## Report of the breakout group on CMSY at the WKLIFE V workshop at IPMA

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Produced by Rainer Froese and Gianpaolo Coro, October 2015

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### General introduction to CMSY

CMSY is a method for estimating maximum sustainable yield (*MSY*) and related fisheries reference points (*Bmsy*, *Fmsy*) from catch data and resilience, developed by Froese et al. (2015). It is an advanced implementation of the Catch-MSY method of Martell & Froese (2013). CMSY was tested and found satisfactory at the WKLIVE IV workshop in Lisbon, October 2014 (ICES 2014) and at an ICCAT workshop on data limited stocks in Madrid, June 2015 (Froese 2015). If managers, experts or stakeholders have a perception about the depletion history and the current status of a given stock, then CMSY can test such hypotheses against observed catches and the known resilience of the species. If combinations of productivity and stock size are found that are compatible with catches and resilience, then the stock status and exploitation rate are presented in an MSY-framework. CMSY has been tested against simulated data, where the “true” parameter values were known, and against over one hundred fully assessed stocks, with good agreement between CMSY predictions and “true” or observed data. The full documentation of these tests was available to the participants of WKLIFE V and will be published as online supplement to Froese et al. (2015), which was accepted pending revision as of this writing. This report contains several examples of applying CMSY to catch data made available at WKLIFE V. Note that part of the CMSY code is a Bayesian state-space implementation of a full Schaefer model (BSM). If abundance data are made available, e.g. as total biomass, catch per unit of effort, or stock size index, then BSM will analyze these data and show the results in the printout and in the graphical output, so that CMSY results are put in perspective. BSM results can also be used in their own right. Note that time series of abundance can be shorter (=start later) than those for catches. If abundance data are available for fewer than e.g. 9 years, then they are not analyzed by BSM but shown with a second Y-axis in the CMSY graphical output.

With the CMSY method, prior parameter ranges for the maximum intrinsic range of population increase (*r*) and for unexploited population size or carrying capacity (*k*) are filtered with a Monte Carlo approach to detect ‘viable’ *r-k* pairs. A parameter pair is deemed ‘viable’ if the corresponding biomass trajectories calculated with a Schaefer model are compatible with the observed catches, in the sense that predicted biomass does not overshoot assumed carrying capacity nor crash the stock. Also, predicted biomass shall be compatible with prior estimates of relative biomass ranges for the beginning and the end of the respective time series. Optionally, a third intermediate prior biomass range can be provided to reflect extraordinary year classes or stock depletions. Also optionally, an indication whether the stock is likely to crash within three years if current catches continue can be given. This will improve the estimation of biomass in the final years. Examples of questions to be put to experts to derive the priors required by CMSY are shown in Table 1.

**Table 1**. Examples 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/B0* | What was the most likely exploitation level at the beginning and end of that time series: light, full, or overfishing? Given this exploitation level, what was the most likely status of the stock, good or bad? |
| Relative intermediate biomass  *B/B0* | Is there an intermediate year where, e.g., exploitation changed from light to full, or where an extraordinary large year class entered the fishery? |
| 2 *M* ≈ *r* | What is your best guess for the range of values including natural mortality of adults (*M*)? |
| 2 *Fmsy* ≈ *r* | What is your best guess for the range of values including maximum sustainable fishing mortality (*Fmsy*)? |
| Resilience | What is the classification of resilience for this species: very low, low, medium or high? |
| *B/B0* < 0.2 : Possible / No | If current catches continue, is it likely that the stock will be outside of safe biological limits within the next 3 years? |

Based on the answers of the experts, the most probable ranges for relative biomass are chosen from Table 2 and the most probable ranges for *r* are chosen from Table 3.

**Table 2**. Prior relative biomass ranges *B/k* used by CMSY for analyzing the simulated data.

|  |  |  |
| --- | --- | --- |
| **Point in time series** | **Strong depletion** | **Low depletion** |
| Beginning | 0.1 – 0.5 | 0.5 – 0.9 |
| Intermediate | 0.01 – 0.4 | 0.3 – 0.9 |
| End | 0.01 – 0.4 | 0.4 – 0.8 |

**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 |

A fit-for-use-in-assessments version of the R code for CMSY and BSM was produced and tested at the WKLIVE V meeting, together with a user manual. These were made available at the share point of the meeting and will be publicly available as part of the online material of Froese et al. (2015).

## How to find the most probable estimates of *r* and *k* among viable *r-k* pairs

A question that came up during the WKLIVE V meeting was how CMSY determines the most probable *r-k* pair.

A plot of viable *r-k* pairs typically results in a triangular-shaped cloud in log *r-k* space. A special algorithm is applied by CMSY to select the most probable *r-k* pair from the tip-side section of the triangle and to establish approximate confidence limits. This algorithm is guided by the following considerations:

(1) We are searching for the highest rate of increase that a given population can support. Obviously, this rate should be found among the highest *r*-values identified as “viable” within the prior *r*-range, i.e., in the tip-side of the triangle.

(2) The uniform prior ranges for *r* as used by CMSY (see Table 3) are derived from expert knowledge, basically saying that a central value with a log-normal distribution of *r* is expected to occur somewhere within these ranges, with a low probability that the central value will fall on the upper or lower bound of the ranges. However, by design, the triangle of “viable” *r-k* pairs found by CMSY always touches the lower bound of the prior *r*-range, because observed catches can always be explained by large stock sizes, such as predicted for low values of *r*. Including these low-*r-*high*-k* pairs in the search for the most probable *r-k* pair makes the most probable *r* highly dependent on the lower bound of the prior *r* range, and it creates a bias of underestimating *r* and overestimating *k*, such as documented in Martell and Froese (2013). Figure 1 shows some examples (black dots) of probable *r-k* pairs as identified by a full Schaefer model (BSM). As can be seen, these clouds of probable *r-k* pairs typically occur in the right-hand or tip-side of the triangle of viable *r*-values, and very rarely in the left-hand side.

|  |  |
| --- | --- |
| **A** | **B** |
| **C** | **D** |

**Figure 1.** The ellipsoid clouds of black dots show the distribution of probable *r-k* pairs based on a Bayesian Schaefer model analysis. These clouds typically overlap with the right-hand side of viable *r-k* pairs estimated by CMSY. The green cross shows the most probable *r-k* pair from a full Schaefer analysis, whereas the blue cross shows the most probable *r-k* pair from CMSY analysis. The extension of the cross indicates approximate 95% confidence limits.

CMSY overcomes the bias in Martell and Froese (2013) by a very simple procedure: it estimates the geometric mean of the viable *r*-values and discards values below the geometric mean. The remaining *r*-values are then split into 25 bins of equal width in log-space. The median of the mid-values of occupied bins is taken as the most probable estimate of *r*. This procedure gives equal weight to all occupied bins and reduces the bias caused by the triangular (instead of ellipsoid) shape of the tip section. Taking the median instead of the mean gives less weight to outliers. Approximate 95% confidence limits of *r* are obtained as 2.5th and 97.5th percentiles of the mid-values of occupied bins.

### Testing the sensitivity of CMSY to depletion patterns and resilience of stocks

CMSY assessments of 48 simulated stocks were analysed to detect the sensitivity of the CMSY method to different patterns and contrasts in stock biomass and to different levels of resilience of the species. Resilience ranges of Very low, Low, Medium and High resilience were analysed (Table 3). The simulations covered a range of biomass scenarios, including strongly as well as lightly depleted stocks, with monotone stable or monotone changing (i.e., steadily decreasing or increasing) or with alternating biomass trajectories: patterns of high-high (HH), high-low (HL), high-low-high (HLH), low-low (LL), low-high (LH), and low-high-low (LHL) biomass trends. Resilience categories were translated into *r*-ranges as shown in Table 3. The detailed analyses of the 48 simulated stocks were available to WKLIFE V participants (on the share point). The results of the sensitivity analysis are shown in Table 4 for the intrinsic rate of population increase *r* and in Table 5 for the unexploited stock size *k*.

**Table 4.** CMSY estimates of *r* relative to the “true” r used in the simulations. Four estimates that diverge 20% or more from the “true” value are shown in bold.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Very low** | **Low** | **Medium** | **High** | **Median** |
| **HH** | 1.19 | 1.18 | 1.14 | **1.20** | 1.18 |
| **HL** | 1.13 | 0.89 | 0.94 | 1.08 | 1.01 |
| **HLH** | **1.22** | 1.18 | 1.10 | 1.08 | 1.14 |
| **LL** | 1.16 | 0.92 | 0.94 | 0.87 | 0.93 |
| **LH** | **1.52** | 1.09 | 0.94 | **1.26** | 1.18 |
| **LHL** | 1.16 | 1.06 | 1.02 | 1.06 | 1.06 |
| **Median** | 1.17 | 1.08 | 0.98 | 1.08 |  |

With regard to resilience, CMSY estimates exceeded the “true” values of *r* by 17% (median) in simulated stocks with very low resilience and deviated 2-8 % (medians) in the low to high resilience categories. With regard to biomass patterns, CMSY overestimated the “true” value of *r* by 14-18% in lightly exploited stocks, where the catches took only a small fraction of the available biomass (HH, HLH, LH). For the other biomass patterns, deviations of CMSY estimates ranged from -7% to +6% (medians). The combination of very low resilience with very light exploitation (LH) led to the largest overestimation of *r* by 52%.

**Table 5.**  CMSY estimates of unexploited biomass *k* relative to the “true” *k* used in the simulations. Two estimates that diverge 20% or more from the “true” value are shown in bold.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Very low** | **Low** | **Medium** | **High** | **Median** |
| **HH** | 0.87 | 0.85 | 0.94 | 0.96 | 0.90 |
| **HL** | 0.91 | 1.07 | 1.03 | 0.89 | 0.97 |
| **HLH** | 1.02 | 0.94 | 0.91 | 0.97 | 0.95 |
| **LL** | 0.86 | 1.00 | 0.87 | 1.00 | 0.93 |
| **LH** | **0.36** | 1.14 | 1.11 | **0.73** | 0.92 |
| **LHL** | 0.90 | 0.94 | 0.96 | 0.92 | 0.93 |
| **Median** | 0.89 | 0.97 | 0.95 | 0.94 |  |

CMSY underestimated the “true” value of unexploited stock size *k* by 11% (median) in simulated stocks with very low resilience and underestimated the “true” value by 3-5 % (medians) in the low to high resilience categories. In lightly exploited stocks, where the catches took only a small fraction of the available biomass (HH, HLH, LH), CMSY underestimated the “true” values of *k* by 5-10% (medians). For the other biomass patterns, “true” unexploited stock size was underestimated by 3-8% (medians). The combination of very low resilience and very light exploitation (LH-VL) led to the strongest underestimation of “true” *k* by 64%.

In conclusion, CMSY analysis appears to be less well suited for lightly exploited stocks where the catches have very little impact on biomass, and for species with very low resilience, where sustainable levels of exploitation represent a very small fraction of biomass.

## CMSY analysis of catch data of fully assessed stocks

Species: *Melanogrammus aeglefinus* , stock: had-faro

Name and region: Faroes grounds haddock , Faroes grounds, ICES Vb

Catch data used from years 1957 - 2014 , biomass = observed

Prior initial relative biomass = 0.4 - 0.8

Prior intermediate rel. biomass= 0.3 - 1 in year 2002

Prior final relative biomass = 0.01 - 0.4

If current catches continue, is the stock likely to crash within 3 years? Possible

Prior range for r = 0.2 - 0.8 , prior range for k = 33.9 - 407

Results from Bayesian Schaefer model using catch & observed biomass

r = 0.476 , 95% CL = 0.399 - 0.521 , k = 153 , 95% CL = 130 - 196

MSY = 18.1 , 95% CL = 14.9 - 22.2

Biomass in last year = 20.9 or 0.136 k

Exploitation rate in last year = 0.14 or 0.589 u.msy

Results of CMSY analysis with altogether 1224 viable trajectories for 1053 r-k pairs

489 r-k pairs above r = 0.237 and 419 trajectories within r-k CLs were analyzed

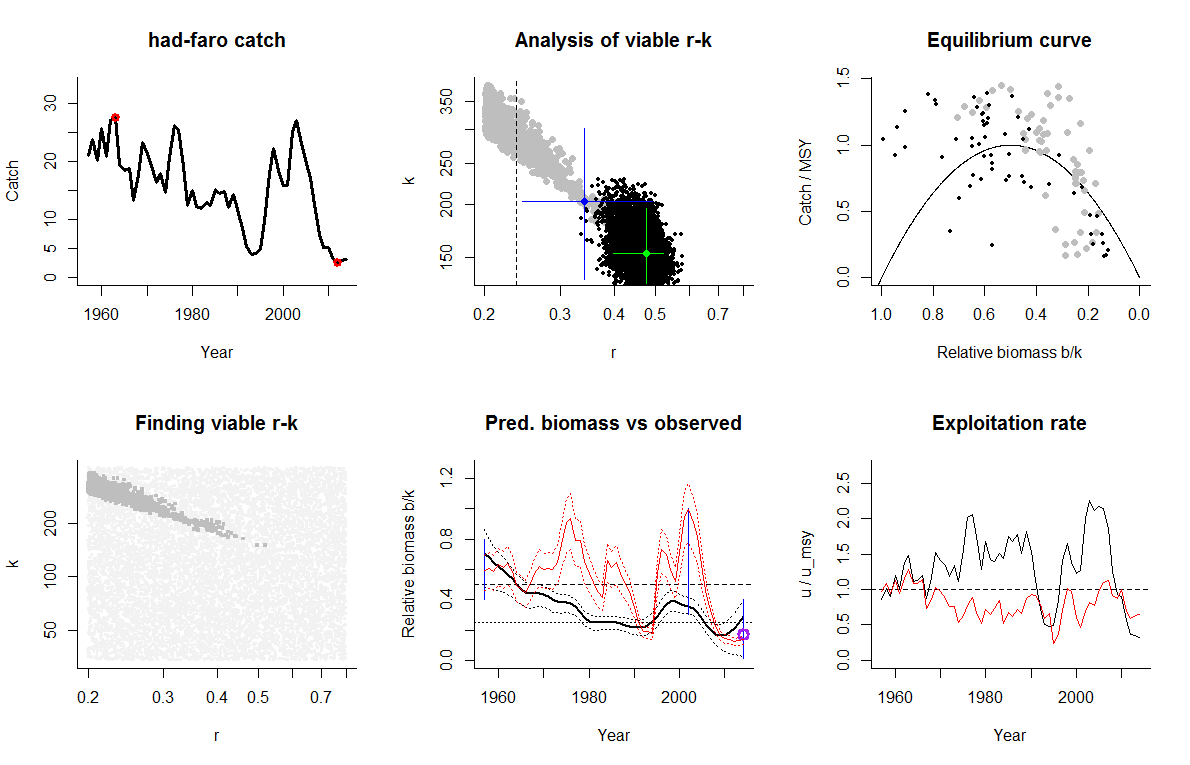
r = 0.341 , 95% CL = 0.245 - 0.492 , k = 204 , 95% CL = 133 - 302

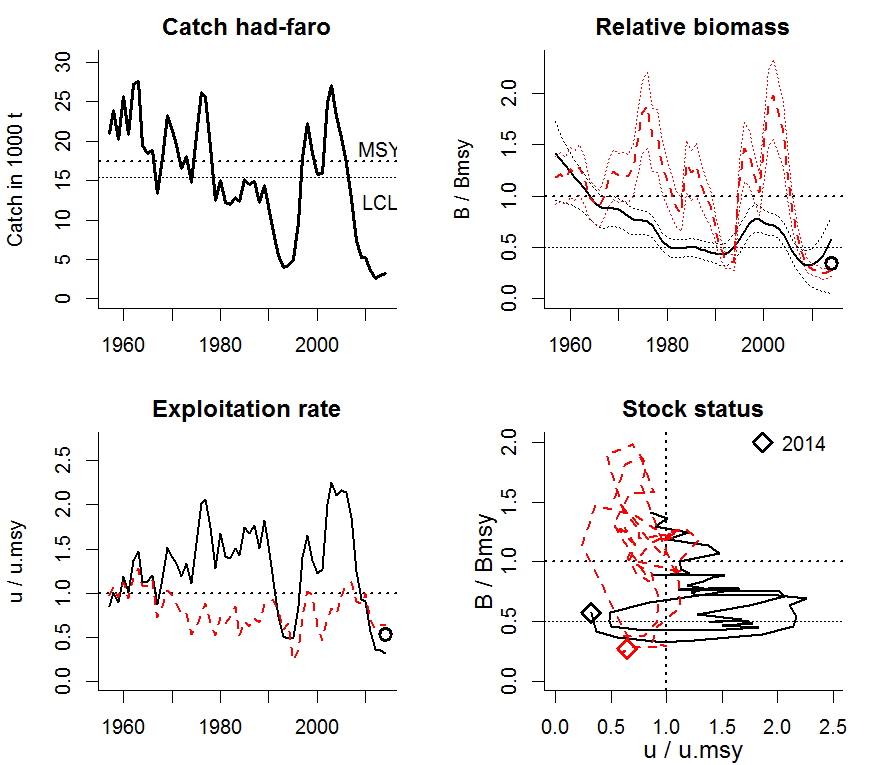
MSY = 17.4 , 95% CL = 15.4 - 19.6

Relative biomass last year= 0.287 , 2.5th = 0.0246 , 25th = 0.173 , 97.5th = 0.396

Relative biomass next year= 0.33 , 2.5th = 0.0197 , 25th = 0.207 , 97.5th = 0.456

Relative exploitation rate in last year= 0.321 , 25th = 0.532





**Comment:** Good agreement in reference points between CMSY results based on catch and BSM results based on catch and biomass; also good agreement in overall trends and start and end values. But CMSY did not reproduce the observed abundance variability and underestimates total biomass in intermediate years. A higher prior on start biomass (0.4 – 0.8 instead of 0.2 – 0.6) slightly improved the fit. CMSY overestimates stock size and underestimates exploitation in the last years, because CMSY assumes constant productivity, whereas the stock is likely to suffer from reduced recruitment (red curve below half of *Bmsy*, which is a proxy for *Bpa*). Therefore, the black circles derived from the 25th percentile of predicted biomass should be used for management advice from CMSY.

Species: *Gadus morhua* , stock: cod-farp

Name and region: Faroe Plateau cod , ICES Vb1

Catch data used from years 1959 - 2014 , biomass = observed

Prior initial relative biomass = 0.1 - 0.4

Prior intermediate rel. biomass= 0.3 - 0.9 in year 1975

Prior final relative biomass = 0.01 - 0.3

If current catches continue, is the stock likely to crash within 3 years? Possible

Prior range for r = 0.2 - 0.8 , prior range for k = 49.7 - 597

Results from Bayesian Schaefer model using catch & observed biomass

r = 0.499 , 95% CL = 0.449 - 0.554 , k = 199 , 95% CL = 167 - 267

MSY = 25 , 95% CL = 21.1 - 32.4

Biomass in last year = 27.7 or 0.139 k

Exploitation rate in last year = 0.219 or 0.876 u.msy

Results of CMSY analysis with altogether 333 viable trajectories for 324 r-k pairs

128 r-k pairs above r = 0.248 and 101 trajectories within r-k CLs were analyzed

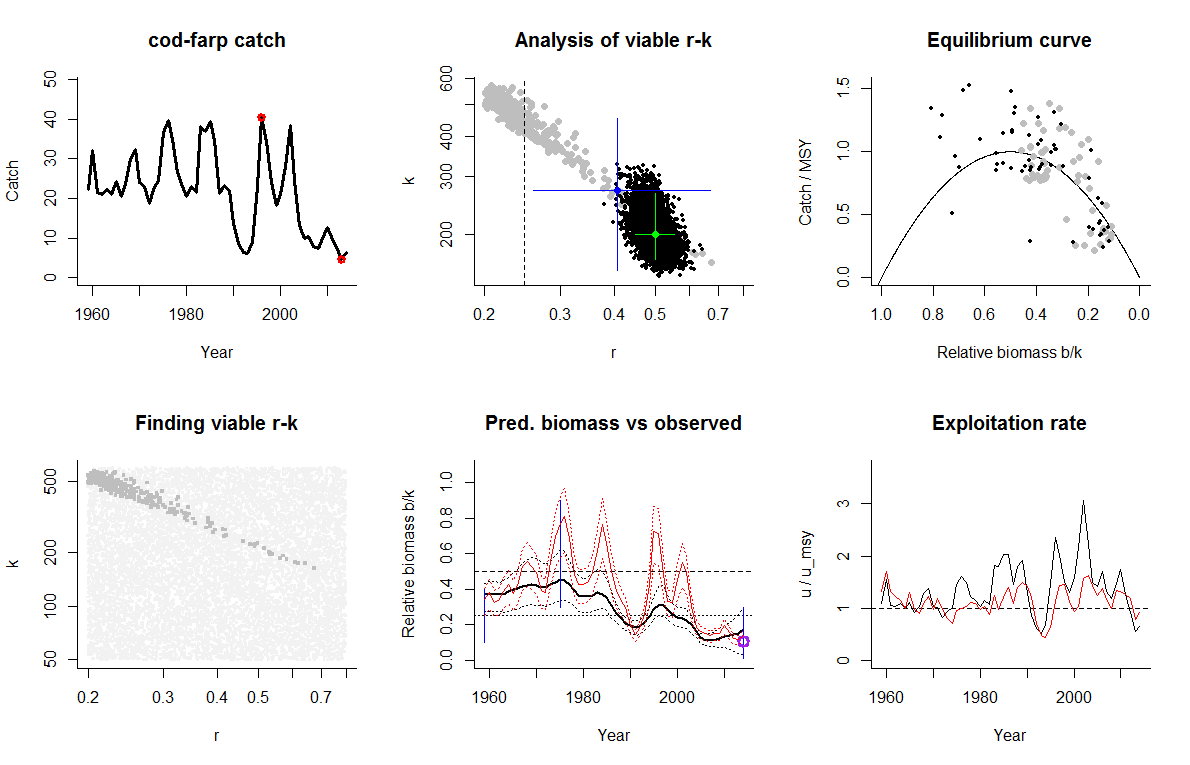
r = 0.407 , 95% CL = 0.259 - 0.671 , k = 272 , 95% CL = 154 - 455

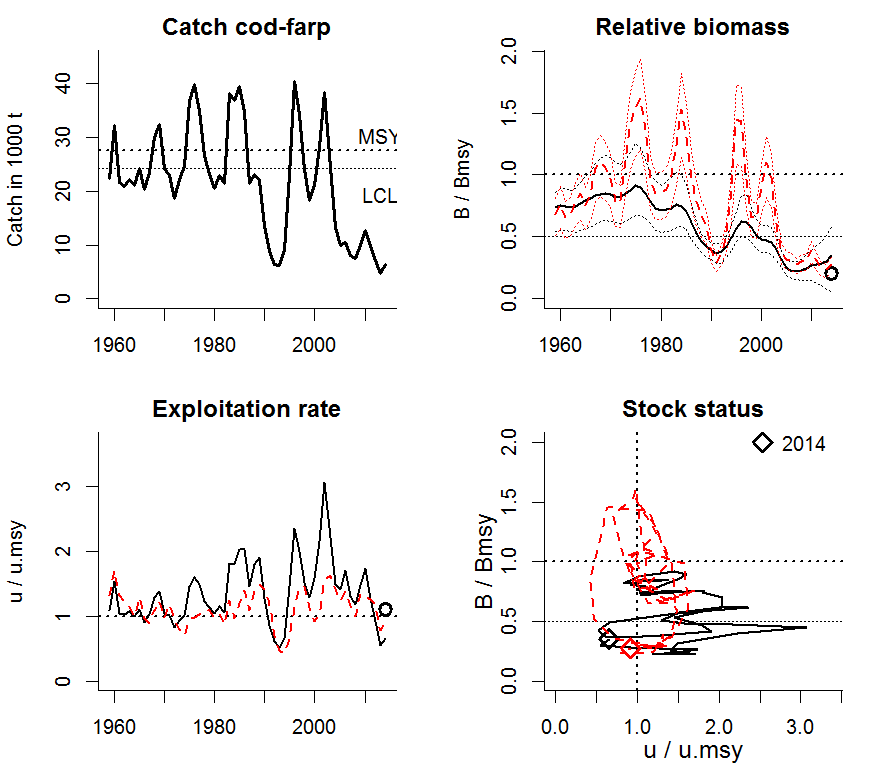
MSY = 27.6 , 95% CL = 24.3 - 31.3

Relative biomass last year= 0.175 , 2.5th = 0.0309 , 25th = 0.104 , 97.5th = 0.289

Relative biomass next year= 0.204 , 2.5th = 0.0246 , 25th = 0.117 , 97.5th = 0.338

Relative exploitation rate in last year= 0.656 , 25th = 1.105





**Comment:** Reasonable agreement between CMSY results and biomass and exploitation rate trends from the full stock analysis. Note that CMSY slightly overestimates stock size and underestimates exploitation in the last years, because CMSY assumes constant productivity, whereas the stock is likely to suffer from reduced recruitment (red curve below half of *Bmsy*, which is a proxy for *Bpa*). Therefore, the black dots derived from the 25th percentile of predicted biomass should be used for management advice based on CMSY.

Species: *Pollachius virens* , stock: sai-faro

Name and region: Faroe saithe , ICES Vb

Catch data used from years 1961 - 2014 , biomass = observed

Prior initial relative biomass = 0.1 - 0.5

Prior intermediate rel. biomass= 0.4 - 0.9 in year 2005

Prior final relative biomass = 0.2 - 0.6

If current catches continue, is the stock likely to crash within 3 years? No

Prior range for r = 0.2 - 0.8 , prior range for k = 83.6 - 1004

Results from Bayesian Schaefer model using catch & observed biomass

r = 0.486 , 95% CL = 0.412 - 0.524 , k = 360 , 95% CL = 320 - 442

MSY = 43.3 , 95% CL = 38.5 - 49.2

Biomass in last year = 213 or 0.592 k

Exploitation rate in last year = 0.134 or 0.553 u.msy

Results of CMSY analysis with altogether 8802 viable trajectories for 1199 r-k pairs

550 r-k pairs above r = 0.384 and 4229 trajectories within r-k CLs were analyzed

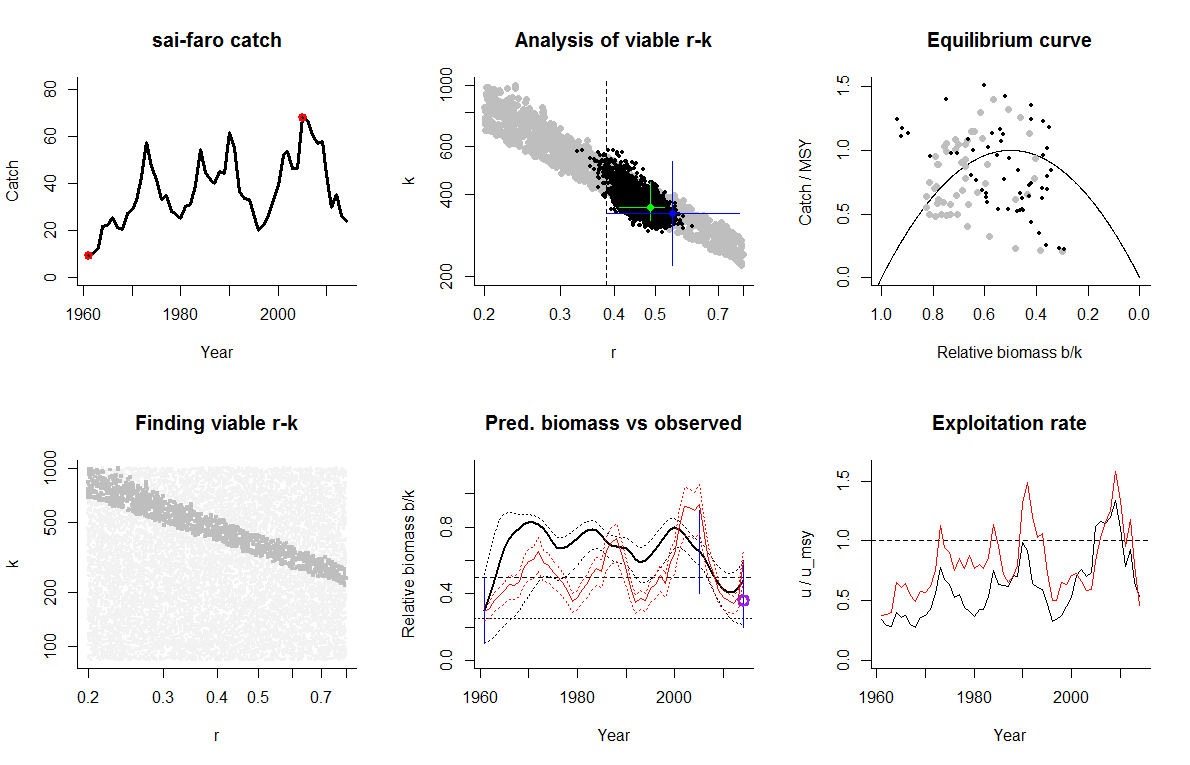
r = 0.549 , 95% CL = 0.384 - 0.784 , k = 340 , 95% CL = 219 - 528

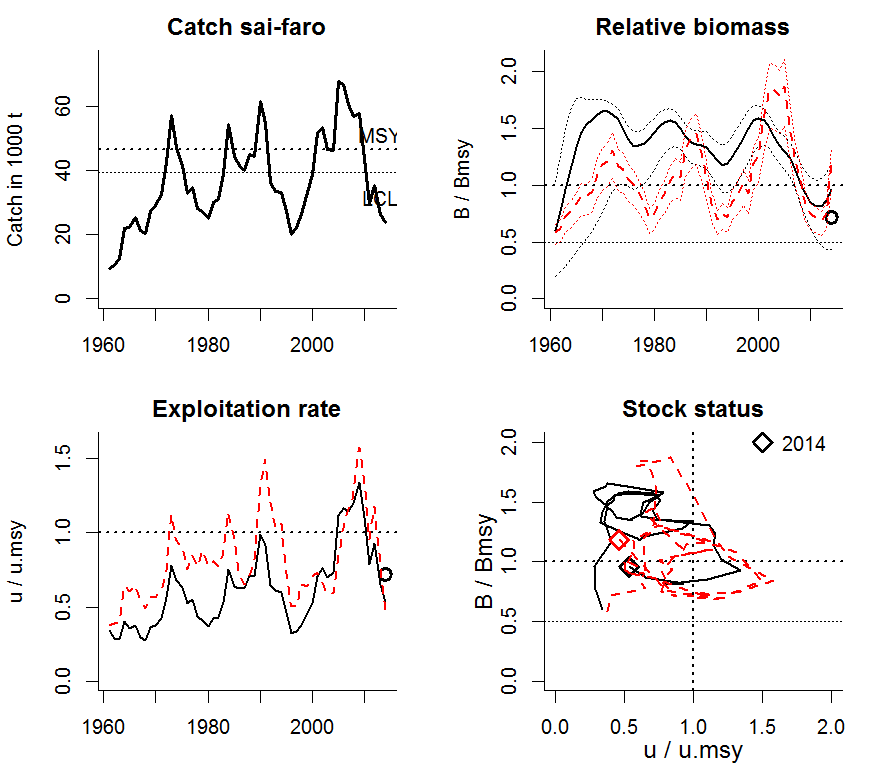
MSY = 46.7 , 95% CL = 39.6 - 55

Relative biomass last year= 0.48 , 2.5th = 0.215 , 25th = 0.356 , 97.5th = 0.596

Relative biomass next year= 0.529 , 2.5th = 0.215 , 25th = 0.394 , 97.5th = 0.661

Relative exploitation rate in last year= 0.532 , 25th = 0.717





**Comment:** Reasonable match between CMSY results and results of full stock assessment.

## Running CMSY on catch data and CPUE of data-limited stocks

Species: *Gadus morhua* , stock: cod-farob

Name and region: Faroebank cod , ICES Vb2

Catch data used from years 1965 - 2014 , biomass = CPUE

Prior initial relative biomass = 0.1 - 0.5

Prior intermediate rel. biomass= 0.01 - 0.4 in year 1992

Prior final relative biomass = 0.01 - 0.3

If current catches continue, is the stock likely to crash within 3 years? Possible

Prior range for r = 0.2 - 0.8 , prior range for k = 6.38 - 76.5

Prior range of q = 0.0457 - 0.183

Results from Bayesian Schaefer model using catch & CPUE

r = 0.499 , 95% CL = 0.439 - 0.562 , k = 37.6 , 95% CL = 27.5 - 59

MSY = 4.67 , 95% CL = 3.42 - 7.44

q = 0.0803 , lcl = 0.062 , ucl = 0.103

Biomass in last year from q\*CPUE = 0.321 or 0.00854 k

Exploitation rate in last year = 0.183

Results of CMSY analysis with altogether 489 viable trajectories for 478 r-k pairs

215 r-k pairs above r = 0.235 and 182 trajectories within r-k CLs were analyzed

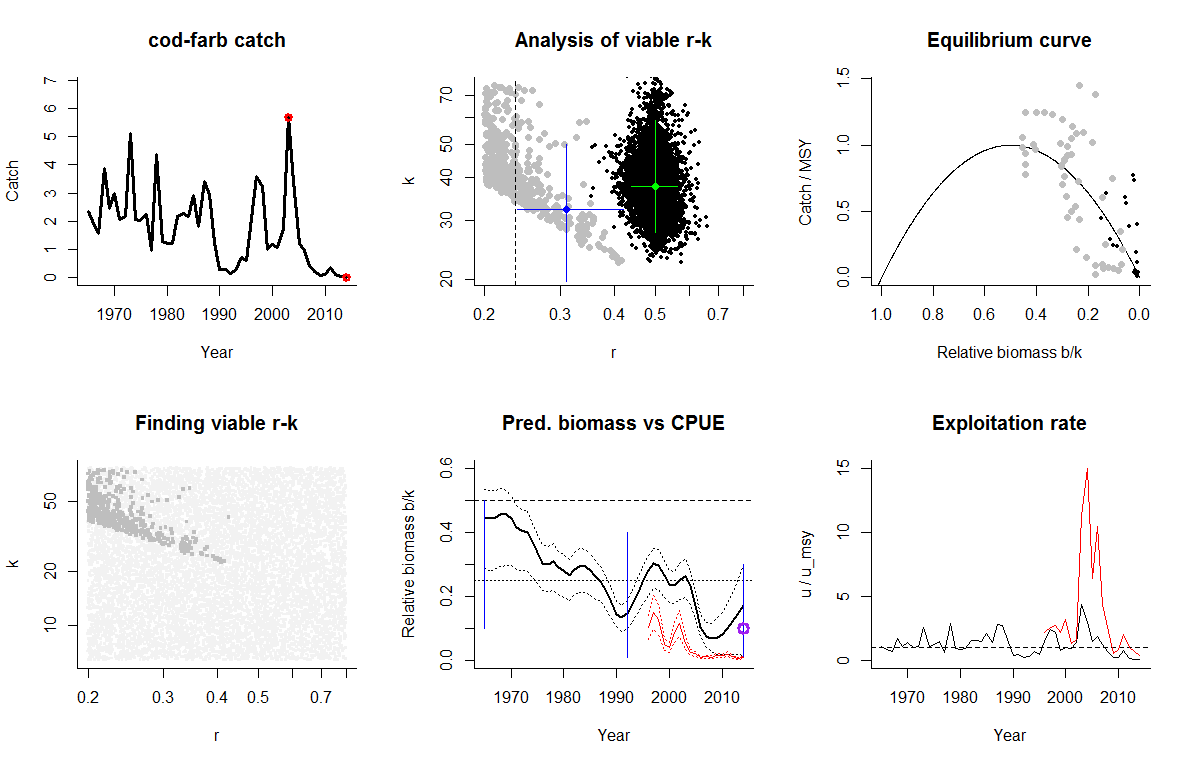
r = 0.31 , 95% CL = 0.238 - 0.421 , k = 32.1 , 95% CL = 19.8 - 50.2

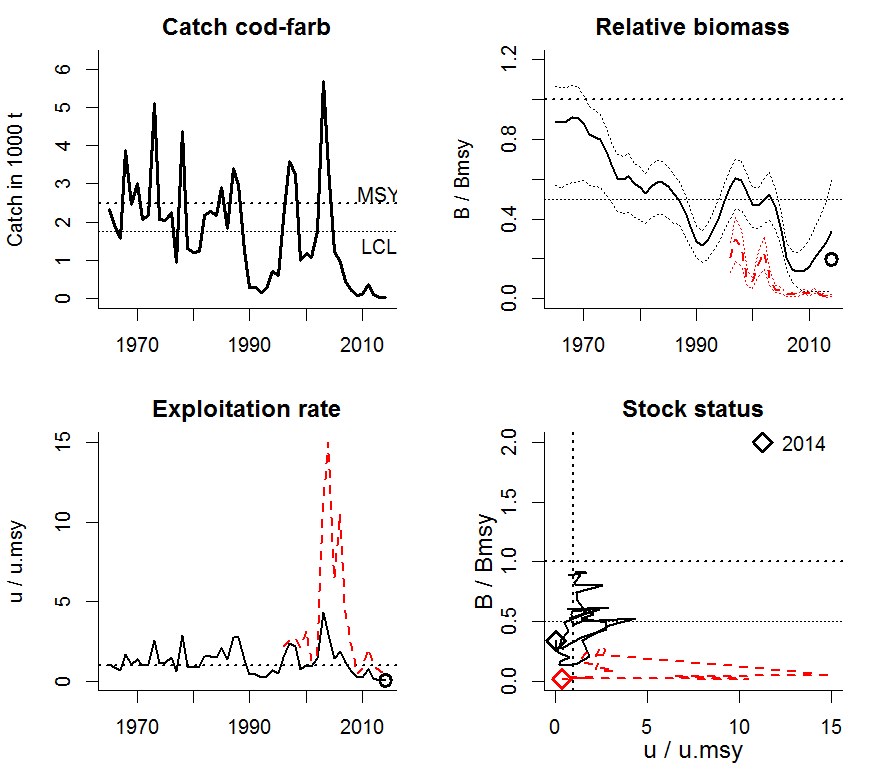
MSY = 2.49 , 95% CL = 1.75 - 3.55

Relative biomass last year= 0.17 , 2.5th = 0.0167 , 25th = 0.1 , 97.5th = 0.296

Relative biomass next year= 0.205 , 2.5th = 0.0195 , 25th = 0.124 , 97.5th = 0.355

Relative exploitation rate in last year= 0.0355 , 25th = 0.06





**Comment:** CMSY overestimates stock size and underestimates exploitation, because CMSY assumes ongoing productivity as in the 1970s and 1980s, whereas the stock is clearly suffering from reduced recruitment at least since the late 1990s. Even the black dots derived from the 25th percentile of predicted biomass are too optimistic. Here, precautionary management would not follow CMSY but rather the CPUE results as scaled by BSM. But both CMSY and BSM show the stock as well outside of safe biological limits.

Species: *Nephrops norvegicus* , stock: nep-2829

Name and region: Nephrops , Southwest and South Portugal

Catch data used from years 1997 - 2014 , biomass = CPUE

Prior initial relative biomass = 0.1 - 0.5

Prior intermediate rel. biomass= 0.1 - 0.9 in year 2005

Prior final relative biomass = 0.1 - 0.5

If current catches continue, is the stock likely to crash within 3 years? Possible

Prior range for r = 0.2 - 0.8 , prior range for k = 0.448 - 5.37

Prior range of q = 0.00781 - 0.0313

Results from Bayesian Schaefer model using catch & CPUE

r = 0.511 , 95% CL = 0.465 - 0.602 , k = 2.3 , 95% CL = 1.63 - 3.31

MSY = 0.298 , 95% CL = 0.213 - 0.422

q = 0.01 , lcl = 0.00792 , ucl = 0.0124

Biomass in last year from q\*CPUE = 0.762 or 0.331 k

Exploitation rate in last year = 0.259

Results of CMSY analysis with altogether 4993 viable trajectories for 2236 r-k pairs

1220 r-k pairs above r = 0.341 and 2030 trajectories within r-k CLs were analyzed

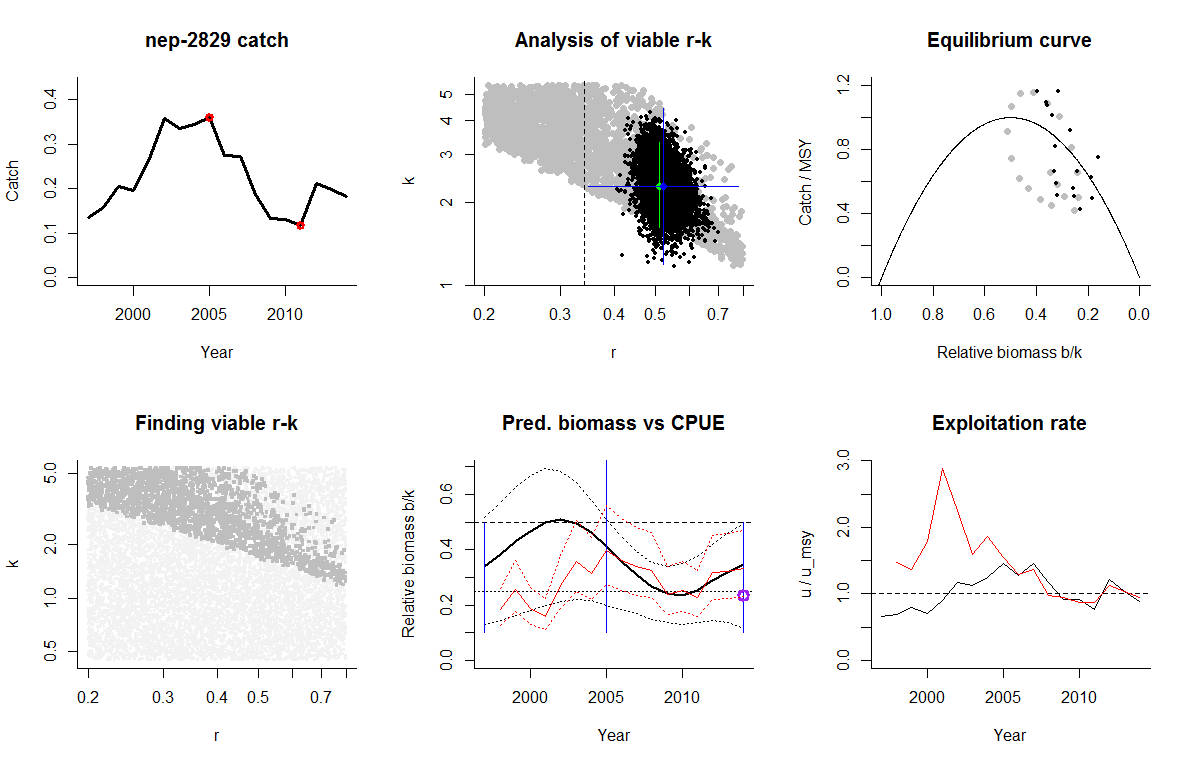
r = 0.522 , 95% CL = 0.349 - 0.782 , k = 2.3 , 95% CL = 1.19 - 4.44

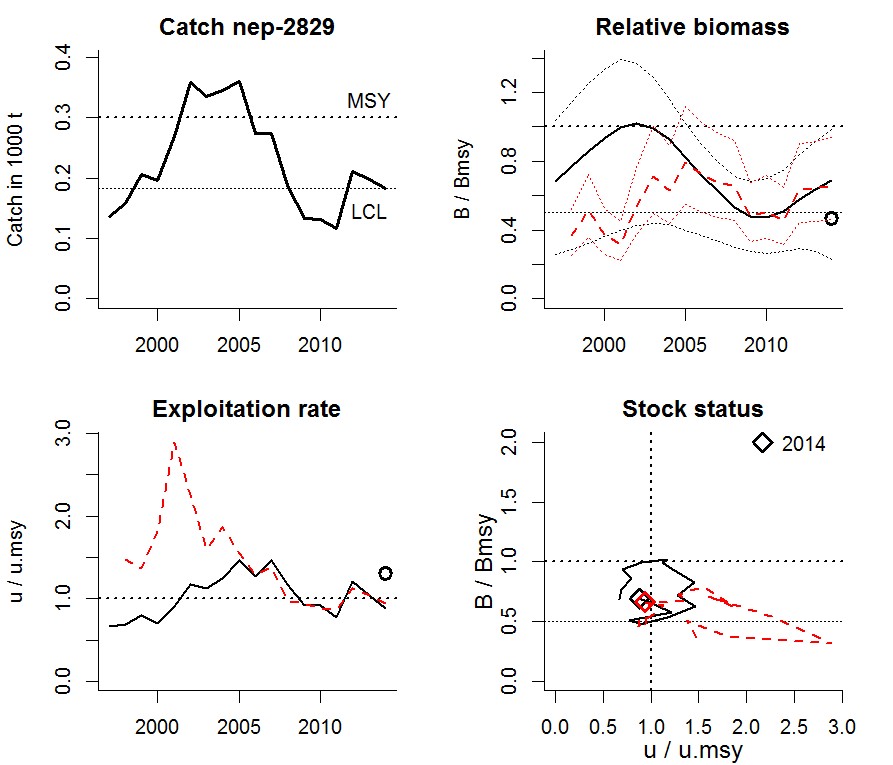
MSY = 0.3 , 95% CL = 0.183 - 0.493

Relative biomass last year= 0.345 , 2.5th = 0.115 , 25th = 0.234 , 97.5th = 0.494

Relative biomass next year= 0.364 , 2.5th = 0.0675 , 25th = 0.229 , 97.5th = 0.534

Relative exploitation rate in last year= 0.882 , 25th = 1.305





**Comment:** Good agreement after 2005 between CMSY results and biomass and exploitation rate trends from commercial cpue, as scaled by BSM.

Species: *Argentina silus* , stock: arg-5b6a

Name and region: Greater silver smelt , Northeast Atlantic

Catch data used from years 1996 - 2014 , biomass = CPUE

Prior initial relative biomass = 0.2 - 0.8

Prior intermediate rel. biomass= 0.1 - 0.9 in year 2005

Prior final relative biomass = 0.01 - 0.5

If current catches continue, is the stock likely to crash within 3 years? Possible

Prior range for r = 0.2 - 0.8 , prior range for k = 28.9 - 347

Prior range of q = 0.000349 - 0.00139

Results from Bayesian Schaefer model using catch & CPUE

r = 0.502 , 95% CL = 0.448 - 0.571 , k = 133 , 95% CL = 110 - 181

MSY = 16.7 , 95% CL = 14.4 - 22

q = 0.000589 , lcl = 0.000455 , ucl = 0.000739

Biomass in last year from q\*CPUE = 33.3 or 0.25 k

Exploitation rate in last year = 0.471

Results of CMSY analysis with altogether 9037 viable trajectories for 2443 r-k pairs

1161 r-k pairs above r = 0.368 and 3681 trajectories within r-k CLs were analyzed

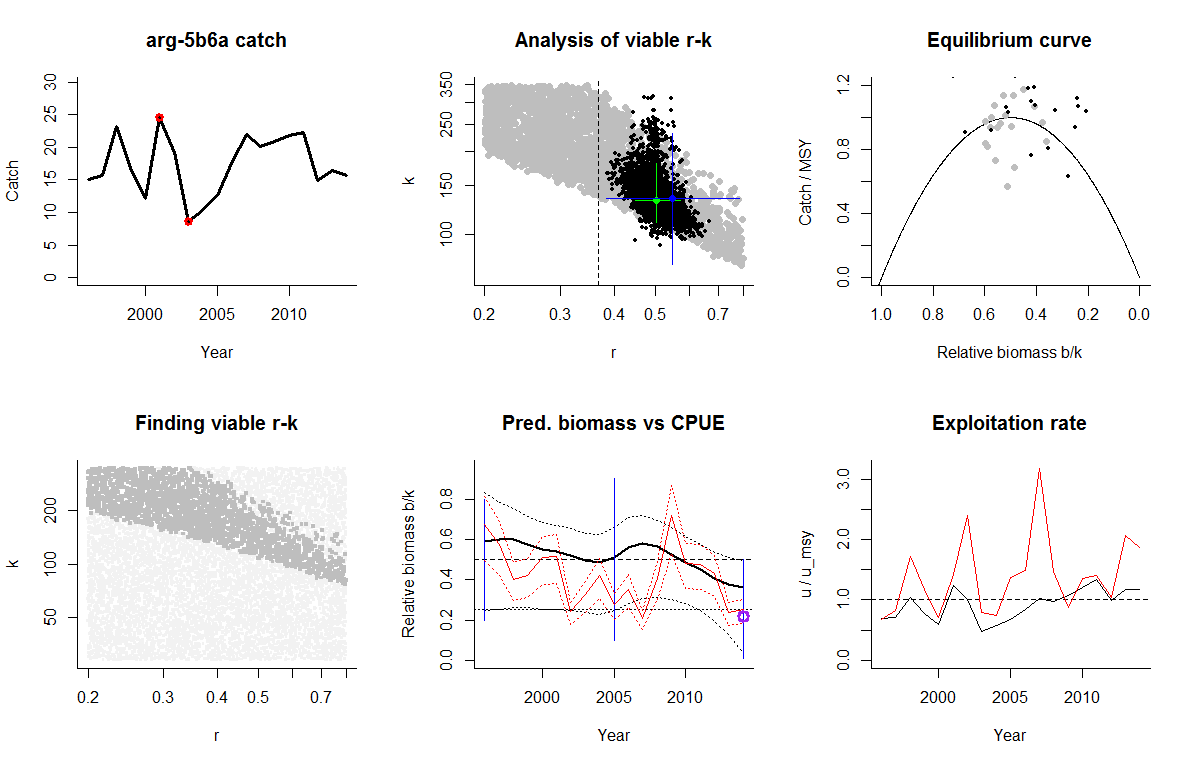
r = 0.549 , 95% CL = 0.384 - 0.784 , k = 134 , 95% CL = 77.6 - 233

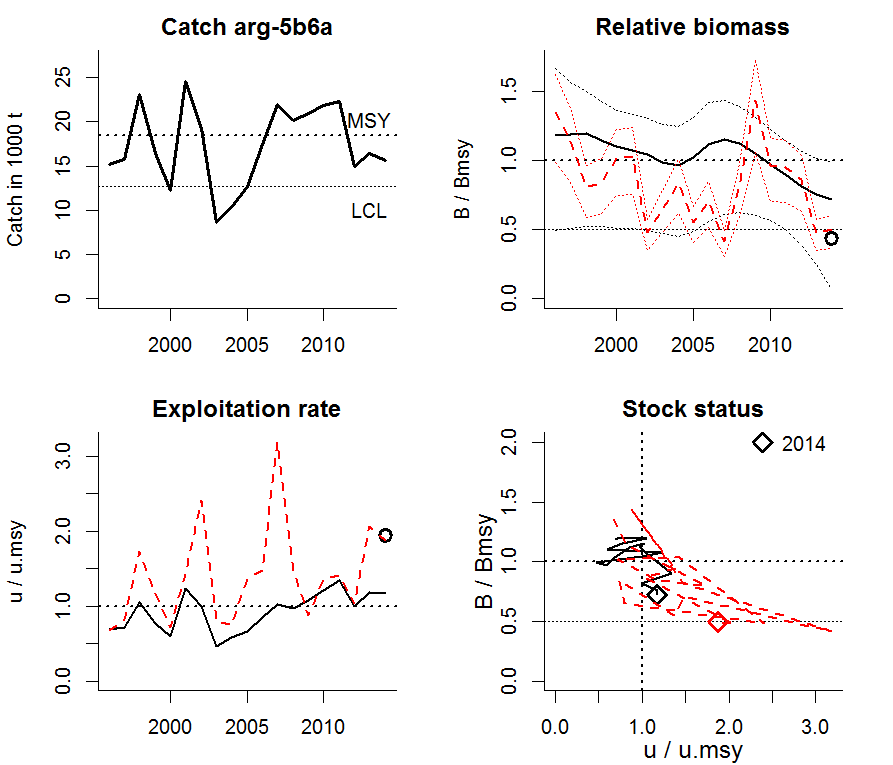
MSY = 18.4 , 95% CL = 12.6 - 26.9

Relative biomass last year= 0.361 , 2.5th = 0.0348 , 25th = 0.218 , 97.5th = 0.496

Relative biomass next year= 0.359 , 2.5th = -0.0847 , 25th = 0.18 , 97.5th = 0.523

Relative exploitation rate in last year= 1.17 , 25th = 1.947





**Comment:** Reasonable agreement between CMSY results and biomass and exploitation rate trends from cpue data, as scaled by BSM. Note that CMSY overestimates stock size and underestimates exploitation in the last years, because CMSY assumes constant productivity, whereas the stock may suffer from reduced recruitment (red curve at half of *Bmsy*, which is a proxy for *Bpa*). Therefore, the black dots derived from the 25th percentile of predicted biomass should be used for management.

Species: *Limanda limanda* , stock: dab-2232

Name and region: Western Baltic dab , Baltic areas 22 - 32

Catch data used from years 1970 - 2014 , biomass = CPUE

Prior initial relative biomass = 0.2 - 0.8

Prior intermediate rel. biomass= 0.1 - 0.5 in year 2001

Prior final relative biomass = 0.2 - 0.8

If current catches continue, is the stock likely to crash within 3 years? No

Prior range for r = 0.2 - 0.8 , prior range for k = 3.68 - 44.1

Prior range of q = 0.00809 - 0.0324

Results from Bayesian Schaefer model using catch & CPUE

r = 0.508 , 95% CL = 0.46 - 0.599 , k = 13.9 , 95% CL = 9.9 - 19.6

MSY = 1.81 , 95% CL = 1.25 - 2.49

q = 0.0117 , lcl = 0.00893 , ucl = 0.0157

Biomass in last year from q\*CPUE = 12.3 or 0.882 k

Exploitation rate in last year = 0.107

Results of CMSY analysis with altogether 4611 viable trajectories for 1047 r-k pairs

403 r-k pairs above r = 0.35 and 1985 trajectories within r-k CLs were analyzed

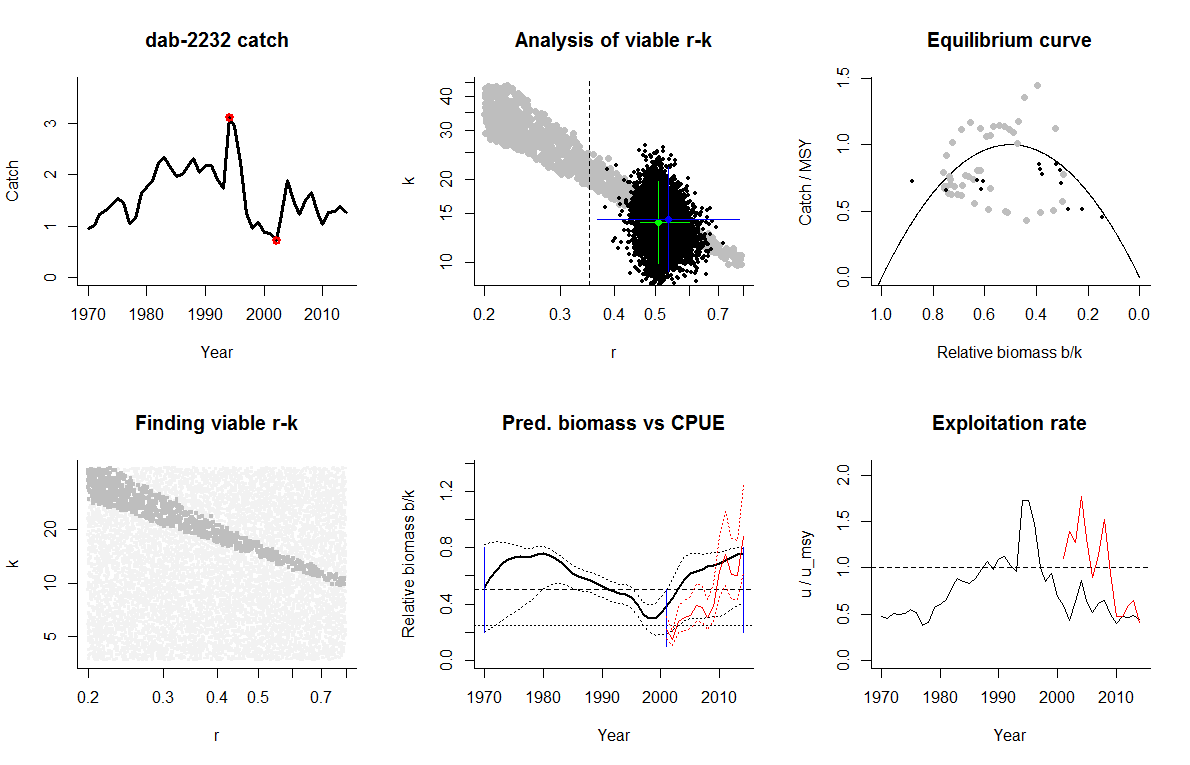
r = 0.535 , 95% CL = 0.366 - 0.783 , k = 14.3 , 95% CL = 9.23 - 22.1

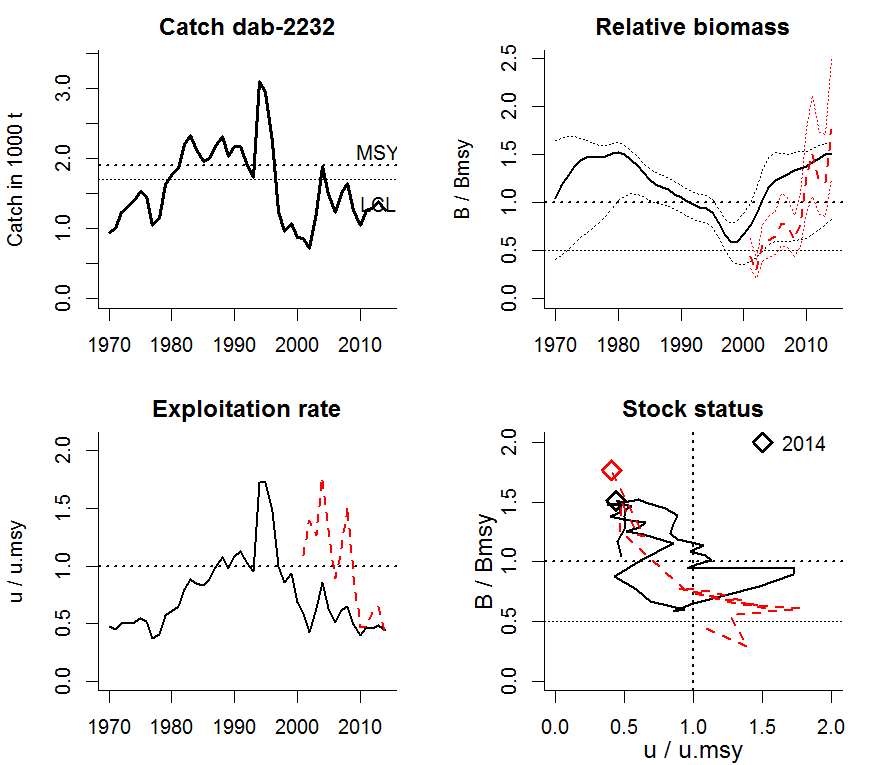
MSY = 1.91 , 95% CL = 1.71 - 2.14

Relative biomass last year= 0.755 , 2.5th = 0.413 , 25th = 0.712 , 97.5th = 0.797

Relative biomass next year= 0.76 , 2.5th = 0.443 , 25th = 0.725 , 97.5th = 0.802

Relative exploitation rate in last year= 0.44





**Comment:** Landings data used, though discards may be substantial. No good idea of stock size, so very wide prior biomass windows (0.2 – 0.8) for start and end biomass used. Drop in unrestricted catches in 1998-2001 was interpreted as low biomass (0.1-0.5) for intermediate year (2001). Good agreement between CMSY and CPUE as scaled by BSM, with similar and converging estimates in the last years.

Species: *Gadus morhua* , stock: cod-2532

Name and region: Eastern Baltic cod , Eastern Baltic, areas 25-32

Catch data used from years 2003 - 2014 , biomass = CPUE

Prior initial relative biomass = 0.1 - 0.5

Prior intermediate rel. biomass= 0.1 - 0.9 in year 2007

Prior final relative biomass = 0.01 - 0.4

If current catches continue, is the stock likely to crash within 3 years? Possible

Prior range for r = 0.2 - 0.8 , prior range for k = 95.6 - 1147

Prior range of q = 0.000733 - 0.00293

Results from Bayesian Schaefer model using catch & CPUE

r = 0.512 , 95% CL = 0.464 - 0.61 , k = 643 , 95% CL = 386 - 1011

MSY = 83.3 , 95% CL = 50 - 131

q = 0.000864 , lcl = 0.00067 , ucl = 0.00124

Biomass in last year from q\*CPUE = 146 or 0.227 k

Exploitation rate in last year = 0.356

Results of CMSY analysis with altogether 5641 viable trajectories for 2612 r-k pairs

1623 r-k pairs above r = 0.371 and 2520 trajectories within r-k CLs were analyzed

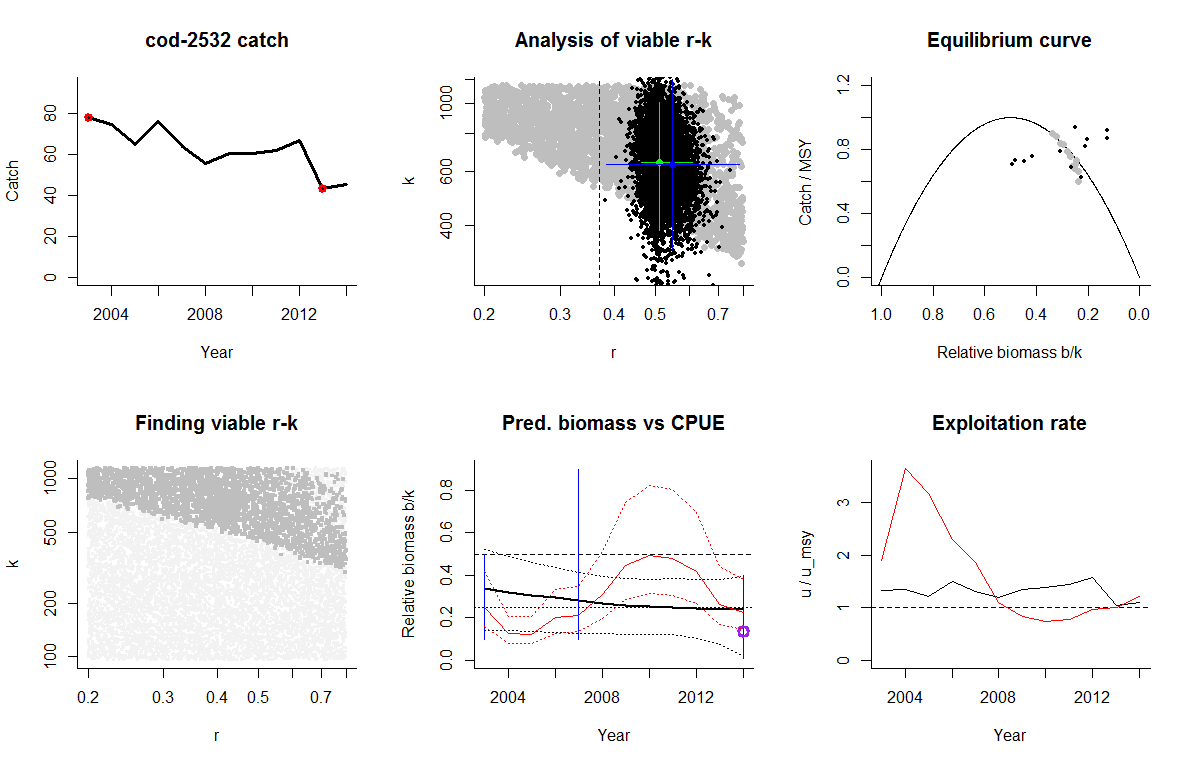
r = 0.549 , 95% CL = 0.384 - 0.784 , k = 632 , 95% CL = 333 - 1198

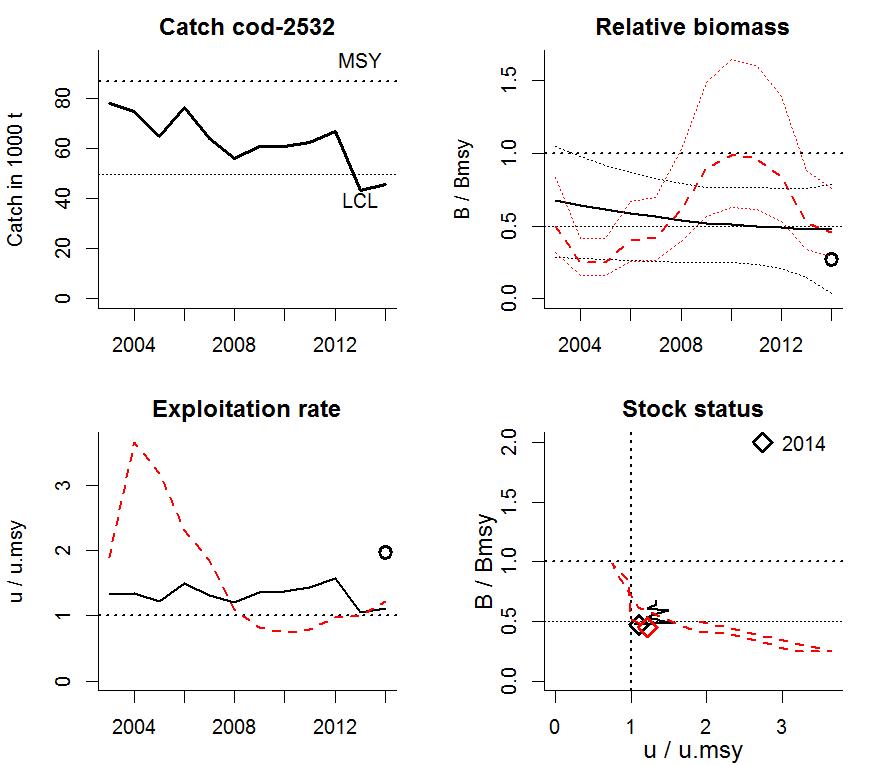
MSY = 86.7 , 95% CL = 49.7 - 151

Relative biomass last year= 0.237 , 2.5th = 0.0197 , 25th = 0.134 , 97.5th = 0.395

Relative biomass next year= 0.247 , 2.5th = -0.0559 , 25th = 0.106 , 97.5th = 0.45

Relative exploitation rate in last year= 1.11 , 25th = 1.964





**Comment:** Short time series. CMSY does not capture the variability in stock index data as scaled by BSM, but gives similar results for final biomass and exploitation rate.

## Comparing results with observation error of catch with sigma 0.1 and 0.2

CMSY analysis with sigma 0.1 on catch

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Species: Merluccius merluccius , stock: hke-nrtn

Name and region: Northern hake , Subareas IV, VI, and VII and Divisions IIIa, VIIIa,b,d

Catch data used from years 1978 - 2014 , biomass = observed

Prior initial relative biomass = 0.2 - 0.6

Prior intermediate rel. biomass= 0.1 - 0.4 in year 2005

Prior final relative biomass = 0.5 - 0.9

If current catches continue, is the stock likely to crash within 3 years? No

Prior range for r = 0.2 - 0.8 , prior range for k = 245 - 1961

Results from Bayesian Schaefer model using catch & observed biomass

r = 0.807 , 95% CL = 0.715 - 0.892 , k = 520 , 95% CL = 385 - 735

MSY = 104 , 95% CL = 81.3 - 140

Biomass in last year = 275 or 0.528 k

Results of CMSY analysis

Altogether 244 viable trajectories for 244 r-k pairs were found

111 r-k pairs above r = 0.286 and 103 trajectories within r-k CLs were analyzed

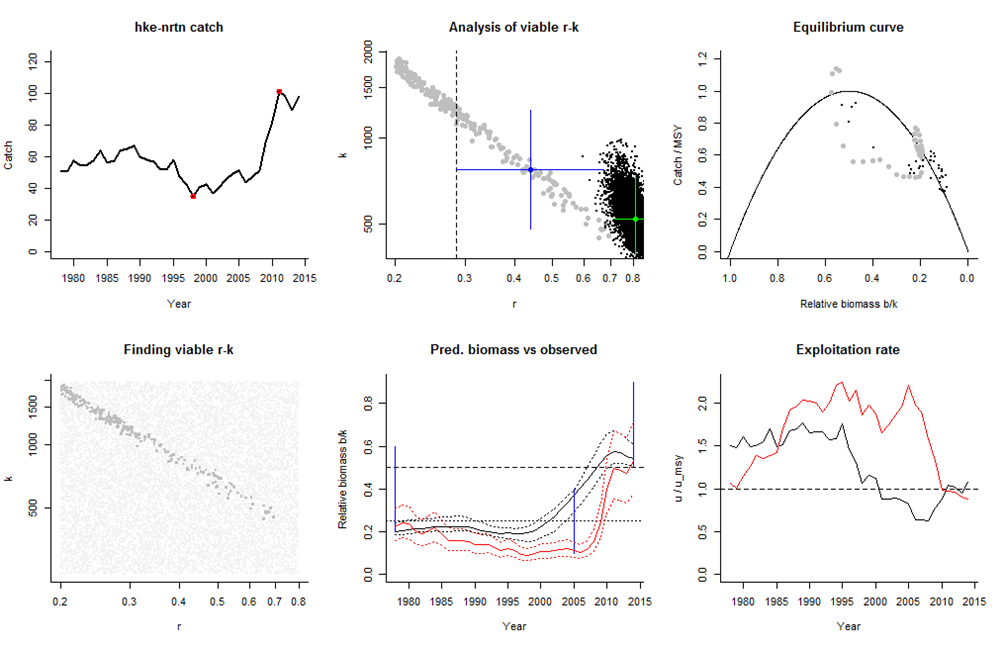
r = 0.438 , 95% CL = 0.286 - 0.672 , k = 772 , 95% CL = 477 - 1247

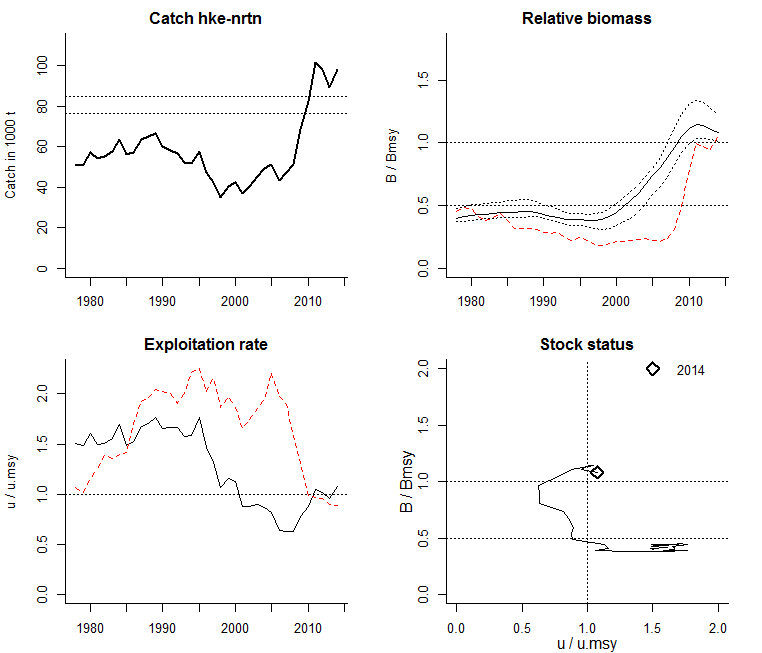
MSY = 84.5 , 95% CL = 76.3 - 93.7

Predicted biomass in last year = 0.54 , 2.5th perc = 0.505 25th perc = 0.521 97.5th perc = 0.608

Predicted biomass in next year = 0.528 , 2.5th perc = 0.475 25th perc = 0.507 , 97.5th perc = 0.596

Comment: Strange recent increase in biomass after 2008





**Comment:** Northern Hake had a modest biomass in the beginning of the time series and a very strong increase in biomass in 2007, which lasted until the end of the time series. Accordingly, prior biomass windows were set 0.2-0.6 for the beginning and 0.5-0.9 for the end. CMSY assumes average productivity of the stock and thus has difficulties to reproduce the extraordinary biomass increase in 2007. CMSY modelling was improved by setting a low (10-40% of unexploited biomass) intermediate biomass window to 2005, before the increase, effectively informing the system of the common knowledge that the stock had low biomass throughout most of the time series until it increased drastically in 2007.

Repetition of previous analysis with sigma=0.2 uncertainty on catch

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Species: Merluccius merluccius , stock: hke-nrtn

Name and region: Northern hake , Subareas IV, VI, and VII and Divisions IIIa, VIIIa,b,d

Catch data used from years 1978 - 2014 , biomass = observed

Prior initial relative biomass = 0.2 - 0.6

Prior intermediate rel. biomass= 0.1 - 0.4 in year 2005

Prior final relative biomass = 0.5 - 0.9

If current catches continue, is the stock likely to crash within 3 years? No

Prior range for r = 0.2 - 0.8 , prior range for k = 245 - 1961

Results from Bayesian Schaefer model using catch & observed biomass

r = 0.799 , 95% CL = 0.701 - 0.89 , k = 542 , 95% CL = 392 - 850

MSY = 108 , 95% CL = 83.2 - 157

Biomass in last year = 275 or 0.507 k

Results of CMSY analysis

Altogether 385 viable trajectories for 384 r-k pairs were found

189 r-k pairs above r = 0.29 and 163 trajectories within r-k CLs were analyzed

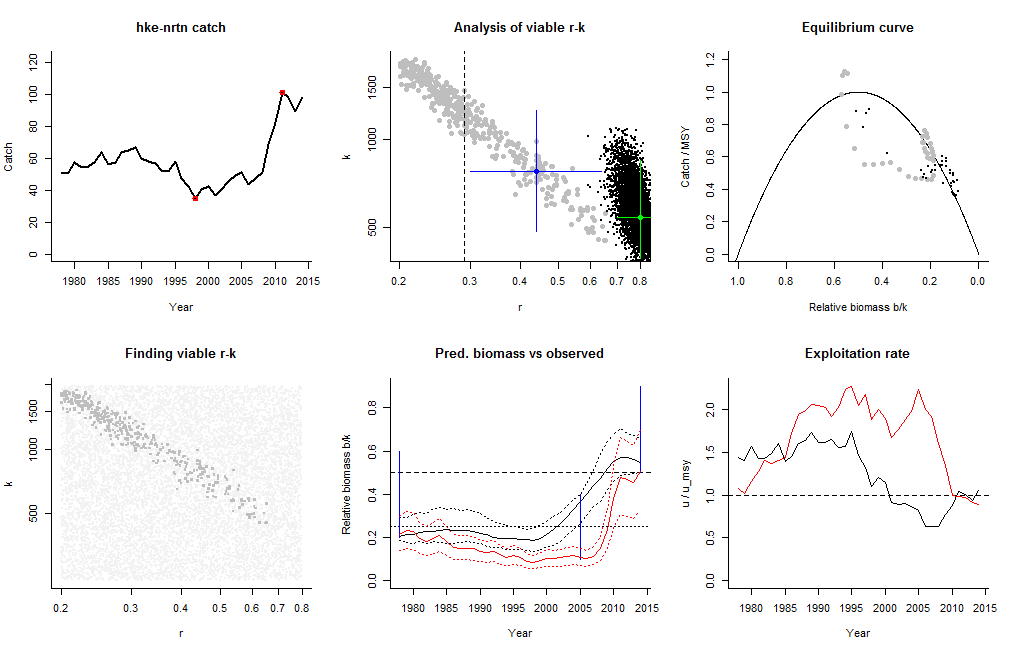
r = 0.438 , 95% CL = 0.3 - 0.641 , k = 779 , 95% CL = 483 - 1255

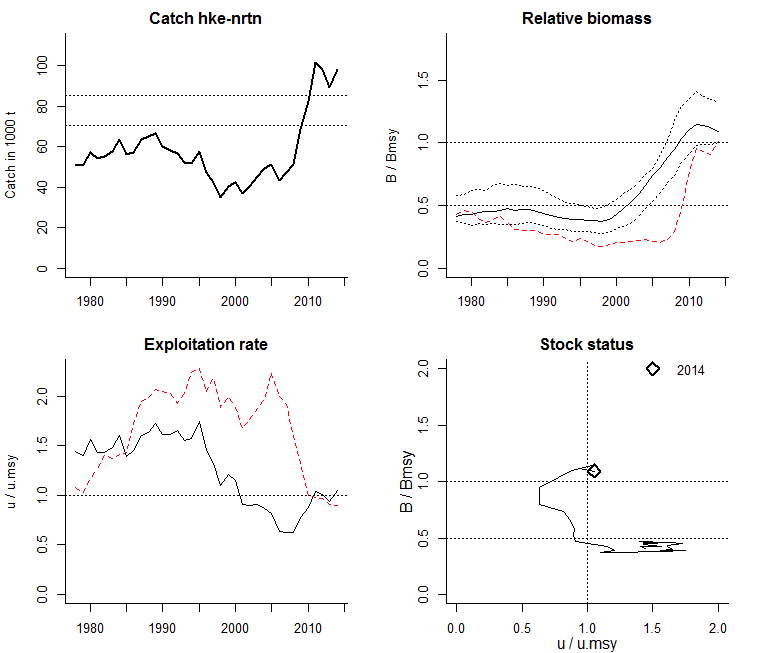
MSY = 85.3 , 95% CL = 70.5 - 103

Predicted biomass in last year = 0.547 , 2.5th perc = 0.501 25th perc = 0.519 97.5th perc = 0.66

Predicted biomass in next year = 0.533 , 2.5th perc = 0.444 25th perc = 0.499 , 97.5th perc = 0.637

Comment: Strange recent increase in biomass after 2008





**Comment:** CMSY assumes as default a process error of sigma=0.05 and an observation error on catch of sigma=0.1. In the latest version of CMSY\_WKLIFEV\_7.r, observation error and process error can be set independently. Above analysis of northern hake used an observation error of 0.2 instead of 0.1. This doubling of uncertainty in the catch increased the variability in viable *r-k* pairs found by CMSY (compare lower left graphs in the CMSY output between the two runs), but the increased uncertainty did not affect the estimates of the fisheries reference points in any significant way.

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