A Simple User Guide for CMSY+ and BSM (CMSY_2019_9f.R)

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This is an advanced version of the accompanying document for Froese R., Demirel N., Coro G., Kleisner K.M., Winker, H. (2017) Estimating Fisheries Reference Points from Catch and Resilience. *Fish and Fisheries*, 18: 506-526 DOI: 10.1111/faf.12190. CMSY+ is a Monte-Carlo method that estimates fisheries reference points (*MSY*, F_{msy}, B_{msy}) as well as relative stock size (B/B_{msy}) and exploitation (F/F_{msy}) from catch data, a prior for resilience or productivity (*r*), and broad priors for the ratio of biomass to unfished biomass (*B/k*) at the beginning, an intermediate year and the end of the time series. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The main advantage of BSM compared to other implementations of surplus production models is the focus on informative priors and the acceptance of short and incomplete (= fragmented) catch-per-unit-of-effort (CPUE) data. This document provides a simple step-by-step guide for researchers who want to apply CMSY+ or BSM to their own data.

The CMSY+ version referred to in this guide (CMSY_2019_9f.R) is a further development of the one used in Froese et al. (2017). The main differences are faster execution because of parallel processing and more emphasis on the graphical presentation of the outputs, e.g. by the addition of a Kobe stock status plot and several analytical plots. Also, estimation of default B/k priors has been improved and some labels in the input files have changed, as indicated below. A major improvement for both CMSY+ and BSM is the introduction of multivariate normal priors for *r* and *k* in log space, replacing the previous uniform prior distributions. This allowed also for a simplified determination of the 'best' *r-k* pair in CMSY+, associated with faster run times. In addition, when CPUE data from commercial fisheries are used, assumed annual increase in efficiency of the fishery, i.e., effort-creep and resulting increase in catch per unit of effort can be indicated, e.g. as 2% per year.

The R-code and some example input files (Stocks_Catch_EU_1.csv, Stocks_ID_EU_8.csv) can be downloaded from http://oeanrep.geomar.de/33076/

Installation instructions

1) Install a recent version of R on your computer. CMSY was tested under different R versions up to 3.6.1, available from http://www.r-project.org/, but newer versions should also work.

2) We suggest using RStudio as an R development environment. RStudio is a free software that is available for several operating systems (Windows, OS, Linux, ...) and can be downloaded at http://www.rstudio.com/products/rstudio/download/ .

3) Install the Gibbs sampler JAGS for your Operating System from the following web site: http://sourceforge.net/projects/mcmc-jags/files/JAGS/3.x/

If you are using an Operating System different from MS Windows and you get error messages, try commenting out (#) all the lines in the code containing the windows(..) function, because display of graphs in dedicated windows is operating system specific. We tried to capture this in the code, but it may not work in all cases.

4) If you want to generate reports in PDF format, you have to install a LaTeX program. See the steps required in the Appendix to this document. Also, you have to set write.pdf to TRUE in the “General settings for the analysis” section of the code.

5) In order to run the code, several R-packages are required. These are downloaded and installed automatically when you run the code for the first time and are connected to the internet. If R still alerts you of a missing package, install it through the Tools option in RStudio.

6) Two different data files are required by CMSY+, which should be placed in the same directory as the R-script. Examples are provided and their structure is explained in the next section. The names of these files are specified in the code section “Required settings, File names”. You can replace them with your own file names (see 9).

7) Make sure that the data files and the R script are in the same directory.

8) The code should set its own directory automatically as working directory. Otherwise, use the tab “Session” in RStudio and select “Set Working Directory” -> “To Source File Location”, so that the code will find the data files.

9) If you want to use your own input files, just change the file names for the *catch_file* and *id_file* variables in the “Required settings, File names” section of the code (Lines 43-44). If you create your own input files, make sure you use the same headers (case sensitive) as in the provided example files. Make sure you are using comma-delimited (.csv) files (look at the data in a simple text editor such as Notepad to check for consistent use of commas; semi-colons are not accepted and will result in cryptic error messages).

10) The R-code can either analyze all stocks in the data files or a single stock as specified in the “Select stock to be analyzed” section of the code. To specify the stock to analyze just enter the unique stock name (e.g. stocks <- “fle-

2732"). To make the code run on all the stocks in the files, comment out this line (put # in front). You can analyze the stocks in alphabetic order or in the sequence in the ID file or by Region or subregion, according to settings in the "Analyze stocks" section, lines 268 ff. Uncomment (remove #) the row of code you want to use.

11) In RStudio, click on "Source" (or press Ctrl+A followed by Ctrl+R or Ctrl + Shift + S) to execute the code.

12) When the analysis is complete, results can be found in the console as well as in the graph windows, which can be saved manually in different formats. If write.output is set to TRUE in the "General settings for the analysis" section (Lines 56-79), another output file in .csv format is produced and contains the results in Table format, which can then be opened in e.g. Excel for documentation or further analysis.

Structure of the input files

Structure of the catch file (.csv)
For each stock, the following information must be specified (in the corresponding columns):

Stock: a unique fish stock name or identifier (e.g. "cod-2532"), repeated for each year.
yr: the reporting year of the catch (e.g. 2004). One row for each year. Years have to be consecutive from the first to the last year without any missing years.
ct: catch value, in tonnes (e.g. 12345). One row for each year. Gaps with no entries are not accepted and must be filled by interpolating missing or incorrect values, e.g., do not accept zero as entry if data are missing, instead use mean of adjacent values to replace zero or fill any gaps.
bt: the value of the biomass (in tonnes, e.g. 34567), or the value of the CPUE or stock size index (e.g. 0.123), or NA if there is no information. Gaps filled with NA are acceptable for bt, i.e., abundance data can be fewer than catch data.

Structure of ID file (.csv)

For each stock, the following information must be specified (in the corresponding columns):
Region: a string indicating the catch area, e.g. "Northeast Atlantic"
Subregion: a string indicating the subarea, e.g. "Baltic Sea"
Stock: a unique fish stock name or identifier (corresponding to the one in the 'Stock' column in the catch file)
Name: optional; a common name of the species, e.g. "Makala"
EnglishName: optional; a common English name of the species, e.g. "Greater forkbeard"
ScientificName: optional; the scientific name of the species, e.g. "Phycis blennoides"
SpecCode: optional; the code number used in FishBase for fish or SealifeBase for non-fish
Group: optional; the functional group that a species belongs to, e.g. "Large predators" or "Pelagic plankton feeders" or "Benthic organisms".
Source: optional; the source where the data were taken from, e.g. http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2014/2014/gfb-comb.pdf
MinOfYear: the start year of the catch report
MaxOfYear: the last year of the catch report
StartYear: the start year of the catch time series to be used for the analysis (from when on the data are thought to be reliable)
EndYear: the end year of the catch time series to be used.
Flim, Fpa, Blim, Bpa, Bmsy, FMSY, MSYBtrigger, B40, M, Fofl, last_F: optional; fisheries reference points from assessments, for comparison, not used in the analysis

Resilience: prior estimate of resilience, corresponding to intrinsic growth rate ranges (see next section). Allowed values are “High”, “Medium”, “Low”, “Very Low”. Get default values from www.FishBase.org for fish and from www.SeaLifeBase.org for invertebrates.
r.low / r.hi: an optional pair of parameters to specify the range of intrinsic growth rate for the species. Set these to NA to use the range specified in Resilience. If values are given, the Resilience column will be ignored. Check www.FishBase.ca and www.SeaLifeBase.se for prior estimates.
stb.low / stb.hi: the prior biomass range relative to the unexploited biomass (B/k) at the beginning of the catch time series (see next section).
int.yr: a year in the time series for an intermediate biomass level. Set it to NA to have it estimated by default rules.
intb.low / intb.hi: the estimated intermediate relative biomass range (see next section). Set it to NA to have it estimated from maximum or minimum catch, according to some simple rules (note: these may not be appropriate for your stock).
endb.low/ endb.hi: the prior relative biomass (B/k) range at the end of the catch time series (see next section). Set to NA if you want to use the defaults.
q.start / q.end: the start and end year for determining the catchability coefficient. Set to a recent period of at least 5 years where catch and abundance were relatively stable or had similar trends. If set to NA the default is last 5 years (or last 10 years in slow growing species).
e.creep: An indication of assumed increase of catchability q per year in percent for commercial CPUE data, typically in the range of 1 – 5%, with 2% being a good default assumption (Pauly and Palomares, in review). This will cause a decrease in the CPUE considered by BSM. The difference between the provided and the corrected CPUE can be made visible by setting ‘e.creep.line’ to TRUE in code line 62. This will cause the provided CPUE to be plotted in green in the biomass plot, while the used CPUE is plotted in red. No correction is needed for standardized CPUE data such as resulting from scientific surveys.
btype: the type of information in the bt column of the catch file. Allowed values are “biomass” (when total biomass is reported, but note that this setting gives misleading results if the biomass does not exactly represent the whole stock that is exploited, such as if biomass is SBB or TB includes recruits that are not yet fished; set btype to CPUE instead), “CPUE” (when cpue or cpue index or SSB are reported) or “None” (if no abundance data are available).
force.cmsy: set to TRUE if the management analysis should use the CMSY results rather than available BSM results. Useful when the abundance data are deemed unreliable. Default is FALSE or F.
Comment: a comment on the stock or the quality of the analysis or special settings. This comment is shown in the output.

Remember that the files must be saved in “csv” (comma delimited) format. Double-check that indeed a comma (and not a semi-colon) is used as delimiter, as this is a very common error.

Suggestions for parameters settings

Table 1 reports a set of questions that can help to set the CMSY input parameters. Please note that priors are preferably derived with other stock assessment tools, such as length frequency analysis with the LBB package.

Table 1. Example of questions to be put to experts to establish priors for CMSY analysis.

Prior	Question to experts
Start year for catch time series	From what year onward are catch data deemed reliable?
Relative start and end biomass *B/k*	What is the most likely stock status for the beginning and end of the time series: lightly fished, fully exploited, or overfished?
Relative intermediate biomass *B/k*	Is there an intermediate year where biomass is considered to have been particular low or high, e.g., exploitation changed from light to full, or where an extraordinary large year class entered the fishery?
Resilience prior *r*	What is your best guess for the range of values including natural mortality of adults (*M*)? Consider the empirical relationship $r \approx 2 M$.
Resilience prior *r*	What is your best guess for the range of values including maximum sustainable fishing mortality (F_{msy})? Considering the relationship $r \approx 2\ F_{msy}$ *Use this question to reinforce or change the answer to previous question*
Resilience prior *r*	Alternatively and better, get the prior range of *r* from the section "Estimates based on models" in the species summary page of FishBase (www.fishbase.org) or SeaLifeBase (www.sealifebase.org).

Table 2 suggests ranges for relative biomass to be used as input parameters, depending on the depletion status of the stock.

Table 2. Prior relative biomass (*B/k*) ranges for CMSY+.

Very strong depletion	Strong depletion	Medium depletion	Low depletion	Nearly unexploited
0.01 – 0.2	0.01 – 0.4	0.2 – 0.6	0.4 – 0.8	0.75 – 1.0

Table 3 reports the *r* ranges automatically assigned by CMSY based on resilience categories, which can be found in www.FishBase.org and www.SealifeBase.org.

Table 3. Prior ranges for parameter *r*, based on classification of resilience.

Resilience	prior *r* range
High	0.6 – 1.5
Medium	0.2 – 0.8
Low	0.05 – 0.5
Very low	0.015 – 0.1

When choosing the B/k prior for the intermediate year, it often improves the CMSY+ analysis if the intermediate B/k prior is placed at the end of period of sustained very high catches that are suspected to have led to low biomass by specifying a respective relative range, e.g. as 0.01 – 0.3. Similarly, a longer period of low catches from the start to some intermediate may indicate a period of large biomass if followed by a substantial increase in catches thereafter. In this case, it is advisable to set the intermediate B/k prior to the last year with high biomass and indicate a respective range, e.g. as 0.4 – 0.8.

In general, the range of the B/k prior should not be less than 0.4, unless the stock is known to be very strongly depleted, in which case ranges of 0.01-0.3 or 0.01 – 0.2 are appropriate. If the stock was nearly unexploited 0.75-1.0 is appropriate for the relative start biomass. Setting a range of 0.01 to 1 is also possible, and would indicate no information at all about stock status, which is, however, unlikely. If a stock is fished it must be smaller than 1. If it is delivering decent catches, it must be larger than 0.01. See Table 1 for guidance on how to get priors from interviews with fishers or experts (or yourself).

Note that if abundance information is provided, an additional surplus production analysis is performed with an advanced Bayesian state-space implementation of a Schaefer model (BSM). This analysis is then used for management advice, because it contains more information. If instead you want to use the CMSY+ results because you do not trust the CPUE data, set "force.cmsy" to TRUE in the respective row in the stock ID input file.

Results of CMSY analysis

When running CMSY+ it will first do a Monte-Carlo analysis of catch and priors for *r* and *B/k*. Progress will be indicated on screen and in graphs (Figure 1 B). If CMSY+ does not find any viable points, review all your priors if these are indeed plausible. Increase the final prior biomass range if it is very narrow (e.g. change 0.01-0.1 to 0.01 – 0.3). If at least 3 years with abundance data have been provided, the BSM model will run an additional full surplus production model on catch and abundance.

The text screen output for flounder (*Platichthys flesus*) in the eastern Baltic Sea (fle-2732) is shown on the next page, first with only catch and priors as input (btype=None in the ID file). The text should be largely self-explanatory.

```
-------------------------------------------
CMSY Analysis, Thu Dec 05 11:19:55 2019
-------------------------------------------
Parallel processing will use 8 cores
Files Stocks_Catch_EU_1.csv, Stocks_ID_EU_8.csv read successfully
Processing fle-2732, Platichthys flesus
startbio=0.35-0.65 expert, intbio=2010, 0.01-0.4 default, endbio=0.01-0.4 default
First Monte Carlo filtering of r-k space with 20000 points...

Found 13938 viable trajectories for 8070 r-k pairs
---------------------------------------
Species: Platichthys flesus, stock: fle-2732
Flounder in Subdivisions 27 and 29–32 (Northern Central and Northern Baltic Sea)
Region: Northeast Atlantic, Baltic Sea
Catch data used from years 2000 - 2014, abundance = None
Prior initial relative biomass = 0.35 - 0.65 expert
Prior intermediate rel. biomass= 0.01 - 0.4 in year 2010 default
Prior final relative biomass   = 0.01 - 0.4 default
Prior range for r = 0.36 - 0.86 expert, prior range for k = 1.56 - 4.68

Results of CMSY analysis
-------------------------
Altogether 13938 viable trajectories for 8070  r-k pairs were found
r   = 0.570, 95% CL = 0.413 - 0.786, k = 2.40, 95% CL = 1.75 - 3.27
MSY = 0.343, 95% CL = 0.271 - 0.438
Relative biomass in last year = 0.29 k, 2.5th perc = 0.0245, 97.5th perc = 0.396
Exploitation F/(r/2) in last year = 0.923, 2.5th perc = 0.677, 97.5th perc = 11

Results for Management (based on CMSY analysis)
-------------------------------------------------------------
Fmsy = 0.285, 95% CL = 0.207 - 0.393 (if B > 1/2 Bmsy then Fmsy = 0.5 r)
Fmsy = 0.285, 95% CL = 0.207 - 0.393 (r and Fmsy reduced if B < 1/2 Bmsy)
MSY  = 0.343, 95% CL = 0.271 - 0.438
Bmsy = 1.20 , 95% CL = 0.877 - 1.64
Biomass in last year = 0.696, 2.5th perc = 0.0586, 97.5 perc = 0.949
B/Bmsy in last year  = 0.581, 2.5th perc = 0.0489 , 97.5 perc = 0.792
Fishing mortality in last year = 0.263, 2.5th perc = 0.193, 97.5 perc = 3.12
Exploitation F/Fmsy  = 0.923, 2.5th perc = 0.677 , 97.5 perc = 11
Comment: btype set to None for demonstration
```

Figure 1 shows the CMSY+ assessment for flounder in the eastern Baltic Sea. The black curve in **A** shows the time series of catches and the blue curve shows the smoothed data with indication of highest and lowest catch in red, as used in the estimation of prior biomass by the default rules. Panel **B** shows the explored log *r-k* space and in dark grey the *r-k* pairs which were found by the model to be compatible with the catches and the prior information. The dotted rectangle indicates the range of the priors provided in the ID file. The point in the center of the blue cross is the most likely r-k pair predicted by CMSY and horizontal and vertical error bars approximate 95% confidence limits for *r* and *k,* respectively, which are again closer view in Panel **C**. The blue curve in **D** shows the median of the biomass trajectories estimated by CMSY. Dotted lines indicate the 2.5th and 97.5th percentiles. Vertical blue lines indicate the prior biomass ranges. Panel **E** shows median exploitation (F/F_{msy}) as blue curve, with the dotted curves indicating 2.5th and 97.5th percentiles. The steep increase in the upper confidence limit in the last year results from catch relative to the lower confidence limit of biomass in panel **D**. Panel **F** shows the Schaefer equilibrium curve of catch/MSY relative to *B/k*, indented at $B/k < 0.25$ to account for reduced recruitment at low stock sizes. The blue curve shows the predictions by CMSY, from first year (square) to last years (triangle).

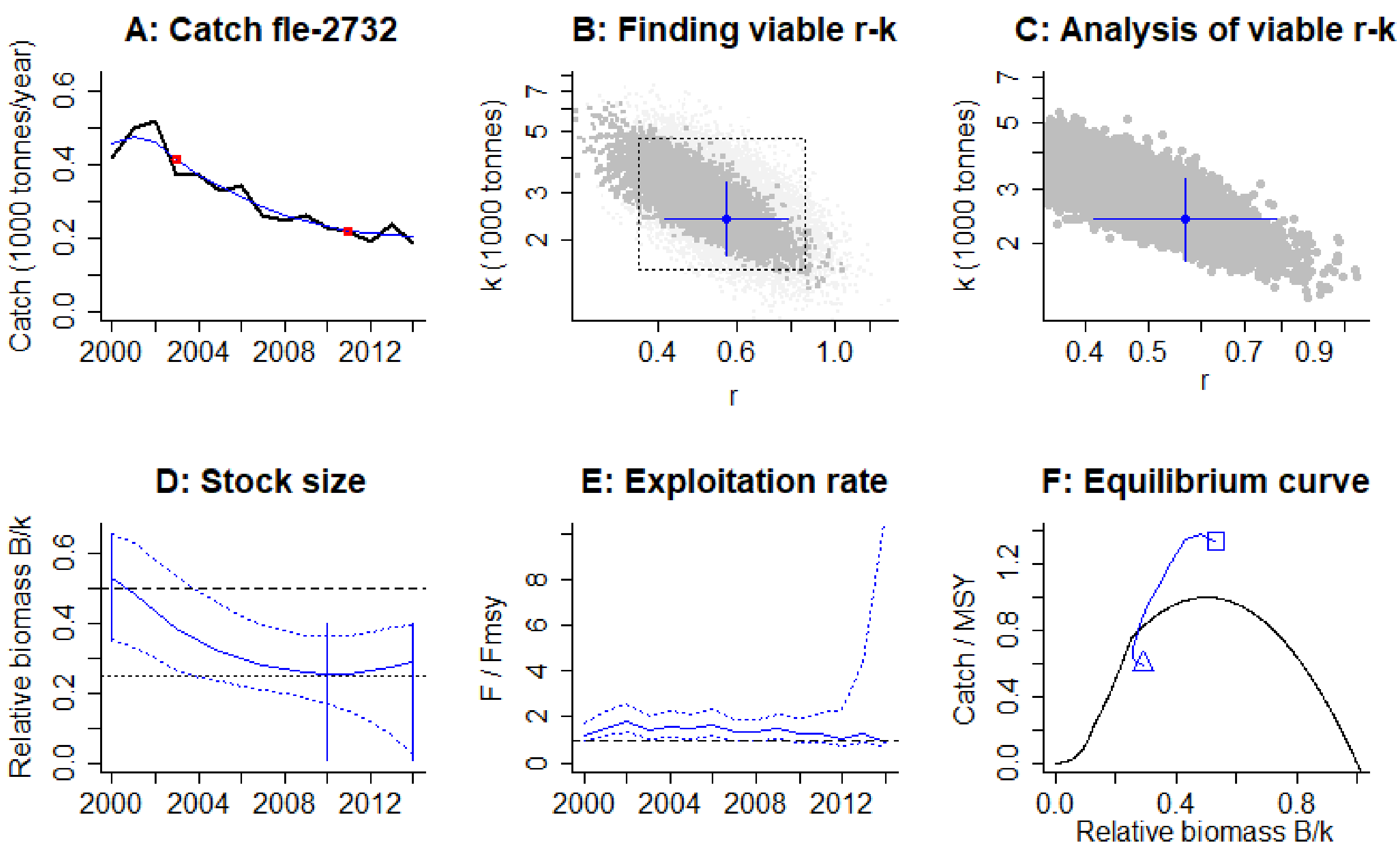

Figure 1. Results of CMSY analyses for flounder in the Baltic Sea.

Figure 2 shows the graphs meant to inform management about the stock status. The upper left panel shows catches relative to *MSY*, with indication of 95% confidence limits in grey. The upper right panel shows the development of predicted relative total biomass (B/B_{msy}), with the grey area indicating uncertainty. The lower left graph shows relative exploitation (F/F_{msy}). The lower-right panel shows the trajectory of relative stock size (B/B_{msy}) as a function of fishing pressure (F/F_{msy}). The “banana” shape around the assessment of the final year triangle indicates uncertainty with yellow for 50%, grey for 80% and dark grey for 95% confidence levels.

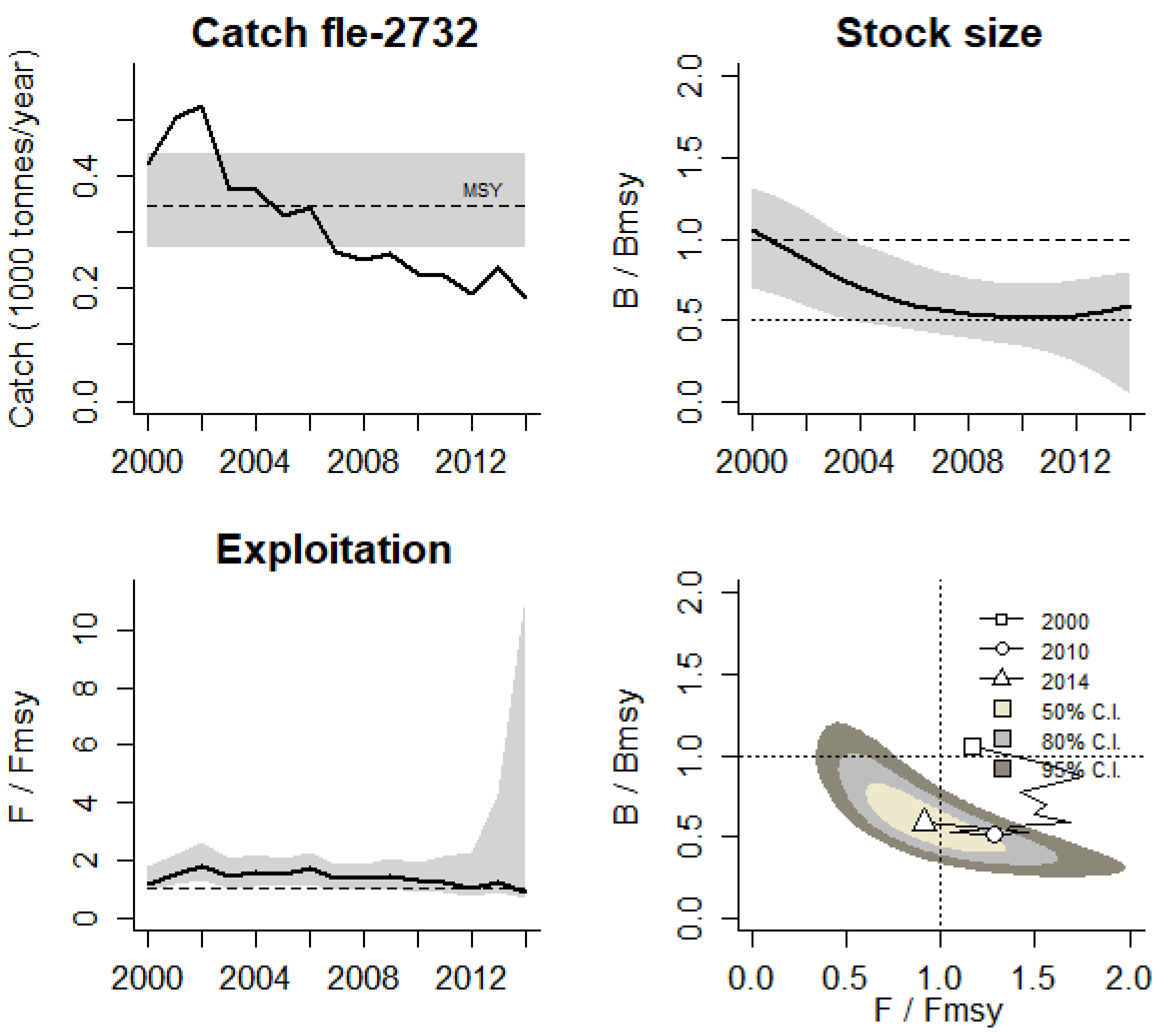

Figure 2. Graphical output of CMSY for management purposes, for flounder in the Baltic Sea.

Figure 3 is a Kobe phase plot, representing the time series of pressure (*F/F_{MSY}*) on the Y-axis and of state (*B/B_{MSY}*) on the X-axis. The plot is divided into four quadrants, defined for the stock biomass and fishing mortality relative to *B_{MSY}* and *F_{MSY}*, respectively. The orange area indicates healthy stock sizes that are about to be depleted by overfishing. The red area indicates that is overfished and is undergoing overfishing, with biomass levels being too low to produce maximum sustainable yields. The yellow area indicates reduced fishing pressure on stocks recovering from still too low biomass levels. The green area is the target area for management, indicating sustainable fishing pressure and healthy stock size capable of producing high yields close to MSY. The “banana” shape around the assessment of the final year triangle indicates uncertainty with yellow for 50%, grey for 80% and dark grey for 95% confidence levels. The legend in the upper right graph also indicates the probability of the last year falling into one of the colored areas, i.e., in this example there is a 3.7% probability that the stock is in the green area and a 56.1% probability that it is in the yellow area.

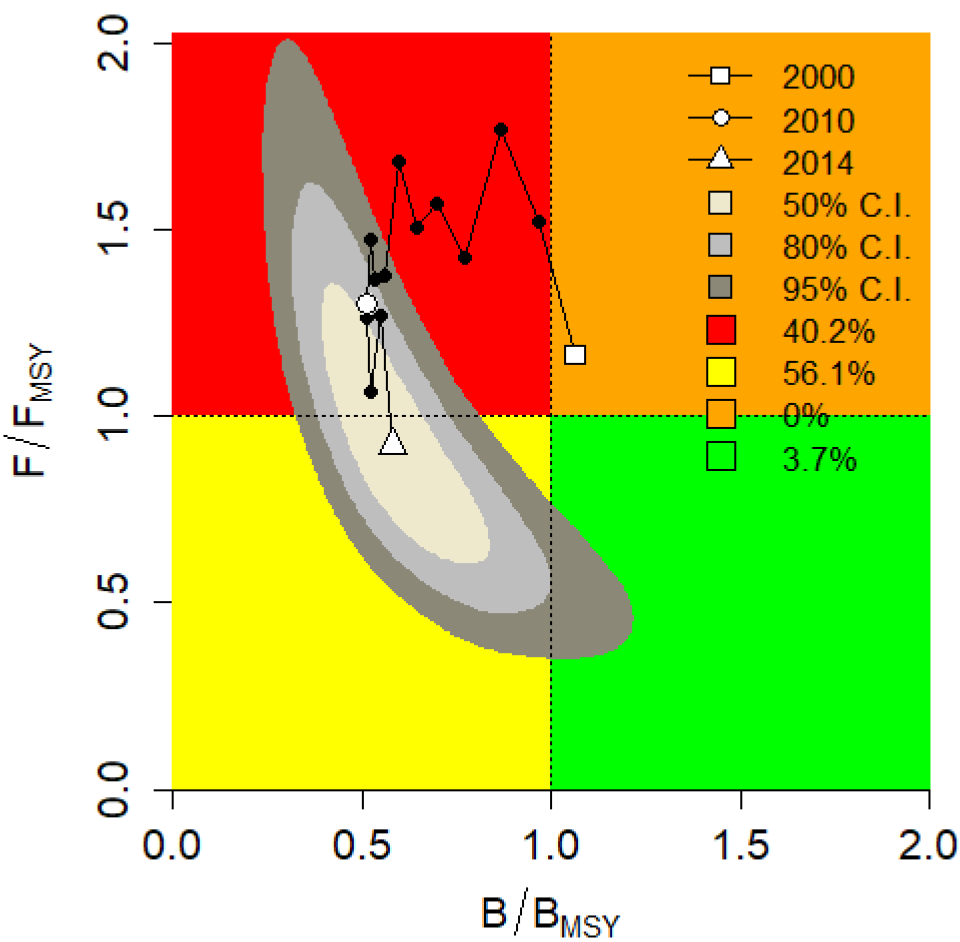

Figure 3. CMSY results for eastern Baltic flounder presented in a Kobe plot.

A common misconception of Bayesian analyses is that the priors determine the results. Instead, as **Figure 4** nicely shows, the priors (light grey) inform the results, with posterior understanding (dark grey) of the stock clearly improved compared to prior perceptions. The lower the prior-posterior variance ratio (PPVR), the more the posterior knowledge is improved relative to prior knowledge. If CPUE data are available, a similar graph is produced for BSM results. Display of these graphs is triggered by setting pp.plot <- TRUE in the "General settings for the analysis" section in the R-code.

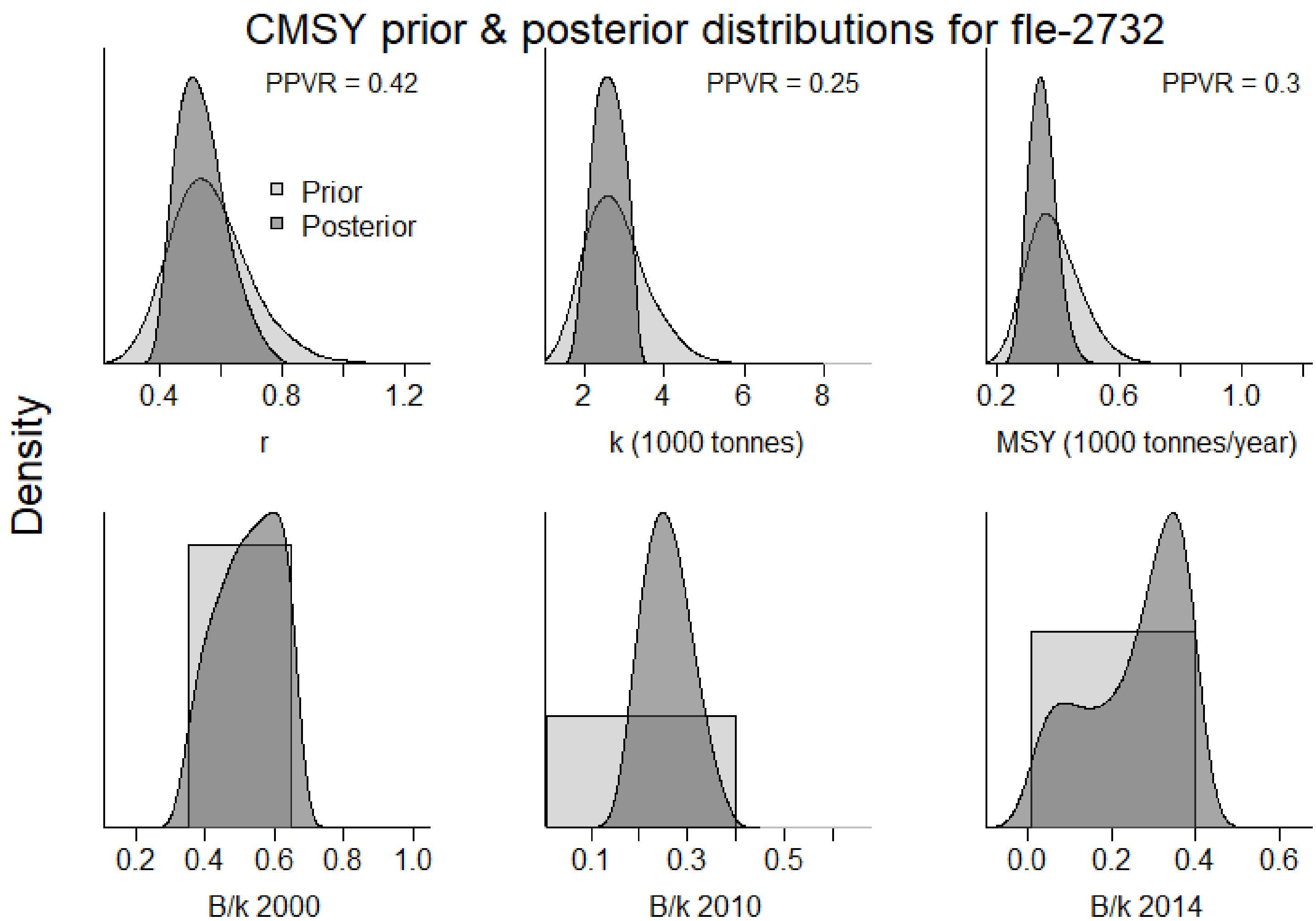

Figure 4. Comparison of prior and posterior densities (same area under curves) for productivity (r), maximum stock size (k), maximum sustainably yield (MSY), and relative stock size (B/k) at the beginning, the end, and an intermediate year of the available time series of catch data.

CMSY+ also provides an option for a retrospective analysis, i.e., a comparison of results if the last one, two, or three years are omitted from the analysis. The retrospective results are displayed on screen and a new graph (Figure 5) is produced for comparing predicted time series of exploitation (F/F_{msy}) and relative stock size (B/B_{msy}). In the example for eastern Baltic flounder (**Figure 5**), the results are not changed much by omitting years. If, however, the predictions for all years differ substantially from those without the last year, i.e. in the presence of a strong retrospective discrepancy, then it might be prudent to, e.g. not increase allowed catch until the data for the last year are confirmed.

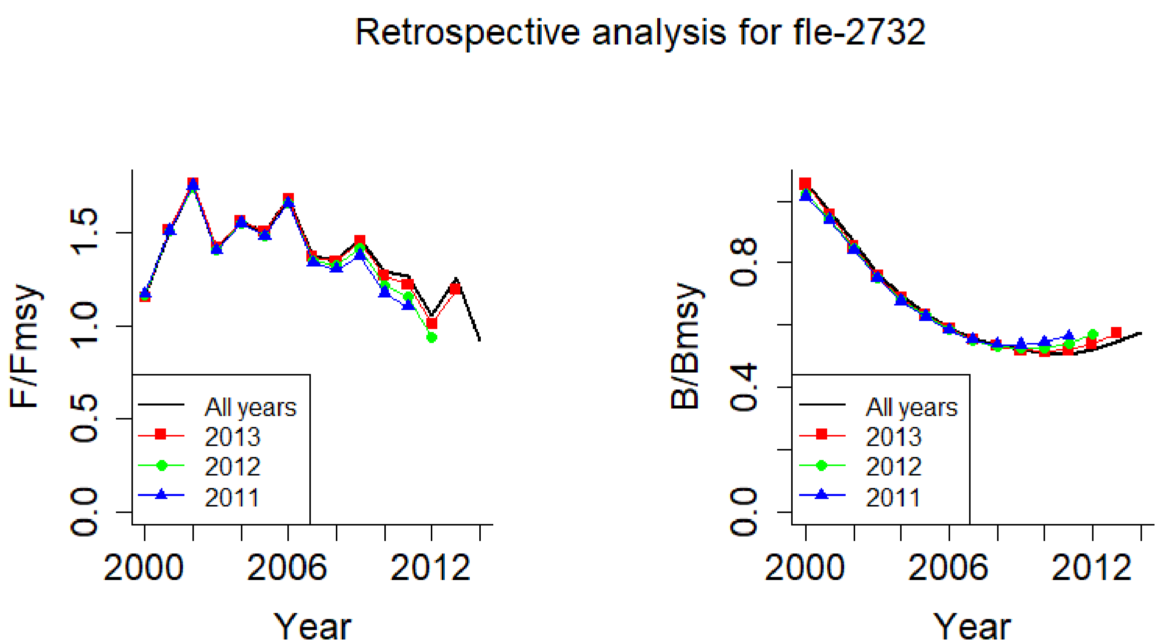

Figure 5. Comparison of predictions for exploitation (F/F_{msy}) and relative stock size (B/B_{msy}) when the last 1-3 years are omitted from the analysis.

If CPUE data are available in addition to the catch data, a Bayesian state-space implementation of a full Schaefer model is performed automatically by the CMSY+ package. The screen output then changes as indicated on the next page. If a BSM analysis is available, it is used automatically for management advice unless force.cmsy is set to TRUE in the ID file. Note that in this example, an increase of efficiency of fishers to find and catch the species of 2% per year was considered by setting e.creep to 2 in the ID file.

```
-------------------------------------------
CMSY Analysis, Thu Dec 05 12:09:38 2019
-------------------------------------------
Parallel processing will use 8 cores
Files Stocks_Catch_EU_1.csv, Stocks_ID_EU_8.csv read successfully
Processing fle-2732, Platichthys flesus
startbio=0.35 0.65 expert, intbio=2010 0.01 0.4 default, endbio=0.01 0.4 default
First Monte Carlo filtering of r-k space with 20000 points...

Found 13819 viable trajectories for 8074 r-k pairs
Running MCMC analysis....
---------------------------------------
Species: Platichthys flesus, stock: fle-2732
Flounder in Subdivisions 27 and 29-32 (Northern Central and Northern Baltic Sea)
Region: Northeast Atlantic, Baltic Sea
Catch data used from years 2000 - 2014, abundance = CPUE
Prior initial relative biomass = 0.35 - 0.65 expert
Prior intermediate rel. biomass= 0.01 - 0.4 in year 2010 default
Prior final relative biomass   = 0.01 - 0.4 default
Prior range for r = 0.36 - 0.86 expert, prior range for k = 1.56 - 4.68
Prior range of q = 0.00085 - 0.00263, assumed effort creep 2 %

Results of CMSY analysis
-------------------------
Altogether 13819 viable trajectories for 8074 r-k pairs were found
r   = 0.570, 95% CL = 0.428 - 0.759, k = 2.41, 95% CL = 1.77 - 3.27
MSY = 0.344, 95% CL = 0.274 - 0.438
Relative biomass in last year = 0.289 k, 2.5th perc = 0.0235, 97.5th perc = 0.396
Exploitation F/(r/2) in last year = 0.923, 2.5th perc = 0.674, 97.5th perc = 11.4

Results from Bayesian Schaefer model (BSM) using catch & CPUE
------------------------------------------------------------
q   = 0.00113, lcl = 0.000806, ucl = 0.00159
r   = 0.540, 95% CL = 0.384 - 0.76, k = 2.53, 95% CL = 1.84 - 3.49
r-k log correlation = -0.86
MSY = 0.341, 95% CL = 0.286 - 0.407
Relative biomass in last year = 0.296 k, 2.5th perc = 0.16, 97.5th perc = 0.434
Exploitation F/(r/2) in last year = 1.01, 2.5th perc = 0.658, 97.5th perc = 2.88

Results for Management (based on BSM analysis)
-------------------------------------------------------------
Fmsy = 0.27, 95% CL = 0.192 - 0.38 (if B > 1/2 Bmsy then Fmsy = 0.5 r)
Fmsy = 0.27, 95% CL = 0.192 - 0.38 (r and Fmsy linearly reduced if B < 1/2 Bmsy)
MSY  = 0.341 , 95% CL = 0.286 - 0.407
Bmsy = 1.26, 95% CL = 0.918 - 1.74
Biomass in last year = 0.750, 2.5th perc = 0.404, 97.5 perc = 1.10
B/Bmsy in last year  = 0.593, 2.5th perc = 0.320, 97.5 perc = 0.867
Fishing mortality in last year = 0.271, 2.5th perc = 0.185, 97.5 perc = 0.503
Exploitation F/Fmsy  = 1.01 , 2.5th perc = 0.658 , 97.5 perc = 2.88
Comment: Effort creep 2% set for demonstration purpose
```

If CPUE data are present and a BSM analysis is performed, the graphical output changes as shown below in **Figure 6**. The red cross in panel **B** now indicates the best *r-k* estimate of BSM. In panel **C**, the black dots are the viable *r-k* pairs found by BSM, with indication of a red cross for best estimate with 95% confidence limits. The red curves in panel **D** show the BSM predictions for biomass, the dots indicate the CPUE data scaled by BSM, and the green line indicates the raw cpue while the dots show the cpue corrected for effort creep. The red curves in panel **E** show the BSM predictions for exploitation, with the dots showing catch per CPUE as scaled by BSM. The red curve in panel **F** shows the BSM predictions for exploitation and stock size, with the dots showing predicted catch per predicted biomass as scaled by BSM. The management graph, the Kobe plot and the prior-posterior graphs will look similar as shown above for CMSY+, but will be based on BSM results (not shown here).

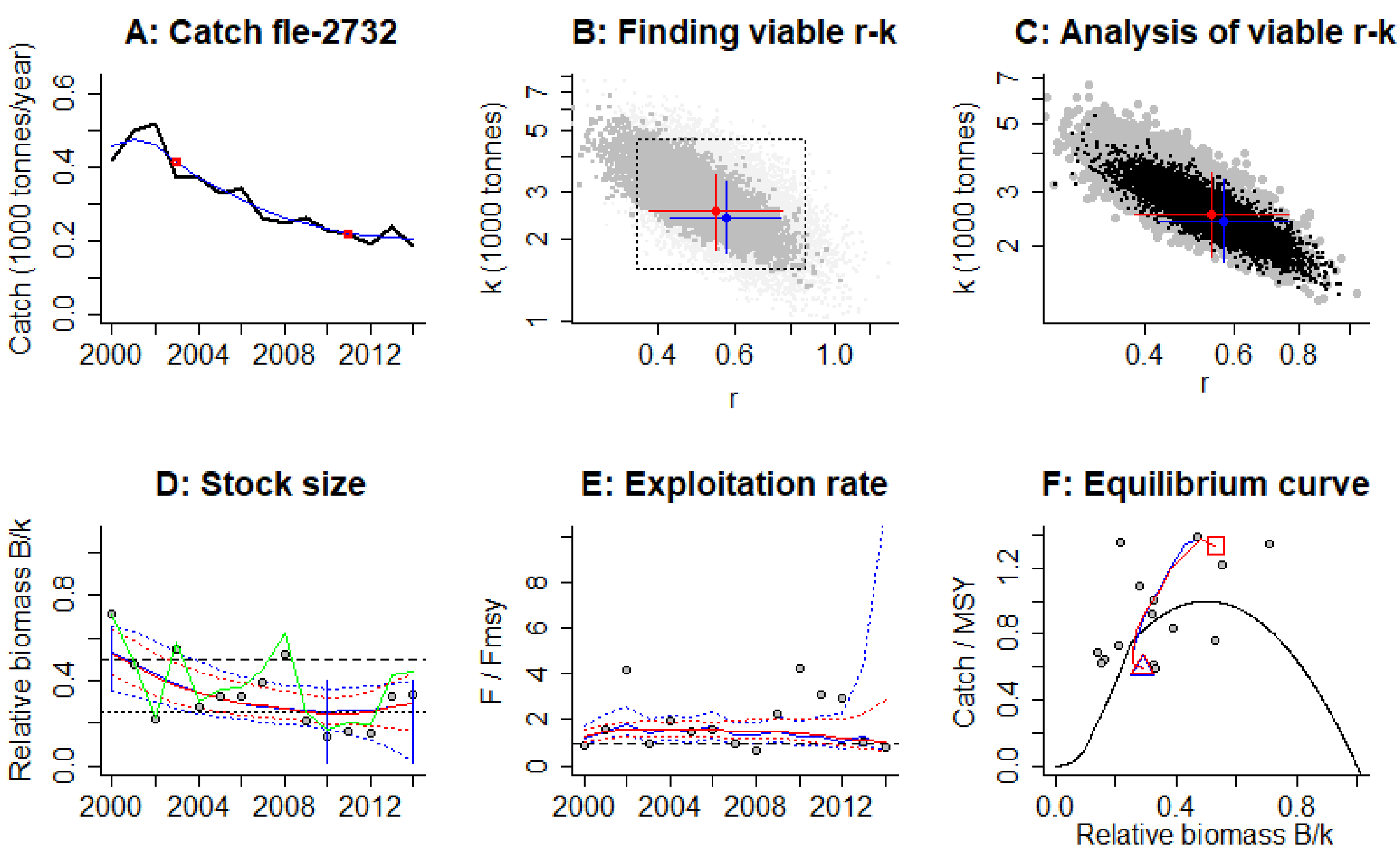

Figure 6. Analysis of Baltic flounder with CMSY+ and BSM.

If CPUE data are available and BSMfits.plot <- TRUE in the "General settings for the analysis" section in the R-code, the analytical graph shown below is produced (**Figure 7)**. The upper left panel shows the fit represented by the median of predicted catch posterior, with 95% confidence limits (grey shaded area), compared to the observed catch (points). The upper right panel shows a similar graph for predicted versus observed CPUE. The lower left panel shows the deviation between deterministic expectation (surplus production minus catch) and the stochastic realization (after adding process error), where a strong deviation of the bold curve from the dashed line would indicate that changes in biomass diverge from the Schaefer model expectations due to, e.g., (1) strong environmental variation, (2) CPUE not properly describing the abundance or (3) the priors are mis-specified and require re-evaluation. The lower right graph shows an analysis of the log-CPUE residuals, with a white or green background if autocorrelation of residuals is deemed negligible (and red otherwise), as judged by a non-parametric Runs test for testing randomness in time series.

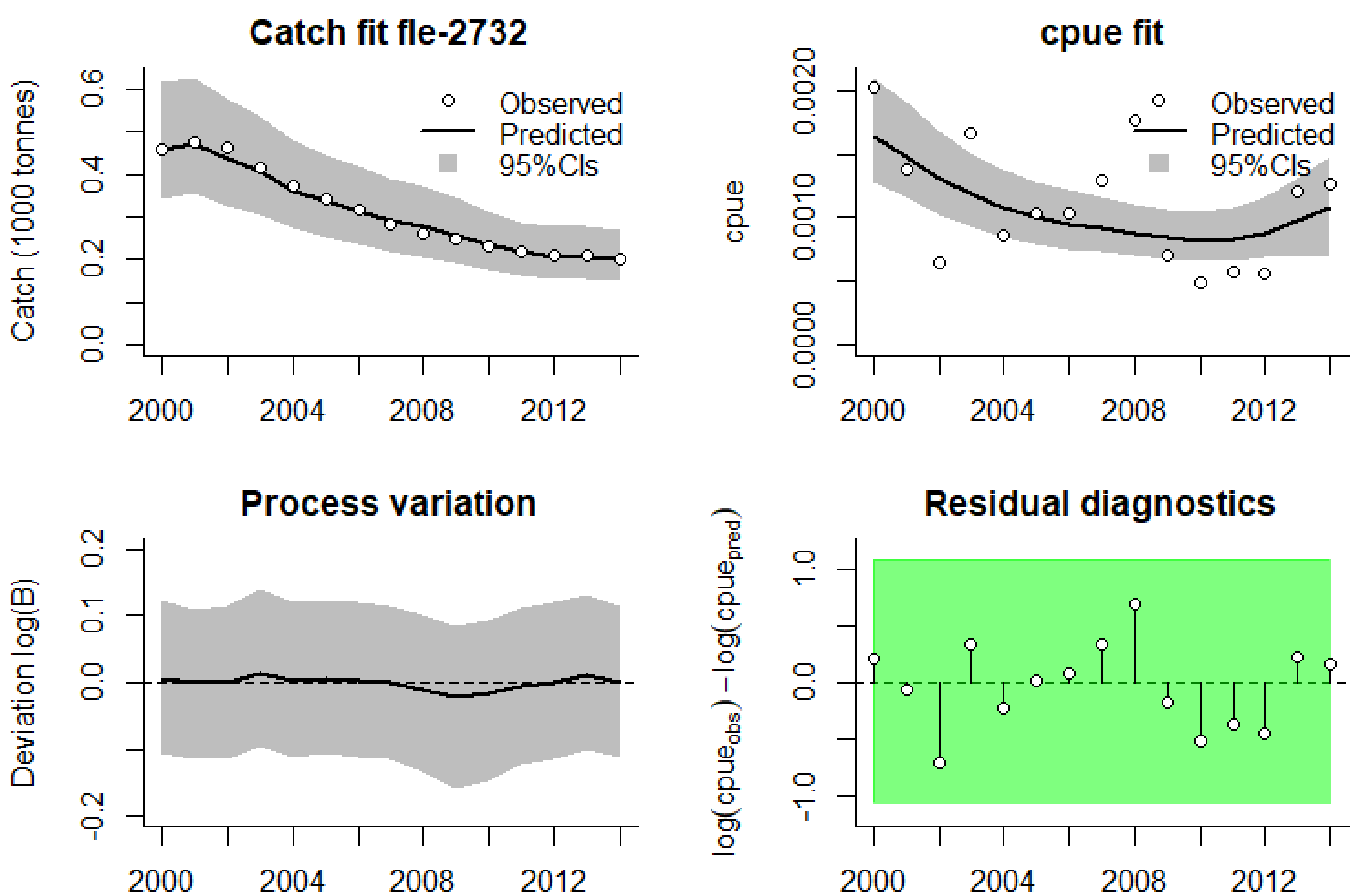

Figure 7. Analytical graph for BSM analysis of Baltic flounder, showing the fit of the predicted to the observed catch, the fit of predicted to observed CPUE, the deviation from observed to predicted biomass, and an analysis of the log-CPUE residuals, with a white or green background if autocorrelation of residuals is deemed negligible and red otherwise.

If you have any questions, contact us:

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Enjoy using CMSY+ and BSM.

Appendix: Generating PDFs with CMSY

CMSY requires LaTeX installed and configured on the PC in order to generate PDF documents.

For non-LaTeX users, one easy way to configure LaTeX for the first time and make it work with CMSY is to follow these steps:

1. Install MikTex for "all PC users" and with administrator rights (https://miktex.org/download)

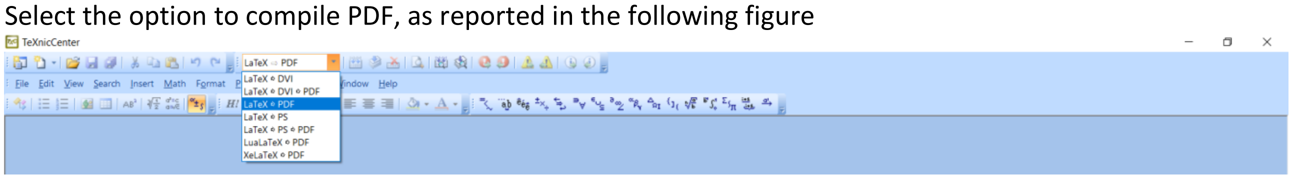
2. Install TexnicCenter for "all PC users" and with administrator rights (http://www.texniccenter.org/download/)

3. Run CMSY focussed on one stock

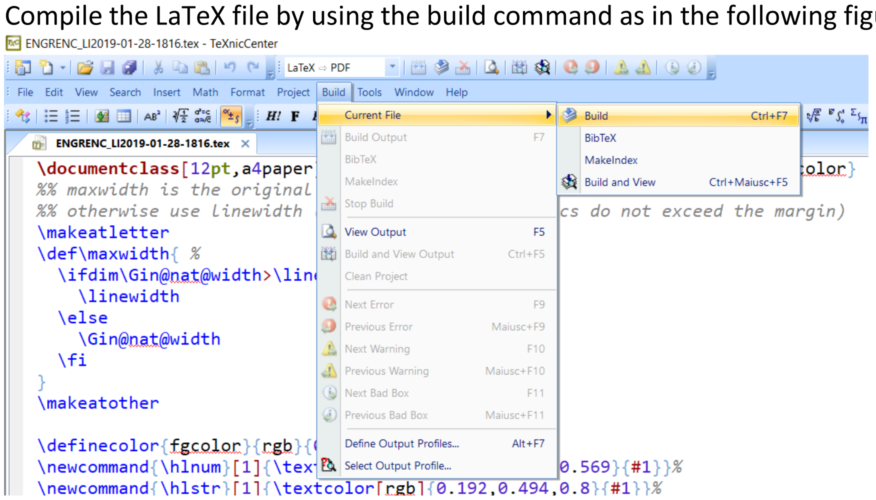
4. Open the .tex file produced by CMSY with TexnicCenter and administrator rights

5. In the start configuration dialog window, select to use MikTek as compilation engine and skip the PostScript setup

6. Select the option to compile PDF, as reported in the following figure



7. Compile the LaTeX file by using the build command as in the following figure



8. A pop-up window will open to ask for automatic installation of required packages

9. The current latex file will be compiled and the first PDF will be generated

10. From this point on, LaTeX compilation and PDF production will work directly and transparently from CMSY in RStudio