA}}(i, y)$  values are considered as minimum values of the standard deviation of the log(Index).

The tau2(i) terms are treated as unknown parameters and estimated within the stock assessment in JABBA. The following “non-informative” (i.e. very wide) prior distributions is assigned to them:

$$1/\text{tau2}(i) \sim \text{Gamma}(\text{shape}=0.001, \text{rate}=0.001)$$

In the runs in this document, a separate tau2 parameter is estimated for each abundance index, although the software JABBA also allows for the possibility that multiple indices share the same tau2 parameter.

#### 2.2.4 Process error

Process error, which means that the population biomass is allowed to deviate from the deterministic production model through a logNormal distribution, was incorporated in all the runs. The CV of the logNormal distribution (let us call it  $CV_{\text{process}}$ ) was:

- fixed to 0.01 for the years before any abundance index started,
  - treated as an unknown parameter, and estimated within the stock assessment, for all subsequent years.
- The following prior distribution was used in this case:

$$\text{isigma2} = 1/\log\{1 + (CV_{\text{process}})^2\} \sim \text{Gamma}(\text{shape}=4, \text{rate}=0.01).$$

For  $CV_{\text{process}}$ , this results in a prior median of 0.05 and a 95% prior probability interval of (0.034, 0.096).

#### 2.2.5 Uncertainty in catch

In all the runs it was assumed that the catch values used as data inputs are “Reported Catch” values and that the “True Catch” values may differ from the “Reported Catch” as follows:

$$\text{“True Catch”} \sim \text{logNormal}(\text{median}=\text{Reported Catch}, \text{CV}=0.1).$$

### 3. Results and discussion

The settings indicated above resulted in 5 configurations on (r,m) x 2 options for the standard deviation of the log(CPUE) indices x 5 scenarios of CPUE series included in the model = 50 JABBA runs in all, which were all conducted.

In addition, retrospective runs, where all data (catches and CPUE) of up to 5 years of the final part of the time series were removed before fitting the model in order to check model stability as additional years of data are added in the future, and peels runs, where CPUE data of up to 5 years of the final part of the time series were removed (while keeping the entire series of catches) before fitting the model in order to check model predictive capabilities, were conducted, at least for some of the 50 runs.

The available data, consisting of total catches by year, CPUE indices and input CV values (as in bottom row of **Table 1**) are displayed in **Figures 1-3**.

Basic goodness of fit information from all 50 JABBA runs is presented in **Tables 2-6**. In principle, the scenario “All” (**Table 2**), including all CPUE indices, is considered as the base case, but the other scenarios indicated by the ICCAT Blue Shark Data Preparatory Meeting were also evaluated (**Tables 3-6**).

#### 3.1 Results for scenario “All”

**Table 2** indicates that implementations with “OEest”, i.e., with an additional CV component estimated within JABBA for each CPUE series, results in considerably lower DIC values than implementations with “Oef”. Therefore, here we focus on the results corresponding to “OEest” implementations. Within the 5 implementations with “OEest”, the differences in goodness of fit statistics are minor (5 left-most columns of **Table 2**). This document presents detailed results for the “Pellam, 23”, i.e., Case 1 from Section 2.2 (“Model settings”). Results from all 50 runs are available on the ICCAT Blue Shark stock assessment meeting cloud server and comparisons of main results across all runs are presented in this document.

Raw residuals of the indices, i.e.  $\log(\text{observed}) - \log(\text{fitted})$ , are shown in **Figures 4** and **5**, and standardized residuals, i.e.,  $(\log(\text{observed}) - \log(\text{fitted})) / (\text{fitted standard deviation})$  in **Figure 6**. From **Figures 4** and **5** it can be seen that the largest residuals correspond to VEN and CTP. There are obvious trends in the residuals of POR and MOR throughout their time series (**Figure 5**). Serial autocorrelation of the residuals, based on runs tests p-values lower than 0.05, is detected for POR, MOR, JPN and VEN (**Table 2**), and can also be appreciated visually in **Figure 5**. The remaining series, i.e. SPN, USA1, USA2 and CTP have p-values bigger than 0.05 in the runs tests.

**Figures 7 and 8** evaluate the predictive ability of the model. **Figure 7** shows the observed  $\log(\text{CPUE})$  values and the posterior predictive intervals for them (90% posterior predictive probability intervals, i.e. covering from 5% to 95% quantiles). The trends seen in the residual plots can also be appreciated in **Figure 7**. However, **Figure 7** also shows that virtually all observed CPUE values are within their 90% posterior predictive intervals. In **Figure 8**, the last 5 years of the indices (i.e., 2017-2021) were removed from the data used to fit the model and these  $\log(\text{CPUE})$  values were plotted against the corresponding 90% posterior predictive intervals (hindcasting); the observed CPUE values generally fall within the 90% posterior predictive intervals, including those of the hindcasting period (2017-2021).

**Table 7** and **Figure 9** display posterior distributions of model parameters, including reference points. **Table 8** and **Figure 10** present stock trajectories relative to  $B_{\text{MSY}}$  and  $H_{\text{MSY}}$ . For the most recent years, the model estimates a harvest rate lower than  $H_{\text{MSY}}$  since 2019 and a stock biomass a bit below  $B_{\text{MSY}}$  although reaching  $B_{\text{MSY}}$  by 2021 and slightly exceeding it by the beginning of 2022 (**Table 8**).

**Figure 11** shows assessment results ( $B/B_{\text{MSY}}$  1971-2022, and  $H/H_{\text{MSY}}$  1971-2021) obtained when peeling up to 5 years (2017-2021) of the abundance indices, while keeping the entire time series of catches (1971-2021). These results suggest that model projections, under some level of assumed catches, result in robust predictions of stock status.

**Figure 12** shows assessment retrospective results, obtained when peeling up to 5 years (2017-2021) of all data (catch and abundance indices). These results suggest stable retrospective model behaviour.

### 3.2 Results comparing all 50 JABBA runs

**Figure 13** displays model results (posterior medians of  $B/B_{\text{MSY}}$  1971-2022, and  $H/H_{\text{MSY}}$  1971-2021) for all 25 runs with “OEest” implementation, whereas **Figure 14** does the same for the “OEF” implementation. In these figures, each column represents a setting on  $r$  and  $m$  (i.e. Cases 1 to 5 of Section 2.2, “Model settings”). The colours in each panel correspond to the different scenarios for CPUE inclusion: “All” (black), and the clusters indicated at the ICCAT Blue Shark Data Preparatory Meeting, i.e., “Trend1” (red), “Trend2” (green), “Target” (darker blue), “non-Target” (sky blue).

The results differ depending on the groups of CPUE included, but for each CPUE grouping the results are very similar across the 5 cases of  $r$  and  $m$  settings and also across “OEest” and “OEF” configurations. All CPUE groupings, with the exception of the “non-Target” cluster (sky blue) generally estimate that the harvest rate has been below  $H_{\text{MSY}}$  for some years now and that the stock biomass is currently around or above  $B_{\text{MSY}}$ .

## References

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- Winker H., Carvalho F., and Kapur M. 2018. JABBA: Just Another Bayesian Biomass Assessment. Fish. Res. 204, 275–288

**Table 1.** Input observation error for the abundance indices after applying the procedure described in Section 2.2.3 “Observation equations on the abundance indices”. The bottom row of the table displays the resulting average SD values for the log(CPUE).

	<i>VEN</i>	<i>SPN</i>	<i>POR</i>	<i>USA1</i>	<i>USA2</i>	<i>JPN</i>	<i>CTP</i>	<i>MOR</i>
$SD_{\text{reported}}(\bar{i}, \text{aver})$	0.970	0.028	0.078	0.291	0.277	0.145	0.070	0.062
$RMSE_{\text{loess}}(\bar{i})$	0.624	0.079	0.085	0.294	0.012	0.151	0.639	0.196
$\max\{SD_{\text{reported}}(\bar{i}, \text{aver}), RMSE_{\text{loess}}(\bar{i})\}$	0.970	0.079	0.085	0.294	0.277	0.151	0.639	0.196

**Table 2.** Goodness of fit results for the scenario with “All” CPUE indices

<i>All</i>	<i>OEst</i>					<i>OEf</i>				
	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15
N	155	155	155	155	155	155	155	155	155	155
p	21	21	21	21	21	21	21	21	21	21
DF	134	134	134	134	134	134	134	134	134	134
RMSE	53	53	53	53	53	53.3	53.4	53.9	53.5	53.4
RMSE2	53.1	53	53.2	53.1	53.1	53.5	53.5	53.6	53.5	53.4
SDNR	0.9	0.9	0.89	0.9	0.9	1.5	1.5	1.49	1.5	1.5
SDNR2	0.91	0.92	0.91	0.91	0.92	1.52	1.52	1.51	1.52	1.52
DIC	320.3	317.2	323.4	319.2	317.5	419.1	417.8	415.1	418.8	420.5
Runs Test pval VEN	0.007	0.007	0.007	0.007	0.007	0.01	0.01	0.01	0	0.007
Runs Test pval SPN	0.155	0.155	0.168	0.155	0.033	0.00	0.00	0.00	0.004	0.004
Runs Test pval POR	0.001	0.001	0.001	0.001	0.001	0.00	0.00	0.00	0.001	0.001
Runs Test pval USA1	0.092	0.092	0.011	0.092	0.092	0.09	0.09	0.09	0.092	0.092
Runs Test pval USA2	0.181	0.181	0.181	0.181	0.181	0.18	0.18	0.18	0.181	0.181
RunsTest pval JPN	0	0	0	0	0	0.00	0.00	0.00	0	0
Runs Test pval CTP	0.342	0.342	0.251	0.342	0.251	0.34	0.54	0.54	0.537	0.342
Runs Test pval MOR	0.001	0.001	0.001	0.001	0.001	0.04	0.30	0.04	0.035	0.301



**Table 3.** Goodness of fit results for the scenario with the “Trend1” set of CPUE indices.

<i>Trend1</i>	<i>OEst</i>					<i>OEf</i>				
	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15
N	57	57	57	57	57	57	57	57	57	57
p	11	11	11	11	11	11	11	11	11	11
DF	46	46	46	46	46	46	46	46	46	46
RMSE	70.9	70.3	71.2	70.6	70.7	71.8	71.8	71.8	71.6	71.3
RMSE2	70.8	70.7	71	70.7	70.6	71.6	71.5	71.8	71.5	71.4
SDNR	0.81	0.81	0.8	0.81	0.81	0.9	0.91	0.9	0.91	0.92
SDNR2	0.84	0.84	0.83	0.84	0.84	0.96	0.96	0.95	0.96	0.97
DIC	-92.6	-94.4	-92.6	-92.9	-92.3	-105.8	-104.9	-105.3	-105.2	-105.8
Runs Test pval VEN	0	0	0	0	0	0	0	0	0	0
Runs Test pval POR	0.757	0.757	0.757	0.757	0.757	0.757	0.757	0.925	0.757	0.757
Runs Test pval MOR	0.767	0.767	0.767	0.767	0.875	0.875	0.875	0.875	0.875	0.875

**Table 4.** Goodness of fit results for the scenario with the “Trend2” set of CPUE indices.

<i>Trend2</i>	<i>OEst</i>					<i>OEf</i>				
	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15
N	98	98	98	98	98	98	98	98	98	98
p	15	15	15	15	15	15	15	15	15	15
DF	83	83	83	83	83	83	83	83	83	83
RMSE	42.3	42.5	42.4	42.4	42.4	42.6	42.7	43.2	42.5	42.7
RMSE2	42.6	42.5	42.6	42.5	42.5	42.9	42.8	43	42.9	42.8
SDNR	0.89	0.9	0.88	0.89	0.9	1.31	1.31	1.3	1.31	1.31
SDNR2	0.9	0.9	0.89	0.9	0.9	1.32	1.33	1.32	1.33	1.33
DIC	-25.1	-26.4	-21.7	-26.1	-27.2	5.7	6.4	2.8	6.2	6.8
Runs Test pval SPN	0.014	0.077	0.014	0.077	0.077	0	0	0	0	0
Runs Test pval USA1	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092	0.092
Runs Test pval USA2	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181
Runs Test pval JPN	0	0	0	0	0	0.001	0.001	0.001	0.001	0.001
Runs Test pval CTP	0.096	0.052	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096

**Table 5.** Goodness of fit results for the scenario with the “Target” set of CPUE indices.

<i>Target</i>	<i>OEst</i>					<i>OEf</i>				
	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15
N	62	62	62	62	62	62	62	62	62	62
p	11	11	11	11	11	11	11	11	11	11
DF	51	51	51	51	51	51	51	51	51	51
RMSE	23.1	23	23.2	23.2	23	20.8	20.7	20.7	20.7	20.8
RMSE2	23.3	23.2	23.4	23.3	23.2	20.7	20.7	20.7	20.7	20.7
SDNR	0.88	0.88	0.87	0.88	0.88	1.57	1.57	1.57	1.57	1.57
SDNR2	0.88	0.88	0.87	0.88	0.89	1.58	1.58	1.57	1.58	1.58
DIC	238.9	239.1	239.3	239.2	238.8	273.1	273.2	272.6	273.6	274.6
Runs Test pval SPN	0.005	0.037	0.037	0.037	0.037	0	0	0	0	0
Runs Test pval POR	0.001	0.001	0.001	0.001	0.001	0.001	0.014	0.001	0.001	0.014
Runs Test pval MOR	0.035	0.035	0.035	0.035	0.035	0.301	0.301	0.301	0.301	0.301

**Table 6.** Goodness of fit results for the scenario with the “non-Target” set of CPUE indices.

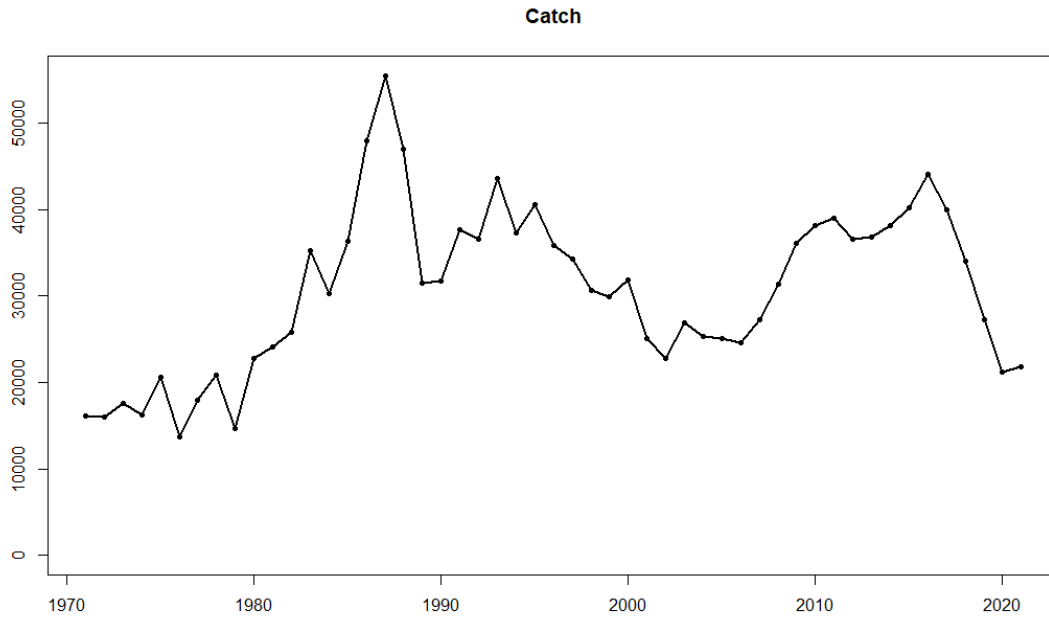
<i>non Target</i>	<i>OEst</i>					<i>OEf</i>				
	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15	Pellam 23	PellaDeta 23	PellaDetb 23	Pellam 15	Schaefer 15
N	93	93	93	93	93	93	93	93	93	93
p	15	15	15	15	15	15	15	15	15	15
DF	78	78	78	78	78	78	78	78	78	78
RMSE	64.7	64	64.8	63.7	63.9	65.3	64.3	65.3	64.5	64.4
RMSE2	64.9	63.9	64.9	64.1	63.8	65.5	64.3	65	64.4	64.2
SDNR	0.84	0.84	0.84	0.84	0.84	0.95	0.94	0.95	0.94	0.93
SDNR2	0.86	0.86	0.86	0.86	0.86	0.99	0.98	0.99	0.98	0.97
DIC	-349.9	-341	-349.2	-343.4	-341.4	-358.7	-357.8	-358.3	-357.6	-358.7
Runs Test pval VEN	0	0	0	0	0	0	0	0	0	0
Runs Test pval USA1	0.285	0.285	0.285	0.285	0.285	0.285	0.285	0.285	0.285	0.285
Runs Test pval USA2	0.113	0.181	0.113	0.181	0.181	0.113	0.181	0.113	0.181	0.181
Runs Test pval JPN	0.943	0.545	0.816	0.603	0.545	0.99	0.789	0.99	0.938	0.789
Runs Test pval CTP	0.002	0.002	0.002	0.002	0.037	0.002	0.037	0.002	0.002	0.002

**Table 7.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Posterior distributions (median and 95% probability interval) of model parameters. SQRT(tau2) is the JABBA-estimated additional CV term for the process error of each abundance index.

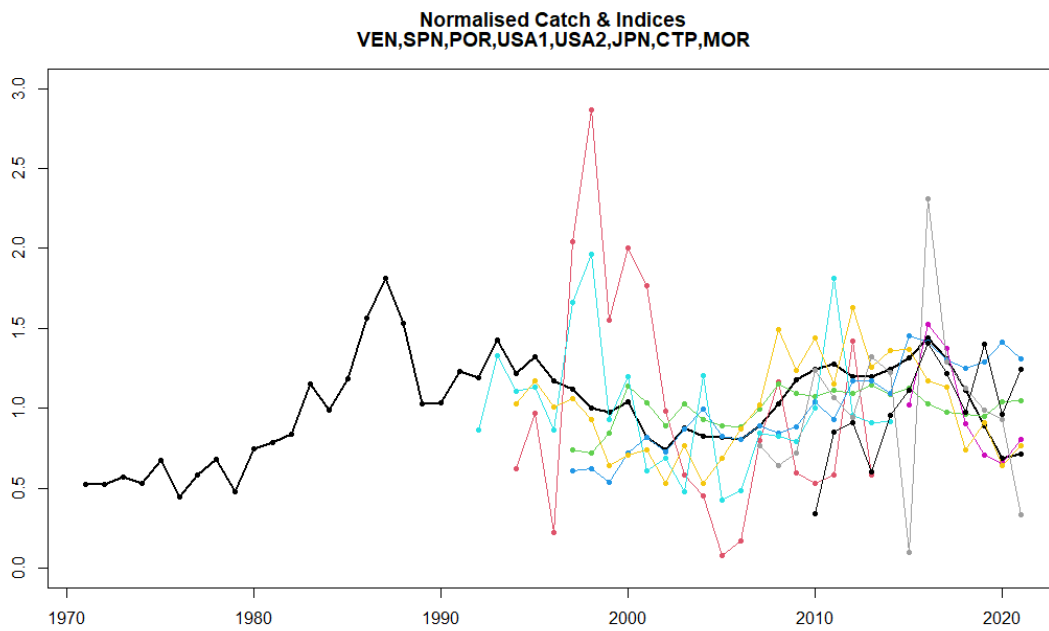
	50%	2.50%	97.50%
K	310378	219402	437169
r	0.37	0.24	0.56
m	1.50	1.03	2.15
Bmsy/K	0.44	0.37	0.51
Bmsy	136744	93498	202994
Hmsy	0.25	0.16	0.38
MSY	33794	30868	37782
psi	0.70	0.44	0.92
cvProcErr	0.06	0.04	0.09
SQRT(tau2)VEN	0.14	0.03	0.66
SQRT(tau2)SPN	0.08	0.03	0.16
SQRT(tau2)POR	0.19	0.12	0.28
SQRT(tau2)USA1	0.26	0.04	0.48
SQRT(tau2)USA2	0.12	0.03	0.49
SQRT(tau2)JPN	0.22	0.13	0.33
SQRT(tau2)CTP	0.14	0.03	0.49
SQRT(tau2)MOR	0.29	0.13	0.56
qVEN	7.22E-07	3.64E-07	1.40E-06
qSPN	2.02E-03	1.15E-03	3.41E-03
qPOR	2.06E-03	1.17E-03	3.49E-03
qUSA1	5.87E-05	3.34E-05	9.97E-05
qUSA2	3.73E-05	2.02E-05	6.68E-05
qJPN	7.75E-06	4.42E-06	1.31E-05
qCTP	6.18E-06	3.30E-06	1.12E-05
qMOR	1.98E-03	1.10E-03	3.45E-03

**Table 8.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Posterior distributions (median and 95% probability interval) of stock trajectory relative to reference points. Biomass refers to the start of the year, so an estimate exists for the start of 2022.

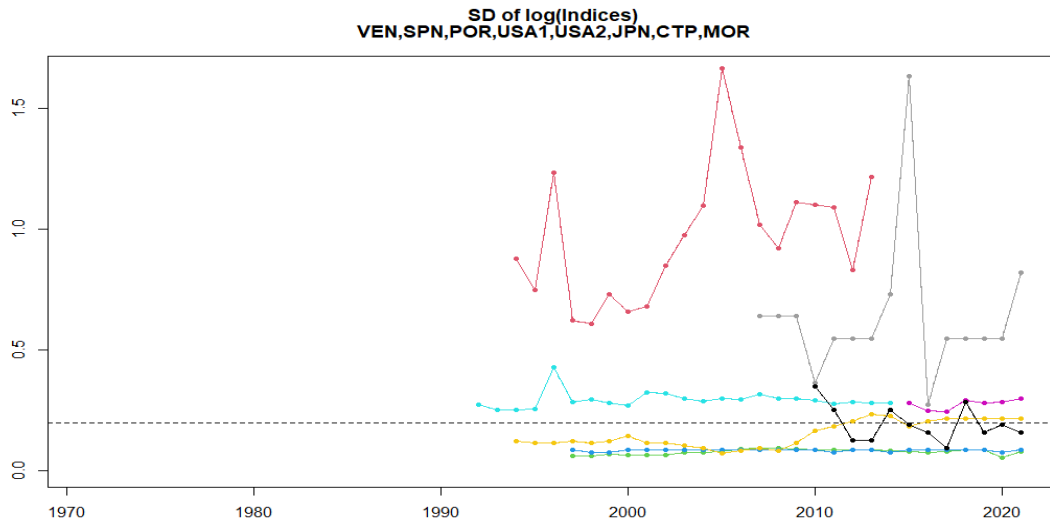
	Reported Catch	B/B <sub>MSY</sub> 50%	B/B <sub>MSY</sub> 2.5%	B/B <sub>MSY</sub> 97.5%	H/H <sub>MSY</sub> 50%	H/H <sub>MSY</sub> 2.5%	H/H <sub>MSY</sub> 97.5%
1971	16081	1.57	0.97	2.19	0.30	0.21	0.50
1972	15968	1.64	1.08	2.15	0.29	0.21	0.44
1973	17509	1.70	1.18	2.13	0.31	0.23	0.45
1974	16205	1.73	1.27	2.12	0.28	0.22	0.39
1975	20652	1.77	1.36	2.12	0.35	0.27	0.46
1976	13663	1.76	1.42	2.09	0.23	0.18	0.30
1977	17896	1.81	1.50	2.13	0.29	0.24	0.37
1978	20891	1.81	1.54	2.12	0.34	0.28	0.42
1979	14637	1.80	1.55	2.09	0.24	0.20	0.29
1980	22782	1.83	1.59	2.12	0.37	0.30	0.45
1981	24075	1.79	1.57	2.08	0.40	0.32	0.48
1982	25742	1.76	1.55	2.03	0.43	0.35	0.52
1983	35273	1.72	1.52	1.99	0.61	0.49	0.72
1984	30213	1.62	1.44	1.87	0.55	0.45	0.65
1985	36308	1.58	1.41	1.82	0.68	0.55	0.80
1986	47885	1.50	1.34	1.74	0.94	0.76	1.11
1987	55483	1.35	1.18	1.58	1.22	0.96	1.43
1988	46985	1.17	0.98	1.40	1.20	0.92	1.44
1989	31440	1.06	0.87	1.31	0.88	0.66	1.08
1990	31686	1.08	0.88	1.32	0.88	0.65	1.08
1991	37641	1.09	0.90	1.34	1.03	0.76	1.27
1992	36529	1.04	0.85	1.34	1.04	0.74	1.30
1993	43587	1.02	0.82	1.35	1.28	0.88	1.60
1994	37242	0.93	0.74	1.28	1.20	0.79	1.51
1995	40525	0.89	0.70	1.25	1.36	0.88	1.73
1996	35866	0.80	0.62	1.16	1.33	0.84	1.71
1997	34285	0.75	0.57	1.10	1.37	0.84	1.78
1998	30604	0.72	0.55	1.09	1.27	0.76	1.66
1999	29886	0.74	0.55	1.13	1.21	0.71	1.60
2000	31867	0.80	0.58	1.25	1.20	0.69	1.62
2001	25045	0.78	0.56	1.23	0.97	0.55	1.33
2002	22742	0.76	0.55	1.20	0.89	0.51	1.22
2003	26861	0.80	0.58	1.26	1.01	0.58	1.36
2004	25266	0.79	0.57	1.23	0.96	0.56	1.30
2005	25009	0.79	0.58	1.22	0.95	0.56	1.28
2006	24639	0.82	0.61	1.26	0.90	0.53	1.21
2007	27277	0.89	0.67	1.35	0.91	0.55	1.21
2008	31379	0.96	0.73	1.45	0.98	0.59	1.28
2009	36135	0.98	0.75	1.46	1.10	0.67	1.44
2010	38172	0.99	0.75	1.47	1.16	0.70	1.51
2011	39007	1.00	0.76	1.49	1.17	0.71	1.53
2012	36605	1.00	0.76	1.49	1.09	0.66	1.43
2013	36748	1.01	0.77	1.50	1.09	0.66	1.43
2014	38133	1.03	0.78	1.53	1.11	0.68	1.45
2015	40191	1.05	0.81	1.57	1.14	0.69	1.49
2016	44085	1.05	0.80	1.57	1.26	0.76	1.64
2017	40004	0.98	0.74	1.47	1.22	0.74	1.62
2018	33979	0.92	0.68	1.40	1.11	0.66	1.48
2019	27212	0.91	0.66	1.39	0.90	0.53	1.22
2020	21147	0.93	0.68	1.42	0.68	0.40	0.92
2021	21848	1.00	0.74	1.50	0.65	0.39	0.88
2022	NA	1.09	0.79	1.60	NA	NA	NA



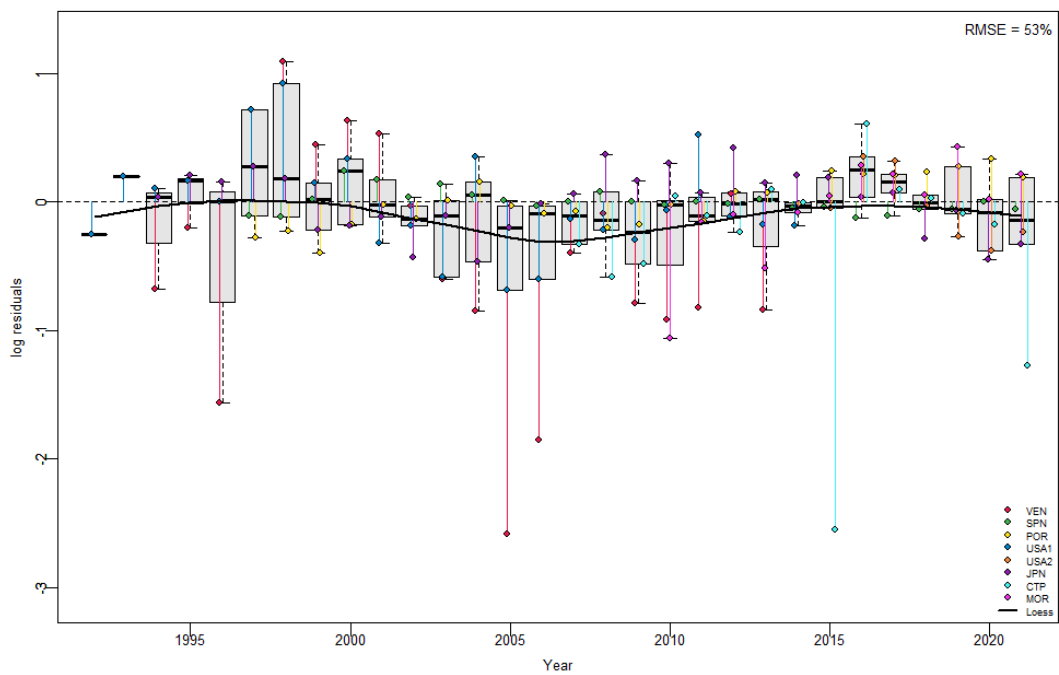
**Figure 1.** Catch data used in the JABBA assessment.



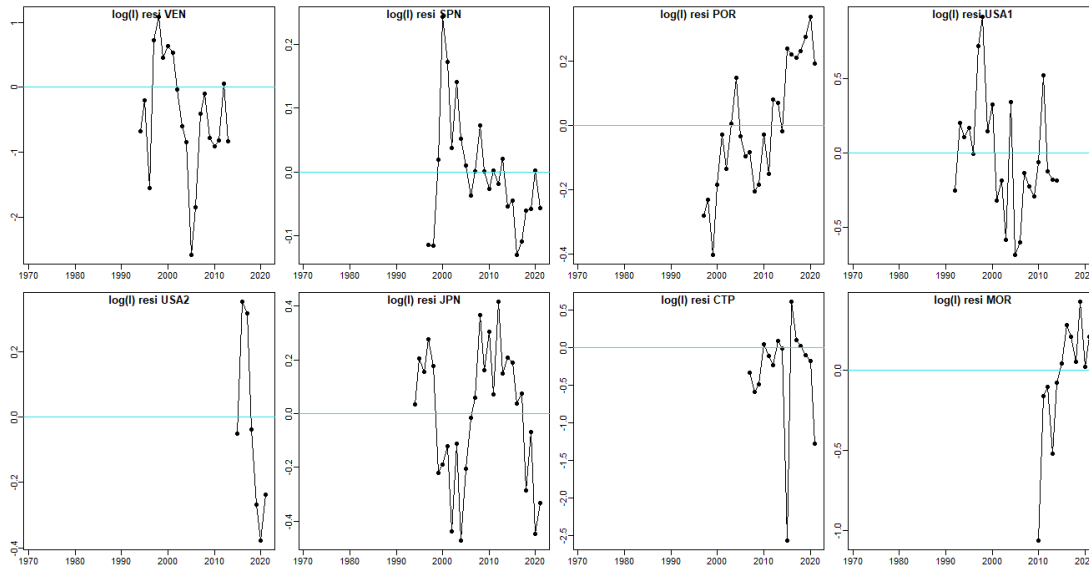
**Figure 2.** Catch and CPUE indices used in the JABBA assessment. All series are normalised in the plot, so that each has a mean value of 1 over the corresponding time series. Colours are: catch (black), VEN (red), SPN (green), POR (darker blue), USA1 (sky blue), USA2 (pink), JPN (yellow), CTP (grey), MOR (black).



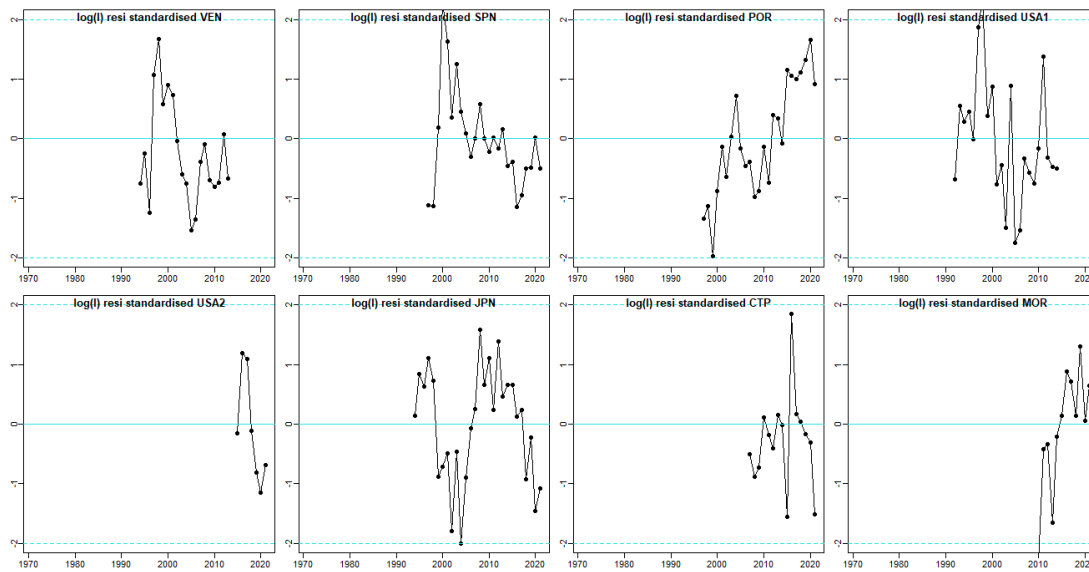
**Figure 3.** Standard Deviation of log(CPUE indices) used as inputs in the JABBA assessment (Oef case), obtained as explained in Section 2.2 (“Model settings”, Oef case). Colours are: VEN (red), SPN (green), POR (darker blue), USA1 (sky blue), USA2 (pink), JPN (yellow), CTP (grey), MOR (black). The horizontal line is at 0.2.



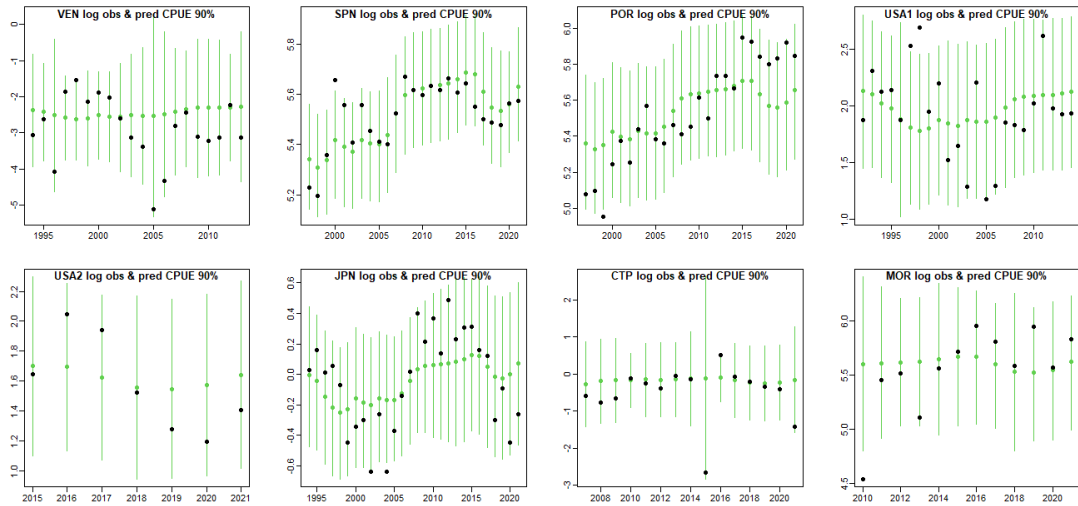
**Figure 4.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Residuals of the model fit to the log(Indices). The colours for the indices are indicated in the legend on the bottom right corner of the figure.



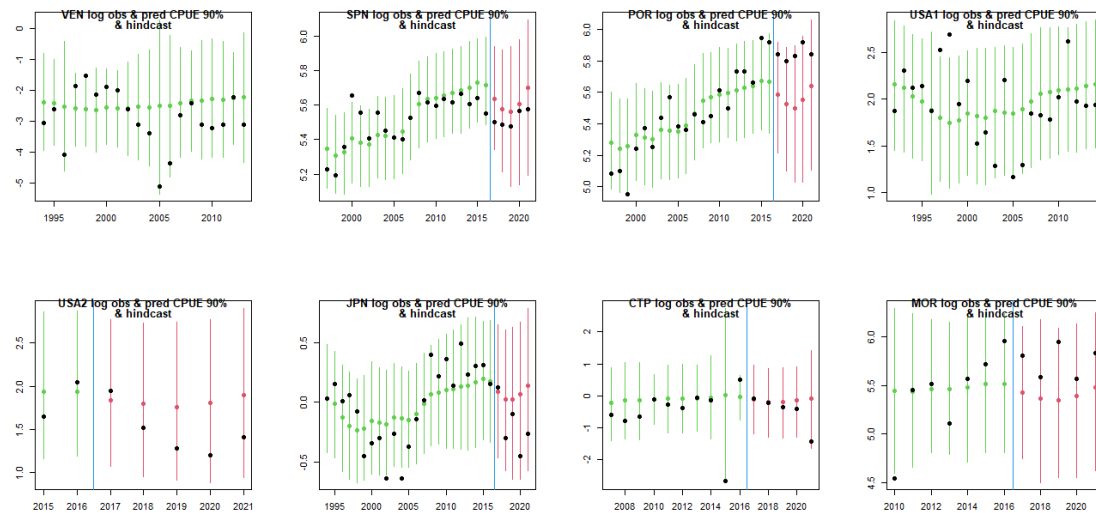
**Figure 5.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Residuals of the model fit to the  $\log(\text{Indices})$ .



**Figure 6.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Standardized residuals of the model fit to the  $\log(\text{Indices})$ , i.e.  $(\log(\text{Observed}) - \log(\text{Fitted})) / (\text{Fitted Standard Deviation of } \log)$ . They are expected to be between -2 and 2.

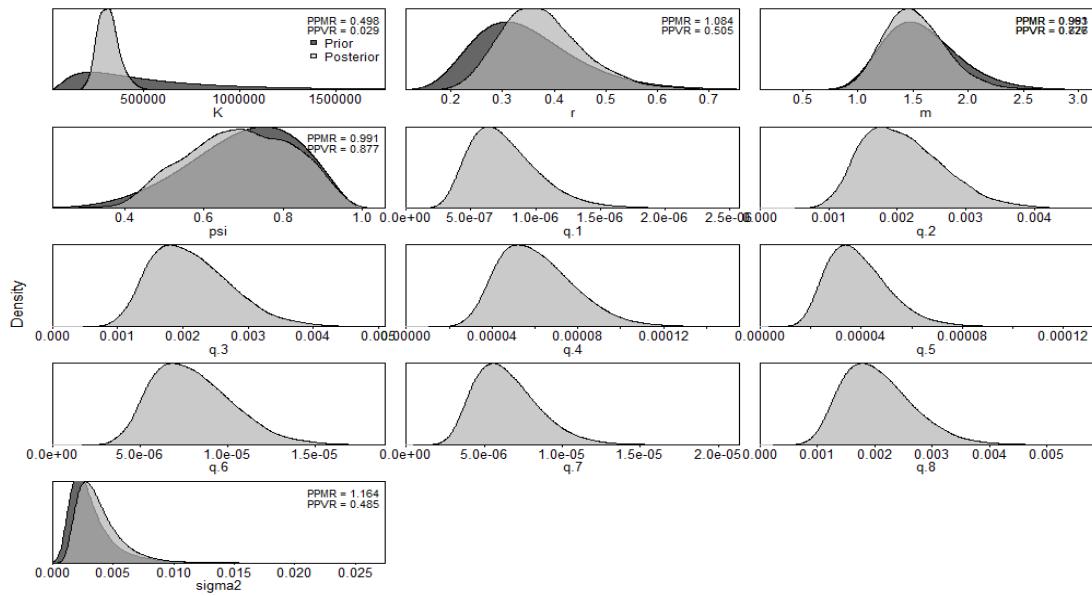


**Figure 7.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Observed log(Indices) in black, and posterior predicted values from the model fits (90% posterior predictive probability intervals, i.e. 5% to 95% quantiles).

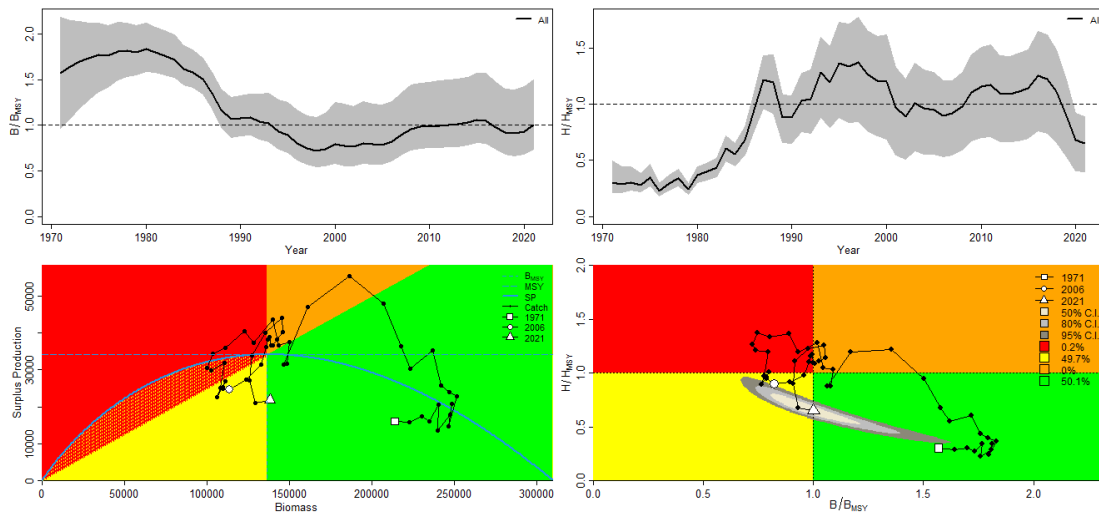


**Figure 8.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”, with the model fitted after removing the CPUE data for 2017-2021. Observed log(Indices) in black, and posterior predicted values from the model fits (90% posterior predictive probability intervals, i.e. 5% to 95% quantiles), including also the hindcast period (intervals plotted in red).

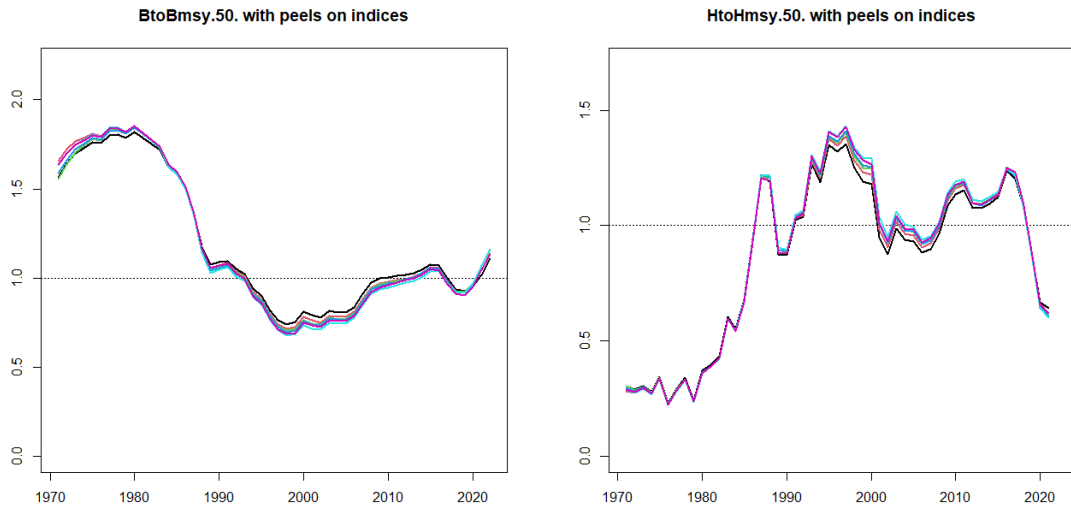




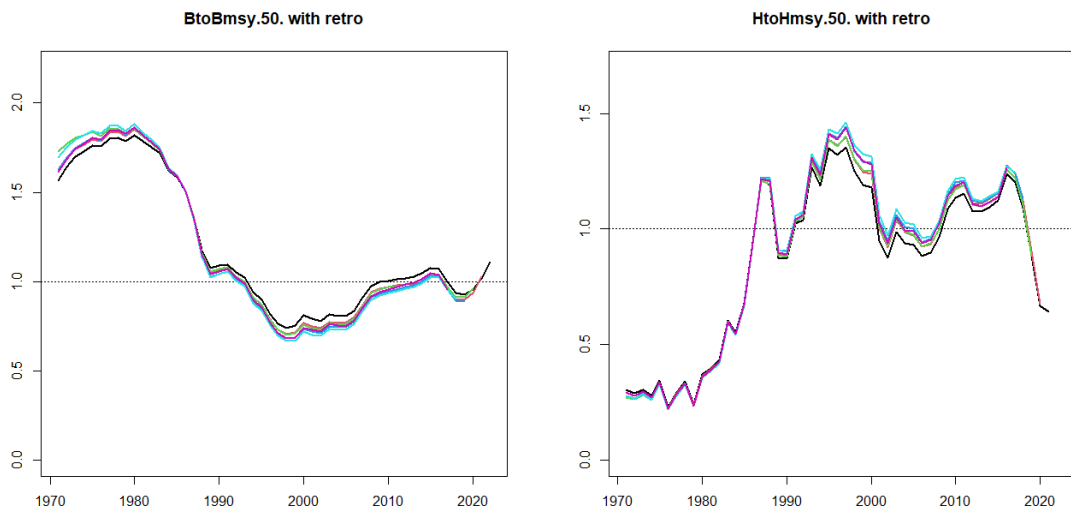
**Figure 9.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Prior and posterior distributions of several key model parameters, produced automatically by the software JABBA. The prior distributions on  $q$  are non-informative (Uniform( $10^{-30}$ , 1000)), i.e. completely flat, and can not be appreciated in the graph. The parameter  $\sigma^2$  corresponds to the variance of the process error for  $\log(B(y))$ .



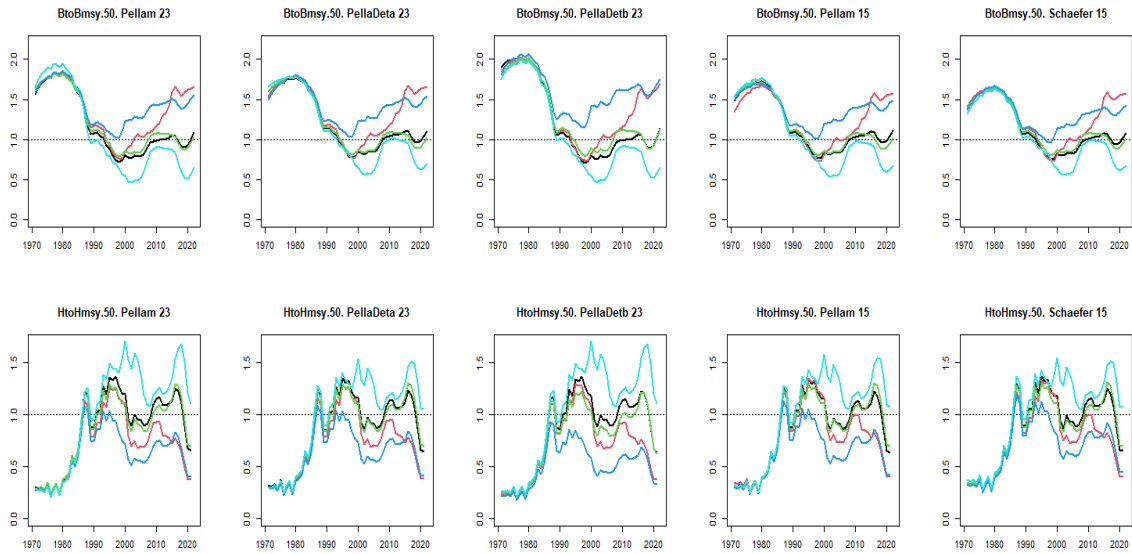
**Figure 10.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Summary plot for the period 1971-2021.



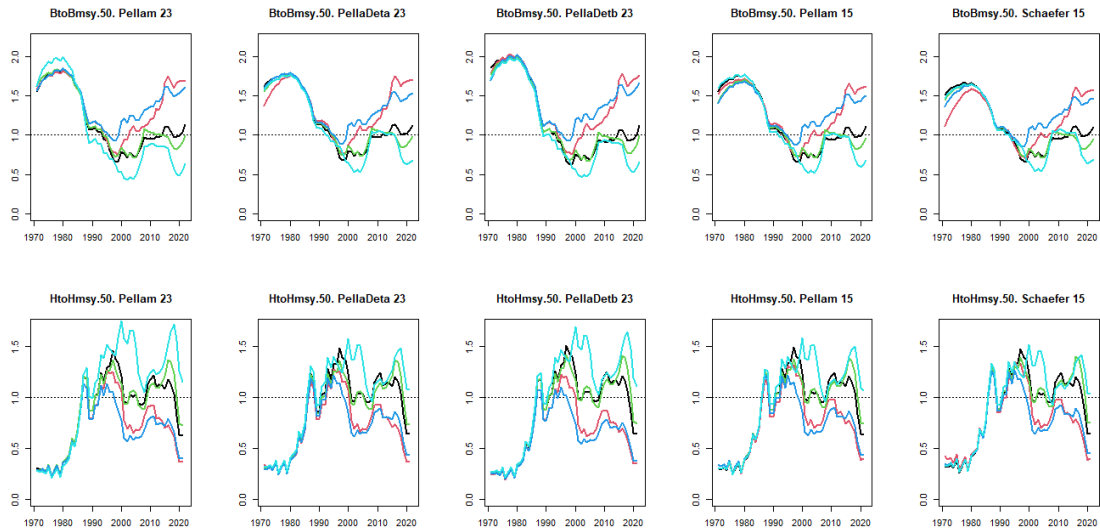
**Figure 11.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Assessment results (posterior medians of  $B/B_{MSY}$  1971-2022, and  $H/H_{MSY}$  1971-2021) obtained when peeling between 0 and 5 years (2017-2021) of the CPUE indices, while keeping the entire time series of catches (1971-2021).



**Figure 12.** Results for Case 1 (Pellam, 23) in the scenario with “All” CPUE indices and “OEest”. Retrospective results, i.e., assessment results (posterior medians of  $B/B_{MSY}$  and  $H/H_{MSY}$ ) peeling between 0 and 5 years (2017-2021) of all data (CPUE indices and catches).



**Figure 13.** Posterior estimates (medians) of  $B/B_{MSY}$  (top, 1971-2022) and  $H/H_{MSY}$  (bottom, 1971-2021) for all 25 JABBA runs with “OEest” configuration. Each column represents a setting on  $r$  and  $m$  (i.e. Cases 1 to 5 of Section 2.2, “Model settings”). The colours correspond to the different scenarios for CPUE inclusion: “All” (black), and the clusters indicated at the ICCAT Blue Shark Data Preparatory Meeting, i.e. “Trend1” (red), “Trend2” (green), “Target” (darker blue), “non-Target” (sky blue).



**Figure 14.** Posterior estimates (medians) of  $B/B_{MSY}$  (top, 1971-2022) and  $H/H_{MSY}$  (bottom, 1971-2021) for all 25 JABBA runs with “OEF” configuration. Each column represents a setting on  $r$  and  $m$  (i.e. Cases 1 to 5 of Section 2.2, “Model settings”). The colours correspond to the different scenarios for CPUE inclusion: “All” (black), and the clusters indicated at the ICCAT Blue Shark Data Preparatory Meeting, i.e. “Trend1” (red), “Trend2” (green), “Target” (darker blue), “non-Target” (sky blue).