Applying SPiCT to anchovy (*Engraulis encrasicolus*) in Division 9a South (Atlantic Iberian waters)

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Introduction

Small and mid-size pelagic fish occupy intermediate levels in the marine trophic webs where they play an essential role (Cury *et al.*, 2000). These fish act as links between the upper and lower trophic levels, capturing energy from lower levels and making it available to higher trophic levels (Morello & Arneri, 2009). Global captures of finfish, the taxon where small and mid-size pelagic fish are included, account for the 85% of the marine captures, with small pelagics as the main group (FAO, 2024a).

According to the economic importance of *Engraulis encrasicolus*, the species under study, it accounted for approximately 4% of the total european countries fisheries in 2022 (FAO, 2024b). Concerning Spain and Portugal, *Engraulis encrasicolus* covers more than 5% and 2% of the total fisheries, respectively (FAO, 2024b). Therefore, the knowledge and correct management of the *Engraulis encrasicolus* fishery is of utmost importance for the fishing sector of both countries.

In this study we apply the Stocastic Surplus Production Model in Continuous Time (SPiCT) with 4 different model configurations to evaluate the *Engraulis encrasicolus* stock status in ICES Division 9a South. Model results allow us to establish reference points for Maximum Sustainable Yield, Biomass at Maximum Sustainable Yield and Fishing Mortality at Maximum Sustainable Yield as well as to determine how model configuration could affect the estimates and model robustness.

Material & Methods

Data

We used data from commercial landings as catch obervations and independent scientific survey data as exploitable biomass indices. In this sense, we used quarterly commercial landings data comprised from 1989 to 2023 and yearly data from PELAGO (1999-2023), ECOCADIZ (2004-2023), ECOCADIZ-RECLUTAS (2012-2023) and BOCADEVA (2005-2023) surveys. We obtained the corresponding exploitable biomass index for each period and survey considering the minimum length observed in the landings during that period. In addition, we added as much uncertainty as possible, without compromising the stability of the model, to the 2012 estimate of the ECOCADIZ-RECLUTAS survey since it was only sampled in Spanish waters.

SPiCT

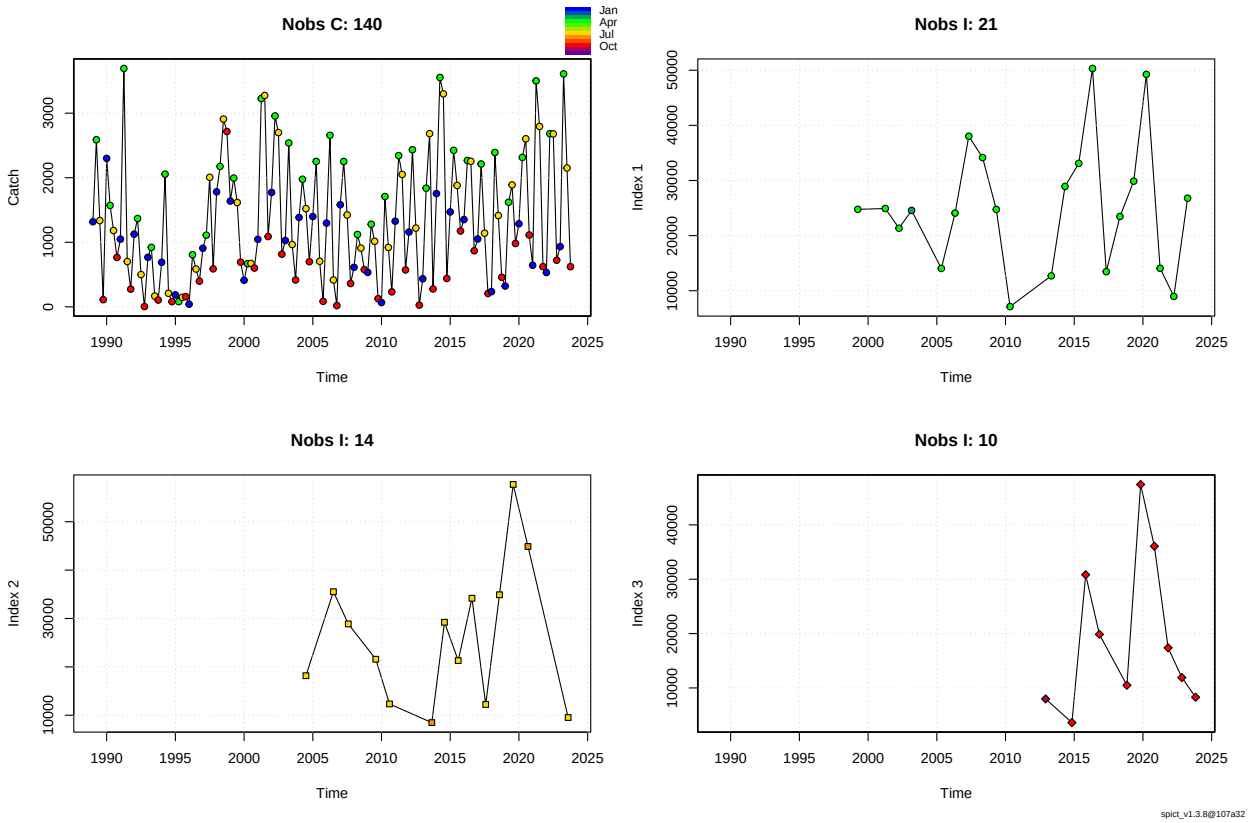
Stocastic Surplus Production Model in Continuos Time (Pedersen & Berg, 2017) is a model that has been widely used in data-limited situations (i.e. Bluemel *et al.*, 2021; González Herraiz *et al.*, 2023; Soto *et al.*, 2023). This stochastic state-space model aggregates biomass across size and age groups, using the equations reported by Pella and Tomlinson (1969), providing stock status estimates and reproducing population dynamics (Derhy *et al.*, 2022). By relaxing the common assumption that catches are known without error, SPiCT permits to assess fish stock status with a more realistic quantification of uncertainty (Pedersen & Berg, 2017), allowing for a broader perspective of the stock situation and a better understanding of the risks associated with management decisions.

Scenarios

We tested the SPiCT model with 4 different configurations of the input data:

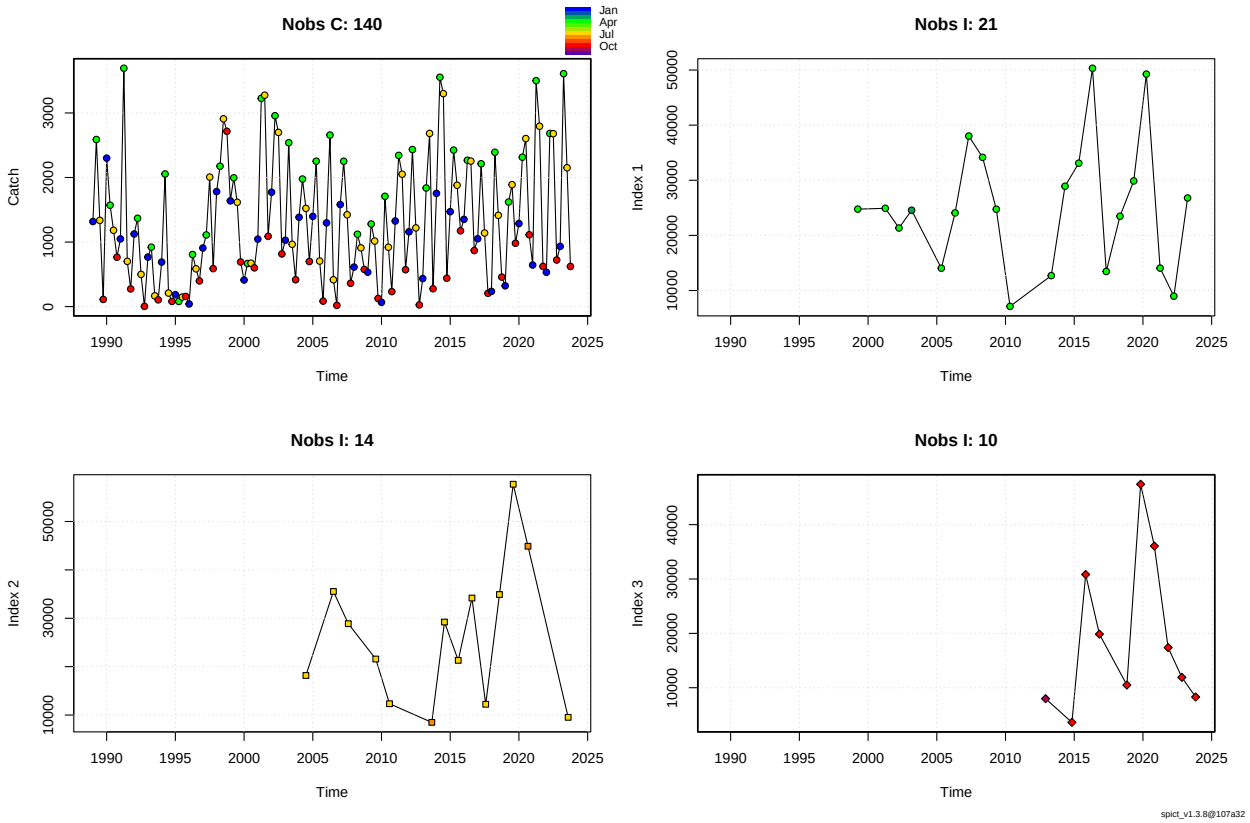
- Scenario 1: commercial landings data and exploitable biomass indices from PELAGO, ECOCADIZ and ECOCADIZ-RECLUTAS.

```
plotspict.data(sc_1_data, qlegend = TRUE)
```



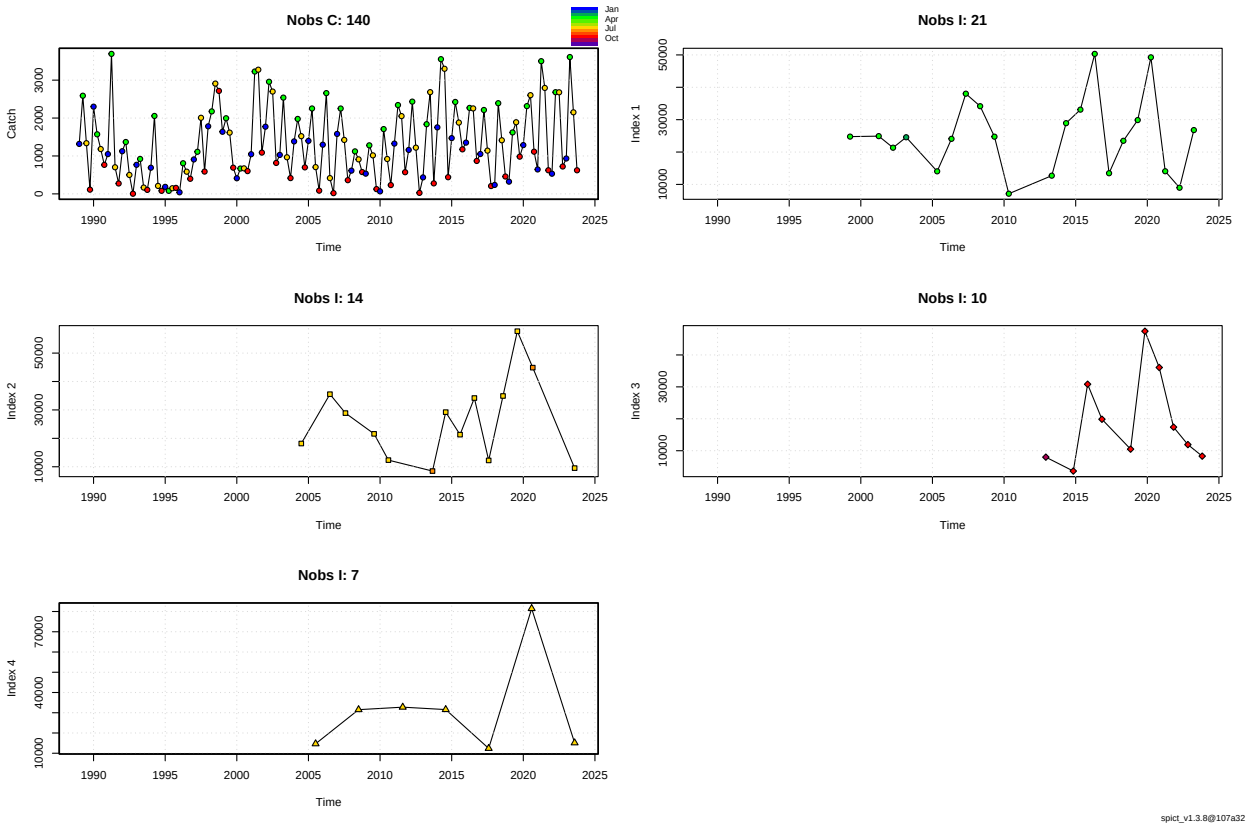
- Scenario 2: identical to Scenario 1 but adding uncertainty to the 2012 ECOCADIZ-RECLUTAS exploitable biomass estimate.

```
plotspict.data(sc_2_data, qlegend = TRUE)
```



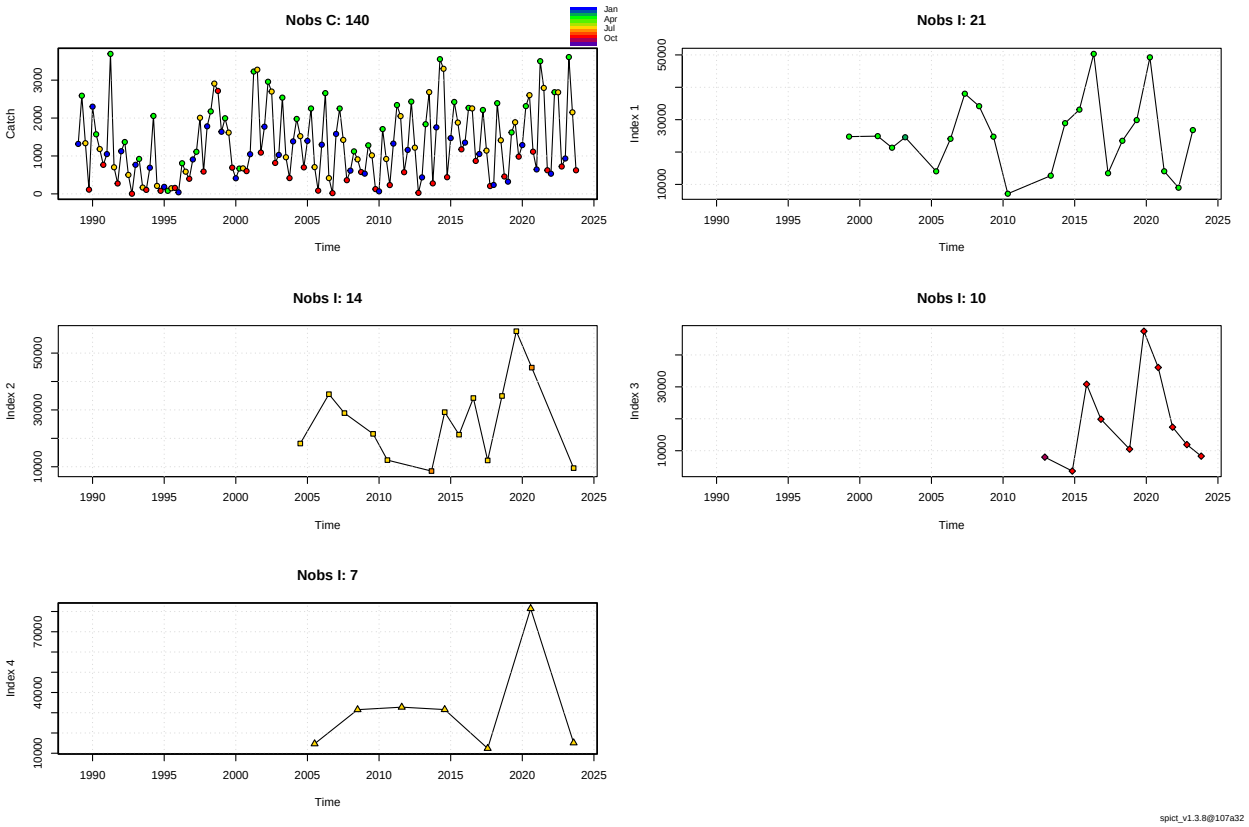
- Scenario 3: commercial landings data and exploitable biomass indices from PELAGO, ECOCADIZ, ECOCADIZ-RECLUTAS and BOCADEVA.

```
plotspict.data(sc_3_data, qlegend = TRUE)
```



- Scenario 4: identical to Scenario 3 but adding the uncertainy to the 2012 ECOCADIZ-RECLUTAS exploitable biomass estimate and to the BOCADEVA estimates.

```
plotspict.data(sc_4_data, qlegend = TRUE)
```



Implementation

We implemented the model and scenarios using the *SPiCT* package (Pedersen & Berg, 2017) from R (R Core Team, 2024) and the default priors.

Results

We obtained two types of results: a) model parameter estimates, reference points & state estimations and b) model diagnostics for model acceptance.

Scenario 1

Model Fit

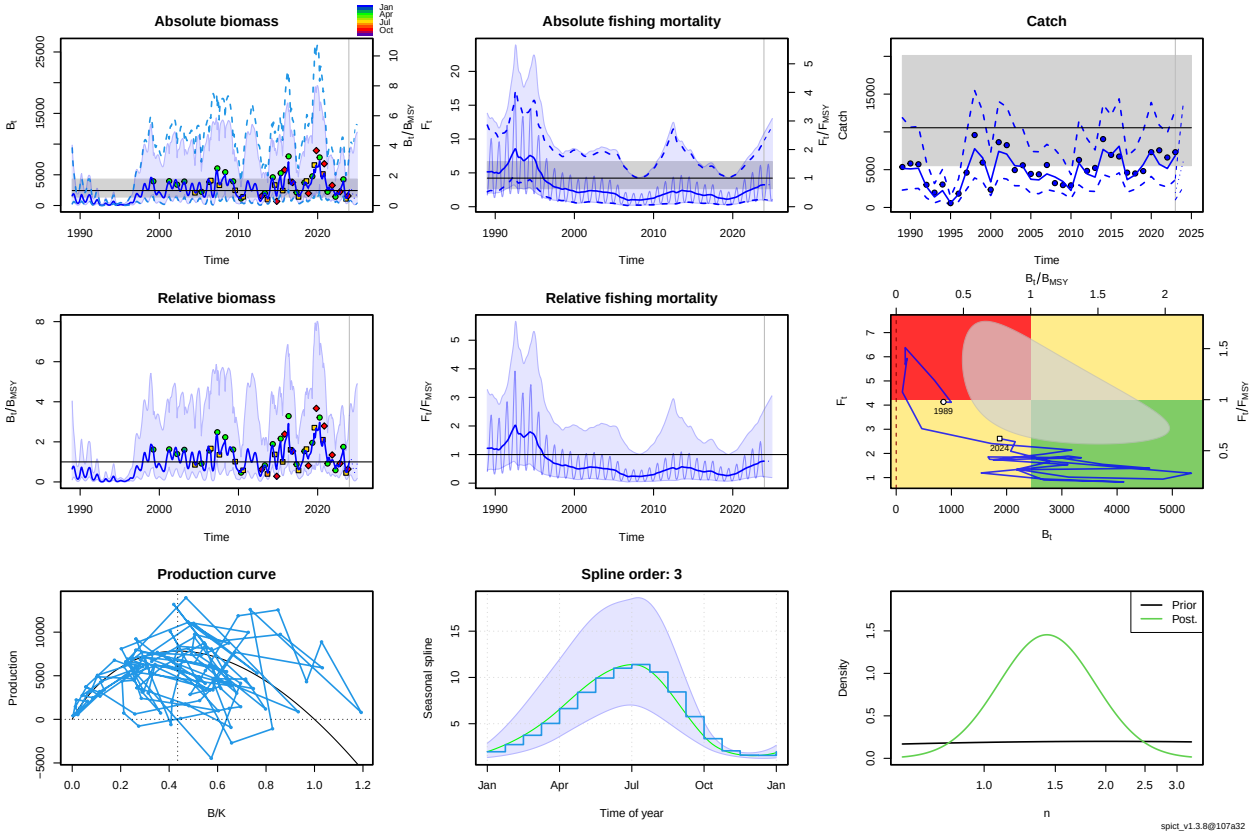
The model obtained acceptable uncertainty levels and an estimated exploitable biomass of 2219.43 tonnes and a fising mortality of 3.25 in 2023. Predicted catchabilities were 6.29, 8.75 and 5.31 for PELAGO, ECOCADIZ and ECOCADIZ-RECLUTAS, respectively. Additionally, Kobe plot shows that the stock has suboptimal biomass estimates as well as lower fishing mortality than fishing mortality at Maximum Sustainable Yield (MSY).

```
res_sc_1 <- fit.spict(sc_1_data)
summary(res_sc_1)
```

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 217.9455143
Euler time step (years):  1/16 or 0.0625
Nobs C: 140,  Nobs I1: 21,  Nobs I2: 14,  Nobs I3: 10

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1472304    0.0251668 8.613235e-01 -1.9157567
 alpha2    0.1707301    0.0319501 9.123218e-01 -1.7676714
 alpha3    0.3986602    0.1161241 1.368622e+00 -0.9196458
 beta      1.6935246    0.8889400 3.226343e+00  0.5268119
 r         4.2377969    1.1869716 1.513004e+01  1.4440435
 rc        5.9281435    2.5109657 1.399577e+01  1.7797111
 rold      9.8617303    3.7699535 2.579706e+01  2.2886616
 m      7830.0805345 5311.6801952 1.154252e+04  8.9657281
 K      6069.6185357 2297.6358114 1.603399e+04  8.7110510
 q1        6.2913041    2.3604551 1.676817e+01  1.8391684
 q2        8.7530111    2.3391956 3.275280e+01  2.1693978
 q3        5.3056998    1.5223404 1.849156e+01  1.6687817
 n         1.4297214    0.8350964 2.447745e+00  0.3574796
 sdb       1.1780900    0.6023364 2.304188e+00  0.1638945
 sdf       0.3449096    0.1755653 6.775977e-01 -1.0644729
 sdi1      0.1734506    0.0387140 7.771132e-01 -1.7518622
 sdi2      0.2011354    0.0431693 9.371339e-01 -1.6037769
 sdi3      0.4696576    0.2032237 1.085397e+00 -0.7557513
 sdc       0.5841129    0.4477046 7.620825e-01 -0.5376610
 phi1      3.8831595    1.8088397 8.336243e+00  1.3566491
 phi2     11.3419666    6.3157292 2.036823e+01  2.4285097
 phi3     11.4554653    5.8256527 2.252583e+01  2.4384669

Deterministic reference points (Drp)
          estimate       cilow        ciupp  log.est
 Bmsyd 2641.663622 1134.936110  6148.704437 7.879164
 Fmsyd    2.964072    1.255483     6.997883 1.086564
 MSYd  7830.080534 5311.680195 11542.517419 8.965728
Stochastic reference points (Srp)
          estimate       cilow        ciupp  log.est rel.diff.Drp
 Bmsys  2435.613471 1380.317367  4297.716688 7.797954  -0.08459887
 Fmsys     4.224397    2.676875     6.666552 1.440876   0.29834440
 MSYs  10548.688285 5533.814449 20108.159670 9.263757   0.25771998

States w 95% CI (inp$msytype: s)
                   estimate       cilow       ciupp    log.est
 B_2023.94      2219.4307185 623.5240116 7900.052961  7.7050060
 F_2023.94         3.2466487   1.0825588    9.736864  1.1776233
 B_2023.94/Bmsy    0.9112409   0.2854531    2.908919 -0.0929479
 F_2023.94/Fmsy    0.7685473   0.2309132    2.557953 -0.2632532

Predictions w 95% CI (inp$msytype: s)
```

```
                 prediction        cilow        ciupp    log.est
B_2025.00      2280.2387517  396.1363036 13125.504321  7.7320354
F_2025.00         3.2466502    0.8842016    11.921192  1.1776238
B_2025.00/Bmsy    0.9362072    0.1787497     4.903415 -0.0659185
F_2025.00/Fmsy    0.7685476    0.1914702     3.084895 -0.2632528
Catch_2024.00  6151.1230310 2718.4802992 13918.186037  8.7243900
E(B_inf)       3001.0968823           NA           NA  8.0067331
```

```
plot(res_sc_1)
```



Model Diagnostics

According to the diagnostic checklist for model acceptance, the model meets all requirements except normality of catch residuals.

- 1- The assessment converged:

```
# if 0 => OK
res_sc_1$opt$convergence
```

```
[1] 0
```

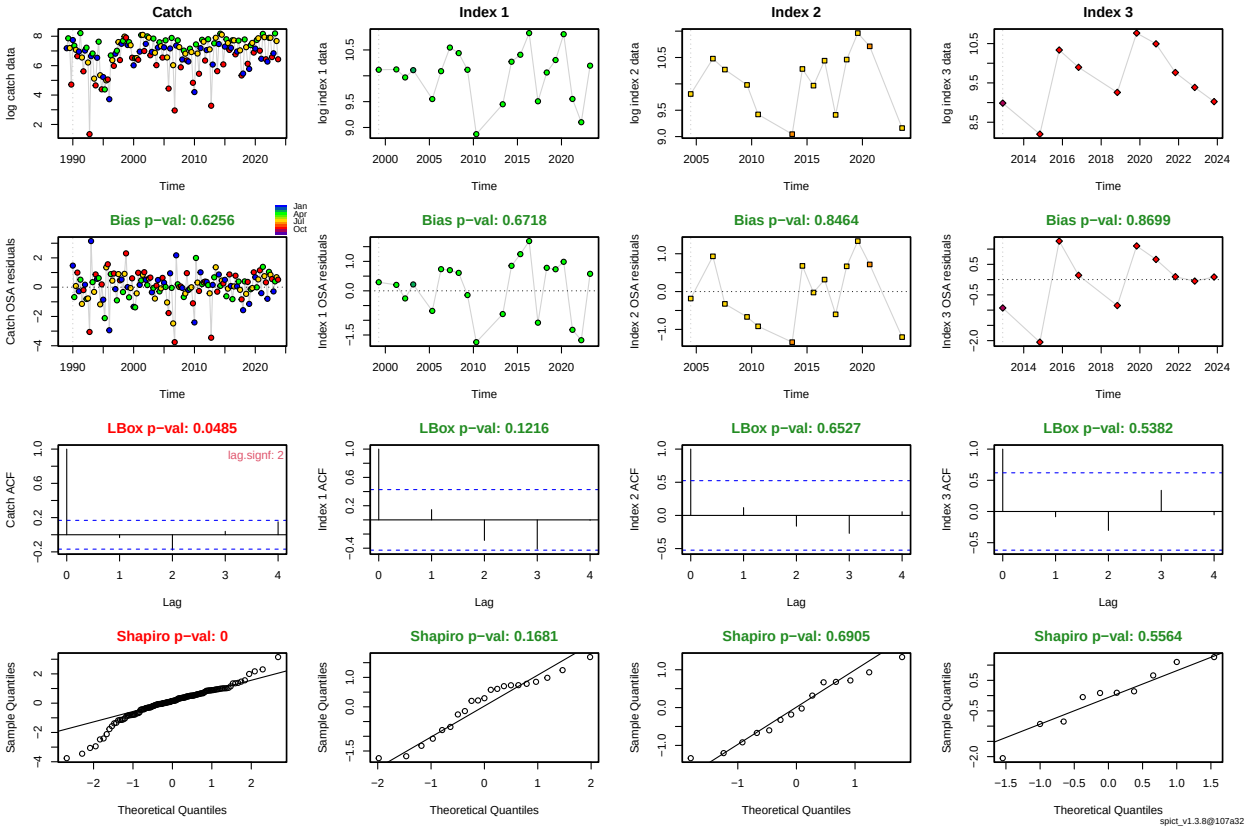
- 2- All variance parameters of the model parameters are finite:

```
# if TRUE => OK
all(is.finite(res_sc_1$sd))
```

```
[1] TRUE
```

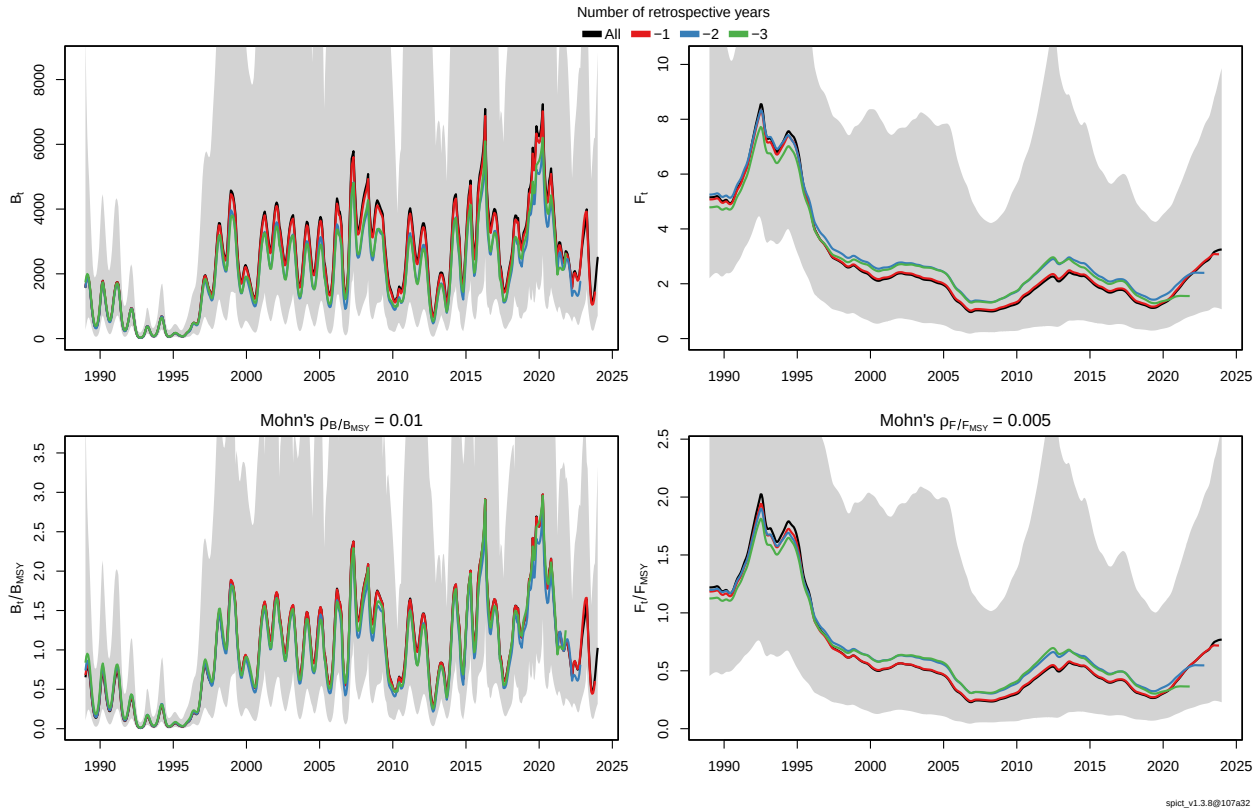
- 3- No violation of model assumptions:

```
res_sc_1 <- calc.osa.resid(res_sc_1)
plotspict.diagnostic(res_sc_1)
```



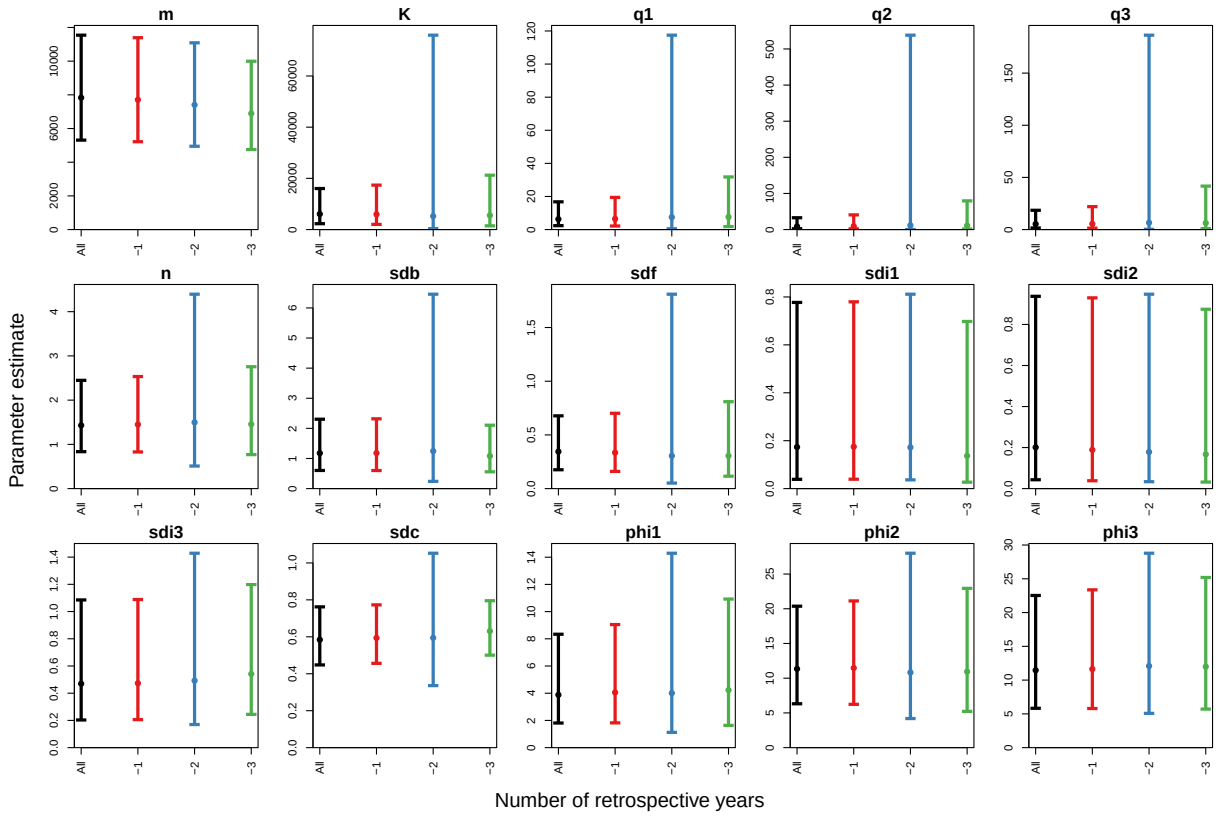
- 4- Consistent patterns in the retrospective analysis:

```
# if -0.2 < mohns_rho < 0.2 => OK
retro_sc_1 <- retro(res_sc_1, nretroyear = 3)
plotspict.retro(retro_sc_1)
```




```
      FFmsy       BBmsy
0.004889144 0.010451340
```

```
plotspict.retro.fixed(retro_sc_1)
```

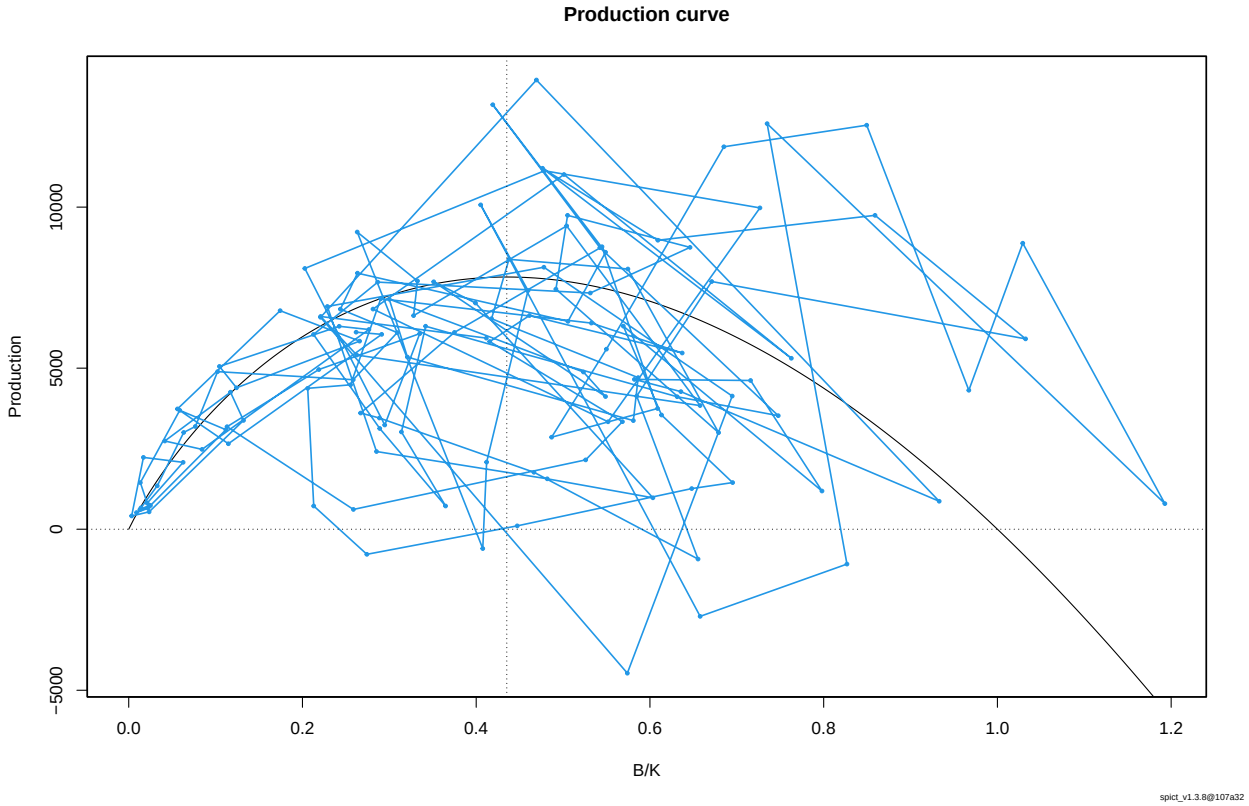


- 5- Realistic production curve:

```
# if between 0.1 and 0.9 => OK
calc.bmsyk(res_sc_1)
```

```
[1] 0.4352273
```

```
plotspict.production(res_sc_1)
```



- 6- High assessment uncertainty:

```
# Main variance paramterers (logsdb, logsdc, logsdi, logsdf) should not be unreallistically high:
get.par("logsdb", res_sc_1)
```

```
              ll       est        ul        sd       cv
logsdb -0.5069392 0.1638945 0.8347282 0.3422684 2.088346
```

```
get.par("logsdc", res_sc_1)
```

```
              ll       est         ul        sd         cv
logsdc -0.8036216 -0.537661 -0.2717005 0.1356966 -0.2523832
```

```
get.par("logsdi", res_sc_1)
```

```
              ll        est          ul        sd         cv
logsdi -3.251555 -1.7518622 -0.25216928 0.7651635 -0.4367715
logsdi -3.142625 -1.6037769 -0.06492909 0.7851409 -0.4895574
logsdi -1.593448 -0.7557513  0.08194539 0.4274041 -0.5655354
```

```
get.par("logsdf", res_sc_1)
```

```
              ll       est         ul        sd         cv
logsdf -1.739744 -1.064473 -0.3892015 0.3445326 -0.3236649
```

```
calc.om(res_sc_1) # if order of magnitude < 2 => OK)
```

```
       lower  est upper CI range order magnitude
B/Bmsy  0.29 0.91  2.91     2.62               1
F/Fmsy  0.06 0.21  0.73     0.67               1
```

- 7- Initial values do not influence the parameter estimates:

```
check_sc_1$check.ini$resmat  # Trials that converged should have same or similar estimates.
```

```
         Distance       m       K    q    q    q    n  sdb  sdf  sdi sdi  sdi
Basevec      0.00 7830.08 6069.62 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 1      0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 2      0.05 7830.08 6069.67 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 3      0.02 7830.08 6069.64 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 4      0.13 7830.07 6069.75 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 5      0.02 7830.08 6069.64 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 6      0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 7      0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 8      0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 9      0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 10     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 11     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 12     0.11 7830.09 6069.51 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 13     0.08 7830.11 6069.69 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 14     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 15     0.03 7830.08 6069.65 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 16     0.01 7830.08 6069.63 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 17     0.05 7830.06 6069.66 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 18     0.02 7830.10 6069.61 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 19     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 20     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 21     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 22     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 23     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 24     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 25     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 26     0.03 7830.08 6069.64 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 27     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 28     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 29     0.01 7830.08 6069.63 6.29 8.75 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 30     0.00      NA      NA   NA   NA   NA   NA   NA   NA   NA  NA   NA
          sdc  phi   phi   phi
Basevec  0.58 3.88 11.34 11.46
Trial 1    NA   NA    NA    NA
Trial 2  0.58 3.88 11.34 11.46
Trial 3  0.58 3.88 11.34 11.46
Trial 4  0.58 3.88 11.34 11.46
Trial 5  0.58 3.88 11.34 11.46
Trial 6    NA   NA    NA    NA
Trial 7    NA   NA    NA    NA
Trial 8    NA   NA    NA    NA
```

```
Trial 9    NA   NA    NA    NA
Trial 10   NA   NA    NA    NA
Trial 11   NA   NA    NA    NA
Trial 12 0.58 3.88 11.34 11.46
Trial 13 0.58 3.88 11.34 11.46
Trial 14   NA   NA    NA    NA
Trial 15 0.58 3.88 11.34 11.46
Trial 16 0.58 3.88 11.34 11.46
Trial 17 0.58 3.88 11.34 11.46
Trial 18 0.58 3.88 11.34 11.46
Trial 19   NA   NA    NA    NA
Trial 20   NA   NA    NA    NA
Trial 21   NA   NA    NA    NA
Trial 22   NA   NA    NA    NA
Trial 23   NA   NA    NA    NA
Trial 24   NA   NA    NA    NA
Trial 25   NA   NA    NA    NA
Trial 26 0.58 3.88 11.34 11.46
Trial 27   NA   NA    NA    NA
Trial 28   NA   NA    NA    NA
Trial 29 0.58 3.88 11.34 11.46
Trial 30   NA   NA    NA    NA
```

Scenario 2

Model Fit

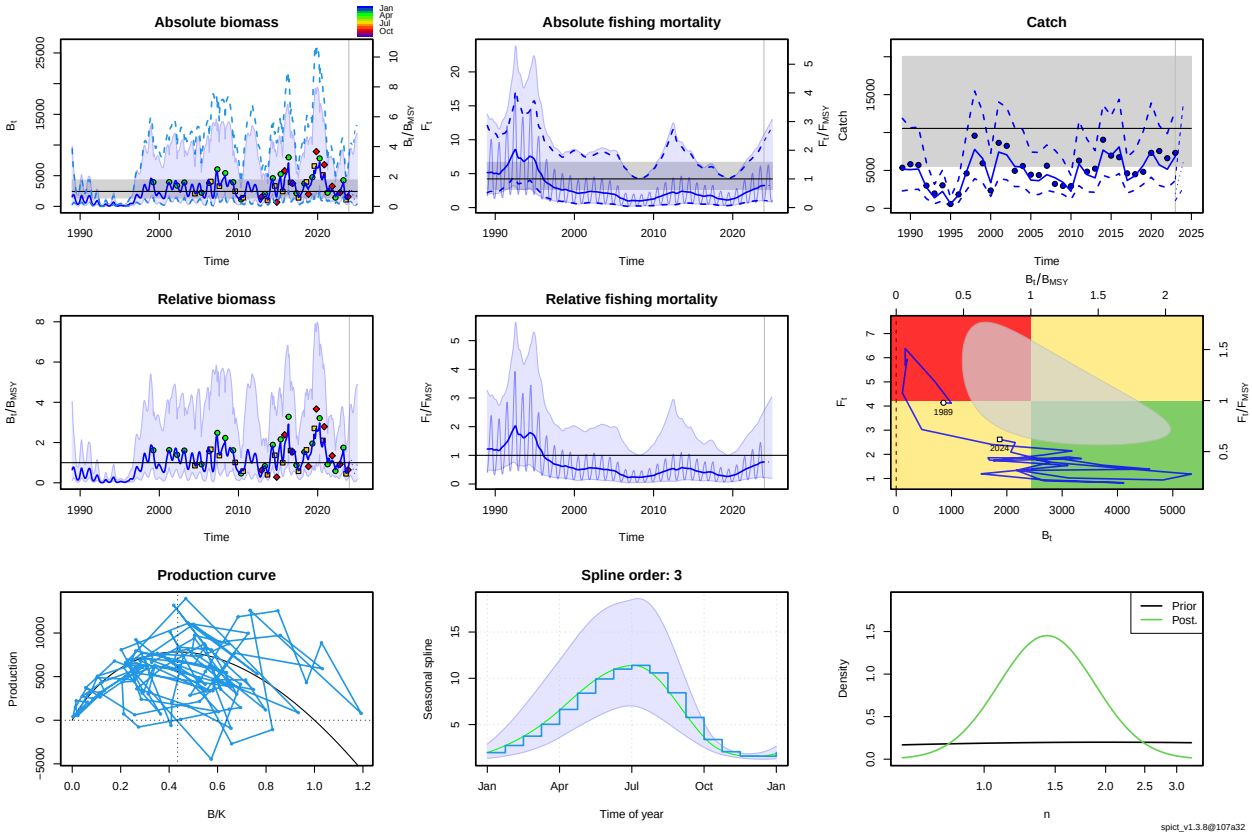
In this second configuration of the model, the uncertainty levels were also acceptable and the estimated exploitable biomass was 2217.19 tonnes and the fishing mortality was 3.25 for 2023. Predicted catchabilities were estimated at 6.30, 8.77 and 5.31 for PELAGO, ECOCADIZ and ECOCADIZ-RECLUTAS, respectively. Additionally, Kobe plot also shows that the stock has suboptimal biomass estimates as well as lower fishing mortality than fishing mortality at MSY.

```
res_sc_2 <- fit.spict(sc_2_data)
summary(res_sc_2)
```

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 217.9459292
Euler time step (years):  1/16 or 0.0625
Nobs C: 140,  Nobs I1: 21,  Nobs I2: 14,  Nobs I3: 10

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1469549    0.0250799 8.610786e-01 -1.9176298
 alpha2    0.1704595    0.0318803 9.114243e-01 -1.7692575
 alpha3    0.3977649    0.1155602 1.369130e+00 -0.9218942
 beta      1.6934230    0.8885506 3.227370e+00  0.5267520
 r         4.2466456    1.1853627 1.521391e+01  1.4461294
```

```
 rc        5.9369191    2.5087730 1.404950e+01  1.7811903
 rold      9.8624104    3.7767789 2.575399e+01  2.2887306
 m      7831.8636127 5312.1014581 1.154686e+04  8.9659558
 K      6060.4068303 2290.4188151 1.603573e+04  8.7095322
 q1        6.3010912    2.3609741 1.681668e+01  1.8407228
 q2        8.7714196    2.3392162 3.289042e+01  2.1714987
 q3        5.3134927    1.5229434 1.853858e+01  1.6702494
 n         1.4305890    0.8348883 2.451328e+00  0.3580863
 sdb       1.1795620    0.6017959 2.312024e+00  0.1651432
 sdf       0.3447639    0.1752830 6.781157e-01 -1.0648955
 sdi1      0.1733424    0.0386606 7.772137e-01 -1.7524866
 sdi2      0.2010675    0.0431220 9.375297e-01 -1.6041144
 sdi3      0.4691883    0.2028282 1.085341e+00 -0.7567511
 sdc       0.5838311    0.4469616 7.626130e-01 -0.5381435
 phi1      3.8811312    1.8075853 8.333316e+00  1.3561267
 phi2     11.3374494    6.3114390 2.036584e+01  2.4281114
 phi3     11.4590398    5.8278906 2.253124e+01  2.4387789

Deterministic reference points (Drp)
         estimate       cilow       ciupp  log.est
 Bmsyd 2638.359567 1132.275821  6147.74340 7.877913
 Fmsyd    2.968459    1.254387     7.02475 1.088043
 MSYd  7831.863613 5312.101458 11546.85921 8.965956
Stochastic reference points (Srp)
           estimate       cilow        ciupp  log.est rel.diff.Drp
 Bmsys  2434.171731 1376.685553  4303.954524 7.797362  -0.08388391
 Fmsys     4.225844    2.677389     6.669839 1.441219   0.29754632
 MSYs  10543.172099 5544.367419 20048.901799 9.263234   0.25716250

States w 95% CI (inp$msytype: s)
                    estimate       cilow       ciupp    log.est
 B_2023.94      2217.1929789 622.8802453 7892.279043  7.7039973
 F_2023.94         3.2509177   1.0836816    9.752372  1.1789373
 B_2023.94/Bmsy    0.9108614   0.2860864    2.900063 -0.0933646
 F_2023.94/Fmsy    0.7692943   0.2321613    2.549149 -0.2622816

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2025.00      2277.6312923  395.5390189 13115.278281  7.7308913
 F_2025.00         3.2509192    0.8852964    11.937782  1.1789378
 B_2025.00/Bmsy    0.9356905    0.1789278     4.893129 -0.0664706
 F_2025.00/Fmsy    0.7692947    0.1924187     3.075660 -0.2622812
 Catch_2024.00  6150.3446013 2717.8426494 13917.928149  8.7242634
 E(B_inf)       2993.6033459           NA           NA  8.0042331
```

```
plot(res_sc_2)
```



Model Diagnostics

According to the diagnostic checklist, the model meets all requirements except normality of catch residuals, as in Scenario 1.

- 1- The assessment converged:

```
# if 0 => OK
res_sc_2$opt$convergence
```

```
[1] 0
```

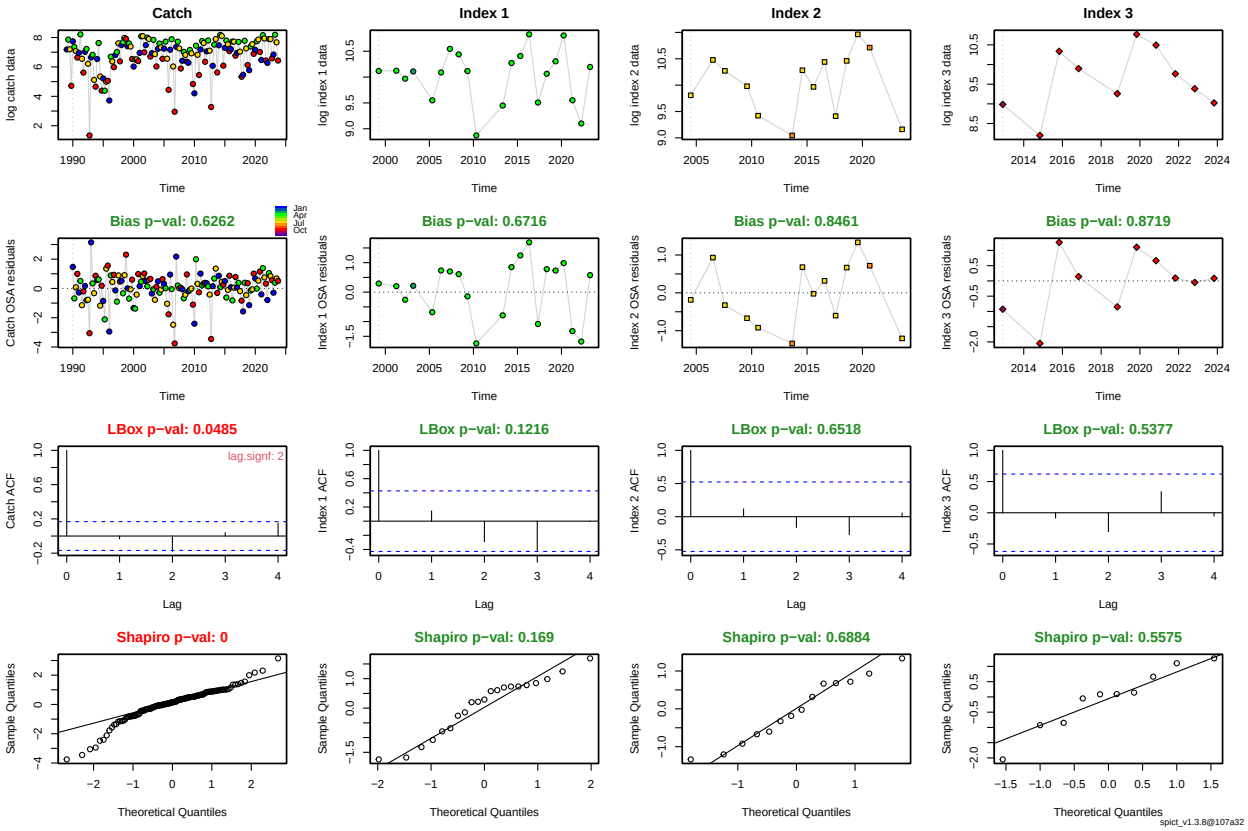
- 2- All variance parameters of the model parameters are finite:

```
# if TRUE => OK
all(is.finite(res_sc_2$sd))
```

```
[1] TRUE
```

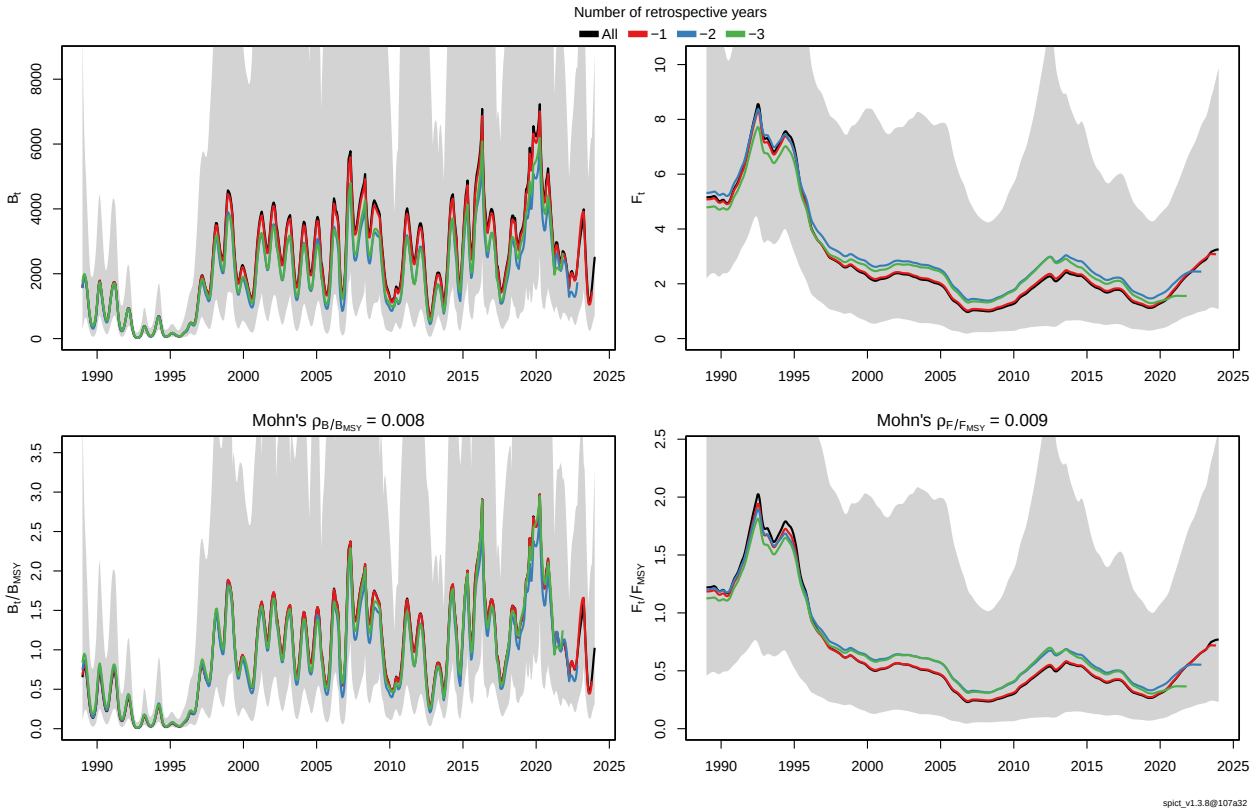
- 3- No violation of model assumptions:

```
res_sc_2 <- calc.osa.resid(res_sc_2)
plotspict.diagnostic(res_sc_2)
```



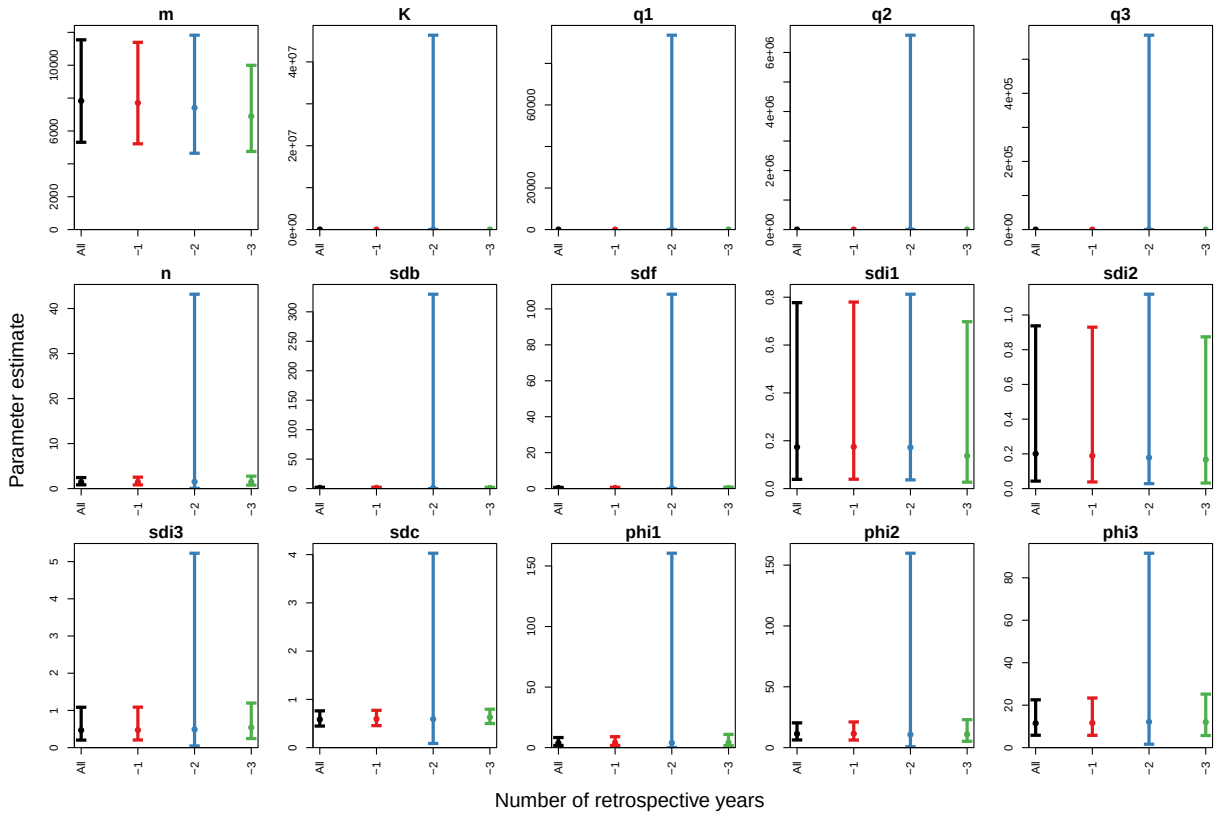
- 4- Consistent patterns in the retrospective analysis:

```
# if -0.2 < mohns_rho < 0.2 => OK
retro_sc_2 <- retro(res_sc_2, nretroyear = 3)
plotspict.retro(retro_sc_2)
```




```
      FFmsy       BBmsy
0.009121556 0.008218423
```

```
plotspict.retro.fixed(retro_sc_2)
```

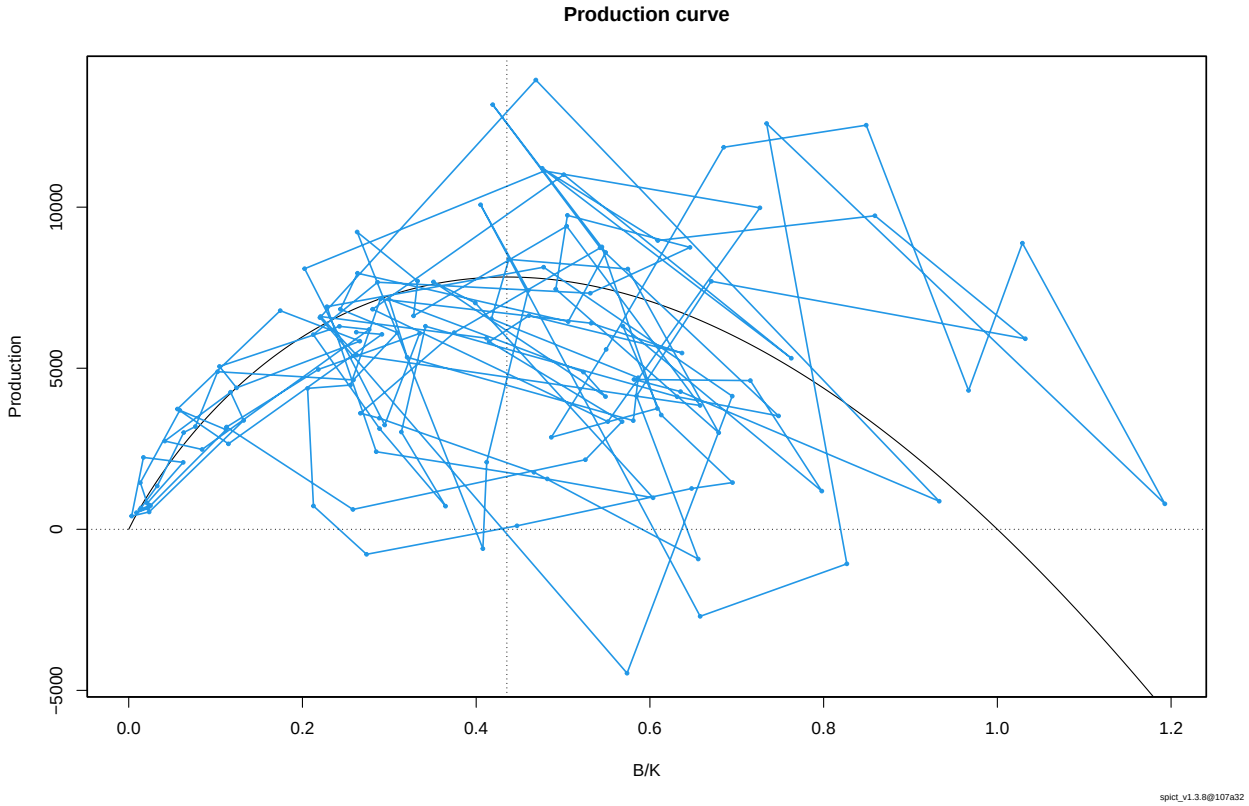


- 5- Realistic production curve:

```
# if between 0.1 and 0.9 => OK
calc.bmsyk(res_sc_2)
```

```
[1] 0.4353436
```

```
plotspict.production(res_sc_2)
```



- 6- High assessment uncertainty:

```
# Main variance paramterers (logsdb, logsdc, logsdi, logsdf) should not be unreallistically high:
get.par("logsdb", res_sc_2)
```

```
              ll       est        ul        sd       cv
logsdb -0.5078369 0.1651432 0.8381233 0.3433635 2.079187
```

```
get.par("logsdc", res_sc_2)
```

```
              ll        est         ul        sd         cv
logsdc -0.8052825 -0.5381435 -0.2710046 0.1362979 -0.2532742
```

```
get.par("logsdi", res_sc_2)
```

```
              ll        est          ul        sd         cv
logsdi -3.252933 -1.7524866 -0.25203991 0.7655481 -0.4368353
logsdi -3.143722 -1.6041144 -0.06450683 0.7855285 -0.4896961
logsdi -1.595396 -0.7567511  0.08189393 0.4278880 -0.5654276
```

```
get.par("logsdf", res_sc_2)
```

```
              ll       est         ul       sd         cv
logsdf -1.741354 -1.064895 -0.3884374 0.345138 -0.3241051
```

```
calc.om(res_sc_2) # if order of magnitude < 2 => OK)
```

```
       lower  est upper CI range order magnitude
B/Bmsy  0.29 0.91  2.90     2.61               1
F/Fmsy  0.06 0.21  0.73     0.67               1
```

- 7- Initial values do not influence the parameter estimates:

```
check_sc_2$check.ini$resmat  # Trials that converged should have same or similar estimates.
```

```
         Distance       m       K   q    q    q    n  sdb  sdf  sdi sdi  sdi
Basevec      0.00 7831.86 6060.41 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 1      0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 2      0.13 7831.78 6060.50 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 3      0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 4      0.15 7831.77 6060.52 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 5      0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 6      0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 7      0.13 7831.77 6060.51 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 8      0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 9      0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 10     0.16 7831.76 6060.53 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 11     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 12     0.32 7831.73 6060.70 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 13     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 14     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 15     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 16     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 17     0.14 7831.77 6060.50 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 18     0.13 7831.77 6060.49 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 19     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 20     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 21     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 22     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 23     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 24     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 25     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 26     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 27     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
Trial 28     0.14 7831.77 6060.50 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 29     0.14 7831.77 6060.52 6.3 8.77 5.31 1.43 1.18 0.34 0.17 0.2 0.47
Trial 30     0.00      NA      NA  NA   NA   NA   NA   NA   NA   NA  NA   NA
          sdc  phi   phi   phi
Basevec  0.58 3.88 11.34 11.46
Trial 1    NA   NA    NA    NA
Trial 2  0.58 3.88 11.34 11.46
Trial 3    NA   NA    NA    NA
Trial 4  0.58 3.88 11.34 11.46
Trial 5    NA   NA    NA    NA
Trial 6    NA   NA    NA    NA
Trial 7  0.58 3.88 11.34 11.46
Trial 8    NA   NA    NA    NA
```

```
Trial 9    NA   NA    NA    NA
Trial 10 0.58 3.88 11.34 11.46
Trial 11   NA   NA    NA    NA
Trial 12 0.58 3.88 11.34 11.46
Trial 13   NA   NA    NA    NA
Trial 14   NA   NA    NA    NA
Trial 15   NA   NA    NA    NA
Trial 16   NA   NA    NA    NA
Trial 17 0.58 3.88 11.34 11.46
Trial 18 0.58 3.88 11.34 11.46
Trial 19   NA   NA    NA    NA
Trial 20   NA   NA    NA    NA
Trial 21   NA   NA    NA    NA
Trial 22   NA   NA    NA    NA
Trial 23   NA   NA    NA    NA
Trial 24   NA   NA    NA    NA
Trial 25   NA   NA    NA    NA
Trial 26   NA   NA    NA    NA
Trial 27   NA   NA    NA    NA
Trial 28 0.58 3.88 11.34 11.46
Trial 29 0.58 3.88 11.34 11.46
Trial 30   NA   NA    NA    NA
```

Scenario 3

Model Fit

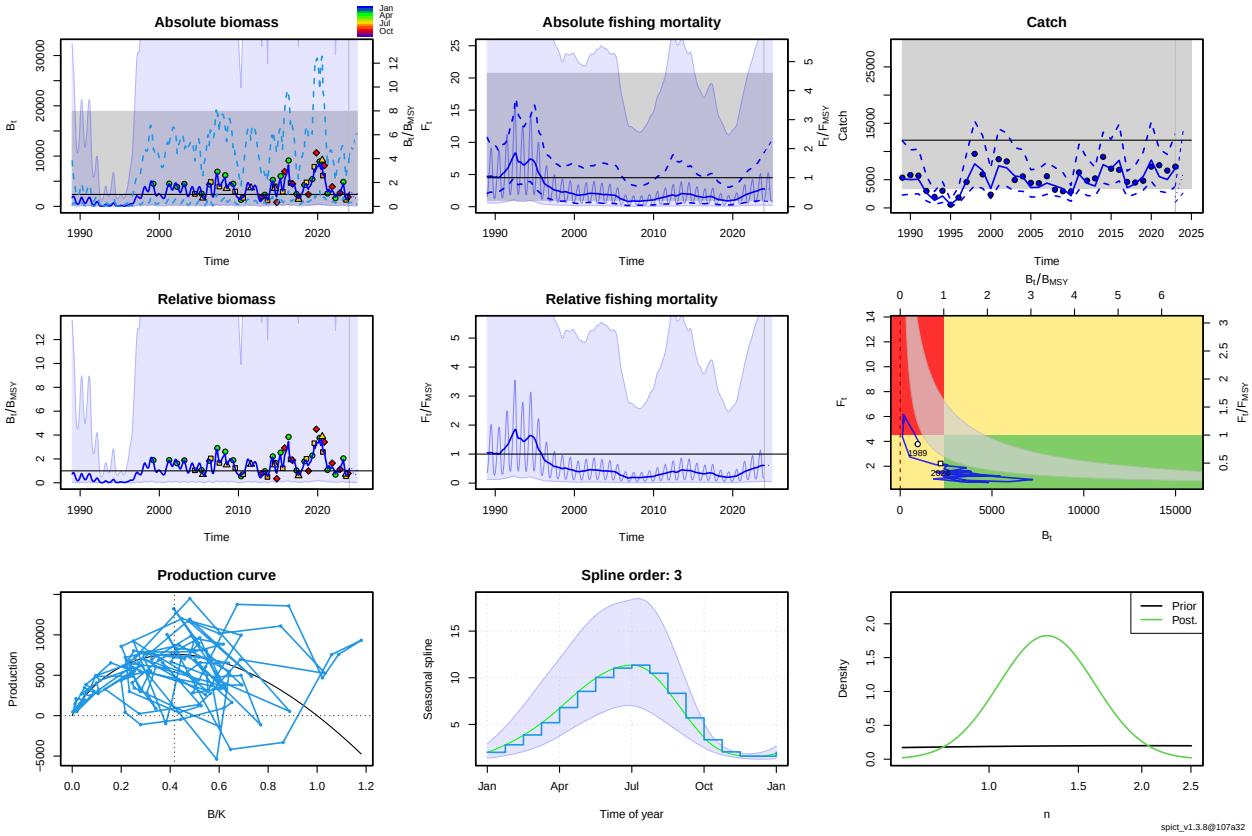
Results when BOCADEVA data is included in the model indicate that uncertainty levels are higher. According to the estimated exploitable biomass, the model estimated an exploitable biomass of 2513.81 tonnes and a fishing mortality of 2.75. Predicted catchabilities were 5.52, 7.33, 4.45 and 8.86 for PELAGO, ECOCADIZ, ECOCADIZ-RECLUTAS and BOCADEVA, respectively. Moreover, as in the two previous scenarios, Kobe plot determines that the stock biomass is in suboptimal levels and the fishing mortality is lower than fishing mortality at MSY.

```r
res_sc_3 <- fit.spict(sc_3_data)
summary(res_sc_3)
```

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 220.8719401
Euler time step (years):  1/16 or 0.0625
Nobs C: 140,  Nobs I1: 21,  Nobs I2: 14,  Nobs I3: 10,  Nobs I4: 7

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1492717    0.0284465 7.832967e-01 -1.9019871
 alpha2    0.1587590    0.0458762 5.494010e-01 -1.8403677
 alpha3    0.4369255    0.1556105 1.226806e+00 -0.8279926
 alpha4    0.1322751    0.0261861 6.681678e-01 -2.0228717
```

```
 beta      1.6438885    0.9015020 2.997630e+00  0.4970645
 r         3.2607914    1.2203602 8.712805e+00  1.1819699
 rc        5.0159124    2.5258119 9.960907e+00  1.6126153
 rold     10.8628311    3.2319933 3.651032e+01  2.3853470
 m      7589.0191643 5237.2155476 1.099691e+04  8.9344576
 K      7255.2039430 3033.3622138 1.735302e+04  8.8894743
 q1        5.5171546    2.1782544 1.397403e+01  1.7078623
 q2        7.3343738    2.1296352 2.525927e+01  1.9925720
 q3        4.4537980    1.3198273 1.502948e+01  1.4937572
 q4        8.8623509    2.5640604 3.063160e+01  2.1818121
 n         1.3001788    0.8470871 1.995621e+00  0.2625018
 sdb       1.0674449    0.6589232 1.729243e+00  0.0652678
 sdf       0.3632356    0.2025167 6.515024e-01 -1.0127036
 sdi1      0.1593393    0.0352388 7.204843e-01 -1.8367192
 sdi2      0.1694665    0.0549095 5.230222e-01 -1.7750998
 sdi3      0.4663939    0.2135365 1.018670e+00 -0.7627247
 sdi4      0.1411963    0.0300516 6.634054e-01 -1.9576039
 sdc       0.5971188    0.4864066 7.330305e-01 -0.5156391
 phi1      4.0426228    1.9031506 8.587234e+00  1.3968937
 phi2     11.4571298    6.4915431 2.022105e+01  2.4386122
 phi3     11.2542578    5.7112408 2.217702e+01  2.4207465

Deterministic reference points (Drp)
          estimate       cilow        ciupp   log.est
 Bmsyd 3025.977578 1375.735821  6655.740271 8.0149895
 Fmsyd    2.507956    1.262906     4.980453 0.9194682
 MSYd  7589.019164 5237.215548 10996.914554 8.9344576
Stochastic reference points (Srp)
          estimate        cilow       ciupp  log.est rel.diff.Drp
 Bmsys  2373.58976  298.3070405 18886.34053 7.772159   -0.2748528
 Fmsys     4.50693    0.9803418    20.71973 1.505616    0.4435334
 MSYs  12001.70964 3424.8397796 42057.74390 9.392804    0.3676718

States w 95% CI (inp$msytype: s)
                   estimate       cilow       ciupp    log.est
 B_2023.94      2513.8097970 695.7095338 9083.158112  7.8295547
 F_2023.94         2.7535907   0.9059081    8.369791  1.0129058
 B_2023.94/Bmsy    1.0590751   0.0597899   18.759704  0.0573960
 F_2023.94/Fmsy    0.6109681   0.0562845    6.632060 -0.4927105

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2025.00      2568.9390262  457.4582694 14426.338228  7.8512483
 F_2025.00         2.7535921    0.7267465    10.433170  1.0129063
 B_2025.00/Bmsy    1.0823012    0.0492211    23.798247  0.0790895
 F_2025.00/Fmsy    0.6109684    0.0504034     7.405899 -0.4927100
 Catch_2024.00  6120.2249729 2689.7488405 13925.892691  8.7193541
 E(B_inf)       4158.0545086           NA           NA  8.3328026
```

```
plot(res_sc_3)
```



Model Diagnostics

In relation to the diagnostic checklist, the model meets all requirements except normality of catch residuals and order of magnitudes of *B/BMSY* and *F/FMSY*. In this sense, *B/BMSY* and *F/FMSY* orders of magnitude were 3 and 2, respectively. Moreover, the retrospective analysis could not converge with peel -3.

- 1- The assessment converged:

```
# if 0 => OK
res_sc_3$opt$convergence
```

```
[1] 0
```

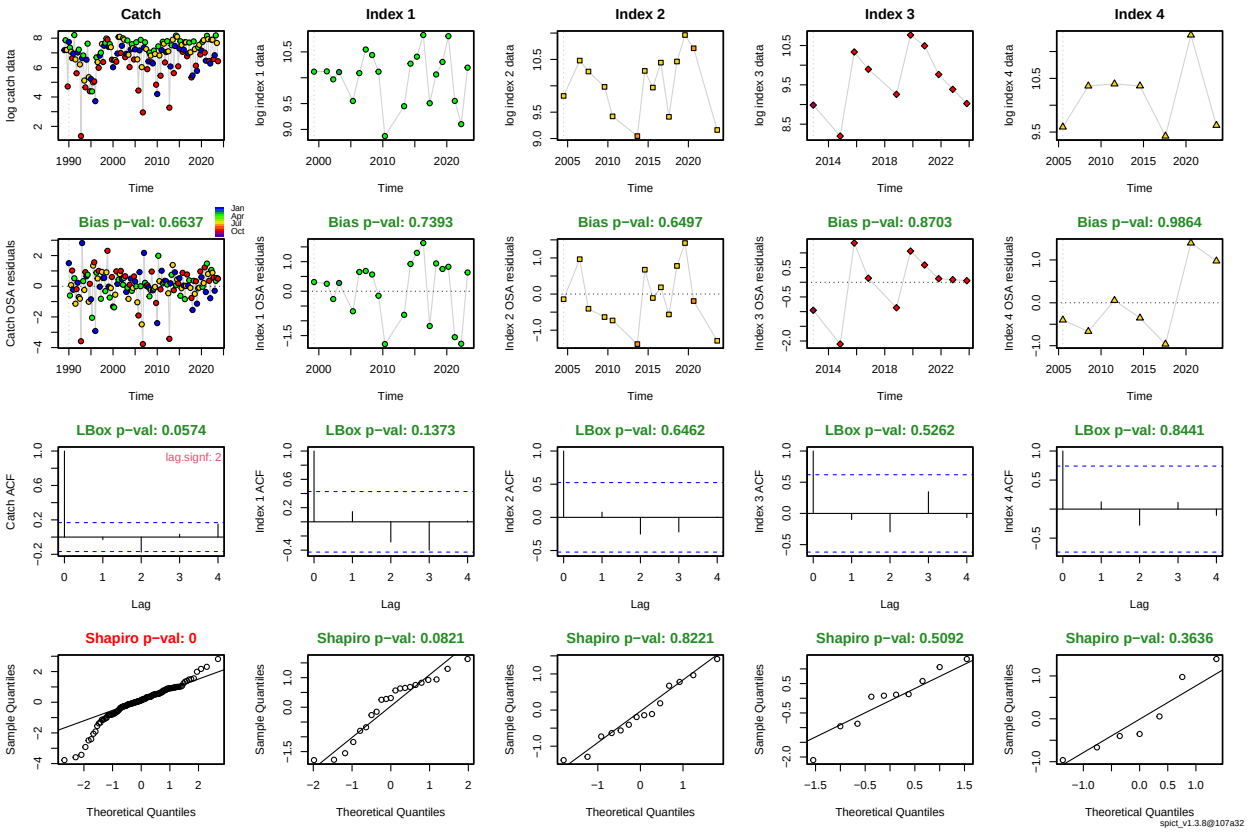
- 2- All variance parameters of the model parameters are finite:

```
# if TRUE => OK
all(is.finite(res_sc_3$sd))
```

```
[1] TRUE
```

- 3- No violation of model assumptions:

```
res_sc_3 <- calc.osa.resid(res_sc_3)
plotspict.diagnostic(res_sc_3)
```



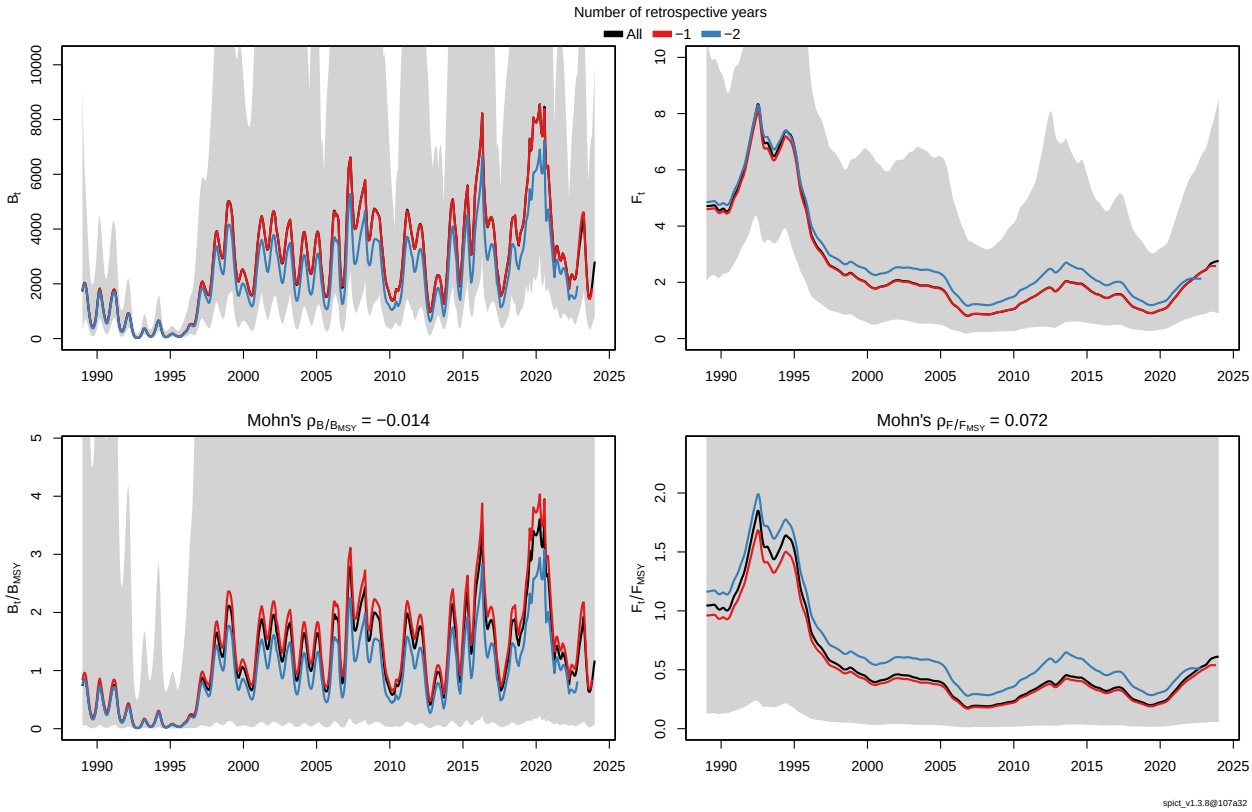
- 4- Consistent patterns in the retrospective analysis:

```
# if -0.2 < mohns_rho < 0.2 => OK
retro_sc_3 <- retro(res_sc_3, nretroyear = 3)
```

```
Error in calc.osa.resid(rep) :
  Could not calculate OSA residuals because estimation did not converge.
```

```
plotspict.retro(retro_sc_3)
```

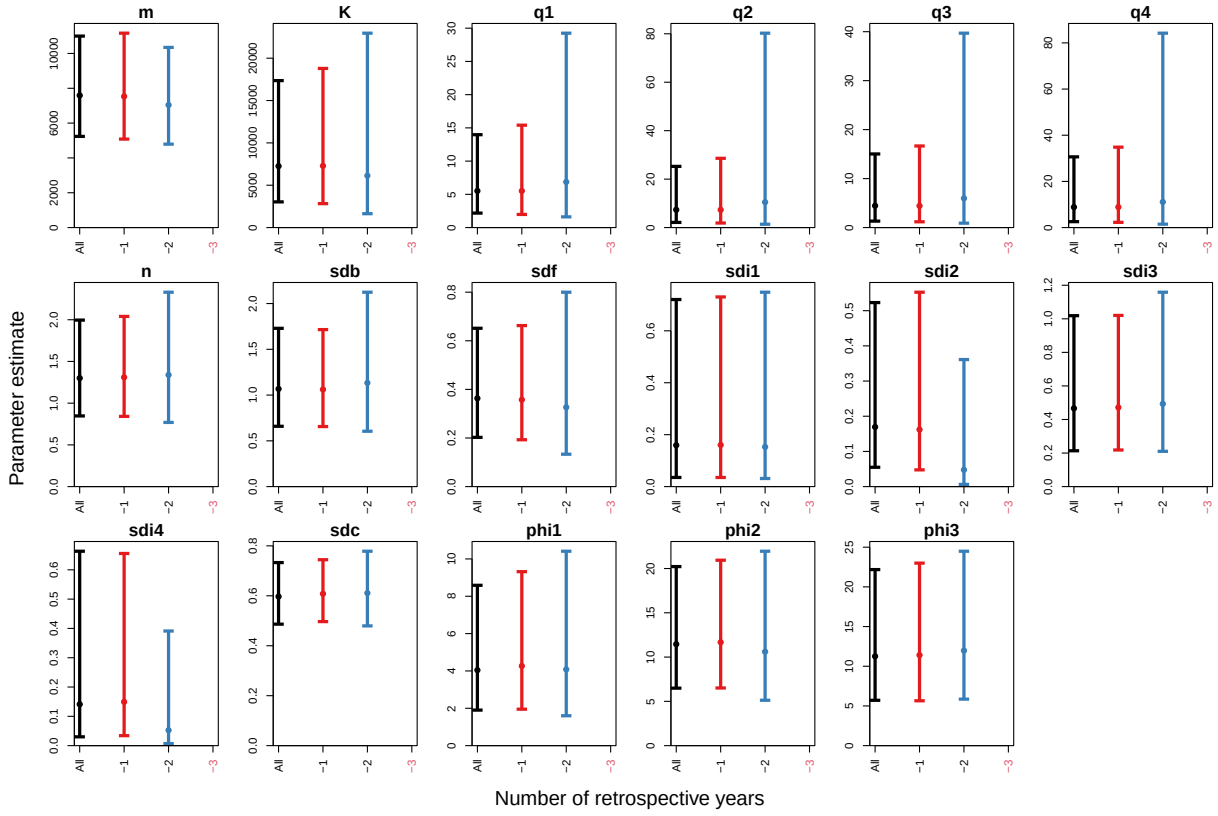
```
Excluded 1 retrospective runs that was not converged: 3
```




```
     FFmsy       BBmsy
0.07179524 -0.01381742
```

```
plotspict.retro.fixed(retro_sc_3)
```

```
Excluded 1 retrospective run that was not converged: 3
```

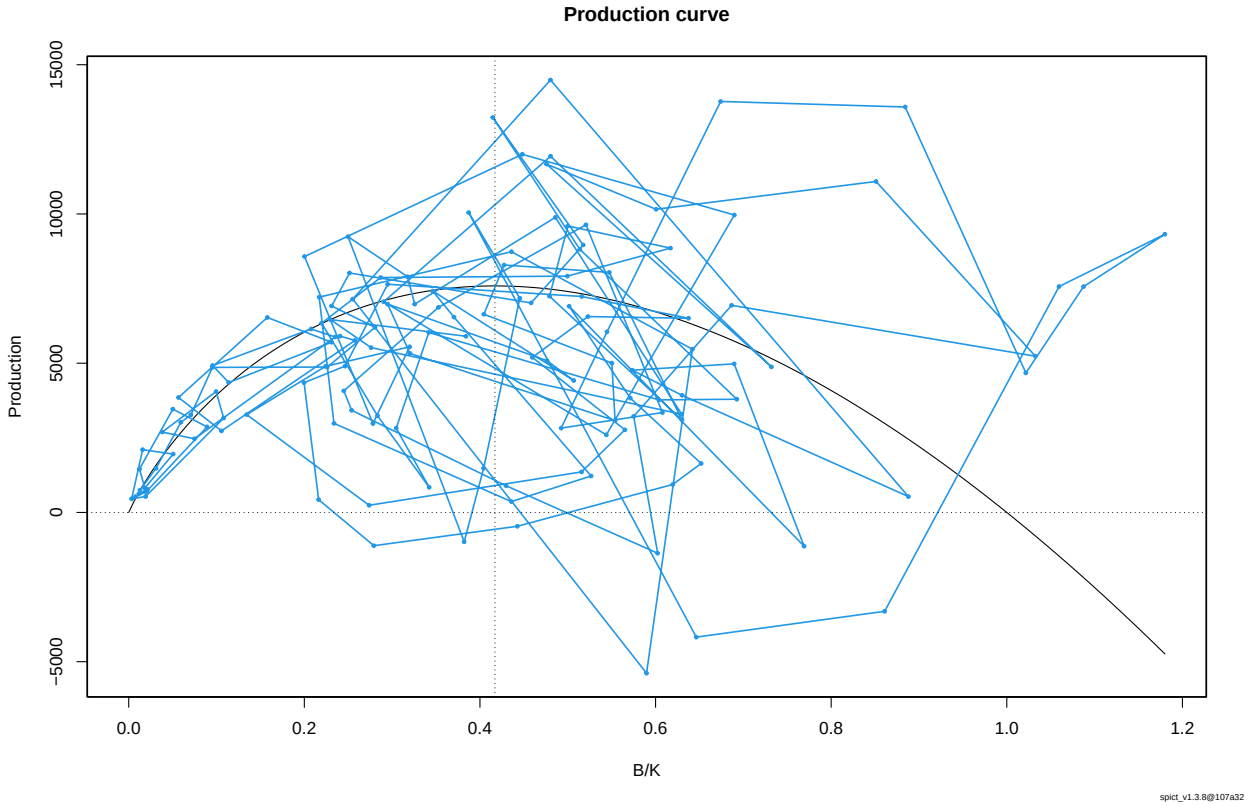


- 5- Realistic production curve:

```
# if between 0.1 and 0.9 => OK
calc.bmsyk(res_sc_3)
```

```
[1] 0.4170768
```

```
plotspict.production(res_sc_3)
```



- 6- High assessment uncertainty:

```
# Main variance paramterers (logsdb, logsdc, logsdi, logsdf) should not be unreallistically high:
get.par("logsdb", res_sc_3)
```

```
              ll        est       ul        sd       cv
logsdb -0.4171483 0.06526784 0.547684 0.2461352 3.771156
```

```
get.par("logsdc", res_sc_3)
```

```
              ll        est         ul        sd         cv
logsdc -0.7207103 -0.5156391 -0.3105679 0.1046301 -0.2029134
```

```
get.par("logsdi", res_sc_3)
```

```
              ll        est          ul        sd         cv
logsdi -3.345607 -1.8367192 -0.32783169 0.7698547 -0.4191467
logsdi -2.902068 -1.7750998 -0.64813136 0.5749945 -0.3239223
logsdi -1.543948 -0.7627247  0.01849811 0.3985904 -0.5225875
logsdi -3.504839 -1.9576039 -0.41036897 0.7894201 -0.4032583
```

```
get.par("logsdf", res_sc_3)
```

```
              ll       est         ul        sd         cv
logsdf -1.596933 -1.012704 -0.4284742 0.2980817 -0.2943425
```

```
calc.om(res_sc_3) # if order of magnitude < 2 => OK)
```

```
       lower  est upper CI range order magnitude
B/Bmsy  0.06 1.06 18.76    18.70               3
F/Fmsy  0.01 0.16  1.87     1.85               2
```

- 7- Initial values do not influence the parameter estimates:

```
check_sc_3$check.ini$resmat  # Trials that converged should have same or similar estimates.
```

```
         Distance        m       K      q      q      q      q    n  sdb  sdf
Basevec      0.00  7589.02 7255.20   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 1      0.01  7589.02 7255.21   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 2      0.01  7589.03 7255.21   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 3      0.02  7589.01 7255.22   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 4      0.00  7589.02 7255.20   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 5      0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 6      0.06  7588.97 7255.24   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 7      0.04  7589.02 7255.24   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 8      0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 9      0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 10  6747.17 10001.28  989.54 119.93 223.10 584.88 232.28 1.12 0.15 0.52
Trial 11     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 12     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 13     0.02  7589.01 7255.23   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 14     0.02  7589.00 7255.20   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 15     0.05  7588.98 7255.18   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 16     0.17  7589.02 7255.03   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 17     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 18     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 19     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 20     0.06  7589.04 7255.15   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 21     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 22     0.01  7589.03 7255.20   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 23     0.01  7589.03 7255.20   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 24     0.10  7589.04 7255.11   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 25     0.03  7589.01 7255.23   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 26     0.01  7589.02 7255.19   5.52   7.33   4.45   8.86 1.30 1.07 0.36
Trial 27     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 28     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 29     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
Trial 30     0.00       NA      NA     NA     NA     NA     NA   NA   NA   NA
          sdi  sdi  sdi  sdi  sdc  phi   phi   phi
Basevec  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 1  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 2  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 3  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 4  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 5    NA   NA   NA   NA   NA   NA    NA    NA
Trial 6  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 7  0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 8    NA   NA   NA   NA   NA   NA    NA    NA
```

```
Trial 9    NA   NA   NA   NA   NA   NA    NA    NA
Trial 10 0.08 0.28 0.60 0.06 0.35 0.62  0.37  0.96
Trial 11   NA   NA   NA   NA   NA   NA    NA    NA
Trial 12   NA   NA   NA   NA   NA   NA    NA    NA
Trial 13 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 14 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 15 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 16 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 17   NA   NA   NA   NA   NA   NA    NA    NA
Trial 18   NA   NA   NA   NA   NA   NA    NA    NA
Trial 19   NA   NA   NA   NA   NA   NA    NA    NA
Trial 20 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 21   NA   NA   NA   NA   NA   NA    NA    NA
Trial 22 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 23 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 24 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 25 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 26 0.16 0.17 0.47 0.14 0.60 4.04 11.46 11.25
Trial 27   NA   NA   NA   NA   NA   NA    NA    NA
Trial 28   NA   NA   NA   NA   NA   NA    NA    NA
Trial 29   NA   NA   NA   NA   NA   NA    NA    NA
Trial 30   NA   NA   NA   NA   NA   NA    NA    NA
```

Scenario 4

Model Fit

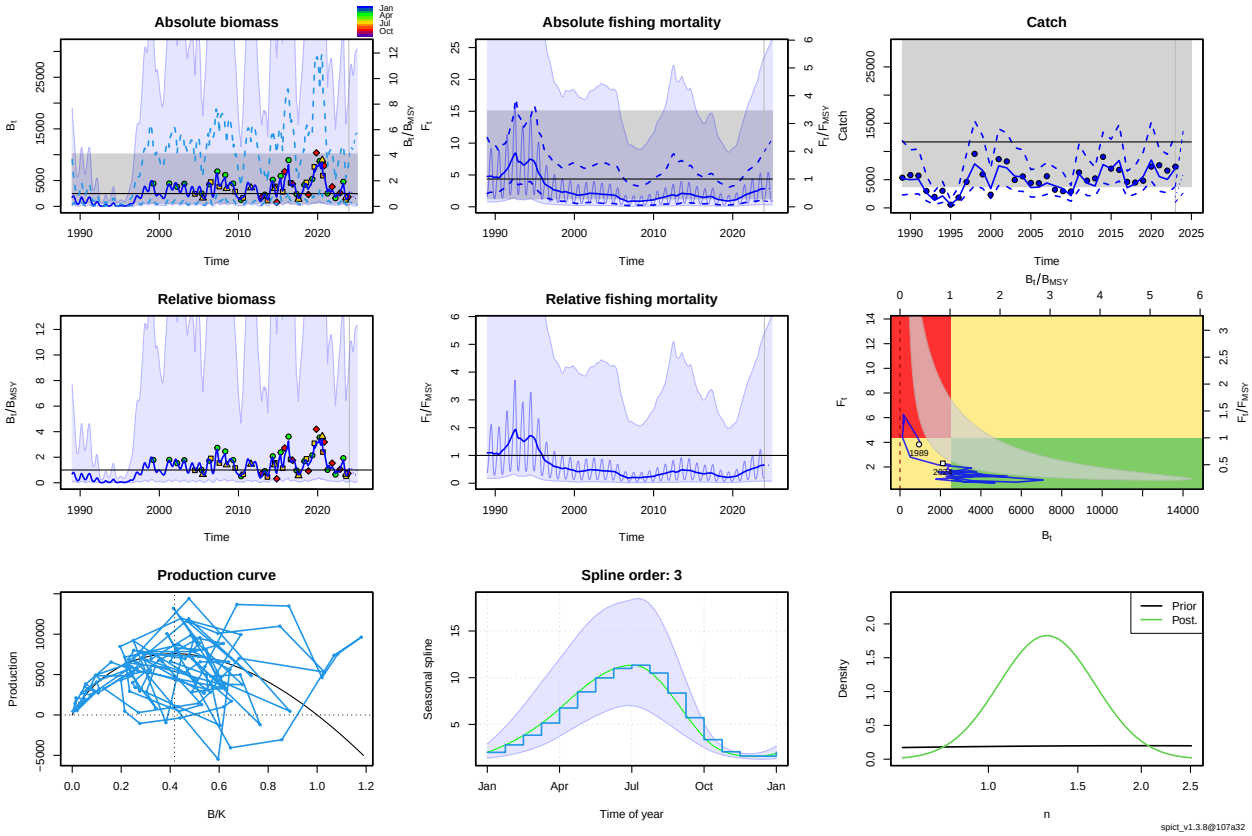
Results when BOCADEVA data and it's uncertainty levels were included in the model also show high uncertainty levels of model estimations. According to the estimated exploitable biomass, the model estimated an exploitable biomass of 2440.36 tonnes and a fishing mortality of 2.84. Predicted catchabilities were 5.62, 7.55, 4.58 and 9.08 for PELAGO, ECOCADIZ, ECOCADIZ-RECLUTAS and BOCADEVA, respectively. Kobe plot again defines stock biomass in suboptimal levels and the fishing mortality in lower levels than fishing mortality at MSY.

```
res_sc_4 <- fit.spict(sc_4_data)
summary(res_sc_4)
```

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 220.42738
Euler time step (years):  1/16 or 0.0625
Nobs C: 140,  Nobs I1: 21,  Nobs I2: 14,  Nobs I3: 10,  Nobs I4: 7

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1475009    0.0280514 7.755940e-01 -1.9139211
 alpha2    0.1420530    0.0348073 5.797358e-01 -1.9515554
 alpha3    0.4267707    0.1500109 1.214133e+00 -0.8515084
 alpha4    0.2502797    0.0532823 1.175625e+00 -1.3851760
```

```
 beta      1.6429756    0.9033329 2.988233e+00  0.4965090
 r         3.3269404    1.2402004 8.924794e+00  1.2020531
 rc        5.1036921    2.5632432 1.016200e+01  1.6299642
 rold     10.9532980    3.3277610 3.605269e+01  2.3936406
 m      7587.9997108 5250.7683247 1.096558e+04  8.9343233
 K      7120.5758661 2979.0337578 1.701981e+04  8.8707439
 q1        5.6240096    2.2269346 1.420315e+01  1.7270449
 q2        7.5484102    2.1855796 2.607020e+01  2.0213370
 q3        4.5753142    1.3554758 1.544365e+01  1.5206754
 q4        9.0768836    2.6402405 3.120542e+01  2.2057309
 n         1.3037387    0.8497476 2.000282e+00  0.2652361
 sdb       1.0813576    0.6654948 1.757090e+00  0.0782173
 sdf       0.3624569    0.2023657 6.491961e-01 -1.0148497
 sdi1      0.1595012    0.0352494 7.217332e-01 -1.8357038
 sdi2      0.1536100    0.0420065 5.617230e-01 -1.8733381
 sdi3      0.4614917    0.2089301 1.019358e+00 -0.7732912
 sdi4      0.2706419    0.0617029 1.187093e+00 -1.3069587
 sdc       0.5955078    0.4836252 7.332735e-01 -0.5183407
 phi1      4.0102790    1.8849893 8.531793e+00  1.3888608
 phi2     11.3755379    6.4251603 2.014002e+01  2.4314653
 phi3     11.3034089    5.7492505 2.222325e+01  2.4251043

Deterministic reference points (Drp)
          estimate       cilow        ciupp  log.est
 Bmsyd 2973.533507 1354.117240  6529.642530 7.997506
 Fmsyd    2.551846    1.281622     5.080999 0.936817
 MSYd  7587.999711 5250.768325 10965.583711 8.934323
Stochastic reference points (Srp)
           estimate       cilow       ciupp  log.est rel.diff.Drp
 Bmsys  2474.098015  603.346879 10145.34292 7.813631   -0.2018657
 Fmsys     4.361733    1.263216    15.06054 1.472870    0.4149468
 MSYs  11695.277848 3760.353370 36374.11447 9.366940    0.3511912

States w 95% CI (inp$msytype: s)
                    estimate       cilow       ciupp    log.est
 B_2023.94      2440.3596567 676.2632860 8806.267289  7.7999007
 F_2023.94         2.8432254   0.9420090    8.581585  1.0449391
 B_2023.94/Bmsy    0.9863634   0.1067080    9.117520 -0.0137305
 F_2023.94/Fmsy    0.6518568   0.0793537    5.354723 -0.4279304

Predictions w 95% CI (inp$msytype: s)
                  prediction        cilow        ciupp    log.est
 B_2025.00      2485.4785739  436.3576031 14157.204316  7.8182205
 F_2025.00         2.8432268    0.7554802    10.700397  1.0449396
 B_2025.00/Bmsy    1.0045999    0.0818640    12.328024  0.0045893
 F_2025.00/Fmsy    0.6518571    0.0701220     6.059692 -0.4279299
 Catch_2024.00  6097.2496810 2672.7504817 13909.436712  8.7155931
 E(B_inf)       3921.6866360           NA           NA  8.2742771
```

```
plot(res_sc_4)
```



Model Diagnostics

Diagnostic checklist determined that model met all requirements except normality of catch residuals and order of magnitude of *F/FMSY*. In this sense, *F/FMSY* order of magnitude was 2. Additionally, the retrospective analysis could not converge with peel -3.

- 1- The assessment converged:

```
# if 0 => OK
res_sc_4$opt$convergence
```

```
[1] 0
```

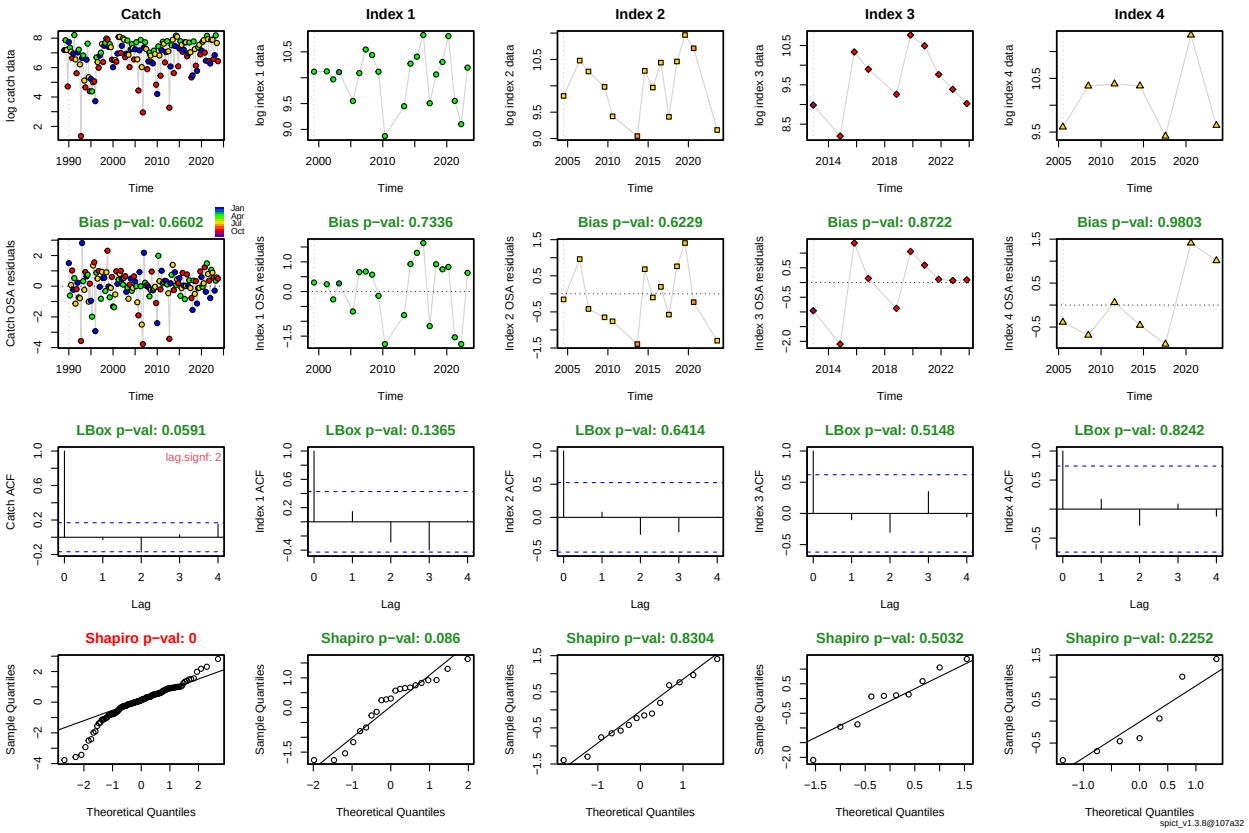
- 2- All variance parameters of the model parameters are finite:

```
# if TRUE => OK
all(is.finite(res_sc_4$sd))
```

```
[1] TRUE
```

- 3- No violation of model assumptions:

```
res_sc_4 <- calc.osa.resid(res_sc_4)
plotspict.diagnostic(res_sc_4)
```



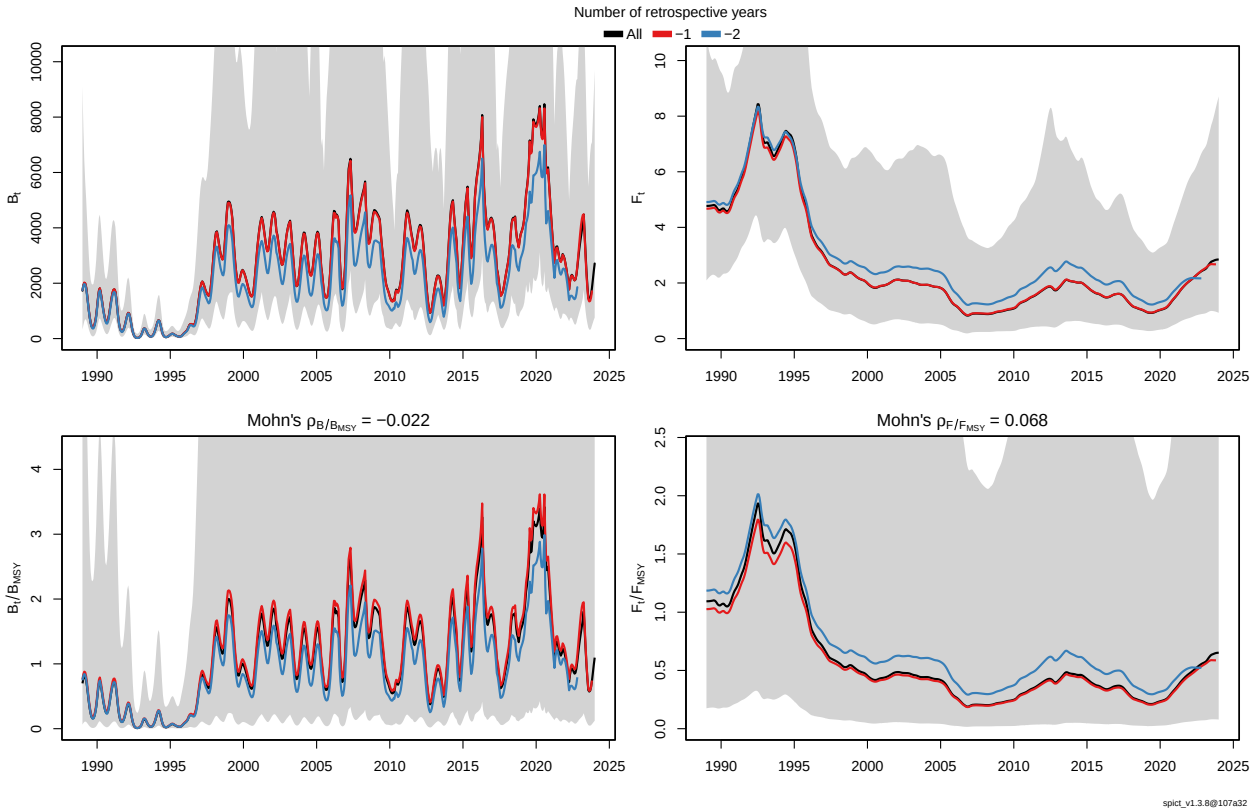
- 4- Consistent patterns in the retrospective analysis:

```
# if -0.2 < mohns_rho < 0.2 => OK
retro_sc_4 <- retro(res_sc_4, nretroyear = 3)
```

```
Error in calc.osa.resid(rep) :
  Could not calculate OSA residuals because estimation did not converge.
```

```
plotspict.retro(retro_sc_4)
```

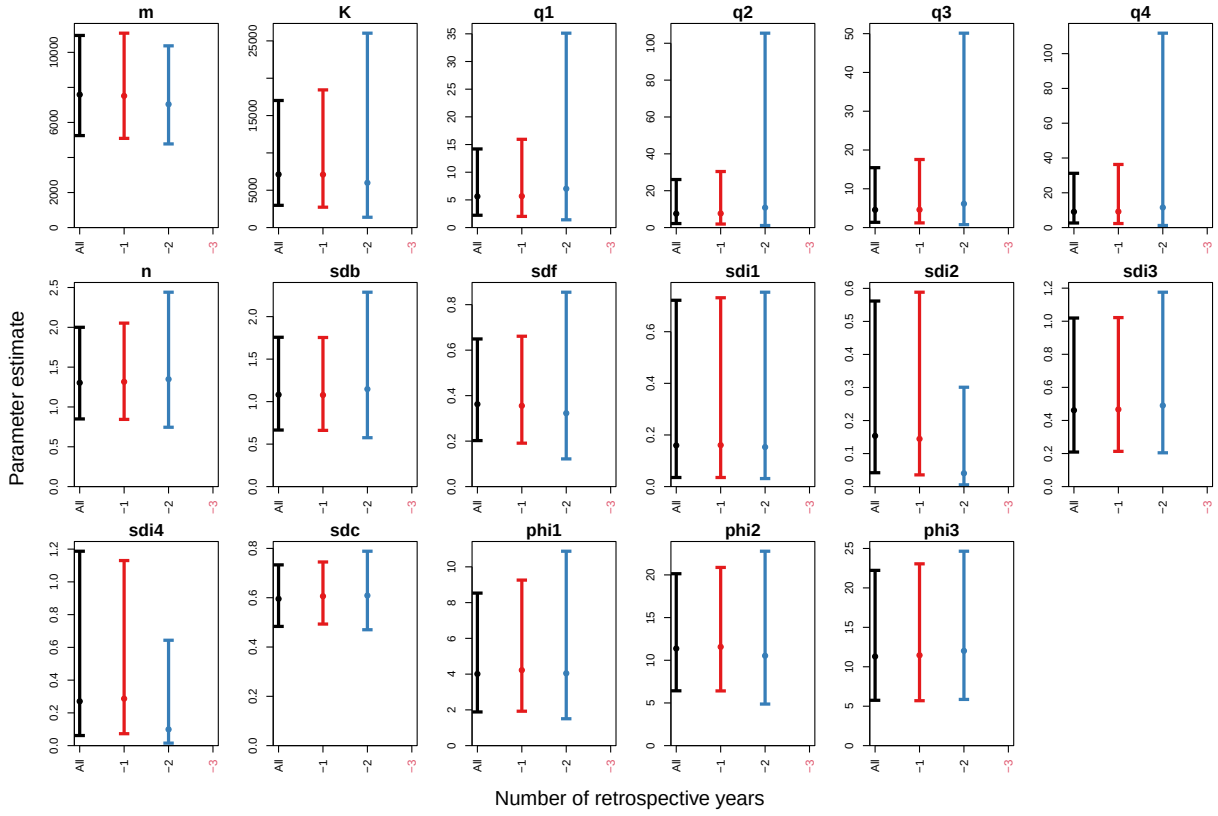
```
Excluded 1 retrospective runs that was not converged: 3
```




```
      FFmsy        BBmsy
 0.06803314 -0.02170606
```

```
plotspict.retro.fixed(retro_sc_4)
```

```
Excluded 1 retrospective run that was not converged: 3
```

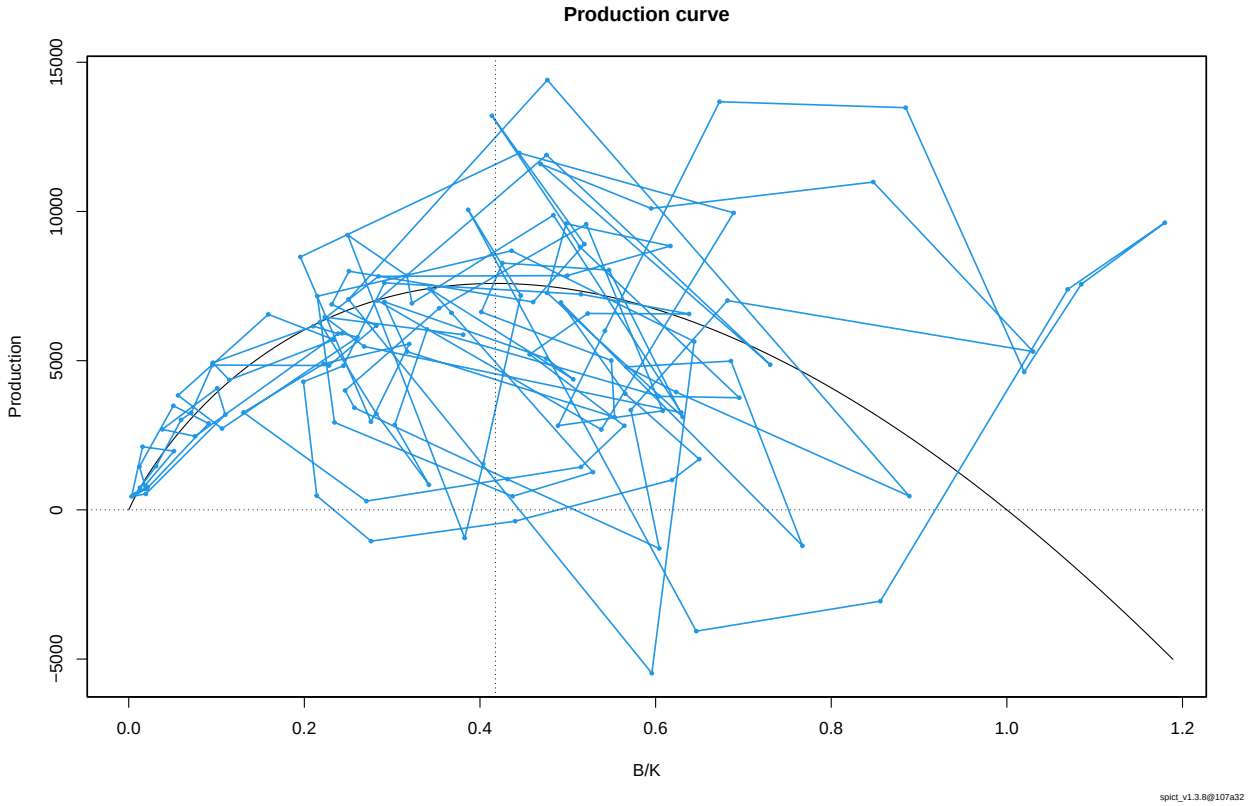


- 5- Realistic production curve:

```
# if between 0.1 and 0.9 => OK
calc.bmsyk(res_sc_4)
```

```
[1] 0.4175973
```

```
plotspict.production(res_sc_4)
```



- 6- High assessment uncertainty:

```
# Main variance paramterers (logsdb, logsdc, logsdi, logsdf) should not be unreallistically high:
get.par("logsdb", res_sc_4)
```

```
              ll        est       ul        sd       cv
logsdb -0.4072245 0.07821726 0.563659 0.2476789 3.166551
```

```
get.par("logsdc", res_sc_4)
```

```
              ll        est         ul        sd         cv
logsdc -0.726445 -0.5183407 -0.3102365 0.1061776 -0.2048413
```

```
get.par("logsdi", res_sc_4)
```

```
              ll        est          ul        sd         cv
logsdi -3.345308 -1.8357038 -0.32609972 0.7702203 -0.4195777
logsdi -3.169930 -1.8733381 -0.57674647 0.6615385 -0.3531335
logsdi -1.565755 -0.7732912  0.01917312 0.4043259 -0.5228638
logsdi -2.785425 -1.3069587  0.17150763 0.7543334 -0.5771670
```

```
get.par("logsdf", res_sc_4)
```

```
              ll      est         ul        sd         cv
logsdf -1.597679 -1.01485 -0.4320205 0.2973673 -0.2930161
```

```
calc.om(res_sc_4) # if order of magnitude < 2 => OK)
```

```
       lower  est upper CI range order magnitude
B/Bmsy  0.11 0.99  9.12     9.01               1
F/Fmsy  0.02 0.18  1.52     1.50               2
```

- 7- Initial values do not influence the parameter estimates:

```
check_sc_4$check.ini$resmat  # Trials that converged should have same or similar estimates.
```

```
         Distance        m        K    q    q    q    q    n  sdb  sdf  sdi
Basevec      0.00  7588.00  7120.58 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 1      0.08  7588.02  7120.66 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 2      0.10  7588.01  7120.67 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 3      0.07  7588.01  7120.64 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 4      0.12  7588.00  7120.70 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 5      0.10  7588.03  7120.67 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 6      0.10  7588.02  7120.67 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 7      0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 8      0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 9      0.18  7588.04  7120.75 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 10     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 11     0.12  7588.01  7120.70 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 12     0.02  7588.02  7120.58 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 13     0.10  7588.02  7120.68 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 14     0.08  7588.01  7120.66 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 15     0.12  7588.03  7120.69 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 16     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 17     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 18     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 19     0.10  7588.02  7120.67 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 20     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 21     0.01  7587.99  7120.57 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 22 11314.52 12366.37 17376.57 2.00 2.14 1.34 2.58 1.68 0.99 0.41 0.15
Trial 23     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 24     0.13  7588.04  7120.70 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 25     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 26     0.13  7588.02  7120.71 5.62 7.55 4.58 9.08 1.30 1.08 0.36 0.16
Trial 27     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 28     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 29     0.00       NA       NA   NA   NA   NA   NA   NA   NA   NA   NA
Trial 30 11314.42 12366.25 17376.52 2.00 2.14 1.34 2.58 1.68 0.99 0.41 0.15
          sdi  sdi  sdi  sdc  phi   phi   phi
Basevec  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 1  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 2  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 3  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 4  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 5  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 6  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 7    NA   NA   NA   NA   NA    NA    NA
Trial 8    NA   NA   NA   NA   NA    NA    NA
```

```
Trial 9  0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 10   NA   NA   NA   NA   NA    NA    NA
Trial 11 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 12 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 13 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 14 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 15 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 16   NA   NA   NA   NA   NA    NA    NA
Trial 17   NA   NA   NA   NA   NA    NA    NA
Trial 18   NA   NA   NA   NA   NA    NA    NA
Trial 19 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 20   NA   NA   NA   NA   NA    NA    NA
Trial 21 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 22 0.17 0.50 0.25 0.65 5.90 15.00  8.43
Trial 23   NA   NA   NA   NA   NA    NA    NA
Trial 24 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 25   NA   NA   NA   NA   NA    NA    NA
Trial 26 0.15 0.46 0.27 0.60 4.01 11.38 11.30
Trial 27   NA   NA   NA   NA   NA    NA    NA
Trial 28   NA   NA   NA   NA   NA    NA    NA
Trial 29   NA   NA   NA   NA   NA    NA    NA
Trial 30 0.17 0.50 0.25 0.65 5.90 15.00  8.43
```

Conclusions

Results indicate that the most robust scenario was Scenario 2. This scenario obtained better results than Scenario 3 and 4 in the diagnostic checklist and included an uncertainty level in ECOCADIZ-RECLUTAS 2012 estimate, making it more realistic than Scenario 1. The greater robustness shown by Scenario 2 compared to Scenarios 3 and 4 could be due to the number of estimates from the BOCADEVA campaign (7 estimates). The low number of estimates from BOCADEVA index may have negatively affected the model fit introducing some noise or additional uncertainty. Thus, we recommend using the scenario 2 estimates over the other scenarios. Finally, a larger number of estimates in the BOCADEVA survey could improve the model obtained in both scenario 3 and scenario 4. Therefore, in order to define the influence of BOCADEVA estimates in the model, we recommend repeating the same exercise in a few years when more BOCADEVA campaigns have been carried out.

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