cat3advice

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Contents

`cat3advice`

`cat3advice` is an R package that allows the application of the ICES category 3 data-limited harvest control rules (rfb/rb/chr rules) and follows the ICES Technical Guidelines (ICES 2022) (https://doi.org/10.17895/ices.advice.19801564).

Documentation

The package documentation contains help files for its functions which also include code examples. See `help(package = "cat3advice")` for available functions.

The main functions are `rfb()`, `rb()`, and `chr()`. Each of these functions has a help file with code examples (see `?rfb`, `?rb` `?chr`).

Installation

The latest version of the `cat3advice` R package can be installed from GitHub with

```
library(remotes)
install_github("shfischer/cat3advice", build_vignettes = TRUE)
```

Tutorial

This tutorial uses data from the ICES Western English Channel plaice stock (ple.27.7e) to illustrate the application of the rfb/rb/chr rules. The data are included in the `cat3advice` R package.

Before reading this vignette, please first read the ICES Technical Guidelines (ICES 2022).

For more details on the rfb rule, please refer to Fischer et al. (2020; 2021b, 2021a, 2023) and for the chr rule, please refer to Fischer et al. (2022, 2023).

```
### load package
library(cat3advice)
```

The rfb rule

The rfb rule is an index adjusted harvest control rule that uses a biomass index and catch length data. The method is defined as Method 2.1 in the ICES Technical Guidelines (ICES 2022, 9) as

$$A_{y+1} = A_y \times r \times f \times b \times m$$

where A_{y+1} is the new catch advice, A_y the previous advice, r the biomass ratio from a biomass index, f the fishing pressure proxy from catch length data, b a biomass safeguard and m a precautionary multiplier. Furthermore, the change in the advice is restricted by a stability clause that only allows changes of between $+20\%$ and -30% relative to the previous advice, but the application of the stability clause is conditional on $b = 1$ and turned off when $b < 1$.

The rfb rule should be applied biennially, i.e. the catch advice is valid for two years.

Please note that any change from the default configuration should be supported by case-specific simulations.

Reference catch A_y

The reference catch A_y is usually the most recently advised catch. In a typical ICES setting, an assessment is conducted in an assessment (intermediate) year y to give advice for the following advice year $y + 1$, this is the advice for year y:

```
### load plaice catch and advice data
data("ple7e_catch")
tail(ple7e_catch)
#>    year advice landings discards catch
#> 31 2017   2714     2128      821  2949
```

```
#> 32 2018   3257     1880      633  2513
#> 33 2019   3648     1725      366  2091
#> 34 2020   2721     1373      514  1888
#> 35 2021   2177     1403      211  1615
#> 36 2022   1742       NA       NA    NA
### get reference catch
A <- A(ple7e_catch, units = "tonnes")
A
#> An object of class "A".
#> Value: 1742
```

The ICES Technical Guidelines (ICES 2022) specify that if the realised catch is very different from the advised catch, the reference catch could be replaced by an average of recent catches:

```
### use 3-year average
A(ple7e_catch, units = "tonnes", basis = "average catch", avg_years = 3)
#> An object of class "A".
#> Value: 1864.66666666667
```

The reference catch can also be defined manually:

```
### define manually
A(2000, units = "tonnes")
#> An object of class "A".
#> Value: 2000
```

Biomass index trend (ratio) r

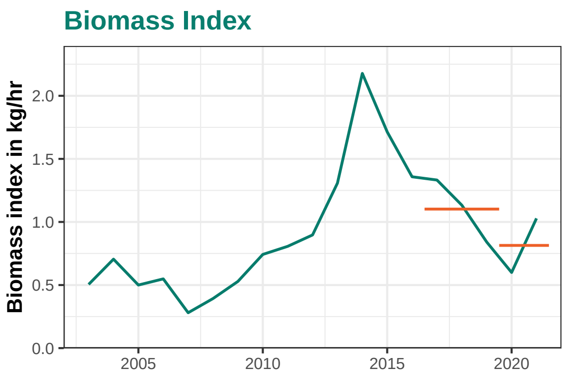
The biomass index trend r calculates the trend in the biomass index over last the five years, by dividing the mean of the last two years by the mean of the three preceding years:

$$r = \Sigma_{i=y-2}^{y-1}(I_i/2) \ / \ \Sigma_{i=y-5}^{y-2}(I_i/3)$$

The ratio is calculated with the function `r`. Index data should be provided as a `data.frame` with columns `year` and `index`.

```
### load plaice data
data("ple7e_idx")
tail(ple7e_idx)
#>    year     index
#> 14 2016 1.3579990
#> 15 2017 1.3323659
#> 16 2018 1.1327596
#> 17 2019 0.8407277
#> 18 2020 0.5996326
#> 19 2021 1.0284297

### calculate biomass trend
r <- r(ple7e_idx, units = "kg/hr")
r
#> An object of class "rfb_r".
#> Value: 0.73871806243358

### ICES advice style table
advice(r)
```

```
#> -----------------------------------------------------------------------------------
#> Stock biomass trend
#> -----------------------------------------------------------------------------------
#> Index A (2020,2021)                                |                     0.81 kg/hr
#> Index B (2017,2018,2019)                           |                     1.10 kg/hr
#> r: stock biomass trend (index ratio A/B)           |                           0.74

### plot index
### horizontal orange lines correspond to the the 2/3-year averages
plot(r)
```




```
### when the value of r is known
r(1)
#> An object of class "r".
#> Value: 1
```

Biomass index data are usually available until the year before the advice year. More recent data can be used and the function automatically picks the most recent data provided to it.

Biomass safeguard b

The biomass safeguard reduces the advice when the biomass index I falls below a threshold value I_{trigger}:

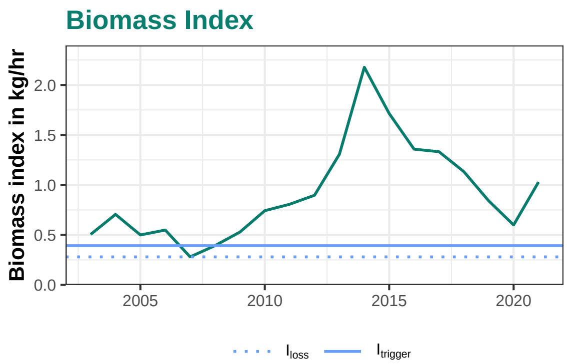
$$b = \min\{1,\ I_{y-1}/I_{\text{trigger}}\}$$

By default, the trigger value is defined based on the lowest observed index value I_{loss} as $I_{\text{trigger}} = 1.4 I_{\text{loss}}$.

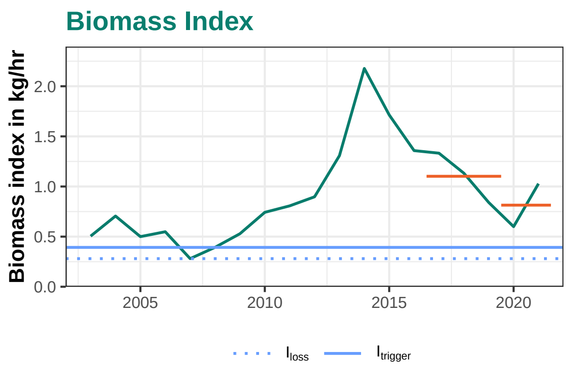
The biomass safeguard is calculated with the function `b`:

```
### use same plaice data as before
### application in first year with new calculation of Itrigger
b <- b(ple7e_idx, units = "kg/hr")
b
#> An object of class "b".
#> Value: 1

### ICES advice style table
advice(b)
#> -----------------------------------------------------------------------------------
#> Biomass safeguard
#> -----------------------------------------------------------------------------------
#> Last index value (I2021)                           |                     1.03 kg/hr
```

```
#> Index trigger value (Itrigger = Iloss x 1.4)      |                        0.39 kg/hr
#> b: index relative to trigger value,               |                              1.00
#>    min{I2021/Itrigger, 1}                         |

### plot
plot(b)
```




```
### plot b and r in one figure
plot(r, b)
```



Please note that I_{trigger} should only be defined once in the first year of the application of the rfb rule. In the following years, the same value should be used. For this purpose, `b` allows the direct definition of I_{trigger}, or, more conveniently, I_{trigger} can be based on the year in which I_{loss} is defined:

```
### in following years, Itrigger should NOT be updated
### i.e. provide value for Itrigger
b(ple7e_idx, units = "kg/hr", Itrigger = 0.3924721)
#> An object of class "b".
#> Value: 1
### alternatively, the reference year for Iloss can be used
b(ple7e_idx, units = "kg/hr", yr_ref = 2007)
#> An object of class "b".
#> Value: 1
```

Fishing pressure proxy f

Catch length data are used to approximate the fishing pressure. The mean length of fish in the catch compared to a reference length is used as the indicator.

Length data

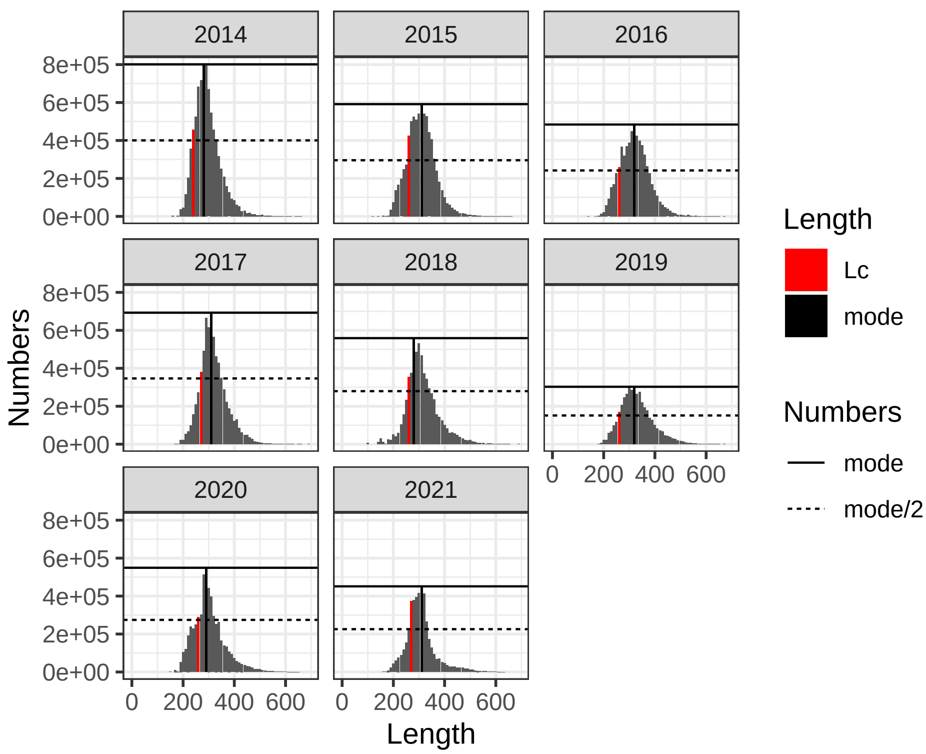
The fishing pressure proxy requires length data from the catch. Ideally, length data for several years are provided in a `data.frame` with columns `year`, `length` and `numbers`. An additional column `catch_category` specifying the catch category, such as discards and landings, is optional.

```
data("ple7e_length")
head(ple7e_length)
#>   year              catch_category length numbers
#> 1 2018                 BMS landing    100    0.00
#> 2 2018                    Discards    100 5887.55
#> 3 2018 Logbook Registered Discard     100    0.00
#> 4 2015                    Discards    120  128.60
#> 5 2016                 BMS landing    140    0.00
#> 6 2018                 BMS landing    140    0.00
```

Length at first capture L_c

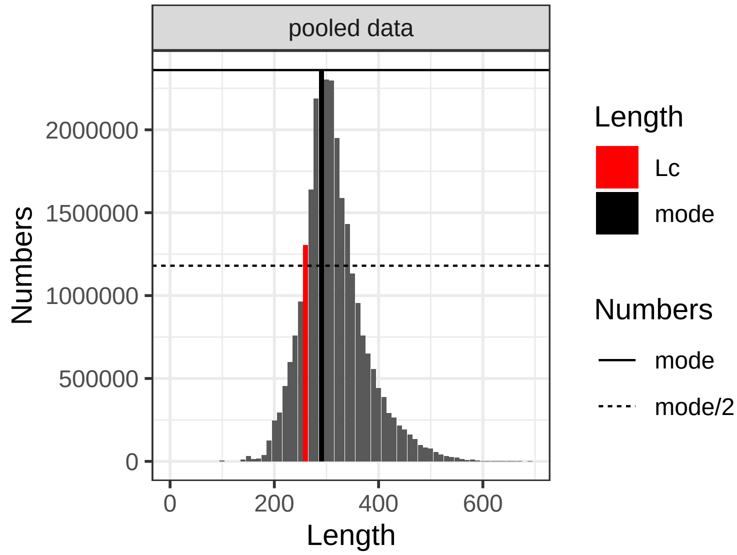
Only length data above the length at first capture L_c are used to avoid noisy data from fish that are not fully selected. L_c is defined as the first length class where the abundance is at or above 50% of the mode of the length distribution and can be calculated with the function `Lc()`:

```
lc <- Lc(ple7e_length)
lc
#> 2014 2015 2016 2017 2018 2019 2020 2021
#>  240  260  260  270  260  260  260  270
plot(lc)
```



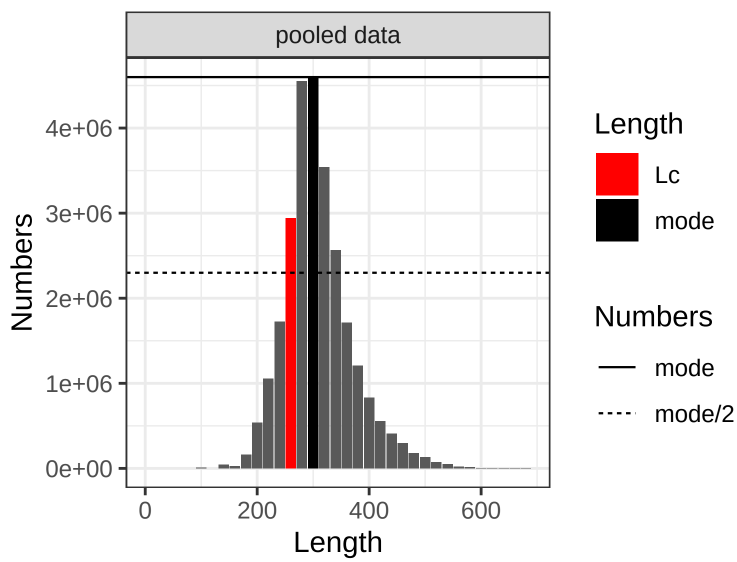
L_c can change from year to year. Therefore, it is recommended to pool data from several (e.g. 5) years:

```r
lc <- Lc(ple7e_length, pool = 2017:2021)
lc
#> [1] 260
plot(lc)
```



If length data are noisy, the size of the length classes can be increased:

```r
### use 20mm length classes
plot(Lc(ple7e_length, pool = 2017:2021, lstep = 20))
```

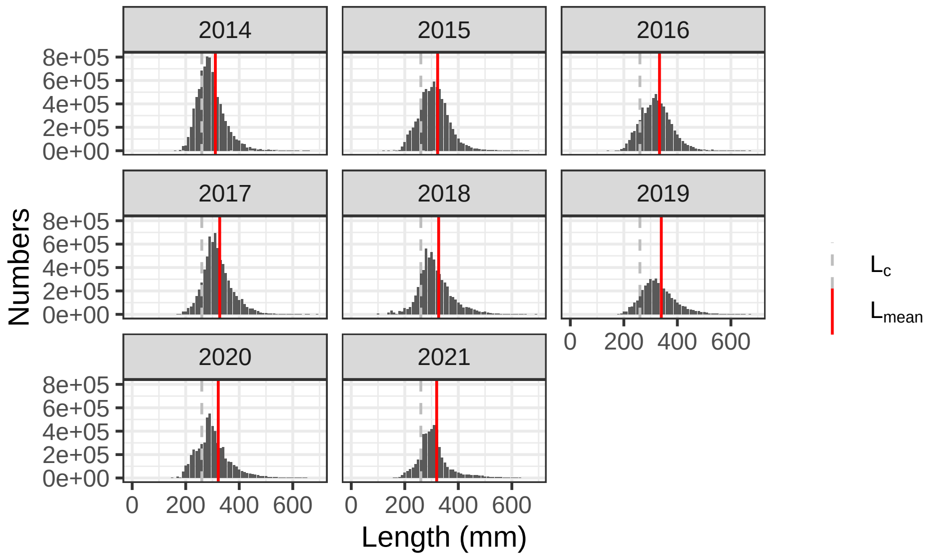


Once defined, L_c should be kept constant and the same value used for all data years. L_c should only be changed if there are strong changes in the fishery or data.

Mean length

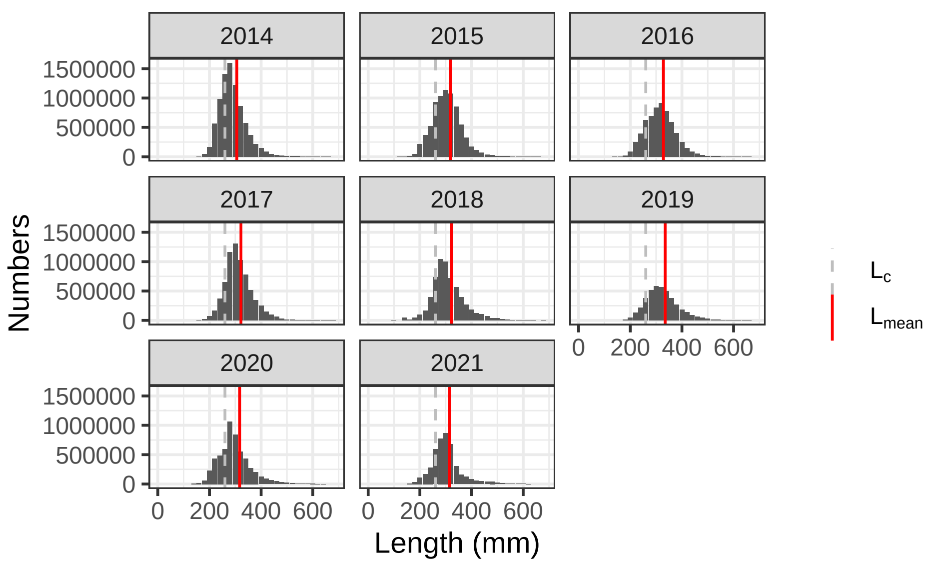
After defining L_c, the mean (annual) catch length L_{mean} above L_c can be calculated:

```r
### calculate annual mean length
lmean <- Lmean(data = ple7e_length, Lc = lc, units = "mm")
lmean
#>     2014     2015     2016     2017     2018     2019     2020     2021
#> 310.6955 322.8089 333.1876 326.9434 326.5741 339.8752 321.5979 319.1974
plot(lmean)
```



If length data are noisy, the size of the length classes can be increased:

```r
### use 20mm length classes
plot(Lmean(data = ple7e_length, Lc = lc, units = "mm", lstep = 20))
```



Reference length

The reference length follows the concepts of Beverton and Holt (1957) and is calculated as derived by Jardim, Azevedo, and Brites (2015):

$$L_{F=M} = 0.75L_c + 0.25L_\infty$$

where $L_{F=M}$ is the MSY reference length, L_c the length at first capture as defined above, and L_∞ the von Bertalanffy asymptotic length. This simple equation assumes that fishing at $F = M$ can be used as a proxy for MSY and that $M/k = 1.5$ (where M is the natural mortality and k the von Bertalanffy individual growth rate). The reference length can be calculated with

```
lref <- Lref(Lc = 264, Linf = 585, units = "mm")
lref
#> [1] 344.25
```

The reference length $L_{F=M}$ should only be defined once in the first year of the application of the rfb rule. In the following years, the same value should be used.

Deviations from the assumptions of $F = M$ and $M/k = 1.5$ are possible following Equation A.3 of Jardim, Azevedo, and Brites (2015) $L_{F=\gamma M,k=\theta M} = (\theta L_\infty + L_c(\gamma + 1))/(\theta + \gamma + 1)$ and can be used by providing arguments `gamma` and `theta` to `Lref()`.

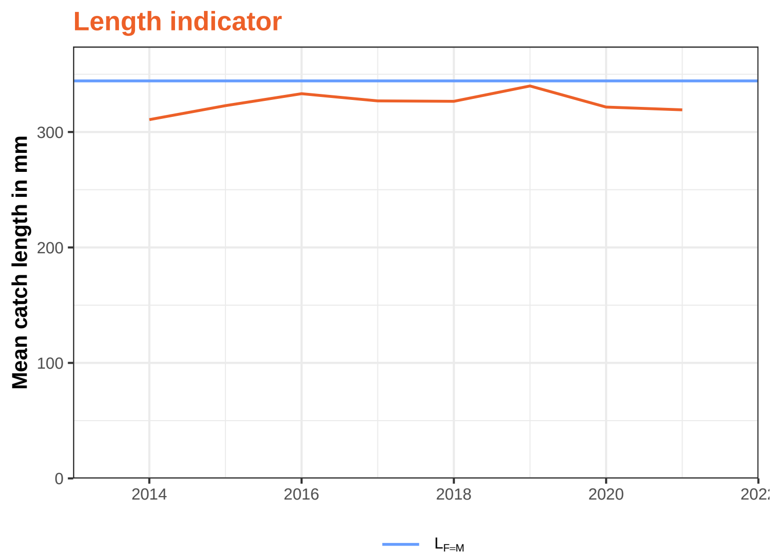
Indicator

The length indicator f is defined as

$$f = L_{\text{mean}}/L_{F=M}$$

and can be calculated with `f()`:

```
f <- f(Lmean = lmean, Lref = lref, units = "mm")
f
#> An object of class "f".
#> Value: 0.927225455656142
### ICES advice style table
advice(f)
#> --------------------------------------------------------------------------------
#> Fishing pressure proxy
#> --------------------------------------------------------------------------------
#> Mean catch length (Lmean = L2021)                |                        320 mm
#> MSY proxy length (LF=M)                          |                        340 mm
#> f: Fishing pressure proxy relative to MSY proxy  |
#>    (L2021/LF=M)                                  |                          0.93
### plot
plot(f)
```



In this case, the mean catch length (orange curve) is always below the MSY proxy reference length (blue horizontal line), indicating that the fishing pressure was above F_{MSY}.

Multiplier m

The multiplier m is a tuning parameter and ensures that the catch advice is precautionary in the long term.

The value of m is set depending on the von Bertalanffy parameter k (individual growth rate), with $m = 0.95$ for stocks with $k < 0.2/\text{year}$ and $m = 0.90$ for stocks with $0.2\text{year}^{-1} \leq k < 0.32\text{year}^{-1}$. The multiplier can be calculated with the function `m()`:

```
# for k=0.1/year
m <- m(hcr = "rfb", k = 0.1)
#> Multiplier (m) for the rfb rule: selecting value based on k: m=0.95
m
#> An object of class "m".
#> Value: 0.95

### alias for rfb rule
rfb_m(k = 0.1)
#> Multiplier (m) for the rfb rule: selecting value based on k: m=0.95
#> An object of class "rfb_m".
#> Value: 0.95

### ICES advice style table
advice(m)
#> --------------------------------------------------------------------------------
#> Precautionary multiplier to maintain biomass above Blim with 95% probability
#> --------------------------------------------------------------------------------
#> m: multiplier                                      |                          0.95
#>    (generic multiplier based on life history)      |
```

Please note that the multiplier m does not lead to a continuous reduction in the catch advice. The components of the rfb rule are multiplicative, this means that m could be considered as part of component f and essentially adjusts the reference length $L_{F=M}$ to $L'_{F=M}$:

$$A_{y+1} = A_y\ r\ f\ b\ m = A_y\ r\ \frac{L_{\text{mean}}}{L_{F=M}}\ b\ m = A_y\ r\ \frac{L_{\text{mean}}}{L_{F=M}/m}\ b = A_y\ r\ \frac{L_{\text{mean}}}{L'_{F=M}}\ b$$

Application of rfb rule

Now we have all the components of the rfb rule and can apply it:

```
advice <- rfb(A = A, r = r, f = f, b = b, m = m, discard_rate = 27)
advice
#> An object of class "rfb".
#> Value: 1219.4
```

A discard rate in % can be provided to the argument `discard_rate` and this means the advice is provided for the catch and landings.

The rfb rule includes a stability clause that restricts changes to $+20\%$ and -30%. This stability clause is conditional on the biomass safeguard and is only applied if $b = 1$ but turned off when $b < 1$.

`cat3advice` can print a table similar to the table presented in ICES advice sheets in which all numbers are rounded following ICES rounding rules:

```
advice(advice)
#> --------------------------------------------------------------------------------
#> Previous catch advice Ay (advised catch for 2022) |                  1742 tonnes
#> --------------------------------------------------------------------------------
#> Stock biomass trend
#> --------------------------------------------------------------------------------
#> Index A (2020,2021)                              |                  0.81 kg/hr
#> Index B (2017,2018,2019)                         |                  1.10 kg/hr
#> r: stock biomass trend (index ratio A/B)         |                        0.74
#> --------------------------------------------------------------------------------
#> Fishing pressure proxy
#> --------------------------------------------------------------------------------
#> Mean catch length (Lmean = L2021)                |                      320 mm
#> MSY proxy length (LF=M)                          |                      340 mm
#> f: Fishing pressure proxy relative to MSY proxy  |
#>    (L2021/LF=M)                                  |                        0.93
#> --------------------------------------------------------------------------------
#> Biomass safeguard
#> --------------------------------------------------------------------------------
#> Last index value (I2021)                         |                  1.03 kg/hr
#> Index trigger value (Itrigger = Iloss x 1.4)     |                  0.39 kg/hr
#> b: index relative to trigger value,              |                        1.00
#>    min{I2021/Itrigger, 1}                        |
#> --------------------------------------------------------------------------------
#> Precautionary multiplier to maintain biomass above Blim with 95% probability
#> --------------------------------------------------------------------------------
#> m: multiplier                                    |                        0.95
#>    (generic multiplier based on life history)    |
#> RFB calculation (r*f*b*m)                        |                 1134 tonnes
#> Stability clause (+20%/-30% compared to Ay,      |
#>    only applied if b=1)                          |      Applied |          0.7
#> Catch advice for 2023 and 2024                   |
#>    (Ay * stability clause)                       |                 1219 tonnes
#> Discard rate                                     |                         27%
```

```
#> Projected landings corresponding to advice       |                           890 tonnes
#> % advice change                                  |                                 -30%
```

The rb rule

The rb rule is essentially a simplified version of the rfb rule without component f, i.e. applicable to stocks without reliable catch length data. This method is meant as a last resort and should be avoid if possible.

The rb rule is an index adjusted harvest control rule that adjusts the catch advice based on a biomass index but does not have a target. The method is defined as Method 2.3 in the ICES Technical Guidelines (ICES 2022, 15) as

$$A_{y+1} = A_y \times r \times b \times m$$

where A_{y+1} is the new catch advice, A_y the previous advice, r the biomass ratio from a biomass index, b a biomass safeguard and m a precautionary multiplier. Furthermore, the change in the advice is restricted by a stability clause that only allows changes of between $+20\%$ and -30% relative to the previous advice, but the application of the stability clause is conditional on $b = 1$ and turned off when $b < 1$.

The rb rule should be applied biennially, i.e. the catch advice is valid for two years.

Please note that any change from the default configuration should be supported by case-specific simulations.

Reference catch A_y

The reference catch A_y is usually the most recently advised catch. In a typical ICES setting, an assessment is conducted in an assessment (intermediate) year y to give advice for the following advice year $y + 1$, this is the advice for year y:

```
### load plaice catch and advice data
data("ple7e_catch")
tail(ple7e_catch)
#>    year advice landings discards catch
#> 31 2017   2714     2128      821  2949
#> 32 2018   3257     1880      633  2513
#> 33 2019   3648     1725      366  2091
#> 34 2020   2721     1373      514  1888
#> 35 2021   2177     1403      211  1615
#> 36 2022   1742       NA       NA    NA
### get reference catch
A <- A(ple7e_catch, units = "tonnes")
A
#> An object of class "A".
#> Value: 1742
```

The ICES Technical Guidelines (ICES 2022) specify that if the realised catch is very different from the advised catch, the reference catch could be replaced by an average of recent catches:

```
### use 3-year average
A(ple7e_catch, units = "tonnes", basis = "average catch", avg_years = 3)
#> An object of class "A".
#> Value: 1864.66666666667
```

The reference catch can also be defined manually:

```r
### use 3-year average
A(2000, units = "tonnes")
#> An object of class "A".
#> Value: 2000
```

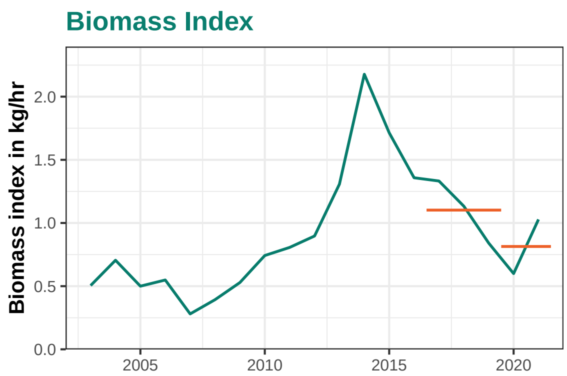
Biomass index trend (ratio) r

The biomass index trend r calculates the trend in the biomass index over last the five years, by dividing the mean of the last two years by the mean of the three preceding years:

$$r = \Sigma_{i=y-2}^{y-1}(I_i/2) \; / \; \Sigma_{i=y-5}^{y-2}(I_i/3)$$

The ratio is calculated with the function `r`. Index data should be provided as a `data.frame` with columns `year` and `index`.

```r
### load plaice data
data("ple7e_idx")
tail(ple7e_idx)
#>    year     index
#> 14 2016 1.3579990
#> 15 2017 1.3323659
#> 16 2018 1.1327596
#> 17 2019 0.8407277
#> 18 2020 0.5996326
#> 19 2021 1.0284297

### calculate biomass trend
r <- r(ple7e_idx, units = "kg/hr")
r
#> An object of class "rfb_r".
#> Value: 0.738718062433358

### ICES advice style table
advice(r)
#> --------------------------------------------------------------------------------
#> Stock biomass trend
#> --------------------------------------------------------------------------------
#> Index A (2020,2021)                           |                      0.81 kg/hr
#> Index B (2017,2018,2019)                      |                      1.10 kg/hr
#> r: stock biomass trend (index ratio A/B)      |                            0.74

### plot index
### horizontal orange lines correspond to the the 2/3-year averages
plot(r)
```




```
### when the value of r is known
r(1)
#> An object of class "r".
#> Value: 1
```

Biomass index data are usually available until the year before the advice year. More recent data can be used and the function automatically picks the most recent data provided to it.

Biomass safeguard b

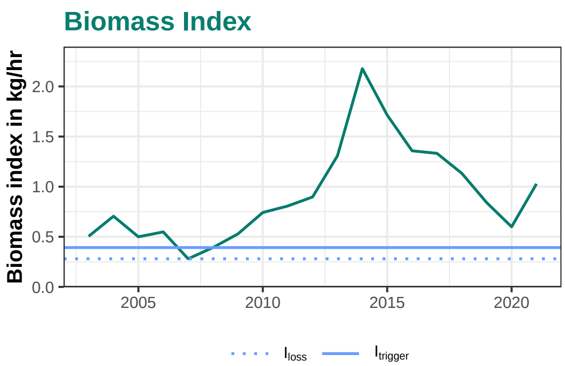
The biomass safeguard reduces the advice when the biomass index I falls below a threshold value I_{trigger}:

$$b = \min\{1,\ I_{y-1}/I_{\text{trigger}}\}$$

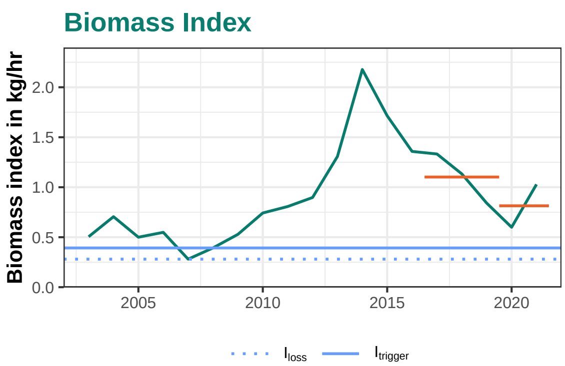
By default, the trigger value is defined based on the lowest observed index value I_{loss} as $I_{\text{trigger}} = 1.4 I_{\text{loss}}$.

The biomass safeguard is calculated with the function `b`:

```
### use same plaice data as before
### application in first year with new calculation of Itrigger
b <- b(ple7e_idx, units = "kg/hr")
b
#> An object of class "b".
#> Value: 1

### ICES advice style table
advice(b)
#> --------------------------------------------------------------------------------
#> Biomass safeguard
#> --------------------------------------------------------------------------------
#> Last index value (I2021)                          |                    1.03 kg/hr
#> Index trigger value (Itrigger = Iloss x 1.4)      |                    0.39 kg/hr
#> b: index relative to trigger value,               |                          1.00
#>    min{I2021/Itrigger, 1}                         |

### plot
plot(b)
```




```
### plot b and r in one figure
plot(r, b)
```



Please note that I_{trigger} should only be defined once in the first year of the application of the rb rule. In the following years, the same value should be used. For this purpose, `b` allows the direct definition of I_{trigger}, or, more conveniently, I_{trigger} can be based on the year in which I_{loss} is defined:

```
### in following years, Itrigger should NOT be updated
### i.e. provide value for Itrigger
b(ple7e_idx, units = "kg/hr", Itrigger = 0.3924721)
#> An object of class "b".
#> Value: 1
### alternatively, the reference year for Iloss can be used
b(ple7e_idx, units = "kg/hr", yr_ref = 2007)
#> An object of class "b".
#> Value: 1
```

Multiplier m

The multiplier m is a tuning parameter and ensures that the catch advice is precautionary in the long term.

The value of m is set to $m = 0.5$ for all stocks. The multiplier can be calculated with the function `m()`:

```
m <- m(hcr = "rb")
m
#> An object of class "m".
#> Value: 0.5

### alias for rb rule
rb_m()
```

```
#> An object of class "rb_m".
#> Value: 0.5

### ICES advice style table
advice(m)
#> --------------------------------------------------------------------------------
#> Precautionary multiplier to maintain biomass above Blim with 95% probability
#> --------------------------------------------------------------------------------
#> m: multiplier                                     |                         0.50
#>    (generic multiplier based on life history)     |
```

Please note that for the rb rule, the multiplier m does lead to a continuous reduction in the catch advice because the rb rule does not include a target.

Application of rb rule

Now we have all the components of the rb rule and can apply it:

```
advice <- rb(A = A, r = r, b = b, m = m, discard_rate = 27)
advice
#> An object of class "rb".
#> Value: 1219.4
```

A discard rate in % can be provided to the argument `discard_rate` and this means the advice is provided for the catch and landings.

The rb rule includes a stability clause that restricts changes to +20 and −30. This stability clause is conditional on the biomass safeguard and is only applied if $b = 1$ but turned off when $b < 1$.

`cat3advice` can print a table similar to the table presented in ICES advice sheets in which all numbers are rounded following ICES rounding rules:

```
advice(advice)
#> --------------------------------------------------------------------------------
#> Previous catch advice Ay (advised catch for 2022) |                  1742 tonnes
#> --------------------------------------------------------------------------------
#> Stock biomass trend
#> --------------------------------------------------------------------------------
#> Index A (2020,2021)                               |                  0.81 kg/hr
#> Index B (2017,2018,2019)                          |                  1.10 kg/hr
#> r: stock biomass trend (index ratio A/B)          |                         0.74
#> --------------------------------------------------------------------------------
#> Biomass safeguard
#> --------------------------------------------------------------------------------
#> Last index value (I2021)                          |                  1.03 kg/hr
#> Index trigger value (Itrigger = Iloss x 1.4)      |                  0.39 kg/hr
#> b: index relative to trigger value,               |                         1.00
#>    min{I2021/Itrigger, 1}                         |
#> --------------------------------------------------------------------------------
#> Precautionary multiplier to maintain biomass above Blim with 95% probability
#> --------------------------------------------------------------------------------
#> m: multiplier                                     |                         0.50
#>    (generic multiplier based on life history)     |
#> RB calculation (r*b*m)                            |                   643 tonnes
#> Stability clause (+20%/-30% compared to Ay,       |
#>    only applied if b=1)                           |       Applied |          0.7
```

```
#> Catch advice for 2023 and 2024                    |
#>    (Ay * stability clause)                         |                         1219 tonnes
#> Discard rate                                       |                                 27%
#> Projected landings corresponding to advice         |                          890 tonnes
#> % advice change                                    |                                -30%
```

The chr rule

The chr rule is a (relative) harvest rate-based harvest control rule. The relative harvest rate is defined by dividing the catch by the values from a biomass index. It is not an absolute harvest rate because the absolute stock size is unknown. The method is defined as Method 2.2 in the ICES Technical Guidelines (ICES 2022, 13) as

$$A_{y+1} = I_{y-1} \times F_{\text{proxyMSY}} \times b \times m$$

where A_{y+1} is the new catch advice, I_{y-1} the last biomass index value, F_{proxyMSY} the (relative) harvest rate target, b a biomass safeguard and m a precautionary multiplier. Furthermore, the change in the advice is restricted by a stability clause that only allows changes of between $+20\%$ and -30% relative to the previous advice, but the application of the stability clause is conditional on $b = 1$ and turned off when $b < 1$.

The chr rule should be applied annually, i.e. the catch advice is valid for one year.

Please note that any change from the default configuration should be supported by case-specific simulations.

Reference catch A_y

A reference catch A_y is needed for the application of the stability clause. The reference catch A_y is usually the most recently advised catch. In a typical ICES setting, an assessment is conducted in an assessment (intermediate) year y to give advice for the following advice year $y+1$, this is the advice for year y:

```
### load plaice catch and advice data
data("ple7e_catch")
tail(ple7e_catch)
#>    year advice landings discards catch
#> 31 2017   2714     2128      821  2949
#> 32 2018   3257     1880      633  2513
#> 33 2019   3648     1725      366  2091
#> 34 2020   2721     1373      514  1888
#> 35 2021   2177     1403      211  1615
#> 36 2022   1742       NA       NA    NA
### get reference catch
A <- A(ple7e_catch, units = "tonnes")
A
#> An object of class "A".
#> Value: 1742
```

The ICES Technical Guidelines (ICES 2022) specify that if the realised catch is very different from the advised catch, the reference catch could be replaced by an average of recent catches:

```
### use 3-year average
A(ple7e_catch, units = "tonnes", basis = "average catch", avg_years = 3)
#> An object of class "A".
#> Value: 1864.66666666667
```

The reference catch can also be defined manually:

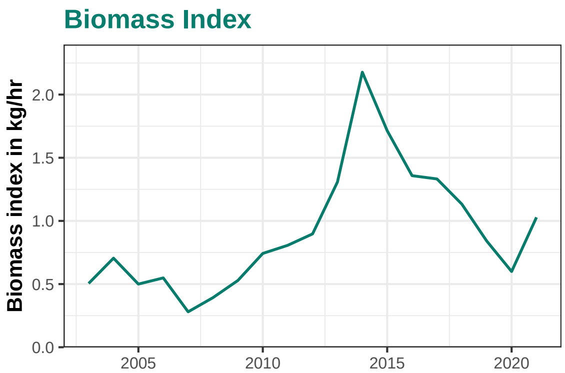
```
### use 3-year average
A(2000, units = "tonnes")
#> An object of class "A".
#> Value: 2000
```

Biomass index value I_{y-1}

I_{y-1} is the most recent value from the biomass index. This is usually a value from the year before the assessment year (y) but a more recent value can be used if available.

Index data should be provided as a `data.frame` with columns `year` and `index`.

```
### load plaice data
data("ple7e_idx")
tail(ple7e_idx)
#>    year     index
#> 14 2016 1.3579990
#> 15 2017 1.3323659
#> 16 2018 1.1327596
#> 17 2019 0.8407277
#> 18 2020 0.5996326
#> 19 2021 1.0284297

### get most recent value
i <- I(ple7e_idx, units = "kg/hr")
i
#> An object of class "I".
#> Value: 1.028429723

### ICES advice style table
advice(i)
#> --------------------------------------------------------------------------------
#> Biomass index
#> --------------------------------------------------------------------------------
#> I: most recent biomass index (I2021)              |                    1.03 kg/hr

### plot index
plot(i)
```




```
### when the value of r is known
I(1)
#> An object of class "I".
```

```
#> Value: 1
```

Biomass safeguard b

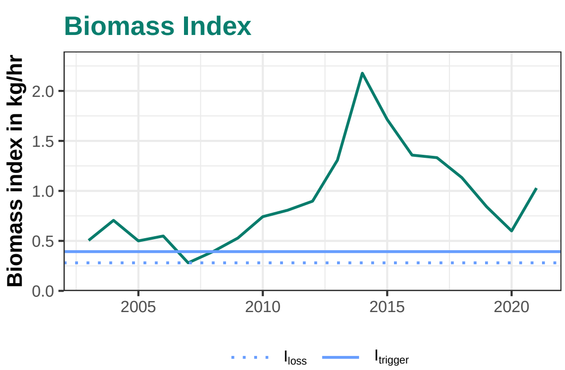
The biomass safeguard reduces the advice when the biomass index I falls below a threshold value I_{trigger}:

$$b = \min\{1,\ I_{y-1}/I_{\text{trigger}}\}$$

By default, the trigger value is defined based on the lowest observed index value I_{loss} as $I_{\text{trigger}} = 1.4 I_{\text{loss}}$.

The biomass safeguard is calculated with the function `b`:

```
### use same plaice data as before
### application in first year with new calculation of Itrigger
b <- b(ple7e_idx, units = "kg/hr")
b
#> An object of class "b".
#> Value: 1

### ICES advice style table
advice(b)
#> --------------------------------------------------------------------------------
#> Biomass safeguard
#> --------------------------------------------------------------------------------
#> Last index value (I2021)                          |                    1.03 kg/hr
#> Index trigger value (Itrigger = Iloss x 1.4)      |                    0.39 kg/hr
#> b: index relative to trigger value,               |                          1.00
#>    min{I2021/Itrigger, 1}                         |

### plot
plot(b)
```



Please note that I_{trigger} should only be defined once in the first year of the application of the chr rule. In the following years, the same value should be used. For this purpose, `b` allows the direct definition of I_{trigger}, or, more conveniently, I_{trigger} can be based on the year in which I_{loss} is defined:

```
### in following years, Itrigger should NOT be updated
### i.e. provide value for Itrigger
b(ple7e_idx, units = "kg/hr", Itrigger = 0.3924721)
#> An object of class "b".
#> Value: 1
### alternatively, the reference year for Iloss can be used
b(ple7e_idx, units = "kg/hr", yr_ref = 2007)
```

```
#> An object of class "b".
#> Value: 1
```

Target harvest rate F_{proxyMSY}

The target harvest rate F_{proxyMSY} defines the target for the chr rule and is a proxy for MSY. The standard approach to define F_{proxyMSY} is to use catch length data, find years in which the mean catch length L_{mean} is above a reference length ($L_{F=M}$), calculate the harvest rate for these years, and use their average. The approach is the same as the one used for component f of the rfb rule described above. This needs to be done only once in the first year of the application of the chr rule. In subsequent years, no length data are required.

Length data

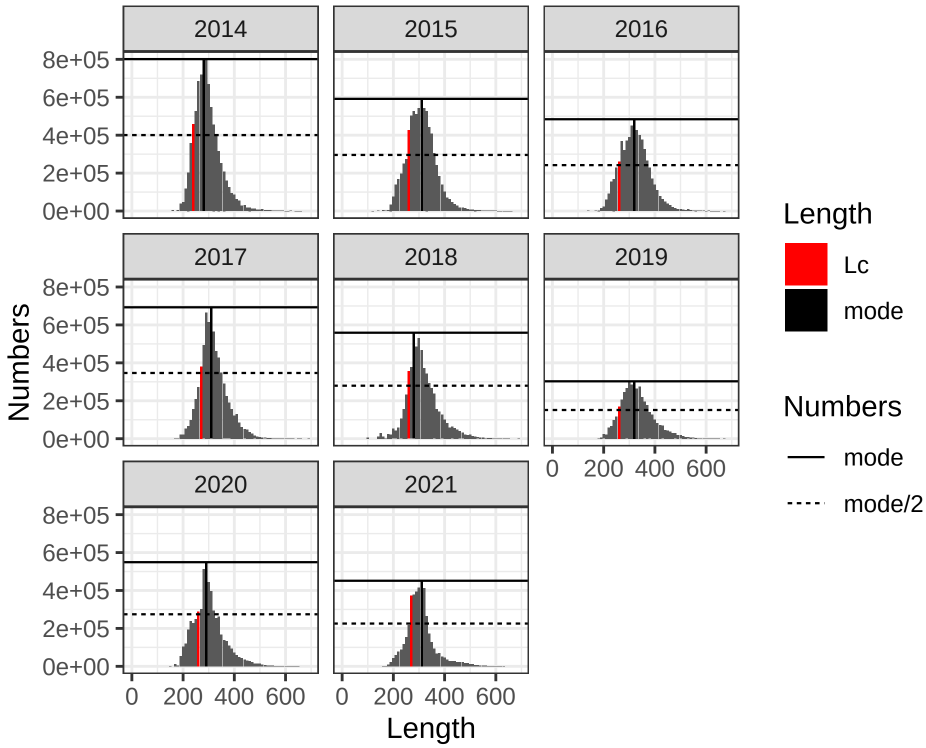
Ideally, length data for several years are provided in a `data.frame` with columns `year`, `length` and `numbers`. An additional column `catch_category` specifying the catch category, such as discards and landings, is optional.

```
data("ple7e_length")
head(ple7e_length)
#>   year            catch_category length numbers
#> 1 2018               BMS landing    100    0.00
#> 2 2018                  Discards    100 5887.55
#> 3 2018 Logbook Registered Discard    100    0.00
#> 4 2015                  Discards    120  128.60
#> 5 2016               BMS landing    140    0.00
#> 6 2018               BMS landing    140    0.00
```

Length at first capture L_c

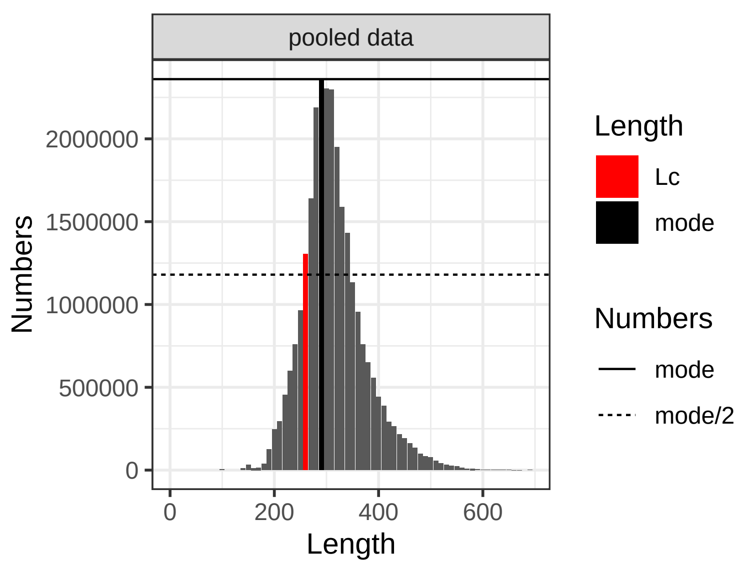
Only length data above the length at first capture L_c are used to avoid noisy data from fish that are not fully selected. L_c is defined as the first length class where the abundance is at or above 50% of the mode of the length distribution and can be calculated with the function `Lc()`:

```
lc <- Lc(ple7e_length)
lc
#> 2014 2015 2016 2017 2018 2019 2020 2021
#>  240  260  260  270  260  260  260  270
plot(lc)
```



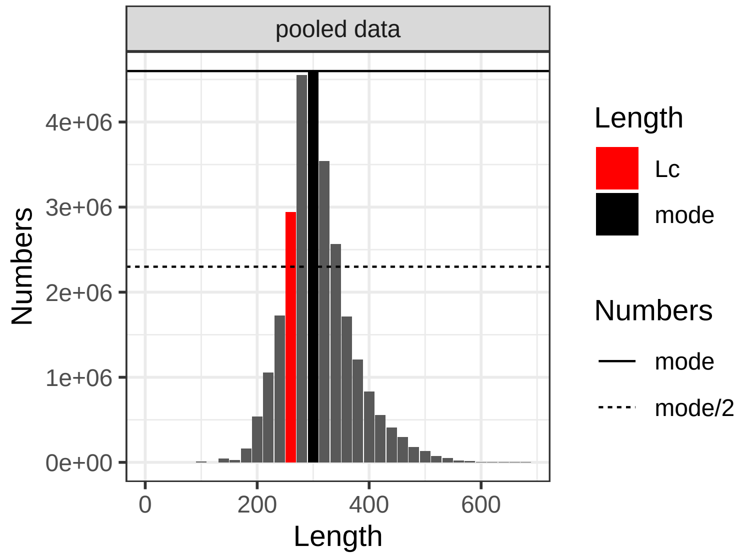
L_c can change from year to year. Therefore, it is recommended to pool data from several (e.g. 5) years:

```
lc <- Lc(ple7e_length, pool = 2017:2021)
lc
#> [1] 260
plot(lc)
```



If length data are noisy, the size of the length classes can be increased:

```
### use 20mm length classes
plot(Lc(ple7e_length, pool = 2017:2021, lstep = 20))
```

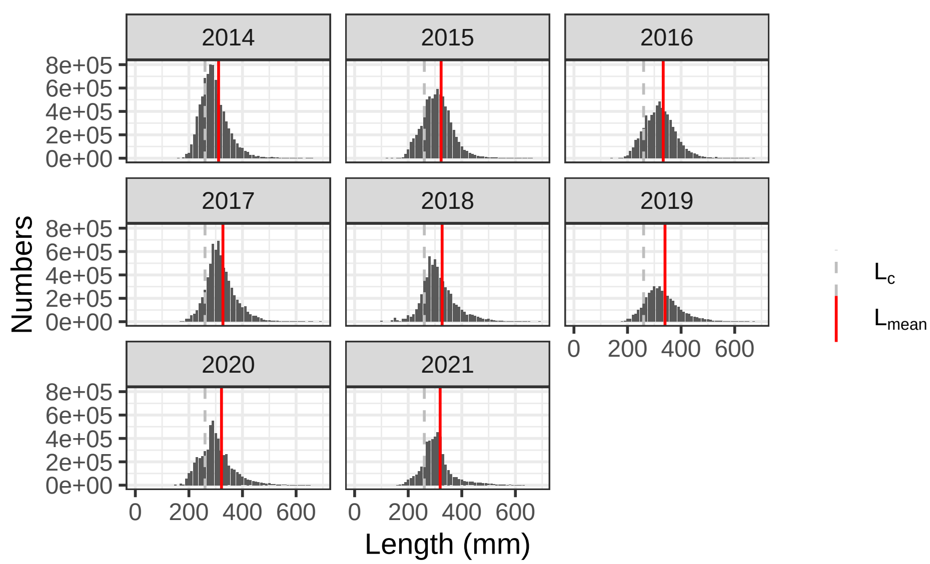


Once defined, L_c should be kept constant and the same value used for all data years. L_c should only be changed if there are strong changes in the fishery or data.

Mean length

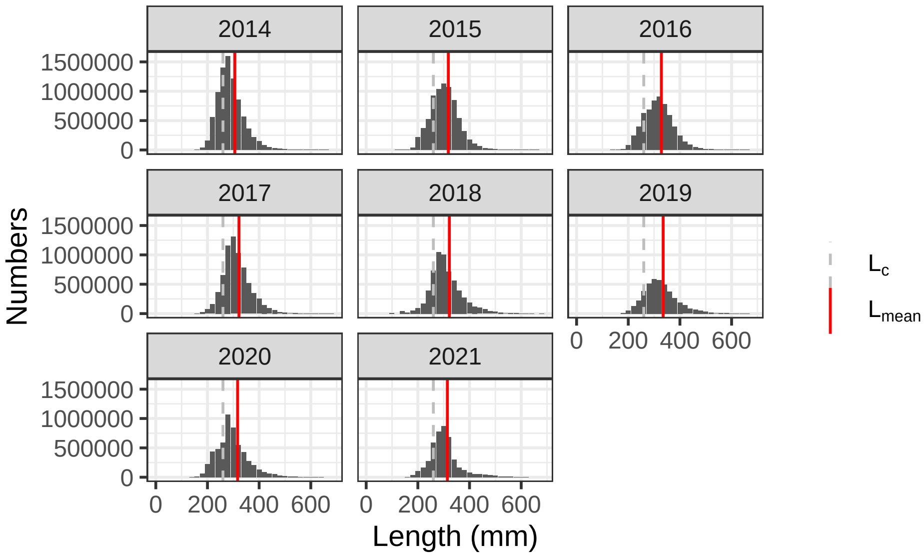
After defining L_c, the mean (annual) catch length L_{mean} above L_c can be calculated:

```
### calculate annual mean length
lmean <- Lmean(data = ple7e_length, Lc = lc, units = "mm")
lmean
#>     2014     2015     2016     2017     2018     2019     2020     2021
#> 310.6955 322.8089 333.1876 326.9434 326.5741 339.8752 321.5979 319.1974
plot(lmean)
```



If length data are noisy, the size of the length classes can be increased:

```
### use 20mm length classes
plot(Lmean(data = ple7e_length, Lc = lc, units = "mm", lstep = 20))
```



Reference length

The reference length follows the concepts of Beverton and Holt (1957) and is calculated as derived by Jardim, Azevedo, and Brites (2015):

$$L_{F=M} = 0.75L_c + 0.25L_\infty$$

where $L_{F=M}$ is the MSY reference length, L_c the length at first capture as defined above, and L_∞ the von Bertalanffy asymptotic length. This simple equation assumes that fishing at $F = M$ can be used as a proxy for MSY and that $M/k = 1.5$ (where M is the natural mortality and k the von Bertalanffy individual growth rate). The reference length can be calculated with

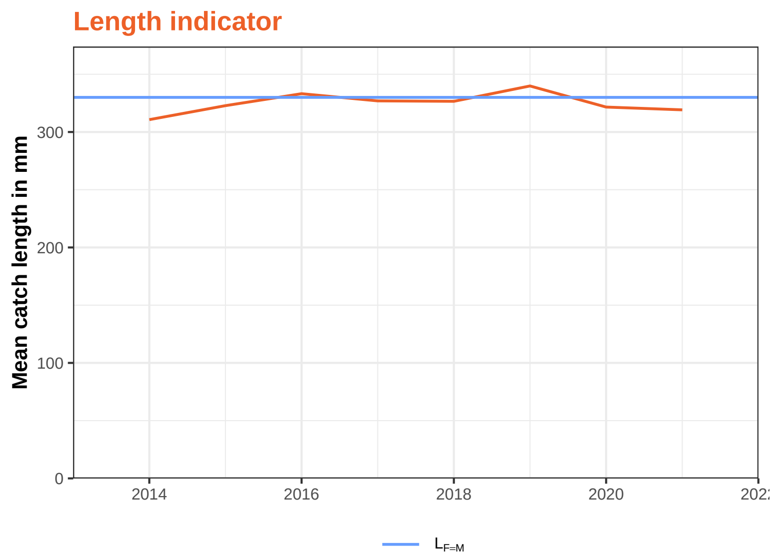
```
lref <- Lref(Lc = 264, Linf = 585, units = "mm")
lref
#> [1] 344.25
### use a dummy value here for illustrative purposes of the chr rule
lref <- Lref(330, units = "mm")
```

Deviations from the assumptions of $F = M$ and $M/k = 1.5$ are possible following Equation A.3 of Jardim, Azevedo, and Brites (2015) $L_{F=\gamma M,k=\theta M} = (\theta L_\infty + L_c(\gamma + 1))/(\theta + \gamma + 1)$ and can be used by providing arguments `gamma` and `theta` to `Lref()`.

Indicator

The mean catch length relative to the reference $f = L_{\text{mean}}/L_{F=M}$ is used as an indicator. The same function (`f()`) as used in the rfb rule (described above) can be used to calculate the indicator time series:

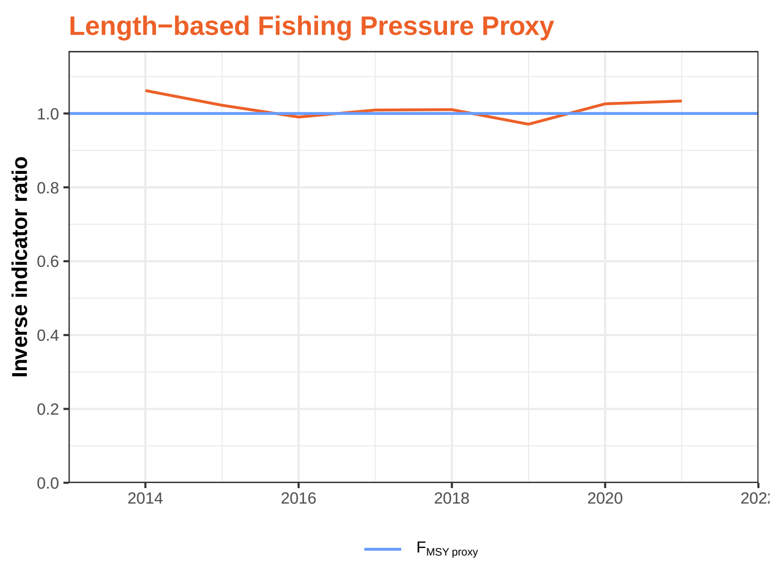
```
f <- f(Lmean = lmean, Lref = lref, units = "mm")
plot(f)
```



In this case, the mean catch length (orange curve) is above the reference length in two years, indicating that the fishing pressure was below F_{MSY} in these two years.

ICES advice sheets typically show the inverse indicator ratio. This can be plotted by adding an `inverse = TRUE` argument to `plot()`:

```
plot(f, inverse = TRUE)
```



The time series of the indicator values can be printed with

```
indicator(f)
#> # A tibble: 8 x 6
#> # Groups:   year, Lc [8]
#>    year    Lc Lmean  Lref indicator inverse_indicator
#>   <int> <int> <dbl> <dbl>     <dbl>             <dbl>
#> 1  2014   260  311.   330     0.942             1.06
#> 2  2015   260  323.   330     0.978             1.02
#> 3  2016   260  333.   330     1.01              0.990
```

```
#> 4  2017   260  327.   330     0.991              1.01
#> 5  2018   260  327.   330     0.990              1.01
#> 6  2019   260  340.   330     1.03               0.971
#> 7  2020   260  322.   330     0.975              1.03
#> 8  2021   260  319.   330     0.967              1.03
```

and the inverse values also with

```
inverse_indicator(f)
#> # A tibble: 8 x 2
#> # Groups:   year [8]
#>    year inverse_indicator
#>   <int>             <dbl>
#> 1  2014             1.06
#> 2  2015             1.02
#> 3  2016             0.990
#> 4  2017             1.01
#> 5  2018             1.01
#> 6  2019             0.971
#> 7  2020             1.03
#> 8  2021             1.03
```

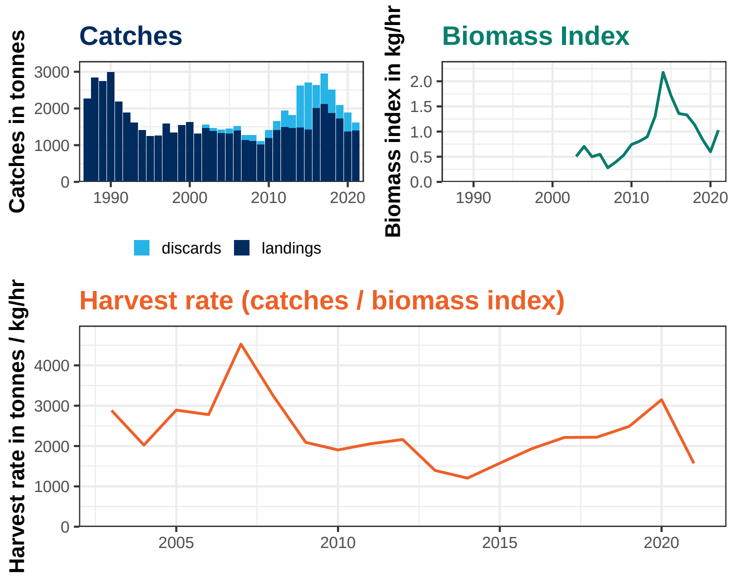
Harvest rate

For the estimation of the target harvest rate, the harvest rate needs to be calculated with `HR()`.

```
### catch data
data("ple7e_catch")
### index data
data("ple7e_idx")

### combine catch and index data into single data.frame
df <- merge(ple7e_catch, ple7e_idx, all = TRUE) # combine catch & index data

### calculate harvest rate
hr <- HR(df, units_catch = "tonnes", units_index = "kg/hr")
hr
#> An object of class "HR".
#> Value(s):
#>     2003     2004     2005     2006     2007     2008     2009     2010     2011     2012     2013
#> 2882.668 2023.556 2890.803 2779.141 4526.691 3242.396 2091.990 1903.229 2056.537 2161.624 1394.154
#>     2014     2015     2016     2017     2018     2019     2020     2021
#> 1204.222 1575.161 1937.409 2213.356 2218.476 2487.131 3148.595 1570.355
```

The harvest rate can only be calculated for years in which both catch and index data are available. The harvest rate and its input data can be plotted automatically:

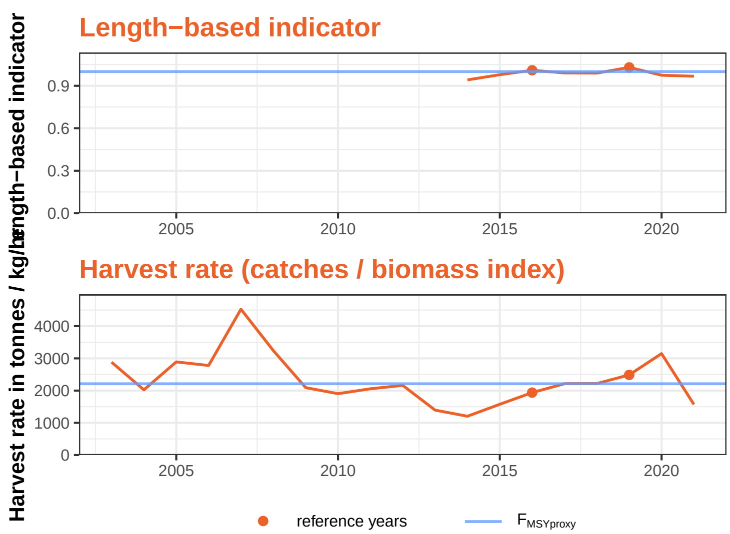
```
plot(hr)
```



Harvest rate target F_{proxyMSY}

Now we can use the indicator and (relative) harvest rate time series to calculate the target harvest rate:

```r
### calculate (relative) target harvest rate
F <- F(hr, f)
F
#> An object of class "F".
#> Value: 2212.27020813614
plot(F)
#> Warning: Removed 17 rows containing missing values (`geom_line()`).
```



The years selected for the target harvest rate are indicated by orange points.

Multiplier m

The multiplier m is a tuning parameter and ensures that the catch advice is precautionary in the long term.

By default, the value of m is set to $m = 0.5$. The multiplier can be calculated with the function `m()`:

```
m <- m(hcr = "chr")
m
#> An object of class "m".
#> Value: 0.5

### alias for chr rule
chr_m()
#> An object of class "chr_m".
#> Value: 0.5

### ICES advice style table
advice(m)
#> --------------------------------------------------------------------------------
#> Precautionary multiplier to maintain biomass above Blim with 95% probability
#> --------------------------------------------------------------------------------
#> m: multiplier                                      |                        0.50
#>    (generic multiplier based on life history)      |
```

Please note that the multiplier m does not lead to a continuous reduction in the catch advice. The components of the chr rule are multiplicative, this means that m could be considered as adjusting the target harvest rate F_{MSY} to F'_{MSY}:

$$A_{y+1} = I \times F_{\text{proxyMSY}} \times b \times m = I \times \frac{F_{\text{proxyMSY}}}{1/m} \times b = I \times F'_{\text{proxyMSY}} \times b$$

Application of chr rule

Now we have all the components of the chr rule and can apply it:

```
advice <- chr(A = A, I = i, F = F, b = b, m = m, discard_rate = 27)
advice
#> An object of class "chr".
#> Value: 1219.4
```

A discard rate in % can be provided to the argument `discard_rate` and this means the advice is provided for the catch and landings.

The chr rule includes a stability clause that restricts changes to $+20\%$ and -30%. This stability clause is conditional on the biomass safeguard and is only applied if $b = 1$ but turned off when $b < 1$.

`cat3advice` can print a table similar to the table presented in ICES advice sheets in which all numbers are rounded following ICES rounding rules:

```
advice(advice)
#> --------------------------------------------------------------------------------
#> Previous catch advice Ay (advised catch for 2022) |                  1742 tonnes
#> --------------------------------------------------------------------------------
#> Biomass index
#> --------------------------------------------------------------------------------
#> I: most recent biomass index (I2021)              |                  1.03 kg/hr
#> --------------------------------------------------------------------------------
#> MSY proxy harvest rate
#> --------------------------------------------------------------------------------
#> FMSYproxy: MSY proxy harvest rate (average of     |
#>   the ratio of catch to biomass index for the     |
```

```
#>   years for which f>1, where f=Lmean/LF=M)       |           2200 tonnes / kg/hr
#> ----------------------------------------------------------------------------------
#> Biomass safeguard
#> ----------------------------------------------------------------------------------
#> Last index value (I2021)                         |                      1.03 kg/hr
#> Index trigger value (Itrigger = Iloss x 1.4)     |                      0.39 kg/hr
#> b: index relative to trigger value,              |                            1.00
#>    min{I2021/Itrigger, 1}                        |
#> ----------------------------------------------------------------------------------
#> Precautionary multiplier to maintain biomass above Blim with 95% probability
#> ----------------------------------------------------------------------------------
#> m: multiplier                                    |                            0.50
#>    (generic multiplier based on life history)    |
#> CHR calculation (I*F*b*m)                        |                     1138 tonnes
#> Stability clause (+20%/-30% compared to Ay,      |
#>    only applied if b=1)                          |       Applied |             0.7
#> Catch advice for 2023                            |
#>    (Ay * stability clause)                       |                     1219 tonnes
#> Discard rate                                     |                             27%
#> Projected landings corresponding to advice       |                      890 tonnes
#> % advice change                                  |                            -30%
```

References

Beverton, Raymond J. H., and Sidney J. Holt. 1957. *On the Dynamics of Exploited Fish Populations*. Fishery Investigation Series 2. London: HMSO for Ministry of Agriculture, Fisheries; Food.

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